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Summary of Progress

PHASES I AND II: EFFECTS OF PULP AND PAPER MILL EFFLUENTS ON GROWTH AND PRODUCTION OF FISH

Research Grants #B-004ORE and B-013-ORE
Office of Water Resources Research
United States Department of Interior

For period from July 1, 1966 through October 31, 1971

Department of Fisheries and Wildlife
and
Water Resources Research Institute
Oregon State University
Corvallis, Oregon
November 1, 1971

1) fish
2) industrial wastes

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For period from July 1, 1966 through October 31, 1971

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GENERAL INTRODUCTION

The Office of Water Resources Research, the National Council for Air and Stream Improvement of the Paper Industry, and the Northwest Pulp and Paper Association have since July 1, 1966, been jointly supporting at Oregon State University a research project on the effects of untreated and biologically stabilized kraft mill effluents on the growth and production of salmon and trout. This research, as originally proposed to the Office of Water Resources Research and the pulp and paper industry, was planned to be conducted in two phases.

Phase I, extending from July 1, 1966 through June 30, 1969, has been concerned with two kinds of laboratory studies of the effects of kraft mill effluents on salmon. In some of these laboratory studies, juvenile chinook salmon (*Oncorhynchus tshawytscha*) have been held in continuous-flow aquaria or in exercise channels at different concentrations of effluent and fed different ration levels, in order to determine the concentrations that have little or no direct effect on the relationship between the food consumption and growth rates of the fish. In other studies, juvenile chinook salmon have been held at different concentrations of kraft mill effluents in laboratory stream communities contained in troughs, in which insect larvae and crustaceans, produced in the streams, are the food organisms of the young fish. These studies have made it possible to determine not only the direct effects of kraft mill effluents on the growth of the fish but also their effects on the food chain of the fish, which also can influence fish growth and production.

But laboratory stream studies, though providing necessary insight into the problem, cannot provide a final answer as to the effects of kraft mill effluents on fish in nature, because laboratory streams, being more restrictive as to food organisms and other factors, may not be an entirely adequate model of natural streams. For these reasons a second phase of this research was planned and has been pursued. Phase II of this research, to extend from July 1, 1969 through June 30, 1972, is being conducted in three large experimental stream channels--closely representing natural streams--constructed at the site of a kraft mill, where river water and both treated and untreated effluents are available. Construction of these experimental stream channels was completed on October 1, 1969. Each stream channel is about 6 feet wide and 350 feet long, and each receives a flow of 0.67 cfs of water pumped from the Willamette River.

This progress report covers the research completed on Phase I and Phase II to date, although experiments and data analysis for Phase II will not be complete until June 30, 1972.

PHASE I: LABORATORY STUDIES

EFFECTS OF KRAFT MILL EFFLUENTS ON GROWTH OF SALMON FED IN AQUARIA AND IN EXERCISE CHANNELS

A toxic substance may have a direct effect on the amount of food a fish will consume as well as on its utilization of food for growth at any given consumption rate, regardless of food availability. Moreover, the effect of a toxic substance on food utilization for growth may be different at different food consumption rates. Because in nature food availability varies, it is important that we have information on the effects of toxic substances on the growth of fish consuming different amounts of food, from all they can or will eat down to barely enough for them to maintain their weight.

Thus, we have exposed juvenile chinook salmon to different concentrations of untreated and biologically stabilized kraft mill effluents and have fed different groups at each concentration different known amounts of live tubificid worms. Experiments were conducted both in aquaria and in exercise channels. Water and effluent in these tests were continuously renewed by constant exchange flows (Figure 1).

Individual experiments were generally of 2 or 3-week duration. The fish were weighed at the beginning and the termination of each experiment, in order to determine their mean changes in weight. This value was divided by the mean weight of the fish during the experiment and by the number of days in the experiment to obtain the mean growth rate. The fish were fed each day weighed amounts of food. The total amount of food consumed by the fish in a particular treatment was divided by the mean weight of the fish and the number of days in an

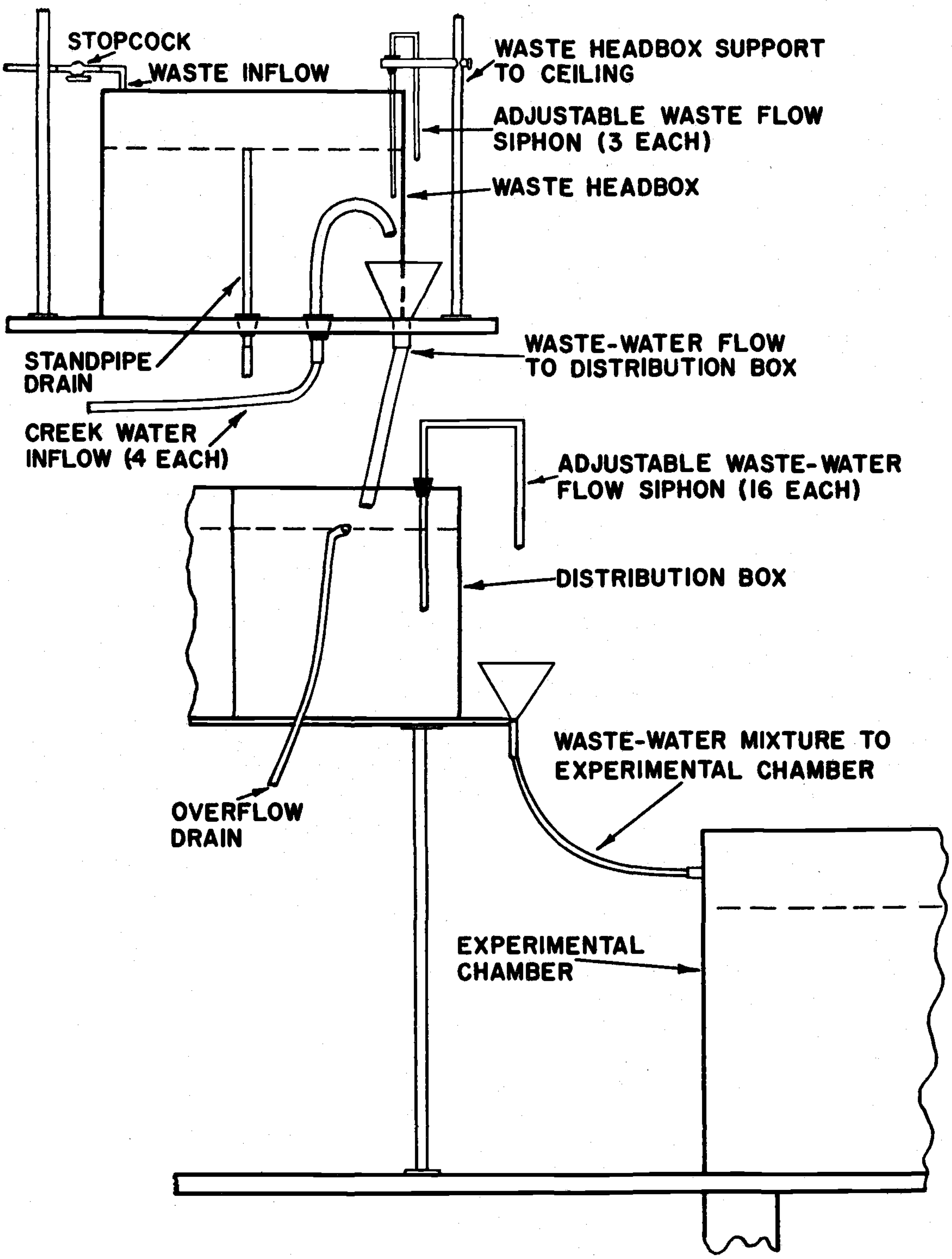

Figure 1. Diagram of the experimental apparatus used for studies of direct effects of untreated and biologically stabilized kraft mill effluents on the food consumption and growth of juvenile chinook salmon fed in aquaria.

experiment to obtain mean rates of food consumption. In each experiment, four rates of food consumption were tested at each of four effluent concentrations, including a control. The relationship between food consumption rate and growth rate could then be determined for each effluent concentration tested.

Untreated Effluents

The relationships between food consumption rate and growth rate of juvenile chinook salmon at different concentrations of untreated kraft mill effluent from mill A shown in Figure 2 are typical for this mill. At an effluent concentration of 0.5 mg/l BOD (about 0.25 percent effluent by volume), any effect on growth at particular rates of food consumption was slight, except at the highest food consumption rate. At 2 and 3 mg/l BOD, the effects were greater. Effluent concentrations slightly higher than 3 mg/l BOD were lethal to the fish when effluents from mill A were tested.

In order to plot the results of several experiments on the effects of effluents from mill A and a second mill (mill B) on the same graph, it was necessary to normalize the growth rates of the fish by taking the growth of fish in each control test to represent 100 percent. When this is done, as in Figure 3, two things become apparent. First, the effect on the growth of the fish of untreated effluent from mill A becomes appreciable at a concentration near 1 mg/l BOD when the fish are fed the next to highest ration level. Second, untreated effluent from mill B has little or no effect on the growth of the fish at concentrations as high as 2 mg/l BOD, and little at even 4 mg/l. In relation to BOD, then, the effluent from mill B appears to contain smaller amounts of toxic substances than does the effluent from mill A. These differences, due

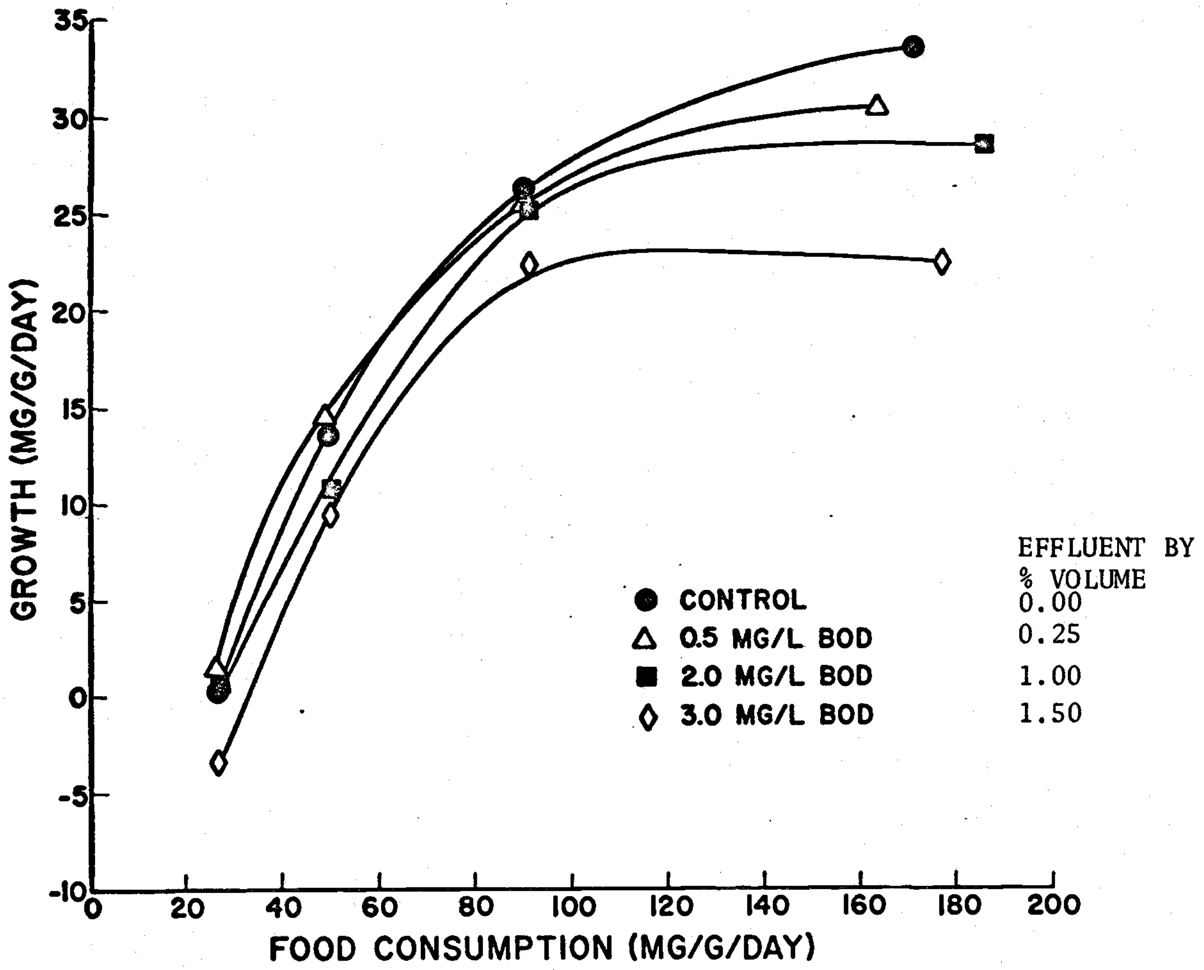

Figure 2. Relationships between the food consumption rate and the growth rate of juvenile chinook salmon held in aquaria at different concentrations of untreated effluent from mill A.

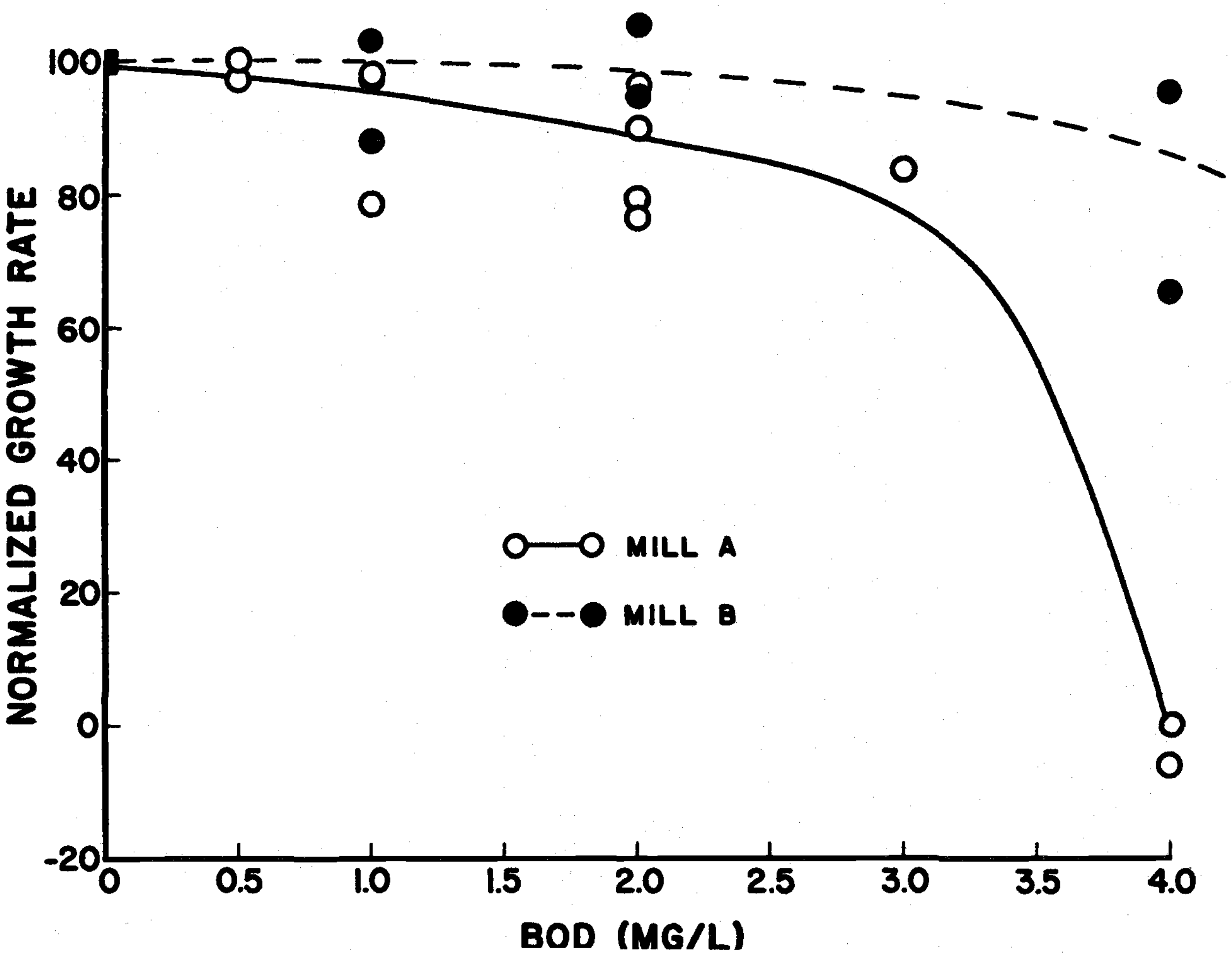

Figure 3. The relationship of normalized growth rates of juvenile chinook salmon kept on high restricted (daily repletion) rations to the concentrations of effluents of two kraft mills to which they were exposed.

to plant design and operation, must be expected and be taken into account in planning waste disposal programs for particular plants.

Similar experiments were conducted with neutralized bleach kraft effluent having a BOD of about 150 mg/l. This effluent was composited by combining acid and caustic lime effluents from a bleach kraft mill located in northwestern Oregon with unbleached kraft pulp effluent from mill B at a 2:1:1 volume ratio of acid to caustic to pulp effluent. On a volume basis this composite waste was less toxic than unbleached kraft effluent. Concentrations as high as 3 percent by volume did not adversely affect salmon growth rate (Figures 4 and 5). Salmon exposed to a 6 percent concentration, however, did exhibit reductions in growth rate (Figure 5).

Biologically Stabilized Effluents

With increasing utilization of our waters, waste treatment has become the order of the day. It is important, then, not only to know the effects of low concentrations of untreated kraft mill effluents on the growth and production of fish, but also to know the effects of treated effluents. The first objective of treatment of high BOD wastes is usually BOD reduction in order to conserve oxygen resources in natural waters. When decomposable toxic substances also are present in effluents, reduction in the concentration of these may be accomplished, but not necessarily in proportion to BOD reduction. And higher permissible discharge rates of treated effluents on the basis of their BOD may sometimes lead to toxicity problems due to the increased concentration of refractive substances in the receiving waters. These problems merit closer examination.

The methods used in aquarium and exercise channel experiments on stabilized wastes were similar to those described for untreated effluents.

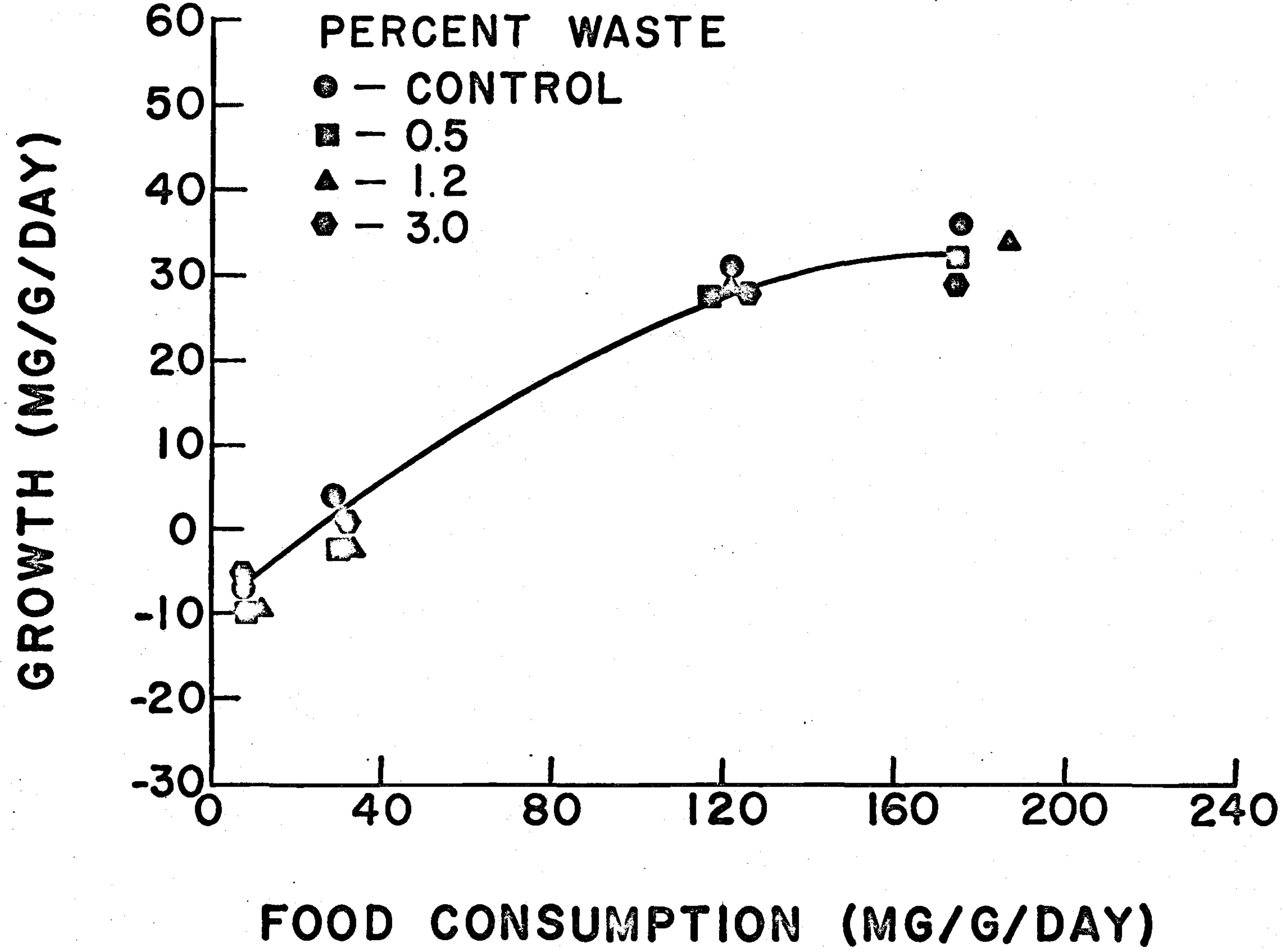

Figure 4. The effects of a composite bleached kraft effluent on the relationship between food consumption and growth rates of juvenile chinook salmon.

