THE FERTILIZATION OF A MARL LAKE

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THE FERTILIZATION OF A MARL LAKE

By

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ABSTRACT

Hoffman Lake, a 120 acre marl lake in northern Michigan, was fertilized twice during the summer of 1954 with inorganic commercial fertilizer.

The additions of the fertilizer resulted in immediate increases in the concentrations of total and soluble phosphorus, ammonia nitrogen, and sulfate. However, these increases were only temporary.

Light penetration decreased at all depths immediately following each application of fertilizer, but shortly thereafter increased until the transparency of the water was greater than before treatment. This response was due either to a flocculation or precipitation reaction that occurred following each application of fertilizer.

A ten-to thirtyfold increase in periphyton at the outlet of the lake occurred after fertilization, however these was no increase in the plankton of the lake.

The standing crop of macroscopic benthos was sampled throughout the summer. It was found that the burrowing mayflies comprised more than 90 percent of the total number and volume of organisms. The generation of mayfly nymphs of the genus *Ephemera* produced after fertilization appeared to grow more rapidly than the generation present prior to fertilization.

The game fish, except for the largemouth bass, were growing at a less than average rate. Bass were growing at a rate somewhat above average.

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INTRODUCTION

Michigan has ever-increasing numbers of fishermen. In the last forty years their numbers have nearly doubled every ten years, and at the present time there are approximately 1,200,000 licensed fishermen utilizing the waters of the state. It has become necessary to make the best possible use of the state's lakes and streams to satisfy the public's needs. In an effort to maintain and improve the fishing, attempts are underway to find management procedures for these waters which will increase fish production.

Chemical nutrients are necessary to build the living protoplasm of plant cells. It is believed that the addition of the basic nutrients in the form of inorganic fertilizer is a practical method for increasing the production in natural waters. Bacteria, protozoa, algae, and higher aquatic plants synthesize these nutrients into protoplasm which in turn is utilized as food by animal life, including fish.

In this country artificial fertilization of lakes and streams is a comparatively new practice. The Chinese, however, fertilized carp ponds more than 2,000 years ago. In European literature, fertilization dates back to the nineteenth century. Summaries presented by Davis and Wiebe (1930), and Smith (1934) indicated that the first experiments were directed toward the production of plankton in relation to carp culture. Early American experiments were directed along similar lines by Embody (1921) and Wiebe (1930). Later work by Smith and Swingle (1939), Surber (1945), Swingle (1947), Smith (1948), THE

Langford (1948), Ball (1948), Patriarche and Ball (1949), and Ball and Tanner (1951) have shown that increases in the growth of higher aquatic plants, plankton, bottom fauna, and fish result from the addition of fertilizer. The more important American and some of the European literature dealing with aquatic fertilization has been summarized by Maciolek (1954). Most of the fertilization has been done on lakes under 30 acres in size and little on larger lakes or streams.

The object of this investigation was to test the hypothesis that an addition of fertilizer to a lake would increase the productivity within the lake, and would also bring about an increase in the productivity of a stream fed by the lake. The lake fertilized was Hoffman Lake, Charlevoix County. Additions of fertilizer were traced within the lake and down the West Branch of the Sturgeon River, the outflowing stream.

Results were evaluated in terms of physical, chemical, and biological changes occurring following fertilization. The over-all program of study was planned for a period of three years to permit evaluation of the slower responses and long range effects of fertilization. This thesis deals with the work done on Hoffman Lake during the summer of 1954 (first year of fertilization). The field work on the lake and stream was carried out jointly with Mr. Alfred R. Grzenda. His thesis Grzenda (1956) entitled "The Biological Response of a Trout Stream to Headwater Fertilization," deals with the findings from the stream.

DESCRIPTION OF THE LAKE AND STUDY AREA

Hoffman Lake is located in Hudson Township, Charlevoix County (T. 23 N., R. 4 W., Sec. 26, 27, 34, 35). It lies about 7 1/2 miles west of Vanderbilt, Michigan, in a valley among prominent hills. It is a shallow marl lake having a surface area of 120 acres. The basin has three minor depressions which are approximately 22 feet in depth; this is the maximum depth of the lake. More than 75 percent of the lake is less than 15 feet deep. Thermal stratification was not detected during the summer except in the depression off the south shore which, in June, contained water a few degrees cooler than the remainder of the lake. The water temperature was nearly homothermous throughout the lake for the remainder of the study.

The surrounding soils are composed of sandy glacial drift which has an abundance of calcium and magnesium. The waters of the area are generally alkaline. Alkalinity of the lake was consistently about 130 p.p.m., mostly in the bicarbonate form. A water sample collected September 3 had a total hardness of 155 p.p.m., of which 100 p.p.m. was due to calcium salts. The pH varied from 8.2 to 8.5. Except for small patches of sand adjoining the shore, the bottom of the lake is light gray marl containing very little organic matter. The shore line development was 1.2.

The water has a bluish-green cast which is characteristic of marl bottom lakes. Turbidity of the surface water was less than 5 p.p.m. The principal water supply is furnished by numerous springs entering the south and west shores. Several of these springs unite

THE

Figure 1. Hoffman Lake, from east to west, showing the marl deposition on submerged logs.

deposi-

to form the inlet which enters at the west end of the lake. The watershed of the lake is small due to the hilly topography, and probably contributes little water to the lake as surface runoff (Roelofs, 1941, mimeographed report). The chief vegetative type of the drainage area is second growth hardwoods with scattered clearings. Some areas are being utilized for farming and the grazing of livestock. Cedar swamps occupy the low lands adjacent to the lake, and some of these areas are being cleared and filled for cottage sites.

The bulrush (Scirpus sp.), was the predominant aquatic plant and it occurred in water 1 to 5 feet deep. In the deeper water scattered patches of pondweed (Potamogeton sp.) and stonewort (Chara sp.) were found. There was one small patch of white water lilies (Nymphaea sp.) at the west end of the lake. The vegetation was extremely sparse and the submerged parts of the plants were heavily coated with marl, which may have a decided effect upon plant abundance.

Burrowing mayflies (Ephemeridae) composed the bulk of the bottom organisms. Other forms of aquatic insects were not abundant.

Game fish found in the lake were largemouth bass (Micropterus salmoides), rock bass (Ambloplites rupestris), common sunfish (Lepomis gibbosus), yellow perch (Perca flavescens), and brook trout (Salvelinus fontinalis). One species of coarse fish, the common sucker (Catostomus commersoni) was taken. Forage species were log perch (Percina caprodes), Iowa darter (Etheostoma exile), common shiner (Notropis cornutus), mimic shiner (Notropis volucellus), creek chub (Semotilus atromaculatus), and bluntnose minnow (Pimephales notatus).

Judging from the reports of local residents, the lake in the past furnished good fishing for bass, perch, and trout but the fishing success has reportedly decreased within the past twenty years. All species of game fish except the largemouth bass were growing at a below average rate at the time of this study. Numerous attempts to establish trout in Hoffman Lake have been made. One thousand brook and 1000 rainbow trout were planted in 1941 with little success. Montana grayling were planted in 1926 but apparently did not survive. Two brook trout were taken in trapping operations on the lake during the summer of 1954. Fry and fingerlings of brook trout were abundant in the springs which feed the lake. These fish presumably would stock the lake if conditions were favorable for trout. According to the lake classification of the Michigan Department of Conservation the lake was designated as a trout lake in 1954, but has since been removed from that status. The lake has about a dozen cottages around its south shore and more are being built at other locations at the present time. In Michigan, lakes, other than marl lakes which have similar bottom conformation and depth, tend to be relatively high in productivity, but apparently the influence of the marl deposit and the lack of organic deposition result in a meager production of aquatic life.

METHODS AND EQUIPMENT

Fertilization

Commercial inorganic fertilizer with an analysis formula of 10-10-10 (N-P-K) was applied to Hoffman Lake twice during the summer of

1954. The fertilizer contained nitrogen in the form of ammonium sulfate, phosphorus as super-phosphate, and potassium as potassium chloride. The fertilizer was spread from a moving boat. It was released slowly from the bags to decrease the possibility of its falling to the lake bottom before being completely dissolved. Most of the chemical was spread in shallow water (under four feet deep) so that wave agitation aided mixing. The actual quantities of fertilizer applied were: 3200 pounds on July 30 and 2700 pounds on August 9. The theoretical concentration to be expected in the lake as a result of each application may be found in Table 1. In these calculations it was assummed that the fertilizer dissolved completely, and was evenly distributed throughout the lake. The lake volume used in these calculations was 45,000,000 cubic feet.

Sampling

Five sampling stations were established on Hoffman Lake; these are shown in Figure 2. Stations A, B, and C are locations at which chemical samples were taken. At stations 1 and 2, which were marked by bouys suspended from posts driven into the bottom of the lake, turbidity, plankton, and macroscopic benthos were sampled.

PHYSICAL

Secchi disk. This instrument was employed as one measurement of light transmission. Secchi disk readings are not actual measurements of light penetration, but are useful measurements when used under standard conditions. According to Welch (1948) this measurement can be used to compare light conditions in one body of water at different times. Readings were taken throughout the study.

Table 1

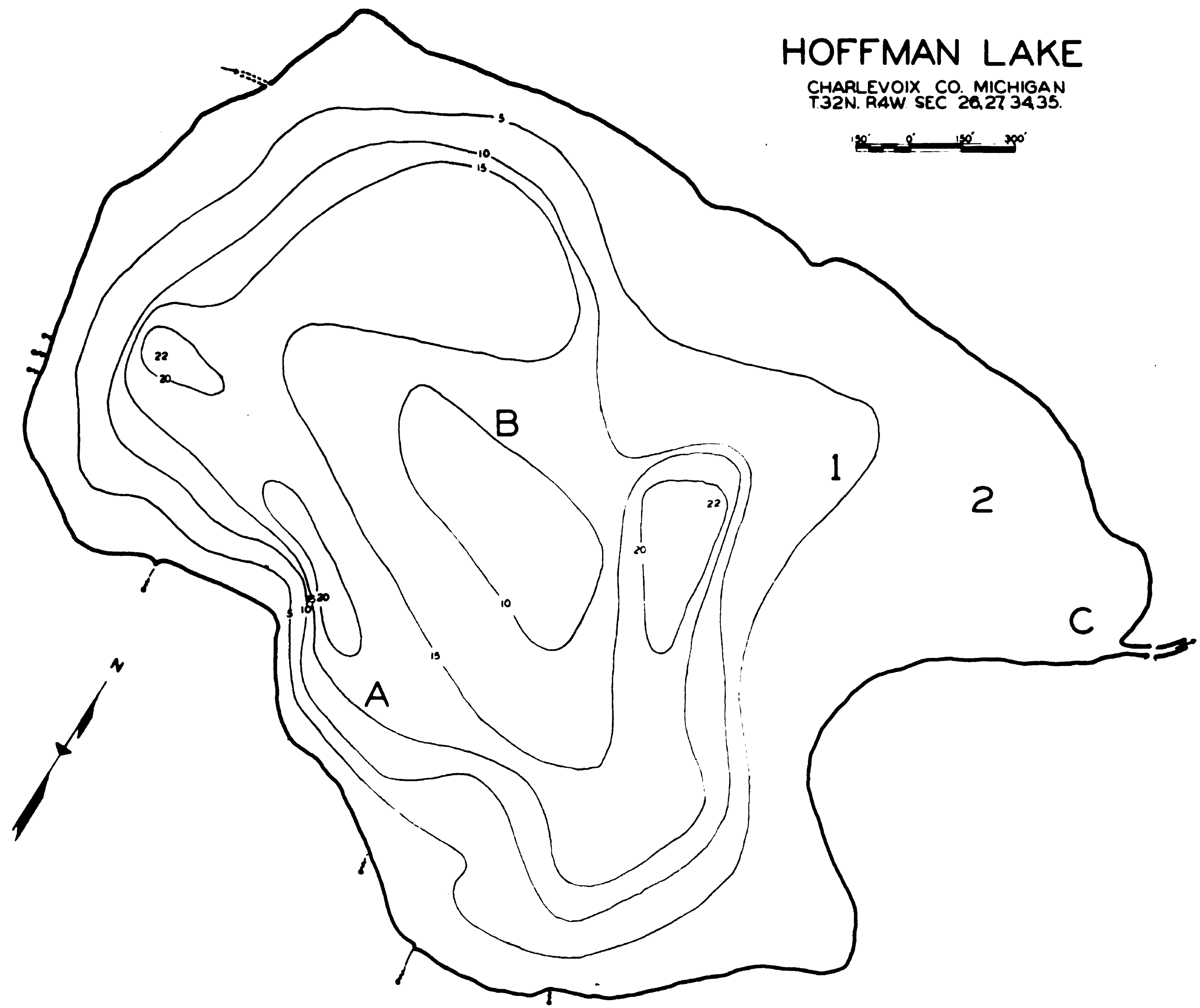
Theoretical Concentration of Chemicals in Hoffman Lake After Fertilization

	Concentration (p.p.m.)	
	First application (3200 pounds)	Second application (2700 pounds)
Fertilizer	1.139	0.968
Nitrogen	0.1139	0.0968
Ammonia	0.1464	0.1244
Sulfate	0.4026	0.3421
Phosphoric acid	0.1139	0.0968
Phosphorus	0.0498	0.0424
Potassium oxide	0.1139	0.0968
Potassium	0.0945	0.0803

Figure 2. Map of Hoffman Lake giving location of sampling stations.

HOFFMAN LAKE

CHARLEVOIX CO. MICHIGAN
T.32N. R4W. SEC. 26,27, 34,35.



Underwater photometer. This instrument described by Greenbank (1945), was utilized to measure light transmission. Readings were taken throughout the experiment when conditions permitted. All measurements were made about the same time of day and under clear sky conditions. Sub-surface measurements were made at depth intervals of three feet. Total survace illumination was measured before and after each vertical series and if the two readings were in disagreement the series was discarded. Eight to twelve series were made and these were averaged to give a mean value for each depth for each day or observation. The majority of the measurements were made at the deepest part of the lake.

Turbidity. A Hellige turbidimeter was used for turbidity measurements. This instrument is particularly useful for determining low tribidities with high precision, Welch (1948). Surface water samples were taken at irregular intervals from stations 1 and 2 from July 8 to August 16. Readings were made in the laboratory on the same day the samples were collected.

Temperature. Water and air temperatures were taken throughout the experiment with a Taylor pocket thermometer.

CHEMICAL

Hydrogen ion concentration. The pH was determined colorimetrically with LaMotte color standards.

Alkalinity. The titration method outlined by Ellis, Westfall, and Ellis (1946) was used to determine alkalinity. Surface water samples were collected from station 1 and 2 at regular intervals during the entire summer's work and the titrations for alkalinity were made in the laboratory on the day of sampling.

Ammonia nitrogen. Ammonia nitrogen was determined by direct nesslerization as outlined in Standard Methods of Water Analysis (1946). A Klett-Summerson photoelectric colorimeter was used to take readings and these were converted to parts per million by comparison with standard solutions. Surface water samples were taken at the three chemical stations A, B, and C (Figure 2).

Phosphorus. Soluble and total phosphorus determinations were made by the molybdate method as outlined by Ellis et al. (1946). The Klett-Summerson colorimeter was used to take readings and these readings were converted to parts per billion by comparison with standard solutions.

Sulfate. The benzidine method as outlined by Ellis et al. (1946) was used for the determination of sulfates.

BIOLOGICAL

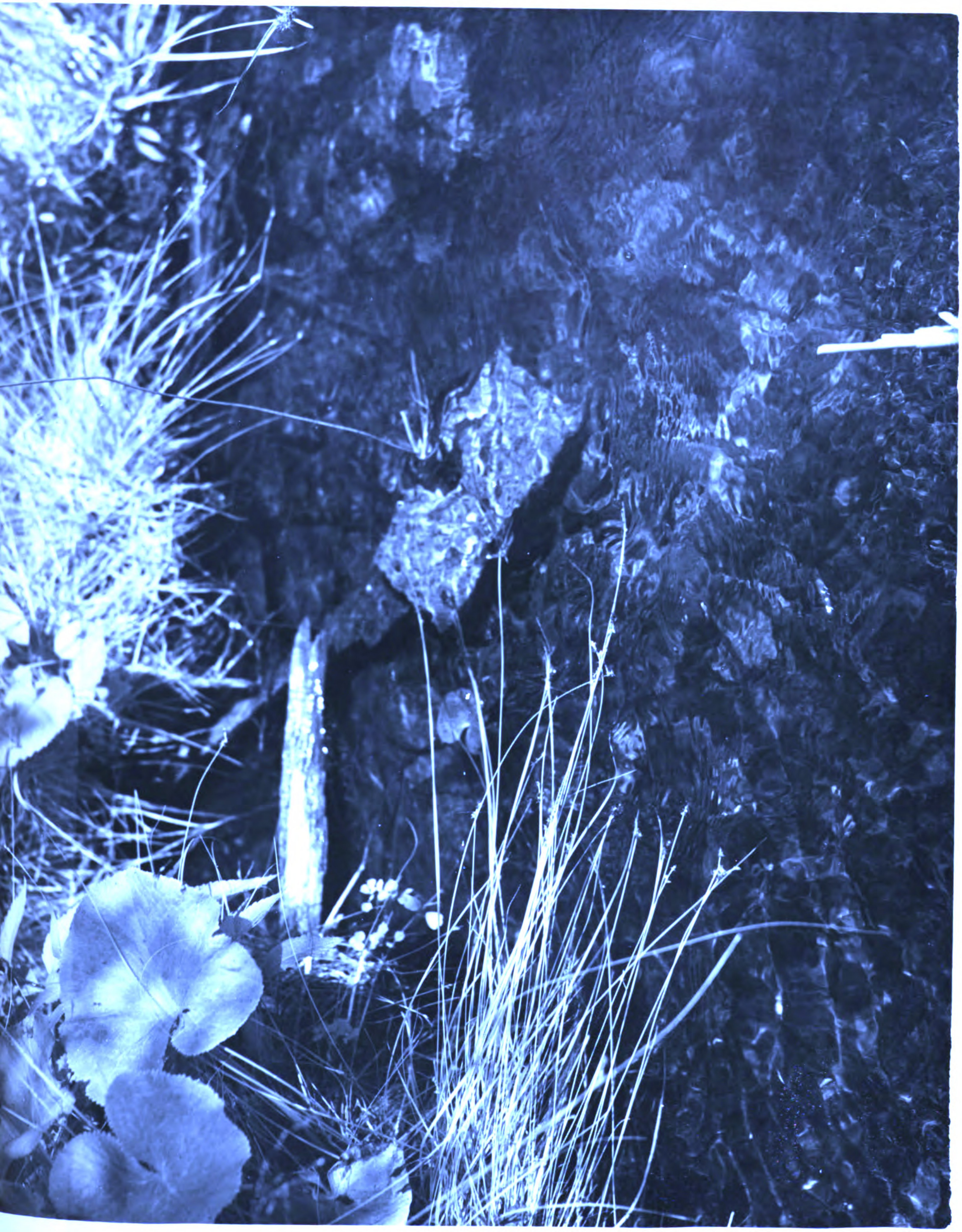
Plankton. Surface water samples for the extraction of plankton were collected periodically at stations 1 and 2 from July 6 until August 30. The Juday water sampler was used for collection of samples. A three-liter water sample was collected at each of the stations. These samples were taken to the laboratory and centrifuged within three hours after collection. The extracted material and several washings of water were poured into a 50 ml. graduated cylinder and enough water and formalin was added to produce a 5 percent preserving solution.

Laboratory examination of the extracted material revealed such extremely low concentrations of plankton that quantitative counts were not practical. There was an increase in extractable material following

Figure 3. The method of collecting periphyton by use of a shingle substrate.

I

Figure 4. The method of collecting periphyton by use of a brick substrate.



both applications of fertilizer, but this was not phytoplankton or zooplankton. The concentrated extract did not contain dissolved solids which had been present in the lake water. These were lost in centrifugation. The parts per million of suspended solids present in the lake water for the various sampling dates were determined by drying and weighing an aliquot of the concentrated sample. By igniting and reweighing the residue from drying the volatile fraction was obtained. The procedures used were those described by Theroux, Eldridge, and Mallman (1943), except that samples were dried at 60° C. instead of 103° C.

An aliquot of the plankton extract was treated with 0.05 N HCl to dissolve acid soluble salts. The sample was then recentrifuged with a laboratory type centrifuge to extract acid insoluble material. Measurement of the amount of suspended solids and volatile material were then made on this insoluble fraction using the method of Theroux et al. (1943). Analysis of phosphorus, total hardness, and calcium ion were made on the liquid fraction.

Periphyton. Periphyton is part of the food complex of every natural body of water. Many organisms of this assemblage are capable of manufacturing food by means of their chlorophyll. In this respect periphyton occupies a position similar to that of phytoplankton. In this paper periphyton is considered as that assemblage of organisms living upon free surfaces of submerged objects. It is a slimy coating that may be black, brown, green, blue-green, or yellow-green in color. Periphyton may appear to be smooth, flocculent, or rough. Sand, silt, marl, and detritus are common constituents. This description follows that of Young (1945).

Because periphyton was almost always present in the water, and conspicuous quantities were often produced, it was used as a biological index to evaluate the effects of fertilization. Other workers have used periphyton as an index of biological production. Patrick (1949) placed glass slides in water for various periods of time and made numerical counts of the periphyton accumulation. Young (op. cit.) made numerical counts on periphyton that grew on Scirpus sp., stones, and brush submerged in water. In a study of a Montana stream Gumtow (1955) reported important effects of temperature and stream-flow upon the periphyton assemblage. He utilized stones from the stream bed and bank to obtain samples.

Due to the inexactness and difficulty of the count method, the method of chlorophyll extraction was used to evaluate quantitatively changes in periphyton abundance. Experiments in pigment extraction as a method of quantitative analysis of phytoplankton have been reported by Harvey (1934). He showed good correlation between colorimetric determinations of pigment extractions and counts of comparable plankton samples. He compared the pigment extracts with an arbitrary color standard consisting of 25 mg. of potassium chromate and 43 mg. of nickel sulfate dissolved in one liter of water, the color intensity being equivalent to one "Harvey Unit." Later work by Tucker (1949) showed good correlation between units of counted phytoplankton and density of the extracted pigments. He suggests that this method has merit for comparing a number of samples from the same lake or from two lakes at one time.

