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Title: EFFECTS OF BIOLOGICALLY STABILIZED KRAFT MILL EFFLUENTS ON JUVENILE SALMONID GROWTH

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The effects of sublethal concentrations of stabilized kraft mill effluents (SKME) on the growth and food consumption of juvenile chinook and coho salmon held in aquaria and exercise channels were studied during 1967 and 1968.

SKME from two mills was used in these studies. KME from Mill A was collected raw and stabilized at the laboratory, and SKME from Mill B was collected already treated from a stabilization pond at the mill. Stabilization of Mill A waste at the laboratory was accomplished by dispersed-floc aeration. Nitrogen and phosphorus were added to promote bacterial growth.

Acute toxicity bioassays of SKME were performed periodically and no 96-hour median tolerance limit (TL_m) was found for salmon as more than 50 percent of the test fish survived in 100 percent SKME.

In aquarium experiments water and wastes were continuously introduced into 16 experimental chambers by a system of head boxes and siphons. In each experiment the growth and food consumption rates of fish held in 1.5, 3.0 and 4.5 percent SKME and in control water were calculated at three or four feeding levels. The growth rates of salmon held in effluent from Mill A were reduced at concentrations as low as 1.5 percent by volume when compared to controls. When salmon received unlimited food they had higher food consumption rates in all concentrations of SKME tested, but the total food consumption of salmon exposed to SKME was higher than control fish in only one experiment. A decrease in the efficiency of food utilization for growth was related to the reduction of growth rates of salmon exposed to SKME. There was no effect upon the growth or food consumption of fish in aquaria which could be attributed to SKME from Mill B.

In exercise channel experiments fish were forced to swim constantly, while exposed to SKME up to 4.5 percent by volume. No effect on the growth and food consumption rates of the fish could be attributed to Mill A SKME at any concentrations tested. The growth rates of fish held in 1.5 and 3.0 percent effluent concentrations from Mill B were slightly higher than those of control fish.

Effects of Biologically Stabilized Kraft Mill Effluents on Juvenile Salmonid Growth

by

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EFFECTS OF BIOLOGICALLY STABILIZED KRAFT MILL EFFLUENTS ON JUVENILE SALMONID GROWTH

INTRODUCTION

The abundant timber in the Pacific Northwest has made it possible for the kraft pulp and paper industry to develop into one of the most economically important industries in this area. Untreated effluents from this industry may be acutely toxic to fish and other aquatic organisms. Although biological treatment can reduce the acute toxicity and biochemical oxygen demand (BOD) of kraft mill effluents (Servizi et al., 1966; Seim, 1970), treated wastes may continue to have sublethal chronic effects on the aquatic community.

Fujiya (1961) performed pathological studies of the fish Sparus macrocephalus that had been exposed to untreated kraft mill effluent (KME) for 12 to 24 hours. The liver, kidney, pancreas and intestine of fish exposed to rather high concentrations of KME were affected. Exposure of fish to KME concentrations from 10 to 50 mg/l chemical oxygen demand (COD) resulted in reduced levels of glycogen in hepatic tissue, reduction of RNA in the pancreas, degeneration of polysaccharides in the kidney, and acceleration of enzyme secretion in the intestine.

The Washington State Department of Fisheries (1960) found that several species of Pacific salmon survived 30 days of exposure

to 6.5 percent solutions of bleach process KME, but growth of these fish was reduced from control levels by concentrations as low as 0.6 percent. Servizi, Stone and Gordon (1966) found that some concentrations of neutralized bleach process KME reduced the growth of alevins of two species of salmon. Growth of pink salmon (Oncorhynchus gorbuscha) and sockeye salmon (Oncorhynchus nerka) alevins was reduced 22 percent and 7 percent, respectively, on exposure to 10 and 20 percent of the 96-hour median tolerance limit (TL_m) for sockeye fingerlings.

Ellis (1967) found that juvenile chinook salmon (Oncorhynchus tshawyscha) growth rates were reduced in laboratory streams receiving untreated KME at 1.5 percent by volume (14 to 36 percent of the 96 hour TL_m). There was no reduction in growth of salmon at a concentration of 0.5 percent by volume. Ellis estimated food consumption to be as great in streams receiving KME as in the control streams and concluded that reduction in growth rate was probably due to a direct toxic effect of the waste.

Tokar (1968) studied the effects of untreated KME on growth of juvenile chinook salmon fed different rations in aquaria. Growth rates of salmon exposed to effluent concentrations above 0.3 percent by volume (2 to 4 percent of the 96 hour TL_m) were less than growth rates of control salmon at unrestricted and high restricted food rations. Tokar found no measurable difference between growth of

salmon exposed to stabilized and unstabilized KME.

Seim (1970) found production (growth rate × biomass) of chinook salmon to be less in laboratory streams receiving 1.5 percent by volume stabilized KME (SKME) than in control streams during spring and fall experiments. This difference was attributed to a direct effect of the SKME on salmon growth, since no reduction in the abundance of food organisms or in the basic capacity of the streams to produce suitable salmon food organisms could be demonstrated. Seim also found salmon production to be greater in streams receiving concentrations of SKME up to four percent by volume than in control streams during summer months. Salmon production was greatest at a concentration of 1.0 percent and somewhat less at concentrations of 2.0 and 4.0 percent. Seim believed that the increase in production may have been due to an increase in the density of the major food organism, the amphipod Crangonyx sp. Williams (1969) also studied the effects of SKME on laboratory stream communities. He found that primary production was greater in streams receiving SKME than in streams receiving no waste. Accumulation of the organic material in treated streams was less than in control streams, and the species composition of the algal community was altered.

The objective of experiments reported in this thesis was to determine any effects stabilized kraft mill effluent might have on the growth of juvenile chinook and coho salmon fed different rations

in aquaria and exercise channels. These experiments were performed at the Pacific Cooperative Water Pollution Laboratories from October 1967 through September 1968. Effluents from two western Oregon kraft mills (non-bleaching) were tested.

EXPERIMENTAL MATERIALS, APPARATUS, AND PROCEDURES

Experimental Materials

Chinook salmon, Oncorhynchus tshawytscha (Walbaum), and coho salmon, Oncorhynchus kisutch (Walbaum), were chosen for use in these experiments because of their importance in the Pacific Northwest. Juvenile chinook salmon used in experiment A-3 were from the Eagle Creek National Fish Hatchery located near Estacada, Oregon; those used in experiments A-1, A-2 and A-4 were reared at the Oak Creek Laboratory from eggs of spring run chinook from Santiam River. Juvenile coho salmon seined from the Yaquina river near Nashville, Oregon, were used in experiments B-1 and B-2.

House fly larvae were fed to salmon in Experiment A-3. Salmon in other experiments were fed tubificid worms (Tubifex sp.).

Kraft mill effluent used in experiments A-1, A-2, A-3 and A-4 was collected each week from the settling lagoon at Mill A and transported to Oak Creek Laboratory. Here, the effluent was biologically stabilized in an 800-gallon redwood tank. Stabilization of the waste was accomplished by dispersed-floc aeration. Phosphate was added at a ratio of 1 part to 100 parts of oxygen required to satisfy the 5-day biochemical oxygen demand (BOD) of the waste, and nitrogen at a rate of 1 part to 20 parts BOD (Helmers and Frame, 1952). After one

week of treatment the floc was permitted to settle and the treated waste was then pumped into two 350-gallon storage tanks. Each batch of effluent was analyzed to determine the degree of treatment (Table 1).

Table 1. Five day biochemical oxygen demand and chemical oxygen demand of mill effluent in mg/liter before and after stabilization.

