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

Research Grants
National Council for Air and Stream Improvement
of the Pulp and Paper Industry
and
Northwest Pulp and Paper Association

For period from July 1, 1966 through June 30, 1972

Department of Fisheries and Wildlife
Oregon State University
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Charles E. Warren
Principal Investigator

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GENERAL INTRODUCTION

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

Phase I, extending from July 1, 1966 through June 30, 1969, was 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*) were held in continuous-flow aquaria or in exercise channels at different concentrations of kraft mill 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 were held at different concentrations of effluent in laboratory streams in which insect larvae and crustaceans, produced in the streams, were the food organisms of the young salmonids living and growing in the streams. These studies made it possible to examine not only the direct effects of kraft mill effluents on the growth of the fish but also 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. Laboratory stream communities differ in important respects from natural streams--for example, in having fewer kinds of food organisms for fish--and may not be for our purposes entirely adequate models of natural streams. Thus, a second phase of this research was planned and has been pursued. Phase II of this research, extending from July 1, 1969 through June 30, 1972, has been conducted in three large experimental stream channels, much more nearly representative of natural streams. Construction of these experimental stream channels was completed on October 1, 1969 at the site of a kraft mill. Each stream channel is about 6 feet wide and 320 feet long, and each receives a flow of 0.67 cfs of water pumped from the Willamette River. Different species of salmon and trout were stocked in these stream channels one of which received primary treated effluent for about one year, then biologically stabilized effluent for more than one year. Studies of the growth and production of the salmonids, their food habits, the kinds and availability of insects and other fish food organisms, and the composition and density of the algal community component were conducted.

The research summarized in this report has been conducted under the general supervision of Charles E. Warren. Other staff members of the Department of Fisheries and Wildlife, particularly Gerald E. Davis, George G. Chadwick and Wayne K. Seim, have had major responsibilities. Harry K. Phinney of the Department of Botany has also participated. During the last two years, Mr. Seim has borne the greatest burden of operational supervision of the research. And most of the actual observation and analysis has been done by our graduate students: Erick M. Tokar, Robert H. Ellis, Dennis L. Borton, James A. Lichatowich, Richard E. Craven, Joseph L. Mahoney, Harvey D. Williams and Wayne K. Seim, before he permanently joined

our staff.

This report represents only a general summary of the most important of our findings. More detailed reporting of these and other experiments is to be found in theses listed in the Literature Cited section at the end of this report. Tokar (1968) and Borton (1970) report studies on the effects of kraft mill effluents on salmonid growth in aquaria; Ellis (1968), Seim (1970), and Lichatowich (1970) report effects on fish in laboratory streams; Williams (1969) effects on algae. Borton (Ph.D.), Craven (Ph.D.), and Mahoney (Ph.D) deal with the effects of effluents on salmonids, insects, and algae in the large experimental stream channels.

THEORETICAL CONSIDERATIONS INVOLVING TROPHIC RELATIONS

Understanding of the growth and production of fish in nature must take into account certain basic relationships which we will briefly outline before proceeding. A more complete treatment can be found in Warren (1971).

Production is defined as the total elaboration of fish tissue regardless of the fate of that tissue in any period of time 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), biomass (g/m^2), and time (days). As in Figure 1, the growth rate of the fish in a system having a limited capacity to produce food must decline as the fish biomass increases, because less food is then available per fish. And, since production is the product of growth rate and biomass, production first increases to some maximum with increase in biomass from low levels, and then declines with further increase in biomass (Fig. 1). This must be taken into account in any production studies, if the results are to be properly analyzed.

In 1968, Brocksen, Davis, and Warren 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 development of this point of view by Brocksen, Davis and Warren (1970) and Warren (1971) indicate that the density of the prey is inversely related to the density of the predator within biological systems having a similar basic capacity to produce the prey. In contrast, the densities of the prey and the predator are directly related between systems having different basic productivities (Fig. 2). Thus, an increase in the productivity or capacity of a stream to produce fish food organisms, as might occur with a change

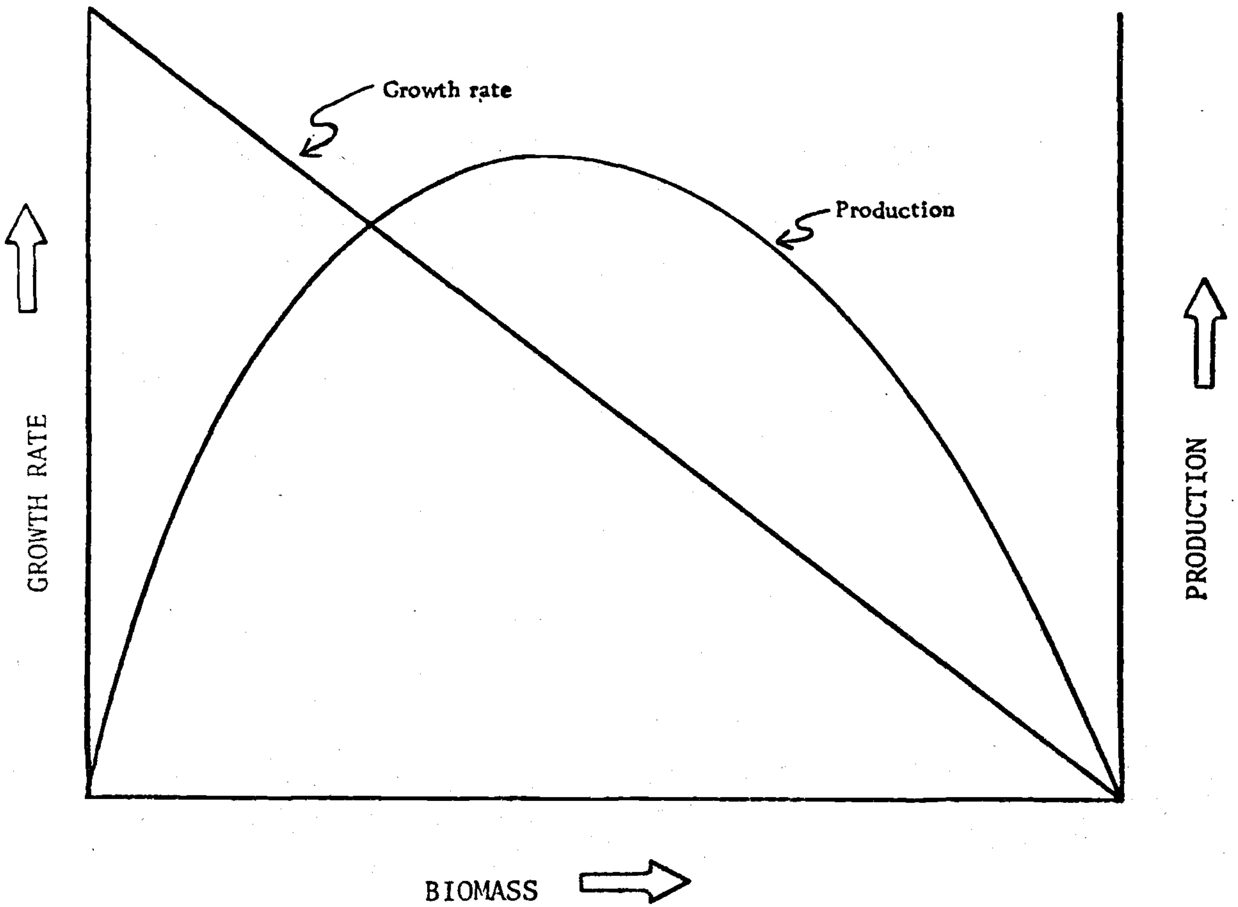

Figure 1. Theoretical relationship between the growth rate of an animal and its biomass and between the production and biomass of the same animal. Production is the product of growth rate and biomass.

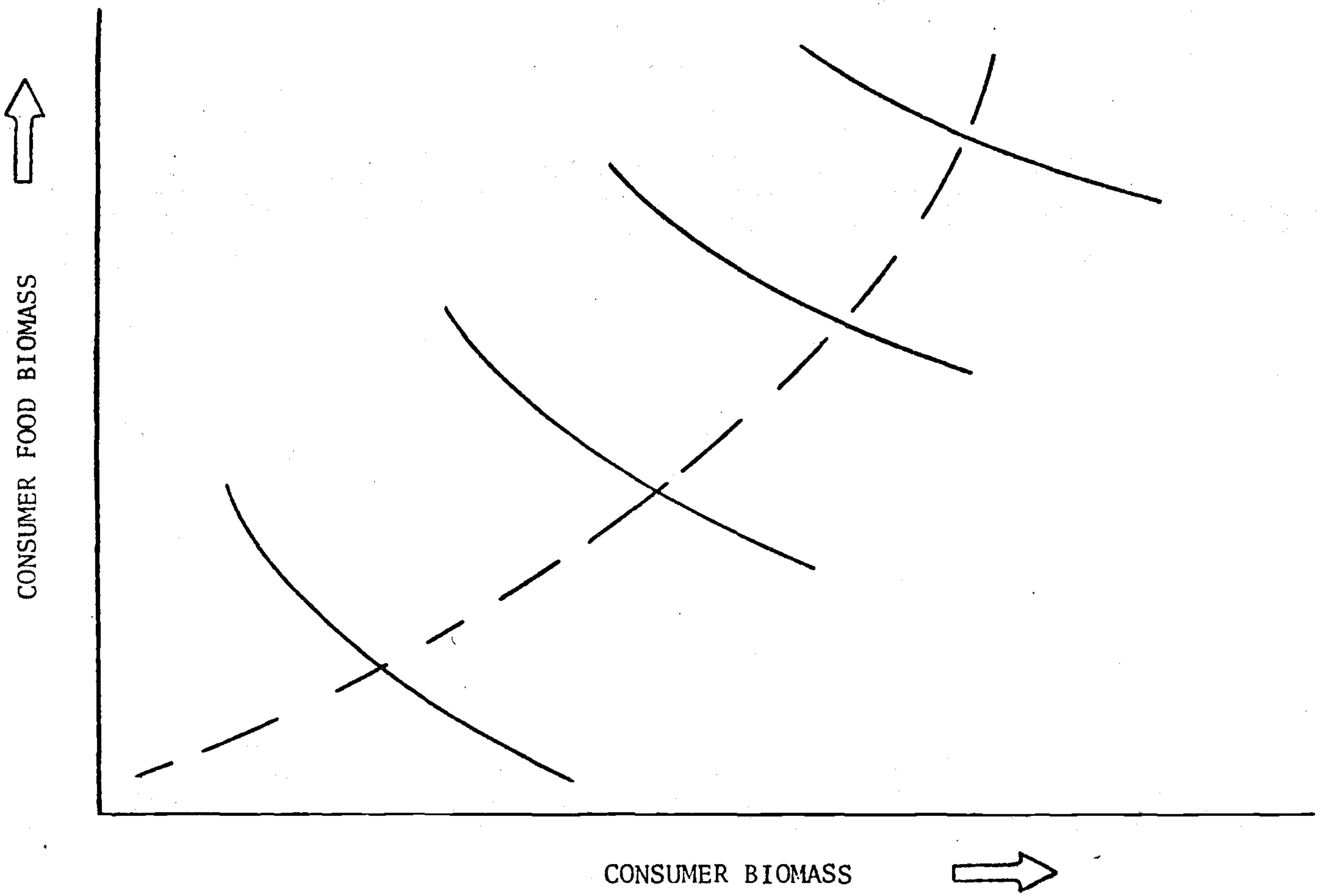

Figure 2. Theoretical relationships between the biomass of a consumer and the biomass of its food. Solid lines represent relationships when basic productivity is constant within a system or equal between systems and the dashed line when systems differ in basic productivity or are changing.

in water quality, would be likely to lead to a higher inverse relation between prey and predator (Fig. 2). For each inverse relationship between the biomass of the prey and the predator (Fig. 2), there exists a corresponding relationship between the biomass of the predator and its growth rate and production (Fig. 1). A change in productivity results in the generation of a new set of relationships between biomass, growth, and production, because of the dependence of prey density on predator density and the dependence of the growth rate of the predator upon the density of the prey, as shown later in Figures 16 and 19. These theoretical relationships are often very helpful in interpreting food and production relations in nature, but they may be obscured in whole or in part in very complex systems, as stream communities often are.

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 food availability varies in nature, it is important that we have information on the effects of toxic substances on the growth of fish at different consumption rates, from all they can or will eat down to just enough for them to maintain their body weight.

Thus, we have measured the growth rates of juvenile chinook salmon exposed to different concentrations of primary treated and of biologically stabilized kraft mill effluents. Groups of fish at each concentration were fed different known amounts of live tubificid worms. Experiments were conducted either in aquaria or in exercise channels, where the fish were forced to swim against a current produced by paddlewheels. Water and effluent in these tests were continuously renewed by constant exchange flows. Figure 3 shows the apparatus most recently used for delivering to the test chambers the concentrations to be tested.

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 body 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 relative growth rate.

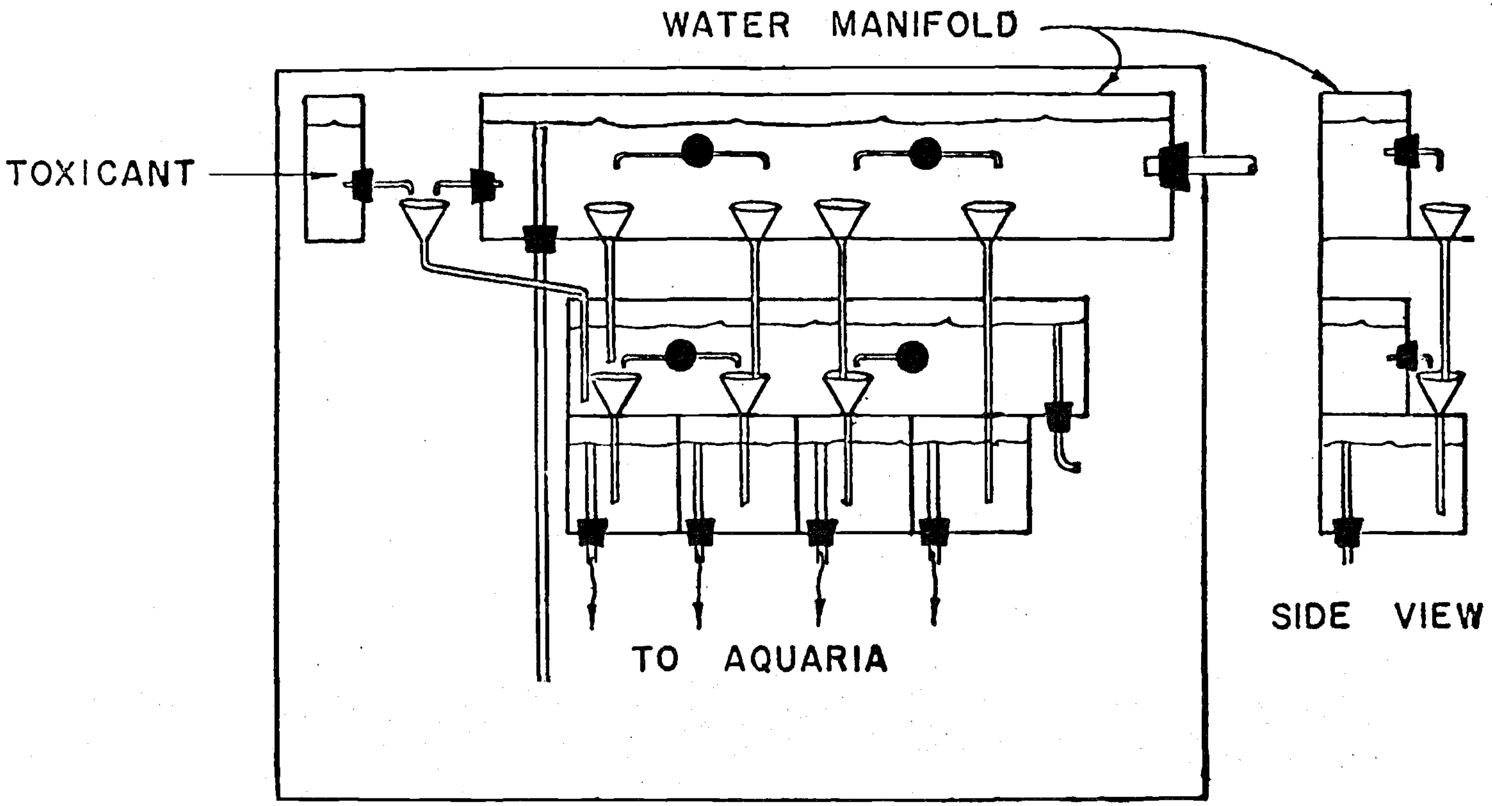

Figure 3. Diagram of the dilution apparatus used for studies of direct effects of primary treated and biologically stabilized kraft mill effluents on the food consumption and growth of juvenile chinook salmon fed in aquaria.

Each day the fish were fed 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 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. Effluents from two local non-bleaching kraft mills, denoted mill A and mill B, were used in these experiments. Effluent samples were characterized by series of tests by personnel of the National Council of the Paper Industry (Appendix I). For one a bleached effluent was formed by combining acid and caustic lime effluents from a bleach kraft mill located in northwestern Oregon with primary treated unbleached kraft pulp effluent from mill B at a 2:1:1 volume ratio of acid to caustic to pulp effluent.

Primary Treated Effluents

The relationships between food consumption rate and growth rate of juvenile chinook salmon at different concentrations of primary treated kraft mill effluent from mill A shown in Figure 4 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 from mill A tested at concentrations higher than 3 mg/l BOD were acutely toxic to some of the fish.

In order to compare results of several experiments on the effects of effluents from mill A and mill B, it was necessary to normalize the growth

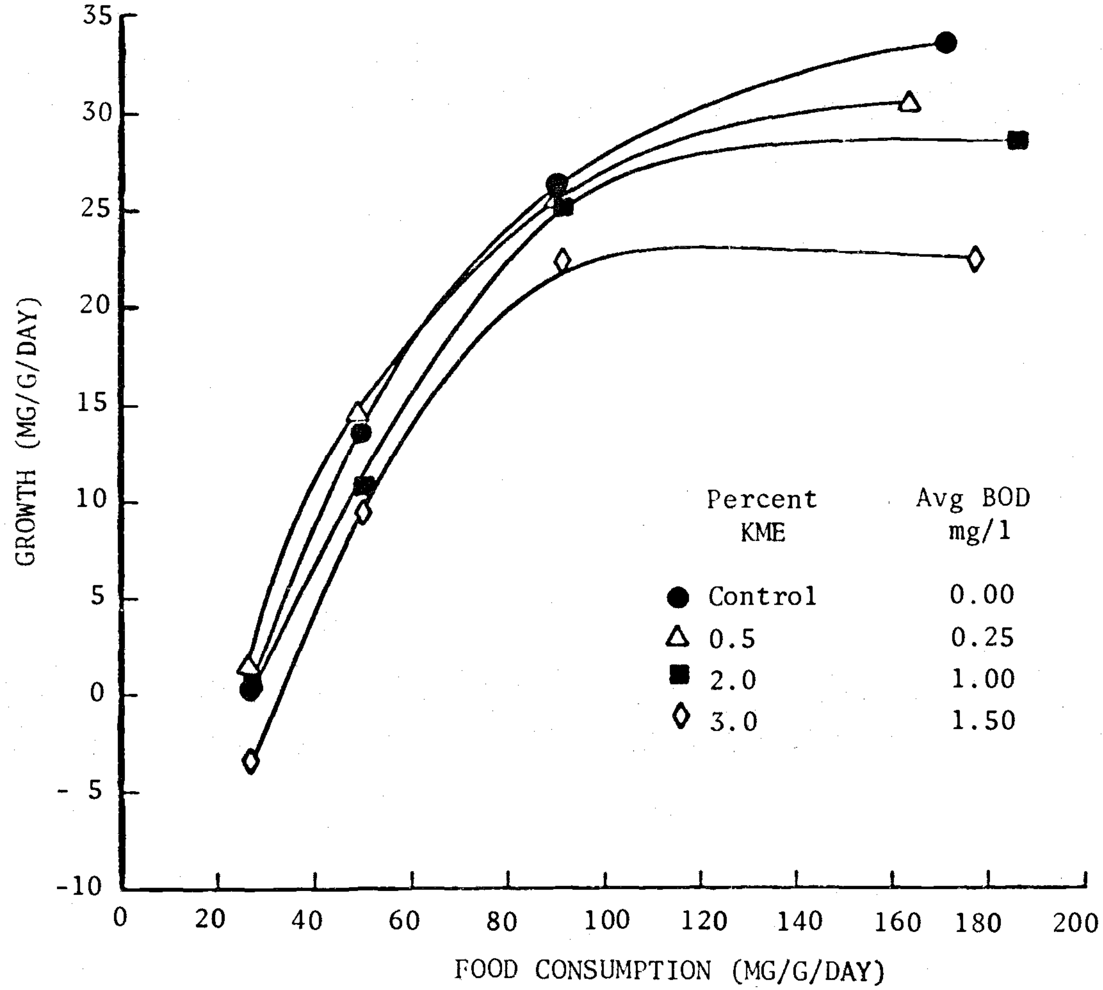

Figure 4. Relationships between the food consumption rate and the growth rate of juvenile chinook salmon held in aquaria at different concentrations of primary treated effluent from mill A. From Tokar, 1968.

rates of the fish by taking the growth of control fish to represent 100 percent. Dividing the growth rates of fish at each treatment by the control growth rate and multiplying by 100 results in a percent growth for each group. When this is done, as in Figure 5, two things become apparent. First, the effect on the growth of the fish of primary treated 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, primary treated 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 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 composited waste was less toxic than unbleached kraft effluent on both a volume and a BOD basis. Concentrations as high as 3 percent by volume did not adversely affect salmon growth rate (Figs. 6 and 7). Salmon exposed to a 6 percent concentration, however, did exhibit reductions in growth rate (Fig. 7).

Biologically Stabilized Effluents

With increasing utilization of our waters, waste treatment has become the order of the day. It has become important, then, to investigate the effects of low concentrations of treated kraft mill effluents on the growth and production of fish. The first objective of treatment of wastes having high BOD is usually BOD reduction in order to conserve oxygen resources in

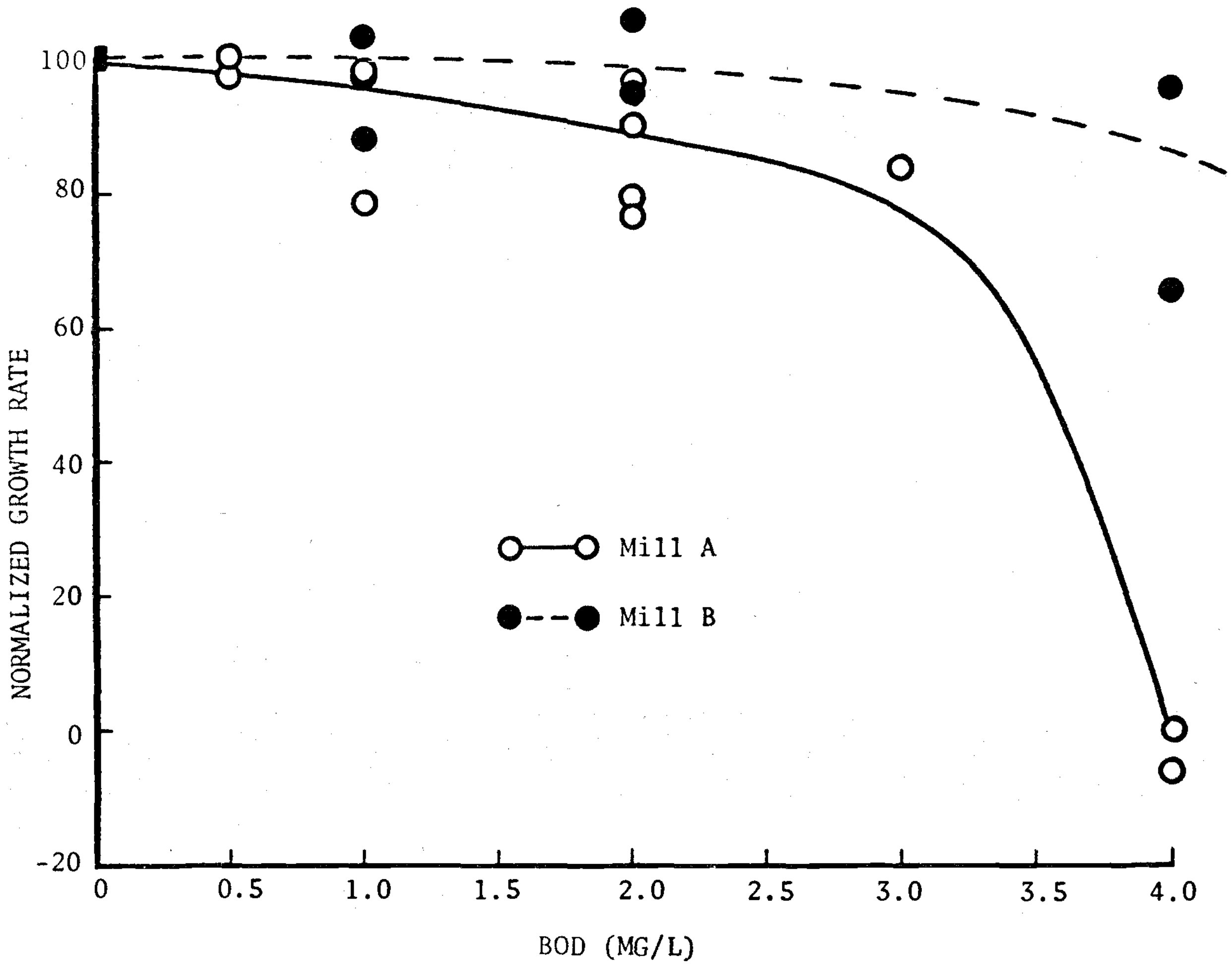

Figure 5. The relationship of normalized growth rates of chinook salmon kept on high restricted (daily repletion) rations to the concentrations of primary effluent from two kraft mills to which they were exposed. From Tokar, 1968.

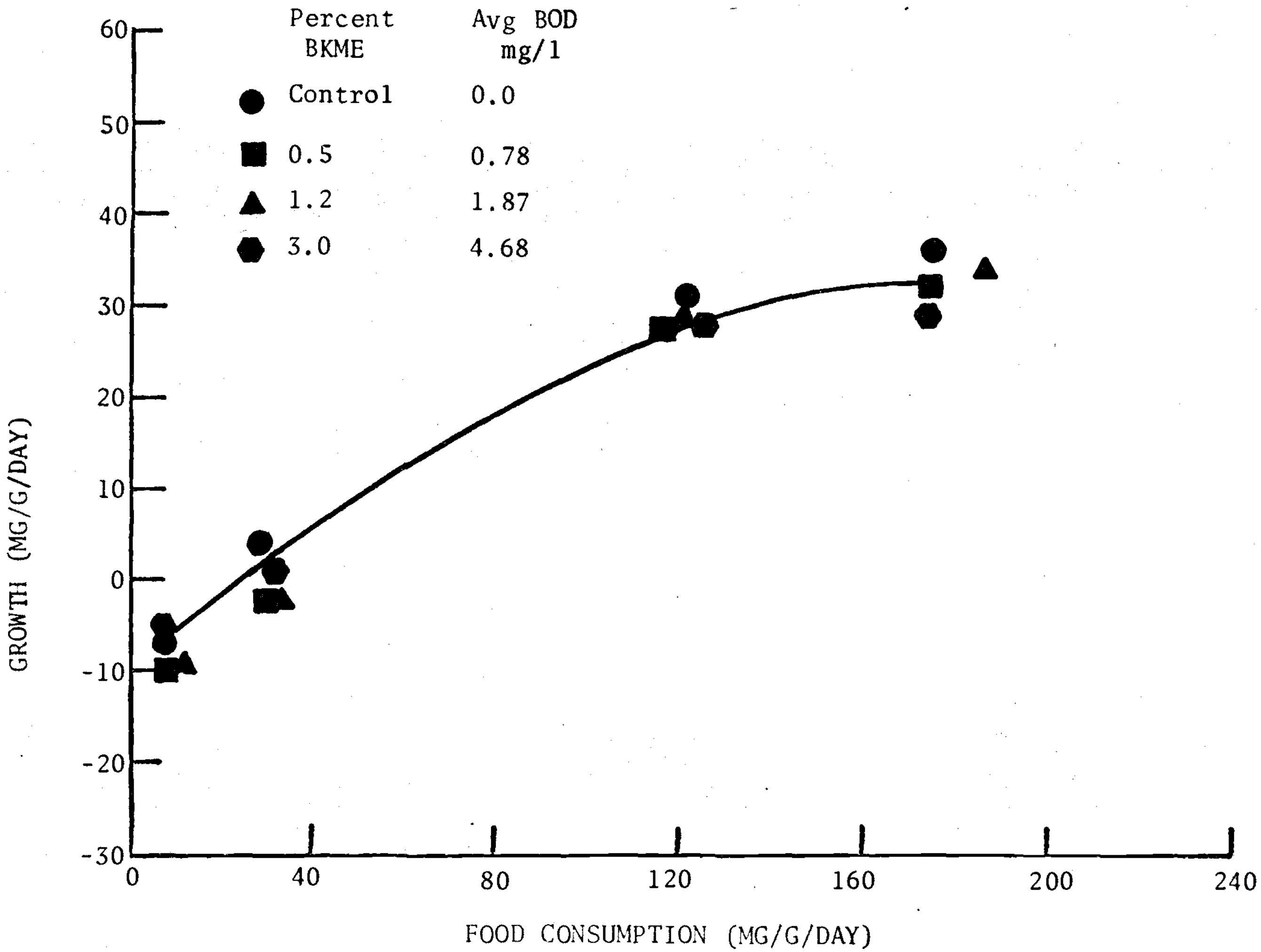

Figure 6. The effects of a composite bleached kraft effluent on the relationship between food consumption and growth rates of juvenile chinook salmon.

