National Park Service
U.S. Department of the Interior

North Cascades National Park Complex

# An Assessment of the Environmental and Human Health Risks of Using Rotenone to Implement the Mountain Lakes Fisheries Management Plan in North Cascades National Park Complex

# Contents

# Executive Summary

North Cascades National Park (NOCA) is proposing to use CFT Legumine™, a rotenone based piscicide, to remove non-native trout from a series of lakes identified in the park's Mountain Lakes Fisheries Management Plan (MLFMP). During the development of the MLFMP antimycin was identified as the preferred piscicide for the eradication of non-native fish populations, however, antimycin is not currently commercially available and all stocks have been depleted. While using piscicides is consistent with the MLFMP, using rotenone instead of antimycin constitutes a change that requires additional analysis to ensure compliance with the National Environmental Policy Act.

Antimycin and rotenone are similar in that both are derived from natural sources. Antimycin is an antibiotic complex that is isolated from the bacterium *Streptomyces griseus*. Rotenone is an alkaloid extracted from the roots of plants found in the pea family. Both are absorbed through the gills of fish and other aquatic organisms and block oxidative pathways in the mitochondria. Additionally, both chemicals rapidly breakdown into harmless naturally occurring compounds within several days.

While the piscicidal action of these chemicals is similar they do possess different characteristics that must be considered when planning field applications. First, rotenone is less toxic than antimycin and unlike antimycin fish can recover from exposure to rotenone when placed in fresh water; therefore rotenone must be applied in higher concentrations than antimycin to eradicate non-native fish. In the past, these characteristics have resulted in using rotenone at concentrations that have caused increased mortality to non-target organisms when compared to antimycin. Fortunately, new formulations of rotenone combined with advances in conducting piscicide applications have resulted in mortality rates similar to antimycin for non-target organisms and a reduced risk to the environment.

To evaluate the potential impacts of using rotenone we identified several endpoints that could potentially be impacted by piscicide treatments. We than compared the potential impacts between rotenone and antimycin. Since the data do not exist to evaluate the potential impacts to all of the species that are known to occur in NOCA, we selected a series of endpoints that represented different components of aquatic and terrestrial ecosystems, as well as human health exposure pathways.

The evidence supports that both rotenone and antimycin pose the highest risk to larval amphibians and groups of invertebrates that use gills for respiration and that neither compound poses a significant risk to algae, aquatic macrophytes, terrestrial organisms or human health when applied at prescribed rates and handled with appropriate personal protective equipment. Limited evidence suggests that tailed frog larvae (*Aschaphus truei*) are one of the most sensitive non-target organisms to rotenone and as such are likely to experience the greatest adverse impact. However, since no studies were found that assessed the impacts of antimycin on tailed frog a comparison between the two compounds could not be made.

Based on the evidence, we conclude that using CFT Legumine™ to remove non-native fish as part of the MFFMP will not have higher adverse environmental impacts than using Fintrol™.

# Introduction

All of the 245 natural mountain lakes in the present day boundaries of North Cascades National Park (NOCA) were naturally free of fish. One of the primary decisions made through the park's Mountain Lakes Fisheries Management Plan (MLFMP) (NPS 2008) was to eliminate high densities of reproducing fish populations from up to 27 lakes using several methods of fish removal, including piscicides. Removing non-native fish is required to protect populations of native, genetically unique Bull Trout and Rainbow Trout in the upper Skagit watershed, isolated populations of Westslope Cutthroat Trout in the Stehekin watershed and to restore the natural communities of zooplankton, insects, and amphibians found in these lakes. The piscicide antimycin was the only chemical approved in the MLFMP and the plan noted that if rotenone was to be used for fish removal actions in the future, additional analysis would be required to assess the environmental and human health risks.

North Cascades National Park (NOCA) is now proposing to use rotenone to remove non-native Eastern Brook Trout, Cutthroat Trout, and Rainbow Trout from a series of lakes identified in the park's MLFMP for the following several reasons (NPS 2008).

- As of March 2012, antimycin is not commercially available and current stocks have been depleted. The supplier, Aquabiotics, is still looking for a production facility that can produce antimycin but has not found one to date.
- While antimycin is chemically effective in removing fish from shallow lakes, it is less effective than rotenone in penetrating through the dense layers of water associated with thermally stratified deeper lakes, such as Sourdough Lake in NOCA, where many fish reside.
- Concerns that prevented the NPS from more thoroughly considering the use of this chemical in the MLFMP have largely been negated or abated. The results from recent rotenone applications and toxicity testing have demonstrated that rotenone is not as toxic to non-target organisms and humans as was previously thought when the MLFMP was developed, and new formulations of rotenone have reduced and/or eliminated many of the additives that were linked to increases in non-target organism mortality.
- Removing non-native fish using rotenone is consistent with the goals and adaptive management principles provided by the MLFMP.

This analysis describes the need for using rotenone in place of antimycin and evaluates the potential aquatic resource and human health-related effects from using rotenone instead of antimycin. This analysis is limited to aquatic resources and human health since there would be no substantive difference in impacts to the other resources and values noted in the MLFP when using rotenone in place of antimycin. Impacts to other resources and values that may be affected by this action are disclosed in the EIS that accompanied the MLFMP.

Rotenone has a long history of use in both the National Park Service (NPS) and in Washington State by the Washington Department of Fish and Wildlife (WDFW), and in developing this assessment we relied heavily on the Native Fish Conservation Plan completed by Yellowstone National Park (NPS 2011) and the Final Supplemental Environmental Impact Statement completed by the WDFW for lake and stream rehabilitation using rotenone (WDFW 2002). We also reviewed and incorporated recently published scientific literature that was not available to the authors of the previously mentioned documents.

# Background

## Impacts of Non-native Fish on NOCA Aquatic Resources

As described in the MLFMP, fish, especially dense reproducing populations, consume zooplankton, insects, and amphibians and in turn reduce the numbers, and possibly the presence, of these species in lakes. Waste products from fish may change the nutrient balance of a lake, which may create a favorable condition for some organisms, causing increases in their numbers. Additionally, the impacts of non-native fish impact native fish populations in the rivers and streams located down-stream from stocked lakes. We have summarized the scientific findings of the impacts related to the presence of non-native fish in NOCA mountain lakes below; more detail on these impacts can be found in the MLFMP and in the research findings published by Liss and others (1995, 1998, 2002).

### *Zooplankton*

Fish feed on larger zooplankton, which can in turn allow smaller herbivorous zooplankton to flourish with resulting impacts on phytoplankton and lake productivity and chemistry. The presence of reproducing fish, therefore, results in a change in the abundance of various organisms and a change in the food web. Because numerous environmental factors also affect zooplankton, the changes caused by the presence of fish in NOCA mountain lakes are measured as conditions lying outside the range of natural variation within a lake or in similar lakes. These effects may be notable among planktonic organisms.

### *Macroinvertebrates*

Macroinvertebrates (such as aquatic insects, worms, and snails) consume a wide range of food resources including phytoplankton, zooplankton, periphyton (microscopic algae growing on a lake substrate such as rocks or sediment or on larger plant surfaces), detritus (dead plant and animal material that drifts to the bottom of a lake), aquatic plants and other macroinvertebrates. In turn, macroinvertebrates are eaten by top predators (including salamanders and fish) in a lake system. Fishery management practices, especially those resulting in high densities of fish over a long period of time, can reduce or eliminate some species of macroinvertebrates, with resulting impacts on salamanders, plankton, detritus, and nutrient concentrations and on the fish population itself. In addition to these generic effects on aquatic food webs, there is a particular interest in a blind amphipod that is found in two mountain lakes in the North Cascades Complex. Although this amphipod could be unique and rare in the North Cascades Complex, neither the U.S. Fish and Wildlife Service nor the Washington Department of Fish and Wildlife has plans to designate or list this species.

### *Amphibians*

Considering that all mountain lakes in NOCA are naturally fishless, salamanders are the natural top vertebrate predator in many of the mountain lakes found in NOCA. When these lakes are stocked with fish, the number of salamanders drops, presumably because fish eat salamander larvae. Long-toed salamanders, which historically occupied many naturally fishless lakes, are particularly vulnerable to predation from stocked fish because they do not have the variety of adaptations (such as noxious secretions) to defend themselves that other more common amphibians, such as the Northwestern salamanders, possess. When salamanders are eliminated or greatly reduced by fish, the aquatic food web is also changed.

