Terminal Progress Report

EFFECTS OF PULP AND PAPER MILL EFFLUENTS ON GROWTH AND PRODUCTION OF FISH IN EXPERIMENTAL STREAM CHANNELS

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INTRODUCTION

The objective of the research herein to be summarized has been to provide a basis for estimating those low concentrations of kraft process pulp and paper mill effluents that would not be expected to either directly or indirectly decrease the production of salmon and trout. Reliable estimation of such concentrations must be based on adequate understanding of relationships between fish populations, their food resources, and physical and chemical conditions. In order to attain such understanding laboratory and large experimental stream systems have been studied, in the presence and absence of kraft mill effluents (KME) receiving only primary treated or both primary and secondary treatment.

The effluents employed in this study were from a kraft mill discharging about 10 million gallons per day of waste waters into the Willamette River. While water use varies greatly between mills, along with type and degree of waste treatment, the magnitude of such use poses concern for the ability of receiving waters to produce valuable fish species. Waste treatment technology can reduce the biochemical oxygen demand (BOD) of paper mill effluents by 90 percent or more. And this results not only in a reduction of the oxygen-depleting capacity of such effluents but also in a reduction in the concentrations of their toxic constituents. The toxicity of such effluents may be reduced to levels permitting fish to live for periods of four or more days in treated but undiluted effluent.

Secondary-treated effluents may, however, still affect the ability of an aquatic system to produce fish because of direct effects on fish growth or indirect effects through changes in the abundance or species composition of food organisms. Direct effects can be meaningfully assessed by growth tests in which fish held at different effluent concentrations are fed a range of measured rations and their relative rate of weight increase determined. Indirect effects on fish growth and production exerted through the aquatic community can be experimentally evaluated in small laboratory stream experiments, or in larger and more natural stream channel studies. Small laboratory stream ecosystems are useful in preliminary studies of the effects of complex effluents on the production of fish populations, but in many respects they are much simpler than natural streams and great care must be taken in the interpretation of results (Warren and Davis, 1971). To make possible experimental validation and extension of the results of our research with laboratory stream communities (Warren et al. 1974), three large experimental stream channels were constructed in 1969 near the site of a kraft process pulp and paper mill. This report summarizes research conducted on these stream channels between December 1969 and October 1975. Because only one effluent concentration could be tested at one time with the three stream channels, when two streams were used as controls, results of previously completed studies on the growth of fish in aquaria and on fish production in laboratory stream communities were used to predict the highest effluent concentrations not likely to have inimical effects on fish production in the larger and more natural experimental stream channels.

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Although the literature on the sublethal effects of kraft mill effluents (KME) is not extensive, several studies have described various direct effects of KME on fish. These include: changes in tissue and blood of fish held in KME and neutralized KME (Fujiya, 1961, 1965; McLeay, 1973); changes in respiration and circulation of salmonids held in KME and bleach process KME (Walden et al., 1970; Davis, 1973): and the effects of KME, bleach process KME, and stabilized KME (SKME) on the growth and food conversion efficiency of various salmonids fed in aquaria (Servizi, et al., 1966; Tokar, 1968; Webb and Brett, 1972; Borton, 1970).

For approximately ten years the Department of Fisheries and Wildlife at Oregon State University has conducted studies on the effects of kraft mill effluents on the growth and production of fish. Tokar (1968) observed a decreased growth rate of juvenile chinook salmon *Oncorhynchus tshawytscha* (Walbaum), exposed to a concentration of 0.5 mg/1 BOD KME from mill A at unrestricted rations in aquaria. A concentration of 2.0 mg/1 BOD KME from mill B did not affect the growth of salmon. Salmon fed tubificid worms that had been exposed to a 100 percent concentration of KME grew more slowly than control fish. Borton (1970) observed a decreased growth rate of chinook salmon exposed in aquaria to a dilution of 1.5 percent (0.23 - 0.73 mg/1 BOD) stabilized KME (SKME) from mill A, while a level of 4.5 percent SKME from mill B did not reduce growth. In experiments in which the fish were forced to maintain a fairly high activity level, Borton could not demonstrate a reduction in growth for fish exposed to mill A SKME at concentrations up to 4.5 percent. Both Borton and Tokar postulated that the observed decreases in growth rate for experiments in aquaria were direct effects of the effluents on the efficiency of utilization of food for growth. Results obtained on effluents from one mill cannot simply be applied to effluents from other mills.

In nature, KME can also affect fish populations by altering the availability of their food. Such indirect effects of KME and SKME were studied by Ellis (1968), Seim (1970) and Lichatowich (1970). They measured the biomass, growth rate, and production of salmonids in laboratory streams where the only food available was that produced within the streams. Here the aquatic communities were, however, quite simple in comparison to those in natural streams.

Ellis (1968) observed a reduction in growth and production rates of juvenile chinook salmon exposed to a dilution of 1.5 percent (3.0 mg/1 BOD) KME but not at a dilution of 0.5 percent (1.0 mg/1 BOD) KME. Since food abundance did not appear to be affected by the effluent, the change in growth rate was attributed to a direct effect of KME on the fish. The decrease in growth rate was, however, aggravated by higher stocking densities. Ellis did observe an increase in amphipod density (Crangonyx) in laboratory streams receiving effluent during another experiment conducted during the summer. Williams (1969) found an increase in algal production in these streams when SKME was being introduced. Species composition of diatoms was altered by SKME.

Seim (1970) observed a decrease in production of chinook salmon exposed to 1.5 percent SKME (0.8 mg/l BOD) in laboratory streams during spring and fall and attributed this to a direct effect of SKME, because food density was not greatly different between streams. In summer experiments, production was enhanced by dilutions up to 4 percent SKME, but was greatest at a dilution of 1 percent. This was attributed to an observed increase in the density of the amphipod *Crangonyx*, greater food availability perhaps masking any direct effects of SKME.

Lichatowich (1970) observed that concentrations of effluent from mill B of 1.5 mg/l BOD (0.75 percent) and 3.0 mg/l BOD (1.5 percent) KME and 1.5 mg/l BOD (7.5 percent) SKME resulted in higher biomasses of juvenile chinook salmon than were observed in control laboratory streams. This was attributed to an observed increase in food organisms in those streams receiving effluent. Thus for KME and SKME from mill A, concentrations between 0.5 and 1.0 mg/l BOD were usually near the minimal level having a direct effect on the growth rate of fish in aquaria, and did not usually inimically affect the production of fish in laboratory stream communities. On this basis, concentrations of KME and SKME around 0.7 mg/l BOD were employed in most of the studies with the three stream channels, from October 1969 until October 1973, when testing of a higher concentration began.

Theoretical Considerations

The design, conduct, and analysis of any experiment is the expression of the conceptual framework of those involved, with the intention of attaining satisfying explanation of the questions under study. The framework within which this research was conducted was developed by Brocksen, Davis and Warren (1968, 1970) and Warren (1971), and further developed as a general theory of productivity and resource utilization by Booty and Warren (manuscript).

Production is defined as the total elaboration of fish tissue, regardless of the fate of that tissue, in any period of time. It can be expressed as the product of the growth per unit biomass of the fish per unit time and the mean biomass present during that time. As illustrated in Figure 1, the growth rate of fish in a system having a limited food resource must decline as the fish biomass increases, because less food is then available per gram of fish. Since production is the product of growth rate and biomass, production first increases to some maximum with increase in biomass and then declines with further increase in biomass (Fig. 1). A fish production curve will be higher and wider for a system having a high capacity to produce fish--a high productivity for fish (Fig. 1A)--than will a fish production curve for a system having a lower capacity (Fig. 1B).

Further development of this point of view has shown 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 predator (Fig. 2C). An increase

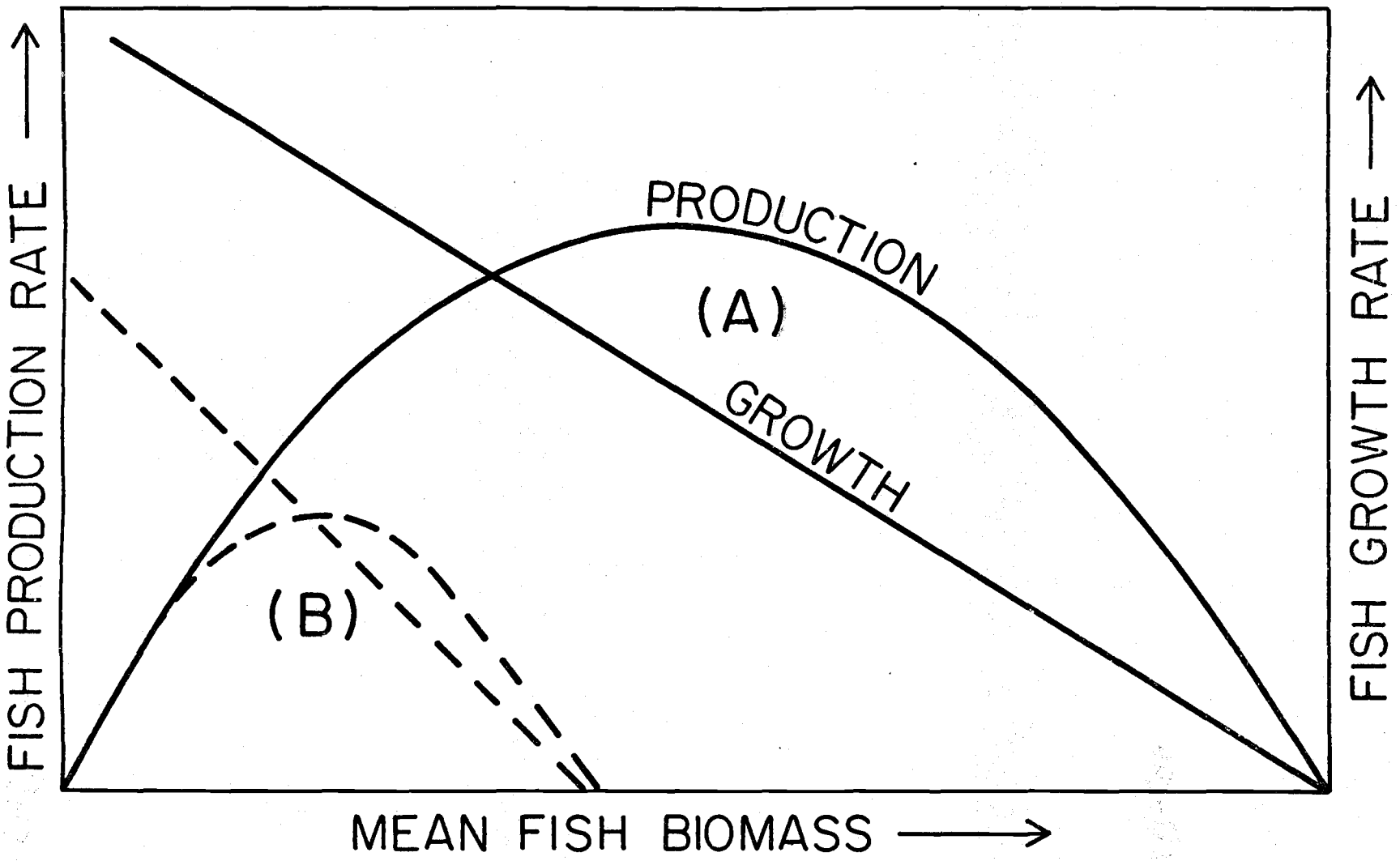

Figure 1. Theoretical relationships between fish production rate and mean fish biomass and between fish growth rate and fish biomass at a high level of productivity (A) and a lower level of productivity (B).

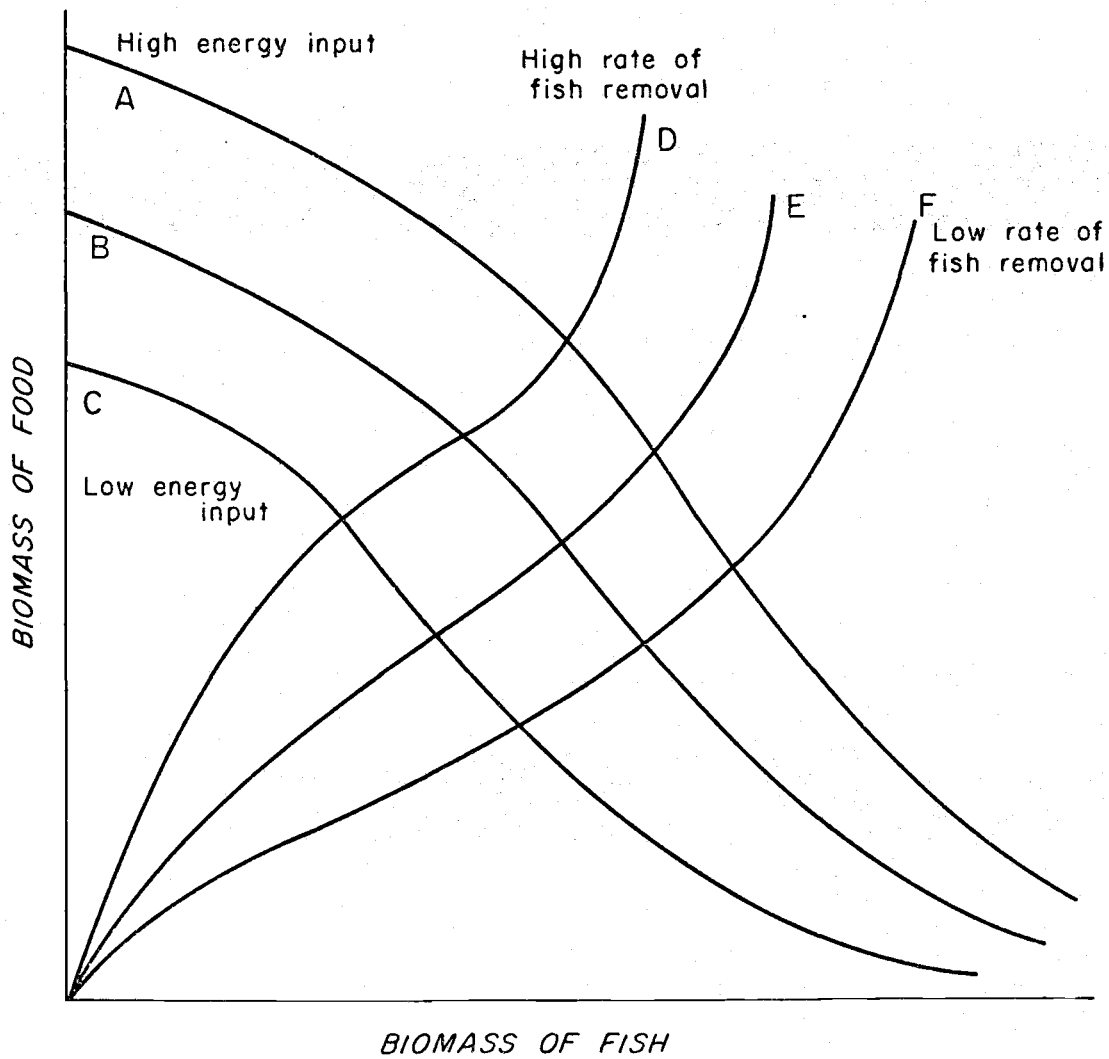

Figure 2. Theoretical relationships between biomass of food and biomass of fish at three levels of energy input (A, B, C) corresponding to three levels of productivity. Curves D, E and F represent paths along which productivity may change at three rates of fish removal (predation)

in the productivity or capacity of a stream to produce fish, as might occur with a change in water quality leading to an increase in energy input to the system, would lead to a higher inverse relation between prey and predator (Fig. 2A). For each inverse relationship between the biomass of the prey and the predator (Fig. 2A, B, C), there exists a corresponding set of relationships between the biomass of the predator and its growth rate and production, as shown in Figure 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.

At a given level of productivity, coordinate values of prey and predator would move along a single inverse relation, such as A, B, or C in Figure 2. A change in productivity would be reflected in a movement of coordinate values upward or downward onto another inverse relation. Were the rate of removal of the predator from the system to be constant, then the movement of coordinate values would be along one or another direct relation such as D, E, or F in Figure 2, when productivity is changing. These theoretical relationships, rigorously deduced by Booty and Warren (MS), are often very helpful in interpreting food and production relations in nature.

FACILITIES, MATERIALS, AND METHODS

Experimental Stream Channels

Each of the three experimental stream channels was approximately 100 meters long, 2 meters wide, and consisted of 11 pools--each about 3 meters long and 0.75 meters deep--alternating with 11 shallow riffles--each about 6 meters long (Fig. 3). The riffle substrate consisted of gravel and rubble up to about 20 cm in diameter, deposited to a depth of 15-20 cm. The stream banks were steeply cut and were covered by native grasses but otherwise unshaded. The mean gradient of the streams was 1.5 percent. Water was pumped from the Willamette River, 200 meters west of the streams, to a weirbox at the head of each stream. From these it flowed through inclined screens of 1.5 mm mesh fiberglass before entering the streams. The screens prevented the introduction of fish and reduced the introduction of larger aquatic insects into the streams from the Willamette River. A trap to capture emigrating fish was located below the weir located at the end of each stream. Monofilament netting was extended over the pool areas to reduce predation on the fish by birds.

Measurements of head in the weirboxes were employed in calculating stream flows. These varied somewhat with changes in the level of the Willamette River. Annual mean flow rate in each stream was approximately 776 liters per minute (0.46 cfs). Water temperature was recorded continuously at the inflow and outflow of stream 2. Outflow temperatures indicated a maximum increase of about 3 C occurred over the length of the stream. A minimum temperature of 3 C occurred in December 1971, and a maximum temperature of 24 C occurred in June 1972 (Fig. 4). Dissolved oxygen was near the air-saturation level in all samples taken.

Data on nitrate and total phosphorus concentrations (Fig. 4) at the Peoria and Buena Vista stations on the Willamette River were made available by the Oregon Department of Environmental Quality. Peoria is about 20 miles upstream and Buena Vista is about 12 miles downstream from the stream channels. The higher nitrate values at Buena Vista are primarily a result of industrial and domestic discharges in the Corvallis and Albany areas. Nitrate determinations made at the stream channel site indicate somewhat higher values than shown for these two stations. Increases in nitrate levels during winter peiods closely followed patterns of rainfall (Fig. 4). Rainfall data were collected at nearby Hyslop Laboratory by the Oregon Agricultural Experiment Station. Nitrate and total phosphorus concentrations were probably sufficiently high not to limit growth of algal populations. Total alkalinity was determined monthly, from April 1970 to November 1971. The mean was 21.6 mg/l and the range was 17.0 to 32.0 mg/l, as $CaCO_3$ (Appendix I). The mean pH was 7.5 and the range was 7.2

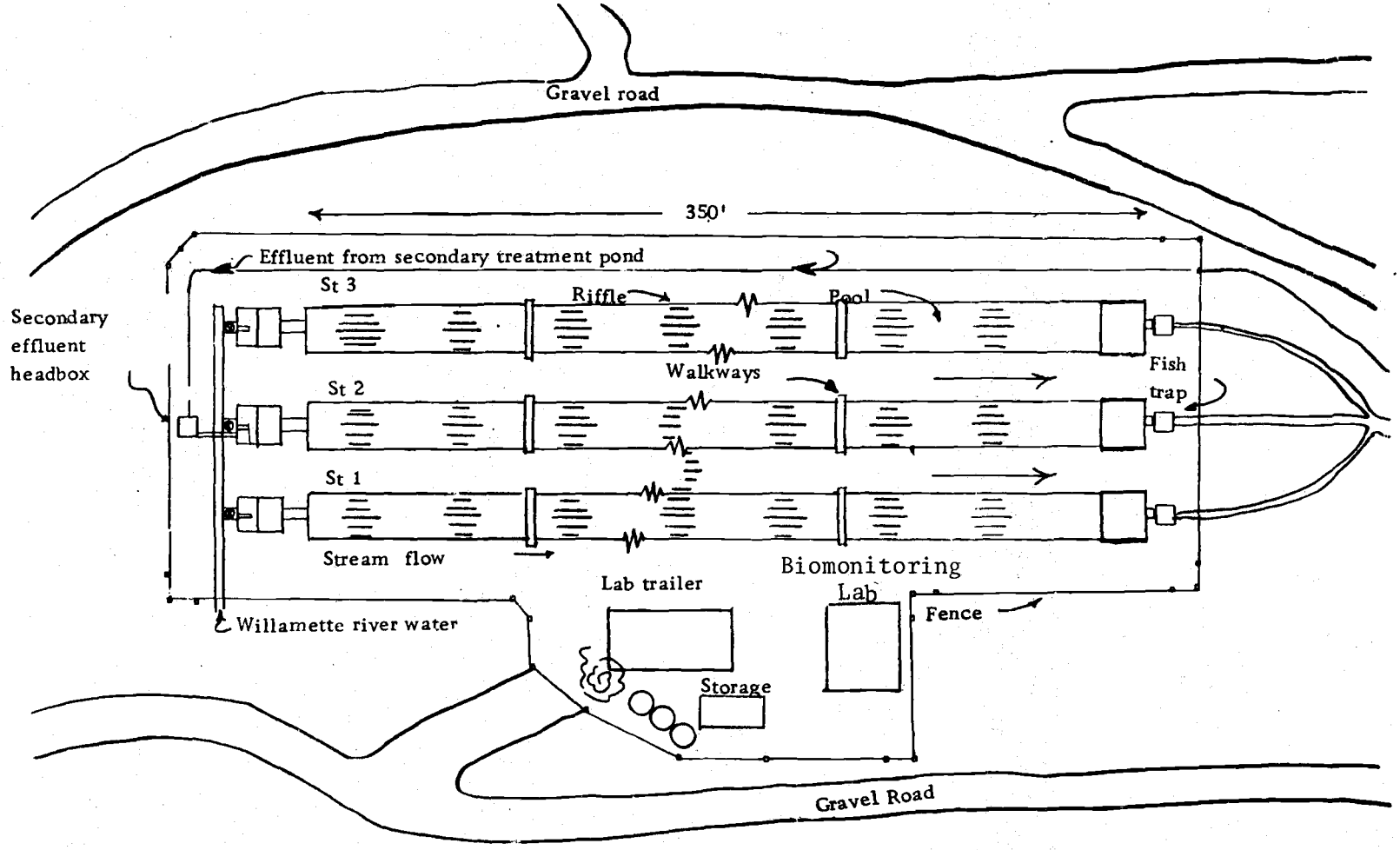

Figure 3. Schematic diagram of the research facility and the three stream channels.

