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Rotenone Effects on Aquatic Invertebrates of The Strawberry, Utah: A Five-year Summary

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ABSTRACT

Before treatment with a 3 mg/l Noxfish (0.15 mg/l active ingredient; rotenone) for 48 hours, benthic invertebrate communities were quantitatively sampled with a modified Surber net. Then spring, summer, and fall post-rotenone samples were taken monthly at each of four Strawberry River stations for five years. Statistical analyses of the data indicated that the application of rotenone had a significant effect on the following species density: *Cinygmula sp., Pteronarcella badia , Hesperoperla pacifica, Hydropsyche sp., and Brachycentrus americanus.* Thirty-three percent of the benthic invertebrate taxa at the four stations showed resistance to rotenone. Up to 100% of Ephemeroptera, Plecoptera and Trichoptera species were missing after the second rotenone application. Forty-six percent of the taxa recovered within one year, but 21% of the taxa were still missing after five years. Of the 19 taxa still missing, 47% were Trichoptera, 21% were Ephemeroptera, 16% were Plecoptera, 11% were Coleoptera, and 5% were Megaloptera.

INTRODUCTION

It is common in management of certain fisheries programs to eradicate all nonnative or exotic species from a freshwater habitat so that desired native species can be given a noncompetitive fresh start in an aquatic ecosystem. This method has generally been used in recovery programs for threatened or endangered fish species. One of the most popular ways to remove fish is by treating aquatic ecosystems with rotenone. The primary action of rotenone is to block important biochemical pathways of cell metabolism (Lindahl and Oberg 1961, Oberg 1962). Rotenone inhibits the respiration of mitochondria by blocking the reduced nicotinamide adenine dinucleotide (NADH)-dehydrogenase segment of the respiratory chain in fish and aquatic insects (Fukami, et al. 1969). Because of this nonspecific poisoning, many non target species such as certain aquatic macroinvertebrates are also eliminated from the ecosystem.

Fish toxicants have generally been applied without specific knowledge concerning possible adverse effects on aquatic macroinvertebrates living in the ecosystems treated. Gilderhaus, et al. (1988) used high performance liquid chromatography to analyze rotenone concentrations in water, bottom sediments, invertebrates, and fish

-none treatment. Decomposition of rotenone in water ... irst-order decay curve; half life was 10.3 days in cold water (0- ...d 0.94 days in warm water (23-27° C). The effects of rotenone on ...nic invertebrates have been recorded by Binns (1967), Cook and Moore (1969), and Engstrom-Heg, et al. (1978). Each of these investigators observed that stream bottom insects varied greatly in their tolerances to rotenone.

We compared pre-rotenone benthic invertebrate communities and taxa to post-rotenone community composition for a five-year period following rotenone treatment of tributaries to Strawberry Reservoir in Utah. This study included more specific taxonomy than found in previous studies. Many taxa were classified to the genus and species levels to determine more specifically the effects of rotenone on species of aquatic insects and other invertebrates in treated streams. This is also the first time recovery or lack of recovery of benthic community members has been followed for a five-year period. The Strawberry River rotenone project, which was the largest ever attempted in the U.S.A., included a 5,666 HA reservoir and 274 km. of perennial tributary streams. The rotenone treatments were applied to remove Utah Chubs (*Gila atraria)* and Utah Suckers *(Catostomus ardens)* from the Strawberry Reservoir and drainage. The target fish species were competing with the trout in the reservoir and tributaries. In the Strawberry ecosystem, three salmonid species were introduced into post-treatment waters. These included sterile *Oncorhynchus mykiss* and Bear Lake *Salmo clarki* to help control rough fish, and *Oncorhynchus nerka*, a noncompetitive plankton feeder.

Aquatic ecosystem quality varied between stations included in this study. The pre-rotenone aquatic macroinvertebrate communities at the lower Strawberry River stations were dominated by tolerant species before the rotenone project began. The upper two stations had more sensitive species in the pre-rotenone benthic communities (Mangum 1995).

