National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Bonneville Cutthroat Trout Restoration Project *Great Basin National Park*

Natural Resource Report NPS/NRPC/NRR—2008/055

ON THE COVER
Reintroduced Bonneville cutthroat trout in South Fork Big Wash
Photo by Tod Williams

Bonneville Cutthroat Trout Restoration Project
Great Basin National Park

Natural Resource Report NPS/NRPC/NRR—2008/055

Gretchen Baker, Neal Darby and Tod Williams
Great Basin National Park
100 Great Basin National Park
Baker, NV 89311

John Wullschleger
National Park Service
Natural Resources Program Center
1201 Oakridge Drive, Suite 250
Fort Collins, CO 80525

September 2008

U.S. Department of the Interior
National Park Service
Natural Resources Program Center
Fort Collins, Colorado

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Views, statements, findings, conclusions, recommendations, and data in this report are solely those of the authors and do not necessarily reflect views and policies of the U.S. Department of the Interior, NPS. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

Printed copies of reports in this series may be produced in a limited quantity and are only available as long as the supply lasts. This report is also available from the Natural Resource Publications Management Web site (http://www.nature.nps.gov/publications/NRPM) on the internet or by sending a request to the address on the back cover.

Please cite this publication as:

Baker, G., N. Darby, T. Williams, and J. Wullschleger. 2008. Bonneville cutthroat trout restoration project—Great Basin National Park. Natural Resource Report NPS/NRPC/NRR—2008/055. National Park Service, Fort Collins, Colorado.

NPS D-102, September 2008

Contents

Page

Contents (continued)

Page

Contents (continued)

Page

Figures

Figures (continued)

Tables

Page

Executive Summary

The Bonneville cutthroat trout (*Onchorynchus clarki utah*; BCT) is the only salmonid native to east-central Nevada and to Great Basin National Park (the Park). It is identified as a priority species in the Park's 1991 General Management Plan. At the time of the Plan's completion, BCT populations throughout the area had been reduced by nearly 95% due to the introduction of nonnative fishes and habitat alterations. Timely actions by the Park and cooperating agencies have reduced the threat of extinction by restoring the species to four of six historically occupied watersheds within the Park.

BCT reintroductions have taken place in Strawberry Creek, South Fork Big Wash, Upper Snake Creek, and South Fork Baker Creek. In addition, a population initially identified as hybridized in Mill Creek was shown by geneticists to be pure Bonneville cutthroat trout. Populations in Pine and Ridge Creeks on the west side of the Park were also identified as pure BCT. Currently, there are seven populations of BCT in 25 km (15 mi) of streams in and near the Park. The Park has instituted a BCT monitoring program that is helping to track the speed with which reintroduced fish populations become viable. Within the next five years, reestablished BCT populations are expected to expand and occupy 31 km (19 mi), or 52%, of their historic stream habitat within the Park.

The BCT reintroduction project has also enabled the Park to obtain data on how other components of the aquatic ecosystem respond to different restoration techniques. In particular, it has added to the body of evidence that the piscicide antimycin is less detrimental to aquatic insects than rotenone. These results may help others planning similar projects.

The Park's work in BCT reintroduction was a major factor in the US Fish & Wildlife Service's decision not to list the species as threatened under the Endangered Species Act (ESA). This was a significant, proactive move by the Service that has eased any ESA regulatory burden on private landowners within the range of BCT in Nevada. As a result of this reintroduction project, the Park has strengthened its relationship with interagency partners and has become a leader in reestablishing BCT in Nevada.

Specific accomplishments included:

- Four populations of Bonneville trout were reestablished in Park stream reaches with a total length of 13.1 km (8.1 miles); two additional populations present in streams in and adjacent to the Park at the time the project began were determined to be genetically pure.
- Reintroductions appear to have been successful, with all reintroduced populations showing recruitment and expansion of territory.
- All populations were verified as genetically pure BCT.
- Three fish removal methods were compared, including cost, effectiveness and impacts.
- Data on recovery of aquatic macroinvertebrates following treatment with two different piscicides was collected and analyzed; results suggest difference in recovery rates under ideal and less than ideal conditions.
- A detailed inventory of the macroinvertebrates and mollusks in the project streams was completed.

- Valuable water chemistry data for five streams and one lake were collected and entered into the Environmental Protection Agency's STORET water quality database.
- Together with other agencies, the Park produced the brochure, *Snake Range Recreational Fisheries,* which informs anglers about the BCT restorations, aquatic ecosystems, potential diseases, and fishing license information, along with a full-color map.

Acknowledgements

Initial funding, from Trout Unlimited Embrace-a-Stream grants in 1999 and 2000, helped the Park purchase two backpack electrofishing units, nets, a portable fish tank, and other supplies necessary to conduct fish surveys. In addition, these grants supported the first macroinvertebrate identifications for the Park done by the National Aquatic Monitoring Center. From 2001 to 2004, the BCT program was funded by the NPS Natural Resources Preservation Program. This money helped hire a crew to do field work, pay for treatments and training and complete more macroinvertebrate analyses. From 2004 to 2005, NPS Pacific West Regional Resource funding was used to complete the reintroductions and to conduct basic monitoring.

Many people have assisted throughout this project. Special thanks go to Meg Horner and Ryan Thomas for their years of help with this project. In addition, we thank the following biological technicians and volunteers: Kelley Garrison, Becky Williams, Patrick O'Brien, Karla Jageman, Sarah Thomas (2007); Brittany Timm and RaeJean Layland (2006); Mark Wiley (2005); Tana Ellis, Maggie Allan, Eric Scott, and Cole Neill (2004); Rob Colvin, Matt Proett, Stephanie Leslie, Nancy Williams, Missy Brickl, Heather Vice, and Bryan Hamilton (2003); Fred Gender, Sabrina DeRusseau, Ray Hickey, Bryan Hamilton and Karinne Knutsen (2002); and Marilyn Keifenhiem (2001). We also thank the numerous volunteers who spent over 1,000 hours assisting on a variety of projects, particularly the Southern Nevada Chapter of Trout Unlimited (Kevin Fedrizzi, Larry McCormick, Jennifer Coons, Jack Coons, Jack Clifton, Roy Creech, Alan Burke, and many more). We would also like to thank the US Fish & Wildlife Service (Bruce Rosenlund and Mark Maley), Nevada Department of Wildlife (Chris Crookshanks, John Elliott, and Bob Layton), Great Smoky Mountains National Park (Steve Moore and Matt Kulp), Crater Lake National Park (Mark Buktenica), Humboldt-Toiyabe National Forest (Kathy Johnson and Jim Harvey), and Ely Office of Bureau of Land Management (Paul Podborny and Shane DeForest). Comments from Mark Grover and Laura Belica improved this document.

All photos are by Gretchen Baker, NPS, unless otherwise noted.

Introduction

Bonneville cutthroat trout (*Onchorynchus clarki utah;* hereafter referred to as BCT) were abundant throughout glacio-pluvial Lake Bonneville, including the Snake Valley arm of the lake, which reached to the edge of present day Great Basin National Park (the Park) (Figure 1). The Snake Valley arm was connected to Lake Bonneville during maximum lake levels 12,000 to 15,000 years ago, when streams on the east side of the southern Snake Range flowed into this arm. When Lake Bonneville's water level dropped, the Snake Valley population of BCT became isolated from the rest of the Bonneville Basin (Behnke 1976). Such reproductive isolation allowed sufficient time for considerable genetic divergence, and biologists consider the Snake Valley fish to be a unique race or group (Behnke 1988, 1992; Shiozawa et al. 1993) called the Western BCT (USDA Forest Service 1996).

Although BCT are known to have occurred in Park streams historically, they are thought to have been eliminated by competition from introduced brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) as well as by hybridization with rainbow trout. Habitat degradation due to intensive livestock grazing and water diversions may have also played a role in BCT disappearance (Sigler and Sigler 1987).

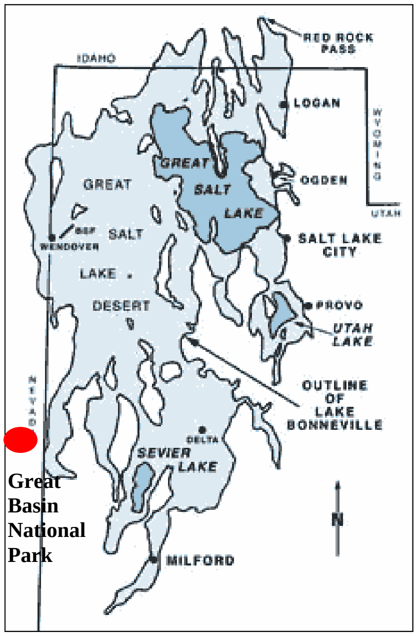

Figure 1. Great Basin National Park in relation to the ancient Lake Bonneville, shown as the light shaded area.

Great Basin National Park was established in 1986, transferring management of many of the streams in the southern Snake Range from the US Forest Service and Nevada Department of Wildlife (NDOW) to the National Park Service (NPS). A General Management Plan, written for the Park in 1991, identified Bonneville cutthroat trout as a priority species because it is the only trout native to the Park and it was believed to have been extirpated. The Plan directed that park staff restore BCT to several park streams, consistent with NPS policies.

In 1999, Park staff wrote a fisheries management plan (Williams et al. 1999) and accompanying environmental assessment for the Park, which identified two main objectives: reintroduce BCT to streams and monitor recreational fishing in streams not targeted for restoration. These documents, along with the Finding of No Significant Impact, were signed by the Regional Director on November 10, 1999.

A ten-year timeline was developed (Table 1) to achieve the following goals: 1) obtain baseline conditions of terrestrial and aquatic organism presence, abundance and diversity; 2) determine if any species of concern were present; 3) determine which streams, if any, contained suitable habitat to support BCT; 4) implement an adaptive management strategy for reintroduction efforts and, 5) establish a baseline for restoration effectiveness monitoring after chemical renovation treatment and reintroduction.

Initial assessments indicated that removal of nonnative salmonids was necessary prior to reintroduction. Because this would likely require the use of piscicides, the effects on non-target organisms (e.g., macroinvertebrates, amphibians, etc.) were of concern. Unfortunately, quantitative information on the effects of piscicides on non-target organisms was limited and not directly applicable to Park streams. Thus, the restoration plan included acquisition of quantitative baseline and post-treatment data on target aquatic species to assess treatment impacts and recovery. An adaptive management approach was used wherein techniques were modified over the course of the project based on the monitoring results.

Table 1. Ten-year timeline for BCT reintroduction set forth in the Great Basin National Park Bonneville cutthroat trout reintroduction and recreational fisheries management plan (Williams et al. 1999).

	Strawberry Creek	Mill Creek	South Fork Big Wash	Snake Creek	Lehman Creek	South Fork Baker Creek
1999	NNS, EPS CT TEM, EES	NNS, EPS	NNS, EPS			
2000	TEM, EES BCT	NNS, EPS CT TEM, EES	NNS, EPS BCT	NNS, EPS		
2001	TEM, EES BPM	TEM, EES BCT	BPM BCT	NNS, EPS CT TEM, EES	NNS, EPS	
2002	TEM, EES ERM	TEM, EES BPM	BPM BCT	TEM, EES BCT	NNS, EPS CT TEM, EES	NNS, EPS
2003	BPM	TEM, EES ERM	BPM	TEM, EES BPM	TEM, EES BCT	EFR TEM, EES
2004	ERM	BPM	BPM	TEM, EES ERM	TEM, EES BPM	TEM, EES BCT
2005		ERM	BPM ERM	BPM	TEM, EES ERM	TEM, EES BPM
2006			BPM	ERM	BPM	TEM, EES ERM
2007			ERM		ERM	BPM
2008						ERM

NNS = pre-treatment surveys of nonnative fish, EPS = pre-treatment surveys of invertebrates, amphibians and water chemistry, CT = chemical treatment, EFR = electrofishing removal, TEM = treatment effectiveness monitoring, EES = ecosystem effects surveys, BCT = BCT reintroduction, BPM = post-reintroduction monitoring of BCT populations, and ERM = ecosystem recovery monitoring.

The Park also became a signatory to the Rangewide Agreement and Strategy for Bonneville cutthroat trout (Lentsch et al. 2000). As such, the Park committed to taking measures to restore and protect the species within Park waters. The Agreement, which was also signed by the states of Utah, Nevada, Wyoming, and Idaho, as well as the US Forest Service, Bureau of Land Management and US Fish and Wildlife Service, was a consideration in the decision not to list the Bonneville cutthroat trout under the Endangered Species Act. The species had been petitioned for listing in 1979 and again in 1998.

Habitat

In 1999, there were an estimated 40 km (24 mi) of stream habitat suitable for trout within the Park unoccupied by BCT. In addition, there were about 91 km (56.5 mi) of suitable stream habitat on the adjacent Humboldt-Toiyabe National Forest, some of which was occupied by BCT. Biologists estimate that approximately 94% of BCT populations in western Utah and eastern Nevada have been extirpated (USDA Forest Service 1996). As of 1999 the only streams known in Nevada to harbor BCT were Hendry's Creek in the northern Snake Range, and Pine/Ridge Creek on the west side of the southern Snake Range, which is outside the historic range.

Optimal cutthroat trout habitat in streams is characterized by clear, cool water, a silt-free rocky substrate in riffle-run areas, approximately a 1:1 pool-riffle ratio with areas of slow and deep water, well-vegetated stream banks, abundant instream cover, and relatively stable water flow, temperatures and stream banks. The average maximum summer temperature for BCT streams is less than 22ºC (72ºF) and the average summer temperature is about 13ºC (55ºF) with diel variations of about 4ºC (9ºF) (Hickman and Raleigh 1982; Binns and Remmick 1994).

Bonneville Cutthroat Trout Life History

BCT generally range in length from 130-300 mm (5 to 12 in) in small streams like those in the Park and live 3 to 4 years, with a maximum estimated age of 8 years. They have a silvery gray or yellowish brown background with large roundish spots scattered across their bodies, more concentrated at the caudal end (Downs et al. 1997; Behnke 2002). A bright red stripe (or "cutthroat" mark) is present under each side of the lower jaw (Figure 2). The coloration of BCT is relatively subdued compared to other cutthroat trout, although some populations display bright reddish-orange spawning colors.

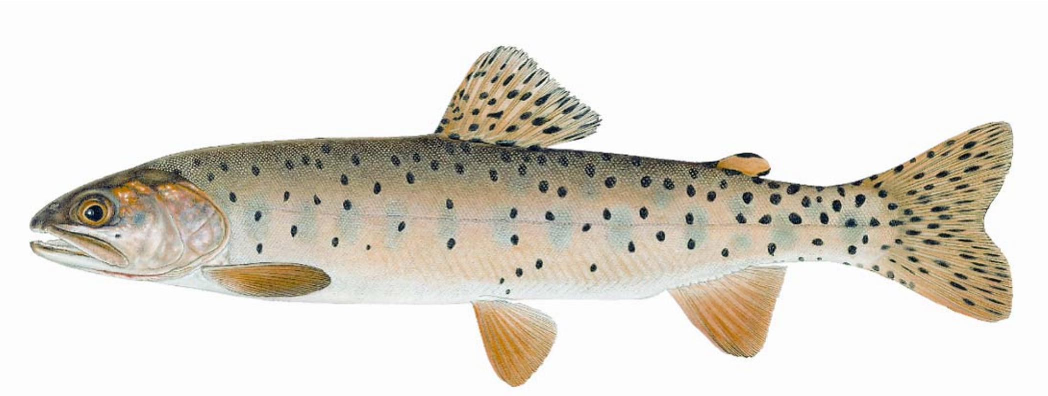

Figure 2. Bonneville cutthroat trout. Illustration © Joseph Tomelleri

BCT are typically sexually mature during the second year for males and the third year for females, although the age at maturity and the annual timing of spawning vary geographically with elevation, temperature and life history strategy (May et al. 1978; Behnke 1992; Kershner 1995). Length may be a better predictor for spawning than age (Downs et al. 1997). Annual spawning of BCT usually occurs during the spring and early summer at higher elevations (Behnke 1992) at temperatures ranging from 4-10ºC (May et al. 1978). Little information exists regarding the fecundity of wild BCT (Lentsch et al. 1997), but in general, trout fecundity is between 1,800 to 2,000 eggs per kilogram of body weight (Behnke 1992). Incubation times for BCT are unknown but may be similar to the 30 day average reported for other species of wild trout. (Gresswell and Varley 1988). Reproductive rates of BCT depend greatly on stream productivity and habitat conditions (Lentsch et al. 1997). The main diet of BCT consists of aquatic and terrestrial invertebrates.

Some cutthroat trout tend to move long distances, with Hilderbrand and Kershner (2000a) finding that some move more than 500 m (547 yd) in the spring and 55 m (60 yd) in the summer. The cutthroat in their study showed a highly nonrandom dispersion pattern, with some cutthroat not moving at all while others moved long distances. In addition, they found that cutthroat often have diel movements, swimming to areas of higher velocity during the day to feed and returning to areas of slower velocity at night. Although Hilderbrand and Kershner (2000b) did not find any cutthroat movement during the winter, Jakober et al. (1998) found that some cutthroat moved 500 - 1,000 m (547-1094 yd) during the autumn and winter.

Bonneville Cutthroat Trout Restoration

Because nonnative trout species out-compete or hybridize with native cutthroat, removal of these species was necessary for restoration. Two methods were investigated: electrofishing and piscicides. Electrofishing is appropriate for small streams with small fish populations. Many passes over different seasons to capture spawning fish and over several years to capture all age classes are needed to insure that all the nonnative fish are removed. Piscicides are used to remove fish from larger, more complex stream habitats with large fish populations. Two piscicides are registered for use in Nevada, rotenone and antimycin. The Park decided to treat one stream system with rotenone and another with antimycin. The chemical exhibiting the least impact to non-target organisms would be used for all subsequent stream treatments. The treatments are compared in Table 2.