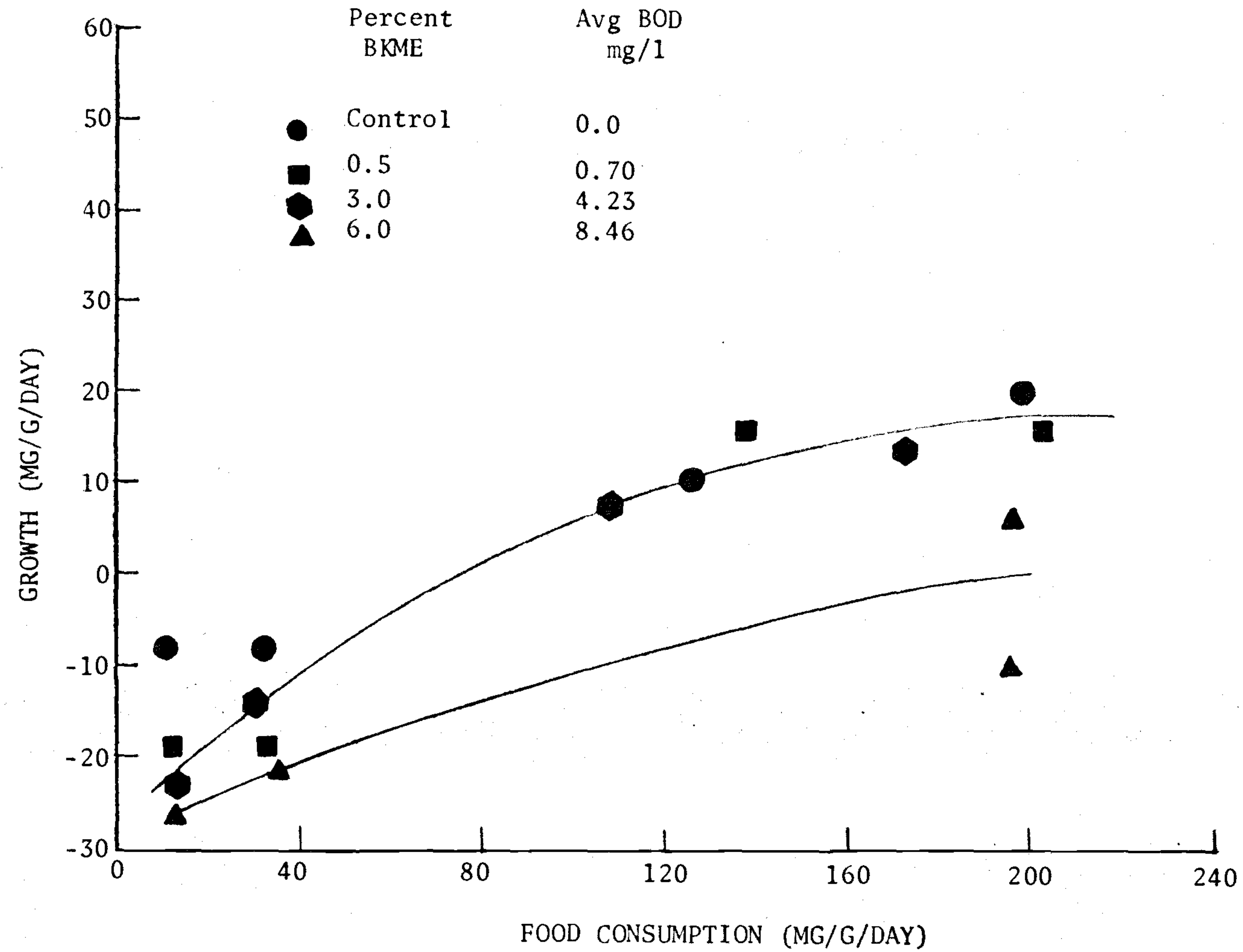

Figure 7. The effects of a composite bleached kraft effluent on the relationship between food consumption and growth rates of juvenile chinook salmon.

natural waters. When decomposable toxic substances also are present in effluents, reduction in the concentration of these may also be accomplished, but not necessarily in proportion to BOD reduction. High discharge rates of treated effluents on the basis of their lowered BOD may sometimes lead to water quality 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 primary treated effluents. Juvenile chinook salmon were exposed to a range of concentrations of effluent in a flow-through system and fed at different known levels of ration. Biologically stabilized effluents from mill A and mill B were studied. Effluent from mill A was collected raw and biologically stabilized over 7 day periods at our laboratory by dispersed-floc aeration, with the addition of nitrogen and phosphorus. 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 (Fig. 8). This reduction in growth was attributed to a decrease in the efficiency of food utilization for growth. There was no apparent 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 (Figs. 5 and 8). Effluent from mills such as mill B, however, would not reduce fish growth rates at these concentrations. Treatment may, of course, permit the maintenance of lower

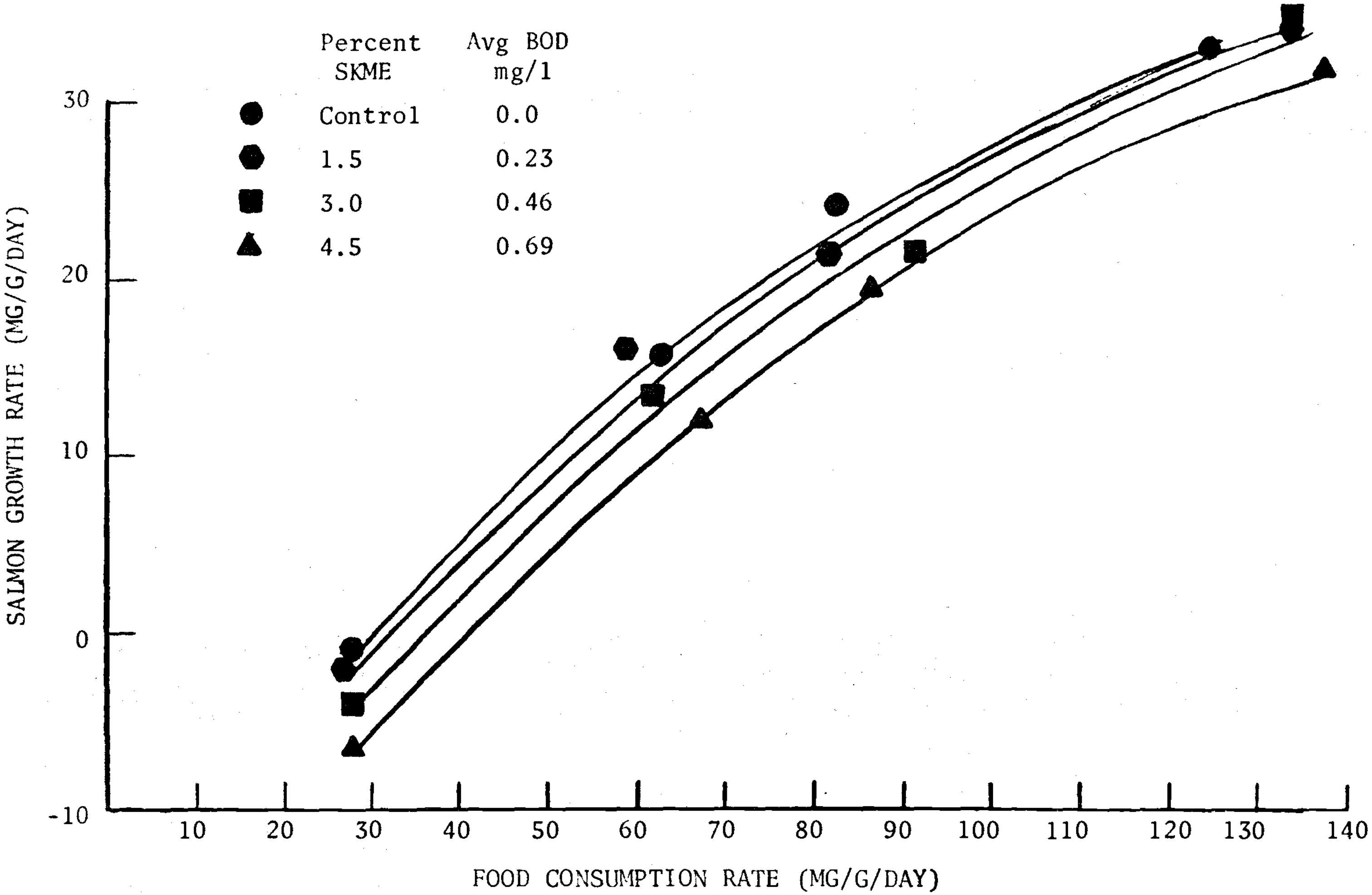

Figure 8. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in aquaria and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. From Borton, 1970.

levels of BOD in receiving waters.

A growth experiment was completed recently (March, 1972) to determine if the addition of a neutral sulfite mill and new chemical recovery equipment at mill A had altered the sub-lethal toxicity of the effluent. In this experiment sixteen groups of five juvenile chinook salmon each were tested at each of the four concentrations including the control. At each concentration, four feeding levels of Oregon moist pellet were used. The BOD of the stabilized waste tested was somewhat high at 78 mg/l.

Control fish grew at faster mean rates than groups of fish exposed to effluent in this relatively short growth experiment of one week (Fig. 9). Fish exposed to the 1.0 percent by volume concentration (0.8 mg/l BOD) grew slightly faster than those at 2.5 percent (1.9 mg/l BOD) except at the highest rations tested. At the 4 percent concentration (3.1 mg/l BOD) however, a large reduction in mean growth rate occurred, and growth of fish at this concentration was well below that of fish in control and the 1.0 and 2.5 percent concentrations. These results are similar to earlier test results, although the extent of the reduction in growth rate is greater in this recent test.

Newly operational chemical recovery equipment and the relatively high BOD of the stabilized waste may have contributed to this greater toxicity. Since this experiment, more aerators have been added to the secondary treatment pond and further BOD reduction has occurred. Another growth experiment is planned to assess the effect of these changes in waste treatment.

Fish in aquaria are not required to engage in much swimming activity. Stress occasioned by the additional swimming activity might be expected to increase the effect of a toxic substance on the growth of fish at particular

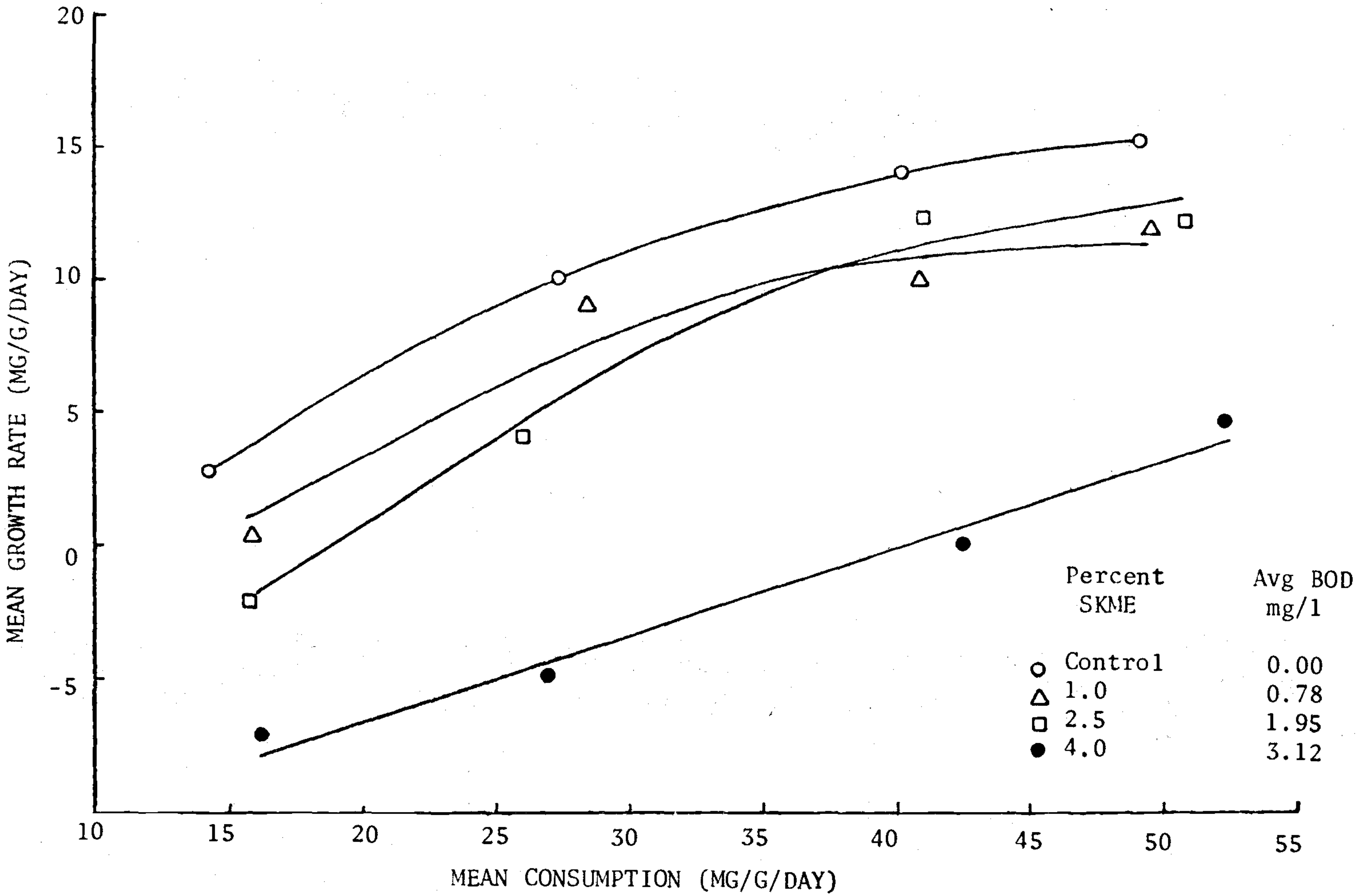

Figure 9. Relationship between food consumption and growth rate of juvenile chinook salmon exposed to stabilized effluent from mill A during March, 1972.

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 and exposed to 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 2.2 mg/l BOD (4.5 percent effluent by volume), as shown in Figures 10 and 11. 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, resulting in similar energy budgets for control fish and fish exposed to effluent. This would 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.

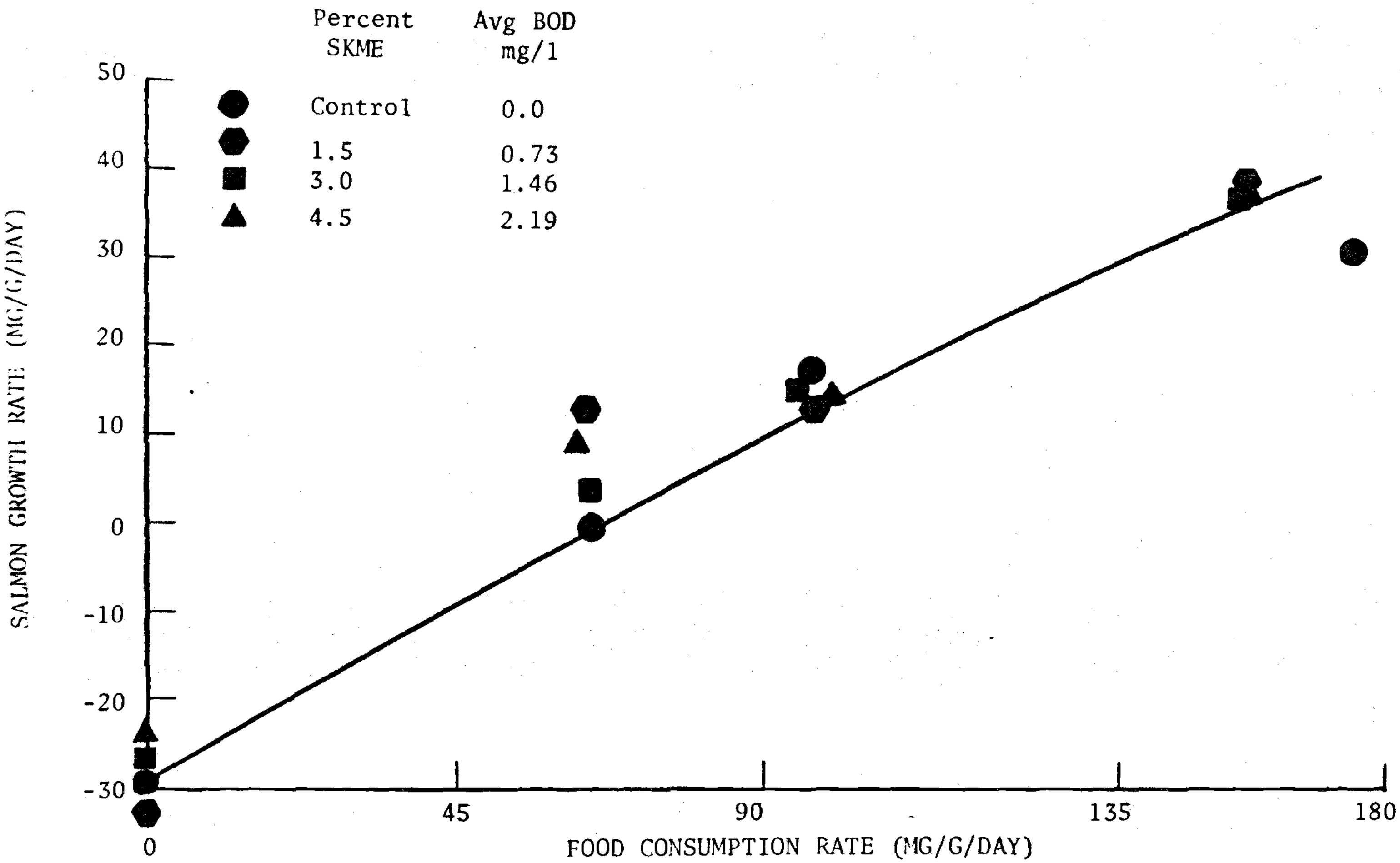

Figure 10. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. From Borton, 1970.

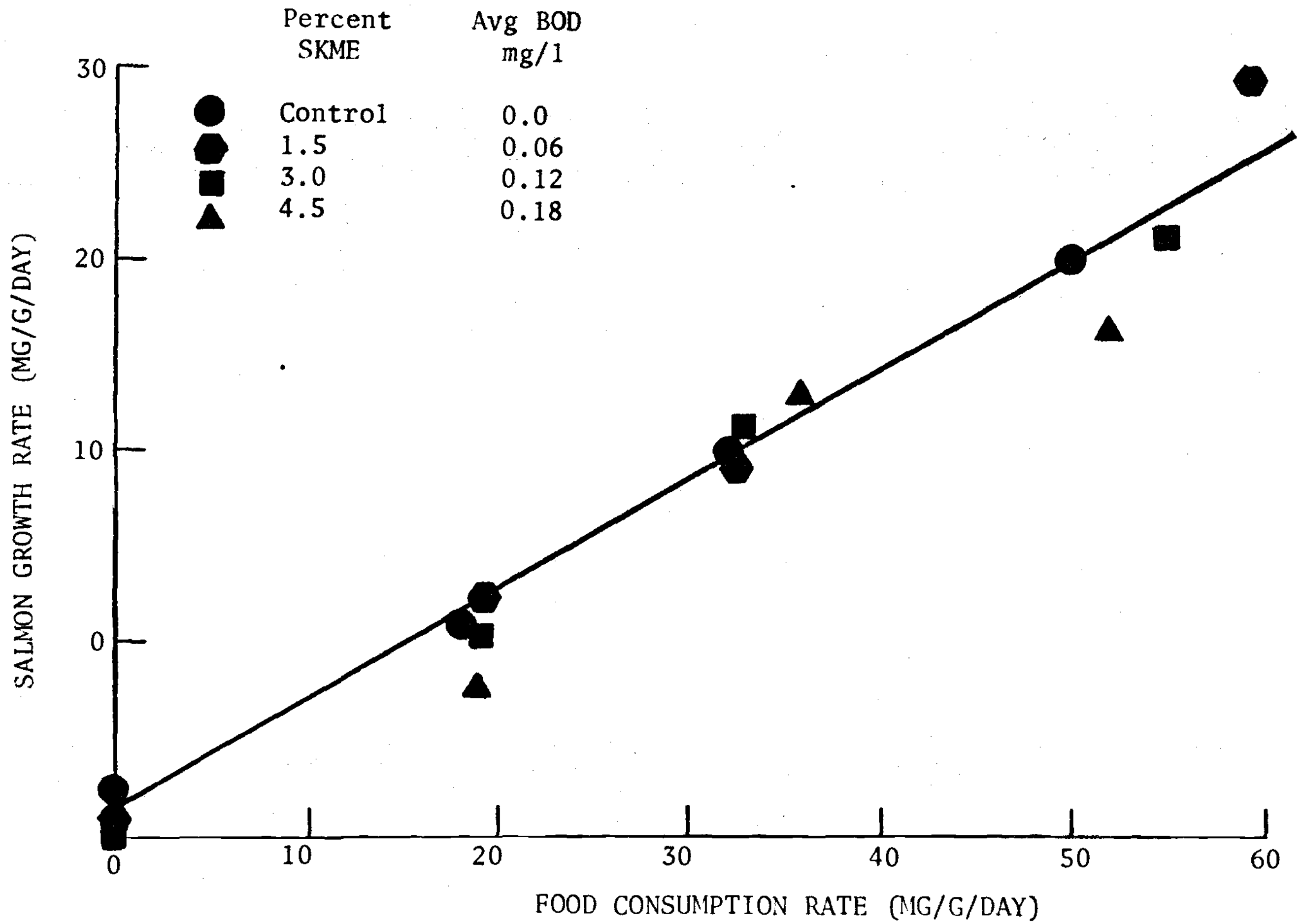

Figure 11. The relationship between growth rates and food consumption rates of juvenile chinook salmon held in exercise channels and exposed to three concentrations of stabilized kraft mill effluent (SKME) from mill A. From Borton, 1970.

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

In order to gain some understanding of the effects primary treated kraft mill effluent and biologically stabilized effluent might have on the growth and production of juvenile chinook salmon, we conducted studies in simple laboratory stream communities. Not only direct effects on the fish but also indirect effects through their food chain could occur in such systems. These communities were maintained in six laboratory streams (Fig. 12) 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 consumed insects and crustaceans for their food, and these invertebrates consumed the microorganisms and organic detritus. Thus, we could study the effects of different concentrations of effluents on the growth and production of salmon and on the availability of their food organisms.

Primary Treated Effluents

In a series of winter and spring experiments, salmon growth rates and production were reduced in laboratory streams that received primary treated 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 T*Lm*'s), as shown in Figure 13. The reductions in production were greater at high stocking densities than at low stocking densities. Primary treated 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 T*Lm*'s) did not result, however, in any reduction of salmon growth rate (Fig. 14). The deleterious effects at 3 mg/1 BOD in these spring experiments appear to be the result of direct

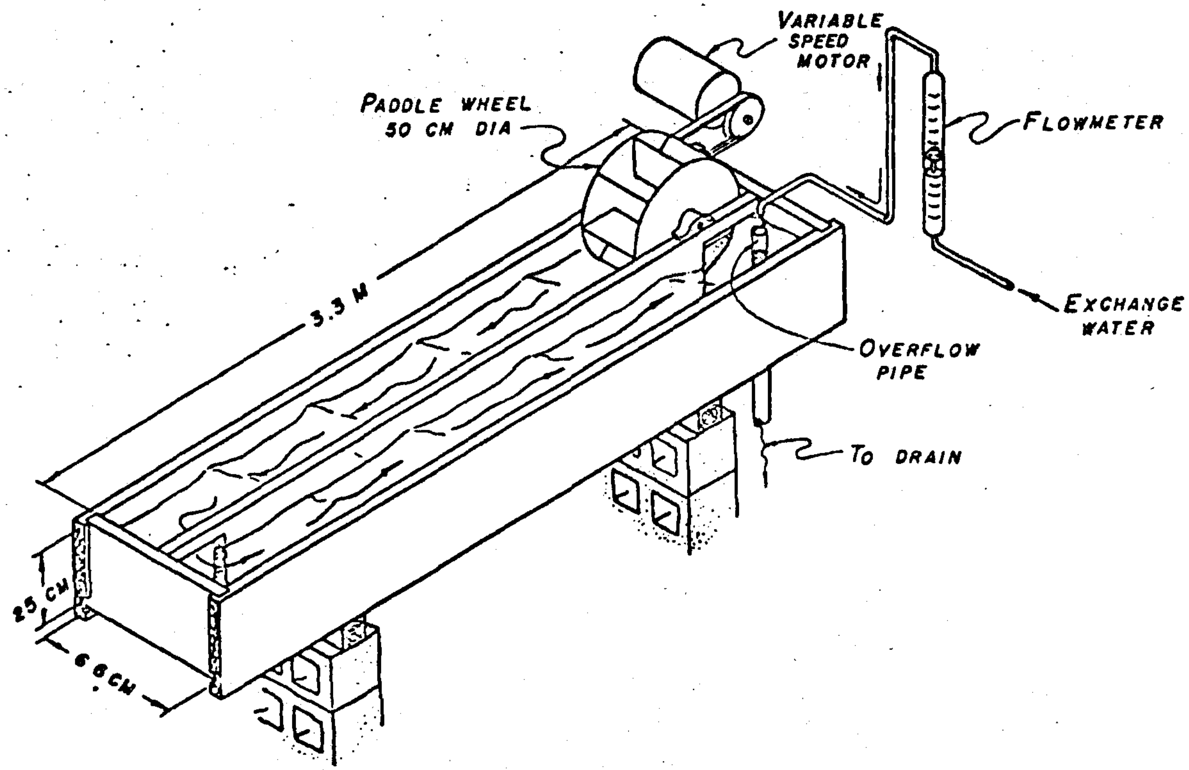

Figure 12. Diagram of a laboratory stream similar to the ones employed for studying the influence of kraft pulp mill effluents on the production of salmonids in simplified biological communities.

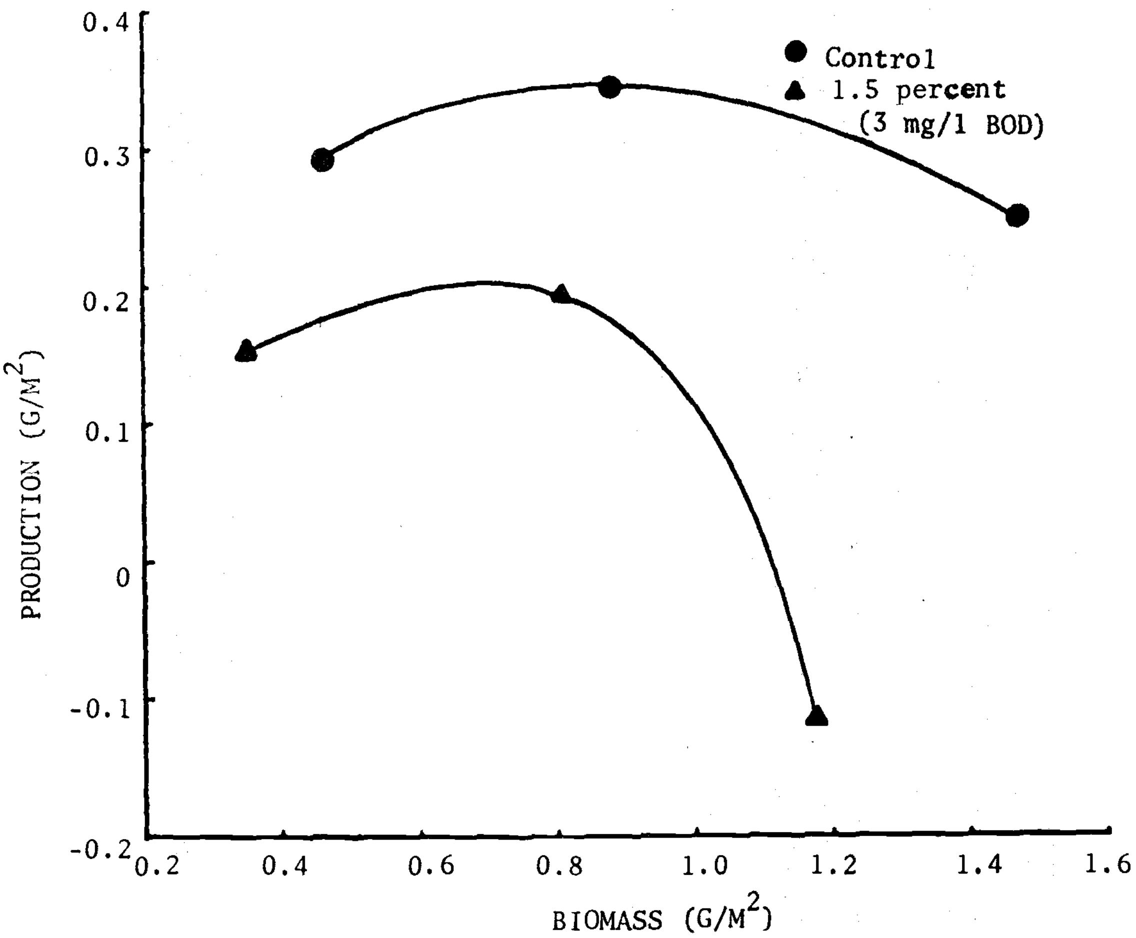

Figure 13. Relationship between salmon production and salmon biomass for control and for laboratory streams receiving 1.5 percent primary treated effluent during spring, 1967. From Ellis, 1968

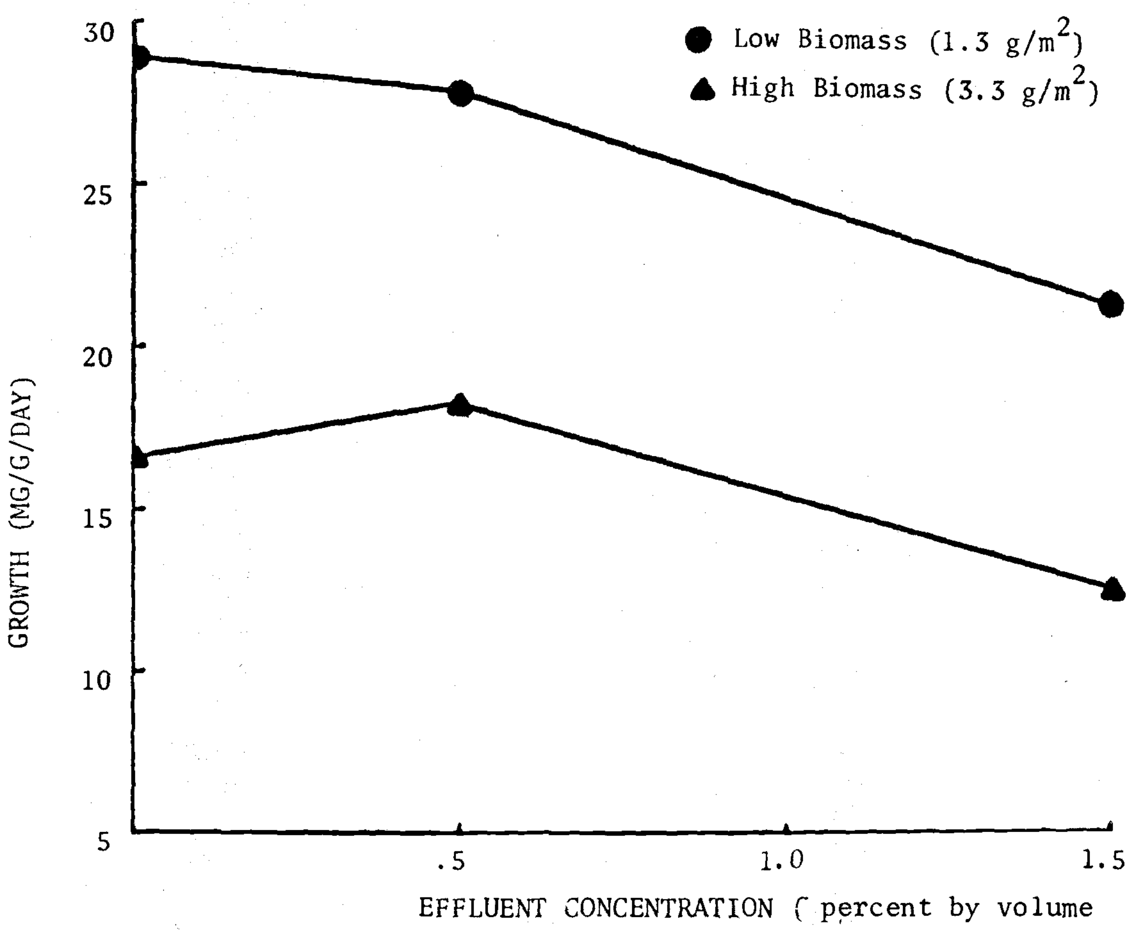

Figure 14. Relationship between growth rate and concentration of KME for two levels of salmon biomass in the laboratory streams during during spring, 1968.

effects on the growth of fish. The biomass of one genus of midge larvae, *Micropsectra*, was reduced at this concentration of effluent during early spring, although no overall reduction in food density was observed. The biomass of amphipods (*Crangonyx*) suitable as fish food was consistently highest in the 1.5 percent concentration streams.