Expt. used	Date collected	Before treatment BOD	Before treatment COD	After treatment BOD	After treatment COD	Mill
A-3	Oct. 18, 1967	201	412	5	--	A
	Oct. 25	252	442	3	78	A
	Nov. 1	214	436	3	70	A
A-1	Feb. 8, 1968	195	265	24	184	A
	Feb. 15	256	575	14	158	A
	Feb. 22	279	632	24	200	A
	Feb. 29	214	440	8	180	A
	March 8	200	424	8	164	A
A-2, 4	April 18	279	719	90	365	A
	April 26	245	674	7	195	A
B-1, 2	August 29			--	--	B
	Sept. 5			19	220	B
	Sept. 12			26	116	B

Experimental Apparatus

Two types of experiments were conducted to determine any effects of stabilized kraft mill effluents on the growth of the fish. In experiments A-1, A-2 and B-1 the fish were held in aquaria. The dilution apparatus used in these experiments was described in detail by Tokar (1968). This apparatus (Figure 1) consisted of a series of head boxes and siphon tubes, which mixed clean water with SKME to produce the desired test concentrations.

In experiments A-3, A-4 and B-2 fish were held in forced exercise channels. These were constructed from 6-inch diameter aluminum tubing that was cut lengthwise and welded together to form continuous channels (Figure 2). Motor driven paddle wheels near the end of each channel were used to circulate the water. Eight compartments were formed in each channel by stainless steel screens. A single fish was held in each compartment. Plexiglas covers over the channels prevented fish from jumping out of their compartments.

Five-gallon constant-head bottles above the channels delivered a constant flow of SKME into the channels through adjustable siphons. The bottles were filled with treated wastes from the 350-gallon storage tanks.

Filtered creek water entered the channels through polyethylene tubing from a constant-head box equipped with an aerator and

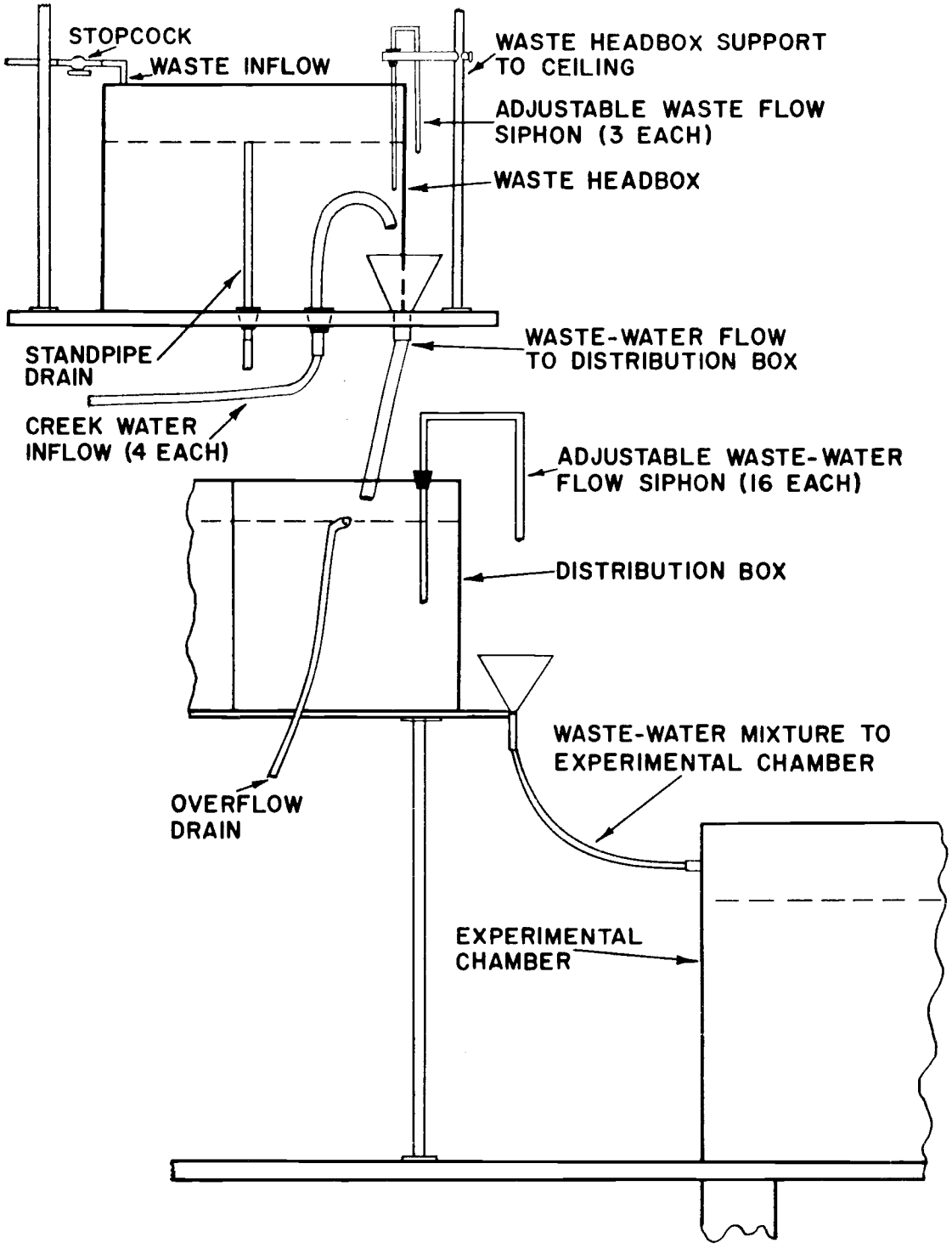

Figure 1. Diagram of the apparatus used in aquarium experiments.

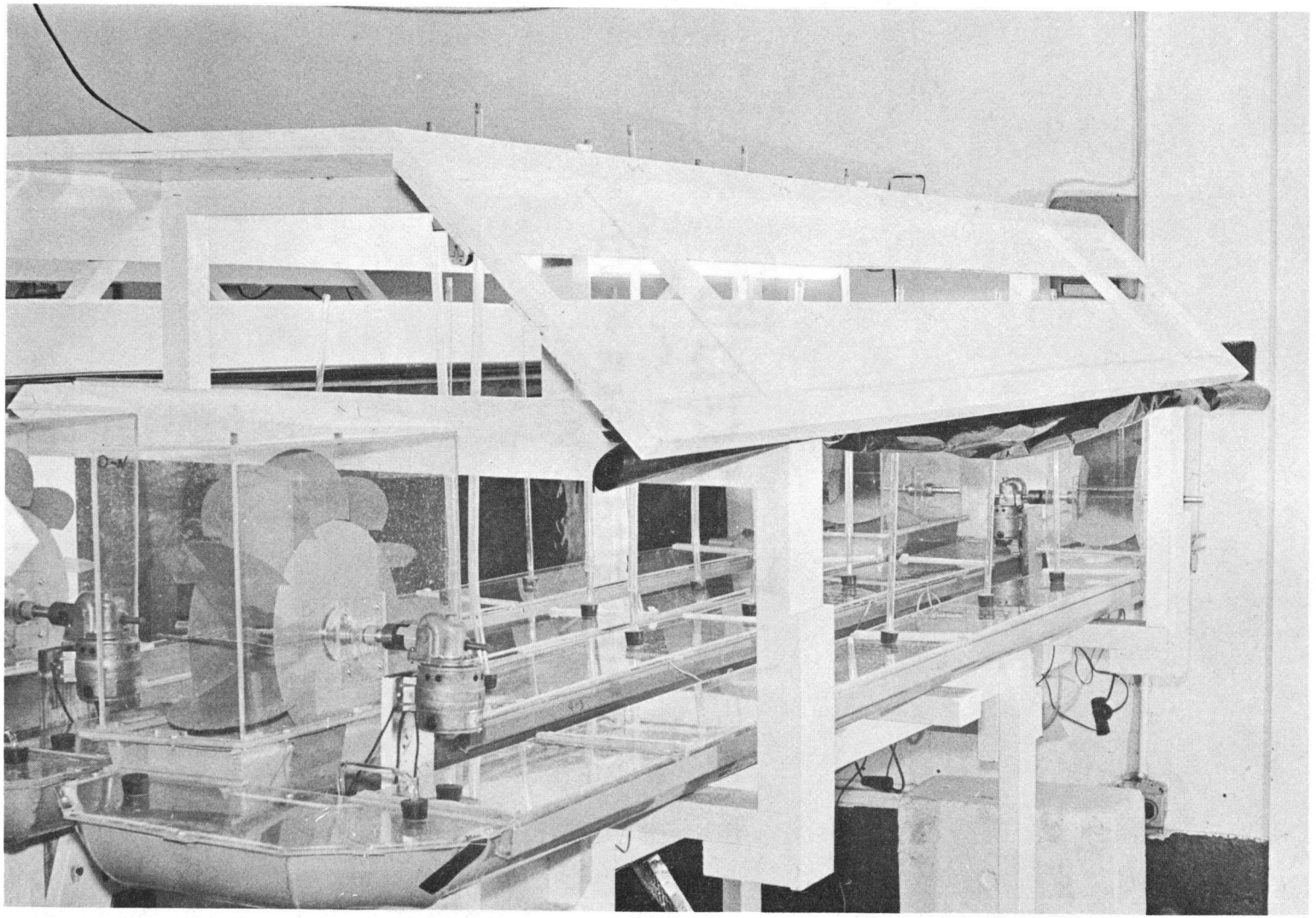

Figure 2. Photograph of the experimental apparatus used in exercise channel experiments.

