NORTHWEST & ALASKA FISHERIES CENTER PROCESSED REPORT

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EFFECT OF LAKE WASHINGTON SEDIMENT FROM THE SAND POINT DREDGING SITE ON COHO SALMON *(ONCORHYNCHUS KISUTCH)* FINGERLINGS

by
Donovan R. Craddock
Joanne G. Parker
Clifford A. Spjut
George F. Slusser

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington 98112

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Interim Report to GSA

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Environmental Conservation Division
Northwest and Alaska Fisheries Center
Mukilteo Field Facility, WA 98272
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
2725 Montlake Boulevard East
Seattle, Washington 98112

Abstract

A study was made of the effect of different concentrations of sediment from the NOAA Sand Point dredge site on the survival of coho salmon (Oncorhynchus kisutch) fingerlings and on water quality. Sediment from the dredging site was mixed in concentrations from 1-60 g/liter and from 70-110 g/liter for bioassays in lake and dechlorinated city water. Aerated and circulated bioassays, and static bioassays were conducted. No mortalities occurred in circulated concentrations up to 60 g/liter over an exposure period of 192 h. Increasing the concentrations to 110 g/liter still did not obtain an LC_{50} after 192 h, but some mortalities did occur. Only one mortality occurred in the static bioassays at concentrations up to 60 g/liter and an exposure of 96 h. Oxygen and pH levels fell sharply in this test, but did not result in mortalities.

The water quality study revealed that the high concentrations of sediment did not deplete the oxygen nor alter the pH appreciably over a 96 h period. The settleable material dropped out rapidly whereas the total nonfilterable residue remained high for 48 h and the turbidity was still high at the end of 96 h.

High concentrations of Lake Washington sediment did not cause mortalities of coho salmon fingerlings approaching LC_{50} even after 192 h exposure.

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) plans to construct a Western Regional Center at Sand Point, Seattle, Washington, which would include docking facilities on Lake Washington for vessels operated by NOAA's National Ocean Survey. The construction of these moorages would entail considerable dredging (275,240 m^3: about 360,000 cubic yards). Dredging naturally puts bottom material in suspension creating turbid conditions as the material is removed. It is important for NOAA to know the effect turbidity, caused by dredging, might have on the aquatic biota of the area. The primary objective of this study, which was conducted in February and March of 1978, was to determine the effect of different concentrations of the Lake Washington sediment on the survival of coho salmon, Oncorhynchus kisutch, fingerlings. The secondary objective of the study was to observe the effect of different concentrations of the sediment on water quality.

Methods

Fish

Some of the most important animals inhabiting the lake are salmonids (e.g., coho; chinook, O. tshawytscha; and sockeye, O. nerka, salmon). The young of these species may spend considerable time in the lake before migrating to sea. Because of their suitability as bioassay animals and their availability, coho salmon fingerlings were selected as the study species. Eggs from the 1976 brood were collected at the Washington State Fish Hatchery at Issaquah, Washington and transported to the hatchery facility at the National Marine Fisheries Service, Northwest and Alaska Fisheries Center's Seattle Laboratory, where they were hatched and reared. Coho fingerlings were subsequently transported to the Center's Mukilteo

Field Station and held one day in the bioassay tanks for acclimation before the experiment began. Fish were not fed for one day before nor during the experiments.

Water

The Mukilteo Field Station does not have a fresh water supply free of chlorine. Therefore, Lake Washington water was pumped from Portage Bay and transported to the field station for the initial 60 liter bioassay and water quality decay study. Since transporting more lake water to Mukilteo was impractical, dechlorinated city water was used in the other bioassays. Large tanks of city water were dechlorinated by aerating them vigorously for at least 24 h prior to use.

Sediment

The sediment used in the study was obtained at Sand Point by drilling at the edge of the lake with an 20.3 cm (8-inch) hollow core drill to depths of 4.6 and 6.1 m (15 and 20 feet). Holes were drilled adjacent to ramps 1 and 3 and at the north end of the main runway of the former airfield; these sites encompassed the area to be dredged. Approximately 265 liters (70 gallons) of sediment were obtained on February 7, 1978.

The sediment was prepared for the bioassays by removal of rocks and gravel larger than 6.35 mm (1/4 inch) in diameter and then homogenizing each of the seven 38 liter (10-gallon) samples in a cement mixer and returning them to their original containers. Equal portions from each container were then put in the cement mixer and homogenized to form one large sample which was stored in a plastic lined garbage can.

Bioassay Methods

Two different bioassay methods were employed. One method used sixty-liter, nontoxic Brute-resin food storage containers modified with a false

concave bottom, a recirculating pump system, and a 6.35 mm (1/4 inch) mesh basket to retain the 15 test fish per container (Figure 1) (Smith et al. 1970[1/])[2/]. This system, plus aeration, and daily stirring maintained adequate oxygen levels and helped keep the sediment in suspension. The pump delivered about 568 liters/h (150 gallons/h) and it and the entire bioassay container were held in a water bath to maintain a steady temperature.

The second bioassay method employed 30 liter rectangular glass aquaria containing 10 fish each and held in a water bath to maintain temperatures. This was a strictly static setup with no circulation or aeration. An identical arrangement of 30 liter tanks was used for the water quality decay experiment but no fish were included.

Preparation of Concentrations

The various concentrations of sediment were prepared in the following manner. Since the different concentrations would be designated by the dry weight of sediment per liter of water we needed to determine the wet to dry weight ratio. This was accomplished by drying and weighing ten 50-ml beakers, filling them with wet sediment (a total of 61 ml each) and weighing them again (all weights to the nearest 0.01 g). The beakers and sediment were placed in a drying oven at 103°C overnight, cooled in a dessicator, and reweighed. They were placed back in the oven for an additional hour,

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1/ Smith, D.W., E.O. Salo, and B.P. Snyder, 1970. Tolerance of Juvenile Chum Salmon (Oncorhynchus kisutch) to suspended solids. University of Washington, Fishery Research Institute, Seattle, Wash. 98195. Unpubl. manuscr.

