BIOLOGICAL, CHEMICAL, AND PHYSICAL CHANGES RESULTING FROM FERTILIZATION OF A MARL LAKE

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BIOLOGICAL, CHEMICAL, AND PHYSICAL CHANGES RESULTING FROM FERTILIZATION OF A MARL LAKE

By

NICKOLAS ANTON

AN ABSTRACT

Submitted to the School of Agriculture of Michigan State
University of Agriculture and Applied Science in
partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1957

Approved Robert C Ball

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ABSTRACT

Five tons of commercial, inorganic fertilizer were added in two applications to Hoffman Lake, a 120 acre marl lake in northern Michigan, during the summer of 1955.

Immediate results of each application were noted in increases in some of the physical and chemical characteristics of the water. These increases were only temporary and conditions returned, or approached those existing prior to fertilization.

Fertilization brought about an increase in turbidity which resulted in the reduction of light penetration at all depths. The turbid condition was due to the action of excess calcium in the water upon the ingredients present in the fertilizer, causing a precipitating "floc". No plankton bloom was noted.

Concentrations of soluble and total phosphorus, ammonia nitrogen and sulfate increased following each application of fertilizer, then rapidly returned to prefertilization levels.

There was a more gradual, but obvious, increase of periphyton in the shoal areas of the lake. Quantitative analyses showed these increases to be significant and related to the increase in nutrients added to the lake.

Macroscopic benthic animals were sparce, both in numbers and species composition. Burrowing mayflies constituted over 90 percent of the total number of bottom organisms sampled.

Studies made of five species of fish sampled in Hoffman Lake revealed that the long-range effects of fertilization produced a change in the length-weight relationship for one species, the common sucker.

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INTRODUCTION

This study deals with the fertilization of a marl lake in northern Michigan. The aim of the project was two-fold: 1. To determine the biological effects of the addition of nutrients on a marl, warm-water lake and 2. To trace the nutrients into and down the course of its highly unproductive effluent stream, the West Branch of the Sturgeon River. The effects of fertilization were sought by investigating physical, chemical and biological characteristics of the lake prior to, during and after fertilization. This project on Hoffman Lake is a continuation of a series of studies started in 1954 by Alexander (1956). Grzenda (1955) and Colby (unpublished) worked on the stream phase of the project; their findings determined to what extent nutrients were carried down the West Branch of the Sturgeon River.

An increase in biological productivity as a result of nutrients added to a body of water in the form of fertilizer, whether organic or inorganic, has been shown by other workers (Hogan, 1933; Meehean, 1933, 1934; Swingle and Smith, 1939, 1940; Surber, 1945; Swingle, 1947; Langford, 1948; Patriarche and Ball, 1949; Ball, 1950, 1951). However, most of the previous work has been conducted on small ponds and lakes, and the results of the present study on a marl lake may help determine the feasibility of adding nutrients to a lake the size and type of Hoffman Lake. The present study reveals certain limitations of fertilization as a tool of fishery management.

The fertilization of an aquatic environment to increase its biological productivity is an old practice, having been used for centuries in European and Asiatic fish-culture work. In this country, however, it has primarily been used in an effort to improve existing sport fisheries which, in some areas, have failed to keep pace with recent increases in fishing pressure.

The theory of fertilization is a simple one; essential nutrients are provided to promote the growth of basic food organisms which, barring any ill-effects of physical and chemical conditions, are reflected in increased fish yields.

DESCRIPTION OF THE STUDY AREA

Hoffman Lake, a 120 acre marl lake, is located in Hudson Township (T. 32 N., R. 4 W., Sec. 26, 27, 34, 35), Charlevoix County, approximately eight miles west of Vanderbilt, Michigan. The lake contains three small depressions with a maximum depth of 22 feet and a mean depth of 8 feet. The shape of the lake is ovoid, except for one projecting arm of the eastern shore.

Using Odum's (1953) classification, Hoffman Lake is morphometrically eutrophic. It is shallow and poor in nutritive materials. Lakes poor in nutritive materials are common in northern Michigan where much of the soil is low in fertility.