To obtain samples for the extraction of pigments from periphyton organisms, cinder bricks and cedar shingles were placed in the vicinity of the outlet of Hoffman Lake. The bricks measured 7.9 x 3.7 x 2.3 inches. Cedar shingles were cut to the dimensions of 12.0 x 3.0 x 0.3 inches. Bricks were suspended in water by means of wires hung from submerged logs or suitable objects above the water. The shingles were attached directly to submerged logs with as little area in contact with the log as possible. The first set of 5 bricks and 10 shingles was placed in the lake July 1, 30 days before the first application of fertilizer. On July 30, the first set was removed and the second placed in exactly the same location and with the same orietation to the current as the first set. Each unit was identified by a station and location number so that pairs from the same location and exposed for the same length of time under similar enviornmental conditions could be compared.

Bricks were removed by clipping the suspending wires and then were carefully placed in a porcelain pan. The mixture of organisms and detritus which had accumulated was then brushed and washed into the pan. This material was then poured into a quart jar for later laboratory treatment. The shingles were not brushed and washed in the field, but were carefully lifted from the water, placed in plastic bags and taken to the laboratory. In the laboratory they were brushed and washed and the resultant mixture put in quart jars.

This heterogeneous mixture of sand, silt, clay, detritus, and periphyton organisms were separated from the liquid by centrifugation with a Foerst centrifuge. The liquid from the overflow tube of the centrifuge was collected and the centrifugation repeated until it appeared free of extractable material. The extracted periphyton

mixture was placed in a 150 ml. storage bottle, and 95 percent ethyl alcohol was added to preserve the living material and to extract the chlorophyll pigments.

In the laboratory the supernatent liquid was filtered or decanted from the preserved sample. The filtrate containing the chlorophyll pigments was then diluted to a volume of 50 ml. with ethyl alcohol. Readings of the pigment density, of the filtrate were made with a Klett-Summerson photoelectric colorimeter. These readings were then converted into Harvey units.

Microscopic benthos. Bottom may be a valuable biological index with which to evaluate the effectiveness of fertilization. However, the responses of macroscopic benthis organisms to nutrients presumably would be slow since the chemicals would first have to be converted into protoplasm which in turn could be used as food for the bottom organisms. Therefore no measureable increase in production of benthos was expected during the first year. The data presented in this thesis serve chiefly as a basis for comparison with data to be gathered in future years. Bottom samples were collected at weekly intervals beginning July 2 and thereafter until September 3 to establish an estimate of the weekly standing crop of bottom organisms for the summer of 1954.

Ten Ekman dredge samples were collected at both stations 1 and 2. Each sample was washed using a 30-mesh wire screen. The organisms were then picked from the bottom material while alive and put in bottles containing a 10 percent formalin solution. In the laboratory the organisms in each preserved sample were identified and counted. Mayflies were predominant in all samples. Since the total sample volume was in most cases very close to the volume of the family Ephemeridae, only the total volume of organisms was determined. May-flies of the genus <u>Ephemera</u> were measured from the anterior end of the rostrum to the posterior end of the abdomen. These measurements were recorded to the nearest tenth of an inch. From these data, emergence period, instantaneous rates of growth, and instantaneous rates of mortality were determined.

Analysis of variance was used to test for differences in the volumes of organisms between the stations and between weeks of sampling. The analyses were made according to procedures given by Snedecor (1946). The total volumes of organisms were recorded in hundredths of a milliliter. To facilitate statistical analysis each sample volume was multiplied by 100. This made it a whole number. Some of the samples had no measurable volume, and since a logarithmic transformation was to be used, and there is no logarithm of zero, a value of 0.01 ml. was added to the total volume of all samples.

<u>Fish</u>. One purpose of this investigation was to determine what effect the fertilization would have upon the growth of the fish. Fish were collected throughout the summer by trapping, seining, and angling. Age and growth determinations were made from 407 scale samples. One hundred scale samples were taken from each of the following species: yellow perch, rock bass, and common sunfish. Scales from 50 white suckers and 57 largemouth bass made up the remainder. The weight of all fish was recorded in grams and total length was measured in inches.

In the laboratory the scales were cleaned and mounted in gelatin medium, and read using a scale projector. The absolute growth and annual increments were determined for the game and coarse species of fish. The length-weight relationship was determined for all species by the use of the formula $W = cL^{n}$ in which L = length, W = weight, and c and n are constants which can be determined by methods described in Lagler (1952) and Rounsefell and Everhart (1953). The preceding formula expressed logarithmically is:

$\text{Log}_e W = \text{Log}_e c + n \text{Log}_e L$. This form was used for computations.

Instantaneous rates of growth were calculated for the last complete year of growth for all species of game and coarse fish. The last complete year of growth of the fish sampled was the 1953 growing season. Computations of the instantaneous rate of growth were made using the following methods:

Linear instantaneous rate of growth $\text{Log}_e \dfrac{L_2}{L_1}$

Gravimetric instantaneous rate of growth $\text{Log}_e \dfrac{L_2}{L_1} \times n$

where Log_e = the natural logarithm

L_2 = length of the fish at last annulus

L_1 = length of the fish at preceding annulus

n = constant derived from length-weight relationship.

The linear instantaneous rate of growth, for the last growing season, is the natural logarithm of the fraction of the length of the fish at the completion of its last growing season, divided by its length at the completion of the preceding growing season. The gravimetric instantaneous rate of growth may be determined by multiplying the linear instantaneous rate by the constant n. This constant n is the power to which the logarithm of the length of the fish must be raised to be equivalent to the logarithm of the weight of the fish. The constant n may be derived from the length-weight relationship.

The following is an example of the calculation of the instanteneous rate of growth of a fish for its last complete growing season. Given a fish 13 inches long when captured. From reading the scales it was determined that the fish had four annuli and presumably was in its fifth growing season when captured. Back calculations made from scale measurements showed that the fish was 12 inches long at the completion of its fourth growing season and 10 inches long upon completion of its third growing season, thus the linear instantaneous rate of growth for the last growing season is equal to the natural logarithm of 1.2 (12 ÷ 10). The same decimal fraction could have been obtained directly from scale measurements instead of backcalculating to actual lengths of the fish. The natural logarithm of 1.2 is 0.18323 and this value is the linear instantaneous rate of growth. To determine the gravimetric instantaneous rate of growth, 0.18232 is multiplied by n. If for example n equals 3.1 then the geometric rate becomes 0.56519 for this fish. This fish would be classified as age group IV and the growth rates determined above would be the rates of growth between the third and fourth annuli formation, or during the fourth growing season.

For the purpose of evaluating changes in the growth rates of fish in Hoffman Lake which may occur following fertilization, the "actual lengths" of the fish at various ages were not computed. Instead the logarithmic fraction used for computing the instantaneous rates was obtained directly from measurements of the fish scales as they were recorded on ruled scale catalog cards. This procedure gives the same result as using actual body lengths of the fish under the assumption that the relationship between the scale length of the body length is a straight line. For the purpose of evaluating changes in growth rates in Hoffman Lake this relationship was assumed to be a straight line.

However, it has been shown in many studies that the scale length to body length relationship is not a straight line and these workers have used a correction factor designated as C which is equal to the calculated lengths of the fish at the time of scale formation. This factor C must be added to each scale measurement is the body-scale relationship is not assumed to be a straight line. However, this procedure is more difficult and does not improve the data if they are used for comparison of growth rates, because the factor C is probably constant for all fish which might be used to determine changes in growth rate after fertilization. The factor C had been established on 0 age group fish and all older groups by the summer of 1954, thus any measurements made from fish which were age group two or older in the following two years of the experiment would have had the factor C established prior to the fertilization.

RESULTS

Sampling

The fertilization brought about several immediate measurable changes in the physical and chemical characteristics of Hoffman Lake. Biological responses were slower to appear but detectable changes occurred in the sessile organisms (periphyton) during the summer of

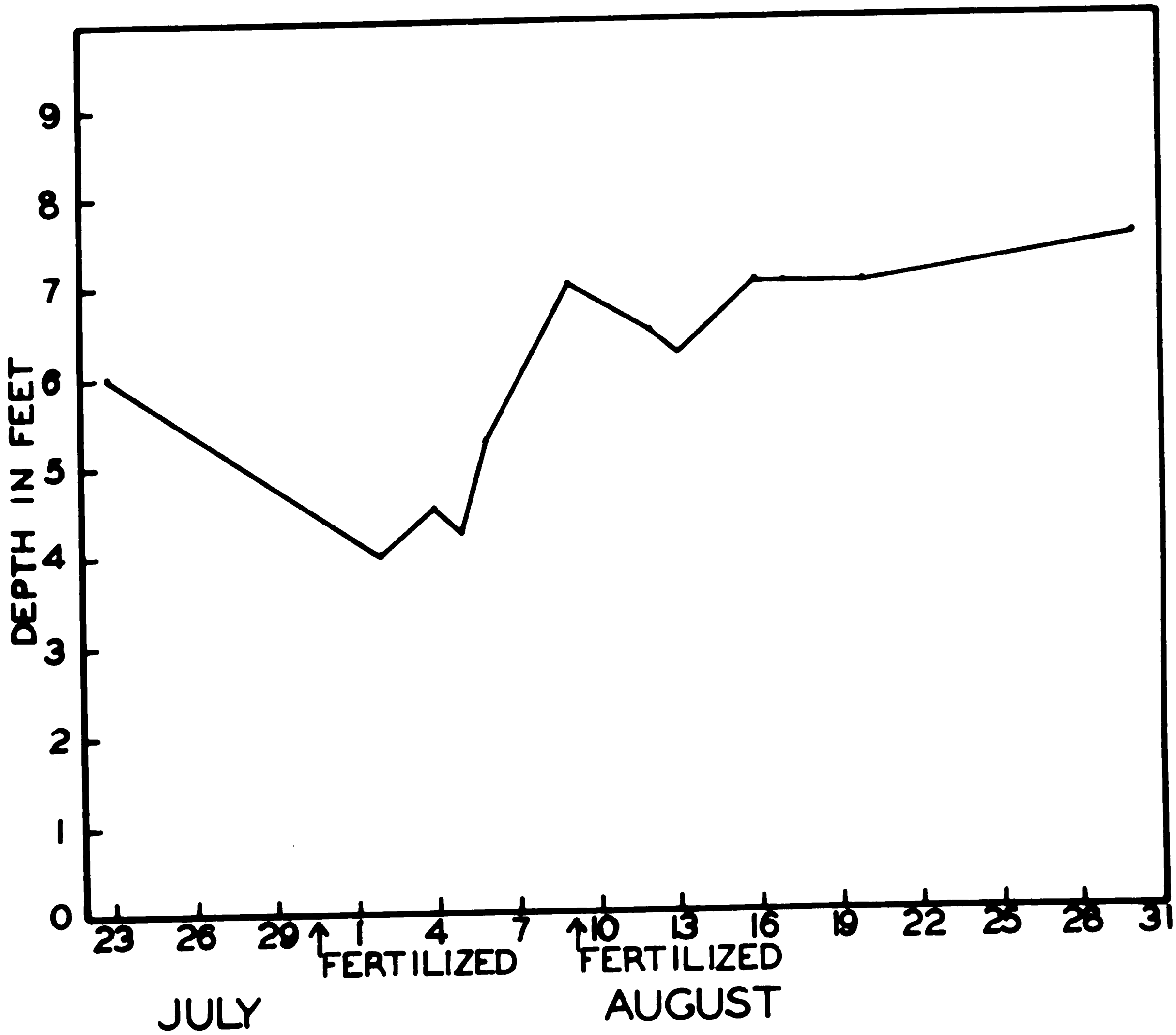
1954. Responses of macroscopic benthos and the growth rates of the fish to fertilization are not to be expected during the first summer. The data presented regarding benthos and fish therefore serve only as records for comparison with data to be gathered in the future.

PHYSICAL

Secchi disk. The transparency of the water decreased following both applications of fertilizer. Figure 5 shows the variation in mean readings for the study period. Before fertilization the Secchi disk was visible to a depth of 6 feet. Three days after the first application of fertilizer the Secchi disk disappeared at the depth of 4 feet. Thereafter the water cleared until after the second application. Prior to the second application the Secchi disk was visible to a depth of 7 feet; immediately following the application a slight decrease in transparency was found. Thereafter transparencies increased for the remainder of the study period. Transparency was greater at the end of the summer than at any other time during the study.

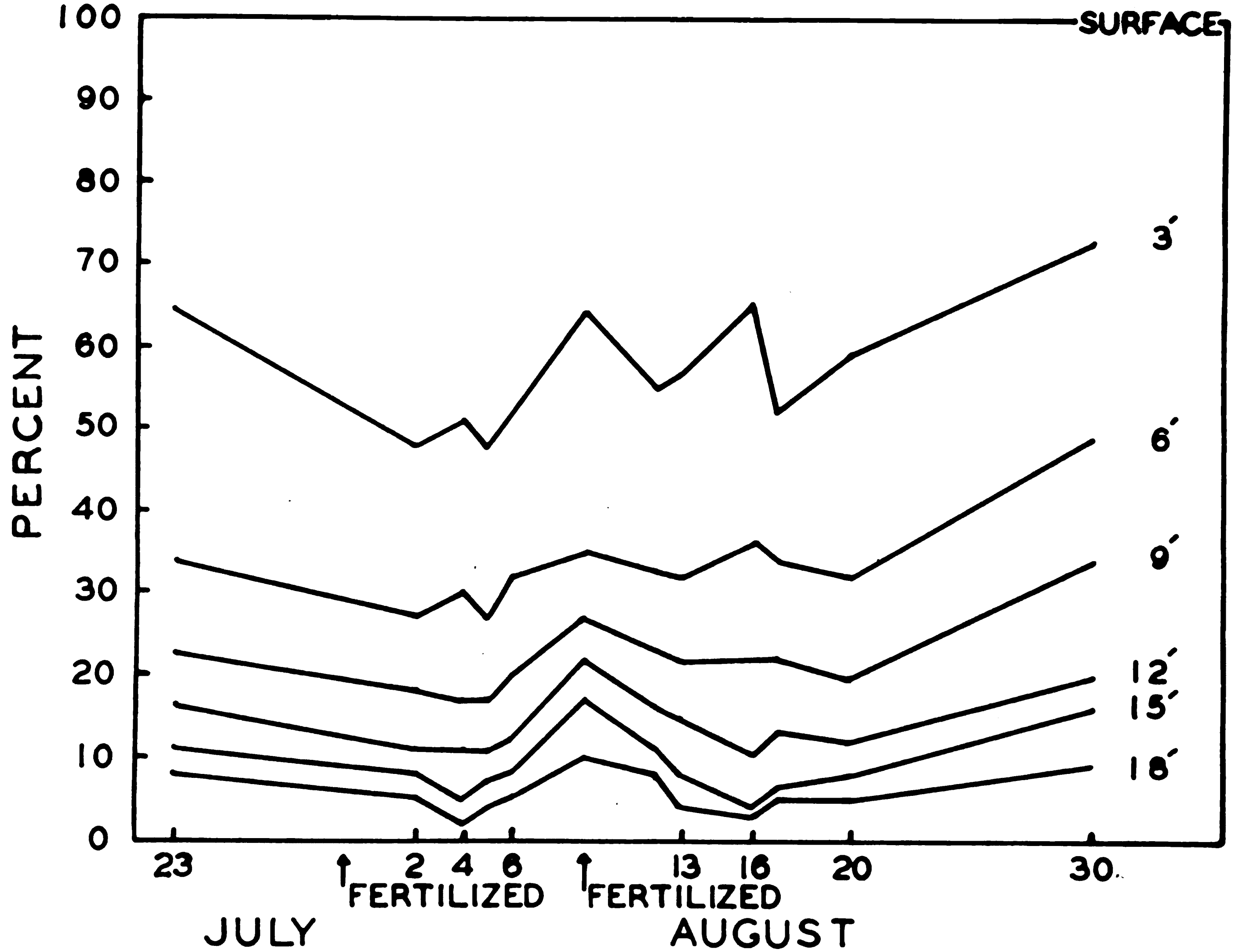
Photometer readings. In general, photometer readings substantiated the findings from the Secchi disk readings. The photometer readings however show fluctuations in transparency at several sub-surface levels. Figure 6 shows the mean variation in the percentage of surface illumination reaching the 3, 6, 9, 12, 15, 18, and 21 foot depths Table 2. Light penetration decreased at all depths immediately following each application of fertilizer; therefore clearing of the water occurred resulting in a greater transparency after fertilization then before

Figure 5. Mean Secchi disk readings in feet.



DEPTH IN FEET
0
1
2
3
4
5
6
7
8
9
23
26
29
1
4
7
10
13
16
19
22
25
28
31
FERTILIZED
FERTILIZED
JULY
AUGUST

Figure 6. Percentage of surface illumination reaching various depths.



PERCENT
100
90
80
70
60
50
40
30
20
10
0
SURFACE
3′
6′
9′
12′
15′
18′
23
2
4
6
13
16
20
30
FERTILIZED
FERTILIZED
JULY
AUGUST

Table 2

Mean Secchi Disk and Photometer Readings

Date	Secchi disk (feet)	Photometer (percentage of surface illumination reaching various depths in feet)						
		3	6	9	12	15	18	21
July 23	6.0	64.1	33.8	23.2	16.5	11.2	8.4	2.9
30*	...	...	...	...	...	...	...	...
Aug. 2	4.0	48.1	26.7	18.5	11.1	7.6	4.8	0
4	4.5	50.6	30.1	17.1	11.0	4.6	2.0	0
5	4.3	48.1	27.2	16.9	10.6	6.6	3.9	1.3
6	5.3	51.7	32.0	19.7	12.2	7.9	4.9	0.1
9*	7.0	64.4	34.9	26.8	21.9	17.0	10.0	0
12	6.5	55.4	32.8	23.0	15.9	11.3	7.8	5.5
13	6.3	56.7	32.5	21.6	14.9	7.8	4.4	0
16	7.0	65.2	35.9	21.6	10.4	4.3	2.9	0
17	7.0	52.3	33.9	21.5	13.4	6.5	5.0	1.8
20	7.0	59.0	32.0	20.00	12.0	7.7	5.0	2.8
30	7.5	72.6	49.4	34.2	19.8	16.5	9.5	0

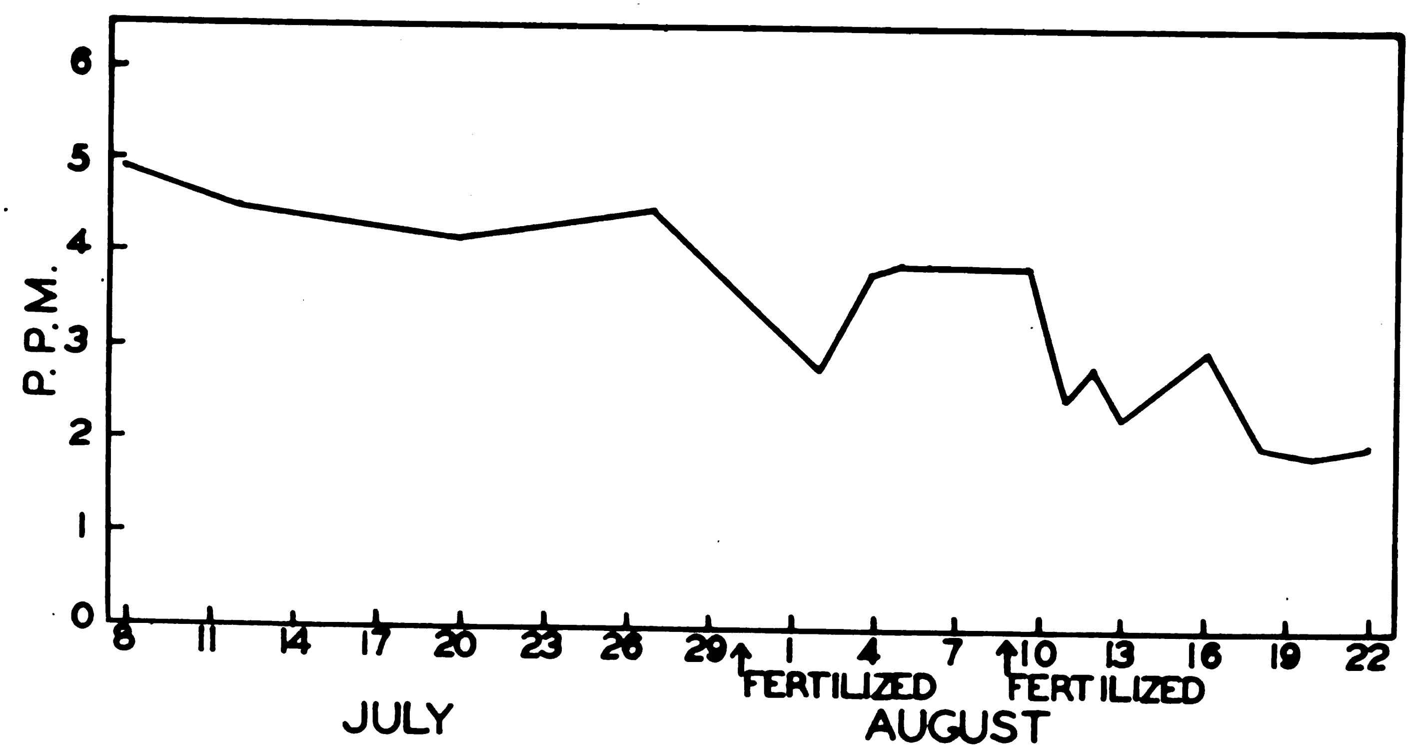
* Dates of application of fertilizer

fertilization. This phenomena occurred following each application of the fertilizer.