2/ Reference to trade name(s) in this report does not imply endorsement of commercial product(s) by the National Marine Fisheries Service, NOAA.

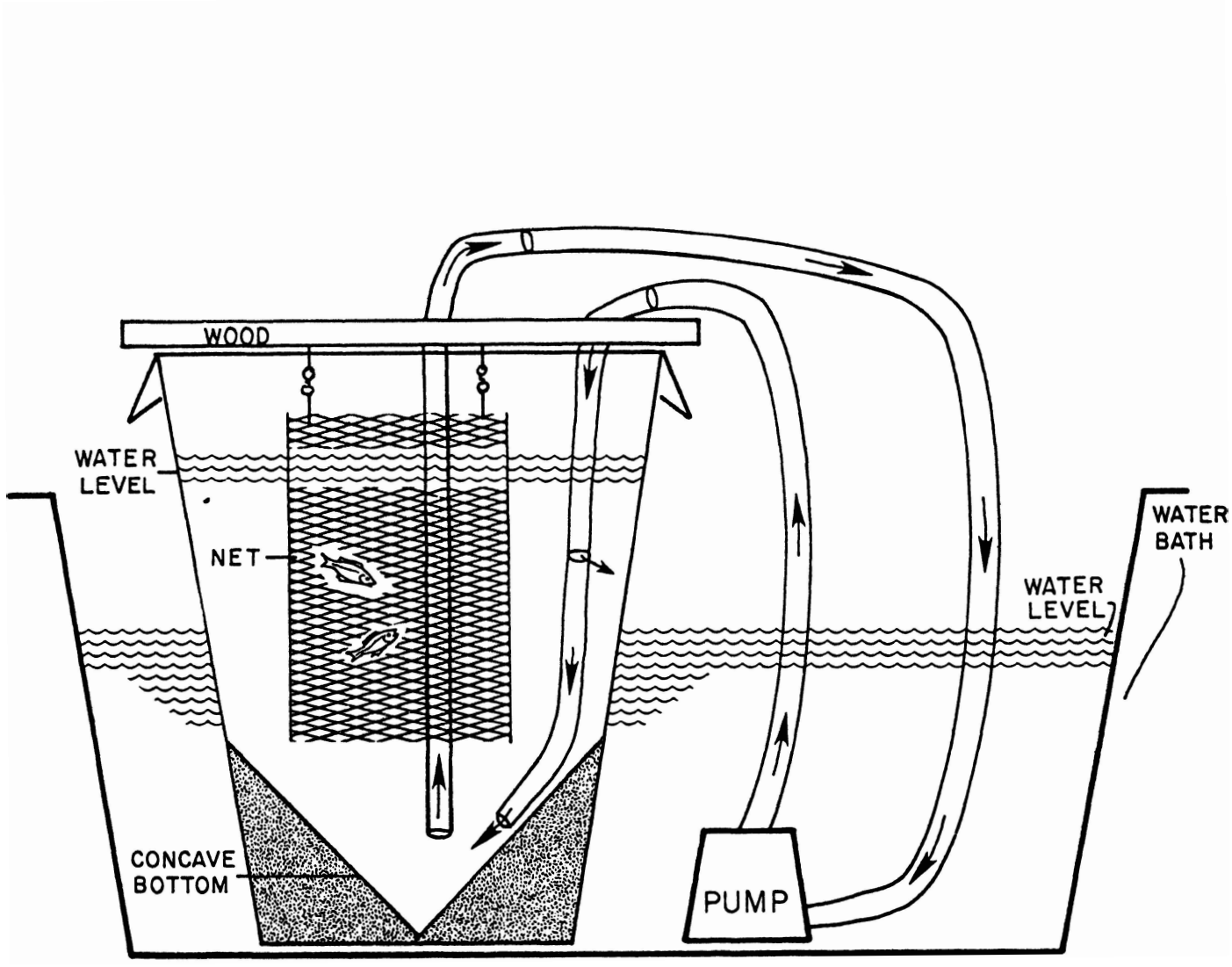

Figure 1.--60 liter bioassay apparatus.

cooled, and reweighed to verify that the sediment was completely dry. There was practically no variation between the two dry weights, and the wet to dry ratio was calculated at 1.21:1. The formula used to determine wet weight of sediment needed for each concentration was as follows:

$$\text{specified concentration} \times \text{volume of tank} \times \frac{\text{(wet wt.)}}{\text{(dry wt.)}} = \text{total weight wet of sediment needed}$$

The volume displaced by this weight of wet sediment was calculated and removed from the bioassay tanks to maintain volumes at a constant 60 or 30 liter. The concentrations for the first two bioassays (30 and 60 liter) were based on information obtained from Smith (1978)[3/] and Noggle (1977)[4/] who had worked with coho salmon fingerlings and sediment in both fresh and salt water. These concentrations ranged from 1 to 60 g/liter as shown in Table 1. These were increased to 70 to 110 g/liter in the second bioassay (60 liter) where the original concentrations did not produce an LC_{50}.

Bioassay Procedure

After the bioassay tanks were set up in the water baths, filled with lake or dechlorinated water, and the pumps and air started (60 liter only), the proper weight of wet sediment was converted to a thin slurry in 4 to 8 liter of water taken from the bioassay tanks. This was then stirred back into the water in the tank. The fish were introduced before the

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3/ D.W. Smith, University of Washington, Fisheries Research Institute, Seattle, Wash. 98195. Pers. Commun., Feb. 1978.

4/ Charles Noggle. 1977. The behavior and physiological effects of suspended sediment on juvenile salmonids. University of Washington, Fisheries Research Institute, Seattle, Wash. 98195. Unpubl. manuscr.

