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DISCHARGE ON THE JORDAN RIVER, NORTHERN
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Michigan State University, Ph.D., 1972
Limnology

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POTAMOLOGICAL EFFECTS OF FISH HATCHERY
DISCHARGE ON THE JORDAN RIVER,
NORTHERN LOWER MICHIGAN

By
Adam T. Szluha

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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Department of Fisheries and Wildlife

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ABSTRACT

POTAMOLOGICAL EFFECTS OF FISH HATCHERY
DISCHARGE ON THE JORDAN RIVER,
NORTHERN LOWER MICHIGAN

By
Adam T. Szluha

The Bureau of Sport Fisheries and Wildlife is operating a lake trout (Salvelinus namaycush) hatchery in the Jordan River Valley utilizing two systems of springs for its water supply. Until the spring of 1972 the hatchery had been discharging its wastes into the Jordan River without any formal treatment. During the winter of 1971 and 1972 two settling basins were built to remove 80-95% of settleable solids from the wastewater.

In order to evaluate the ecological impacts of the hatchery wastes on the receiving stream, periphytic production rates and the oxygen balance were determined at locations above and below the outfalls during March through June, 1971 and again in 1972.

Periphytic production rates increased exponentially during the study periods. Mean productivity rates were seven times greater below the outfalls than at the control station above the discharge in 1971, and five times greater in 1972.

Adam T. Szluha

Diurnal oxygen concentrations and temperature curves were obtained from sections above and below the hatchery discharges in order to estimate gross primary productions and community respirations. However, undeterminable ground and surface water accrual with oxygen concentrations usually lower than in the Jordan River distorted rates of changes of oxygen concentrations which were necessary to calculate gross primary production and community respiration.

A primary production index was calculated from the diurnal oxygen curves. These data indicated that the oxygen balance in the Jordan River was not effected significantly by the hatchery effluent either before or after installation of settling basins.

ACKNOWLEDGEMENTS

During my research connected with the preparation of this dissertation, I encountered a number of friends, associates and professors without the help of whom my work would have proved to be a much more difficult and time consuming effort. I am naturally very grateful for the fact that these individuals were so ready to make themselves available to me when I needed their aid. Their assistance has been undoubtedly of the nature for which I can hardly expect to reciprocate by writing these acknowledgements as a prelude to the rest of this paper; however, it will have to suffice as the only method of expressing gratitude available to me at this time. (I do not mean to imply that other forms of expression will come at a later time.)

First of all, I want to express my appreciation to Dr. Dean Eyman for a friendship which has been invaluable to me since our undergraduate days, as well as his expert assistance in sampling efforts in the Jordan River Valley. Our discussions dealing with ecological philosophy and research have been meaningful and helpful to me.

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Lastly, I want to thank my wife, Kati, for her financial contribution and her moral support to the project--me. Both have been invaluable; the fact that she made excellent use of her training in persuasive speaking by telling me--and everyone else who was interested in listening--that I would certainly finish my degree this summer, has been a source of real motivation for doing just that. She has been instrumental in accomplishing the goal not only by doing rereading and typing for me, but also by reminding me of it--daily.

I want to dedicate this dissertation to my father, Dr. Stephan Szluha, who has at times expressed a doubt that this Ph.D. would ever materialize, and to my sons, Martin and Christopher who have never stopped being amazed at the fact--and found it somewhat embarrassing to explain to friends--that Daddy is still in school. I want them to know that I did it all for them.

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INTRODUCTION

By the end of the 1950's, as a result of lamprey (Petromyzon marinus) predation, the lake trout (Salvelinus namaycush) population of the Great Lakes was facing severe reductions. To compensate for the predatory losses, hatcheries were built and stocking programs initiated. The Jordan Valley National Fish Hatchery, located in Antrim County, Michigan (Figure 1) is part of this program. The hatchery began operation in 1964, utilizing two systems of springs for its water supply. The water was circulated through the race-ways one to seven times, depending on the ambient air temperatures, and then discharged into the Jordan River without any formal treatment.

During the period of 1966 to 1969, several short-term studies were conducted on the Jordan River, investigating potential pollution by the hatchery. In 1966, the Bureau of Sport Fisheries and Wildlife estimated a nutrient budget for the hatchery's effluent and the river. Although nutrient concentrations in the river were high, "the hatchery's contribution to the total load was very small" (Anon. 1966). Another study conducted by the Federal Water Pollution Control Administration (now Environmental Protection Agency) in 1969 established that the "hatchery contributed significant amount of fish-fecal material and unconsumed fish food," which

Figure 1. The Jordan River in the vicinity of the National Fish Hatchery in Antrim County, Northwestern Lower Michigan.

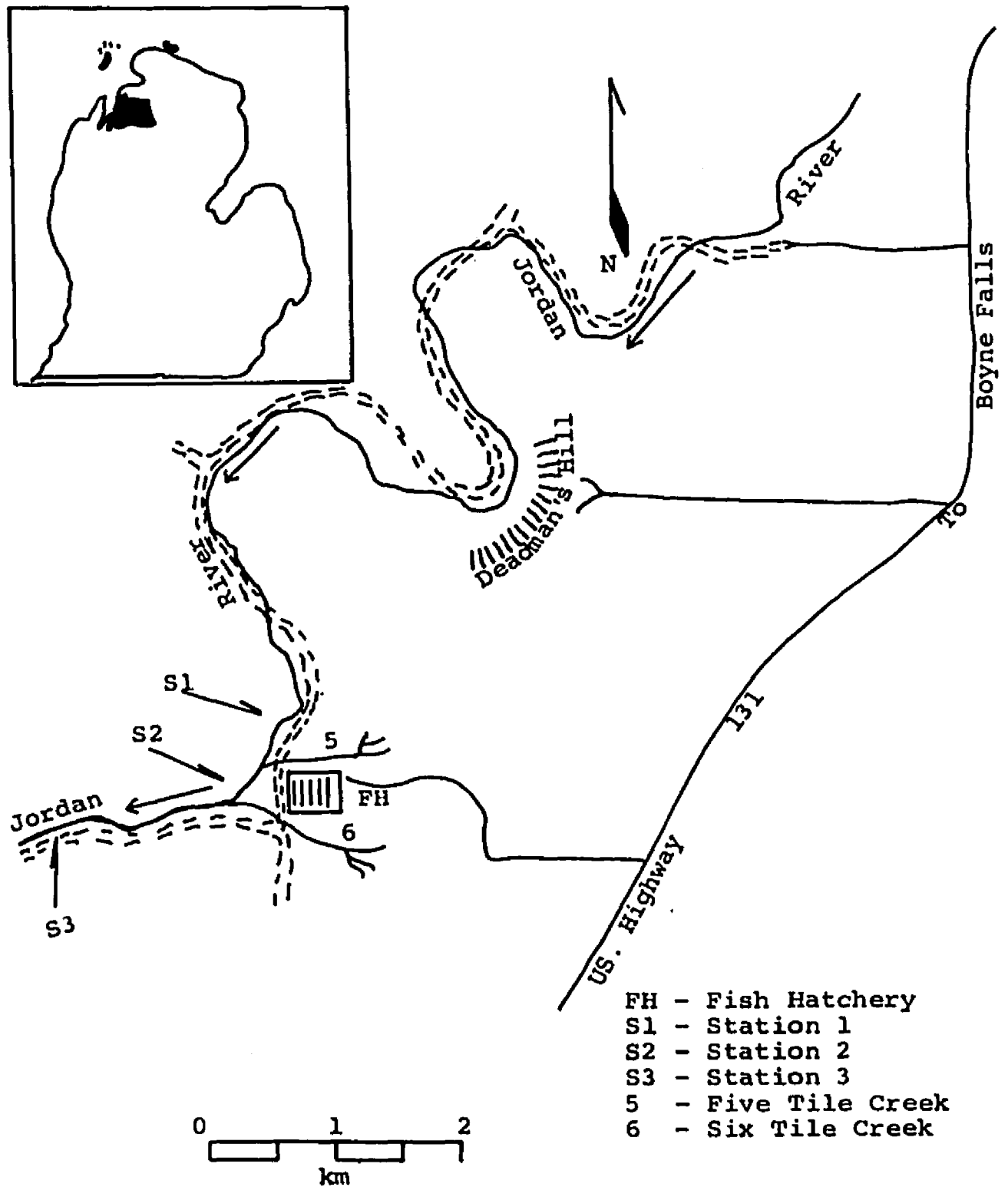


Figure 1

supported pollution tolerant benthic organisms, and recommended construction of settling ponds or lagoons for the removal of solids from the hatchery's effluent (Anon. 1969a). Later in the year, the Michigan Water Resources Commission conducted a similar study (Anon. 1969b). Its findings and conclusions were in agreement with the Federal Water Pollution Control Administration, and also recommended settling pond or lagoon facilities for the removal of suspended solids. The National Fish and Wildlife Service accepted the recommendations of the Federal Water Pollution Control Administration and the Michigan Water Resources Commission, and in the winter of 1971-1972 two 30-m long, 10-m wide and 3-m deep settling basins were built with design to remove 80-95% of the suspended solids from the wastewater.

These circumstances offered an opportunity to initiate a two-phase investigation relating the effects of fish hatchery wastes on the primary production of the Jordan River. The first phase of this study intended to define the effects of untreated hatchery wastes on the river. This period began in February and ended in July of 1971. The second phase of the investigation was intended to differentiate between the effects of treated and untreated wastes on the Jordan River. In order to maintain most of the variables uniform, each phase of the study was programmed for the same seasons (February to July) in both years.

GENERAL STREAM MORPHOLOGY

The Jordan River drains a water shed in an interlobate moraine of the Port Huron Morainic System, cutting its bed out of sand, gravel and wind-blown sandy drifts (Leverett, 1915). It originates from a spring system 1.5 km west of US. Rt. 131 and State Hwy. 32 in Antrim County, Michigan, and empties into the South Arm of Lake Charlevoix at the village of East Jordan, Michigan.

Before the turn of the century, the watershed was part of the vast eastern white pine (Pinus strobus) stands of Michigan and adjacent States. At the present, secondary plant succession is in a seral stage of white oak (Quercus alba), sugar maple (Acer saccharium), and smooth alder (Alnus rugosa). There is considerably more variation in the plant community adjacent to the stream and in the valley proper. The stream is broken into distributaries by small islands, and it is littered with fully and/or partially submerged cedar and white pine logs and stumps. These islands and stream banks are dominated by northern white cedar (Thuja occidentalis) and eastern larch (Larix laricina). Usually, a community of big tooth (Populus grandidentata) and quaking aspens (P. tremuloides), white birch (Betula papyrifera) and red maple (Acer rubrum) occupies the rest of the valley proper.

