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Use of Antimycin for Removal of Brook Trout from a Tributary of Yellowstone Lake

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Abstract.—A major spawning migration of native Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* occurs in Arnica Creek, a tributary of Yellowstone Lake. An introduced population of brook trout *Salvelinus fontinalis* was detected in Arnica Creek in May 1985. Subsequent electrofishing surveys of 40 additional tributaries of Yellowstone Lake revealed that brook trout were restricted to Arnica Creek. Because of undesirable ecological consequences to Yellowstone Lake, the U.S. National Park Service decided to eradicate the brook trout population. The Arnica Creek drainage, including a 23.6-hectare lagoon, was treated with antimycin in August 1985. A second application in August 1986 was limited to the stream. Posttreatment surveys in 1987, 1988, and 1989 indicated that brook trout were eliminated, and spawning migrations of cutthroat from Yellowstone Lake have remained viable. Application techniques and accurate estimates of toxin dispersal within the stream appeared to be the most critical variables affecting treatment success.

Yellowstone Lake supports the largest population of native Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* in the world, and preservation of the subspecies is a primary management objective of the U.S. National Park Service (NPS) (Jones et al. 1988). In May 1985, a routine electrofishing survey revealed an introduced population of brook trout *Salvelinus fontinalis* in Arnica Creek, a tributary of Yellowstone Lake. A fish-distribution map from 1930 indicated that brook trout had been reported in Arnica Creek (U.S. Fish and Wildlife Service, unpublished data). Recollections of NPS employees also suggest that this species inhabited the drainage before 1985 (K. Biastoch, personal communication); however, Arnica Creek was studied intensively from 1950 to 1961, and no brook trout were reported during this period (Welsh 1952; Cope 1956, 1957; Benson 1960; Ball and Cope 1961; Bulkley 1961; Benson and Bulkley 1963). Although nonnative salmonids have been stocked in the Yellowstone Lake drainage (Jones et al. 1980; Varley 1981), brook trout in Arnica Creek represented the first established population of nonnative salmonids with direct access to Yellowstone Lake and the upper Yellowstone River drainage.

Electrofishing surveys of 40 other tributaries of Yellowstone Lake (Jones et al. 1986, 1987, 1988), including portions of the major spawning streams of the West Thumb region (Figure 1), indicated that brook trout were confined to the Arnica Creek drainage. Most brook trout were located in the middle portion of the stream, about 4.5 km upstream from the lake. Brook trout collected during initial surveys varied from age 1 to age 3, and it appeared that most of the age-3 brook trout would spawn in the fall of 1985.

In Yellowstone National Park, the introduction of brook trout has usually resulted in the disappearance of Yellowstone cutthroat trout (Varley 1981). Griffith (1988) suggested that cutthroat trout coexist with brook trout less frequently than with other species. Because of the potential threat to a unique natural and recreational resource, the NPS chose to eliminate brook trout in Arnica Creek and the Arnica Creek Lagoon by using antimycin, a fish toxicant. The purpose of this paper is to describe the application of antimycin in the Arnica Creek drainage and the factors that influenced the successful removal of brook trout.

Study Area

Arnica Creek empties into Yellowstone Lake in the northern portion of West Thumb (Figure 1). The Arnica Creek drainage comprises 44 km of flowing water and is the largest catchment area (5,417 hectares) in the southwestern region of Yellowstone Lake. Arnica Creek empties into a 23.6-hectare lagoon (Figure 2) that is connected to the lake except during prolonged dry periods in late summer (Welsh 1952).

Arnica Creek is a third-order stream with a mean gradient of 1.8%. The stream flows through wet meadows, and springs and seeps are abundant. About 0.5 km above the stream mouth, discharge varied from 0.21 to 0.28 m^3/s in August 1986.

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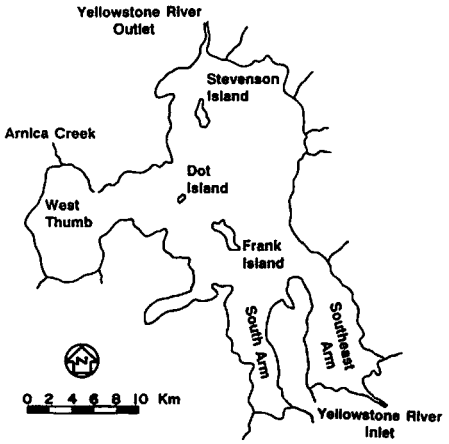

FIGURE 1.—Yellowstone Lake and major tributaries.