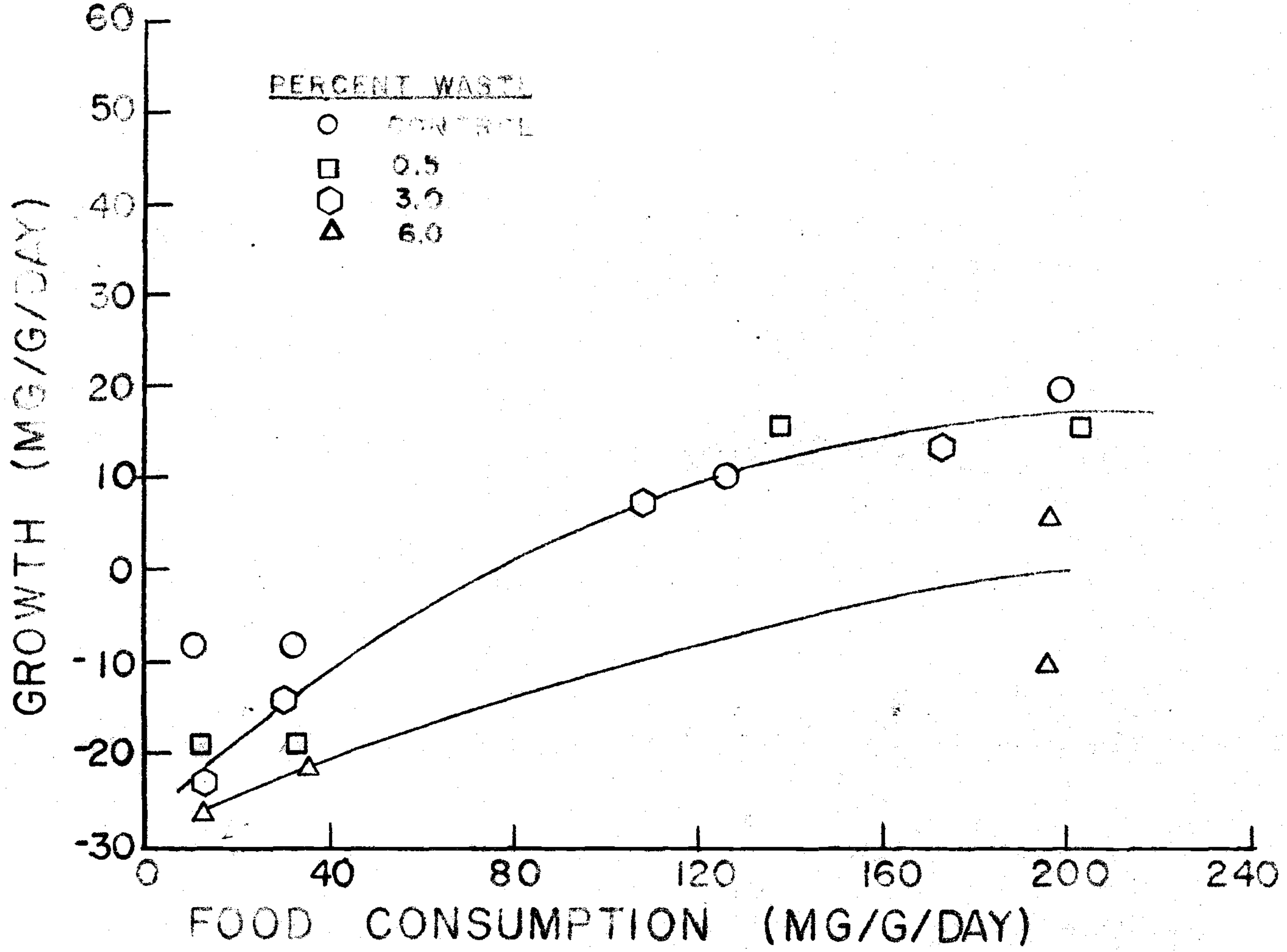

Figure 5. The effects of a composite bleached kraft effluent on the relationship between food consumption and growth rates of juvenile chinook salmon.

Juvenile chinook salmon were exposed to a range of concentrations of effluent in a flow-through system and fed at different known rations. Stabilized effluents from mill A and mill B were studied. Effluent from mill A was collected raw and biologically stabilized at our laboratory by dispersed-floc aeration, with the addition of nitrogen and phosphorus, during a 7-day period. Even after stabilization, effluent from mill A was still more toxic than was effluent from mill B. Stabilized effluent from mill A reduced salmon growth at concentrations of 0.69 mg/l BOD and greater (Figure 6). This reduction in growth was attributed to a decrease in the efficiency of food utilization for growth. There was no effect, however, upon the growth or food consumption of salmon in aquaria that could be attributed to stabilized effluent from mill B tested at concentrations up to 1 mg/l BOD (4.5 percent by volume). Whether treated or not, then, kraft mill effluents from some mills may be expected to reduce the growth rates of fish in aquaria at final BOD concentrations between 0.5 and 1.0 mg/l (Figures 3 and 6). Treatment may, of course, permit the maintenance of lower levels of BOD in receiving waters.

Fish in aquaria are not required to exert themselves much in swimming activity. Stress occasioned by additional swimming activity might be expected to increase the effect of a toxic substance on the growth of fish at particular rates of food consumption. We forced juvenile chinook salmon in special apparatus to swim vigorously throughout the duration of an experiment in which the fish were also fed different ration levels at different concentrations of biologically stabilized kraft mill effluent. Under these conditions, the effluent had little or no effect on the growth of the fish at concentrations as high as

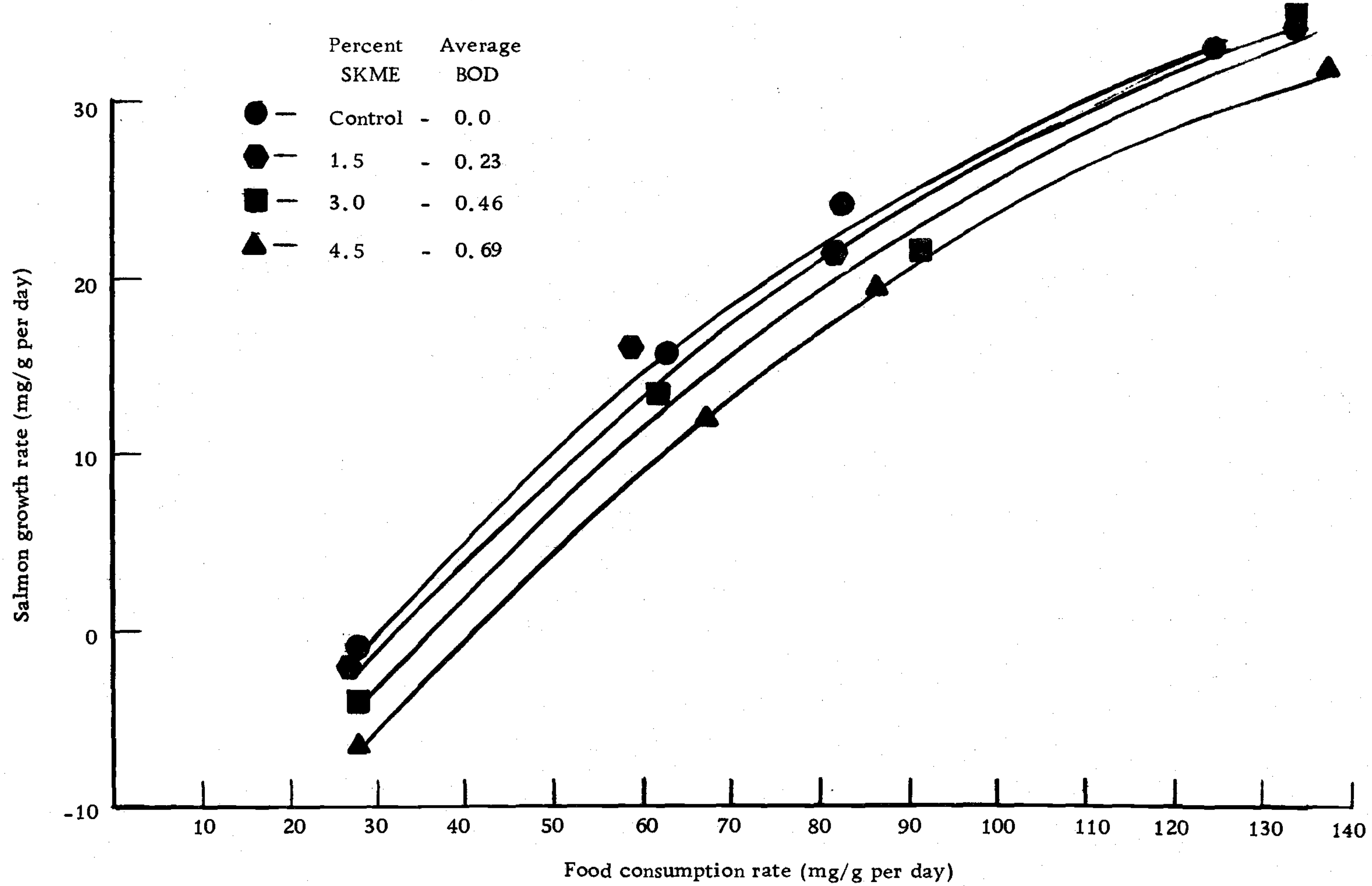

Figure 6. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in aquaria during experiment A-1 and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD.

2.19 mg/l BOD (4.5 percent effluent by volume), as shown in Figures 7 and 8. Because of the increased energy required for swimming, growth of the swimming fish at a given consumption rate was less than would have been expected for the fish in the aquaria. Food energy not effectively used for growth due to the presence of effluent could apparently be utilized for swimming when this was required, but was wasted by fish in the aquaria. This could explain the presence of an effect of effluent on growth in aquaria and the absence of an effect when the fish were required to swim. The levels of energy expenditure by the fish in these experiments were undoubtedly higher than would occur in nature, because of the very vigorous forced activity.

EFFECTS OF KRAFT MILL EFFLUENTS ON PRODUCTION OF SALMON IN LABORATORY STREAM COMMUNITIES

In order to gain some understanding of the effects untreated and biologically stabilized kraft mill effluents might have on the growth and production of juvenile chinook salmon when not only direct effects on the fish but also indirect effects through their food chain could occur, we conducted studies of salmon held in simple laboratory stream communities. These communities were maintained in six laboratory streams (Figure 9) having substrates of stream bottom materials, receiving a continuous exchange flow of water and effluent, and having a biological community composed of algae and other microorganisms, herbivorous insects and an amphipod crustacean, and juvenile chinook salmon. The salmon depended on the insects and crustaceans for their food, and these invertebrates depended on the microorganisms. Thus, we could study the effects of different concentrations of effluents on the

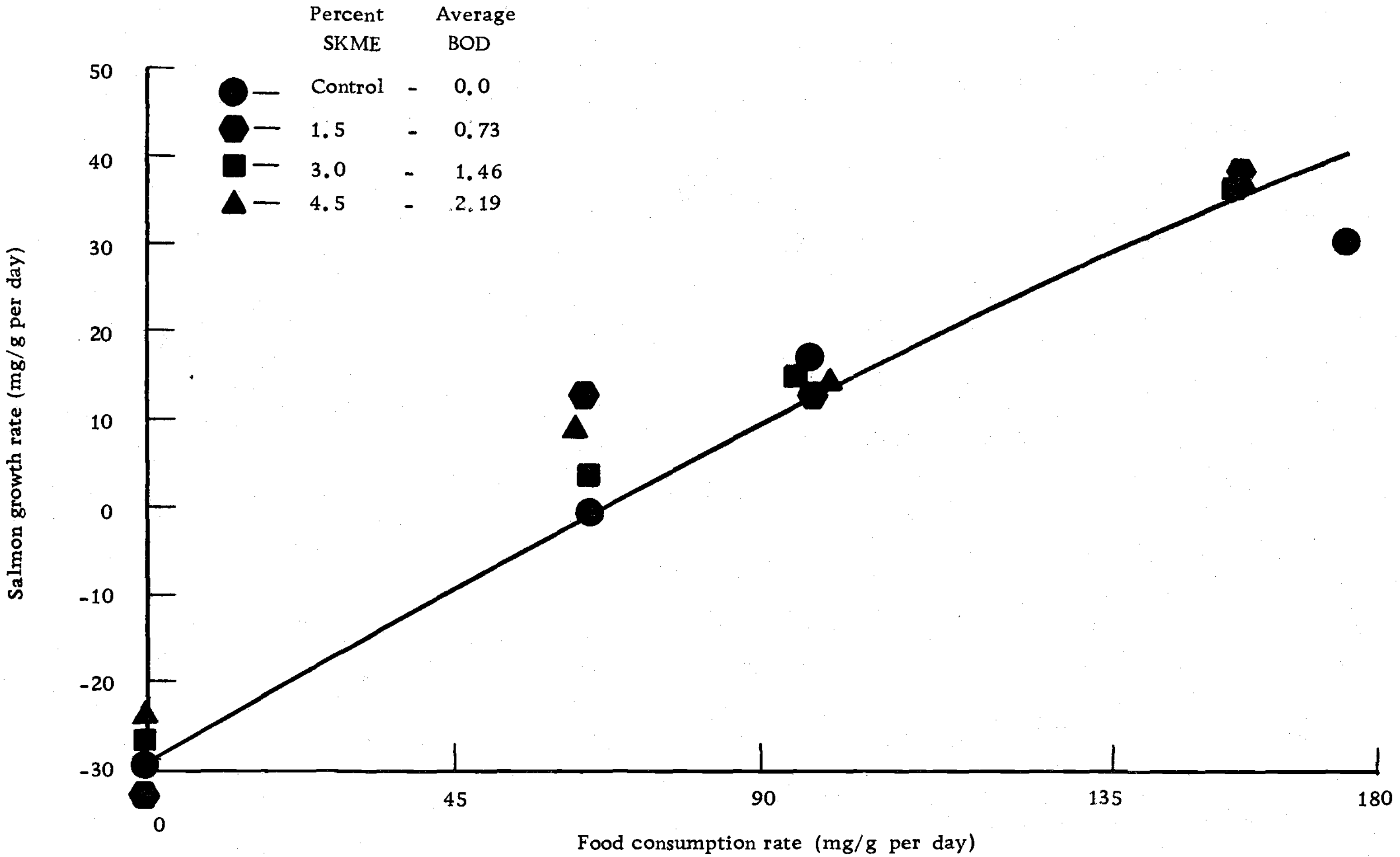

Figure 7. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels during experiment A-4 and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. Effluent concentrations are expressed in percent by volume and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

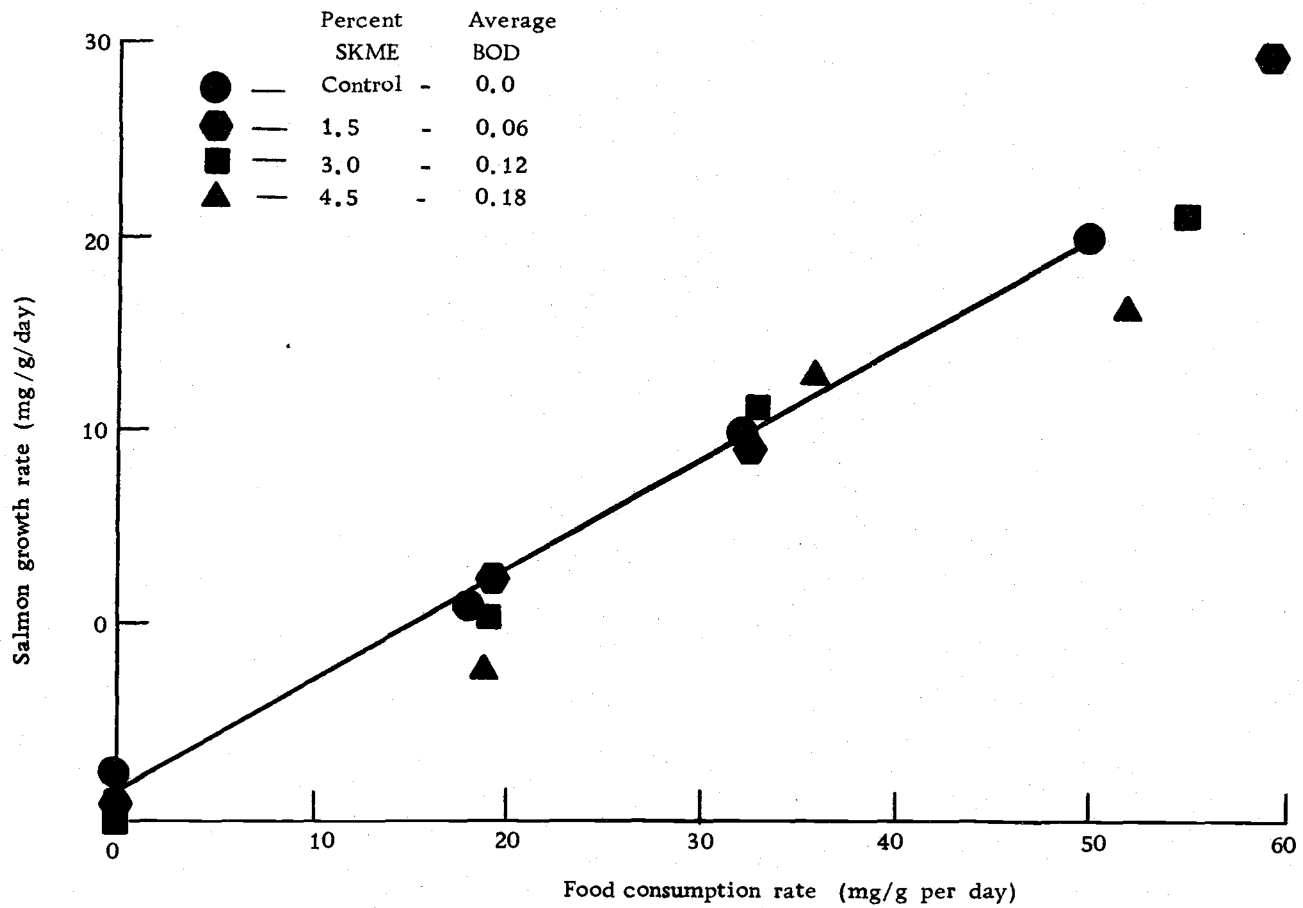

Figure 8. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels during experiment A-3 and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. Effluent concentrations are expressed in percent by volume and mg/l BOD

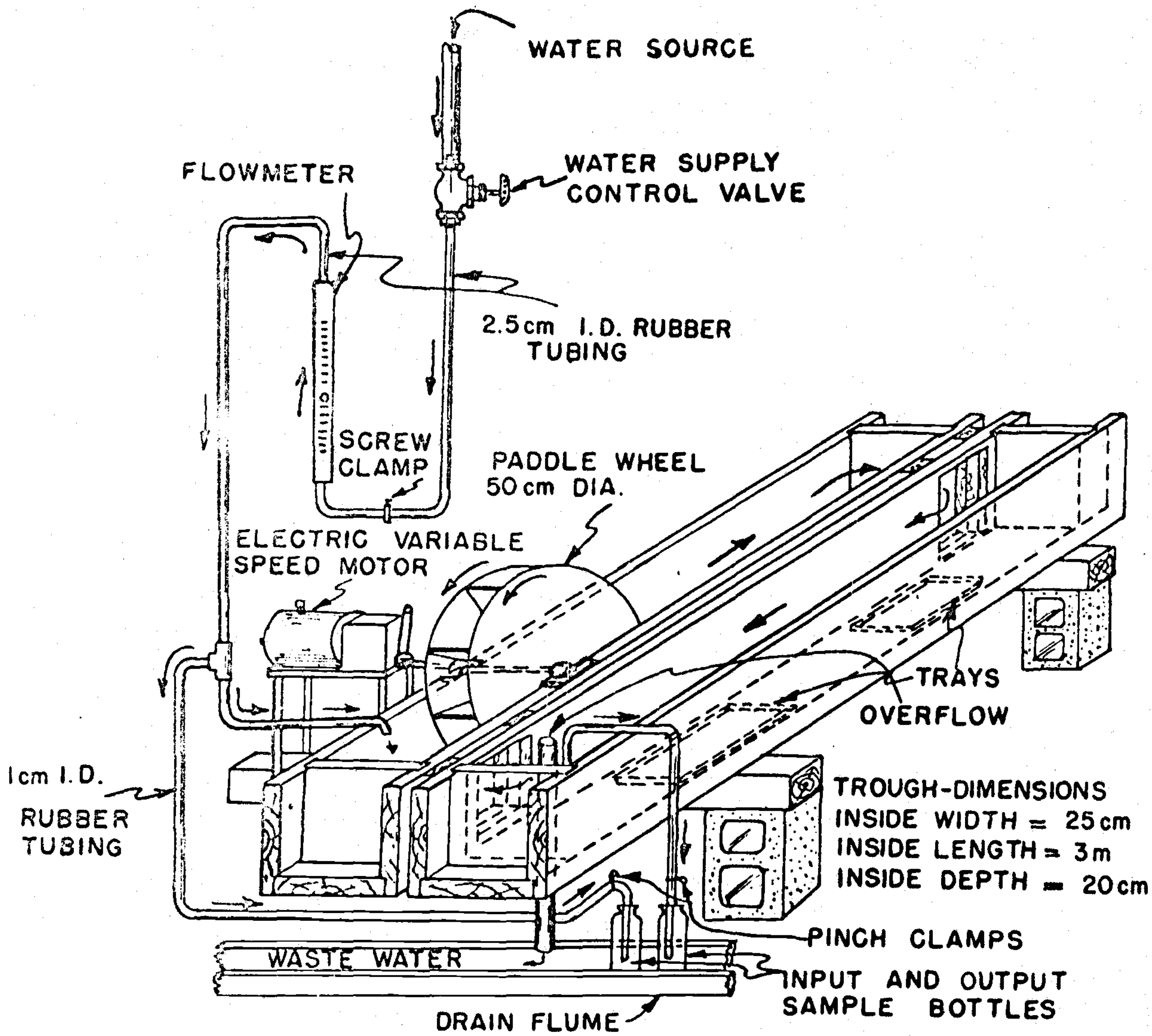

Figure 9. Diagram of a laboratory stream similar to the ones employed for studying the influence of kraft pulp mill effluents on the production of salmonids in simplified biological communities.

growth and production of salmon and on the availability of their food organisms.