Turbidity. Prior to fertilization surface turbidities were 4 to 5 p.p.m. Immediately after the first fertilization the surface turbidity was reduced to about 2.8 p.p.m. After this initial reduction, turbidity increased steadily and reached the prefertilization level by the time of the second fertilizer application. Immediately following the second fertilizer application the turbidity fell to 2 p.p.m. and remained at this point for the duration of the study period. Fluctuation in the surface turbidity averaged for various stations on each date during the summer are shown in Figure 7.

Temperature. Surface water temperatures varied between 64° and 79° F. for the study period. Records of air and surface water temperatures are tabulated in Table 4. In general, water temperatures were the highest in the latter part of June, and decreased during July and August. This general trend was also evident in the records of air temperatures. Most of the water temperatures were taken at the surface, and were for the most part representative of temperatures throughout the lake since the water was in nearly complete circulation. The depression off the south shore contained water at a temperature of 66° F. during June. This may be attributed to the cooler denser waters settling in this depression from the numerous small springs entering the lake in this area. Surface spring had temperatures ranging from 54° and 58° F. throughout the summer.

Figure 7. Turbidity of the surface water on various dates. Values plotted are averages for 2 stations.



P.P.M.
0
1
2
3
4
5
6
8
11
14
17
20
23
26
29
1
4
7
10
13
16
19
22
FERTILIZED
FERTILIZED
JULY
AUGUST

Table 3

Surface Turbidity
(p.p.m.)

Date		Station I	Station II
July	8	4.5	5.2
	12	4.9	4.1
	20	4.4	4.0
	27	5.0	4.1
	30*	...	...
Aug.	2	2.6	3.0
	4	3.8	3.8
	5	4.0	3.8
	6	3.8	4.0
	9*	...	...
	10	3.8	4.0
	11	2.4	2.5
	12	3.0	2.5
	13	2.3	2.2
	16	2.9	3.1
	18	2.0	2.0
	20	1.9	1.8
	22	2.0	2.0
	27	2.4	2.3
Sept.	8	1.8	2.3
	10	2.0	2.4

* Dates of application of fertilizer

Table 4

Air and Surface Water Temperature
(C°)

Date		Water temperature	Air temperature
June	17	25	27
	18	26	27
	19	25	28
	24	22	21
	29	22.5	20
July	5	20	18
	7	20	18
	8	22.5	20
	12	21	23
	15	18	23
	22	23	20.5
	26	24	23.5
Aug.	6	22	20
	10	18	14
	12	18.5	14
	19	23.5	20
	29	20	19
Sept.	3	19	18

CHEMICAL

Hydrogen ion concentration. The pH of the lake water varied between 8.2 and 8.5 during the study. There was no evidence that fertilization affected the pH of the lake although there could have been changes of short duration in the area of application of the fertilizer.

Alkalinity. Alkalinity varied from 128 to 133 p.p.m. within the period of study. About 10 p.p.m. of this was due to carbonate and the remainder was attributed to bicarbonate. Marl particles ($CaCO_3$) could be seen suspended in the water and these were undoubtedly responsible for a large proportion of the carbonate. Fertilization did not seem to alter the alkalinity of the lake water although carbonates are believed to have been flocculated or precipitated in the lake following each application of fertilizer.

Ammoniam nitrogen. There was an increase of ammonia nitrogen following each application of fertilizer. Hoffman Lake was fertilized July 30 and again on August 9. Prior to fertilization the concentration of ammonia was 0.06 p.p.m. (Figure 8). This is slightly lower than concentrations found in surface water of seven Wisconsin lakes during June, July, and August by Domogalla, Juday, and Petersen (1925). One day following the first application of fertilizer the concentration of ammonia was 0.04 p.p.m. for stations A and B, and 0.03 p.p.m. for station C. These are lower than the prefertilization concentrations and this may be due to error in measurement, or the normal decline of ammonia nitrogen in lake waters which occurs at this time of year.

Figure 8. Ammonia nitrogen (p.p.m.)

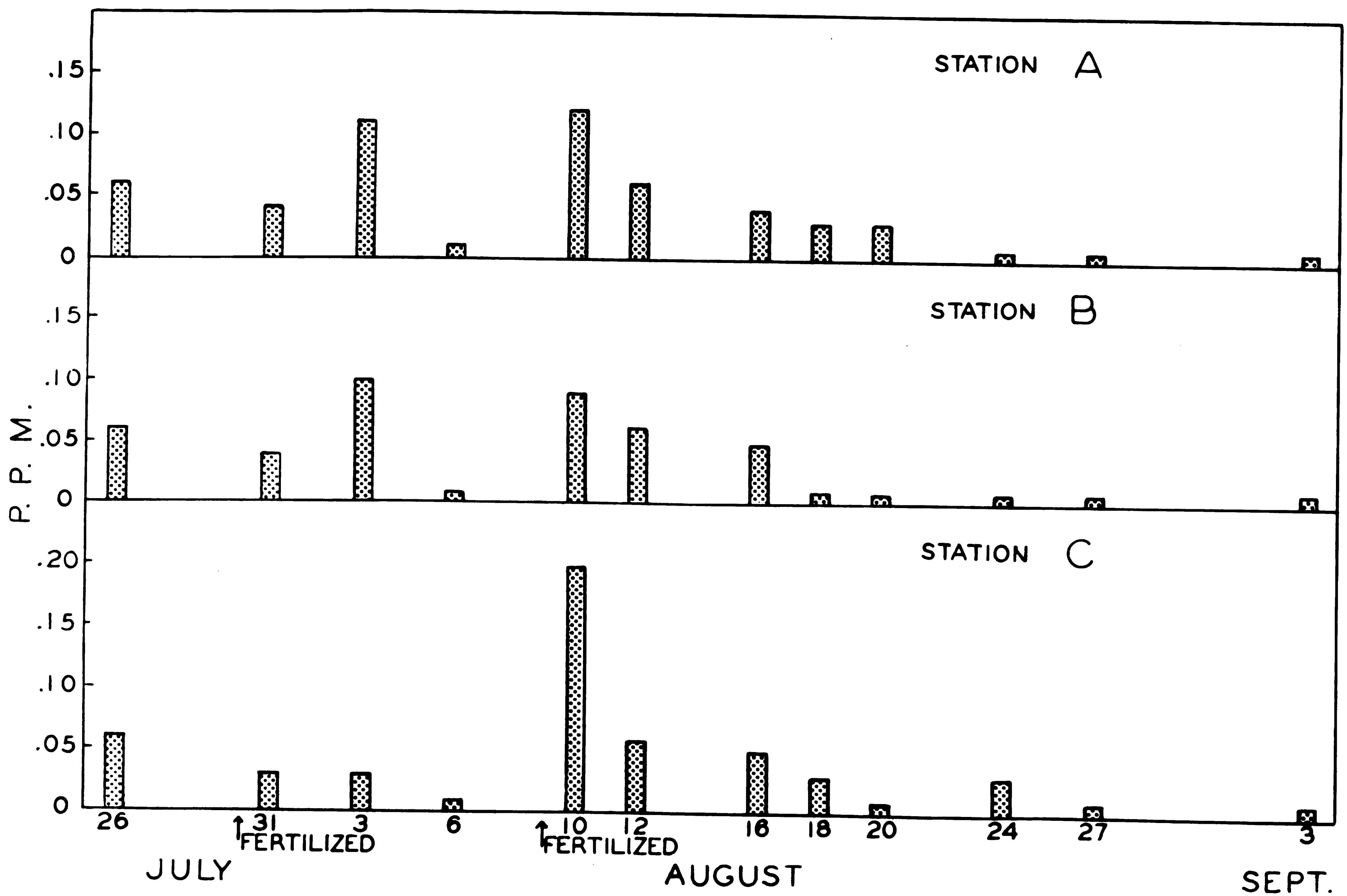

STATION A
STATION B
STATION C
P. P. M.
.20
.15
.10
.05
0
26
31
3
6
10
12
16
18
20
24
27
3
FERTILIZED
FERTILIZED
JULY
AUGUST
SEPT.

Table 5

Ammonia Nitrogen
(p.p.m.)

Date		Station A	Station B	Station C
July	26	0.06	0.06	0.06
	30*	...	...	...
	31	0.04	0.04	0.03
Aug.	3	0.11	0.10	0.03
	6	0.01	0.01	0.01
	9*	...	...	...
	10	0.12	0.09	0.20
	12	0.06	0.06	0.06
	16	0.04	0.05	0.05
	18	0.03	0.01	0.03
	20	0.03	0.00	0.01
	24	0.01	0.01	0.03
	27	0.01	0.01	0.01
Sept.	3	0.01	0.01	0.01
	10	0.01	0.01	0.01

* Dates of application of fertilizer

According to Domogalla et al. (1925), a decline in ammonia, nitrites, and nitrates in the surface zone occurs in the late summer and early fall. Four days following the first application ammonia had increased to 0.11 p.p.m. for stations A and B but remained at 0.04 p.p.m. for station C. Eight days following the first application of fertilizer ammonia was 0.01 p.p.m. at all stations.

One day following the second application ammonia concentrations increased at stations A and B to 0.12 and 0.09 respectively. The theoretical concentration, assuming even distribution throughout the lake, was calculated to be 0.12 p.p.m. At station C ammonia increased to 0.20 p.p.m. theoretical concentration. This phenomena was also observed in the case of phosphorus and it is believed to be due to the high winds present at the time of the second application, which moved the fertilizer waters to the east end of the lake, in the vicinity of station C.

Three days after the second application the samples contained 0.06 p.p.m. ammonia at all three stations, indicating a nearly homogeneous mixture in the lake. Ammonia disappeared rapidly until August 27. After this date only traces of ammonia could be found.

Following the first application of fertilizer the increase in ammonia was not detected until four days after fertilization, whereas ammonia increases were detected on the day following the second application of fertilizer. This might indicate that the windy weather helped to dissolve the ammoniam sulfate. Sulfate analysis also showed the same general trend.

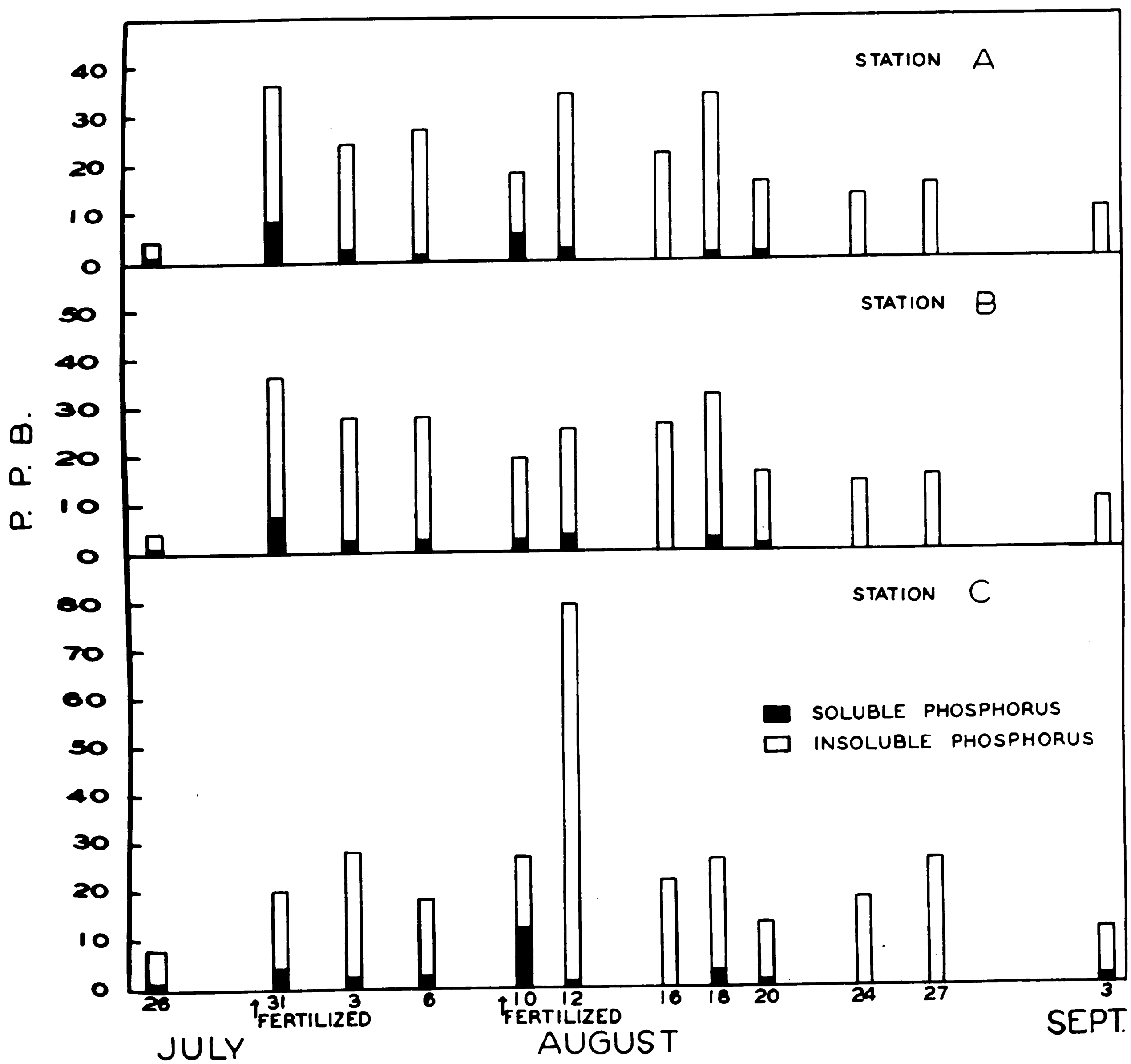
The ammonia disappeared rapidly after each application of fertilizer. This has been the case in many other experiments (Hayes, 1947) and others. The rapid reduction could be due to the uptake of ammonia by plants, oxidation by nitrites and nitrates, flocculation or precipitation and to a lesser degree, dilution of the lake water.

Phosphorus. The concentration of soluble phosphorus prior to fertilization was 1 p.p.b. (microgram per liter) at the three chemical stations (A, B, C). One day following the first application 8 p.p.b. was detected at station A, 7 p.p.b. at B, and 4 p.p.b. at C. (Figure 9). Laboratory tests showed that phosphorus in the fertilizer dissolved in a few minutes. In the lake, however, the soluble phosphorus made up only a small fraction of the total phosphours one day after fertilization. It is believed that the phosphorus in the fertilizer went into solution immediately upon its addition to the lake, and then combined with calcium, carbonate, and possibly others to bring about a flocculation or precipitation reaction; this would account for the rapid reduction of soluble phosphorus to prefertilization levels.

The second application increased the concentration of soluble phosphorus at station A to 5 p.p.b., station B to 2 p.p.b., and station C to 12 p.p.b. These data and the ammonia nitrogen (Figure 8), both show the highest concentrations of nutrients at station C following the second application. Two days later the concentration of soluble phosphorus was again at the prefertilization level at all stations.

Part of the decrease in soluble phosphorus could have been due to activities of plankton, periphyton, and higher aquatic plants, but

Figure 9. Total and soluble phosphorus (p.p.b.)



STATION A
STATION B
STATION C
P. P. B.
SOLUBLE PHOSPHORUS
INSOLUBLE PHOSPHORUS
0
10
20
30
40
50
60
70
80
26
31
3
6
10
12
16
18
20
24
27
3
FERTILIZED
FERTILIZED
JULY
AUGUST
SEPT.

Table 6

Soluble and Total Phosphorus
(p.p.b.)

Date		Station A		Station B		Station C	
		Soluble	Total	Soluble	Total	Soluble	Total
July	26	1	4	1	4	1	2
	30*	...	...	...	...	...	...
	31	8	36	7	36	4	20
Aug.	3	2	24	2	28	2	28
	6	1	27	2	28	2	18
	9*	...	...	...	...	...	...
	10	5	18	2	19	12	27
	12	2	34	3	25	1	79
	16	0	22	0	26	0	22
	18	1	34	2	32	3	26
	20	1	16	1	16	1	13
	24	0	13	1	14	0	18
	27	0	15	0	15	0	26
Sept.	3	0	10	0	10	1	11

* Dates of application of fertilizer

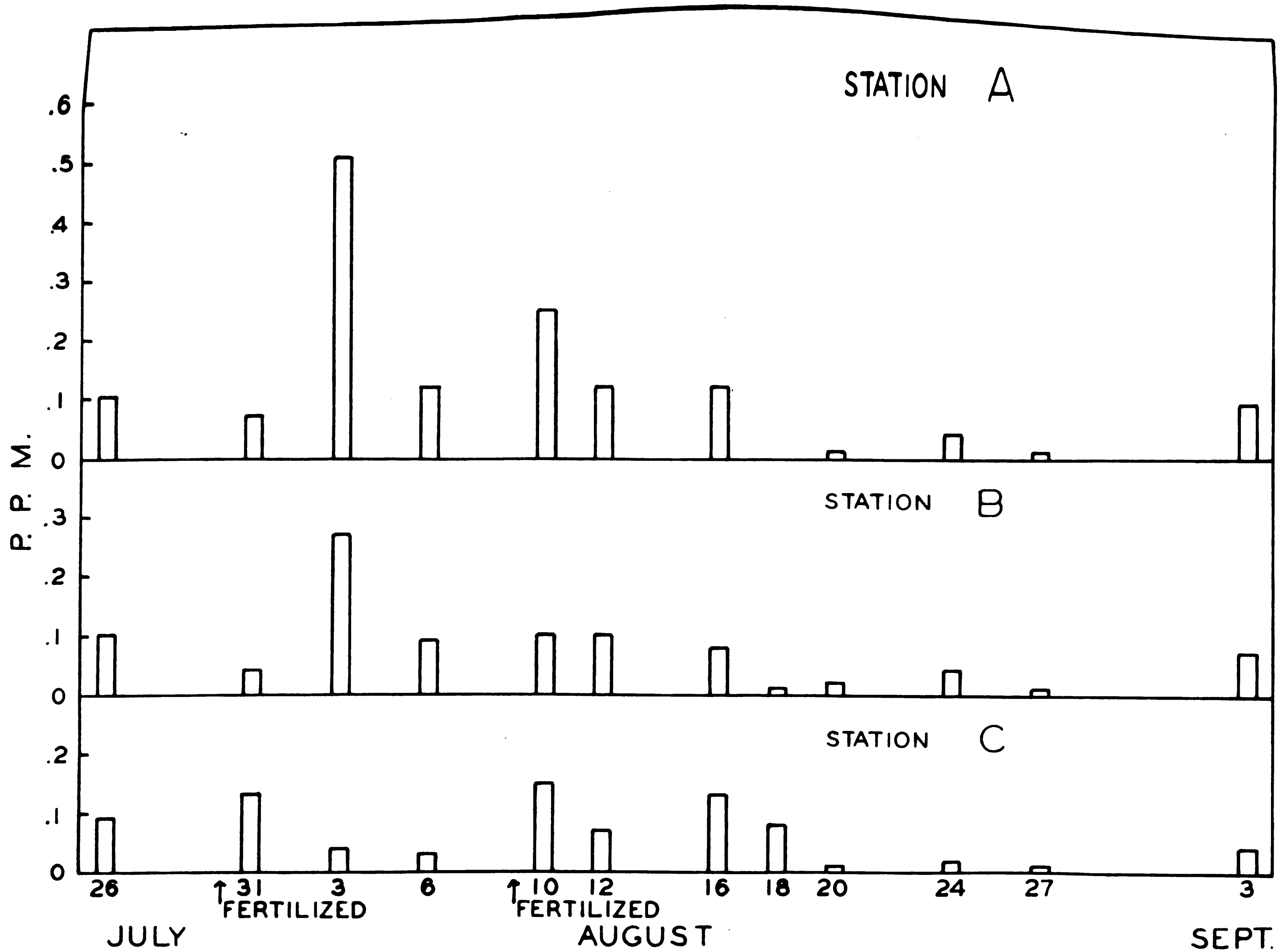
it is believed that most of the phosphorus was precipitated to the bottom or was being held in suspension as an insoluble form.

Before fertilization there was a concentration of total phosphorus of 5 to 8 p.p.b. at the three chemical stations. One day following the first application of fertilizer the total phosphorus was 36 p.p.b. at station A and B, and 20 p.p.b. at station C. Total phosphorus as determined by tests was about 70 percent of the calculated theoretical concentrations one day after fertilization. Four days after the first application total phosphorus concentrations ranged from 24 to 28 p.p.b. It decreased only slightly from these levels up to the time of the second application on August 9.

One day following the second application there was only a slight increase in total phosphorus at station C and concentrations present at stations A and B were lower than before the application. There was however increases in soluble phosphorus. Three days later total phosphorus increased to 34 p.p.b. and 25 p.p.b. at stations A and B. At station C there was a concentration of 79 p.p.b. which was nearly double the theoretical concentration for the entire lake assuming complete mixing had taken place. This higher concentration was evident in ammonia and soluble phosphorus determinations also.

<u>Sulfate</u>. There was an increase in sulfate ion following each application (Figure 10). Prior to fertilization there was about 0.1 p.p.m. of sulfate at all chemical stations. One day after fertilization the concentration had changed very little. Four days after fertilization the concentration had increased to 0.51 p.p.m. at station A and 0.27

Figure 10. Sulfate ion (p.p.m.).



STATION A
STATION B
STATION C
P. P. M.
.6
.5
.4
.3
.2
.1
0
.3
.2
.1
0
.2
.1
0
26
31
3
6
10
12
16
18
20
24
27
3
FERTILIZED
FERTILIZED
JULY
AUGUST
SEPT.

Table 7

Sulfate
(p. p. m.)

Date		Station A	Station B	Station C
July	26	0.10	0.10	0.09
	30*	...	...	...
	31	0.07	0.04	0.13
Aug.	3	0.51	0.27	0.04
	6	0.12	0.09	0.03
	9*	...	...	...
	10	0.25	0.10	0.15
	12	0.12	0.10	0.07
	16	0.12	0.08	0.13
	18	0.00	0.01	0.08
	20	0.01	0.02	0.01
	24	0.04	0.04	0.02
	27	0.01	0.01	0.01
Sept.	3	0.09	0.07	0.04

* Date of application of fertilizer

p.p.m. at station B. No increase was detected at station C. Three days later concentrations were again near prefertilization levels at all stations.