The sandy, loose soil and continuous vegetation provide good percolation of precipitation into the ground water table and prevent surface run-off into the Jordan River. As a result, the stream receives its flow from springs and ground water seepages making the water-level in the Jordan River relatively constant the year around.

Figure 2. Location of waste discharges, settling basins
and study sites near the Jordan River National
Fish Hatchery.

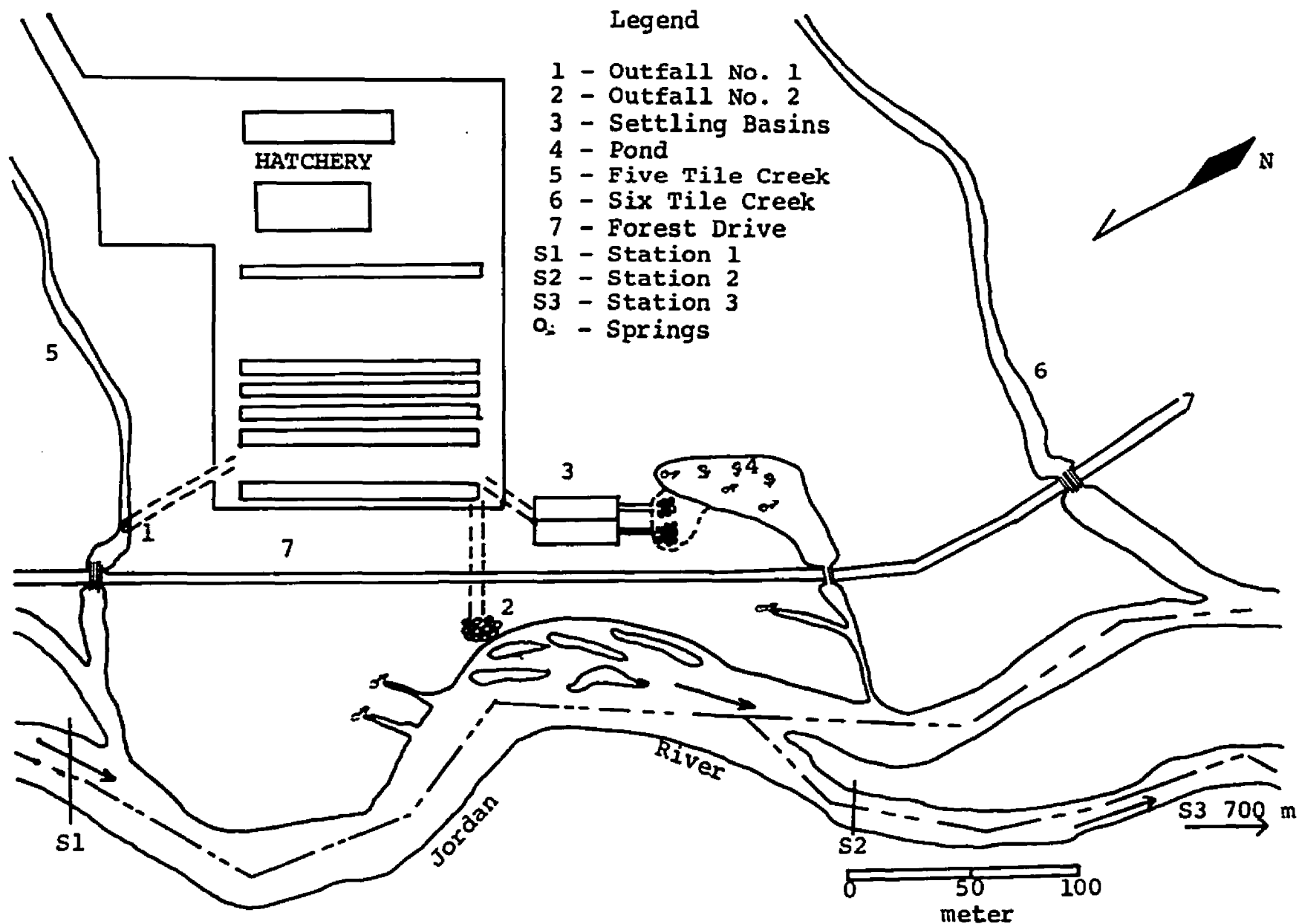


Figure 2

SCIENTIFIC APPROACH

Prior to 1972 the wastes of the National Fish Hatchery entered the Jordan River in two separate outfalls about 250 m apart. The first outfall discharged effluent into Five Tile Creek about 50 m upstream from its confluence with the Jordan River. The second outfall carried effluent into a distributary of the Jordan River (Figure 2). Three stations were selected for this study. Station 1 was located 15-20 m above the confluence of Five Tile Creek and the Jordan River in order to monitor potamological conditions uneffected by the hatchery wastes. Station 2 was 380 m below Station 1 and approximately 180 m below the second outfall. As determined with fluorescein dye, the wastewater from the first outfall was thoroughly mixed with the stream at Station 1; waste from the second outfall followed the south or left bank of the stream and became thoroughly mixed only after it had traveled 900 m downstream. The third station was located in this area of the Jordan River.

Periphyton Collections

According to Liao (1970), fish hatcheries discharge the following three types of pollutants. These are 1) fecal material and residual food, 2) drugs and disinfectants from disease and parasite control, and 3) pathogenic bacteria and

parasites. Basically, they all undergo biological degradation or assimilation in the stream. Although the Jordan Valley National Fish Hatchery did not have any formal waste treatment facility, prior to 1972, mineralization of the above described pollutants was provided in the arrangement of the outfalls. Specifically, wastewater from both outfalls flowed through a labyrinth of distributaries and small islands before entering the main stream of the Jordan River. These provided natural settling basins which served as reservoirs for the periodic slugs of particulate solids which were washed out of the race-ways when workmen scrubbed and flushed them. Between flushings, the stored sludge slowly decomposed and mineralized in the distributaries. Since synoptic observations and conclusions found in the literature (cf. Goldman, 1972) suggested that the pollutants after entering the aquatic ecosystem were quickly mineralized, the effects of fish hatchery wastes could best be evaluated by comparing primary productivity estimates obtained above and below the outfalls in the Jordan River, rather than by the chemical data obtained from the analyses of water samples.

It is generally accepted that true phytoplankton or potamoplankton is only present in large, slowly flowing deep rivers, but not in shallow streams with fast currents (Hynes, 1969; Hooper, 1969), like the Jordan River. If there is primary production in shallow, fast flowing streams, it is usually by either periphyton or by aquatic macrophytes.

Since the Jordan River lacked substantial quantities of aquatic macrophytes, periphyton grown on plexiglass artificial substrates was chosen for primary productivity estimates.

Historically, glass microscope slides were the first used of the artificial substrates for enumerating periphytic algal cells in the aquatic environment. Patrick et al. (1954) constructed the "diatometer" to determine diversity of these algae in polluted and unpolluted environments. Quite accidentally, she also discovered that styro-foam, supporting the apparatus in the water was a better substratum than glass slides (Hohn, 1968). This discovery led to the use of other materials, such as wood shingles, concrete, slate and later plastics. A critical evaluation of the various methods has been compiled by Sladeckova (1962). It was Grzenda (1960) who first used plexiglass plates as artificial substrates for the collection of periphyton biomass in calculation of productivity estimates. The numerous periphyton studies conducted by students at this institution since then have been summarized by Ball et al. (1969).

In the past, investigators have attached plexiglass plates to concrete blocks to withstand flood periods and vandalism (Clifford, 1959; Grzenda, 1960; King, 1964). From 2.5-cm angle iron, 90-cm threaded rods and No. 225 Acco paper clamps, racks (Figure 3) were constructed which would hold eighteen 5 x 10 x 1 cm plexiglass plates. Both of the angle

Figure 3. Rack with plexiglass plates as artificial substrates for periphyton growth.



Figure 3

iron cross-members were adjustable for the depth at which the plates were to be placed. The sand bottom of the Jordan River facilitated pressing the rods as legs into the stream bottom. The top of these rods were usually above water, hence the rack could be pulled up enough to exchange the slides. Starting on 15 February in both years, two of these racks with four plates on each rack were placed at all stations. These plates remained in the stream for 13 to 20 days and then were exchanged for clean ones. At the time of collection, each plate was placed individually in a plastic bag, transported to the laboratory on ice, and kept frozen until processing. Each plate was meticulously picked free of visible macroinvertebrates, and the remaining material from the plate and plastic bags was scraped and washed into aluminum weighing dishes. Organic weight was determined by the difference between dry-weight (105°C) and ash-weight (550°C). Accrual rates of periphyton on artificial substrates were converted to rates of organic production in mg organic material/ m^2 substrate area/day. The genera of dominant algae are indicated in Table A-4 of the Appendix.

Stream Metabolism

When using artificial substrates for periphyton sampling, one cannot assume that the growth rates on artificial substrates are equal or similar to growth rates on natural substrates. Hence, in order to substantiate periphytic production rates obtained on artificial substrates, oxygen concentrations

were measured at the beginning and end of a 500-m section at Station 1 and a 275-m section at Station 3 of the Jordan River on June 7, 8, 9, 30, and July 1, 1971; and June 6, 7, 8, 9, 21 and 22, 1972. At each point of measurement a Delta Scientific Oxygen Probe No. 1921 coupled with a Rustrak Model 192 dissolved oxygen and temperature recorder were placed for 24-hour periods. Originally, these diurnal oxygen and temperature curves were to be utilized to calculate net oxygen production by photosynthesis, and community respiration, as described by Odum (1956). However, the dynamics of dissolved oxygen in this particular section of the stream were such as to make these procedures inappropriate. A critique of this is found in the following section.