MATERIALS AND METHODS

Rotenone Application

Rotenone was applied in 1990 to the entire Strawberry River watershed (Fig. 1). The rotenone used was Noxfish, which had a 5% by volume active ingredient. Drip barrels were set up to apply 3 mg/l Noxfish on the streams. The goal was to maintain a 0.15 mg/l active ingredient concentration in the stream channels for 48 hours. To provide unrestricted flows, beaver dams were breached the day prior to treatment. Ground crews used backpack sprayers to apply liquid rotenone to backwater and side channel areas not reached by flows carrying the rotenone from drip barrels. A powdered rotenone/sandmix mixture was applied to seeps, springs, and weedy areas. All streams, springs, and seeps were treated to the tops of the headwaters in the entire Strawberry Reservoir drainage. Rotenone was applied twice. The first application was in early to mid-August; the second one was applied from September 25 through October 16.

Aquatic Macroinvertebrate Sampling

Three quantitative macroinvertebrate samples were taken monthly with a one meter long, 280 micron mesh, 45.7 cm upper frame Winget-modified Surber net (Winget 1979). This was done from spring (May to June) through fall (September to October) at each station each year.

At Strawberry River stations (Fig. 1), pre-rotenone communities were a composite of taxa present in June and early August 1990. Samples were taken about one week prior to treatment, and again seven to ten days following each of the two rotenone applications. Since ethanol (80%) was used to preserve the organisms, if samples were taken too soon after the rotenone application, it was difficult to determine if the organisms died from rotenone or ethanol. Thus, macroinvertebrates allowed to decay for seven to ten days following rotenone treatment were easily distinguished and were not counted as survivors.

Unprocessed portions of subsamples were scanned for taxa that may not have been included in sorted subsamples. Aquatic macroinvertebrate nymphs and larvae were classified to the species or genus level when possible so that tolerance levels and recovery could be followed more specifically.

Statistical Analysis

The data were analyzed using a generalized linear model approach. This technique is recommended when the response variable is not normal, and/or when the variance is not constant (McCullagh and Nelder, 1989). Construction of a generalized linear model requires choosing an appropriate link function and response probability distribution. The data for this project were modeled using a binomial error distribution with a probit link function. This modeling process was used for each taxon. It is important to mention that station and date were treated as explanatory variables. In all cases, the research hypothesis was:

Ho: Rotenone does not have any effect on a species density
Ha: Rotenone has a significant effect on a species density

The Procedure GENMOD from the statistical software SAS ® was utilized to test the hypothesis. The hypothesis was rejected when the p-value was smaller than 0.05.

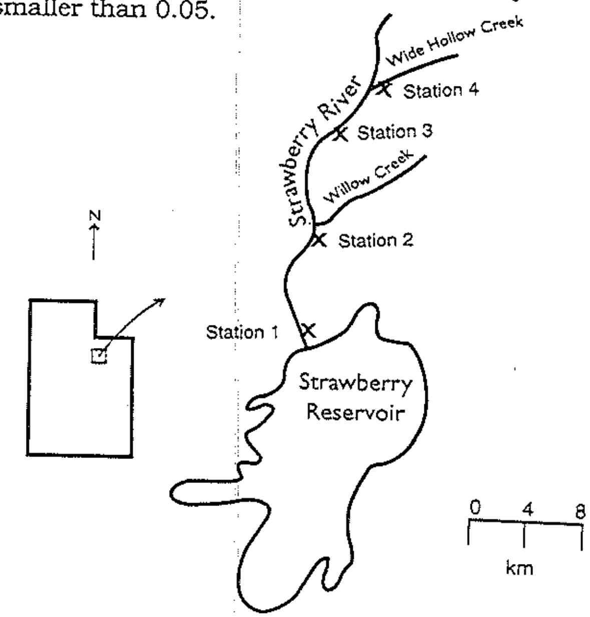

Figure1. Location of sampling sites in the Strawberry River system, Utah.

RESULTS

The statistical analysis was limited to the six more important species (*Drunella doddsi, Cinygmula sp., Pteronarcella badia, Hesperoperla pacifica, Hydropsyche sp., and Brachycentrus americanus*). The results showed significant differences by station and date in the densities (due to rotenone application, p-value=0.0001) of all of the above species except *Drunella doddsi*. A similar behavior was observed through time. In other words, their population densities decreased considerably due to rotenone.