### *Native Fish*
Non-native fish also affect native fish species downstream of stocked lakes expanding the range of their impacts to the watershed level. Hatchery-raised fish of most species are not native stocks and are usually not as genetically fit. When fish escape from lakes into streams that are occupied by native fish of the same species or genus, interbreeding adversely affects the adaptive characteristics of the native population. When interbreeding occurs between fish species (Eastern Brook Trout and Bull Trout or Rainbow Trout and Westslope Cutthroat Trout), genetic introgression occurs eliminating the purity of native fish stocks. In the extreme, this could result in the localized elimination of that species or subspecies in a lake, park, or region. Escaping fish may also prey on native fish species and compete with native fish for food or habitat. All of these factors have been identified as a priority threat that need to be addressed in protecting and recovering threatened species such as the Bull Trout and Westslope Cutthroat Trout.

## The Mountain Lakes Fisheries Management Plan (MLFMP)
Because of the impacts listed above, as well as those documented in the MLFMP and scientific literature, protecting native fish and amphibian populations and restoring the ecological integrity of mountain lakes requires the complete eradication of all existing non-native fish fauna. Complete removal is necessary to ensure that non-native fish do not reproduce and reestablish their populations and to remove the pressure from predation both in mountain lakes and downstream areas in the watershed. In 2008, the National Park Service completed the Mountain Lake Fisheries Management Plan (MLFMP) that identified and assessed three basic methods of fish removal: mechanical, habitat exclusion, and chemical (i.e. piscicides).

### *Mechanical Methods*
The three mechanical methods included in the MLFMP are gillnetting, electrofishing, and trapping. These methods could be used independently or in combination to treat appropriate lakes. A varied combination of gill-netting, electrofishing, fyke nets, and traps near spawning areas would be used to catch and remove fish from lakes generally smaller than 5 acres in surface area and less than 30 feet deep. The exact choice of equipment would depend upon lake conditions and species of non-native that are present. Gillnetting is not expected to be an effective technique for Eastern Brook Trout eradication due to the wide range of age/size classes that are typically present. To minimize the use of the piscicide these methods might also be tried on larger shallow lakes provided they do not have complex substrate or other conditions that might make removal infeasible (NPS 2008).

### *Habitat Exclusion*
Habitat exclusion prevents fish from reproducing by eliminating spawning habitat and/or blocking access to spawning habitat. The goal of spawning habitat exclusion is to break the reproductive cycle and eventually eliminate the population over time. It is believed that this method may be effective in controlling Rainbow and Cutthroat Trout. However, habitat exclusion was not proposed for populations of Eastern Brook Trout in the MLFMP since this species is able to exploit a wide range of habitat types and habitat exclusion is not expected to be effective.

### *Chemical Methods*
For lakes that are larger than 3 hectares and/or deeper than 10 meters, the MLFMP determined that piscicides are the only option available for the eradication of non-native fish populations in

NOCA, and the only piscicides that have been approved by the Environmental Protection Agency (EPA) to remove fish from fresh water habitats are rotenone and antimycin (Table 1) (NOCA 2008). In the final Record of Descision for the MLFMP the NPS indentified antimycin as the preferred piscicide for fish removal in NOCA because it 1) it is highly toxic to trout, 2) degrades rapidly in the environment and 3) has limited toxicity to non-target organisms (based on the results from projects conducted in Rocky Mountain National Park, Great Basin National Park and Crater Lake National Park).

Table 1. Chemicals registered by the U.S. Environmental Protection Agency for use as general piscicides.

| Trade Name | Case Number | EPA Reg. Number | Active Ingredient | Formulation Type | Manufacturer |
|---|---|---|---|---|---|
| Antimycin A* | 1397-94-0 | | Antimycin A | | |
| Fintrol (Concentrate) | | 39096-2 | Antimycin A | Liquid | Aquabiotics Corp. |
| Rotenone* | 83-79-4 | | Rotenone | | |
| CFT Legumine | | 75338-2 | Rotenone | Liquid | Prentiss Inc. |
| Synpren-Fish | | 655-421 | Rotenone | Liquid | Prentiss Inc. |
| Prenfish | | 655-422 | Rotenone | Liquid | Prentiss Inc. |
| Prentox Fish Toxicant Powder | | 655-691 | Rotenone | Powder | Prentiss Inc. |

* Denotes chemical not product.

Although rotenone is often used to remove fish from lakes and streams in Washington State and other units of the national park system, it was not considered in the MLFMP over concerns about its toxicity to non-target organisms and to the people who apply it based on anecdotal information. Concerns were also raised about the effectiveness of rotenone in the cooler water temperatures found in mountain lakes. However, the MLFMP does not preclude the use of rotenone as long as an additional analysis of the environmental impacts were from the use of this chemical is completed (NPS 2008).

Since the MLFMP was completed in 2008, three factors have led NOCA to consider the use rotenone rather than antimycin in treating mountain lakes. First, as of March 2012, antimycin is not commercially available and current stocks have been depleted. The only supplier, Aquabiotics, is still looking for a production facility that can produce antimycin without the previous quality control issues, but has not yet found a viable option. Second, rotenone is more effective than antimycin in penetrating more dense layers in the thermal stratification of deeper lakes that are now on schedule for treatment. Third, concerns that prevented the NPS from more thoroughly considering the use of this chemical in the MLFMP have largely been negated or abated. The results from recent rotenone applications and toxicity testing have demonstrated that rotenone is not as toxic to non-target organisms and humans as was previously thought when the MLFMP was developed and new formulations of rotenone have reduced and/or eliminated many of the additives that were linked to increases in non-target organism mortality.

## Overview of Piscicides

### *Origin* *(adapted from NPS 2011)*
Both antimycin and rotenone are naturally derived products. Antimycin is a product of *Streptomyces griseus* bacteria with fungicidal properties (Lennon 1970; Vinson et al. 2010), while

rotenone is derived from the roots of numerous tropical plants from the pea (*Leguminosae*) family, (NIOSH 2000; Rayner and Creese 2006).

Rotenone

The earliest reference to the use of plant-derived piscicides dates back to Aristotle's Historia Animalium, in which he explains that the mullein plant placed in water will kill fish and noted that it was used as a fishing technique (Thompson 1910). The earliest records of traditional fishing with rotenone were from Brazil in 1649 and North America in 1775 (Krumholz 1948). In both cases, aboriginal peoples used rotenone-bearing plant materials to capture fish for consumption. Aboriginal societies have used rotenone for centuries, harvesting the chemical from the roots of legumes and applying it to localized areas as a form of subsistence fishing (Ball 1948; Ling 2003; Pellerin 2008). Rotenone was an effective way for traditional peoples to harvest fish as it poses little threat to human health through consumption (Betarbet et al. 2000; Robertson and Smith-Vaniz 2008), and has continued to be used, in addition to other fish toxins, as a traditional fishing method by aboriginal people's (Van Andel 2000; Kamalkishor and Kulkarni 2009).

The name rotenone comes from the plant that it was originally identified in, the Peruvian plant rotenone (Lonchocarpus sp.), locally known as barbasco or cube (St. Onge 2002). Rotenone was first isolated as a chemical compound in 1929,  and fisheries managers began to value it as a tool for eradication of undesirable fish species in the 1930s. In 1934, Michigan became the first state where rotenone was applied to treat lakes and ponds (Lennon 1970). It wasn't until the 1960s that fisheries managers began to use it for reclamation projects on rivers and streams, but every state except Hawaii had used rotenone by 1974 (Finlayson et al. 2000; McClay 2000). In addition to its piscicidal use, rotenone has been used world-wide as a pesticide on crops and livestock for over 150 years. It was first registered as a pesticide by the EPA in 1947 (Ling 2003), and Rotenone-based products have since been available as a general use pesticide for residential pest control throughout the United States for decades. However, re-registration for this use is not being pursued (EPA 2007b) it is believed for financial reasons.

Antimycin

Antimycin was discovered in 1945 (EPA 2007a). Produced by many species of *Streptomyces* bacteria, antimycin forms naturally and also has fungicidal properties. It was registered as a Restricted Use Pesticide by the EPA in 1960 and since then has been used solely as a piscicide (EPA 2007a). Of the three products with antimycin as the active ingredient that were originally registered by the EPA, only one, Fintrol, was available on the market before production ceased due to quality control and issues with lack of potency (Aquabiotics Inc., Vancouver, Washington) (Lennon 1970; EPA 2007a; Vinson et al. 2010).

### ***History of Piscicide Use*** *(adapted from NPS 2011)*

Of the general purpose piscicides licensed in the United States, rotenone has the longest history of use. As mentioned above, aboriginal peoples have applied rotenone for hundreds of years to collect fish for consumption (Ball 1948, Krumholz 1948). In conventional fisheries management, piscicides are commonly used for reduction or elimination of undesirable fish and for quantifying fish populations (McClay 2000, Robertson and Smith-Vaniz 2008, Vinson et al. 2010). The first application of rotenone in the U.S. for fisheries management occurred in 1934 (McClay 2000). While improving recreational fishing is sometimes the goal of piscicide use, this type of management action is not the proposed for NOCA. Piscicide use in NOCA is only proposed to eradicate non-native fish with the goals of restoring ecological integrity and protecting native fish species.