Small streams with very small fish populations and simple habitats are good candidates for electrofishing removal.

Rotenone is the most extensively used piscicide in the United States (Cumming 1975; Finlayson et al. 2000). Rotenone is found in Australia, Oceania, southern Asia, and South America as a naturally occurring substance derived from the roots of tropical plants in the bean family (Leguminosae), including jewel vine (*Derris* spp.) and lacepod (*Lonchocarpus* spp.). Rotenone has been used for centuries to capture fish in areas where these plants naturally occur. Fisheries managers in North America began to use rotenone for fisheries management in the 1930s. The piscicide has been used for fish community sampling (Chance 1948; Swingle 1958; Hall 1974; Wegener et al. 1974; Miller et al. 1990) and for either complete or partial reclamation of ponds, lakes and streams (Finlayson et al. 2000). Rotenone does not suffocate fish or interfere with the uptake of oxygen in the blood as was long believed. Instead, it is a metabolic inhibitor, making it impossible for fish to use the oxygen absorbed in the blood and needed in the release of energy during respiration (Finlayson et al. 2000).

Table 2. Comparison of treatment methods and their advantages and disadvantages.

	Description	Advantages	Disadvantages
Electrofishing	A backpack electrofisher is used to remove all fish from a section of stream by stunning fish with an electrical current. Fish are then removed from the stream with a net.	-Selective for fish. -Fewer planning requirements and possibly less NEPA compliance.	-Must be conducted multiple times over multiple years to remove all fish. -Does not work well for complex habitat or large populations. -Size selection bias for larger fish.
Rotenone	Natural compound derived from the roots of the bean family. Has been used by indigenous peoples for centuries to capture fish. Use in the US began in the 1930s. Works as a metabolic inhibitor.	-Effectiveness evident quickly. -Treatment can be conducted in short amount of time. -Effective in large river and deep lake systems and complex stream habitats. -Effective over a wide range of pHs.	-Can have large impact on other organisms. -Fish can detect it and avoid it. -Petroleum based emulsifier more dangerous for applicators.
Antimycin	Discovered in 1945 through isolation of culture of bacterium *Streptomyces* sp. Is sold as Fintrol. Used in fisheries work starting in the 1960s. Works by preventing the use of oxygen in metabolic processes.	-Selective, can be used to target specific fish species (Berger et al. 1969). -Lower lethality to macroinvertebrates. -Doesn't affect adult amphibians. -Fish do not detect it so avoidance not an issue. -Degrades quickly so less harm to downstream users. -Extremely small quantities needed (usually 2-8 ppb), making it easier to transport.	-More labor intensive than rotenone. -More expensive than rotenone. -Degrades quickly so has to be carefully monitored to ensure that enough is being applied. -Effectiveness rapidly decreases at pH > 8.0.

Antimycin is an antibiotic produced by bacteria of the genus *Streptomyces*. Antimycin was isolated and discovered at the University of Wisconsin in 1945. In 1963, antimycin was discovered to be toxic to fish. Antimycin is commercially available and sold by a chemical manufacturer as Fintrol. Fintrol is EPA registered (39096-2) for use by state and federal fish and wildlife agencies in fish management projects. It is a liquid formulation consisting of two parts: an active ingredient, antimycin, and a diluent comprised of acetone and phthalate (Finlayson et al. 2002).

Antimycin enters the bloodstream of fish via the gills and interferes with the ability of fish to utilize oxygen in metabolic processes. No short or long-term public health effects related to the use of antimycin have been documented. Furthermore, antimycin quickly breaks down into its primary degradation products (carbon dioxide and water) due to hydrolysis, oxidation and other chemical reactions naturally present in the stream environment (Finlayson et al. 2002).

Objectives

The objectives for this project were:

1) Reintroduce Bonneville cutthroat trout to 15 km (8 mi) of southern Snake Range streams in five separate watersheds within Great Basin National Park.
2) Evaluate the resilience of stream ecosystems to two different piscicides (rotenone and antimycin).
3) Monitor the reintroduced populations and, if a population does not reach 500 BCT per mile within five years at the relocation site, transplant additional fish into the stream reach.
4) Develop and maintain a database of information collected.
5) Assist other agencies as needed to help protect BCT and avoid the conditions that might require listing under the Endangered Species Act.
6) Accomplish the Park's General Management Plan goal of having viable BCT populations in park streams.

Study Area

Great Basin National Park is located in east-central White Pine County, Nevada, near the Utah border (Figure 3). The Park encompasses 31,201 ha (77,100 acres) of the southern Snake Range and was established in 1986 from lands formerly managed separately as the Humboldt-Toiyabe National Forest (30,492 ha; 76,460 acres) and Lehman Caves National Monument (259 ha; 640 acres). Wheeler Peak, at 3,982 m (13,063 ft), is the centerpiece of the Park and overlooks two expansive basins (Spring Valley to the west and Snake Valley to the east), but Great Basin National Park includes only 32 ha (80 acres) of the basin environment as an administrative site. The Park was mostly surrounded by National Forest lands until 2006, when they were transferred to the Bureau of Land Management (BLM). Cattle grazing was discontinued from the Park in 1999 but is still permitted on adjacent lands. Private lands are also adjacent to the Park boundary in some locations.

Most streams in the study area are isolated, beginning in the mountains, flowing into the basin and then sinking into the soil, evaporating without connecting to another stream or waterbody, or being diverted for agricultural uses. Those streams that make it to the valley bottom are used for irrigation. Six perennial streams that flow eastward into the Snake Valley and the Bonneville Basin and one alpine lake, Johnson Lake, made up the project area. The streams were: Mill, Strawberry, Lehman, South Fork Baker, and Upper Snake creeks and South Fork Big Wash. These streams are first- and second-order streams, with widths varying from 0.3-3 m (1-9 ft), base water flows of 0.006-0.113 m^3/s (0.2-4 ft^3/s) and elevations from 1,700-3,135 m (5,577-10,285 ft). The locations of permanent sampling sites are listed in Table 3.

Mill Creek

Mill Creek is a small stream, often less than 0.3 m (1 ft) wide, located in the northeast part of the Park. It begins at a spring at approximately 2,864 m (9,396 ft) elevation and runs for about 4.2 km (2.6 mi), within the Park boundary. Two sampling locations were designated on Mill Creek, one just above the Park boundary at 2,304 m (7,600 ft) and one in the upper elevation of the stream at 2,518 m (8,260 ft). No fish stocking records exist for the creek.

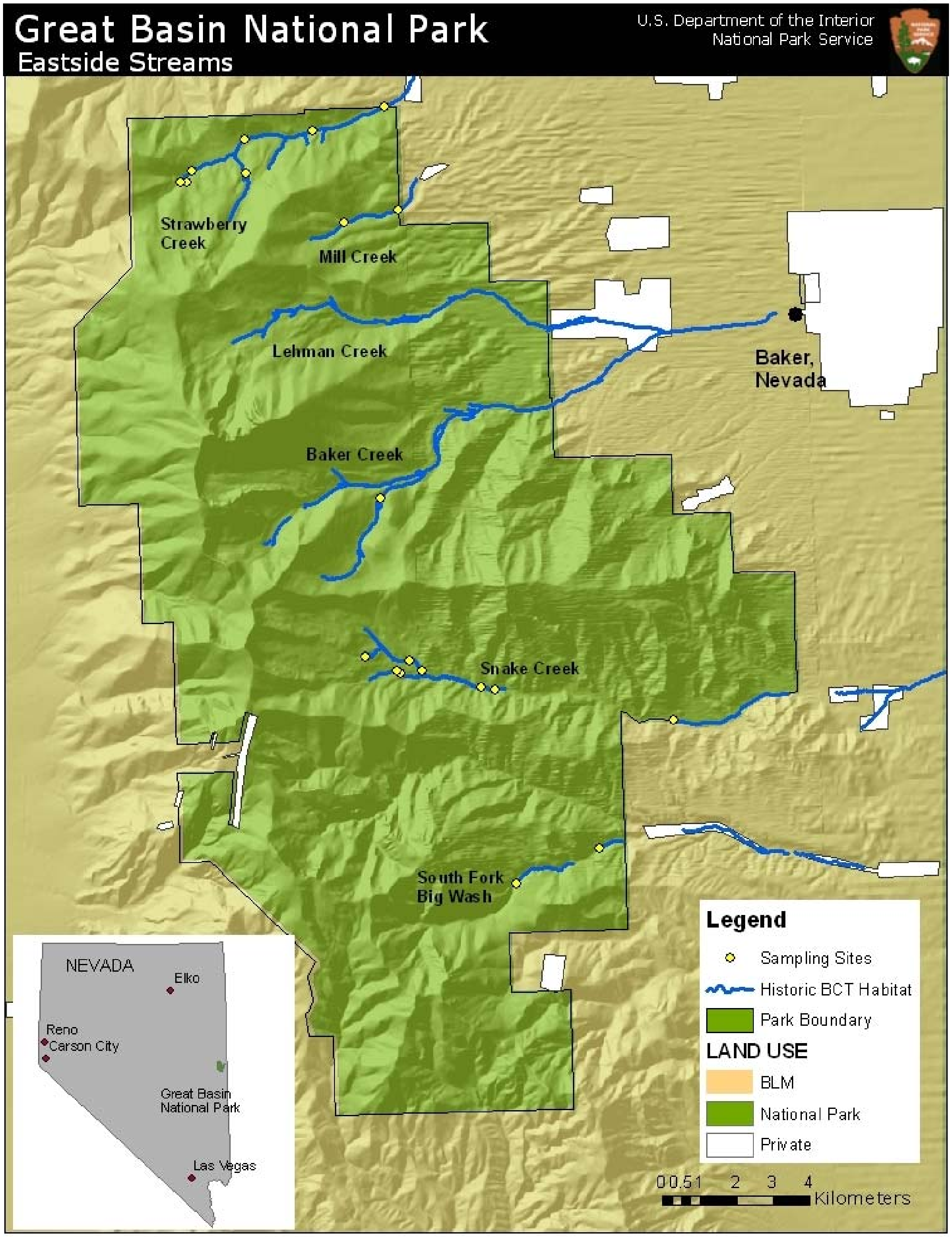

Figure 3. Project area for Bonneville cutthroat trout restoration in Great Basin National Park, Nevada. Sampling sites for water quality, macroinvertebrates and fish populations are indicated by yellow circles.

South Fork Big Wash

South Fork Big Wash (SFBW) is located on the southeast side of the Park. It starts at a large spring at 2,316 m (7,600 ft), continues intermittently for 5.0 km (3.2 miles) to the Park boundary, and then flows 1 km (0.6 mi) to join with the usually dry drainage of the North Fork Big Wash at 2,035 m (6,675 ft), where the stream is called Big Wash Creek. These systems are only connected on years with high water levels during spring runoff. The total length (TL) of perennial, free-flowing stream in SFBW is approximately 3.2 km (2 mi). Sampling locations were designated at the lower perennial spring at 2,134 m (7,000 ft) and at the upper perennial spring at 2,256 m (7,400 ft). Brook trout were stocked historically but were reported to have been flushed out of the creek during a flood in the 1950s (Waite 1974).

Strawberry Creek

Strawberry Creek is a small stream located in the northeast part of the Park (Figure 4). The creek starts at a large spring at 2,591 m (8,500 ft). Blue Canyon Creek, which starts 1.6 km (1 mi) to the east at 2,804 m (9,200 ft), joins Strawberry Creek at 2,423 m (7,950 ft). The combined stream flows for 4.5 km (2.8 mi) within the Park boundary, then 3.8 km (2.4 miles) to US Highway 6 & 50, crossing BLM and private land. The water is diverted above the highway and used for irrigation. The upper 0.5 km (0.3 mi) of Strawberry Creek and all of Blue Canyon Creek are too steep for fish, but the remainder of the creek is confirmed fish habitat. Seven sampling locations were designated along the length of the stream, including one on the Blue Canyon tributary. Although Strawberry Creek is not large, easy access via a road next to the stream has encouraged fishing over the years. Stocking records show that mainly brook trout were planted from 1919-1971 (Dankowski 1984).

Figure 4. Electrofishing survey to check for fish in Strawberry Creek. Note the small size of creek and abundance of woody vegetation (2003).

Upper Snake Creek

Snake Creek has three headwater tributaries and is located in the east-central part of the Park. The North Fork of Snake Creek begins at 2,755 m (9,040 ft) and flows 0.8 km (0.5 miles) to connect with the Middle Fork at 2,627 m (8,620 ft). The Middle Fork begins at three perennial springs at 2,950 m (9,680 ft) and flows 2.1 km (1.3 mi) to the confluence with the North Fork. During snowmelt in high snow years, water from Johnson Lake, elevation 3,292 m (10,800 ft), spills over an earthen dam constructed by historic mining operations and flows into the Middle Fork of Snake Creek. The South Fork of Snake Creek begins at 3,135 m (10,285 ft) and flows 4.0 km (2.5 mi) to connect with the combined North and Middle forks at 2,457 m (8,060 ft). The mainstem of Snake Creek then flows 2.3 km (1.4 mi) before entering a three-mile long diversion pipe installed in 1961 to bypass a losing section of the stream. Prior to the placement of the pipe, porous limestone bedrock absorbed creek water and diverted it to a different watershed (Elliot et al. 2006). The pipeline is a barrier to fish movement between the upstream and downstream segments. Snake Creek runs for an additional 12.4 km (7.7 mi) after leaving the pipeline, including 3 km (2 mi) within the Park boundary. Eight sampling locations were designated, with one below the pipeline and seven above the pipeline, including at least one reach in each of the three tributaries. Records indicate that cutthroat, rainbow and brook trout were stocked between 1925 and 1952 (Haskins 1990). No brown trout are noted in stocking records, although they are the predominant fish species in the lower section of the creek.

South Fork of Baker Creek

South Fork of Baker Creek is the largest tributary to Baker Creek, providing approximately one-quarter of its stream discharge. South Fork of Baker Creek starts at 3,050 m (10,006 ft) and flows for 4.8 km (3.0 mi) before joining the main part of Baker Creek at 2,451 m (8,040 ft). The headwaters flow rather steeply until they reach a large open meadow (Figure 5). Soon after reentering the forest, a 45% gradient for 1.5 km (1 mi) impedes fish passage upstream. One sampling location was designated below the meadow. Cutthroat and rainbow trout were stocked in South Fork Baker in the early 1950s (Frantz 1953).

Figure 5. Electrofishing the meadow area of South Fork of Baker Creek (2002).

Lehman Creek

Lehman Creek is the second largest creek in the Park after Baker Creek. Although it was originally targeted for restoration, its use as a source of drinking water outside the Park precluded the chemical removal of nonnative fish.

Johnson Lake

Johnson Lake (Figure 6) is located at 3,292 m (10,800 ft) and is accessible via a 5.1 km (3.2 mile) trail beginning at the end of the Snake Creek road. The lake, thought to be originally fishless due to the steep terrain, is located between precipitous walls in a glacial cirque. The surface area is 1.0 ha (2.5 acres) with a maximum depth of 4.6 m (15 ft), a mean depth of 2.4 m (8 ft) and a volume of 24,670 m^3 (20 acre-feet). A spring 60 m (197 ft) to the south of the lake serves as the inlet. The outlet is at the east end at a breach in a man-made dam constructed around the turn of the twentieth century to

Figure 6. Johnson Lake is a sub-alpine lake that contained introduced brook trout.

expand the lake’s water storage capacity for mining operations. Old mining equipment can be seen surrounding and at the bottom of the lake. During spring runoff, the outlet stream carries water from the lake to the Middle Fork of Snake Creek. From August to October, water leaving the lake only flows 300 m (327 yd) before it sinks into the substrate or evaporates. The lake has been stocked with brook, rainbow and Lahontan cutthroat trout, but only brook trout have been confirmed since 1974 (Haskins 1990).

Methods

In order to meet the objectives of the project, a suite of methods was employed. Only pure BCT would be allowed for reintroductions, so one of the first actions was to conduct genetic analyses on two populations of possibly pure BCT. Then a multi-step approach was used to evaluate streams, conduct treatments if necessary, monitor streams, reintroduce BCT, and monitor BCT and other aquatic organisms.

Genetic Analysis - Mill Creek and Strawberry Creek

Fish from Mill and Upper Strawberry Creeks exhibited BCT characteristics[1] and were collected to obtain samples for genetic analysis. In 1999, the Park sent 60 fin clips and 20 entire fish to the Department of Zoology genetics lab at Brigham Young University for analysis. The lab used restriction fragment length polymorphisms (RFLPs) and polymerase chain reaction (PCR) to selectively amplify two mitochondrial DNA genes and the ITS region of the rRNA gene from nuclear DNA. In addition, in 2000 the Park collected 60 fin clips and sent them to the Wild Trout and Salmon Genetics Lab at the University of Montana for genetic analysis using the paired interspersed nuclear elements (PINE)-PCR technique.

Steps to Reintroduction

The Park used an adaptive management approach to restoring BCT to several watersheds. A basic nine-step approach was used as a guideline and comprised the following steps:

1. Planning based on reports of fish surveys, water quality and habitat evaluations of watersheds.
2. Pre-treatment surveys of nonnative fish populations.
3. Pre-treatment surveys of other ecosystem components, including aquatic macroinvertebrates, mollusks, amphibians and water chemistry.
4. Chemical or physical treatment of streams to remove nonnative fish.
5. Treatment effectiveness monitoring to determine whether nonnative fish had been eradicated.
6. Post-treatment surveys of aquatic macroinvertebrates, amphibians and water chemistry to document effects of treatment and establish a baseline for recovery monitoring.
7. Reintroduction of BCT into the best habitat available in the stream using a genetically pure source.
8. Ecosystem recovery monitoring to assess the recovery of the entire aquatic ecosystem, including both macroinvertebrates and fish.
9. BCT population monitoring consisting primarily of fish population and distribution surveys to insure that the BCT were reproducing and growing.