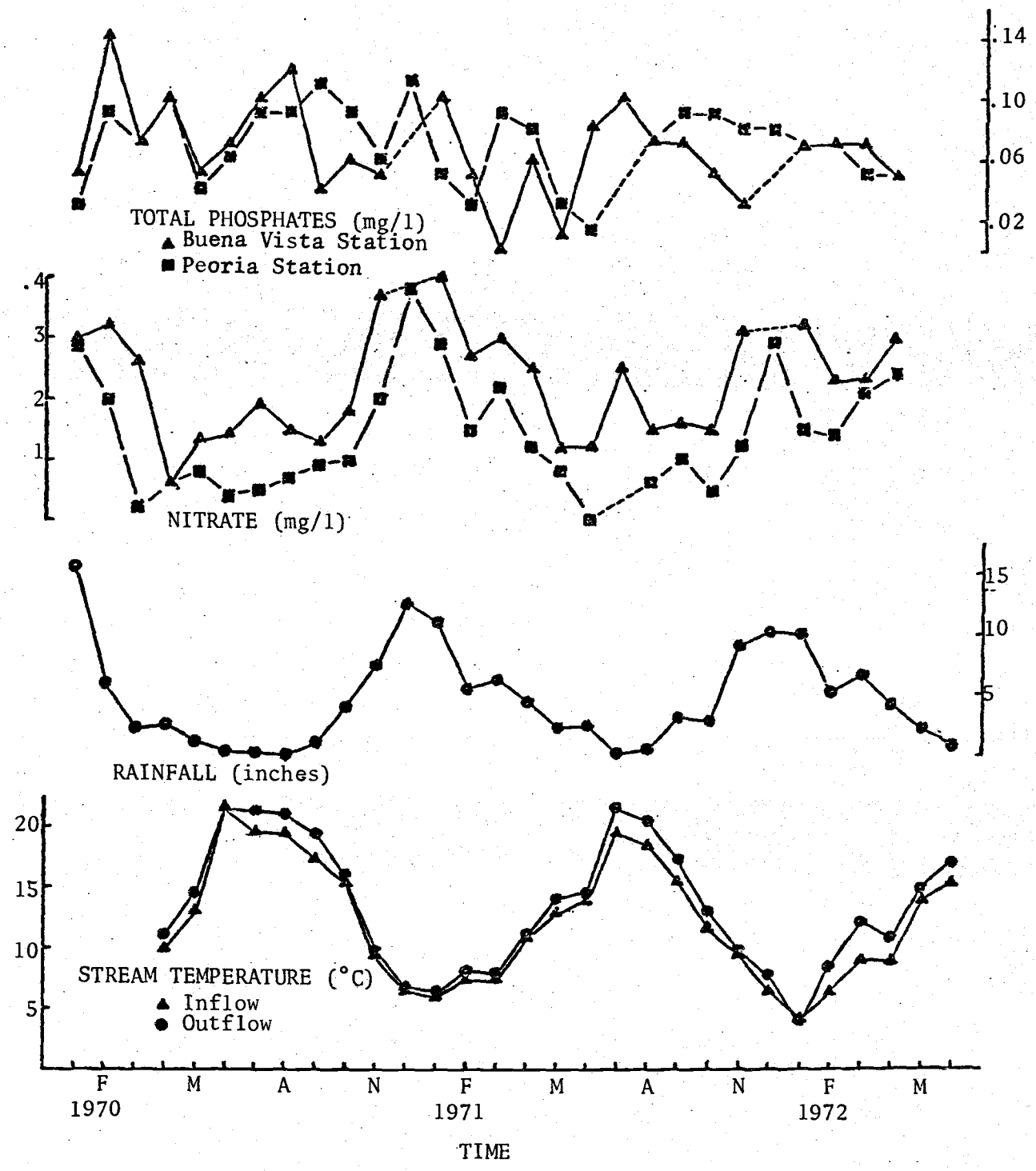

Figure 4. Inflow and outflow stream channel temperatures, local rainfall, and nitrate and total phosphate concentrations from two stations on the Willamette River. The latter data from the Oregon Department of Environmental Quality.

to 8.1, during this period. Total alkalinity during the period October 1973 to May 1974 ranged from 24.0 to 42.0 mg/l, with a mean of 30.8, on the basis of weekly determinations (Appendix I).

Kraft Effluents

Studies of primary treated effluent began January 2, 1970 and ended in February 1971. From March 16, 1971 until the conclusion of this research, biologically stabilized effluent was introduced into Stream 2. The source of kraft effluent was a kraft liner board pulp and paper mill producing approximately 890 tons per day (tpd), consisting of 590 tpd unbleached kraft pulp, 200 tpd neutral sulfite, semi-chemical pulp, and 100 tpd kraft clippings (waste paper). The neutral sulfite process was added in June 1971. Recovery of digestion chemicals and turpene removal is practiced by the mill. The combined effluents from the mill flow into two sedimentation ponds, having a total retention time of 24 hours, this constituting the primary treatment for removal of settleable solids. The effluent is then pumped to a 8.5 hectare (21 acre) basin equipped with ten 50-horsepower aerators for biological stabilization. Diammonium phosphate is occasionally but not regularly introduced into the basin to aid bacterial growth. With a retention time of 8-16 days, a 90 percent reduction in BOD may be achieved. The treated effluent is then discharged to the Willamette River. In summer, flow to the stabilization basin, normally about 10 million gallons per day (mgd), is reduced by diverting half of the effluent to seepage basins.

In order to produce an effluent of higher and more constant quality, one that might represent future levels of treatment, some effluent from the stabilization basin was further stabilized for purposes of stream channel experiments conducted after October 1973. Stabilization basin effluent was then pumped to a 0.2 hectare (0.5 acre) aeration basin equipped with one 5-horsepower aerator for further treatment. Operation of this additional stabilization basin, which was constructed and operated by personnel of the National Council for Air and Stream Improvement, began in October 1973. Here the effluent received biological treatment for an additional ten days. It was then pumped through a plastic pipe to a headbox at the inflow of the Stream 2. Flow of effluents being tested in Stream 2 was controlled by varying the amount of head in the effluent headbox, from where the effluent was introduced into the weirbox at the desired concentration. This was adjusted as necessary on the basis of BOD determinations made by NCASI personnel. Mean weekly BOD's of the effluents tested throughout this study are given in Appendix 2.

Daily measurements of effluent and stream flow were the basis for calculation of mean weekly concentrations of effluent in Stream 2. The actual BOD added to Stream 2 varied because of the fluctuations in effluent BOD concentration. The mean concentration of primary effluent added to Stream 2 from January 2, 1970 until March 1, 1971, was 0.75 mg/l BOD, varying from about 0.4 to

1.4 mg/l. Secondary treated effluent was added to Stream 2 from March 16, 1971 to October 1, 1973 at a mean BOD concentration also about 0.75 mg/l, ranging from 0.3 to 1.5 mg/l. Secondary effluent tested thereafter received extended treatment in a "polishing" pond. Mean concentration was thereafter reduced to 0.65 mg/l BOD (0.5 to 1.1 mg/l) from October 1, 1973 to October 1, 1974. The final experiment tested a concentration near 1.5 mg/l BOD (0.8 - 1.7 mg/l) from October 1, 1974 through October 21, 1975.

Acute toxicity of these effluents is given in Appendix III. Concurrent 96-hour acute toxicity bioassays showed no acute toxicity from salmonids at effluent concentrations of 100 percent at any time after January 1973.

Experimental Fish

Several different salmonid species were stocked in the streams during 1970, 1971, and 1972. Juvenile coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tschawytscha*) as well as juvenile and mature cutthroat trout (*Salmo clarkii*) and brown trout (*Salmo trutta*) were present in the streams, together and separately at different times (Table 1).

After October 25, 1973, only brown trout were stocked, because of their greater resistence to infection by the myxosporidian, *Ceratomyxa shasta*, which became a serious problem with the other species during the late spring and summer months. Schaefer (1968) suggested that brown trout may be more resistant than coho or chinook salmon to *C. shasta*. The fall chinook were from the Bonneville Hatchery of the Oregon Department of Fish and Wildlife. The coho salmon were from the Alsea Salmon Hatchery. The brown trout were collected from Browns Creek, a tributary of the Deschutes River and from the Little Deschutes River. According to Sanders *et al.* (1970), Browns Creek is outside the distribution of *C. shasta*. Cutthroat trout were collected from local streams.

Fish Stocking and Sampling Procedures

Any fish found in the traps below the streams within the first two weeks after stocking or sampling were returned to the streams. Thereafter, fish found in the traps were assumed to be migrating and were not returned to the streams. During different experiments, fish were removed from the streams at monthly or semi-monthly intervals. On some occasions, the sampling date was adjusted slightly to coincide with the sampling of other organisms. Seining was the primary method of fish removal. Electrofishing was sometimes used but was found to be less suitable during winter months, because stunned fish were not visible in the turbid water. The flow of each stream was reduced at each sampling time in order to force fish from the riffles into the pools, where they could more easily be captured. Nearly all fish could be removed by this method.

Table 1. Stocking date, species, number, size, and stocking density of fish used in the stream channels.

Date	Species	Stream 1 Number	Stream 1 Total Weight	Stream 1 Ave. Weight	Stream 1 Density (g/m^2)	Stream 2 Number	Stream 2 Total Weight	Stream 2 Ave. Weight	Stream 2 Density (g/m^2)	Stream 3 Number	Stream 3 Total Weight	Stream 3 Ave Weight	Stream 3 Density (g/m^2)
February 12, 1970	Cutthroat trout Small	24	251.31	10.55	1.09	26	277.50	10.70	1.21	25	277.73	11.10	1.30
	Large	15	397.43	26.50	1.73	12	370.60	30.90	1.61	12	331.77	27.65	1.56
February 25 Fish kill													
February 28 (Replacements for effluent kill)	Cutthroat trout					16	236.94	14.81	1.10				
March 14	Cutthroat trout	2	6.38	3.19	0.01	15	247.69	16.51	1.15	15	180.19	12.01	0.85
April 18	Coho salmon	745	875.20	1.18	3.80	743	873.10	1.18	4.06	747	878.10	1.18	4.12
April 28	Cutthroat trout	28	598.36	21.40	2.60	28	637.11	22.75	2.77	29	604.49	20.84	
June 22	Chinook salmon	54	440.55	8.15	1.91	54	383.80	7.09	1.80	54	432.13	8.00	2.02
July 23	Brown trout	154	506.68	3.29	2.29	161	507.41	3.45	2.36	143	506.74	3.54	2.38
January 30, 1971 Fish kill within 2 days--fish taken out	Chinook salmon	854	977.39	1.14	4.25	820	928.57	1.13	4.31	809	917.31	1.13	4.31
March 22	Chinook salmon	462	874.38	1.86	3.80	434	821.88	1.89	3.82	436	809.38	1.86	3.80
August 2	Brown trout	225	317.31	1.41	1.38	226	307.82	1.36	1.43	211	304.45	1.44	1.43
February 7, 1972	Coho salmon	1449	539.50	0.36	2.35	1329	478.59	0.36	2.23	1312	472.79	0.36	2.22
June 4	Brown trout	580	1380.19	2.37	6.00	532	1296.76	2.43	6.03	544	1280.44	2.35	6.01
March 12) 1973 and) March 27)	Coho salmon	1520	1185.62	0.78	5.1	1380	1074.92	0.78	5.0	1371	1079.79	0.79	5.0
October 25	Brown trout	160	1583.80	9.88	6.87	170	1422.90	8.37	6.68	171	1474.02	8.62	686
April 24, 1975	Brown trout	62	1741.70	28.09	7.57	60	1720.50	28.68	8.08	60	1706.50	28.44	7.94

After removal from the streams, the fish were counted, anesthetized with tricane methyl sulfonate (MS 222), and excess water was blotted from the fish with a soft cloth. The fish were then weighed in a tared container of water on an overhead balance accurate to 0.1 gram. Ten to twenty of the anesthetized fish from each stream were randomly selected and their stomach contents extracted with alligator ear forceps (Wales, 1962), or by use of a 5 cc glass syringe having a smooth tip. By forcing a stream of water down the esophagus, food items were flushed into the mouth and then into a beaker, from which they were transferred to individual vials. By substituting a 20 cc syringe for the smaller one and varying the amount of water used with the size of the fish, it was possible to successfully sample the stomachs of all sizes of fish. When flushing a stomach yielded no organisms, alligator ear forceps were used to carefully enter the stomach through the esophagus and remove any material not flushed out by the syringe. All fish were then redistributed evenly along the length of their respective streams.

The stomach contents were placed in a 4 percent formalin solution and later separated into taxonomic groups, blotted dry, and then weighed on a Mettler analytical balance accurate to 0.1 milligram. The most abundant organisms in the stomach samples were identified to genus, with the exception of chironomids, which were identified only to family. Other less abundant organisms were identified to family or order.

Production, Biomass, and Growth Rate Calculation

Cutthroat trout stocked in the first experimental period were marked by cold branding (Everest and Edmundson, 1967). The growth of individual fish could be estimated by subtracting weight at the beginning of a sampling period from weight at the end of the period. Fish not recovered at the end of a period were considered to have been present for one-half of the sampling period and were assigned a growth rate based upon the mean growth rate of recovered fish. Trout production in grams was then computed by summing the actual or estimated weight gain values for the individual fish. Groups of fish stocked for later experimental periods were of nearly uniform size and their production was calculated by graphing the numbers of fish found in each stream against the mean weight of the individual fish. The area under the curve generated by this graph provides an estimate of fish production for a given age class (Allen, 1951). In general, the curves generated while salmon were present were less j-shaped than those of brown trout. The salmon usually had lower mortality rates than brown trout in the first month after stocking, this reducing the steepness of the first part of the curve. Smooth curves were fitted visually in order to adjust numerical estimates upward for those sampling periods when fewer fish were recovered than later sampling periods showed to have been present.

From values for fish production determined by this graphical method, relative growth rate was calculated with the formula:

$$\text{Growth Rate (mg/g/day)} = \frac{P_n}{B_n \cdot D_n}$$

P_n = total salmonid production during sampling period n.

B_n = the mean biomass during sampling period n

D_n = number of days in sampling period n

Methods Used in Studying Fish Reproduction

In an effort to determine effects of 0.65 mg/l BOD SKME on spawning of salmonids and survival and growth of embryos and alevins, a spawning channel was constructed at the end of each stream. Each channel was 1 meter wide and 10 meters long and had a gradient of approximately 1 percent. A substrate, 15 cm deep, of gravel 1 to 5 cm in diameter was provided. Five styrofoam floats, 50 cm square were anchored in each spawning channel in order to provide cover for the adult fish. Upstream emigration was prevented by the stream channel traps, and downstream emigration was prevented by a screen of 1.8 cm square-mesh hardware cloth. The sides of the spawning channels were lined with Douglas-fir boards. Average water depth of 15 cm and average water velocity of 9 cm/sec were maintained over the substrate. Initially, five pairs of adult brown trout and, later, four pairs of coastal cutthroat trout, *Salmo clarki clarki* Richardson, were stocked in each spawning channel. No spawning or redds were observed and the fish were removed.

On February 22, 1974, fertilized steelhead eggs (*Salmo gairdneri* Richardson) from the Alsea Hatchery of the Oregon Department of Fish and Wildlife were buried in the spawning channels. The eggs from one female were spawned dry into an aluminum dish. Sperm from two males was collected in separate plastic bags. The eggs and sperm were then placed in a portable cooler and transported 80 km (50 miles) to the stream channels where the eggs were fertilized and divided into 15 lots of 105 embryos each. These were then placed in stainless steel baskets, five of which were buried in the gravel in each spawning channel.

These baskets were 10 cm square, 2.5 cm deep, and were constructed of perforated stainless steel with holes 3 mm in diameter at a density of five holes per cm^2. A column 4.5 cm in diameter extended through the center of each basket to allow a greater flow of water. The baskets were buried under 2 cm of gravel lateral to and slightly downstream from each concrete block, in an effort to provide maximum water flow through the baskets. Water velocity above the gravel was calculated to be about 15 cm/sec where the baskets were buried. Four of the baskets in each stream were checked periodically, and the dead embryos recorded and removed. After examination, the baskets were carefully reburied in the gravel. The fifth basket was not disturbed until the eggs in the others had hatched. After hatching, five alevins from each basket were removed at weekly

intervals and weighed. The numbers of dead and live alevins were recorded. Four weeks after hatching, the alevins emerged from the baskets into the streams, and the experiment was terminated.

Two of the five groups of five alevins removed weekly from each stream were blotted dry on a paper towel and weighed on an analytical balance accurate to 0.1 mg. They were then placed in an oven at 70 C for 4 days and in a desiccator for two additional days before dry weights were taken. With the other three groups, the remaining yolk was carefully separated from each alevin, and wet and dry weights were determined.

From these measurements, survival and growth of the embryos and alevins were determined. Measurements included embryo survival until hatching, time until hatching, size of alevins at hatching, alevin survival until emergence, time until emergence, and size at emergence. Mean dry weights of alevins without yolk and of the yolk were plotted against time to determine any effects of 0.65 mg/l BOD SKME on growth and yolk utilization of alevins.

Sampling of Invertebrates and Organic Matter

Samples for analysis of macroinvertebrates and total organic matter were collected from the riffles of the experimental streams twice monthly from February 1970 until the conclusion of this research, except that only monthly samples were taken during February, November, and December 1971 and January 1972. A cylindrical sampler having a cross-sectional area of 0.072 m^2 was placed on the substrate. Foam rubber on the bottom edge of the sampler extended laterally about 10 cm, this providing a very good seal to prevent water and materials from entering or leaving the enclosed area. Substrate rubble and large gravel were removed from the sampler and brushed clean to collect attached materials. The materials removed with brushes along with the slurry remaining inside the sampler were pumped into a 116 micron mesh net. The concentrated sample was put into a polyethylene bag, iced, and transported to a freezer.

This procedure was followed through February 1972, when the sampler and the procedure were altered. The new sampler, which enclosed an area of 0.1 m^2, had metal sides, a bag net with a 471 micron Nitex mesh, a screen front, and a round bottom that could be pushed into the substrate. Substrate materials were removed and cleaned, as in the previously described procedure. Current through the sampler forced invertebrates and suspended material remaining in the sampler into the bag, from which they were removed. The samples were then preserved in formaldehyde.

The riffles in each stream were numbered from upstream to downstream, riffle 1 being the first upstream riffle in each stream. Until July 1972, riffles 1, 4, 7, and 11 in each stream

were sampled one week, and riffles 2, 5, 8, and 10 were sampled two weeks later, so that a particular riffle was usually sampled once each month. After July 1972, other riffles were also sampled according to a similar pattern.

Further processing of the samples was completed at the laboratory. Twenty-five percent aliquots of the four riffle samples from a stream were combined to form a single composite sample for that stream. During 1970, invertebrates were removed without the aid of a dissecting scope from a 25 percent aliquot of the composite. Then that 24 percent sample was halved and most of the remaining macroinvertebrate organisms were removed with the aid of a dissection scope.

After June 29, 1973 this procedure was altered as follows to simplify the splitting process. The four riffle samples were each divided in half using a 50 percent splitter, and the halves combined to form the composite sample. This sample was then sorted by eye to remove the larger and typically uncommon organisms. The sample was then drained through 118 micron Nitex and mixed. Ten percent by weight of this sample was removed and examined under a binocular microscope to remove the remaining invertebrates. The subsample then represented 0.02 m^2 of sampled area. Some species of very small organisms, such as tardigrades, and micro-oligochaetes were not removed.

Material remaining in the various samples after the invertebrates were removed was dried at 70-80 C, weighed, and then ashed at 600 C. The difference between dry weight and ash weight was used as a dry weight estimate of organic matter, mainly plant material, in the benthos.

RESULTS AND INTERPRETATION

Production, Growth, and Biomass of Salmonids when Primary treated Kraft Mill Effluent was Being Tested

Willamette River water first entered the stream channels on October 1, 1969, and colonization by benthic organisms began. After initial samples demonstrated that the benthic communities in the three streams were similar and were sufficient to support fish populations, primary KME was introduced into Stream 2 at 0.75 mg/l BOD on January 2, 1970. Thereafter, primary KME continuously entered Stream 2 until March 12, 1971. Within this time period, there were two experimental periods, when different salmonid species were present. Experimental period I was from February 14, 1970 through May 19, 1970, when cutthroat trout and coho salmon were in the streams. Experimental period II was from June 22, 1970 to January 29, 1971, when chinook salmon and brown trout were present

During experimental period I, cutthroat trout were stocked in all streams on February 14, 1970, and coho salmon were added April 18, 1970. All of these fish were removed by June 1, 1970, because of the prevalence of disease caused by *Ceratomyxa shasta* in late May. The total production of fish in the three stream channels was similar during period I. Salmonid production in control Streams 1 and 3 was 6.2 and 7.2 g/m^2, while Stream 2--which received 0.75 mg/l BOD primary KME--had salmonid production of 6.6 g/m^2.

Theoretical relationships between the production and mean biomass of the salmonids during experimental period I are shown in Figure 5A. Separate curves, fitted according to the theoretical production-biomass relationship discussed earlier (Fig. 1) have been drawn. These indicate that the productivity of the streams was greater for coho salmon than for cutthroat trout during this period.

The growth rates of the coho salmon were much greater than those of the cutthroat trout when both species were in the streams during May (Fig. 5B, points 5). The salmon growth rate in May was higher than the growth rate of the trout in March and April, when only trout were in the streams, even though the mean salmon biomass in May was twice that of the trout in March and April (Fig. 5B). As explained earlier, any increase in fish biomass in a system having a given productivity should result in a decrease in the growth rate of the fish (Fig. 1). The higher growth rates of the coho salmon at higher biomasses indicate a higher productivity--capacity--of the stream channels for coho salmon than for cutthroat trout. Thus separate production-biomass and growth rate-biomass curves have been drawn for the two species (Fig. 5A and B). The cutthroat trout were larger and older than the coho salmon used during period I. This undoubtedly contributed to the lower growth rates of the cutthroat trout, but other factors including food habits were probably also involved.