The first rotenone application eliminated many of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) species from the community. Populations of Diptera and Oligochaeta taxa were initially reduced, but post-rotenone conditions seemed to favor these taxa. Within one to two months after treatment the communities were dominated by simuliids, chironomids, Oligochaeta, and Tipula.

At the four Strawberry River Stations, up to 59% of the taxa were removed from the communities by the first rotenone application. The second rotenone application reduced the pre-rotenone communities by up to 73%.

After the first rotenone application, the benthic communities had 45-82% fewer Ephemeroptera, 50-69% fewer Plecoptera, and 30-75% fewer Trichoptera. Although numbers of most other taxa were obviously reduced, they were not eliminated from the communities. After the second rotenone application, Ephemeroptera diversity was reduced by 67-100%, Plecoptera by 67-100%; and Trichoptera by 61-100%. The percent of taxa, by order, missing after one year were: 20-45% of the Ephemeroptera, 20-100% of the Plecoptera and 20-100% of the Trichoptera (Tables 1-4).

Tolerances and Recovery of Taxa

In this study, a taxon was considered missing if it was no longer found in the community after the first or second application of rotenone. As soon as a taxon reappeared in the sampled community at a given station, it was considered to have recovered.

At Station 1, of the 46 taxa in the pre-rotenone community, 15 taxa were resistant to rotenone. Of the 31 missing after rotenone application, two recovered within two months and twenty others recovered after 12 months. One taxon recovered within 21 months and another recovered in the third year. After five years, six taxa found in the pre-rotenone community were still missing (Table 1).

Brown and Ball (1943) state that leeches were seriously affected by a 0.5 mg/l concentration of 5% *Derris* powder. Leeches in this study recovered after 34 months at Strawberry River Station 1.

At Station 2, of the 56 taxa in the pre-rotenone community, five were resistant to rotenone. Three recovered within two months, twenty more recovered within 12 months, two more by 14 months, six took 19-24 months to recover, and another taxon recovered within 35 months. After five years, eight taxa were still missing (Table 2).

Table 1. Post-rotenone recovery of Strawberry River taxa - Station 1

Recovery Time	Taxa Recovered
0 months (Not Missing)	*Tricorythodes minutus*, *Paraleptophlebia sp.*, *Hydropsyche sp.*, *Cheumatopsyche sp.*, *Helicopsyche borealis*, *Oecetis sp.*, *Optioservus sp.*, *Zaitzevia sp.*, *Tipula sp.*, Chironomidae, *Chelifera sp.*, *Bezzia sp.*, *Physa sp.*, *Oligochaeta*, *Nematoda*, *Hydracarina sp.*
2 months	*Baetis sp.*, Simuliidae
9-12 months	*Heptagenia sp.*, *Drunella grandis*, *Ephemerella inermis*, *Sweltsa sp.*, *Isoperla fulva*, *Pteronarcella badia*, *Arctopsyche sp.*, *Dicosmoecus sp.*, *Limnephilus sp.*, *Brachycentrus occidentalis*, *Hydroptila sp.*, *Protoptila sp.*, *Agabus sp.*, *Hexatoma sp.*, *Euparyphus sp.*, Planorbidae, *Lymnaea sp.*, *Pelecypoda*, *Gammarus* sp.
21 months	*Leucotrichia* sp.
34 months	*Helobdella* sp.
58 months	*Ochrotrichia* sp.
Still missing after 5 years	*Cinygmula sp.*, *Attenuatella margarita*, *Caudatella hystrix*, *Rhyacophila acropedes*, *Agapetus sp.*, *Hydaticus* sp.