National Park Service *(adapted from NPS 2011)*
The NPS used rotenone for the first time in 1938, to remove yellow perch from Goose Lake in Yellowstone National Park and in 1946, the NPS used rotenone to remove non-native suckers from Bear Lake in Rocky Mountain National Park (Barrows 1939, Field 1946). Since then, piscicides have been used frequently in national parks to meet inland salmonid management goals (Table 2).

North Cascades National Park used piscicides for the first time in 2009 to successfully remove a non-native population of Eastern Brook Trout from two mountain lakes and a section of stream habitat that linked the two lakes.

Washington Department of Fish and Wildlife
Piscicides are used by the Washington Department of Fish and Wildlife (WDFW) to protect native fish populations (including threatened and endangered species) and improve recreational fishing. These goals are achieved through either the complete eradication of non-native fish or reduction of undesirable fish populations. Rotenone is the only piscicide applied by WDFW. The first rotenone treatment in Washington State took place in September 1940. Since that time, the WDFW has treated 514 state waters (6 lotic habitats, 508 lakes) at least once. On average, thirteen waters have been treated each year in Washington State by the WDFW (WDFW 2002, 2008).

### *Piscicide Action (adapted from NPS 2011)*
Both antimycin and rotenone function in the same manner in that they enter an aquatic organism's body through the gills where it is transferred directly into the blood stream (Wydoski and Wiley 1999, Ling 2003). Direct exposure to the blood stream contributes greatly to the toxicity of the chemicals. Antimycin and rotenone interfere with cellular respiration during the electron transport chain, inhibiting the cells' ability to make energy (Fukami et al. 1969, Quintanilha and Packer 1977, Finlayson et al. 2000, Durkin 2008). After prolonged exposure, this interruption of cellular respiration kills fish in treated waters. While the specific action of each chemical is slightly different, the result is the same. Rotenone, uncouples oxidative phosphorylation at complex I of the electron transport chain. Antimycin, a much more recently discovered piscicide, interferes at complex III, as shown in Figure 1(Quintanilha and Packer 1977, EPA 2007a, EPA 2007b).

### *Piscicidal Concentration*
The amount of chemical applied to a water body is an important factor in determining potential environmental impacts from application of these piscicides. Trout and char, the taxa introduced into mountain lakes in NOCA and the target for eradication, are very sensitive to both rotenone and antimycin which allows fisheries managers to treat lakes using very low concentrations of these piscicides. The typical concentrations that are needed to eradicate trout from the lakes in NOCA are 8 ppb active ingredient antimycin and 25 to 50 ppb active ingredient rotenone. To put this in context, adding one teaspoon of sugar into an Olympic sized swimming pool would equal a 40 ppb sugar solution. Piscicidal concentrations of rotenone and antimycin are not highly toxic to people, mammals or birds. For example, to obtain a lethal dose of rotenone at a piscicidal concentration an adult person would have to consume approximately 500,000 liters of water (1/5 the volume of an Olympic sizes swimming pool) in a single sitting.

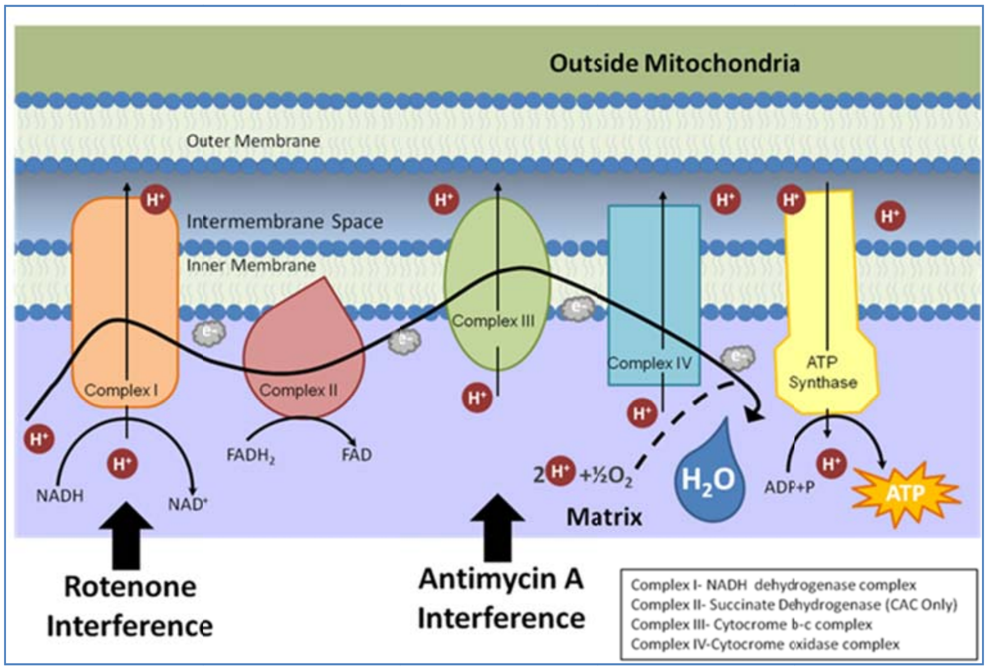
Table 2. A listing of piscicide applications for inland fisheries management conducted by the National Park Service (adapted from NPS 2011).

| Year | National Park | Location | Piscicide | Species Removed | Goal |
|---|---|---|---|---|---|
| 1938 | YELL | Goose Lake | Rotenone | Yellow perch | Enhance sportfishing |
| 1946 | ROMO | Bear Lake | Rotenone | Suckers | Restore native species |
| 1957 | GRSM | Abrams Creek | Rotenone | Native fish | Enhance sportfishing |
| 1957 | GRSM | Indian Creek | Rotenone | Native fish | Enhance sportfishing |
| 1958 | ROMO | Caddis Lake | Rotenone | Non-native cutthroat | Restore native species |
| 1965 | MORA | Tipsoo Lake | Rotenone | Non-native cutthroat | Restore native species |
| 1965 | YOSE | Delaney Creek | Rotenone | BKT | Non-native introduction |
| 1966 | YOSE | Upper and Lower Skeleton Lakes | Rotenone | BKT | Non-native introduction |
| 1966 | GLAC | Two Medicine Creek | Rotenone | Suckers | Enhance sportfishing |
| 1973 | ROMO | Hidden Valley Creek | Antimycin | BKT | Restore native species |
| 1975 | ROMO | Bear Lake | Antimycin | BKT | Restore native species |
| 1975 | YELL | Canyon Creek | Antimycin | BRN | Restore native species |
| 1977 | YELL | Pocket Lake | Antimycin | BKT | Restore native species |
| 1978 | ROMO | West Creek | Antimycin | BKT | Restore native species |
| 1979 | ROMO | Timber Lake and Creek | Antimycin | Non-native cutthroat | Restore native species |
| 1979 | SEKI | Hidden Lake and Soda Springs Creek | Antimycin | BKT | Restore native species |
| 1980 | ROMO | Ouzel Lake and Creek | Antimycin | BKT | Restore native species |
| 1982 | ROMO | Fern Lake and Creek | Antimycin | BKT | Restore native species |
| 1983 | ROMO | Lawn Lake and Roaring River | Antimycin | BKT | Restore native species |
| 1985 | YELL | Arnica Creek | Antimycin | BKT | Restore native species |
| 1985 | ROMO | Bench Lake and Ptarmigan Creek | Antimycin | Non-native cutthroat | Restore native species |
| 1986 | ROMO | N.F. Big Thompson River | Antimycin | BKT | Restore native species |
| 1986 | ROMO | Lake Husted and Lost Lake | Antimycin | BKT | Restore native species |
| 1986 | MORA | Tipsoo Lake | Antimycin | RBT | Restore native species |
| 1987 | PIRO | Spray Creek | Rotenone | BKT | Restore native species |
| 1987 | PIRO | Section 34 Creek | Rotenone | BKT | Restore native species |
| 1987 | ROMO | Lower Hutcheson Lake and Cony Creek | Antimycin | CTX | Restore native species |
| 1988 | ROMO | Pear Lake and Cony Creek | Antimycin | CTX | Restore native species |
| 1988 | ROMO | Sandbeach Lake | Antimycin | RBT | Restore native species |
| 1990 | ROMO | Spruce and Loomis Lake | Antimycin | RBT | Restore native species |
| 1996 | ROMO | Dream Lake | Antimycin | CTX | Restore native species |
| 2000 | GRBA | Strawberry Creek | Rotenone | RBT, BKT | Restore native species |
| 2000 | CRLA | Sun Creek (upper) | Antimycin | BKT | Restore native species |
| 2000 | GRSM | Sams Creek | Antimycin | RBT | Restore native species |
| 2002 | GRBA | Snake Creek | Antimycin | BKT | Restore native species |