---

[1] Fish specimens from Mill Creek analyzed in 1970 by Dr. Robert Behnke were considered to have characteristics similar to fish specimens from other creeks that had previously been identified as pure Bonneville cutthroat trout (Behnke 1970). However, these fish were later described as hybrids and rainbow trout by the Nevada Department of Wildlife (a visual observation and no genetic analyses).

Planning and Pre-treatment Surveys

Nonnative Fish Distribution and Population Surveys

Population surveys for nonnative fishes were conducted using a Smith-Root Model 12-B Battery Powered Backpack Electrofisher to perform 100 m (109 yd) three-pass depletion surveys with block nets at each end. One person operated the electrofisher, followed by two people with dip nets and one person with a bucket. After each pass, all fish were identified, measured (TL to nearest millimeter) and weighed (to the nearest gram). Fish capture data were analyzed by species and site to obtain abundance, average length and weight. Population size was estimated using Microfish 3.0 software (Van Deventer and Platts 1989). These surveys were conducted prior to treatment to determine the carrying capacity of the streams.

In an effort to mitigate effects of piscicide treatments on non-target organisms, nonnative fish distribution was determined so as to minimize the piscicide treatment area. The upstream limit of nonnative fish distribution in each creek was found by using the backpack electrofishers to spot shock along the creek. Spot surveying continued for 1 km (0.6 mi) beyond the last fish captured to verify that it was indicative of the upstream limit of distribution. The locations of the upstream limit of distribution were confirmed over multiple years.

Physical/Chemical Variables

Water temperature, dissolved oxygen, conductivity, pH, and discharge were measured at each monitoring site. In addition, a water sample was collected and analyzed for turbidity, nitrates, phosphates, alkalinity, hardness, sulfates, and silica. Water quality instruments used were pHtestr2 and 3+ for pH; YSI85 for dissolved oxygen, conductivity, salinity, and temperature; Horiba U-10 Water Checker (2002 only) for dissolved oxygen, conductivity, salinity, pH, turbidity, and temperature. These instruments were calibrated according to the manufacturer's instructions, which included daily pH calibration and monthly dissolved oxygen and conductivity calibration. A Global Flow Probe Model FP101 was used to measure water velocity. In the lab, a SmartColorimeter was used to analyze grab samples for turbidity, nitrates, phosphates, sulfates, and silica, and LaMotte test kits were used for alkalinity and hardness. Measurements were taken at each of the designated sampling points for each stream, following standard aquatic resource protocols for the Park (Schenk et al. 2003). Water quality samples were taken and characteristics measured during each fish and macroinvertebrate survey (Table 3).

Macroinvertebrate and Mollusk Sampling

Sample sites for macroinvertebrates were selected based on riparian vegetation types and the extent of fish distribution. Two sampling sites per stream were placed at least 100 meters above the last fish detected so that they would remain untreated. Sites were sampled one year prior to and one day prior to treatment on Strawberry Creek and two years prior to, one year prior to and one day prior to treatment on Snake Creek. Macroinvertebrate surveys followed the EPA's rapid bioassessment protocols (Barbour et al. 1999; Hawkins et al. 2001) and included both riffle-only quantitative and multi-habitat-qualitative surveys. Surveys were conducted one to six times before treatment. Samples were taken at the designated sampling points for each stream, preserved in ethyl alcohol and sent to the National Aquatic Monitoring Center. Plecoptera, Ephemeroptera and Trichoptera (collectively referred to as EPT taxa) were assessed as a group due to their sensitivity to pollutants. As was done with all macroinvertebrates combined, the

Table 3. Pre-treatment surveys at stations. Physical/chemical variables were measured at each of the sampling dates listed below in addition to at least twice a year at each site.

Station	Eleva -tion (m)	Distance from Park Boundary (km)	UTM Easting	UTM Northing	Date of Fish Surveys	Date of Macroinvertebrate Samples
Mill 1	2304	0	737758	4324735	8/24/99, 6/25/02	7/29/99, 7/30/99
Mill 2	2518	1.5	736287	4324386	8/26/99	7/30/99
Strawberry 1	2073	0	737384	4327541	8/16/99	9/11/00
Strawberry 2	2231	2.1	735432	4326908	8/17/99	6/24/99, 7/27/99, 9/11/00
Strawberry 3	2384	4	733588	4326651	8/19/99	6/24/99, 7/27/99, 9/11/00
Strawberry 4	2545	5.8	732125	4325798	8/19/99	6/29/99, 7/27/99, 9/11/00
Strawberry 5	2621	6.1	731996	4325506	1999*	6/25/99, 7/28/99, 9/11/00
Strawberry 6	2533	5.1	733583	4325732	1999*	7/28/99, 9/11/00
Strawberry 7	2606	6.2	731816	4325509	1999*	7/28/99
Snake 1	2059	3.6	745244	4310876	8/22/00	8/16/00, 7/25/01, 5/7/02, 7/31/02, 8/22/02
Snake 2	2335	8.9	740382	4311728	8/28/00, 8/2/02	7/27/00, 7/25/01, 10/11/01, 7/31/02, 8/22/02
Snake 3	2359	9.3	740009	4311795	7/12/00	7/27/00, 7/25/01, 5/7/02
Snake 4	2475	11.1	738382	4312078	8/17/00, 8/1/02	8/7/00, 8/16/00, 7/25/01
Snake 5	2518	11.6	738063	4312514	8/21/00, 8/1/02	8/16/00, 7/24/01, 5/7/02, 7/31/02, 8/19/02
Snake 6	2524	11.6	737826	4312156	7/29/00	8/17/00, 7/24/01, 10/11/01, 7/31/02, 8/19/02
Snake 7	2536	11.7	737728	4312211	2000*	8/23/00, 7/24/01, 10/11/01, 5/7/02, 7/31/02, 8/19/02
Snake 8	2719	13.1	736843	4312607	2000*	8/23/00, 7/24/01, 7/31/02, 8/19/02
SF Baker	2685	6.2	737263	4316901	2000*	8/29/05
SF Big Wash 1	2256	3.4	740949	4306447	1999*	5/30/00, 7/17/00
SF Big Wash 2	2134	0.8	743204	4307404	1999*	6/6/00, 7/18/00
Johnson Lake	3292	16.1	734192	4313992	7/29/03, 8/10/04	7/24/00, 7/29/03, 8/10/04

*Exact date not recorded

EPT group was evaluated in terms of total abundance and the number of taxa represented. Taxa were identified to the lowest level possible; not all larval forms could be identified to the species level. Mollusk surveys were conducted separately from macroinvertebrate surveys in 2001, but combined thereafter since the National Aquatic Monitoring Center also identifies mollusks.

Amphibian Surveys

Surveys were conducted for adults, tadpoles and egg masses using Great Basin National Park Aquatic Resources Protocols (Schenk et al. 2003) and concentrated in May and June. In addition, every site visit to the sampling stations for fish, macroinvertebrates, or water quality sampling also checked for amphibians.

Chemical or Physical Treatment

The removal of nonnative fish was accomplished using chemical (piscicide) or physical (electrofishing) treatment. Electrofishing removal was conducted on South Fork of Baker Creek. Rotenone was used to treat Strawberry Creek, while antimycin was used to treat Upper Snake Creek and Johnson Lake. No chemical treatment was necessary for South Fork Big Wash where the nonnative fish were eliminated by a flash flood in the 1950s (Waite 1974).

Electrofishing Removal – South Fork of Baker Creek

A backpack electrofisher was used to remove fish from the targeted section of South Fork of Baker Creek. A minimum crew size of three electrofished the stream at least twice a year from 2002 to 2005. We began at the bottom of a waterfall at 2,650 m (8,700 ft) elevation and continued through a steep plunge pool section, across a meadow and upstream for 0.5 km (0.3 mi) to 2,700 m (8,900 ft).

Rotenone – Strawberry Creek

Rotenone was used to treat the entire length of Strawberry Creek, beginning above the upstream limit of fish distribution at 2,580 m (8,460 ft) to the point of diversion for irrigation, a small pond leading into a pipeline at 1,880 m (6,160 ft). The rotenone treatment was coordinated with NDOW, since construction of a barrier at the Park boundary was not feasible, and NDOW was agreeable to extending the treatment beyond the Park onto Humboldt National Forest, private and BLM lands, where NDOW has jurisdiction over fish populations. Treating the stream outside the Park boundary also required state approval from the Nevada Division of Environmental Protection (NDEP).

Prior to the treatment, NPS and NDOW personnel spent time walking the length of the stream identifying springs, seeps and areas that might provide refuge to fish during a treatment. In addition, dye studies were conducted to determine flow patterns.

Two forms of rotenone were used to treat Strawberry Creek. The first was Prentox PrenFish Toxicant manufactured by Prentiss, Incorporated. This is a liquid emulsifiable mixture consisting of 5 percent rotenone, 6 percent emulsifiers, 80 percent associated aromatic petroleum solvent, 7.5 percent acetone, and 1.5 percent unspecified (MSDS). The second product used was Rotenone Fish Toxicant Powder. This dry powder was mixed to achieve the same concentrations found in the liquid emulsifiable product above. The concentration targeted for Strawberry Creek was 7 ppm for the first two hours and 2 ppm for the remainder of the treatment.

On September 12, 2000, Strawberry Creek was treated with rotenone dispensed using drip stations. Each drip station consisted of a 18.9 L (5 gal) bucket with a 1.6 mm (1/16 in) diameter hole at its base that allowed the bucket to drain in one hour. Based on the breakdown of rotenone at an average 7.4 percent gradient (rendering it nontoxic to fish), drip stations were set up every 800 m (0.5 mi) for a total of 15 drip stations. Handfuls of rotenone mixed with sand and unflavored gelatin were deposited in rivulets that fed the main channel from seeps and springs. Larger rivulets, where sand eroded away quickly, were treated with backpack sprayers containing 39 ml (1.3 oz) of liquid toxicant per liter of water. These rivulets were treated again on the following day.

Antimycin – Upper Snake Creek

In 2001, in preparation for the antimycin treatment of Snake Creek, data on stream flow and toxicity were collected and evaluated. During the pre-treatment phase, a flow study was conducted to determine the travel time between stations. This information was used to determine the proper spacing and timing of treatment stations. Before conducting the study, the stream was marked and elevation was determined at 100 m (109 yd) intervals (Figure 7). Ten ml (0.3 oz) of fluorescent dye was added to the stream at the upstream limit of distribution and then periodically every 2-4 km (1.2-2.4 mi) downstream, when the dye became too diluted to detect. The time the dye reached each 100 m mark was recorded, and the cumulative time was computed to help determine when the detoxification station would be needed. Antimycin was detoxified

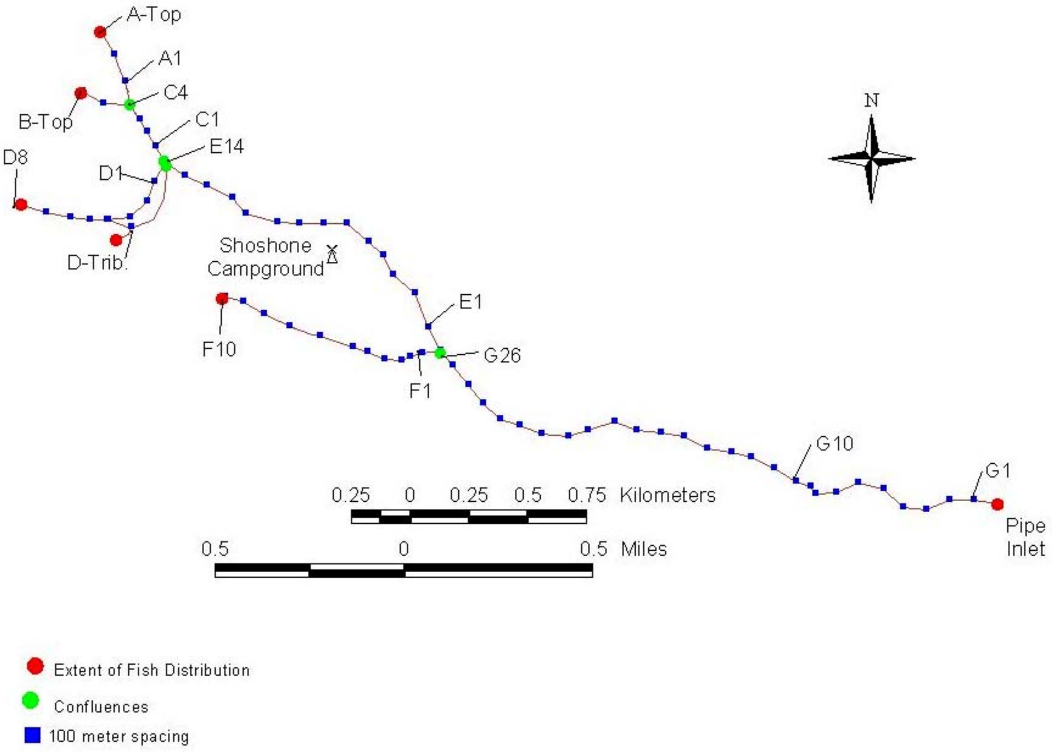

Figure 7. Upper Snake Creek treatment area marked in 100 m elevation intervals.

with potassium permanganate ($KMnO_4$). Based on previous treatments, it was thought that the antimycin would retain toxicity for about 66 m (200 ft) in elevation change (Tiffan and Bergersen 1996).

Toxicity Test: To determine the amount of antimycin (Fintrol) and of detoxification chemical (potassium permanganate, $KMnO_4$) needed to conduct a successful chemical renovation of the upper reaches of Snake Creek, toxicity tests (Figure 8) were performed on October 11-13, 2001. Three tests were conducted: one to test the toxicity of antimycin, one to test the toxicity of $KMnO_4$ and one to determine the demand of $KMnO_4$. One set of buckets with 0, 2, 4, and 8 ppb antimycin, another set with 0, 1, 2, 3, and 4 ppm KMnO4 and a third set with 8 ppb antimycin and 0, 1, 2, 3, and 4 ppm KMnO4 were prepared. Brook trout (mean length = 148.8 mm) were collected from Snake Creek 20-42 hours before the start of the toxicity tests, and 10 were placed in each test solution. Dilution water from Snake Creek ranged in pH from 7.8-7.9. Additions of antimycin and $KMnO_4$ did not change the pH. Temperatures ranged from 3.9-5.5° C and were maintained by placing the buckets in Snake Creek. Dissolved oxygen saturation in the creek water was 77%. A large oxygen tank with four airstones was used to aerate the water for 15 minutes of every hour. Following the eight-hour exposure, fish were moved into holding cages in the creek so that they could be examined 24 and 48 hours post-exposure.

Figure 8. Toxicity test to determine amounts of antimycin and potassium permanganate needed for the treatment (2001).

Equipment Construction: Equipment was constructed to dispense antimycin and $KMnO_4$ into the stream at desired rates. This equipment consisted of antimycin stations using five gallon buckets with an outlet controlled by an on/off valve. A hose ran from the outlet to a dog-watering device (Figure 9) suspended over the stream. The dog-waterer had a float that controlled the flow of antimycin into a dish. A 1.6 mm (1/16 in) hole was drilled in the bottom of the dish to allow antimycin to drain into the stream. The flow was monitored and maintained at 1 gallon per hour for 8 hours with a concentration of 8 parts per billion (ppb).

Figure 9. Antimycin dispenser in Snake Creek (2002).

A detoxification station to dispense $KMnO_4$ was set up at the pipe outlet. Original plans were to set the detox station at the pipe inlet, but after discussions concerning the 50 year old galvanized pipe and the fact that $KMnO_4$ is a very strong oxidizer, concerns over damaging the pipe led to the decision to place the detox station at the pipe outlet. The detox station was made with two 35 gallon drums connected by hoses to "float-boxes" suspended over the stream, which dispensed the $KMnO_4$ in an even flow to maintain the appropriate concentrations.

Antimycin Application: Starting August 4, 2002, streamflow was recorded once daily and used to determine the amount of antimycin to dispense at each station on the following day. For the first day of treatment, antimycin stations (Figure 10) were placed approximately 100 m (109 yd) above the last known fish locations on the Middle and North forks of Snake Creek. A detoxification station was set up below the pipe outlet.

Figure 10. Measuring out antimycin for the drip station (2002).

Fish cages with live fish were placed at approximately 100 m (109 yd) intervals on the stream to monitor how far the antimycin carried in the stream. The cages were monitored each morning to determine where to place that day's antimycin stations. For example, if mortality was complete in three cages (300 m; 327 yd) below a station but not complete at the fourth cage after 24 hours, the next station would be set up just above the third cage on the following day. Due to its lower elevation, the South Fork of Snake Creek was treated beginning on day three.

A backpack sprayer was used to treat back eddies of the streams and adjacent springs and seeps with potential to provide refuge areas for fish (Figure 11).

Figure 11. Using a backpack sprayer to treat a seep (2002).

Potassium permanganate can also be toxic to fish at concentrations exceeding 4 ppm. Cages with fish were placed below the detoxification station at 150 m (164 yd), 1.4 km (0.9 mi), 3.7 km (2.3 mi) (the Park Boundary) and at 5.8 km (3.6 mi) (the Nevada Division of Wildlife Spring Creek Rearing Station) to ensure detoxification was effective and had no unintended effects.