Table 2. Post-rotenone recovery of Strawberry River taxa - Station 2

Recovery Time	Taxa Recovered
0 months (Not Missing)	*Arctopsyche sp.*, *Tipula sp.*, *Hexatoma sp.*, *Euparyphus sp.*, *Lymnaea* sp.
2 months	Simuliidae, *Hemerodromia sp.*, *Chelifera* sp.
8-12 months	*Rhithrogena sp.*, *Heptagenia sp.*, *Drunella Grandis*, *Ephemerella inermis*, *Paraleptophlebia sp.*, *Baetis sp.*, *Sweltsa sp.*, *Pteronarcella badia*, *Isoperla sp.*, *Hydropsyche sp.*, *Hydroptila sp.*, *Rhyacophila vagrita*, *Wormaldia sp.*, *Leucotrichia sp.*, *Hesperophylax sp.*, *Agabus sp.*, *Carabidae*, *Antocha monticola*, Planorbidae, *Pelecypoda*
13-14 months	*Cinygmula sp.*, *Hydaticus* sp.
19-24 months	*Tricorythodes minutus*, *Hesperoperla pacifica*, *Brachycentrus americanus*, *Helicopsyche borealis*, *Dicosmoecus sp.*, *Ostracoda*
35 months	*Serratella tibialis*
60-61 months	Capniidae, *Pericoma* sp.
Still missing after 5 years	*Caudatella hystrix*, *Isogenoides sp.*, *Brachycentrus occidentalis*, *Micrasema sp.*, *Ochrotrichia sp.*, *Glossosoma sp.*, *Oecetis sp.*, *Sialis* sp.

At Station 3, of the 59 taxa in the pre-rotenone community: 16 appeared to be resistant to rotenone. Of the 43 taxa missing after rotenone treatments, twenty recovered within 12 months. Thirteen others recovered within the second year, two more recovered in the third year, and one recovered in the fourth year (Table 3). After five years, there were five taxa still missing (Table 3).

Of the 55 taxa in the pre-rotenone community at Station 4, 16 appeared to be resistant to the rotenone concentration used at this station. Of the 38 taxa missing after rotenone applications, twenty nine recovered within 12 months and one after 14 months. After one year, 16% of the pre-rotenone community was still missing. Four taxa recovered within the second year, and another taxon recovered within 25 months. After five years, four species were still missing (Table 4).

Table 3. Post-rotenone recovery of Strawberry River taxa - Station 3

Recovery Time	Taxa Recovered
0 months (Not Missing)	*Paraleptophlebia sp.*, *Hydropsyche sp.*, *Optioservus sp.*, *Zaitzevia sp.*, *Hexatoma sp.*, *Tipula sp.*, Simuliidae, Chironomidae, *Chelifera sp.*, *Bezzia sp.*, *Pericoma sp.*, *Euparyphus sp.*, *Ostracoda*, *Oligochaeta*, *Hydracarina sp.*, *Nematoda*
8-12 months	*Heptagenia sp.*, *Drunella doddsi*, *Drunella grandis*, *Baetis sp.*, *Cultus sp.*, *Amphinemura sp.*, *Podmosta besameta*, *Capniidae*, *Eucapnopsis sp.*, *Isoperla fulva*, *Hesperoperla pacifica*, *Sweltsa coloradensis*, *Arctopsyche grandis*, *Dicosmoecus sp.*, *Hydroptila sp.*, *Rhyacophila hyalinata*, *Rhyacophila vagrita*, *Agabus sp.*, *Atrichopogon sp.*, *Limnophora* sp.
20-24 months	*Epeorus longimanus*, *Rhithrogena hageni*, *Serratella tibialis*, *Zapada haysi*, *Kogotus modestus*, *Plumiperla diversa*, *Hesperophylax sp.*, *Helicopsyche borealis*, *Rhyacophila acropedes*, *Lepidostoma sp.*, *Antocha monticola*, *Dicranota sp.*, *Sialis* sp.
32-36 months	*Drunella coloradensis*, *Suwallia pallidula*, *Dixa* sp.
47 months	*Brachycentrus americanus*
Still missing after 5 years	*Caudatella hystrix*, *Podmosta delicatula*, *Isogenoides sp.*, *Oligophlebodes sp.*, Carabidae

DISCUSSION

Cushing and Olive (1957) reported that Oligochaeta increased after rotenone treatment. In the Strawberry River study, populations of chironomids and tubificids were adversely affected but recovered to twice their original numbers within one month. Post-rotenone increases in benthic invertebrate populations may be due in part to elimination of fish

and other predators (Tuunainen 1970). Hubbs (1963), observed that application of rotenone on the Concho River in Texas drastically altered the ecological interactions and had selective effects, particularly on game fish food organisms. Little (1966) reported that 34% to 100% of bottom-dwelling organisms were removed by rotenone treatment. He found that all organisms except Plecoptera and *Isopoda* recovered up to their original abundance within one year.