thermostatically controlled heater. Water flow to the channels was controlled by adjustable siphons. Flourescent lights mounted three feet above the aquaria and channels provided continuous illumination during all experiments.

Experimental Procedures

Acute toxicity bioassays were preformed on each batch of SKME, according to methods recommended by Doudoroff et al. (1951). Ten young chinook or coho salmon were placed in various dilutions of SKME in cardboard ice cream cartons lined with disposable polyethylene bags. Pure oxygen was bubbled through the water in each container to maintain the dissolved oxygen concentration at approximately the air saturation level. Each bioassay was performed at the same temperature as the concurrent growth experiment.

All fish to be used in experiments were first acclimated to food, water, temperature, and lighting conditions in the laboratory for at least one week. Salmon used in aquarium studies were sorted into groups of ten individuals. The fish for each experiment were selected for uniformity of body weight. Differences in the total wet weights of fish between groups were 0.5 grams or less within any experiment. Before weighing, the fish were anesthetized in tricane methanesulfonate (MS-222) and blotted on moist cheesecloth. One group of fish was placed in each experimental chamber. Sixteen

groups of fish were used in Experiment A-1 and 12 groups were used in experiments A-2 and B-1.

Two groups of fish were killed in MS-222 and placed in a drying oven for five days at 80°C to determine initial dry weights for each experiment. The initial dry weight of the salmon actually used in the experiments was estimated by multiplying the initial wet weight of each of the experimental groups of fish by the ratio of the dry weight to wet weight obtained for groups of fish initially killed. At the end of each experiment both wet and dry weights were determined.

Growth rates were computed by dividing the dry weight gained in milligrams by the arithmetic mean of the initial and final dry weights of the fish in grams, this quotient then being divided by the experimental period in days.

Fish used in the exercise channel experiments were handled in the manner as those used in the aquarium studies, except individual weights were obtained and a single fish was placed in each compartment. In experiment A-3, 32 fish were used; in A-4, 48 fish; and in B-2, 45 fish.

Three general feeding levels were maintained throughout each aquarium experiment. At the highest ration level, food was available to the salmon at all times. Intermediate and low rations were based on 50 percent and 25 percent of the amounts of food consumed by salmon at the highest ration. In experiment A-1, the change in

weight of the experimental groups of fish that received no food was measured. An additional low ration was fed to an experimental group of salmon in experiment A-2. This ration was ten percent of the highest ration.

Ration levels fed to salmon held in exercise channels in experiments A-3, A-4, and B-2 were based on the maximum amounts of food that salmon at the highest ration level would consume once each day. Lower rations were fixed in the manner described for the aquarium experiments.

The salmon were fed daily and care was taken to spread the food evenly throughout each test chamber. In all experiments, uneaten food organisms were periodically removed from the experimental compartments. All food was removed from the chambers at least 24 hours before each experiment was terminated.

Fly larvae and tubificid worms fed to salmon during the experiments were weighed on an analytical balance that was accurate to 0.005 grams. Excess moisture was removed from tubificid worms with paper towels before weighing. Samples of worms and fly larvae were taken each day to determine dry body weights. These determinations permitted estimates to be made of the dry amounts of food consumed by experimental fish.

Salmon food consumption rates were computed by dividing the dry weight of the food consumed in milligrams by the mean of the

estimated initial and final dry weight of the fish in grams, this quotient then being divided by the number of days in the experiment.

Effluent concentrations used in the experiments were 4.5, 3.0, 1.5, and 0.0 (control) percent effluent by volume. The 4.5 percent level was not used in experiment B-2. Exchange water in all aquaria and exercise channels was maintained at 100 ml/minute (Table 2). Flows of SKME and water into the experimental apparatus were measured daily and adjusted as necessary. The velocity of the water in the exercise channels was kept at 0.45 feet per second for experiment A-3 and 0.3 feet per second for experiments A-4 and B-2. The current velocity was measured with a microcurrent meter.

In all experiments except A-1 and A-3, water temperature was held constant at 15°C by a thermostatically controlled heater installed in the head box. In experiments A-1 and A-3 the temperature fluctuated with the ambient temperature of the water supply. Laboratory room temperature was maintained at 15°C during all aquarium and exercise channel experiments.

Table 2. Dates and experimental conditions for aquarium and exercise channel experiments.

Experimental apparatus	Experiment number	Dates	SKME source (mill)	Temperature (°C)	Flow rate (ml/min per chamber or channel)	Salmon species	Fish per treatment*	Days fed
Aquaria	A-1	February 13 - March 15, 1968	A	6-10	100	Chinook	10	30
Aquaria	A-2	April 27 - May 14, 1968	A	15	100	Chinook	10	15
Aquaria	B-1	September 5 - Sept. 22, 1968	B	15	100	Coho	10	15
Channel	A-3	October 21 - November 6, 1967	A	12-15	100	Chinook	2	15
Channel	A-4	April 26 - May 13, 1968	A	15	100	Chinook	4	15
Channel	B-2	September 6 - Sept. 22, 1968	B	15	100	Coho	5	15

*A treatment is a particular effluent concentration and ration to which the fish were exposed.

RESULTS AND INTERPRETATION

The acute toxicity to salmon of each batch of SKME was tested. The effluents had little or no acute toxicity and more than 50 percent of the test salmon always survived in 100 percent SKME for 96 hours.

All growth and food consumption results are reported in terms of dry weights of salmon or food and are expressed as milligrams of weight change or food consumed per gram mean weight of fish, per day (mg/g per day). Growth rates have been plotted against food consumption rates for easier interpretation. No data are plotted for groups in which three or more fish died during an experiment.

Aquarium Experiments

Experiments A-1 and A-2 were designed to test the effects of SKME from Mill A on growth and food consumption rates of juvenile salmon held in aquaria. In experiment A-1 (Figure 3) the growth rate of juvenile chinook salmon at the 1.5 percent effluent concentration approximated the growth rate of the control fish at all food consumption rates. Salmon growth rate at an effluent concentration of 3.0 percent was less than at 1.5 percent and 0.0 percent for all feeding levels except the highest. At the highest food consumption rate, growth rate of the salmon in 3.0 percent effluent approached the growth rate of the control fish. The fish held in 4.5 percent effl