As we will return to later in this report, some concentrations of primary treated and biologically stabilized effluent may actually increase fish production in laboratory stream ecosystems, when the influence of enrichment and increased food availability is greater than any direct toxic action of the effluent on the growth of the fish.

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 primary treated and biologically stabilized effluents from mill A were simultaneously tested in a series of experiments. In experiments conducted during early fall, late fall, and early spring periods, salmon production was lower in streams receiving a 1.5 percent by volume of stabilized effluent (Fig. 15). The BOD increment to the streams ranged from less than 0.1 to as high as 0.75 mg/l, because of level of treatment and pretreatment differences. The reduced production can be 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

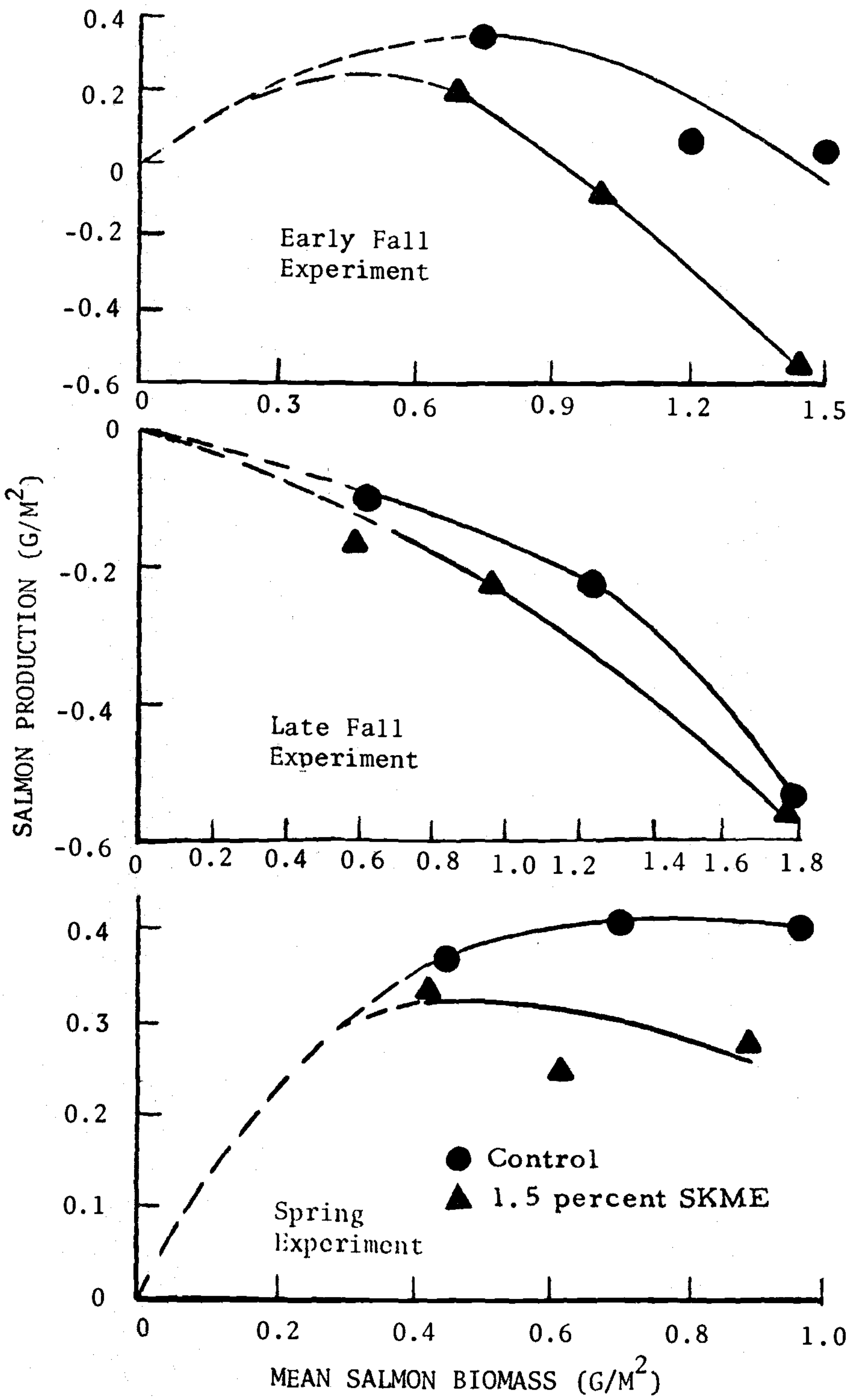

Figure 15. Relationship between salmon production and mean salmon biomass for control and 1.5 percent stabilized kraft mill effluent (SKME) streams, during fall and spring, 1967, 1968. Duration of experiments was 30 days, 18 days and 32 days, respectively. From Seim, 1970.

numerical density of drifting food organisms and salmon growth rate shown in Figure 16 indicate lower fish growth rates in streams receiving effluent even when these streams had food organism densities as high or higher than those occurring in control streams.

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/l BOD) stabilized effluent than in control streams (Fig. 17). Salmon production was greatest at a 1.0 percent concentration (0.3 mg/l 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 that at higher concentrations the effluent had some direct deleterious effect on salmon growth rates during summer months also, although this influence must have been small in relation to beneficial effects of increased food availability.

The effluent tested during the summer had about the same BOD (near 30 mg/l) after biological stabilization as had stabilized effluent used in the spring experiment. This summer experiment was repeated and similar results were obtained (Fig. 17). Our studies of the algal communities in the laboratory streams indicated primary or plant production was greater in streams receiving stabilized kraft waste than in control streams. This may have been the basis for the increased salmon production in streams receiving effluent.

Thus, kraft mill effluents have both toxic and enriching potentials. Their effects on stream communities and fish production will depend on

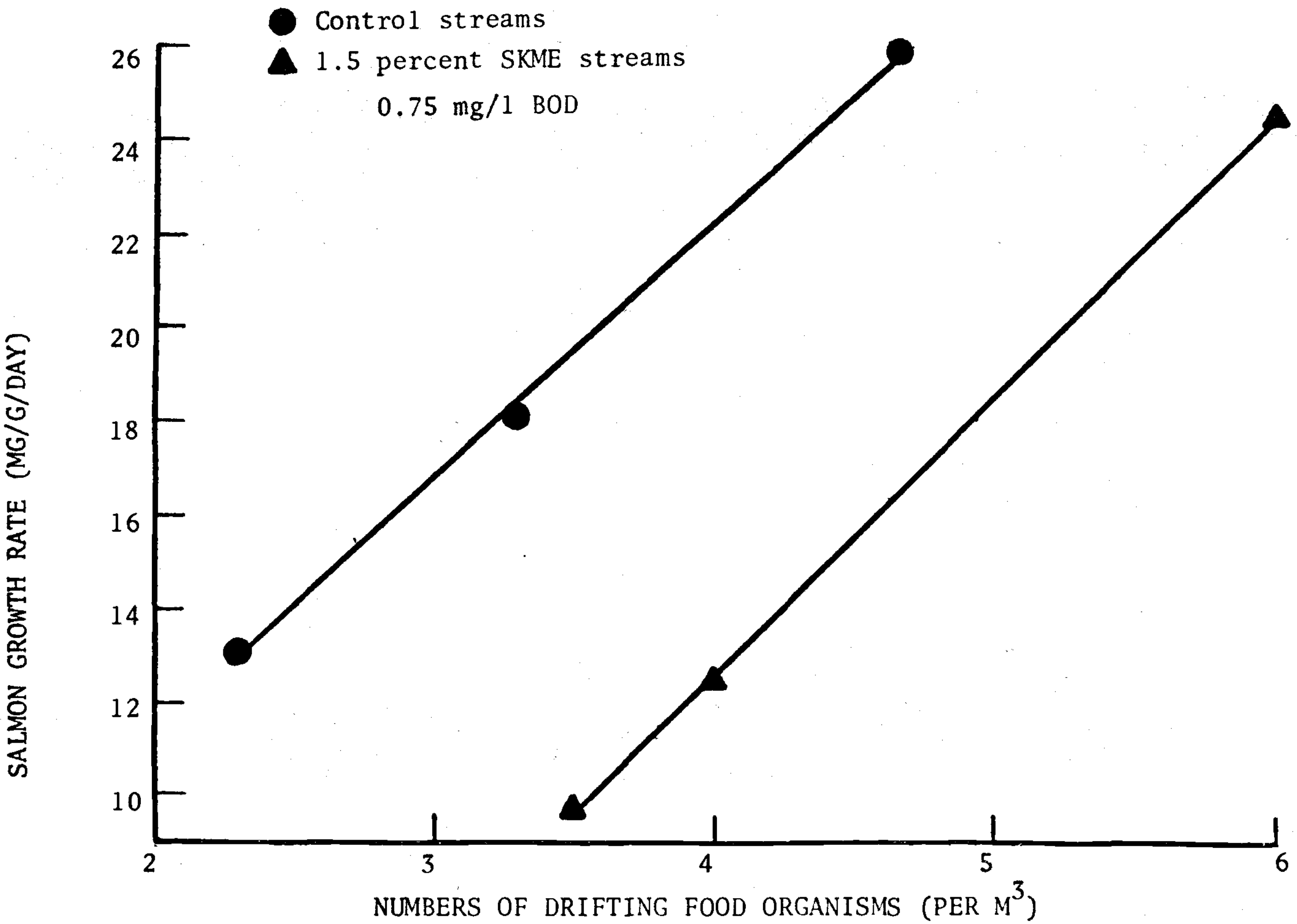

Figure 16. Relationship between salmon growth rate and the numbers of drifting food organisms in control and 1.5 percent stabilized kraft mill effluent (SKME) streams during spring, 1968. From Seim, 1970.

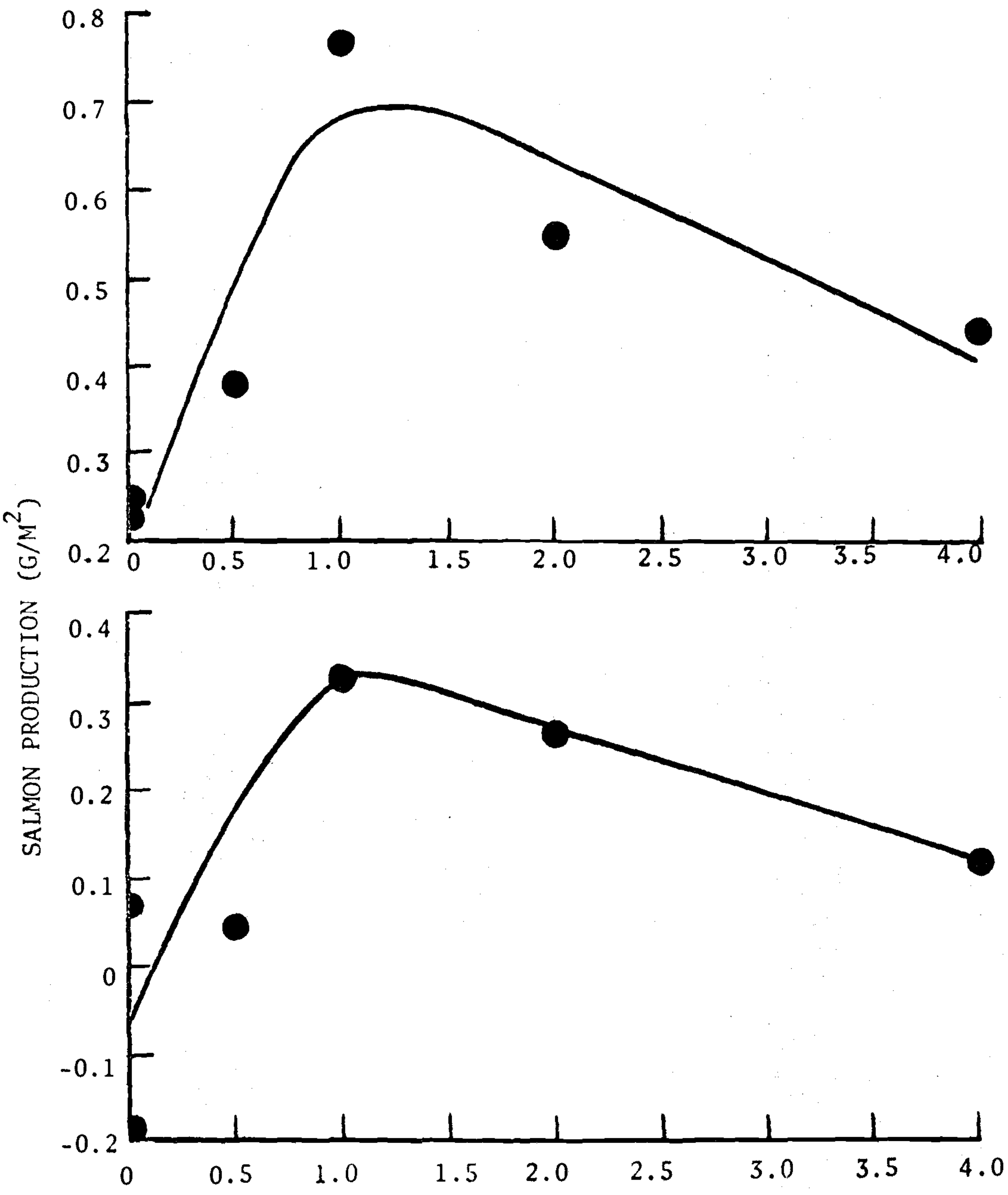

Figure 17. Relationship between juvenile chinook salmon production and stabilized kraft mill effluent (SKME) concentration in laboratory streams during summer experiments in 1968. The duration of each of these experiments was 32 days. From Seim, 1970.

their nature, whether or not they are treated, their concentration in the receiving water, and the composition of the stream community. Because of the simplicity of laboratory stream communities, we must be careful as to the conclusions we draw on the basis of research with laboratory streams (Warren and Davis, 1971).

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, as discussed earlier in the section entitled Theoretical Considerations Involving Trophic Relations. The relationships describing the biomass of fish (predators) and the biomass of the food organisms (prey) were useful in determining if a change in the basic capacity of the streams to produce fish had occurred either because of effects of effluents or because of seasonal changes in the stream communities.

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 primary treated kraft effluent at a rate of 15 ml/l or 1.5 percent by volume (3 mg/l BOD), and another stream receiving stabilized effluent at 1.5 percent (0.3 mg/l BOD). By introducing primary treated effluent at 0.75 percent by volume into one stream and stabilized effluent at 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. This may account for the reduced acute toxicity of the effluent during this summer period (Table 1).

Table 1. 96-hour median tolerance limits (Tl*m*) of chinook salmon for primary treated kraft mill effluents introduced into laboratory streams from February 28 to August 1, 1969.

Date	Tl*m*	Date	Tl*m*
1969			
February 28	14.5	June 11	24.0
March 10	22.3	July 8	16.3
March 21	8.7	July 12	24.0
March 27	13.4	July 18	24.0
April 5	7.5	July 25	24.0
May 23	13.4	August 1	29.0

Streams receiving 1.5 percent by volume of primary treated waste (3 mg/l BOD) and 0.75 percent by volume of primary treated waste (1.5 mg/l BOD) maintained the highest biomass of salmon (Fig. 18). The stream receiving 7.5 percent biologically 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 biologically 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 (Fig. 19).

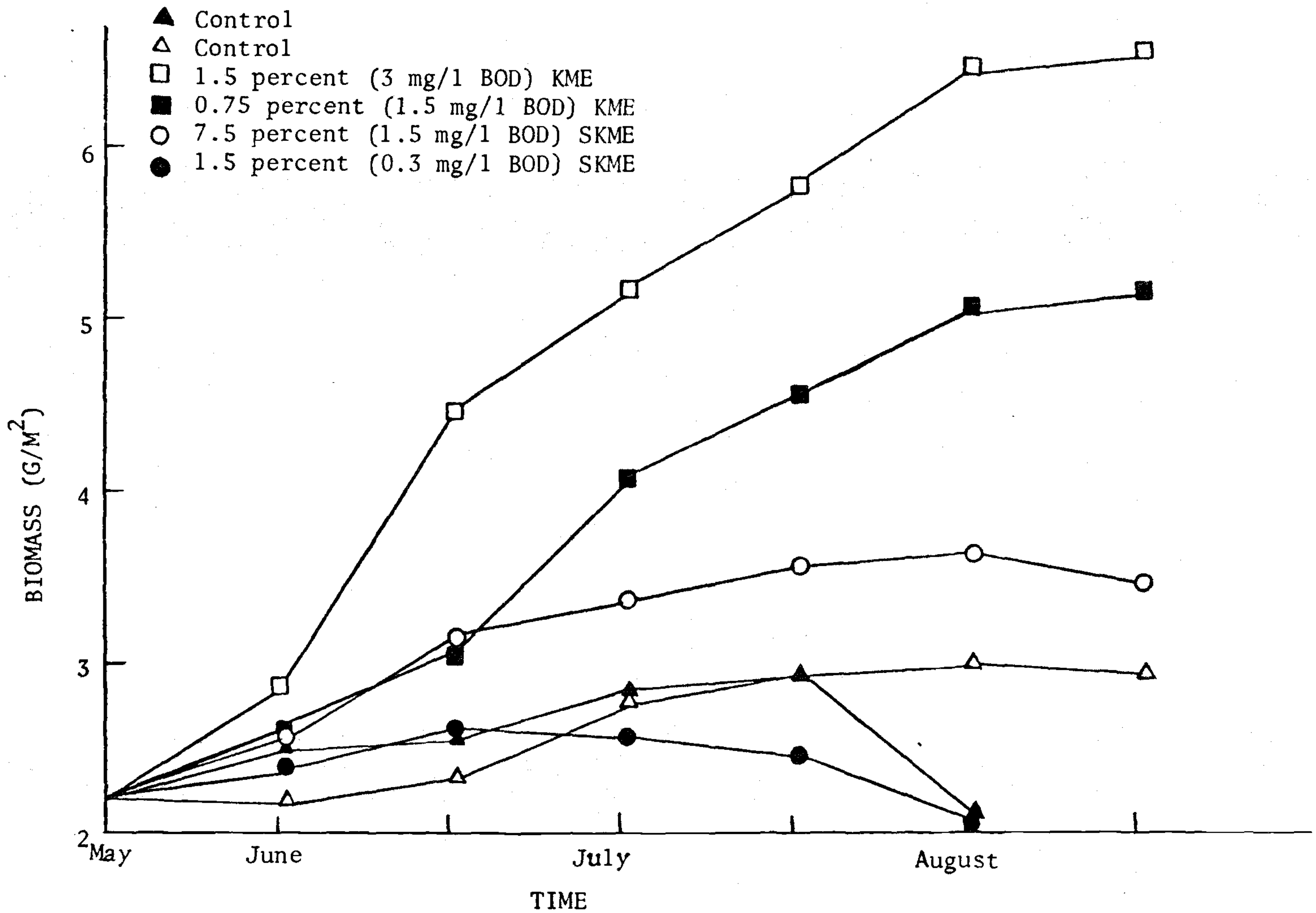

Figure 18. Changes in salmon biomass in laboratory streams during two week intervals between May 16 and August 12, 1969. From Lichatowich, 1970.

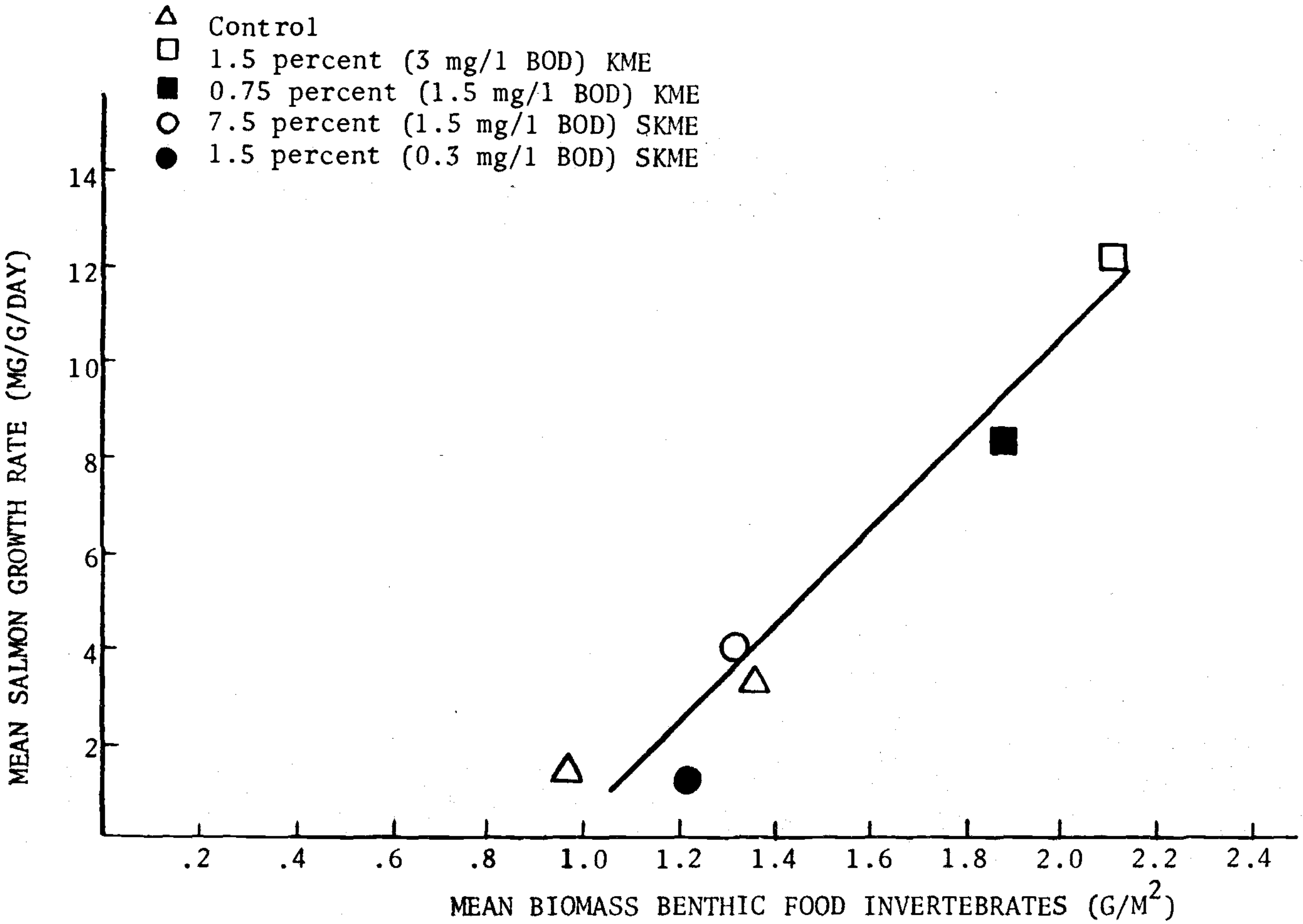

Figure 19. Relationship between mean salmon growth rate and mean biomass of benthic food invertebrates in laboratory streams from May 16 to August 12, 1969. From Lichatowich, 1970.

Figure 19 indicates that the higher fish growth rates in the streams receiving 1.5 percent and 0.75 percent primary treated effluent were the result of higher food densities in these streams. It further indicates that no measurable direct toxic effect of the effluents on the fish occurred during 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 (Fig. 20). Streams receiving 1.5 percent and 0.75 percent primary treated and 7.5 percent stabilized effluent tended to be at a higher general level of productivity for salmon than the two control streams and the stream receiving 1.5 percent stabilized effluent. The addition of kraft waste, both primary treated and stabilized, at these concentrations apparently increased the production of salmon food organisms and resulted in a higher production of the salmon.

The acute toxicity of the primary treated effluent from mill A had decreased to a low level by this summer period, the 96-hour TL*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 (Table 1) and the greater increase in stream productivity noted in this experiment as compared to earlier experiments.

A summary of the results of Phase I and Phase II experiments is included at the end of this report.

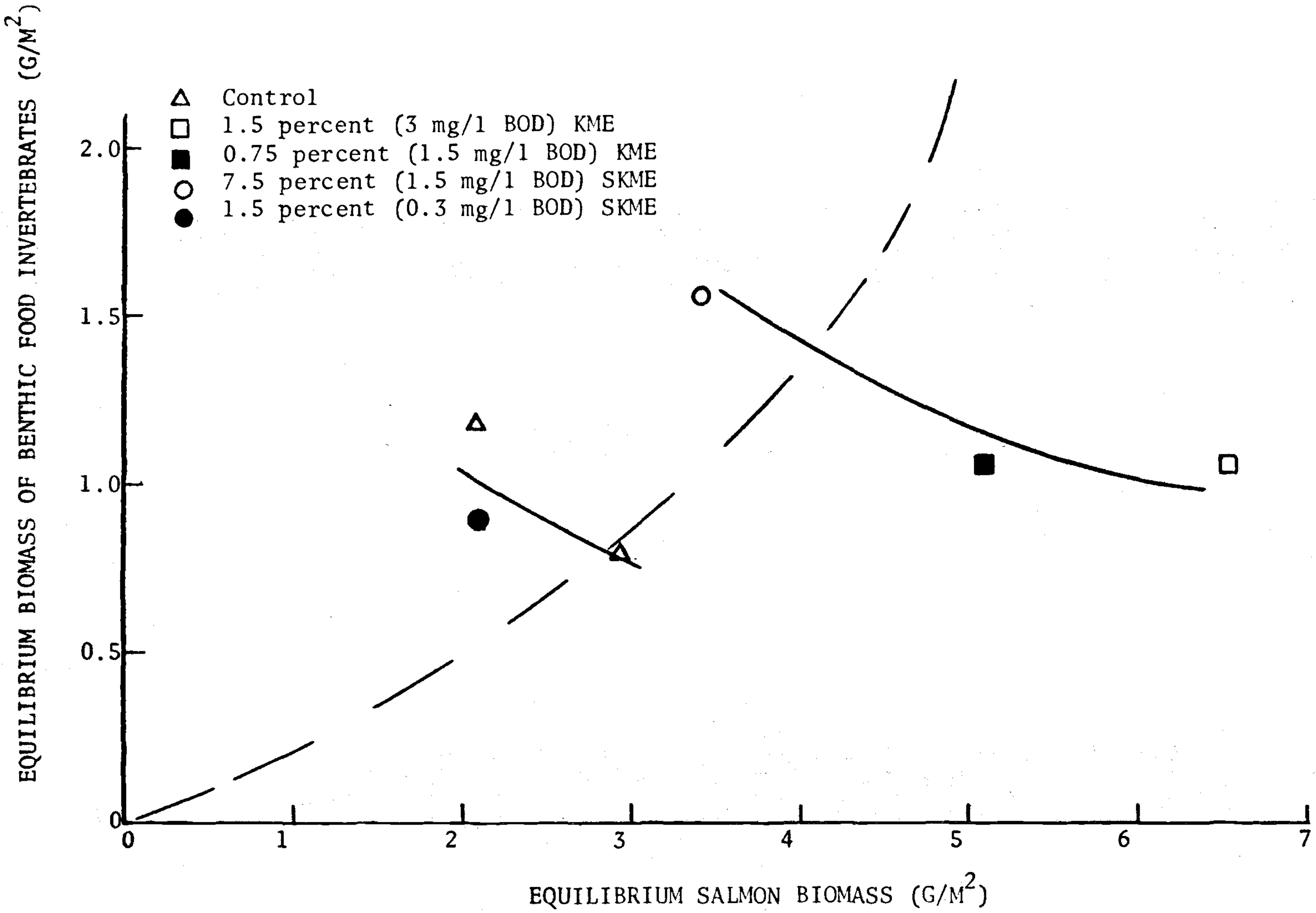

Figure 20. Relationships between equilibrium biomass of benthic food invertebrates and equilibrium salmon biomass in laboratory streams receiving different concentrations of stabilized and primary treated kraft mill effluents. Invertebrate biomass computed as mean of final two benthic samples. Salmon biomasses are terminal biomass shown in Figure 18. From Lichatowich, 1970.

PHASE II: EXPERIMENTAL STREAM CHANNEL STUDIES

FACILITIES

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 (Figs. 21 and 22), a laboratory trailer, a small storage building, and three fish-holding tanks. Constructed on a 1.5 percent grade, the stream channels are 320 feet long and about 6 feet wide. The beds of the eleven riffles in each stream are covered with a gravel and rubble substrate and alternate with eleven pools. 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. Nonbleached kraft effluent is available from either the primary treatment pond or the aerated stabilization basin operated by Western Kraft Corporation.

Six fish exposure tanks, each 4 feet by 6 inches by 9 inches deep and a dilution apparatus were recently added to the site for use in continuous monitoring of direct effects of effluents on fish.

Two emergency devices, which operate in case of water supply failure, were added in May, 1972. A flashing light and a sound alarm are activated by a float switch should the water supply be interrupted. In addition, if this occurs, a float-operated valve will stop the flow of effluent to the treatment stream. A 6-foot high wire fence encloses the entire research area.