Binns (1967) found thatafter application of rotenone, taxonomic groups recovering in twelve months included Tipulidae, Tricorythodidae, Heptageniidae, Perlidae, and Lepidostomatidae. Brachycentridae and Hydropsychidae took 20 months. Oligochaeta took 15 months, and Empididae took 24 months. Baetidae recovered in three months. Recovery was probably assisted by organisms drifting from upstream untreated reaches.

Some of the possible mechanisms for recovery or survival from effects of rotenone treatment could include survival of adults, nymphs, or larvae of species physiologically or structurally resistant to the adverse effects of rotenone. An example of a resistant nymph is *Paraleptophlebia sp.* At most stations on the Strawberry River, its numbers remained consistently high before, during, and after the rotenone application. This genus was observed to be tolerant to rotenone by Engstrom-Heg et al. (1978); they also found the caddisfly Hydropsyche sp. Was tolerant to

Table 4. Post-rotenone recovery of Strawberry River taxa - Station 4

Recovery Time	Taxa Recovered
0 months (Not Missing)	*Ephemerella inermis*, *Paraleptophlebia sp.*, *Baetis sp.*, *Rhyacophila acropedes*, *Rhyacophila vagrita*, *Zaitzevia sp.*, *Optioservus sp.*, Chironomidae, *Hemerodromia sp.*, *Bezzia sp.*, *Pericoma sp.*, *Euparyphus sp.*, *Ostracoda*, *Hydracarina sp.*, *Oligochaeta*, *Nematoda*
8-12 months	*Epeorus sp.*, *Cinygmula sp.*, *Drunella coloradensis*, *Drunella doddsi*, *Tricorythodes minutus*, Chloroperlidae, *Sweltsa sp.*, *Megarcys signata*, *Isoperla sp.*, *Cultus sp.*, *Isogenoides*, *Zapada haysi*, *Zapada cinctipes*, *Hesperoperla pacifica*, Leuctridae, *Arctopsyche grandis*, *Lepidostoma sp.*, *Rhyacophila hyalinata*, *Rhyacophila vepulsa*, *Dicosmoecus sp.*, *Neothremma sp.*, *Hesperophylax sp.*, *Hexatoma sp.*, *Dicranota sp.*, Simuliidae, *Chelifera sp.*, *Atrichopogon sp.*, *Dixa sp.* , *Planaria sp.*
14 months	*Tipula sp.*
20-24 months	*Rhithrogena hageni*, *Serratella tibialis*, *Skwala americana*, *Pelecypoda*
Still missing after 5 years	*Drunella grandis*, *Suwallia sp.*, *Podmosta delicatula*, *Parapsyche elsis*

rotenone. We observed the same for Hydropsyche sp. in the Strawberry River and suggest that instream macrophytes could provide the needed oxygen or advantage for survival of this and other benthic species.

Some of the survivors in the Strawberry River may have been associated with instream or side springs which could locally dilute the rotenone. Also, there may have been incomplete mixing of the rotenone in some stream areas such as under banks or under rocks.

Within a week following the rotenone treatments there were few surviving benthic invertebrates observed in the samples, but within one to two months, populations of chironomids and simuliids were high. When compared with pre-rotenone sampled populations, simuliids at Station 1 had increased 240% by October 1990 and 1,108% by June 1991. Chironomids at Station 2 increased 232% by August 1991.