| Year | National Park | Location | Piscicide | Species Removed | Goal |
|---|---|---|---|---|---|
| 2003 | GRSM | Bear Creek | Antimycin | RBT | Restore native species |
| 2004 | GRBA | Johnson Lake | Antimycin | BKT | Restore native species |
| 2005 | GRSM | Indian Flats Prong | Antimycin | Hatchery BKT | Restore native species |
| 2006 | YELL | High Lake | Rotenone | CTX | Restore native species |
| 2008 | GRSM | Lynn Camp Prong | Antimycin | RBT | Restore native species |
| 2008 | YELL | Specimen Creek | Rotenone | CTX | Restore native species |
| 2009 | NOCA | Middle and Lower Blum Lake | Antimycin | BKT | Restore native species |
| 2011 | YELL | Goose, Gooseneck, Unnamed (Goose) Lakes and 2.5 miles of stream | Rotenone | RBT | Restore native species |
| 2012 | CRLA | Sun Creek (lower) | Antimycin | EBT | Restore native species |

Arctic grayling (GRY), Bonneville Cutthroat Trout (BCT), Eastern Brook Trout (BKT), Brown Trout (BRN) Colorado River Cutthroat Trout (CRC), Cutthroat hybrids (CTX), Golden Trout (GLT), Greenback Cutthroat Trout (GBC), Piute Cutthroat Trout (PCT), Rainbow Trout (RBT), Westslope Cutthroat Trout (WCT), Yellowstone Cutthroat Trout (YCT)

Figure 1. Locations of piscicidal interference in cellular respiration in the electron transport chain; Complex I for rotenone and III for antimycin (Quintanilha, A.T. and L. Packer 1977).



## The Proposed Action

North Cascades National Park is proposing to use CFT Legumine™, a rotenone based piscicide, to remove non-native trout (specifically Brown Trout, Eastern Brook Trout, non-native Rainbow Trout and non-native Cutthroat Trout) from a series of lakes identified in the park's Mountain Lakes Fisheries Management Plan (MLFMP). During the development of the MLFMP, antimycin was identified as the preferred piscicide for the eradication of non-native fish populations, however, antimycin is not currently commercially available and all stocks have been depleted. While using piscicides is consistent with the MLFMP, using rotenone instead of antimycin constitutes a change that requires additional analysis to ensure compliance with the National Environmental Policy Act.

### The Proposed Piscicide

The proposed piscicide, CFT Legume™, is a liquid formulation of rotenone. CFT Legume™ has several advantages over other formulations of rotenone, including a new emulsifier and solvent that reduce the amounts of petroleum hydrocarbon solvents. The hydrocarbons in other rotenone products are highly volatile, resulting in an odor that fish may avoid. This behavioral response is believed to have caused incomplete fish kills and unsuccessful treatments in past applications. Additionally, CFT Legume™ does not contain the synergist piperonyl butoxide which has been demonstrated to increase toxicity to aquatic invertebrates (Finlayson et al. 2010b).

### Application Methods and Rates

Considering the piscicidal concentrations discussed previously, the NPS would introduce CFT Legume™ to NOCA mountain lakes at a piscicidal concentration of 0.5 to 1.0 ppm which would deliver 25 to 50 ppb of active ingredient (ai) rotenone.

CFT Legume™ would be mixed on shore and applied to lakes and streams using boats, backpack sprayers and drip stations. Aerial applications are not being considered within this project proposal. The application methods for rotenone and antimycin are identical and are therefore not covered in this analysis.

### Piscicide Neutralization *(adapted from NPS 2011)*

The neutralization methods for antimycin and rotenone are identical. Both antimycin and rotenone can be readily neutralized with an oxidizing agent, most commonly potassium permanganate ($KMnO_4$), or with other agents such as chlorine bleach and sodium permanganate. For piscicide applications in NOCA, 1 ppm of $KMnO_4$ for every 1 ppm of rotenone formulation used would be applied at the most downstream point where fish removal is desired. In addition to the 1 ppm $KMnO_4$ used to neutralize the rotenone, another 1 ppm would be applied to satisfy the background oxidation demand and another 1 ppm as residual or buffer. In cases where the background demand is more than 1 ppm $KMnO_4$, more neutralizing agent would be used. The typical target concentration for neutralizing a piscicide treatment in a stream is therefore 3 ppm, but in cases where background demand is high it could range up to 5 ppm. Neutralization occurs within 30 minutes of contact between the treated water and the $KMnO_4$, so fish and other aquatic organisms may still be affected by piscicide in outlet streams within the distance that water moves downstream in 30 minutes. This distance would be considered part of the project area and is estimated to typically include a half mile of stream below the treatment area.

Monitoring the efficacy of piscicide neutralization using $KMnO_4$ is done in two ways: (1) placing sentinel fish at 30 and 60 minutes of travel time downstream from the neutralization station and monitoring them for signs of rotenone stress, and (2) measuring the $KMnO_4$ in the water with a pocket colorimeter. Both monitoring methods must be done to ensure that $KMnO_4$concentrations are not too high or low. Given the 30 minutes of contact time to neutralization and the background demand of water, concentrations of $KMnO_4$ should be measured at the 30-minute sentinel cage. At that point the rotenone should be neutralized and the background demand satisfied, so only the 1 ppm residual $KMnO_4$ should be present in the water. If concentrations are less than 1 ppm $KMnO_4$ and fish show signs of stress, it is most likely due to un-neutralized rotenone and the $KMnO_4$ concentration should therefore be increased. If the $KMnO_4$ concentration is significantly higher than 1 ppm and fish show signs of stress, it is most likely a toxic effect from the $KMnO_4$ and the treatment concentration should be reduced.

Potassium permanganate is toxic to aquatic and terrestrial organisms. Much like with rotenone, aquatic organisms display a range of tolerance to $KMnO_4$. The 96-hour $LC_{50}$ for trout is 1.22–1.8 ppm (Phillips et al. 2005), which is why neutralization concentrations at 30 minutes of contact time may cause stress to sentinel fish. The EPA (USFWS and CDFG 2009) cites 1–2 ppm as the concentration at which $KMnO_4$ is toxic to aquatic organisms. This means that normal stream treatments will likely have an adverse impact on aquatic organisms from the neutralization station to 30 minutes of travel time downstream of the station due to $KMnO_4$.This area would be considered part of the affected treatment area for the project, and fish as well as non-target organisms would be monitored in this area. Potassium permanganate does not travel long distances downstream and is not persistent in the environment because it is quickly reduced through natural processes (USFWS and CDFG 2009).

While $KMnO_4$ could be toxic to terrestrial organisms at high concentrations, the chemical is routinely used to treat potable water supplies for organic contaminants, iron, manganese, sulfides, and undesirable colors and odors (USFWS and CDFG 1994) and would not amount to those levels within the proposed action.

Application of $KMnO_4$ to piscicide-treated waters would be accomplished through metered dispensation stations that apply a concentrated liquid directly to piscicide-treated waters. Safety guidelines for handling $KMnO_4$ are provided by the Material Safety Data Sheet and include the use of gloves, goggles, and a particulate filtering respirator. All guidance set forth by the MSDS would be followed for transportation, storage, and handling of $KMnO_4$ during proposed treatments in the park.

# Environmental Analysis

A chemical's toxicity to non-target organisms and persistence in the environment are major considerations in determining the potential risks to human health and the environment from its application and use. Several factors influence rotenone and antimycin toxicity and persistence including the chemical formulation, piscicidal concentration, water temperature, pH, and lake stratification.

### Environmental Fate

Both rotenone and antimycin break down into nontoxic substances when they are exposed to water, sunlight, heat, alkalinity, turbulence and organic matter (Bradbury 1986, Gilderhaus et al.

1982, Gilderhaus et al. 1988, Gresswell 1991, Ling 2003, Finlayson et al. 2001, Brown 2010). It is reasonable to assume that because antimycin and rotenone are both derived from natural substances that both of these compounds will breakdown into naturally occurring constituent components and the EPA has determined that the long-term persistence of both piscicides are not a concern (EPA 2007a, 2007b).