Table 1.--Wet weights of sediment and volumes of sediment and lake water used to obtain various concentrations

Tank		Sediment	Total wet wt of sediment needed	Vol. of sediment	Vol. of water	Total vol.
Type of test	Number	(g/liter)	(g)	(liter)	(liter)	(liter)
Bioassay,	1	control	--	--	60	60
1st 60 liter	2	1	72.6	.04	59.96	60
	3	10	726.0	.36	59.64	60
	4	20	1452.0	.72	59.28	60
	5	30	2178.0	1.08	58.92	60
	6	40	2904.0	1.44	58.56	60
	7	50	3630.0	1.80	58.20	60
	8	60	4356.0	2.16	57.84	60
Bioassay,	9	control	--	--	60	60
2nd 60 liter	10	70	5082.0	2.5	57.5	60
	11	80	5808.0	2.9	57.1	60
	12	90	6534.0	3.2	56.8	60
	13	100	7260.0	3.6	56.4	60
	14	110	7986.0	4.0	56.0	60
Static bioassay	1	control	--	--	30	30
and decay,	2	1	36.3	.02	29.98	30
30 liter	3	10	363.0	.18	29.82	30
	4	20	726.0	.36	29.64	30
	5	30	1089.0	.54	29.46	30
	6	40	1452.0	.72	29.28	30
	7	50	1815.0	.90	29.10	30
	8	60	2178.0	1.08	28.92	30

sediment in the 60 liter test and just afterwards in the 30 liter experiment. Fish were introduced serially to avoid selection (15 fish/60 liter and 10 fish/30 liter).

We checked daily for mortalities by gently lifting the basket to the surface. Any mortalities were recorded and weighed to the nearest 0.01 g and measured to the nearest millimeter for fork length. All fish remaining alive at the end of an experiment were weighed and measured.

Water Quality

Samples for water quality were collected immediately after the initial mixing and after the daily stirring by siphoning from 4 inches below the surface. Approximately 1200 ml was required for the settleable and total nonfilterable residue studies and 300 ml for the pH and turbidity studies.

Settleable material ml/liter was determined using Imhoff cones and the technique described in Standard Methods Handbook (American Public Health Association 1971).

Total nonfilterable residue (TNFR, mg/liter) was also determined using the technique described in Standard Methods. We used a vacuum pump, 150 ml Buchner funnels with 7 cm GF/C filters and a single wall transite oven (Blue M). Because of the density of the concentrations used, the samples were limited to 20-50 ml. After the weight of the dry samples had been determined we used the following calculation:

$$\text{mg/liter total suspended matter} = \frac{A \times 1000}{B}$$

where: A = mg suspended solids

B = ml sample size.

Turbidity was determined using an HF-DTR15 turbidity meter with a full scale of 100 Jackson Turbidity Units (JTU). Again, the samples were so

turbid that most of them required dilution and calculating as outlined in Standard Methods:

$$\text{Turbidity (JTU)} = \frac{A\ (B + C)}{C}$$

where: A = turbidity reading of dilution (JTU's)

B = ml of dilution water

C = ml of original sample.

Dissolved oxygen and temperature were obtained from the bioassay and decay tanks using a YSI 51B DO meter and pH was measured with an Orion 701 pH meter.

Results

Bioassay (60 liters Lake Water)

The lack of mortality in any experimental group was an unexpected result of the test. Only two salmon died during the initial 96 h and both of them were the result of escaping from the basket and being injured by the pump intake. The test was continued for an additional 96 h and no further mortalities occurred. This was surprising because the turbidity was so great in all but the 1 g/liter tank that visibility was limited to less than 13 mm (1/2 inch) below the surface. In the higher concentrations of sediment (40, 50, and 60 g/liter) many of the fish were at the very surface of the water with their dorsal parts actually exposed leading us to suppose they were nearing death. Ten fish from the control, 40, 50, and 60 g/liter tanks were transferred to clear fresh water after the 192 h exposure period, where they survived 6 d with no apparent difficulty. The lowest survival was 93% in the 30 and 50 g/liter tanks. Fish in the tests were exposed to concentrations as high as 60,000 ppm which translated into maximum readings for settleable material of 77 ml/liter; TNFR of 9,500

mg/liter; and turbidity of 4,500 JTU's (Table 2). Temperature ranged from 8.5° to 10°C, dissolved oxygen was consistently above 9 ppm, and pH ranged from 7.31 to 7.76.

Bioassay (60 liter Dechlorinated Water)

The results of the second bioassay extending the concentrations tested from 70 to 110 mg/liter still did not allow us to establish an LC_{50} (Table 3). After 96 h, the lowest survival was 60% in the 100 g/liter test which was also the case after the test was continued to 192 h. Settleables reached a maximum of 15 ml/liter; TNFR 20,500 mg/liter; and turbidity 9,700 JTU's. Dissolved oxygen again remained high (above 9.8 ppm), temperature ranged from 7°-9°C, and pH from 6.88 to 7.76. The lower pH readings were found in the control tank and may relate to the dechlorinated city water used in the tests. The higher pHs in the remaining tanks must be the result of the sediment.