RESULTS

Previous studies of the Bureau of Sport Fisheries and Wildlife (Anon., 1966) and the Federal Water Pollution Control Administration (Anon., 1969a) indicated that the nutrient load from the hatchery was insignificant in relation to the total load of the Jordan River. Neither of these investigations found a substantial increase of nitrogen or phosphorus below the hatchery effluents. Shauver (1969) calculated that 38.3 tons of nitrogen per year and 3.3 tons of phosphorus per year were being discharged to the Jordan River through the Federal Hatchery. His figures combined the nitrogen and phosphorus present in the spring system and that in the waste from the hatchery. These sources of phosphorus and nitrogen were treated separately in this study in order to determine the contribution from both sources. Subtracting quantities of phosphorus and nitrogen contributed by the spring system from the total load to the stream, as determined by periodic sampling was not appropriate. Loading from the hatchery came in slugs of undeterminable duration because of periodic cleaning of settled solids from the race-ways. Since the hatchery diverted all of the water from the springs, this annual loading was calculated by applying the mean of

three samples (Table A-1, Appendix) obtained from the springs to the hatchery flow volume. The hatchery's nutrient loading was estimated by calculating phosphorus and nitrogen contents of fish-food pellets and lake trout fingerlings, and applying the following scheme:

$$P_{\text{in fish-food}} - P_{\text{in fish}} = P_{\text{in waste}}$$

$$N_{\text{in fish-food}} - N_{\text{in fish}} = N_{\text{in waste}}$$

Tonnage of fish-food pellets applied and lake trout fingerlings produced in 1970-1971 and 1971-1972 were graciously provided by the hatchery manager Mr. Charles T. Hiltz. The concentrations of phosphorus and nitrogen in water samples, fish-food pellets of various sizes and fish of various ages were determined by the Water Quality Laboratory of the Institute of Water Research, Michigan State University.

In Table 1 discharges and annual phosphorus and nitrogen budgets of the Jordan River, Five Tile Creek, Six Tile Creek and the hatchery are summarized. The discharge of the Jordan River above the hatchery, the hatchery, and the discharges of Five and Six Tile Creeks have been taken as 100% of flow and load. If the estimates of discharge, and phosphorus and nitrogen loadings at Station 3 below the hatchery were larger than those estimated for these four components, the surplus could have been provided only by other springs and ground water seepages.

Table 1. Mean discharge (m³/min) and phosphorus and nitrogen budgets (kg/yr) of the Jordan River, Five Tile Creek, Six Tile Creek and the hatchery effluent in 1970-1971.

	Discharge m ³ /min	% Discharge	Phosphorus kg/yr	% Phosphorus	Nitrogen kg/yr	% Nitrogen
1. Jordan River above hatchery	98.55 *	81.7	1,739	54.7	64,384	77.6
2. Five Tile Creek	7.48	6.2	236	7.4	4,875	5.9
3. Six Tile Creek	14.58	12.1	306	9.6	9,502	11.5
4. Hatchery effluent	<u>(22.06)**</u>	<u>(18.3)**</u>	<u>898</u>	<u>28.3</u>	<u>4,173</u>	<u>5.0</u>
Subtotal	120.61	100.0	3,179	100.0	82,934	100.0
Jordan River at Station 3	163.12	135.2	3,246	102.1	154,154	185.9

*Discharge of the Jordan River was obtained by determining cross sections, and measuring flow velocities with a Gurley Current Meter.

**The hatchery diverts the flow of Five and Six Tile Creeks. Flow data obtained from hatchery management.

It is indicated in Table 1 that at Station 3 the discharge was $42.5 \text{ m}^3/\text{min}$ or 35.2% greater than the sums of these four main contributors. This additional 35.2% flow was contributed by spring and ground water seepages. The additional flow contributed 2.1% more phosphorus and 85.9% more nitrogen than could be accounted for in the monitored sources. The phosphorus and nitrogen data also reveal that the hatchery's contribution of phosphorus was substantial; 898 kg/yr or 28.3% of the total contributed by the above described major components of flow. However, the nitrogen contribution was relatively small; 4,173 kg/yr or only 5.0% of the total contributed by the four major components. There were an additional 71,220 kg/yr of nitrogen contributed by spring and ground water seepages.

In 1972, only the hatchery's phosphorus and nitrogen loading was recalculated and was found to be 998 kg/yr of phosphorus and 4,604 kg/yr of nitrogen. These quantities were very close to the phosphorus and nitrogen loadings of the National Fish Hatchery in the previous year.

In order to provide a comparison of the hatchery's wastewater to municipal wastewater in terms of phosphorus and nitrogen, 898 kg/yr phosphorus and 4,173 kg/yr nitrogen were converted to population equivalents of municipal wastewater with mean values of phosphorus (as P - 10-15 mg/l) and nitrogen (as total N - 25-35 mg/l) calculated by Rohlick and Uttormark (1972). The hatchery's contribution of phosphorus

was equal to a population equivalent of 341; the population equivalent for nitrogen was 672.

Periphyton

There is an agreement among workers (Patrick et al., 1954; Odum, 1957a; Castenholtz, 1960; Sládeček and Sládečková, 1964; Wetzel and Westlake, 1969) that periphyton communities on sundry artificial substrates are similar if not identical in composition to communities on natural substrates. Since the major objective in this study was to establish a method which would provide some quantitative measure of the effects of hatchery wastes on the Jordan River, the criteria of Newcomb (1949) was accepted, namely that ... "the weight of organic matter [production rate] produced on suitable, uniform submerged surface provide a somewhat more direct measure of the productive capacity of a body of water" ... than what could be obtained from natural substrates, since the positioning of artificial substrates in the stream usually optimizes conditions for periphytic growth.

Periphytic growth rates as ash-free organic weight ($\text{mg}/\text{m}^2/\text{day}$) were calculated from biomass accrual for each station. These rates for 1971 and 1972 are depicted in Figures 4 and 5 respectively on a two dimensional model, in which the abscissae represent time (March-June, 1971 and 1972) and the ordinates represent periphytic growth rates ($\text{mg}/\text{m}^2/\text{day}$). The latter scale is in base-10 logarithm for convenient representation, since growth rates suggested exponential

Figure 4. Periphytic growth rates in the Jordan River,
Michigan, in 1971.

