Acute Toxicity of a Zinc-Polluted Stream to Four Species of Salmonids

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Heavy metal pollution, in all likelihood, has been a serious problem in Colorado trout streams for almost a century. Boom towns like Leadville, Silverton and Creede, supported mainly by heavy-metal mining, came into existence in the last half of the 19th century. Waste products from the mining and milling processes were invariably piled along nearby streams. During periods of high flow, these streams eroded the tailing piles, laden with heavy-metal pollutants, thereby releasing toxic materials into the aquatic environment.

The purpose of this research was to: 1) compare laboratory zinc bioassay results with the toxic effects of a zinc-polluted stream on rainbow trout (Salmo gairdneri), and 2) compare the relative sensitivities of rainbow, brown, cutthroat and brook trout species to zinc.

METHODS AND MATERIALS

A pump capable of pumping 28.3 liters/sec (1 ft^3/sec) was used to lift water from Willow Creek, a zinc-polluted stream near Creede, Colorado, into an aqueduct inside the test facility. This building contained eight concrete raceways (7.6 meters long with a volume of 1,100 liters). Each raceway received 45 liters of water per minute, giving a 99% water turnover every two hours (SPRAGUE 1969). Four concentrations of toxicant, with each concentration replicated, were used in the tests. Each replicate contained the same number of test fish within a given experiment. The number of fish varied from 100 to 130 for the different bioassays. One hundred control fish were maintained in a separate raceway.

Calibrated siphons were used to pull various amounts of toxicant (Willow Creek water) from the aqueduct into the raceways. Well water from calibrated faucets provided the dilution necessary to obtain four different concentrations with two replicates of each concentration. Drip siphons were set up at the end of each raceway to collect 24-hour composite samples of the test waters which were analyzed daily for zinc content by flame atomic absorption spectrophotometry.

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Water quality analyses, according to Standard Methods (1971), were conducted at initiation and termination of the test. Parameters measured included pH, dissolved oxygen, temperature, alkalinity, hardness and conductivity. Willow Creek was sampled quarterly over a two-year period and zinc appeared to be the only toxic heavy metal consistently present (GOETTL et al. 1971, 1972). Lead, copper, silver and cadmium are undoubtedly present, but were not detected by direct atomic absorption analysis.

Each test lasted for 14 days. The incidence of deaths and signs of stress were checked twice daily after initiation of the tests. When deaths began to occur, the dead fish were removed and measured, and the frequency of observations was increased to four or five times daily. Fish found swimming or floating ventral side up (loss of equilibrium) were considered to be dead.

RESULTS

The rainbow trout bioassay (Table 1) was conducted with 125 fish (average length 13.5 cm) per exposure. The conductivity ranged from 200 to 290 µmhos/cm, pH was 7.3 and dissolved oxygen averaged 7.8 mg/liter. The first death occurred after 20 hours of exposure and the last after 286 hours (12 days) of exposure. Determination of the TL_{50} by log-probit analysis, as outlined by SPRAGUE (1969), revealed a 14-day TL_{50} of 0.41 mg zinc/liter (Table 5).

The second test (Table 2) was conducted with 130 brown trout per raceway. These fish averaged 8.3 cm in length. The test was conducted at a pH of 7.2 with the dissolved oxygen averaging 8.5 mg/liter and the conductivity varying between 135 µmhos/cm in the highest zinc concentration to 280 µmhos/cm in the lowest. The first death occurred after 24 hours of exposure and the last after 216 hours (9 days) of exposure. The 14-day TL_{50} value determined by log-probit analysis was 0.64 mg zinc/liter (Table 5).

Cutthroat trout averaging 14.4 cm were used in the third test (Table 3). There were 107 fish per replicate. Conductivity, pH and dissolved oxygen were the same as in the brown trout bioassay. The first death occurred after 24 hours of exposure and the last after 225 hours (9-1/2 days) of exposure. The 14-day TL_{50} value determined by log-probit analysis was 0.67 mg zinc/liter (Table 5).

The last test employed 8.9 cm brook trout as the test organism. One hundred fish were exposed in each replicate. Conductivity increased in Willow Creek and therefore increased the conductivity in the test

to between 310 and 340 μmhos/cm. The dissolved oxygen was lower, 7.5 mg/liter, due to increased temperatures (Table 4). The pH increased slightly to 7.3. The first death occurred after 40 hours of exposure and the last after 186 hours (8 days) of exposure. The 14-day TL_{50} value determined by log-probit analysis was 0.96 mg zinc/liter (Table 5).