Fish in the higher concentrations of this bioassay were obviously more stressed than in the previous one; many were continually at the surface, and many lost equilibrium rolling on to their sides or swam vertically, yet few died during the test. Similar behavior was observed by Wallen (1951) and Smith et al.[1/] The long term effect of such exposure is unknown. Figure 2 depicts the turbidity, TNFR, and settleables from the controls, 20, 50, 80, and 110 g/liter concentrations of sediment of the first and second 60 liter bioassays. Turbidity was much as one would expect: increasing generally with increasing concentration. Total nonfilterable residue and settleable matter, however, show some unexpected variability probably contributable to sampling. Although great care was exercised to collect and process the samples in a uniform and consistent manner, sand and heavy material settled out so fast that any delay in

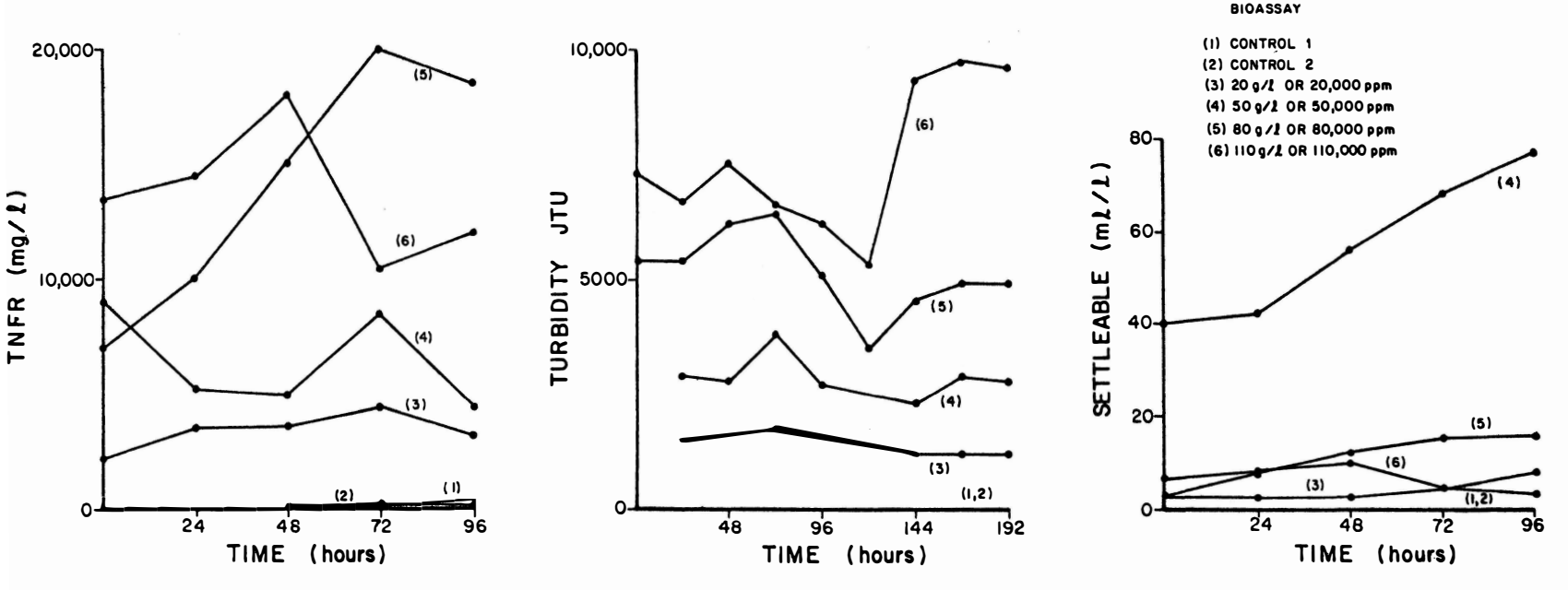

Figure 2.--Total nonfilterable residue (TNFR) (mg/liter), settleable (ml/liter) and turbidity, Jackson Turbidity Units (JTU) for combined 60 liter bioassays.

Table 2.--Bioassay of Lake Washington sediment using coho salmon fingerlings (aerated, circulated, 192 hours, in 60 liter lake water)

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1] (mg/liter)	Turbidity (JTU)[2]	Temp. (°C)	Dissolved O_2	pH	Survival (15)[3]
Control	0	negligible	0	--	9.5	12.65	7.57	15
	4	--	--	--	9.0	11.8	--	--
	24	negligible	0	5	9.3	12.2	7.54	15
	48	0.02	0	4	9.1	12.0	7.16	15
	72	0.01	0	3	8.8	11.5	7.73	15
	96	.08	200	7	8.5	11.6	7.47	15
	144	--	--	25	8.5	10.7	7.62	15
	168	--	--	18	8.0	11.8	7.54	15
	192	--	--	7	7.5	11.8	7.46	15
1	0	0.8	1000	--	9.5	10.20	7.49	15
	4	--	--	--	9.5	11.8	--	--
	24	.16	250	89	9.3	12.0	7.49	15
	48	.20	250	84	9.0	11.4	7.43	15
	72	.30	250	84	8.8	11.4	7.42	15
	96	.10	500	64	8.5	10.9	7.48	15
	144	--	--	46	8.5	10.2	7.35	15
	168	--	--	46	8.0	11.0	7.40	15
	192	--	--	50	7.5	11.3	7.50	15
10	0	2.8	4000	--	9.5	10.90	7.64	15
	4	--	--	--	9.0	12.00	--	--
	24	3.8	2000	720	9.3	11.6	7.55	15
	48	1.2	1000	680	8.8	11.1	7.31	15
	72	2.4	2667	700	8.8	11.9	7.62	15
	96	1.4	2000	800	8.5	11.9	7.68	15
	144	--	--	790	8.5	9.3	7.46	15
	168	--	--	770	8.0	10.6	7.45	15
	192	--	--	660	7.5	10.8	7.50	15

[1] TNFR = Total nonfilterable residue.
[2] JTU = Jackson Turbidity Units.
[3] Number of fish at beginning of experiment.

Table 2.--continued.