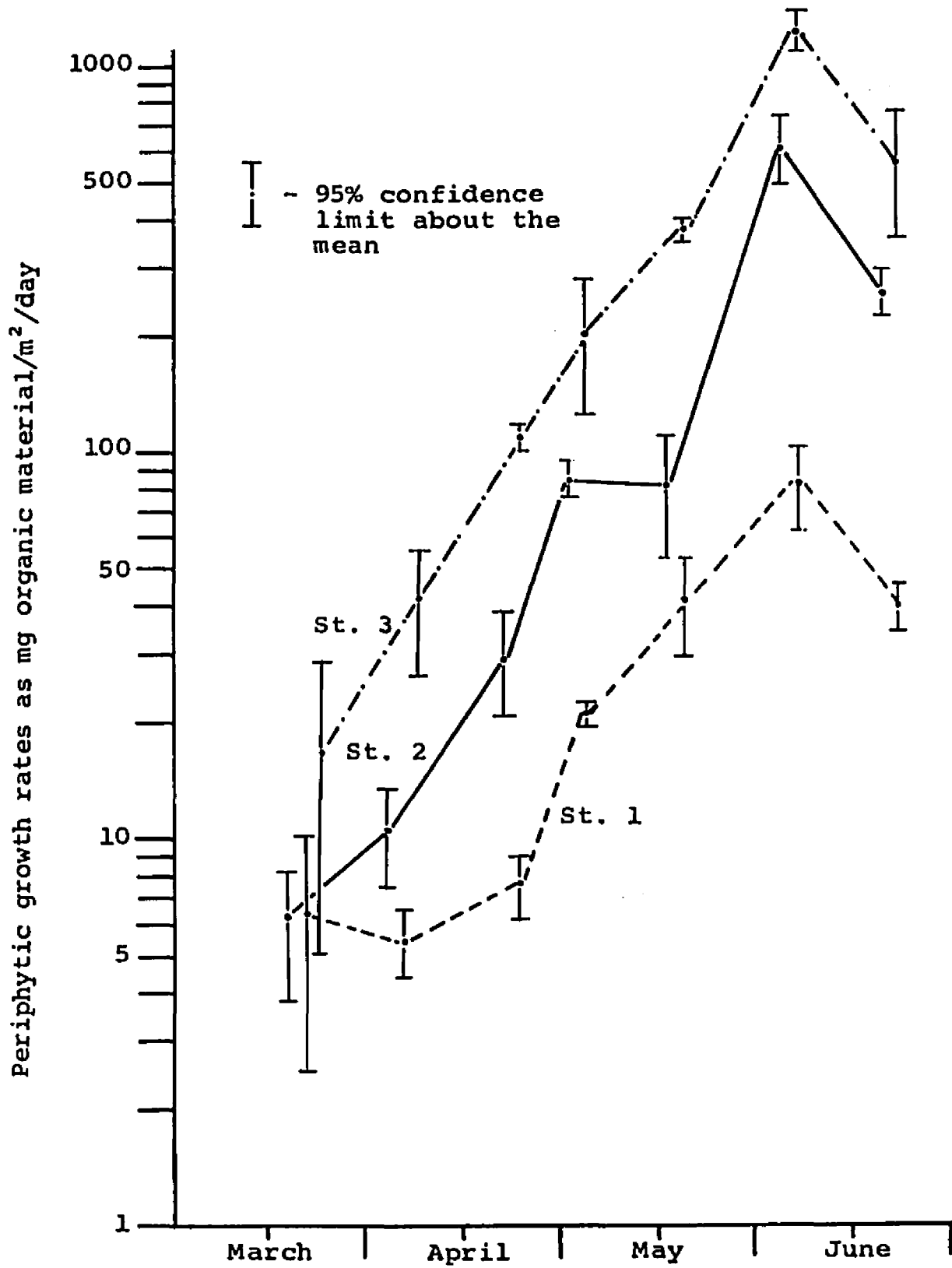


Figure 4

**Figure 5. Periphytic growth rates in the Jordan River,
Michigan, in 1972.**

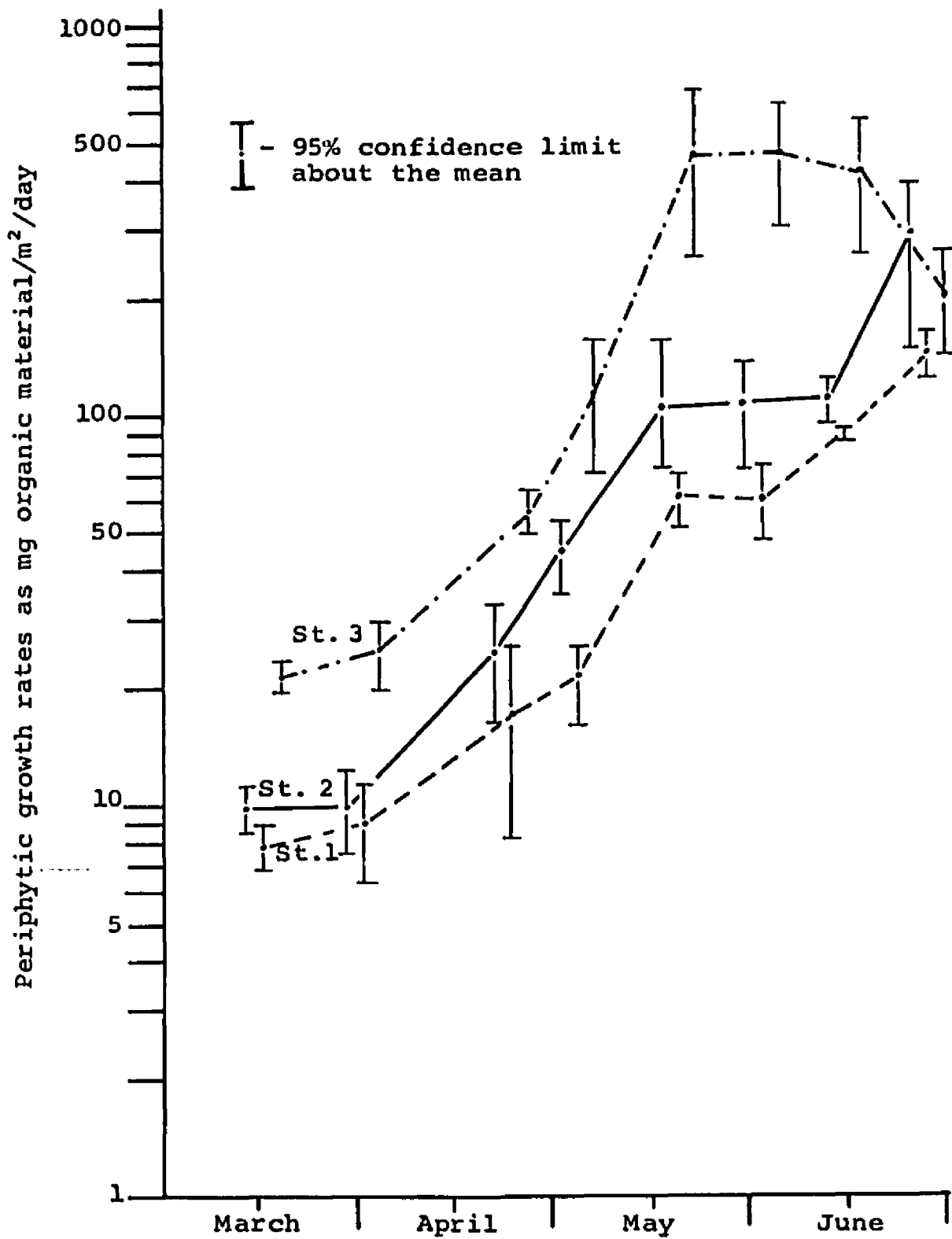


Figure 5

increases during the sampling periods. The mean value per date and the 95% confidence limits about the means are compiled in Tables A-2 and A-3 of the Appendix.

In order to utilize these data for quantifying stream enrichment by the hatchery effluent, a two-way (station x time) analysis of variance was performed. The analysis of variance for 1971 and 1972 data are presented in Tables 2 and 3 respectively. Since some of the variables of the experiments could not be measured in the field, their control was attempted in the statistical analysis by removing possible sources of variation of racks within station, time, and time x station interaction from the error term. The results of the analysis of variance indeed indicated that: 1) production rates were significantly different among stations, 2) production rates were significantly different between racks within the same station, 3) periphytic production rate was a function of time, where time represented functional changes in water temperature, light intensity, photoperiod, etc., 4) significant interaction existed between station and time. In order to identify these differences among stations, and indicate any changes in periphytic production rates between 1971 and 1972, the data were subjected to regression analyses. The regression lines and their equations are shown in Figure 6 and Figure 7 for 1971 and 1972 respectively.

Table 2. Analysis of variance of periphytic growth rates in 1971.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Station	2	15.3686	7.6843	241.276*
Racks w/i Station	3	1.6410	0.5470	17.176*
Time	7	62.6661	8.9523	281.089*
Station x Time	14	4.5104	0.3222	10.116*
Error Term	120	3.8213	0.0318	

*Significant at the 0.001% level.

Table 3. Analysis of variance of periphytic growth rates in 1972.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Station	2	7.7587	3.8793	163.152*
Racks w/i Station	3	0.7765	0.2588	10.886*
Time	7	31.7848	4.5407	190.966*
Station x Time	14	1.6875	0.1205	5.069*
Error Term	121	2.8771	0.0238	

*Significant at the 0.001% level.

Figure 6. Regression lines and equations of periphytic growth rates in the Jordan River, Michigan, in 1971.

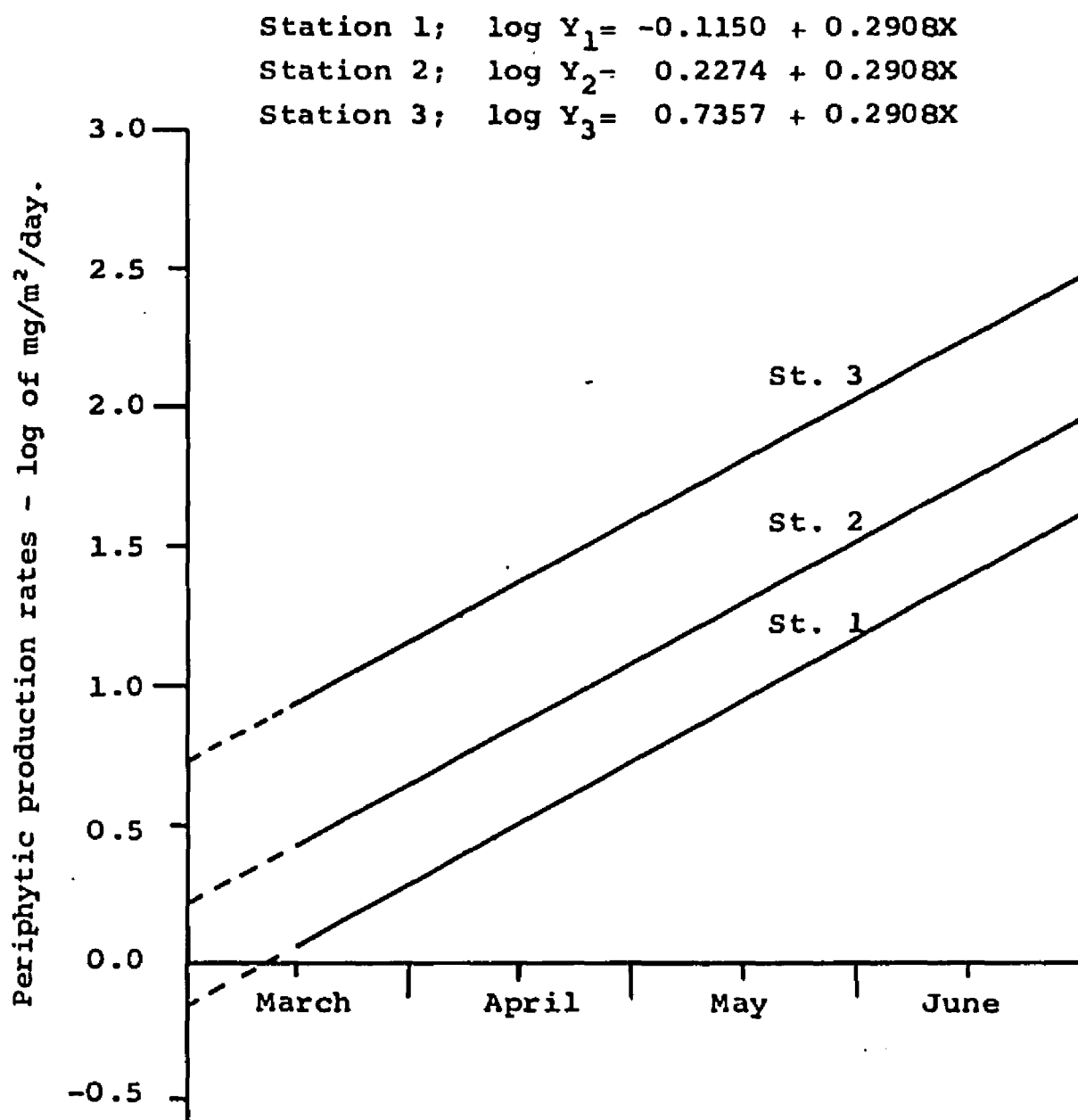


Figure 6

Figure 7. Regression lines and equations of periphytic growth rates in the Jordan River, Michigan, in 1972.