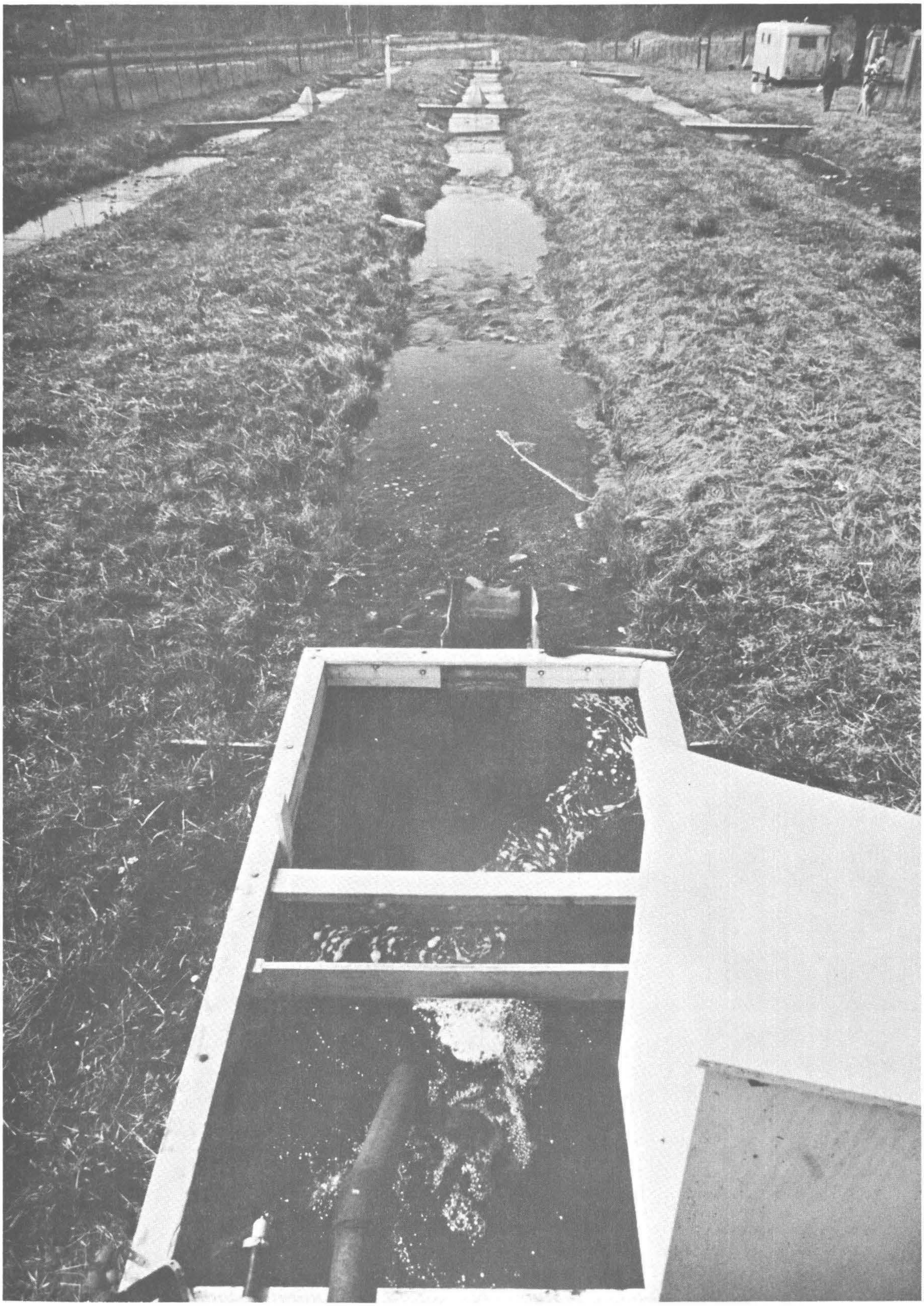

Figure 21. Downstream view of Stream 2.

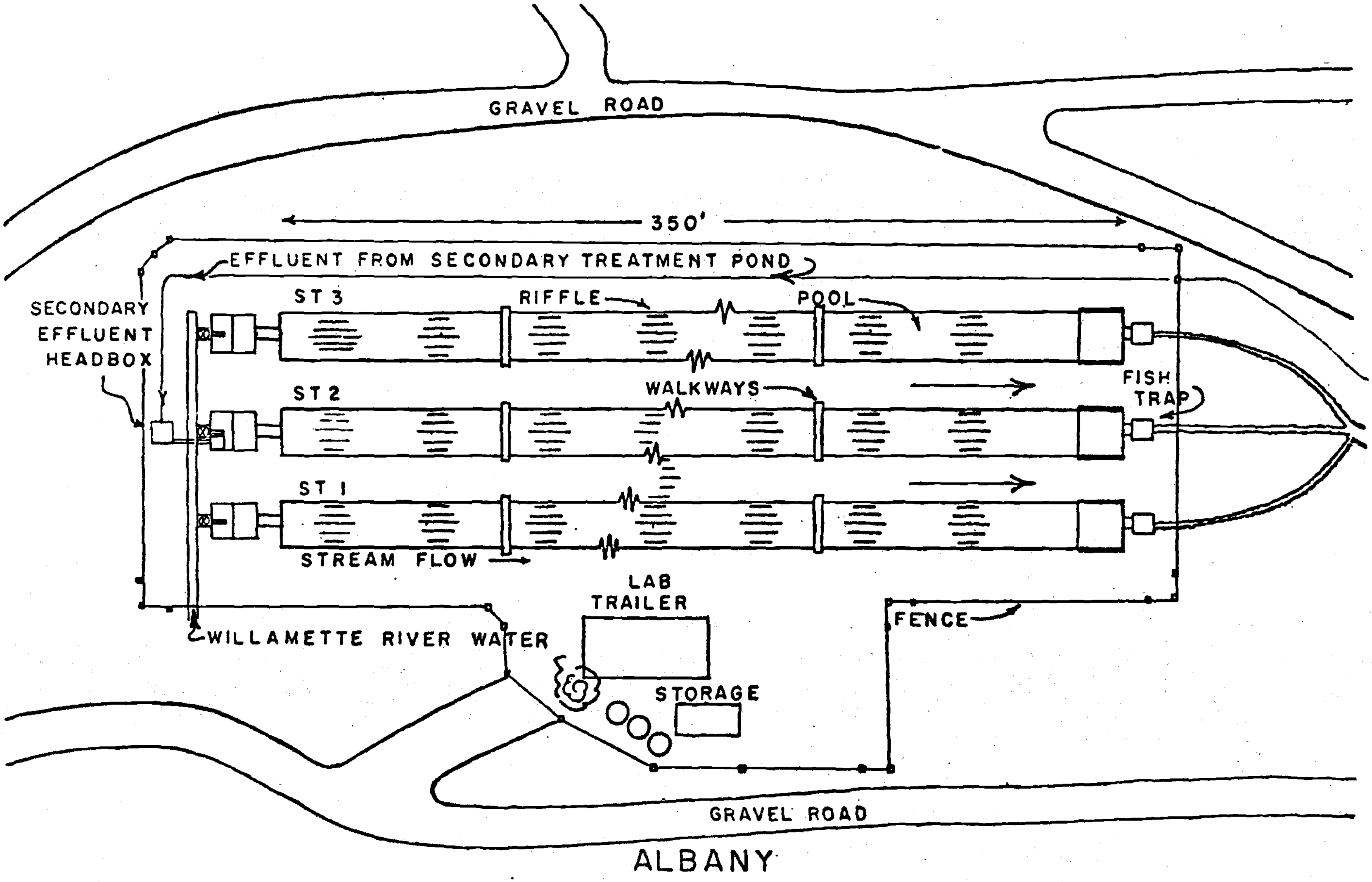

Figure 22. EXPERIMENTAL STREAM CHANNELS

STREAM WATER AND EFFLUENT CHARACTERISTICS

Dilution Water

Temperature recorders continuously monitor inflow and outflow stream temperatures. Maximum outflow temperatures reached 21C in June of 1970 and 19C in August 1971 (Fig. 23, bottom). Outflow temperatures indicated a maximum increase of about 3C over the length of the stream. A minimum temperature of 5C occurred in January 1971.

Both nitrate and total phosphorus concentration (Fig. 23, top) were taken from data of the Oregon Department of Environmental Quality at Peoria and Buena Vista stations along the Willamette River. Peoria station is 20 miles upstream; Buena Vista station is 12 miles downstream from the stream channels. Higher nitrate values at Buena Vista possibly reflect industrial and domestic discharges in the Corvallis and Albany areas. Nitrate determinations made at the stream channel site indicate somewhat higher values than shown here. Increased nitrate levels during winter periods closely follow rainfall patterns (Fig. 23). Rainfall data were collected at nearby Hyslop Laboratory operated by Oregon State University Agricultural Experiment Station. Nitrate and total phosphorus concentrations would not appear to limit growth of algal populations. Alkalinity, pH and dissolved oxygen determinations (Table 2) were made during 1970 and 1971, but were terminated before 1972. Values for total solids and total volatile solids (Table 2) were only slightly higher during late fall and winter when heavy deposition of solids occurred in the stream channels. The grab samples used for this analysis apparently did not effectively represent short periods when the water had high suspended

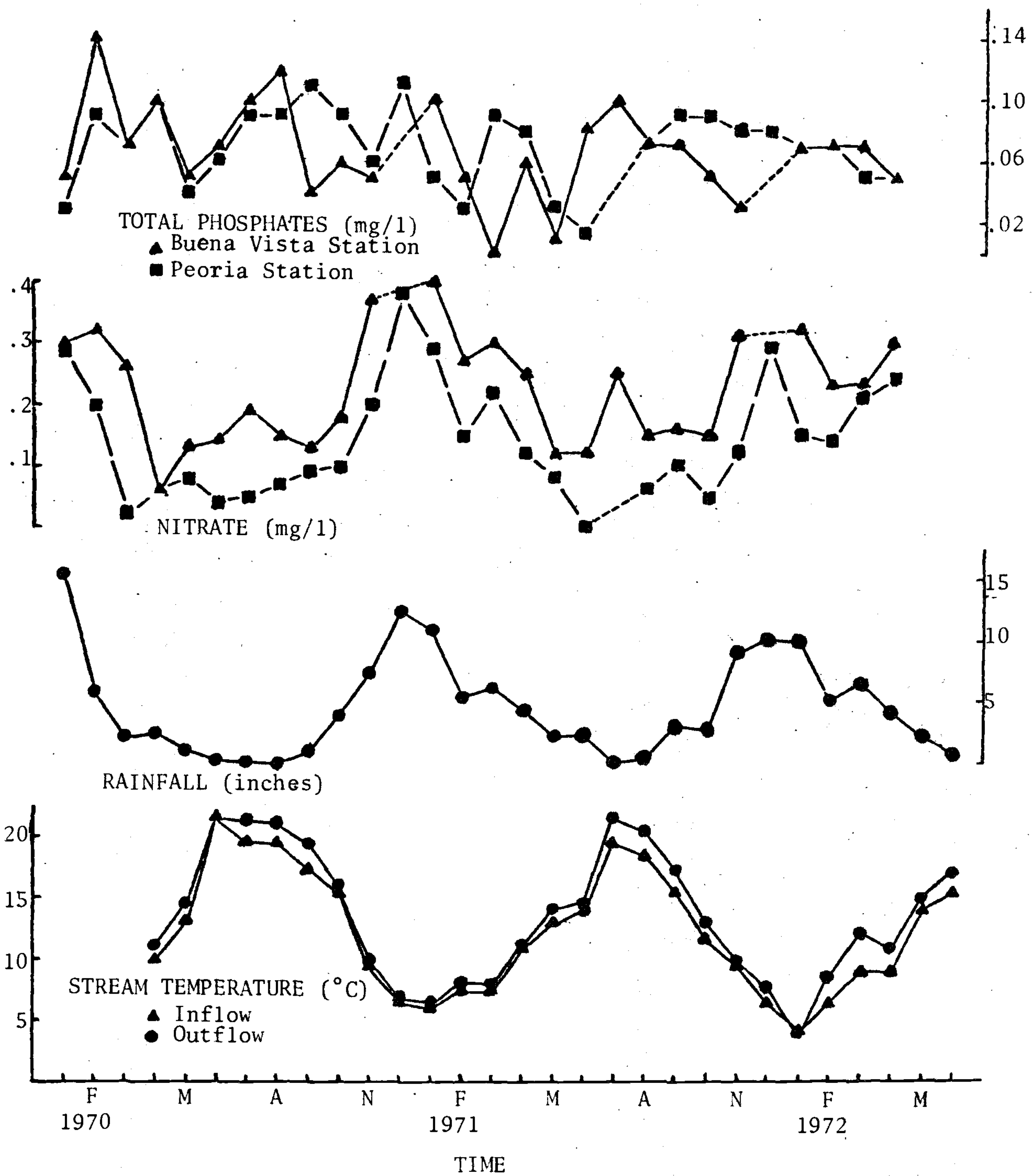

Figure 23. Inflow and outflow stream channel temperatures, local rainfall, and nitrate and total phosphate concentrations from two stations on the Willamette River. The latter data from the Oregon Department of Environmental Quality.

Table 2. Physicochemical characteristics of dilution water at the experimental channels.

Date	Alkalinity inflow (mg/l $CaCO_3$)	pH inflow	Dissolved Oxygen inflow (mg/l)	Dissolved Oxygen outflow (mg/l)	Total solids inflow (mg/l)	Volatile solids inflow (mg/l)
1970						
April 26	25.0	7.5	10.3	12.5	59.2	16.5
May 6		8.1	10.8	11.8	65.3	14.3
June 18			9.7	9.8	65.3	13.4
July 18	28.0	7.5	9.5	11.6	69.3	13.6
August 15	27.5	7.7	9.4	11.3	60.3	9.9
September 10	26.2	7.4	9.7	11.6	45.8	8.1
October 10	28.2	7.2	10.0	11.8	63.4	9.9
November 14	24.0	7.4	10.7	13.2	101.5	18.5
December 13	23.5	7.5	12.4	12.9	84.1	14.0
1971						
January 16	17.0	7.6	11.8	11.8	70.1	10.5
February 16	18.0	7.2	10.9	11.7	78.1	11.9
March 17	19.0	7.3	11.7	13.2	72.2	10.1
April 29	22.0	7.6	10.6	11.4	70.1	9.2
May 13	21.0	7.6	9.9	10.6	70.8	9.3
June 13	21.8	7.5	10.8	10.5	51.1	8.1
July 13	21.6	8.1	10.1	10.5	48.8	8.3
August 15	22.3	7.6	9.7	10.5	50.1	7.9
September 24	-	-	-	-	48.8	8.9
October 19	-	-	-	-	65.5	9.9
November 24	23.5	7.4	10.8	11.0	80.8	13.6
December 20	-	-	-	-	84.8	-
1972						
January 28	-	-	11.6	12.9	96.8	15.6
February 15	-	-	-	-	78.4	14.2
March 15	-	-	-	-	78.0	14.2
April 15	-	-	-	-	73.2	13.6
May 15	-	-	-	-	68.5	12.0
June 15	-	-	-	-	63.4	11.4

solids content. In September 1971, settled solids were pumped from the pools to maintain a suitable water depth. A Belfort pyrheliograph was used to estimate total daily solar radiation.

Kraft Mill Effluents

Western Kraft Corporation of Albany operates a non-bleaching kraft mill producing about 500 tons of dry pulp per day from Douglas fir wood chips. In June 1971, a neutral sulfite mill having a capacity of 200 tons per day was added to the plant. The neutral sulfite mill increased total plant effluent about 10 percent. Stream experiments with primary treated effluent tested only kraft process wastes, but biologically stabilized effluent tested after June 1971 was a mixture of waste waters from the two processes.

In-plant waste treatment operations include recovery of digestion chemicals and turpenes. Primary treatment occurs in two sedimentation ponds having a total retention time of about 24 hours. After primary treatment, waste waters are pumped to the 21 acre aerated stabilization basin. Mill personnel periodically added diammonium phosphate to increase treatment efficiency. Williams (1969) has suggested nutrients added during waste treatment may be a major source of biological changes in receiving waters. The amounts added here may be too small and too irregular, however, to change nutrient concentrations of dilution water used in these experiments.

During summer, part of the effluent is piped from the primary pond directly to seepage basins. This practice increases retention time in the stabilization basin during the summer.

A 200 ml sample of mill effluent was collected daily to form a weekly composite. Samples were refrigerated during storage.

Primary treated effluent used in stream channel experiments in 1970 and 1971 was characterized by COD (chemical oxygen demand), total solids, total volatile solids, suspended solids, suspended volatile solids, and BOD (biochemical oxygen demand) (Appendix II). BOD determinations were made by personnel of the National Council of the Paper Industry. The BOD values for biologically stabilized effluent were made by Western Kraft Corporation personnel. Biological stabilization reduced BOD over 80 percent in some cases, but occasionally would reduce BOD only 60 percent or less. Additional aerators have recently been installed in the stabilization basin; this should increase treatment efficiency. Effluents with BOD's of 90-100 mg/l or more (Appendix II) after passing through the stabilization basin will be referred to here as being biologically stabilized, even though less than 60 percent BOD reduction may have occurred.

The acute toxicity to juvenile chinook salmon of effluents added to the experimental stream channels was determined twice a month for primary wastes, in most cases, and at least monthly for biologically stabilized effluent (Table 3). Acute toxicity was determined as the 96-hour median tolerance limit, the concentration killing just 50 percent of the test animals in 96 hours of exposure. As concentrations in percent by volume, the 96-hr TL_m's for primary treated effluent ranged from 1.3 to 20.1. For biologically stabilized effluent, the TL_m's generally ranged between 50 and 90, but one sample exhibited no acute toxicity.

Table 3. Acute toxicity of primary treated and biologically stabilized kraft mill effluent to juvenile chinook salmon, expressed as 96-hour median tolerance limits (96-hr TL_m) in percent by volume.

Primary treated 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	October 13	90.0
December 18	10.0	November 17	75.0
		December 15	70.0
1971		1972	
January 12	8.4	January 19	50.0
February 3	13.0	February 2	70.0
February 15	6.6	February 16	50.0
February 17	7.4	March 23	75.0
February 19	8.0	April 19	70.0
February 25	2.2	May 17	75.0
March 6	2.2		
March 23	7.5		

EXPERIMENTAL DESIGN

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 primary treated effluent into Stream 2 was begun on January 2, 1970, at a rate of 2.8 liters per minute, a projected stream concentration of 0.5 mg/l BOD. Streams 1 and 3 were used as control streams.

This experimental design was retained until March 16, 1971, when biologically stabilized effluent was first introduced into Stream 2, at the 0.5 mg/l BOD concentration used in the previous experimental period with primary treated effluent. To maintain this BOD level, the volume rate of introduction of the stabilized effluent was, of course, much higher than that of the primary treated effluent. This design continues to date, with Streams 1 and 3 still used as control streams. Effluent flow rates were adjusted weekly in an attempt to maintain a 0.5 mg/l BOD stream concentration, since treatment efficiency varied. Actual BOD added each week was from a low of about 0.3 mg/l to a high of about 1 mg/l, although the mean remained near 0.5 mg/l.

BENTHIC COMMUNITY

Methods

Samples of benthic organisms from the riffles were collected twice monthly beginning February, 1970, although only one sample was taken each month during February, November, December, 1971, and January, 1972. Sampling of the pool benthos was terminated after initial samples indicated few aquatic insects were present.

Each stream has eleven riffles, but only eight were sampled throughout the study. Riffles were numbered from upstream to downstream with number 1 being upstream. Riffles 1, 4, 7, and 11 were sampled one week and riffles 2, 5, 8, and 10 were sampled two weeks later, so that a particular riffle was sampled only once each month.

To obtain a sample, a cylindrical sampler was placed on the substrate, and then the gravel and rubble were removed from inside the sampler until a clay or sand substrate was reached. A foam rubber pad on the bottom edge and extended laterally from the sampler largely prevented the passage of water and materials. Gravel and rubble were removed and scrubbed with brushes in clean water to remove organisms and organic matter for concentrating. The slurry remaining inside the sampler after the rocks were removed was pumped out of the sampler and through a 118 microns mesh net. Concentrated organisms and organic matter were then put in polyethylene bags and transported to the laboratory.

The sample for a given stream was formed by compositing one fourth of each of the four riffle samples. Samples were then frozen until they could be processed.

Plant Analysis

A 12.5 percent aliquot from each composite sample was used for plant analysis. Laboratory control experiments showed that the freezing and storage method used did not introduce significant error. Samples were slowly thawed in the dark for eight hours. The slurry of sand and various organic materials was mixed and partially homogenized in a blender and the volume standardized at 600 ml. Duplicate 50 ml aliquots were extracted for gravimetric analysis. These were then filtered on previously weighed glass fiber filters, placed in weighed crucibles, and dried for 12 hours in an oven at 70C. After cooling 12 hours in a dessicator, aliquots were weighed to determine dry weight. Ignition at 650C for 12 hours in a muffle furnace followed. After cooling 12 hours in a dessicator, a final weighing was made to determine residual ash and ash-free dry weight (weight loss on ignition). The ash-free dry weight is reported here as an estimate of total organic matter/square meter.

Pigment extraction and spectrophotometric analyses were made from duplicate 25 ml aliquots of the homogenized subsample. Aliquots were filtered on a 0.45 μm pore size Millipore filter. Aliquot and filter were placed in test tubes and extracted 12 hours at 0C in the dark with 90 percent acetone to which a trace amount of $MgCO_3$ had been added. The filters were dissolved by the acetone. With a double-beam, grating spectrophotometer and 1 cm path length cells, light extinction of the extract at nine wavelengths was determined. Ratios of various optical densities and appropriate correction factors gave estimates of plant pigments present on a weight/square meter basis. Determinations were made for chlorophylls a, b, and c, carotenoids, and pheophytin.

The remainder of the subsample was used for microscopic quantitative and qualitative description of the algal populations. An aliquot was digested with concentrated nitric acid to clean diatom frustules and destroy organic material. The residue was then mounted on slides in Hyrax for identification and counting. Other aliquots of the homogenized slurry were examined directly. Periodic grab samples of fresh material from the research site were also made and used to supplement this taxonomic and quantitative work.

Invertebrate Samples

A 12.5 percent aliquot of each composite sample was examined with a binocular dissecting scope to remove as many of the macroinvertebrate organisms as possible. After removal, these organisms were classified taxonomically, blotted dry and weighed on an analytical balance having an accuracy of 0.1 mg. Some organisms, such as tardigrades and ostracods, were not removed. To examine biomass differences between riffles of the same stream, on every third month 50 percent of the sample from each riffle was processed without the aid of a binocular scope. Total biomass was the main parameter of concern in this last procedure, and only a small weight of organisms was missed by not using a dissecting scope.

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. This analysis was in addition to organic matter estimates made in association with the algal studies.

Hydropsyche californica were separated into size groups on the basis of head capsule width for preparation of length-frequency graphs. The width at the widest point behind the eyes was measured with an ocular micrometer for this purpose.

Organic Matter

Analysis of ash free dry weights of benthic samples indicates that organic matter on the stream bottoms varies considerably throughout the year (Fig. 24). Total organic matter in the streams varied seasonally, and peaks differed significantly from year to year (Fig. 24). Patterns for 1970 exhibited a spring-early summer peak and a larger fall-winter peak. During 1971, the peaks were generally lower, especially during fall 1971 and winter 1972.

The large increase during January and February 1971 may be the result of high nitrate content of Willamette River water during this period (Fig. 23), although this pattern was not clearly repeated in January 1972. No consistent difference in organic matter between streams is apparent, although values for Stream 2 are lower during several periods, particularly during summer 1970 and spring 1971, when primary treated effluents were being added to Stream 2. During fall 1971 and late winter 1972, when stabilized effluents were used, organic matter tended to be more abundant in Stream 2.

Higher Plants

Assemblages of both rooted and floating higher aquatic plants were well established in the stream channels by summer 1970. The rooted vegetation included occasional grass invaders in the shallow riffles and the pondweeds *Potamogeton pusillus* L. and *Potamogeton crispus* L. grew in dense stands in pools. *Potamogeton pusillus* was most abundant in Stream 3 and invaded the lower riffles. Another aquatic angiosperm, *Elodea canadensis* Michx, was observed, but rarely, and did not become established. Pondweeds were more abundant in 1971 and 1972 than during the first year.

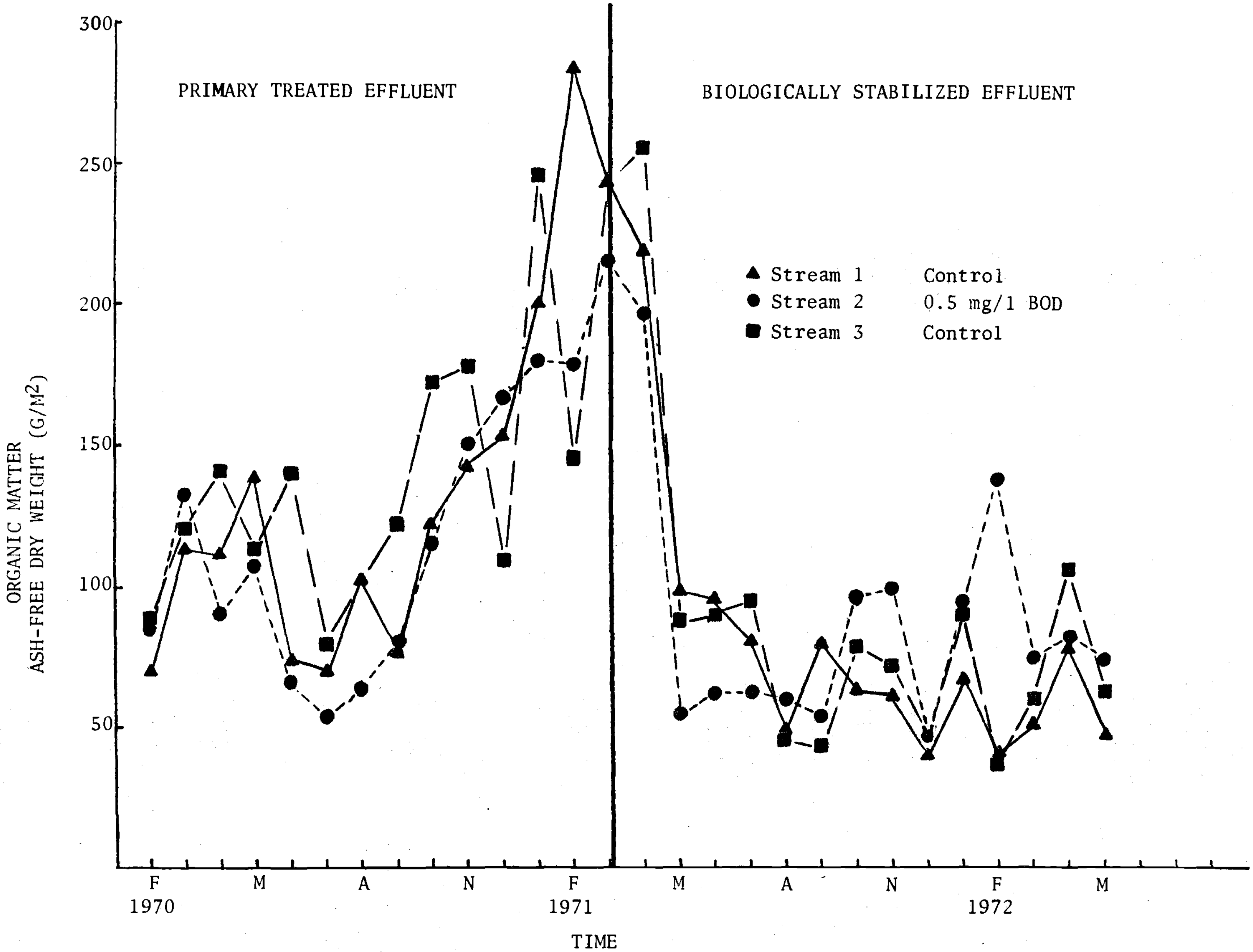

Figure 24. Organic matter from experimental stream channels estimated from ash-free dry weights of benthic samples.

Perhaps silt deposited in the stream was the major factor involved in that it provided a substrate easily penetrated by roots and rhizomes. Beginning in the summer of 1971, attempts were made to control these plants by manual removal.

Floating higher aquatic plant populations grew in floating mats along pool margins and to a lesser extent in riffle areas. Three plants were noted: *Azolla filiculoides* Lam., duckweed fern; *Lemna minor* L., lesser duckweed; *Spirodella polyrhiza* (L) Schleid., greater duckweed. *Azolla* was the dominant plant in the assemblages and remained at high concentrations throughout the two year period studied. *Lemna* and *Spirodella* were not as abundant in winter months. In the autumn months (September-December), as much as 25 percent of a pool surface area was covered with this mat-like growth. Slow surface current velocity is a critical factor for the survival of these plants. They were especially abundant along stream margins where exposed rock and bank vegetation caused eddies in water flow. Periods of high turbidity (silt) and seasonal sloughing of filamentous algae helped eliminate some of this growth. Sampling methods for benthic material and the seining of fish often mechanically aided removal. On a few occasions, an effort was made to break up the growths manually because of their interference with routine sampling of insects and fish.

Algae

Plant biomass in samples consisted primarily of diatoms and filamentous algae. Biomass was estimated using two parameters: ash-free dry weight (total organic matter) which has already been discussed, and Chlorophyll-a content (plant organic matter). Chlorophylls-a,-b, and -c, carotenoids, and pheophytin-a pigment extracts have also been examined to estimate ratios of green algae to diatoms and to partition plant organic matter into living organic matter and detrital organic matter.

General Patterns

Spirogyra and *Oedogonium* species were the most abundant filamentous algae observed in the streams throughout the study. Their relative abundance, based on general field observation, was lower during winter and spring months. *Vaucheria* sp. was common, but mainly restricted to the deeper pool or riffle substrates. Winter and spring increases were noted in *Ulothrix* sp. and *Microspora* sp. *Tetraspora* sp. was common during the spring and summer of each year. Distribution of filamentous green algae was in part determined by water current and availability of suitable substrate for attachment. Traces of the blue-green algae *Phormidium* sp. and *Microcoelous* sp. were noted during August through December. During the autumn of 1970, traces of *Sphaerotilus natans* were seen in Stream 2.

The most abundant algae at all times were the diatoms, which formed a brownish coat on rock and silt in riffles and pools. The most obvious were species of *Melosira*, which grew in long filamentous colonies. The remainder of the diatom assemblage consisted of numerous motile and non-motile species, usually occurring as discrete individuals. Most abundant were species of *Achnanthes*, *Gomphonema*, *Navicula*, *Nitzschia*, and *Synedra*. Fairly common genera were *Cocconeis*, *Cymbella*, *Cymatopleura*, *Epithemia*, *Pinnularia*, *Frustulia*, *Tabellaria*, and *Rhopalodia*. Species attached to the substrate or to other plants were most common, but some species noted were of a more planktonic nature like *Asterionella*.