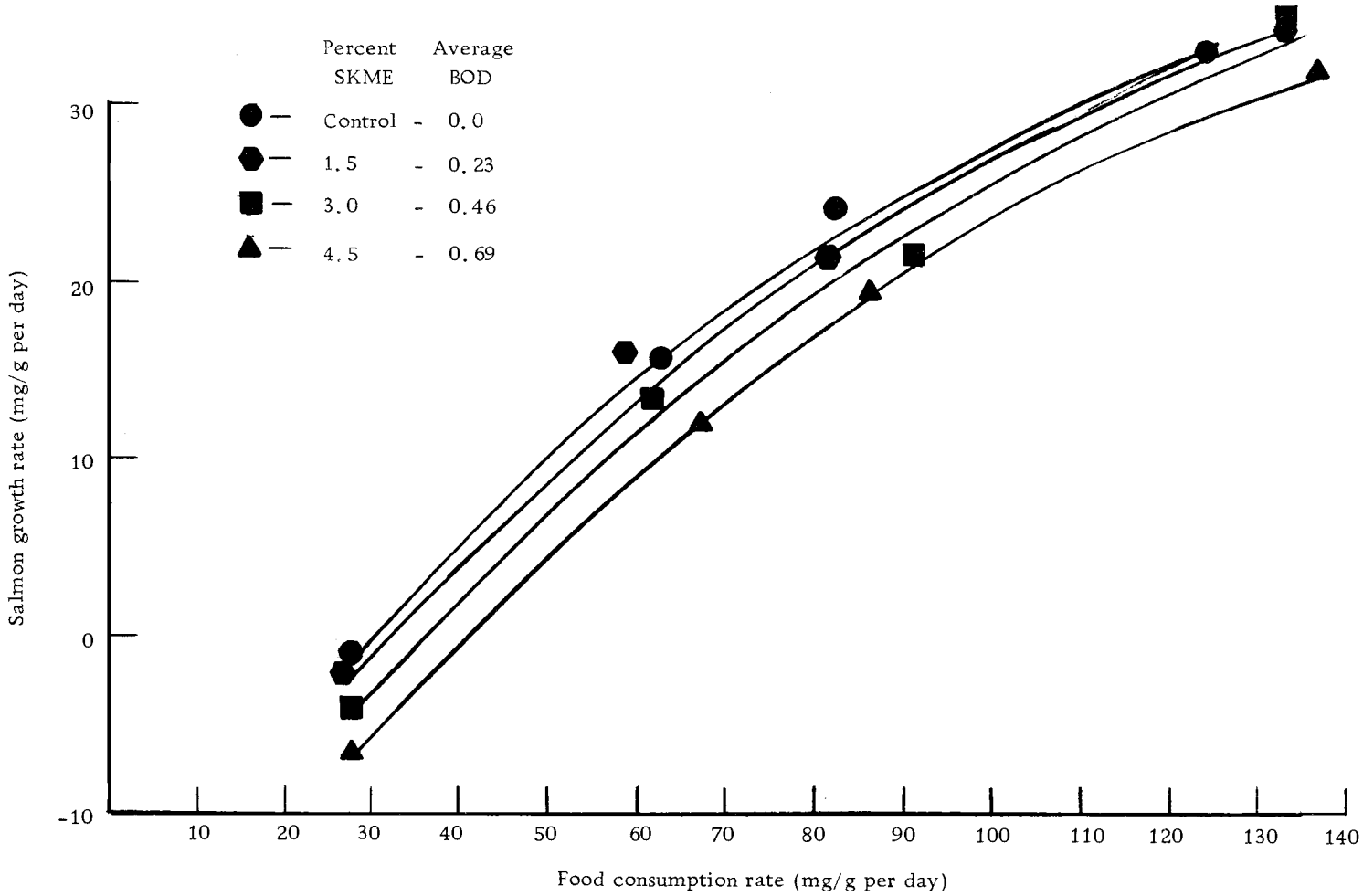

Figure 3. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in aquaria during experiment A-1 and exposed to three concentrations of SKME from Mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD.

had lower growth rates at all feeding levels than the fish in the other treatments.

In experiment A-2 (Figure 4), control fish had higher growth rates at all food consumption levels than fish exposed to SKME. Consistent with the results of experiment A-1, the greatest reduction in the growth rate was at the 4.5 percent effluent level. At 1.5 and 3.0 percent effluent fish grew at about the same rate and showed less growth at all feeding levels than the control fish. The effect of SKME on the growth of salmon in experiment A-2 was most evident at the highest feeding level.

From the results of experiments A-2 and A-1, it is apparent that SKME from Mill A has a depressing effect upon the growth rate of juvenile salmon held in aquaria at concentrations higher than 1.5 percent. This effect is directly related to concentration, higher effluent concentrations causing the greatest reduction in growth rate. Exposure to 1.5 percent effluent resulted in no apparent effect on the growth of salmon in experiment A-1, but no appreciable reduction in growth at this concentration occurred in experiment A-2.

Experiment B-1 (Figure 5) was designed to show the effects of SKME from Mill B on food utilization for growth by fish held in aquaria at different effluent concentrations. Growth rates of fish in this experiment exhibited no differences clearly attributable to SKME. Points representing the growth rates of fish held at SKME

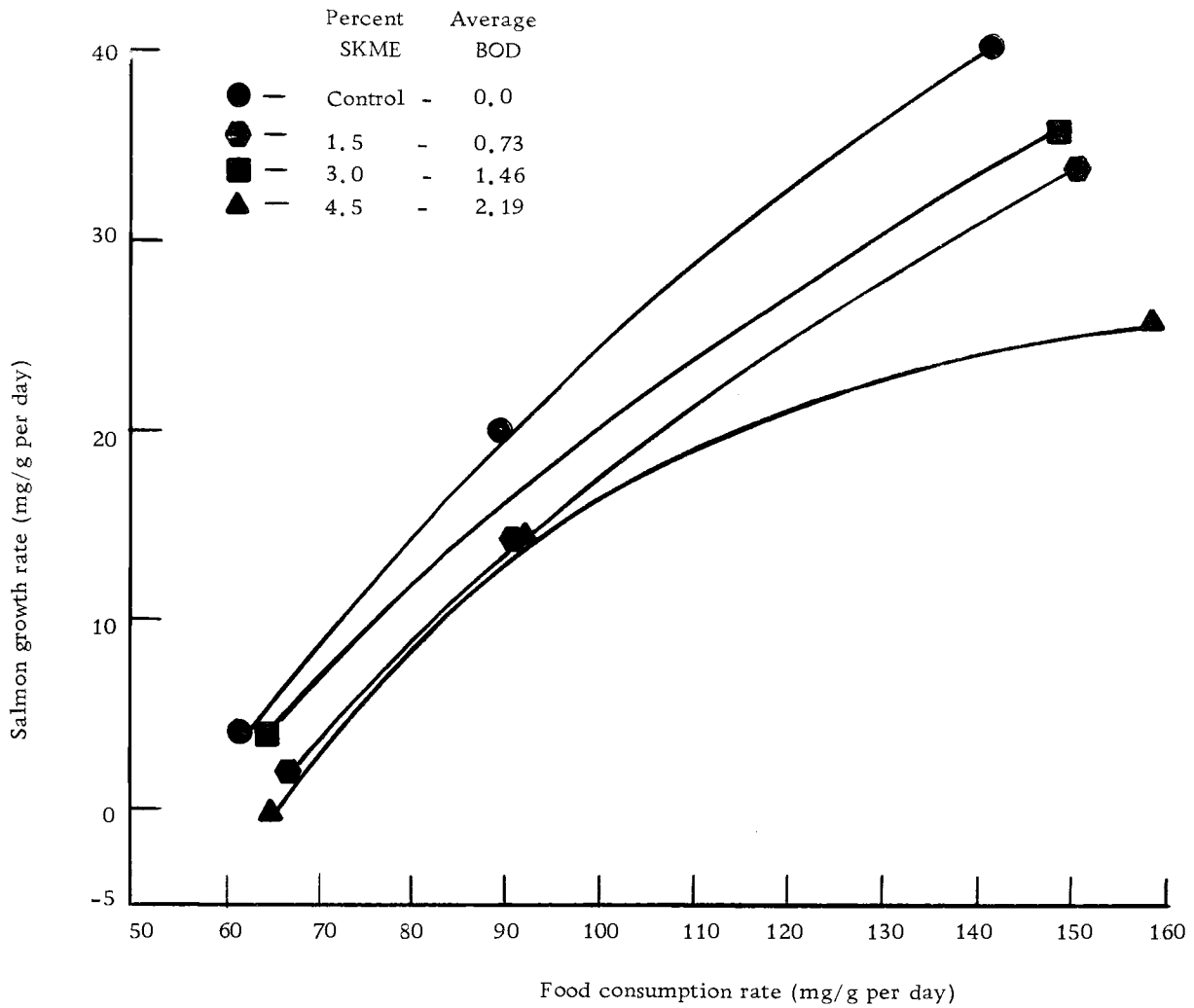

Figure 4. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in aquaria during experiment A-2 and exposed to three concentrations of SKME from Mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD.