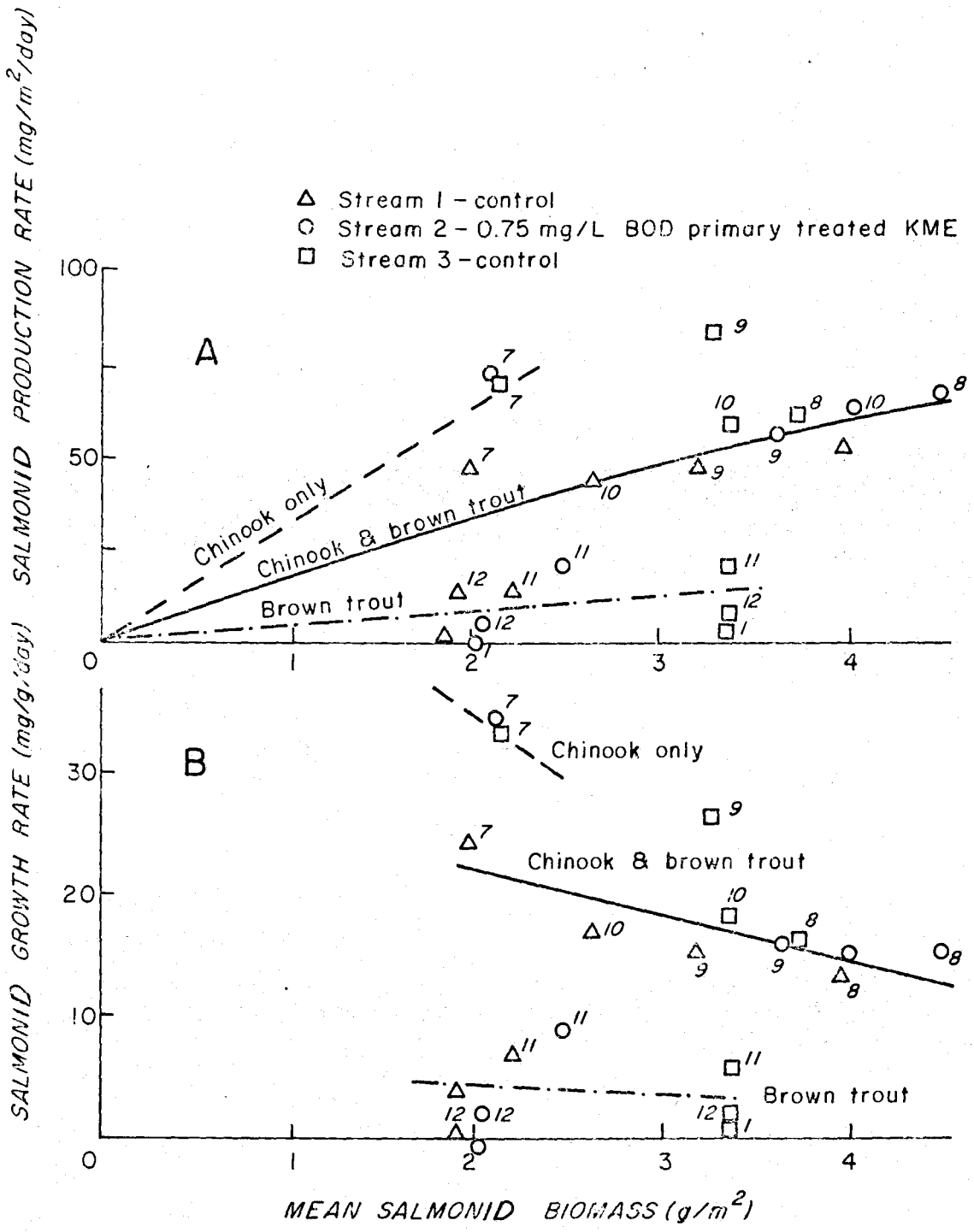

Figure 5. The relationships between chinook salmon and brown trout mean biomass and production (A) and growth rate (B) in the three stream channels during experimental period II, from June 22, 1970 to January 30, 1971. Numbers indicate the month each point represents (3 = March). Chinook salmon were present during July, chinook and brown trout August through October and brown trout through January. Stream 2 received 0.75 mg/l BOD of KME during period II.

On February 15, 1970, a fish kill occurred in Stream 2, which was intended to be receiving 0.75 mg/l BOD primary effluent. This was a short term effect, lasting only one day, yet over 50 percent of the fish stocked were found dead in the trap below the stream. The trout killed were immediately replaced with ones of equal size, no salmon being present in the streams at that time. Bioassays the day of the fish kill showed an unusually toxic effluent, with a 96 hr TL_{50} of 1.3 percent by volume of primary KME. The concentration in the stream was only 0.33 percent by volume, this suggesting that the kill was the result of a very brief discharge of an even more toxic effluent into the stream.

During experimental period II, fall chinook salmon were stocked in the streams on June 22, 1970, and brown trout were added on July 23, 1970. The chinook migrated from the streams during the next 3 months and all had left the streams by September 1, 1970. The brown trout remained until January 30, 1971, when they were removed. The total production of salmonids during period II, from June 22, 1970 to January 30, 1971, was 6.0, 9.0 and 9.4 g/m^2 for Streams 1, 2 and 3, respectively. The production value for Stream 2 which was receiving 0.75 mg/l BOD primary KME, was again intermediate to the values for the two control streams. Control Stream 1 had a much lower value of fish production than did either Stream 2 or 3.

The relationship between salmonid production and biomass was different for each of three time periods in the second half of 1970, experimental period II (Fig. 6A). Productivity for salmonids was greatest in July and successively less in the August-October period and November-January period, higher curves representing higher levels of productivity (Fig. 6A). These productivity changes may have been in part owing to the presence of different fish species, but large changes in mean water temperature and food density in the streams were probably the major factors involved.

Fish production and growth rates were low during the winter months (November-January), as illustrated by the production and growth relationships for this period (Fig. 6A and B, dotted lines). There were probably three levels of productivity within this single period, the dotted line representing only an approximate average of the three. The biomasses of benthic insects did not change much during these months, so the decrease in productivity from November through January was probably not caused by a decrease in food availability. Averett (1969) showed the growth rate of coho salmon fed maximum rations in laboratory experiments decreased substantially when the temperature dropped below 5-8 C. He noted that this was not due to a decrease in the efficiency of utilization of food organisms, but rather was caused by decreased food consumption rates. Iverson (1972) also observed a decrease in the growth of coho salmon in laboratory streams during winter months, even though the biomass of insects found in drift samples was high. Iverson believed the high silt load carried by the water during winter months might also affect the ability of fish to feed. The relatively low production-biomass relationship for winter months probably resulted from reduced food consumption due to the low temperatures, turbidity perhaps also being involved. The

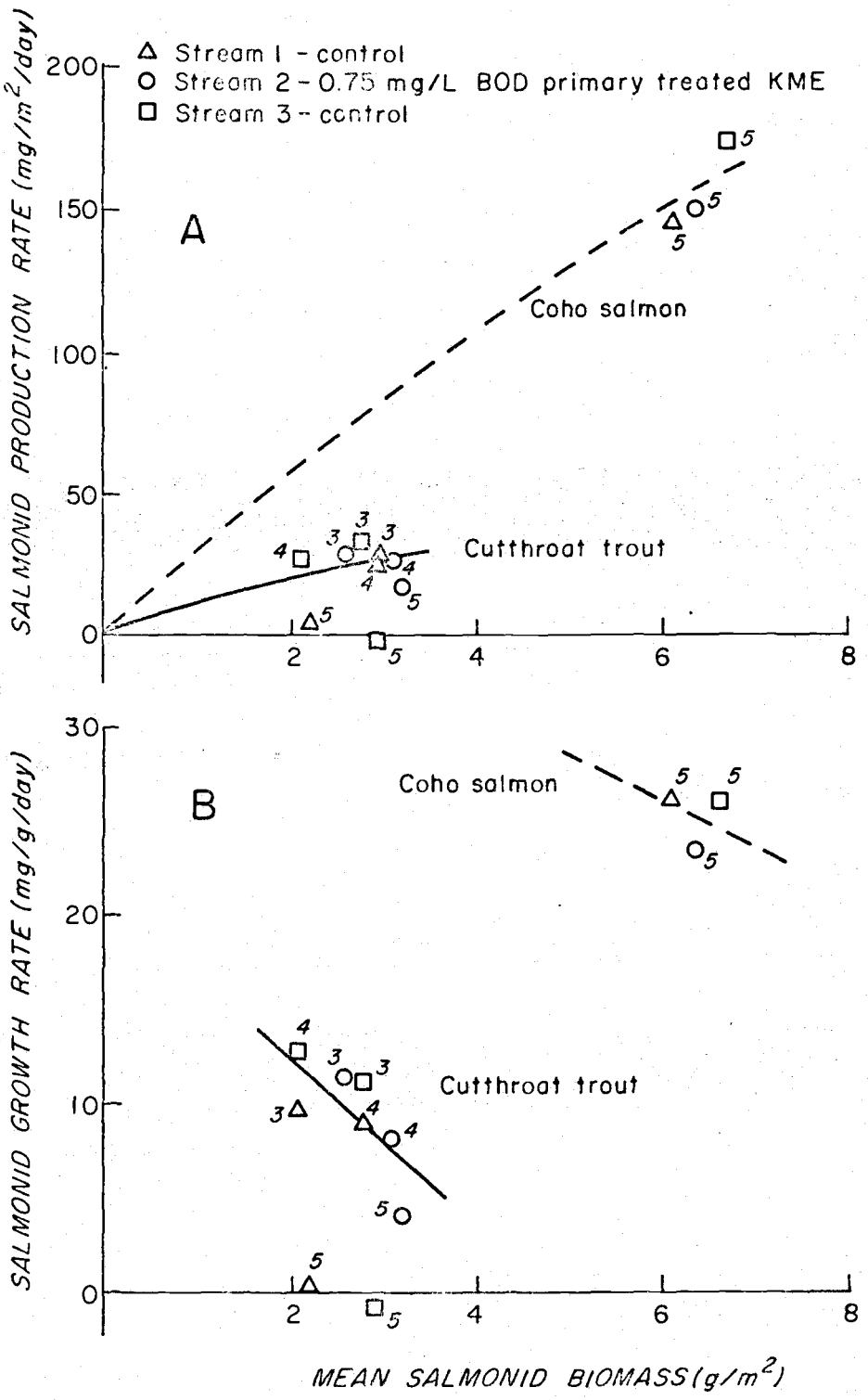

Figure 6. Relationships between salmonid (cutthroat trout and coho salmon) mean biomass and production (A) and growth rate (B) in the three stream channels during experimental period I. Experimental period I extended from February 14, 1970 through May 19, 1970. Numbers indicate months of the year (3 = March). Stream 2 received 0.75 mg/l BOD of KME during this time.

presence of primary treated effluent at 0.75 mg/l BOD in Stream 2 was not shown to measurably influence the ability of Stream 2 to produce trout and salmon during period II.

After the brown trout were removed, chinook salmon were stocked on January 30, 1971. Within two days there was approximately 50 percent mortality of the fish in Stream 2. The 96-hr TL_m at this time dropped to about 1 percent by volume of primary KME (Appendix III). The effluent was periodically very toxic until March 12, when studies with primary KME ended. These increases in effluent toxicity were concurrent with extensive remodeling and new installation of facilities with the pulp and paper mill.

The data for the entire period primary KME was added to Stream 2 indicate there was no appreciable effect of 0.75 mg/l primary KME on the production growth rates of salmonids in Stream 2 as compared to control Streams 1 and 3. Usually the productivity for salmonids of Stream 2 was between that of the two control streams. Of course, fish kills such as occurred in February 1970 and January 1971 could limit production in natural streams where restocking does not occur immediately. The low holding capacity of the primary settling basin was clearly insufficient to buffer what were apparently very short-term increases in toxicity. With larger storage capacity and secondary treatment, such short-term increases in toxicity would present much less of a problem.

Production, Growth, and Biomass of Salmonids when Secondary treated Kraft Mill Effluent was being Tested

Secondary effluent was introduced into Stream 2 at a concentration of 0.75 mg/l BOD from March 16, 1971 until October 1, 1974. There were six experimental periods during this time. Experimental period III was from March 22, 1971 to May 28, 1971, when chinook salmon were in the streams. A large percentage of these fish migrated downstream into the traps, thus the growth and production data for this period are of limited value. Experimental period IV extended from August 2, 1971 until January 24, 1972, when brown trout were present in the streams. Coho salmon were in the streams from February 7, 1972 through May 25, 1972, during experimental period V. Brown trout were present from June 9, 1972 until January 30, 1973, during experimental period VI. During experimental period VII, coho salmon were used from March 12 to April 27, 1973. Brown trout were stocked October 25, 1973 and removed July 19, 1974, for period VIII. During period VIII, average effluent concentration dropped slightly to 0.65 mg/l BOD, partially because of the use of an additional treatment stage, designed to produce a more fully treated effluent. The high volumes of this effluent necessary to achieve the desired 0.75 mg/l BOD in Stream 2 tended to overload the delivery system, a difficulty that was subsequently remedied. The final experiment, conducted from April 24 through October 21, 1975, (period IX) with brown trout, was designed

to determine the influence of a concentration of 1.5 mg/l BOD of this more highly treated effluent.

During period IV, total brown trout production values were nearly the same for Streams 1, 2, and 3, being 3.2, 3.6 and 3.5 g/m^2, respectively. Stream 2 received 0.75 mg/l BOD stabilized kraft mill effluent (SKME) during this period. The growth rates of the brown trout generally declined during this period as their biomasses increased through time (Fig. 7B), all three streams exhibiting similar relationships, although these were quite variable during winter months. Values for all three streams are well represented by a single production-biomass curve during the period August through October, 1971 (Fig. 7A), this indicating that productivity for brown trout in all streams was about equal and relatively constant. Like the previous winter, production and growth fell sharply, again probably due mainly to low temperatures, the biomasses of food organisms remaining fairly high.

After the removal of the brown trout in January, coho salmon were stocked in the streams on February 7, 1974 for experimental period V. The coho salmon were removed from the streams for measurements at 15-day intervals, because of their rapid growth during this time. Total coho salmon production in Stream 3, a control stream, was much lower than in the two other streams during this period. During period V, the values for total salmon production in Streams 1, 2, and 3 were 13.98, 16.73, and 7.68 g/m^2, respectively. Stream 3 also had lower biomasses of salmon during this time period than did Stream 1 or Stream 2. Low production was a major factor in the much smaller increase of biomass in Stream 3. In addition, the salmon in Stream 3 suffered a higher mortality rate, apparently because of greater predation by kingfishers on fish in this stream. During period V, Stream 1 and Stream 2 maintained nearly equal biomasses, although Stream 2, the stream receiving 0.75 mg/l BOD SKME, had slightly higher production.

Three production-biomass relationships were needed to adequately describe the apparently different levels of productivity of the streams during the four months of period V (Fig. 8A). These changes in productivity resulted in higher salmon growth rates occurring during May, even after biomasses had increased to nearly six times the initial stocking density (Fig. 8B). Without an increase in productivity, growth rates would have decreased as fish biomass increased, because less food would then have been available per gram of fish present.

The production rates and biomasses of coho salmon in control Stream 3 tended to be lower than those of fish in the other two streams, especially during April and May, this indicating productivity of control Stream 3 was lower than that of Streams 1 and 2 during this period. Decline in biomass and production in Stream 3 during the latter part of experimental period V was probably due at least in part to early infection by *Ceratomyxa shasta*, because a few dead fish appeared

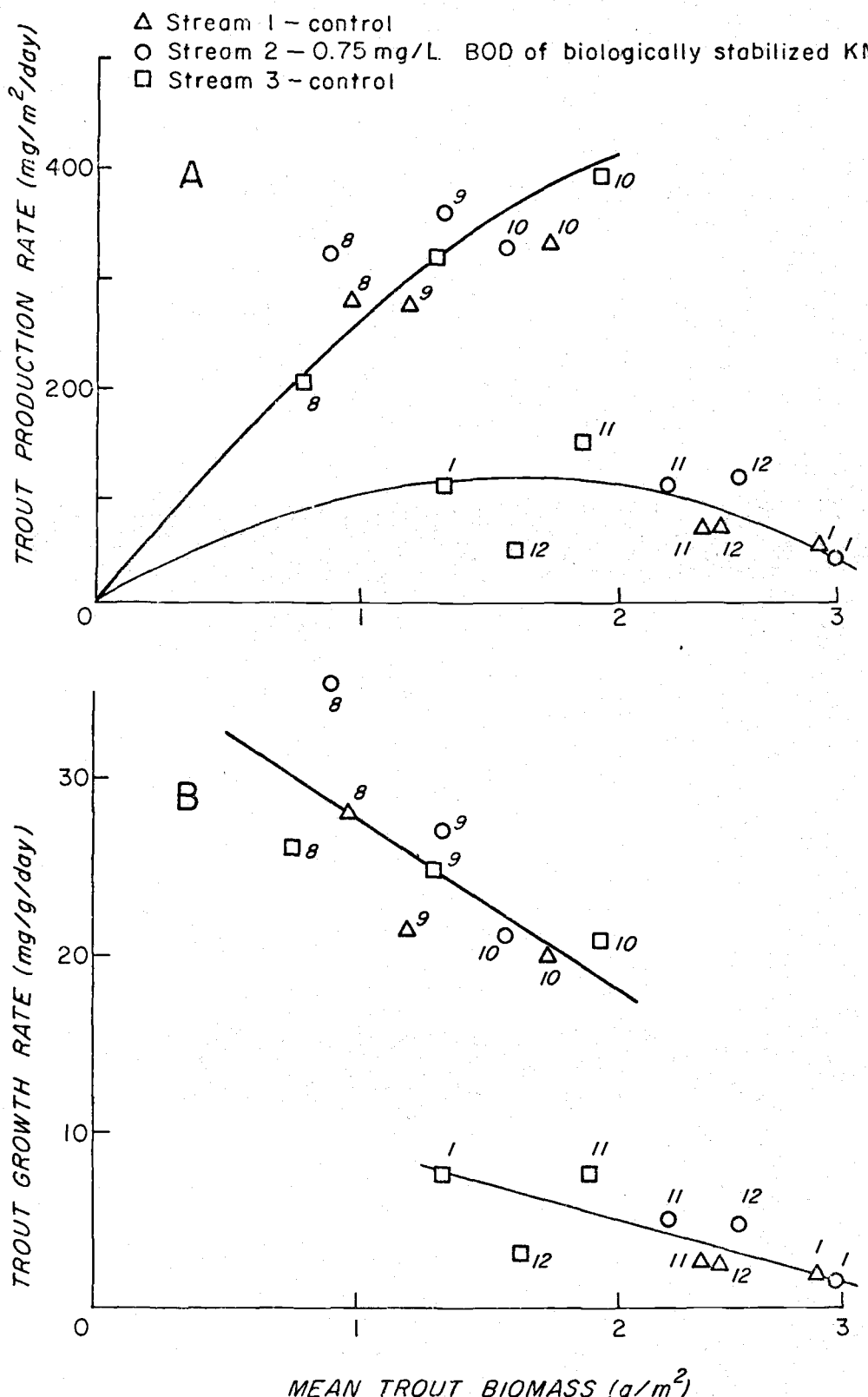

Figure 7. Relationship between brown trout mean biomass and brown trout production (A) and growth rate (B) in the three stream channels during experimental Period IV. Experimental period IV was from August 2, 1971 to January 24, 1972. Numbers indicate the month each point represents (8 = August). Stream 2 received 0.75 mg/l BOD of SKME during experimental period IV.

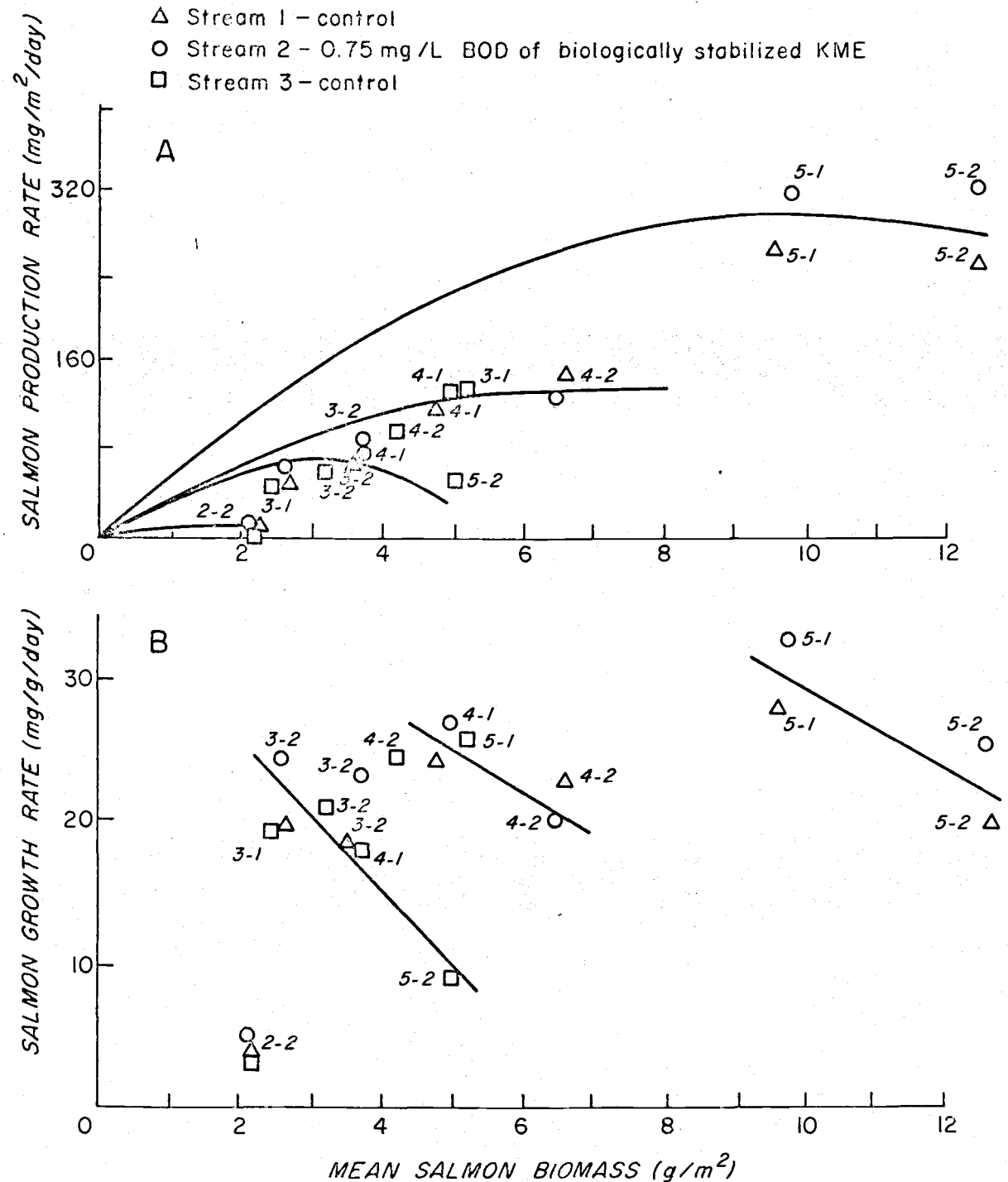

Figure 8. Relationship between coho salmon mean biomass and coho salmon production (A) and growth rate (B) in the three stream channels during experimental period V. Experimental period V was from February 7, 1972 through May 25, 1972. Numbers indicate each one-half month the samples were taken (2-2-February, second half of the month) Stream 2 received 0.75 mg/l BOD of SKME during experimental period V.

in the traps and had disease spores present in the abdomen. According to Johnson (1975), fish with this stage of the disease would usually discontinue feeding 10-20 days earlier. Infection of fish in Streams 1 and 2 appeared to occur later, mortality beginning within the next 15 days. Growth and production in Streams 1 and 2 may have been affected somewhat in the last sampling period.