By the first day following the second application sulfate had increased to 0.25 p.p.m. at station A and 0.15 p.p.m. at station B. No significant increase occurred at station C. Two days later sulfate concentrations were again at prefertilization levels. They remained at this point until August 18 when they dropped to a trace. Only a trace could be detected until September 3, when they rose to prefertilization levels.

The changes in sulfate concentration were similar to changes in ammonia. After the first application of fertilizer increases in ammonia and sulfate were not detected until the fourth day, whereas increases occurred one day after the second application. This difference may have been due to the high winds which agitated the water and resulted in a more rapid dissociation of the ammonium sulfate following the second application.

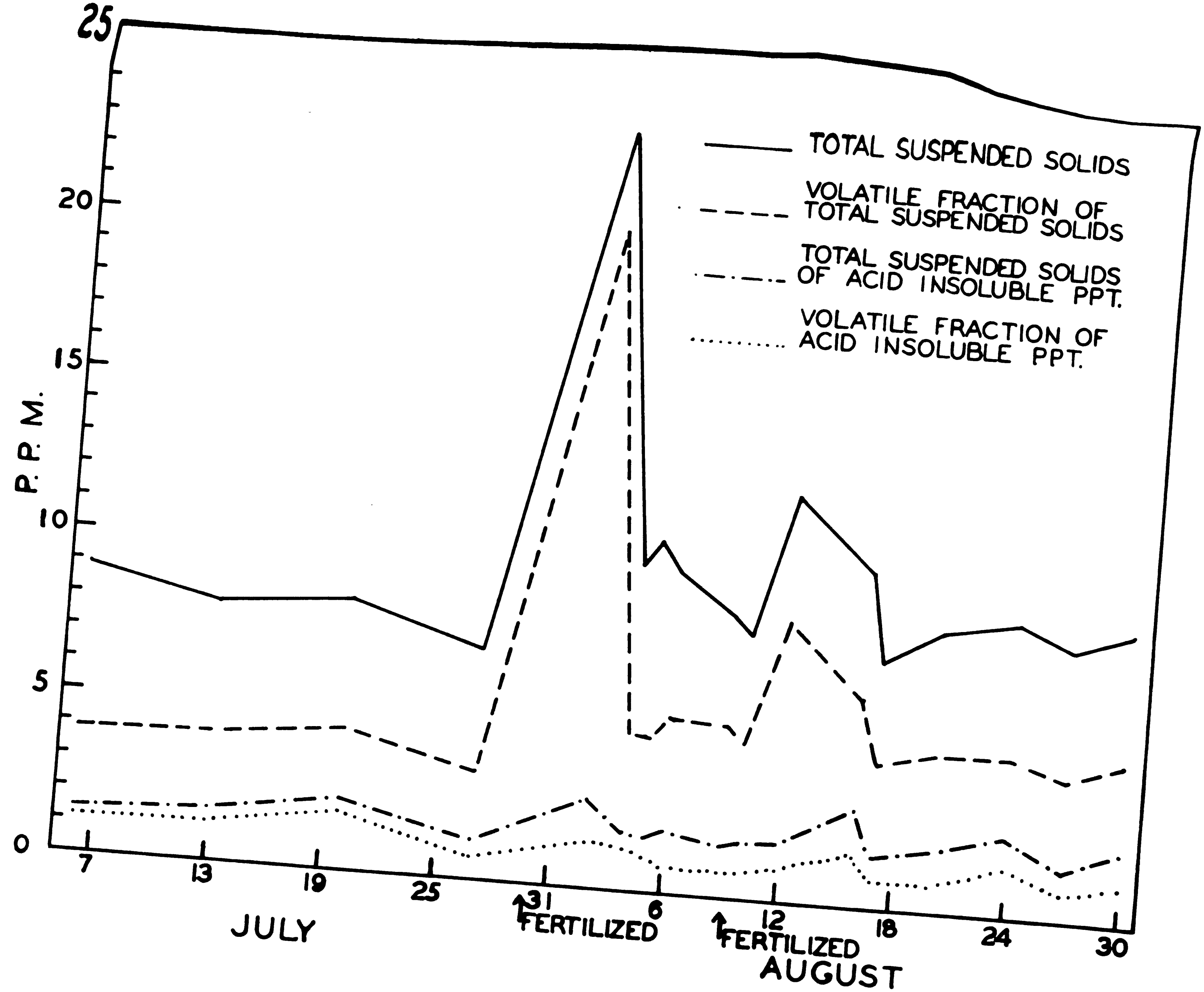
BIOLOGICAL

Plankton. This section of the discussion is primarily chemical in nature since no detectable increase in the plankton was observed following fertilization. The plankton samples, however, did show a visible increase in cloudiness which was due to a material that was flocculent in nature. Analysis of the plankton samples were undertaken to determine the relationship of the flocculent material to the addition of fertilizer. The methods used have been discussed previously. In the following discussion total suspended solids, volatile fraction, phosphorus, calcium ion, and total hardness were determined from the centrifuged plankton samples. This is not necessarily the total amount that was suspended in the water at the time of sampling, since part of the material was presumed to be lost in centrifugation. Thus the results of these analyses may be lower than the actual concentrations in the lake at the time of sampling. To what extent the volumes are low was not determined. Only relative abundance of a substance from one date to another is indicated by these analyses.

Analyses of the total suspended solids in the centrifuged plankton samples showed increases after each application of fertilizer (Figure 11). For 20 days preceding fertilization the total suspended solids ranged between 8 and 9 p.p.m. Four days after the first application of fertilizer the total suspended solids increased to 23 p.p.m. Two days later they had decreased to nearly the prefertilization level. This decrease in suspended solids can be correlated with photometer readings taken on the same date for the 3-and 6-foot depths. It should be kept in mind that the plankton samples were surface samples and presumably the waters would show faster clearing at the surface than at the deeper levels.

At the time of the second application of fertilizer the total suspended solids were near the prefertilization level (Figure 11). Three days after the second application the total suspended solids had increased to 15 p.p.m. Six days later (August 17) levels were again

Figure 11. Relationships between total and acid insoluble suspended solids and their volatile fraction.



25
20
15
10
5
0
P. P. M.
7
13
19
25
31
6
12
18
24
30
JULY
AUGUST
FERTILIZED
FERTILIZED
TOTAL SUSPENDED SOLIDS
VOLATILE FRACTION OF TOTAL SUSPENDED SOLIDS
TOTAL SUSPENDED SOLIDS OF ACID INSOLUBLE PPT.
VOLATILE FRACTION OF ACID INSOLUBLE PPT.

Table 8

Total and Acid Insoluble Suspended Solids,
Their Losses on Ignition, and Carbonate Fraction.
(p.p.m.)

Date		Total suspended solids	Loss on ignition	Acid insoluble suspended solids	Loss on ignition	Carbonate fraction**
July	6	8.9	3.9	1.3	1.2	2.7
	13	8.0	4.0	1.6	1.2	2.8
	20	8.3	4.4	2.2	1.8	2.6
	27	7.1	3.3	1.2	0.7	2.6
	30*	...	...	...	...	...
Aug.	2	23.6	20.3	2.7	1.4	18.9
	4	10.0	4.9	1.8	1.3	3.6
	5	10.8	4.8	1.7	1.1	3.6
	6	9.9	5.4	1.9	0.8	4.6
	9*	8.7	5.3	1.6	0.7	4.7
	10	8.2	4.8	1.7	0.8	4.0
	12	12.5	8.6	1.8	1.0	7.6
	16	10.3	6.4	3.0	1.6	4.8
	17	7.6	4.4	1.6	0.9	3.5
	20	8.6	4.8	1.9	0.8	3.9
	24	9.0	4.9	2.4	1.5	3.4
	27	8.3	4.3	1.5	0.9	3.4
	30	8.9	4.8	2.2	1.1	3.7

** Difference between loss upon ignition of total suspended solids and acid insoluble suspended solids.

* Dates of application of fertilizer.

near the prefertilization level and they remained there for the duration of sampling.

The volatile fraction of the total suspended solids gave an estimate of the organic matter and carbonates present. Organic matter and carbonates lose weight during ignition by the loss of carbon dioxide. It may be seen from Figure 11 that the volatile fraction (ash-free dry-weight) follows the same general pattern as the total suspended solids. Therefore variations in suspended solids probably reflected variations in either carbonate or some form of organic matter.

To test whether these variations were due to a carbonate or organic material, an aliquot of the plankton sample was treated with 0.05 N HCl to dissolve acid soluble compounds that were present in the precipitate. A total suspended solids determination was then made on the remaining acid insoluble residue or "floc." This determination gave the p.p.m. of inorganic material plus the organic matter. Burning this residue above at dull red heat in a muffled furnace gives a loss in weight due to organic matter.

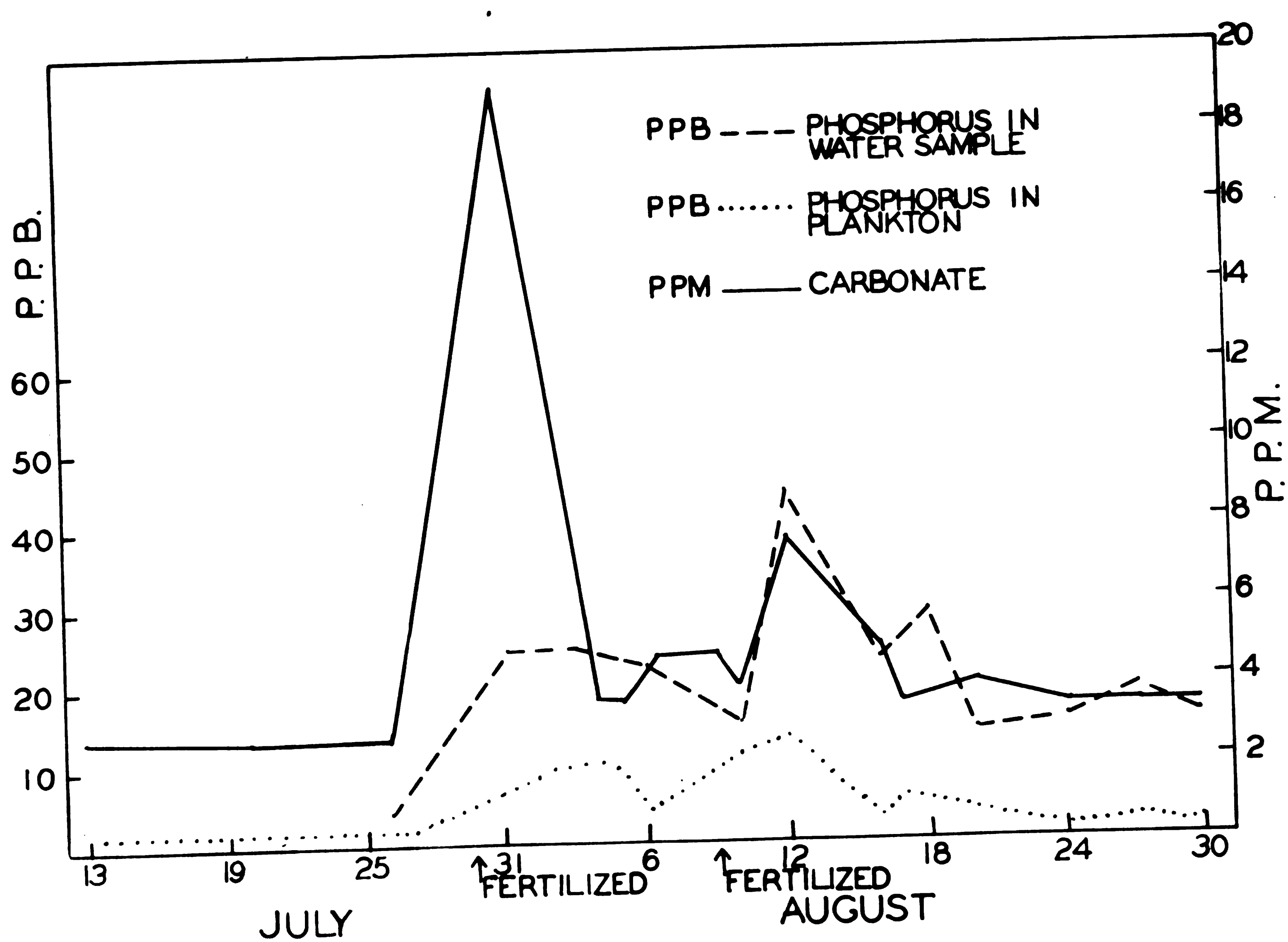
The results from the above procedure showed that the larger share of the total suspended solids went into the acid solution. By burning the acid insoluble precipitate the organic fraction was determined. It showed little variation throughout the summer. These data support the belief that there was no increase in plankton and suggest that the suspended material was some form of carbonate. It is doubtful that there was any increase in bacteria. The centrifuge used does not remove all bacteria but normally removes large bacteria which should have been present in the organic fraction of the determination. Since there was no increase in the organic fraction there is no reason to suspect that the suspended material was bacteria.

Analysis of the acid extract also revealed the content of phosphorus, total hardness and calcium present in the suspended material. To be sure that all the phosphorus and calcium had been dissolved by the 0.05 N HCl, the residue remaining after burning the acid insoluble precipitate was treated with concentrated HCl. This solution was tested for phosphorus and calcium. Tests showed that these two substances were absent and indicated that the 0.05 N HCl completely dissolved the acid soluble salts.

Determination of the phosphorus content of the suspended material showed that its phosphorus content increased following each fertilization and fluctuated in the same way as the phosphorus content of the lake water. This is shown in Figure 12 which compares the phosphorus content of the precipitate with insoluble phosphorus of the lake water. The quantity of phosphorus in the precipitate was not as great as the insoluble phosphorus in the lake water but was a proportionate fraction of it. It is not likely that all the suspensoids were centrifuged out of the water and, if they had been, it is believed that the insoluble phosphorus content of the lake water would agree with the phosphorus content of the suspended material in the plankton samples.

The analyses of the acid extract of the plankton samples for total hardness and calcium showed a reduction in these substances following each application of fertilizer. Before fertilization the calcium

Figure 12. Relationships of phosphorus in plankton samples to total phosphorus less soluble phosphorus in lake water, and to carbonates.



PPB - - - PHOSPHORUS IN WATER SAMPLE
PPB ...... PHOSPHORUS IN PLANKTON
PPM —— CARBONATE
P.P.B.
60
50
40
30
20
10
P.P.M.
20
18
16
14
12
10
8
6
4
2
13
19
25
31
6
12
18
24
30
FERTILIZED
FERTILIZED
JULY
AUGUST

Table 9

Determinations for Phosphorus, Calcium Ion and Total Hardness Made From Plankton Samples

Date		Phosphorus (p.p.b.)	Ca ion (p.p.m.)	Total Hardness (p.p.m.)
July	6	...	7.2	10.7
	13	1.7	6.9	9.3
	20	1.9	7.2	9.3
	27	1.7	8.3	10.7
	30*	...	...	...
Aug.	2	9.2	7.5	9.3
	4	10.0	4.0	6.7
	5	8.7	4.5	5.3
	6	4.5	4.3	5.3
	9*	9.1	2.9	4.0
	10	11.1	2.4	4.0
	12	12.8	2.7	5.3
	16	3.3	2.9	5.3
	17	5.3	2.9	5.3
	20	3.6	2.9	5.3
	24	1.8	3.2	5.3
	27	2.2	3.5	5.3
	30	...	3.5	6.7

* Dates of application of fertilizer.

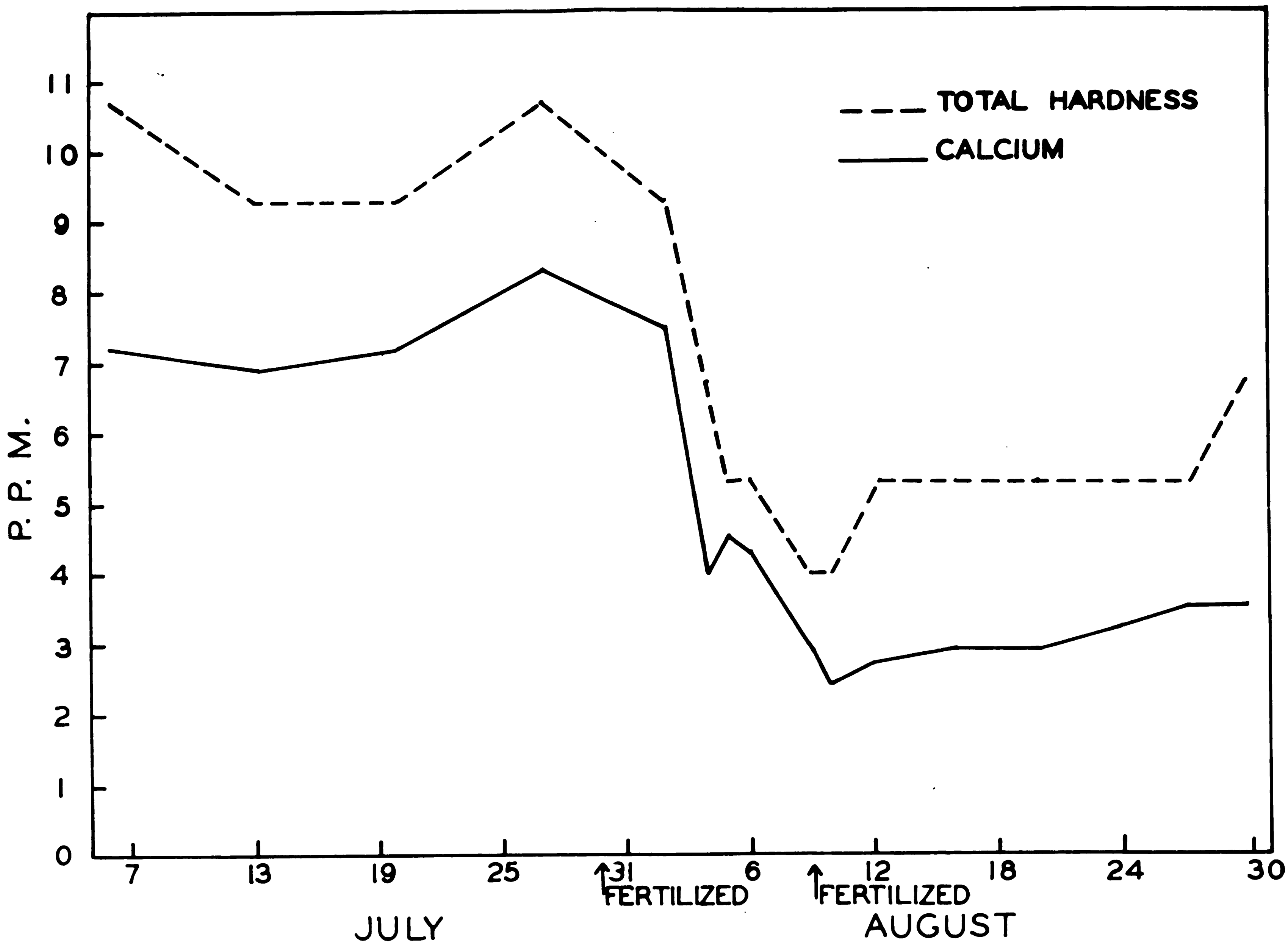
content of the suspensoids was 7 to 8 p.p.m. Following the first application of fertilizer the calcium fell to about 4.5 p.p.m. (Figure 13). Following the second application calcium fell to 3 p.p.m. The total hardness and calcium content of the lake water during the summer was not measured. One sample of lake water taken on September 3, had a total hardness of 155 p.p.m. Of this 100 p.p.m. was due to calcium. The alkalinity on this date was 130 p.p.m. Thus there was about 25 p.p.m. of noncarbonate hardness which was probably present as sulfates or chlorides of calcium and magnesium.

It has been shown from the preceding determinations that carbonates and phosphorus increased, and calcium and total hardness decreased in the suspended material following fertilizer applications.

Increases in phosphorus in the precipitate after each application of fertilizer may be due to various apatites or tricalcium phosphate that remained suspended in the water after their formation. Upon the addition of a high phosphorus fertilizer in the presence of abundant calcium and high pH (8.5) phosphorus would tent to be precipitated by calcium. Other workers have demonstrated under laboratory conditions the formation of a precipitate in a calcium carbonate solution which they believed to be tricalcium phosphate. Hayes (1951), Barrett (1953) and others have concluded that phosphorus was immoblized by calcium in the form of tricalcium phosphate.

Volatile precipitates of inorganic material, presumably carbonates, increased following each application of the fertilizer. This increase could occur by the transformation of soluble bicarbonates to monocarbonates.

Figure 13. Relationship between calcium ion and total hardness in plankton samples.


TOTAL HARDNESS
CALCIUM
P. P. M.
0
1
2
3
4
5
6
7
8
9
10
11
7
13
19
25
31
6
12
18
24
30
FERTILIZED
FERTILIZED
JULY
AUGUST

Periphyton. A number of cinder bricks and cedar shingles were placed in Hoffman Lake at station C to test for a possible increase of periphyton following fertilization. As discussed under "Methods," five bricks and ten shingles were placed in the lake. Due to losses, only three bricks and four shingles were useful in comparing the standing crop of periphyton organisms accumulated during 30 day periods before and after the first fertilization. There was a tenfold increase of periphyton on the bricks for the period following fertilization; on the shingles there was a thirtyfold increase (Table 10). The increases were believed to be due to added nutrients, although from this study it is not possible to separate the individual effects of the nitrogen, potassium, and phosphorus.

Two seasonal effects have an important influence upon periphyton production; these are the seasonal changes in light and temperature. The quantity of radiant energy for the period from July 1 to July 30 is greater than from July 31 to August 29. Secondly, water temperatures were higher for the period prior to fertilization than for the period following fertilization. Gumtow (1955) in a study of periphyton on a Montana stream found that periphyton abundance varied directly with the water temperatures. These facts suggest that factors other than light and temperature caused the increase in periphyton growth after fertilization. The large increase in periphyton apparently was brought about by fertilization.