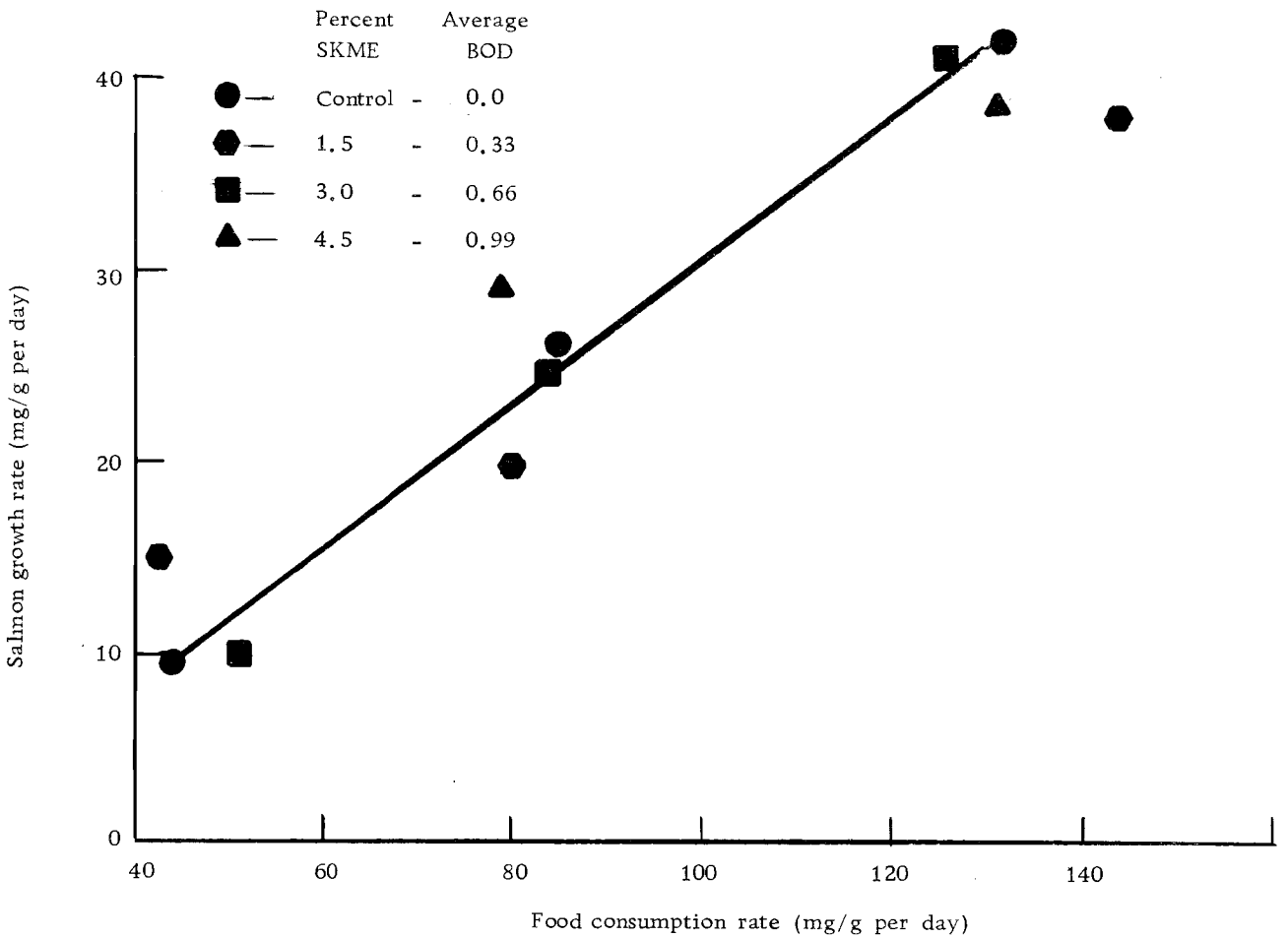

Figure 5. The relationship between growth rates and food consumption rates of juvenile coho salmon held in aquaria during experiment B-1 and exposed to three concentrations of SKME from Mill B. Effluent concentrations are expressed in percent by volume and mg/l BOD.

concentrations of 1.5, 3.0 and 4.5 percent are distributed on both sides of a line drawn through points representing growth rates of control fish. From results obtained by these methods, it appears that SKME from Mill B has no measurable direct affect on food utilization for growth by fish at effluent concentrations as high as 4.5 percent in aquaria.

In experiment A-1, both food consumption rate and total food consumed was higher for fish at all effluent concentrations than for fish held in control water, so long as food was not limited (Figure 3 and Appendix Table 1). In experiment A-2, all groups of fish held in control and SKME concentrations consumed nearly the same total amount of food, but fish exposed to SKME had a lower mean weight indicating a lower food conversion efficiency for growth in these fish.

Differences in food consumption rates of fish in experiment B-1 did not appear to be attributable to SKME (Figure 5).

That portion of assimilated food that can be used for growth depends on the energetic costs of food transformation, standard metabolism, and activity (Warren and Davis, 1967). Kraft mill effluents, or any pollutant, could affect growth either by direct toxic action on the fish which can decrease the efficiency of food conversion for growth or by an indirect effect through changes in the availability of their food organisms. Since the food consumption of control fish and fish exposed to SKME was nearly equal, any differences in

growth rates at each feeding level would also cause differences in the efficiency of food conversion for growth.

Table 2 shows the efficiency of food conversion for growth for each group of fish at the high and medium rations in all experiments. Percentages of food conversion for growth were computed by dividing the total food consumed in milligrams by the total growth of fish in milligrams and multiplying this quotient by 100. The conversion ratios for the low and starvation rations were not computed, because these fish generally lost weight.

The efficiency of food conversion for growth at medium and high feeding levels was directly related to the SKME concentration in experiments A-1 and A-2. In experiment B-1, the control fish had a slightly higher efficiency of food conversion for growth, but no other pattern was evident.

From these data I have concluded that SKME from Mill A reduces the growth of salmon held in aquaria causing a decrease in the efficiency of food conversion for growth. These effects were not evident in fish exposed to Mill B effluent in aquaria.

Exercise Channel Experiments

Experiments A-3, A-4 and B-2 were designed to show the effects of SKME from Mill A and Mill B on the growth and food consumption rates of fish forced to swim in exercise channels. In

Table 3. Efficiency of food conversion for growth expressed as percent.

Aquarium experiments				Channel experiments			
Expt. no.	Percent effluent concentration	Feeding level	Percent food conversion	Expt. no.	Percent effluent concentration	Feeding level	Percent food conversion
A-1	0.0	High	26.6	A-3	0.0	High	30.1
		Med.	29.3			Med.	39.6
	1.5	High	25.8		1.5	High	29.0
		Med.	26.4			Med.	42.5
	3.0	High	23.5		3.0	High	34.1
		Med.	22.4			Med.	38.0
	4.5	High	22.7		4.5	High	36.5
		Med.	23.4			Med.	31.5
A-2	0.0	High	29.4	A-4	0.0	High	17.4
		Med.	22.1			Med.	17.0
	1.5	High	23.6		1.5	High	13.2
		Med.	15.7			Med.	24.7
	3.0	High	24.3		3.0	High	16.6
		Med.	--			Med.	22.5
	4.5	High	16.1		4.5	High	14.5
		Med.	16.1			Med.	23.2
B-1	0.0	High	31.8	B-2	0.0	High	17.1
		Med.	30.8			Med.	22.3
	1.5	High	26.4		1.5	High	18.7
		Med.	23.3			Med.	24.4
	3.0	High	32.3		3.0	High	18.4
		Med.	28.5			Med.	24.7
	4.5	High	29.4				
		Med.	26.6				

experiments A-3 and A-4 SKME from Mill A was used. No difference in growth rates or food consumption rates between fish held in control water and those exposed to SKME could be attributed to the effects of SKME (Figure 6 and 7). In experiment A-3 at the high feeding level, the food consumption rate of fish held in control water was less than for any of the fish held in SKME, but in experiment A-4 the consumption rate of fish held in control water was higher than that of fish held in SKME.