During experimental period VI, brown trout were stocked in the streams on June 9, 1972 and were removed from the streams on January 30, 1973. Total trout production during period VI in Streams 1, 2, and 3 was 17.82, 16.72, and 11.88 g/m^2, respectively. Thus Stream 3, a control stream, again had the lowest production and fish biomass. All streams had an initial loss of fish owing to an early infection of *Aeromonas liquefacians*, a bacterial disease organism. Stream 3, however, had a heavier infection and greater losses than did Streams 1 and 2.

The growth rate-biomass and production-biomass relationships for brown trout during period VI are probably best represented by four growth-biomass curves and the four production-biomass curves derived from these (Fig. 9A and B), production being the product of growth rate and mean biomass. Each set of curves then represents a level of productivity of the streams for brown trout. Productivity was high during July (Fig. 9, Curve IV) and was somewhat lower during August through October (Curve III). A rapid drop to level II occurred in November. During December and January, productivity was very low (Curve I), largely due to low temperatures and perhaps high turbidity, because food organisms remained relatively abundant. Throughout this entire period, the productivity of Stream 2, in which SKME was present, remained similar to that of the control streams. Control Stream 3 productivity was similar to that of Streams 1 and 2, but lower brown trout biomass, mainly a result of higher mortality rates, led to generally lower production rates in that stream.

Stream 2, which received 0.75 mg/l SKME during experimental periods III, IV, V and VI, had a slightly higher total production than Stream 1, a control stream. Stream 3, also a control stream, had a lower total production than the other streams, mainly because disease and predation caused a lower biomass in that stream, although effects of disease on growth may also have been a factor. This concentration of effluent, then, had no apparent deleterious effect on the production or growth of salmonids in the experimental stream system.

Experiment VII began March 12, 1973, and was terminated April 27 when symptoms of *Ceratomyxa shasta* appeared in Stream 3. Initially, the coho salmon grew very rapidly in all streams, but the growth of fish in Stream 3 decreased markedly by the last sample period.

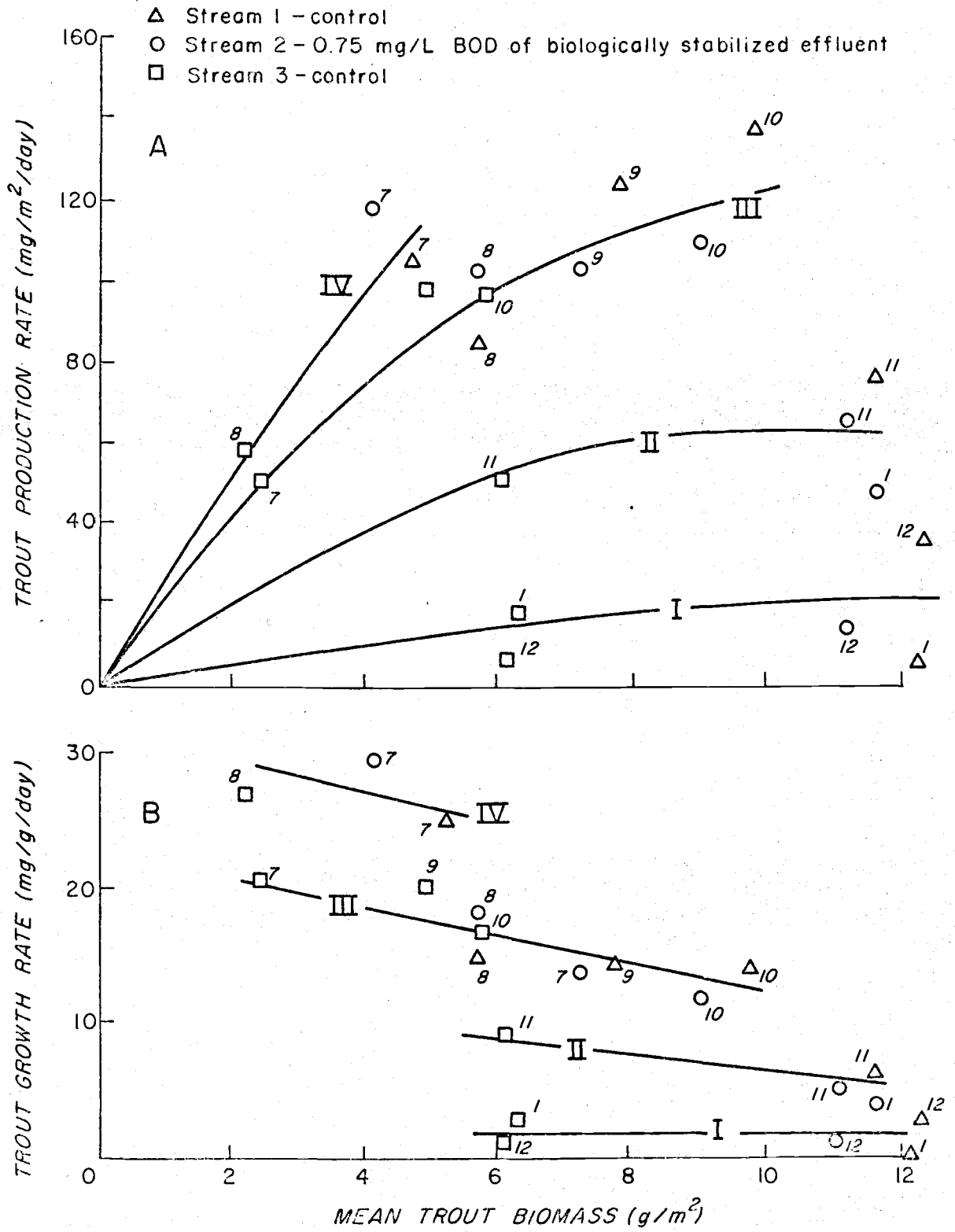

Figure 9. Relationships between brown trout mean biomass and brown trout production (A) and growth rate (B) in the three stream channels during experimental period VI. Experimental period VI was from June 1972 to January 1973. Stream 2 received 0.75 mg/l BOD of SKME during experimental period VI.

Because high mortality occurred in all streams, these data will not be presented.

In the final experiment before the test concentration was increased to 1.5 mg/l BOD, effluent from the 0.5 acre pond providing additional treatment was tested at 0.65 mg/l BOD. This effluent had a BOD generally between 15 and 20 mg/l and was not acutely toxic at a concentration of 100 percent, that is, undiluted. For period VIII, brown trout were stocked on October 25, 1973, and the experiment was terminated on July 19, 1974. Thus this rather long period encompassed a wider range of seasonal effects than did earlier and shorter experimental periods.

The general trend for growth rate and production was an initial rapid decline in fall and winter, a rapid increase in early spring until April or May, which was followed by a gradual decline from May through July. These changes in growth rate and production define changes in levels of productivity, which can be represented as five growth-biomass relationships having negative slopes (Fig. 10B) and five corresponding production-biomass relationships (Fig. 10A). As explained earlier, if productivity is constant, growth rate should decline with increasing biomass of the fish, because of food limitation. And if productivity increases, a higher growth rate-biomass and correspondingly higher and wider production-biomass relationship are generated. The somewhat arbitrarily drawn curves in Figure 10 were drawn, for explanation, on the basis of reasonable visual fitting, consistent with the theoretical considerations presented and previous experience. The lines may better be though of as bands rather than lines. The slope of the best defined relationship (Fig. 10B, line IV) was used in defining the other lines.

From each growth curve, a production-biomass curve was constructed (Fig. 10A). In Figure 10A and B, lines I represent a period of declining growth and low production, probably owing mainly to low temperatures and high turbidity, since food biomass remained relatively high. Lines II and III define the level of productivity for both in the beginnings of the fall-winter decline and the early spring increase. The three streams were not greatly or consistently unlike through these periods. Lines IV represent the highest productivity attained by Stream 1, a level it maintained from late March until the fish were removed on July 19. Productivity of Stream 3 was similar to that of Stream 1, the other control stream, until late May when the productivity of Stream 3 increased to a level intermediate to lines IV and V.

Brown trout in Stream 2, which was receiving 0.65 mg/l BOD of effluent, exhibited higher growth and production relationships than did those in the control streams during the April through July period (Fig. 10 A and B, line V). Productivity, then, or the capacity to produce fish, was probably enhanced at this time by this highly treated effluent. An increase in production of salmon in laboratory streams

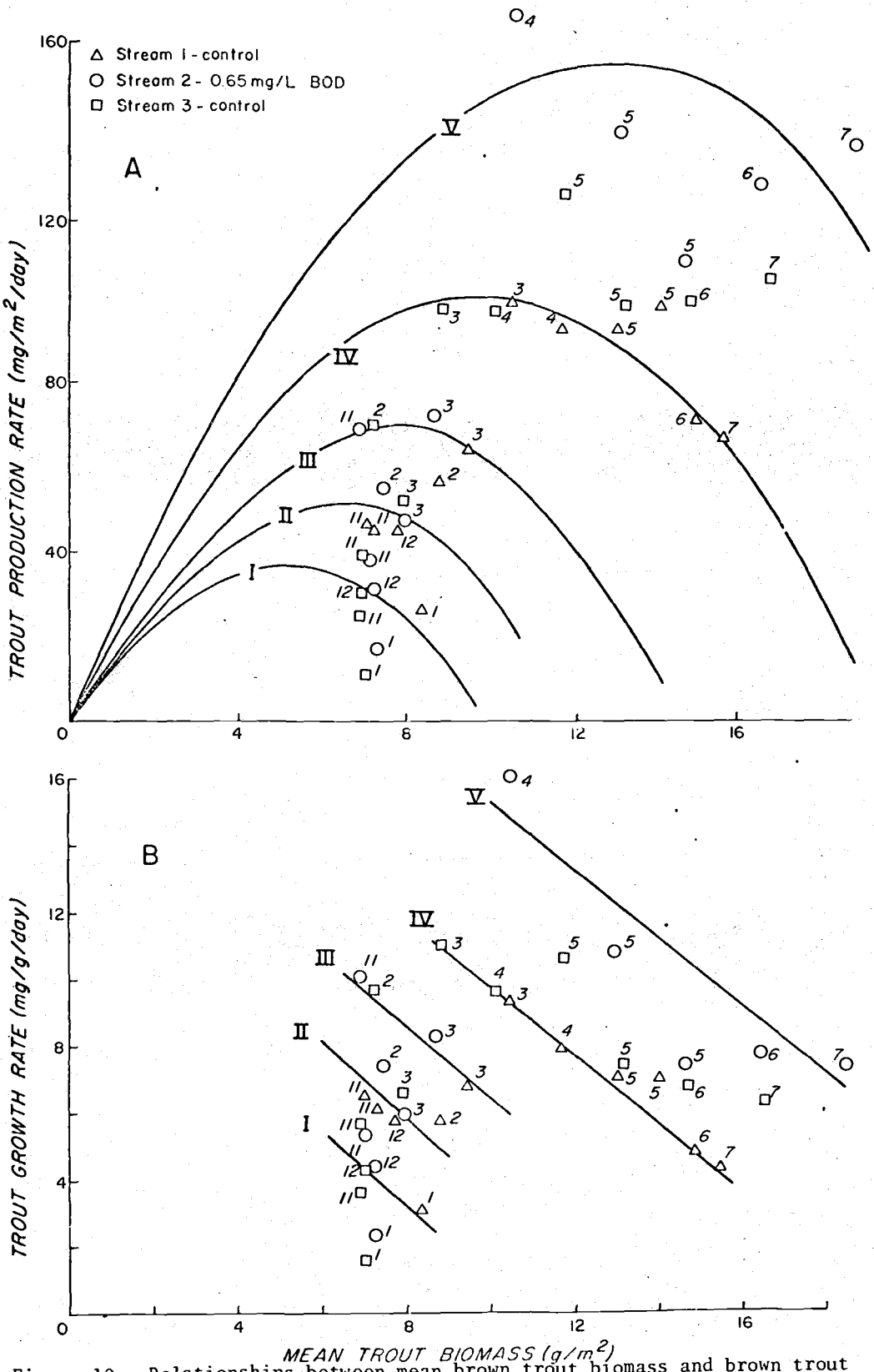

Figure 10. Relationships between mean brown trout biomass and brown trout production (A) and growth rate (B) in the stream channels during experimental period VIII, October 25, 1973, to July 19, 1974. Stream 2 received 0.65 mg/l BOD of SKME during this period.

receiving SKME at about 0.5 mg/l BOD was described by Seim et al. (Ms) for summer experiments.

On October 15, 1974, the concentration in Stream 2 was increased to about 1.5 mg/l BOD. A sufficient number of brown trout were not collected and stocked until April 24, 1975, the beginning of the final experimental period (IX), which was terminated October 21, 1975.

The general trend for trout growth rate and production during period IX was a high value for May followed by a steady decline as biomass increased. The relationships between trout growth rate and biomass (Fig. 11B) and trout production and biomass (Fig. 11A) for this period indicated two general levels of productivity occurred. Except for May values, treatment Stream 2 and control Stream 1 had a productivity for trout defined by lines I, while all values for Stream 3 indicated a higher productivity, defined by lines II (Fig. 11 A and B). The May production value for Stream 2 was lower than those for control Streams 1 and 2. Stream 2 was thereafter similar to control Stream 1 in productivity for trout. No other indication of the influence of 1.5 mg/l BOD of this highly treated effluent occurred, although laboratory growth experiments with this effluent conducted by Robinson-Wilson (Ms) show that often, though not always, 1.5 mg/l BOD would directly influence conversion of food to growth. Whatever direct physiological effects on growth may have occurred, they were not large enough or consistent enough to influence the capacity of the stream to produce salmon. The reason for the greater productivity for salmon in Stream 3 will be examined in the following section on invertebrates.

Organic Matter in the Experimental Stream Channels

Organic matter, mainly living and decomposing plant material, on the riffles of the three experimental stream channels was quite variable through time, but differences between streams were small and exhibited no consistent pattern (Fig. 12). Although there were some qualitative differences in the plant communities present in the treatment and control streams, the evidence strongly supports the conclusion that the presence of kraft mill effluent at different concentrations and treated to various degrees had little or no effect on the total amount of organic matter present in Stream 2 as compared to the control streams.

Most apparent were annual peaks in abundance of organic material present in the stream riffles (Fig. 12). Early in the study, these tended to occur during the winter, but during the last two years of the study they were during late summer and fall, the winter peaks no longer occurring. Peaks as well as mean annual levels tended to decline markedly throughout the duration of the study. Changes in the character of the stream substrates, owing to siltation, and changes in the composition of the biological community appear to have been involved in this.

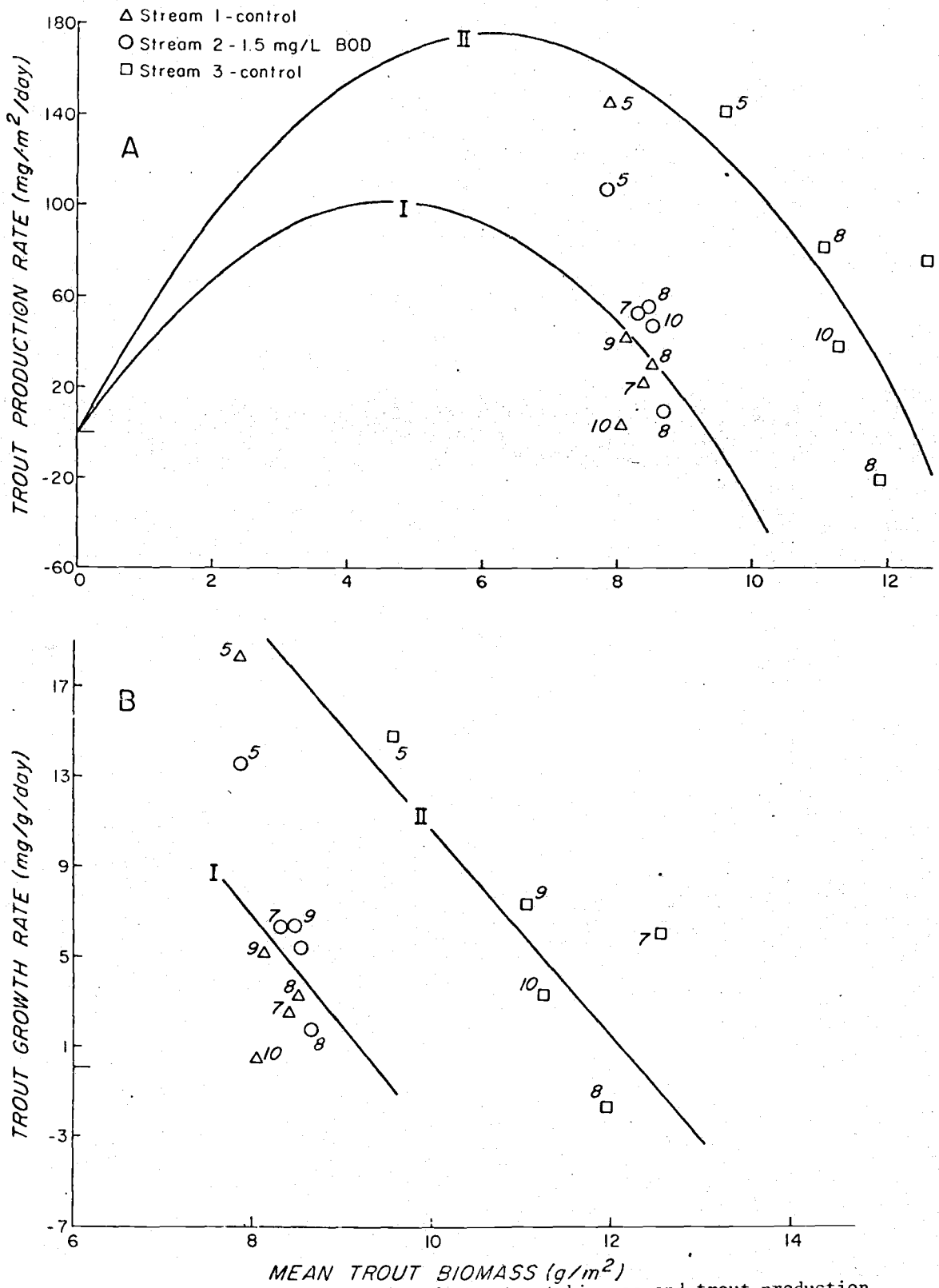

Figure 11. Relationships between mean brown trout biomass and trout production (A) and growth rate (B) during experimental period IX, April 24, 1975 to October 21, 1975. Stream 2 received 1.5 mg/l BOD of SKME.