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1] (mg/liter)	Turbidity (JTU)[2]	Temp. (°C)	Dissolved O_2	pH	Survival (15)[3]
20	0	2.6	2200	--	9.5	11.50	7.60	15
	4	--	--	--	9.5	9.00	--	--
	24	2.7	3500	1500	9.2	11.5	7.32	15
	48	2.7	3600	1600	8.8	12.1	7.72	15
	72	4.3	4400	1700	8.8	12.0	7.70	15
	96	3.4	3200	1600	8.5	12.2	7.65	15
	144	--	--	1200	8.5	11.6	7.66	15
	168	--	--	1200	8.0	11.8	7.69	15
	192	--	--	1200	7.5	11.9	7.69	15
30	0	33.0	6750	--	9.5	11.50	7.48	15
	4	--	--	--	9.5	12.00	--	--
	24	32.7	3333	1700	9.0	12.2	7.61	15
	48	40.0	6000	2000	8.9	11.9	7.66	15
	72	39.0	5000	2000	8.8	11.6	7.68	15
	96	41.0	5500	1800	8.5	12.1	7.76	14
	144	--	--	1700	8.5	11.2	7.53	14
	168	--	--	1600	8.0	11.7	7.62	14
	192	--	--	1700	7.5	11.7	7.66	14
40	0	5.0	7000	--	9.5	11.50	7.65	15
	4	--	--	--	9.5	12.00	--	--
	24	3.4	4333	2000	9.0	12.2	7.61	15
	48	4.3	5000	2700	8.8	12.0	7.68	15
	72	4.0	6000	2800	8.8	12.0	7.68	15
	96	3.0	4500	2600	8.5	12.1	7.67	15
	144	--	--	2200	8.5	11.1	7.55	15
	168	--	--	2100	8.0	10.8	7.48	15
	192	--	--	1700	7.5	11.6	7.00	15

Table 2.--continued

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1] (mg/liter)	Turbidity (JTU)[2]	Temp. (°C)	Dissolved O_2	pH	Survival (15)[3]
50	0	40.0	9000	--	10.0	11.50	7.54	15
	4	--	--	--	9.5	12.00	--	--
	24	42.0	5200	2900	9.0	12.2	7.57	15
	48	56.0	5000	2800	8.8	12.0	7.62	15
	72	68.0	8500	3800	8.8	11.6	7.62	14
	96	77.0	4500	2700	8.5	11.6	7.60	14
	144	--	--	2300	8.5	10.9	7.42	14
	168	--	--	2900	8.0	11.0	7.42	14
	192	--	--	2800	7.5	10.3	7.46	14
60	0	11.2	7600	--	10.0	11.50	7.54	15
	4	--	--	--	9.5	11.90	--	--
	24	5.4	7000	3800	9.0	12.1	7.60	15
	48	7.0	9000	4100	8.8	12.0	7.63	15
	72	9.0	9500	4500	8.8	11.9	7.71	15
	96	10.0	7000	4200	8.5	12.1	7.73	15
	144	--	--	3500	8.5	11.6	7.70	15
	168	--	--	4100	8.0	12.0	7.67	15
	192	--	--	3500	7.5	11.7	7.73	15

Table 3.--Bioassay of Lake Washington sediment using coho salmon fingerlings (aerated, circulated, 192 hours, in 60 liter dechlorinated city water)

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1] (mg/liter)	Turbidity (JTU)[2]	Temp. (°C)	Dissolved O_2	pH	Survival (15)[3]
Control	0	negligible	0	12	7.0	12.7	6.88	15
	24	negligible	0	4.6	7.0	12.4	7.12	15
	48	negligible	0	5.0	7.0	10.0	6.89	15
	72	negligible	250	3.5	8.0	9.9	6.89	15
	96	negligible	0	3.0	9.0	11.5	6.87	15
	120	--	--	3.2	9.0	11.9	6.95	15
	144	--	--	4.6	9.0	12.1	6.98	15
	168	--	--	2.7	9.0	12.0	7.01	14
	192	--	--	4.0	9.0	10.4	6.92	13
70	0	2.6	5500	3600	7.0	11.8	7.63	15
	24	1.4	4500	3200	7.0	12.2	7.44	15
	48	7.5	10000	5300	7.0	10.9	7.56	15
	72	8.0	9000	4800	8.0	10.2	7.53	15
	96	7.3	9000	4700	9.0	11.3	7.47	15
	120	--	--	5200	9.0	10.5	7.37	15
	144	--	--	4300	9.0	11.6	7.49	15
	168	--	--	5900	9.0	11.5	7.42	15
	192	--	--	6000	9.0	11.7	7.42	15
80	0	3.0	7000	5400	7.2	11.8	7.72	15
	24	7.8	10000	5400	7.0	12.2	7.52	15
	48	12.0	15000	6200	7.0	11.0	7.62	15
	72	15.0	20000	6400	8.0	10.3	7.58	15
	96	15.6	18500	5100	9.0	11.8	7.57	15
	120	--	--	3500	9.0	11.1	7.53	15
	144	--	--	4500	9.0	11.8	7.60	15
	168	--	--	4900	9.0	11.8	7.55	15
	192	--	--	4900	9.0	12.0	7.61	15

[1] TNFR = Total nonfilterable residue.
[2] JTU = Jackson Turbidity Units.
[3] Number of fish at beginning of experiment.

Table 3.--continued

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1]/ (mg/liter)	Turbidity (JTU)[2]/	Temp. (°C)	Dissolved O_2	pH	Survival (15)[3]/
90	0	2.4	9000	5600	7.5	11.0	6.67	15
	24	8.0	12500	5500	7.0	11.8	7.38	15
	48	4.0	10000	5600	7.0	10.7	7.43	15
	72	13.5	20500	5500	8.0	9.8	7.43	15
	96	8.1	11500	5700	9.0	10.8	7.35	15
	120	--	--	4400	9.0	9.4	7.19	14
	144	--	--	6500	9.0	11.1	7.36	14
	168	--	--	6700	9.0	8.2	7.21	14
	192	--	--	7000	9.0	11.7	7.48	14
100	0	5.0	13500	6100	7.3	11.4	7.76	15
	24	4.5	11500	5900	7.0	11.3	7.46	15
	48	14.5	20000	7700	7.0	10.0	7.44	15
	72	7.5	11500	6300	8.0	9.7	7.60	15
	96	6.7	12000	6300	9.0	11.6	7.42	14
	120	--	--	5000	9.0	10.6	7.47	9
	144	--	--	7700	9.0	11.3	7.51	9
	168	--	--	9200	9.0	10.7	7.55	9
	192	--	--	9200	9.0	10.8	7.43	9
110	0	6.5	13500	7300	7.2	11.8	7.53	15
	24	8.0	14500	6700	7.0	12.3	7.51	15
	48	10.0	18000	7500	7.0	10.9	7.52	15
	72	4.7	10500	6600	8.0	10.4	7.52	13
	96	8.0	12000	6200	9.0	11.4	7.50	13
	120	--	--	5300	9.0	10.9	7.59	11
	144	--	--	9300	9.0	11.0	7.56	11
	168	--	--	9700	9.0	10.8	7.56	10
	192	--	--	9600	9.0	11.1	7.57	10