During the spring and summer of 1970, large "blooms" of the green alga *Hydrodictyon reticulatum* (L.) Lagerh occurred in the pools of all streams. This was not observed during 1971 or 1972, although *Hydrodictyon* was present in small amounts. As this was mainly a pool phenomenon, it did not appear in the riffle data.

Quantitative estimates of changes in relative species abundance and diversity parameters are being made, based on detailed microscopic identification and counts of the various species found in the subsamples.

Pigment Analysis

Chlorophyll-a is a ubiquitous pigment in green plants. Figure 25 (bottom) indicates that a period of high chlorophyll-a density occurs in the spring and again in the fall. During summer and winter seasons, the streams exhibit a generally reduced chlorophyll-a content. The peak periods may result from spring and fall algal blooms, followed by periods of increased grazing by snails and insects and sloughing and export of old or dying algae. April, October, and February peaks in chlorophyll-a are directly related to high diatom biomass at these times.

During spring and summer 1970, chlorophyll-a concentrations in Stream 2 (receiving primary treated effluent) were higher than those of the control streams, this indicating higher plant biomass in Stream 2 (Fig. 25). In spring 1971, Stream 2 (receiving stabilized effluent) was lower in chlorophyll-a than controls. The concentration in Stream 2 increased in the summer and fall and was intermediate between controls.

The Pigment Diversity Index (Margalef, McIntire) is based on the optical density ration D480/D665 in acetone extracts of samples. It is

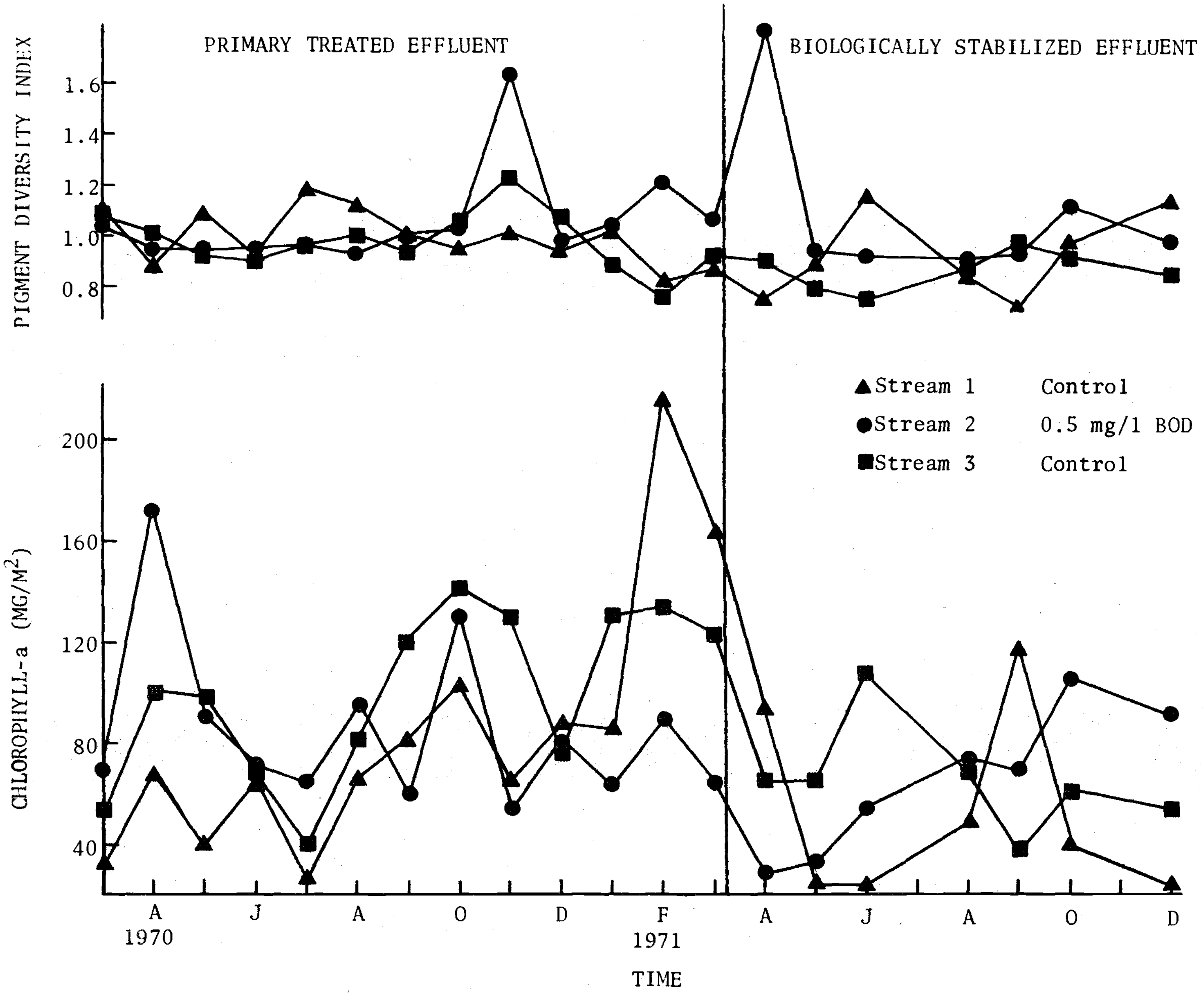

Figure 25. Top, Pigment Diversity Index (see text); Bottom, Chlorophyll-a concentrations in streams determined from benthic samples. March 1970-March 1971, Streams received primary treated effluent, March 1971-December 1971; Streams received stabilized effluent. Data of Joseph Mahoney.

thought to be a reliable indication of changes in many pigment types. This index appears to be related to nutrition and diversity of the plant community and it tends to increase with increase in biomass, with decrease in production per unit biomass, and with increase in community diversity. In Figure 25 (top), the control streams have similar, stable indices during 1970. The large index increase in Stream 2 (primary treated effluent) in November is related to increasing biomass and dominance of diatoms seen in the following month. During 1971, the index for each stream is quite variable, indicating some instability in the environmental conditions and fluctuating production and community structure. In April 1971, the large increases in the index for Stream 2 (stabilized effluent) indicate the rapid growth of plants replacing those lost in export and an early spring stabilization period and establishment of a more diverse community.

Chlorophyll-c is found in diatoms and not in filamentous green algae. Chlorophyll-b, on the other hand, is absent from the diatoms. Chlorophyll-c is relatively more abundant in the streams than chlorophyll-b, because of the great abundance of diatoms (Fig. 26). Preliminary work with these pigments indicates some seasonal variation. Chlorophyll-b maxima occurred in the autumn of both 1970 and 1971 and reach minimum levels in the early spring, when chlorophyll-c maxima occurred, suggesting a reciprocal relation between the abundance of the groups of algae having the different pigments.

It was noted in the field that green algae were less abundant in the upper half of Stream 2 during the autumn and winter (especially in 1970) but reached more normal levels in the lower half of Stream 2 during the same periods. Thus, a short zone of low green alga abundance was noted nearest the effluent outfall in Stream 2. During 1971, all the streams

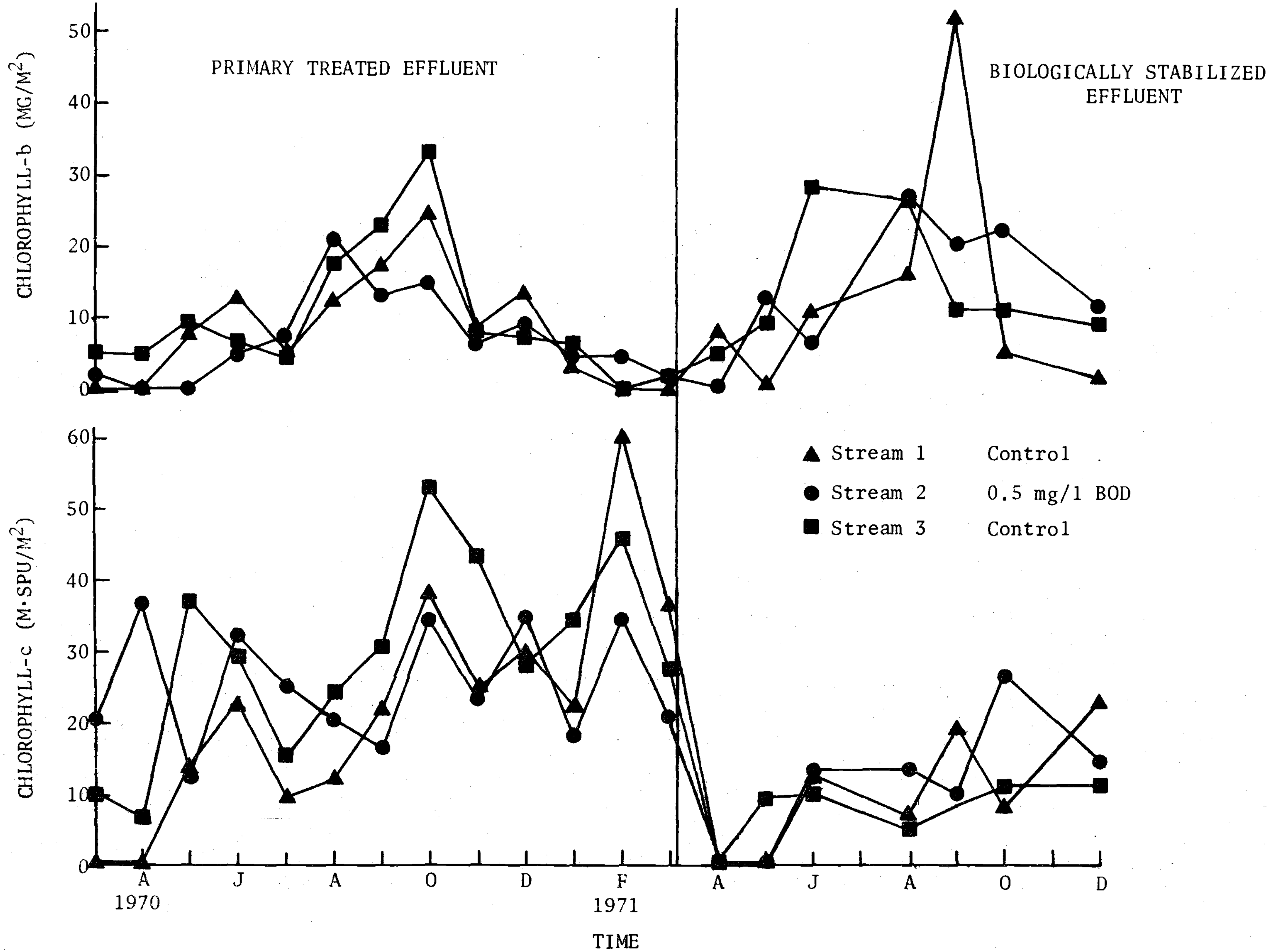

Figure 26. Top, Chlorophyll-b concentration; Bottom, Chlorophyll-c concentration determined from benthic samples. Streams received primary treated effluent March 1970-March 1971 and stabilized effluent March 1971-December 1971. Data of Joseph Mahoney.

had higher concentrations of chlorophyll-b, the green algae estimator, than the previous year and relatively more green algal biomass (Fig. 26, top).

Chlorophyll-c content was generally higher in all streams during 1970 than in 1971 (Fig. 26, bottom). Only trace amounts of chlorophyll-c were found in the April 1971 sample from all streams. Large decreases in organic matter and chlorophyll-a were also noted during this period. Large losses of plant material by sloughing and grazing may have caused these decreases. While receiving primary treated effluent, Stream 2 showed lower chlorophyll-c than controls in fall and winter (Fig. 26, bottom). With the exception of July and August 1970, this stream was also slightly lower in chlorophyll-b content. In 1971, when Stream 2 received stabilized effluent, it had higher chlorophyll-c concentrations than control streams during summer and fall (Fig. 26, bottom), this indicating higher diatom biomass in the effluent stream. Chlorophyll-b concentrations were somewhat higher than the chlorophyll-c, this indicating the dominance of green algae. The ratio chlorophyll-b/chlorophyll-c was lower in Stream 2 than in the controls; although green algae were more successful and dominant than other algae, they did not reach the relative proportions and degree of dominance seen in control streams.

Invertebrates

Diversity

The most abundant immature insects in the streams were caddisflies (*Hydropsyche californica*), blackflies (*Simulium*) and midges (Tendipedidae). Beetles (Coleoptera), biting midges (Ceratopogonidae), danceflies

(Empididae), crane flies (Tipulidae), stoneflies (Plecoptera), Lepidoptera, other caddisflies (*Agraylea* and *Oxythira*), and mayflies (Ephemeroptera) were also present in low numbers. Snails of the genus *Physa* were abundant in the streams, particularly during fall and winter. Limpets and fingernail clams were found occasionally. Amphipods of the genus *Crangonyx* were abundant in the streams. Table 4 is a list of the macroinvertebrates identified.

Diversity of the invertebrate assemblage has been expressed by means of a formula used by Patten (1962):

$$\bar{d} = -\Sigma\left[\left(\frac{n_i}{N}\right) \log_2 \left(\frac{n_i}{N}\right)\right]$$

where n_i = number of organisms in the i^{th} species

N = total number of organisms.

Diversity is equated with the uncertainty of selecting, at random, an individual of a particular species from an assemblage of populations. The greater the number of species present, and the more similar their abundance, the greater the uncertainty of selecting any given one at random, and thus the greater the diversity (Wilhm and Dorris, 1968).

Changes in the diversity of benthic animal communities are generally supposed to indicate environmental changes affecting that community (Warren, 1971). The diversity index ($\bar{d}$) that we have used here is probably the most sensitive and meaningful one. Our use of this index suggests that the primary treated and biologically stabilized kraft mill effluents, at 0.5 mg/l BOD, had little if any effect on the diversity of the benthic animal community in Stream 2 as compared to control Streams 1 and 3 (Table 5). During the first year of this study, diversity increased in

Table 4. Invertebrate organisms in experimental stream channels identified from benthic samples.

- Diptera
  - Tendipedidae
    - *Pelopia*
    - *Metriocnemus*
    - *Pentaneura*
    - *Tanytarsus*
    - *Eukiefferiella*
    - *Cardiocladuis*
    - *Tendipes*
    - *Psectrocladuis*
    - *Cricotopus*
    - *Orthocladuis*
    - *Corynoneura*
  - Simuliidae
    - *Simuluim*
  - Tipulidae
    - *Antocha*
    - Unidentified genus
  - Empididae
    - *Chelopoda*?
  - Ceratopogonidae
    - Unidentified genus
  - Psychodidae
    - *Pericoma*
- Lepidoptera
  - Pyralidae
    - *Parargyractis*
- Coleoptera
  - Hydrophilidae
    - *Berosus*
    - Unidentified genus
  - Dytiscidae
    - *Bidessus*
    - *Laccophilus*
  - Elmidae
    - Unidentified genus
- Ephemeroptera
  - Baetidae
    - *Caenis*
    - *Paraleptophlebia*
    - *Ephemerella infrequens*?
    - *Ephemerella micheneri*
    - *Baetis bicaudatus*
    - *Baetis tricaudatus*
  - Heptageniidae
    - *Stenonema*
    - *Rithrogena morrisoni*?
- Plecoptera
  - Perlodidae
    - *Isoperla*
  - Nemouridae
    - *Nemoura*
- Trichoptera
  - Glossosomatidae
    - *Glossosoma*
  - Hydroptilidae
    - *Agraylea*
    - *Oxythira*
  - Hydropsychidae
    - *Cheumatopsyche*
    - *Hydropsyche californica*
  - Lepidostomatidae
    - *Lepidostoma strophis*
- Crustacea
  - Amphipoda - *Crangonyx pseudogracilis*?
  - Decopoda - Unidentified
- Mollusca
  - Ancylidae
    - Unidentified genus
  - Sphaeriidae
    - *Pisidium*
  - Physidae
    - *Physa*
  - Pleuroceridae
    - *Oxytrema silicula*
  - Lymnaeidae
    - *Redix auricularia*

Table 5. Species diversity of benthic macroinvertebrates in three experimental streams. Unidentified members in the subfamily Orthocladiinae were not included in the analysis. Values given for $\bar{d}$ (see text).

Date	Stream 1 control	Stream 2 effluent 0.5 mg/1 BOD	Stream 3 control
1970		Primary treated	
February 1	1.4775	1.3300	1.2302
May 16	1.9803	1.2876	1.7435
August 6	2.5293	2.3202	2.0290
November 7	2.8192	2.7238	2.6857
1971			
January 23	2.8043	2.9555	3.2398
		Biologically stabilized	
April 4	2.8782	2.9526	3.0227
July 15	2.8404	2.5264	2.8406
October 6	1.8200	1.7173	1.8564

all three streams as they were colonized by animals. Relatively high levels of diversity were then maintained through July 1971. The considerable drop in diversity in all streams by October 1971 was associated with a very great decline in numbers of midge (Tendipedidae) larvae of different species about this time (Fig. 28), which we will consider below and which appear to be associated with gradual silting of the streambeds.

The diversity values for the experimental streams are high enough to suggest that we are studying a moderately complex and realistic stream community. Many natural streams of this size have lower values, though some--such as our Berry Creek Experimental Stream (Warren et al. 1964)--have much higher values. Diversity in the experimental streams is probably similar to that in the Willamette River, with regard to insect community.

Total Insect Abundance

Total numbers of insects fluctuated markedly throughout each year, generally with major peaks in spring and in fall (Fig. 27, top). In 1972, however, the spring peak was reduced or absent. The fall peak in 1971 was lower than in 1970 for all streams. Total biomass of insects followed a pattern similar to numbers although the peaks were higher in 1971 and 1972 than in 1970 (Fig. 27, bottom). Biomass exhibited a marked peak in spring 1972. Numbers of individuals did not increase markedly at this time, so this increase in biomass appears to have resulted primarily from the presence and growth of larger insects.

The general patterns of change in insect populations in these streams

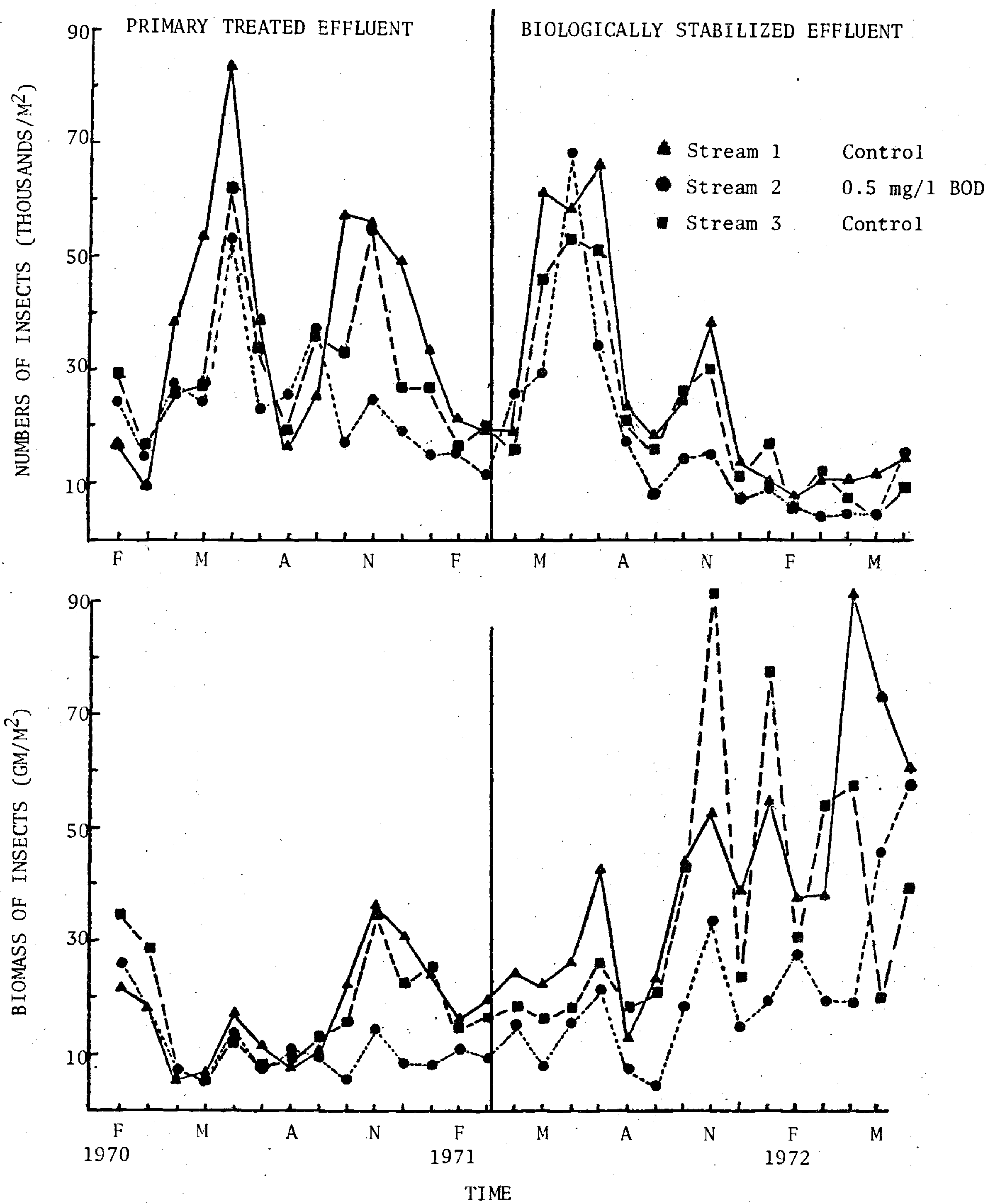

Figure 27. Numbers (upper figure) and biomass (lower figure) of insects per M^2 from benthic samples. Data of Richard Craven.

can be associated with periods of reproduction, growth, and emergence into adult stages. Warm spring temperatures result in resumption of growth and finally emergence to the adult stage for those insects that overwinter as larvae. An increase in numbers in the spring reflects hatching of some overwintering eggs and eggs oviposited late in winter or early spring. Growth and development during spring increase insect biomass. By late spring, emergence to adult stages and natural mortality again reduce the population to low levels. The major fall peaks, as well as lesser peaks in other seasons, are in general related to the same phenomena.

A general pattern of decreasing numbers and increasing biomass of insects in all three experimental streams is apparent over the entire 1970-72 period of study (Fig. 27). Changes in the streams themselves, particularly silting of their bottoms, and successional changes in the composition of the insect communities--some groups becoming less abundant, others more abundant--are responsible for this overall long-term trend.

Total numbers of insects as well as biomasses were lower in Stream 2 during fall and winter 1970-71, when this stream was receiving 0.5 mg/l primary treated effluent (Fig. 27).

Introduction of biologically stabilized waste, in place of primary treated waste, into Stream 2 was initiated in March 1971. Both total numbers and biomasses of insects were lower in Stream 2 than in the control streams during the 1971-72 fall and winter (Fig. 27). Thus the data in Figure 27 indicate that insect abundance was reduced, mainly in the fall and winter, by exposure of the Stream 2 aquatic community to 0.5 mg/l BOD of either primary treated or biologically stabilized kraft mill effluent; but, as will be explained, the apparent effects of stabilized waste are probably incidental to other conditions.

Tendipedidae (midges)

Midges accounted for the greatest numbers of insects and determined the general pattern in total insect numbers until September 1971. The pattern of abundance of the numerous midge species consisted of large population peaks in spring 1970 and 1971, and a lower peak in the 1970-71 fall and winter (Fig. 28, top). A marked decline in numbers of midge larvae occurred in all streams during the 1971-72 fall and winter, perhaps owing to heavy siltation of the riffles.

Biomass generally followed a pattern similar to that of numbers of midges, but there were important differences (Fig. 28). The biomass peak in June 1970 coincided with the large peak in numbers, but the peak in biomass in March, when numbers were low, was due to smaller numbers of larger individuals of *Tendipes*, which were relatively abundant early in the study. The 1971 spring peak was lower, presumably due to the absence of *Tendipes* in all streams. But both numbers and biomasses of other genera were more constantly high, this suggesting a more stable and diverse community by this time.

Numbers of midges were lower in Stream 2 than in the control streams during the 1970-71 fall and winter, when primary treated effluent was being introduced (Fig. 28, top). The low numbers were primarily due to reduced abundance of *Tanytarsus* from October 1970 to January 1971 and fewer Orthocladiinae during October and November 1970. Biomass of midges was not lower in Stream 2 than in the control streams during the 1970-71 fall and winter (Fig. 28, bottom). This situation indicates the changes in species composition resulted, for Stream 2, in an assemblage of fewer but larger midges.

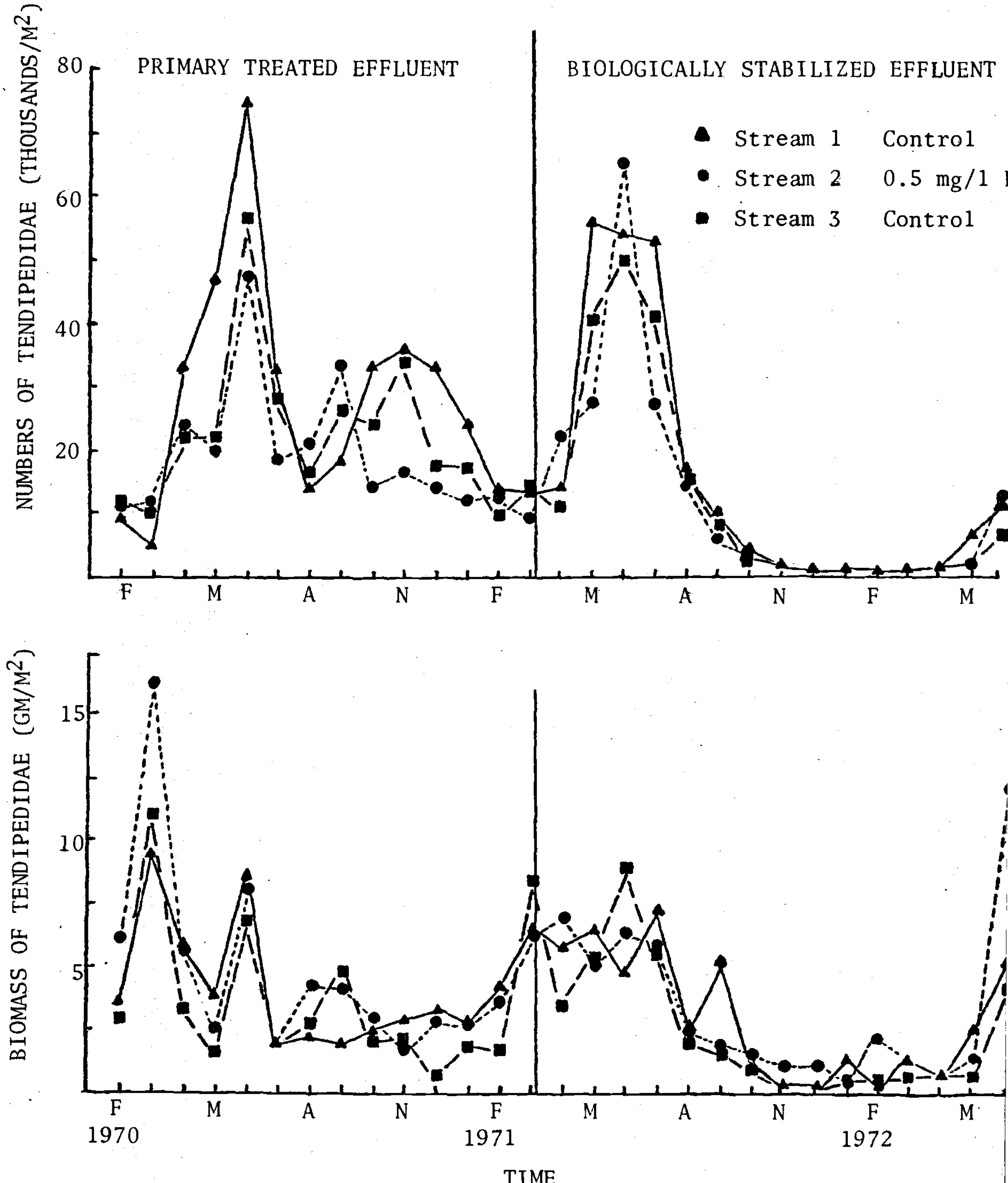

Figure 28. Numbers (upper figure) and biomass (lower figure) of Tendipedidae (midges) per M^2 from benthic samples. Data of Richard Craven.

Both total numbers and biomasses of midges were similar in all streams when biologically stabilized effluent was being introduced (Fig. 28). On July 15, 1971, however, *Tanytarsus* did not occur in samples from Stream 2, but numbers of these were estimated to be 5800 and 7800 per meter square in Streams 1 and 3, respectively.

Simulium (blackflies)

Blackflies, in the genus *Simulium*, rapidly colonized the streams after the water flow was started in October 1969 and had practically disappeared by February 1972 (Fig. 29). Blackflies are filter feeders commonly attached to rocks exposed to relatively high water velocity in streams. The large populations during the first year may have been possible because of few competitor organisms and the small amount of silt on the substrate. Siltation apparently altered the substrate and flow characteristics previously suitable for this organism.

Numbers of blackflies were lower in the stream receiving primary treated effluent during summer, fall, and winter 1970-71, while biomass was lower only during fall and winter (Fig. 29). The size class distribution (not reported here) indicated that there were relatively few larvae present in the smallest class in Stream 2, this suggesting that embryonic and larval stages may have been most sensitive to direct or indirect effects of the effluent.

After March 1971, when stabilized effluent was being introduced into Stream 2, there was some indication of adverse effect of the effluent on numbers and biomass of blackflies, particularly during July 1971 (Fig. 29).