In experiment B-2 (Figure 8) the 4.5 percent effluent concentration was not used so that more fish could be tested at the lower effluent concentrations. In this experiment fish exercised in control water had a slightly lower growth rate than fish exposed to SKME from Mill B at all feeding levels. There was no apparent effect by SKME on the food consumption rate of these fish. Tokar (1968) also found the growth of fish in aquaria was increased in Mill B effluent concentrations of 0.5 and 1.5 percent.

Stabilized KME from both Mills A and B at the concentrations tested appears to have no discernible effect upon the efficiency of food conversion for growth or growth rates of fish forced to exercise.

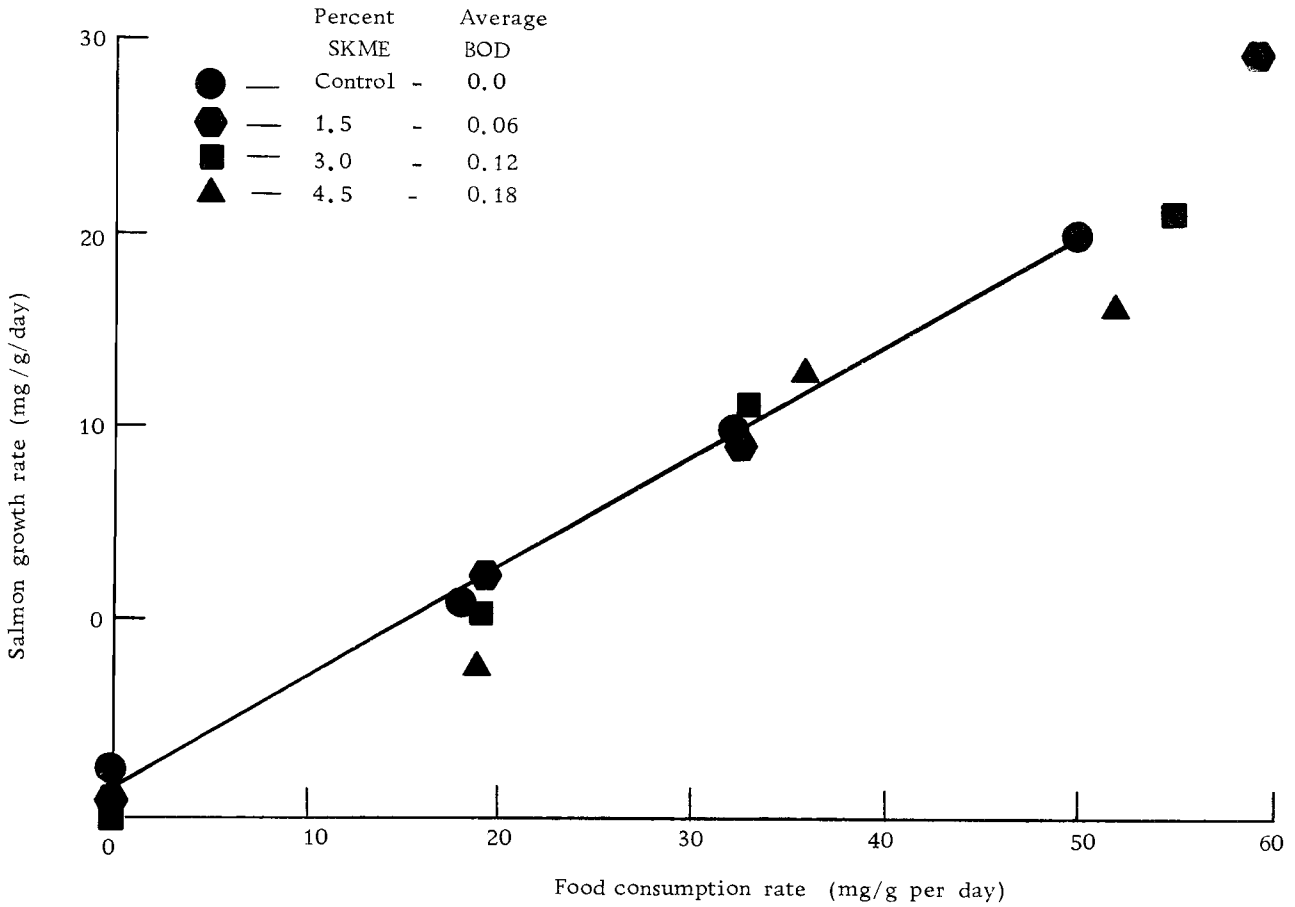

Figure 6. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels during experiment A-3 and exposed to three concentrations of SKME from Mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD.

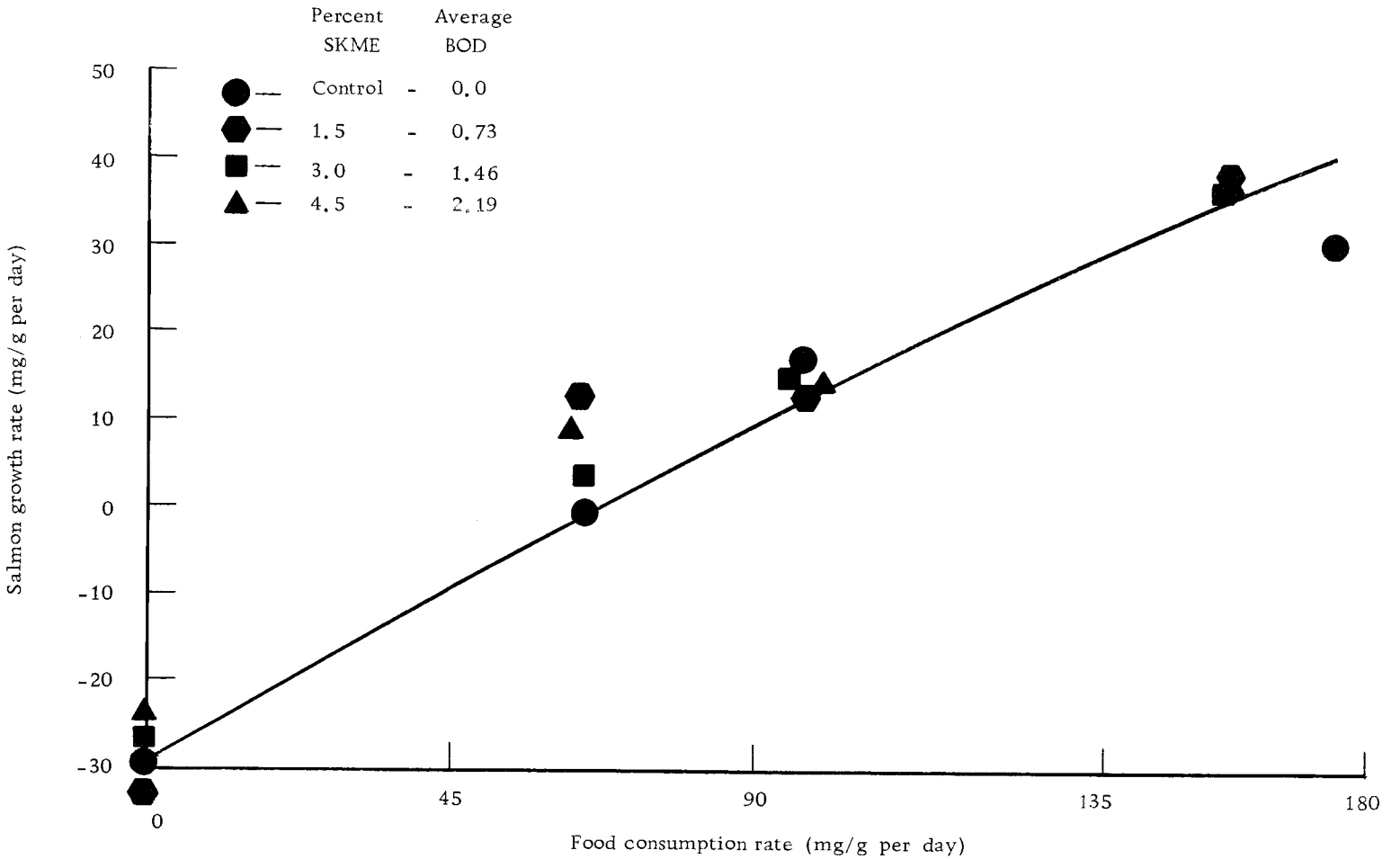

Figure 7. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels during experiment A-4 and exposed to three concentrations of SKME from Mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD.