There were measureable increases in the quantities of periphyton for about 10 miles downstream from Hoffman Lake on the West Branch of

Table 10

Production of Periphyton on Bricks and Shingles Placed in Outlet of Hoffman Lake

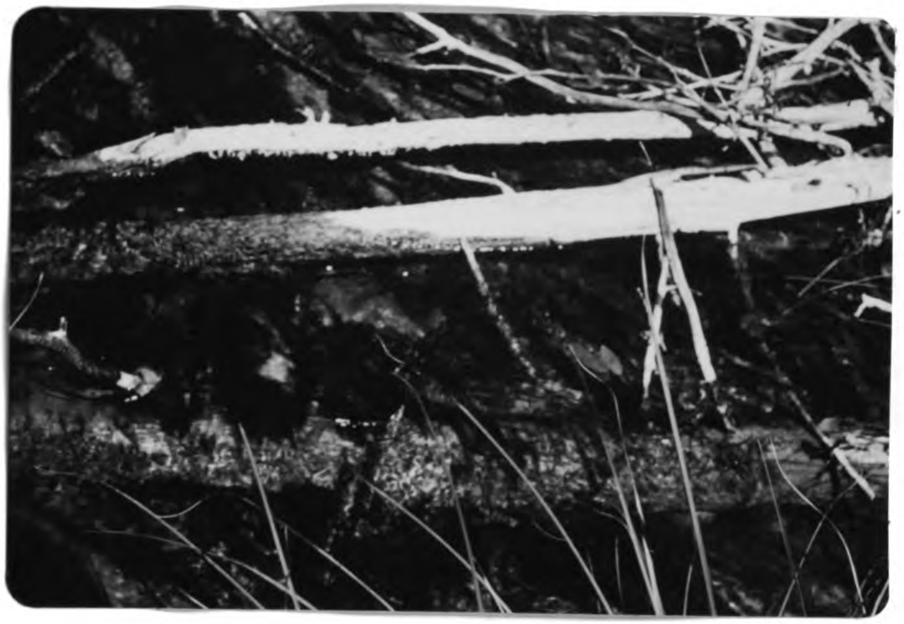
Brick	30 days before fertilization (Harvey units)	30 days after fertilization (Harvey units)	Increase (Harvey units)
1-C	5	65	60
1-D	5	67	62
1-E	6	44	38
	5.33*		53.3*
Shingle			
1-1	3	79	76
1-2	1	90	89
1-3	4	86	82
1-4	3	90	87
	2.75*		83.5*

* Mean value

Figure 14. The appearance of a shingle substrate after a 30 day exposure period prior to fertilization.

Figure 15. The appearance of a shingle substrate after a 30 day exposure period following the application of fertilizer.

Figure 16. Periphyton nearly completely covered this pair of shingle substrata, which were exposed for a 30 day period following fertilization, the yellow patches are where the periphyton was scraped off of the shingles.



the Sturgeon River following fertilization, Grzenda (1955). Increases in lake periphyton were accompanied by little or no increase in plankton. Increased amounts of periphyton were not only detectable by chlorophyll extraction but increases were apparent from visual observation. The outlet area of the lake had a green blanket of filamentous algae on the bottom. Shallow water areas at the east end of the lake had a brown diatomaceous growth on the bottom. The fuzzy growth of periphyton on the stems of the bulrushes was much more apparent after the fertilization than before fertilization. Filamentous algae accumulated on the wire fish traps following fertilization but there was no noticeable accumulation before fertilization.

Periphyton growth was greater on shingles than on bricks. The increase in periphyton growth brought about by fertilization was 0.48 Harvey units per square inch in the case of bricks and 1.03 Harvey units per square inch in the case of shingles.

Macroscopic benthos. The macroscopic bottom fauna of Hoffman Lake was composed of relatively few groups of organisms. The dominant organisms were aquatic insects; burrowing mayflies (Ephermeridae) made up more than 90 percent of the total number and volume of organisms collected. The midges (Tendipedidae) were quite numerous but comprised little of the total volume. Two famlies of dragonflies (Gomphidae) and (Libellulidae) were present; these nymphs were not abundant, but due to their relatively large size, one specimen would be sufficient to comprise 50 percent of the volume of the samples in which they were taken. The disproportionate volumes of some

samples were usually due to a dragonfly nymph. Other families of insects sampled were alderflies (Sialidae), biting midges (Heleidae), caddis flies (Psychomyiidae), and trash inhabiting mayflies (Ephemerellidae). Other groups of bottom organisms were scud (Amphipoda), aquatic worms (Oligocheata), and leeches (Hirudinea). An enumeration of bottom fauna data for all groups of organisms from station 1 and 2 may be found in Table 11 and 12.

Burrowing mayfly nymphs were the dominant group of bottom organisms. Among this group there was great diversity. Mayflies comprised about 84 percent of the total number of organisms collected at station 1 (Ephemera simulans, 66 percent, Hexagenia limbata, 18 percent.) An entirely different situation existed at station 2. Mayflies comprised 95 percent of the total numbers of organisms. All of these mayflies were Ephemera simulans except for a fraction of 1 percent (Figure 17).

Bottom deposits at the two stations appeared to be similar, and representative of most of the lake bottom at the time of sampling. Apparently station 2 was more favorable to Ephemera than Hexagenia.

Both stations had bottoms of nearly pure marl, and were lacking in any bottom vegetation other than an occasional patch of filamentous algae or a rhizome from a bulrush. Station 1 was located in 5 feet of water and station 2 was at a depth of 3 feet. Station 1 had a slightly softer and coarser bottom of marl and probably received less bottom agitation from wave action than station 2.

According to Lyman (1943) the character of the bottom is one of the most important enviornmental factors influencing the distribution

Figure 17. Percentage composition of the total number of macroscopic benthos collected from stations 1 and 2.

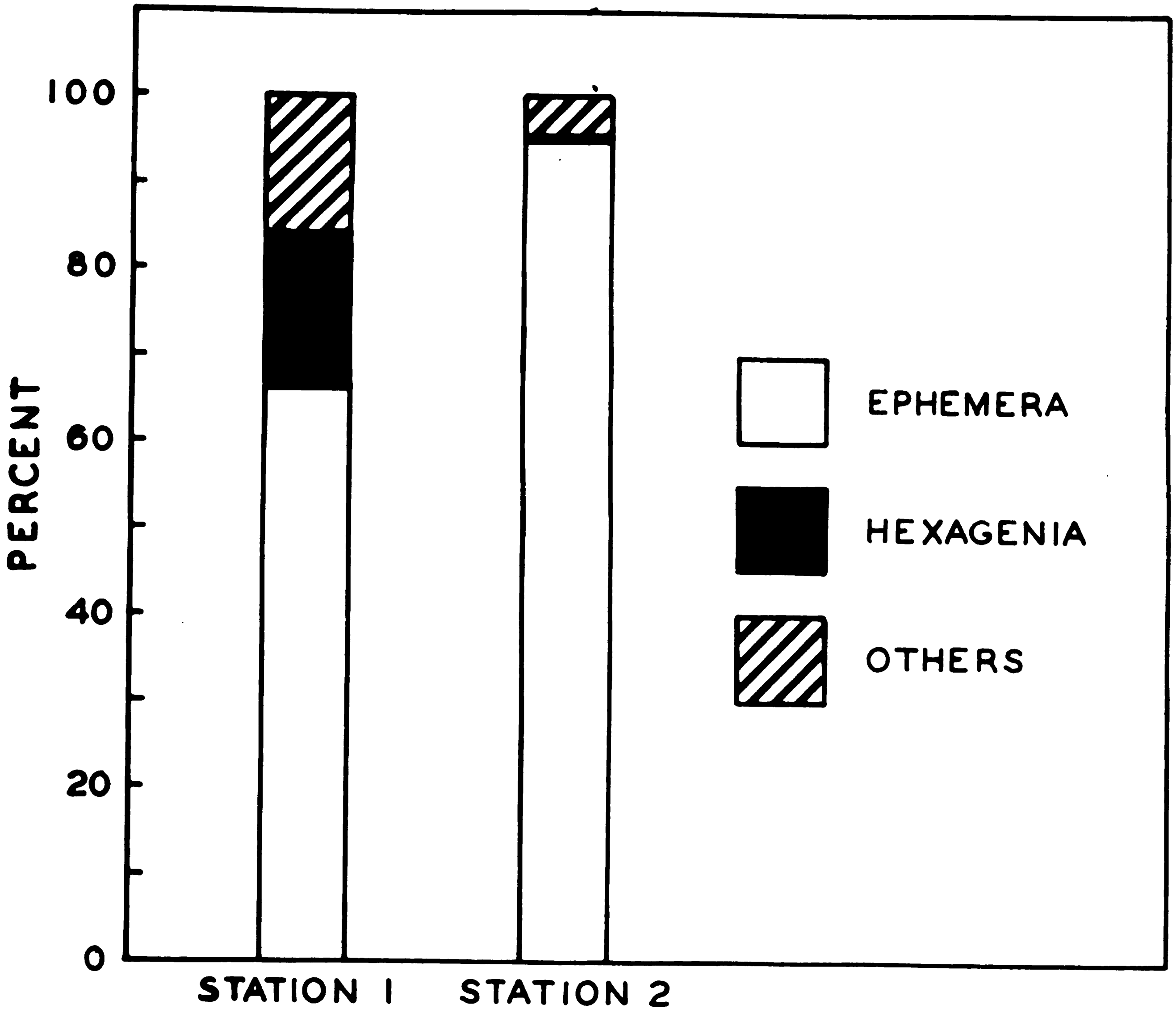

100
80
60
40
20
0
PERCENT
STATION 1
STATION 2
EPHEMERA
HEXAGENIA
OTHERS

Table 11

Enumeration of Macroscopic Benthos From Station I

Collection date	July					August				September	Total
	2	9	16	23	30	6	13	20	27	3	
Number of samples.....	10	10	10	10	10	10	10	10	10	10	100
Total area sampled (square feet).......	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25.0
Total number organisms...........	27	22	30	24	5	20	81	149	72	151	581
Number of organisms per square foot.....	10.8	8.8	12.0	9.6	2.0	8.0	32.4	59.6	28.8	60.4	23.2*
Total volume organisms (milliliters).......	1.25	1.00	1.40	1.10	0.25	0.85	1.05	2.70	2.20	2.90	14.7
Volume of organisms per square foot.....	0.50	0.40	0.56	0.44	0.10	0.34	0.42	1.08	0.88	1.36	0.61*
Ephemera simulans.....	11	16	1	6	3	10	44	118	31	142	382
Hexagenia limbata.....	7	4	22	12	2	4	8	19	27	0	105
Ephemerelli sp........	...	...	...	...	...	...	...	...	1	...	1
Polycentropus sp......	...	...	...	...	...	...	...	...	...	1	1
Libellulidae..........	1	...	...	...	...	...	...	4	1	5	11

(Continued)

Table 11 (Continued)

Collection date	July					August				September	Total
	2	9	16	23	30	6	13	20	27	3	
Gomphidae	2	1	1	2	...	1	1	1	4	2	15
Sialis sp	...	...	...	1	...	2	3	1	4	...	11
Tendipedidae	6	1	3	1	...	3	22	5	2	1	44
Heleidae	...	...	...	...	...	...	3	1	...	...	4
Oligochaeta	...	...	1	2	...	...	...	...	...	...	3
Amphipoda	...	...	1	...	...	...	...	...	2	...	3
Hirudinea	...	...	1	...	...	...	...	...	...	...	1

* Average figure

Table 12

Enumeration of Macroscopic Benthos from Station 2

Collection date	July					August				September	Total
	2	9	16	23	30	6	13	20	27	3	
Number of samples.....	10	10	10	10	10	10	10	10	10	10	10
Total area sampled (square feet).......	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25.0
Total number organisms...........	39	38	27	22	14	37	57	266	218	145	865
Number organisms per square foot.....	15.6	15.2	10.8	8.8	5.6	14.8	23.6	106.4	87.2	58.0	34.6*
Total volume organisms (milliliters).......	1.20	1.80	1.30	0.95	0.90	1.60	1.60	2.70	3.00	2.50	17.6
Volume of organisms per square foot.....	0.48	0.72	0.52	0.38	0.36	0.64	0.64	1.08	1.20	1.00	0.70*
<u>Ephemera</u> <u>simulans</u>.....	34	36	26	19	11	33	53	255	209	144	820
<u>Hexagenia</u> <u>limbata</u>.....	1	...	...	...	...	...	2	1	1	...	5
<u>Ephemerella</u> sp........	...	...	...	...	...	...	...	...	...	...	...
<u>Polycentropus</u> sp......	...	...	...	...	...	...	...	...	...	...	...
Libellulidae..........	...	...	...	...	1	...	...	2	...	...	3

(Continued)

Table 12 (Continued)

Collection date	July					August				September	Total
	2	9	16	23	30	6	13	20	27	3	
Gomphidae.............	...	1	...	...	...	...	...	1	...	...	2
Sialis sp.............	...	...	...	...	...	...	1	6	2	...	9
Tendipedidae..........	4	1	1	1	2	4	3	1	6	1	24
Heleidae..............	...	...	...	...	...	...	...	...	...	...	...
Oligochaeta...........	...	...	...	2	...	...	...	...	...	...	2
Amphipoda.............	...	...	...	...	...	...	...	...	...	...	...
Hirudinea.............	...	...	...	...	...	...	...	...	...	...	...

* Average figure

of Hexagenia nymphs. He found that these nymphs could not burrow successfully in clean sand taken from a wave swept shore, but that they could burrow in marl, or a sand and marl mixture. However he gave no reference to the compactness of the marl used in his experiment. Needham (1920) observed Ephemera simulans nymphs during several seasons in Lake Michigan and Lake Ontario. In both localities the bottom was sandy, not muddy, and Hexagenia was not observed. Burks (1953) states that Ephemera simulan n mphs are found near the shore of lakes having considerable wave action and their characteristic habitat is small rivers with a fairly rapid flow. Hunt (1953) found Ephemera simulans abundant in sandy-mud bottoms of Big Silver and Gun lakes in southern michigan. He concluded that bottom type is of great importance in determining the local distribution of Hexagenia nymphs. Hexagenia nymphs are usually found in large numbers only in bottoms composed of soft marl, mud or clay and are largely restricted to a substratum which is soft, yet firm enough to permit maintenance of a burrow. Hexagenia do not ordinarily inhabit sand, gravel, rubble, peat or a bottom which is flocculent.

It appears from the literature that Ephemera simulans is a stronger digger than Hexagenia and can dig and maintain burrows in harder bottoms. The difference in the distribution of these genera in Hoffman Lake is probably related to the slight difference in bottom texture noted above. Currents and agitation may also influence their distribution.

Some studies indicate that Hexagenia nymphs are more available than Ephemera nymphs. Leonard (1947) found that Birch Lake, an oligotropic lake in southern Michigan, supported populations of Hexagenia and Ephemera in about equal numbers, as shown by bottom sampling. Hexagenia were commonly utilized by rainbow trout throughout the study, but Ephemera were rarely taken by the trout, other than at the time of mass emergence. The author concluded that E. simulans spends its nymphal life too deeply imbedded in the substrate to be available to bottom feeding rainbow trout and that Hexagenia nymphs, on the other hand, either leave their burrows occasionally or at least come near enough to the surface of the lake bottom to be consistently taken by trout. Assuming that other bottom feeding fish are not more successful in capturing Ephemera than rainbow trout, then the majority of the volume of bottom organisms in Hoffman Lake are not readily available to the fish, except at the time of emergence.

To summarize, there is a difference in the distribution of Ephemera simulans and Hexagenia limbata in Hoffman Lake, and this is presumed to be due to a slight difference in bottom compactness. The preceding discussion indicates the need for a comprehensive study of the mayflies, particularly the genus Ephemera, to determine their availability and utilization by fish.

The weekly variations in total number and volume of macroscopic benthos from station 1 and 2 may be seen from Figure 18. Analysis of variance was used to test the null hypothesis that there was no statistically significant difference in the total volumes of organisms

Table 13

Analysis of Variance of ~~Differences~~ Volumes Between the Standing Crop of Macroscopic Benthos From Station 1 and Station 2

Source of variability	Degrees of freedom	Sum of squares	Mean square	"F" ratio
Total	199	33.8059		
Stations	1	.4910	.4910	51.68*
Weeks	9	13.6480	1.5164	159.62*
Stations x Weeks	9	1.6906	.1878	19.77*
Error	180	17.0763	.0095	

* Significant at the 1 percent level.

Note: Calculations in this table are in error.
See attached sheet.

Table 14

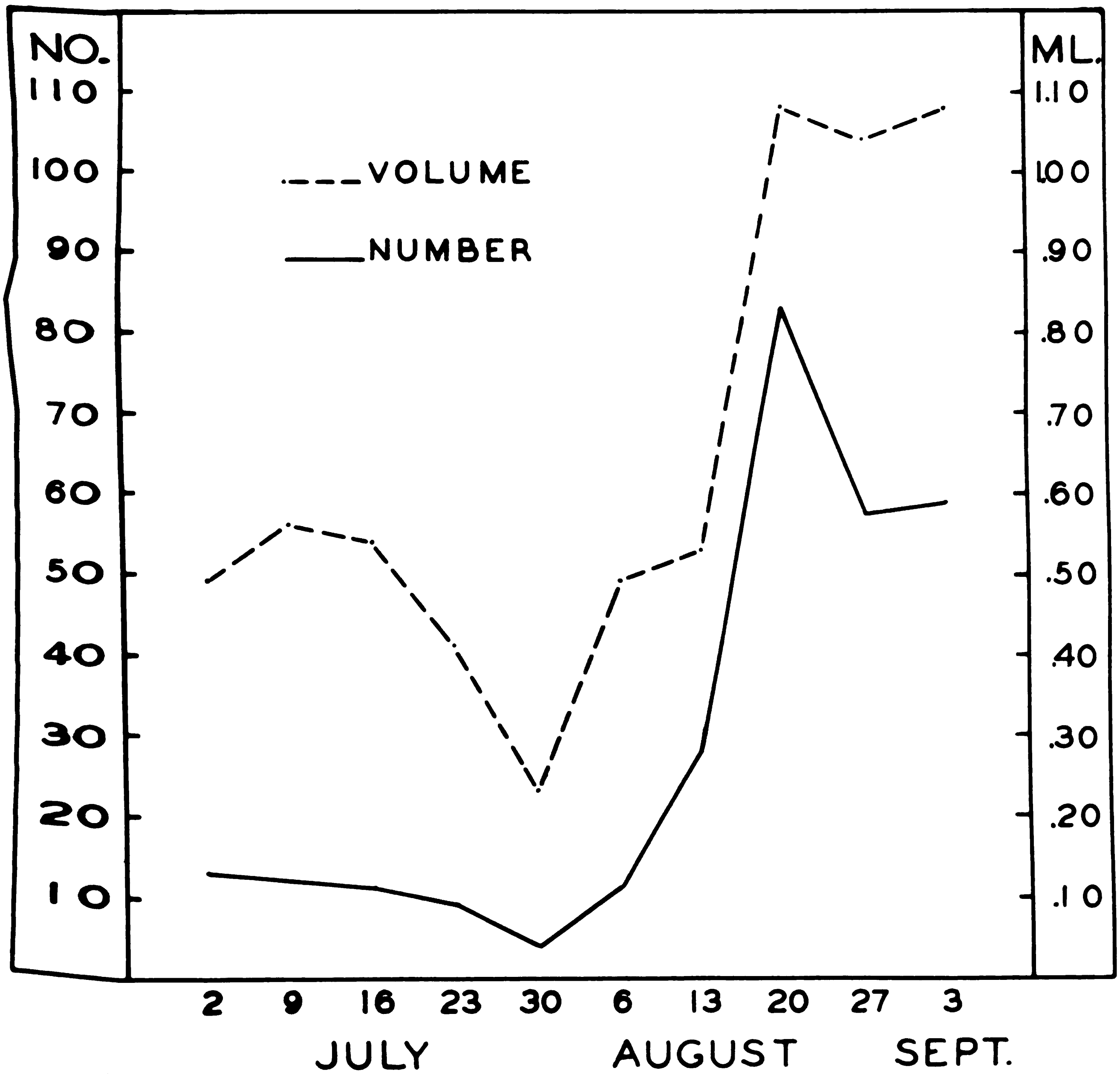
Enumeration of Total Volume of Macroscopic Benthis Organisms.
(Milliliters per Ekman Dredge sample)

Collection date	July					August				September
	2	9	16	23	30	6	13	20	27	3
	Station 1									
Sample number										
1.	0.05	0.10	0.10	0.05	0.05	0.10	0.05	0.20	0.30	0.30
2.	0.05	0.10	0.20	0.05	0.05	0.10	0.20	0.15	0.20	0.30
3.	0.10	0.10	0.10	0.10	0.05	0.30	0.20	1.10	0.40	0.10
4.	0.30	0.10	0.10	0.10	0.05	0	0.10	0.15	0.10	0.20
5.	0.20	0.10	0.20	0.15	0.05	0.20	0.05	0.30	0.10	0.40
6.	0.10	0.10	0.20	0.10	0	0.05	0.20	0.20	0.20	0.30
7.	0.10	0.10	0.10	0.10	0	0.10	0.05	0.20	0.20	0.30
8.	0.10	0.10	0.10	0.15	0	0	0.10	0.20	0.20	0.20
9.	0.20	0.10	0.20	0.30	0	0	0.05	0.10	0.30	0.20
10.	0.05	0.10	0.10	0.10	0	0	0.05	0.10	0.20	0.60
	Station 2									
Sample number										
1.	0.10	0.10	0.10	0.10	0.05	0.20	0.10	0.30	0.30	0.10
2.	0.15	0.10	0.10	0.05	0.05	0.20	0.30	0.30	0.20	0.60
3.	0.10	0.30	0.10	0.05	0.20	0.05	0.10	0.30	0.40	0.20
4.	0.15	0.10	0.20	0.10	0.15	0.20	0.05	0.20	0.40	0.20
5.	0.10	0.20	0.10	0.20	0.40	0	0.20	0.40	0.30	0.30
6.	0.20	0.10	0.10	0.30	0.05	0.20	0.05	0.20	0.10	0.20
7.	0.10	0.20	0.20	0	0	0.20	0.10	0.30	0.30	0.30
8.	0.10	0.20	0.10	0.15	0	0.25	0.20	0.20	0.40	0.20
9.	0.10	0.30	0.10	0	0	0.20	0.30	0.25	0.30	0.30
10.	0.10	0.20	0.20	0	0	0.10	0.20	0.25	0.30	0.10

between the two sampling stations or between the weeks of sampling. The analysis showed that there was a highly significant difference in total volume between stations 1 and 2. Station 2 had a higher standing crop of organisms than station 1. The standing crop does not necessarily mean that station 2 is more productive than station 1, but because the writer believes that predation by fish on most of the bottom fauna of Hoffman Lake was insufficient to alter the general population trends, it may be assumed that the larger crop at station 2 indicates higher production at this station.