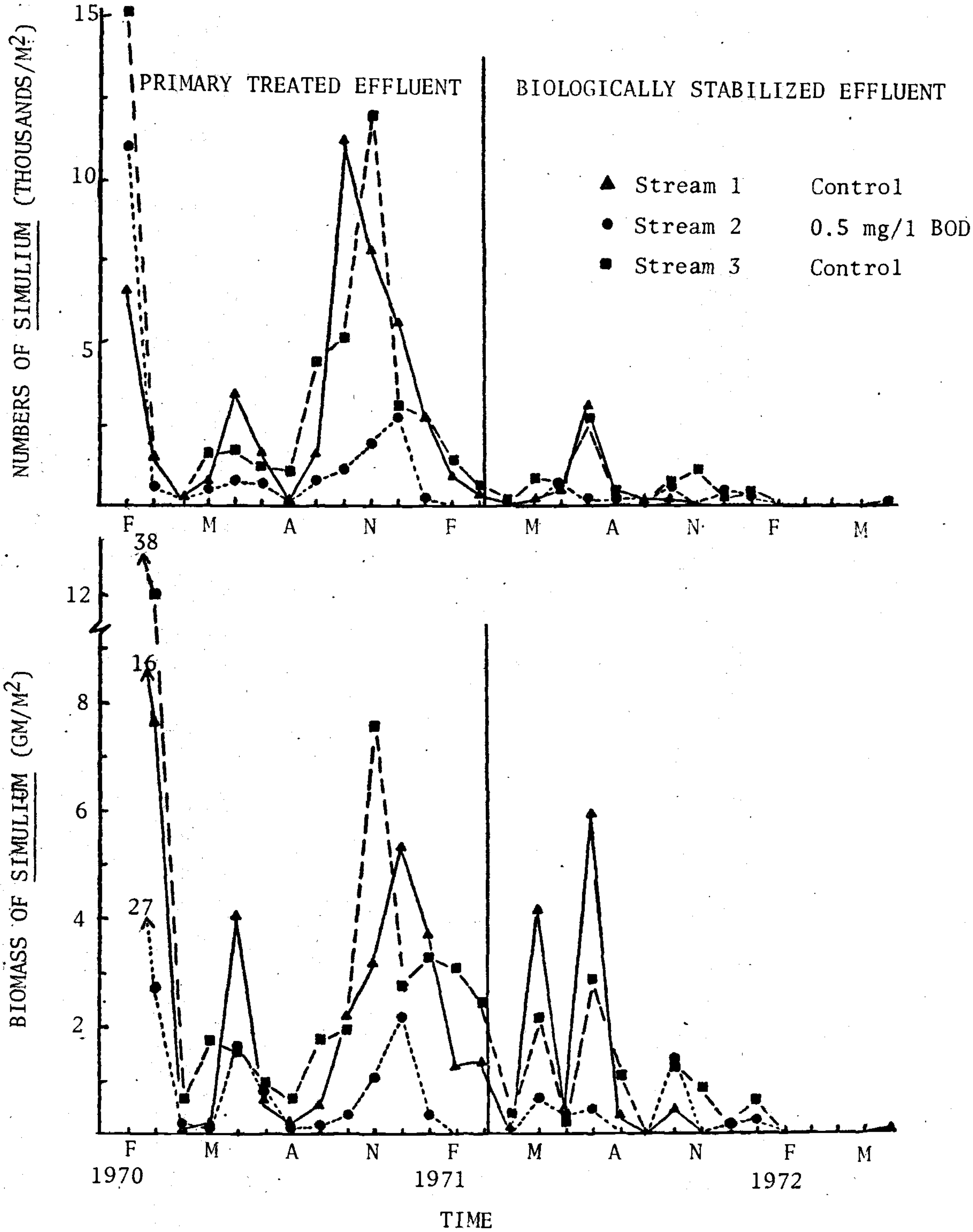

Figure 29. Numbers (upper figure) and biomass (lower figure) of Simulium (blackfly) per M^2 from benthic samples. Data of Richard Craven.

Hydropsyche (caddisfly)

Caddisflies colonized the streams during spring 1970 by means of larvae in the water supply and from deposition of eggs by adults in the stream. By far the most abundant of these were species of the genus *Hydropsyche*. The complete life cycle of *Hydropsyche californica*, the only species of this genus we could identify from the adult form, takes about one year to complete, the larval stage living from one summer or fall to the next spring or summer. Members of the genus *Hydropsyche* comprise a very large part of the total biomass of insects in the streams; numerically their proportion is not so large, because individuals of this genus tend to be large. *Hydropsyche*, both in terms of numbers and biomasses, are most abundant in the streams in fall and winter (Fig. 30). Numbers tend to peak about November and then decline. Biomasses tend to remain high longer, as biomass lost through mortality of individuals is replaced by growth of other individuals (Fig. 30). Numbers and biomasses of *Hydropsyche* exhibited overall increase from the time of colonization to the present.

The major group of larvae hatch from eggs between September and November, after which a sharp decline in numbers and a lesser decline in biomass occur (Fig.30). Growth is slowed during winter until March, and no emergence occurs during winter. Growth rates increase in March or April, and emergence begins shortly thereafter. Numbers of larvae never drop to zero, since there are overlapping generations having a majority of their larvae hatching in the summer and early fall.

After August 1970, when the recruitment period began, there were consistently lower numbers and biomasses of *Hydropsyche* in Stream 2 than

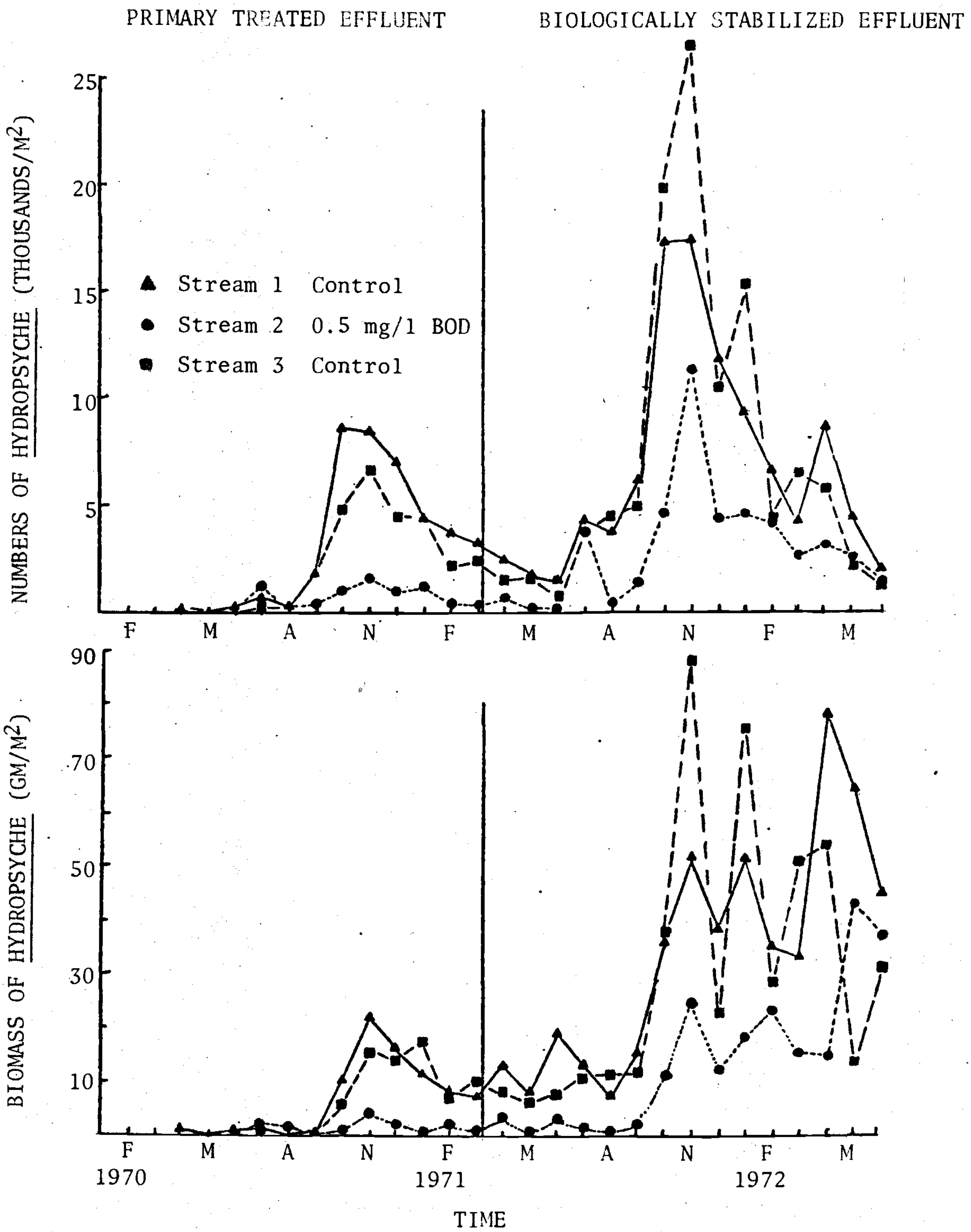

Figure 30. Numbers (upper figure) and biomass (lower figure) of Hydropsyche (caddisfly) per M^2 from benthic samples. Data of Richard Craven.

in the control streams, this suggesting a rather marked effect of the effluent on the quantitatively important group. The proportion of small to large larvae in Stream 2 was less than in the control streams. This probably indicates that the effect of primary treated effluent was directly or indirectly on ovipositing adult females or on the viability of eggs or newly hatched larvae. Flowing water bioassays in which medium sized larvae were exposed to 0.5 mg/l BOD primary treated effluent for 2-3 weeks resulted in no mortality or observed abnormal behavior. Only concentrations above 5 to 6 percent by volume (BOD's about 10 mg/l) consistently led to mortality. Nevertheless, sublethal toxic effects could have occurred, and, in the streams, of course, changes in the benthic conditions could have affected these larvae.

Beginning March 1971, stabilized waste was introduced into Stream 2, after this stream had received primary effluent for about one year. Effects of the primary effluent on population numbers would tend to persist to the end of the life cycle of any organisms affected. The life cycle of most of the caddisflies began in summer and fall. Thus, increases in larval numbers due to reproduction under the new conditions of stabilized waste could hardly be apparent until summer 1971 (Fig. 30).

By July 1971 the first major larval recruitment period occurred, and all streams had comparable numbers of small larvae (Fig. 30). As already noted, large numbers of small larvae were not present in Stream 2 when it was receiving primary treated effluent. Biomass was still higher in Streams 1 and 3, however, because of the presence of more large larvae. Scarcity of large larvae in Stream 2 at this time was not believed to be an effect of stabilized waste but a carry-over of an age class reduced by the primary waste.

After July 1971, numbers decreased precipitously in Stream 2 (Fig. 30, top). The decrease could have resulted from several factors. Stabilized waste could have been detrimental to the larvae, but the decrease most probably was a result of water supply failure in all streams for 40 hours. Waste continued to enter Stream 2. Emergency valves now prevent such occurrences. Emergence to the adult stage could not account for the decrease, since there was not enough time to complete the life cycle that started only two months earlier. The stabilized effluents, then, was probably not detrimental to *Hydropsyche*, although several more months of data should be collected. Numbers and biomasses of *Hydropsyche* remained lower in Stream 2 until May 1972, by which time populations in the three streams appeared similar (Fig. 30).

Flowing water toxicity bioassays were conducted with stabilized waste concentrations up to 11 percent by volume with no mortality of *Hydropsyche* occurring, this substantiating somewhat the apparently lesser effects of the stabilized as compared to the primary effluent on this organism in the stream channels.

Figure 31 shows the total numbers and biomasses of all insect except *Hydropsyche*. The pattern of numbers (Fig.31, top) through time is similar to that for midge larvae alone (Fig. 28, top). When summed in this manner, the insects exhibit the effect of primary effluent in Stream 2 during the fall 1970 that was so apparent for the midge larvae. But this is to be expected, if we consider the numerical dominance of the midges.

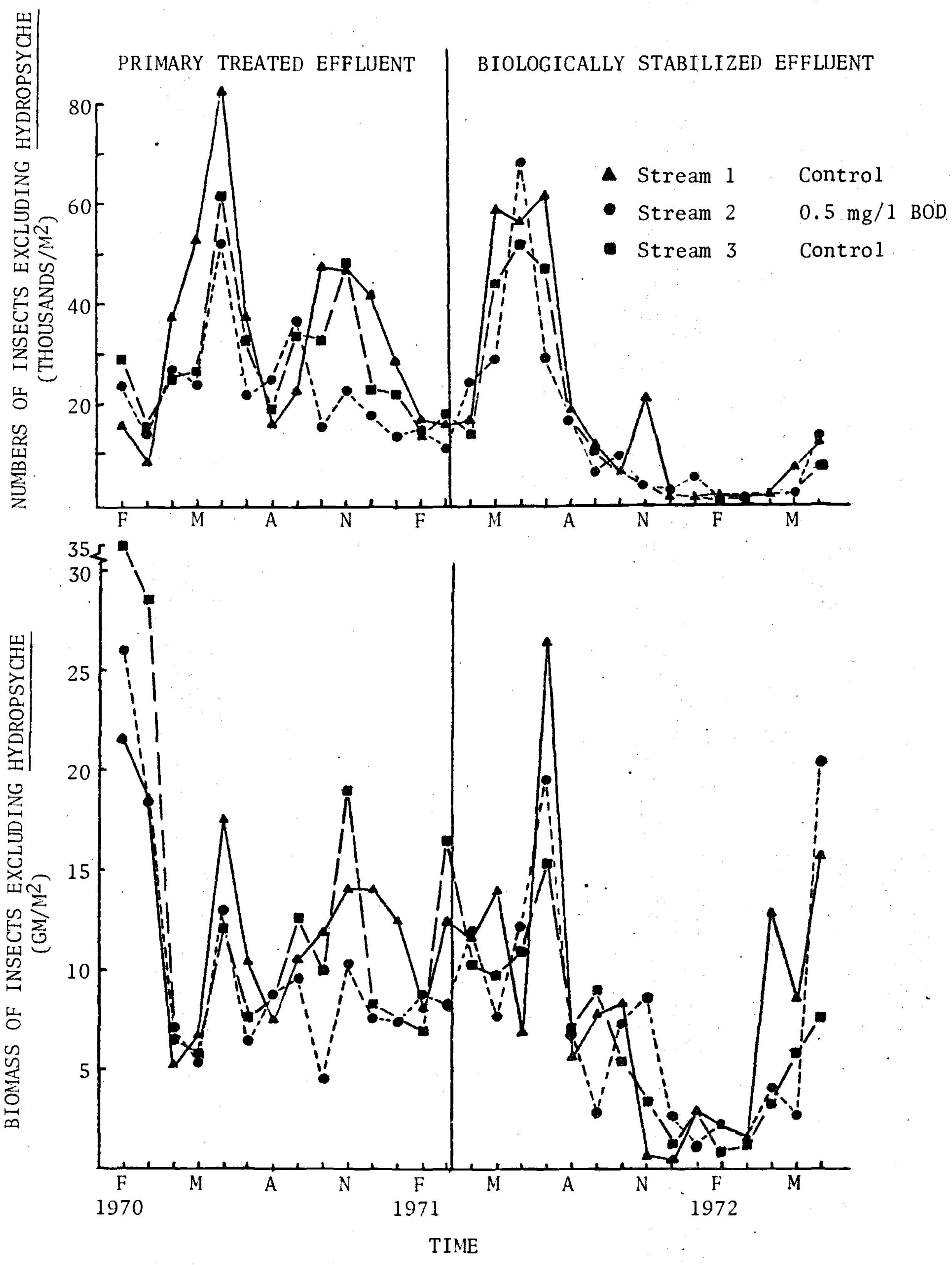

Figure 31. Numbers (upper figure) and biomass (lower figure) of insects, excluding Hydropsyche, per M^2 from benthic samples. Data of Richard Craven.

Total biomass patterns for insects except *Hydropsyche* followed an overall downward trend during the period of the study in all streams (Fig. 31, bottom). It is obviously the *Hydropsyche* that led to the general increase in total biomass of all insects together (Fig. 27, bottom). Only during fall and winter 1970-71 were numbers and biomasses lower in Stream 2 than in the control streams, when summed in this way (Fig. 31, bottom). Taken together, the evidence indicates that whereas the primary effluent decreased the abundance of the more important groups of insects, the biologically stabilized effluent did not.

Crangonyx (amphipod)

Amphipods began appearing in the samples from the experimental streams in April 1970 (Fig. 32). Reproduction occurred in summer and fall of both years as indicated by the two peaks in numbers during July and November (Fig. 32, top). Lower population levels in all streams during 1970 than during 1971 probably are because of the gradual increase in population numbers after colonization of the streams. More than one peak of reproductive activity appears evident during the fall-winter periods. Biomass did not increase in proportion to numbers during the second fall-winter.

Greater numbers in 1971 while biomass was about the same in both years period, suggests that the proportion of small individuals increased, as would be expected.

When primary treated effluent was present, numbers and biomasses were generally lower in Stream 2 than in the control streams during the 1970 summer and the 1970-71 fall and winter (Fig. 32). Mean weight per

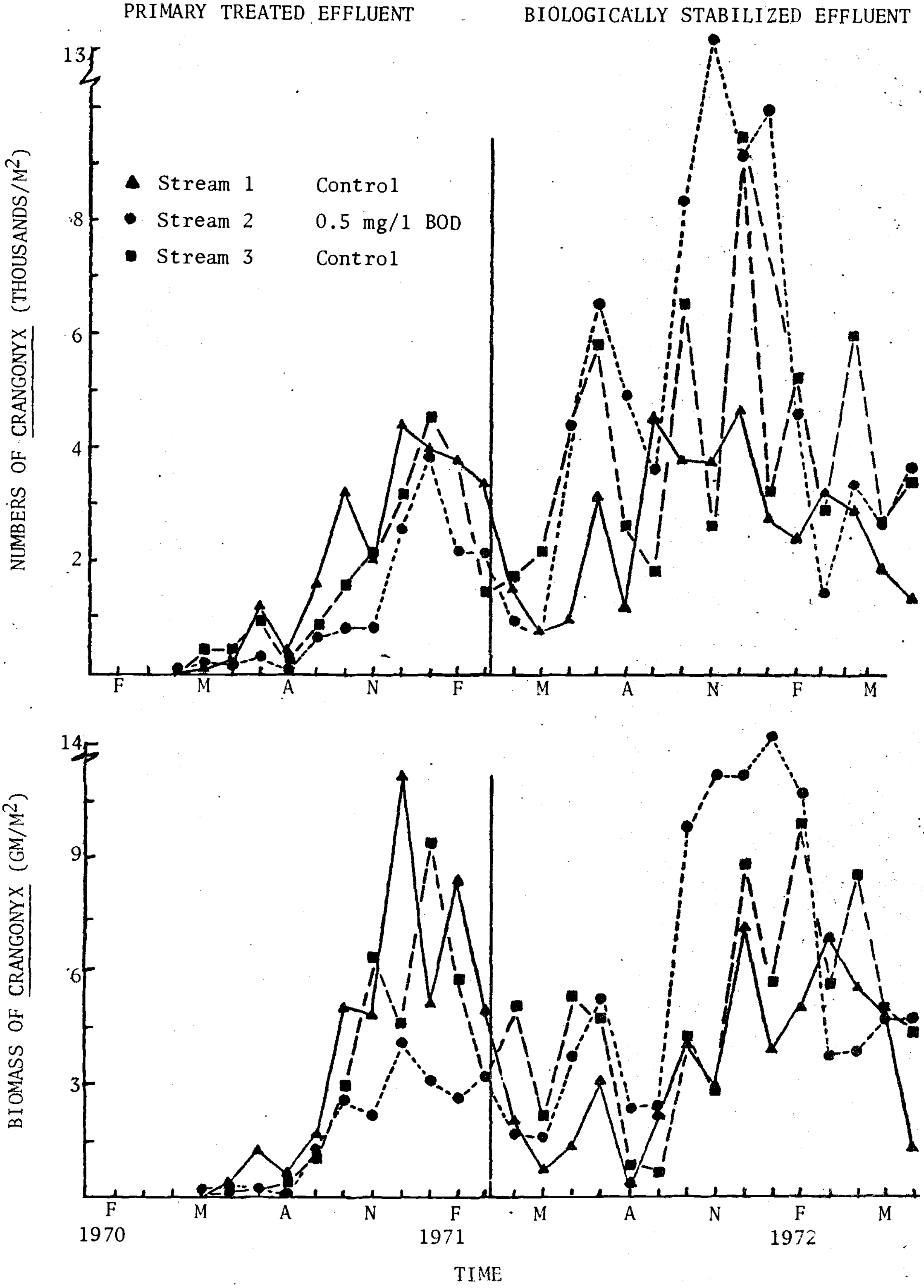

Figure 32. Numbers (upper figure) and biomass (lower figure) of Crangonyx (amphipod) per M^2 from benthic samples. Data of Richard Craven.

individual was about the same in all streams over this period, which suggests that reduction in total biomass was mainly due to reduction of numbers of amphipods, rather than to reductions of their individual growth rates.

Stabilized waste was started in Stream 2 in March 1971 while amphipod populations in all streams were declining because of natural mortality (Fig. 32). Numbers and biomasses of *Crangonyx* remained lower in Stream 2 than in controls through April 1971. After April, when reproduction was occurring, numbers and biomasses became as great or greater in Stream 2 as compared to the control streams. Numbers and particularly biomass of *Crangonyx* were much greater in the stream receiving stabilized effluent during the 1971-72 fall and winter. Data of Ellis (1969) and Seim (1970) suggest that both primary and secondary effluent can sometimes be beneficial to amphipod populations in laboratory streams. In experimental stream channels only stabilized waste could be considered beneficial to *Crangonyx*, the primary effluent appearing to be harmful.

Physa (snail)

The streams were colonized during June 1970 by snails in the genus *Physa* (Fig. 33). The reproductive period extended from June or July until October of 1970 and 1971, as indicated by increases in numbers. Biomass increased to about October during each year, after which both numbers and biomasses tended to decrease (Fig. 33). A residual population was present from February until June or July of both 1971 and 1972. A complete life cycle takes about one year, adults rapidly disappearing from the population after reproduction.

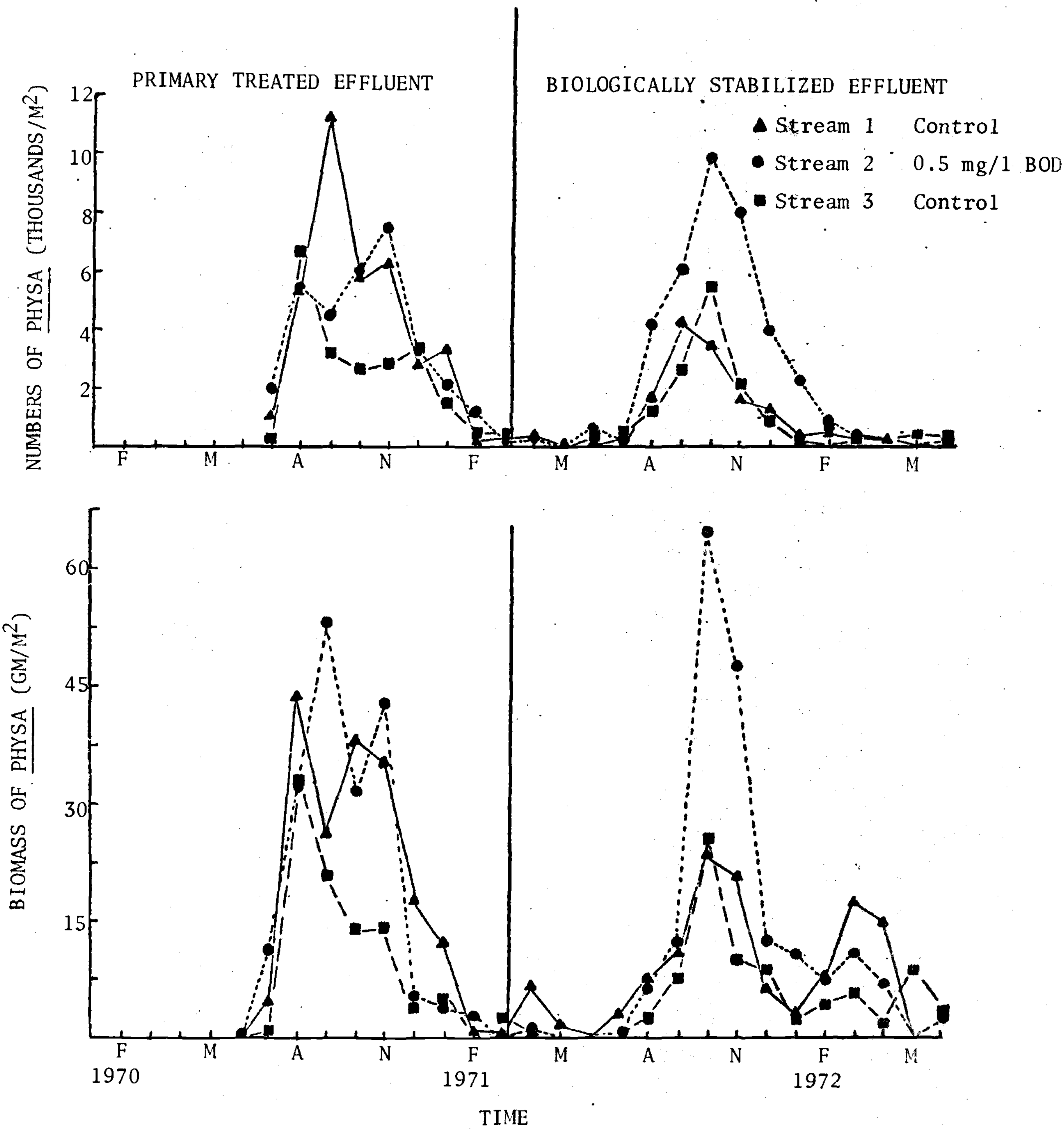

Figure 33. Numbers (upper figure) and biomass (lower figure) of Physa (snail) per M^2 from benthic samples. Data of Richard Craven.

Populations of *Physa* were less abundant in Stream 3 than in the other control stream or in the treatment stream, during the 1970-71 fall and winter, for reasons we have yet to explain (Fig. 33). Primary effluent at 0.5 mg/1 BOD did not appear to influence the population of *Physa* in the experimental stream channels. During the 1971-72 fall and winter, less variation in snail populations occurred between the two control streams (Fig. 33).

Stream 2 was usually higher in both numbers and biomass after July 1971, when stabilized effluent was being introduced (Fig. 33). Reproduction or survival of young snails appears to have been more successful in Stream 2. These snails are omnivorous and feed on dead and decaying organisms and living algae as well as other microorganisms on the rocks (Pennak, 1953). Total organic matter appeared to have been somewhat higher in Stream 2 than in the control streams during this period (Fig. 24), and reductions in *Hydropsyche* populations (Fig. 30) could have reduced competition for food. The presence of biologically stabilized effluent at 0.5 mg/1 BOD may be beneficial to these snails, though reductions in the *Hydropsyche* populations cannot be attributed to the stabilized effluent at this concentration, as we explained earlier.

GROWTH AND PRODUCTION OF SALMONID FISH IN EXPERIMENTAL STREAM CHANNELS

General 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 trout (*Salmo clarki*) were first stocked on February 12, 1970, and coho salmon (*Oncorhynchus kisutch*) were added on April 18, 1970. All these fish were killed in June 1970 as a result of an epidemic of *Ceratomyxis shasta*, a protozoan disease previously unknown in the upper Willamette River. For this reason, more resistant species, fall chinook salmon, (*Oncorhynchus tshawytscha*) and brown trout (*Salmo trutta*) were stocked in the streams. The chinook juveniles, however, migrated from the experimental stream channels by June. Both chinook salmon and coho salmon were suitable test fish during spring until June; brown trout could be used throughout the year.

Fish were removed from the streams at monthly or semi-monthly intervals by seining and electrofishing. The fish were then anesthetized, weighed, counted, and 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 mean weight of the individual fish. Areas under such curves yield estimates of fish production very nearly equal to those obtained by means of mathematical models (Allen, 1951). Relative growth rate of the fish was calculated by dividing production estimates by the product of mean fish biomass and the number of days the fish were in the streams. Food samples were taken from the stomachs of 10 or 20 of the fish anesthetized for weighing. The food was taken from the stomachs by means of alligator ear forceps and placed in preservative. The preserved specimens were later sorted into taxonomic groups and weighed.

The percentage of the total food contributed by each taxonomic group for a given experimental period was then calculated by dividing the total weight of each taxonomic group by the total weight of all food organisms found in the stomachs.

Growth and Production

Primary Treated Effluent

Figure 34 (top) shows that cutthroat trout and coho salmon production was quite similar in all three streams during the spring of 1970. Production of fish in control Stream 3 was slightly higher than in either of the other two streams. Growth rate in Stream 3 was also higher during this period. Stream 2, which received 0.5 mg/l BOD primary effluent, was more like control Stream 1 (Fig. 34, top).

Figure 34 (bottom) shows that fish production was also similar in all three streams during the last five months in 1970. Stream 1, a control stream, was slightly lower in fish production than Streams 2 and 3 from August to November, then higher or equal in December and January. Stream 2 was generally intermediate between the two control streams in production of fish, when it was receiving primary treated effluent at 0.5 mg/l BOD

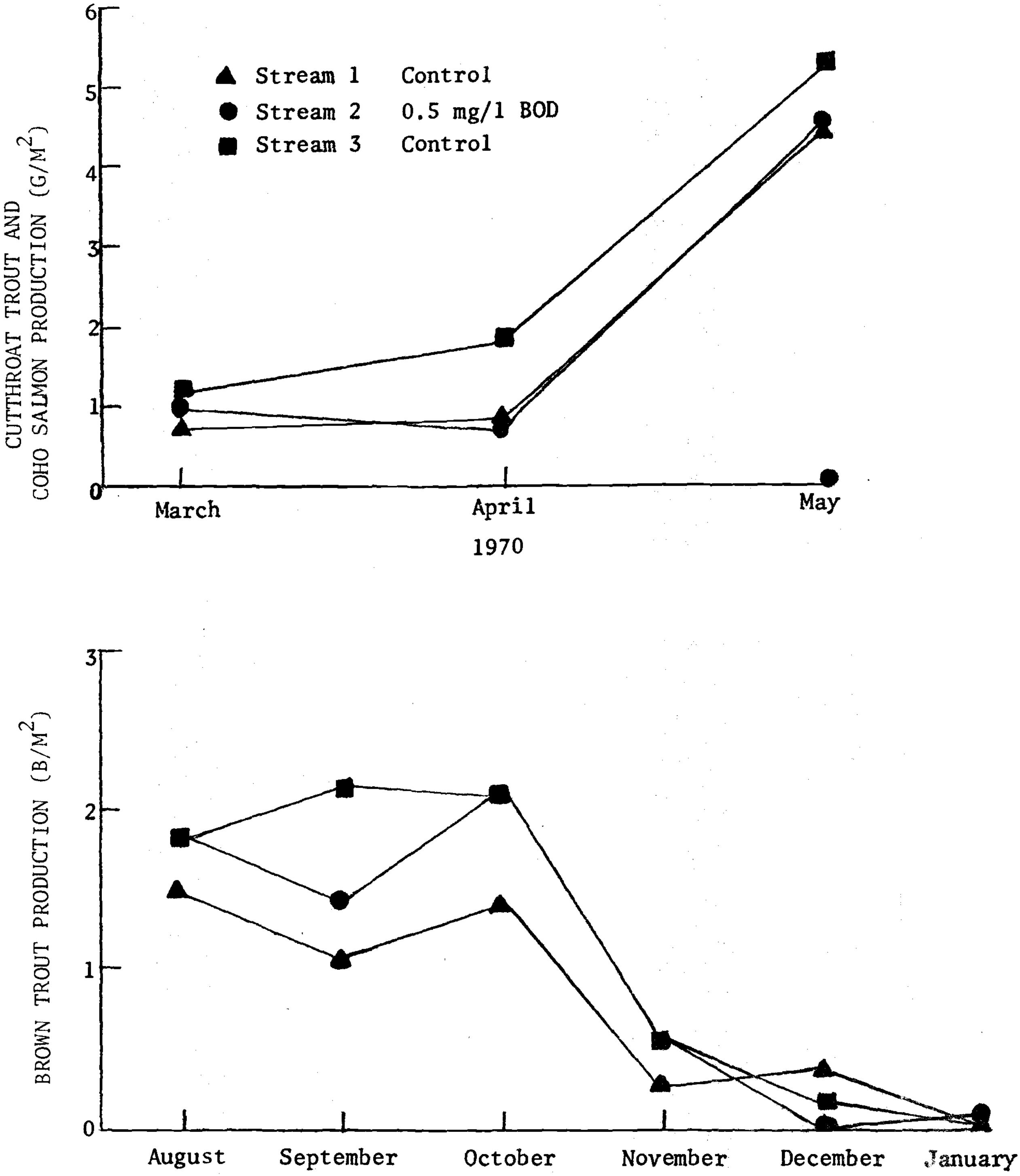

Figure 34. Salmonid production in experimental stream channels during 1970. Stream received primary treated effluent at 0.5 mg/l BOD during this period. Data of Dennis Borton.