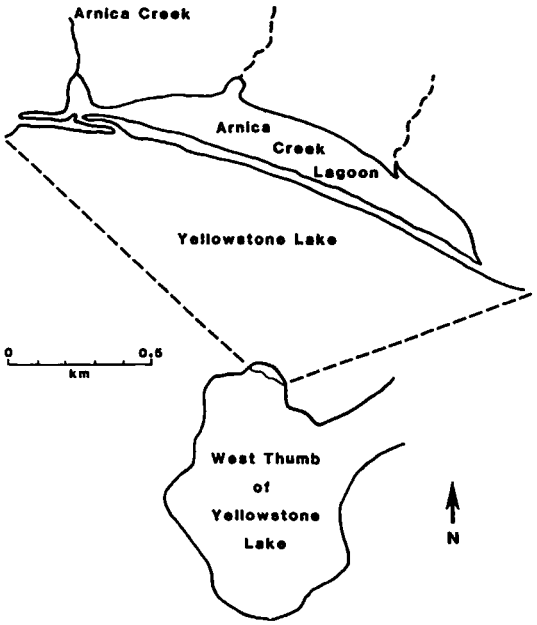

FIGURE 2.—Arnica Creek Lagoon, West Thumb of Yellowstone Lake.

Summer maximum water temperature in Arnica Creek ranged between 9 and 16°C in 1985 and 1986. In July 1985, pH was 7.4 near the stream mouth.

Cutthroat trout in Yellowstone Lake are adfluvial, and spawners annually ascend about 68 lake tributaries from May through July (Jones et al. 1987). One of the larger spawning migrations occurs in Arnica Creek (Ball and Cope 1961), and Benson (1960) reported that an average of 4,400 cutthroat trout entered the stream annually between 1951 and 1958. Most age-0 cutthroat trout leave the stream before October, but some remain there for up to 2 years (Benson 1960).

Yellowstone Lake supports one other native fish—longnose dace *Rhinichthys cataractae*—and three introduced fishes—redside shiner *Richardsonius balteatus*, lake chub *Couesius plumbeus*, and longnose sucker *Catostomus catostomus*. All were present in the Arnica Creek Lagoon in the 1950s (Biesinger 1961). With the exception of lake chub, these fishes were also present in Arnica Creek at that time, and lake chub were collected in the lower portion of the stream in 1985.

Methods

Antimycin (trade name, Fintrol) was selected as the fish toxicant. Antimycin has several desirable qualities, including specificity (Walker et al. 1964; Herr et al. 1967; Schnick 1974a, 1974b), lack of repellency (Binns 1967; Lennon et al. 1970), short exposure time (Gilderhus 1972), and rapid biodegradation (Walker et al. 1964; Lee et al. 1971; Marking and Dawson 1972). This toxin has been widely used since the early 1960s for renovation projects (Lennon et al. 1970), and it has been used in several national parks (including Yellowstone National Park) and wilderness areas in conjunction with programs designed to protect or reintroduce native fishes (Varley et al. 1976; USFWS 1985; Coman, no date).

Arnica Creek, 1985.—A comprehensive stream survey of Arnica Creek began in June 1985. Streams were mapped, and brook trout distribution was determined. Stream discharge was estimated periodically according to the midsection method (Buchanan and Somers 1969). Stream pH was measured colorimetrically.

Although Aquabiotics Corp. (circa 1985) recommended 7.5 μg of antimycin/L for waters with pH below 8.5 and water temperatures less than 15.5°C, B. Rosenlund (U.S. Fish and Wildlife Service, personal communication) reported that a higher concentration was often necessary in streams. Because 8 μg antimycin/L was effective for removal of brook trout in streams in Rocky Mountain National Park, this concentration was chosen for the Arnica Creek project.

By late summer, flow in portions of Arnica Creek was intermittent, and several sections of stream were no longer connected to the main stem. Final estimates of the amounts of toxin to be used were calculated for about 16 km in the Arnica Creek drainage.