starting the siphon could have affected the sample. The other main source of variability, especially in the TNFR, resulted from the necessarily small samples (20 to 50 ml). Larger samples of these extreme concentrations would be impossible to filter in a reasonable time. The concentrating effect of removing a 1,500 ml sample from the tanks daily may have contributed to the variability. Temperature, concentration of dissolved oxygen, and pH remained reasonable constant during the tests.

Static Bioassay (30 liters Dechlorinated Water)

The static bioassay (30 liter) again showed very high survival; 100% in all tests except the highest concentration where it was 90% after 96 h (Table 4). The initial turbidity in the 60,000 ppm concentration was 3,900 JTU's which fell to a low of 1,300 after 2 d. The movement of the fish helped to keep the sediment stirred up. Oxygen levels fell drastically from near saturation at the start to levels as low as 2 ppm. Some of the lowest concentrations of dissolved oxygen were in the control tank, whereas, the tank with the greatest sediment concentration had the highest concentrations of dissolved oxygen; never falling below 5.5 ppm. This may be explained by the much greater activity of the control fish compared to fish in the heavy concentrations. As might be expected, pH levels fell rather sharply in the static tests as a result of the buildup of CO_2 and the resultant carbonic acid.

Decay (30 liters Lake Water)

In the decay experiment, where no fish were involved, the setteable material and TNFR levels were zero or greatly reduced after 24 h (Table 5, Fig. 3). The turbidity remained at comparatively high levels in all concentrations to 96 h (1 g/liter - 25 JTU; 60 g/liter - 340 JTU). Dissolved oxygen decreased only slightly during the period as did the pH. An

Table 4.--Bioassay of Lake Washington sediment using coho salmon fingerlings (static, 96 hours, in 30 liter dechlorinatd water)

Sediment (g/liter)	Time (h)	Turbidity (JTU)[1/]	Temperature (°C)	Dissolved O_2	pH	Survival (10)[2/]
Control	0	2.6	8.9	12.0	7.04	10
	24	5.2	8.5	5.3	6.31	10
	48	2.4	8.5	3.5	6.24	10
	72	4.6	8.7	2.6	6.39	10
	96	3.0	7.8	3.4	6.40	10
1	0	65	8.9	12.0	7.01	10
	24	39	8.6	5.0	6.22	10
	48	38	8.5	2.5	6.28	10
	72	28	8.7	2.5	6.39	10
	96	28	7.5	3.5	6.45	10
10	0	530	8.9	11.9	7.32	10
	24	420	8.6	5.8	6.61	10
	48	380	8.5	2.8	6.30	10
	72	290	8.7	2.0	6.54	10
	96	270	7.5	3.3	6.56	10
20	0	1500	8.9	11.7	7.47	10
	24	760	8.4	6.0	6.73	10
	48	700	8.5	3.8	6.62	10
	72	640	8.7	3.7	6.65	10
	96	550	7.5	4.0	6.63	10
30	0	1800	8.9	11.5	7.63	10
	24	1100	8.4	5.4	6.81	10
	48	970	8.5	3.5	6.70	10
	72	810	8.7	3.0	6.71	10
	96	800	7.5	4.0	6.70	10
40	0	2900	8.9	11.2	7.72	10
	24	1500	8.4	5.8	6.91	10
	48	1500	8.5	4.1	6.89	10
	72	1300	8.7	3.6	6.80	10
	96	1200	7.5	4.4	6.81	10
50	0	2700	8.9	11.1	7.74	10
	24	1700	8.2	5.4	6.88	10
	48	1900	8.5	5.0	6.96	10
	72	1400	9.7	4.4	6.85	10
	96	1400	7.5	5.2	6.86	10
60	0	3900	9.0	11.1	7.76	10
	24	1700	8.1	6.1	7.06	10
	48	1300	8.5	5.7	6.89	10
	72	1700	8.7	5.5	6.95	10
	96	1400	7.5	6.2	6.97	9

[1/] JTU = Jackson Turbidity Units.
[2/] Number of fish at beginning of experiment.

Table 5.--Decay of Lake Washington sediment
(96 hours, in 30 liter lake water)