(Fig. 34). Production falls very low during the winter months in all three streams, probably because of low temperatures and reduced feeding activity, as food organisms were relatively abundant.

Figure 35 shows relationships between fish growth and biomass during this August-January period. Streams 2 and 3 are approximately the same level of biomass and growth rate and therefore have nearly equal production. Stream 1, however, has growth rates nearly equal to Streams 2 and 3, but at a lower biomass,this indicating control Stream 1 is somewhat less productive than the other two streams in this experimental period. Thus, our evidence indicates that the primary treated effluent, at 0.5 mg/l BOD, had little or no influence on the growth and production of the salmonid fish.

Chinook salmon were stocked in January of 1971, but due to a short-term presence of very toxic effluent, the fish in Stream 2, which was receiving 0.5 mg/l primary treated effluent, died almost immediately after stocking. After we had tested several waste streams from within the plant and talked with plant employees, we attributed the toxic conditions to activities associated with extensive construction at the plant. Apparently a very toxic waste existed for only a relatively short period, after which toxicity returned to normal levels. The chinook were restocked in March at equal densities in all streams. Chinook then began leaving Stream 2 in the first month and by the next month had also emigrated from Streams 1 and 3. The combination of toxic effluent conditions and the emigration of the salmon makes data collected during this period of reduced value; therefore it is not included in this report.

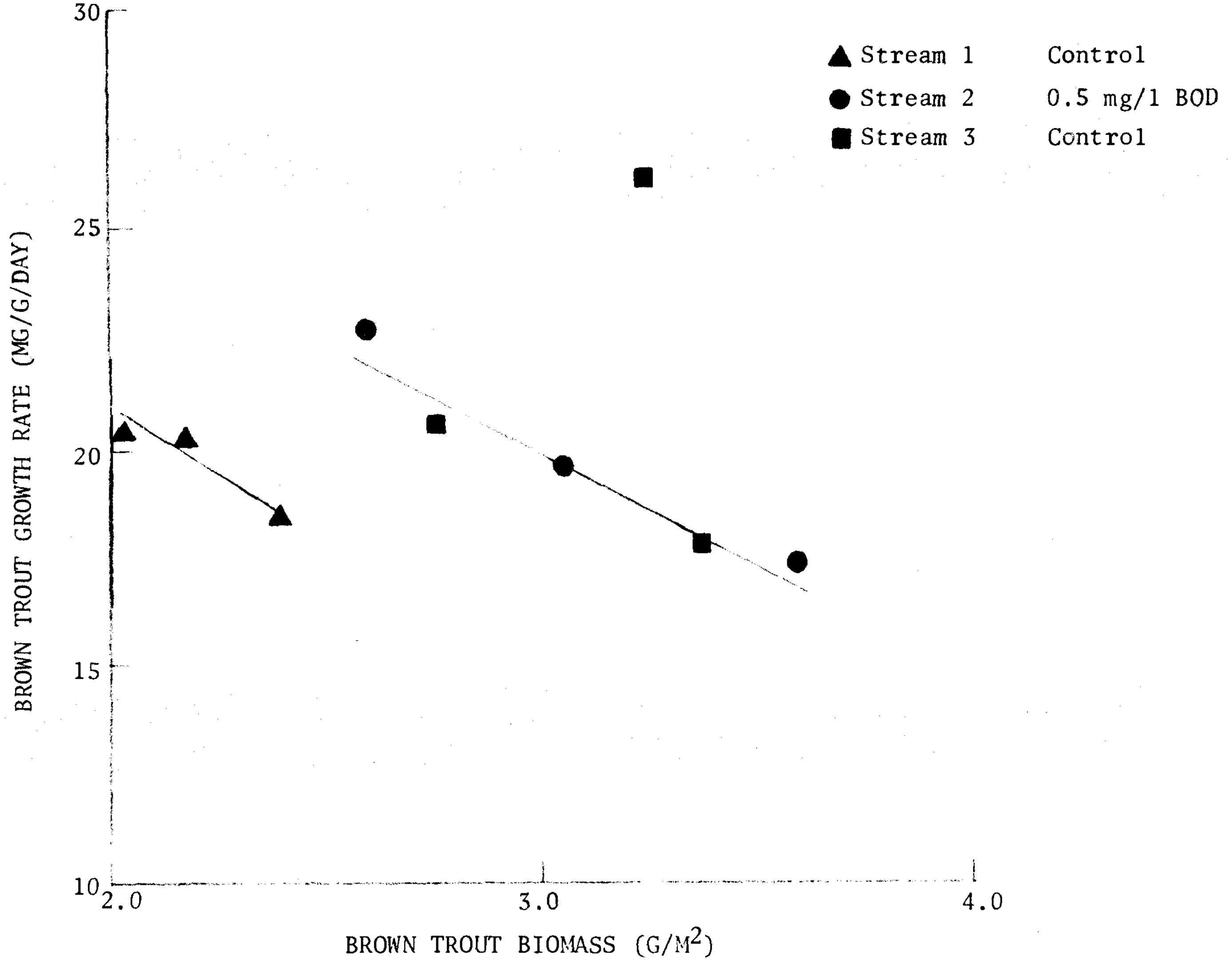

Figure 35. Relationship between brown trout growth rate and biomass in experimental stream channels. Stream 2 received 0.5 mg/1 of primary treated kraft mill effluent. Data of Dennis Borton.

Biologically Stabilized Effluent

Beginning in March 1971, biologically stabilized effluent was introduced into Stream 2 at 0.5 mg/l BOD. The biomass of brown trout present in Streams 1 and 2 increased regularly over the period from August 1971 to February 1972 but declined in Stream 3 after sometime in November or December (Fig. 36). Nevertheless, total production of trout over this period was very similar in the three streams: 2.7 g/m^2 for Stream 1 and 3.0 g/m^2 for Streams 2 and 3. Again, Stream 1, a control stream, had a slightly lower production value than did either Stream 2 or Stream 3.

Coho salmon stocked during February of 1972 were removed for measurement every 15 days during the spring months of 1972. Figure 37 shows that salmon production was about the same in Streams 1, 2, and 3 during the early spring months, but production in Stream 3, a control stream, was lower than in Streams 1 or 2 later in the period. In general, Stream 2, which received 0.5 mg/l BOD stabilized kraft effluent, had slightly higher fish production than either Streams 1 or 3 for the entire period. The lower production in Stream 3 was probably the result of the loss of fish to emigration and predation or an early incidence of *Ceratomyxis* disease. By June, the expected symptoms of *Ceratomyxis shasta* infection appeared in all streams, and the fish were subsequently removed. The last data points in Figure 37 may reflect some sub-lethal influence of this disease.

As illustrated earlier by means of Figure 1, a hump-shaped curve should result when salmon biomass is plotted against salmon production, so long as the capacity of the system to produce salmon (its productivity for salmon) does not change. The ascending limb of such a curve has been generated in Figure 38, which demonstrates that the production of all three streams is

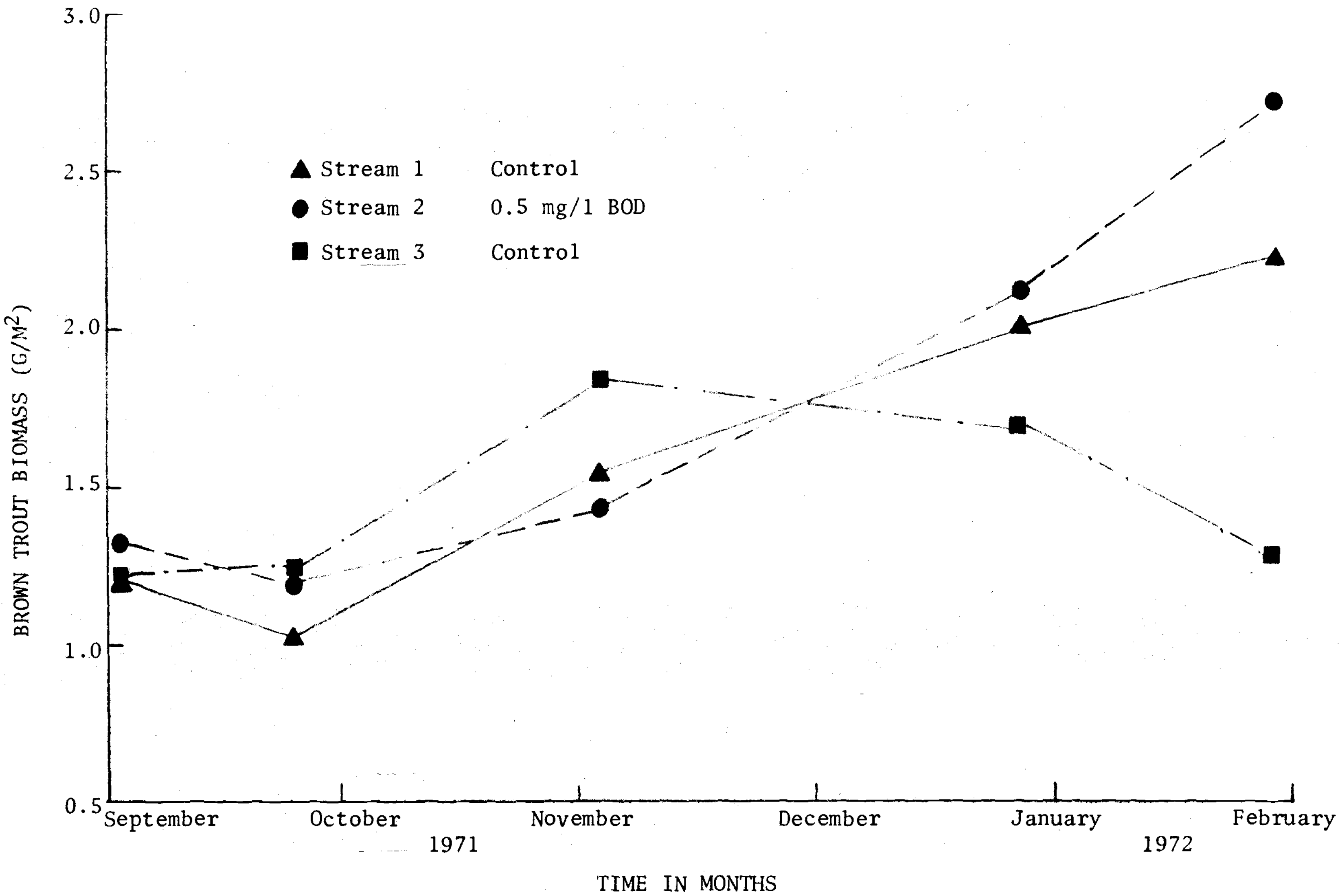

Figure 36. Brown trout biomass in the experimental stream channels expressed in grams per square meter. Stream 2 received 0.5 mg/1 BOD of stabilized kraft effluent. Data of Dennis Borton.

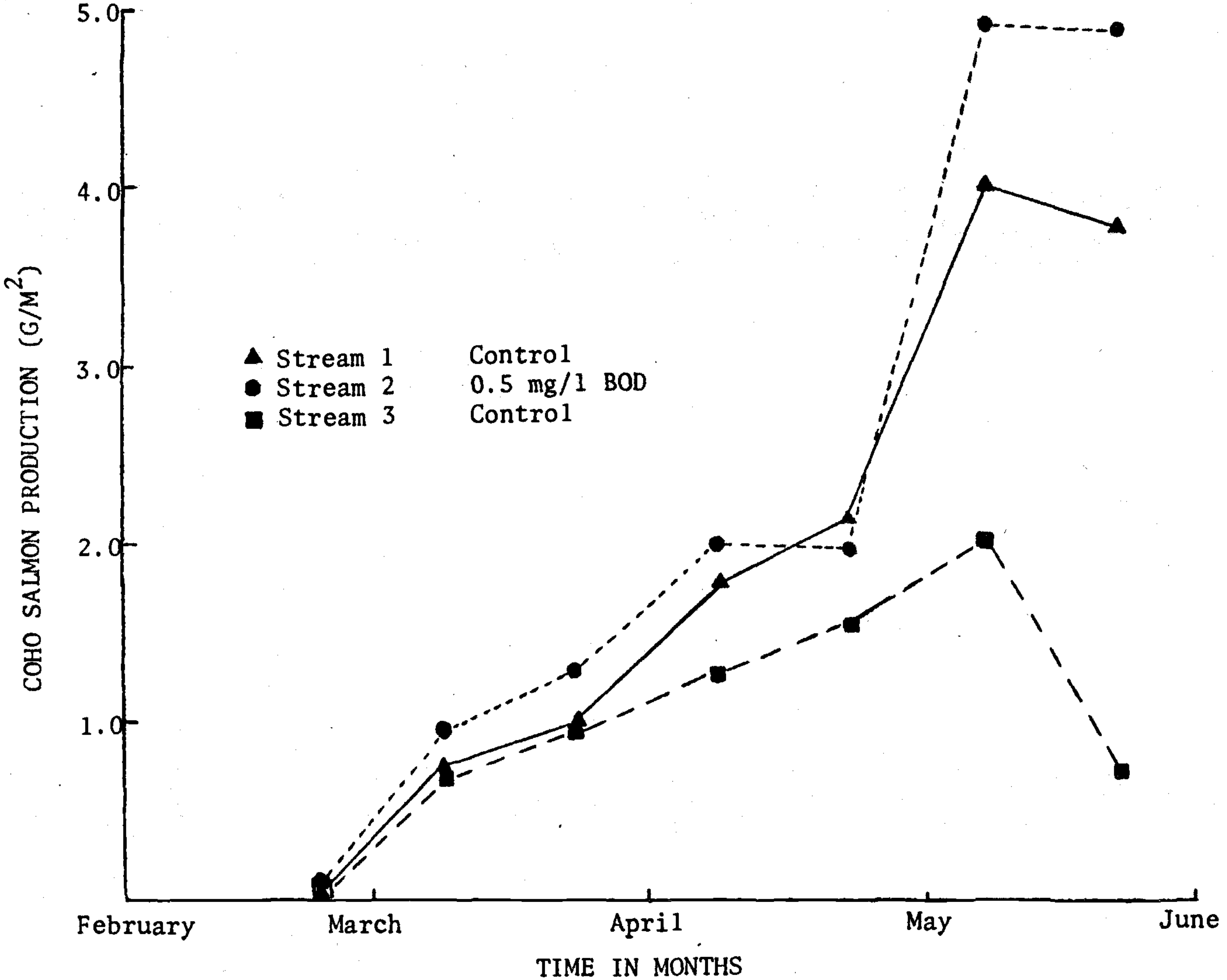

Figure 37. Production of juvenile coho salmon exposed to 0.5 mg/l BOD stabilized kraft mill effluent in experimental stream channels during spring, 1972. Data of Dennis Borton.

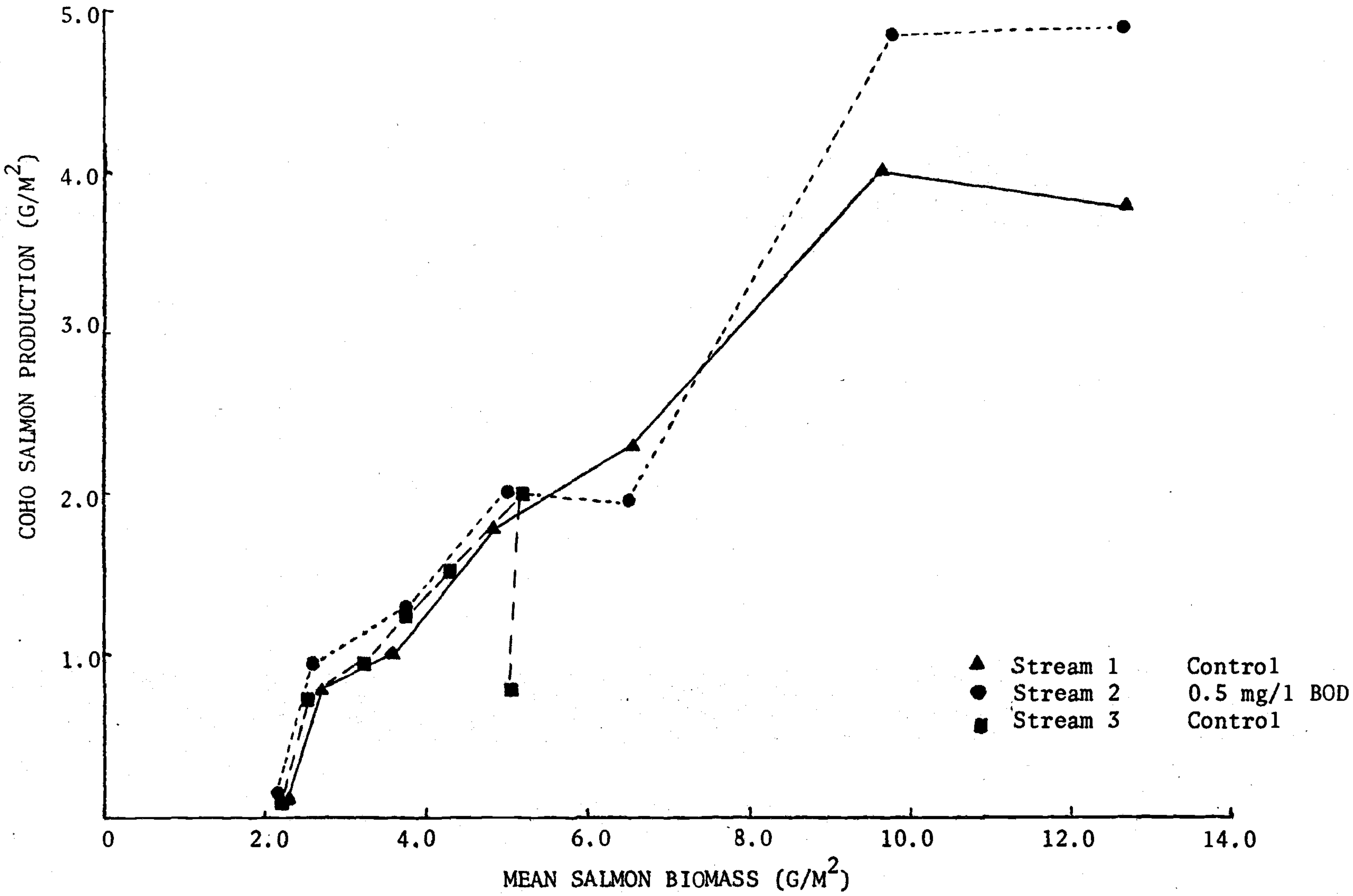

Figure 38. Relationship between production and biomass of juvenile coho salmon exposed to 0.5 mg/1 BOD stabilized kraft effluent at the experimental stream channels during spring, 1972. Data of Dennis Borton.

nearly equal at any biomass. The biomass of control Stream 3 lags behind the others, because production, leading to biomass change in any given period, was lower in Stream 3 than in Stream 1 or 2. It should be noted that the last points on the curves for Streams 1 and 2 show a leveling off of production. This should not be interpreted as meaning the maxima of the theoretical production curves has been reached. The probable cause was the presence of *Ceratomyxis shasta*, which appeared among many of the fish in all streams at this time. Stream 3 appears to have contacted an early infection, this evidenced by the sharp decline of growth rate in Stream 3 (Fig. 39), even though the biomass of food organisms in this stream was relatively high. Growth rates at given biomasses tended to be higher in Stream 2, the stream receiving stabilized effluent, than in Streams 1 and 3. The biomass of fish in the streams, particularly Streams 1 and 2, was quite high during this period, as compared to most Oregon coastal streams. This reflects the high food density, especially the *Hydropsyche*. Our evidence indicates that the introduction of biologically stabilized kraft effluent at 0.5 mg/1 did not appreciably affect the growth and production of salmonid fish in Stream 2; nor did the introduction of primary treated effluent at this BOD concentration.

Food Density Relations

Primary Treated Effluent

Tables 6 and 7 give percentages of each identifiable taxonomic group present in fish stomachs in each of the three streams, during the period when primary treated effluent was present in Stream 2. Table 6 shows that dipterans, particularly Tendipedidae (midges), were very important food

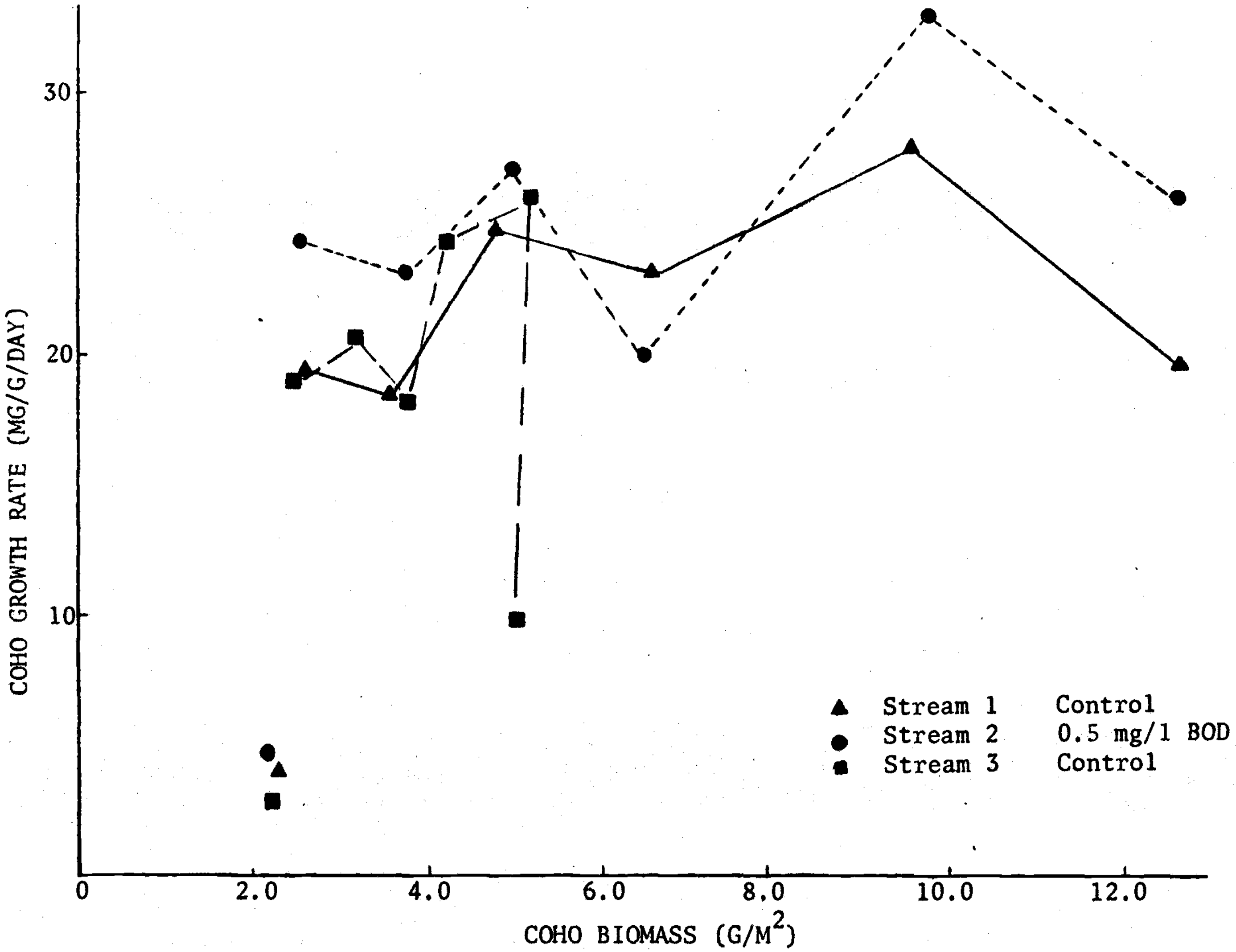

Figure 39. Relationship between growth rate and biomass of juvenile coho salmon exposed to 0.5 mg/l BOD stabilized kraft effluent at the experimental stream channels during spring, 1972. Data of Dennis Borton.

Table 6. Percentages by weight of identifiable food organisms found in cutthroat trout stomachs from March to June 1970. Data of Dennis Borton.

Taxonomic group	Stream 1 (control)		Stream 2 BOD .5 mg/1 primary effluent		Stream 3 (control)	
Ephemeroptera	2.5		2.9		7.7	
Trichoptera	2.9		.1		12.4	
Hydropsychidae		2.9		.1		12.4
Plecoptera	.1					
Coleoptera	1.9		3.0		2.5	
Diptera	54.7		94.0		77.4	
Tipulidae		1.1				
Simuliidae		7.9		8.3		3.0
Tendipedidae		42.9		84.6		73.4
Empididae		2.8		1.1		1.0
Annellida	37.8					
Total	99.9		100.0		100.0	

Table 7. Percentages by weight of identifiable food organisms found in stomachs of brown trout in the three streams from August, 1970 to January, 1971. Data of Dennis Borton.

Taxonomic group	Stream 1 (control)		Stream 2 BOD (.5 mg/l primary effluent)		Stream 3 (control)	
Aquatics						
Collembola	Negl		0.0		Negl	
Plecoptera	.2		0.0			
Ephemeroptera	4.9		2.3		2.1	
Coleoptera	1.1		0.0		1.4	
Dytiscidae		.2				.3
Hydrophilidae		.9				1.1
Trichoptera	8.7		19.2		18.7	
Limnephilidae		.7		3.8		3.5
Hydropsychidae		8.0		15.0		14.7
Hydroptilidae		Negl		.4		.5
Lepidoptera			.2		.5	
Diptera	31.9		14.1		25.4	
Tipulidae		7.0		1.4		10.0
Simuliidae		16.5		4.8		9.6
Tendipedidae		4.1		4.1		3.5
Tabanidae		.2		.5		.3
Empididae		4.1		3.3		1.8
Ephidridae						.2
Annelida	13.2		7.2			
Gastropoda	22.3		41.5		30.1	
Physidae		22.3		38.0		30.1
Limacidae				3.5		
Crustacea	12.7		8.2		12.7	
Amphipoda		12.2		7.6		9.5
Ostracoda		.5		0.6		.1
Isopoda						3.1
Pisces	3.7					
Cyprinidae		3.7				
Terrestrials						
Hymenoptera			.2		.1	
Hemiptera	.6		.3		1.8	
Orthoptera			5.6		7.1	
Arachnida	.4					
Coleoptera			1.3			
Total	99.7		100.1		99.9	

organisms during the spring months. Other groups such as the Ephemeroptera (mayflies) and Trichoptera (caddisflies) contributed much smaller amounts to the diet of the fish. Fish from Stream 1 had a large percentage of oligochaete worms in their stomach contents during this time, fish from Streams 2 and 3 apparently having none. Relationships between the growth rate of small cutthroat trout and the density of midge larvae in the streams (Fig. 40) tends to confirm the results of spring stomach sampling (Table 6). Figure 40 also suggests that the fish in Stream 3 had greater growth rates than those in Streams 1 or 2 at similar densities of midge larvae. Because both Streams 1 and 3 were controls, there should have been no great differences in the efficiency of physiological utilization of food for growth by fish between these streams. The differences in growth rate may have resulted from a greater availability of midge larvae at given densities, or perhaps closely correlated utilization of other available food organisms in Stream 3 during this period. From August 1970 to January 1971, (Table 7) midge larvae became less important in terms of abundance in stomach samples, and other taxonomic groups such as Simuliidae, gastropods (snails), annelids, and trichopterans became more important. Nevertheless, the growth rate of brown trout was closely correlated to density of midge larvae, during the August through October period (Fig. 41). At a given density of midge larvae, the growth rate of fish in Stream 2, which received 0.5 mg/l BOD of primary effluent, was lower than that of fish in Streams 1 or 3. Actually, fish growth rate was generally similar in Streams 1, 2, and 3, but because midge density tended to be higher in Stream 2, the curve is shifted to the right, and is below the curve for Stream 1 and 3 (Fig.41). The effluent might have had some

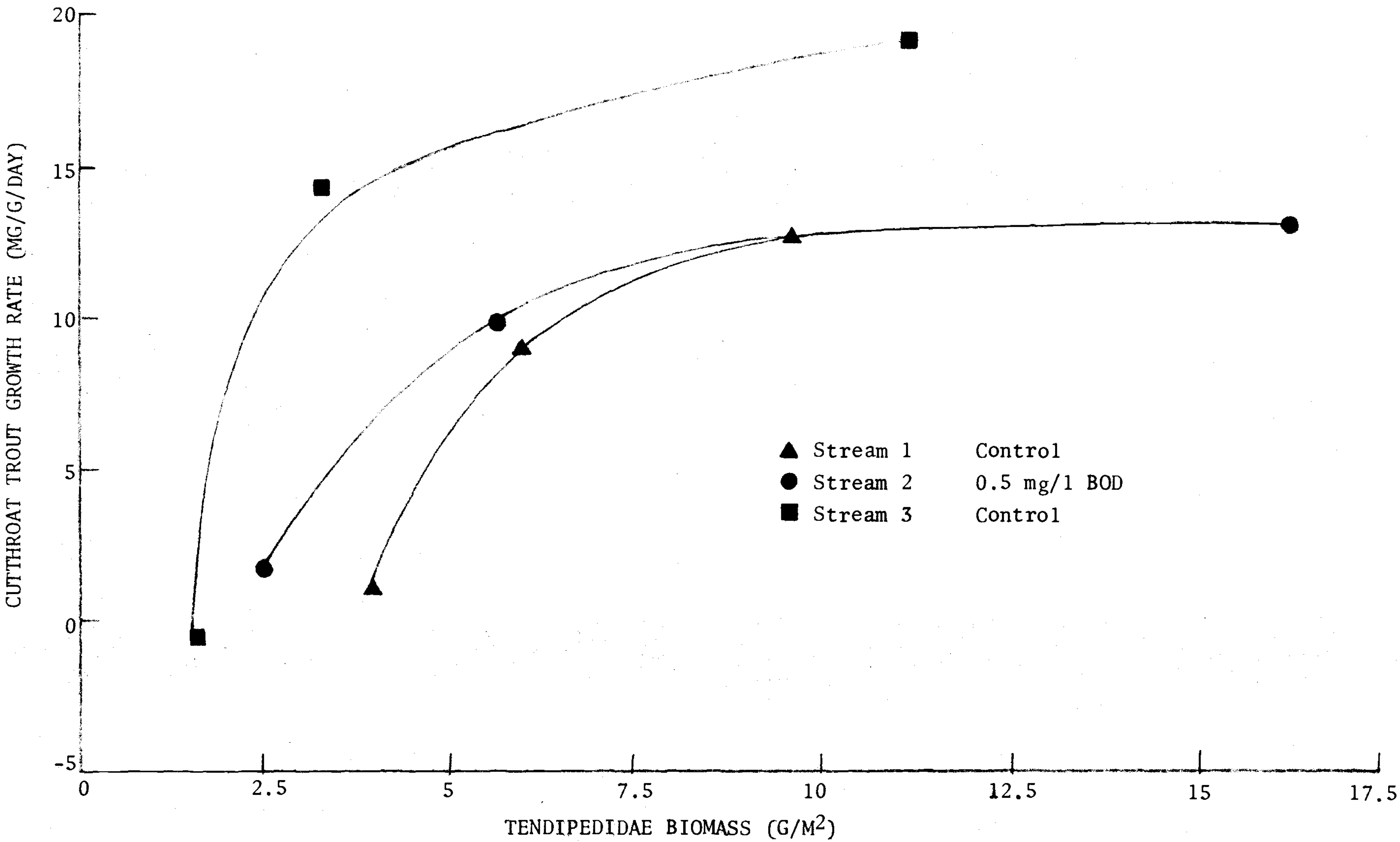

Figure 40. Relationship between cutthroat trout growth rate and the biomass of Tendipedidae (midges) larvae in experimental stream channels. Stream 2 received 0.5 mg/l BOD of primary treated kraft mill effluent during spring 1970. Data of Dennis Borton.