Several studies have demonstrated that the degradation of antimycin and rotenone occur rapidly, however the rate of decay is slower for rotenone than antimycin (Table 3). Lab and field studies indicate that two of the primary factors affecting the rate of decay for rotenone in NOCA will be water temperature and water depth. Rotenone degrades at a slower rate as water temperatures decrease and as depth increases (Table 3). Bradbury (1986) assessed the persistence of rotenone in 113 lakes that were treated in Washington State from 1977 through 1984 and found that on average, rotenone remained toxic to fish for 4.6 weeks in Eastern Washington and 4.8 weeks in Western Washington with a state wide range of 0.5 to 11 weeks. While Bradury (1986) did not provide reasons for the variability of rotenone toxicity, it's possible that it was related to the concentrations of rotenone that were used. Bradbury (1986) cited elsewhere in his report that rotenone treatment concentrations ranged from 20 to 225 ppb in Washington State from 1977 through 1984 (the concentration proposed in NOCA is 25-50ppb, atleast 22% less than the highest concentration used in Bradbury's study). The California Department of Fish and Game evaluated the breakdown of rotenone under field conditions by monitoring nine rotenone projects conducted in ten lakes and reservoirs and seven streams. They found that rotenone applied at concentrations up to four times higher than those planned for at NOCA degraded to non-detectable levels in surface waters within three weeks and that no rotenone residues were detected below detoxification stations (Finlayson et al. 2001). In their review of the literature, Yellowstone National Park found that the longest reported persistence of rotenone in a lake was 160 days (EPA 2007b in NPS 2011). However, it is important to note that this was in a lake with cold water treated with 250 ppb of rotenone, a concentration five times higher than the proposed piscicidal concentration that would be used in implementation of the MLFMP and the proposed action. Testing conducted in two deep, cold-water lakes after

Table 3. Degradation rates of antimycin and rotenone.

| Piscicide | Mechanism | Temperature (°C) | pH | Depth | Half Life (water column) | Source |
|---|---|---|---|---|---|---|
| Antimycin | Hydrolysis (lab) | 25 | 7 | NR | 3 days | USEPA 2006 |
| Antimycin | Hydrolysis (lab) | NR | 7 - 8 | NR | 5.5 hours | USEPA 2006 |
| Antimycin | Hydrolysis (lab) | NR | 7.55 | NR | 46 hours | USEPA 2006 |
| Antimycin | Hydrolysis (lab) | NR | 7 | NR | 7.1 hours | USEPA 2006 |
| Rotenone | Hydrolysis (lab) | 25 | 7 | NR | 3.2 days | USEPA 2006 |
| Rotenone | Phytolysis (lab) | 25 | NR | 1 cm | 21 hours | USEPA 2006 |
| Rotenone | Phytolysis (lab) | 25 | NR | 2 m | 191 days | USEPA 2006 |
| Rotenone | Field Application | 5 | NR | NR | 20 days | USEPA 2006 |
| Rotenone | Field Application | 23 - 27 | NR | NR | 10.6 hours | USEPA 2006 |
| Rotenone | Field Application | 0 - 5 | 8.62 | < 1 m | 10.3 days | Gilderhaus et al. 1988 |
| Rotenone | Field Application | 23 - 27 | 8.35 | < 1 m | 0.94 days | Gilderhaus et al. 1988 |
| Rotenone | Field Application | 10 - 22 | 8.3 | 30 m | 3.5 days | Finalyson et al. 2001 |
| Rotenone | Field Application | 1 - 12 | 7.5 - 9.2 | 33 m | 7.7 days | Finalyson et al. 2001 |
| Rotenone | Field Application | 5 - 11 | 7.7 | > 1 m | 2.9 days | Finalyson et al. 2001 |

a rotenone treatments, Lake Davis in California and Diamond Lake in Oregon, revealed that rotenone fell below detection limits (2 ppb) within thirty-nine days (USEPA 2006c; David Lumis, Oregon Department of Fish and Wildlife, Project Manager, telephone communication, May 15, 2007 in Turner et al. 2007). Based on this information and guidance obtained from the American Fisheries Society manual on rotenone treatments (Finlayson et al. 2000), rotenone could remain toxic to gill breathing organisms in the surface of NOCA's lakes for and up to four weeks after an application.

### *Acute Toxicity*

Several sources of information were used to evaluate the toxicity of rotenone and antimycin. The primary sources of information were the Environmental Protection Agency's (EPA) ECOTOX data base (accessed on-line at http://cfpub.epa.gov/ecotox/ April 2012) and the EPA's supporting data related to the registration of rotenone and antimycin (accessed on-line at http://impcenters.org/Ecotox/index.cfm April 2012). Both of these sources were supplemented with relevant peer reviewed scientific literature and government reports. Our evaluation of acute toxicity was limited to $LC_{50}$ after 96 hours of exposure for taxa that are representative of taxa found in NOCA waters. Records that did not include information about the concentration of the active ingredient (ai) were excluded to minimize erroneous conclusions about a piscicide's toxicity.

Salmonids

Salmonids (including trout and char) are the most sensitive taxa to both rotenone and antimycin (Table 4). This characteristic makes both of these compounds highly desirable for controlling non-native fish populations in NOCA's lakes since they are highly specific and minimize the mortality to non-target organisms. Both rotenone and antimycin are classified as very highly toxic to salmonids by the USEPA based on lethal concentration values that kill fifty percent of the organisms, exposed for 96 hours ($LC_{50}$). While rotenone is less toxic than antimycin to both fish and other non-target organisms the piscicidal concentration for eradicating trout is higher for rotenone (up to 50ppb rotenone vs. 8ppb antimycin).

Table 4. Lethal concentration values of a piscicides active ingredient (ai) for several salmonid taxa that killed 50 percent of the test population when exposed to rotenone or antimycin for 96 hours. The piscicidal concentrations of antimycin and rotenone proposed for use as part of the MLFMP is 8 ppb and 50 ppb respectively.

| Piscicide | Species | 96-hour $LC_{50}$ ppb ai | Source |
|---|---|---|---|
| Antimycin | Brook Trout | 0.03-0.06 | Berger et al. 1969 |
| Antimycin | Cutthroat Trout | 0.057 | USEPA |
| Antimycin | Rainbow Trout | 0.012 | USEPA |
| Rotenone | Brook Trout | 47.0 | USEPA |
| Rotenone | Brook Trout | 44.3 | Marking and Bills 1976 |
| Rotenone | Rainbow Trout | 0.84-52.0 | USEPA |
| Rotenone | Rainbow Trout | 3.1-46.0 | Marking and Bills 1976 |

Microbes

No data are available to assess the toxicity of either antimycin or rotenone to microbes. However, since antimycin is closely related to compounds used as antibiotics it is likely that it would have some effects on bacteria.

Algae and Aquatic Macrophytes

Neither antimycin nor rotenone are expected to have effects on algae or aquatic plants since the action of these chemicals takes place in the mitochondria disrupting cellular respiration, and plants do not have mitochondria. Circumstantial information supports this contention (Bradbury 1986, Berger 1969, Walker et al. 1964), however, no standardized data are available to access the toxicity of either antimycin or rotenone to algae. Additionally, since rotenone has been used as a pesticide on terrestrial crops it would be surprising to see it adversely impact aquatic macrophytes.

Aquatic Invertebrates

Aquatic invertebrates (insects and zooplankton) have a wide range of sensitivities to rotenone and antimycin. More is known about the response of invertebrates to rotenone than antimycin, and in general, laboratory toxicity testing of rotenone has found that 1) benthic invertebrates are less sensitive than zooplankton, 2) smaller sized organisms are more sensitive than larger organisms, 3) invertebrates that use gills to respire are more sensitive than those that respire via other means (lamella, spiracles or breathe directly from the atmosphere), and 4) stream and river invertebrates are more sensitive than lake invertebrates (Vinson et al. 2010).

Based on the data queried from the USEPA ECOTOX database, taxa representative of those found in NOCA were found to be less sensitive to rotenone than trout (Table 5) indicating that many of these organisms would survive a treatment with a piscicidal concentration of 50 ppb ai. These data are consistent with the results from two recently conducted studies (Hamilton et al. 2009, Finlayson et al. 2010). In their study, Finlayson et al. (2010) found that six representative taxa of mayflies, stoneflies and caddisflies were more resistant to rotenone than fish and that four of these taxa had 8-hour $LC_{50}$ values greater than a piscicidal concentrations of rotenone of 50 ppb ai. This study also found no significant differences in benthic invertebrate richness (including the number of rare taxa) between sites treated with rotenone and a control location. Hamilton et al. (2009) compared piscicide treatments in streams using synergized rotenone and antimycin. They found that both piscicides had large short-term impacts on benthic invertebrate communities but that these communities recovered over time (within one year for antimycin and up to three years for rotenone).

