

AN ABSTRACT OF THE THESIS OF

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Title: GROWTH AND PRODUCTION OF SALMONIDS EXPOSED TO A  
STABILIZED KRAFT MILL EFFLUENT IN EXPERIMENTAL  
STREAM CHANNELS

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The growth and production of brown trout, Salmo trutta Linnaeus, exposed to a concentration of 0.65 mg/l BOD (4.1 percent by volume) stabilized kraft mill effluent (SKME) were studied from October 1973 until May 1974 in three experimental stream channels located near a kraft mill in Albany, Oregon. Growth rate was generally influenced by stream temperature and was modified by changing food biomass until April, as productivities of the streams for fish constantly changed.

On the basis of theoretical production-biomass and growth rate-biomass relationships developed from a model, there appeared to be no consistent adverse effect of 0.65 mg/l BOD SKME on the growth and production of brown trout. The model demonstrated possible periodic effects of SKME on growth and production. At times the fish

may have been affected directly or indirectly through influences on the biomasses of important food organisms which were identified from analysis of trout stomach contents.

In a separate experiment, the survival and development of steelhead, Salmo gairdneri Richardson, embryos and alevins were not adversely affected by the 0.65 mg/l BOD concentration of SKME in spawning channels under adequate conditions of water flow and dissolved oxygen concentrations.

Growth and Production of Salmonids Exposed  
to a Stabilized Kraft Mill Effluent in  
Experimental Stream Channels

by

Barry Francis Mower •

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Typed by Mary Jo Stratton for Barry Francis Mower

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# GROWTH AND PRODUCTION OF SALMONIDS EXPOSED TO A STABILIZED KRAFT MILL EFFLUENT IN EXPERIMENTAL STREAM CHANNELS

## INTRODUCTION

Increasing population of the world combined with progressive industrial development has led to keen competition for available water resources among the many users. Industrial use of water resources, such as for pulp and paper waste disposal, may diminish their value for other uses. Adequate technology now often makes it possible to provide levels of waste treatment allowing for better use of receiving waters. Determination of levels of waste that can be introduced into receiving waters without diminishing the value for other uses is an important problem. The use of rivers and other receiving waters for disposal of pulp and paper waste has been extensive. The kraft pulping process accounts for approximately 80 percent of the chemical pulping in the United States (Gehm and Cove, 1968).

In the research reported in this thesis, the growth and production of brown trout, Salmo trutta Linnaeus, were studied in three experimental stream channels, one of which received biologically-stabilized kraft mill effluent (SKME), from October 1973 until May 1974. Brown trout were stocked at nearly equal biomasses in each stream and periodically caught and weighed. Growth rate and production values were computed for each stream and compared to

examine the influence of a concentration of 0.65 mg/l BOD (4.1 percent) SKME on the growth and production of trout in experimental stream channels.

Walden and Howard (1971) have reviewed much of the previous literature on the effects of kraft mill effluents (KME) on fish. While most of the earlier work reviewed has dealt with the acute toxicity of these wastes to fish, much of the more recent work has been concerned with sublethal effects. Various levels of resolution have been pursued to determine the effects of sublethal levels of KME on fish, such as studies of histological changes in vital organs of fish, and stress responses measured by changes in respiration, swimming performance, temperature tolerance, and blood chemistry.

One useful approach is to study the effects of KME on the growth and production of fish. All fish must grow during some period of their life. Growth, being an outcome of many integrated processes within a fish and environmental factors external to the fish, may thus be a sensitive indicator of the sublethal effects of KME on fish. And production of fish populations determines possible yields to man.

Production of a product of interest is defined by Warren (1971) as the total tissue elaboration of a population per unit area per unit time regardless of the fate of that tissue, with the exception that tissue elaborated and subsequently metabolized for maintenance is not included. Ricker (1946) and Allen (1950) formulated the equation

$P = G \times B$  as a measure of production (P) of a consumer of interest, where G is the relative growth rate of the consumer of interest expressed as a change in body weight per unit time relative to existing body weight, and B is the mean biomass of its population. In cases where food is limiting, as the biomass of the consumer increases, its relative growth rate decreases since there is then less food for each individual. The plot of production (the product of mean biomass and relative growth rate) versus mean biomass increases from zero at zero biomass to a maximum at some intermediate biomass and then decreases to zero at higher biomasses, where growth reaches zero (Davis and Warren, 1965; Brocksen, Davis, and Warren, 1968). Thus, those factors affecting growth or biomass will also affect production.

Those systems having different productivities (different capacities to produce the product of interest) will have different production curves. Levels of productivity may be analyzed into different density-dependent relationships between growth rate of the consumer and food biomass and between consumer biomass and food biomass.

The growth of a fish in a natural system is primarily dependent upon its food consumption. Warren and Davis (1967) have developed an energy budget to account for the fates of food energy consumed. The amount of food energy available for growth (scope for growth) is the difference between total energy value of the food consumed and the

energy lost to wastes and respiration. Included in respiration are standard metabolism, specific dynamic action, and activity. Environmental factors may affect growth by changing food consumption, the portion of energy lost to wastes, or the energy used in respiration.

Warren (1971) discusses how one such factor, temperature, might affect growth. He assumes food consumption in nature is some function of activity, increasing from a low level at a low temperature, to a maximum at some intermediate temperature and then decreasing slightly at higher temperatures. At the same time, energy used in total respiration tends to increase exponentially. The difference in energy value of these two items minus the energy value of wastes, the scope for growth, then increases from zero at low temperatures to a maximum at some intermediate temperature and then decreases at higher temperatures, where all the energy consumed is utilized in maintenance. Other factors might influence scope for growth at a given temperature, through one or more of the terms in the energy budget.

Food consumption is in part determined by food availability, which is some function of the density of the food organisms. Growth rate and production of a consumer then may be density-dependent functions of the biomass of the food organisms in a stream. The biomass of the consumer is inversely related to the biomass of the food in systems having the same basic capacity to produce food, and

directly related to the biomass of its food in systems having different capacities to produce food. At very high food densities these relationships may be less clearly defined, since other possible fates of the food then become more important (Brocksen, Davis, and Warren, 1970).

In natural systems, however, the capacity of a system to produce food is constantly changing, and consequently the consumer biomass that can be supported also changes. Figure 1 may be helpful in understanding this idea. Using a systems approach as proposed by Booty (MS), levels of productivity might be represented by curves A, B, and C, while curves 1, 2, and 3 might represent different rates of removal of fish biomass due to disease, cropping by man, predation, etc. At a given moment there will be some food biomass and some fish biomass (assume that point B-1 is defined by the intersection of curves B and 1). If productivity remains constant, then there exists an inverse relationship between the biomass of the food and the biomass of the consumer, and the curve B is generated as the biomass of the consumer and the biomass of its food resource change. At some point in time related to some point on the curve B (assume B-2), productivity (capacity to produce food) may increase from level B to level A generating curve 2. In temperature zones, the productivity of systems for fish exhibits seasonal cycles. Theoretically, there exists an equilibrium at every intersection of every possible

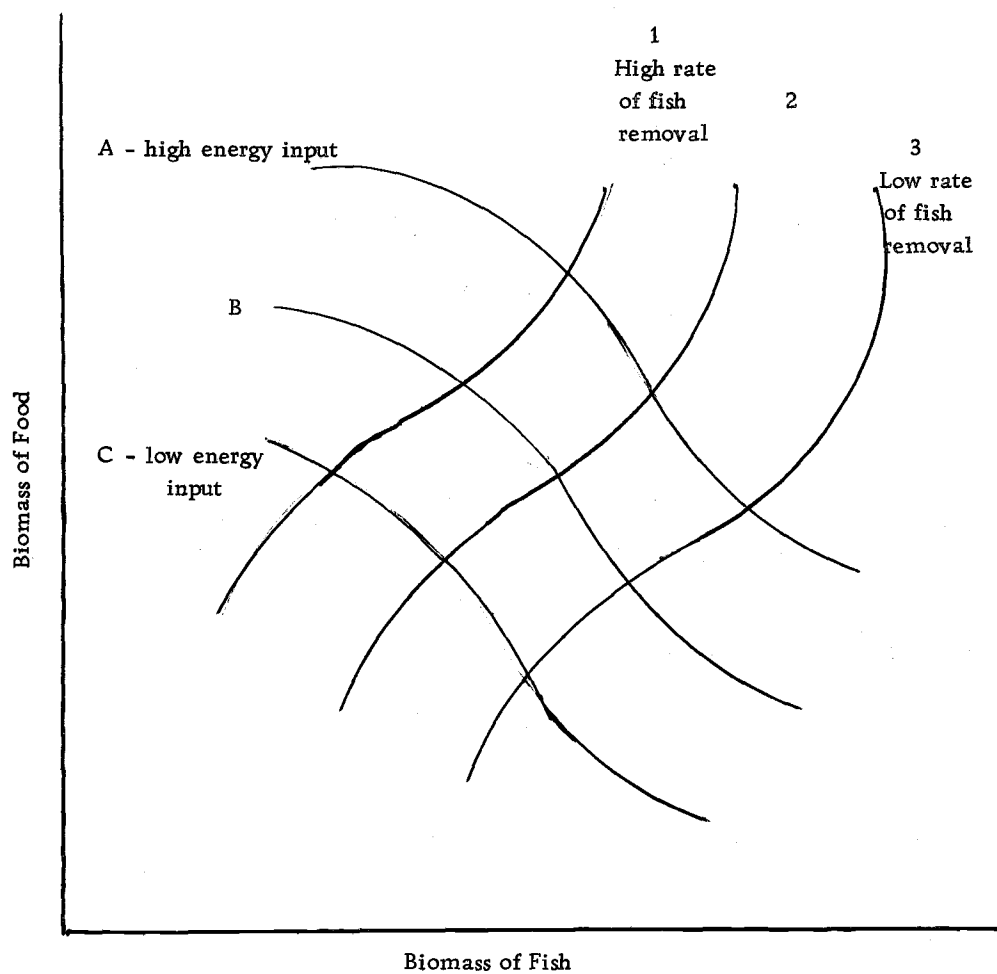


Figure 1. Theoretical relationships between biomass of food and biomass of fish.

isocline. In reality, productivity is constantly changing so that the biomass of the fish and of the food do not remain at a single equilibrium point but rather constantly tend toward a shifting equilibrium point. The result is a matrix of inverse relationships representing changes within systems having constant productivity and direct relationships representing changes within systems having changing productivities. Environmental factors such as seasonal temperature changes may result in a change in the productivity of the system with the resulting change in growth and production on the basis of changing density-dependent relationships. Such a framework will prove useful in analyzing data to be presented here.

For approximately ten years the Department of Fisheries and Wildlife at Oregon State University has conducted studies on the effect 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/l BOD KME from mill A at unrestricted rations in aquaria. A concentration of 2.0 mg/l BOD KME from mill B did not affect the growth of salmon. Salmon fed tubificid worms which 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/l BOD) stabilized KME (SKME) from mill A, while a level of 4.5



percent SKME from mill B did not reduce growth. Both Borton and Tokar postulated that the observed decreases in growth rate were direct effects of the waste on the efficiency of utilization of food for growth, since effects were observed at the same food consumption rate of exposed and control fish. These results point out the difficulty involved in trying to apply results obtained on effluents from one mill directly to other mills, because physical, chemical, and operating factors and resulting toxicity and BOD vary between mills.

In laboratory streams, Ellis (1968) observed a reduction in growth rate of juvenile chinook salmon exposed to a dilution of 1.5 percent (3.0 mg/l BOD) KME but not at a dilution of 0.5 percent (1.0 mg/l 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. Perhaps harmful effects at lower stocking densities were compensated by increased food consumption, or social stress among the fish at high densities may have been involved. Ellis did observe an increase in food density in laboratory streams receiving effluent during another experiment conducted during the summer. Williams (1969), in studying the same streams, measured an increase in primary production in streams receiving SKME. Species composition of diatoms was altered by SKME.

Seim (1970) observed a decrease in production of chinook salmon exposed to 1.5 percent (0.5 mg/l) SKME in laboratory streams during spring and fall and attributed this to a direct effect of SKME, since food density did not vary. In summer experiments, growth 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 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 in laboratory streams than were observed in controls. This was attributed to an observed increase in food organisms in those streams receiving effluent.

Borton (1975) found no effect of 0.75 mg/l BOD KME or SKME on the growth and production of salmonids in the large outdoor experimental stream channels used in the present study. In studying these same streams, Craven (unpublished data) observed that a level of 0.75 mg/l BOD KME decreased the abundance but not the diversity of food organisms. A concentration of 0.75 mg/l BOD SKME resulted in a change in composition of the invertebrate community but little or no change in total abundance. Thus, changes that did occur in the stream

communities had little or no effect on the growth and production of fish at the effluent concentrations.