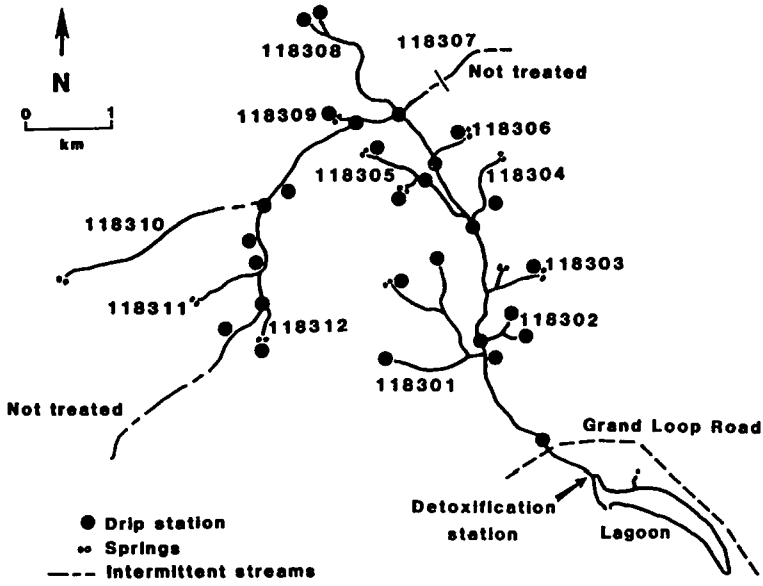

FIGURE 3.—Antimycin drip stations, Arnica Creek (11830), 1986.

Thirteen drip stations were placed within the drainage to dispense toxin (Figure 3). To maintain toxin concentration, booster stations were positioned at the heads of major tributaries and at several points along the main stem. Sites were selected to maintain the target concentration throughout the treatment area for at least 10 h.

To estimate the amount of antimycin required to attain the desired concentration in Arnica Creek, discharge estimates at each station were converted to cubic meters per hour. The volume was then expanded by the amount of Fintrol concentrate necessary to treat about 1,234 m^3 at 8 μg/L (98.4 mL) for the required time period (Aquabiotics Corp. circa 1985).

In the first year, most drip stations consisted of a 10- or 20-L plastic carboy with a nozzle inserted on one side near the bottom. A 50-cm piece of Tygon tubing was attached to the nozzle with hose clamps, and a 1-mL plastic pipette was inserted into the opposite end of the tubing. An adjustable metal clamp was placed on the hose to regulate flow.

To ensure accurate delivery of toxin, each drip station was calibrated to dispense at a set rate over time. Water was placed in the carboy, and flow was adjusted until the required delivery rate was accomplished. Delivery rates changed as head pressure decreased, but in most cases changes were negligible during pretreatment tests.

At three locations drip stations were constructed from animal waterers available at farm supply stores. A small hole was drilled in the pan of each waterer, and the flow rate was estimated by measuring discharge over time. Because head pressure is almost constant in these waterers, there was virtually no change in delivery rate. The necessary amount of toxin was calculated according to delivery rate, streamflow, and target concentration (8 μg/L).

In many areas, streamflow was insufficient to adequately distribute the toxin downstream. Backpack fire pumps (both rigid and collapsible) were used to apply additional antimycin. All tributaries and the upper portions of the main stem were treated in this manner. A 6-mm-mesh hardware-cloth screen was placed at the mouth of all seeps before treatment to prevent brook trout from entering freshwater refuges during the project.

Drip stations were started at 0630 hours and remained in operation for about 24 h. Additional spraying was conducted the following day. An attempt was made to collect all dead fish from Arnica Creek.

Fish numbers and biomass were estimated for seven sample stream sections that varied in length between 200 and 330 m. Fish within each section were identified to species, counted, and measured to the nearest 5 mm in total length (TL). For each species, individuals were grouped into 25-mm length-groups, and if available, a subsample of 20 fish was obtained for each length-group. Length

and weight were measured to the nearest 1 mm and 1 g, respectively, for all fish in the sample.

Arnica Creek, 1986.—In preparation for the second treatment, a more comprehensive survey of Arnica Creek was initiated in July 1986, and fish distribution was determined within the drainage. Captured brook trout were measured to the nearest 1 mm; sex and stage of maturity were noted.

To increase the accuracy of estimated toxin concentrations, linear distance of the entire drainage was estimated by pacing. Most estimates of stream discharge were obtained as described previously. At some sites, a colored velocity marker (Hamilton and Bergersen 1984) was used to estimate mean velocity, and discharge was calculated according to the equation of continuity (Hamilton and Bergersen 1984). Because of difficulties with toxin distribution during the previous year, fluorescein dye was used to determine dispersion rates throughout the drainage. Water temperature and pH were measured periodically.

By mid-August, flow had again become intermittent. Final estimates for toxin concentrations were based on about 25 km of the Arnica Creek drainage.