Results from rotenone treatments and whole lake experiments indicate that most invertebrate populations will recover after exposure to piscicidal concentrations of rotenone (Blakely et al. 2005, Havens 1980). An experiment conducted with a paired set of four wetlands (treated and untreated) found that exposure to rotenone at 300 ppb (a concentration six times higher than the piscicidal concentration proposed at NOCA) primarily resulted in only short-term decreases in the abundances of most zooplankton taxa. No significant response was detected in the benthic invertebrate community and most zooplankton taxa recovered seven months after the exposure to rotenone (Melaas et al. 2001).

Vinson et al. (2010) reviewed published laboratory toxicity tests and twenty-two field studies that examined the effects of rotenone on invertebrate communities in lakes, rivers, and streams. They found that zooplankton abundances recovered to pretreatment abundances between one month to three years and that species assemblages can recover within six months of a piscicidal treatment. They also found that benthic invertebrate communities in lakes demonstrated similar recovery patterns with recovery times ranging between six months to one year.

Table 5.Lethal concentration values of a piscicides active ingredient (ai) for several non-target organisms of invertebrates that killed 50 percent of the test population when exposed to rotenone or antimycin for 96 hours. The piscicidal concentrations of antimycin and rotenone proposed for use as part of the MLFMP are 8 ppb and 50 ppb respectively.

| Piscicide | Taxa | 96-hour $LC_{50}$ ppb ai | Source |
|---|---|---|---|
| Antimycin | Crustacean - Benthic (*Gammarus fasciatus*) | 0.008 | USEPA |
| Antimycin | Crustacean – Benthic (*Gammarus pseudolimnaeus*) | 7.2 - 9.0 | USEPA |
| Antimycin | Crustacean - Benthic (*Asellus brevicaudus*) | >1.0 | USEPA |
| Antimycin | Crustacean - Benthic (*Hyalella azteca)* | 1.4 | USEPA |
| Antimycin | Crustacean - Zooplankton (*Daphnia magna*) | <10 | USEPA |
| Antimycin | Insect - Benthic (*Chironomus tentans*) | 0.15 | USEPA |
| Antimycin | Mollusk - Clam (*Corbicula manilensis*) | 65-86 | USEPA |
| Antimycin | Mollusk - Snail (*Viviparus bengalensis*) | 5.8 | USEPA |
| Antimycin | Tubellaria - Flat Worm (*Dugesia dorotocephala*) | 15 | USEPA |
| Rotenone | Crustacean - Benthic (*Gammarus lacustris*) | 3,520 | USEPA |
| Rotenone | Crustacean – Zooplakton (*Cyridopsis* sp.) | 340 | USEPA |
| Rotenone | Crustacean - Benthic (*Gammarus fasciatus*) | 2,600 | USEPA |
| Rotenone | Insect - Beetle (*Gyrinus* sp.) | 700 | USEPA |
| Rotenone | Insect – True Bug (*Notonecta* sp.) | 1,580 | USEPA |
| Rotenone | Insect - Caddisfly (*Hydropsyche* sp.) | 605 | USEPA |
| Rotenone | Insect - Dragonfly (*Macromia* sp.) | 1,000 | USEPA |
| Rotenone | Mollusk - Clam (*Corbiculamanilensis)* | 7,500 | USEPA |
| Rotenone | Mollusk - Snail (*Physapomilia*) | 4,000 | USEPA |
| Rotenone | Turbellaria - Flat Worm (*Catenula* sp.) | 1,720 | USEPA |

Amphibians

Amphibians are most sensitive to piscicides during their larval (gill-breathing) life history stage (Gilderhus et al. 1969, Ling 2003, Grisak et al. 2007), and piscicide treatments using either rotenone or antimycin would likely have impacts on larval amphibians when they are present (Table 6). Tailed frogs are particularly sensitive to piscicides even as adults. Both of these conditions elevate the importance of piscicide deactivation below treatment areas.

Table 6. Lethal concentration values of a piscicides active ingredient (ai) for several amphibian species that killed 50 percent of the test population when exposed to rotenone or antimycin for 96 hours. The piscicidal concentrations of antimycin and rotenone proposed for use as part of the MLFMP are 8 ppb and 50 ppb ai respectively.

| **Piscicide** | **Taxa** | **96-hour $LC_{50}$ ppb ai** | **Source** |
|---|---|---|---|
| Antimycin | Columbia Spotted Frog (adult) (*Rana luteiventris*) | 192 | USEPA |
| Antimycin | Long-toed Salamander (larvae) (*Ambystoma macrodactylum*) | 81.7 | USEPA |
| Antimycin | Tailed Frog (adult) (*Ascaphus truei)* | 13.7 | USEPA |
| Rotenone | Boreal Toad (larvae) (*Anaxyrus boreas*) | 25-50 | Billman et al. 2011 |
| Rotenone | Columbia Spotted Frog (larvae) (*Rana luteiventris*) | 25-50 | Billman et al. 2011 |
| Rotenone | Leopard Frog (adult) (*Rana pipiens*) | 3,200-4,600 | USEPA |
| Rotenone | Long-toed Salamander (adult) (*Ambystoma macrodactylum*) | 3,500 | Grisak et al. 2007 |
| Rotenone | Long-toed Salamander (larvae) (*Ambystoma macrodactylum*) | <230 | Grisak et al. 2007 |
| Rotenone | Southern Leopard Frog (larvae) (*Rana sphenocephala*) | 500 | USEPA |
| Rotenone | Spotted Frog (adult) (*Rana luteiventris*) | 9,650 | Grisak et al. 2007 |
| Rotenone | Tailed Frog (larvae) (*Ascaphus truei)* | 9 | Grisak et al. 2007 |

Because the $LC_{50}$ levels for adult amphibians are several times higher than piscicidal concentrations, impacts to the reproductive class of these are organisms is not expected. Several projects have documented the rapid recolonization of amphibian populations after piscicide treatments using rotenone and antimycin (DeMong 2001, DOI 2007, Koel et al. 2008, Reed Glesne, Lead Aquatic Ecologist NOCA, interview, 10-2-2011).

Recent findings have illustrated that rotenone toxicity to larval stages of amphibians is more nuanced than simple interpretations of 96 hour LC50 values. In their study, Billman et al. (2011) found that older stages of larval frogs and toads are more tolerant to rotenone and that rotenone treatments using less than 50 ppb ai will result in reduced morality to these organisms. These results imply that the proposed piscicidal concentrations of rotenone for use in NOCA may not kill all age classes of amphibian larvae when they are present, and if sensitive amphibians are present in a proposed treatment area, managers have the option of using lower rotenone concentrations (e.g. 40 ppb instead of 50 ppb) to reduce the impacts to these organisms.

Terrestrial Organisms

The route of piscicide exposure for terrestrial organisms is either through ingestion or dermal contact. Ingestion can potentially occur when animals eat the tissue of fish killed during a piscicide treatment or drink treated water. Extensive toxicology studies have been conducted to assess the effects of piscicides on terrestrial wildlife. Many of these data have been used by Turner et al. (2007a, 2007b) in risk assessments of rotenone and antimycin applications for the

Washington Department of Fish and Wildlife. In their risk assessments Turner et al. (2007a, 2007b) found the acute oral $LD_{50}$ for both piscicides to be many times higher than piscicidal concentrations for birds and mammals (Table 7). The EPA (2006a) found that Rainbow Trout killed by antimycin has antimycin concentrations of 172 μg/Kg of body weight or a concentration of 0.172 ppm. In a similar environmental fate study, the EPA (2006c) found that rotenone had a low potential for bioaccumulation and Turner et al. 2007 "conservatively suggest a maximum exposure concentration of about 0.7 ppm." These finding indicate that mammal and avian consumption of fish killed with either rotenone or antimycin would have no effect on the health of these organisms.

Table 7. Lethal dose values of a piscicides active ingredient (ai) for several bird and animal species that killed 50 percent of the test population when administered an oral dose. The piscicidal concentrations of antimycin and rotenone proposed for use as part of the MLFMP are 8 ppb and 50 ppb ai respectively.

| Piscicide | Taxa | Oral $LD_{50}$ (mg/Kg body weight) |
|---|---|---|
| Antimycin | Mallard Duck (*Anas platyrhynchos*) | 2.9 |
| Antimycin | Bobwhite Quail (*Colinus virginianus*) | 39 |
| Antimycin | Rat (female) (*Rattus norvegicus)* | 361 |
| Antimycin | Rat (male) (*Rattus norvegicus)* | 286 |
| Rotenone | Mallard Duck (*Anas platyrhynchos*) | 2,200 |
| Rotenone | Ring-neck Pheasant (*Phasianus colchicus*) | 1,680 |
| Rotenone | Rat (female) (*Rattus norvegicus)* | 39.5 |
| Rotenone | Rat (male) (*Rattus norvegicus)* | 102 |

### *Additives*

Liquid formulations of rotenone (CFT Legumine™) and antimycin (Fintrol™) contain additives to increase their dispersion in water. As mentioned earlier, CFT Legume™ has several advantages over other formulations of rotenone, including a new emulsifier and solvent that reduce the presence of petroleum hydrocarbon solvents and it does not contain piperonyl butoxide was is an additive older forumlations of rotenone. At piscicidal concentrations, the additives occurring in CFT Legumine™ are found in exceeding low concentrations and have not been demonstrated to cause elevated risks relative to the risk posed by rotenone itself (Durkin 2008).