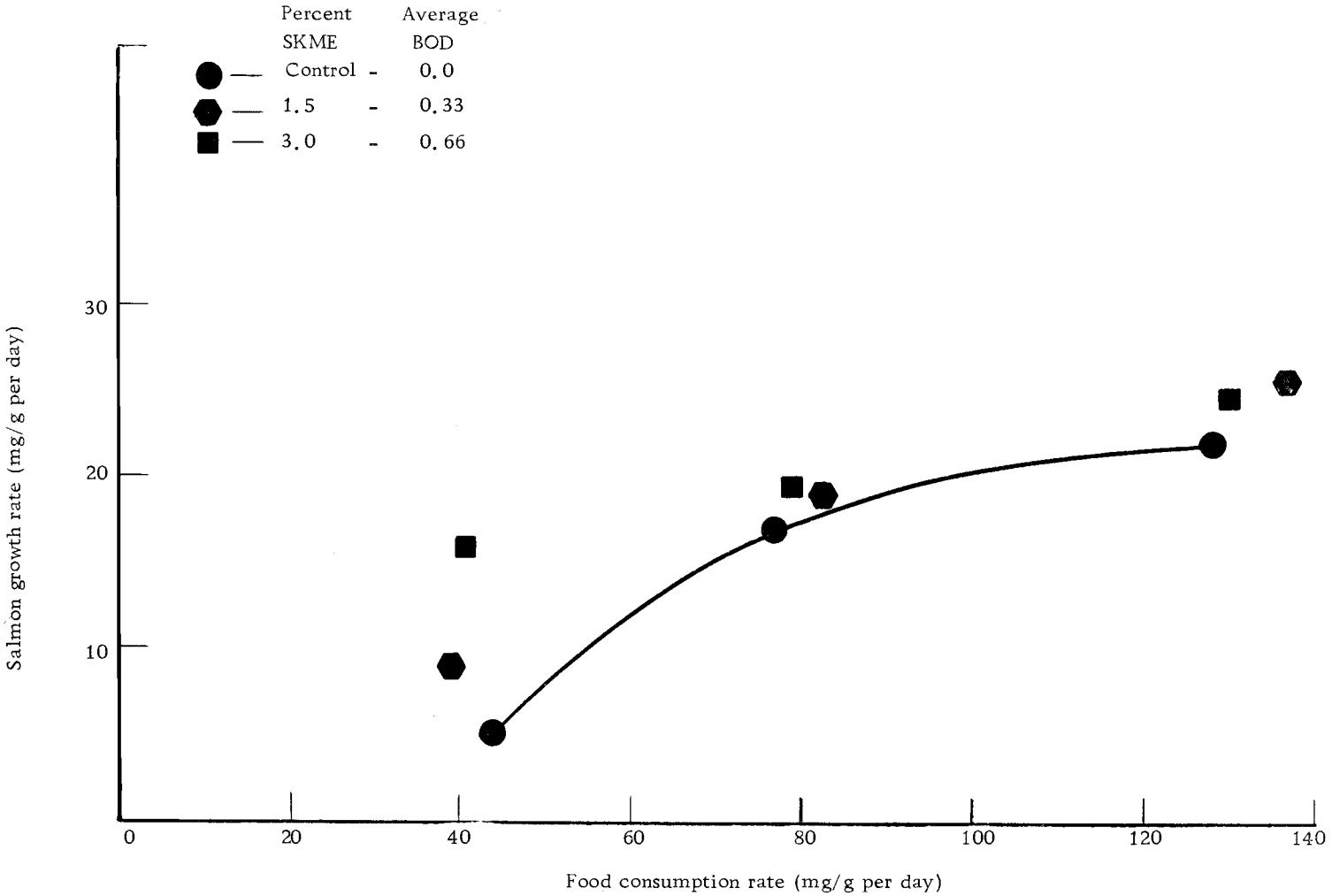

Figure 8. The relationship between growth rates and food consumption rates of juvenile coho salmon held in exercise channels during experiment B-2 and exposed to two concentrations of SKME from Mill B. Effluent concentrations are expressed in percent by volume and mg/l BOD.

DISCUSSION

Kraft mill effluents from Mills A and B that had been stabilized were not acutely toxic to juvenile salmon in static bioassays when fish were placed in 100 percent effluent. Tokar (1968) conducted static bioassays on untreated effluents from Mills A and B and found that the 96-hour TL_ms of juvenile salmon for Mill A effluent ranged from 3.9 to 13 percent by volume, and the TL_ms for two samples of Mill B effluent were 35 and 42 percent by volume. Biological stabilization of wastes used for the present study clearly reduced their acute toxicity. Stabilization of effluent from Mill B eliminated effects of this effluent on food utilization for growth at the effluent levels tested in the present experiment, but a comparable amount of stabilization of Mill A wastes did not eliminate its effect on food conversion.

In aquarium experiments similar to those described in this thesis Tokar showed that untreated KME from Mill A caused a reduction of the growth rates of juvenile chinook salmon at concentrations as low as 0.15 percent by volume, but concentrations of Mill B effluent up to 2.5 percent caused only small differences in the growth of salmon. By comparison, my experiments show that treated effluents from Mill A caused a slight decrease in the growth rate of juvenile salmon held in aquaria at a concentration of 1.5 percent, but very

great differences in growth were not observed at concentrations lower than 4.5 percent. Stabilized effluent from Mill B had no effect upon the growth rates of salmon held in aquaria in these experiments. From these data it can be concluded that biological stabilization significantly reduces the sublethal effect of effluent from Mill A upon the growth of chinook salmon held in aquaria.

Seim (1970) found that an SKME concentration of 1.5 percent by volume reduced growth rates of juvenile salmon held in laboratory streams during spring and fall experiments, but growth rates were higher at this concentration during summer experiments. Since food in the streams receiving SKME was not reduced it was concluded the waste had some direct effect on the fish. My experiment A-2 shows a substantial reduction of growth rates at 1.5 percent effluent concentration, but experiment A-1 does not show an effect at this concentration. This may indicate a difference in the toxicity of different batches of SKME, possibly due to differences in treatment of wastes.

Fish in the exercise channels grew less than fish in aquaria. Reduction in growth of exercised fish was assumed to be associated with increased expenditures of energy for swimming.

Effluent had little or no effect on the growth of juvenile salmon that were forced to swim in concentrations as high as 4.5 percent effluent, but at this concentration SKME from Mill A reduced the

growth of salmon in aquaria. If food energy which was not effectively used for growth due to the presence of effluent could be utilized for swimming when this was required, but was not used by fish in aquaria, the absence of an effect when the fish were required to swim could be explained. Tokar found no effect on swimming performance of fish exposed to concentrations of KME up to 4.5 percent from both Mills A and B.

When exposed to SKME fish may become more active due to their avoidance reaction to the effluent (Jones et al., 1956), and expend more energy for swimming than unexposed fish when held in aquaria. In exercise channels the fish were forced to swim at a nearly constant rate, and would have to expend the same amount of energy for swimming at all exposure levels. Thus, by removing the random swimming movement, the effect of the effluent would have been reduced.