Antimycin - Johnson Lake

Johnson Lake was treated with antimycin in August and September of 2004. Treatment was conducted using a Zodiac inflatable raft with a wooden floor and 4.5 hp outboard motor. Antimycin was injected into the outwash of the outboard motor and pumped into the deeper waters of the Lake via tubing. Antimycin stations, as described in the previous section, were used to treat the outlet stream, and a backpack sprayer was used to treat the inlet and edges of the Lake. Gillnets were used to obtain fish from the lake for live-cars and to evaluate the effectiveness of the treatment. All equipment was transported to the Lake by mule team.

During treatment, the raft traveled back and forth across the Lake (Figure 12), applying antimycin to achieve a concentration of 8 ppb based on estimated lake volume. Four live-cars with fish were placed around the perimeter of the Lake and one was placed downstream of the Lake outlet. The drip station at the lake outlet was filled with 10 ml (0.3 oz) antimycin in 18.9 L (5 gallons) of water. Following application of antimycin from the boat, a sprayer filled with 3785 ml (3 gallons) of water and 50 ml (1.7 oz) antimycin was used to treat shallow water at the east end of the Lake.

Figure 12. View of Zodiac spreading antimycin in Johnson Lake (2004).

Treatment Effectiveness Monitoring

Following the stream treatments, the entire treatment area was electrofished with a Smith Root backpack Model 12-B electrofisher two times during the year following the treatment to ensure that no non-native fish remained in the system. A gill net was used one year following treatment on Johnson Lake to determine effectiveness.

Ecosystem Recovery Monitoring

Ecosystem recovery monitoring was conducted on all four streams to which BCT were reintroduced, although sampling frequency was greater on the two streams that were chemically treated. Water chemistry, macroinvertebrates, and mollusks were sampled using the protocols previously described. Macroinvertebrate, mollusk and water chemistry surveys were conducted at one month, nine months, one year and two years after treatment, and will continue to be conducted in the future as funding permits.

Reintroduction of BCT

Following verification that no non-native fish remained in the treatment area and that macroinvertebrate composition and abundance had returned to at least 75% of pre-treatment levels, BCT were reintroduced to the stream. This typically occurred within one to three years after treatment. Both hard-plant and streamside incubator methods were attempted. In either case, a genetically pure population of BCT was used as the source.

Hard plants involved collecting all size classes of BCT from a donor stream using electrofishing equipment, transporting them in aerated tanks to the recipient stream and releasing two to three fish per pool in the best available habitat. All age classes were taken, and fish were measured and weighed before transport.

Streamside incubators were used to take advantage of the fact that one BCT can produce over a thousand eggs. Park staff monitored streams known to have populations of pure BCT for signs of spawning every few days beginning in mid-April. Signs of spawning included fish pairing, redd building, strong color changes and, if caught, a fish that easily extruded milt or eggs by gently running fingers along its belly. In addition, water temperature was measured on each spawning survey, and a HOBO datalogger recorded temperature hourly.

Streamside incubators made of converted Coleman coolers were prepared, using instructions from Trout Unlimited (Duff unpublished). Water was filtered and then flowed into a baffled chamber in the cooler, providing oxygenated water for the fertilized eggs while minimizing the amount of sediment.

We set up incubators on Strawberry Creek in May to test them and work out problems (Figure 13). The largest problem was the deposition of fine sediment in the incubator. To combat this problem, sediment traps were constructed and installed upstream of the incubator. These sediment traps reduced the amount of sediment entering the incubator, but also restricted water flow. Daily maintenance was required to clean out the sediment traps and incubator.

Figure 13. Streamside incubator with intake pipe (2002).

In late June 2002, ripe male and female BCT were collected and artificially spawned to obtain milt and eggs, which were combined. The milt was left with the eggs for about a minute to fertilize them and then drained out. Water was added to harden the eggs for transport. After 45 minutes of water hardening, the fertilized eggs were placed in cheesecloth, packed on ice and taken to the previously installed streamside incubator at Strawberry Creek (Figure 14).

Fertilized eggs were put into a Whitlock-Vibert box (W-V Box), designed to keep the eggs off the bottom of the incubator, on June 27, 2002. Each day the eggs were checked, taking precautions to ensure they did not receive any direct sunlight. Any eggs infected with fungus were removed with an eyedropper.

Figure 14. Putting fertilized eggs into the Whitlock-Vibert box (2002).

BCT Population Monitoring

Monitoring for BCT began one to two years after reintroduction using standard three-pass depletion population surveys and spot-shocking distribution surveys with a Smith Root backpack electrofisher. Fish were weighed using an Ohaus electronic scale and measured to TL. BCT population surveys were conducted a minimum of once every two years.

Creel Survey

No special fishing regulations were instituted for the reintroduced populations, so anglers were allowed to catch up to 10 BCT per day. To determine angling pressure in the Park, a stratified random creel survey was conducted from June to August 2005. This survey was designed to gather angler use, catch, harvest and economic value information using an Office of Management and Budget approved survey form. Surveys were completed along four streams and one lake two to three times each month (Wiley and Baker 2005).

Results

Genetic Analyses - Mill Creek and Strawberry Creek

When this project was initiated, it was believed that BCT had been extirpated from Park streams. However, genetic testing by labs at Brigham Young University and the University of Montana identified fish from Mill Creek as pure Bonneville cutthroat trout with no sign of introgression (Shiozawa and Evans 2000; Cremins and Spruell 2003). This allowed Mill Creek to be used as a donor population of BCT to other park streams. Analysis of fin clip samples collected from fish in upper reaches of Strawberry Creek and sent to the genetics lab at the University of Montana revealed that they were Bonneville cutthroat/rainbow hybrids (Cremins and Spruell 2003).

Planning and Pre-treatment Surveys

Nonnative Fish Distribution and Population Surveys

The upstream limit of nonnative fish distribution ranged from 2,530 m (8,300 ft) to 2,713 m (8,900 ft) (Table 4). The uppermost fish in Strawberry Creek were cutthroat/rainbow hybrids. It is possible that cutthroat persisted in the watershed since Lake Bonneville days, or more likely (due to the small size of the stream) entered the creek via the Osceola Ditch about 1900. South Fork Baker Creek had the distinction of having rainbow trout as the species found farthest upstream. Stocking records show that this is likely due to the thousands of rainbow trout that were introduced into the upper section of South Fork Baker Creek until Great Basin National Park was established in 1986 (Haskins 1990). No fish were found in South Fork Big Wash, where a flash flood in the 1950s removed all fish (Waite 1974).

Table 4. Upstream limit of nonnative fish distribution in restoration streams of Great Basin National Park.

Stream	Elevation (m) of upstream distribution	Species
Mill	2,560	Bonneville cutthroat trout
South Fork Big Wash	n/a	No fish found in stream
Strawberry	2,597	Hybridized Bonneville cutthroat/rainbow trout
Snake Creek-North Fork	2,652	Brook trout
Snake Creek-Middle Fork	2,713	Brook trout
Snake Creek-South Fork	2,530	Brook trout
South Fork of Baker Creek	2,697	Rainbow trout

Estimated densities for nonnative trout in the streams that were targeted for treatment ranged from 12 per mile to over 2,000 per mile (Table 5). Only brook trout were found in Upper Snake Creek, while the percentage of brook trout in Strawberry Creek increased with elevation. The Mill Creek fish population was estimated at 100 to 600 BCT per mile, while South Fork of Baker Creek had an estimate of 12 rainbow trout per mile.

Table 5. Pre-reintroduction fish populations in selected streams.

Stream	Site	Year	Estimated Number of Fish Species (fish/mile)
Mill	BCT1	1999	612 BCT
Mill	BCT2	1999	113 BCT
South Fork Big Wash	n/a	1999	0 fish
Strawberry	Near park boundary	1999	1125 rainbow 98 brook
Strawberry	2 km above park boundary	1999	889 rainbow 399 brook
Strawberry	5 km above park boundary	1999	97 rainbow 869 brook
Snake Creek-North Fork	Shoshone campground	2000	2,270 brook
Snake Creek-Middle Fork	Main stream	2000	2,447 brook
Snake Creek-South Fork	200 m above confluence	2000	708 brook
South Fork Baker Creek	Near meadow area	2002	12 rainbow

Chemical/Physical Parameters

Water quality measurements fell within the normal range for Great Basin mountain streams (Table 6). South Fork Big Wash had the highest specific conductance, consistent with the fact that the stream repeatedly goes underground in a limestone area. The other streams in the project area are primarily underlain by metamorphic rock. The pH of all the streams was 8.0 or less, which was important since the piscicide antimycin works best at pH values of less than 8.0.

Table 6. Basic water quality parameters in selected streams-average June measurements, 2001-2002.

Stream	Temp. (C^o)	pH	Dissolved Oxygen (mg/L)	Specific Conductance (µS/cm @ 25°C)	Water Flow (high flow) (cfs)
Mill Creek	7.5	7.6	8.0	66	0.6
South Fork Big Wash	8.6	7.5	9.0	309	0.8
Strawberry Creek	9.4	8.0	8.4	75	3.2
Upper Snake Creek	9.5	8.0	9.5	76	15.5
Johnson Lake	9.5	7.2	n/a	24	(20 acre-ft)
South Fork Baker Creek	8.1	6.9	8.5	35	approx. 2

Macroinvertebrate Surveys

A total of 136 distinct macroinvertebrate taxa were found in project streams, and 8 different taxa were found in Johnson Lake during pre-treatment surveys (Table 7). Strawberry Creek had the largest number of EPT taxa and total taxa of macroinvertebrates, followed by Upper Snake Creek. South Fork Baker Creek had the least number of total and EPT taxa for unknown reasons. All sites had assemblages indicative of good water quality. No endemic or sensitive species were found.

Table 7. Macroinvertebrates collected prior to stream treatments.

Stream	# Sites	# EPT	Total taxa	# Sampling Trips
Mill Creek	3	37	63	1
South Fork Big Wash	2	29	62	1
Strawberry Creek	6	59	112	2
Upper Snake Creek	8	46	93	3
South Fork Baker Creek	1	12	15	1
Johnson Lake	1	0	8	2

Amphibian Surveys

No amphibians were found in any park watersheds, despite in-depth searches.

Chemical or Physical Treatment

South Fork of Baker Creek Electrofishing Removal

Electrofishing removals of fish from South Fork of Baker Creek began in 2002, with each 1 km (0.6 mile) section of stream being fished repeatedly. Twelve rainbow trout were found and removed. Large fish had their adipose fin clipped and were transported downstream of a natural fish barrier. Small fish were discarded in the upland area. Fish removal continued in 2003, with several rainbow trout removed. In 2004, only one small trout was found in six electrofishing passes. In addition, the stream was spot-surveyed 3 km (1.8 mi) above the upstream limit of distribution to the location where trout had been released in the 1980s. No fish were encountered in this section despite the presence of suitable trout habitat. In 2005, no fish were found in three electrofishing passes.

Strawberry Creek Rotenone Treatment

A total of 125 L (33 gallons) of 5% liquid rotenone and 10.9 kg (24 lbs) of 8.5% rotenone dry powdered toxicant was used on 11.9 km (7.4 mi) of Strawberry Creek on September 12 and 13, 2000. The application rate over the two days was 766.2 ml/hour of liquid toxicant for the first hour and 295 ml/hour for seven hours each day. This maintained rotenone concentrations at five ppm and two ppm, respectively.

No detoxification of rotenone was necessary. Strawberry Creek empties into a large meadow and then drops into Weaver Creek approximately 1.6 km (1 mi) from the last drip station. No fish habitat existed in the meadow. Observations of live fish after the treatment in Weaver Creek below the meadow indicated that rotenone detoxified prior to reaching it.

Upper Snake Creek Antimycin Treatment

The flow test and toxicity test conducted during the pre-treatment preparation period showed that the stream was suitable for using antimycin (Appendix A).

Antimycin Application: From August 5-10, 2002, a total of 4,005 ml (135 oz) of antimycin was dispensed into Snake Creek from antimycin stations (Table 8). An additional 250 ml (8.5 oz) of antimycin was sprayed into springs, seeps and tributaries over the five day period. Areas sprayed corresponded to the treated reach for that day.

Although antimycin in some streams retains toxicity within an elevation drop of 60-75 m (197-246 ft) with a low pH (≤ 7.0) and a warm water temperature ($\geq 10°$ C) (Tiffan and Bergersen 1996), in Upper Snake Creek the antimycin completely broke down and became non-toxic at approximately every 18 m (60 ft) drop in elevation. Water temperature was fairly warm, ranging from 7.9-10.8° C with a mean of 9.6° C, and the pH ranged from 7.3 to 7.9 with a mean of 7.7. Apparently, these small differences from what is considered to be ideal had a large impact on antimycin effectiveness. Stations had to be added to maintain an antimycin concentration of 8 ppb and moved closer together to accomplish effective treatment, requiring the use of up to eight stations a day to finish the project in the planned timeframe. Since we had anticipated using no more than three antimycin stations a day, this resulted in an increase in the amount of antimycin used, from a planned 1,700 ml (57 oz) to 4,005 ml (135 oz).

Detoxification: A total of 32,538 grams (71.7 lb) of $KMnO_4$ was dispensed during the treatment (Table 9). This was far below that anticipated in the permit application (82,000+ g or 180 lb), due to the rapid degradation of the antimycin. Antimycin only reached the detox station August 9 and 10. On these dates, the nearest antimycin station was at 500 m (547 yd) above the pipe inlet, 5.3 km (3.3 mi) from the detox station. Despite the rapid breakdown of antimycin in Snake Creek, the pipe apparently allowed antimycin to remain intact over 305 m (1,000 ft) loss in elevation.

No fish mortality occurred at any detox station live car on any day except August 9, when fish mortality occurred at the cage 150 m (164 yd) below the detox station. On that day, the detox station was running at a concentration of 4 ppm. These fish exhibited no signs of antimycin toxicity. Cages 1.4 km (0.9 mi) downstream of the detox station, at the Park boundary (5 km downstream of detox station) and at the rearing station (8 km downstream of detox station) experienced no mortality throughout the treatment. Clearly fish were affected (moving lethargically) by the $KMnO_4$ up to 150 m (164 yd) below the detox station. However, the $KMnO_4$ visibly broke apart before reaching the 1.4 km (0.9 mi) cage and had completely dissipated by the time it reached the Park boundary.

Table 8. Antimycin dispensed during August 2002 Upper Snake Creek treatment.

Date	Location (m above pipeline inlet)	Flow (ft^3/s) measured near that section	ml of antimycin dispensed at each drip station	Antimycin concentration at station (ppb)	Antimcyin dispensed in backpack sprayers (ml)
Aug. 5, 2002	470-north fork	0.3	33	13.4	32
	460-tributary	0.3	33	13.4	
	480-middle fork	0.8	130	20.3	
Aug. 6, 2002	420-north fork	0.12	33	33.8	35
	400-north fork	0.12	33	33.8	
	480-middle fork	0.7	65	11.4	
	460- middle fork	0.7	65	11.4	
	420- middle fork	0.7	65	11.4	
	400- middle fork	0.09	13	17.8	
Aug. 7, 2002	410- middle fork	0.12	33	33.8	36
	450- middle fork	0.7	96	16.8	
	440- middle fork	0.7	80	14.0	
	400-middle fork	1.3	96	9.1	
	360-middle fork	1.3	96	9.1	
	330-middle fork	1.3	96	9.1	
	400-tributary	0.09	30	40.1	
	395-tributary	0.09	36	49.2	
Aug. 8, 2002	300-middle fork	1.3	98	9.26	69
	280-middle fork	1.0	85	10.5	
	360-south fork	2.3	176	9.4	
	340-south fork	2.3	176	9.4	
	320-south fork	2.7	176	8.0	
	290-south fork	2.7	176	8.0	
	270-south fork	2.7	215	9.8	
	250-main stem	3.0	215	8.8	
Aug. 9, 2002	220-main stem	3.0	195	8.0	78
	190-main stem	3.0	195	8.0	
	170-main stem	3.0	195	8.0	
	120-main stem	3.0	195	8.0	
	90-main stem	3.0	195	8.0	
	50-main stem	3.0	195	8.0	
Aug. 10, 2002	340-middle fork	3.0	113	7.4	0
	330-south fork	2.7	176	8.0	
	140-main stem	3.0	196	8.1	
Total			4,005		250

Table 9. $KMnO_4$ amounts and concentrations dispensed August 5-10, 2002.

Date	Flow (cfs)	KmnO4 used (grams)	Concentration at dispensing station (ppm)
Aug. 5, 2002	3.5	2244	1.5
Aug. 6, 2002	2.8	1224	1
Aug. 7, 2002	2.9	1224	1
Aug. 8, 2002	3.0	8262	3
Aug. 9, 2002	2.9	12240	4
Aug. 10, 2002	2.9	7344	3
Total		32,538	

Johnson Lake Antimycin Treatment

First Treatment: Water temperature on the first day of treatment, August 10, 2004, was approximately 9° C, and pH was 7.8-8.1. This caused concern because the previous pH levels had been lower, and antimycin quickly becomes less effective as pH rises (Marking 1975). About 3.5 units (480 ml/unit) of antimycin were spread throughout the lake from 1238 to 1438 hours, with the antimycin being pumped into the boat prop wash. About one-half unit of this antimycin was released at 3 m (10 ft) depth through extended tubing. All antimycin solutions had Nonoxonyl-9, a detergent, added at 20 ml (0.7 oz) per unit to help spread antimycin throughout the water column. Concurrently, 10 ml (0.3 oz) of antimycin diluted in 18.9 L (5 gal) of water was expended into the outlet stream over the course of 5 hours. The drip station was recharged with 10 ml (0.3 oz) of antimycin and 5 gallons of water at 1745 hours. Following the application via the Zodiac, the backpack sprayer spent approximately 1 hour in the shallows at the east end of the lake to use all the piscicide, and then the backpack sprayer was refilled and sprayed at the north end. At 1700 hours, the backpack sprayer was filled for the third time and antimycin applied at the east end of the lake again. The amount of antimycin applied to the lake was estimated to result in a concentration of 7.5 ppb.