In concurrent growth studies conducted in aquaria with the effluent being used in the present stream channel studies, growth of salmonids exposed to 1.5 mg/l BOD (approximately 9 percent) SKME was reduced (Wilson, unpublished data).

Servizi, Stone, and Gordon (1966) observed lower mean dry weights and slower yolk adsorption of pink salmon alevins, Oncorhynchus gorbuscha (Walbaum), exposed to 1 percent neutralized bleach KME (NBW). Yolk utilization of sockeye salmon alevins, Oncorhynchus nerka (Walbaum), was not retarded by 2 percent NBW, but mean dry weights at complete yolk adsorption were reduced at 1 percent NBW. Older alevins were found to be more sensitive to NBW than younger alevins, fingerlings, or adults.

Studies conducted by the Washington Department of Fisheries (1960) demonstrated a statistically significant reduction in the growth of salmonids exposed to a 1:169 dilution of KME. Webb and Brett (1972) showed no effect of bleached KME on the growth of sockeye salmon held in 1 and 2.5 percent dilutions but did observe an effect at 10 percent (12.0 mg/l BOD). This they attributed to a decrease in efficiency of conversion of food for growth.

The purpose of the present study was to determine any effects of more fully stabilized KME on the growth and production of salmonids in a more natural system.

## 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 0.75 meters deep) alternating with 11 riffles (each about 12 cm deep) (Fig. 2). The riffle substrate consisted of 15 cm of gravel and rubble ranging in diameter from about 1 to 20 cm. 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. No trees were present which could shade the streams. The middle stream, stream II, received effluent while the two outer ones served as controls.

The river water passed through weirs 33 cm in width and then through inclined screens of 1.5 mm mesh fiberglass before entering the streams. The screens prevented the introduction of fish and greatly reduced the introduction of aquatic insects from the Willamette River into the streams. The screens were cleaned daily with a fiber scrub brush. Head measurements in the weirbox were the basis for calculations of mean weekly stream flow, which varied from 725 to 860 liters per minute and averaged 788 liters per minute (Appendix 1).

Emigration of fish from the streams was prevented by a rectangular trap at the end of each stream channel. These were

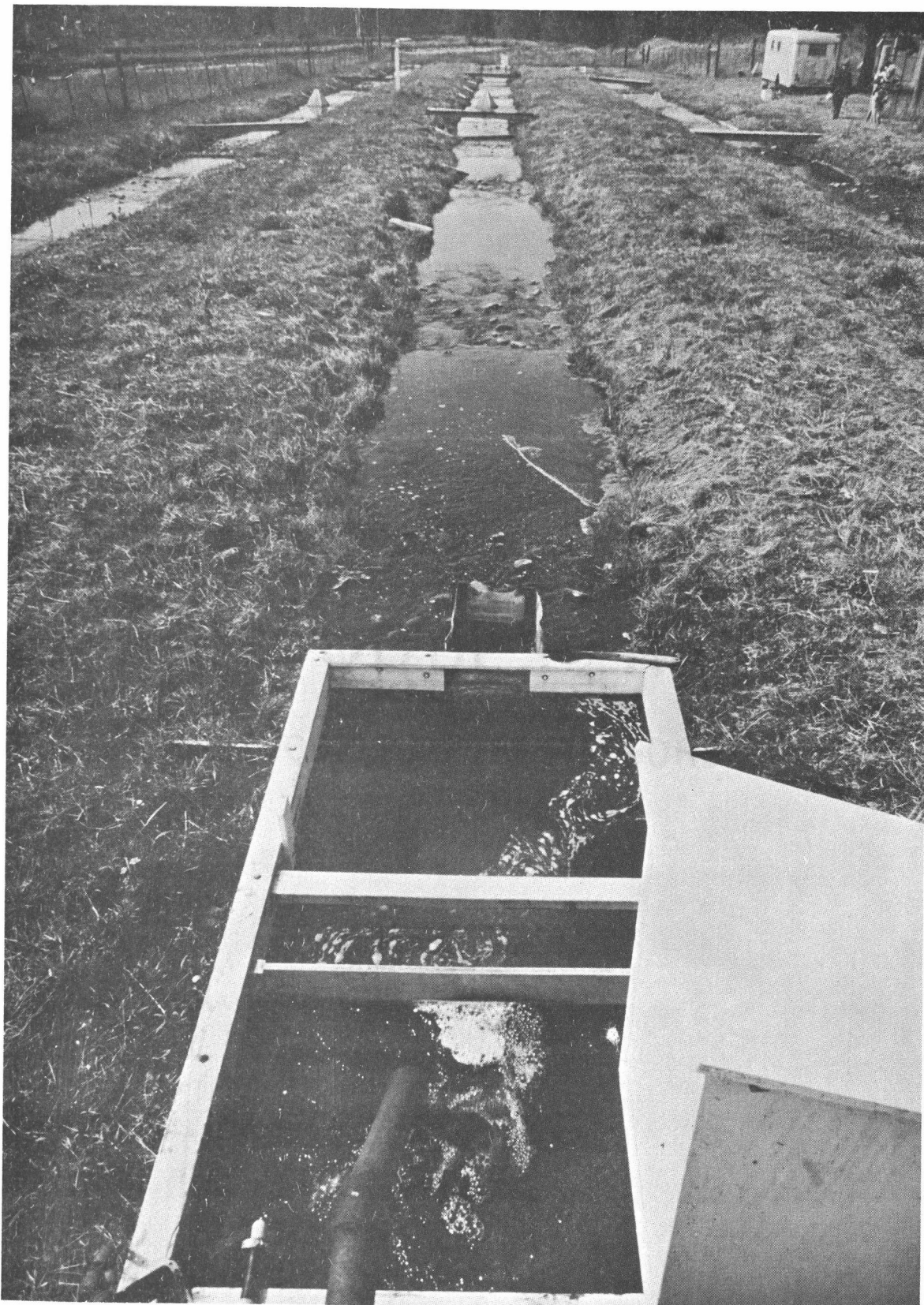


Figure 2. Experimental stream channels, Albany, Oregon. Downstream view of stream II.

constructed from 6 mm square mesh metal hardware cloth. The traps were cleaned daily and the numbers of dead and live fish recorded. The live fish were returned to pools near the middle of each stream. Predation by birds was minimized by stretching over the streams nylon gill nets having 5 cm square mesh.

Recording thermographs monitored the temperatures of stream II at the weirbox and at the trap. Periodic measurements showed no appreciable differences in temperature among the three streams. Appendix 1 gives mean weekly water temperatures for the period of these studies.

In concurrent studies by Wilson (unpublished data), pH and dissolved oxygen of the river water entering the study streams were determined daily and hardness and total alkalinity were determined weekly (Appendix 1). Monthly rainfall (Appendix 1) was determined at the Hyslop Farm, Oregon Agricultural Experimental Station, approximately 10 km from the streams.

#### Kraft Effluents

The source of kraft effluent was a 900 tons per day (tpd) kraft liner board pulp and paper mill producing approximately 525 tpd unbleached kraft pulp, 175 tpd neutral sulfite semi-chemical pulp, and 200 tpd kraft clippings from Douglas-fir wood chips. Chemical recovery of digestion chemicals is practiced by the mill. The

combined effluents from the mill flow into two sedimentation ponds, having a total retention time of 24 hours, where solids are removed. The waste is then pumped to a 8.5 hectare (21 acre) aerated stabilization basin equipped with ten 50-horsepower aerators for biological treatment. Diammonium phosphate is periodically added to the basin to aid bacterial growth. With a retention time of 8-16 days, a 90 percent reduction in BOD of the waste usually results. The treated effluent is then discharged to the Willamette River. In summer, flow to the basin, normally 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, additional treatment of the effluent was practiced for purposes of this experiment. Effluent from the aeration basin was pumped to a 0.2 hectare (0.5 acre) aeration basin, or "polishing pond," equipped with one 5-horsepower aerator. Here the effluent received biological treatment for ten additional days. The effluent was then pumped through a plastic pipe to a headbox at the head of the stream II. The flow of effluent into the weirbox of stream II was controlled by varying the amount of head in the headbox by means of a siphon tube, so as to obtain the desired effluent concentration. This was adjusted as necessary on the basis of BOD determinations made by personnel of the National

Council for Air and Stream Improvement. Appendix 2 gives the mean weekly BOD of the effluent for the period of this study.

Daily measurements of effluent and stream flow were the basis for calculations of mean weekly concentrations of effluent in stream

II. These varied from 0.38 to 1.07 mg/l BOD (2.0 to 5.7 percent by volume) and averaged 0.65 mg/l BOD (4.1 percent) (Appendix 2).

Concurrent 96-hour acute toxicity bioassays showed no acute toxicity of 100 percent effluent to salmonids at any time during these studies (Wilson, unpublished data).

#### Experimental Fish and Stocking Procedures

Brown trout were used in an attempt to avoid an annual summer infection of a myxosporidian, Ceratomyxa shasta Noble, which Borton (1975) observed to heavily infect juvenile coho salmon, Oncorhynchus kisutch (Walbaum), and juvenile chinook salmon in previous summers in the stream channels. Borton showed that, although brown trout were not immune to the pathogen, they exhibited better survival than did the salmon. Shaefer (1968) also suggests that brown trout may be more resistant than coho or chinook salmon to C. shasta.

The experiment began on October 25, 1973 and was concluded on May 17, 1974. At the beginning of the experiment, the streams were stocked with nearly equal biomasses and densities of yearling brown trout obtained by electro-fishing Browns Creek, a small



tributary of the Deschutes River in the Cascade Mountains of Oregon (Appendix 3). According to Sanders et al. (1970), Browns Creek is outside the distribution of C. shasta; thus these fish had no previous exposure to this protozoan.

### Sampling Procedure

Periods between sampling of the fish varied from two to four weeks. In December and January, when growth was slow, the fish were sampled only once a month. At other times, the fish were caught and weighed every two or three weeks. As Chapman (1968) points out, shorter periods between sampling allow for better estimates of growth rates which may change during the year with different diets and changes in season. The sampling periods were coded with consecutive numbers from one to ten (Appendix 2).

Before collecting the fish, water flow in each stream was reduced to force the fish from the riffles into the pools. Each pool was seined until no more fish were caught in that pool. Use of an electro-fishing device immediately after seining in February indicated that about 90 percent of the fish in a stream could be caught with the seine. After the fish were collected from one stream, they were then transferred to a sink supplied with running water in a small laboratory trailer at the stream site. Five to ten fish at a time were blotted dry on a cotton towel, placed in water in a plastic container, and then

weighed on a top-loading balance having an accuracy of 0.01 g. The fish were then transferred to a tank containing river water and held until all fish from one stream were weighed. Then, all but 15 fish, selected at random for food habits analysis, were returned to the stream by placing nearly equal numbers of them into each pool. The water flow in each stream was returned to normal immediately after the fish were captured.

The 15 fish selected for food habits analysis were anesthetized with MS 222 and their stomach contents removed 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 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. These fish were then redistributed evenly along the length of their respective streams.

The most abundant organisms in the stomach samples were identified to genus, with the exception of chironomids, which were identified to family. Other less abundant organisms were identified to family or order; such organisms were not identified to lower taxa

in stream benthos studies (Seim, unpublished data). After being separated into groups, the organisms were blotted dry on a paper towel and weighed on a balance accurate to 0.1 mg. The relative importance of each group was then determined by computing the percent by weight of each group for each sampling period. Fish growth rates could then be compared to estimates of the biomass of important food organisms in the streams (Seim, unpublished data) to evaluate any indirect effects of 0.65 mg/l BOD SKME on the growth and production of fish through their food relationships.

#### Calculation of Production and Growth Rates

The number of fish captured at each sampling was not constant. Since there was neither immigration nor recruitment, the numbers were adjusted upward for sampling periods which showed fewer fish than later periods. It was assumed that they had just not been caught. A smooth curve was then visually fitted to the points, allowance being made for some mortality as indicated by the numbers of dead fish found in the traps, which were checked daily. A conservative 5 percent allowance was also made for a few fish not caught each sampling period. Estimates of numbers from this curve are believed to have been quite close to true values (Fig. 3 and Appendix 3).