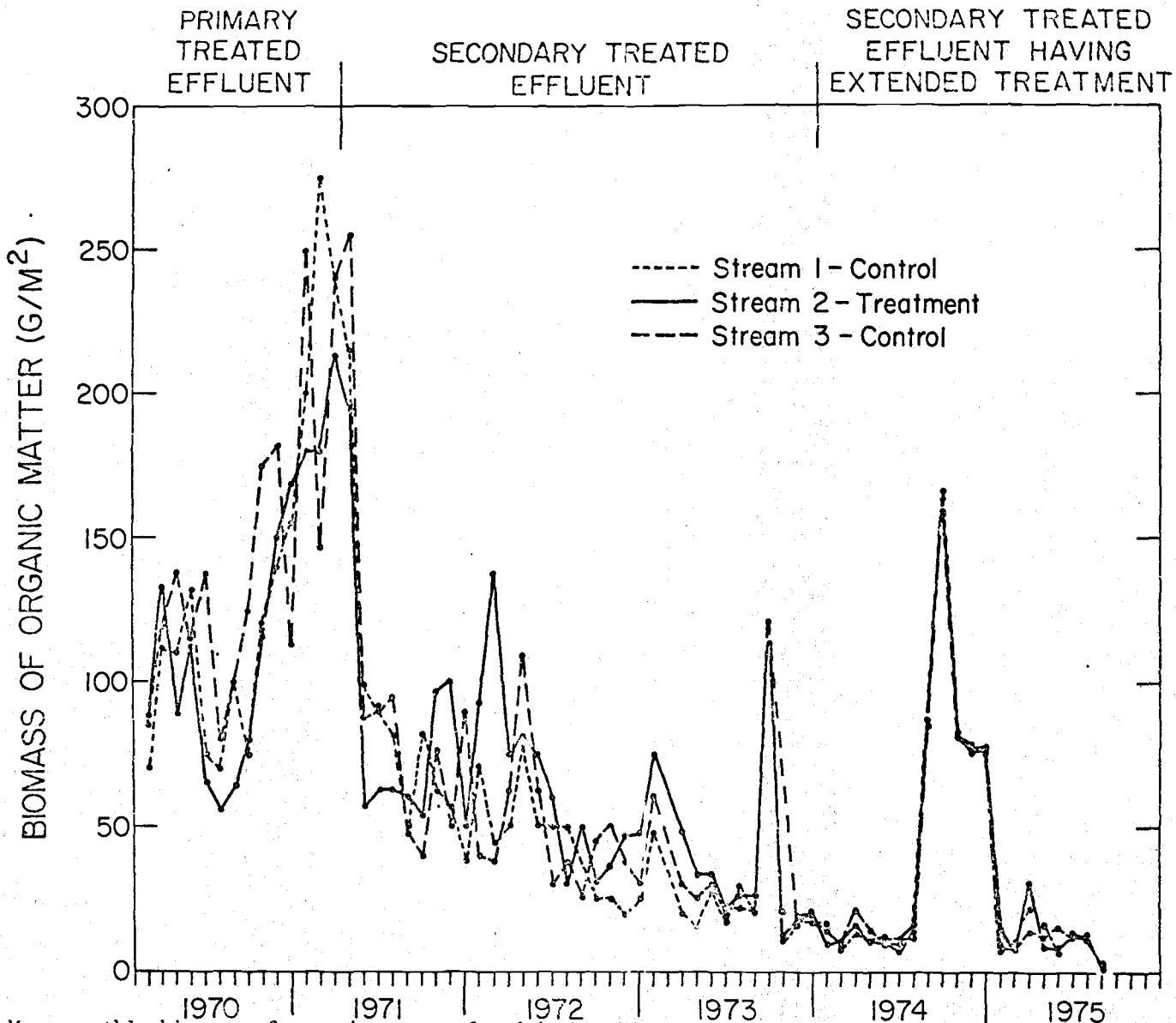

Figure 12. Mean monthly biomass of organic matter found in benthic samples measured by ash-free dry weight. Stream 2 successively received 0.75 mg/l BOD of KME until March, 1971 SKME at 0.75 mg/l BOD until October, 1973; and SKME having extended treatment at 0.65 mg/l until October, 1974 and at 1.5 mg/l BOD until November, 1975.

Invertebrate Organisms

Total Invertebrates. Monthly mean biomasses and numbers of up to 46 invertebrate taxa were estimated from the benthic samples collected twice each month. Changes in biomass of all groups together and of the major groups will be considered for the period February 1970 through July 1975. The total biomass of organisms exhibited large seasonal changes, which sometimes differed in pattern from one year to the next (Fig. 13). The general pattern, however, was one of low values during early spring and very high values during fall and winter. There was a general increase in total invertebrate biomass until the summer of 1973, after which there was an overall decline until the study ended. Numbers of organisms (not shown) exhibited a general decline after 1971.

In general, there were not persistent differences between the streams in their total biomasses of invertebrates. But biomass was lower in Stream 2 than in the control streams from December 1970 to September 1971, and also in the winter and spring of 1971-72. Primary treated effluent and then secondary treated effluent may have been responsible for the lower biomass in Stream 2 during these periods. During several short periods after January 1973, when SKME was present, samples indicated invertebrate biomass to be higher in Stream 2 than in the control streams (Fig. 13).

Hydropsyche. Larvae of the caddisfly *Hydropsyche* build a net between rocks to filter food from flowing water. The biomass of *Hydropsyche* larvae first became abundant in the fall of 1971, after which this group constituted about 50 percent of the biomass of invertebrates in the control streams (Fig. 14). Biomass declined somewhat after January 1973, in all streams. Numbers and biomasses typically increased rapidly in late summer or fall, as a result of reproduction and growth. Numbers were lower in Stream 2 than in the control streams from September 1970 until the beginning of the 1971 life cycle in June. Biomass of *Hydropsyche* was lower in Stream 2 than in the control stream from October 1970 until May 1972, a period during which primary and then secondary treated effluents were present in Stream 2 (Fig. 14). But we believe effects of the primary treated effluent at the experimental concentration of 0.75 mg/l BOD were primarily responsible for the reduced abaundance of *Hydropsyche* in Stream 2, the population being slow to recover numerically from these effects, even after primary effluent was replaced with secondary effluent.

Secondary treated effluent was introduced in Stream 2 in March 1971, after this stream had received primary treated effluent for about one year. Neither biomass nor numbers of *Hydropsyche* appeared to change in Stream 2, as compared to the control streams, immediately after secondary treated effluent was introduced. The life cycle of most of the larvae began in summer and fall, any large increase in numbers could not occur until then (Fig. 14). Failure of the water pump occurred in July 1971, and this allowed some undiluted effluent to enter Stream 2 for a short period. This was probably detrimental to larvae present

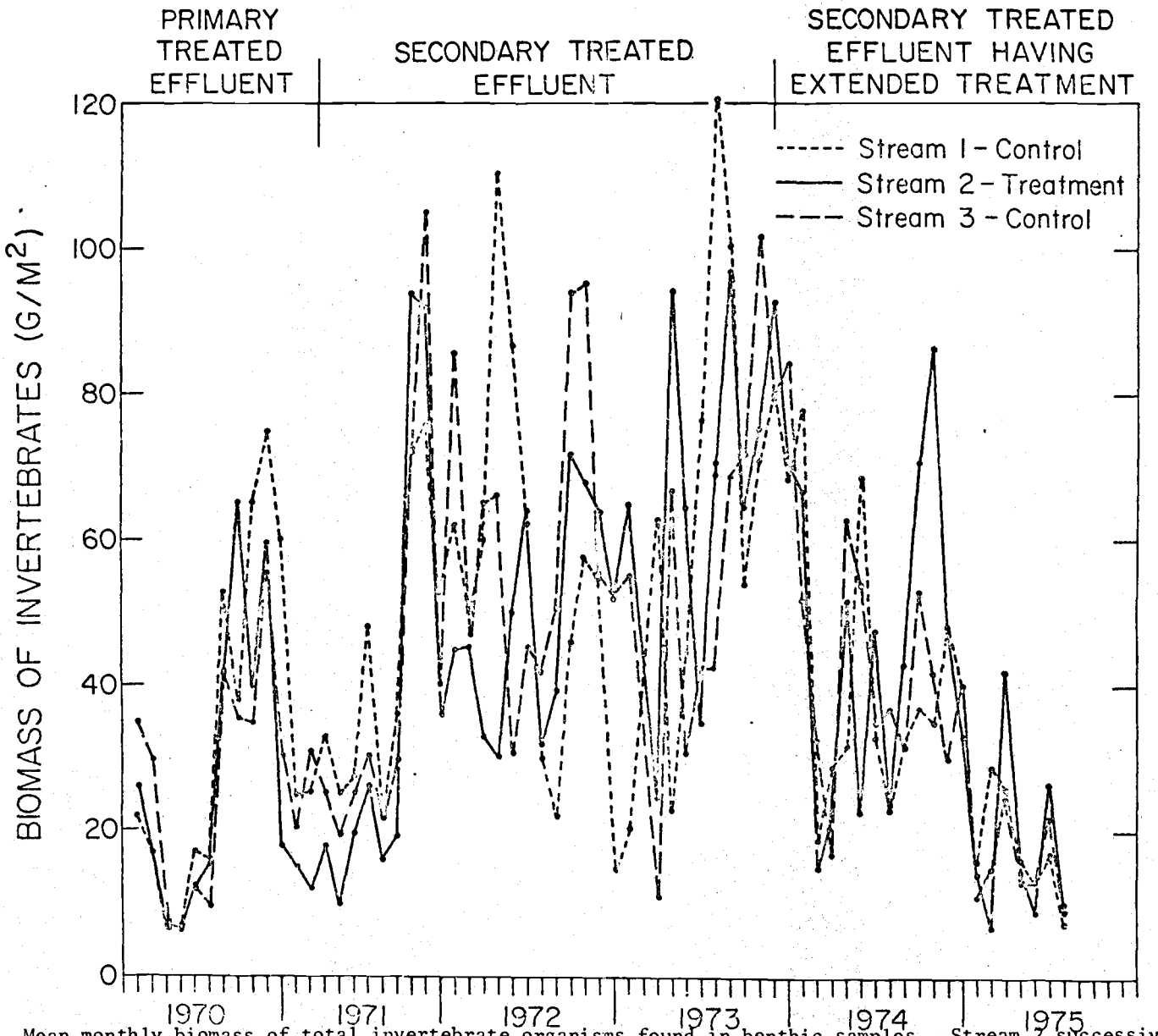

Figure 13. Mean monthly biomass of total invertebrate organisms found in benthic samples. Stream 2 successively received 0.75 mg/1 BOD of KME until March, 1971; SKME at 0.75 mg/1 BOD until October 1973; and SKME having extended treatment at 0.65 mg/1 until October, 1974 and at 1.5 mg/1 BOD until November, 1975.

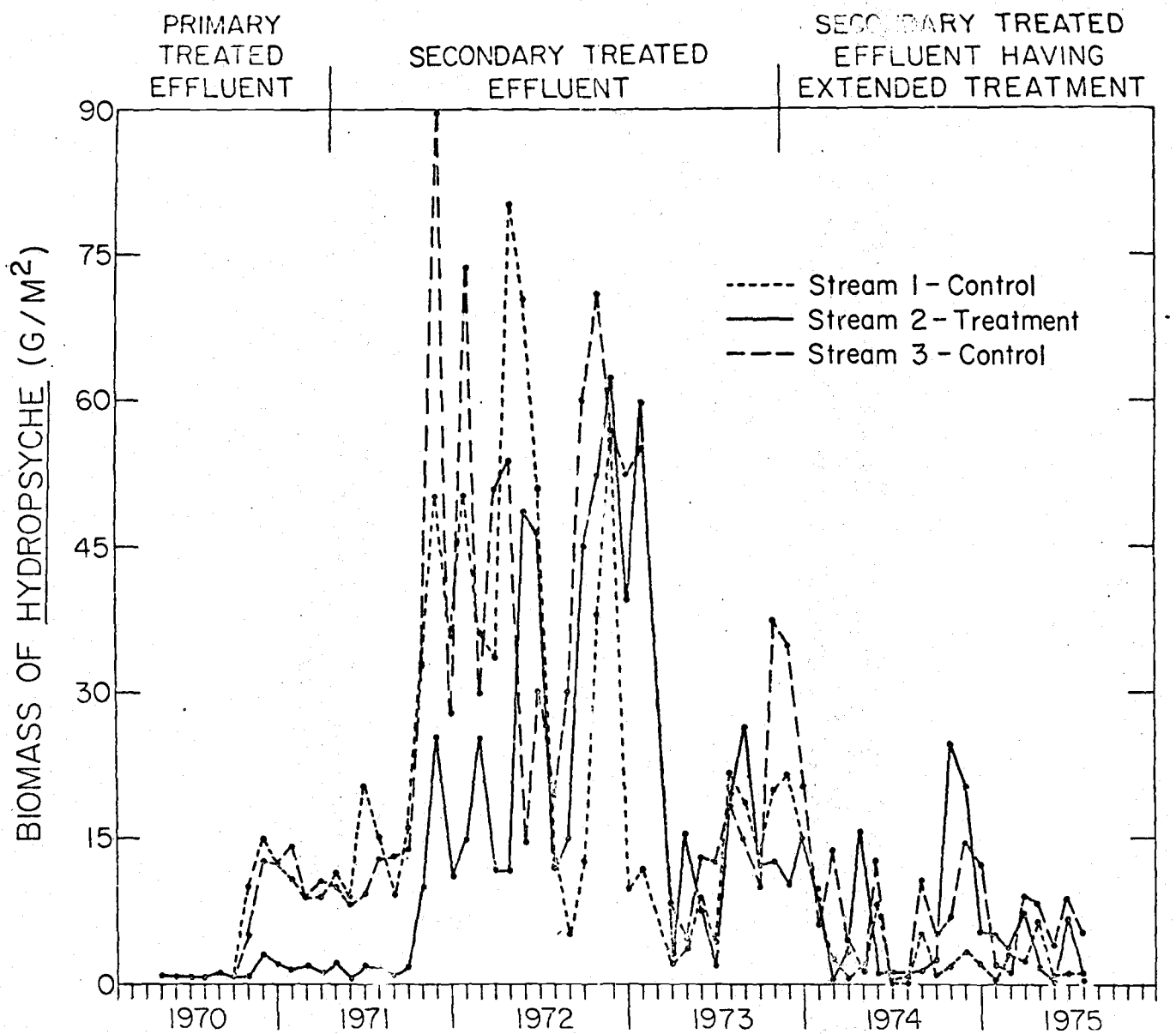

Figure 14. Mean monthly biomass of the trichopteran *Hydropsyche* found in benthic samples. Stream 2 successively received 0.75 mg/1 BOD of KME until March, 1971; SKME at 0.75 mg/1 BOD until October, 1973; and SKME having extended treatment at 0.65 mg/1 until October, 1974, and at 1.5 mg/1 BOD until November, 1975.

in the stream at that time. *Hydropsyche* biomass remained lower in Stream 2 than in the control streams until May 1972 and thereafter appeared to be as great in Stream 2 as in control streams. The eventual recovery of the *Hydropsyche* population in Stream 2 after 1972 suggests, then, that only primary effluent at 0.75 mg/l BOD was detrimental to this insect. SKME at 0.65, 0.75 and 1.5 mg/l BOD was probably not detrimental.

Amphipods. One species of *Crangonyx* comprised almost all the amphipods present in the streams, *Hyallela* occurring in samples only occasionally in low numbers. *Crangonyx* remained abundant in the streams throughout most of the study (Fig. 15). Data on numbers indicate reproduction occurred during summer and fall. Biomass generally increased in summer and fall, peaked in winter, and declined to low levels in early spring. Biomasses of *Crangonyx* in Stream 2 were similar to or lower than those in control streams when KME at 0.75 mg/l BOD was present in Stream 2. Biomasses of *Crangonyx* were generally higher in Stream 2 than in controls when SKME at concentrations as high as 1.5 mg/l BOD were present (Fig. 15). Seim et al. (Ms) found KME and SKME apparently beneficial to reproduction and growth of this species under some conditions in laboratory stream experiments.

Chironomidae. Although many species of midges, the family Chironomidae, were present in the experimental streams, only data on their total abundance will here be presented. The species diversity analysis, to be presented later, was based on further taxonomic breakdown. A general decline in annual mean biomass and in peak abundances of midge larvae occurred in all streams throughout the duration of this study. Peaks in total abundance tended to occur in the spring and, to a lesser extent, in the fall of each year (Fig. 16). Changes in midge biomass through time corresponded only generally to the pattern of changes in number of midges.

Numbers of Chironomidae were lower in Stream 2 than in the control streams during fall and winter 1970-71 when primary treated effluent was present. Such lower numbers were primarily due to fewer *Tanytarsus*, and *Pentaneura* from October 1970 into January 1971. Biomasses of midges, however, were not lower in Stream 2 than in the control streams during this period, fewer but larger midges being present in Stream 2.

Both numbers and biomasses of midges were similar in all streams during the period secondary treated effluent was being introduced into Stream 2 at concentrations up to 1.5 mg/l BOD. *Tanytarsus* was not present in some samples from Stream 2 during 1972 and 1973. Numbers of two Tanypodinae species, in the same subfamily as *Pentaneura*, were at times, more numerous in Stream 2 than in the control streams. The total abundance of midge larvae as a group was, then, apparently little affected by stabilized kraft mill effluent, the abundance of some species perhaps being increased, other decreased.

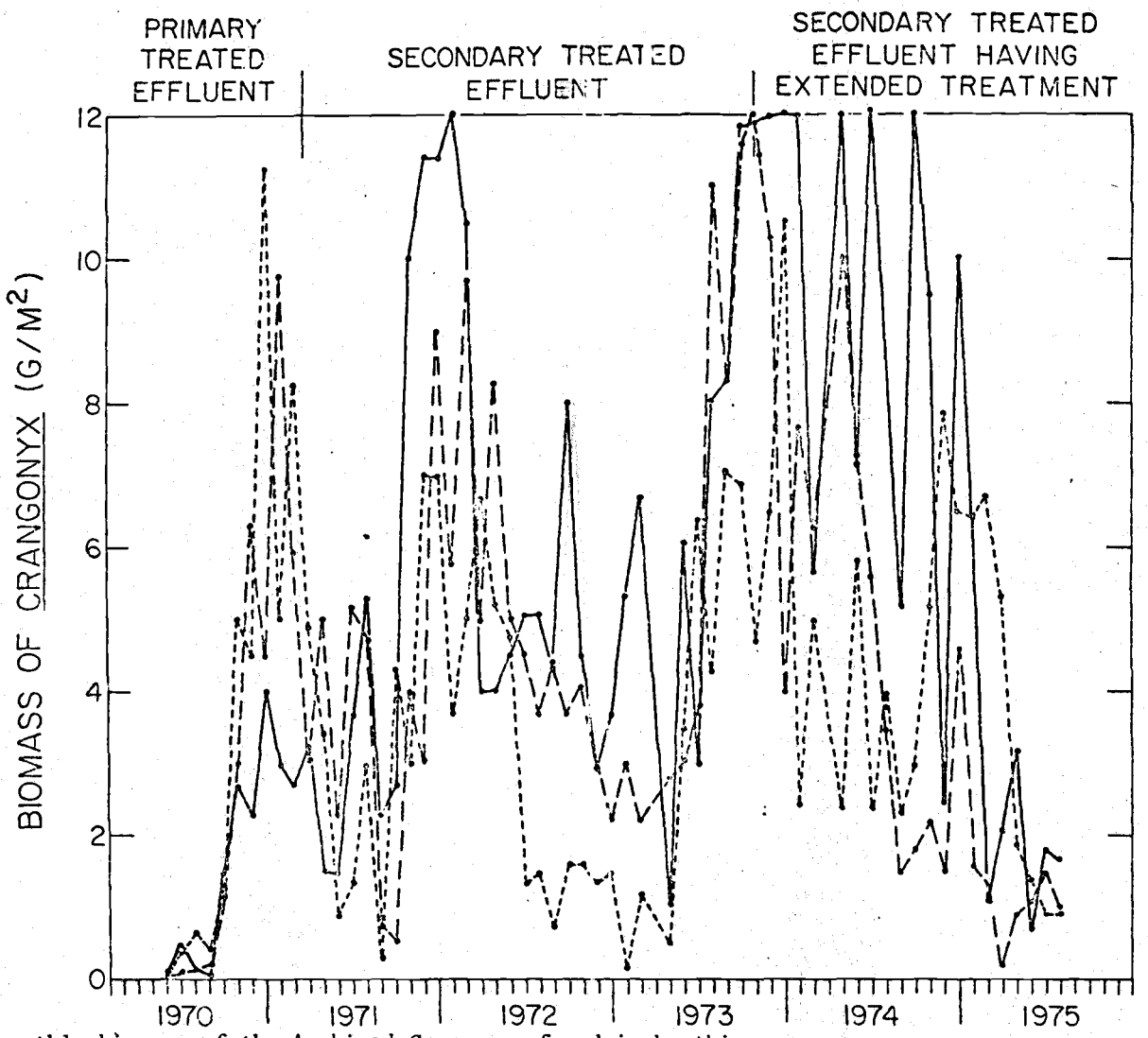

Figure 15. Mean monthly biomass of the Amphipod *Crangonyx* found in benthic samples. Stream 2 successively received 0.75 mg/l BOD of KME until March, 1971; SKME at 0.75 mg/l BOD until October, 1973; and SKME having extended treatment at 0.65 mg/l until October, 1974, and at 1.5 mg/l BOD until November, 1975.

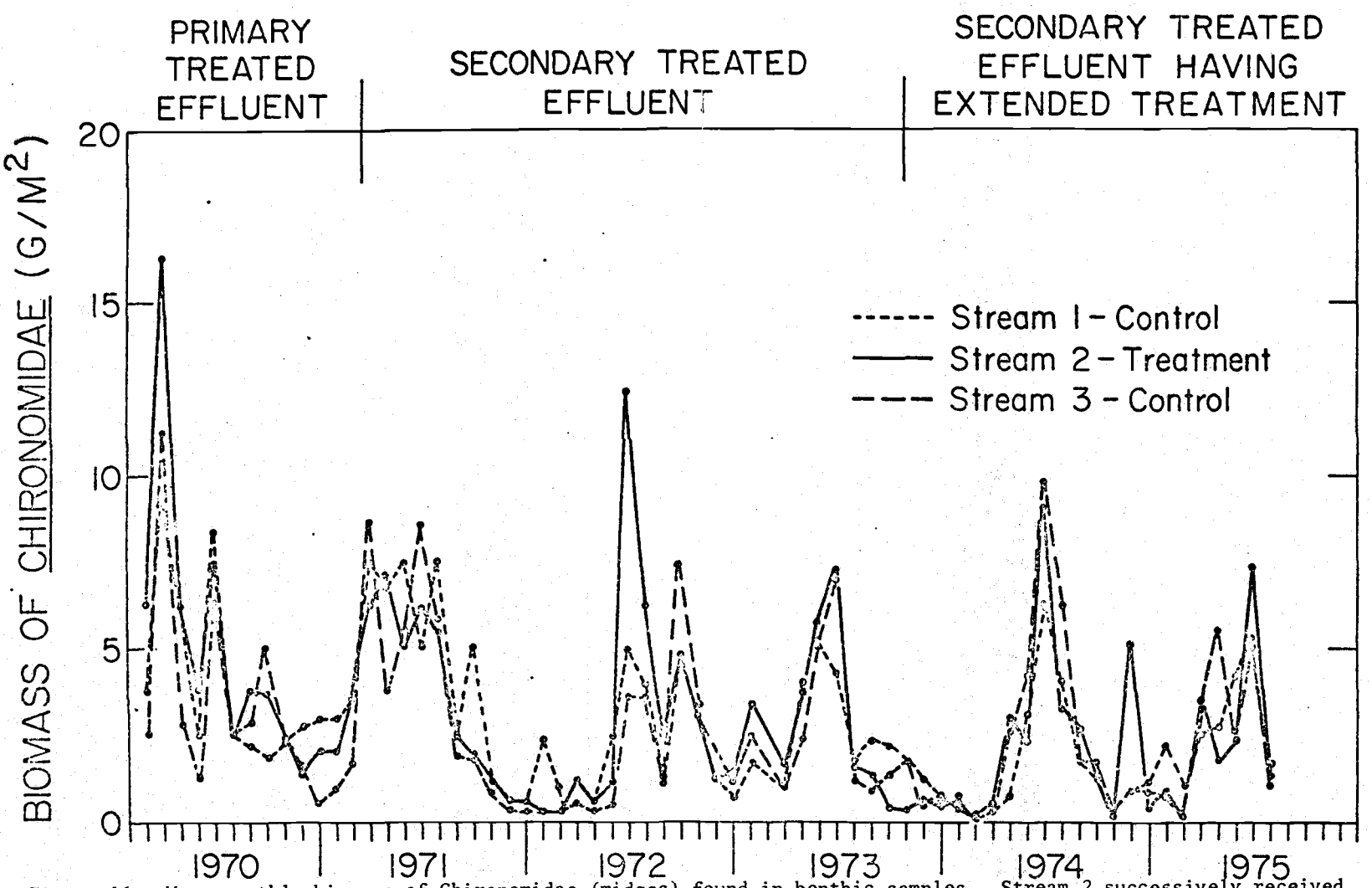

Figure 16. Mean monthly biomass of Chironomidae (midges) found in benthic samples. Stream 2 successively received 0.75 mg/l BOD of KME until March, 1971; SKME at 0.75 mg/l BOD until October, 1973; and SKME having extended treatment at 0.65 mg/l until October, 1974, and at 1.5 mg/l BOD until November, 1975.