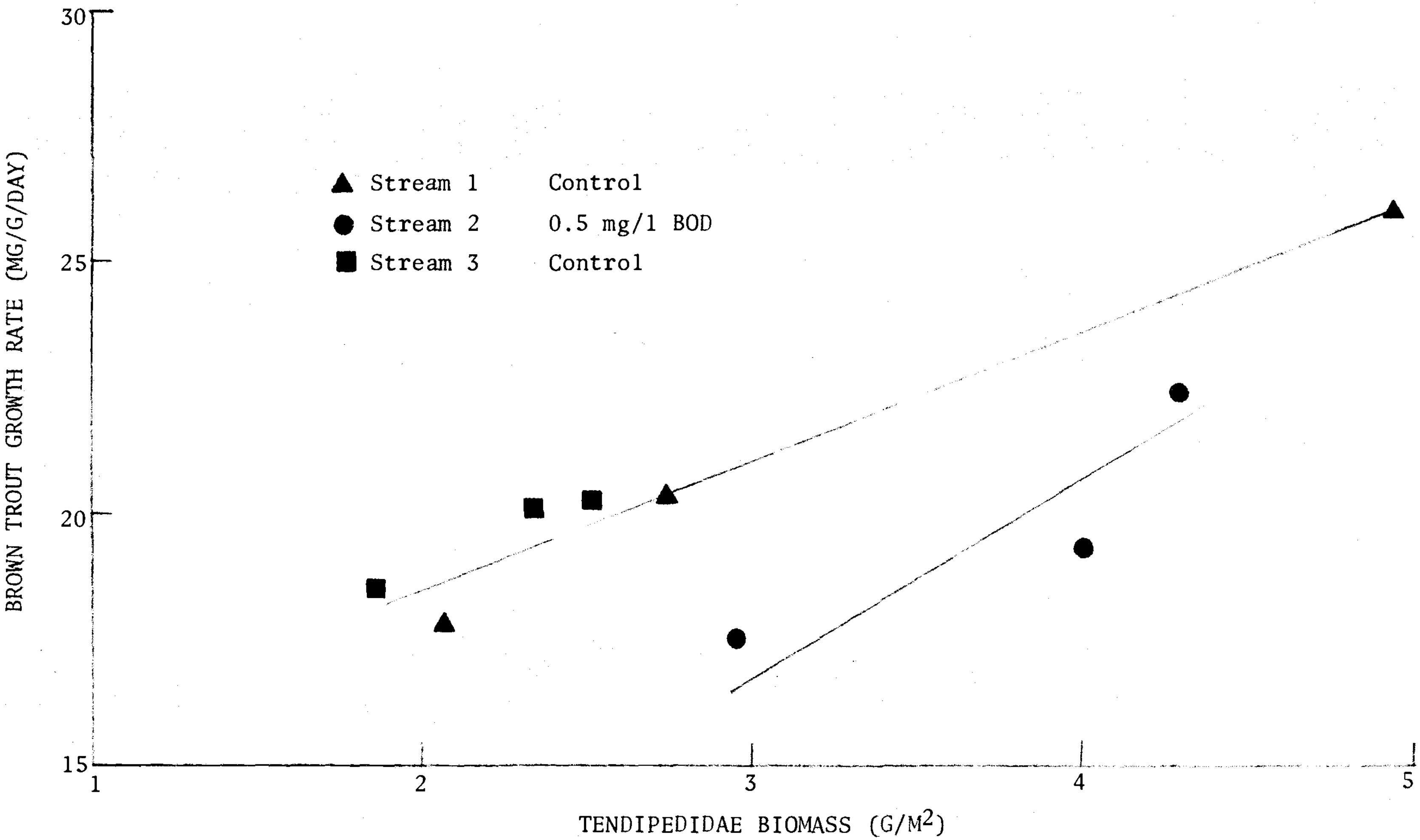

Figure 41. Relationship between trout growth rate and Tendipedidae (midge) larvae biomass in experimental stream channels. Stream 2 received primary treated effluent at 0.5 mg/1 BOD. Data of Dennis Borton.

direct depressing effect on the growth of the fish in Stream 2 which was offset by greater food availability or the midge larvae might not have been as readily available to the fish in Stream 2 as in the two control streams in this summer-fall period. Greater availability of other food organisms in Streams 1 and 3, at given midge densities could also explain this. Previously it was indicated that midge larvae might have been more available to fish in Stream 3 than in Streams 1 or 2 during the spring months. One possible reason for these differences is that midges become available to fish almost entirely as pupae, but they are sampled from the benthos as larvae. There is a time lag between the larval and pupal stages, and the time of pupation varies between the populations of midges. Thus the larval or benthic biomass of an insect such as midges may be great, but it may not become available to fish until pupation occurs.

During November, December, and January 1970-71, Hydropsychidae made up a moderate percentage of stomach contents of the fish (Table 7). The following spring, chinook were stocked in all three streams (Table 8). As in the previous spring, Diptera, particularly midges made up a great deal of the diet. But unlike the previous spring, amphipods and *Hydropsyche* were important in the diet. *Hydropsyche* was especially abundant in stomachs of fish from Streams 1 and 3. This reflects changes in insect and amphipod biomass present in the benthos, as shown in an earlier section. Stabilized effluent was present in Stream 2, during the period covered by Table 8, but since this effluent was introduced in March 1971, the period from March through May 1971 must be considered a transitional period, when food conditions were probably determined more by the previous exposure to primary effluent.

Table 8. Percentages by weight of identifiable food organisms found in chinook salmon stomachs from March through May, 1971. Data of Dennis Borton.

Taxonomic group	Stream 1 (control)		Stream 2 BOD .5 mg/l stabilized effluent		Stream 3 (control)	
Aquatics						
Ephemeroptera	.5				5.1	
Trichoptera	13.4		2.6		18.6	
Limniphilidae		2.6				2.4
Hydropsychidae		10.8		2.6		15.6
Hydroptilidae						.6
Diptera	54.9		72.7		53.1	
Tipulidae				2.4		4.3
Simuliidae		.8		3.5		
Tendipedidae		54.1		66.6		44.2
Empididae				.2		.6
Tabanidae						3.3
Ragionidae						.7
Annelida			1.2			
Crustacea	29.0		23.8		21.5	
Amphipoda		28.6		23.8		21.0
Ostracoda		.4		Negl		.5
Terrestrials	2.2					
Hemiptera		1.1				
Dermaptera		.6				
Arachnida		.5				
Diptera						
Total	100.0		100.3		100.1	

Stabilized Kraft Mill Effluent

Tables 9 and 10 give percentages of each identifiable taxonomic group present in stomachs of fish from Streams 1, 2, and 3, when stabilized kraft mill effluent was being introduced into Stream 2. In summer and fall months of 1971, Diptera were important as fish food in all three streams, as they had been the previous summer (Table 7). Fish stomachs from all three streams contained higher percentages of Hydropsychidae and decreased percentages of gastropods. Once again, the changes in the amounts of each taxonomic group present in the stomachs reflect changes we have already demonstrated in the abundance of such groups in the streams.

Table 10 shows that Diptera, including midges, were no longer as important during the 1972 spring months as they had been in the past in all three streams. The percentages of Hydropsychidae increased again during the spring to become the dominant food organisms in coho salmon stomachs. Figure 42 shows direct relationships between the biomass of Hydropsychidae in the benthos and the growth rate of the salmonids. Salmon in Stream 2, which received stabilized effluent at 0.5 mg/l BOD, exhibited a higher growth rate at given Hydropsychidae biomasses than did salmon in Streams 1 and 3, the control streams. In aquarium experiments, 0.5 mg/l stabilized effluent at times did lead to a very slight increase in growth rate of salmonids at particular ration levels, but it is unlikely the effect shown here can be explained in this way. Fish in Stream 2 probably consumed more organisms other than Hydropsychidae than did fish in control Streams 1 or 3. Stomach contents substantiate this idea, as stomachs of fish in Stream 2 contained a lower percentage of Hydropsychidae and a higher percentage of annelids and dipterans (Table 10).

Table 9. Percentages by weight of identifiable food organisms found in stomachs of brown trout from August, 1971 to January, 1972. Data of Dennis Borton.

Taxonomic group	Stream 1 (control)		Stream 2 BOD .5 mg/l stabilized effluent		Stream 3 (control)	
Aquatics						
Ephemeroptera	1.8		6.1		9.2	
Coleoptera			.8		.9	
Hydrophilidae						.9
Dytiscidae				.8		
Trichoptera	26.4		29.4		24.8	
Limnephilidae				.9		
Lepidostomatidae				2.5		
Hydroptilidae		.1				
Hydropsychidae		26.3		26.0		24.8
Diptera	14.4				21.9	
Tipulidae		.2	26.7			1.4
Simuliidae		2.8		.9		7.7
Tendipedidae		8.6		23.1		12.8
Empididae		2.8		2.7	21.5	
Gastropoda	12.4		2.3			
Physidae		6.9		2.3		15.9
Limacidae		5.5				5.6
Annelida	32.8		10.3		5.5	
Crustacea	12.0		23.0		14.4	
Amphipoda		10.7		19.5		12.3
Ostracoda		1.3		3.5		2.1
Terrestrials			1.4		1.9	
Hemiptera						.6
Diptera	.2		.1			1.3
Arachnida	Negl					
Total	100.0		100.1		100.1	

Table 10. Percentages by weight of identifiable food organisms found in stomachs of coho salmon from April to June 1972. Data of Dennis Borton.

Taxonomic group	Stream 1 (control)		Stream 2 BOD .5 mg/l stabilized effluent		Stream 3 (control)	
Collembola	.1		Negl		.3	
Ephemeroptera	1.9		.3		.5	
Trichoptera	59.2		42.3		73.3	
Hydropsychidae		59.2		42.3		73.3
Lepidoptera	1.5		0.0		1.0	
Diptera	3.8		5.0		3.9	
Tipulidae		.1		1.4		1.3
Tendipedidae		3.3		3.6		2.6
Empididae		.4				
Annelida	26.1		46.2		8.6	
Gastropoda	4.7		2.8		5.6	
Physidae		.9				
Limacidae		3.8		2.8		5.6
Crustacea	2.6		3.3		6.9	
Amphipoda		2.6		3.3		6.9
Total	99.9		99.9		100.1	

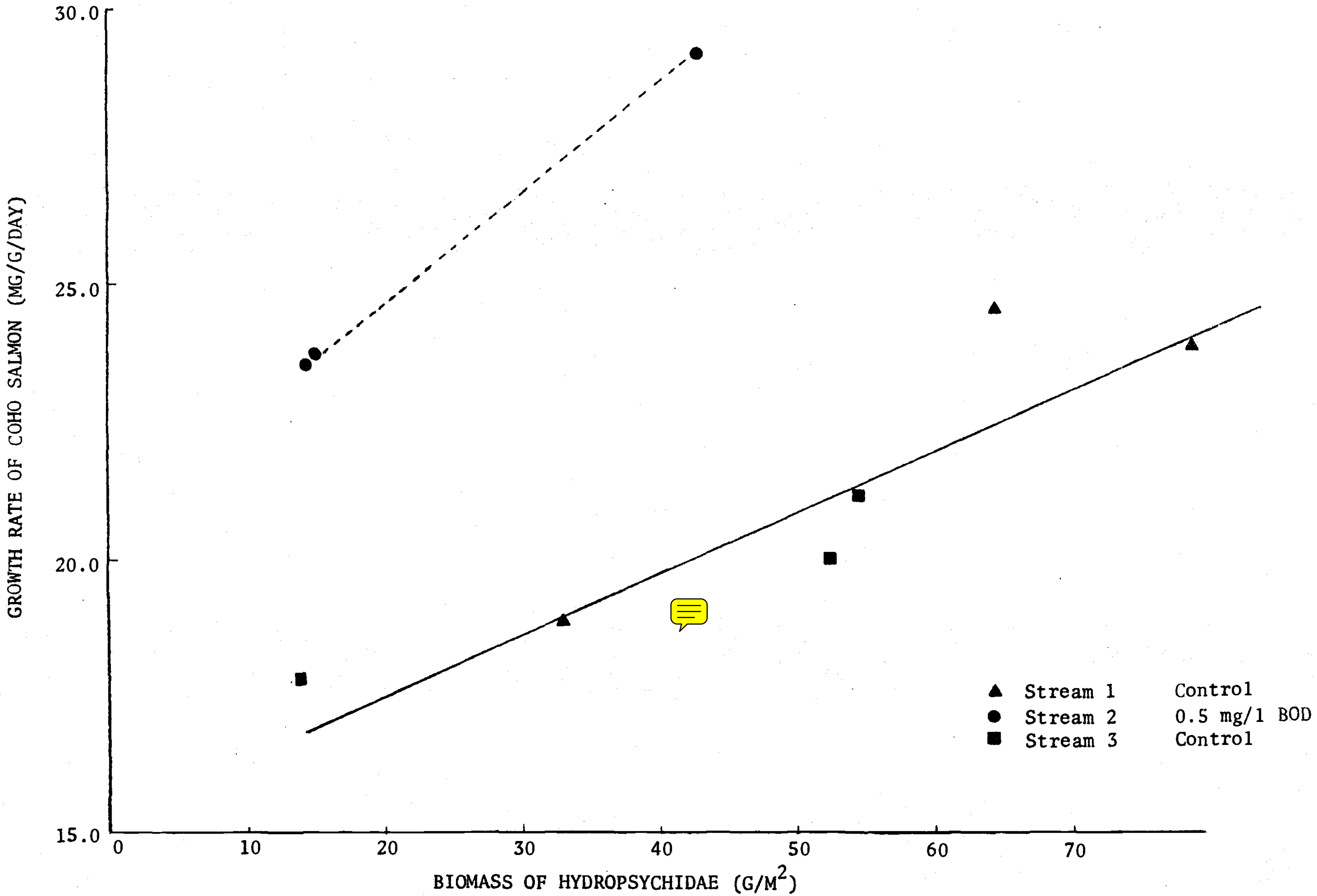

Figure 42. Relationship between growth rate of juvenile coho salmon and biomass of Hydropsyche (caddisfly) for streams receiving 0.5 mg/l stabilized kraft mill effluent in experimental stream channels during spring, 1973. Data of Dennis Borton.

CONCLUSIONS BASED ON RESULTS OF PHASE I AND PHASE II

AQUARIUM STUDIES

Primary Treated Kraft Effluents

1. In aquarium studies, concentrations of 0.5 mg/l BOD (0.25 percent by volume) and greater of primary treated kraft effluent from mill A were found to decrease the growth rate of chinook salmon fed on tubificid worms. The effect on salmon growth rate became 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 (about 4 mg/l BOD) 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 Effluents

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 about 0.7 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.

There is a bioenergetic explanation for this. But this result probably does not apply to nature, because the levels of forced exercise were far greater than we believe juvenile salmon must maintain in nature.

LABORATORY STREAM EXPERIMENTS

Primary Treated Kraft Effluents

5. Production of chinook salmon was reduced during spring in laboratory streams receiving primary treated 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, primary treated and stabilized kraft effluent appeared to be less toxic. Summer experiments during 1969 indicated primary treated 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 probably contributed to the reduced toxicity of the effluent at this time.

Biologically Stabilized Effluents

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, not to changes in food availability. When stabilized effluent was introduced 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, and after mill A began operation of turpene recovery equipment, production in streams receiving stabilized waste at 7.5 percent by volume (1.5 mg/l BOD) was slightly greater than production in control streams.

EXPERIMENTAL STREAM CHANNEL STUDIES

8. There were successional changes in the benthic plant and animal communities of the three experimental streams during the three year period of this study. Some of these changes occurred in all three streams and were not related to the introduction of either primary treated or biologically stabilized effluents. In the early part of the study, the changes were primarily resultant from colonization by different groups of organisms. But as the study progressed, silting of the stream bottoms may have been the major factor.

9. The introduction of primary treated and of biologically stabilized effluents caused differences in the composition of the benthic plant and animal community of the treatment stream as compared to the control streams, some groups being favored, others not so. But no differences in diversity of the insect community could be attributed to the 0.5 mg/l level of either primary treated or biologically stabilized kraft mill effluent.

10. Primary treated effluent at 0.5 mg/l BOD reduced the abundance of insects in the treatment stream as compared to the control streams.

11. During the period in which biologically stabilized effluent was being introduced into the treatment stream, the abundance of insects in that stream was lower than in the control streams. But this is not

believed to be the result of the 0.5 mg/l level of BOD of stabilized effluent in this stream. Rather, it is believed this was caused by earlier effects of the primary effluent still influencing this community and by a water supply failure that resulted in very high concentrations of stabilized effluent entering the stream. We do not believe that 0.5 mg/l BOD of stabilized effluent reduced insect abundance in the treatment stream.

12. Amphipod populations were probably reduced by 0.5 mg/l BOD primary effluent and increased by this concentration of stabilized effluent. Snail populations were probably increased by both the primary and stabilized effluents at this concentration. These organisms were sometimes quite important as food for the fish.

13. Production of salmonid fish--cutthroat and brown trout, and coho and chinook salmon--was not affected, either favorably or unfavorably, by the presence of either primary treated or biologically stabilized kraft mill effluent at the 0.5 mg/l BOD level tested. Overall food organism abundance was not much affected by the presence of the effluents, though there were changes in the relative abundance of different kinds of food organisms. Adjustments in the feeding habits of the fish apparently prevented the presence of the effluents from having any appreciable influence on the overall growth and production of the salmonid species studied.

Appendix I. Total solids, volatile solids, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) expressed in mg/l for kraft mill effluent during Phase I experiments. Only BOD and COD are presented for stabilized effluents. Data from National Council.

Date	Total solids (mg/l)	Volatile solids (mg/l)	Primary treated effluent COD (mg/l)	Primary treated effluent BOD (mg/l)	Biologically stabilized effluent COD (mg/l)	Biologically stabilized effluent BOD (mg/l)
1966						
February 18	752	204	844	329	-	-
March 21	742	248	745	246	-	-
July 7	690	257	610	220	-	-
August 18	542	115	275	122	-	-
October 11	465	79	410	192	-	-
1967						
January 25	582	222	462	171	-	-
February 8	502	185	528	206	-	-
February 15	787	290	746	267	-	-
March 1	598	230	575	230	-	-
March 8	628	215	536	200	-	-
March 15	684	235	600	195	-	-
March 29	716	277	753	260	-	-
April 11	591	217	542	180	-	-
April 19	764	275	750	235	-	-
April 26	686	247	670	290	-	-
May 3	570	197	593	166	-	-
May 10	547	171	526	222	-	-
May 17	693	234	575	221	-	-
May 24	654	209	624	257	-	-
June 29	625	191	554	230	-	-
July 8	875	324	748	260	-	-
July 12	-	-	512	183	-	6
July 17	-	-	431	135	-	5
July 26	-	-	-	170	-	8
August 2	-	-	422	156	-	6
August 9	-	-	439	156	-	5
August 16	-	-	481	135	-	8
August 23	-	-	-	188	-	2

Appendix I. Continued

Date	Total solids (mg/l)	Volatile solids (mg/l)	Primary treated effluent COD (mg/l)	Primary treated effluent BOD (mg/l)	Biologically stabilized effluent COD (mg/l)	Biologically stabilized effluent BOD (mg/l)
1967						
August 30	-	-	-	138	-	1
September 6	-	-	-	192	-	7
September 13	-	-	-	143	-	3
September 20	-	-	-	184	71	-
September 27	-	-	594	191	122	-
October 11	-	-	481	174	-	-
October 18	-	-	412	201	-	5
October 25	-	-	442	252	78	3
November 1	-	-	436	214	70	3
November 8	-	-	473	195	75	2
November 22	-	-	716	262	-	10
December 6	-	-	587	214	232	72
December 13	-	-	645	-	332	35
December 20	-	-	538	273	240	31
December 28	-	-	609	239	165	53
1968						
January 18	-	-	325	222	210	30
January 25	-	-	555	230	226	42
March 1	-	-	720	279	203	18
March 8	-	-	265	195	184	24
March 15	-	-	575	256	158	14
March 22	-	-	632	279	200	24
March 29	-	-	440	214	180	8
March 8	-	-	424	200	164	8
March 15	-	-	664	243	254	26
March 21	-	-	545	256	322	46
March 28	-	-	752	213	358	43
April 4	-	-	1008	317	396	55
April 12	-	-	675	224	349	53

Appendix I. Continued

Date	Total solids (mg/l)	Volatile solids (mg/l)	Primary treated effluent COD (mg/l)	Primary treated effluent BOD (mg/l)	Biologically stabilized effluent COD (mg/l)	Biologically stabilized effluent BOD (mg/l)
1968						
April 18	-	-	719	279	365	90
April 26	-	-	674	245	195	7
May 16	-	-	608	236	226	15
May 23	-	-	731	246	227	15
May 29	-	-	644	220	-	15
June 7	-	-	679	219	-	13
June 13	-	-	891	240	-	7
June 20	-	-	-	268	-	13
1969						
March 11	-	-	-	-	-	29
March 13	-	-	-	179	-	-
March 18	-	-	-	-	-	50
March 20	-	-	-	223	-	-
March 25	-	-	-	-	-	65
March 27	-	-	-	260	-	-
April 1	-	-	-	-	-	89
April 3	-	-	-	-	-	-
April 24	-	-	-	-	-	52
April 29	-	-	-	-	-	-
May 6	-	-	-	347	-	-
May 8	-	-	-	-	-	74
May 13	-	-	-	214	-	-
May 15	-	-	-	-	-	70
May 20	-	-	-	280	-	-
May 22	-	-	-	-	-	85
May 27	-	-	-	234	-	-
May 29	-	-	-	-	-	41

Appendix I. Continued

Date	Total solids (mg/l)	Volatile solids (mg/l)	Primary treated effluent COD (mg/l)	Primary treated effluent BOD (mg/l)	Biologically stabilized effluent COD (mg/l)	Biologically stabilized effluent BOD (mg/l)
1969						
June 1	-	-	-	167	-	-
June 4	-	-	-	-	-	20
June 9	-	-	-	170	-	-
June 10	-	-	-	-	-	29
June 17	-	-	-	-	-	39
June 19	-	-	-	244	-	-
June 24	-	-	-	-	-	34
June 26	-	-	-	194	-	-
June 30	-	-	-		-	32
July 1	-	-	-	234	-	-
July 8	-	-	-	-	-	37
July 12	-	-	-	200	-	-
July 16	-	-	-	-	-	29
July 17	-	-	-	156	-	-
July 22	-	-	-	-	-	12
July 24	-	-	-	204	-	-
July 31	-	-	-	174	-	-
August 5	-	-	-	-	-	24
August 10	-	-	-	186	-	-
August 12	-	-	-	-	-	18
August 15	-	-	-	160	-	-
August 19	-	-	-	-	-	17
August 26	-	-	-	-	-	12
August 28	-	-	-	168		-
September 2	-	-	-	-	-	17
September 9	-	-	-	-	-	17
September 11	-	-	-	220	-	-
September 16	-	-	-	-	-	12
September 18	-	-	-	238	-	-
September 23	-	-	-	-	-	39

Appendix II. Physicochemical analyses of 7-day composite samples of primary treated and biologically stabilized kraft mill effluent, 1970-1972.

Date	BOD (mg/l)	COD (mg/l)	Total solids (mg/l)	Total volatile (mg/l)	Suspended solids (mg/l)	Suspended volatile (mg/l)
1970						
Feb 10-17	282	610	-	-	-	-
17-25	310	650	832	335	114	
25-Mar 3	250	616	711	273	-	-
Mar 4-10	276	640	742	346	-	-
11-18	272	580	704	299	80	76
21-24	245	568	622	263	100	88
25-31	240	650	813	261	120	100
Apr 1- 7	177	600	669	237	36	24
8-14	260	607	620	240	20	18
15-21	243	582	625	221	44	34
22-28	270	645	709	246	27	22
29-May 5	-	607	674	220	30	20
May 6-12	267	578	672	183	41	25
12-19	147	810	633	182	95	50
20-26	202	528	602	198	32	22
27-June 2	211	671	714	295	165	120
June 3- 7	190	683	527	425	56	52
11-16	217	571	658	476	30	32
17-23	235	585	582	231	48	-
24-30	338	548	659	213	55	53
July 1- 7	177	413	644	202	45	30
8-14	210	551	679	146	46	38
15-21	186	655	683	269	85	83
22-27	214	617	664	314	53	17
28-Aug 3	198	576	628	208	53	43
Aug 4-10	210	546	627	174	28	-
11-17	204	581	661	205	43	30
18-24	186	518	619	127	-	-
25-31	246	670	807	286	-	-
Sept 1- 7	198	607	714	208	-	-
8-14	186	562	694	209	-	-
15-21	195	509	748	238	-	-
22-28	237	580	701	196	-	-
29-Oct 6	195	702	773	260	-	-
Oct 6-12	195	650	767	265	-	-
13-19	180	585	790	274	-	-
20-26	180	565	666	218	-	-
27-Nov 2	350	-	746	300	-	-
Nov 3- 8	180	-	708	220	-	-
9-16	230	-	670	269	-	-
17-23	220	-	696	260	-	-
24-29	320	-	729	236	-	-
30-Dec 5	240	-	733	258	-	-

Appendix II. Continued

Date	BOD (mg/l)	COD (mg/l)	Total solids (mg/l)	Total volatile (mg/l)	Suspended solids (mg/l)	Suspended volatile (mg/l)
1970						
Dec 6-12	210	-	733	258	-	-
13-20	200	-	-	-	-	-
21-28	194	-	-	-	-	-
29-Jan 4	214	-	-	-	-	-
1971						
Jan 5-13	258	-	-	-	-	-
14-20	204	-	-	-	-	-
21-27	222	-	-	-	-	-
Feb 4-11	280	-	-	-	-	-
12-17	245	-	-	-	-	-
18-24	222	-	-	-	-	-
25-Mar 3	282	-	-	-	-	-
		Biologically stabilized effluent				
Mar 12-28	40	244	-	-	-	-
28-Apr 3	48	-	-	-	-	-
Apr 4-10	49	-	-	-	-	-
11-16	67	294	-	-	-	-
17-23	93	-	-	-	-	-
24-30	90	-	-	-	-	-
May 1- 8	60	-	-	-	-	-
9-15	75	302	-	-	-	-
16-24	100	-	-	-	-	-
25-July 1	60	-	-	-	-	-
July 2-8	65	-	-	-	-	-
9-16	32	216	-	-	-	-
17-29	42	-	-	-	-	-
30-Aug 11	40	-	-	-	-	-
Aug 12-19	30	220	-	-	-	-
20-25	51	-	-	-	-	-
26-Sept 1	36	-	-	-	-	-
Sept 2- 9	33	-	-	-	-	-
10-15	24	184	-	-	-	-
16-22	26	-	-	-	-	-
23-29	57	-	-	-	-	-
30-Oct 6	54	-	-	-	-	-
Oct 7-13	71	-	-	-	-	-
14-20	54	260	-	-	-	-
21-27	27	-	-	-	-	-
28-Nov 3	64	-	-	-	-	-
Nov 4-10	43	-	-	-	-	-
11-17	33	222	-	-	-	-
18-24	52	-	-	-	-	-
25-Dec 1	62	-	-	-	-	-

Appendix II. Continued

Date		BOD (mg/l)	COD (mg/l)	Total solids (mg/l)	Total volatile (mg/l)	Suspended solids (mg/l)	Suspended volatile (mg/l)
1971							
Dec	2-8	78	-	-	-	-	-
	9-15	71	-	-	-	-	-
	16-22	62	-	-	-	-	-
	23-29	56	-	-	-	-	-
	30-Jan 5	57	-	-	-	-	-
1972							
Jan	6-12	119	-	-	-	-	-
	13-19	83	344	-	-	-	-
	20-27	88	-	-	-	-	-
	28-Feb 2	66	-	-	-	-	-
Feb	3- 9	112	-	-	-	-	-
	10-16	129	410	-	-	-	-
	17-23	81	-	-	-	-	-
	24-Mar 1	78	-	-	-	-	-
Mar	2- 8	76	-	-	-	-	-
	9-15	76	-	-	-	-	-
	16-23	68	-	-	-	-	-
	24-30	89	-	-	-	-	-
	31-Apr 5	77	-	-	-	-	-
Apr	6-12	96	-	-	-	-	-
	13-19	112	395	-	-	-	-
	20-26	91	-	-	-	-	-
	27-May 3	103	-	-	-	-	-
May	4-10	100	-	-	-	-	-
	11-17	98	360	-	-	-	-
	18-24	77	-	-	-	-	-
	25-June 1	60	-	-	-	-	-
June	2- 9	53	-	-	-	-	-
	10-14	35	224	-	-	-	-

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