Production values were calculated by plotting the number of survivors against the mean weight of the fish for each

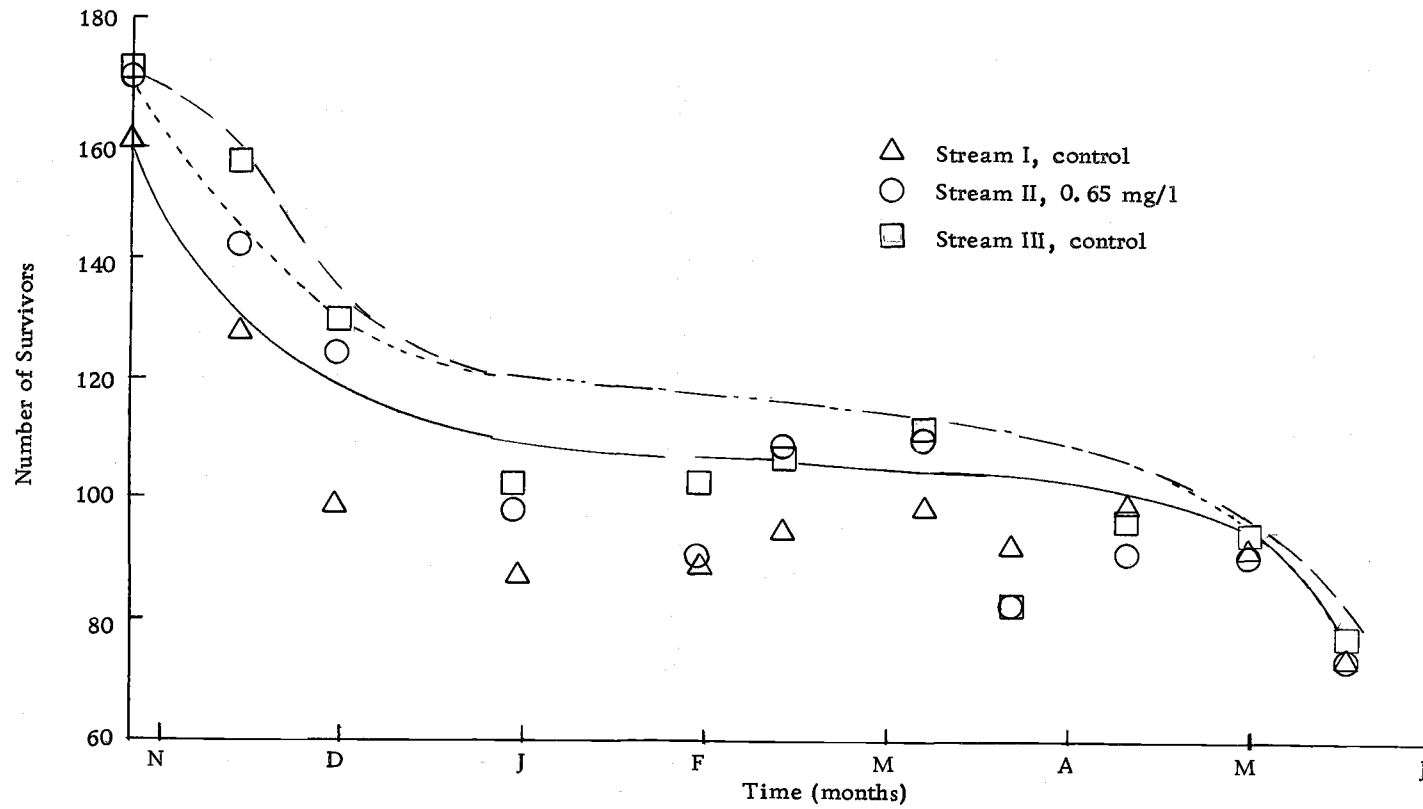


Figure 3. Estimated survivorship curve for brown trout in the three experimental stream channels from October 25, 1973 through May 17, 1974.

sampling period. The area under such a curve provides an estimate of production for the period of interest (Allen, 1951). Because of the relatively high frequency of sampling, the points were connected by straight lines and production values for periods between sampling data were calculated as the areas of trapezoids or rectangles. It was believed that this method would provide a more accurate measure of the area than would the use of a planimeter or counting squares on graph paper. Mean relative growth rates were determined from the formula  $P = G \times B$ , proposed by Ricker (1946) and Allen (1950), where  $P$  is production taken from the Allen curve, and  $B$  is the mean total biomass of the fish during the sampling period. Relative growth rate (mg / g / day) is the quotient  $P/B$  multiplied by 1,000 and divided by the number of days in the sampling period.

### Biomonitoring

As part of a biomonitoring program on the effluent, weekly 96-hour acute toxicity bioassays and monthly 21-day growth experiments were conducted in aquaria in a small laboratory building at the stream site, from November 1973 through May 1974. The results of these studies provide additional information on the quality of the effluent and its effects on growth of salmonids during the experiment (Wilson, unpublished data).

### Effects on Reproduction

In an effort to determine the effect 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 with a gradient of approximately 1 percent and contained 15 cm of gravel 1 to 5 cm in diameter. Five styrofoam floats 50 cm square, each wired to a standard cement building block, were placed in each spawning channel to provide cover for the adult fish. Upstream emigration was prevented by the stream channel traps, and downstream emigration was prevented by 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.

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, fertilized steelhead eggs, Salmo gairdneri Richardson, from the Alsea Hatchery of the Oregon Wildlife Commission 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 two 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 and placed in stainless steel baskets. Five baskets were buried in the gravel in each spawning channel.

The baskets were 10 cm square and 2.5 cm deep and were constructed of perforated stainless steel with holes 3 mm in diameter at a density of five holes per  $\text{cm}^2$ . A column 4.5 cm in diameter extended through the center of each basket to allow a greater water flow. 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 at 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 boxes were carefully returned to the gravel and reburied. The fifth box was not disturbed until the eggs in the others had hatched. After hatching, five alevins from each basket were removed weekly. The dead and remaining live ones were counted and their numbers 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 use of a scalpel, the remaining yolk was carefully separated from each alevin in the other three groups. Wet and dry weights without the yolk were then determined in the same manner as for the other groups.

From these measurements, survival and growth of the embryos and alevins were determined. Parameters measured included embryo survival until hatching, time until hatching, size of alevins at hatching and weekly thereafter, 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.



## RESULTS AND INTERPRETATION

### Changes in Biomass and Production with Time

Brown trout production values, mean biomass, and relative growth rates were calculated for each sampling period (Appendix 3).

Daily production through time exhibited generally similar trends in all three streams, the stream receiving effluent, stream II, consistently exhibiting the same trends as one or both controls (Fig. 4). The general trend was a decrease in production from the beginning of the experiment through period 4, an increase in production through period 8, followed by a decrease in production through period 10. Variations from these trends occasionally occurred.

During period 2, there was a marked decrease in the growth and production of fish in all streams. The cause has not been determined. Temperature (Appendix 1) and biomass of food organisms (Appendix 4) were higher than during later periods in which growth and production were greater. There was an abnormally high rainfall during this period (Appendix 1) and flooding was common to the whole Willamette River watershed. The lower growth and production of fish in all streams during this period may be related in some unresolved way to rainfall.

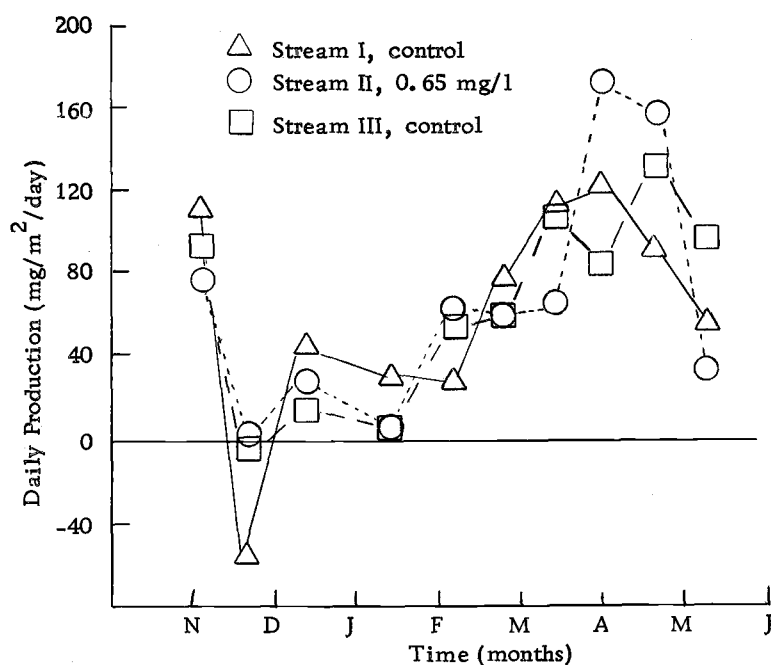


Figure 4. Relationship between daily production of brown trout and time, from October 25, 1973 through May 17, 1974.

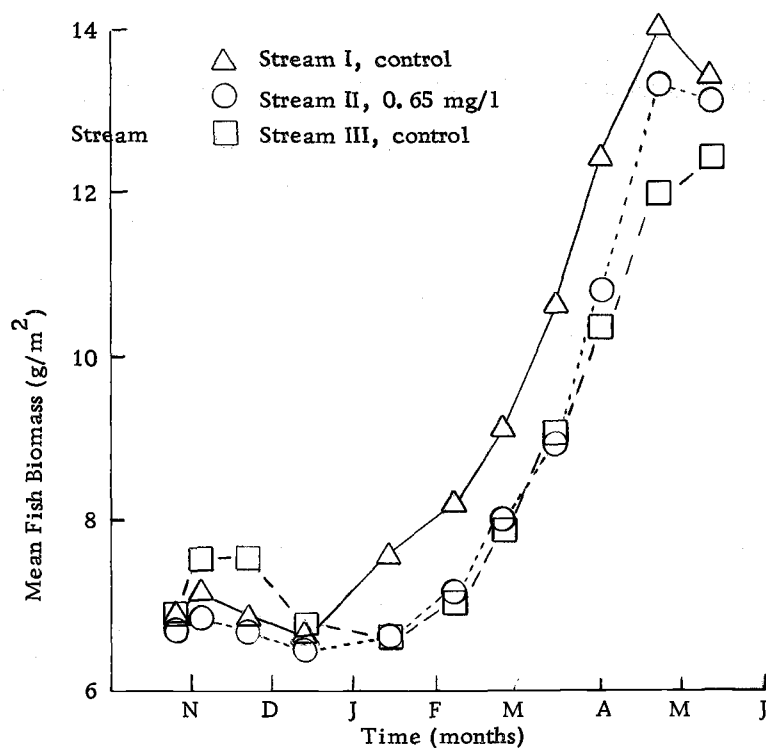


Figure 5. Relationship between mean biomass of brown trout and time, from October 25, 1973 through May 17, 1974.

Another possible cause of lower growth during period 2 could be an infection of Ceratomyxa shasta Noble. Such infection resulted in the mortality of brown trout in the streams in an earlier experiment. Studies conducted by the Oregon State University Department of Microbiology have shown that fish stop eating 10 to 20 days after becoming infected (J. Fryer, personal communication). Had infection occurred during period 1, the incubation time of C. shasta might have precluded an effect on food consumption until period 2. Indeed, mortality was relatively high in all streams during this period (Fig. 3). Growth of brown trout in aquaria was also greatly reduced during this period in on-site laboratory studies also using Willamette River water (Wilson, unpublished data).

Production in stream II, which received effluent, did not differ greatly from controls, except during period 7 when it was lower and during period 8 when it was higher. Small variations between the production of brown trout in stream II and production of brown trout in the control streams during periods 1, 9, and 10 represent no greater differences than frequently occurred between controls and probably do not represent important differences. Total production for the streams during the experiment was quite similar, 12.80, 12.93, and 12.04 g/m<sup>2</sup> for streams I, II, and III, respectively. There seemed to be no consistent differences in production of fish between

stream II and control streams that could be attributed to the presence of 0.65 mg/l BOD SKME.

Mean biomass of fish through time showed the same general trends for all three streams (Fig. 5). After an initial increase in fish biomass during period 1, due to growth, there was a slight decrease through period 3, probably as a result of low growth and high mortality during period 2 and high mortality during period 3 (Appendix 3). Mean biomass of fish then increased until period 10, when the biomasses in streams I and II decreased, probably as a result of an infection of C. shasta which occurs annually at this time. Mean biomasses in stream II were similar to those in the control streams. Stream I tended to have the highest fish biomass, except early in the experiment, and streams II and III had nearly identical biomasses of fish, except early and late in the experiment.

Growth rate through time followed essentially the same pattern as production (Appendix 3). There were no consistent differences in growth between stream II and the control streams that might be attributed to the presence of 0.65 mg/l BOD SKME in stream II.

On the basis of production, mean biomass, and relative growth rates of brown trout through time, it appears that there were no consistent differences between stream II and the control streams that could be attributed to 0.65 mg/l BOD SKME. Periodic differences in trends and in magnitude of production and growth rates did, however,

occur. Lower growth and production in stream II during period 7 and a higher growth and production in stream II during period 8 are examples of this.

In order to better evaluate these periodic differences and to determine effects of any masking or compensatory factors, such as a possible increased food consumption of stream II fish, a different point of view was needed. Such a conceptual framework has been developed by Warren (1971) and was discussed in the Introduction to this thesis.