The analysis showed a highly significant difference between weeks of sampling (Table 13). This phenomena is of common occurrence in bottom fauna data because, normally, bottom organisms are at a low abundance during the summer because of emergence at this time. Figure 18 shows that minimum numbers and volumes occurred about July 30. This was due to the emergence of Ephemera simulans. It may be seen from Figure 18 that there was a very rapid increase in both numbers and volumes after July 30. This was due to the appearence of newly hatched mayfly nymphs in the samples. Ephemera and Hexagenia nymphs present in Hoffman Lake were small as compared with individuals of the same species which have been found in southern Michigan lakes. The largest Ephemera found was 0.8 inches and the largest Hexagenia was 0.9 inches and both of these genera are commonly over an inch long at the time of maturity in southern Michigan. Nomenclature used in this paper for mayflies is given by Burks (1953).

Figure 18. The number and volume of macroscopic benthic organisms per square foot of lake bottom.


NO.
110
100
90
80
70
60
50
40
30
20
10
ML.
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
VOLUME
NUMBER
2
9
16
23
30
6
13
20
27
3
JULY
AUGUST
SEPT.

To evaluate the effects of fertilization instantaneous rates of growth and mortality were calculated from the weekly standing crop data. Howell (1942) and Patriarche and Ball (1949) report significant increases in bottom organisms resulting from fertilization. If fertilization enhances more favorable conditions for Ephemera in Hoffman Lake it should be reflected in the rates of growth and possibly mortality. The changes in the production of a benthic organism cannot always be determined from a measure of the standing crop, because the production may be cropped off by fish. In this study no effort was made to establish total production figures for Hoffman Lake, because the data from the two stations showed that the bottom fauna was not distributed homogeneously throughout the lake, and not enough is known about the distribution of the organisms in relation to the different types of marl bottom to justify the estimate.

Because the population of Ephemera simulans is believed relatively free from predation by fish, this population affords an excellent opportunity to estimate the natural mortality rates and growth of a burrowing mayfly population. Natural as used here means mortalities and growths not affected by fish predation. Although the analysis of variance showed a difference in volumes between the two sampling stations the data for E. simulans has been clumped to compute mortality and growth rates. This is believed justifiable because the same stations will be used for sampling in following years of investigation and thus the data will be comparable.

Table 15

Grouped Macroscopic Benthos From Station 1 and 2

Collection date	July					August				September	Total
	2	9	16	23	30	6	13	20	27	3	
Total number of organisms (5 square feet sampled)	66	60	57	46	19	57	104	415	290	296	1446
Number per square foot	13.2	12.0	11.4	9.2	3.8	11.4	28.0	83.0	58.0	59.2	28.9*
Total volume of organisms in milliliters (5 square feet sampled)	2.45	2.80	2.70	2.05	1.15	2.45	2.65	5.40	5.20	5.40	32.3
Volume milliliters per square foot	0.49	0.56	0.54	0.41	0.23	0.49	0.53	1.08	1.04	1.08	0.65*

* Average figure

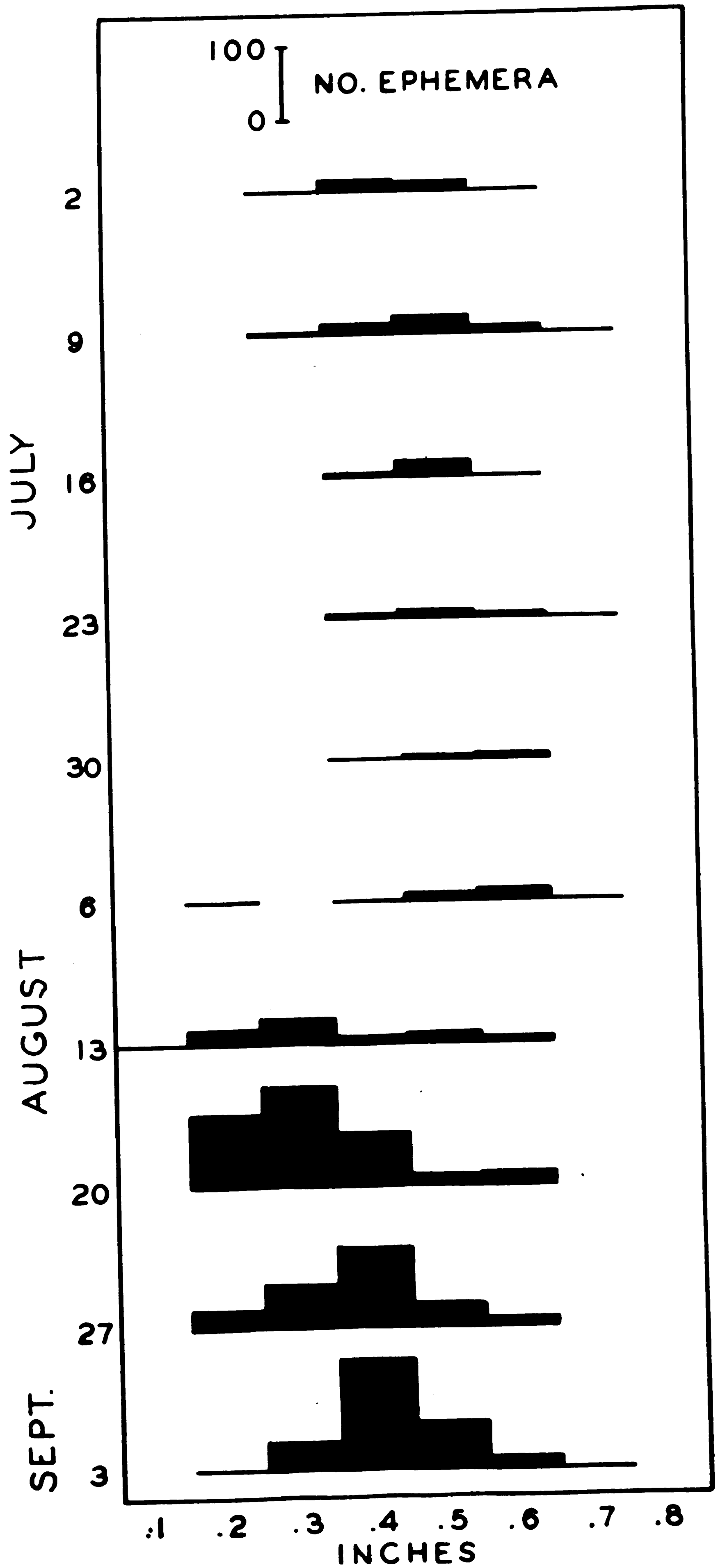
Figure 19, a frequency distribution, shows that the lowest numbers of E. simulans occurred around July 30. This was due to an emergence at this time.

There are two different populations of E. simulans represented in the data and they are designated as life cycle (generation) 1953-54 and life cycle (generation) 1954-55. It may be seen from Figure 19 that the 1954-55 life cycle first appeared on August 6. Samples contained nymphs of the 1953-54 life cycle until about August 20. July 30 is about in the middle of the emergence period of the 1953-54 life cycle and it appears from the data that emergence probably began about July 16 and continued until August 20. In a southern Michigan lake Leonard and Leonard (1946) found E. simulans emerged in late may, whereas emergence in Hoffman Lake was in late July. After July 30 most of the E. simulans represented in the bottom samples belong to the 1954-55 life cycle. Leonard (1947) found that E. simulans has an annual cycle and the data from Hoffman Lake supports this conclusion (Figure 19).

Estimates of the instantaneous rates of mortality and growth have been computed from Figure 10. The instantaneous rate of mortality, based on reduction in numbers of organisms, was -0.187 per week for the 1953-54 life cycle.

The gravimetric instantaneous rate of growth was calculated to be +0.073 per week for the 1953-54 life cycle. This computation was made from the semi-log plot of the average lengths of nymphs. Weight was computed from length by multiplying this logarithm of the length times 3.

Figure 19. Frequency distribution of the number of *Ephemera simulans* collected weekly from Hoffman Lake.



100
0
NO. EPHEMERA
JULY
2
9
16
23
30
AUGUST
6
13
20
27
SEPT.
3
.1
.2
.3
.4
.5
.6
.7
.8
INCHES

Table 16

Size Distribution of *Ephemera simulans*.
(Grouped in One-tenth Inch Frequency Classes.)

Collection date	Frequency classes in tenths of inches							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
July								
2	...	...	4	18	16	7	...	...
9	...	...	3	17	26	5	1	...
16	...	...	...	4	22	1	...	...
23	...	...	...	4	12	8	1	...
30	...	...	...	2	5	7	...	...
Aug.								
6	...	6	...	2	12	19	3	...
13	3	22	32	10	15	9	...	...
20	...	103	140	74	14	19	...	...
27	...	17	60	107	34	12	...	1
Sept.								
3	...	2	38	154	67	16	1	...

Table 17

Number and Mean Length of *Ephemera simulans* Used for the Calculation of Instantaneous Rates of Growth and Mortality

Collection date	Life cycle 1953-54 Number	Life cycle 1953-54 Mean length (inches)	Life cycle 1954-55 Number	Life cycle 1954-55 Mean length (inches)
July				
2	45	0.46	...	...
9	52	0.47	...	...
16	27	0.47	...	...
23	25	0.52	...	...
30	14	0.54	...	...
Aug.				
6	37	0.56	6	0.20
13	17*	0.52*	79	0.30**
20	...	...	350	0.32
27	...	...	231	0.39
Sept.				
3	...	...	278	0.42

* One-half frequency group 0.5 and all larger.

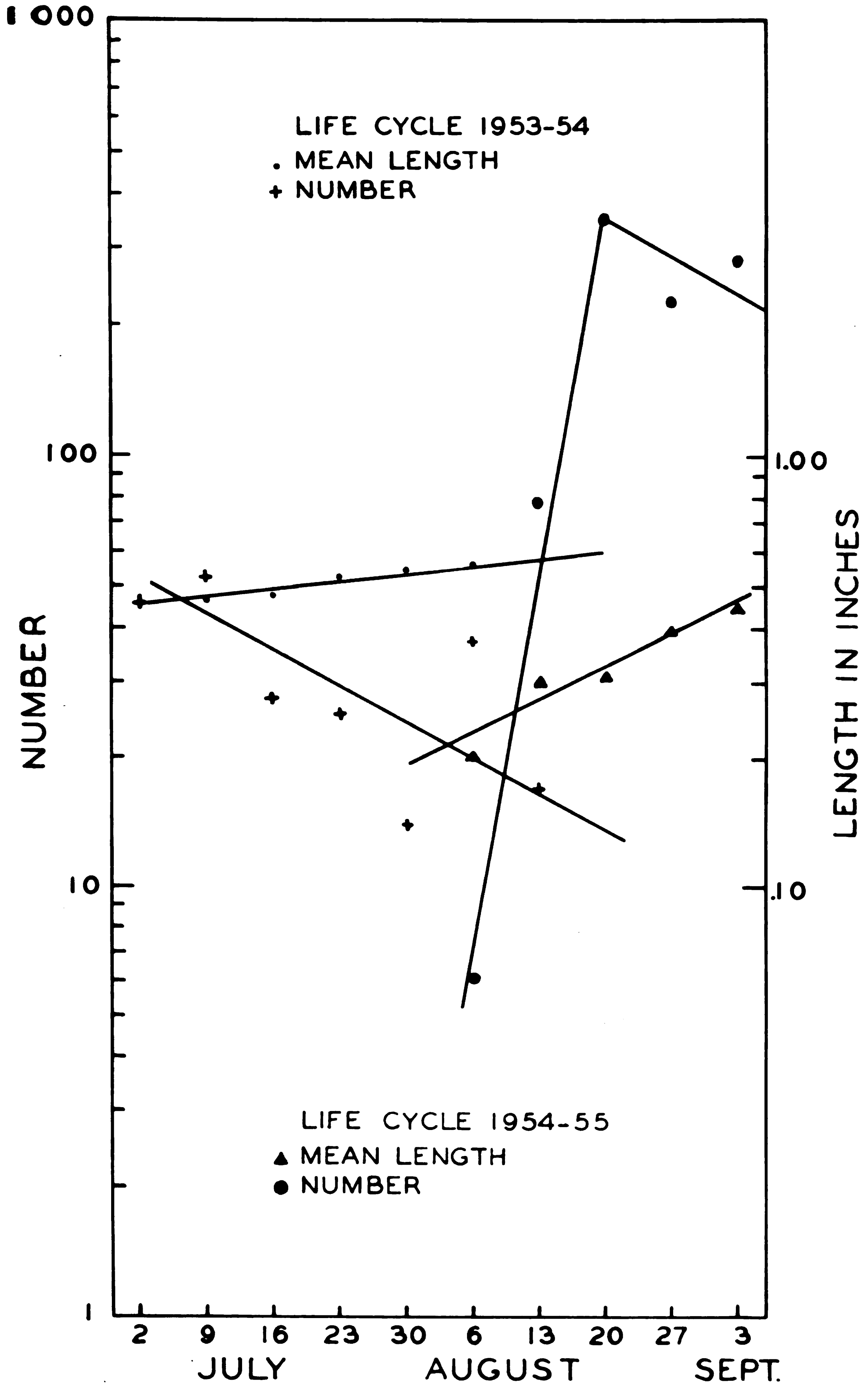
** One half frequency group 0.5 and all smaller.

The instantaneous rate of mortality for the 1954-55 cycle was computed to be -0.192. This computation was made from the descending right limb of the catch curve (Figure 20). Since this curve was fitted by inspection to only three points; it gives a rough estimate, but shows that the mortality rate of the young individuals of the 1954-55 life cycle is nearly the same as the nearly mature individuals of the 1953-54 life cycle. The biological significance of this is not known.

The numbers of Ephemera nymphs of the 1954-55 life cycle that were taken in samples during the latter part of the summer appear to form a typical catch curve when plotted on semi-log paper. Such a curve results from the escapement of smaller individuals from the catch, either in the process of washing or in sorting. Figures 19 and 20 illustrate such a phenomena. In Figure 20 it appears in the ascending left limb of the catch curve of the 1954-55 life cycle. In Figure 19 it appears as a chopping off of the smaller sizer from a normal frequency distribution.

The instantaneous rate of growth for the 1954-55 life cycle was computed to be +0.519 and this is much higher than the older numphs of the 1953-54 cycle. The primary use of the instantaneous rate of growth and mortality will be to compare with the rates computed from later years of sampling. It may be seen from Figure 20 and Table 17 that the mean length of the 1953-54 life cycle of nymphs taken on July 2 was 0.45 inch, and the mean length of nymphs taken at the end of the summer of the 1954-55 life cycle was 0.42 inch. Thus nymphs hatched in mid-summer were nearly as large by the end of the summer as nymphs taken in samples at the beginning of July which hatched the preceding summer.

Figure 20. Number and mean length of Ephemera simulans taken each week from Hoffman Lake; instantaneous rates of growth and mortality were determined from the slope of the lines.


1 000
100
10
1
NUMBER
1.00
.10
LENGTH IN INCHES
LIFE CYCLE 1953-54
. MEAN LENGTH
+ NUMBER
LIFE CYCLE 1954-55
▲ MEAN LENGTH
● NUMBER
2 9 16 23 30 6 13 20 27 3
JULY
AUGUST
SEPT.

Whether this indicates exceptional growth of the 1954-55 life cycle (due to fertilization) or that there is little or no growth of Ephemera from September to July could not be decided from the data at hand.

Fish. The primary objective of fertilizing natural waters is to increase the production of desirable fish. Fish cannot utilize inorganic nutrients directly, but do so indirectly through plankton, periphyton, benthos, and other forage groups. The fisheries biologist can determine whether or not fertilization increases fish production entirely from sampling the fish, but this approach does not give any information as to the succession of events responsible for additional production. Determining changes induced by fertilization in the physical, chemical, and biological conditions of a body of water may reveal factors that are limiting the production of fish. With this information management methods may be employed to produce the maximum of desirable fish.

Fertilization may increase the production of fish in one of two ways: (1) The growth rates of the individual fish may increase. (2) The population may increase in size. Fish were collected throughout the summer for age and growth studies. Species taken were largemouth bass, common sunfish, rock bass, common suckers, and yellow perch. Sampling suggested that except for yellow perch the fish populations were not large. All captured fish were marked by fin clipping and returned to the lake. During subsequent sampling many of the sunfish and rock bass, and a few suckers and largemouth bass

were recaptured. Of the 57 largemouth bass marked during trapping operations eleven were reportedly caught by anglers during the summer.

No game species under 3 inches in length were taken or even seen in the lake. Twice during the summer the lake was seined in an attempt to obtain the smaller fish. A bag seine 150 feet long, 6 feet deep, and having a one-quarter inch mesh size was used. All seining was carried out in water less than 4 feet deep. Using this procedure sunfish, rock bass, suckers, largemouth bass, and yellow perch, all of which were over 3 inches long were collected. It did not seem likely that the small game fish escaped through the mesh of the seine, because numerous small shiners and darters were captured. Due to the paucity of fish food, and the lack of cover for young fish, the scarcity of young fish may have been due to the predation of larger fish.

The principal objective of sampling fish was to establish growth rates and length-weight relationships for the game species of fish in Hoffman Lake. These determinations will be considered to be characteristic of conditions prior to fertilization and will be used at a later date to determine if the fertilization resulted in changes in growth. No attempt was made to estimate the size of the various fish populations. There is the possibility that fertilization may produce conditions which are more favorable for the survival of young fish, and may result in an increase in population density.

Yellow perch were probably the most numerous of the game species. In general they exhibited slow growth as compared with average growth of various age groups of Michigan yellow perch (Beckman 1946). The largest specimen taken was 13.6 inches in length. Most fish were from age groups I to IV. Very few older fish were present. These older and larger fish exhibited faster growth in their early years of life than other fish. Absolute growth and annual growth increments for yellow perch are found in Table 18. The length-weight relationship was computed to be $\text{Log}_e\ W = -2.0965 + 3.0855\ \text{Log}_e\ L$ and is shown graphically in Figure 21. Mean instantaneous rates of growth for age groups II through V are given in Table 19. Of the game species rock bass were believed to be second in abundance. This species exhibited very slow growth. On the average they did not reach a length of 6 inches until their seventh growing season. Most fish were in poor condition and were heavily parasitized with Neascus sp. The largest specimen taken was 10.0 inches in length and belonged to age group XII. A wide ranging habit was exhibited by a rock bass; one fish 9.3 inches long was marked after being trapped at the west end of the lake and the next day this fish was trapped at the east end of the lake. Age groups IV through XII were represented in the scale samples. Absolute growth and annual increments of growth for rock bass may be found in Table 20. The length-weight relationwhip was computed to be $\text{Log}_e\ W = -0.5341 + 2.6558\ \text{Log}_e\ L$ and is shown graphically in Figure 22. Mean instantaneous rates of growth for the last complete years growth are given in Table 21.

Sunfish were common and probably furnished the best fishing of any species. In the sample taken by trapping age group V and VI were

Table 18

Absolute Growth of Yellow Perch From Hoffman Lake 1954

Age group	Number of fish	Mean total size		Increment growth	
		Length (inches)	Weight (grams)	Length (inches)	Weight (grams)
I	8	3.8	7.3	3.8	7.3
II	46	4.6	13.6	0.8	6.3
III	28	5.0	20.4	0.4	6.8
IV	13	5.5	27.9	0.5	7.5
V	4	8.0	91.0	2.5	63.1
VIII	1	13.6	461.0	...	...

Table 19

Mean Instantaneous Rate of Growth for Yellow Perch From Hoffman Lake, 1954

Age group	Number of fish	Linear rate of growth	Gravimetric rate of growth	Standard deviation	Coefficient of variability (%)
II	46	0.43	1.32	0.317	24.0
III	28	0.26	0.79	0.197	24.9
IV	13	0.21	0.64	0.116	18.1
V	4	0.19	0.58	0.095	16.4
VIII	1	0.17	0.52	...	...

Figure 21. Length-weight relationship of the yellow perch. Curve A shows the absolute values; curve B shows the log-log transformation.