Physa. Populations of snails in the genus *Physa* increased markedly in abundance in late summer and early fall of each year and declined to low levels during the winter months, except during 1975, when the decline occurred in late spring (Fig. 17). A complete life cycle took about one year, as indicated by the size of the snails, trends in numbers, and the virtual absence of large adults by September of all years. After the fall peak, both biomass and numbers decreased until winter or spring. A residual population, some of which would mature into adults, was present until summer. Biomasses of *Physa* in Stream 2 were usually similar to or greater than those in the control streams (Fig. 17). During some periods when SKME was present, *Physa* biomasses tended to be higher in Stream 2, although the differences were hardly consistent enough to support a contention that SKME was somehow beneficial to the snails.

Relationships Between Fish and their Food Organisms

The primary food organisms of both cutthroat trout and coho salmon while primary effluent was being tested during experiment I were chironomids (midge larvae), which accounted for well over 40 percent of the organisms found in the stomachs of fish from each stream. Figure 18 shows the relationship between salmonid growth rates and the benthic biomass of midge larvae during this experimental period. When coho salmon and cutthroat trout were in the streams together, the salmon had very high growth rates at densities of midge larvae at which growth rates of the trout approached zero. The growth rates of the salmon in May were even higher than those of the trout during March and April, when salmon were not present in the streams and the densities of midge larvae were higher. These differences in growth rate at given densities of midge larvae are further evidence that the streams had a greater capacity to produce coho salmon than cutthroat trout. Dipterans, including midge larvae, were a major food source for the fish in all the streams from August through October 1970, also while primary effluent was being tested. During this experimental period, a good relationship existed between salmonid growth rate and the benthic biomass of dipterans (not shown). Neither of these relationships indicated any direct effect of KME at 0.75 mg/l BOD on the ability of trout or salmon to utilize food for growth.

Relationships between the growth rates of the fish and the biomasses, or densities, of their food organisms were not always apparent. The density of food organisms was not always a reliable parameter of their availability and utilization by the fish. For example, the percentage of the snail *Physa* sp. found in the stomachs was generally less than or equal to the percentage of midge larvae in the stomachs, even though the benthic biomass of *Physa* was 5 to 20 times that of these larvae during the same time period. Total availability and use of these two groups of food organisms is thus poorly reflected by simple summation of their biomasses, and this would tend to obscure simple relationships.

During experiment 5, when Stream 2 was receiving stabilized kraft mill effluent, *Hydropsyche* was the main food organism for coho salmon in all three streams, but the percentage of this organism found in the stomachs of salmon in Stream 2 was less than that for either control

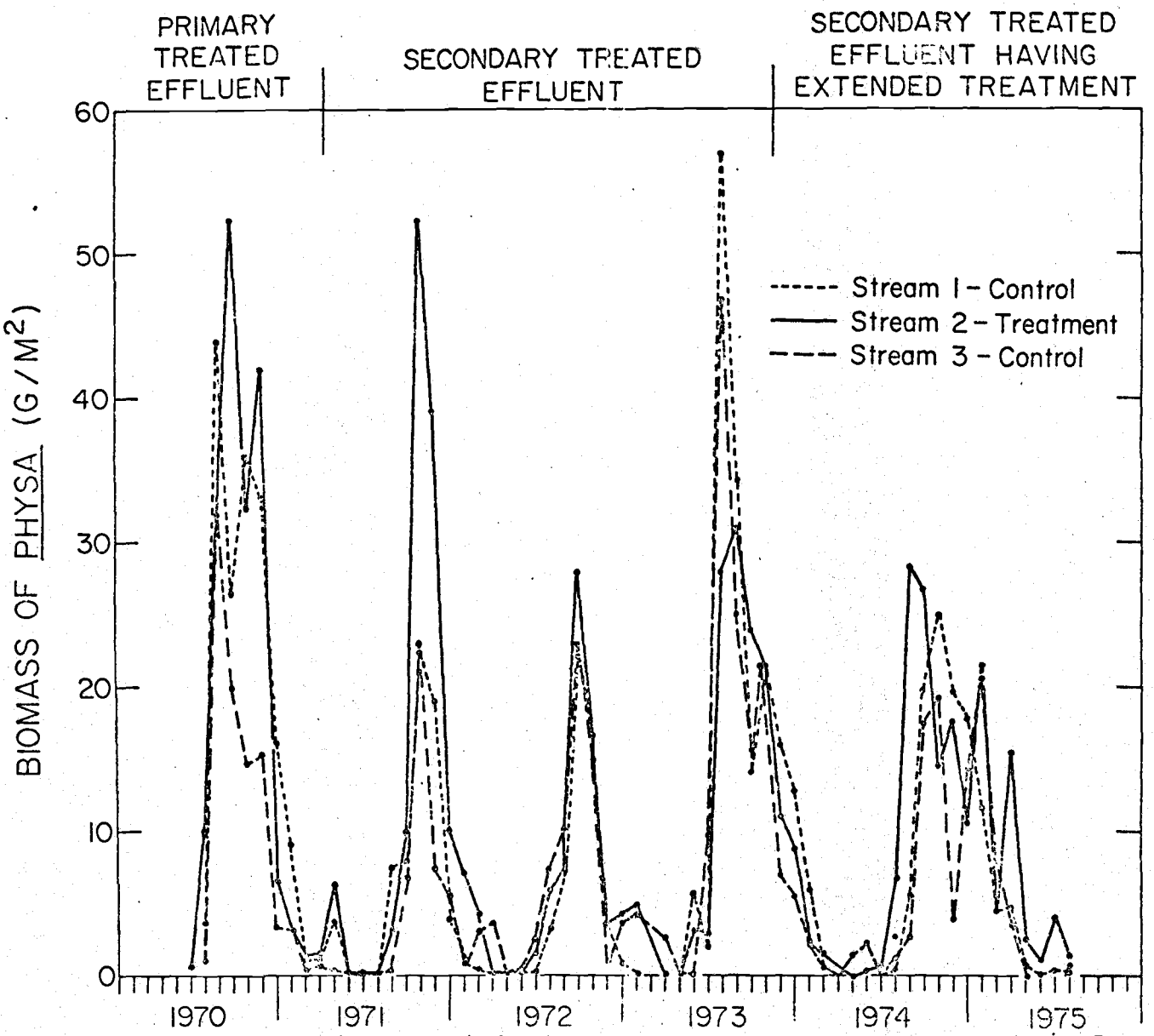

Figure 17. Mean monthly biomass of *Physa* found in benthic samples. Stream 2 successively received 0.75 mg/l BOD of KME until March, 1971; SKME at 0.75 mg/l BOD until October, 1973; and SKME having extended treatment at 0.65 mg/l until October, 1974, and at 1.5 mg/l BOD until November, 1975.

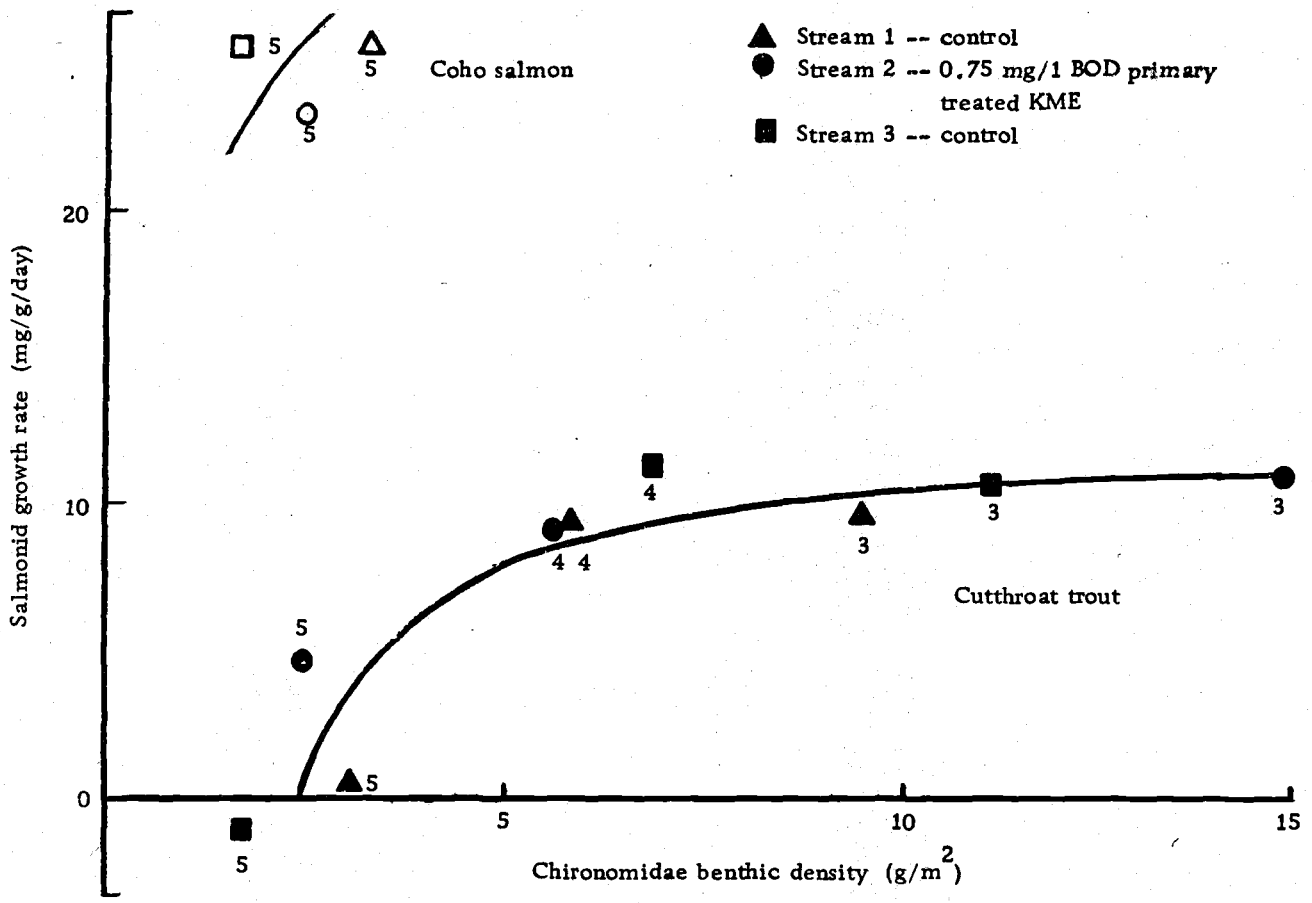

Figure 18. Relationship between salmonid growth rate and the density of chironomids in the benthos for experimental period I. Solid points represent cutthroat trou. /alues, open points represent coho salmon values. Experimental period I was from February 1970 until May 1970. Numbers indicate month of the year (3 = March). Stream 2 received 0.75mg/1 BOD of primary KME during this time.

stream. The growth rate of the coho salmon was related to the benthic biomass of *Hydropsyche* during experiment 5 (Fig. 19). Because insect biomasses were reported as monthly means, the mean monthly growth rates of the coho salmon during March, April, and May are plotted against the biomass of *Hydropsyche* in the benthos for those months.

Fish in Stream 2 had much higher growth rates at given *Hydropsyche* biomasses than did fish in Streams 1 or 3 (Figure 19). This could have been caused by greater availability of this organism at given biomasses to the coho salmon in Stream 2, but it was probably the result of fish in Stream 2 consuming other organisms available to them to a greater extent than did fish in the control streams. Fish in Stream 2 did feed more heavily on annelid worms that did the fish in the other two streams. No measurements of annelid biomasses were available before November 1972, but apparently this and other food organisms contributed to the higher growth rates of the salmon in Stream 2, at given *Hydropsyche* biomasses. Figure 19, representing only growth in relation to one species of food organism, cannot alone establish differences in productivity of the streams for fish, but rather suggests the fish in the different streams were depending on somewhat different food organism combinations.

Brown trout were found to consume a wider variety of organisms than were the other species of fish studied, perhaps because of a greater tendency to feed directly from the stream bottom (Horton, 1961). Appendix IV lists those organisms found in brown trout stomachs when SKME was present in Stream 2 at a concentration of 0.65 mg/1 BOD. The food organisms most utilized by brown trout were *Crangonyx*, midge larvae *Hydropsyche*, *Physa*, and the earthworm, *Lumbricus*. The relative abundances of each of these in the diets of the fish, on the basis of stomach content analyses, differed between streams and through time. Because of its large size, *Lumbricus* tended to make up the largest proportion of the stomach contents, by weight, although *Crangonyx* was more regularly present in the stomach contents. Midge larvae were the major food organism in late spring 1974, a period of seasonal emergence.

Stream 2 fish apparently consumed slightly more *Crangonyx* than control fish during several periods in 1974, this perhaps being related to the higher biomasses of *Crangonyx* in Stream 2 during this time (Fig. 15). The greater growth rate of fish in Stream 2 as compared to fish in the control streams during April and May 1974 may have resulted from these higher biomasses of *Crangonyx*. During the period October 1973 through July 1974, when a concentration of 0.65 mg/1 BOD SKME was present in Stream 2, relationships between the growth of fish and the total biomasses of organisms comprising the largest percent of the stomach contents were better than those between the growth of fish and the biomasses of particular species of organisms, apparently because no single organism was consistently most abundant in the diets of fish. The five major food organisms at this time were *Lumbricus*, *Crangonyx*, *Physa*, midge larvae, and *Hydropsyche*.

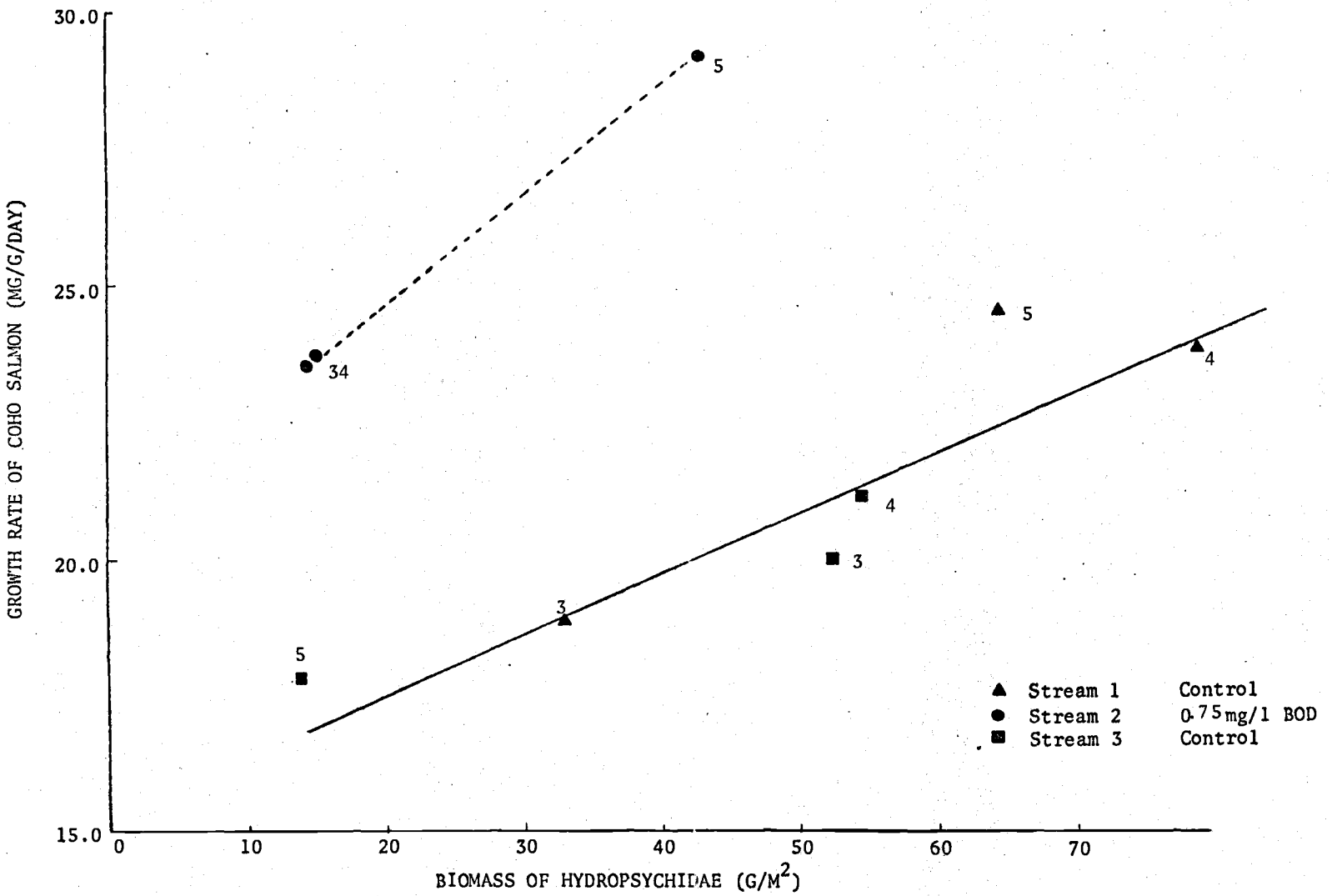

Figure 19. Relationship between growth rate of juvenile coho salmon and biomass of Hydropsyche (caddisfly) for streams receiving 0.75 mg/l stabilized kraft mill effluent in experimental stream channels during spring, 1972. Data of Dennis Borton.

Throughout the long period SKME was being tested, the productivity of the streams changed seasonally as shown earlier for the relationship between fish production and mean fish biomass (Fig. 10). Changes in the relationship between trout growth and the total biomass of their food organisms may be involved in changes in productivity. In Figure 20, great variation in the coordinate values of growth rate and food organism biomass is apparent. Three growth response functions, perhaps roughly indicative of influences of changing productivity, can be written onto these data. Line I indicates the lowest level of productivity, during November, December and January. Low temperature, which reduces fish activity and food consumption, was probably the major factor contributing to low productivity at this time, because the food level was high. Higher growth rates occurred at similar food densities during spring and summer, as shown by lines II and III. The highest growth values occurred in March and April (Fig. 20). Although fish in Stream 2 grew at the fastest rates in April, the growth relationship, as it is involved in determining productivity, does not alone show productivity of Stream 2 to be much if at all greater than that of the other streams. This does not, however, preclude the possibility of an indirect effect of SKME through food biomass and availability during these periods. Indeed, the greater biomasses of food organisms in Stream 2 than in the control streams during June and July 1974, and the resulting greater growth, biomasses, and production, may well reflect an indirect effect of 0.65 mg/l BOD SKME on fish production through increased biomass and availability of food organisms.

Biomasses of food organisms were plotted against biomasses of fish (Fig. 21) for this same period, in order to examine theoretical levels of productivity of the stream systems. These levels (A, B, C, and D in Figure 21) may be thought of as "prey isoclines," even though they have not been mathematically defined as such (Booty and Warren, Ms). Line D represents the highest level of productivity, line A the lowest. Lines E, F, G and H can be parameterized and thus identified by trout mortality, H representing the lowest rate of fish loss and E representing the highest rate of fish loss.

The low productivity levels, represented by lines A and B, were usually during winter and early spring periods for all streams. Lines C and D include a few November and December coordinate values, but mainly represent late spring and summer values (Fig. 21). Along line D, Stream 2 appears to exhibit higher productivity than do the control streams during early May, June, and July. December and April values are also higher for Stream 2 (Fig. 21, lines C and D).