On the day following the initial treatment, live fish of a range of size classes were observed in the lake. The pH was 8.5, the upper limit for using antimycin effectively. Due to the high pH, which results in rapid breakdown of antimycin, and the apparent vigor of the fish, the treatment was determined to have been unsuccessful. The pH continued to rise over the course of the day, reaching a value of 9.5 by 1630 hours, and although sufficient antimycin was applied to achieve concentrations of 8 ppb, live fish were captured in the gill nets shortly after the treatment was completed. The capture of additional live fish one week later confirmed that the treatment had not been successful.

Second Treatment: The pH at Johnson Lake was monitored throughout the remainder of August and September 2004 (Table 10). When it dropped to 8.35 on September 27, it was decided to conduct a second two-day treatment. Treatment began early on September 28 to take advantage of the low morning pH values. Application by boat began at 0700 hours and was completed by 0930 hours. Methods were identical to those used during the first treatment. Three units of antimycin were dispensed throughout the lake via the Zodiac, with an additional 7/8 of a unit dispensed into deep water using extra tubing. Eighty ml (2.7 oz) of antimycin was distributed with the backpack sprayer.

Table 10. Weekly pH readings for Johnson Lake, autumn 2004.

Date	Time	pH
8/17/04	1600	9.1
8/18/04	1010	8.9
9/9/04	1100	8.7
9/16/04	1100	8.0
9/23/04	1430	8.6
9/27/04	1400	8.3

Because live fish were observed along the shoreline at the end of the day, treatment was repeated on September 29 with approximately 2 units of antimycin dispensed from the boat and 40 ml

(1.6 oz) applied with a backpack sprayer along the shoreline. During treatment, all of the fish that were observed were dead. By the time treatment was completed on the second day, the pH had risen to 8.5. However, it is believed that intermittent storm activity on September 28 may have prevented pH from rising to a level that would have prevented the antimycin from being effective. The estimated concentrations of antimycin in the lake were 7.8 ppb the first day and 3.9 ppb the second day.

Fourteen units (6.72 L) of Fintrol (Antimycin-A) were applied for this project. The amount used was approximately three times the quantity expected due to the high pH levels in the lake.

Treatment Effectiveness Monitoring

No fish were encountered in Strawberry Creek following treatment during two electroshocking trips down the entire creek. No brook trout were found in Snake Creek following the treatment, but one brown trout was encountered near Shoshone Campground. Due to the fact that brown trout had never been found in that section of the creek, it is likely that an angler transplanted this fish. No additional brown trout were found in subsequent surveys. No non-native fish were seen in South Fork Baker Creek in 2005. Two years of gillnetting in Johnson Lake found no brook trout. Water chemistry following the treatments was within the natural range of variation for the waterbodies. Macroinvertebrates were sampled and are discussed below.

Ecosystem Recovery Monitoring

Although ecosystem recovery monitoring was conducted at some level in all four streams to which BCT were reintroduced, results presented here are limited to Strawberry and Snake creeks, the two streams that were treated with piscicides. Neither stream exhibited measureable differences in water quality following treatment. However, chemical treatment had substantial, but different, effects on the aquatic invertebrate communities of the two streams. The results suggest that macroinvertebrate communities respond differently to rotenone and antimycin (Figures 15-18).

Macroinvertebrate Recovery Comparison

Pre-treatment: Prior to the treatments, Strawberry Creek had higher macroinvertebrate abundance and richness than Snake Creek. Strawberry Creek macroinvertebrate total abundance averaged 1,762 specimens/m^2 and EPT abundance averaged 833 specimens/m^2. Average number of taxa (richness) for all Strawberry Creek sites was 47 total taxa and 26 EPT taxa. Snake Creek macroinvertebrate total abundance averaged 1,642 specimens/m^2, and EPT abundance averaged 766 specimens/m^2. Average number of taxa (richness) for all Snake Creek sites was 38 total taxa and 22 EPT taxa.

Short-term Response: At one-month post treatment, it was obvious that rotenone had severely impacted the macroinvertebrate communities in Strawberry Creek, while antimycin had moderately impacted macroinvertebrate communities in Snake Creek. Strawberry Creek macroinvertebrate total abundance had declined by 85%, and EPT abundance had declined by 99%. The taxa that were most resistant to rotenone were in the orders Coleoptera, Diptera and Amphipoda (Table 11). Specimens from these orders were collected during all three sampling events: one-day, one-week and one-month post-treatment. Snake Creek macroinvertebrate total abundance had declined by 61%, and EPT abundance had declined by 54%. Macroinvertebrate richness in Strawberry Creek for overall taxa had declined 68%, and EPT taxa had declined 86%. Macroinvertebrate richness in Snake Creek for overall taxa had declined 29%, and EPT taxa had declined 26%.

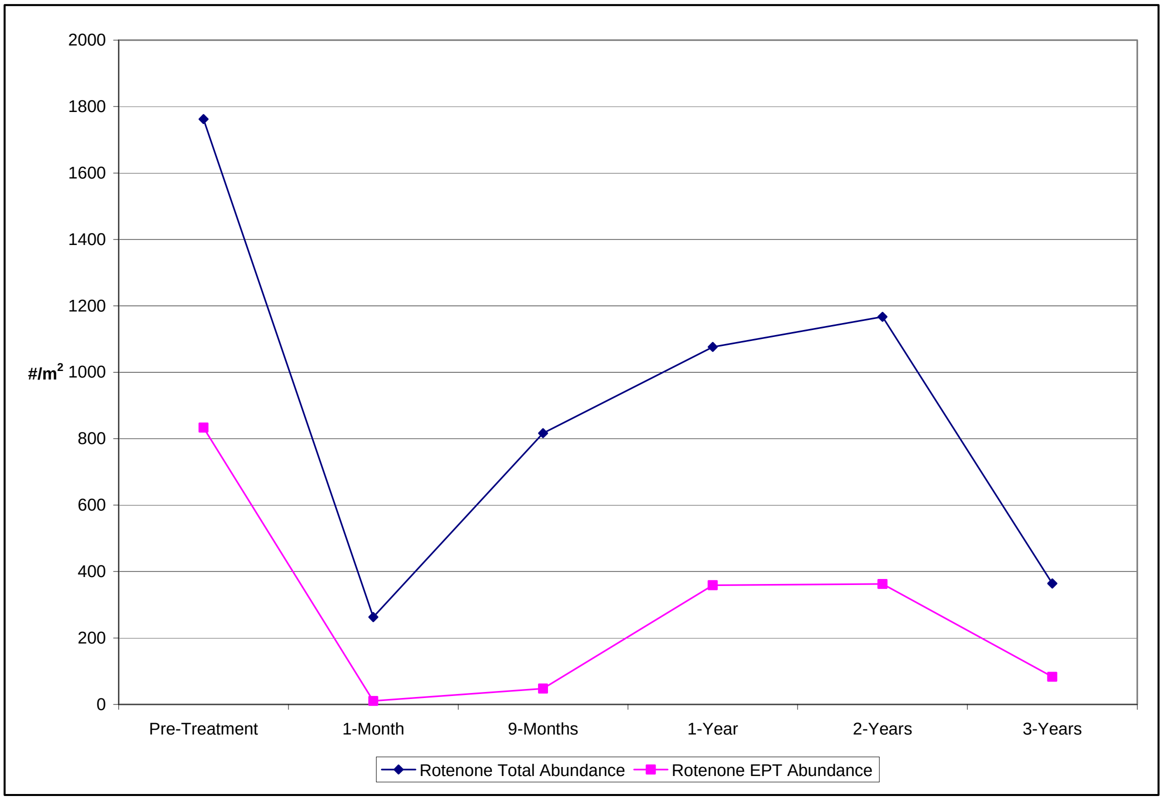

Figure 15. Total and EPT group abundance in Strawberry Creek prior to rotenone treatment and up to three years post-treatment.

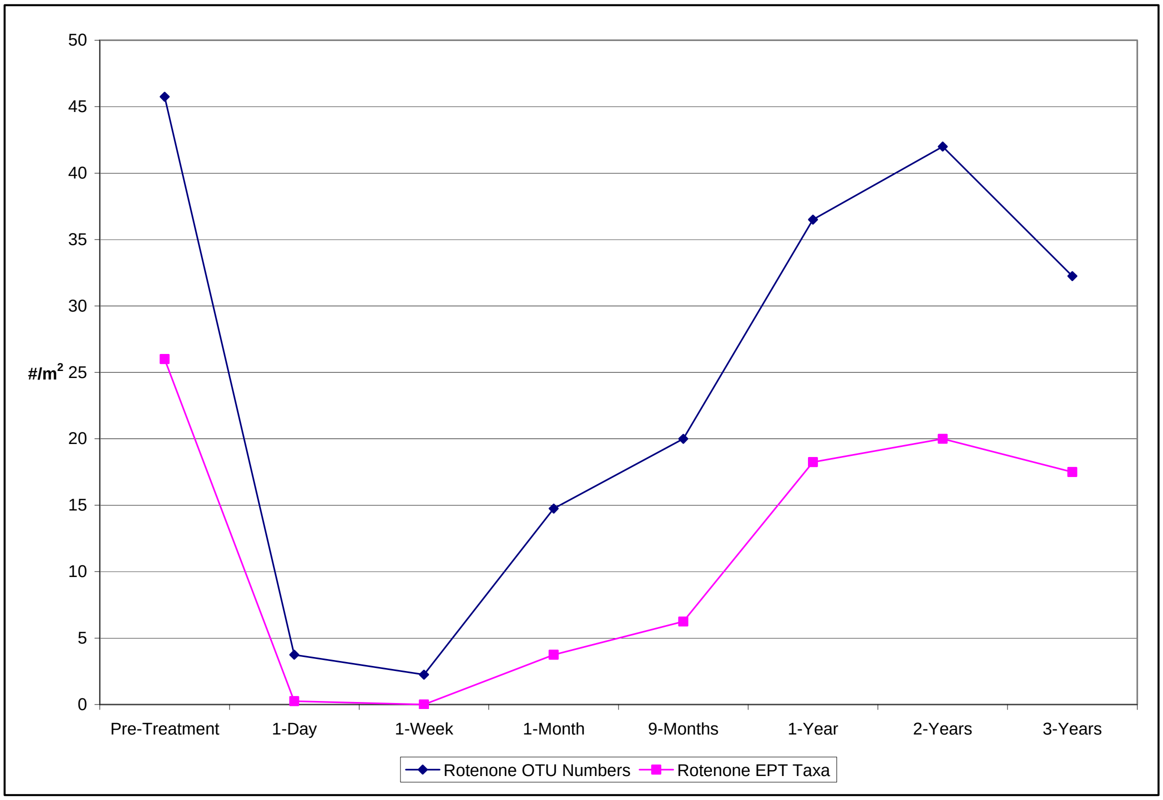

Figure 16. Total and EPT group richness in Strawberry Creek prior to rotenone treatment and up to three years post-treatment.

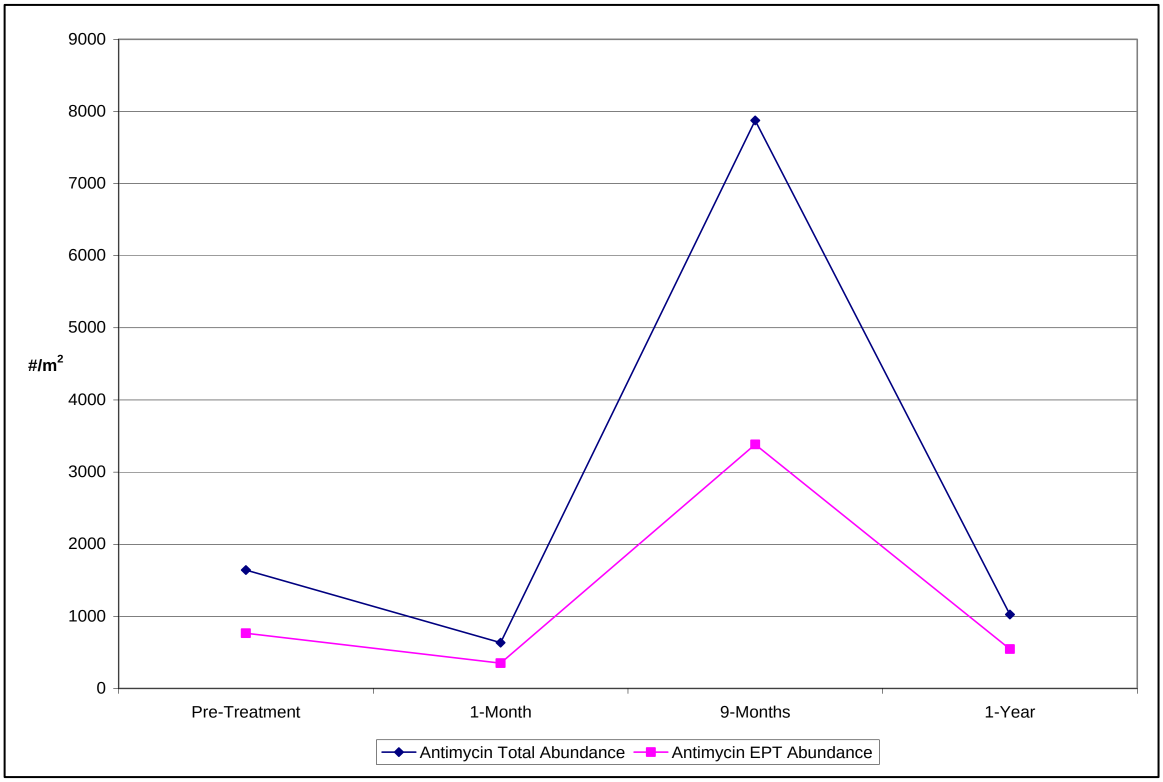

Figure 17. Total and EPT group abundance in Snake Creek prior to antimycin treatment and up to one year post-treatment.

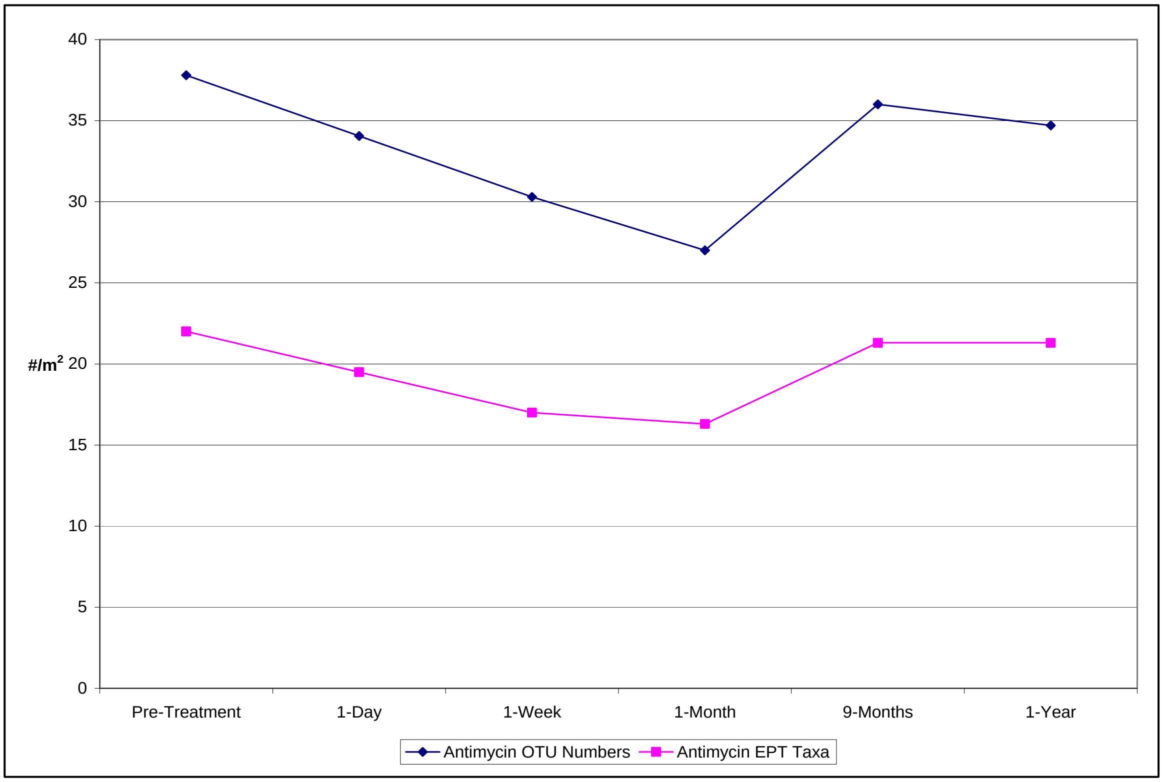

Figure 18. Total and EPT group richness in Snake Creek prior to antimycin treatment and up to one year post-treatment.

Table 11. Taxonomic groups and the percent increases or decreases of contribution to differences in pre- and post-treatment similarity indices by treatment type (from Hamilton et al. 2007).

Taxonomic Group	Rotenone % Contribution	Antimycin % Contribution
Trichoptera	-14.22	7.48
Ephemeroptera	-13.10	-19.14
Plecoptera	-7.27	-9.65
Platyhelminthes	-3.45	3.44
Amphipoda	-1.95	
Trombidiformes	-0.77	1.88
Diptera	12.83	5.79
Coleoptera	3.92	3.40
Annelida	0.78	2.53

Long-term Response: By nine-months post treatment, macroinvertebrate communities in both creeks were increasing in number and diversity. Strawberry Creek macroinvertebrate total abundance was 46% of pre-treatment numbers, but EPT abundance was just 6%. Strawberry Creek richness for overall taxa was 44% of pre-treatment numbers and 24% for EPT taxa. Snake Creek showed an increase, with macroinvertebrate total abundance of 479% of pre-treatment numbers and EPT abundance of 442%. Richness was also high, with overall taxa at 95% and EPT taxa at 97% of pre-treatment numbers.