Production is defined as the total elaboration of fish tissue, and is determined by the growth per unit biomass of the fish and the biomass present. Thus, for any given period of time, production can be estimated as the product of growth rate (mg/g/day) and biomass (g/M^2). The growth rate of the fish in a system having a limited capacity to produce food must decline as biomass increases, because less food is then available per fish (Figure 10). But, since production is the product of growth rate and biomass, production first increases to some maximum and then declines with increasing biomass (Figure 10). This must be taken into account in any production studies, if the results are to be properly analyzed.

Untreated Effluents

In a series of winter and spring experiments, salmon growth rates and production were reduced in laboratory streams that received untreated kraft effluent from mill A at a concentration of 1.5 percent by volume (3 mg/1 BOD and a toxicity ranging from 0.14 to 0.36, of the 96-hr $TL_{\underline{m}}$'s) as shown in Figure 11. The reductions in production were greater at high stocking densities than at low stocking densities. Untreated effluent introduced into laboratory streams at 0.5 percent by volume (1 mg/1 BOD and 0.05 to 0.08 of the 96-hr $TL_{\underline{m}}$'s) did not result, however, in any reduction of salmon growth or production. The deleterious effects at 3 mg/1 BOD in these spring experiments appear to be the result of direct effects on the growth of fish. The biomass of one genera of chironomid, *Micropsectra*, was reduced at this concentration of effluent, although no overall reduction in food density was observed.

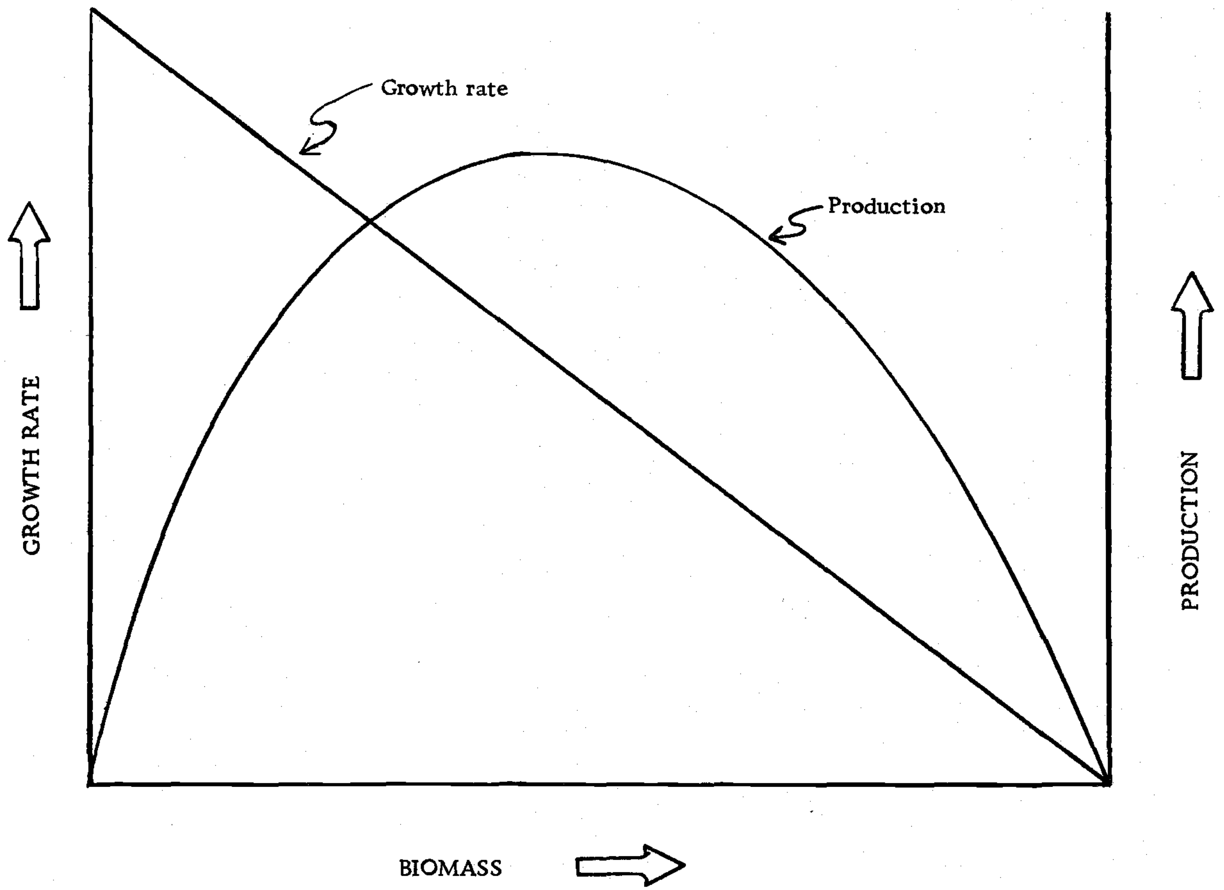

Figure 10. Theoretical relationship between the growth rate of an animal and its biomass and between the production and biomass of the same animal. Production is the product of growth rate and biomass.

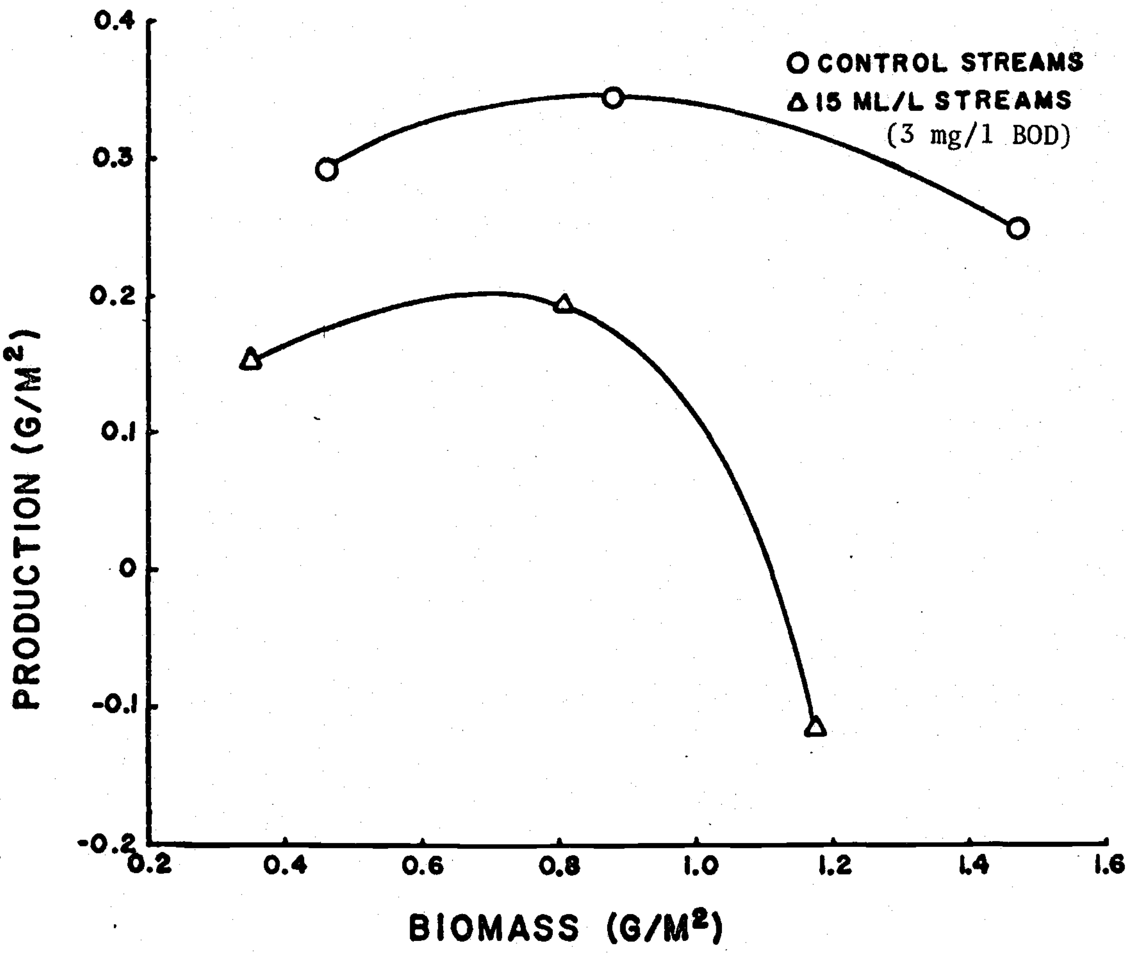

Figure 11. Relationship between salmon production and salmon biomass for control and 15 ml/liter streams during the last 17 days of Experiment 3.

At the 1 mg/l BOD concentration, a slight increase in fish production occurred.

As we will return to later in this report, concentrations of untreated and biologically stabilized effluent having no very great deleterious direct effect on the growth of the fish may, if they through enrichment lead to increased food availability, actually increase fish production in laboratory stream ecosystems.

Biologically Stabilized Effluents

The effects of biologically stabilized effluent from kraft mills A and B on the production of juvenile salmon and on the biomass of their food organisms in laboratory streams were also studied. A pattern of reduced effluent toxicity during summer months as compared to the rest of the year emerged during this series of experiments and later when both treated and biologically stabilized effluents from mill A were simultaneously tested in a series of experiments. In experiments conducted during spring and fall periods, salmon production was lower in streams receiving a 1.5 percent by volume of stabilized effluent, which averaged about 0.5 mg/l BOD (Figure 12). This difference was attributed to a direct effect of the effluent on the growth of the fish, since no reduction in the abundance of food organisms or in the basic capacity of the stream to produce food organisms was demonstrated. Relationships between the density of drifting food organisms and salmon growth rate shown in Figure 13 demonstrate lower fish growth rates in streams receiving effluent even when these streams have food organism densities as high or higher than those occurring in control streams.

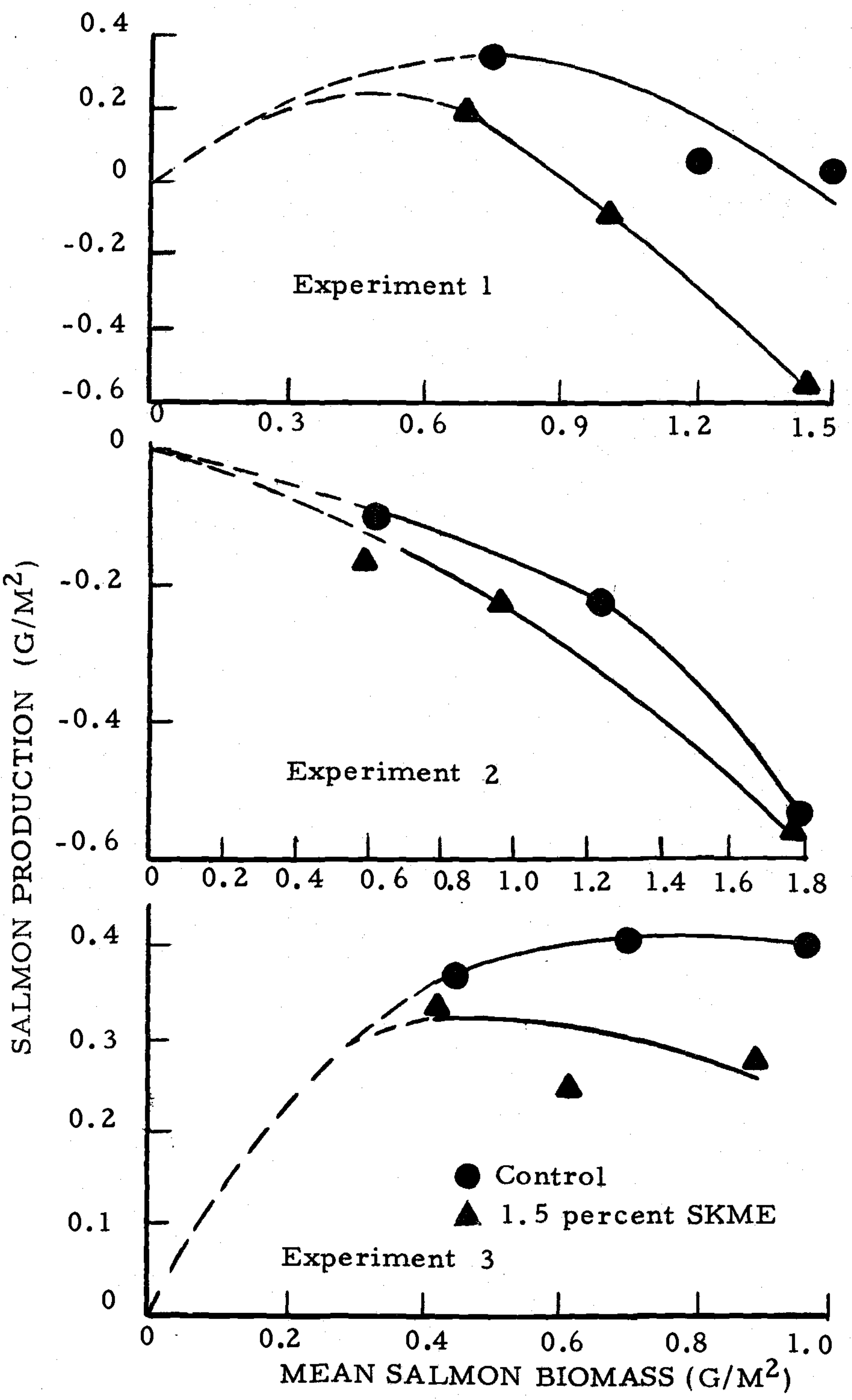

Figure 12. Relationship between salmon production and mean salmon biomass for control and 1.5 percent stabilized kraft mill effluent (SKME) streams, during experiments 1, 2 and 3. Duration of experiments was 30 days, 18 days and 32 days, respectively.

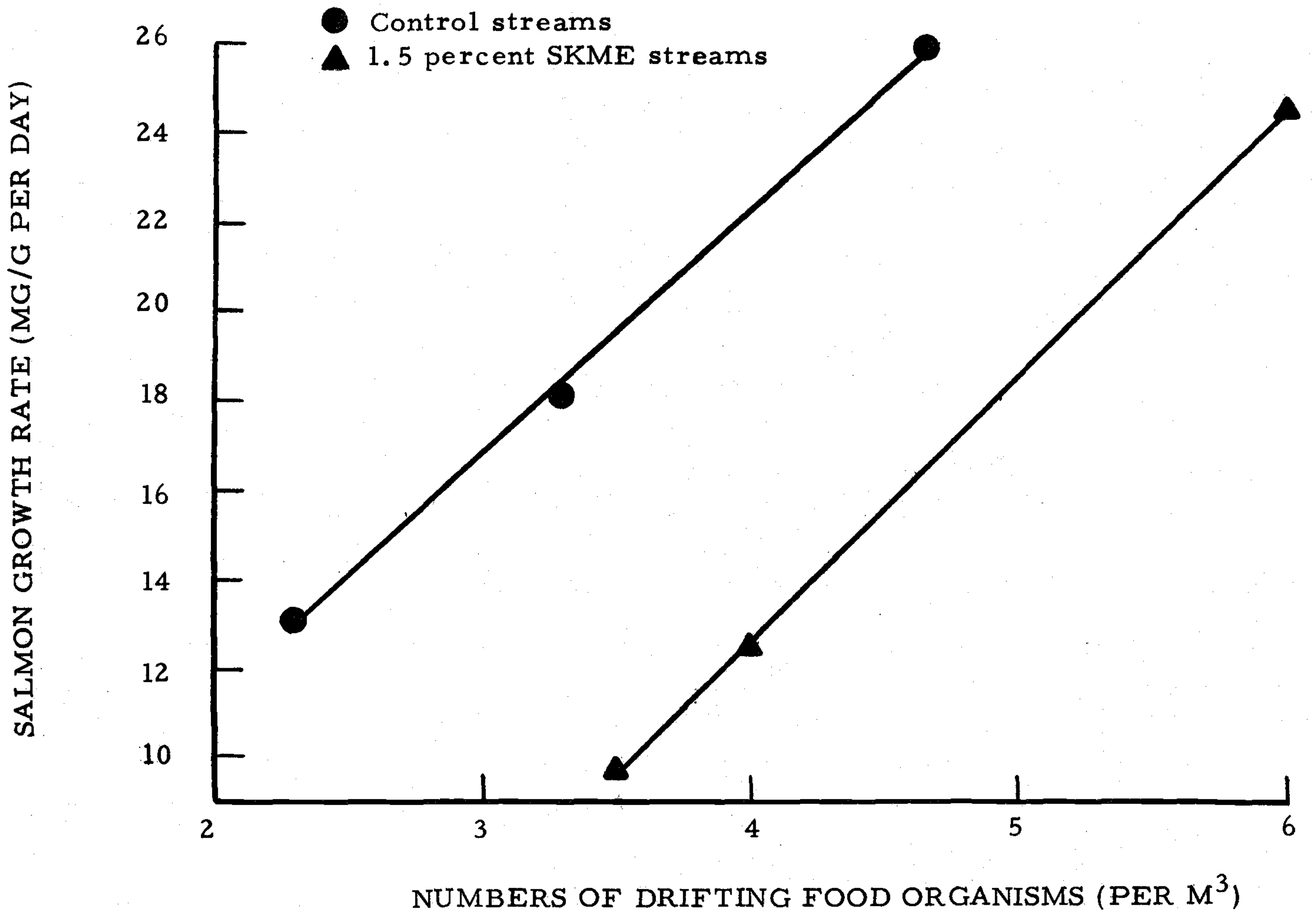

Figure 13. Relationship between salmon growth rate and the numbers of drifting food organisms in control and 1.5 percent stabilized kraft mill effluent (SKME) streams during Experiment 3.

When stabilized effluent was added to laboratory streams during summer months, however, salmon production was found to be greater in streams receiving up to 4.0 percent by volume (about 1.2 mg/1 BOD) stabilized effluent than in control streams (Figure 14). Salmon production was greatest at a 1.0 percent concentration (0.3 mg/1 BOD) and declined at concentrations of 2.0 and 4.0 percent. This increase in production appeared to be the result of an important increase in the numbers of the major food organism, an amphipod identified as *Crangonyx* sp. The decline in salmon production at concentrations above 1.0 percent suggested the effluent was directly affecting salmon growth rates during summer months also, although this influence must have been small in relation to beneficial effects on food production.