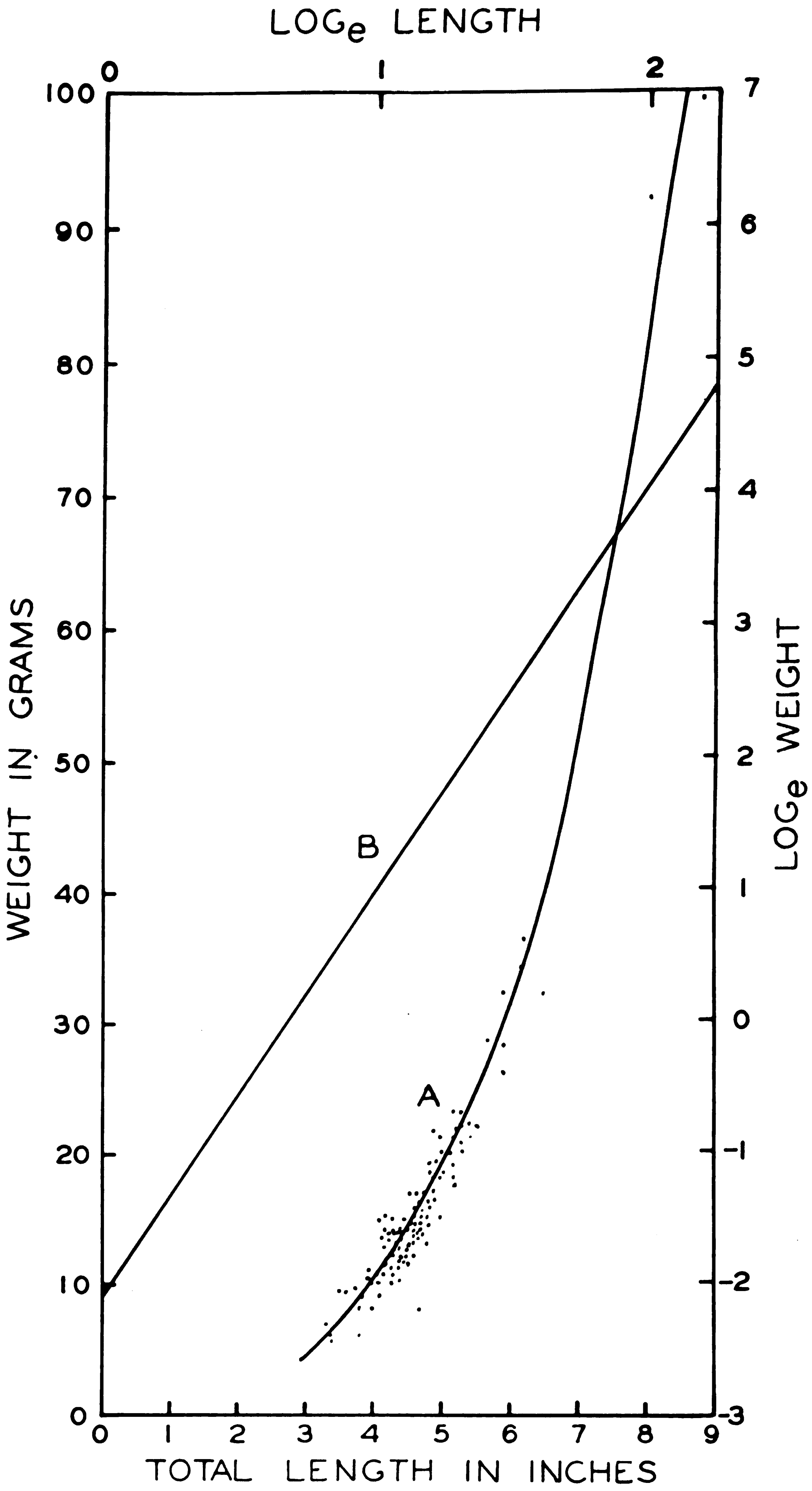

LOGe LENGTH
WEIGHT IN GRAMS
LOGe WEIGHT
TOTAL LENGTH IN INCHES
A
B

Table 20

Absolute Growth of Rock Bass From Hoffman Lake 1954

Age group	Number of fish	Mean total size Length (inches)	Mean total size Weight (grams)	Increment growth Length (inches)	Increment growth Weight (grams)
I	8	2.1*	4.2**	2.1	4.2**
II	8	3.0*	10.8**	0.9	6.6**
III	8	3.9*	21.8**	0.9	11.0**
IV	2	4.7	34.0	0.8	12.2**
V	15	5.3	50.8	0.6	16.8
VI	32	5.7	60.7	0.4	9.9
VII	26	6.1	72.8	0.4	12.1
VIII	10	6.8	107.7	0.7	34.9
IX	10	7.4	125.9	0.6	18.2
X	3	8.5	184.7	1.1	58.8
XI	1	9.3	234.0	0.8	49.3
XII	1	10.0	348.0	0.7	114.0

* Back calculation from scales.

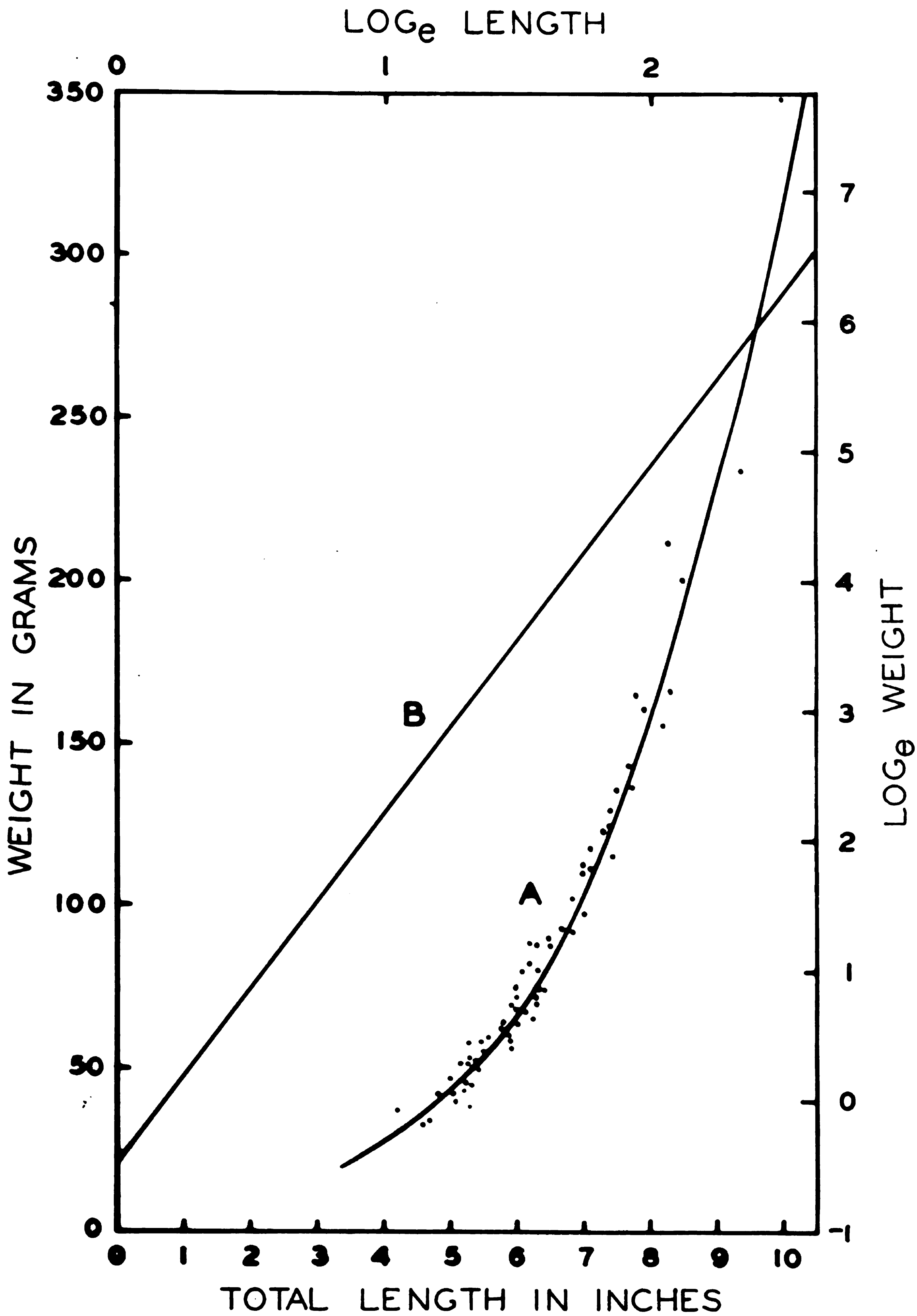
** Calculated from $\log_e W = -0.5341 + 2.6558 \log_e L$.

Table 21

Mean Instantaneous Rate of Growth for Rock Bass From Hoffman Lake, 1954

Age group	Number of fish	Linear rate of growth	Gravimetric rate of growth	Standard deviation	Coefficient of variability (%)
IV	2	0.29	0.78	0.120	15.4
V	15	0.21	0.56	0.132	23.5
VI	32	0.12	0.33	0.085	25.8
VII	26	0.10	0.27	0.066	24.4
VIII	10	0.09	0.24	0.077	32.1
IX	10	0.08	0.22	0.050	22.7
X	3	0.08	0.20	0.033	16.5
XI	1	0.06	0.16	...	...
XII	1	0.03	0.08	...	...

Figure 22. Length-weight relationship of the rock bass. Curve A shows the absolute values; curve B shows the log-log transformation.


LOGe LENGTH
0
1
2
350
300
250
200
150
100
50
0
WEIGHT IN GRAMS
7
6
5
4
3
2
1
0
-1
LOGe WEIGHT
B
A
0
1
2
3
4
5
6
7
8
9
10
TOTAL LENGTH IN INCHES

more numerous than age groups III and IV. This could be interpreted to mean that trapping selected the larger fish but this was also evident in fish caught by hook and line. Sunfish were growing slightly slower than the state average (Beckman op. cit.) and appeared to be in average condition. About one-half of the sunfish were heavily parasitized with Neascus sp. The largest specimen taken was 7.1 inches in length. Age groups III through VII were represented in the scale samples. Absolute growth and annual increments for common sunfish are shown in Table 22. The length-weight relationship was computed to be $\text{Log}_e\ W = -1.3224 + 3.1370\ \text{Log}_e\ L$ and is shown graphically in Figure 23. Mean instantaneous rates of growth for the various age groups may be found in Table 23.

Common suckers were taken throughout the summer but the relative abundance of this species is not known. Suckers were taken in about equal numbers in traps set at all depths. In water over 15 feet in depth they were the species trapped most frequently. Only four other fish (two large yellow perch and two brook trout) were taken in water deeper than 15 feet. The suckers were in poor condition; they had a thin body which narrowed abruptly behind a head that was disproportionately large for the body size. Since suckers feed mostly on organisms which are low in the food chain and as they are at present in extremely poor condition, they may respond more rapidly to fertilization than other species. Age groups III through VIII were represented in the scale samples. Absolute growth and annual increments

Table 22

Absolute Growth of Common Sunfish From Hoffman Lake, 1954

Age group	Number of fish	Mean total size Length (inches)	Mean total size Weight (grams)	Increment growth Length (inches)	Increment growth Weight (grams)
I	24	2.4*	4.2**	2.4	4.2**
II	24	3.5*	13.6**	1.1	9.4**
III	8	4.7	35.1	1.2	21.5**
IV	12	5.6	61.7	0.9	26.6
V	38	5.8	65.5	0.2	3.8
VI	37	6.3	85.8	0.5	20.3
VII	7	6.9	118.3	0.6	32.5

* Back calculation from scales.

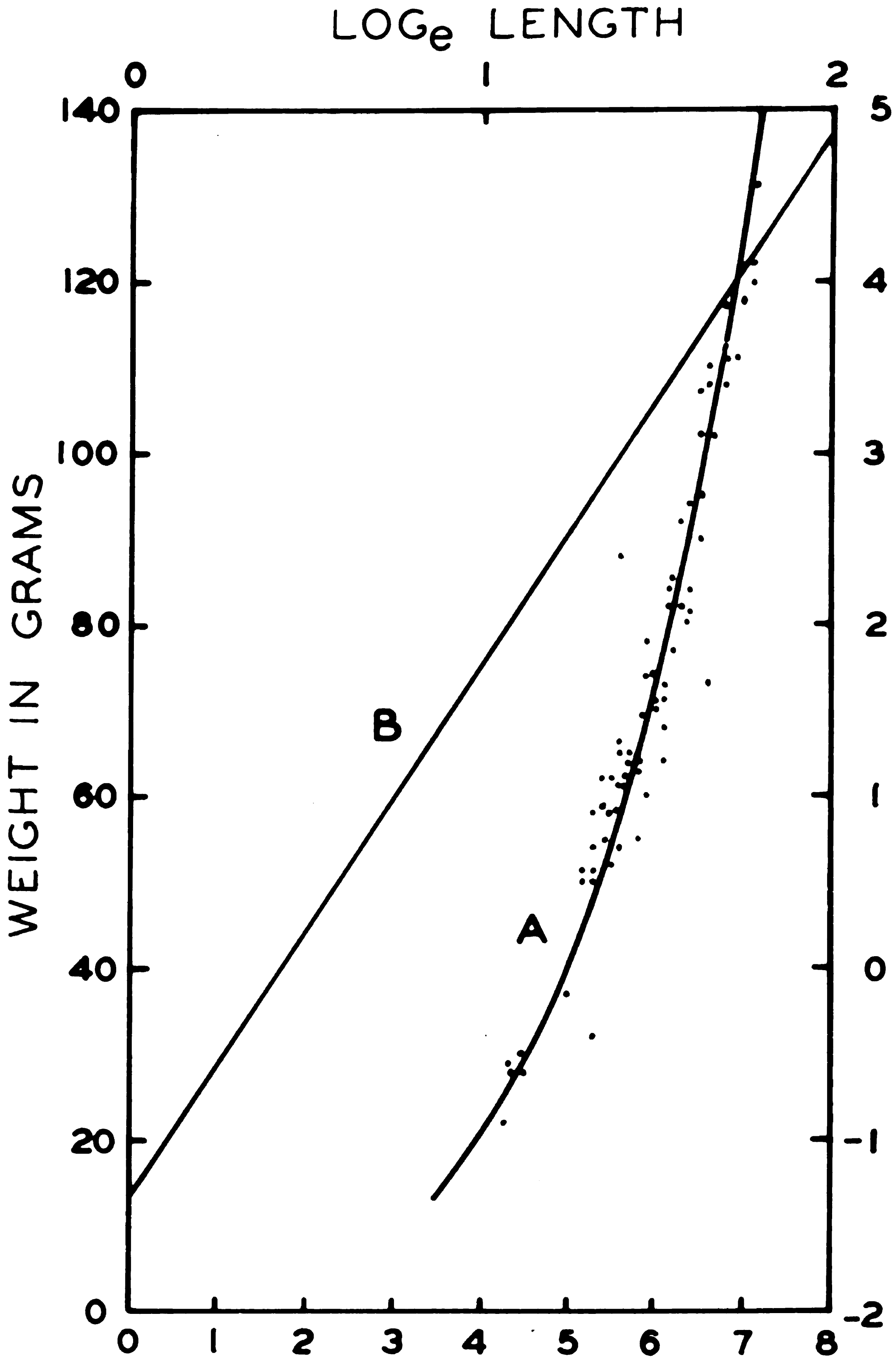
** Calculated from $\text{Log}_e W = -1.3224 + 3.1270 \text{ Log}_e L$.

Table 23

Mean Instantaneous Rate of Growth for Common Sunfish from Hoffman Lake, 1954

Age group	Number of fish	Linear rate of growth	Gravimetric rate of growth	Standard deviation	Coefficient of variability (%)
III	8	0.39	1.22	0.393	32.2
IV	12	0.18	0.55	0.132	24.0
V	38	0.16	0.49	0.103	21.0
VI	37	0.13	0.41	0.074	18.0
VII	7	0.09	0.27	0.047	17.4

Figure 23. Length-weight relationship of the common sunfish. Curve A shows the absolute values; curve B shows the log-log transformation.


LOGe LENGTH
0
1
2
140
120
100
80
60
40
20
0
5
4
3
2
1
0
-1
-2
WEIGHT IN GRAMS
LOGe WEIGHT
B
A
0
1
2
3
4
5
6
7
8
TOTAL LENGTH IN INCHES

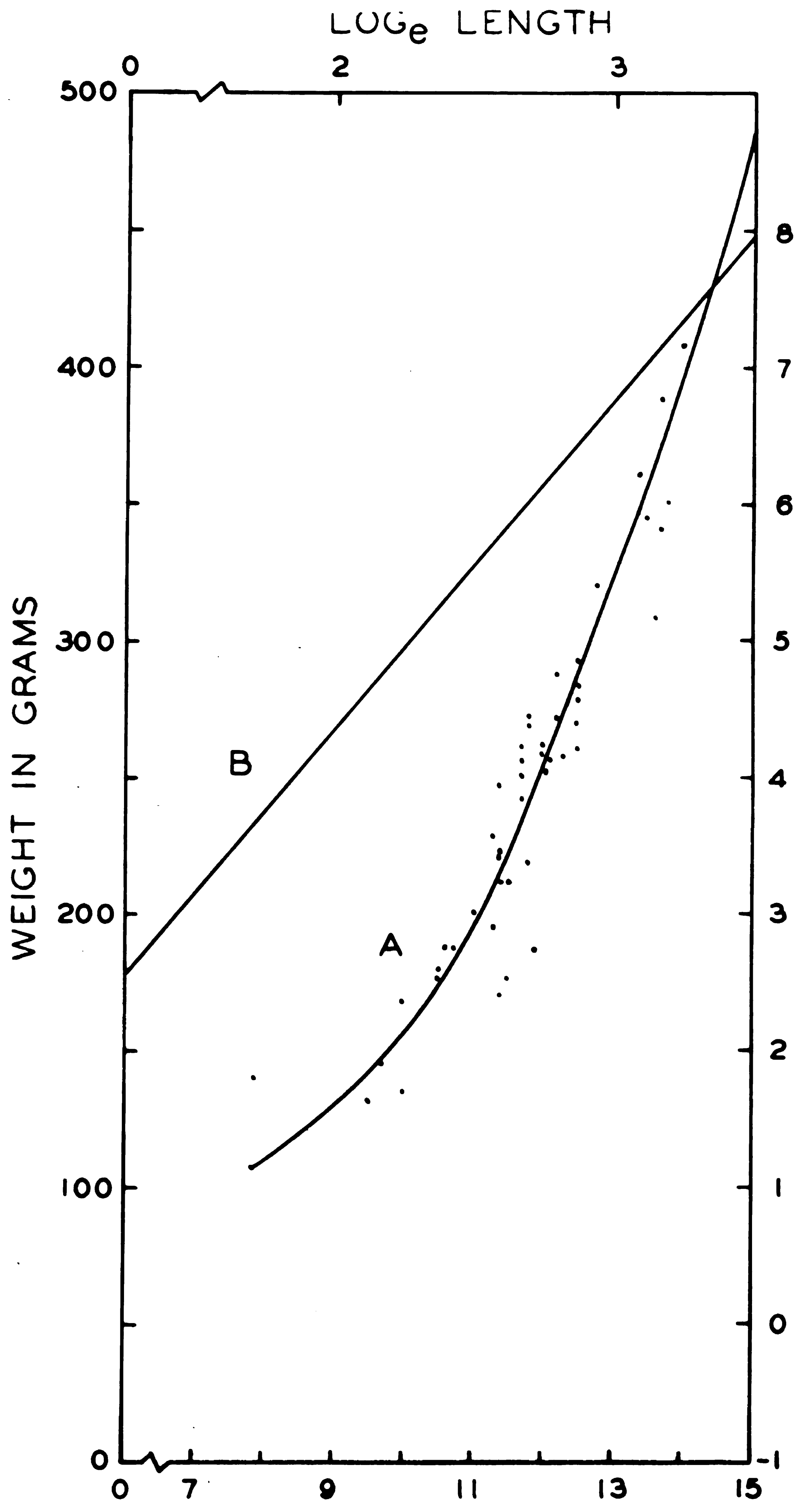
for suckers may be found in Table 24. The length-weight relationship was computed to be $\text{Log}_e\ W = -0.4388 + 2.3852\ \text{Log}_e\ L$ and is shown graphically in Figure 24. Mean instantaneous rates of growth may be found in Table 25.

Largemouth bass were probably the least abundant of the game fish. Their growth was below the state average for the first two growing seasons, but following their second year their growth rate was above the state average. All largemouth bass taken from Hoffman Lake were in excellent condition. The larger bass were probably the only group of fish in the lake that have an abundant food supply. The largest specimen taken was 18.6 inches in length and weighed 4 3/4 pounds. Some bass were heavily parasitized with *Neascus* sp. Age groups II through VIII were represented in the scale samples. Absolute growth and annual increment for largemouth bass may be found in Table 26. The length-weight relationship was computed to be $\text{Log}_e\ W = -2.0813 + 3.2765\ \text{Log}_e\ L$ and is shown graphically in Figure 25. Mean instantaneous rates of growth for the last complete growing season for the various age groups may be found in Figure 26.

Two brook trout were taken from the traps placed in the depression off the south shore. One was 14 inches long and the other one 12 inches long, and both were in excellent condition. Growth rates were not determined for this species.

The instantaneous rate of growth for all species were the highest for the youngest age group, and they decreased for each succeding age group, showing that as fish get older their rate of growth

Figure 24. Length-weight relationship of the common sucker. Curve A shows the absolute values; curve B shows the log-log transformation.



LOG$_e$ LENGTH
0
2
3
500
400
300
200
100
0
WEIGHT IN GRAMS
8
7
6
5
4
3
2
1
0
-1
LOG$_e$ WEIGHT
B
A
0
7
9
11
13
15
TOTAL LENGTH IN INCHES

Table 24

Absolute Growth of Common Suckers From Hoffman Lake, 1954

Age group	Number of fish	Mean total size Length (inches)	Mean total size Weight (grams)	Increment growth Length (inches)	Increment growth Weight (grams)
I	18	4.8*	27.0**	4.8	27.0**
II	18	7.8*	86.0**	3.0	59.9**
III	7	9.9	175.7	2.1	89.7**
IV	13	11.0	199.7	1.1	24.0
V	38	11.8	250.8	0.8	51.1
VI	8	12.7	307.0	0.9	56.2
VII	4	13.5	334.0	0.8	27.0
VIII	2	14.2	389.0	0.7	55.0

Table 25

Mean Instantaneous Rate of Growth for Common Suckers From Hoffman Lake, 1954

Age group	Number of fish	Linear rate of growth	Gravimetric rate of growth	Standard deviation	Coefficient of variability (%)
III	7	.34	.81	.167	20.6
IV	13	.20	.47	.115	24.4
V	38	.16	.38	.069	18.2
VI	8	.11	.26	.047	18.1
VII	4	.10	.25	.029	11.6
VIII	2	.09	.19	.050	26.3

Table 26

Absolute Growth of Largemouth Bass From Hoffman Lake, 1954

Age group	Number of fish	Mean total size: Length (inches)	Mean total size: Weight (grams)	Increment growth: Length (inches)	Increment growth: Weight (grams)
I	21	4.8*	21.5**	4.8	21.5**
II	23	8.6	151.7	3.8	130.2**
III	15	11.4	380.0	2.8	228.3
IV	7	13.7	672.5	2.3	292.5
V	8	14.6	830.8	0.9	158.3
VI	2	15.9	1064.0	1.3	233.2
VII	1	17.3	1248.0	1.4	184.0
VIII	1	18.6	2213.0	1.3	965.0

* Back calculation from scales.