#### Changes in Theoretical Production-Biomass Relationships

Daily production of fish was plotted against mean biomass of fish for each of the three streams (Fig. 6). In line with the rationale developed in the Introduction, production (determined from the formula  $P = G \times B$ ) increases from near zero at near zero biomass (high growth rate) to a maximum at an intermediate biomass (intermediate growth rate) and then declines to zero at a higher biomass (zero growth rate). Any one such curve defines a level of productivity of a system for fish. Since productivity is continually changing, a particular production curve is usually only partially defined before a change in productivity leads to a new production curve.

Theoretical production curves were drawn that identify six general levels of productivity for the experimental stream systems

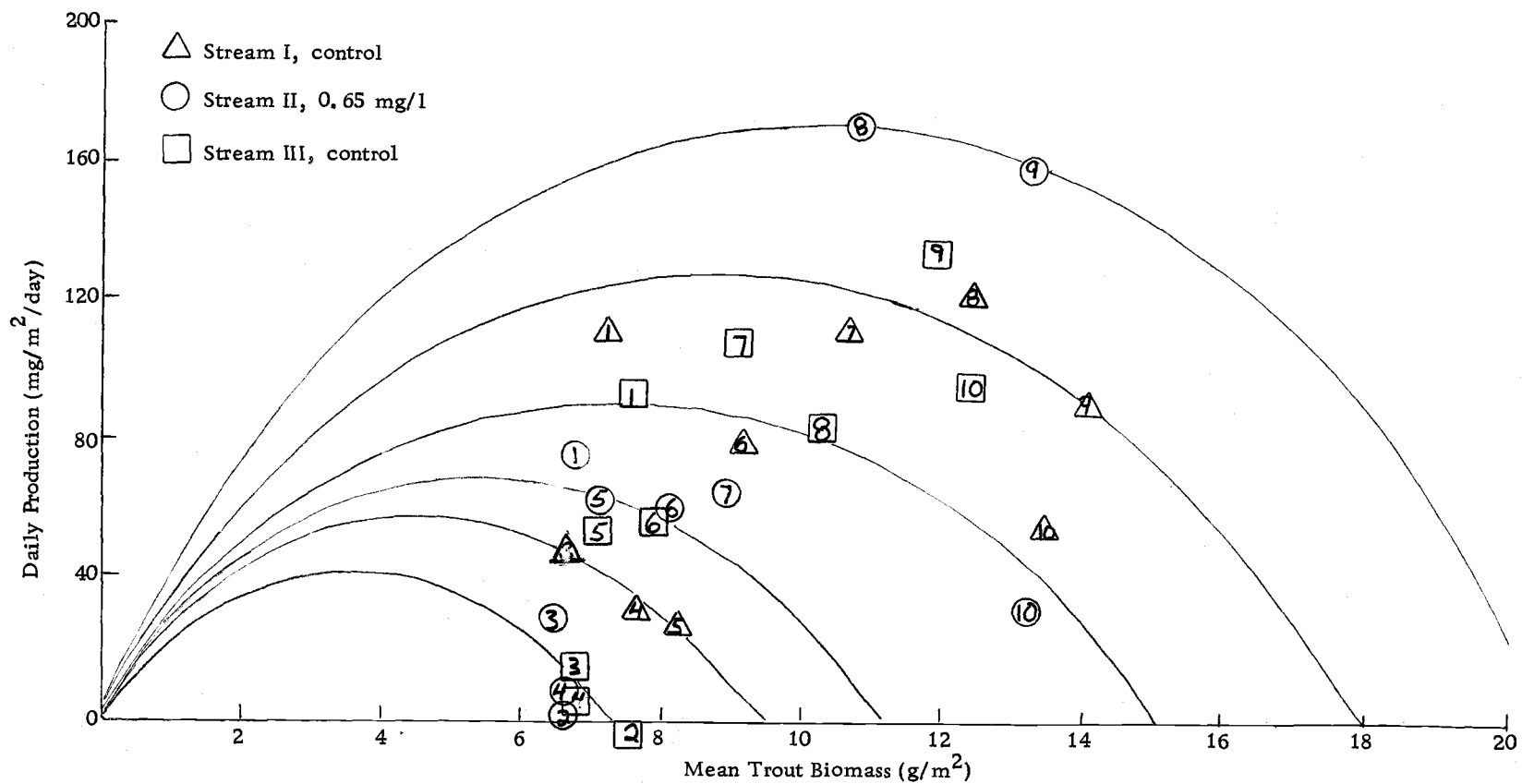


Figure 6. Relationship between daily production and mean trout biomass. Enclosed numbers refer to sampling periods.

(Fig. 6). The production curves were fitted to the variable data on the basis of theoretical relationships between production values and biomasses through time and other considerations discussed in the Introduction and to be further discussed. The production values tended to be on the descending limbs of the production curves (Fig. 6), indicating that generally the biomasses of brown trout were greater than the optimum for maximum production at each level of productivity. As productivities increased, there was a tendency for biomasses to approach the optimum level for maximum production.

Since all three streams were similar in construction and operation except for the addition of 0.65 mg/l BOD SKME to stream II, production values for all streams should lie on the same general production curve (indicating the same productivity) during a given period, unless the presence of SKME in stream II affected its productivity. Production values might lie on different parts of the same curve due to the influence of fish biomass but this would be no indication of a difference in productivity. If production values of stream II fish were consistently on different production curves than values for fish in control streams during the same periods, this would be evidence that SKME was affecting productivity.

Stream II did not consistently evidence productivity different from control streams (Fig. 6). Slight periodic differences in productivity between stream II and controls occurred during periods 1 and

10. There were, however, also differences between the productivities of the control streams. For example, during periods 3 and 4, stream I apparently had a higher productivity than did streams II or III. During period 5, stream I had lower productivity than streams II and III. Differences between the productivities of control streams were similar in magnitude to differences between stream II and the control streams during periods 1 and 10.

During period 10, mortality of fish in all streams increased greatly (Fig. 3), indicating the C. shasta infection typically occurring in May. For this reason, differences occurring during this period were not extensively analyzed.

The greatest differences occurred during period 7, when the productivity of stream II was apparently lower than that of either control stream, and during periods 8 and 9, when productivity of stream II was higher (Fig. 6). These differences may suggest some effect of SKME on production during these periods.

Relative growth rate, one determinant of production, was plotted against mean biomass (Fig. 7). In line with rationale developed in the Introduction, in a system having a single basic capacity to produce food organisms, relative growth rate decreases as mean fish biomass increases. One growth rate-biomass curve identifies one level of productivity, as long as there is only one relationship between the biomass of the fish and the biomass of their food. Higher growth



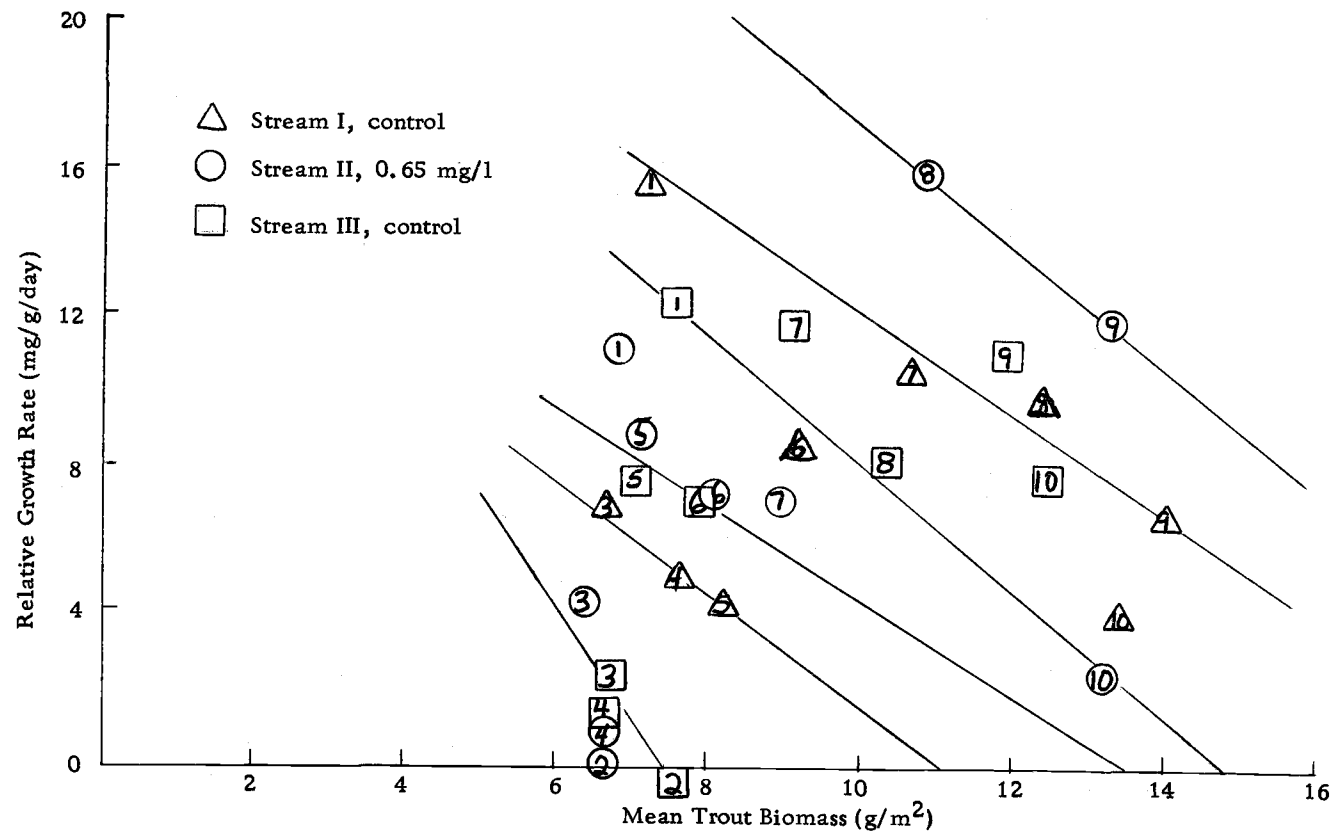


Figure 7. Relationship between relative growth rate and mean biomass of brown trout. Enclosed numbers refer to sampling periods.

rate-biomass relationships are associated with high levels of productivity. Six general growth rate-biomass relationships were identified in Figure 7, which are associated with the six general levels of productivity in Figure 6.

Production-biomass and growth-biomass relationships indicate that the productivity of stream II did not consistently differ from controls. Periodic differences--such as a lower productivity during period 7 and a higher productivity during periods 8 and 9--are related to growth rate, which may be directly or indirectly influenced by SKME. In order to further evaluate any influence of SKME, it is necessary to examine more closely those factors that may affect productivity.

#### Growth- and Density-Dependent Relations between Fish and Food Organisms

Possible effects of temperature on the growth rates of fish were discussed in the Introduction. At relatively low levels, a temperature increase may directly affect the growth of salmonids by increasing activity, food consumption, and digestion of food and thus increase scope for growth. As temperature increases further, however, the food energy used or "cost" of respiration increases exponentially and scope for growth decreases (Warren, 1971). As a result, a relatively low temperature can act as a controlling factor and restrict growth

in the presence of excess food. Averett (1969) observed that growth rate of coho salmon fed unrestricted rations decreased as temperature dropped below 5 to 8 C as a result of decreased food consumption.

Temperature may also influence growth of fish indirectly by influencing the growth, emergence, and availability of fish food organisms. Thus, temperature may influence the productivity of a system for fish either by direct or indirect effects on their growth. There could be some time differential between temperature change and change in availability of food organisms. Then, changes in productivity would lag changes in temperature. Any such change could, of course, be obscured by other factors such as light, nutrient supply, turbidity or interspecific competition.