This effluent had about the same BOD (near 30 mg/1) after biological stabilization as had stabilized effluent used in earlier experiments. This summer experiment was replicated (Figure 14), and the results appear to be confirmed. Our studies of the algal communities in the laboratory streams indicate primary production was greater in streams receiving stabilized kraft waste than in control streams. Also, the species composition of diatoms was significantly altered and the abundance of organic material was reduced in treatment streams.

Thus, kraft mill effluents have both toxic and enriching potentials. Their effects on stream communities and fish production will depend on their nature, whether or not they are treated, their concentration in the receiving water, and the composition of the stream community. Because of their simplicity, we must be careful as to the conclusions we draw on the basis of research with laboratory stream communities.

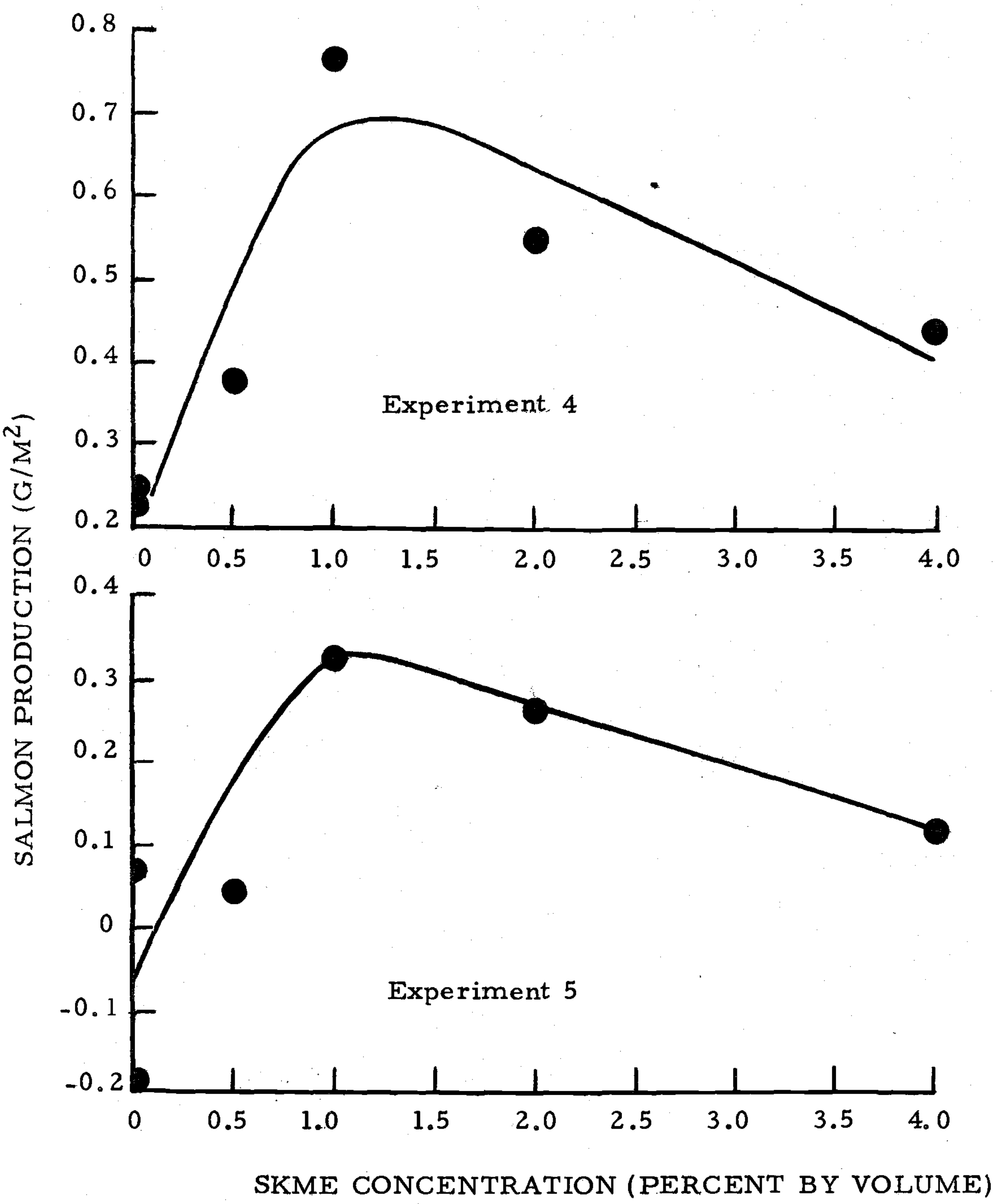

Figure 14. Relationship between juvenile chinook salmon production and stabilized kraft mill effluent (SKME) concentration in laboratory streams during summer Experiments 4 and 5. The duration of each of these experiments was 32 days.

Studies Concluding Phase I

The final experiments of Phase I were designed to permit an analysis of the results on the basis of density dependent relationships between the abundance of the food organisms in the streams and the biomass and growth rates of the experimental fish. Brocksen, Davis, and Warren (1968) have proposed a rationale for examining these relationships. Their model defines the production of a predator as a function of its biomass and the abundance of its food. Further developments of this point of view by Brocksen, Davis and Warren (1970) and Warren (1971) indicate that the density of the predator is inversely related to the density of the prey within biological systems having a similar basic capacity to produce the prey. In contrast, the densities of the predator and the prey are directly related between systems having different basic productivities (Figure 15).

This approach was used to facilitate the analysis of an experiment conducted from May through August, 1969. Laboratory streams were initially stocked with similar biomasses of juvenile chinook salmon.

Two streams were used as controls. Of the four remaining streams, two received effluent at identical flow rates, one stream receiving untreated kraft effluent at a rate of 15 ml/l or 1.5 percent (3 mg/l BOD), and one stream receiving stabilized effluent at 15 ml/l (0.3 mg/l BOD). By introducing untreated effluent at 7.5 mg/l (0.75 percent) into

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Brocksen, R. W., G. E. Davis, and C. E. Warren. 1968. Competition, food consumption, and production of sculpins and trout in laboratory stream communities. Journal of Wildlife Management 32:51-75.

Brocksen, R. W., G. E. Davis, and C. E. Warren. 1970. Analysis of trophic processes on the basis of density dependent function. In J. H. Steele (Editor). Marine Food Chains. University of California Press, Berkeley.

Warren, C. E. 1971. Biology and Water Pollution Control. W. B. Saunders. Philadelphia. 434p.

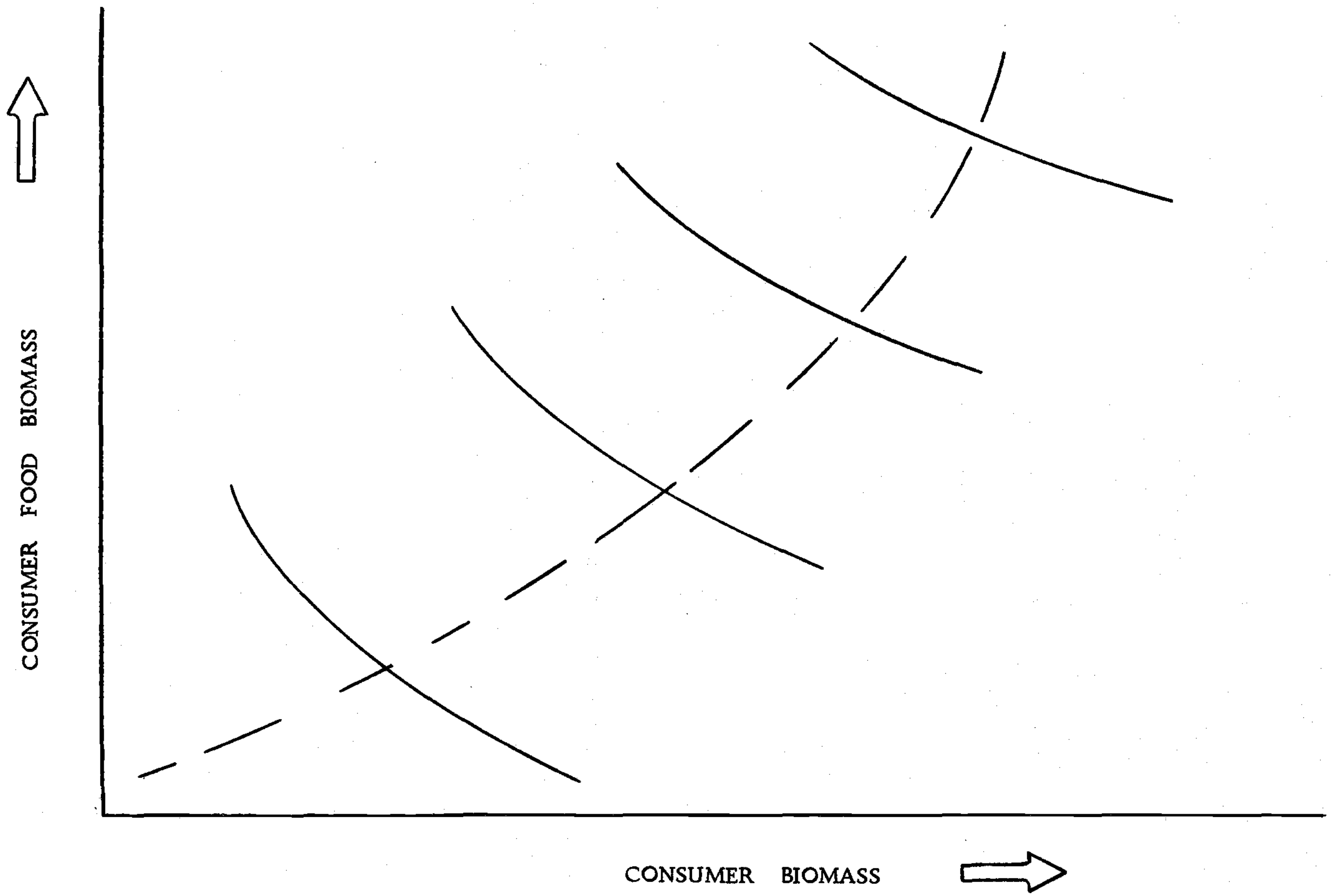


Figure 15. Theoretical relationships between the biomass of a consumer and the biomass of its food. Solid lines represent relationships when basic productivity is constant within a system or equal between systems and the dashed line when systems differ in basic productivity or are changing.

one stream and stabilized effluent at 75 ml/l (7.5 percent) into another stream, the effects of the two effluents could be compared at the same BOD level (1.5 mg/l). It might be noted, before a presentation of the results of this experiment, that on April 15, 1969, mill A began operation of a turpentine recovery system.

Streams receiving 1.5 percent by volume of unstabilized waste (3 mg/l BOD) and 0.75 percent by volume of unstabilized waste (1.5 mg/l BOD) maintained the highest biomass of salmon (Figure 16). The stream receiving 7.5 percent stabilized waste (1.5 mg/l BOD) produced a salmon biomass slightly higher than the control streams, and the stream receiving 1.5 percent by volume of stabilized effluent (0.3 mg/l BOD) produced a salmon biomass about the same as those of the control streams.

The density dependent relationships briefly described earlier apply to consumers, in this case salmon, that are limited by their food resource. In these experiments, a good relationship was found between the biomass of benthic food organisms and the growth rate of salmon (Figure 17). Figure 17 indicates that the higher fish growth rates in the streams receiving 1.5 percent and 0.75 percent untreated effluent were the result of higher food densities in these streams. It further indicates that no direct toxic effect of the effluents on the fish occurred during the season of this experiment.

When the relationship between the terminal or "equilibrium" biomass of benthic food organisms and the terminal biomass of salmon is examined, two general levels of productivity can be identified (Figure 18). Streams receiving 1.5 percent and 0.75 percent untreated and 7.5 percent stabilized effluent were of the same general level of productivity for salmon; a much higher level than the two control streams and the stream

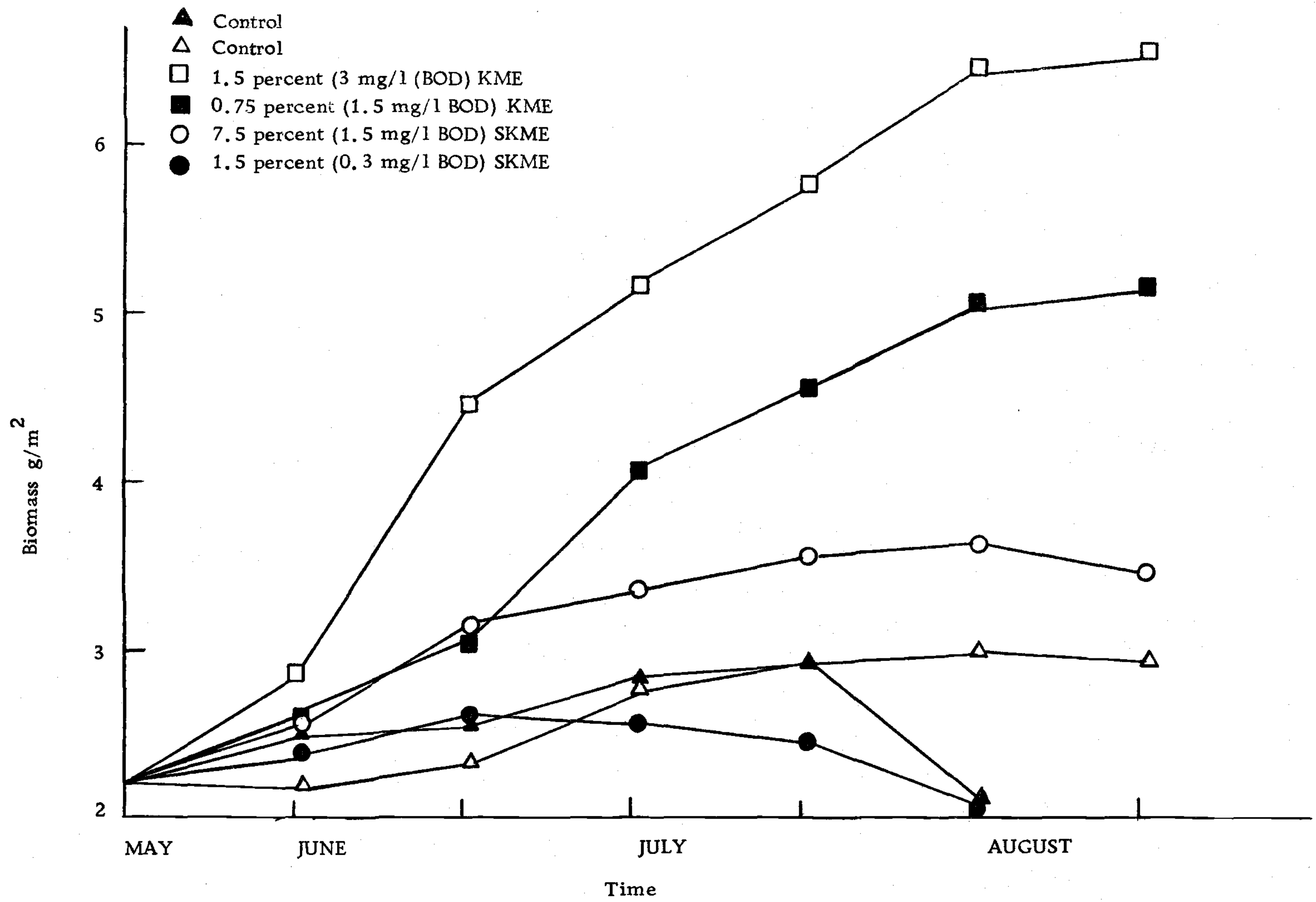


Figure 16 Changes in salmon biomass in laboratory streams during two week intervals between May 16, and August 12, 1969.

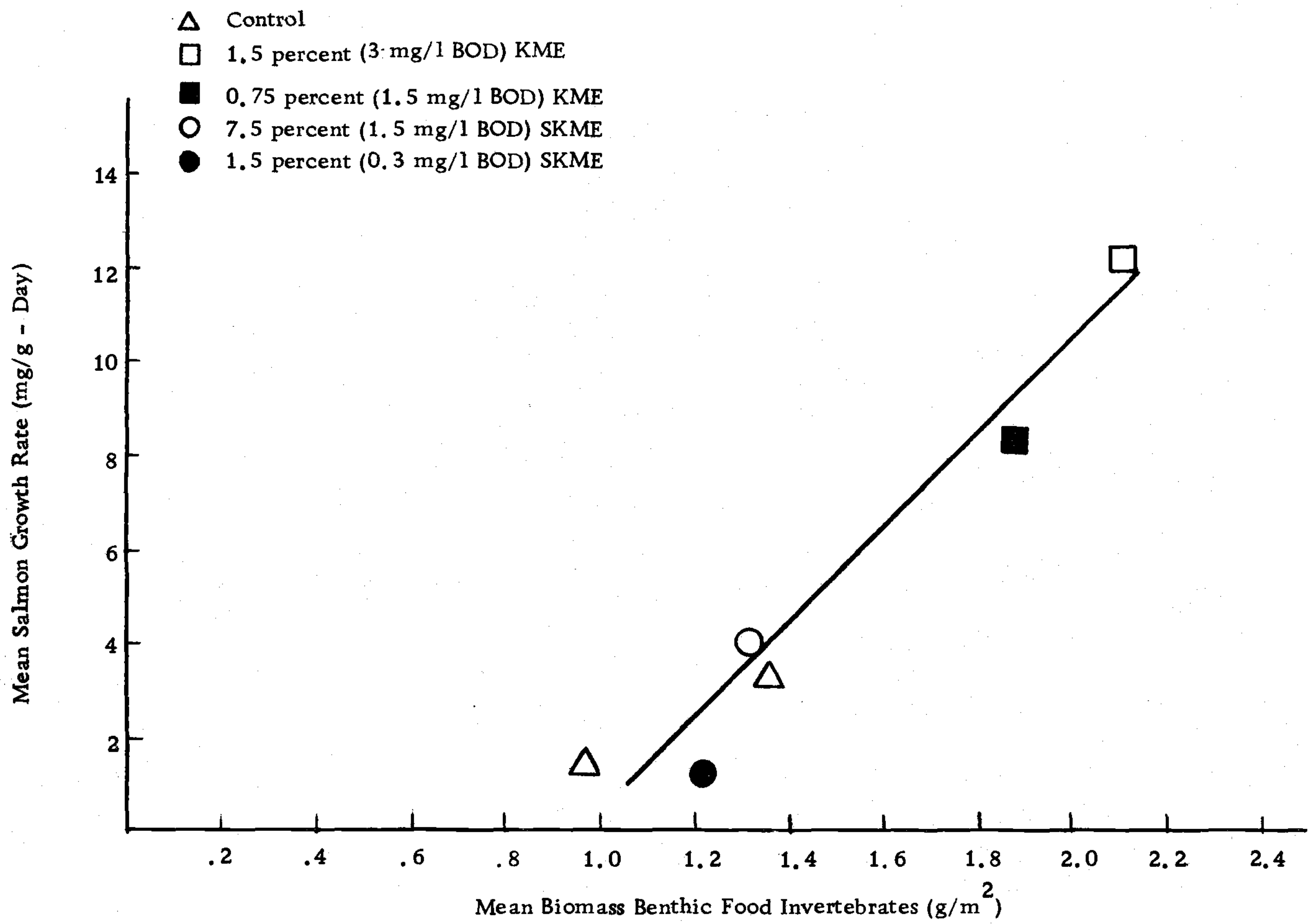


Figure 17 Relationship between mean salmon growth rate and mean biomass of benthic food invertebrates in laboratory streams from May 16 to August 12, 1969.