** Calculated from $\text{Log}_e W = -2.0813 + 3.2765 \text{Log}_e L$.

Figure 25. Length-weight relationship of the largemouth bass. Curve A shows the absolute values; curve B shows the log-log transformation.

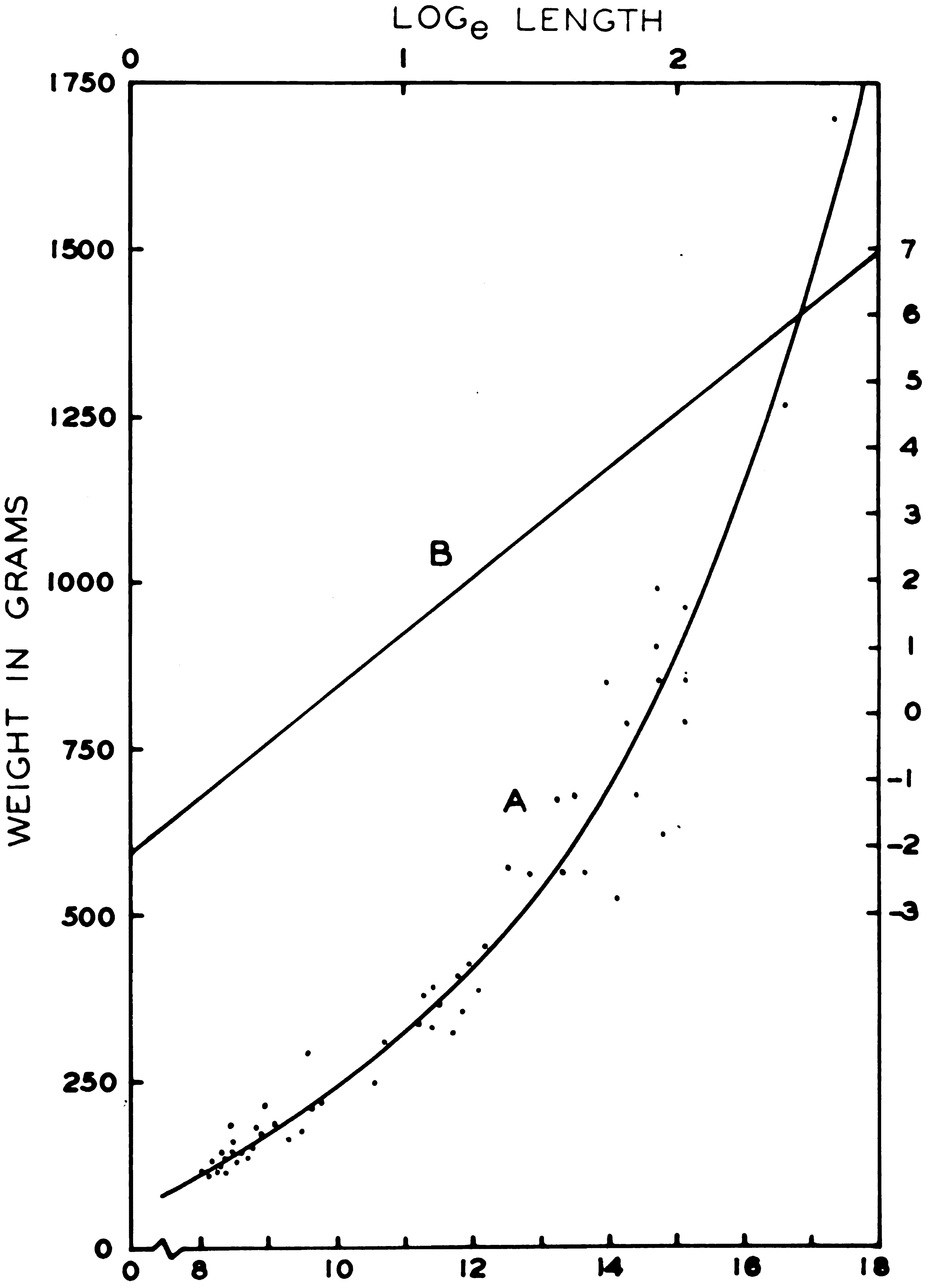
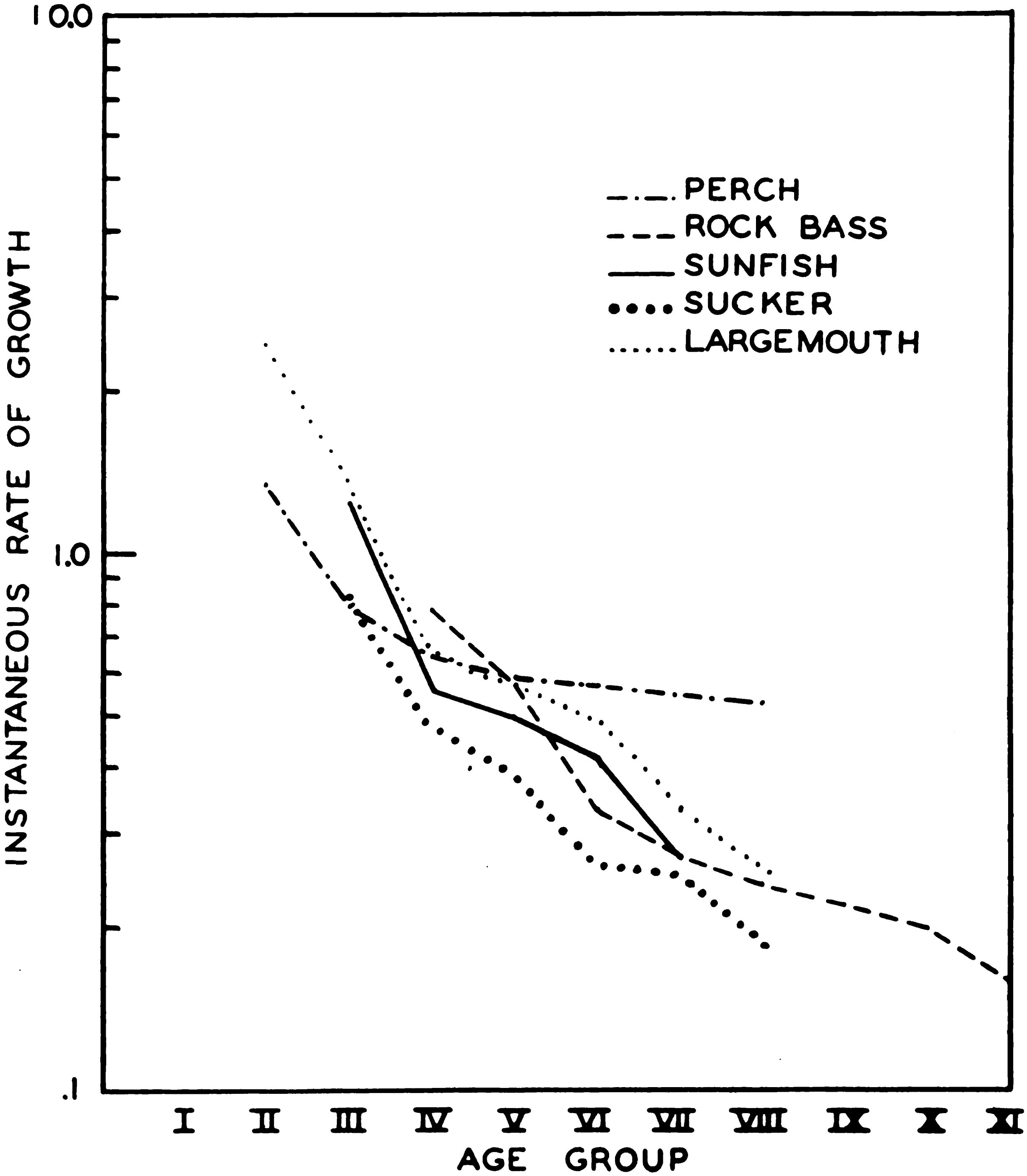

LOGe LENGTH
0
1
2
1750
1500
1250
1000
750
500
250
0
WEIGHT IN GRAMS
7
6
5
4
3
2
1
0
-1
-2
-3
LOGe WEIGHT
B
A
0
8
10
12
14
16
18
TOTAL LENGTH IN INCHES

Figure 26. Gravimetric instantaneous rate of growth of various species. Mean rate is plotted on semi-log scale.



10.0
1.0
.1
INSTANTANEOUS RATE OF GROWTH
PERCH
ROCK BASS
SUNFISH
SUCKER
LARGEMOUTH
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
AGE GROUP

decreases. Variability in the rate of growth was greater among fish of the younger age groups than among the older fish. Mean instanttaneous rates of growth for all species are shown in Tables 19, 21, 23, 25, and 27.

Condition factors of the fish were not computed, but the relative state of condition (robustness) may be shown from the constant, *n*, derived from the length-weight relationship. This constant (slope of the log-log transformation, Figures 21, 22, 23, 24, and 25) is usually near 3. A value of *n* higher than 3 means the fish is heavier in relation to its length than normal. A fish with an *n* value less than 3 has less weight in relation to its length. Hoffman Lake fish had *n* values as follows: largemouth bass 3.28, sunfish 3.14, perch 3.09, rock bass 2.66, and suckers 2.39. The *n* values for Hoffman Lake perch and sunfish were nearly the same as the state averages which were determined by Beckman (1945). Hoffman Lake largemouth bass were much higher and rock bass much lower than state average.

INTERRELATIONSHIPS BETWEEN PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF HOFFMAN LAKE

Because of immediate decreases in transparency after each application of fertilizer, followed by a rapid clearing of the water which resulted in a greater transparency after fertilization than before fertilization, it was concluded that fertilization caused a flocculation or precipitation reaction. Following this

Table 27

Mean Instantaneous Rate of Growth for Largemouth Bass From Hoffman Lake, 1954

Age group	Number of fish	Linear rate of growth	Gravimetric rate of growth	Standard deviation	Coefficient of variability (%)
II	23	0.74	2.41	0.469	19.5
III	15	0.40	1.32	0.190	14.4
IV	7	0.20	0.65	0.076	11.7
V	8	0.17	0.56	0.125	22.3
VI	2	0.15	0.48	0.017	3.5
VII	1	0.10	0.33	...	...
VIII	1	0.08	0.26	...	...

decrease in transparency at all depths, the upper 6 feet of water cleared and simultaneously there was a further decrease in transparency of the bottom waters. These transparency changes may be explained by assuming there was a homogeneous mixture of suspended material in the lake water immediately following fertilization that settled out of the upper strata and accumulated in the lower levels. The rate of settling of the suspensoids would depend on the specific gravity of the material and the amount of mixing due to wind action. Records of wind action, other than a note on the windy condition during second application of fertilizer, were not taken.

Some workers in evaluating fertilization experiments upon hard water lakes have used decreases in transparency, as measured by the Secchi disk, as an indication of a biological response to fertilization in the form of a plankton bloom. The Hoffman Lake experiment suggests that some of these workers may have arrived at erroneous conclusions by the use of this measurement.

The rapid loss of added nutrients from fertilized lakes has been assumed by some workers to be due to the increased biological activities of organisms transforming the added nutrients into living protoplasm. Hayes (1951) has demonstrated by the use of radioactive phosphorus that decreases in added nutrients can and does occur by ion exchange. It has been concluded from many experiments that phosphorus becomes precipitated by calcium in the form of tricalcium phosphate in hard water lakes. The experiment on Hoffman Lake neither proves or disproves this, but suggests the formation inorganic precipitates containing phosphorus. Determinations point to the possibility of ammonium carbonate complexes being formed when ammonia is added to a hard water lake. It is possible that such an ammonia complex, if formed, would not be stable, but could account for the immediate and temporary decreases in water transparency.

Loss of the fertilizer by drainage through the outlet is believed to be small. The outlet stream had an average flow of 3 cu. ft./sec. It was calculated that it would take approximately 173 days for the entire volume of water in the lake to drain through the outlet. Assuming no mixing and no loss of fertilizer by flocculation, precipitation, ion exchange or uptake by organisms, it is calculated that 34 pounds of fertilizer would have left the lake each day as a result of both applications of fertilizer. The fertilizer that left the lake was sufficient to produce an increase in periphyton for about 10 miles downstream on the West Branch of the Sturgeon River. By the use of standard chemical methods increased amounts of ammonia in the stream were detected three miles below the lake after the second application of fertilizer. Increases in phosphorus were not detected more than one mile below the lake following either application. This may indicate that the suspended material containing the phosphorus was being settled or strained out of suspension whereas the ammonia was either soluble or a more bouyant form of insoluble material than the phosphorus and consequently was carried further downstream.

Biological increases occurred in the form of periphyton following fertilization. These increases were measured quantitatively by chlorophyll extraction. Increases in periphyton were observed on logs that had fallen in the lake, on patches of bottom in shallow areas, on the submerged parts of bulrushes, and on the trap nets used to collect fish samples. Except on the bulrushes, periphyton was not evident prior to fertilization.

The reason for the appreciable increases in periphyton and little or no increase in plankton are not known. Possible explanations may include: (1) There was sufficient seed stock of periphyton to utilize the nutrients, but no enough plankton stock because plankton organisms may have been flocculated out of suspension. (2) Nutrients may have precipitated and settled too rapidly to be of much use to plankton organisms, but the insoluble flocculent material settled upon the substrate occupied by periphyton organisms and these organisms were in some way able to utilize the insoluble material.

SUMMARY

1. Inorganic fertilizer was applied to Hoffman Lake, a 120-acre marl lake located in northern Michgan. A study was made of the physical, chemical, and biological characteristics of the lake before and after fertilization.

2. Transparency of the water decreased immediately after each application of fertilizer, thereafter the transparency increased to higher values than existed before the fertilization. This response from fertilization was due to the formation of a flocculant material which formed immediately after each application of fertilizer.

3. No change in the pH or alkalinity of the lake was found following fertilization.

4. Concentrations of ammonia nitrogen, total and soluble phosphorus, and sulfate ion increased after each application of fertilizer, but these increases were only temporary and concentrations returned to prefertilization levels within a week.

5. No detectable increase in phytoplankton or zooplankton was found.

6. Determinations made on water samples collected for plankton extraction showed increases in suspended material after each application of fertilizer and the increase was due to a flocculent material which contained carbonates, phosphorus, and calcium.

7. The standing crop of periphyton produced during a 30-day period following the first fertilization was 10 to 30 times greater than the crop produced during a 30-day period before fertilization.

8. The standing crops of macroscopic benthos were sampled and measured for future evaluation of fertilization upon this group. No immediate measureable change in the benthos was expected the first summer, however, the rate of growth of the 1954-55 life cycle of Ephemera is possibly higher than the 1953-54 life cycle which were produced before fertilization.

9. Fish, like macroscopic invertebrates, were not expected to show a detectable response to fertilization the first summer. Data has been compiled for future evaluation of changes in growths which may occur following fertilization.

LITERATURE CITED

American Public Health Association

1946. Standard methods for the examination of water and sewage. 9th ed., New York, 286 pp.

Ball, Robert C.

1948. Relationships of lake productivity to total fish production and to fish feeding habits. Mich. State Coll., Agric. Exper. Sta. Tech. Bull., 206 pp.

Ball, Robert C. and Howard Tanner

1951. The biological effects of fertilizer on a warm-water lake. Mich. State Coll., Agric. Exper. Sta. Tech. Bull. 223, 32 pp.

Barrett, Paul H.

1953. Relationships between alkalinity and adsorption and regeneration of added phosphorus in fertilized trout lakes. Trans. Am. Fish. Soc., 82: 78-90.

Beckman, William C.

1945. The length-weight relationship, factors for conversions between standard and total lengths, and coefficients of condition for seven Michigan fishes. Trans. Am. Fish. Soc., 75: 237-256.

Beckman, William C.

1949. The rate of growth and sex ratio for seven Michigan fishes. Trans. Am. Fish. Soc., 76: 63-81.

Burks, B. D.

1953. The mayflies, or Ephemeroptera, of Illinois. Bull. of the Ill. Nat. Hist. Surv., 26: 1-211.

Davis, H. and A. Wiebe

1930. Experiments in the culture of the black bass and other pondfish. U. S. Bur. Fish., Doc. 1085: 177-203.

Domogalla, B., C. Juday, and W. Peterson

1925. The forms of nitrogen found in certain lake waters. Jour. Biol. Chem., 63(2): 269-285.

Ellis, M. M.

1937. Detection and measurement of stream pollution. Bull. 22, U. S. Bur. Fish. 58: 365-437.

Ellis, M. M., B. A. Westfall, and M. D. Ellis

1946. Determination of water quality. U. S. Dept. Inter., Fish and Wildlife Serv. Research Rept. No. 9: 199.

Embody, G.

1921. The use of certain milk waste in the propagation of natural fish food. Trans. Am. Fish. Soc., 51: 76-79.

Greenbank, John

1945. Limnological conditions in ice-covered lakes, especially as related to winter-kill of fish. Ecol. Monogr., 15: 343-392.

Grzenda, Alfred R.

1956. The biological response of a trout stream to headwater fertilization. Masters thesis Michigan State University.

Gumtow, Ronald B.

1955. An investigation of the periphyton in a riffle of the West Gallatin River, Montana. Trans. Amer. Micros. Soc., 124(3): 278-292.

Harvey, H. W.

1934. Measurement of phytoplankton. Journ. Mar. Biol. Assoc. 19: 761-773.

Hayes, F. R.

1951. On the theory of adding nutrients to lakes with the object of increasing trout production. Canad. Fish. Cult., 10: 1-7.

Howell, Henry H.

1942. Bottom organisms in fertilized and unfertilized fish ponds in Alabama. Trans. Am. Fish. Soc., 1941, 71: 165-179.

Hunt, Burton P.

1953. The life history and ecomonic importance of a burrowing mayfly, Hexagenia limbata, in southern Michigan lakes. Bull. of the Institute for Fisheries Research No. 4, Mich. Dept. of Cons., 129 pp.

Lagler, Karl F.

1952. Fresh water fishery biology. Wm. C. Brown Co., Dubuque, Iowa, 360 pp.

Langford, R. R.

1948. Fertilization of lakes in Algonquin Park, Ontario. Trans. Am. Fish. Soc., 78: 133-144.

Leonard, Justin W.

1947. Differences in the occurrence of nymphs of two species of burrowing mayflies in fish stomachs. Ann. Ent. Soc. Amer., 40: 688-691.

Leonard, J. W. and F. A. Leonard

1946. An analysis of the feeding habits of rainbow trout and lake trout in Birch Lake, Cass County, Michigan. Trans. Am. Fish. Soc., 76: 301-314.

Lyman, Earle F.

1943. Swimming and burrowing activities of mayfly numphs of the genus Hexagenia. Ann. Ent. Soc. of Amer., 36: (2).

Maciolek, John A.

1954. Artificial fertilization of lakes and ponds--A review of the literature. U. S. Dept. of Int., Fish. and Wildlife Serv., Spec. Sci. Rept., Fish No. 113: 41.

Needham, James G.

1920. Burrowing mayflies of our larger lakes and streams. Bull. U. S. Bur. Fish., 36: 267-292.

Neese, J.

1949. Development and status of pond fertilization in central Europe. Trans. Am. Fish. Soc., 76: 335-358.

Patriarche, Mercer H., and Robert C. Ball

1949. An analysis of the bottom fauna production in fertilized and unfertilized ponds and its utilization by young-of-the-year fish. Mich. State Coll., Agric. Exper. Sta. Tech. Bull. 207: 35 pp.

Patrick, Ruth

1949. A proposed biological measure of stream conditions based on a survey of Conestaga Basin Lancaster County, Pennsylvania Pro. Acad. Nat. Sci. Phil., 101: 277-347.

Roelofs, Eugene

1941. Fisheries survey of Hoffman Lake, Charlevoix County Michigan. Report No. 698. Institute for Fisheries Research, Michigan Dept. of Conservation. Mimeograph Report.

Rounsefell, G. A. and W. H. Everhart

1953. Fishery science: its methods and applications. John Wiley and Sons, New York. 444 pp.

Smith, E. V. and H. S. Swingle

1939. The relationship between plankton production and fish production in ponds. Trans. Am. Fish. Soc., 68: 309-315.

Smith, M. W.

1934. Physical and biological conditions in heavily fertilized water. Jour. Biol. Bd. Canada, 1: 67-93.

Smith, M. W.

1948. Fertilization of a lake to improve trout angling. Note No. 105, Prog. Rept. Atl. Biol. Sta., Fish. Res. Bd. Canada, 48: 3-6.

Snedecor, George W.

1946. Statistical methods. 4th ed. The Iowa State Coll. Press, Ames, Iowa, 485 pp.

Surber, E. W.

1945. The effects of various fertilizers on plant growths and their probable influence on the production of small-mouth bass in hard water ponds. Trans. Am. Fish. Soc., 1943, 73: 377-393.

Swingle, H. S.

1947. Experiments on pond fertilization. Ala. Exp. Sta. Ala. Poly. Inst. Bull. No. 254: 23.

Theroux, Eldridge, and Mallman

1943. Laboratory manual for chemical and bacterial analysis of water and sewage. 3rd. ed., McGraw-Hill, New York, 274 pp.

Tucker, Allen

1949. Pigment extraction as a quantitative analysis of phytoplankton. Trans. Amer. Micros. Soc., 68 (1): 21-23.

Welch, P. S.

1948. Limnological Methods. Blakiston Co. Philadelphia, Toronto, 381 pp.

Wiebe, A.

1930. Investigations on plankton production in fish ponds. U. S. Bur. Fish., Bull., 46 (1982): 137-176.

Young, O. W.

1945. A limnological investigation of periphyton in Douglas Lake, Michigan. Amer. Micros. Soc., 64 (1): 1-20.

Date Due

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JUN 1 '56			
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