At one-year post treatment, Strawberry Creek showed increased macroinvertebrate abundance, particularly for EPT taxa, which in three months had gone from 6% to 43% of pre-treatment numbers. Overall taxa abundance was up to 61%, while richness of overall taxa and EPT taxa rose to 80% and 70%, respectively, of pre-treatment levels. Five taxa that were found pre-treatment were missing one-year post-treatment: Plecoptera (Nemouridae), Trichoptera (Glossomomatidae, Philopotamidae *Dolophilodes*), Diptera (Tipulidae *Antocha*) and Ephemeroptera (Baetidae *Baetis bicaudata*). The last two taxa were still absent after three years.

At two-years post treatment, Strawberry Creek had a total abundance of 66% of pre-treatment average and EPT 43% of pre-treatment average. After three years, total abundance exceeded pre-treatment levels at one sample site, while EPT abundance remained below pre-treatment levels at all sites. A steep decline in total and EPT group abundance occurred at three-years post-treatment. The likely cause was a worsening drought that significantly reduced water flows. Total number of taxa remained unchanged three-years post-treatment. Overall taxa numbers recovered to an average of 42 taxa (91% of pre-treatment average) by the second year, while EPT group taxa numbers recovered to an average of 20 taxa (77% of pre-treatment average). Taxa numbers had not returned to pre-treatment levels after three years.

At one-year post treatment, Snake Creek still had lower macroinvertebrate abundance but exhibited richness similar to pretreatment levels. Snake Creek macroinvertebrate overall abundance was 62% of pre-treatment numbers and EPT abundance was 71%. Richness of overall taxa was 92%, and richness of EPT taxa was 97%. One taxon, Trichoptera (Philopotamidae), was still missing one-year post treatment.

For Johnson Lake, the number and diversity of macroinvertebrates increased following the treatment and removal of fish. Three kick-net samples in the littoral zone were taken prior to the treatment, in July 1998, July 2000 and August 2004, with an average of 7 taxa and 23 individuals. Two samples were taken post-treatment, in August 2005 and July 2007, with an average of 9 taxa and 181 individuals. New taxa that were found in the lake post-treatment included Coleoptera (Dysticidae *Agabus* and *Rhantus*), Heteroptera (Corixidae *Cenocorixa* and Notonectidae *Notonecta*) and Trichoptera (Limnephilidae *Hesperophylax* and an unidentified genus).

Reintroduction of BCT

Over the course of five years, more than 350 BCT were released in four different streams within the Park (Table 12). The first reintroduction took place in South Fork Big Wash in 2000, using Mill Creek as the donor source. Two years following the rotenone treatment, 34 BCT from Mill Creek were released in Strawberry Creek at a mid- elevation site. In 2005, an additional 30 BCT from Mill Creek were released in Strawberry Creek, upstream of a fish barrier (culvert). BCT from Mill Creek were also released in 2005 in South Fork of Baker Creek above 2,682 m (8,800 ft) elevation. Upper Snake Creek had 104 BCT stocked in 2005 (Figure 19) and 100 in 2008 using Hendry's Creek (outside the Park in the northern Snake Range) as the donor source.

Table 12. BCT reintroduction sites and number of fish reintroduced.

Reintroduction Stream	Site	Date	# of BCT	Donor Source
South Fork Big Wash	Below perennial spring	2000	56	Mill Creek
Strawberry Creek	About one mile into Park; Below and above second culvert near corral area	2003, 2005	34, 30	Mill Creek
Upper Snake Creek	Along main stem, South Fork, Shoshone Camground; along main stem	2005, 2008	104, 100	Hendry's Creek
South Fork Baker	Below and above meadow	2005	45	Mill Creek

Use of the streamside incubators did not contribute to BCT reintroductions, due to problems with fungus growing on and destroying the eggs (Figure 20). Despite treatment with formaldehyde to

Figure 19. Volunteers help reintroduce Bonneville cutthroat trout into Upper Snake Creek (2005).

Figure 20. Silt accumulation in streamside incubator after one day encouraged fungus growth (2002).

disinfect the eggs, all succumbed to fungus. Low streamflow, which resulted in low flow through the incubators, may have facilitated the fungal growth. Nevertheless, the attempt to use streamside incubators did provide important information about spawning requirements of BCT in the southern Snake Range. Definitive signs of spawning in Mill Creek were seen June 26 through July 3, 2002, when the daily mean water temperature reached 12° C (Figure 21) following peak discharge.

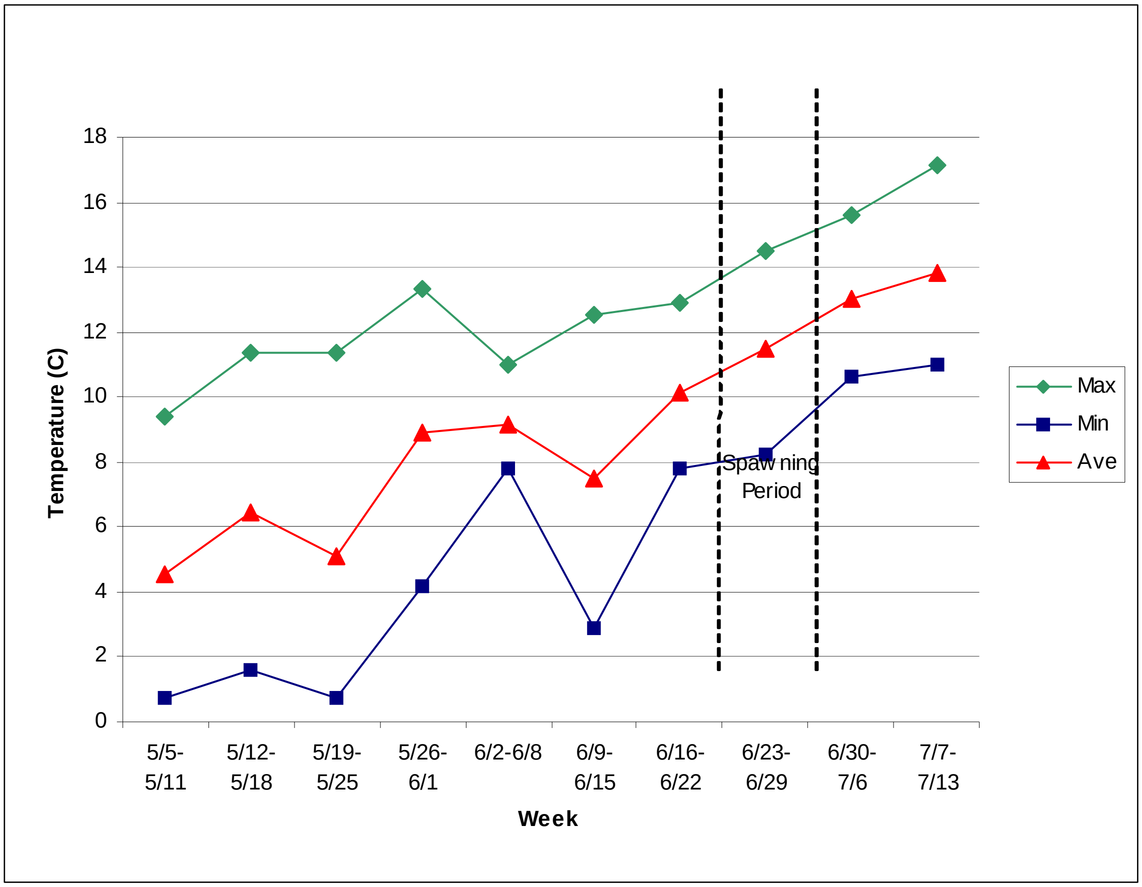

Figure 21. Spawning period and water temperatures in Mill Creek, 2002.

BCT Population Monitoring

As a result of reintroductions conducted during this project and natural expansion of these newly established populations, BCT now occupy 13.1 km (8.1 mi) of streams (Figure 22, Table 13) within Great Basin National Park. BCT populations on the southern Snake Range on adjacent BLM and private land in Pine and Ridge Creeks and Big Wash include an additional 5 km (3 mi) of occupied habitat.

Reintroduced populations were monitored with electrofishing, beginning two years following the stocking, and in all cases showed good recruitment. The number of mature adults (Figure 23) increased in both South Fork Big Wash and Strawberry Creeks from two to four years post-reintroduction. Fish total abundance, density, biomass, condition, and mean TL increased in Strawberry Creek, but fluctuated in South Fork Big Wash, possibly due to a large wildfire and

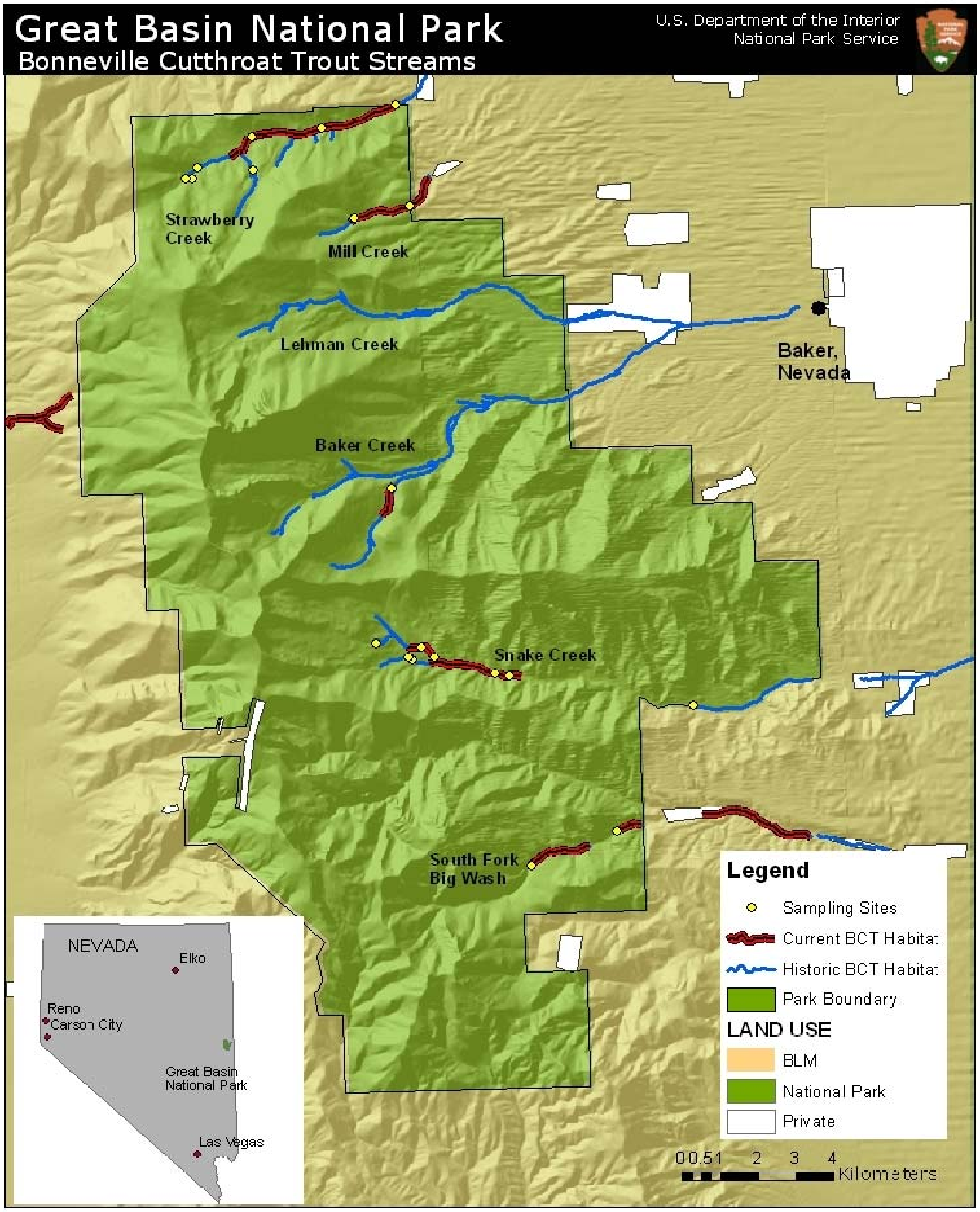

Figure 22. Streams with reintroduced populations of Bonneville cutthroat, Great Basin National Park and vicinity.

subsequent flash flood that added extra sediment to the stream system and reduced spawning habitat. Because the reintroductions in Snake and South Fork Baker creeks were relatively recent, data are based on only one year of one survey each. These surveys found a small number of mature adults in both creeks, but good recruitment, especially in Snake Creek.

Table 13. BCT population status in streams in Great Basin National Park.

Creek Name	Year Stocked	Date of Survey	Site	Adult fish / 100 m	Fish / 100 m	Fish / 100 m^2	Biomass (kg/ha)	Condition (K)	Mean TL (mm)	Occupied Stream Km (mi)	BCT/ mile
Mill	NA	8/24/1999	BCT1	12	38	24.0	71.6	1.23	121.4	1.7 (1.1)	480
Mill		8/26/1999	BCT2	0	7	4.4	8.5	1.4	110.4		
Mill		8/29/2005	BCT1	4	24	15.1	38.1	1.09	119.8		
Mill		8/29/2005	BCT2	12	36	22.7	68.1	1.05	134.5		
SFBW	2000	8/22/2002	BCT2	2	31	16.3	77.3	1.11	132.5	2.6 (1.6)	700
SFBW		9/10/2004	BCT2	7	65	40.8	73.5	1.28	93.5		
SFBW		8/29/2006	BCT2	18	43	18.3	72.0	1.07	125.5		
Strawberry	2002	9/08/2004	BCT2	3	28	17.3	27.6	1.06	93.6	4.8 (3.0)	850
Strawberry	2005	8/31/2006	BCT2	15	53	27.9	79.5	1.17	110.5		
Snake	2005	8/29/2007	1st campsite	0	18	7.6	7.5	1.78	83.8	3.0 (1.9)	1040
Snake	2008	8/29/2007	below confluence	4	112	36.9	36.1	1.26	73.7		
SF Baker	2005	9/13/2007	below meadow	4	23	9.5	26.2	1.03	89.1	1.0 (0.6)	368

Figure 23. Mature Bonneville cutthroat trout in the South Fork of Big Wash (2002).

Population estimates are based on the number of fish captured in 100 m extrapolated to one mile for compatibility with NDOW reporting practices. The population estimates for Strawberry and Upper Snake Creeks are high (850 and 1040 BCT/mile, respectively) compared to population estimates for other similar-sized streams in Nevada within five years of reintroductions. But, at this time, the majority of these fish are less than 150 mm TL and, thus, not of reproductive age (Table 13). In fact, although 112 fish were captured at the second site on Snake Creek, only four were of mature adult size (≥150mm). Length/frequency histograms on each of the creeks indicate that it may take several years for fish populations to develop into strong multiple age classes (Figures 24-35).

Biomass is a measure of fish population status that incorporates both individual and population growth. Before Mill Creek was used as a source of fish for other streams, standing crop biomass for the BCT population was 71.6 kg/ha. The standing crop biomass of the SBFW population exceeded this within two years after reintroduction and remained over 70 kg/ha during the next

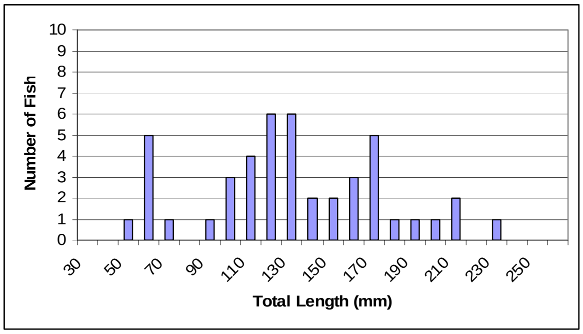

Figure 24. BCT length/frequency histogram for Mill Creek in August 1999. Data for two sampling sites are pooled.

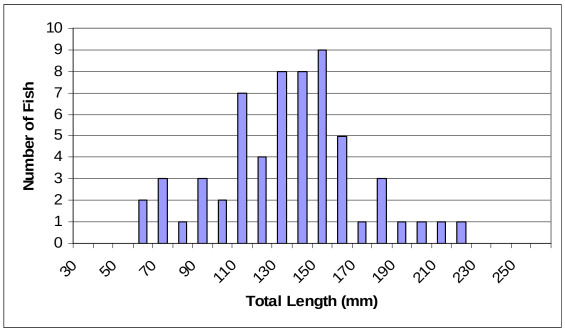

Figure 25. BCT length/frequency histogram for Mill Creek in August 2005. Data for two sampling sites are pooled.

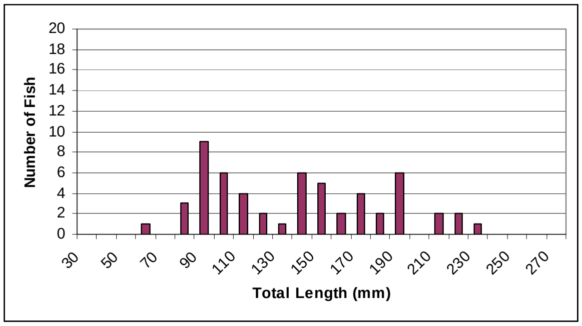

Figure 26. Length/frequency histogram for BCT moved from Mill Creek to South Fork Big Wash in July 2000.