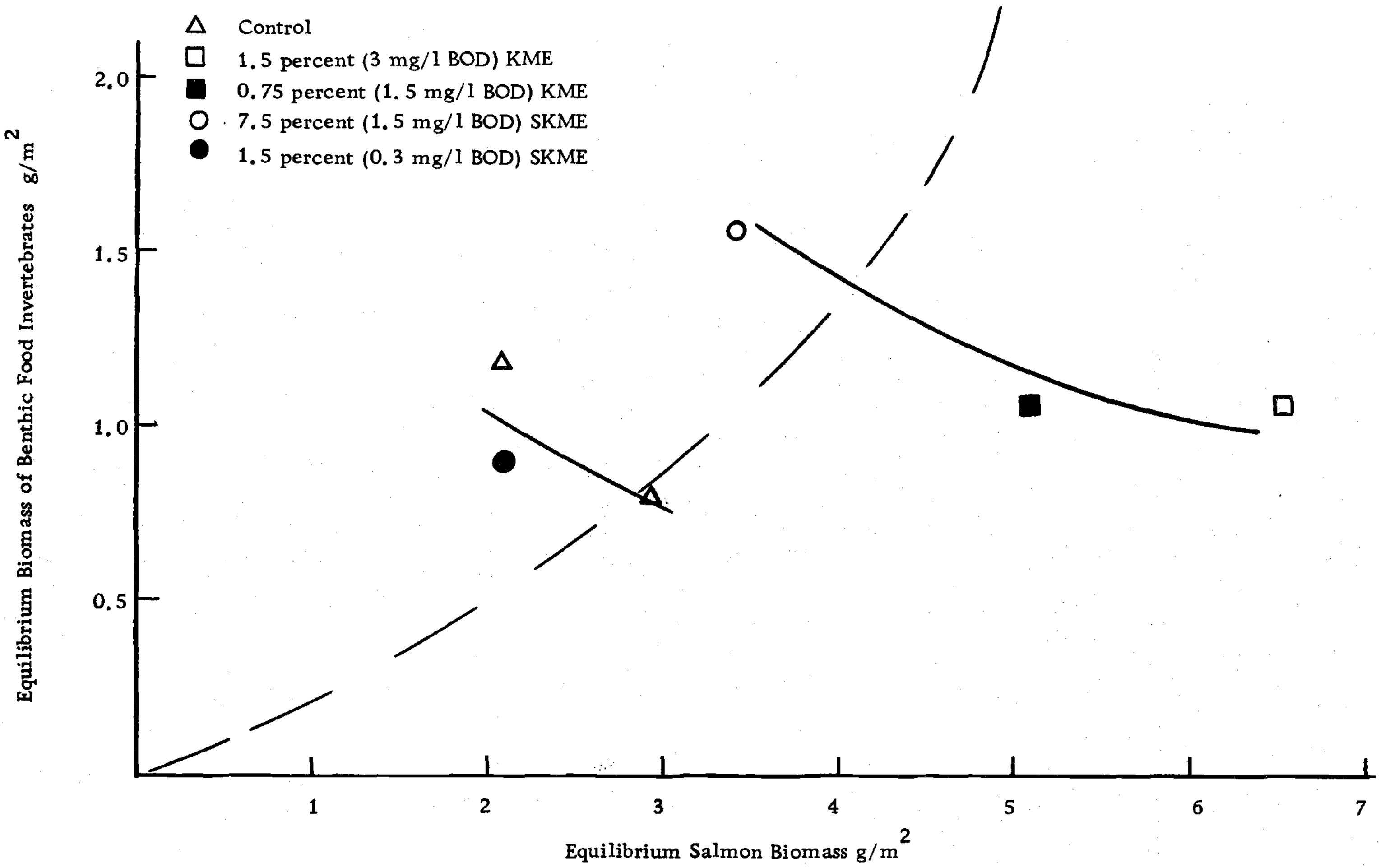


Figure 18 Relationships between equilibrium biomass of benthic food invertebrates and equilibrium salmon biomass in laboratory streams receiving different concentrations of stabilized and unstabilized kraft mill effluents. Invertebrate biomass computed as mean of final two benthic samples. Salmon biomasses are terminal biomass shown in Figure 16.

receiving 1.5 percent stabilized effluent. The addition of kraft waste, both untreated and stabilized, at these concentrations apparently increased the production of salmon food organisms, this resulting in a higher production of the salmon.

The acute toxicity of the untreated effluent from mill A had decreased to a low level by this summer period, the 96-hour $TL_{\underline{m}}$ being about 24 percent by volume. Previous summer experiments in laboratory streams had also shown increased salmon production at concentrations of stabilized waste up to 4.0 percent by volume. The addition of a turpene recovery system at mill A just prior to this final experiment of Phase I may account in part for the reduced acute toxicity of the effluent and the greater increase in stream productivity noted in this experiment as compared to earlier experiments.

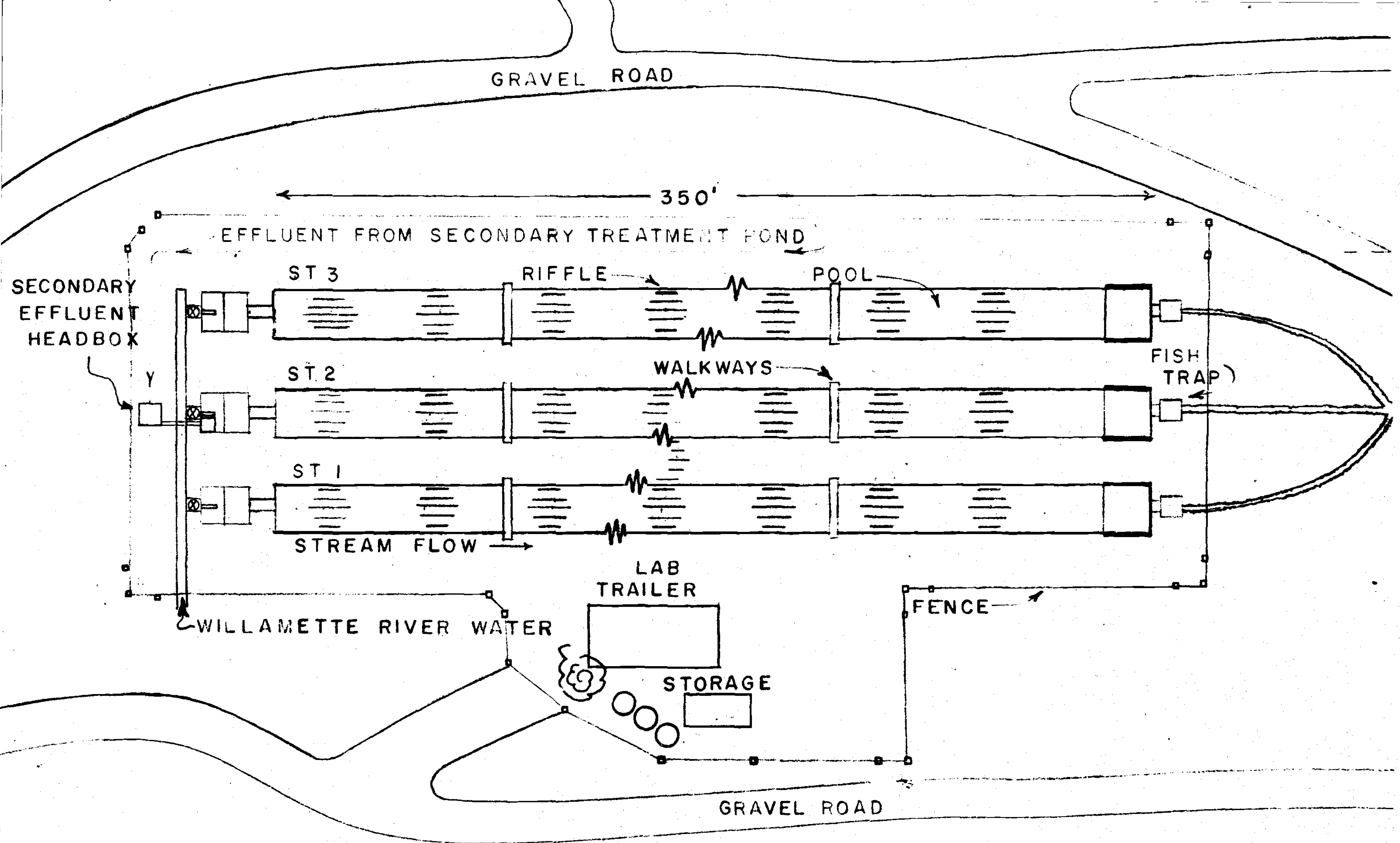
PHASE II: EXPERIMENTAL STREAM CHANNEL STUDIES

Construction of a carefully designed system of experimental stream channels was completed on October 1, 1969, on a site near the Western Kraft Corporation paper mill at Albany, Oregon. This installation consists of three experimental stream channels (Figures 19 and 20), a laboratory trailer, a small storage building, and three fish holding tanks. The stream channels are 350 feet long and about 6 feet wide. The stream beds are covered with a gravel and rubble substrate and are divided into alternating pools and riffles. Water pumped from the Willamette River supplies the streams with about 0.7 cubic feet per second of flow through each upstream weir box. Screened fish traps are located below the downstream weirs to capture emigrating fish. Non-bleached kraft effluent is available from either the primary treatment pond or the aerated stabilization basin operated by Western Kraft Corporation. A 6-foot high wire fence encloses the entire research area.

KRAFT MILL EFFLUENT: CHARACTERISTICS AND USE

On October 1, 1969, the water flow was started in the three stream channels. Colonization by algae and insect species was rapid. Bottom samples taken December 29, 1969, indicated a substantial invertebrate community was established in the streams. Introduction of untreated effluent into Stream 2 was begun on January 2, 1970, at a rate of 2.8 liters per minute or a stream concentration of 0.5 ppm BOD. Streams 1 and 3 were used as control streams.

This experimental design was retained until March 16, 1971, when Stream 2 began receiving biologically stabilized effluent from



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EXPERIMENTAL STREAM CHANNELS

Figure 19.

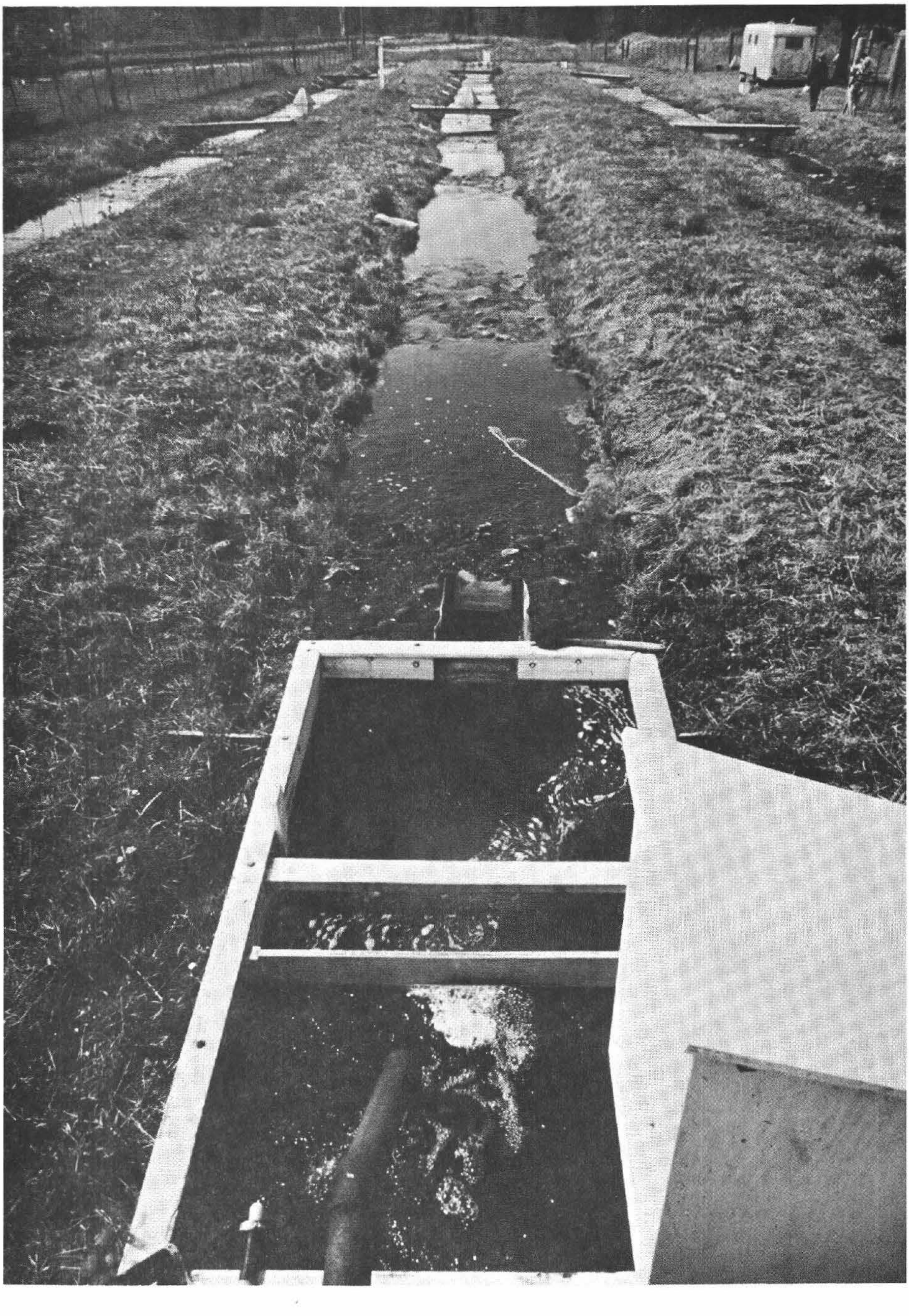

Figure 20. Downstream view of stream 2.

Western Kraft Corporation's secondary treatment facility. An electric pump delivered stabilized effluents to the streams through about 2500 feet of 1 1/2 inch plastic pipe. In order to prevent a drastic change in the aquatic community, when the untreated effluent was shut off, the concentration of stabilized effluent in Stream 2 was also maintained at 0.5 mg/l BOD. This experimental design has been continued to the present, with periodic adjustment of the flow rate of stabilized effluent to maintain about 0.5 mg/l BOD. Such adjustment has been necessary because the effluent BOD has varied with treatment efficiency and operating procedures. The 96-hour $TL_{\underline{m}}$ (median tolerance limit) for the kraft effluents entering the streams are given in Table 1.

Each day, a 200 ml sample of effluent was collected and combined to form a weekly composite sample. The following analyses were performed on the composite sample: total solids, total volatile solids, and chemical oxygen demand (COD) for the untreated and the stabilized effluent, and biochemical oxygen demand (BOD) for the untreated effluent. Data on the BOD of the stabilized effluent was obtained from the Western Kraft Corporation (Table 2).

Total and suspended solids, pH and alkalinity were determined every 2 to 4 weeks on the water entering the streams (Table 3). Phosphate and nitrate analyses were performed monthly (Figure 21).

Table 1. Acute toxicity of untreated (sedimentation only) and biologically stabilized kraft mill effluent to juvenile chinook salmon, expressed as 96-hour median tolerance limits (96-hr TL_m's) in percent by volume.

Untreated effluent		Biologically stabilized effluent	
Date collected	96-hour TL_m	Date collected	96-hour TL_m
1970		1971	
January 2	7.5	March 12	70.0
February 26	1.3	April 3	75.0
March 23	7.5	April 17	70.0
June 12	8.4	May 15	65.0
June 29	10.0	June 1	50.0
July 14	18.0	June 15	75.0
August 3	15.0	July 1	70.0
August 19	20.1	July 16	90.0
September 8	13.7	July 29	90.0
September 28	6.4	August 11	(20% mortality at 100% concentration)
October 13	4.2	August 25	90.0
October 25	6.4	September 1	80.0
November 12	7.5	September 15	no mortality
November 22	7.5		
December 18	10.0		
1971			
January 12	8.4		
February 3	13.0		
February 15	6.6		
February 17	7.4		
February 19	8.0		
February 25	2.2		
March 6	2.2		
March 23	7.5		

Table 2. Analyses of 7-day composite samples of untreated and biologically stabilized kraft mill effluent during 1970 and 1971.

Date	COD (mg/1)	Total solids (mg/1)	volatile (mg/1)	Suspended solids (mg/1)	Suspended volatile (mg/1)	BOD (mg/1)
1970			Untreated	Effluent		
February 17	610	-	-	-	-	282
February 25	650	832	335	114	78	310
February 25-March 3	616	711	273	-	-	250
March 4-10	640	742	346	-	-	276
March 11-18	580	704	299	80	76	272
March 21-24	568	622	263	100	88	245
March 25-31	650	813	261	120	100	240
April 1-7	600	669	237	36	24	177
April 8-14	607	620	240	20	18	260
April 15-21	582	625	221	44	34	243
April 22-28	645	709	246	27	22	270
April 29-May 5	607	674	220	30	20	-
May 6-12	578	672	183	41	25	267
May 12-19	810	633	182	95	50	147
May 20-26	528	602	198	32	22	202
May 27-June 2	671	714	295	165	120	211
June 3-7	683	527	425	56	52	190
June 11-16	571	658	476	30	32	217
June 17-23	585	582	231	48	-	235
June 24-30	548	659	213	55	53	338
July 1-7	413	644	202	45	30	177
July 8-14	551	679	146	46	38	210
July 15-21	655	683	269	85	83	186
July 22-27	617	664	314	53	17	214
July 28-August 3	576	628	208	53	43	198
August 4-10	546	627	174	28	-	210
August 11-17	581	661	205	43	30	204
August 18-24	518	619	127	-	-	186
August 25-31	670	807	286	-	-	246
September 1-7	607	714	208	-	-	198
September 8-14	562	694	209	-	-	186
September 15-21	509	748	238	-	-	195
September 22-28	580	701	196	-	-	237
September 29-October 6	702	773	260	-	-	195
October 6-12	650	767	265	-	-	195
October 13-19	585	790	274	-	-	180
October 20-26	565	666	218	-	-	180
October 27-November 2	-	746	300	-	-	350
November 3-8	-	708	220	-	-	180
November 9-16	-	670	269	-	-	-
November 17-23	-	696	260	-	-	-
November 24-29	-	729	236	-	-	-

(continued on next page)

Table 2. Continued

Date	COD (mg/l)	Total solids (mg/l)	Total volatile (mg/l)	Suspended solids (mg/l)	Suspended volatile (mg/l)	BOD (mg/l)
1970			Untreated Effluent			
November 30-December 5	-	733	258	-	-	-
December 6-12	-	709	201	-	-	-
1971			Biologically Stabilized Effluent			
March 12-13						40
March 28						48
April 3, 4, 5						49
April 10, 11, 12						67
April 16, 17, 18						93
April 23, 24, 25						90
May 15						90
June 1						130
June 15						80
July 1						65
July 8						32
July 16						42
July 29						40
August 11						30
August 19						51
August 25						36
September 1						33
September 9						24
September 15						26
September 22						57

Table 3. Water quality characteristics of experimental streams at Albany.