## Human Health

### *Exposure Pathways, Duration and Risk* *(adapted from NPS 2011)*

The exposure pathway is a significant factor in the risk posed by any chemical to humans or other organisms and the exposure pathways that pose the most risk for humans are the same for antimycin and rotenone. In general, the more direct the pathway into the bloodstream, the greater the risk. Thus, intravenous, respiratory, and subcutaneous pathways of exposure are very dangerous. Ingestion can also be dangerous but may be mitigated by the body's ability to degrade the toxin in the digestive tract. Dermal exposure can result in toxic effects but is a much less direct pathway into the body and therefore generally presents a lower risk. At NOCA, the primary pathways of exposure for rotenone application would be through dermal contact with rotenone and/or ingestion with either the concentrated piscicides and/or diluted piscicidal concentrations after they have been applied to lakes and streams.

A second important factor in assessing the risk of a chemical to humans or the environment is the concentration at which the chemical is used. The piscicide proposed for use in NOCA is CFT Legume which contains 5% active ingredient rotenone in the undiluted products. While the product prior to application would be in its most concentrated form, application rates would range from 25 to 50 parts per billion (ppb), respectively. The planned target concentration for CFT Legumine when used for trout eradication is 1 ppm formulation or 50 ppb active ingredient. That means that 1 gallon of CFT Legumine effectively treats more than 300,000 gallons of water. This extremely low concentration can be used because fish are very sensitive to rotenone and they are exposed to the chemical through a respiratory pathway (see Piscicidal Concentration).

Duration of exposure is also important in assessing the risk a chemical poses to humans. Most exposure to both rotenone and antimycin is expected to be short-term (1-30 days). Exposure that lasts no more than 96 hours generally requires higher chemical concentrations to cause toxic effects (Newman and Unger 2003) than does chronic exposures (WHO 2001). The application of piscicides as proposed in implementing the MFFMP is very unlikely to result in chronic exposure (> 6 months) to humans or the environment because duration treatment in streams is short (8 hours maximum) and the persistence in the surface of lakes will last less than a month. Considering these factors, the EPA (2006a) has determined that long-term exposure is not a concern for rotenone. In streams, the piscicide is present during the application and for the short time it takes to be flushed out of the system, neutralized, or naturally broken down. Rotenone can persist for longer periods in lakes, from a few days to several weeks depending on the temperature and depth of the lake, with longer persistence in colder deeper water. The longest reported persistence of rotenone documented in a lake was 160 days (EPA 2007b), but that was a cold-water lake treated to 250 ppb rotenone, five times higher concentrations than proposed for implementation of the MLFMP.

The two groups of people for whom piscicide exposure is a concern are the piscicide applicators and the general public who may use a treated lake or a section of stream in the project area. Because piscicides are restricted use pesticides and a certification from the Washington Department of Agriculture is required to handle them, the general public has almost no risk of coming into contact with undiluted piscicides due to NOCA's secure storage, transportation, and labeling practices. Piscicide applicators, however, are routinely exposed to undiluted products.

Liquid piscicides are the only proposed formulations that will be used in implementing the MLFMP. Risks posed by liquid piscicides are largely from dermal and ingestion pathways. All piscicide MSDS and labels recommend or require the use of respirator, goggles, gloves and a Tyvek suit or apron. When handling undiluted liquid piscicides, NPS staff would always wear respirators and meet or exceed the other PPE requirements set forth in the product labels. Undiluted product would always be measured and dispensed by certified applicators, as these steps pose the greatest risk of human contact. Trained project staff other than certified applicators would only come into contact with undiluted liquid piscicide when mixing a pre-measured amount of product into a dispensing station, reservoir, or backpack sprayer during a treatment. After it has been diluted to the level used during application, the liquid piscicide would still only be handled by certified applicators and trained project staff wearing the required PPE. Following application to project waters, rotenone would become extremely dilute (≤1 ppm formulation; ≤ 50 ppb active ingredient), significantly reducing but not eliminating the dermal and ingestion risk.

After application to project waters, piscicides pose a significantly reduced risk because of their extremely low concentrations (AFS 1985; Finlayson et al. 2000). Product labeling provides guidance and restrictions for use near drinking water supplies and for public re-entry following piscicide application, and none of the waters to be treated with piscicides are close to sources of drinking water. Public awareness is the most important means of limiting piscicide risk to human health. Project areas would be closed for fourteen days following piscicide treatments and park staff would use press releases, signage, and neutralization following treatment of project waters to reduce the risk of public contact with the chemicals. Additionally, all equipment is triple rinsed before removed from the project area to reduce the potential of accidental contact by people not wearing personal protective equipment.

### *Human Health Effects*

Even with the most careful practices and detailed planning, complete elimination of the potential for human exposure to piscicides is not possible. Therefore, it is important to understand the risks posed by piscicides in the case of human exposure. Because very little direct evidence concerning the effects of piscicides on humans exists, animal models are often substituted for toxicological trials and the results are extrapolated to apply to humans. Information from risk analyses conducted by the World Health Organization (WHO 2004), the American Fisheries Society (Finlayson et al. 2000), the Environmental Protection Agency (EPA) (2007a and 2007b), the State of Washington (Turner et al.2007a and 2007b), the United States Forest Service (Durkin 2008), the Federal Government of New Zealand (Ling 2003), and the National Park Service (Moore et al. 2008) is summarized below, along with information from federal and state environmental compliance documents, peer reviewed literature, and other scientific publications.

In a review of incidents of human exposure to rotenone for all previously registered uses (piscicidal, agricultural, and residential), the EPA (2007b) found that eye irritation was the most commonly reported symptom. Also common were dermal irritation, throat irritation, nausea, and coughing. Less common but more severe symptoms, including headache, dizziness, peripheral neuropathy, numbness, and tremor, have occasionally been reported (EPA 2007b). The EPA (2007b) also noted that "No fatalities or systemic poisonings were reported in relation to ordinary use." Estimates of the acute oral lethal concentration of rotenone range from 300 to 500 mg/kg (Gleason et al. 1969; USFWS 2005; EPA 2007b; Durkin 2008; USFWS and CDFG 2009).The World Health Organization (WHO 2004), which ranks pesticides as slightly, moderately, highly, and extremely hazardous based on their oral and dermal toxicity, ranked rotenone as moderately toxic to humans (oral LD50 200–2000 mg/kg).

In their review of the literature, Yellowstone National Park, found two cases of human fatality from exposure to rotenone-based pesticide (NPS 2011). One fatality occurred when a child accidentally ingested Galicide, a 6% rotenone product that was registered in Europe for external use on animals (not a fisheries management product) that is no longer available (Hisata 2002).

The dose was estimated to be 40 mg/kg, significantly less than the expected lethal dose. Other constituents (etheral oils) in Galicide allegedly promoted abnormal rotenone absorption from the gastrointestinal tract and caused kidney failure that reduced the body's ability to clear the toxicant (DeWilde et al.1986; EPA 1999). The second occurred when an adult woman with type 2 diabetes intentionally ingested 200 ml of a 0.8% rotenone product commercially available in the United Kingdom (Wood et al. 2005); the estimated rotenone dose was 25 mg/kg.

No human fatalities have been associated with rotenone used for fishery management projects (Gleason et al. 1969; CDFG 1994; Ling 2003), nor could any evidence be found of human fatalities related to antimycin. Assuming a lethal dose of 25 mg/kg of concentrated rotenone for humans (Wood et al. 2005), a person would have to consume 500 times their body weight in treated water (50 ppb) to achieve that dose. If ingestion or inhalation of rotenone occurs, the National Institute for Occupational Safety and Health (NIOSH 2000) indicates that the symptoms of both are easily treatable.

Rotenone is not considered carcinogenic, teratogenic, or an endocrine disruptor (USEPA 2006). In fact, some evidence suggests that rotenone may be useful in treating certain kinds of cancers (Fang and Casida 1998, from Ling 2003). Chronic effects of rotenone exposure are not well documented, but one study that administered oral doses of up to 75mg/kg to mice found no observed changes in their brains after two years (Marking 1988). This study and others indicate that chronic exposure to piscicidal concentrations of rotenone, would pose little threat to human health (Siegler and Pillsbury 1946; Hansen et al. 1965; Durkin 2008).