Tokar's (1968) results indicated that although the BOD may be a reliable index of the relative chronic toxicity of the wastes from a given mill it did not provide a satisfactory basis for judging the relative chronic toxicity of the wastes from different mills. Some reduction of both BOD and toxicity occurs when KME is stabilized, but toxicity reduction is not protportional to BOD reduction, and measurement of BOD may not be a reliable indication of toxicity remaining in the treated waste.

Henderson and Tarzwell (1957) suggested that "application factors" be used in estimating permissible concentrations of toxic waste in receiving waters. These factors were based on acute toxicity bioassay results in order to insure adequate protection against chronic damage to fisheries resources in nature. They suggest that any waste which has no TL_m could be allowed to reach 30 percent by volume in receiving waters. The results of the present aquarium experiments and Seim's (1970) work indicate that SKME concentrations in receiving waters based on these application factors would be damaging to fish life.

These experiments indicate that SKME reduces the growth of salmon in laboratory aquaria studies, but it is not yet known to what extent this effect on growth will occur in salmon populations inhabiting water receiving SKME. Further research is needed to determine the chronic effects of low concentrations of SKME on factors affecting salmonid production in the natural aquatic environment.

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APPENDIX

APPENDIX: GROWTH AND FOOD CONSUMPTION DATA FOR THE GROWTH EXPERIMENTS.

Aquaria Experiment A-1

% effluent	Feeding ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	944	2824	1880	1884	7068	33.26	125.05	10	10
	Med.	899	1940	1041	1420	3541	24.44	83.12	10	10
	Low	871	1410	541	1141	2174	15.80	63.51	10	10
	Low R.	864	839	-25	852	710	-.98	27.78	10	10
1.5	High	881	2774	1893	1828	7342	34.52	133.88	10	10
	Med.	926	1910	884	1368	3354	21.54	81.73	10	9
	Low	934	1536	602	1235	2174	16.24	58.68	10	10
	Low R.	897	840	-57	869	710	-2.18	27.23	10	10
3.0	High	902	2816	1914	1859	7459	34.80	133.75	10	10
	Med.	871	1712	841	1292	3541	21.70	92.65	10	10
	Low	962	1367	465	1165	2174	13.30	62.20	10	10
	Low R.	878	776	-102	827	710	-4.11	28.62	10	10
4.5	High	938	2654	1716	1796	7315	32.33	137.84	10	10
	Med.	963	1756	793	1360	3541	19.43	86.79	10	10
	Low	864	1257	393	1056	2174	12.40	68.62	10	10
	Low R.	890	717	-173	833	710	-6.92	28.41	10	10

Aquaria Experiment A-2

% effluent	Feeding ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	1055	2029	974	1542	3306	42.1	143.0	10	10
	Med.	1090	1471	381	1281	1727	19.8	89.9	10	10
	Low	1106	1186	080	1146	1068	4.7	62.1	10	10
1.5	High	1074	1835	761	1455	3317	34.9	151.5	10	10
	Med.	1119	1390	271	1255	1727	14.4	91.7	10	10
	Low	1041	1070	029	1056	1068	1.8	67.4	10	10
3.0	High	1079	1885	806	1482	3309	36.3	148.9	10	10
	Med.	1087	x	x	x	x	x	x	10	7
	Low	1090	1145	065	1113	1068	4.0	63.8	10	10
4.5	High	1108	1641	533	1380	3319	25.8	159.9	10	10
	Med.	1106	1384	278	1245	1727	14.9	92.5	10	10
	Low	1090	1085	-005	1088	1068	-.3	65.4	10	10

Exercise Channel Experiment A-3

% effluent	Feeding ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	2637	3548	931	3093	2298	20.07	49.53	2	2
	Med.	2747	3181	434	2964	1441	9.76	32.41	2	2
	Low	2650	2681	031	2666	733	0.78	18.32	2	2
	Starv.	2608	2320	-288	2464	0	-7.79	0.00	2	2
1.5	High	2432	3578	1146	3005	2665	25.42	59.12	2	2
	Med.	2724	3138	414	2931	1430	9.42	32.52	2	2
	Low	2470	2561	91	2516	730	2.41	19.34	2	2
	Starv.	2546	2321	-225	2434	0	-9.24	0.00	2	2
3.0	High	2586	3551	965	3060	2535	21.02	55.22	2	2
	Med.	2730	3230	500	2980	1465	11.19	32.77	2	2
	Low	2449	2472	020	2461	713	0.54	19.31	2	2
	Starv.	2515	2146	-369	2331	0	-10.55	0.00	2	2
4.5	High	2401	3078	668	2740	2143	16.25	52.14	2	2
	Med.	2419	2951	532	2685	1455	13.21	36.13	2	2
	Low	2623	2531	-092	2577	728	-2.38	18.83	2	2
	Starv.	2548	2225	-323	2387	0	-9.02	0.00	2	2

Exercise Channel Experiment A-4

% effluent	ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	298	470	172	384	1009.2	29.9	175.2	4	3
	Med.	418	539	121	479	697.6	16.8	97.1	4	4
	Low	436	434	-002	435	427.2	-0.3	65.5	4	4
	Starv.	458	294	-164	376	0.0	-29.0	0.0	4	4
1.5	High	408	739	331	574	1345.6	38.4	156.3	4	4
	Med.	312	382	70	347	523.2	13.4	100.5	4	3
	Low	408	496	88	452	427.2	12.9	63.0	4	4
	Starv.	444	265	-179	355	0.0	-33.6	0.0	4	4
3.0	High	425	728	303	577	1345.6	35.0	155.5	4	4
	Med.	329	416	87	377	532.2	15.4	92.5	4	3
	Low	426	455	29	442	427.2	4.4	64.4	4	4
	Starv.	329	227	-102	278	0.0	-24.5	0.0	4	3
4.5	High	403	714	311	559	1345.6	37.1	160.4	4	4
	Med.	413	514	101	464	697.6	14.5	100.2	4	4
	Low	319	365	46	342	320.4	9.0	62.5	4	3
	Starv.	350	230	-120	290	0.0	-27.6	0.0	4	3

Aquaria Study B-1

% effluent	ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	2896	5540	2644	4218	8348	41.8	131.9	10	10
	Med.	2642	3935	1293	3289	4203	26.2	85.2	10	9
	Low	2625	3022	397	2824	1870	9.3	44.1	10	9
1.5	High	2660	4777	2117	3719	8019	37.9	143.7	10	9
	Med.	2723	3610	887	3167	3803	19.5	80.1	10	8
	Low	2783	3528	745	3156	2052	15.7	43.4	10	10
3.0	High	2746	5170	2424	3958	7495	41.0	126.2	10	10
	Med.	2904	4180	1272	3506	4455	24.2	84.7	10	10
	Low	2874	3300	426	3087	2052	9.2	50.0	10	10
4.5	High	2810	5110	2300	3960	7803	38.7	131.4	10	9
	Med.	2816	4392	1576	3604	4302	29.2	79.6	10	10
	Low	2735							10	7

Exercise Channel Experiment B-2

% effluent	Feeding ration	Dry weights of fish (mg) initial	final	gain	mean	Dry weight of food cons. (mg)	Growth rate mg/g/dy	Food consumption rate mg/g/dy	No. of fish starting	No. of fish surviving
0.0	High	1173	1638	465	1406	2725	22.0	129.2	5	5
	Med.	1167	1511	344	1339	540	17.1	77.0	5	5
	Low	1016	1142	81	1079	720	5.0	44.5	5	5
1.5	High	1074	1584	510	1329	2725	25.6	136.7	5	5
	Med.	1058	1434	360	1246	540	19.3	82.6	5	5
	Low	1126	1292	166	1209	720	9.2	39.7	5	5
3.0	High	1135	1657	522	1396	2725	24.9	130.1	5	5
	Med.	1100	1482	382	1291	1540	19.7	79.5	5	5
	Low	828	1050	222	939	576	15.8	40.9	5	4