Twenty-eight drip stations constructed from plastic or metal animal waterers were placed within the drainage (Figure 3). Toxin volumes were calculated as before. Stations were positioned at the upstream end of major tributaries. Fluorescein dye tests provided information concerning toxin dispersal in the main stem, and selection of mainstem drip station sites (booster stations) was based on the toxin movement during a 2-h period (B. Rosenlund, personal communication).

Backpack sprayers were necessary to complete application in areas with insufficient streamflow. Three types of sprayers were used in the second year, including fire pumps (both galvanized steel and collapsible bag) and knapsack sprayers. Concentrated antimycin was diluted to 6 mL/L; each sprayer contained enough toxin to treat about 3,000 m^3 at 8 μg/L.

Drip stations were operated for 10 h. Most dead fish were age-0 cutthroat trout; however, no effort was made to collect dead fish, regardless of species.

Because Arnica Creek was connected to Yellowstone Lake through the lagoon during the second year, a detoxification station was situated on the stream about 100 m upstream from the lagoon to prevent discharge of toxin into the lake. A target concentration of 1,000 μg potassium permanganate ($KMnO_4$)/L was used to detoxify Arnica Creek (Aquabiotics Corp. circa 1985). The drip station was constructed from a 114-L garbage can with a spigot attached near the bottom. The system was calibrated to deliver the detoxicant at a rate of 80 L/h, but changes in head pressure necessitated frequent adjustments to maintain a constant flow.

Arnica Creek Lagoon.—In August 1985, flow from the lagoon outlet was blocked with sandbags to prevent treated water from entering Yellowstone Lake. Retention of water within the lagoon increased effective contact time and made detoxification unnecessary. Because contact time was longer, the target concentration was reduced to 4 μg/L.

Detailed bathymetric surveys were conducted in May and August. Mean water depth (1.7 m) was estimated from resulting maps and subsequently multiplied by the surface area to calculate total volume (m^3). The amount of antimycin required to achieve the desired concentration was calculated by expanding the amount needed to treat about 1,234 m^3 at 4 μg/L (49.2 mL).

Initial application lasted about 4.5 h. Toxin was siphoned into the propeller wash of an outboard motor with a venturi pump. Two boats were used for the application. In one boat, antimycin was dispensed from a sealed 210-L metal drum fitted with a faucet. In the second boat, the intake hose from the venturi pump was submerged in an open 130-L galvanized garbage can. When the toxin was dispensed, the boats continued moving through the lagoon for several hours to enhance mixing.

Because pH of the lagoon was relatively high (8.8) and macrophyte cover was extensive, a single application was judged to be inadequate. A second application lasting 3 h was undertaken the next day. Target concentration of this application was 2 μg/L. Fish were collected for 4.5 h after treatment.

Relatively high lake levels prevented isolation of Arnica Lagoon from Yellowstone Lake in 1986. In August, the lagoon was sampled by electrofishing from a boat with boom-mounted dropper electrodes (Novotny and Priegel 1974). Pulsed (80 pulses/s), 100–300-V DC was used. No brook trout were captured. These results suggested that brook trout were limited to Arnica Creek, and thus, the lagoon was not treated with antimycin the second year.

Posttreatment evaluation.—Portions of Arnica Creek were surveyed annually from 1987 through 1989. In May 1987, electrofishing with a gasoline-powered backpack shocker (100–300-V DC) was concentrated about 4 km above the mouth of Arnica Creek near the confluence with streams 118307

and 118308 (Figure 3). In June and September 1987, rotenone was used to collect samples in this area; additionally, tributary streams 118303, 118304, and 118305 were sampled in September. In June 1988, rotenone was used to collect fish from Arnica Creek between streams 118306 and 118307, and between streams 118302 and 118303; stream 118303 was also sampled at this time. In June and October 1989, electrofishing was conducted on the main stem of Arnica Creek in the vicinity of tributaries 118307 and 118308, below the confluence with 118301, and on tributaries 118301 and 118303.

To assess the success of the lagoon treatment, three experimental gill nets were set overnight on three occasions in water depths of 0.5–3 m in open water and in areas of dense vegetation. The monofilament nets (38 m long) had 7.6-m graduated-mesh panels with mesh sizes of 19, 25, 32, 38, and 51 mm (bar measure).