Date	Temperature (C) inflow	Temperature (C) outflow	Alkalinity mg/l $CaCO_3$	pH	Dissolved oxygen (mg/l) inflow	Dissolved oxygen (mg/l) outflow	Total solids (mg/l)	Total vol. solids (mg/l)
1970								
March 31	11.3	-	-	-	-	-	-	-
April 8	11.5	12.0	-	-	-	-	66.6	18.7
April 26	10.0	11.0	25.0	7.5	10.3	12.5	59.2	16.5
May 6	13.0	14.5	-	8.1	10.8	11.8	65.3	14.3
May 14	12.5	13.5	24.0	7.3	11.2	13.1	-	-
May 30	16.0	17.3	22.9	7.6	10.7	11.8	-	-
June 18	21.7	21.7	-	-	9.7	9.8	65.3	13.4
July 18	19.5	21.3	28.0	7.5	9.5	11.6	69.3	13.6
August 1	19.5	20.7	25.5	7.8	10.1	11.3	-	-
August 15	19.5	21.0	27.5	7.7	9.4	11.3	60.3	9.9
August 29	19.0	19.7	28.1	7.7	9.4	10.4	-	-
Sept. 10	17.5	19.3	26.2	7.4	9.7	11.6	45.8	8.1
Sept. 25	14.7	15.5	27.7	7.7	9.8	10.9	-	-
Oct. 10	15.5	16.0	28.2	7.2	10.0	11.8	63.4	9.9
Oct. 31	11.0	12.0	28.0	7.6	10.6	11.3	-	-
Nov. 14	9.5	9.7	24.0	7.4	10.7	13.2	101.5	18.5
Nov. 28	8.3	9.5	18.5	7.4	11.6	11.8	-	-
Dec. 13	6.5	6.5	23.5	7.5	12.4	12.9	84.1	14.0
Dec. 31	6.5	7.0	18.0	7.3	11.5	12.2	-	-
1971								
Jan. 16	6.0	6.3	17.0	7.6	11.8	11.8	70.1	10.5
Feb. 1	7.5	8.0	19.5	7.6	11.8	11.8	-	-
Feb. 16	7.6	8.1	18.0	7.2	10.9	11.7	78.1	11.9
March 2	5.5	5.5	20.5	7.3	12.0	13.0	-	-
March 17	7.5	8.0	19.0	7.3	11.7	13.2	72.2	10.1
April 1	9.5	10.5	18.7	7.4	10.9	12.2	-	-
April 29	10.9	11.0	22.0	7.6	10.6	11.4	70.1	9.2
May 13	13.0	14.0	21.0	7.6	9.9	10.6	70.8	9.3
June 13	14.0	14.5	21.8	7.5	10.8	10.5	51.1	8.1
June 27	14.5	15.3	19.7	7.3	10.1	10.5	-	-
July 13	19.5	21.5	21.6	8.1	10.1	10.5	48.8	8.3
August 3	21.5	23.7	32.0	7.7	9.3	10.4	-	-
August 15	18.7	20.5	22.3	7.6	9.7	10.5	50.1	7.9
August 29	16.5	16.7	23.3	7.4	9.5	9.5	-	-
Oct. 3	15.5	16.5	24.1	7.6	10.3	10.7	-	-

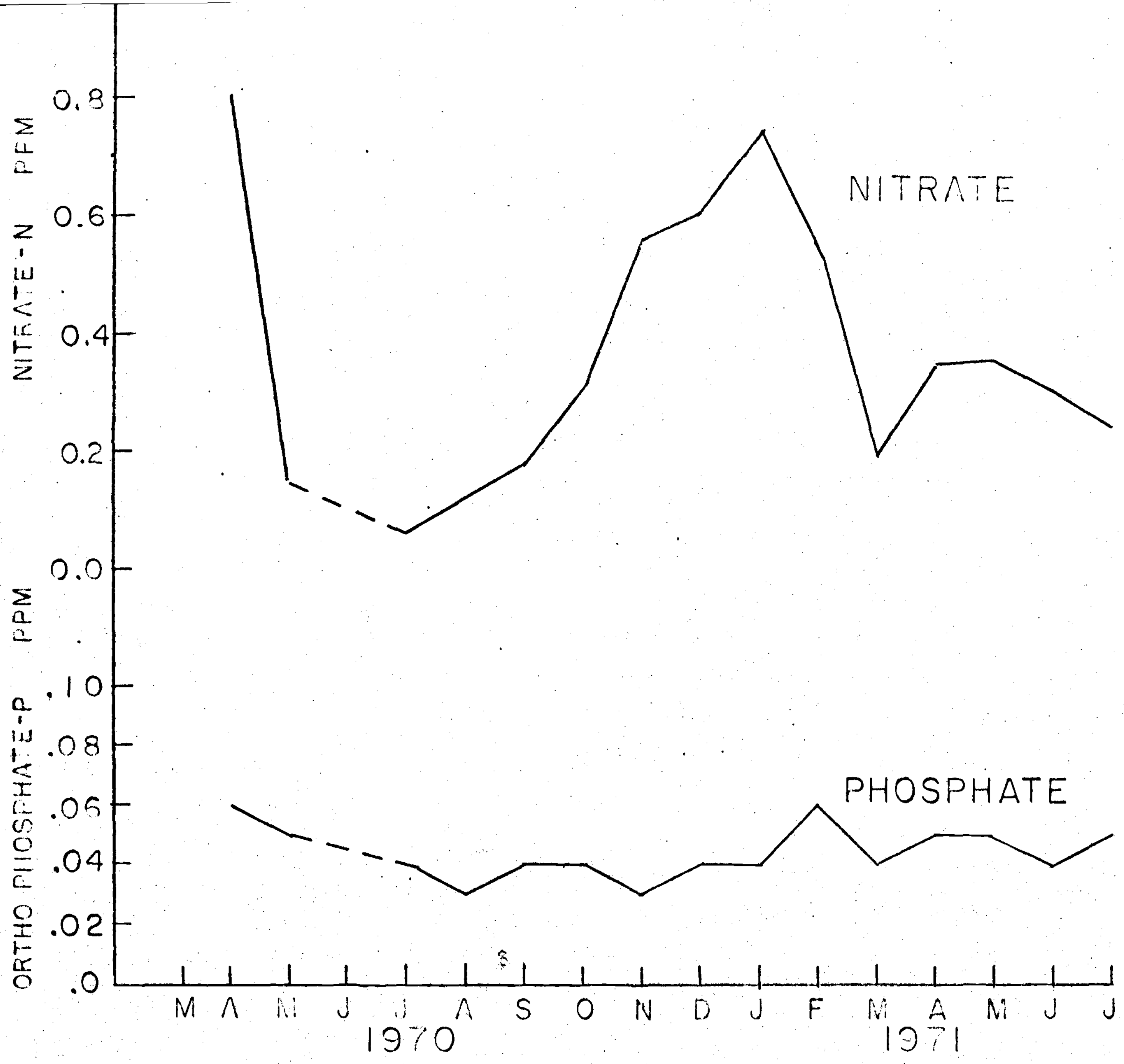

Figure 21. Monthly determinations of nitrate and phosphate in ppm in water entering the experimental stream channels.

THE INVERTEBRATE FAUNA COMMUNITY

Methods

To collect data for an algal and insect analysis, benthos sampling was done twice each month beginning February, 1970. The sampling method consisted of placing a cylindrical sampler on the substrate and removing the large rocks and gravel from inside of the sampler until a "solid" substrate was reached. A foam rubber pad on the bottom edge and extending laterally from the sampler provided a nearly complete seal to water. The rocks and gravel as they were removed were scrubbed with brushes to remove and collect algae and insects. The slurry remaining in the enclosed area was pumped out of the sampler and through a 118 microns mesh net.

A sample of the filtrate was collected to provide an estimate of the algal material lost in the filtering process. All samples were placed in polyethylene bags and frozen.

Each stream has 11 riffles, only eight of which were sampled. For example: riffles 1, 4, 7, 11 were sampled one week and riffles 2, 5, 8, 10 were sampled two weeks later. Thus, a particular riffle was sampled only once each month. The samples from the individual riffles were kept in separate bags. Then 25 percent of each riffle sample from a given stream was combined with those of the other riffles to form a composite sample for that stream. A composite sample for each of the three streams was thus collected on each sampling date. A 12.5 percent aliquot of each composite sample was sorted under a binocular dissecting scope to remove nearly all of the salmon food organisms. Another 12.5 percent aliquot of each composite sample was refrozen for the algal analyses. On selected dates, 50 percent of the sample from each riffle was processed without the aid of a binocular scope. Biomass was the parameter being estimated, and only a negligible amount was missed by not using a dissecting scope.

The plant material remaining in the various samples after the insects were removed was dried at 70-80C, weighed, and ashed at 600C. The difference between dry weight and ash weight was considered to be an estimate of organic matter. The insects were blotted dry before being weighed on an analytical balance with an accuracy of 0.1 mg.

Results

Soon after water flow was started in October, 1969, the streams underwent a period of rapid natural colonization from organisms in the Willamette River water used and from egg deposition by adult insects. The insects that have colonized the stream are typical river species. The species diversity is somewhat lower than in some woodland streams, such as Oak Creek (Kerst, 1969) and Berry Creek (Warren, et al, 1964), but it is apparently rather similar to the Willamette River fauna.

The major immature insect groups are caddisflies (*Hydropsyche*), blackfly larvae (*Simulium*), and midge larvae (Chironomidae). Immature insects such as beetles (Coleoptera), dance fly larvae (Empididae),

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Kerst, Cary D. 1970. The seasonal occurrence and distribution of stoneflies (Plecoptera) of a Western Oregon stream. M.S. Thesis. Oregon State University, Corvallis.

Warren, Charles E., J. H. Wales, G. E. Davis, and P. Doudoroff. 1964. Trout production in an experimental stream enriched with sucrose. J. Wildl. Mgmt. 28(4):617-660.

crane fly larvae (Tipulidae), stoneflies (Plecoptera) Lepidoptera, other caddisflies, *Agraylea* and *Oxythira*, and mayflies (Ephemeroptera) are also present, although no definite trends in biomass through time have been noted. Snails (Physidae) are also present in the streams, but their abundance varies greatly. *Gammarus*, an amphipod, is relatively abundant. The following presentation of results will be based mainly on the midge larvae (as the family Chironomidae), *Hydropsyche*, *Simulium*, *Agraylea*, dance flies, craneflies, *Gammarus*, total mayflies, and snails.

Total biomasses of insects in the three streams were similar until September, 1970 (Figure 22). Then stream 2, the stream receiving effluent, became consistently lower in insect biomass. The lower biomasses in stream 2 were due primarily to low biomasses of *Hydropsyche* (Figure 23). This insect did not appear in large numbers in the streams until September, 1970. *Simulium* was present from December, 1969, but during August and September, 1970, became less abundant in Stream 2 (Figure 24). Both of these genera forage by filtering the water.

Individual riffle samples (1, 4, 7, 11) taken during August to November, 1970, were compared for biomass of *Hydropsyche*. It appears that riffles 1 and 4 were less productive in stream 2 than in streams 1 and 3, but on riffle 7 and 11, biomass of *Hydropsyche* in stream 2 was comparable to biomasses in streams 1 and 3. The biomass of *Simulium* was too variable on individual riffles to determine if they likewise recovered by riffle 7. *Sphaerotilus* was quite apparent in the upper riffles of stream 2 during August and later. The decrease in *Hydropsyche* and *Simulium* in stream 2 could be due to a direct toxic effect or to an indirect effect such as a change in substrate, because of an altered plant community, or to a combination of toxicity effects and substrate changes.

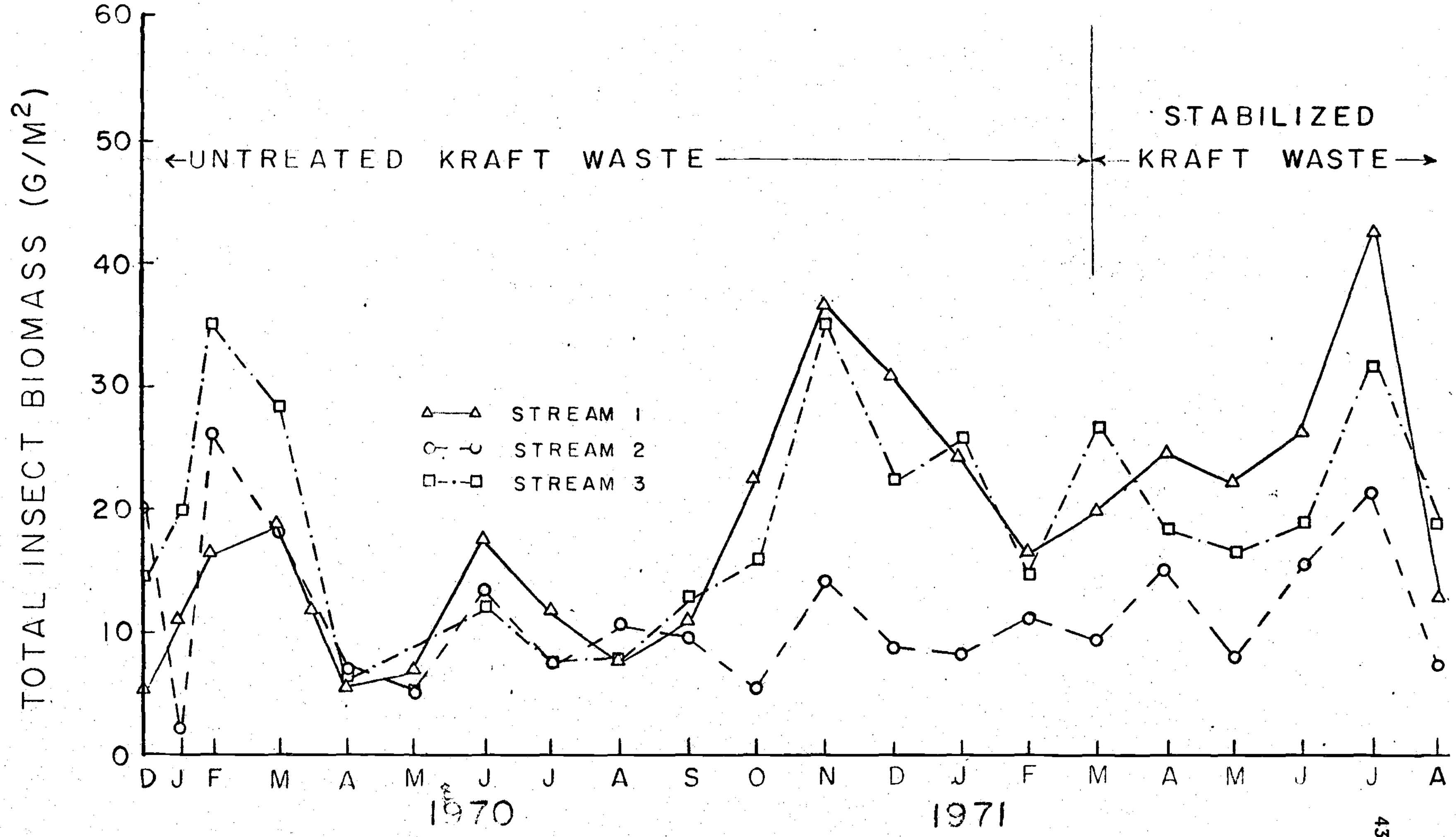


Figure 22. Total insect biomass in the experimental stream channels expressed in grams per square meter. Stream 2 received 0.5 mg/l BOD of kraft mill effluent.

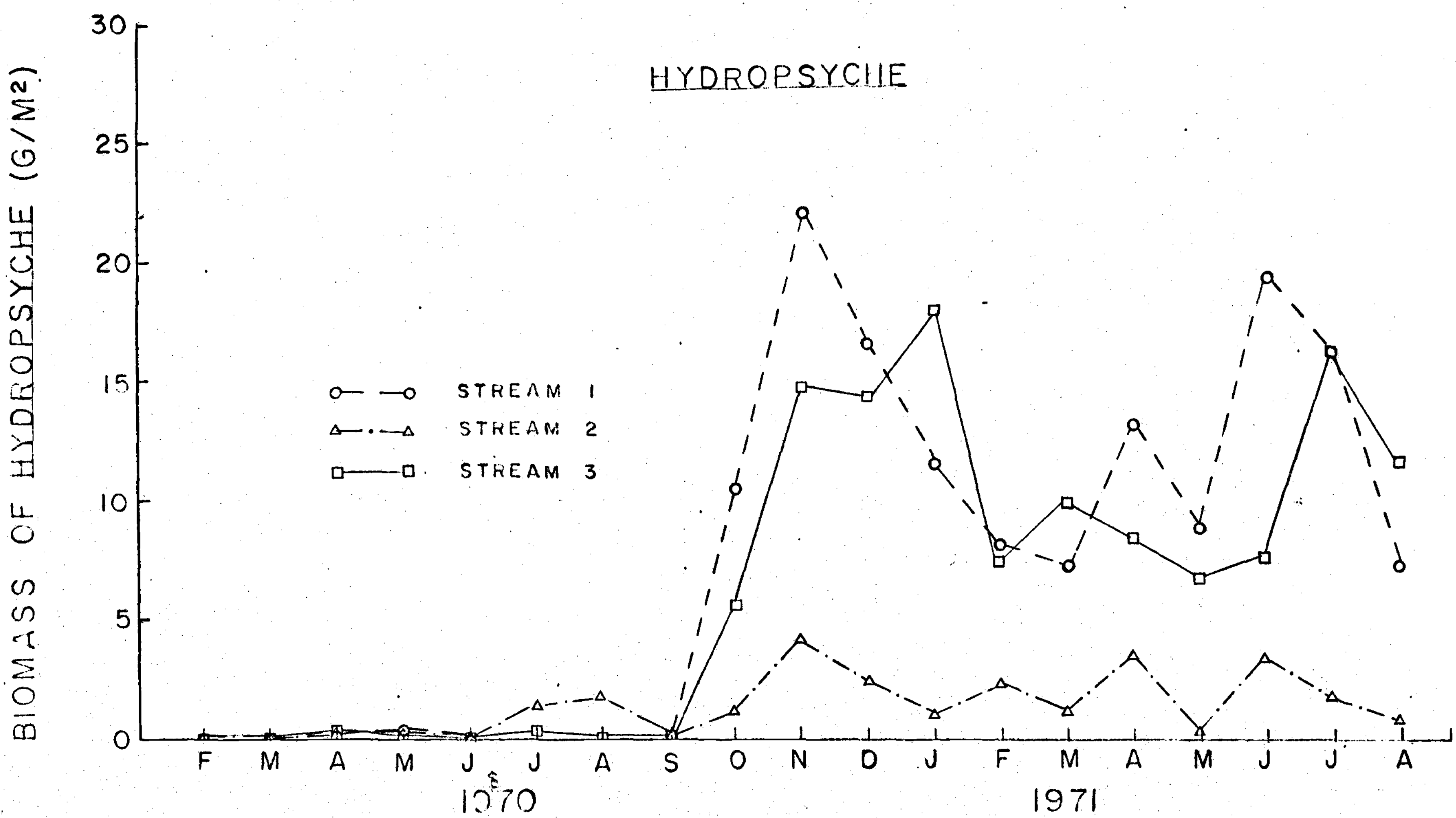


Figure 23. Biomass of *Hydropsyche* (Tricoptera) in the experimental stream channels, expressed in grams per square meter. Stream 2 received 0.5 mg/l BOD of kraft mill effluent.

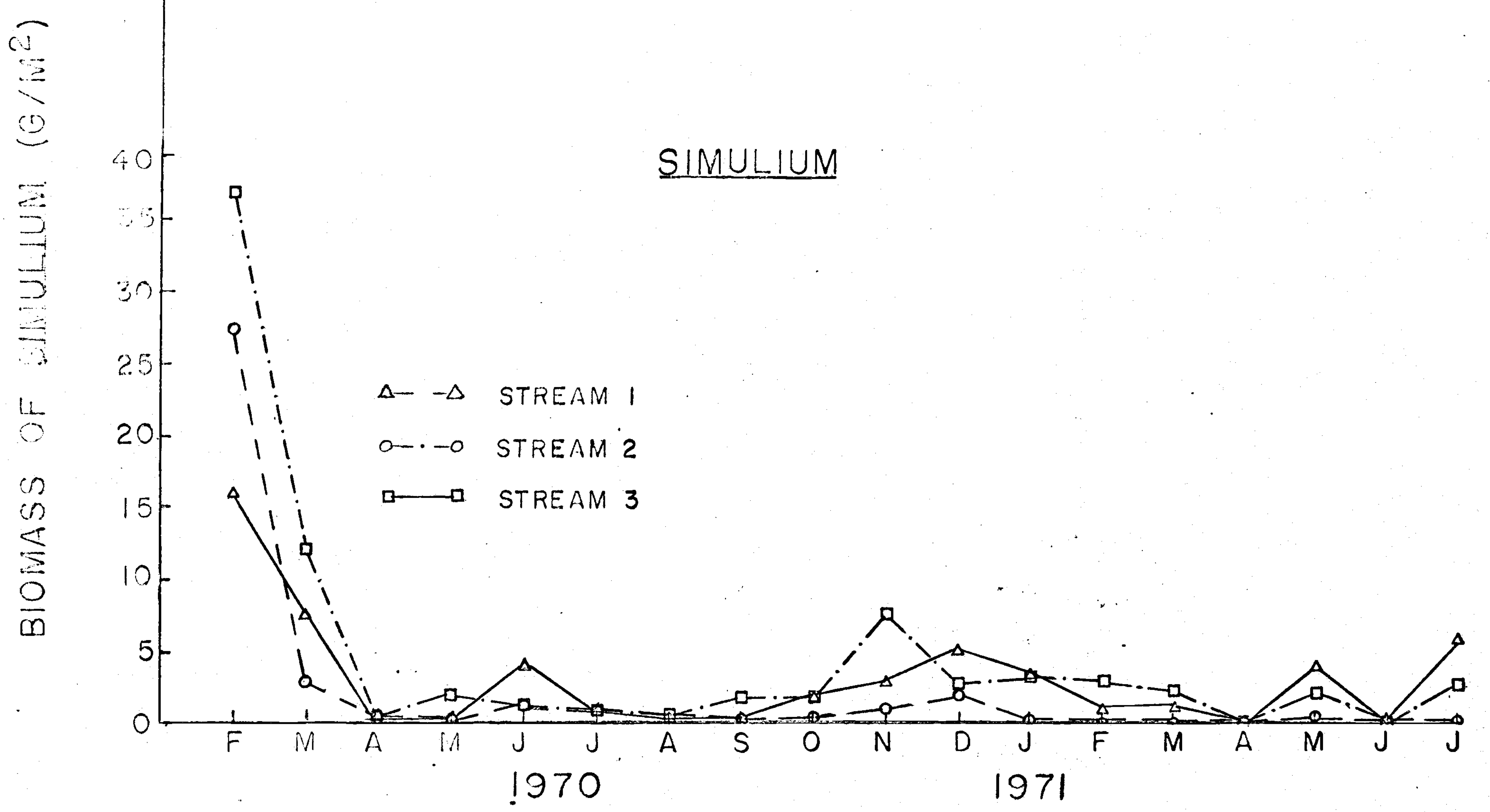


Figure 24. Biomass of *Simulium* (blackfly) larvae in the experimental stream channels, expressed in grams per square meter. Stream 2 received 0.5 mg/1 BOD of kraft mill effluent.

No biomass difference in the streams was observed for the family Chironomidae (Figure 25). This may be because all genera have been grouped into 1 taxon. If each genus were separated, differences would perhaps be found. Preliminary generic identification of midge larvae samples for January, April, and July, 1971, samples indicate that *Cricotopus* may be more abundant in stream 2. It appears that *Tanytarsus* was less abundant in stream 2.

Gammarus became abundant in the streams from about September, 1970, and was consistently lower in stream 2 until April 1, 1971 (Figure 26). Stabilized effluent was started in stream 2 in March, 1971.