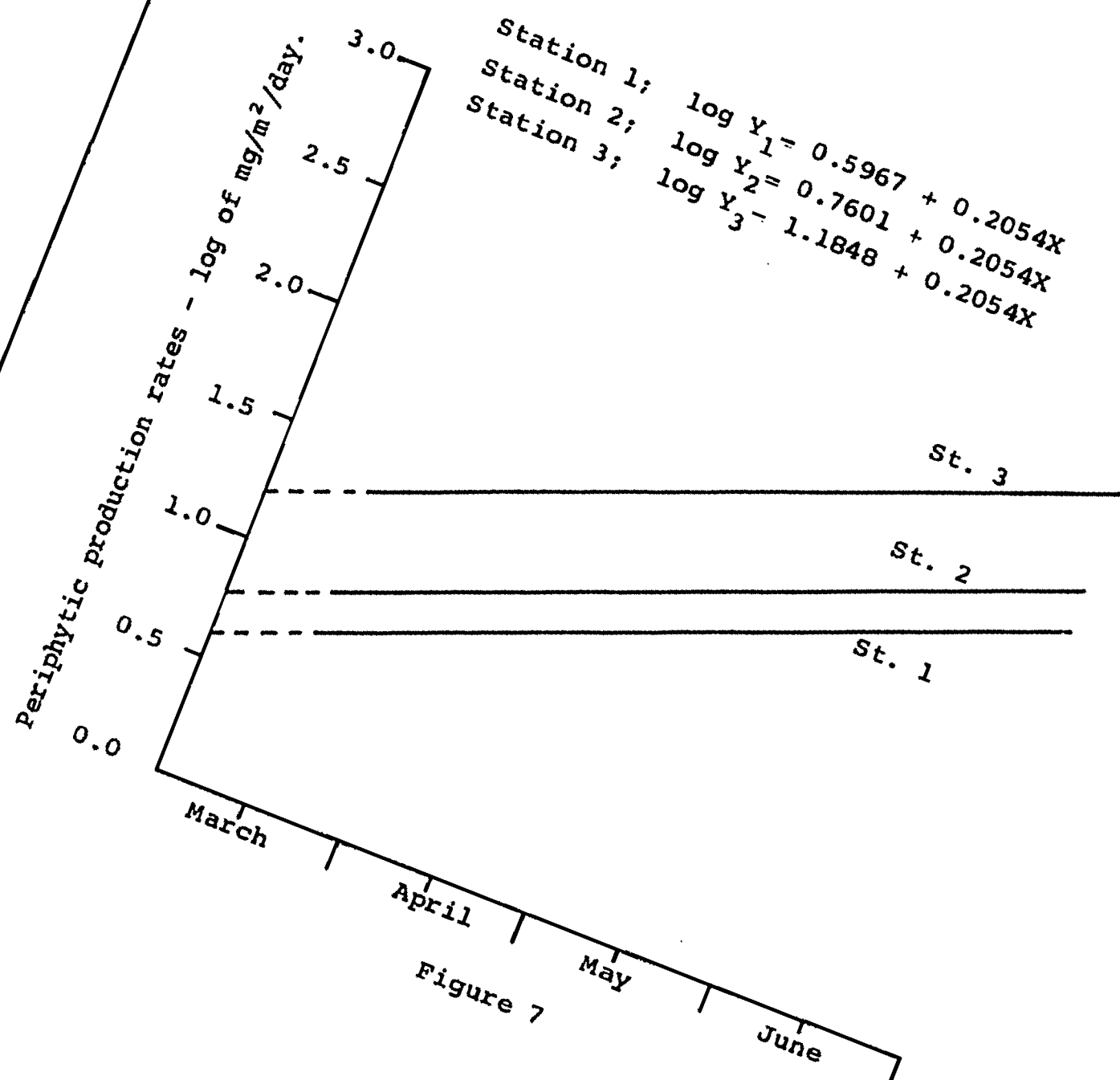


Figure 7

Stream Metabolism

As described by Odum (1956) there are essentially four main processes effecting oxygen (and carbon-dioxide) concentrations in streams. These are 1) photosynthetic release of oxygen during the day, 2) uptake of oxygen as a result of community respiration, 3) diffusion of oxygen between air and water as a function of saturation gradient, and 4) influx resulting from accrual of water with different oxygen concentrations. If diurnal concentrations of dissolved oxygen are measured between stations, these processes may be quantitatively expressed as:

$$Q = P - R + D + A; \text{ where}$$

Q = rate of change of dissolved oxygen per unit area between stations,

P = rate of gross primary production,

R = community respiration,

D = rate of oxygen diffusion,

A = rate of accrual from tributary water between stations.

The rates of gross primary production and community respiration expressed in $\text{g O}_2/\text{m}^2/\text{day}$ would have been valuable tools in 1) quantifying the effects of hatchery wastes on the stream community, 2) substantiating the periphytic production rates, and 3) detecting any changes of stream metabolism resulting from the treatment of the hatchery wastes in the second year of study. However, component "A", rate of oxygen accrual resulting from the accrual of ground and surface water with different oxygen concentrations (usually lower) could not be determined since innumerable springs entered this

section of the Jordan River above and below the stream's surface. This has been documented in the discharge data in Table 1. Therefore, absolute values of primary production and community respiration could not be estimated with this commonly used technique. However, the diurnal oxygen concentrations and temperature curves were treated in the following manner. A mean curve was calculated for each station from the data obtained in June, 1971 and June, 1972. These curves are presented in Figures 8 through 11. Each of these curves revealed the following common characteristics: 1) dissolved oxygen ranged between 8.0 and 11.0 mg/l; 2) dissolved oxygen usually approached or reached 100% saturation (corrected for 300 m above mean sea level elevation) between 1000 and 1400 hours, and steadily declined after reaching a maximum in the daylight hours until about 2000-2200 hours; 3) during the hours of darkness (2200-0500 hours) dissolved oxygen curves paralleled 100% saturation. Respiration, accrual and diffusion working together produced an oxygen deficit which was constant during these hours of darkness. Quantitatively, this can be expressed as follows: $D - (R + A) = K$. This constant "K" was expanded into the daylight hours by use of dotted lines in Figures 8 through 11. The area between the dotted line and the dissolved oxygen curve is gross production of oxygen by photosynthesis. For the determination of "K", I have taken the distance between 100% saturation and D.O. at 2100 hours and extended it to the daylight hours. Then I

calculated the rate of oxygen produced in $\text{g O}_2/\text{m}^2/\text{hr}$ from the shaded area between 0900 and 1600 hours. These mean rates are presented in Table 4 with their statistical treatment of a student-t test. Although these rates were a little higher at Station 3 in both years, their differences were not significant at the 0.20% level.

Figure 8. Mean diurnal dissolved oxygen concentrations and temperatures measured at Station 1 in June, 1971.

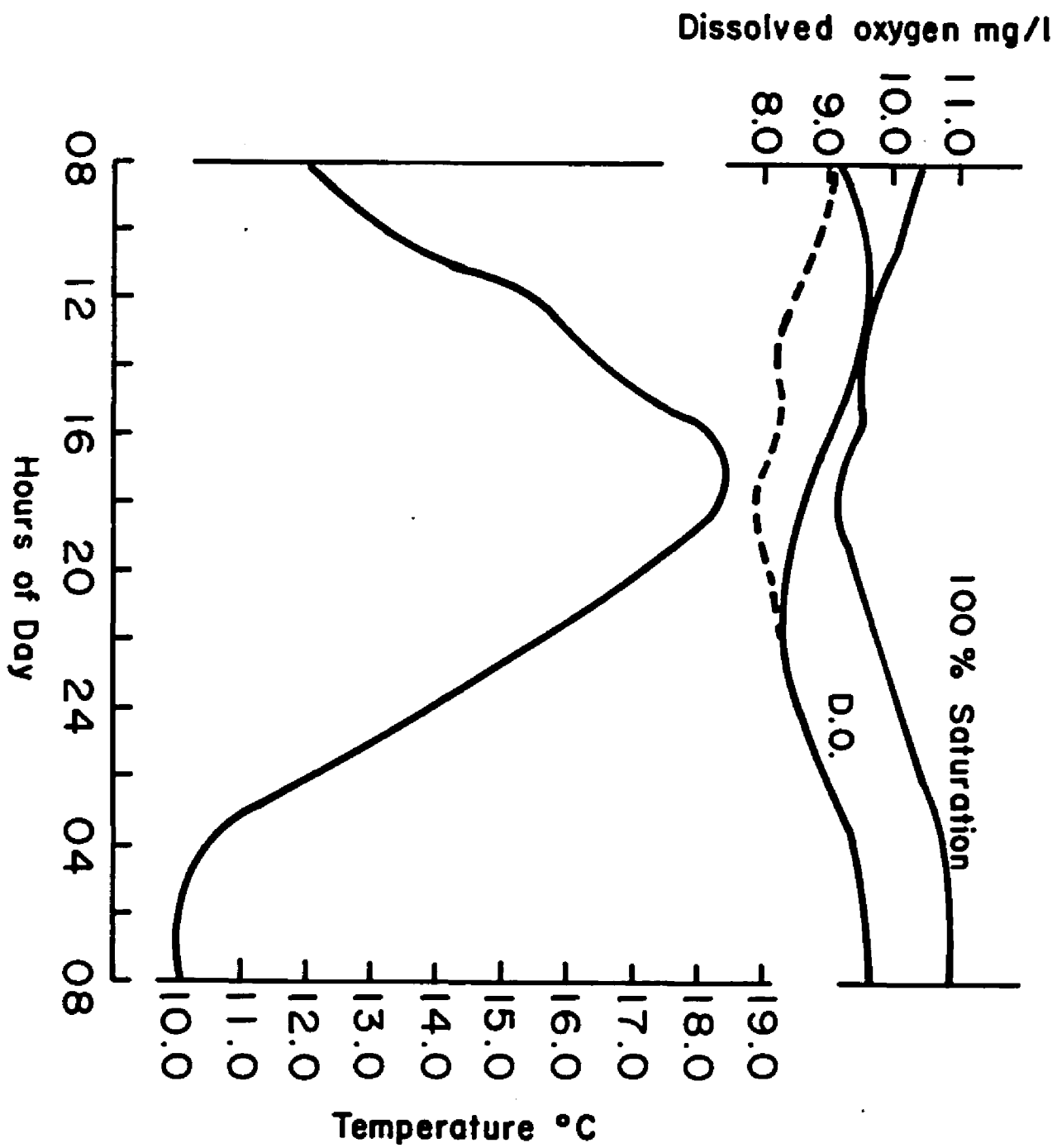


Figure 8

Figure 9. Mean diurnal dissolved oxygen concentrations and temperatures measured at Station 3 in June, 1971.