Sediment (g/liter)	Time (h)	Settleable (ml/liter)	TNFR[1] (mg/liter)	Turbidity (JTU)[2]	Temp. (°C)	Dissolved O_2	pH
Control	0	negligible	0	2.8	8.9	12.0	7.29
	24	.02	200	7.4	8.8	11.8	7.45
	48	negligible	0	1.5	8.5	11.6	7.30
	72	negligible	0	1.0	8.7	11.4	7.27
	96	negligible	0	1.5	8.0	11.1	7.37
1	0	.10	250	94	8.9	12.0	7.56
	24	negligible	200	45	8.8	11.8	7.57
	48	negligible	0	39	8.5	11.5	7.56
	72	negligible	0	26	8.7	11.4	7.42
	96	negligible	0	25	8.0	11.2	7.59
10	0	1.7	2333	580	8.9	11.8	7.68
	24	negligible	400	560	8.6	11.3	7.60
	48	negligible	200	360	8.5	10.9	7.63
	72	negligible	0	260	8.7	10.5	7.56
	96	negligible	0	220	7.5	9.8	7.53
20	0	2.0	2000	1400	8.9	11.5	7.69
	24	negligible	750	660	8.6	10.6	7.71
	48	negligible	250	516	8.5	10.0	7.55
	72	negligible	0	430	8.7	10.0	7.52
	96	negligible	0	340	7.5	8.8	7.56
30	0	3.5	4000	1800	8.9	11.2	7.68
	24	negligible	1000	1100	8.6	10.4	7.66
	48	negligible	500	840	8.5	9.5	7.55
	72	negligible	0	580	8.7	9.1	7.49
	96	negligible	0	440	7.5	8.2	7.50
40	0	3.7	4500	3000	8.9	11.0	7.71
	24	negligible	2000	1000	9.0	10.0	7.66
	48	negligible	1333	1000	8.5	9.4	7.64
	72	negligible	500	590	8.7	9.1	7.50
	96	negligible	500	430	7.5	7.4	7.51
50	0	3.6	5000	2700	8.9	11.0	7.72
	24	negligible	1000	990	9.0	10.0	7.64
	48	negligible	667	960	8.5	9.2	7.71
	72	negligible	0	590	8.7	9.0	7.58
	96	negligible	0	440	8.0	8.4	7.53
60	0	5.2	8500	3900	8.9	10.7	7.72
	24	negligible	1143	910	8.8	9.5	7.70
	48	negligible	500	832	8.5	9.2	7.70
	72	negligible	0	480	8.7	8.6	7.59
	96	negligible	500	340	7.5	7.9	7.62

[1] TNFR = Total nonfilterable residue.
[2] JTU = Jackson Turbidity Units.

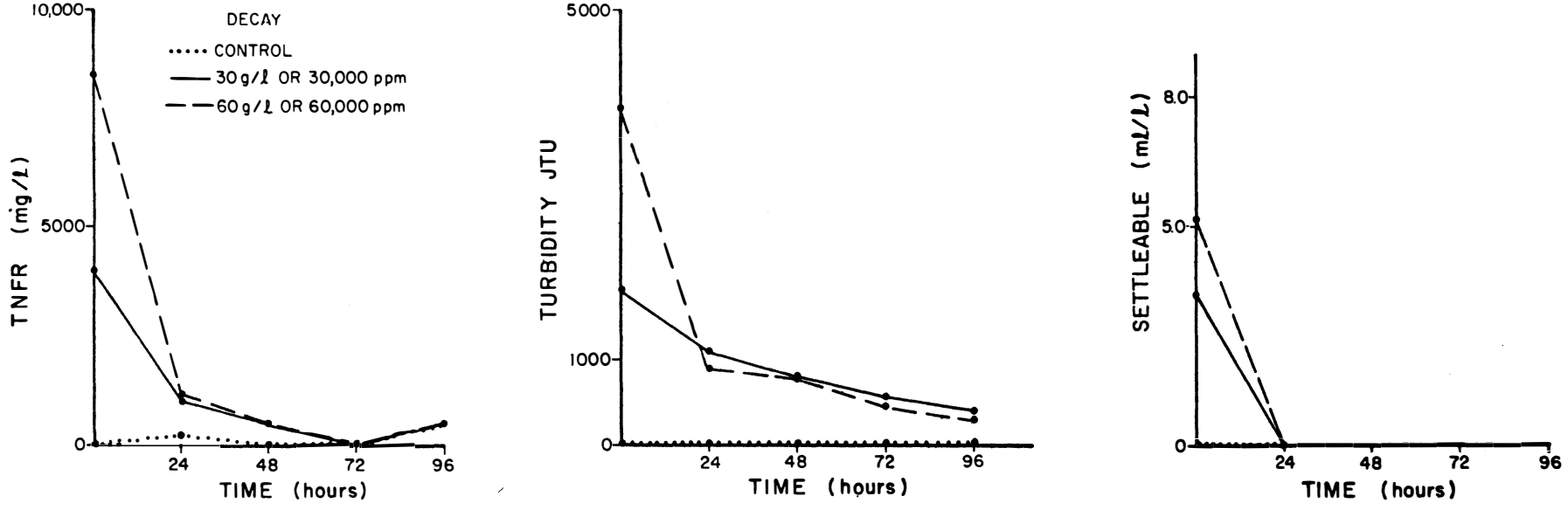

Figure 3.--Total nonfilterable residue (TNFR) (mg/liter), settleable (ml/liter) and turbidity, Jackson Turbidity Units (JTU) for decay experiment.

examination of Figure 4 shows the dramatic drop in the oxygen levels in the bioassay as compared to the decay experiment as well as the drop in pH associated with the fish.

Lengths and weights of fish used in the experiments are given in Table 6. It is apparent from the bioassay data presented that coho fingerlings can survive high concentrations (up to 110,000 ppm) of the Lake Washington sediment for extended periods (up to 192 h) with out sustaining direct losses in excess of 50%. The long-term effects of such exposure are not known.