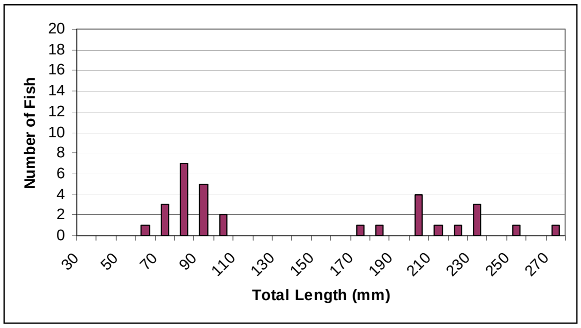

Figure 27. BCT length/frequency histogram for South Fork Big Wash in 2002.

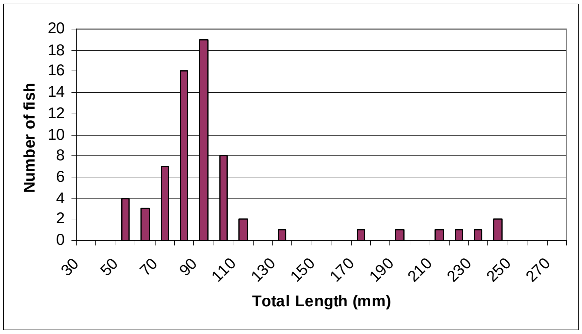

Figure 28. BCT length/frequency histogram for South Fork Big Wash in 2004.

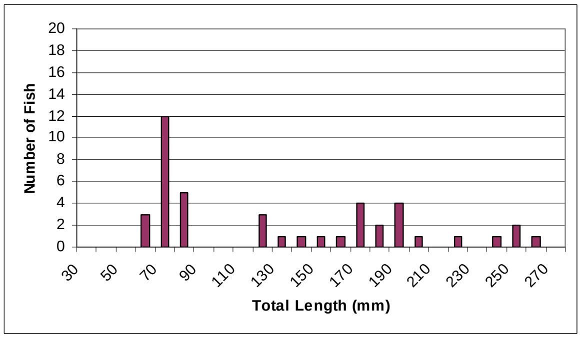

Figure 29. BCT length/frequency histogram for South Fork Big Wash in 2006.

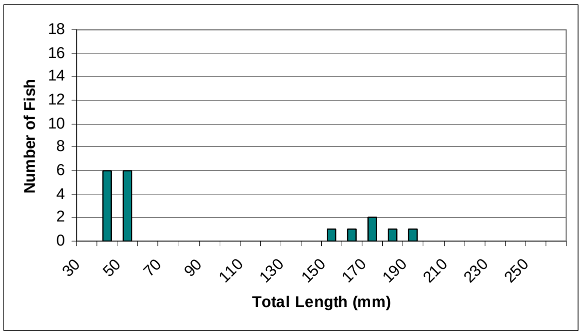

Figure 30. BCT length/frequency histogram for Strawberry Creek in 2003.

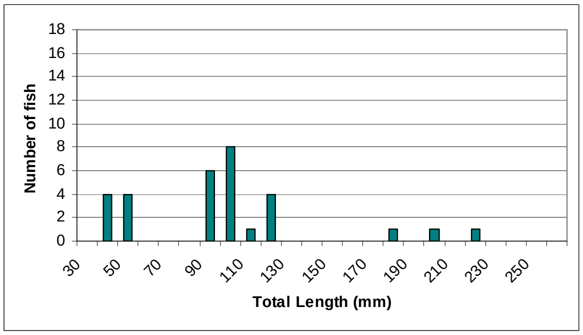

Figure 31. BCT length/frequency histogram for Strawberry Creek in 2004.

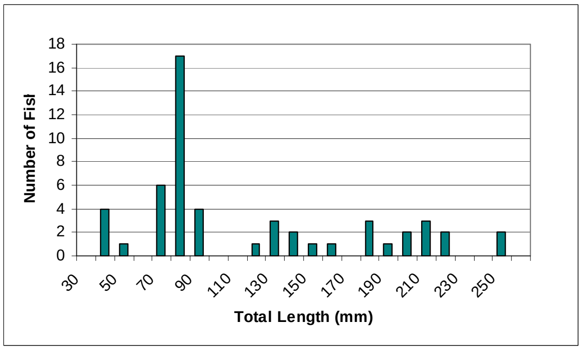

Figure 32. BCT length/frequency histogram for Strawberry Creek in 2006.

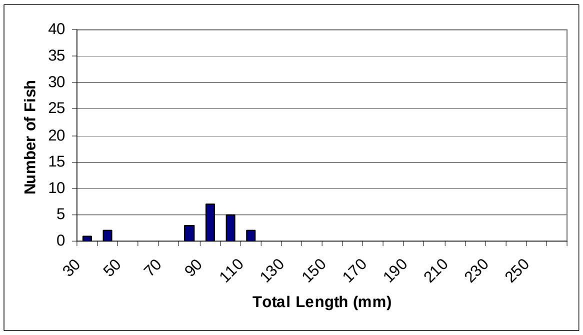

Figure 33. BCT length/frequency histogram for Snake Creek at lower site in 2007.

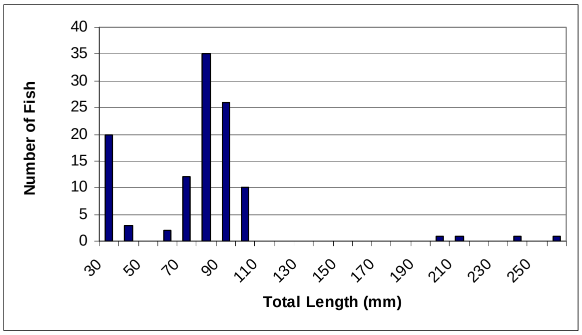

Figure 34. BCT length/frequency histogram for Snake Creek at upper site in 2007.

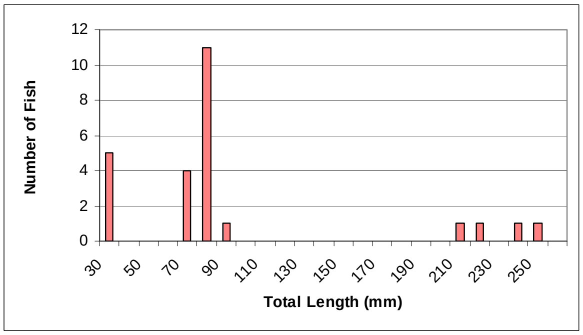

Figure 35. BCT length/frequency histogram for South Fork Baker Creek in 2007.

two surveys. Standing crop biomass was higher in Strawberry Creek than in Mill Creek four years after reintroduction. It should be noted that the sampling locations in SFBW and Strawberry Creeks were the same locations that the fish were originally stocked. Further upstream or downstream, these high numbers are not likely to exist for many years until fish distribution expands.

Fulton Condition Factor (K) is an index of fish health based on the weight/length relationship. The condition of BCT in all streams appears to be similar to brown, brook and rainbow trout in Baker, Lehman and Snake Creeks.

Fish distribution surveys found that BCT expanded their distribution 2 km (1.6 mi) downstream in South Fork Big Wash and 1.9 km (1.2 mi) upstream in Strawberry Creek from the reintroduction sites within three years.

Johnson Lake was historically fishless, so following NPS Management Policies (2001), no BCT were introduced into the lake. Effectiveness monitoring on Johnson Lake included gill netting and angling during the 2005 summer. No fish were caught by either method.

Creel Survey

A stratified random creel survey was conducted for a total of 42 half-days in 2005. Eleven anglers were encountered, for an estimated 56 ± 11 anglers for the four creeks surveyed from June to August. Despite this low angling pressure, a large amount of money was spent in order to go fishing. For the 11 anglers surveyed, a combined amount of $50 was spent in the Park and $981 within 160 km (100 miles) of the Park on fishing related items, with gas, food and fishing licenses as the top three expenses. The average trip expenditure totaled $94 per angler. Most anglers experienced good catch rates (mean=0.7 fish/hr) and were satisfied with their angling experience (Wiley and Baker 2005).

Comparison of Treatment Methods

The Park had the opportunity to use and compare three different treatment techniques to remove nonnative fish: electrofishing removal, rotenone and antimycin (Table 14). These costs are solely for the treatment and do not include planning, travel for experts or monitoring before or after the treatment.

The cost of the antimycin treatment and electrofishing removal per kilometer differ greatly from results in Great Smoky Mountains National Park (Moore et al. 2005). We were able to achieve a much lower cost for electrofishing ($3,036/km versus $12,416-$15,089/km) due to the low number of fish inhabiting the targeted stream reach, smaller stream size and less complex habitat. The cost of antimycin for this project was higher than anticipated ($6,597/km versus $3,939/km), due to the increased pH and steeper stream gradient which required additional antimycin and time for treatment.

In view of the fact that the cost does not reflect the benefits of preserving ecosystem components (such as the macroinvertebrate community), it should not be the only factor that is considered in deciding which method is best suited to a particular project. When community or ecosystem restoration is the goal, other factors may be more important than the monetary cost.

Table 14. Comparison of fish removal treatment costs.

Treatment	Length Treated (km)	Hours	Hours/Km	Total Cost	Cost/Km	Notes
Electrofishing Removal (South Fork Baker)	1.0	288	288	\$3,036	\$3,036	Conducted from 2003-2005; 3 electrofishing trips/year *4 people * 8 hours*\$16/hr[2] Electrofishing gear = \$1,500
Rotenone (Strawberry Creek)	11.9	320	27	\$10,950	\$920	2 days of treatment * 20 people * 8 hours * \$20/hr Rotenone = \$3550 for powder and 33 gallons Backpack sprayers and other equipment = \$1,000
Antimycin (Snake Creek)	3.4	864	254	\$21,430	\$6,303	6 days of treatment * 18 people * 8 hours * \$20/hr Antimycin = \$3,150 for 9 units Potassium permanganate = \$500 for 15 kg Backpack sprayers and other equipment = \$1,000

---

[2] The rate of \$16/hr was used for electrofishing removal since the crew consists of one biologist and three biological technicians. The rate of \$20/hr was used for the piscicide treatments since over half of the crew consisted of biologists and supervisory biologists.

Discussion

Planning and Pre-treatment Surveys

We learned quickly during the initiation of the planning and pre-treatment surveys that adaptive management would be necessary to make this project work. A project this large is bound to present unanticipated difficulties. Lessons learned in overcoming these difficulties have guided other restoration projects within the Park. One important lesson is that native fish restoration is controversial. Views on which waters are appropriate for reintroduction and how restoration should proceed vary among agencies, organizations and various segments of the public. We found that frequent face-to-face meetings with cooperating agencies and other interested parties contributed to developing consensus and maintaining progress toward achieving restoration objectives. In addition, the reliance on NPS management policies, such as using the closest genetic match for reintroductions and, when that is not possible, the closest geographic population, provided a basis for making decisions with potential ecological consequences.

Adaptive management was extremely important to the success of this project. For example, when it was determined that the fish in Mill Creek were genetically pure Bonneville cutthroat trout, it became necessary to preserve the population. In addition to its status as the last relict BCT population within the Park, the Mill Creek population provides the closest and, thus, the best source of BCT for introduction to other Park streams. The ability to use this population as a source enabled Park staff to accelerate the schedule for restoration in other streams. Another example of adaptive management occurred when the Park learned that Johnson Lake, which was not believed to have a surface outlet, spilled over into Snake Creek during runoff in high snow years. Because the lake supported nonnative fish, project staff made the decision to treat the Lake to protect the reestablished BCT population in Snake Creek. Furthermore, the small number of fish in South Fork Baker Creek allowed the creek to be treated with electrofishing rather than a piscicide. The low numbers of rainbow trout may be because conditions at this high elevation are near the limits of the species' life history requirements.

From the beginning of the project, it was recognized that limitations on funding would preclude following the standard timetable used by NDOW for fisheries restoration projects. This timetable requires waiting 3-5 years after treatment to reintroduce BCT. Therefore, park staff decided to monitor the macroinvertebrate population intensively to assess how soon after treatment BCT could be stocked into the stream and have a sufficient invertebrate food base. Data collected over the course of this project suggest that BCT can be stocked to a stream sooner, and, as a result, NDOW has changed their timetable and stocked BCT into Big Wash Creek only two years after treating it with rotenone.

The ten-year timeline the Park initially set out to follow was extremely ambitious. Fortunately, despite some changes in timing due to various unforeseen circumstances, the Park was able to reintroduce BCT into four of the six streams originally targeted for BCT restoration. A fifth stream, Mill Creek, was found to already support a BCT population. No plans have been made for the sixth stream, Lehman Creek, due to the continuation of its use as a drinking water source for residents just outside the Park boundary. Having a timeline greatly helped in planning, but it was important to recognize that the timeline was a guide, and that changes in it were inevitable and acceptable.

Chemical or Physical Treatment

While the rotenone and electrofishing treatments went as planned, the Park had to adapt the antimycin treatment to make it successful. The Snake Creek treatment used nearly three times the anticipated amount of antimycin due to its quick degradation in the steep stream habitat and relatively high pH (~8.0). While it appears that the Park could do nothing to change this, other agencies contemplating antimycin projects in similar habitats with comparable water quality parameters (mean water temperature of 9.7° C and mean pH of 7.7) should plan their project accordingly.

The Johnson Lake treatment was hampered by insufficient data on pH. Past data suggested that the lake pH would not be high, but upon closer examination, it was found that most of this data represented instantaneous measurements. Without continuous measurements, there was not a clear understanding of the seasonal water chemistry dynamics and the effects of annual algal blooms. Macroinvertebrate monitoring on Johnson Lake will continue to quantify the diversity and estimate the population abundance.

Treatment Effectiveness Monitoring

The discovery of a brown trout in an area that had been treated the previous year to remove brook trout reminds us that all of these systems will need to be monitored periodically to ensure that the reintroduction efforts are not undermined by unauthorized fish relocations. In addition, a strong education component, consisting of articles in the Park newspaper and park resource management newsletter, along with fishing brochures and training of park interpretive staff, will help to inform the public of the importance of native fish and the need to protect them.

Ecosystem Recovery Monitoring

The comparison of macroinvertebrate recovery provided useful information about the effects of two piscicides. Other monitoring efforts have noted the rapid eradication of many, if not all, macroinvertebrate taxa as a result of stream rotenone treatments (Binns 1967; Cook and Moore 1969; Engstrom-Heg et al. 1978; Mangum and Madrigal 1999; Whelan 2002). Minckley and Mihalick (1981) noted the “decimation” of macroinvertebrates from an antimycin treatment in Arizona, and Walker (2003) measured macroinvertebrate abundance declines of up to 64% from an antimycin treatment on Sam’s Creek, Tennessee. Conversely, Jacobi and Degan (1977) found a high retention of taxa diversity from an antimycin treatment in Wisconsin.

The ability to retain high abundance and diversity after a piscicide treatment may improve recovery rates of aquatic invertebrates. The ability of taxa to recolonize treated areas is likely a function of overall population size, distribution within the basin, upstream and local habitat conditions, and the dispersal abilities of various taxa. With greatly reduced abundance and/or the complete elimination of some taxa from certain reaches, recovery would depend primarily on the dispersal capabilities of the affected taxa from unaffected habitat. Under these conditions, recovery would be expected to be slower and more likely to result in altered community composition (Mangum and Madrigal 1999). Where a treatment retains the majority of pre-treatment taxa, reproduction within the treated reach can contribute to recovery. In addition, recovery should be facilitated in habitats where predation pressure has been reduced due to the eradication of fish.

Non-treated refuges appeared to contribute to recovery of most, but not all, macroinvertebrates to treated areas. In project streams, five taxa were still missing after one-year and two taxa were absent from the Strawberry Creek three-years after rotenone treatment. Though 48 springs and seeps located throughout the watershed were not treated, these habitats are unique and may not support all of the taxa that are found in streams. The majority of the non-treated stream areas on Strawberry Creek were located in the headwaters, which greatly increases dispersal distances between non-treated and downstream treated areas. Also, some taxa show an elevation restriction (Darby et al. 2004). Lack of untreated low-elevation stream reaches may be hampering the recovery of *Antocha* spp., which, prior to treatment, was collected only at lower elevation sites. *Baetis bicaudata* was collected at untreated sites following the Strawberry Creek rotenone treatment but never exceeded four individuals per sample per square meter, so numbers were low. The single taxon from the Trichoptera family Philopotamidae, missing after the Snake Creek antimycin treatment, has also been collected in non-treated area samples but has never exceeded three individuals per sample per square meter. Low abundance of *Baetis bicaudata* and Philopotamidae at non-treated sites may reduce the rate at which these taxa recolonize treated sites.

An extended drought is another factor that could be affecting recovery. Stream flows have declined after numerous years of below-average precipitation, desiccating headwater reaches and reducing the area of habitat available, especially in Strawberry Creek, where mean summer flows decreased from 0.04 m^3/s (1.5 ft^3/s) in 2000 to 0.02 m^3/s (0.6 ft^3/s) in 2003.

Our results indicate that leaving some areas untreated and using antimycin rather than rotenone for the removal of nonnative fish reduces the impact to the invertebrate community and facilitates rapid recovery to pre-treatment conditions. Another advantage of antimycin relative to rotenone is that the more rapid recovery of aquatic invertebrates (Hamilton et al. 2007) will reduce the time between removal and reintroduction. We hope the information provided here will allow fisheries and land managers to make more informed decisions related to piscicide treatments.