Results

Arnica Creek

Expanded estimates suggest that about 12,500 cutthroat trout and 4,000 brook trout were removed from Arnica Creek in 1985 (Jones et al. 1986). Cutthroat trout (N = 1,840) ranged between 27 and 261 mm TL, with a mean of 57 mm; 90% were shorter than 80 mm TL. A sample of 577 brook trout had a mean total length of 108 mm (range, 45 to 275 mm). Length-frequency analysis indicated a cluster of brook trout from 40 to 90 mm TL, and a second group between 100 and 160 mm TL; only 11% were longer than 170 mm. About 850 redside shiners and 800 longnose dace were killed.

Although eradication appeared to be successful in 1985, some problems were identified. Plastic carboy drip stations did not operate well; tubes became clogged, and flow was often blocked. Small debris in the stream water used to dilute the toxin was not always filtered effectively, and an increase in viscosity, thought to be related to a chemical reaction of the plastic tubing and the toxin, reduced flow to a negligible level. The animal waterers worked well and required only occasional monitoring to prevent plugging from debris. If the drain hole became clogged, it was easy to remove problem debris.

In 1985, low streamflows reduced antimycin distribution both downstream and within the stream channel. These areas were retreated by spraying, which increased the effort and amount of toxin needed.

The eradication project appeared to be successful in 1986. A total of 25 brook trout (mean length, 160 mm TL) were found during pretreatment surveys; 72% displayed sufficient gonadal development to spawn in the fall of 1986. During eradication, about 40 brook trout were observed either dead or moribund. Although no brook trout were collected, sizes appeared to be similar to those observed in previous surveys. Brook trout distribution was confined to the main stem between tributaries 118303 and 118306 and near the confluence of tributaries 118307 and 118308. These areas apparently provide the best overwinter habitat, and toxin dispersion was poor in the latter area in 1985.

All drip stations worked well, and spraying was effective for low-flow areas. Knapsack sprayers were more efficient than fire pumps, and the sprayers seldom leaked, a major problem with the collapsible pumps.

Arnica Creek Lagoon

In August 1985, many distressed fish appeared in the lagoon 6 h after treatment; however, few fish over 250 mm TL were killed. The absence of large dead fish in the Arnica Creek Lagoon suggested that the initial lagoon treatment was unsuccessful. A second application of antimycin the following day was successful, and by midafternoon, larger fishes were moribund.

Over 4,000 fish, including longnose suckers, redside shiners, lake chub, longnose dace, and cutthroat trout, were killed. Redside shiners and small longnose suckers were the most abundant; less than 10% were cutthroat trout. Most importantly, no brook trout were recovered from the lagoon.

Posttreatment Evaluation

Brook trout were not captured in any posttreatment sample. In 1987, the first year after treatment, cutthroat trout spawners were numerous in May. Age-0 cutthroat trout were abundant in June, but few were collected in September. In 1988, most fish collected in June were age-1 and age-0 cutthroat trout, but several cutthroat trout spawners and small longnose suckers were also captured. In 1989, cutthroat trout and longnose suckers were abundant in June, and redside shiners and lake chub were found in tributary 118301 and in the main stem below the confluence with 118301. In October, age-0 cutthroat trout were sparsely distributed throughout the sample area. Redside shiners were observed in the uppermost section, but were most abundant within 1 km of the lagoon.

Longnose suckers were also numerous in the lower section.

Gill nets set in Arnica Creek Lagoon during August 1985 yielded about 20 cutthroat trout and 10 longnose suckers. In early September, only 4 cutthroat trout were captured, and in late September, no fish were captured. These data suggest that, despite a slow reaction, the antimycin was effective in the lagoon.

Discussion

Arnica Creek

Results of posttreatment surveys indicate that brook trout have been eradicated from the Arnica Creek drainage. Reduced production of cutthroat trout from Arnica Creek in 1985 and 1986 was an unavoidable consequence of the eradication; however, at least five year-classes of cutthroat trout in Yellowstone Lake contribute to the spawning migration (Jones et al. 1987). Posttreatment sampling in Arnica Creek verified that cutthroat trout spawned successfully in 1987, 1988, and 1989, and other nontarget species also began to redistribute within the drainage.

Animal waterers functioned better than plastic carboys as drip stations. Waterers were easy to calibrate, and toxin flow was unaffected by changes in head pressure. Use of a fine-mesh filter when antimycin was mixed with stream water reduced drain plugging. Animal waterers are relatively light and compact, two factors that make them desirable for use in remote areas.