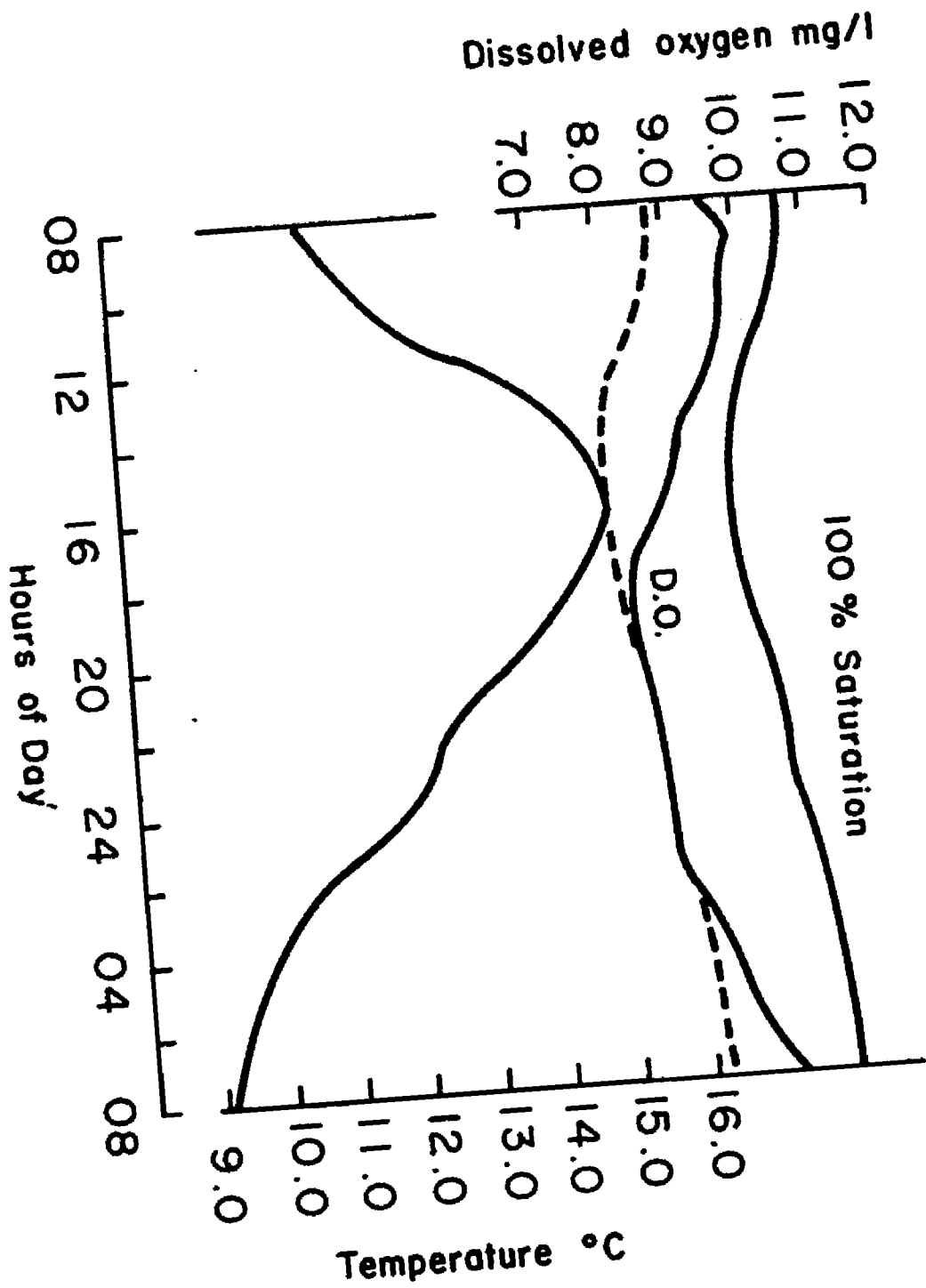


Figure 9

Figure 10. Mean diurnal dissolved oxygen concentrations and temperatures measured at Station 1 in June, 1972.

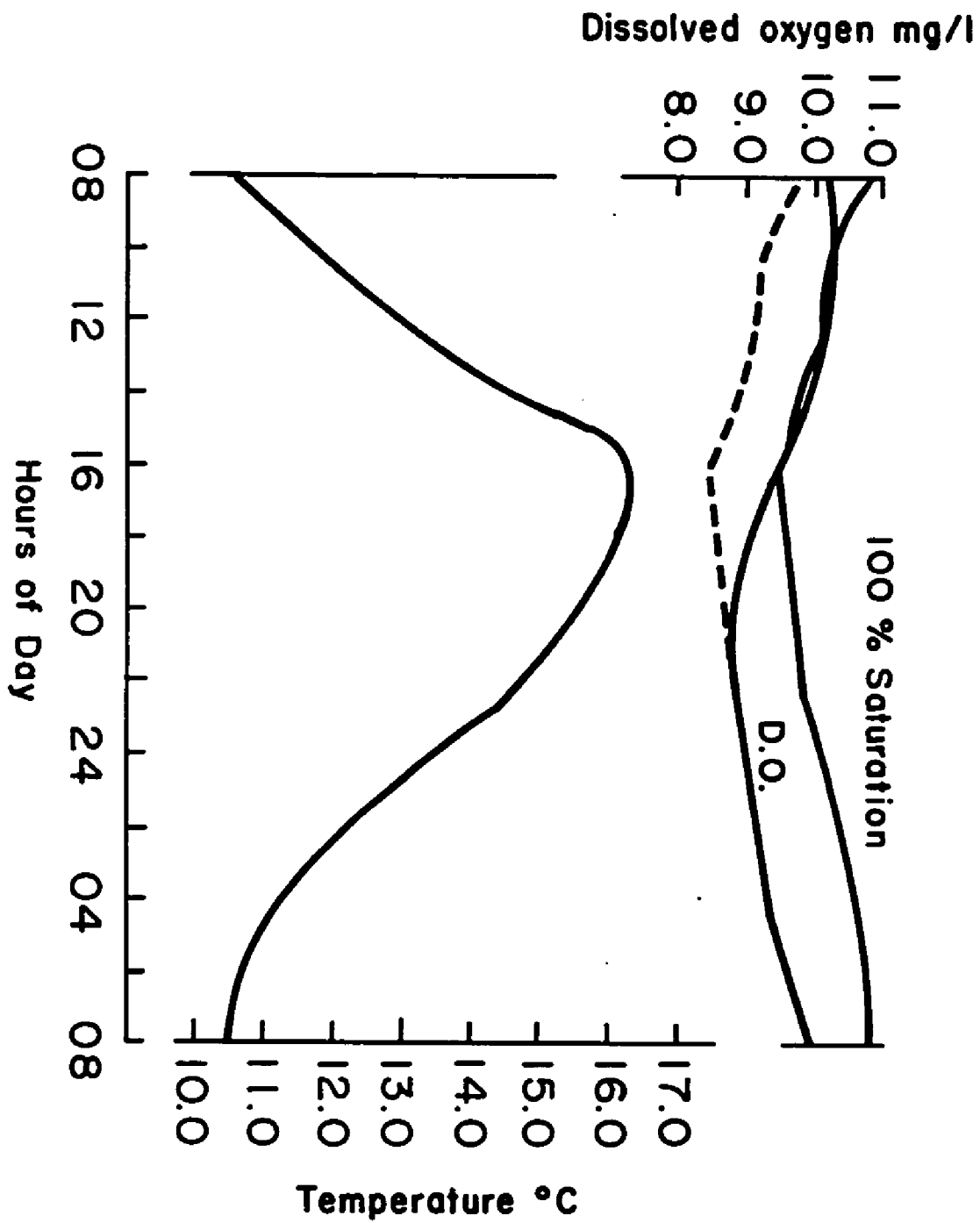


Figure 10

Figure 11. Mean diurnal dissolved oxygen concentrations and temperatures measured at Station 3 in June, 1972.

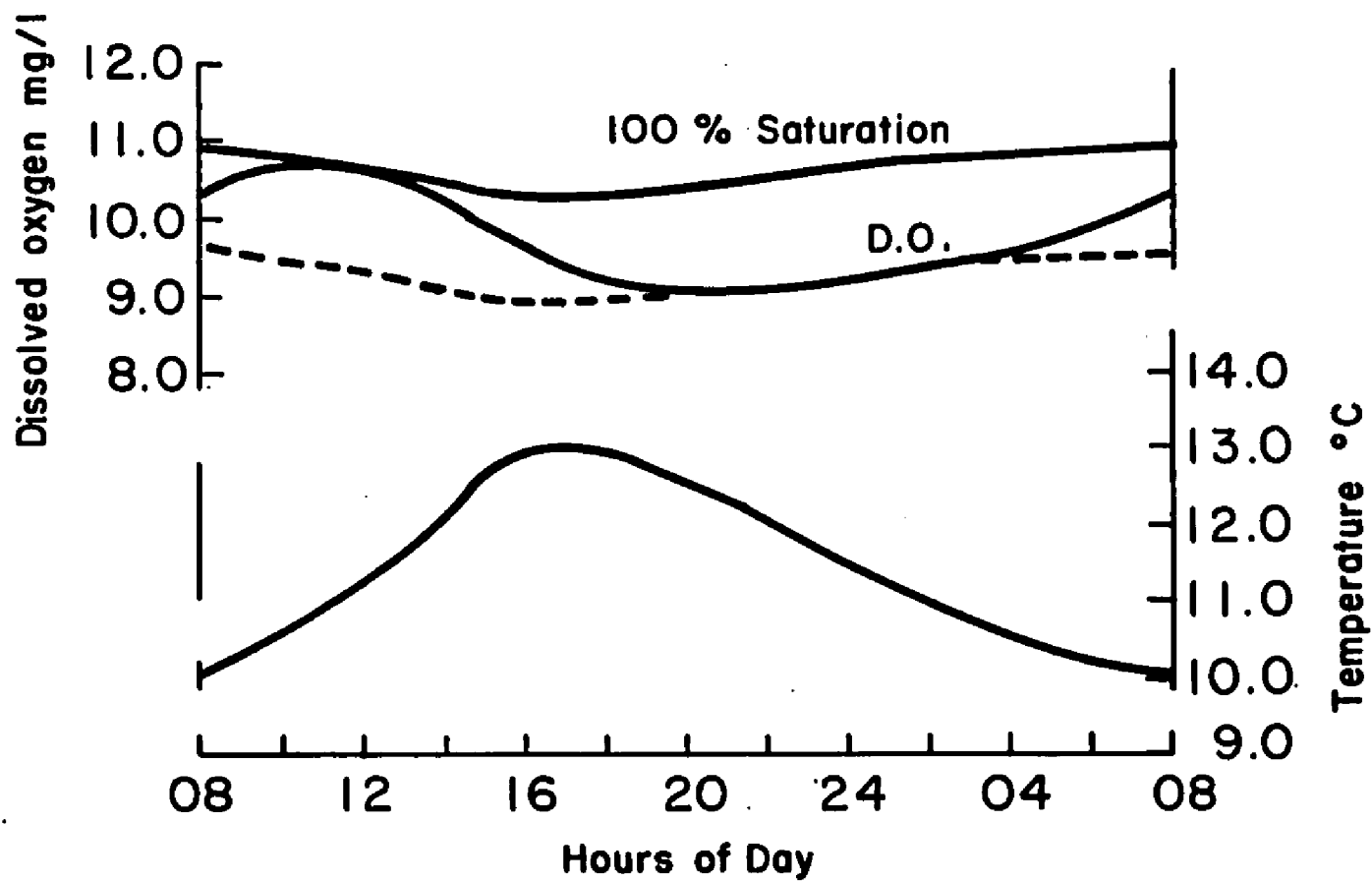


Figure 11

Table 4. Mean gross primary production estimates at Station 1 and 3 in June, 1971 and 1972.