A potential connection between rotenone and Parkinson's disease has emerged as a significant human health concern in the last 10 years. Parkinson's disease (PD) is a degenerative neurological disorder associated with a decrease in the production of the neurotransmitter dopamine. The cause of the disease is poorly understood, but genetic predisposition, exposure to environmental toxins, drug use, and severe head trauma may contribute to the risk of developing PD. In a study published by Emory University, several weeks of exposure to rotenone administered intravenously to the jugular veins of rats produced physical and neurological symptoms similar to PD (Betarbet et al. 2000). Another article, published simultaneously, used the findings of that study to infer that additional questions were likely to be raised about the safety of rotenone, but the role of rotenone in causing PD remains to be determined (Giasson and Lee 2000). In fact, the authors of the original study noted that "rotenone seems to have little toxicity when administered orally," indicating that oral exposure did not produce PD-like symptoms. A more recent study concluded that a 30-day inhalation of rotenone does not cause PD symptoms in mice and rats (Rojo et al. 2007). These studies demonstrate the differential risk posed by varied exposure pathways.

Since the original study, many others have used the rotenone-PD model to advance scientific research on the disease (Betarbet et al. 2000, Giasson et al. 2000, Gao et al. 2003, Sherer et al. 2003, Panov et al. 2005, Höglinger et al. 2006, Rojo et al. 2007). The intravenous and subcutaneous exposure of rats to rotenone provides a valuable model for studying PD-like symptoms; however, some researchers have questioned its use because although PD-like symptoms are observed, the model does not completely replicate the disease (Höglinger et al. 2006, Hirsch et al. 2003). Because of the exposure pathway and the doses used to produce the rotenone-PD model, the American Fisheries Society and others maintain that the Betarbet et al. 2000 study is not relevant to the risks associated with fisheries management use of rotenone (AFS 2001, Durkin 2008, Robertson and Smith-Vaniz 2008). The Yellowstone National Park literature review (NPS 2011) also found no evidence of piscicidal or pesticidal exposure of rotenone directly linked to PD in humans. Huntington's disease (HD) is another neurodegenerative disorder that is sometimes mentioned as having a possible connection to rotenone. HD is caused by a well-known genetic mutation, however, it is suspected that onset may be affected by environmental factors (Coppede 2009). Regardless, no evidence has been found to suggest a connection between the piscicidal application of rotenone and either PD or HD.

## Conclusion

Naturally reproducing populations of non-native fish have significant negative impacts to the ecosystems of mountain lakes (Anderson 1980, Carlisle and Hawkins 1998, Hoffman and Pilliod 1999, Knapp et al. 2001, Liss et al.2002, Tyler et al. 1998). To help restore these lakes and protect native fish population downstream NOCA developed the MLFMP and identified a series of high priority lakes that require the use of piscicides for successful restoration.

To evaluate the potential impacts of using rotenone instead of antimycin, we identified several endpoints (Table 9) that could potentially be impacted by piscicide treatments. We then compared the potential impacts of piscicidal concentrations between the proposed rotenone based piscicide, CFT Legumine™, and the currently approved antimycin based piscicide, Fintrol™.  Since the data do not exist to evaluate the potential impacts to all of the species that are known to occur in NOCA we selected a series of higher level endpoints that represented different components of aquatic and terrestrial ecosystems, as well as human health exposure pathways. Impacts were described by the type, intensity and duration of the impact (Table 8). Since the impacts of piscicidal treatments are not expected to occur outside of the project area, due to detoxification, we did not evaluate the scale of the impact which is typically a part of an environmental analysis for the National Environmental Policy Act.

Table 8. Descriptions of the terminology used to evaluate the impacts of using rotenone and antimycin in North Cascades National Park.

| Type, Intensity or Duration of Impact | Description |
|---|---|
| Beneficial | The proposed piscicide improves the quality or quantity of the endpoint. |
| Adverse | The proposed piscicide harms or kills the endpoint. |
| No Effect | The proposed piscicide has no effect on the endpoint. |
| Negligible | The impact to the endpoint would not be measureable. |
| Minor | The impact would be measureable; however the overall viability and health of the endpoint would not be affected. Recovery is likely following natural processes without human intervention. |
| Moderate | The impact would be sufficient to cause a significant change in the health, abundance, distribution, quantity or quality of the endpoint. The overall viability and health of the endpoint is at risk. Recovery is possible following natural processes but may require human intervention. |
| Major | The impact would be substantial and highly noticeable. The overall viability and health of the endpoint is greatly diminished. Recovery unlikely without human intervention. Human health is compromised. |
| Short-term | Less than two years from the time of exposure. |
| Long-term | More than two years from the time of exposure. |

Table 9. A summary of the predicted responses by the endpoints of concern in North Cascades National Park to the application of Fintrol™ at 8 ppb ai antimycin and CFT Legumine™ at 50 ppm ai rotenone in mountain lakes. The responses are evaluated according to Type, Intensity and Duration as follows: Type (A – adverse/negative, B – benficial/positive), Instensity (N – negligible, Mi – minor, Mo – moderate, Ma – major),Duration (S – short-term, L – long-term), U - uncertain.

| Endpoint of Concern | Fintrol™ (Antimycin-a) | CFT Legume™ (rotenone) |
|---|---|---|
| Human Health (general public, consumption) | No Effect | No Effect |
| Human Health (general public, contact) | No Effect | No Effect |
| Human Health (applicators) | No Effect | No Effect |
| Mammals (carnivores) | No Effect | No Effect |
| Mammals (herbivores) | No Effect | No Effect |
| Birds (raptors) | No Effect | No Effect |
| Birds (waterfowl) | No Effect | No Effect |
| Birds (passerines) | No Effect | No Effect |
| Amphibians (adults) | No Effect | No Effect |
| Amphibians (larvae) | A-Mi-S | A-Mi-S |
| Macroinvertebrates | A-Mi-S | A-Mi-S |
| Fish (target) | A-Ma-S | A-Ma-S |
| Fish (non-target) | A-Ma-S | A-Ma-S |
| Zooplankton | A-Mi-S | A-Mi-S |
| Aquatic Macrophytes | No Effect | No Effect |
| Algae and Phytoplankton | No Effect | No Effect |
| Microbes | A-U-S | U-U-U |

In comparing all endpoints, rotenone and antimycin pose the highest risk to larval amphibians and groups of invertebrates that use gills for respiration, and neither compound poses a significant risk to algae, aquatic macrophytes, terrestrial organisms or human health when applied at the planned piscicidal concentrations and handled with appropriate personal protective equipment.

Limited evidence suggests that tailed frog larvae (*Aschaphus truei*) are one of the most sensitive non-target organisms to rotenone and as such are likely to experience the greatest adverse impact. However, no research has been conducted to assess the impacts of antimycin on tailed frog so a comparison between the two compounds could not be made. In addition, impacts to tailed frog, for both rotenone and antimycin, are expected to be limited since this species inhabits streams during its larval stage and only small sections of lake-outlet habitat are expected to be impacted. It should also be noted that amphibian surveys conducted in lakes with naturally reproducing populations of fish have not detected any larval amphibians (Reed Glesne, Aquatic Ecologist, North Cascades National Park, personal communication). These findings are most likely the result of fish predation which has eliminated this vulnerable life history stage. Additionally, since adult amphibians are not affected by rotenone these populations make rapid recoveries with population numbers exceeding pretreatment levels due to the absence of fish predation (Mike Ruhl, Fisheries Biologist, Yellowstone National Park, personal communication; Ashley Rawhouser, Aquatic Ecologist, North Cascades National Park, personal communication).

Both rotenone and antimycin are derived from natural sources and quickly break down into benign byproducts and the EPA has determined that the long-term persistence of these compounds is not a concern. However, rotenone is expected to break down at a slower rate than antimycin in NOCA mountain lakes and this may increase the impact on certain taxa of zooplankton and insects. As part of the MLFMP, rotenone would only be applied to lakes containing populations of high density naturally reproducing fish. While this impact may be detectable in lakes with low density, non-reproducing fish populations it is not expected to produce a significant impact in lakes with high density reproducing fish populations since these populations have eliminated most of the larger taxa from the food web through predation.

Since the MLFMP is based on the principles of adaptive management lakes treated with rotenone will be monitored prior to a treatment and for several years after a treatment to determine the environmental effects of fish removal and piscicide application. If monitoring activities determine that rotenone applications are negatively impacting aquatic resources, outside of short-term impacts, NOCA will discontinue the use rotenone in favor of other means.

The conclusion of this assessment is that using CFT Legumine™ to remove non-native fish as part of the MFFMP will not have higher adverse environmental impacts than using Fintrol™.

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