Reintroduction of BCT

Hard plants of BCT worked well for reintroducing BCT to target streams. Streamside incubators, which were used in an attempt to help hasten the reestablishment of BCT populations, were not a successful method for reintroduction in this project. Trout Unlimited provided the first incubators and the expertise how to use them (Duff undated). Although eggs held in incubators failed to survive due to a combination of low stream flows and high sediment levels that accelerated fungus growth, egg collection provided important information about BCT spawning in Mill Creek.

BCT Population Monitoring

Two of the BCT populations, Strawberry Creek and upper Snake Creek, occupy habitat sizes larger than 2 ha (5 acres), which is what Harig et al. (2000) recommended for sustainable greenback cutthroat trout populations. Over the next few years, BCT have the potential to expand 4.5 km within the park (1.0 km in Strawberry, 2.1 km in South Fork Baker, and 1.4 km in Snake Creek) without additional renovation treatments. BCT in streams smaller than 2 ha (5 acres) will need more monitoring and possible augmentations in the future. In addition, since all the reintroductions consisted of less than the 250 adults recommended (Hilderbrand 2002), it is likely that future translocations will be conducted to improve genetic diversity. Hilderbrand noted that even very small populations persist when stocked with 10 adults every 10-20 years. It appears that cutthroat populations fluctuate greatly from year to year even with constant habitat conditions (House 1995), so the Park must take these natural population fluctuations into consideration. The small park populations are extremely vulnerable to habitat and environmental variations that could affect survival and reproductive success over near-term and, therefore, ultimate success of reintroductions. Reestablished populations are currently vulnerable given the small number of sexually mature fish. It will be some time before sexually mature fish recruit into the population. It should be noted that electrofishing has an inherent bias towards larger fish so it will underestimate recruitment.

Hopefully, with the careful planning put into this project, the Park will experience greater than the 38% translocation success rate experiences for greenback cutthroat trout (Harig et al. 2000). The success criteria used in that study included amount of occupied habitat, number of adult fish and presence of at least two year-classes within five years and isolation from nonnative salmonids. It was noted that achieving short-term (5-25 yr) success did not necessarily equate to long-term success (Harig et al. 2000). However, the BCT population in Mill Creek has persisted for over 100 years in a habitat that is smaller than the 8 km (5 mi) recommended by Hilderbrand and Kershner (2000a). Also, having multiple populations in separate locations reduces the potential that a single catastrophic event such as a wild fire will affect all populations. Monitoring of BCT populations is ongoing in all five streams and will continue into the foreseeable future.

Restoring Native Fish Communities

With BCT populations restablished in four streams and verified in one stream, the Park is turning its attention to completing the aquatic assemblage in some of these streams by restoring other native species. Redside shiner (*Richardsonius balteatus*), mottled sculpin (*Cottus bairdi*) and speckled dace (*Rhinichthys osculus*) once inhabited the streams of Great Basin National Park with BCT, and in 2005, the Park began its first restoration efforts on these species, moving 50 of each species into the South Fork Big Wash from Lake Creek, Utah, in adjacent Snake Valley. An additional 50 of each species were added the following year, with 150 of each species stocked into Strawberry Creek. Preliminary monitoring data show that all three species can survive the winter temperatures in Strawberry Creek with mottled sculpin showing recruitment. Monitoring will continue in conjunction with BCT surveys.

Literature Cited

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Behnke, R. J. 1976. A summary of information on a unique form of cutthroat trout native to the Snake Valley section of the Bonneville Basin, Utah-Nevada. Report for the U.S. Bureau of Land Management, Salt Lake City, UT.

Behnke, R. J. 1970. Analysis of fish in Mill Creek. White paper to Nevada Fish and Game Department.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6. American Fisheries Society, Bethesda, MD.

Behnke, R. J. 1988. Phylogeny and classification of cutthroat trout. *In* R. E. Gresswell, editor. Status and management of interior stocks of cutthroat trout. American Fisheries Society Symposium **4**:1-7.

Behnke, R. J. 2002. Trout and salmon of North America. The Free Press, New York.

Berger, B. L., R. E. Lennon, and J. W. Hogan. 1969. Laboratory studies on antimycin A as a fish toxicant. Investigations in fish control, #26. U.S. Fish and Wildlife Service, Washington, D.C.

Binns, N. L. 1967. Effects of rotenone treatment on the fauna of the Green River, Wyoming. Fisheries Research Bulletin 1, Wyoming Fish and Game Commission.

Binns, N. A., and R. Remmick. 1994. Response of Bonneville cutthroat trout and their habitat to drainage-wide habitat management at Huff Creek, Wyoming. North American Journal of Fisheries Management **14**:669-680.

Chance, C. J. 1948. How should population surveys be made. Proceedings of the Annual Conference of the Southeastern Association Game and Fish Commissioners. **11**:84-89.

Cook, S. F. Jr., and R. L. Moore. 1969. The effects of a rotenone treatment on the insect fauna of a California Stream. Transactions of the American Fisheries Society **3**:539-544.

Cremins, D. M., and P. Spruell. 2003. Detection of hybridization between Bonneville cutthroat trout and two introduced trout. Wild Trout and Salmon Genetics Lab Report WTSGL03-104. University of Montana, Missoula.

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

Dankowski, Macaluso, and Williams. 1984. Field trip reports of trout population surveys in Strawberry Creek. Nevada Department of Wildlife, Ely.

Darby, N. W., T. B. Williams, G. M. Baker, and M. R. Vinson. 2004. Minimizing effects of piscicides on macroinvertebrates. Pages 326-327 in S. Moore and C., editors. Wild Trout VIII Symposium Proceedings. Wild Trout Symposium, Inc., Bozeman, MT.

Degan, D. J. 1973. Observations on aquatic macroinvertebrates in a trout stream before, during and after treatment with Antimycin. M.S. thesis. University of Wisconsin, Stevens Point.

Downs, C. C., R. G. White, and B. B. Shepard. 1997. Age at sexual maturity, sex ratio, fecundity, and longevity of isolated headwater populations of westslope cutthroat trout. North American Journal of Fisheries Management **17**:85-92.

Duff, D. n.d. TU's trout in a fridge. White paper. U.S. Forest Service TU National Partnership Liaison, Salt Lake City.

Elliot, P. E., D. A. Beck, and D. E. Prudic. 2006. Characterization of surface-water resources in the Great Basin National Park area and their susceptibility to ground-water withdrawals in adjacent valleys, White Pine County, Nevada. USGS Scientific Investigations Report 2006-5009.

Engstrom-Heg, R., R. Colesante, and E. Silco. 1978. Rotenone tolerances of stream bottom insects. New York Fish and Game Journal **25**:31-41.

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

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, C. W. Thompson. 2002. Potential of antimycin A use in fisheries – assessment of reregistration. Fisheries **27**:10-18.

Frantz, T. C. 1953. Surveys of watersheds in the south Snake Range (1952-1953) with emphasis on fisheries. Nevada Fish and Game Commission. Carson City.

Gresswell, R. E., and J. D. Varley. 1988. Effects of a century of human influence on the cutthroat trout of Yellowstone Lake. American Fisheries Society Symposium 4:45-52.

Hall, G. E. 1974. Sampling reservoir fish populations with rotenone. Pages 249-259 *in* R. Welcomme, editor. Symposium on the methodology for the survey, monitoring and appraisal of fishery resources in lakes and large rivers. Food and Agriculture Organization of the United Nations, European Inland Fisheries Advisory Commission, Technical Paper No. 23. Rome, Italy.

Hamilton, B. T., T. B. Williams, and N. Darby. 2007. Comparative effects of rotenone and antimycin on macroinvertebrate diversity. *In* Wild Trout IX Symposium Proceedings. Wild Trout Symposium, Inc., Bozeman, MT.

Harig, A. L., K. D. Fausch, and M. K. Young. 2000. Factors influencing success of greenback cutthroat trout translocations. North American Journal of Fisheries Management. **20**:994-1004.

Haskins, R. L. 1990. Field trip reports of trout population surveys in Lehman, Baker, and Snake Creeks. Nevada Department of Wildlife, Ely.

Hawkins, C., J. Ostermiller, M. Vinson, and R. J. Stevenson. 2001. Stream algae, invertebrate and environmental sampling associated with biological water quality assessments: Field protocols. Department of Fisheries and Wildlife, Utah State University, Logan.

Hickman, T., and R. F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. U.S. Fish and Wildlife Service. FWS/OBS-82/10.5.

Hilderbrand. R. H. 2002. Simulating supplementation strategies for restoring and maintaining stream resident cutthroat trout populations. North American Journal of Fisheries Management. **22**:879-887.

Hilderbrand. R.H. and J.L. Kershner. 2000a. Conserving inland cutthroat trout in small streams: how much stream is enough? North American Journal of Fisheries Management **20**:513-520.

Hilderbrand. R. H. and J. L. Kershner. 2000b. Movement patterns of stream-resident cutthroat trout in Beaver Creek, Idaho-Utah. Transactions of the American Fisheries Society **129**:1160-1170.

House, R. 1995. Temporal variation in abundance of an isolated population of cutthroat trout in Western Oregon, 1981-1991. North American Journal of Fisheries Management **15**:33-41.

Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Rise of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society **127**:223-235.

Kershner, J. 1995. Bonneville cutthroat trout. *In* M.K. Young, editor. Conservation assessment for inland cutthroat trout. General Technical Report RM-256. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Jacobi, G. Z. and D. J. Degan. 1977. Aquatic macroinvertebrates in a small Wisconsin stream before, during, and two years after treatment with the fish toxicant antimycin. Investigations in Fish Control No. 81. U.S. Fish and Wildlife Service, Washington, D.C.

Lentsch, L., Y. Converse, and J. Perkins. 1997. Conservation agreement and strategy for Bonneville cutthroat trout in the state of Utah. Utah Department of Natural Resources. Publication Number 97-19.

Lentsch, L. D., C. A. Toline, J. Kershner, J. M. Hudson and J. Mizzi. 2000. Range-wide Conservation Agreement and Strategy for Bonneville cutthroat trout (*Onchorynchus clarki utah*). Publication No. 00-19, Utah Division of Wildlife Resources, Salt Lake City.

Mangum, F. A., and J. L. Madrigal 1999. Rotenone effects on aquatic macroinvertebrates of the Strawberry River, Utah: a five year summary. Journal of Freshwater Ecology **14**:125-135.

Marking, L. L. 1975. Effects of pH on toxicity of antimycin to fish. Journal of Fisheries Resources Board Canada. **32**:769-773.

May B. E., and S. Albeke. 2005. Range-wide status of Bonneville cutthroat trout (*Oncorhynchus clarki utah*): 2004. Utah Division of Wildlife Resources, Publication Number 05-02. Salt Lake City.

May, B. E., J. D. Leppink, and R. S. Wydoski. 1978. Distribution, systematics, and biology of the Bonneville cutthroat trout, *Salmo clarki utah*. Utah Division of Wildlife Resources, Ogden. Publication 78-15.

Miller, S. J., J. G. Wullschleger, L. A. Bull, L. J. Davis, D. McCall, D. D. Fox, and D. W. Brown. 1990. Comparisons of Wegener Ring and 0.08-hectare block net samples of fishes in vegetated habitats. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 44:67-75.

Minckley, W. L., and P. Mihalick. 1981. Effects of chemical treatment for fish eradication on stream-dwelling invertebrates. Journal of the Arizona-Nevada Academy of Science **16**:79-82.

Moore, S. E., M. A. Kulp, J. Hammonds, and B. Rosenlund. 2005. Restoration of Sams Creek and an assessment of brook trout restoration methods, Great Smoky Mountains National Park. National Park Service Water Resources Division Technical Report NPS/NRWRD/NRTR-2005/342. Fort Collins, CO.

Rosenlund, B. D., and D. R. Stevens. 1992. Application of antimycin (Fintrol) to alpine lakes and streams in Rocky Mountain National Park and the headwaters of Leadville National Fish Hatchery to establish populations of greenback and Colorado River cutthroat trout. US Fish and Wildlife Service Report. Colorado Field Office, Golden.

Schenk, G., N. Darby, and B. Hamilton. 2003. Aquatic resources protocols manual. Great Basin National Park. Baker, Nevada.

Shiozawa, D. K., and R. P. Evans. 2000. The genetic status of cutthroat trout from Mill Creek, tributary to the Bonneville Basin in Great Basin National Park, Nevada. Department of Zoology. Brigham Young University, Provo.

Shiozawa, D. K., and R. P. Evans. 2002. The genetic status of cutthroat trout from Pine and Ridge Creeks, Great Basin National Park, Nevada. Department of Zoology, Brigham Young University, Provo, Utah.

Shiozawa, D. K., R. P. Evans, and R. N. Williams. 1993. Relationships between cutthroat populations from ten Utah Streams in the Colorado River and Bonneville drainages. Utah Division of Wildlife Resources, Ogden. Interim report. Contract 92-2377.

Sigler, W. F., and J. W. Sigler. 1987. Fishes of the Great Basin. University of Nevada Press. Reno.

Swingle, H. S. 1958. How fish population surveys should be reported. Proceedings of the Annual Conference of the Southeastern Association of Game Fish Commissioners. 11:103-104.

Tiffan, K. F. and E. P. Bergersen. 1996. Performance of antimycin in high-gradient streams. North American Journal of Fisheries Management **16**:465-468.

USDA Forest Service. 1996. Conservation assessment for inland cutthroat trout: Distribution, status, and habitat management implications. USFS Intermountain Region, Ogden, Utah.

Van Deventer, J. S., and W. S. Platts. 1989. Microcomputer Software System for Generating Population Statistics from Electrofishing Data – User's Guide for MicroFish® 3.0. USFS Intermountain Research Station General Technical Report INT-254.

Waite, R. S. 1974. The proposed Great Basin National Park: a geographical interpretation of the southern Snake Range, Nevada. Ph.D thesis, University of California, Los Angeles.

Walker, C. A. 2003. Effects of antimycin treatment on benthic macroinvertebrates in Sams Creek and Starkey Creek, Great Smoky Mountains National Park, Blount/Sevier counties, Tennessee. M.S. thesis. University of Tennessee, Knoxville.

Wegener, W. D., D. Holcomb, and V. Williams. 1974. Sampling shallow water fish populations using the Wegner Ring. Proceedings of the Annual Conference of the Southeastern Association of Game and fish Commissioners. 27:663-673.

Whelan, J. E. 2002. Aquatic macroinvertebrate monitoring results of the 1995 and 1996 rotenone treatments of Manning Creek, Utah. Utah Division of Wildlife Resources Publication Number 02-04.

Wiley, M., and G. Baker. 2005. Creel survey final report. Great Basin National Park, Baker, NV.

Williams, T. B., A. H. Pfaff, K. Pfaff, J. Jasper, and W. Cole. 1999. Great Basin National Park Bonneville cutthroat trout reintroduction and recreational fisheries management plan. U.S. National Park Service.

Appendix: Flow Test and Toxicity Test Results

Flow Test

The flow test using fluorescein dye determined that the section of Upper Snake Creek to be treated had a total flow time of 430 minutes, or 7.17 hours. The average time for the water to flow 100 m (109 yd) was 6 minutes. This measurement determined how far apart antimycin stations would be placed.

Toxicity Tests

A series of toxicity tests was performed July 22-25, 2002, prior to treatment, to refine the amounts of antimycin and $KMnO_4$ needed in Snake Creek waters. The first test, measuring how much antimycin was needed for fish mortality, found that antimycin was effective at 2, 4 and 8 ppb with an 8-hour exposure (Table 15). The second test involved 8 ppb antimycin in each bucket with varying concentrations of $KMnO_4$ to determine how much $KMnO_4$ was needed to detoxify stream water (Table 16). This test showed that fish exposed to a full dose of antimycin survived if 1 or 2 ppm $KMnO_4$ was present in the water. When 3-4 ppm $KMnO_4$ was present, 60-70% of those fish survived. The third test used 0 to 4 ppm $KMnO_4$ in the buckets to determine how toxic it was to fish and found that it induced 10-30% fish mortality (Table 17). Based on these tests, it was decided to use a concentration of 8 ppb antimycin and 0-4 ppm $KMnO_4$ depending on the distance of the antimycin stations from the detoxification station.

Table 15. Toxicity of antimycin in Snake Creek water.

	% Mortality through time (hours)								% mortality in livecars	
Antimycin Concentration	1	2	3	4	5	6	7	8	24	48
0 ppb (Control)	0	0	0	0	0	0	0	0	0	0
2 ppb	0	0	0	0	0	0	0	20	100	100
4 ppb	0	0	0	0	0	0	0	0	100	100
8 ppb	0	0	0	10	10	10	80	100	100	100

Table 16. $KMnO_4$ demand in Snake Creek water.

		% mortality through time (hours)								% mortality in livecars	
Antimycin Concentration	$KMnO_4$ Concentration	1	2	3	4	5	6	7	8	24	48
8 ppb	1 ppm	0	0	0	0	0	0	0	0	0	0
8 ppb	2 ppm	0	0	0	0	0	0	0	0	0	0
8 ppb	3 ppm	0	0	0	0	0	0	10	40	40	40
8 ppb	4 ppm	0	0	0	0	0	0	0	30	30	30
0 ppb (Control #1)	0 ppm	0	0	0	0	0	0	0	10	10	10
8 ppb (Control #2)	0 ppm	0	0	0	0	0	0	0	30	100	100

Table 17. $KMnO_4$ toxicity in Snake Creek.

	% Mortality through time (hours)								% Mortality in livecars	
$KMnO_4$ Concentration	1	2	3	4	5	6	7	8	24	48
0 ppm (Control)	0	0	0	0	0	10	10	10	10	10
1 ppm	0	0	0	0	0	0	0	0	0	0
2 ppm	0	0	0	0	0	0	0	10	10	10
3 ppm	20	20	20	20	20	20	30	30	30	30
4 ppm	0	0	0	0	0	0	0	10	10	10

NPS D-102, September 2008

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™