Assuming lines E-F are parameterized and thus identified by mortality rates of fish, line E may have resulted from the relatively high mortality which occurred in all streams just after fish stocking occurred for this period. Such a high initial mortality rate occurred in all instances of brown trout stocking. Later mortality, however, appears to have been mainly a result of kingfisher depredation and perhaps losses owing to disease. As productivity increased, Stream 1 appeared to follow line H, this indicating the highest rate of mortality. Stream 2

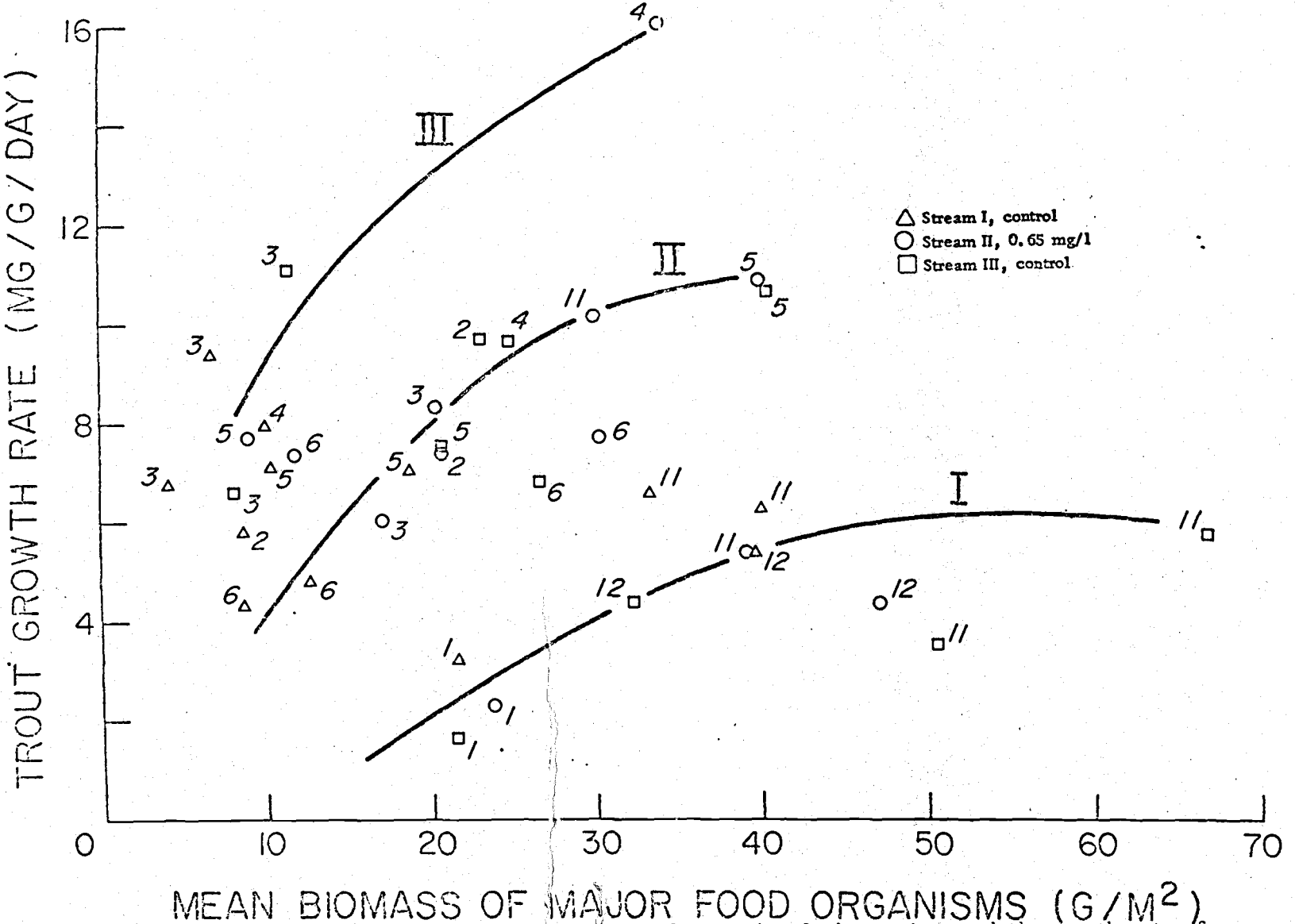

Figure 20. The relationship between the benthic biomass of the major food organisms and the growth rate of brown trout during experimental period VIII, testing SKME having extended treatment at 0.65 mg/l BOD. The numbers indicate the month each point represents.

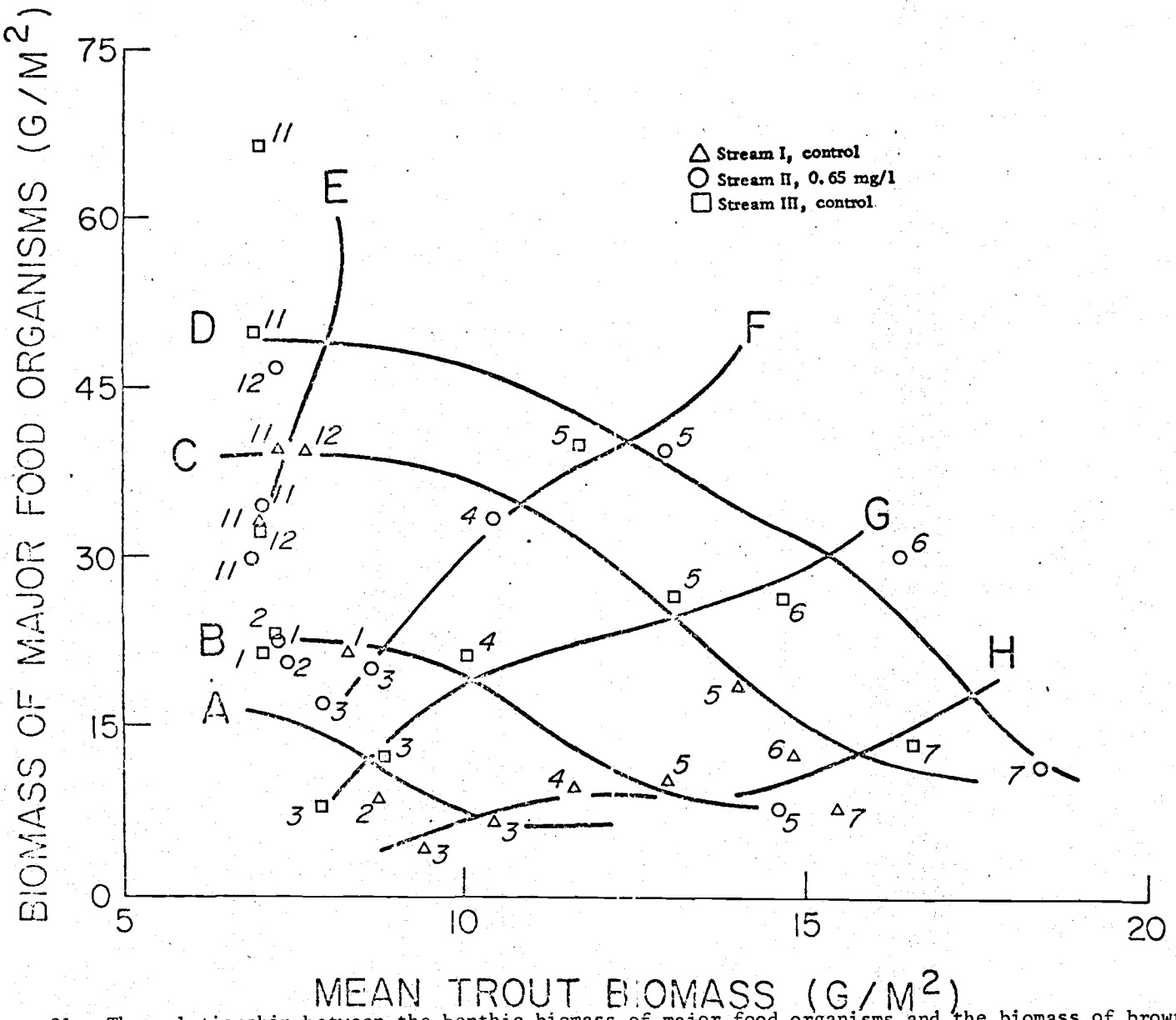

Figure 21. The relationship between the benthic biomass of major food organisms and the biomass of brown trout during period VIII, testing SKME having extended treatment at 0.65 mg/1 BOD. The numbers indicate the month each point represents.

followed line F until late May, and Stream 3 generally followed line G (Fig. 21). Mortality estimates suggest only slightly higher rates of loss for Stream 1, intermediate rates of loss for Stream 3, and highest rates of loss for Stream 2.

Diversity of Macroinvertebrates

Species diversity indices, determined separately on the basis of numbers and on the basis of biomasses of the different invertebrate taxa, were calculated for all three streams from February 1970 through December 1972. Between January 1973 and July 1975, diversity indices were determined for Streams 1 and 2 only, in order to reduce the effort required by the greater degree of taxonomic identification necessary for diversity determination. A species diversity index, derived from information theory (Shannon and Weaver, 1949) and discussed relative to biological use by Pielou (1966), was used to summarize the structure of the invertebrate assemblages:

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

where:

$\bar{d}$ = species diversity

n_i = number of biomass of organisms in the i^{th} taxon

N = total number or biomass of organisms in the sample.

According to this equation, species diversity is equated with the uncertainty of selecting, at random, an individual of a particular taxon. Maximum diversity exists in a sample if each individual belongs to a different taxon and minimum diversity exists if all individuals belong to a single taxon. Thus, the number of individuals in a given taxon as well as the number of taxa determine species diversity as defined by this formula. The greater the unevenness in distribution of numbers, or biomasses, among the taxa in a sample, if the number of taxa remains constant, the lower the diversity.

Not all taxa that we employed in calculating species diversity were species. Some taxa were not identifiable beyond genus, but several species appeared to be present as judged by external characteristics. These were numbered as separate taxa. In the family Chironomidae (midges) there was, at times, a large group in the subfamily Orthocladiinae that appeared to be a mixture of several species but that could not be satisfactorily separated. This group was not included in the diversity analysis.

Species diversities shown in Figures 22 and 23 were calculated for both numbers and biomass data, from the composite samples collected during the study. When primary treated effluent was being tested, species diversity increased and peaked in the winter or spring of 1971, mainly because of colonization by additional species. Species diversity, especially on the basis of numbers, then decreased until fall as a result of increased redundancy resulting from hatching of *Physa* and *Hydropsyche*. Continued decrease in species diversity from

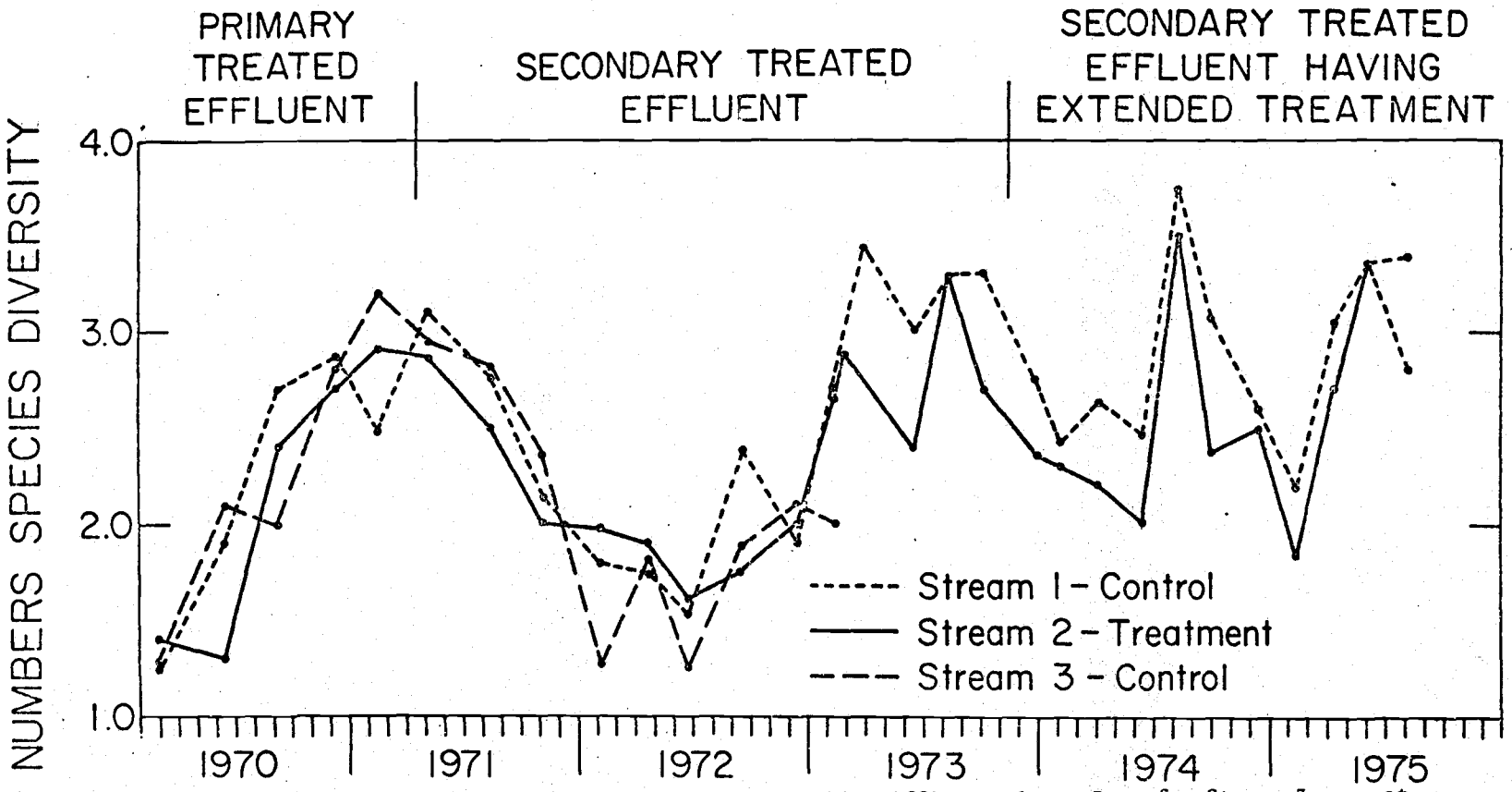

Figure 22. Numbers species diversity of invertebrates from benthic riffle samples. Data for Stream 3 was not calculated after January 16, 1973. Stream 2 successively received 0.75 mg/l BOD of KME until March, 1971; SKME at 0.75 mg/l BOD until October, 1973; and SKME having extended treatment at 0.65 mg/l until October, 1974, and at 1.5 mg/l BOD until November, 1975.

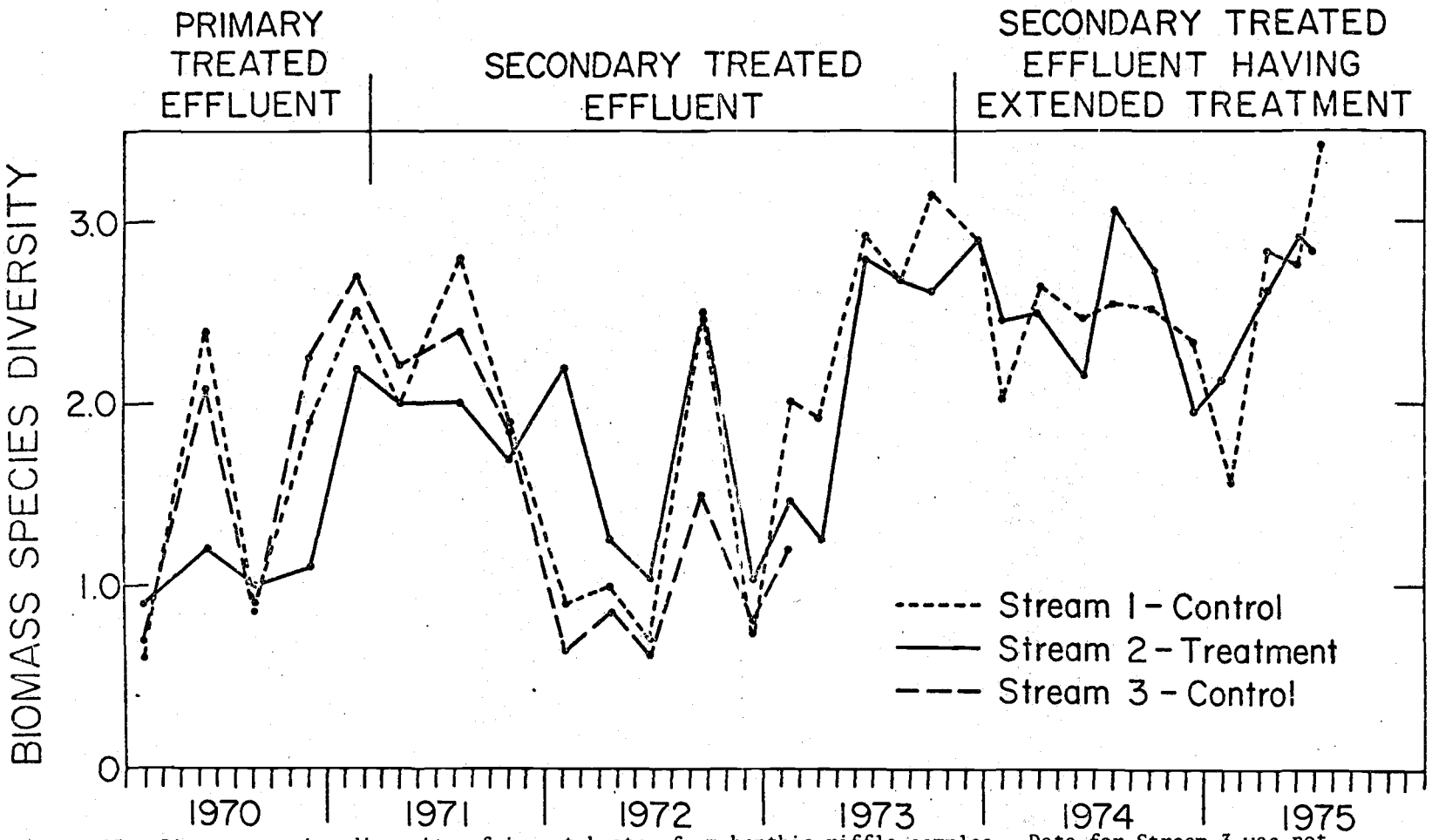

Figure 23. Biomass species diversity of invertebrates from benthic riffle samples. Data for Stream 3 was not calculated after January 16, 1973. Stream 2 successively received 0.75 mg/1 BOD of KME until March, 1971; SKME at 0.75 mg/1 BOD until October, 1973; and SKME having extended treatment at 0.65 mg/1 until October, 1974, and at 1.5 mg/1 BOD until November, 1975.

fall 1971, until summer 1972, was due to a decrease in total number of species, especially from decreases in the number of midge taxa. The increase in species diversity in late summer 1972, was due to the appearance of several taxa of midges (Fig. 22). The increase in diversities during the spring of 1973 resulted mainly from an increase in the numbers of various taxa rather than from any increase in evenness.

All streams had similar patterns of change in diversity throughout the period when primary treated effluent was present in Stream 2 (Figs. 22 and 23). Numbers and biomass species diversities on May 16, 1970, were lower in Stream 2 than in the control streams and coincided with lower numbers of taxa present in Stream 2. At this time, there were six taxa of mayflies in the control streams. These same taxa were not in both controls, some being in Stream 1 while others were in Stream 3, but all six taxa were absent from Stream 2 on this date.

During 1970-71, the lower biomass of *Hydropsyche* in Stream 2 as compared to the control streams resulted in a shift in evenness of biomass in Stream 2, so that *Physa* contributed a much greater percentage of the total biomass, thus reducing species diversity in this stream (Fig. 23). Because the life cycle of the majority of individuals in both taxa starts in late summer and ends during the following summer, this trend continued into 1971 when secondary treated effluent was added. *Crangonyx* also was lower in Stream 2 than in the control streams during fall and winter of 1970-71 (Fig. 15), which contributed to higher redundancy and lower diversity in Stream 2, because *Physa* then constituted proportionally more of the total biomass present in that stream.

Both numbers and biomass species diversity were lower, generally, in Stream 2 than in control streams when secondary treated effluent was first introduced during 1971 (Fig. 22 and 23). By 1972, however, diversity in Stream 2 had apparently recovered to levels similar to those in the control streams. Numbers diversity was lower in Stream 2 than in control Stream 1 again in the fall and winter of 1973-74, apparently because of increased numbers of midge taxa in Stream 1. After the spring of 1974, numbers diversity was again similar in these two streams, even after October 1974 when Stream 2 was receiving 1.5 mg/l BOD of SKME. Biomass species diversity in Stream 2 was somewhat lower than that in control Stream 1 in fall 1974, apparently because of greater unevenness resulting from increased *Crangonyx* biomass in Stream 2. Biomass diversity in Stream 2 was similar to that in control Stream 1 during 1975, when 1.5 mg/l BOD SKME was being maintained in Stream 2.

In general, diversity was similar among the three streams, although KME in Stream 2 probably reduced diversity somewhat, by reducing the biomass of *Hydropsyche*. SKME at 0.65 mg/l BOD may have reduced biomass diversity in Stream 2 by increasing amphipod biomass. Both of these differences were owing to changes in evenness of distribution of total biomass among the taxonomic groups present.

Salmonid Reproduction

Results of the steelhead development experiment indicate no appreciable differences in time until hatching, weight of yolk, nor weight of alevins at hatching that could be attributed to the 0.65 mg/l BOD (4.1 percent) SKME present in Stream 2 (Table 2). Mean survival of embryos until hatching was somewhat lower in Stream 2 (82 percent) than in the control streams (88 percent). This difference resulted from low survival (57 percent) in only one of the five incubation boxes in Stream 2. Disregarding this box, the mean value for the other four boxes was 87 percent, similar to controls at 88 percent. Servizi, Stone, and Gordon (1966) found no effect of 5 percent neutralized bleach waste (NBW) on the survival and hatching of pink and sockeye salmon embryos.

Table 2. Survival and development of steelhead embryos and alevins during a period in which 0.65 mg/l BOD SKME was present in Stream 2.

	Stream		
	1	2	3
Embryos			
Days until hatching	45	45	45
Percent survival to hatching	88	82	88
Size at hatching (mg)	5.5	5.4	4.8
Weight of yolk at hatching (mg)	62.9	60.7	62.2
Alevins			
Days to emergence	25	25	25
Percent survival to emergence	96	96	95
Size at emergence (mg)	54.2	53.6	54.0

Time until emergence, survival to emergence, and size of alevins at emergence were similar for all streams (Table 2). Figure 24 shows for each stream the increase in mean dry weights of alevins (separated from yolk) and the decrease in mean dry weights of yolk through time from hatching until emergence. No differences between dry weights of yolk and alevins in Stream 2 and dry weights of these in the control streams were apparent. Servizi, Stone, and Gordon (1966) did observe slower development and delayed emergence of pink salmon alevins and lower mean dry weights of sockeye salmon alevins at complete yolk adsorption at 1 percent NBW.