In the three experimental streams there was some positive correlation between growth rate of brown trout and temperature through period 8, and then a negative correlation in periods 9 and 10 (Fig. 8), the latter possibly directly related to the occurrence of disease organisms stimulated by the higher temperatures. Variation from the general positive relationship reflects the influence of factors other than temperature on the growth of the fish. There could be some influence of changes in biomass of food organisms lagging changes in temperature. In order to evaluate this possibility, the relationships between growth rate of brown trout and the biomass of food organisms were analyzed. According to Warren (1971), the biomass of the fish

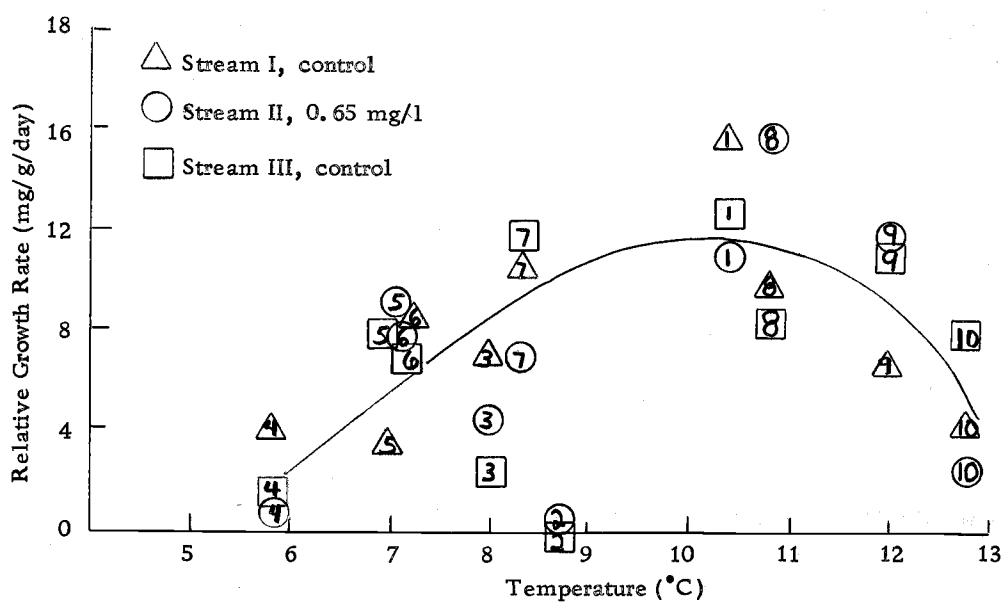


Figure 8. Relationship between relative growth rate of brown trout and stream temperature. Enclosed numbers refer to sampling periods.

may determine the biomass of the food which in turn determines the growth rate and hence the production of the fish at a given level of productivity.

Brown trout growth rate was plotted against the biomass of all invertebrates sampled in the riffles (Fig. 9). Four general relationships were identified, although considerable scattering of the points was present. The fits of the curves were improved by plotting growth rate against the sum of the biomasses of only the five most important food organisms determined from food habit analysis (Fig. 10).<sup>1</sup> Remaining scattering of values may be due to differences in food organism availabilities not reflected by their biomasses, the influence of other factors on growth rate, or the fact that only the riffles of the streams were sampled. General correlation between growth rate and food biomass is evident for four groups of values, each representing one or more levels of productivity, which depends also on the relationships between fish and food organism biomasses. Generally, the curves positioned higher on the graph represent periods of time during which temperatures were higher.

That points for stream II, during most periods, are along relationships between growth and food biomass defined for one or both control streams indicates that there is no persistent direct effect of

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<sup>1</sup>Period 10 was not included due to previously discussed mortality.

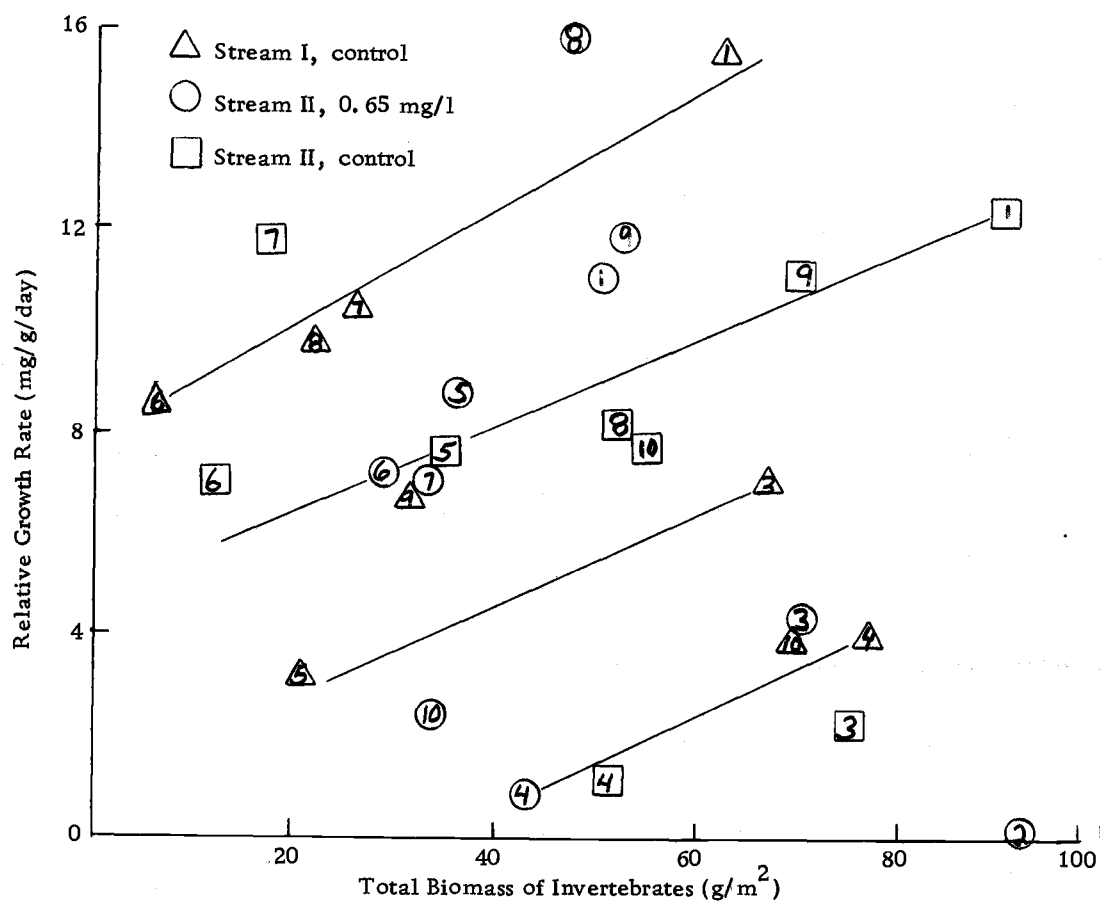


Figure 9. Relationships between relative growth rate of brown trout and biomass of total invertebrates. Enclosed numbers refer to sampling periods.

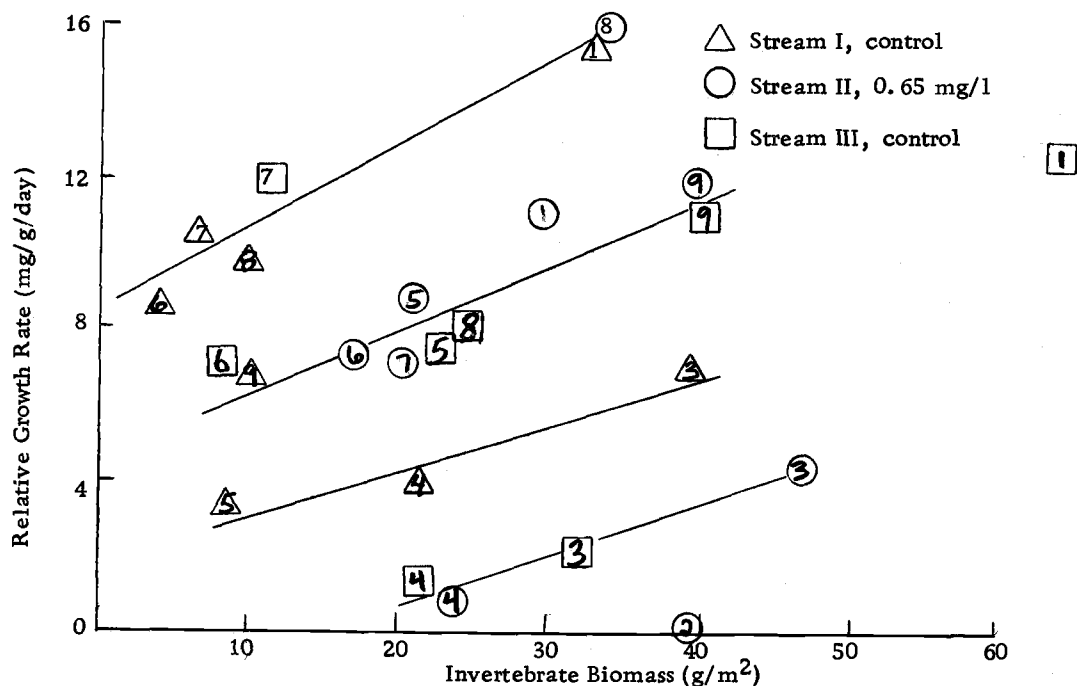


Figure 10. Relationships between relative growth rate of brown trout and the biomass of Crangonyx, Hydropsyche, Physa, Lumbricus, and chironomids. Enclosed numbers refer to sampling periods.

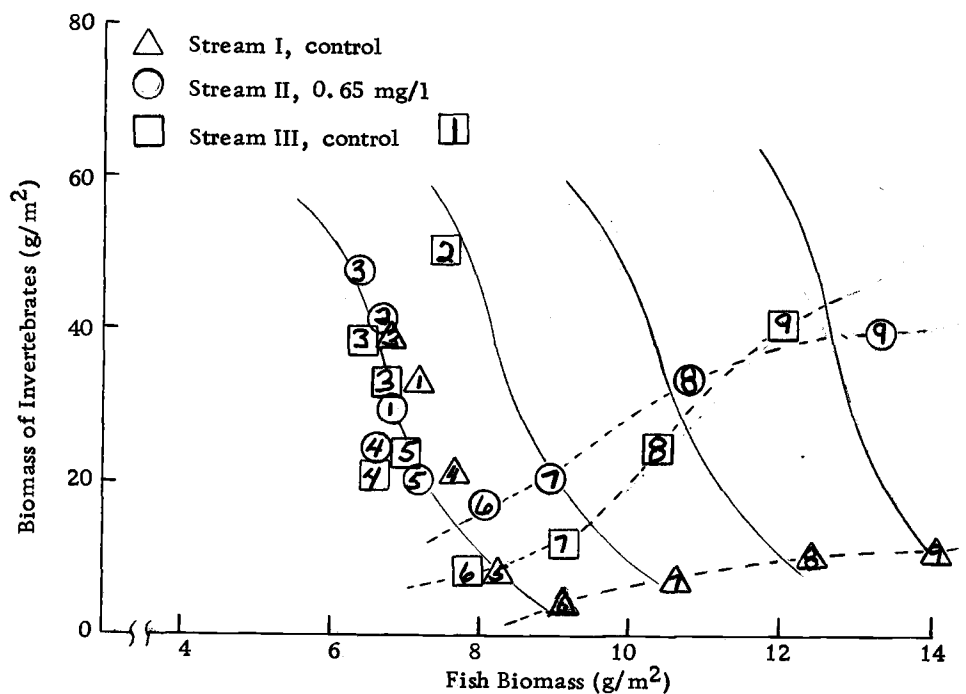


Figure 11. Relationships between mean fish biomass and biomass of Crangonyx, Hydropsyche, Physa, Lumbricus, and chironomids. Enclosed numbers refer to sampling periods.

the effluent on the growth of fish (Fig. 10). Only during period 7 is the point for stream II on a different general curve than the point for both controls. This suggests an effect of some factor other than food biomass during this period, possibly a change in food availability or a direct effect of SKME on growth. In periods 1, 8, and 9 the productivity of stream II differed from that of controls as previously discussed. Figure 10 indicates that any such differences were probably not the result of direct effects of SKME on the growth of fish. This does not, however, preclude the possibility of an indirect effect of SKME through food biomass and availability during these periods. Indeed, the apparent greater biomass of food organisms in stream II than in control streams during period 8, and resulting greater growth and production may well reflect an indirect effect of SKME through increased biomass and availability of food organisms.

The biomass of food organisms was plotted against the mean biomass of fish (Fig. 11) to consider the theoretical likelihood that the biomass of the food would be inversely related to the biomass of the fish, at a given level of productivity. One level of productivity will generally have only one food biomass versus fish biomass curve, but two levels of productivity may share the same biomass curve, being differentiated into separate levels of productivity in having different growth rate versus food biomass curves (Fig. 10). For example, all streams exhibit the same general biomass relationship during periods



3 and 4 (Fig. 11). Stream I, however, exhibits a different growth curve than streams II and III during these periods (Fig. 10) and hence a different level of productivity (Fig. 6). On the other hand, two levels of productivity may have the same growth relationship and be differentiated by having different food biomass versus fish biomass curves. These relationships were utilized in identifying six levels of productivity (Fig. 6) from combinations of four empirical growth relationships (Fig. 10) and four empirical biomass relationships (Fig. 11).