Although fish eradication is a widely accepted and commonly used tool in fishery management, information about successful procedures is scarce (Lennon et al. 1970). The need for extensive planning is evident from the inconsistent results of studies for which data are available (Lennon et al. 1970; INHS 1975). Given the difficulties encountered in completely eliminating a target species (Lennon et al. 1970; Varley et al. 1976), it is often necessary to plan a multiyear project. The Arnica Creek project took two consecutive years, and the second treatment was undoubtedly required to eradicate brook trout from the drainage.

Stream reclamation often presents unique problems with toxin dispersion and dilution (Lennon and Parker 1959), especially in streams like Arnica Creek, where springs and seeps are numerous. Low streamflow was a major problem in much of the drainage in 1985. Bruce Rosenlund (personal communication) recommended using fluorescein dye to evaluate streamflow patterns before applying toxin in 1986. Fluorescein is compatible with antimycin (Marking 1969) and can be used to monitor the toxin movement. This technique greatly enhanced our understanding of toxin dispersion in Arnica Creek and was an important factor in the eventual success of the project.

Fluorescein dye provided a visual marker in this study, and if a color comparator is used in conjunction with a known quantity of dye, concentration can be estimated at any point downstream from the application site (Lennon et al. 1970). The salt-resistivity technique (Lennon 1959) is based on the same principle, but a resistivity meter is used to measure salt concentration as it disperses. Both techniques provide comparable estimates of toxin concentration (Lennon 1959; Lennon and Parker 1959; Lennon et al. 1970), but the salt-resistivity method is easier to use in turbid water, at night, and over long distances. Equipment for the dye-comparator technique, however, is lighter and easier to transport, features that are advantageous in remote areas such as Arnica Creek. Given the difficulty in estimating dispersion rate in Arnica Creek, either technique would increase the probability of success; their use is strongly recommended for future stream reclamations.

Although information concerning the toxin concentration required for removal of particular species has increased in the last two decades (Herr et al. 1967; Gilderhus 1972), streamside bioassays are still important. Toxicity trials before initial application provide valuable information concerning the effects of water temperature and pH on toxin effectiveness, and pretreatment bioassays are recommended for future eradication projects.

Arnica Creek Lagoon

One important quality of antimycin is that it does not repel target species. Repellency is especially important near springs or whenever toxin distribution is poor, because fish repelled by toxin often seek areas of low toxin concentration (Binns 1967; Lennon et al. 1970).

Thick vegetative mats impaired toxin dispersion in the Arnica Creek Lagoon, and although the nonrepellent quality of antimycin may partially compensate for incomplete mixing of toxin in the water column, efforts to improve mixing would probably increase toxin effectiveness. Submerged pipes and electric pumps, for example, might allow application at a greater depth in areas of dense vegetation.

Results from laboratory experiments suggest that antimycin is not seriously affected by vegetation

(Gilderhus 1982); however, in field applications, vegetation may elevate pH and dissolved oxygen levels, and thus decrease toxin effectiveness (Marking and Dawson 1972; INHS 1975). Plants may also increase the surface area for toxicant adsorption and thereby reduce the effective toxin concentration (Lennon et al. 1970; INHS 1975). In the Arnica Creek Lagoon, these factors apparently reduced the effective concentration of antimycin and necessitated an additional application of toxin.

Two interrelated attributes of antimycin are short exposure time and rapid biodegradation. Gilderhus (1972) reported that the effective contact time (ECT) for rainbow trout was only 2 h at 5 μg/L. Toxin effectiveness increases rapidly at higher temperatures (Gilderhus 1972), and antimycin concentrations can be decreased when water temperature is above 15.5°C (Aquabiotics Corp. circa 1985). Antimycin degrades naturally within 1–14 d, and most frequently between 4 and 7 d (Walker et al. 1964). Degradation rate greatly increases at higher pH, and it is recommended that toxin concentrations be increased when pH is above 8.5 (Lee et al. 1971; Marking and Dawson 1972; Aquabiotics Corp. circa 1985). Higher temperature also reduces persistence of antimycin (Marking and Dawson 1972). Thus, the short exposure time required for antimycin to be effective is a positive attribute, especially when high water temperature and high pH accelerate degradation.

The additional dosage of 2 μg of antimycin/L appeared to be effective in the Arnica Creek Lagoon, but increasing the initial concentration to 8 μg/L probably would have compensated for elevated pH and water temperature, and improved initial results. Bioassay experiments consisting of submerged cages with adult cutthroat trout and longnose suckers would provide a means of accurately measuring renovation success in the lagoon, and pretreatment trials are recommended to verify minimum effective concentrations in field applications.

Acknowledgments

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