Table 6. Length and weight of coho salmon fingerlings used in bioassay experiments

Tank size and type of water	Fish length (mm)		Fish weight (g)	
	Ave.	Range	Ave.	Range
60 liter Lake water	96.4	8.1-11.3	9.2	4.3-14.3
60 liter Dechlorinated water	95.5	8.0-10.9	8.9	5.2-16.6
30 liter Dechlorinated water	94.0	8.6-11.4	9.0	5.5-14.6

Discussion

The most surprising aspect of the bioassays reported here was the high survival of coho salmon fingerlings subjected to extremely high concentrations of the Lake Washington sediment for relatively long periods. Work reported by Smith et al.[1/] to determine the tolerance of juvenile chum salmon, O. nerka, to the direct effects of suspended solids dredged from Hood Canal, Washington, established a 96 h LC_{50} in sediment at 55 g/liter. Working in freshwater Noggle (1977)[4/] determined LC_{50}'s for coho salmon ranging in sediment concentrations from 1.2 to 35 g/liter depending on the season of the year, the size of the fish, and the temperature. The greatest

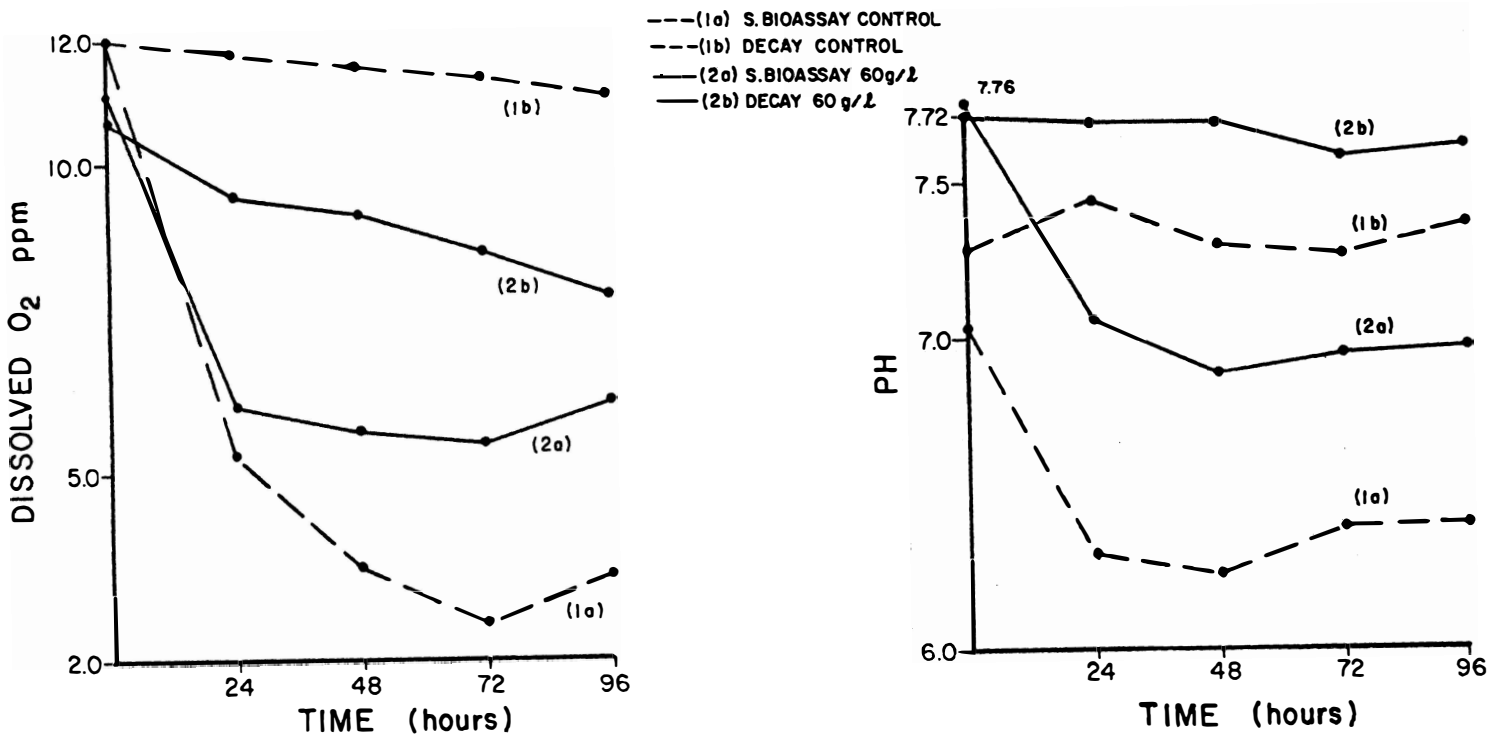

Figure 4.--Comparison of dissolved oxygen (ppm) and pH in decay and static bioassay 30 liter.

tolerance observed by Noggle was at the lowest temperature (8°C) which was in the same range as our tests. Pattern (1976)[5/] tested coho salmon fingerlings in Lake Washington sediment and found no mortality at concentrations up to 37,000 ppm after 96 h at 16.6°C. A review by Cordone and Kelley (1961) covers a study by Wallen (1951) on the tolerance of warm water fish to high turbidity caused by silt and montmorillonite clay. Wallen stated that most individuals of all species tested endured exposures to more than 100,000 ppm for a week or longer, but these same fish finally died at turbidities of 175,000 to 225,000 ppm. Apparently the ability of different species of fish to withstand high turbidities is not rare.

Salmon fingerlings, especially chinook and coho that spend extended periods of their juvenile existence in small freshwater streams, may be well adapted to resist the high turbidities associated with freshets and flooding.

Wallen (1951) attributed survival of fish in turbid water to the ability to prevent clogging of the gills and he thought maintenance of movement and aeration of the water were important factors in this ability. Conditions provided in our 60 liter bioassays may have been advantageous for survival, but the high concentrations tolerated also indicate the comparatively innocuous character of the Lake Washington sediment as far as direct effects of coho salmon fingerlings are concerned. We have no knowledge of the long-term effect these exposures might have on the individual fish. However, it has been well established that prolonged sedimentation

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5/ B.G. Patten, 1976. Bioassay of selected Lake Washington fish and arthropods in a high sediment suspension. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, Wash. 98112. Proc. Rep.

is harmful to aquatic life in general by reducing productivity (Cordone and Kelley 1961).

Salmon fingerlings encountering high turbidities in a lake would probably try to avoid them unless trapped in some manner. Studies by Patten (1976)[5/] demonstrated that given a choice, coho salmon fingerlings would choose clear over turbid water. Therefore salmon encountering turbidity in Lake Washington probably would not be exposed for periods approaching the length of our exposures (8 d).

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