In Figure 11, the four curves having negative slopes each represent one or more levels of productivity. Transitions from one curve to another represent changes in productivity. Time tracks of fish biomass versus food biomass (dashed lines) show the transitory nature of productivity from period 6 through period 9. According to Booty (MS), higher levels such as for streams II and III represent greater rates of removal of fish biomass than occurred in stream I, this resulting in lower fish biomasses and higher food biomasses at the same levels of productivity. A matrix of inverse and direct relationships was generated as the plot of food biomass versus fish biomass followed changes in productivity. The productivity of stream III lagged behind streams I and II from period 6 through period 9.

Stream II fish generally exhibited the same biomass relationships to their food as controls (Fig. 11). Differences in productivity

between stream II and the control streams during periods 7 and 8 do not appear to have been a result of any differences in biomass relationships resulting from SKME.

On the basis of the theoretical concept developed, it seems that growth and production were greatly influenced by temperature and modified by changing food availability. There was a possible direct influence of SKME on growth during period 7. Higher productivity of stream II during period 8 may have been the result of increases in food availability not reflected in the biomass relationships.

#### Fish Food Habits and Food Availability

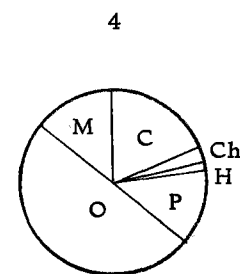
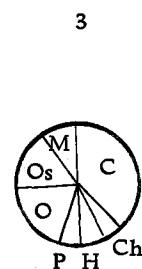
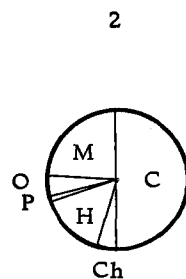
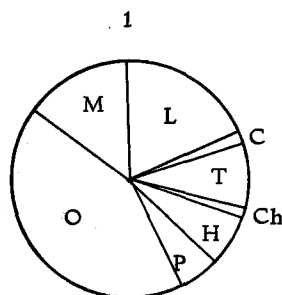
The results of stomach sample analyses make it possible to identify important food organisms. Growth rates could then be plotted against estimates of the biomass of individual kinds and groups of kinds of important food organisms in the streams (determined from riffle benthos samples) to determine any effect of SKME on growth through influence on the biomass of food organisms. Such a graph has already been shown for relationships between growth of brown trout and the total biomass of Crangonyx, Hydropsyche, Physa, Lumbricus, and chironomids (Fig. 10). Since salmonids are primarily drift feeders, however, estimates of the biomass of organisms in the benthos may not well represent food availability to fish.

The problem of food availability has been discussed by Warren (1971). He suggests that measurements of the density of drifting organisms may be better indications of what is available to salmonids than are measurements of benthic biomasses, although the difficulties of measuring drift have led to the practice of correlating of growth with benthic biomasses of food organisms. Feeding solely on drift, salmonids might not be able to much influence biomass of their food resource and growth would decrease only as an effect of division of given amounts of drifting organisms among more fish. If drift is proportionally related to the biomass of organisms in the benthos, then relationships between growth rate of fish and the biomass of organisms in the benthos may exist. The growth rate of cutthroat trout did show a positive correlation with the biomass of benthic organisms in a study of Berry Creek, a small woodland stream in western Oregon (Warren, 1971). Also, brown trout may feed more on the bottom than other salmonids (Horton, 1961). But the biomasses of food organisms may not be additive if their influences on growth of fish, if availability of organisms of different kinds at the same biomasses, or selectivity of organisms by fish differ.

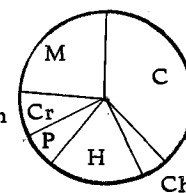
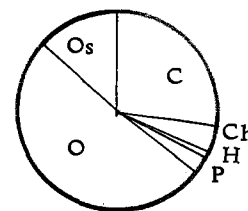
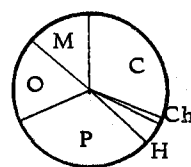
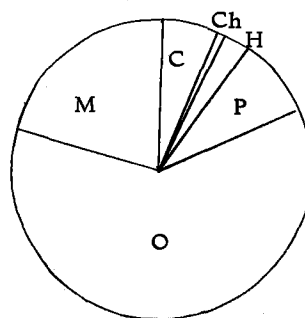
Appendix 4 lists those organisms found in brown trout stomachs. Figure 12 represents the relative abundances of the most abundant food organisms found in the stomach sample analyses. The area of each circle represents the relative magnitude of the total amount of

Sampling Period:

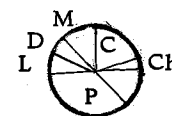
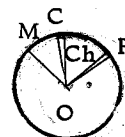
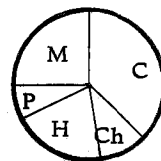
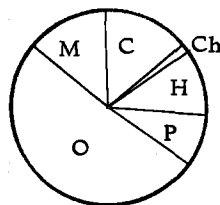
Stream  
I Control



II 0.65 mg/l



III Control



C Crangonyx spp.  
Ch Chironomidae  
Cl Sphaeriidae  
Co Collembola  
Cr Misc. Crustacea  
D Misc. Diptera  
H Hydropsyche spp.  
L Lepidostomatidae  
M Miscellaneous  
O Lumbricus spp.  
Os Ostracoda  
P Physa spp.  
S Sialis spp.  
T Tubificidae

Figure 12. Relative abundance of food organisms in fish stomachs.

Sampling Period:

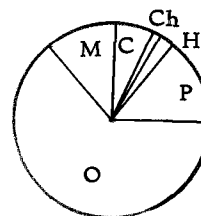
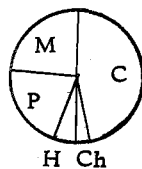
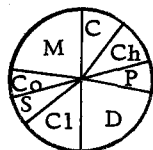
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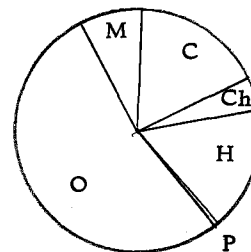
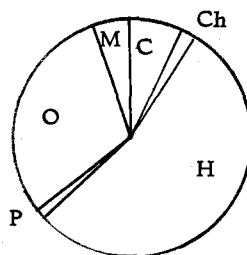
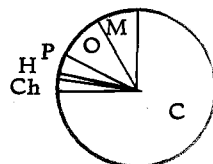
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Stream

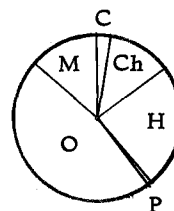
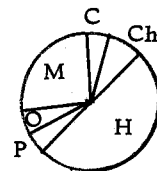
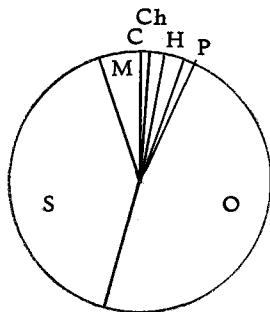
I Control



II 0.65 mg/l



III Control

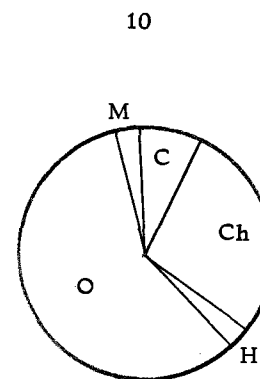
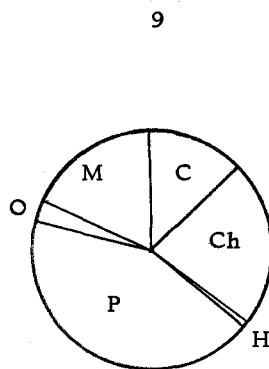
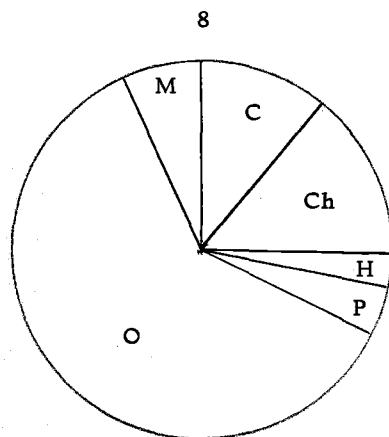


C Crangonyx spp.  
Ch Chironomidae  
Cl Sphaeriidae  
Co Collembola  
Cr Misc. Crustacea  
D Misc. Diptera  
H Hydropsyche spp.  
L Lepidostomatidae  
M Miscellaneous  
O Lumbricus spp.  
Os Ostracoda  
P Physa spp.  
S Sialis spp.  
T Tubificidae

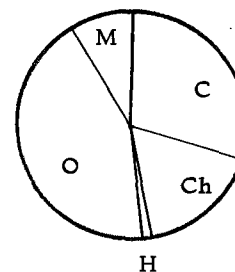
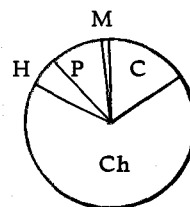
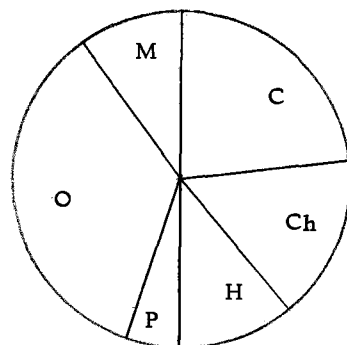
Figure 12. (Continued)

Sampling Period:

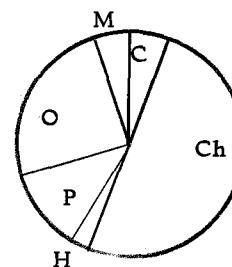
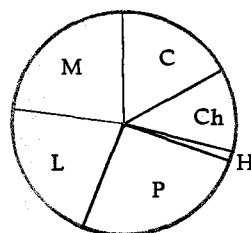
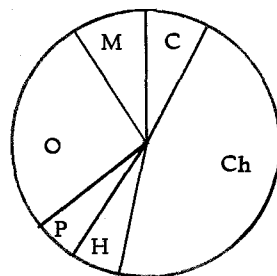
Stream  
I Control



II 0.65 mg/l



III Control



C Crangonyx spp.  
Ch Chironomidae  
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D Misc. Diptera  
H Hydropsyche spp.  
L Lepidostomatidae  
M Miscellaneous  
O Lumbricus spp.  
Os Ostracoda  
P Physa spp.  
S Sialis spp.  
T Tubificidae

Figure 12. (Continued)

food in the sets of stomach samples, while relative amounts of particular kinds of food organisms are represented by the areas of the sections. If food consumption rate is correctly reflected by the amounts of food in the stomachs of fish at particular times, then stream II fish apparently ate more than control fish during periods 1, 3, 6, and 7. Estimates of the biomass of organisms in the stream were higher for stream II only during periods 7 and 8 (Appendix 5). If, indeed, the consumption by stream II fish during periods 1 and 3 was greater than that of fish in stream I or stream III, it may have been due to an increased availability (although not abundance) of food organisms. The growth rates of stream II fish, however, were not greater than controls during any of these periods. Stream II fish, on the basis of stomach contents, ate less than stream I fish during period 8, when growth was higher than that of control streams, even though the biomass of food organisms in the stream was not less than that of control streams (Appendix 5). The lower growth of stream II fish during period 7 and higher growth during period 8 could not be explained on the basis of total stomach contents. Any conclusions, however, regarding total consumption rate based on stomach contents must be very tentative for several reasons (Davis and Warren, 1967).

The most utilized food organisms were Crangonyx spp., Chironomids, Hydropsyche spp., Physa spp., and Lumbricus spp. (Fig. 12). The relative abundance of each of these in the diets of the

fish, according to stomach content analysis, differed between streams and through time. The most abundant organism in stomachs (percent by weight) was Lumbricus although Crangonyx was consistently the food item taken most frequently (unpublished data). Chironomids became more important in periods 8, 9, and 10, corresponding to seasonal emergence patterns.

Stream II fish apparently consumed slightly more Crangonyx than control fish, during periods 4, 5, 7, 8, and 10 (Fig. 12). Estimates of the density and biomass of Crangonyx in stream II were greater than those for the controls through period 8 (Appendix 5). Craven (unpublished data) observed a greater biomass of Crangonyx in stream II, receiving 0.75 mg/l BOD SKME in a previous experiment. Lichatowich (1970) also reported an increased biomass of organisms in laboratory streams as a result of SKME. Perhaps as Seim (1970) observed in laboratory streams, any direct harmful effect of SKME on growth during periods 1 through 7 could have been compensated by a greater biomass and availability of Crangonyx induced by SKME, resulting in greater food consumption. Generally, however, there is little evidence to support an explanation based on direct effects of SKME on growth. The greater growth rate of stream II fish during period 8 may have been the result of greater biomass of Crangonyx in the stream during this period. But the total amount of food in the stomachs of stream II fish did not greatly differ from that in the stomachs



of control fish (Fig. 12). Stream II fish appear to have eaten more Crangonyx "instead of" rather than "in addition to" other organisms.