TABLE 1 Rainbow Trout Bioassay

Zinc level (mg/liter)	% Mortality	Temp. (C)	Alkalinity (mg/liter)	Hardness (mg/liter)
1.30	100 (63 hr)	8.0	20	20
1.27	100 (63 hr)	8.0	19	20
0.92	100 (136 hr)	7.8	24	27
0.83	100 (120 hr)	7.8	25	28
0.58	85.7	7.8	35	39
0.60	87.2	7.8	35	38
0.31	20.0	7.7	53	54
0.29	17.6	7.7	52	51

TABLE 2 Brown Trout Bioassay

Zinc level (mg/liter)	% Mortality	Temp. (C)	Alkalinity (mg/liter)	Hardness (mg/liter)
0.81	96.2	7.0	32	23
0.80	97.7	7.0	34	22
0.57	16.8	7.8	36	35
0.57	12.8	7.8	37	35
0.42	4.0	7.8	43	44
0.44	0.8	7.8	43	44
0.23	0.0	7.7	52	54
0.20	0.0	7.7	54	55

TABLE 3 Cutthroat Trout Bioassay

Zinc level (mg/liter)	% Mortality	Temp. (C)	Alkalinity (mg/liter)	Hardness (mg/liter)
0.98	100 (56 hr)	8.5	21	24
1.00	100 (72 hr)	8.5	20	22
0.85	100 (153 hr)	8.3	30	34
0.83	100 (129 hr)	8.4	30	34
0.59	29.2	8.6	42	47
0.61	27.1	8.6	43	48
0.36	0.0	8.3	51	58
0.42	5.7	8.3	49	58

TABLE 4 Brook Trout Bioassay

Zinc level (mg/liter)	% Mortality	Temp. (C)	Alkalinity (mg/liter)	Hardness (mg/liter)
1.14	69	12.0	35	--
1.16	67	12.0	34	--
0.93	45	10.9	41	--
0.90	31	11.0	40	--
0.59	32	10.0	45	--
0.63	17	10.0	45	--
0.28	3	8.6	54	--
0.31	2	8.6	52	--

DISCUSSION

The 14-day TL_{50} value determined for rainbow trout (Table 5) was 0.41 mg/liter zinc, which corresponds almost exactly with 96-hour TL_{50} values of 0.41 and 0.43 determined by GOETTL *et al.*(1971) using similar sized rainbow trout in similar water quality. These results indicate that laboratory data may be applicable to the natural situation, provided the species of fish is the same and the water quality and fish size are similar.

TABLE 5

Comparison of 14-day TL_{50} and TL_{95} values as mg/liter zinc for four species of salmonids.

Species	TL_{50}	95% CI	TL_{95}	95% CI
Rainbow	0.41	0.37-0.45	0.71	0.61-0.92
Cutthroat	0.67	-- --	1.09	-- --
Brown	0.64	0.62-0.66	0.81	0.78-0.86
Brook	0.96	0.89-1.05	2.57	2.09-3.47

The 14-day TL_{50} value determined for zinc on cutthroat trout in this test (Table 5) was 0.67 mg/liter. The average fish size was slightly larger than the rainbow trout in Test One. Comparison of water quality data in Tables 2 and 4 reveals no gross differences. On the basis of similar water quality and fish size in the two tests, cutthroat trout must be considered more tolerant of zinc than rainbow trout.

The brown trout bioassay produced a 14-day TL_{50} value of 0.64 mg/liter zinc. This is similar to the 0.67 mg/liter value obtained with cutthroat trout (Table 5). The size difference between these species was great, with the average cutthroat being 14.4 cm and the brown trout at 8.3 cm. This indicates that the brown trout are more tolerant of zinc than the cutthroat based on the effects of fish size reported by GOETTL et al. (ibid.) which reported increased toxicity of zinc with decrease in fish size.

The 14-day TL_{50} value of zinc for brook trout was 0.96 mg/liter (Table 5). Based on size similarities between brook trout and brown trout (8.9 cm versus 8.3 cm), brook trout are more tolerant of zinc than brown trout. Temperature in the brook trout test was 5 C higher than in the brown trout test. Higher temperatures tend to increase the toxic effects of zinc (ibid.).

Brook trout are more tolerant of zinc pollution than rainbow trout. Rainbow trout used in the test were larger than brook trout (13.5 cm versus 8.9 cm) and were tested in colder water (8.0 C versus 12.0 C), yet the brook trout were about 2-1/2 times as tolerant of zinc (14-day TL_{50} values of 0.96 mg/liter versus 0.41 mg/liter).

Of the four species tested, rainbow trout were the least tolerant of zinc pollution. Cutthroat trout were more tolerant than rainbow trout. Brown trout were more tolerant than cutthroat trout based on the smaller size of the test fish. Brook trout were the most resistant of the species tested.

ABSTRACT

Four species of salmonids were exposed to different dilutions of water from a stream polluted by zinc. Test duration was 14 days for all species. The TL_{50} for rainbow trout (Salmo gairdneri) was 0.41 mg zinc/liter. TL_{50} values for zinc to brown trout (Salmo trutta), cutthroat trout (Salmo clarki), and brook trout (Salvelinus fontinalis) were 0.64, 0.67, and 0.96 mg/liter, respectively. Rainbow trout were least tolerant of zinc and brook trout were the most tolerant. Cutthroat trout were considered more susceptible to zinc than brown trout.

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