	Station 1	Station 3
1971	$X_1 = 4.10 \text{ g O}_2/\text{m}^2/\text{hr}$	$X_2 = 4.50 \text{ g O}_2/\text{m}^2/\text{hr}$
1972	$X_3 = 3.93 \text{ g O}_2/\text{m}^2/\text{hr}$	$X_4 = 4.43 \text{ g O}_2/\text{m}^2/\text{hr}$

Statistical Hypothesis

$$H_0: X_1 = X_2$$

$$H_0: X_3 = X_4$$

$$H_1: X_1 \neq X_2$$

$$H_1: X_3 \neq X_4$$

$$t = 0.788$$

$$t = 0.493$$

$$t_{.20[10]} = 1.372$$

$$t_{.20[6]} = 1.440$$

Conclusion: $H_0: X_1 = X_2$ and $H_0: X_3 = X_4$ are accepted as being equal.

DISCUSSION

It would be in order to briefly recall certain portions of the geochemical cycles of phosphorus and nitrogen so that some explanation could be provided for the phosphorus and nitrogen budget estimates for the hatchery and receiving stream system. The spatial distribution or partitioning of phosphorus and nitrogen in an aquatic ecosystem has long intrigued researchers. These two major nutrients essential for plant growth exhibit two entirely different partitionings within the components of an aquatic ecosystem. The following discussion will pursue the route each of these elements may take in an aerobic, open system such as the Jordan River. Basically, phosphorus tends to form relatively insoluble precipitates with Fe, Mg, and Ca ions, and adsorbs to particulate organic and inorganic material, with only a small quantity in equilibrium solution. Hayes and Phillips (1958) traced radioactive phosphorus (^{32}P) through the components of lentic ecosystems, and found that its spatial distribution was quickly established with turn over time from a few minutes in phytoplankton cells to a few days in zooplankton, higher aquatic plants, the decomposer community and the bottom sediments. Clifford (1959) found similar results of partitioning of ^{32}P in a lotic system. He found ^{32}P being rapidly distributed in

the periphyton community, higher aquatic plants and in the stream bottom after application. Nitrogen, on the other hand, presents an entirely different partitioning. The inorganic forms, such as $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, and $\text{NO}_3\text{-N}$ are readily soluble in water and escape precipitate complexing or adsorption in an aquatic system. Some fraction may be assimilated by growing primary producers. Certain transformations occur with the presence of bacteria from $\text{NH}_3\text{-N}$ to $\text{NO}_2\text{-N}$ to $\text{NO}_3\text{-N}$. Since all of these forms are highly soluble, they tend to be transported from an open lotic system.

In view of these basic cyclic differences, certain stipulations can be presented for the phosphorus and nitrogen influx of the Jordan River for the hatchery's input. Although there were 898 and 998 kg of phosphorus entering the Jordan River via hatchery operation in 1970-1971 and 1971-1972 respectively, these quantities were rapidly taken up by the components of the system, and slowly released in equilibrium concentrations. It was shown in Table 1 that there was an additional 35.2% more discharge at Station 3. This volume of water represented only an additional 2.1% phosphorus. This would suggest that the additional 35.2% discharge was practically free of phosphorus, which is obviously not so. If a mean concentration of 0.03 mg/l of phosphorus obtained from the Jordan River measurements (Table A-1, Appendix) is applied to the additional 35.2% flow, which must represent other springs and ground water seepages in the vicinity of the study

area, it will result in quantity of 804 kg phosphorus in a year added to the Jordan River. It is incorporated into the various components of the ecosystem, and only 67 kg (Table 1) is transported downstream. The additional 85.9% nitrogen at Station 3 is brought into the Jordan River by numerous springs and groundwater seepages is not tied up in the system and is transported downstream.

In summary, it may be stipulated that since this section of the Jordan River ecosystem readily assimilated the phosphorus load from the National Fish Hatchery, its capacity for phosphorus is not yet overloaded. The additional nutrients increase production at each trophic level providing a higher harvest of game fish. Similar idea was reported by Hynes (1969), that in poorly producing streams limited enrichment may be beneficial to fish harvesting. The aspect which demands consideration is the long term effects of the phosphorus and nitrogen loads transported to Lake Michigan via the Jordan River and Lake Charlevoix. However, Shauver (1968), in his study of the Jordan River Watershed, indicated that there are more significant contributors of phosphorus and nitrogen than the National Fish Hatchery. The combined effect of these sources needs further attention.

Periphyton

The periphyton community responded distinctly to the enrichment of the river by the hatchery wastes. The periphyton production rates among stations were significantly different

at the 0.001% level. The rates of periphytic production rates represented by the slope of each regression line (Figures 6 and 7), were the same for all three stations during each sampling period, indicating that ecological factors such as temperature regime, light intensity, photoperiod and current velocity are similar at all three stations. However, additional nutrients at Station 3 could support a larger standing crop at any given time.

At the time the second phase of this study was to begin in early March, 1972, the hatchery waste discharges were diverted into the newly built settling basins. These two basins were to provide variable detention time for the effluent when residual food and fish-fecal material was scraped and washed from the race-ways. Liao (1970b) summarized the characteristics of salmonid hatchery wastes indicating that the normal hatchery effluent contained 5 mg/l BOD which is usually lower than BOD concentrations in a final effluent of a well operating secondary municipal waste treatment facility. But BOD concentrations at the time of cleaning operations may be as high as 49 mg/l. This BOD concentration in the effluent is usually in violation of state and federal standards. Following construction of settling basins, the hatchery effluent flowed through these and into an area bordered by natural elevations on three sides and by the Forest Drive on the fourth. The addition of hatchery effluent to the springs which were originally present in this area, formed a small

pond (Figure 2). The water left this pond through culverts under Forest Drive, and gradually joined the Jordan River. This diversion of hatchery wastes excluded the second station from receiving enrichment. The 1972 sampling program, in duplication of 1971 procedures, included this station. Periphytic production rates of 1972 (Figures 5 and 7) indicated that the production rates at Station 1 and 2 were very close. The 95% confidence intervals of the means of these two stations overlap or closely approach each other in all but two cases. On the other hand, the results of the analysis of variance indicated station differences significant at 0.001% level. Since the 95% (0.05%) confidence intervals of Stations 1 and 2 overlapped, the contribution to significant differences at the 0.001% level is due to differences between Stations 1 and 3, and Stations 2 and 3. Since Station 2 did not receive wastes after February of 1972, it is understandable that the stream responded immediately to the reduction of available phosphorus and possibly nitrogen. Mean periphytic production rates were higher at all stations in 1972 than in 1971; however, if production rates of Station 1 and 3 were compared in the same years, the ratio of Station 1 and 3 for 1971 was 1:7; for 1972 it was only 1:5. This reduction may be due to the operation of the detention basins.

Primary production estimates have long been used to classify aquatic ecosystems in regard to their natural successional stage and their degree of cultural perturbation.

In Table 5 selected periphytic growth rates obtained by other researchers from lakes and streams are compared with the present study. It appears that since the primary producer element in a limnetic section of a lake is phytoplankton, periphytic production there is limited by competition for available nutrients and light. This is indicated by low periphytic production rates obtained by Newcomb (1949,1950), Nielson (1953), Sladeczek and Sladeckova (1964). In streams, periphytic algae benefit from constant fresh supply of nutrient salts (and transport of metabolic waste products) resulting from the current (Hynes, 1969). Planktonic algae do not compete for required resources. When substrates are provided, higher periphytic production rates can be found in streams than in open lakes. For example, interesting results were observed in Tesar (1971) who found a mean periphytic production rate of $281 \text{ mg/m}^2/\text{day}$ in the Pine River. This is a marginal trout stream receiving some domestic wastes and farm-land runoff in central lower Michigan. King (1964) characterized different pollution zones of the Red Cedar River by using periphytic production rates as indicators. In his study, Zone I was the section of the stream at the vicinity of Michigan State University Campus receiving domestic wastes from storm drains and septic tank overflows. Zone II was a section of the stream meandering through woodland and farm-land; Zone III received primarily treated domestic sewage from the village of Williamston, Michigan. Productivity values found at each of these zones are listed in Table 4.

Table 5. Comparison of periphytic production rates in mg organic matter per m² per day measured by artificial substrate methods.

References	Locations	Production mg/m ² /day
Newcomb (1949)	Sodon Lake, Mich.	37.6
Newcomb (1950)	Walnut Lake, Mich.	11.8
Nielson (1953)	Cloverleaf Lake, Cal.	65.0
Grzenda (1960)	Red Cedar River, Mich.	777
Kevern (1962)	Artificial Stream	143
Sladecek and Sladeckova (1964)	Sledlice Res., Chec.	21.0
King (1964)	Red Cedar River, Mich.	
	Zone I	187
	Zone II	389
	Zone III	379
Kevern et al. (1966)	Artificial Stream	310
King and Ball (1966)	Red Cedar River, Mich.	327
Tesar (1971)	Pine River, Mich.	281
Present Study	Overall mean for Jordan River, 1971	28
	Mean for Station 1	11
	Mean for Station 2	24
	Mean for Station 3	74
	Overall mean for Jordan River, 1972	47
	Mean for Station 1	21
	Mean for Station 2	38
	Mean for Station 3	101

In comparing productivity values of the Jordan River to values in the literature, it appeared that periphytic production rates at Station 1 and 2 were closer to periphytic production rates found in limnetic waters, while rates at Station 3 were similar to low stream productivity estimates.

Stream Metabolism

The methods described by Odum (1956) for estimating primary production in flowing water has been utilized by many investigators in basic and applied research alike. Odum put this method to vigorous scrutiny in the study of Silver Springs (Odum, 1957a), and others in Florida (Odum, 1957b). Primary productivity of flowing marine environments was estimated utilizing this method by Odum and Hoskin (1958), Odum, Burkholder and Rivero (1959), and Odum and Wilson (1962). Among others McIntire et al. (1964) and McIntire and Phinney (1965) employed diurnal oxygen curves to estimate primary production and community metabolism in laboratory streams. In applied limnology, Duffer (1965) and Baumgardner (1966) used this method to estimate the effects of domestic and oil refinery enrichment in streams of southeastern Oklahoma. Data obtained by some of these authors are presented in Table 6. It appears that the success of these studies depended on 1) a wide fluctuation of oxygen concentrations from day to night, and 2) a well-defined drainage accrual. Neither of these fit the case of this study. Saturation varied between 80-100%, and oxygen accrual from ground and surface tributaries

Table 6. Some primary productivity estimates compiled from the literature.