Chironomids were generally about equally abundant in the diets of fish in the three streams and became more abundant during periods 8, 9, and 10. Similar biomasses of chironomids occurred in all three streams. There appears to have been no effect of SKME on the growth and production of fish through effects on the biomass of chironomids in stream II.

Hydropsyche was occasionally an important food item for stream II fish (periods 4, 6, 7, and 8; Fig. 12). None of these periods corresponded to a period when estimates of the biomass of Hydropsyche in stream II were lower than those for control streams (Appendix 5). The biomass of Hydropsyche in stream II was higher than in controls only during period 7, when growth of stream II fish was lower than that of control fish. Generally, differences between the biomass of Hydropsyche in stream II and in controls were reflected by differences in stomach contents during the same periods. There were no great differences in biomass of Hydropsyche among the three streams. Numbers of Hydropsyche, however, were consistently lower in stream II than control streams until period 6 (Seim, unpublished data). There was no correlation between the observed lower growth of stream II fish as compared to control fish during period 7 and higher growth during period 8, and changes in the biomass of Hydropsyche that could be attributed to SKME.

The biomass of Physa in the streams did not consistently differ among the streams (Appendix 5). Periods when the biomass of Physa in stream II differed from controls (periods 1 and 4) did not coincide with periods when growth of stream II fish differed greatly from control fish (periods 7 and 8). Growth was, however, slightly lower in stream II during period 1, when the biomass of Physa in stream II was lower than that in most control streams. In general, however, there could have been no great effect of SKME on growth through an effect on the biomass of Physa.

Lumbricus was frequently an important food item and generally of equal importance in all streams (Fig. 12). The biomass of Lumbricus in the streams was generally similar for all streams. In period 7, however, when Lumbricus constituted 54 percent of the stomach contents of stream II fish, the biomass of Lumbricus in stream II was lower than that in control stream III. Growth rate of brown trout was lower in stream II than in both control streams during this period. Nevertheless, the total amount of food and of Lumbricus in the stomachs of stream II fish were greater than for control fish. There is no readily apparent relationship between the abundance of Lumbricus in the benthos, in the stomachs of fish, the growth of fish, and the presence of SKME.

Better correlations occur between the growth of fish and the sum of the biomasses of groups of organisms than between the growth

of fish and the biomasses of single organisms (Figs. 9 and 10). This is not surprising since no single organism was consistently most abundant in the diets of fish.

### Effects on Reproduction

Results of the steelhead development experiment indicate no considerable differences in time until hatching, weight of yolk, or weight of alevins at hatching that could be attributed to 0.65 mg/l BOD (4.1 percent) SKME (Table 1). Survival of embryos until hatching was lower in stream II (82 percent) than controls (88 percent). This difference resulted from low survival (57 percent) in only one of the five incubation boxes in stream II. 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.

Time until emergence, survival to emergence, and size of alevins at emergence were similar for all streams (Table 1). Figure 13 shows 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 for each stream. No differences between dry weights of yolk and alevins in stream II and dry weights in controls were apparent. Servizi, Stone, and Gordon (1966), however,

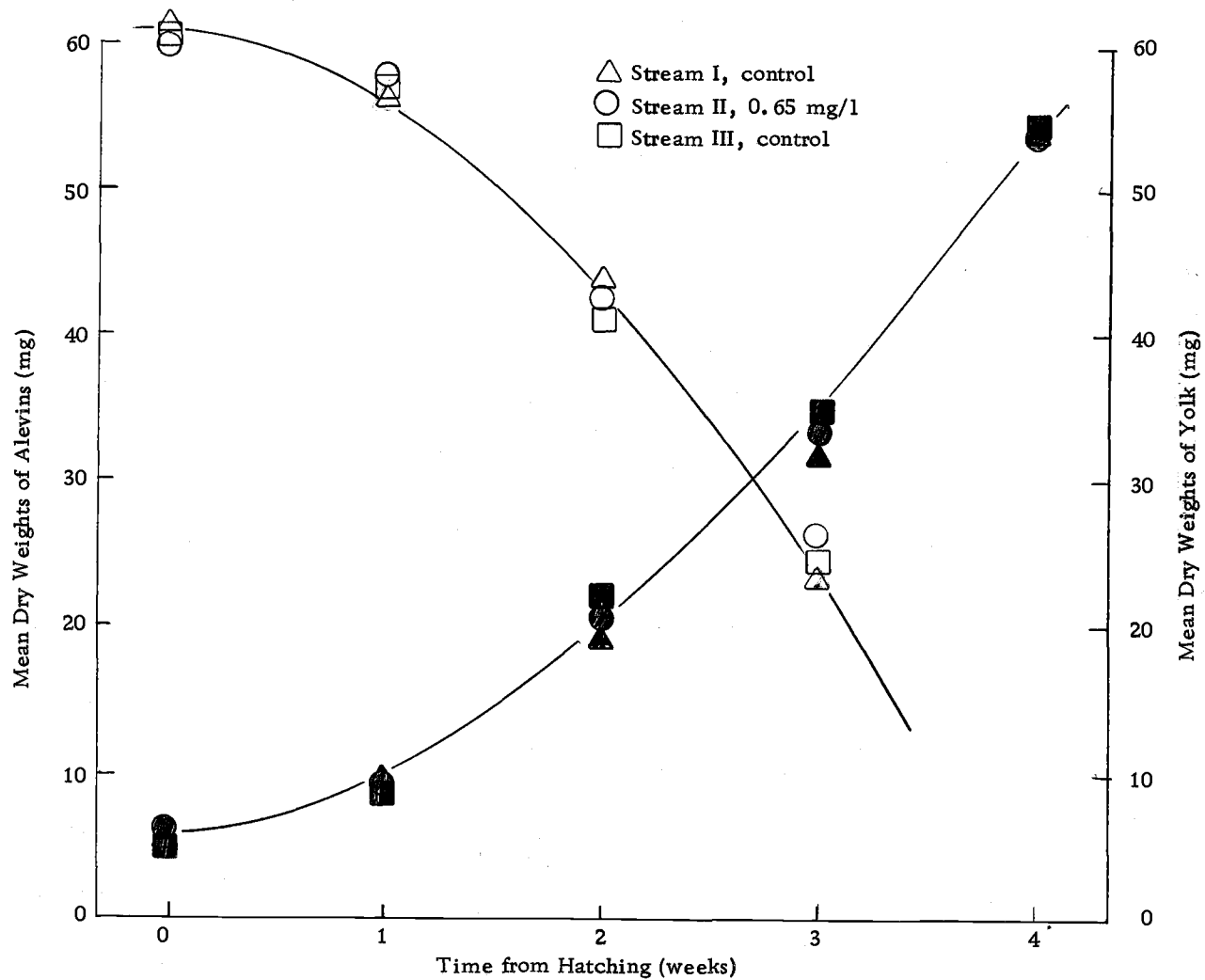


Figure 13. Relationships between mean dry weights of steelhead alevins minus yolk (solid symbols) and mean dry weights of yolk (open symbols) and time following hatching.

Table 1. Survival and development of steelhead embryos and alevins.

	Stream		
	I	II	III
<u>Embryos</u>			
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
<u>Alevins</u>			
Days to emergence	25	25	25
Percent survival to emergence	96	96	95
Size at emergence (mg)	54.2	53.6	54.0

observed 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 growths restricting water flow. Filamentous growths of the bacterium Sphaerotilus natans can occur in streams receiving relatively high concentrations of SKME, such growths blocking the interstices of the gravel and reducing flow of water and oxygen critical 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 growths of Sphaerotilus occurred in wooden stakes used to mark egg basket location in streams. In a previous study, Borton (1975) observed growth of Sphaerotilus in stream II, when this stream was receiving about the same BOD of less fully stabilized 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 AND CONCLUSIONS

Previous studies in aquaria (Borton, 1970; Tokar, 1968) and in laboratory streams (Seim, 1970) have indicated that levels above 0.5 mg/l BOD KME or SKME can reduce growth rate and production of salmonids. Nevertheless, Borton (1975) showed no adverse effect of 0.75 mg/l BOD SKME on the growth and production of salmonids in the experimental stream channels used in the present study. Borton observed total production of coho salmon of 13.98, 16.73, and 7.68 g/m<sup>2</sup> in streams I, II, and III respectively, from February to May 1972, a period of three months when stream II was receiving 0.75 mg/l BOD SKME. The production of brown trout in the three streams from June 1972 until January 1973, a period of seven months when stream II was receiving 0.75 mg/l BOD SKME, was 17.82, 16.72, and 11.88 g/m<sup>2</sup> for the three streams respectively. Higher production was observed in both of these studies than the present study in which production values of 12.80, 12.93, and 12.04 g/m<sup>2</sup> were observed in streams I, II, and III respectively from October 1973 until May 1974, a period of seven months, during which stream II was receiving 0.65 mg/l BOD SKME.

Apart from the obvious differences in seasons when these experiments were performed, there may be other reasons for the slightly lower production in the present experiment. The productivity of the

streams for coho salmon is apparently greater than for brown trout (Borton, 1975). Borton's brown trout were initially of the 0+ age class while those in the present experiment were initially in the 1+ age class. According to Warren (1971), younger fish generally achieve higher relative growth rates than do older and larger fish. In addition, the mean biomass of fish was higher during the present study than in Borton's study. Production values were generally well down the descending limb of the production biomass curves (Fig. 6) while those in Borton's study tended to be nearer the maximum of the production curves. Production in the present study was less than the maximum possible because of high mean biomasses.

The growth of fish in a growth stanza may reach an ecological threshold and become limited by the size of the food. That is, the metabolic cost of activity for a large fish to catch enough small food organisms to fulfill its maintenance requirements is so great that scope for growth is reduced and growth approaches an asymptote for the growth stanza. If the fish are able to shift their diet to larger food items, they may enter a new growth stanza and begin to grow more rapidly again (Warren, 1971). The larger brown trout in this experiment may have experienced such a phenomenon, since there were no large food items present in the stream channels.

Borton (1975) reported a much lower production of fish in stream III than in streams I and II for both studies. He tentatively



attributed this to the effect of disease on growth and biomass of fish and to predation by kingfishers. In the present study, production of brown trout in stream III was only slightly lower than in streams I and II. Apparently the productivity of stream III for brown trout is less than streams I and II and the effects of disease on growth and biomass of fish may be involved in this.

The effluent used by Borton was treated for 8 to 16 days in the 8.5 hectare aeration basin and frequently exhibited a 96-hour TLM to salmonids of 70 to 80 percent by volume. The source of effluent used in the present experiment was the same, additionally treated in a 0.2 hectare polishing pond for 10 days. The effluent seldom resulted in any mortality of salmonids exposed to a 100 percent concentration in 96-hour acute toxicity bioassays being run concurrently (Wilson, in progress).

Borton was not able to consistently correlate growth rate with the biomass of any one particular organism in the riffle benthos, since no single organism was consistently dominant in stomach samples. The same conclusion was reached in this study. Borton also concluded the productivities of the streams were changing about every three months, and he observed changes in November in both studies. A change in productivity in November was also observed in the present study. Frequent changes in growth rate-biomass and production-biomass relationships indicate, however, that productivity

is probably not constant for periods as long as three months. In the present study of 0.65 mg/l BOD SKME, as in Borton's study of 0.75 mg/l BOD SKME, growth and production of salmonids in experimental stream channels were apparently not limited by the level of SKME used. Contemporaneous studies by Wilson (in progress) showed no effect of 0.75 mg/l BOD of the polished effluent used in the present experiment on the growth of salmonids in aquaria. Growth rates of salmonids exposed to 1.5 mg/l BOD SKME were reduced.

The productivity of the streams for salmonids seems quite high compared to other trout streams. The production of brown trout during this experiment was much greater ( $\approx 12 \text{ g/m}^2/7 \text{ months}$ ) than the production of coastal cutthroat trout (0.60-0.70  $\text{g/m}^2/\text{yr}$ ) in a study of Berry Creek, a small stream in western Oregon (Warren *et al.*, 1964). Hopkins (1971) measured a production of 14  $\text{g/m}^2/\text{yr}$  of brown trout at biomasses ranging from 3 to 8  $\text{g/m}^2$  in New Zealand. At lower densities of fish than in the present study, Egglshaw (1970) observed production of 6 to 12  $\text{g/m}^2/\text{yr}$  of brown trout and 16 to 25  $\text{g/m}^2/\text{yr}$  of brown trout and Atlantic salmon, Salmo salar, in a stream in Scotland. In chalk streams in England, LeCren (1968) measured production of 2 to 12  $\text{g/m}^2/\text{yr}$  of brown trout. Total fish production, however, was 60  $\text{g/m}^2/\text{yr}$  due mostly to sculpins, Cottus gobio. The numerical density (0.1-0.5/ $\text{m}^2$ ) and biomass (0.6-11.6  $\text{g/m}^2$ ) of 1+ age class brown trout was less than the density

( $0.35-0.85/\text{m}^2$ ) and biomass ( $6.50-14.50 \text{ g}/\text{m}^2$ ) of fish in the present study. In the present study, however, no competition for food and space from other species existed.