Many of the aquatic macroinvertebrates in the Strawberry tributaries that reappeared within a year following rotenone application may have been from eggs deposited in the stream before the project. Eggs are generally more resistant to adverse conditions than are nymphs or larvae, which are more dependent upon a sustained source and use of oxygen. Even fish eggs are more resistant to toxicants than young or mature fish (Lennon et al. 1970). It appears that some of the recovering species may have been reintroduced into the aquatic ecosystem through mechanisms such as wind current carrying aerial adults.

Most of the species sensitive to rotenone were in the orders Ephemeroptera, Plecoptera, and Trichoptera, (EPT). This was shown by the high mortality rate (up to 100%) for these taxa after the rotenone applications at each station. Twenty-two to 53% of these taxa recovered within one year, but 7 to 14% of the species were still missing after five years. Most of the aquatic macroinvertebrate species that are sensitive to different types of environmental perturbations are in the EPT orders. EPT species were the most sensitive to rotenone, but some recovered more quickly than expected. Recovery of some aquatic macroinvertebrate species could be delayed by ecosystem stress from past or current cattle or sheep grazing activities.

Because of the differences in habitat quality at the stations sampled, the benthic invertebrate community composition was different at each station monitored; however, some of the same species were still missing from the sampled communities after five years. *Caudatella hystrix* was still missing at Stations 1, 2, and 3, *Oecetis sp* and *Sialis* sp. at Station 2 on the Strawberry River, and *Podmosta delicatula* at Stations 3 and 4. Binns (1967) observed that none of the taxonomic groups were missing at the end of a two-year Green River study. However, more specific taxonomy used in the present study revealed that some taxa were still missing after five years. Long-term effects of rotenone were most evident for Trichoptera. Of the 19 taxa still missing at the four stations, 21% were Ephemeroptera, 16% were Plecoptera, 47% were Trichoptera, 11% were Coleoptera, and 5% were megalopterans.

Aquatic invertebrate taxa that were tolerant to the rotenone concentration used are identified as not-missing or briefly missing in the station taxa lists. Nine percent to 33% of the benthic invertebrates at the stations sampled were resistant to rotenone. Of the 27 resistant taxa, 11% were Ephemeroptera, none were Plecoptera, 26% were Trichoptera, 8%

were Coleoptera, 33% were Diptera and 22% were other invertebrates. Members of the family Simuliidae (blackflies) compete best and thrive where there is organic nutrient loading (Mangum 1995). The riffle beetles (Elmidae) and a mayfly, *Tricorythodes sp.*, are tolerant to fine sediments (Mangum 1995). Many species in the dipteran family Chironomidae, the mayfly family Baetidae and aquatic worms (Oligochaeta) compete best and can become dominant in communities where there is an abundance of sediment and organic enrichment. Other tolerant taxa include the water mites (Hydracarina sp.).

Binns (1967) observed that after rotenone treatment the dominant benthos at the various stations were water beetles, midges, cranefly larvae, Perlodidae, Rhagionidae, Simuliidae, and *Tricorythodes sp.*. We found immediate changes in benthic invertebrate community composition and dominance, and there were changes in sets of dominant taxa during the five-year post-rotenone recovery period. Some of the taxa such as *Tipula sp.* and *Paraleptophlebia* sp. which were relatively obscure in diverse pre-rotenone communities became dominant survivors in post-rotenone communities. Numbers of benthic invertebrate organisms found in pre-rotenone samples were reestablished in one to 36 months. Binns (1967) similarly observed that although numbers of organisms were drastically reduced after rotenone applications, numbers soon became high again but dominance in the communities changed.

Not only are aquatic invertebrate species affected but the nutrient cycle and food chain components can be changed by rotenone. Some species not found in pre-rotenone communities were collected in post-rotenone samples. It will be of interest to see if they permanently fill the niches of missing species. We found that rotenone can cause long-term changes in aquatic macroinvertebrate community stability and composition.

We suggest that pre and post-treatment monitoring should be a part of any project using rotenone as a management tool. Rotenone concentrations used should be just enough to remove the target fish species, which could limit the number of non-target aquatic invertebrates eliminated by the treatment. To prevent loss of sensitive aquatic invertebrates, representative species of communities from stream reaches to be treated should be collected and placed in a suitable habitat and then returned to the stream reaches after rotenone toxicity subsides.

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