The other minor groups of insects such as *Agraylea*, Empididae, Tipulidae and Emphemeroptera were not present in sufficient quantities to warrant definite conclusions, but some evidence suggests that the untreated effluent was detrimental to these groups. There is insufficient evidence to warrant any conclusions concerning the stabilized effluent.

Snails were abundant in the streams during July, 1970, through February, 1971. It appears that no detrimental effect occurred on the snails. After February, 1971, snail biomasses were too low for comparisons to be made. It should be noted that Figures 22 through 26 indicate control streams 1 and 3 supported quite similar biomasses of insects and appear to be serving as effective controls for comparison with stream 2.

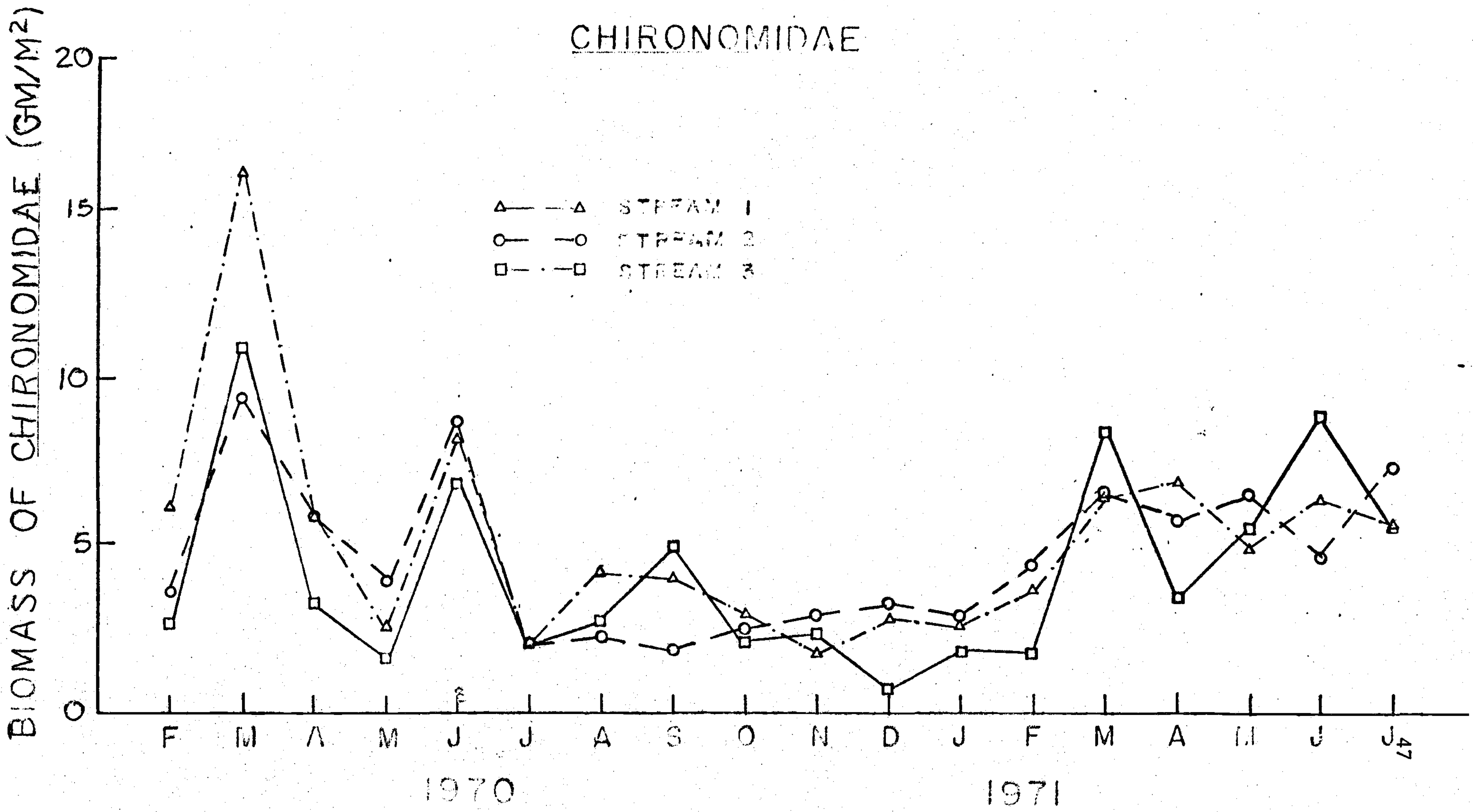


Figure 25. Biomass of the Chironomidae (midge) larvae in experimental stream channels, expressed in grams per square meter. Stream 2 received 0.5 mg/l BOD of kraft mill effluent.

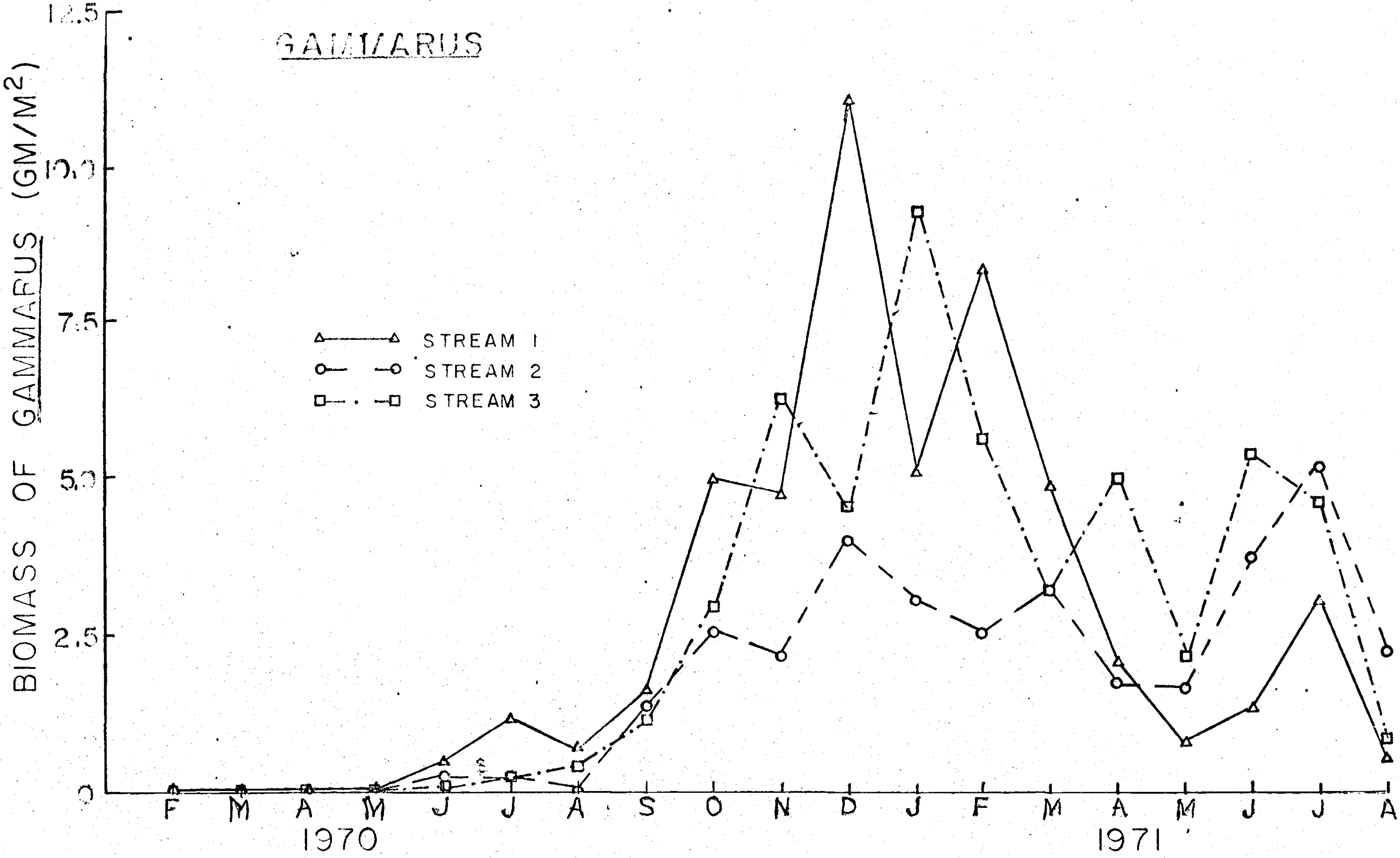


Figure 26 Biomass of *Gammarus* (Amphipoda) in experimental stream channels, expressed in grams per square meter. Stream 2 received 0.5 mg/l BOD of kraft mill effluent.

THE ALGAL COMMUNITY

Methods

Excepting periodic grab samples, samples used for plant studies were taken in conjunction with the insect sampling program. Plant analyses have been generally of five types: (1) Dry weight and ash-free dry weight of subsamples provided one kind of estimate of organic material present; (2) pigment extracts (chlorophyll a, pheophytin a, non-astasin carotenoids) were prepared in order to estimate actual plant content and relation of living to detrital organic matter; (3) an aliquot was dried for later calorimetric analysis; (4) fractions were used to prepare microscope slides to examine plant community structure including the larger, filamentous species and the diatom flora; and (5) on site observations and miscellaneous grab samples have been used to get an overall idea of plant distribution, abundance, succession, and estimate of abundance of higher plants such as *Azolla* (a floating fern), *Lemna*, *Spirodela*, and *Potomogeton* (Angiosperms).

Results

Analysis of ash free dry weights of benthic samples indicates the biomass of organic matter varies considerably throughout the year (Figure 27). The large increase during January and February 1971 may be the result of high nitrate content of Willamette River water during this period (Figure 21). No consistant difference in organic matter between streams is apparent, although values for stream 2 are lower during several periods.

Table 4 is a partial list of concentrations of plant pigments

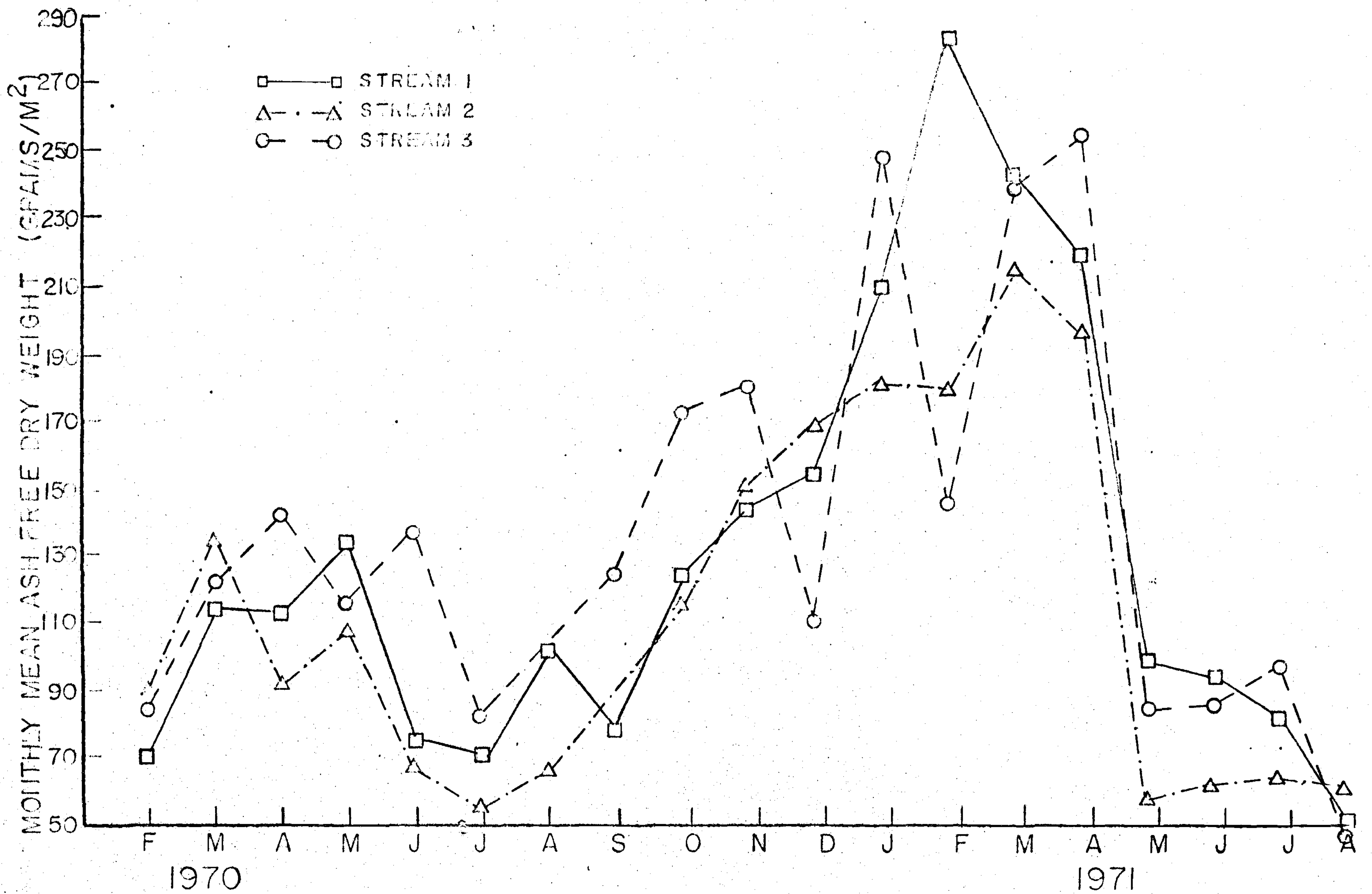


Figure 27. Monthly means of ash-free-dry-weight of benthic samples from experimental stream channels, expressed in grams per square meter. Insects were removed before analysis. Stream 2 received 0.5 mg/l BOD of kraft mill effluent.

Table 4. Pigment analyses of plant material from experimental stream channels.

Date	Stream 1			Stream 2			Stream 3		
	Chlorophyll	Pheophytin (degradated chlorophyll)	Carotonoids	Chlorophyll	Pheophytin (degradated chlorophyll)	Carotonoids	Chlorophyll	Pheophytin (degradated chlorophyll)	Carotonoids
1970									
March 3-21	0.298	6.305	0.142	0.688	13.798	0.223	-	-	-
April 4-18	0.686	16.286	0.260	1.730	44.216	0.566	1.012	26.300	0.411
March 5-16	0.397	9.398	0.158	0.906	23.008	0.352	0.973	21.932	0.308
June 6-13	0.650	15.254	0.202	0.730	15.474	0.223	0.683	11.926	0.204
July 7-10	0.265	3.516	0.098	0.642	1.466	0.206	0.384	1.587	0.122
August 8-16	0.688	14.023	0.278	0.956	21.434	0.386	0.824	18.501	0.339
Sept. 9-14	-	-	-	-	-	-	-	-	-
Oct. 10-17	1.040	23.261	0.384	1.308	26.845	0.565	1.414	32.216	0.514
Nov. 11-17	-	-	-	-	-	-	-	-	-
Dec. 12-15	0.888	-	-	0.826	-	-	0.716	-	-

analysed from benthic riffle samples during 1970. No significant differences in pigment density can be attributed to the effluent. Further partitioning of chlorophyll type is in progress but definitive results are not now available.

Data on diversity and distribution of algae is now being obtained. The primary component in terms of variety and numbers of individuals is made up of diatoms, followed by the green algae. The following brief preliminary list includes the dominant forms observed in grab samples and in the filtrate obtained in regular sampling. Regular samples from the streams will also be examined.

DIATOMS
- *Achnanthes lanceolata*
- *Cocconeis placentula* var *lineata*
- *Cymbella*
- *Diatoma*
- *Epithemia turgida*
- *Fragillaria*
- *Gomphonema*
- *Melosira granulata*
- *Melosira varians*
- *Navicula cryptocephala* var *veneta*
- *Navicula*
- *Nitzschia*
- *Pinnularia*
- *Surirella angustata*
- *Rhoiocosphenia curvata*
- *Tabellaria*
- *Hannaea*
- *Frustulia vulgaris*

OTHER ALGAE
- *Hydrodictyon reticulatum*
- *Oedogonium*
- *Phormidium-Oscillatoria*
- *Spirogyra*

SALMON AND TROUT GROWTH AND PRODUCTION

Methods

Each species of salmonid was stocked in the streams at an initial density of about 2 g/m^2, which is approximately equal to the density of trout alone in local coastal streams. Cutthroat (*Salmo clarki*) were stocked on February 12, 1970. Coho salmon (*Oncorhynchus kisutch*) were added on April 18, 1970. All of these fish were killed in June 1970 as a result of an epidemic of *Ceratomyxis shasta*. For this reason, the more resistant species, fall chinook (*Oncorhynchus tshawytscha*) and brown trout (*Salmo trutta*), were stocked in the streams. When small fish were stocked, great numbers of fish were used, but the initial stocking density for each species was 2 g/m^2.

Fish were removed from the streams at monthly intervals by seining and electrofishing. The fish were then anesthetized, weighed, and the food removed from the stomachs by means of forceps. The fish were then returned to the streams. Any fish attempting to leave the streams were caught in traps below the streams. Fish found in the traps within the first two weeks after weighing were returned to their respective streams; but after the first two weeks, fish found in the traps were assumed to be migrating fish and were therefore weighed and not returned to the streams.

Fish production was calculated by graphing the numbers of fish found in each stream against the average weight of the fish. The area under this curve yields an estimate of fish production very nearly the same as an estimate obtained mathematically. Relative growth rate of the fish was calculated by dividing the production by the product of the fish biomass and number of days the fish were in the streams.

Results

Untreated Effluent

From studies of the composition of food found in trout stomachs, it is evident that the order Diptera and particularly the chironomids are an important food source for salmonids in the three streams. Figure 28 shows the relationship between the growth rate of small cutthroat trout and the density of chironomids in each stream during spring months. Similar relationships were found for the growth rates of large cutthroat trout. Figure 28 suggests that stream 3 fish have greater growth rates than streams 1 or 2 at similar chironomid densities. Because both streams 1 and 3 are controls, there should be no great differences in the efficiency of food utilization between these streams. The differences in growth rate then could be because of a greater availability of other species of food organisms in stream 3 during this period or because of better physical conditions for holding trout in this stream. Stream 3 had slightly higher production of trout and coho salmon than stream 1 or 2 (Figure 29).