Reference	Location	P	R
Odum (1957a)	Silver Springs, Florida		
	Winter	8.0	2.8
	Spring	35.0	5.0
Odum (1957b)	Homosassa Springs	63.8	70.7
	Blue Springs	2.0	2.5
	Rainbow Springs	23.9	13.2
McIntire et al. (1964)	Laboratory		
	Stream	2.9-4.1	1.6-4.2
McIntire et al. (1965)	Laboratory		
	Stream	1.7-6.4	1.2-3.8
Duffer (1965)	Blue River		
	Winter	10.1	9.1
	Summer	48.0	19.0
Baumgardner (1966)	Skeleton Creek		
	Winter	2.8-13.5	11.5-41.2
	Summer	4.2-60.4	4.9-81.8

P - Primary productivity - g O₂/m²/day

R - Community respiration - g O₂/m²/day

were impossible to determine. In view of the wide use of this method, it should be pointed out that its successful application is limited to situations such as those referenced above.

The oxygen data as treated here provided reasonable evidence that local conditions of primary productivity, community respiration, ground and surface water accrual and stream aeration in the Jordan River were not effected significantly by the hatchery effluent either before or after installation of settling basins. If there was any change resulting from the treatment facilities, it was buffered and made undetectable by the factors influencing oxygen balance of the stream.

SUMMARY

This investigation was conducted to determine the effects of fish hatchery wastes on the receiving stream before and after the installation of two settling basins.

1. The Jordan Valley National Fish Hatchery discharged the equivalent of 900 kg of elemental phosphorus and 4,170 kg of elemental nitrogen between July 1970 and June 1971, and 1,000 kg of phosphorus and 4,604 kg of nitrogen between July 1971 and June 1972. These quantities comprised approximately 28% and 5% of the yearly influx of phosphorus and nitrogen respectively in the Jordan River at the vicinity of the National Fish Hatchery.

2. Periphytic production rates were determined at one station above (Station 1) and two stations below (Stations 2 and 3) the waste outfalls for March to June, 1971 and March to June 1972. These rates increased exponentially during both of the study periods.

3. Mean production rates during March to June 1971, were 11.72 mg/m²/day at Station 1, 24.85 mg/m²/day at Station 2, 79.24 mg/m²/day at Station 3. These mean production rates were significantly different at the 0.001% level.

4. Mean production rates during March to June, 1972 were 20.81 mg/m²/day at Station 1; 38.17 mg/m²/day at Station 2;

101.50 mg/m²/day at Station 3. Significant differences existed between production rates at Station 1 and Station 3; also between Station 2 and 3.

5. Diurnal oxygen concentration and temperature curves were obtained from sections above and below the hatchery discharges. Ground and surface water accrual with different oxygen concentrations which were necessary to calculate gross primary production and community respiration values. A primary production index was calculated from the diurnal oxygen curves. These data indicated that the oxygen balance on the Jordan River was not effected significantly by the hatchery effluent either before or after installation of settling basins.

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APPENDIX

Table A-1 Concentrations of phosphorus as P and nitrogen as N expressed in mg/l in Five Tile Creek (5TC), Six Tile Creek (6TC), Jordan River above (JRA) and Jordan River below (JRB) the hatchery's discharge.

Phosphorus				Nitrogen			
	<u>5TC</u>		<u>6TC</u>		<u>5TC</u>		<u>6TC</u>
4/1/71	0.05 mg/l		0.06 mg/l		0.98 mg/l		0.77 mg/l
4/18/71	0.06 "		0.02 "		1.51 "		1.72 "
5/14/71	0.04 "		0.05 "		1.25 "		1.30 "
	X=0.05 "		X=0.04 "		X=1.24 "		X=1.24 "
	<u>JRA</u>		<u>JRB</u>		<u>JRA</u>		<u>JRB</u>
5/14/71	0.02 mg/l		0.03 mg/l		0.90 mg/l		1.51 mg/l
6/18/71	0.05 "		0.04 "		1.25 "		1.48 "
7/13/71	0.02 "		0.02 "		1.06 "		1.39 "
8/10/71	0.02 "		0.04 "		0.98 "		1.67 "
9/10/71	0.03 "		0.04 "		2.15 "		2.98 "
10/16/71	0.05 "		0.05 "		1.43 "		2.28 "
11/16/71	0.04 "		0.05 "		0.92 "		1.26 "
	X=0.03 "		X=0.04 "		X=1.27 "		X=1.79 "
			<u>6TC</u>				<u>6TC</u>
6/23/72			0.01 mg/l				1.92 mg/l
	<u>JRA</u>		<u>JRB</u>		<u>JRA</u>		<u>JRB</u>
2/3/72	0.07 mg/l		0.03 mg/l		1.24 mg/l		1.24 mg/l
3/6/72	0.01 "		0.02 "		2.13 "		1.39 "
4/10/72	0.03 "		0.07 "		1.46 "		1.95 "
5/16/72	0.01 "		0.02 "		1.03 "		1.20 "
6/23/72	0.01 "		0.02 "		1.33 "		1.62 "
	0.03 "		0.03 "		1.44 "		1.48 "

P as total elemental phosphorus

N as total elemental nitrogen

Table A-2 Means ($\bar{X}$), standard errors (S.E.), 95% confidence limits about the means ($S.E. \times 1.96$) and the number of observations (n) on the periphytic production rates in 1971.

Date	Station	$\bar{X}$	S.E.	S.E. $\times$ 1.96	n
I-2/25	(Data irregular--not used.)				
II-3/20	St. 1	6.44	1.99	3.90	5
	St. 2	6.03	1.15	2.25	6
	St. 3	16.85	6.00	11.77	6
III-4/6	St. 1	5.49	.56	1.10	6
	St. 2	10.94	1.53	3.00	6
	St. 3	41.06	7.48	14.65	6
IV-4/22	St. 1	7.65	.72	1.42	6
	St. 2	29.14	4.81	9.43	6
	St. 3	109.86	4.23	8.28	6
V-5/6	St. 1	21.10	.74	1.45	6
	St. 2	85.63	4.64	9.10	6
	St. 3	204.33	40.22	78.82	6
VI-5/20	St. 1	41.37	5.93	11.62	6
	St. 2	80.85	15.00	29.34	6
	St. 3	379.74	13.38	26.23	3
VII-6/8	St. 1	83.15	10.72	21.00	3
	St. 2	613.85	64.68	126.78	6
	St. 3	1237.10	79.89	156.59	9
VIII-6/22	St. 1	39.67	3.00	5.87	5
	St. 2	261.18	17.85	34.98	9
	St. 3	560.94	101.78	199.48	5

Table A-3 Means ($\bar{X}$), standard errors (S.E.), 95% confidence limits about the means ($S.E. \times 1.96$) and the number of observations (n) on the periphytic production rates in 1972.

Date	Station	$\bar{X}$	S.E.	S.E. $\times$ 1.96	n
I-2/25	St. 1				
	St. 2	6.37	.52	1.02	7
	St. 3	13.64	.70	1.37	8
II-3/16	St. 1	8.12	.56	1.10	8
	St. 2	10.13	.71	1.39	6
	St. 3	22.70	1.38	2.70	8
III-4/3	St. 1	9.10	1.10	2.16	9
	St. 2	10.10	1.25	2.45	7
	St. 3	25.43	2.75	5.39	6
IV-4/21	St. 1	17.03	4.46	8.74	6
	St. 2	24.79	4.75	8.31	5
	St. 3	57.28	3.77	7.39	7
V-5/8	St. 1	21.51	2.48	4.86	8
	St. 2	45.38	4.83	9.47	6
	St. 3	116.20	22.80	44.84	8
VI-5/20	St. 1	63.27	4.87	9.54	8
	St. 2	107.01	15.60	30.57	6
	St. 3	482.50	114.23	223.89	8
VII-6/2	St. 1	61.11	6.74	13.21	6
	St. 2	107.93	17.31	33.93	6
	St. 3	477.48	85.64	167.85	6
VIII-6/15	St. 1	89.79	1.00	1.96	5
	St. 2	111.05	7.78	15.25	7
	St. 3	421.38	82.88	162.44	3
IX-6/28	St. 1	146.95	10.38	20.34	4
	St. 2	277.81	64.57	126.56	2
	St. 3	206.37	30.99	60.74	4

Table A-4 Community composition of periphyton on artificial substrates in the Jordan River.

	Station 1	Station 2	Station 3
5/14	<u>Gomphonema</u> spp. 68% <u>Synedra</u> spp. 16% <u>Cymbella</u> spp. 8%	<u>Gomphonema</u> spp. 44% <u>Cymbella</u> spp. 26% <u>Diatoma</u> spp. 12% <u>Meridion</u> spp. 10% <u>Synedra</u> spp. 8%	<u>Synedra</u> spp. 38% <u>Meridion</u> spp. 21% <u>Gomphonema</u> spp. 14% <u>Cymbella</u> spp. 11% <u>Diatoma</u> spp. 8%
5/30	<u>Synedra</u> spp. 45% <u>Gomphonema</u> spp. 36% <u>Cymbella</u> spp. 6%	<u>Cymbella</u> spp. 38% <u>Gomphonema</u> spp. 31% <u>Synedra</u> spp. 20%	<u>Synedra</u> spp. 38% <u>Gomphonema</u> spp. 27% <u>Cymbella</u> spp. 18%
6/18	<u>Gomphonema</u> spp. 49% <u>Synedra</u> spp. 36%	<u>Gomphonema</u> spp. 26% <u>Synedra</u> spp. 25% <u>Navicula</u> spp. 21% <u>Cymbella</u> spp. 18%	<u>Gomphonema</u> spp. 48% <u>Synedra</u> spp. 29% <u>Tabellaria</u> spp. 9% <u>Meridion</u> spp. 7%
7/1	<u>Synedra</u> spp. 44% <u>Gomphonema</u> spp. 32% <u>Meridion</u> spp. 13%	<u>Synedra</u> spp. 58% <u>Gomphonema</u> spp. 23% <u>Cymbella</u> spp. 14%	<u>Synedra</u> spp. 57% <u>Gomphonema</u> spp. 18% <u>Cymbella</u> spp. 13%
		<u>Genera Representing 1-5%</u>	
		<u>Achnanthes</u> spp. <u>Amphora</u> spp. <u>Cocconeis</u> spp. <u>Eunotia</u> spp. <u>Nitzschia</u> spp.	