A level of 0.65 mg/l BOD SKME did not measurably affect either embryos or alevins under the experimental conditions employed in this study. The experimental conditions, however, were designed to overcome some of the expected problems. Perhaps the most important effect of SKME on developing embryos and alevins would be from oxygen depletion owing to biological growth restricting water flow. Filamentous growth of the bacterium *Sphaerotilus natans* can occur in streams receiving relatively high concentrations of SKME, such growth blocking the interstices of the gravel and reducing flow of water and oxygen critical

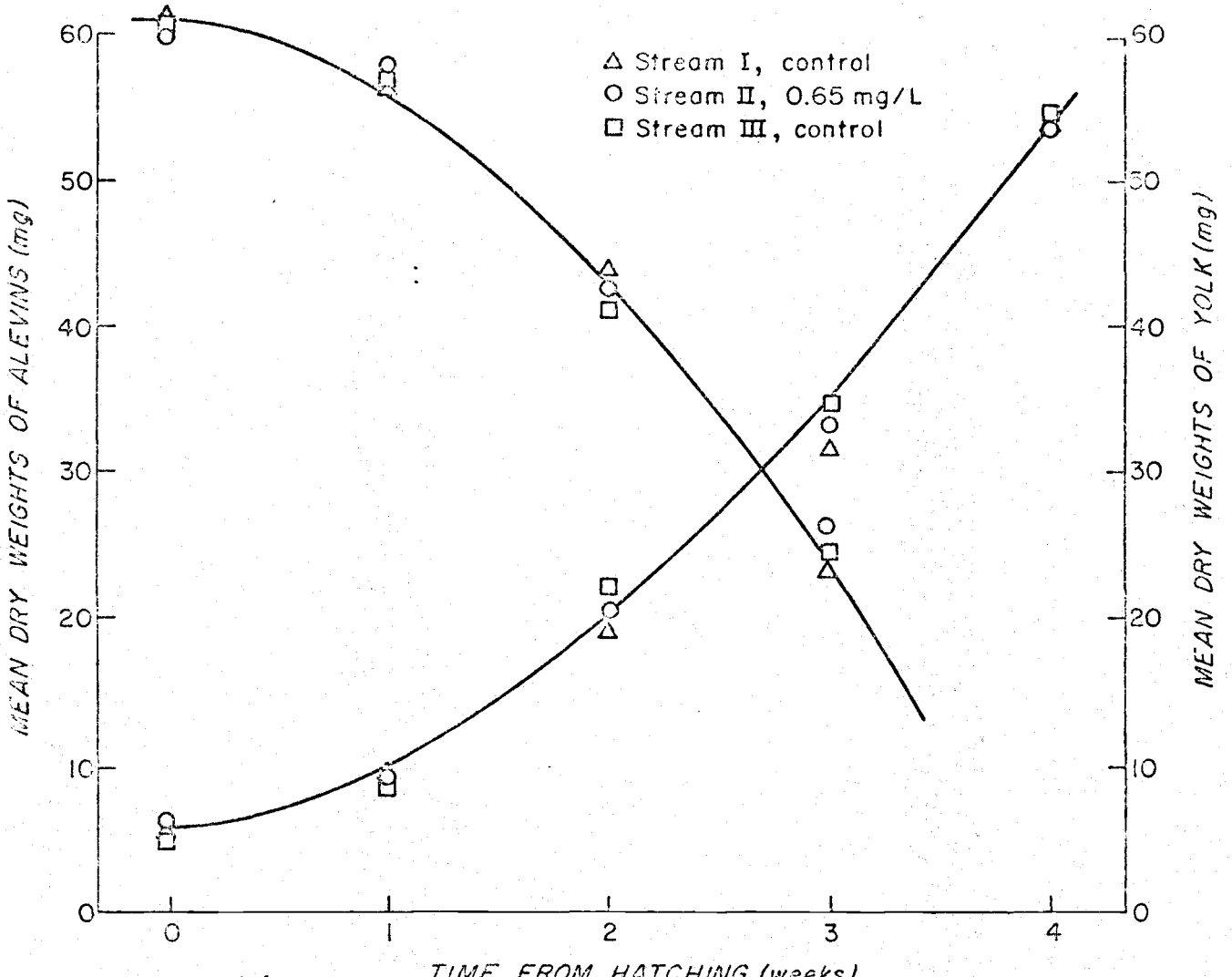

Figure 24. The mean dry weight of steelhead alevins minus yolk (solid symbols) and of yolk only (open symbols) during the four weeks following hatching of embryos buried in incubation boxes. Stream 2 received 0.65 mg/l BOD of SKME having extended treatment during this period.

for developing embryos and alevins. In this experiment, however, the spawning channels were designed to provide a maximum flow (15 cm/sec) over the gravel by positioning of the cement blocks and incubation baskets, which were covered with only 2 cm of gravel, much less than would occur in natural redds. No growth of *Sphaerotilus* was observed in egg baskets or gravel, although slight growth occurred on wooden stakes used to mark egg basket location in streams. *Sphaerotilus* growth did occur during experiment 1 in Stream 2, when this stream was receiving about the same BOD of primary treated effluent. Four of the five baskets in each stream were checked periodically and the dead eggs and fungus removed. The fifth basket was not disturbed until hatching was observed in the other four baskets, and weights and survivals of embryos were generally similar in all five baskets in each stream.

Thus, there was no direct effect of 0.65 mg/l BOD (4.1 percent) SKME on developing embryos and alevins. Any other possible adverse effects of SKME on embryos and alevins could not be adequately evaluated under these experimental conditions.

DISCUSSION

Previous studies in aquaria (Borton, 1970; Tokar, 1968) and in laboratory streams (Seim, 1970) have indicated that concentrations of primary treated (KME) and biologically stabilized (SKME) kraft mill effluents above about 0.5 mg/l can reduce growth rate and production of salmonids. Nevertheless, no clear evidence was found in the present studies, over about five and one-half years of stream research, of any deleterious influence of KME concentrations of 0.75 mg/l BOD and SKME concentrations up to 1.5 mg/l BOD on salmonid growth or production or on stream capacity to produce salmonids. Some enhancement of production of brown trout was by 0.65 mg/l BOD SKME indicated in a 1973-74 experiment. Enhancement of fish production was also reported by Seim et al. (Ms) on the basis of laboratory stream experiments conducted during summers at concentrations of SKME up to 4 percent by volume (0.3-0.9 mg/l BOD) Two fish kills in Stream 2 when KME was present were obviously detrimental occurrences, although of short duration, because the fish were soon restocked. The presence of secondary treatment systems will help to prevent most such instances from affecting fish in receiving waters. In some cases, enhancement of fish production may not constitute improvement of receiving waters but rather evidence of eutrophication that if made progressive by additional downstream discharges could lead to undesirable changes in downstream communities and the production of less valuable fish species. Increases in fish production noted in Stream 2 during early 1974 do not appear large or consistent enough to suggest much change in the productivity of this stream as a result of introduction of SKME.

Both KME and SKME did cause some changes in the invertebrate community. The major changes here reported were the reduction in *Hydropsyche* at 0.75 mg/l BOD of KME and the probable increase in *Crangonyx* by SKME at concentrations up to 1.5 mg/l BOD. These and other changes resulted in some differences in species diversity. Thus, these effluents altered community composition somewhat but had little or no influence on the productivity of Stream 2 for salmon and trout, which adjusted their food habits to changes in the composition of the invertebrate community.

Hatching and development of steelhead trout embryos were not deleteriously affected by SKME at 0.65 mg/l BOD under tested conditions. Further studies of development and hatching under other conditions and with other kraft mill effluents are certainly necessary. Any reduction in water flow through streambed interstices by settling particles or plant growth would probably be detrimental to salmonid reproduction.

Of some importance was the observed increase in color of Stream 2, especially when SKME at 1.5 mg/l was being introduced. This level of SKME was probably not harmful to the salmonids in this study, but

even most casual observers of Stream 2 did not find its tea-like color aesthetically acceptable. Such well-treated effluents may be discharged to receiving waters at higher volume concentrations because of their reduced BOD and toxicity, this resulting in an increased color problem.

Any application of these results warrants care. Pulp and paper mill effluents vary greatly in their characteristics, owing to differences in mill construction and operation, raw materials, treatment facilities, and other factors. Careful comparison of the characteristics of other effluents with those of the ones here studied should be made before any application of these results. Moreover, the experimental streams we have studied certainly differ in some respects from many natural receiving waters. It is our opinion that these streams have provided a rather realistic and very helpful model for study of an extremely complex problem. But any apparent differences between these streams and natural receiving waters should be taken into account in interpreting and applying our results.

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Appendix I, Table 1. Water quality characteristics of the experimental stream channels from April 8, 1970 through June 15, 1972.

Date	Alkalinity[1] mg/l $CaCO_3$	pH	Dissolved[1] oxygen (mg/l) inflow	outflow	Total[1] solids (mg/l)	Total[1] vol. solids (mg/l)	Hardness[2] (mg/l $CaCO_3$)
1970							
March 31	-	-	-	-	-	-	23
April 8	-	-		-	66.6	18.7	
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	
May 14	24.0	7.3	11.2	13.1	-	-	23
May 30	22.9	7.6	10.7	11.8	-	-	20
June 18	-	-	9.7	9.8	65.3	13.4	21
July 18	28.0	7.5	9.5	11.6	69.3	13.6	
August 1	25.5	7.8	10.1	11.3	-	-	
August 15	27.5	7.7	9.4	11.3	60.3	9.9	20
August 29	28.1	7.7	9.4	10.4	-	-	
Sept. 10	26.2	7.4	9.7	11.6	45.8	8.1	22
Sept. 25	27.7	7.7	9.8	10.9	-	-	
Oct. 10	28.2	7.2	10.0	11.8	63.4	9.9	15
Oct. 31	28.0	7.6	10.6	11.3	-	-	
Nov. 14	24.0	7.4	10.7	13.2	101.5	18.5	20
Nov. 28	18.5	7.4	11.6	11.8	-	-	
Dec. 13	23.5	7.5	12.4	12.9	84.1	14.0	
Dec. 31	18.0	7.3	11.5	12.2	-	-	
1971							
Jan 16	17.0	7.6	11.8	11.8	70.1	10.5	13
Feb 1	19.5	7.6	11.8	11.8	-	-	
Feb 16	18.0	7.2	10.9	11.7	78.1	11.9	18
March 2	20.5	7.3	12.0	13.0	-	-	
March 17	19.0	7.3	11.7	13.2	72.2	10.1	17
April 1	18.7	7.4	10.9	12.2	-	-	
April 29	22.0	7.6	10.6	11.4	70.1	9.2	23
May 13	21.0	7.6	9.9	10.6	70.8	9.3	20
June 13	21.8	7.5	10.8	10.5	51.1	8.1	19
June 27	19.7	7.3	10.1	10.5	-	-	-
July 13	21.6	8.1	10.1	10.5	48.8	8.3	21
August 3	32.0	7.7	9.3	10.4	-	-	-
August 15	22.3	7.6	9.7	10.5	50.1	7.9	16
August 29	23.3	7.4	9.5	9.5	-	-	-
Oct 3	24.1	7.6	10.3	10.7	-	-	-
Oct 19	-	-	-	-	65.5	9.9	16.2
Nov 24	23.5	7.4	-	-	80.8	13.6	16.5
Dec 20	-	-	-	-	84.8	-	-
1972							
January 28	-	7.3	-	-	96.8	15.6	17.6
February 15	-	-	-	-	78.4	14.2	19.6
March 15	-	-	-	-	78.0	14.2	17.7
April 15	-	-	-	-	73.2	13.6	21.8
May 15	-	-	-	-	68.5	12.0	
June 15	-	-	-	-	63.4	11.4	

1 Standard Methods 1965

2 Data from Oregon Department of Environmental Quality. Reported on closest corresponding date .

Appendix I, Table 2. Water quality characteristics of the experimental stream channels from October 21, 1973 through June 22, 1974

Date	Alkalinity[1] (mg/l $CaCO_3$)	ph	Inflow dissolved oxygen (mg/l)	Hardness[2] (mg/l $CaCO_3$)
1973				
Oct 21	-	-	-	-
Oct 28	24.2	-	10.2	36.0
Nov 4	25.6	7.8	11.0	38.0
Nov 11	25.6	7.6	10.6	36.0
Nov 18	25.8	7.5	10.5	37.0
Nov 25	26.8	7.4	11.1	39.0
Dec 2	-	7.4	10.6	-
Dec 9	28.0	7.2	-	41.0
Dec 16	26.2	7.0	10.5	40.0
Dec 23	28.2	7.3	11.1	42.0
Dec 30	28.0	7.4	12.2	40.0
Jan 6	34.0	7.2	11.6	40.0
Jan 13	42.0	7.1	11.4	41.0
Jan 20	36.0	7.1	-	41.0
Jan 27	40.0	7.2	11.9	42.0
Feb 3	42.0	7.0	11.8	43.0
Feb 10	-	6.8	11.6	-
Feb 17	42.0	7.0	-	45.0
Feb 24	40.2	6.9	11.4	47.6
March 8	43.3	6.9	12.8	42.1
March 16	40.0	6.9	11.8	40.0
March 22	38.0	7.2	11.8	6.0
March 30	36.2	7.0	-	34.0
April 7	32.0	7.2	11.4	40.0
April 14	27.8	7.1	10.1	41.0
April 21	26.8	7.2	9.9	38.0
April 28	23.4	7.1	11.8	36.0
May 2	24.0	7.1	10.5	34.0
May 11	24.0	-	-	36.0
May 18	27.0	-	-	36.0
May 25	29.5	7.0	10.7	37.6
June 1	27.2	7.1	10.8	36
June 8	30.5	7.2	10.1	37
June 15	31.5	7.2	10.1	38
June 22	32.5	7.0	9.5	39

[1] Standard Methods, 1965.

[2] Data from the Department of Environmental Quality. Reported on closest corresponding date.

Appendix II, Table 1. Analyses of 7-day composite samples of primary treated kraft mill effluent during 1970. Data of the National Council for Air and Stream Improvement, Inc.

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

(continued on next page)

Appendix II, Table 1 (continued)

Date	COD (mg/l)	Total solids (mg/l)	Total volatile (mg/l)	Suspended solids (mg/l)	Suspended volatile (mg/l)	BOD (mg/l)
October 7-12	650	767	265	-	-	195
October 13-19	585	790	274	-	-	180
October 20-26	565	666	218	-	-	180
October 27-November 2	-	746	300	-	-	350
November 3-8	-	708	220	-	-	180
November 9-16	-	670	269	-	-	-
November 17-23	-	696	260	-	-	-
November 24-29	-	729	263	-	-	-
November 30-December 5	-	733	258	-	-	-
December 6-12	-	709	201	-	-	-

Appendix II, Table 2 — Mean weekly BOD concentrations of stabilized kraft mill effluent.

Week Beginning		Mean BOD (mg/l)	Week Beginning		Mean BOD (mg/l)
1971			1972		
March	12	40	January	6	119
	28	48		13	83
April	4	49		20	88
	11	67		28	66
	17	93	February	3	112
	24	90		10	129
May	1	60		17	81
	9	75		24	78
	16	100	March	2	76
	25	60		9	76
June	1	85		16	68
	9	80		24	89
	16	80		31	77
	24	80	April	6	96
July	2	65		13	112
	9	32		20	91
	17	42		27	103
	30	40	May	4	100
August	12	30		11	98
	20	51		18	77
	26	36		25	60
September	2	33	June	2	55
	10	24		10	35
	16	26		15	32
	23	57		24	38
	30	54		29	27
October	7	71	July	6	30
	14	54		13	47
	21	27		20	37
	28	64		27	41
November	4	43	August	3	30
	11	33		10	43
	18	52		17	31
	25	62		24	31
December	2	78		31	52
	9	71	September	6	38
	16	62		14	46
	23	56		21	21
	30	57		28	25
			October	5	32
				12	29

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Appendix II, (continued)
Table 2

Week Beginning		Mean BOD (mg/l)
1972 (continued)		
October	19	41
	26	31
November	2	34
	9	32
	16	32
	21	28
December	1	29
	7	32
	14	--
	21	118
	29	65
1973		
January	5	75
	7	--
	12	45
February	9	42
	14	43
	21	48
March	5	48
	15	44
SKME having extended treatment		
October	14	8
	21	23
November	11	13
	25	17
December	2	16
	9	20
	16	19
	23	11
	30	14
1974		
January	6	19
	13	19
	20	17
	27	14
February	3	16
	10	19
	17	19
	24	20
March	3	18
	10	17
	17	18
	24	24
	31	8
April	7	17
	14	15
	21	16
	28	17
May	5	11
	12	15
	19	16
	26	14
June	2	15
	9	19
	16	19
	23	19
	30	17
July	7	55
	14	45
	21	39
	28	24
August	4	20
	11	14
	18	14
	25	18
September	1	19
	8	14
	15	13
	22	18
	29	12
October	6	18
	13	20
	20	21
	27	21
November	3	17
	10	16
	17	16
December	1	18
	8	17
	15	11

(continued on next page)

Appendix II, Table 2 (continued)

Week Beginning		Mean BOD (mg/l)	Week Beginning	Mean BOD (mg/l)
SKME having extended treatment				
1975				
January	12	15		
	19	11		
	26	8		
February	2	21		
	9	21		
	16	18		
	23	25		
March	30	0		
April	13	17		
	20	16		
	27	16		
May	4	20		
	11	15		
	25	33		
June	8	10		
	15	10		
	22	8		
	29	19		
July	6	21		
	13	18		
	20	16		
	27	9		
August	3	15		
	10	16		
	17	13		
	24	12		
	31	12		
September	14	10		
	21	6		
October	5	15		
	12	12		

Appendix II, Table 3. Range and mean concentration in mg/l of three resin acids found in SKME having extended treatment. Determination made by the National Council for Air and Stream Improvement from November 1973 through September 1975

Date	No. Samples	Resin Acid Concentration, mg/l					
		Isopimaric Acid		Abietic Acid		Dehydroabietic Acid	
		Range	Mean	Range	Mean	Range	Mean
Nov 1973	8	0.30-0.86	0.57	0.10-0.44	0.24	0.20-0.33	0.27
Dec 1973	14	0.46-1.37	0.41	0.26-1.33	0.56	0.31-0.51	0.41
Jan 1974	26	0.36-1.09	0.67	0.22-0.69	0.40	0.19-0.39	0.26
Feb 1974	18	0.39-0.93	0.72	0.21-0.56	0.41	0.20-0.38	0.29
Mar 1974	22	0.46-0.78	0.62	0.27-0.49	0.37	0.22-0.35	0.28
Apr 1974	14	0.41-0.68	0.53	0.17-0.46	0.34	0.12-0.35	0.26
May 1974	12	0.43-0.76	0.55	0.24-0.51	0.36	0.22-0.42	0.29
Jun 1974	13	0.29-0.48	0.42	0.21-0.36	0.27	0.19-0.29	0.22
Jul 1974	12	0.20-0.29	0.26	0.10-0.21	0.16	0.12-0.19	0.15
Aug 1974	13	0.14-0.53	0.30	0.09-0.35	0.21	0.09-0.26	0.18
Sep 1974	16	0.17-0.44	0.31	0.13-0.36	0.24	0.11-0.26	0.18
Oct 1974	6	0.35-0.62	0.50	0.25-0.56	0.43	0.20-0.47	0.34
Nov 1974	9	0.24-0-62	0.38	0.20-0.43	0.28	0.19-0.40	0.26
Dec 1974	3	0.27-0.34	0.31	0.13-0.25	0.21	0.16-0.23	0.20
Jan 1975	4	0.27-0.30	0.28	0.08-0.14	0.10	0.12-0.15	0.14
Feb 1975	6	0.25-0.44	0.32	0.07-0.16	0.13	0.14-0.29	0.21
Mar 1975	3	0.29-0.53	0.42	0.17-0.78	0.40	0.20-0.28	0.24
Apr 1975	9	0.11-0.62	0.35	0.08-0.38	0.23	0.11-0.43	0.27
May 1975	4	0.08-0.23	0.14	0.08-0.19	0.10	0.08-0.18	0.12
Jun 1975	5	0.11-0.40	0.25	0.04-0.14	0.08	0.10-0.27	0.19
Jul 1975	9	0.15-0.55	0.27	0.03-0.17	0.10	0.11-0.38	0.21
Aug 1975	5	0.10-0.28	0.22	0.03-0.19	0.13	0.13-0.23	0.19
Sep 1975	3	0.26-0.33	0.30	0.10-0.20	0.15	0.19-0.23	0.22

Appendix III. Acute toxicity of primary treated and biologically stabilized kraft mill effluent to juvenile chinook or coho salmon expressed as 96-hr median tolerance limits in percent by volume.

Primary treated effluent		Biologically stabilized effluent	
Date collected	96-hour TL_{50}	Date collected	96-hour TL_{50}
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 2	1.8	February 2	70.0
February 13	3.0	February 16	50.0
February 15	6.6	March 23	75.0
February 17	7.4	April 19	70.0
February 19	8.0	May 17	75.0
February 25	2.2	June 15	90.0
March 6	2.2	July 1	no mortality
March 23	7.5	August 2	90.0
		September 2	no mortality
		October 4	no mortality
		November 5	no mortality
		December 3	90.0
		1973	
		January 5 to October 18, 1975	75.0 no mortality

Appendix IV. Brown trout food organisms

- Annelida
  - Oligochaeta
    - Plesiopora
      - Lumbricidae
        - *Lumbricus*
      - Tubificidae
- Arthropoda
  - Arachnoidea
    - Hydracarina
  - Crustacea
    - Amphipoda
      - Gammaridae
        - *Crangonyx*
      - Tilitridae
        - *Hyalella*
    - Cladocera
    - Eucopepoda (Copepoda)
    - Isopoda
    - Podocopa (Ostracoda)
  - Insecta
    - Coleoptera
      - Carabidae
      - Dytiscidae
      - Hydrophilidae
      - Psephenidae
    - Collembola
    - Diptera
      - Ceratopogonidae
      - Chironomidae
      - Culicidae
      - Dixidae
      - Empididae
      - Simuliidae
      - Tabanidae
      - Tipulidae
    - Ephemeroptera
      - Baetidae
        - *Bætis*
      - Heptageniidae
- Arthropoda (cont'd)
  - Insecta (cont'd)
    - Hemiptera
      - Aphididae
      - Coroxidae
      - Gerridae
    - Hymenoptera
      - Formicidae
    - Lepidoptera
      - Pyralidae
    - Megaloptera
      - Sialidae
        - *Sialis*
    - Tricoptera
      - Hydropsychidae
        - *Hydropsyche*
      - Lepidostomatidae
- Mollusca
  - Gastropoda
    - Pulmonata
      - Physidae
        - *Physa*
      - Lymnaeidae
        - *Radix*
    - Pelecypoda
      - Eulamellibranchia
        - Spheriidae