During summer months, brown trout of approximately equal size were stocked in the streams. Figure 30 indicates the growth rate of these trout was also directly related to the chironomid density. At a given food density, the growth rate of fish in stream 2 was lower than that of stream 1 or 3, the control streams. Actually, fish growth rate in stream 2 was about the same as the growth rates in streams 1 and 3, but because the chironomid density was higher in stream 2, the curve is shifted to the right and is below the curve for streams 1 and 3. This

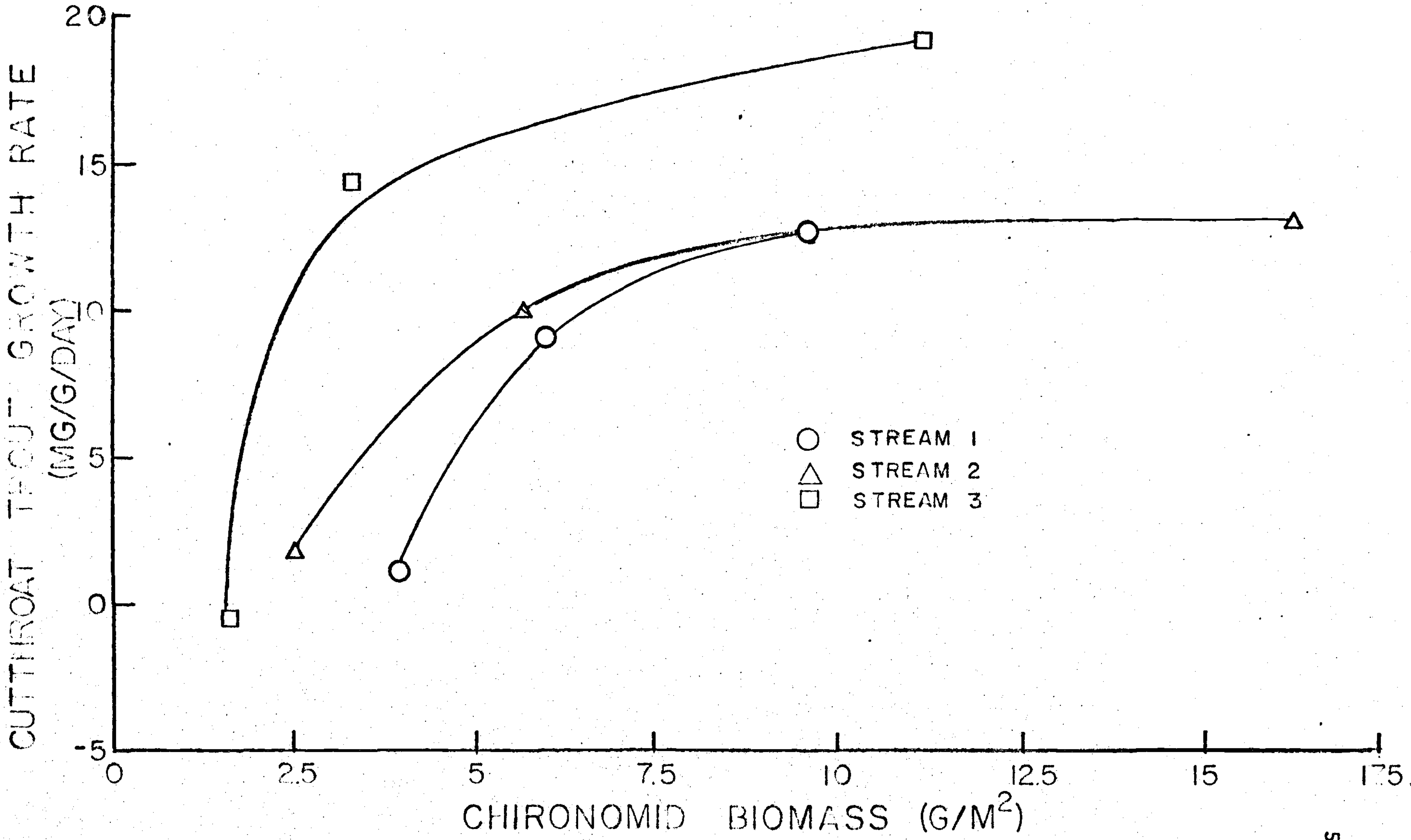
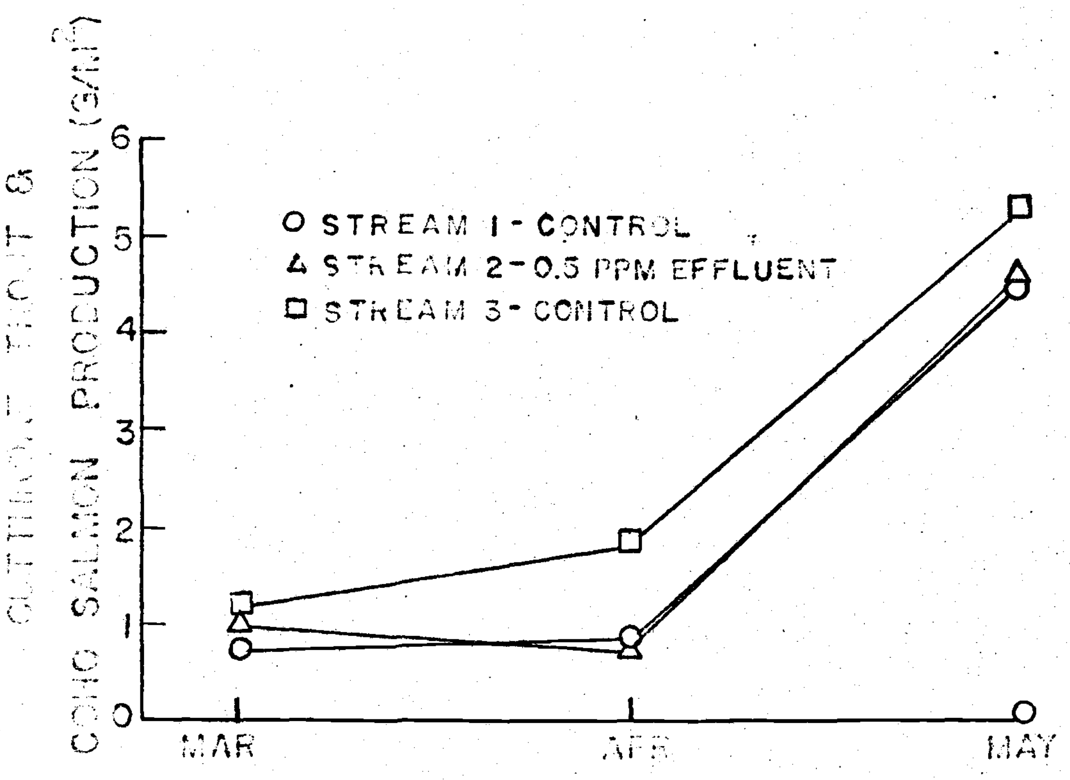


Figure 28. Relationship between cutthroat trout growth rate and the biomass of chironomid (midge) larvae in experimental stream channels. Stream 2 received 0.5 mg/l BOD of untreated kraft mill effluent.



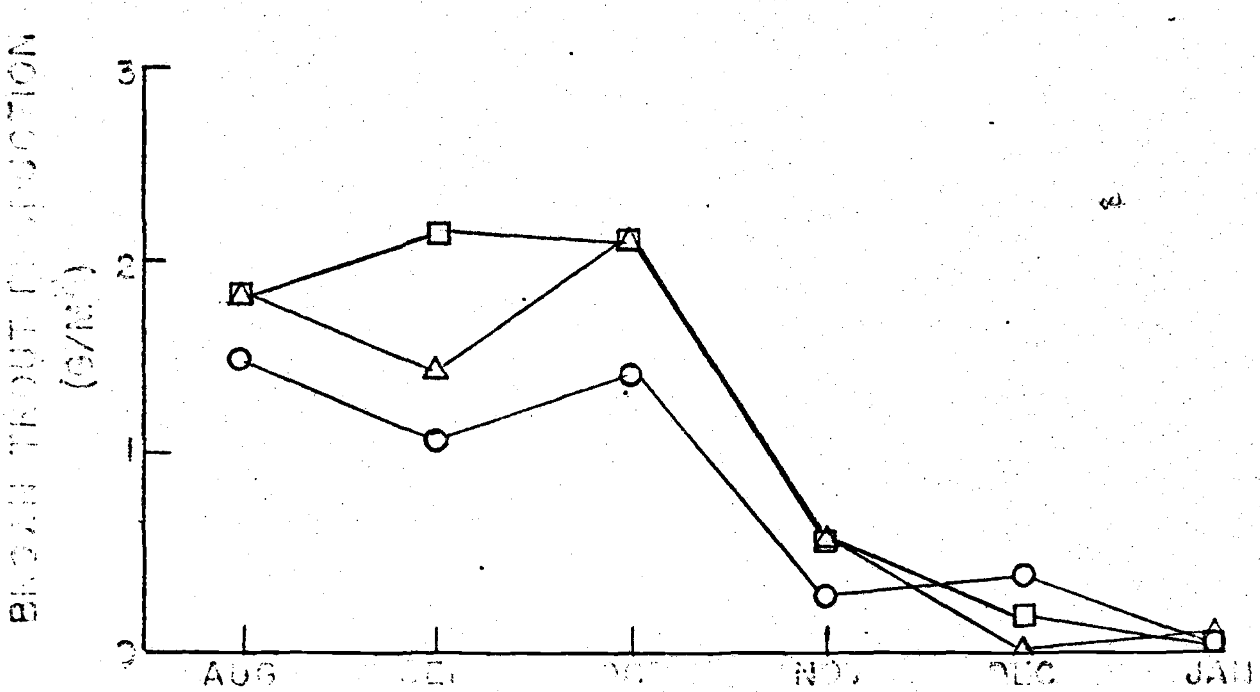


Figure 29. Salmonid production in experimental stream channels during 1970. Stream 2 received untreated effluent at 0.5 mg/1 BOD during this period.

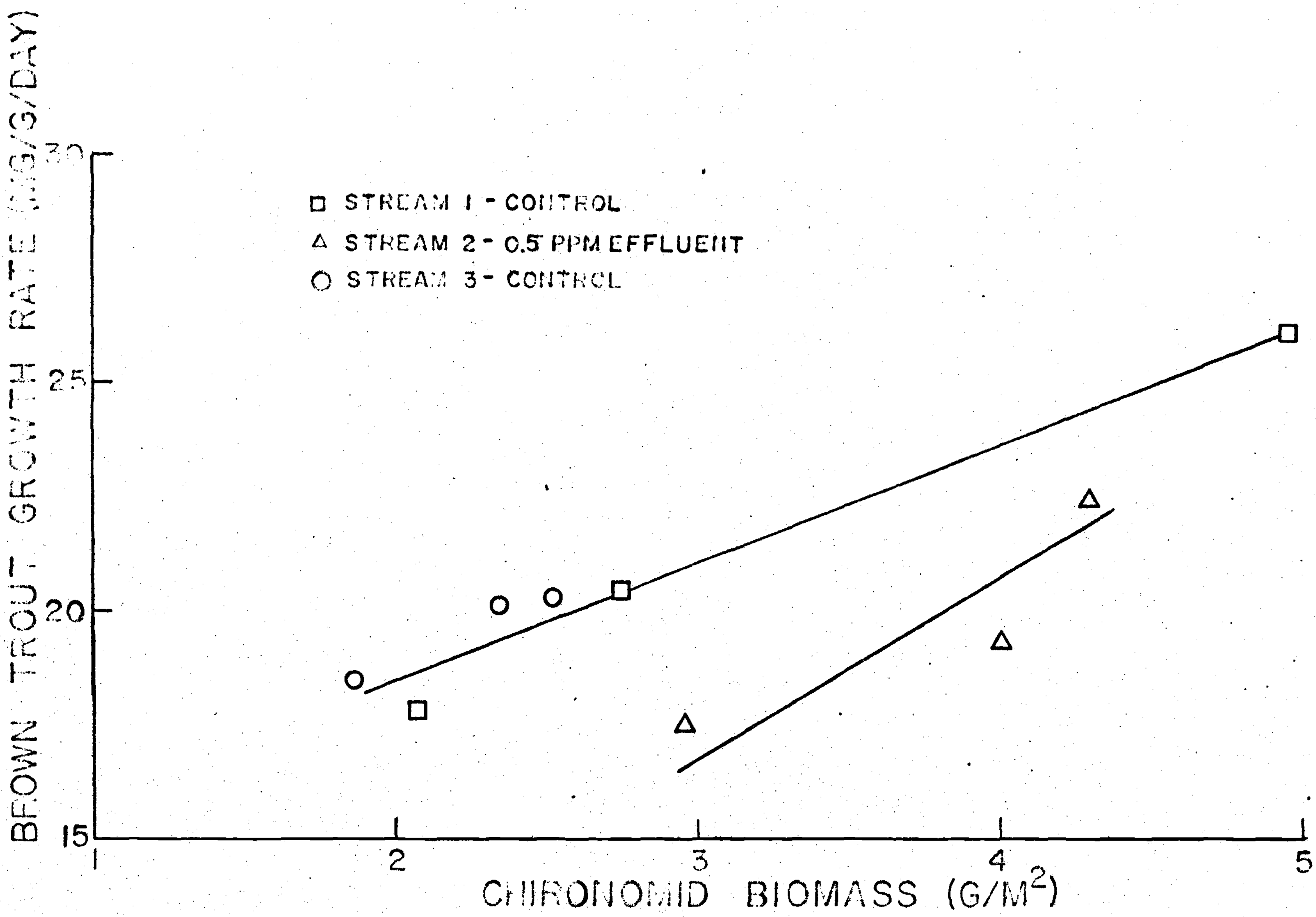


Figure 30. Relationship between trout growth rate and chironomid (midge) larvae biomass in experimental stream channels. Stream 2 received untreated effluent at 0.5 mg/l BOD during this period.

suggests that the untreated effluent at 0.5 mg/l BOD may have had some direct depressive effect on the growth of the fish in stream 2, but that this was offset by greater food availability. Similar results were discussed earlier for aquarium and laboratory stream studies. The production of trout in stream 2 during this period was actually higher than in stream 1 and nearly equal that in stream 3. This is because growth rates were similar in the three streams but biomass of trout was lower in stream 1. Fish were originally stocked at equal densities in all streams, but were allowed to emigrate. The biomass of fish in stream 1 was lower after the first month and did not attain the biomass levels of streams 2 or 3 (Figure 31). Stream 1 was apparently at a lower level of productivity than streams 2 or 3 during this period, and it may have a lower physical capacity to hold fish. In winter months, the production of fish drops severely. This is probably because of the large temperature drop during the winter months, as food is still moderately abundant. In summary, the stream receiving untreated effluent at 0.5 mg/l BOD was not found to have a significantly different capacity to produce valuable salmonid species when compared to the two control streams. Production in the treatment stream was generally intermediate with stream 1 slightly lower and stream 3 slightly higher.

Stabilized Effluent

Stabilized kraft effluent was introduced into stream 2 on March 16, 1971, at a concentration of 0.5 mg/l BOD. Chinook salmon present in the streams began their normal seaward migration later that spring and so were replaced by brown trout during the summer and fall. Preliminary analysis of this recent data indicates that no large differences in

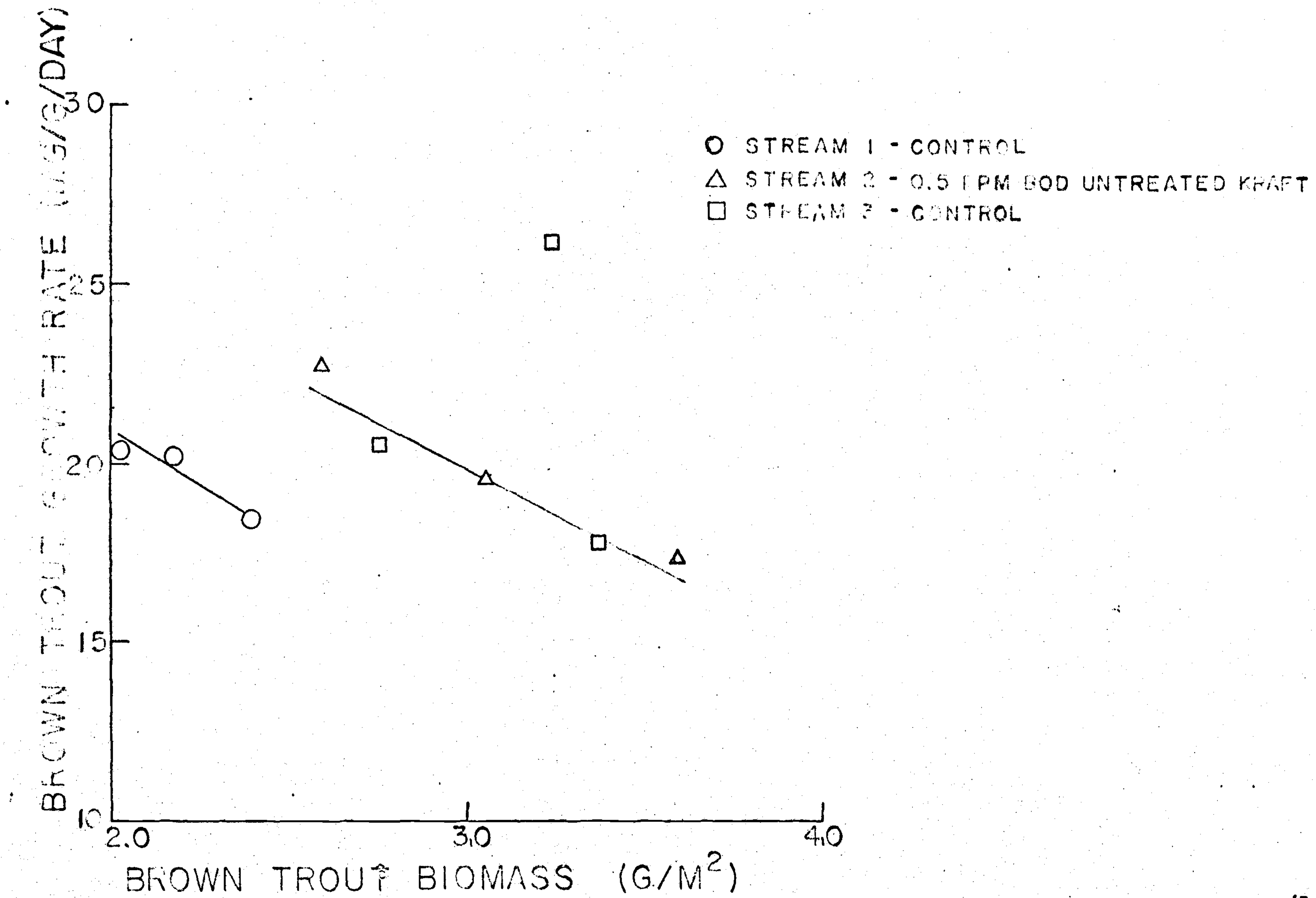


Figure 31. Relationship between brown trout growth rate and biomass in experimental stream channels. Stream 2 received 0.5 mg/l of untreated kraft mill effluent.

the production of salmonids in the three streams occurred.

Discussion

Since some reduction in populations of insects could be demonstrated during this research, with several species apparently being more sensitive to kraft mill effluent than others, the similarity in salmon production in the three streams should be examined. The importance of one insect family, the Chironomidae, to the success of salmonids in these streams is demonstrated by the close relationship between Chironomidae biomass and fish growth rate in Figures 28 and 30. Examining the density of chironomids through time (Figure 25), indicates that this family of insects was at least as abundant in stream 2 as in 1 or 3. These biomasses were, in fact, remarkably similar in all streams. This similarity in fish production even when total insect biomass was reduced in stream 2 resulted, apparently, from the existence of approximately equal biomasses of the most important food organisms, the Chironomidae, in all streams. This appears to demonstrate the greater resiliency to water quality changes of more diverse communities as compared to simplified laboratory stream communities.

CONCLUSIONS BASED ON RESULTS OF PHASE I AND PHASE II

Aquarium Studies

Untreated Kraft Effluent

1. In aquarium studies, concentrations of 0.5 mg/l BOD (0.25 percent by volume) and greater of untreated kraft effluent from mill A were found to be detrimental to chinook salmon fed on tubificid worms. The effect on salmon growth rate becomes quite apparent at 1 mg/l BOD. Effluent from mill B had little or no effect on the growth of the fish at concentrations as high as 2 mg/l BOD, and little at even 4 mg/l. Mill B was operating a turpene recovery system during this period and was also reusing the evaporator condensates while mill A was not. This may account for the greater toxicity of mill A effluent.

2. Neutralized bleached kraft effluent at concentrations as high as 3 percent by volume did not adversely affect salmon growth rate. Salmon exposed to a 6 percent concentration, however, did exhibit important reductions in growth rate.

Biologically Stabilized Kraft Effluent

3. Biologically stabilized effluent from mill A remained more toxic to fish than stabilized effluent from mill B. Stabilized effluent from mill A reduced growth of salmon in aquaria at concentrations of 0.69 mg/l BOD and greater. No effect upon the growth or food consumption of salmon in aquaria occurred at concentrations of stabilized effluent from mill B as high as 1 mg/l BOD (4.5 percent by volume).

4. When fish are forced to exercise vigorously, concentrations of stabilized effluent as high as 2.2 mg/l BOD may not affect growth rate.

Laboratory Stream Experiments

Untreated Effluents

5. Production of chinook salmon was reduced during spring in laboratory streams receiving untreated effluent from mill A at 1.5 percent by volume (3 mg/l BOD) but not in streams receiving 0.5 percent by volume (1 mg/l BOD). The effect at 3 mg/l BOD was attributed to a direct effect on fish growth rate as no reduction in salmon food density was found.

6. During summer experiments, untreated and stabilized kraft effluent appeared to be less toxic. Summer experiments during 1969 indicated untreated effluent at concentrations as high as 3 mg/l BOD could substantially increase salmon production in laboratory streams. Mill A began operation of a turpene recovery system during this period, which could also have contributed to the reduced toxicity of this effluents.

Biologically Stabilized Effluent

7. In laboratory stream experiments conducted during the spring, winter and fall, stabilized effluent from mill A reduced salmon production at a concentration of 1.5 percent by volume (0.5 mg/l BOD and lower). This was attributed to a direct effect on fish growth rate.

When stabilized effluent was added during summer months, however, salmon production was found to be greater in streams receiving up to 4.0 percent by volume stabilized effluent (about 1.0 mg/l BOD) than in control streams. In summer experiments, after mill A began operation of turpene recovery equipment, production in streams receiving 7.5 percent stabilized waste (1.5 mg/l BOD) was slightly greater than production in control streams.

Experimental Stream Channel Studies

8. Untreated and biologically stabilized effluent added to experimental stream channels at 0.5 mg/l BOD reduced total insect density as compared to two control streams. This reduction was mainly the result of low biomasses of *Hydropsyche* (Tricoptera) and partially due to lower biomasses of *Simulium* (Diptera) and *Gammarus* (Amphipoda).

9. No differences in fish production that could be attributed to untreated or stabilized effluent were observed. The stream receiving 0.5 mg/l BOD of effluent was generally intermediate in fish production compared to the two control streams.

10. Fish growth rate was related only to the biomass of one group of insects, the chironomids (midges). The biomass of this family was not reduced by untreated or stabilized kraft effluent at 0.5 mg/l BOD, which is apparently the reason fish production was as high in the treatment stream as in controls.