Chapman (1967) states the average production for brown trout reported in the literature is near  $14 \text{ g}/\text{m}^2/\text{yr}$ . Thus, the production that occurred in the present study is indicative of a highly productive system. If the production occurring in preliminary studies from June until October 1973 is combined with the production occurring during this experiment, a total production of 23.44, 23.28, and  $19.66 \text{ g}/\text{m}^2$  of brown trout (for the three streams respectively) was observed. Except for low biomasses of brown trout caused by disease problems during June to October (which is the reason the experiments were not included), an annual production of near  $30 \text{ g}/\text{m}^2$  would have been realized, an indication of a highly productive system. Production of brown trout in this study was, however, lower than that found in a study of the Horokiwi stream in New Zealand,  $54.7 \text{ g}/\text{m}^2/\text{yr}$  (Allen, 1951).

In summary, growth rate and production were affected little if at all by  $0.65 \text{ mg}/\text{l}$  BOD (4.1 percent) SKME. A conceptual framework developed by Warren (1971) was useful in exploring these relationships. Changing productivities in the streams appeared to be temperature related until period 8, but were modified by changing biomasses of food organisms, after which production was greatly

influenced by fish biomass. The survival and development of steel-head embryos and alevins was not affected by 0.65 mg/l (4.1 percent) BOD SKME under the experimental conditions.

This experiment was designed to determine whether a level of 0.65 mg/l (4.1 percent) BOD SKME would reduce the growth and production of brown trout in experimental stream channels and to help identify a threshold for effects of SKME on growth and production of salmonids in natural systems. More generally, the experiment is an attempt to aid in the explanation of the distribution and abundance of animals in space and time.

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# APPENDIX 1

Rainfall and water quality of Willamette River water from October 1973 through May 1974.

Week Begins		Mean Flow (l/min)	Mean Temp. (°C)	D. O. (mg/l)	pH	Alkalinity (mg/l CaCO <sub>3</sub> )	Hardness (mg/l CaCO <sub>3</sub> )	Monthly Rainfall (cm)
October	21	770	-	-	-	-	-	6.9
	28	792	11.5	-	-	24.2	36.0	
November	4	830	9.4	11.0	7.8	24.0	38.0	46.4
	11	810	9.4	10.6	7.6	25.6	36.0	
	18	810	8.4	-	7.5	25.8	37.0	
	25	860	8.0	-	7.4	26.8	39.0	
December	2	830	8.0	-	7.4	-	-	31.5
	9	761	7.9	-	7.2	28.0	41.0	
	16	774	8.0	-	7.0	26.2	40.0	
	23	761	6.9	-	7.3	28.2	42.0	
	30	774	5.0	-	7.4	28.0	40.0	
January	6	830	4.6	-	7.2	34.0	40.0	29.4
	13	830	5.8	-	7.1	42.0	41.0	
	20	810	6.9	-	7.1	36.0	41.0	
	27	810	7.2	-	7.2	40.0	42.0	
February	3	810	6.9	-	7.0	42.0	43.0	19.1
	10	810	6.8	-	6.8	-	-	
	17	830	7.1	-	7.0	42.0	45.0	
	24	810	7.2	-	6.9	40.2	47.6	

(Continued on next page)

Appendix 1. (Continued)

Week Begins		Mean Flow (l/min)	Mean Temp. (°C)	D. O. (mg/l)	pH	Alkalinity (mg/l CaCO <sub>3</sub> )	Hardness (mg/l CaCO <sub>3</sub> )	Monthly Rainfall (cm)
March	3	774	7.1	-	6.9	43.3	42.1	22.5
	10	792	8.3	12.8	6.9	40.0	40.0	
	17	774	10.0	11.8	7.2	38.0	36.0	
	24	761	10.8	11.8	7.0	36.2	34.0	
	31	761	10.8	11.8	7.1	32.2	40.0	
April	7	774	11.2	11.4	7.2	27.8	41.0	6.1
	14	748	12.1	10.1	7.1	26.8	38.0	
	21	736	12.7	9.9	7.2	23.4	36.0	
	28	736	12.7	11.8	7.1	24.2	34.0	
May	5	725	12.6	10.5	7.1	24.0	36.0	3.7
	12	748	12.8	-	-	-	-	

## APPENDIX 2

Mean weekly concentrations of stabilized kraft mill effluent in stream  
II from October 1973 through May 1974.

Week Beginning		Mean BOD (mg/l)	SKME Concentration (mg/l)	Percent by Vol.
October	21	23.0	0.50	2.2
	28	23.0	0.48	2.1
November	4	23.0	0.46	2.0
	11	12.0	0.49	4.3
	18	12.0	0.58	5.1
	25	17.0	0.67	4.1
December	2	16.0	0.83	5.5
	9	20.0	1.07	5.7
	16	19.0	0.80	4.4
	23	10.0	0.38	3.9
	30	13.0	0.48	3.8
January	6	19.0	0.65	3.6
	13	19.0	0.67	3.7
	20	17.0	0.61	3.7
	27	14.0	0.49	3.6
February	3	15.0	0.54	3.7
	10	18.0	0.63	3.6
	17	19.0	0.66	3.6
	24	20.0	0.87	4.5
March	3	18.0	0.72	4.2
	10	16.0	0.64	4.2
	17	16.0	0.65	4.2
	24	24.0	1.01	4.4
	31	20.0	0.77	4.0
April	7	17.0	0.73	4.5
	14	15.0	0.68	4.7
	21	16.0	0.70	4.6
	28	16.0	0.75	4.9
May	5	11.0	0.49	4.6
	12	<u>14.0</u>	<u>0.59</u>	<u>4.4</u>
Mean October-May		17.0	0.65	4.1

## APPENDIX 3

Survival, growth rate, production, and biomass of brown trout for each sampling period from October 1973 through May 1974.

Sampling Period: Date Sampled:	Stocking Oct 25	1 Nov 13	2 Nov 27	3 Dec 27	4 Jan 29	5 Feb 13	6 Mar 7	7 Mar 21	8 Apr 10	9 May 1	10 May 17
<u>Stream I</u>											
Number caught	160	128	99	87	89	95	99	92	99	92	74
Estimated numbers	-	131	119	114	112	110	108	106	104	97	78
Mean weight (g)	9.88	13.26	11.78	14.58	16.65	17.45	21.29	24.67	30.03	34.35	36.66
Present biomass (g/m <sup>2</sup> )	6.87	7.55	6.09	7.23	8.11	8.35	10.00	11.37	13.58	14.49	12.43
Mean biomass (period)		7.21	6.82	6.66	7.67	8.23	9.17	10.68	12.47	14.03	13.46
Daily production (mg/m <sup>2</sup> /day)		112.5	57.4	47.2	30.8	27.5	79.1	112.3	122.3	90.7	54.9
Relative growth rate (mg/g/day)		15.6	-8.4	7.0	4.0	3.3	8.6	10.5	9.8	6.7	4.0
<u>Stream II</u>											
Number caught	170	142	124	98	90	108	110	82	91	90	74
Estimated numbers	-	145	130	121	118	116	113	111	106	96	78
Mean weight (g)	8.37	10.34	10.36	11.84	12.20	13.95	16.36	18.10	24.93	32.03	33.29
Present biomass (g/m <sup>2</sup> )	6.68	7.04	6.32	6.73	6.76	7.60	8.69	9.43	12.41	14.44	12.19
Mean biomass (period)		6.80	6.62	6.46	6.68	7.11	8.07	8.98	10.82	13.30	13.19
Daily production (mg/m <sup>2</sup> /day)		75.9	0.9	27.8	6.0	63.4	58.8	64.0	172.3	158.8	31.8
Relative growth rate (mg/g/day)		11.1	0.1	4.3	0.9	8.9	7.2	7.1	15.9	11.9	2.4
<u>Stream III</u>											
Number caught	171	156	130	104	104	107	111	82	97	94	77
Estimated numbers		159	135	121	118	116	113	111	106	99	80
Mean weight (g)	8.62	10.95	10.87	11.62	12.07	13.65	15.87	18.75	22.06	27.90	31.57
Present biomass (g/m <sup>2</sup> )	6.86	8.10	6.83	6.54	6.62	7.36	8.34	9.68	10.88	12.85	11.75
Mean biomass (period)		7.55	7.53	6.75	6.64	7.06	7.93	9.10	10.37	11.97	12.41
Daily production (mg/m <sup>2</sup> /day)		94.1	-3.9	15.0	7.6	54.2	56.8	108.1	84.3	133.8	96.3
Relative growth rate (mg/g/day)		12.4	-0.5	2.2	1.1	7.6	7.1	11.8	8.1	11.1	7.7

## APPENDIX 4

## BROWN TROUT FOOD ORGANISMS

## Annelida

Oligochaeta

Plesiopora

Lumbricidae

Lumbricus spp.

Tubificidae

## Arthropoda

Arachnoidea

Hydracarina

Crustacea

Amphipoda

Gammaridae

Crangonyx spp.

Tilitridae

Hyalella spp.

Cladocera

Eucopepoda (Copepoda)

Isopoda

Podocopa (Ostracoda)

## Insecta

Coleoptera

Carabidae

Dytiscidae

Hydrophilidae

Psephenidae

Collembola

Diptera

Ceratopogonidae

Chironomidae

Culicidae

Dixidae

Empididae

Simuliidae

Tabanidae

Tipulidae

## Arthropoda (cont'd)

Insecta (cont'd)

Ephemeroptera

Baetidae

Baetis spp.

Heptageniidae

Hemiptera

Aphididae

Corixidae

Gerridae

Hymenoptera

Formicidae

Lepidoptera

Pyralidae

Megaloptera

Sialidae

Sialis spp.

Tricoptera

Hydropsychidae

Hydropsyche spp.

Lepidostomatidae

## Mollusca

Gastropoda

Pulmonata

Physidae

Physa spp.

Lymnaeidae

Radix spp.

Pelecypoda

Eulamellibranchia

Spheriidae

## APPENDIX 5

Biomass ( $\text{g/m}^2$ ) of food organisms in riffle benthos (from Seim, ).

	Sampling Period									
	1	2	3	4	5	6	7	8	9	10
<u>Stream I</u>										
<u>Crangonyx</u>	5.6	6.5	10.5	3.4	5.0	1.2	4.0	1.9	2.4	5.8
<u>Chironomidae</u>	1.2	1.3	0.7	0.2	0.2	0.1	0.2	0.6	0.7	3.3
<u>Hydropsyche</u>	12.6	22.0	14.1	10.7	3.0	2.7	0.8	0.3	1.7	8.2
<u>Physa</u>	13.7	9.0	10.8	3.0	0.3	0.1	0.1	0.0	0.0	0.0
<u>Lumbricus</u>	0.0	1.1	3.6	4.2	0.0	0.0	1.6	7.1	5.5	1.5
All organisms	60.3	80.3	68.2	77.6	20.6	6.5	15.5	22.5	31.5	69.6
<u>Stream II</u>										
<u>Crangonyx</u>	14.8	23.8	21.0	13.0	12.5	8.8	11.9	21.0	15.2	1.8
<u>Chironomidae</u>	0.4	0.5	0.4	0.6	0.6	0.5	0.4	1.2	1.7	2.3
<u>Hydropsyche</u>	7.4	9.6	15.1	9.0	5.0	3.5	5.9	8.0	16.8	0.7
<u>Physa</u>	4.9	4.5	7.7	0.8	0.7	0.3	0.0	0.7	0.7	0.4
<u>Lumbricus</u>	2.2	0.6	2.9	0.0	1.9	3.9	2.0	2.7	5.2	3.7
All organisms	50.5	93.8	71.3	42.6	36.4	29.8	31.7	47.1	52.5	34.0
<u>Stream III</u>										
<u>Crangonyx</u>	14.8	10.3	4.0	7.7	6.3	3.6	3.5	3.5	10.2	4.3
<u>Chironomidae</u>	0.9	0.5	0.6	0.4	0.1	0.1	0.2	2.5	2.8	4.3
<u>Hydropsyche</u>	34.3	35.6	20.1	6.1	14.8	3.6	3.4	9.1	8.1	13.8
<u>Physa</u>	9.9	4.0	2.9	2.4	1.1	0.1	0.1	0.0	0.1	2.0
<u>Lumbricus</u>	6.6	0.0	4.5	4.9	0.6	0.6	4.1	9.5	18.9	2.3
All organisms	91.2	80.4	75.5	50.5	35.0	12.6	17.1	52.4	69.9	55.0