The topography of the area surrounding the lake is wooded moraine. The lake has a small drainage area of 5120 acres and lies in the podzol region of the state. The soil series of the area are Montcalm, Wexford, Emmet and Leelanau (Whiteside, Schneider and Cook, 1956). These soils are typical of the morainic areas in the northern part of the lower peninsula of Michigan and are characterized by their sandy to sandy-loam texture. Soils of this type are well-drained and in this area contain a considerable amount of limy materials. Hoffman Lake is alkaline in character, due to the leaching out of calcium and magnesium salts which come to the lake via springs originating in the surrounding moraines. The deposition of calcium carbonate on the lake bottom and that in suspension gives the water a blueish-green cast characteristic of marl lakes.

Hoffman Lake is a drainage lake which receives its water supply from a creek, entering on the west shore, and from several springs located along the south and west shores. The creek drains two small, shallow lakes : Kidney Lake, one-half mile to the west; and Black Lake, three-quarters of a mile southwest of Hoffman Lake. The amount of water leaving the lake was 2.8 cubic feet per second. This value was determined from measurements taken at the lake's only outlet, located on the east shore, which constitutes the origin of the West Branch of the Sturgeon River.

The original forest of the area was chiefly sugar maple along with other hardwoods. Much of the drainage area has been cleared to provide farming and pasture land. Cedar swamps occupy the lower areas.

Vegetation in Hoffman Lake is limited in both abundance and species compositon. This reflects a lack of biological productive capacities within the lake due to the low level of nutrients and the limiting effects of marl deposition on plant growth.

The bulrush (*Scirpus* sp.) was the most common aquatic plant in the lake and grew in sparse patches on the shoal areas, especially along the eastern shore. Scattered patches of muskgrass (*Chara* sp.) and pondweed (*Potamogeton* sp.) constituted the deeper-growing submerged vegetation. A single patch of white water-lilies (*Nymphaea odorata*), intermingled with a few floating-leaf pondweeds (*Potamogeton natans*), was located near the western shore of the lake. Cattails (*Typha* sp.) and sedges (*Carex* sp.) were common on shore in the vicinity of the outlet and other low-lying areas.

Two species of burrowing mayflies (*Ephemera simulans* and *Hexagenia limbata*) accounted for the greatest volume of macro-benthic animals. Alderfly larvae (*Sialis* sp.), dragonfly nymphs (*Gomphus* sp. and *Macromia* sp.) and midge larvae (Tendipedidae) were less common and together made up about 5 percent of the total number and about 1 percent of the total volume. Aquatic annelids, snails, clams and biting-midge larvae showed up rarely in the samples; their number and volume were insignificant.

Four species of game and pan fish and one coarse species were present in the lake; these were:

Micropterus salmoides	Largemouth bass
Perca flavescens	Yellow perch
Ambloplites rupestris	Rock bass
Lepomis gibbosus	Common sunfish
Catostomus commersonnii	Common sucker

Roelofs (mimeographed report) lists the following six species of forage fish present in Hoffman Lake:

Notropis volucellus	Mimic shiner
Notropis cornutus	Common shiner
Hyborhynchus notatus	Bluntnose minnow
Percina caprodes	Log perch
Poecilichthys exilis	Iowa darter
Semotilus atromaculatus	Creek chub

METHODS

Fertilization

During the summer of 1955, commercial inorganic fertilizer having an analysis of 12-12-12 (N-P-K) was added to Hoffman Lake. The nitrogen was in the form of ammonium sulfate; phosphorus as super-phosphate and potassium as potassium chloride. Six thousand pounds were added on July 31 and 4000 pounds on August 6.

The fertilizer was broadcast along the southwest shoal area from the stern of a moving boat. Wave action in the shoal area and the churning action of the propeller insured a thorough mixing of the fertilizer.

The 10,000 pounds of 12-12-12 fertilizer added in 1955 was the equivalent of twice the concentration of the ingredients from the previous year, when 5900 pounds of 10-10-10 (N-P-K) were added to the lake. Since phosphorus and nitrogen are considered to be limiting factors in a marl lake (Welch, 1952), it was postulated that an increase of these nutrients would be reflected in the production of organic material higher than the previous year.

Table 1 shows the theoretical concentration of chemicals in the lake immediately following fertilization for the years 1954 and 1955. Values used for the year 1954 were obtained from a table prepared by Alexander (1956). These values are based on the assumption that the fertilizer dissolved completely. The volume of the lake was calculated to be 45,000,000 cubic feet (Alexander, op. cit.).

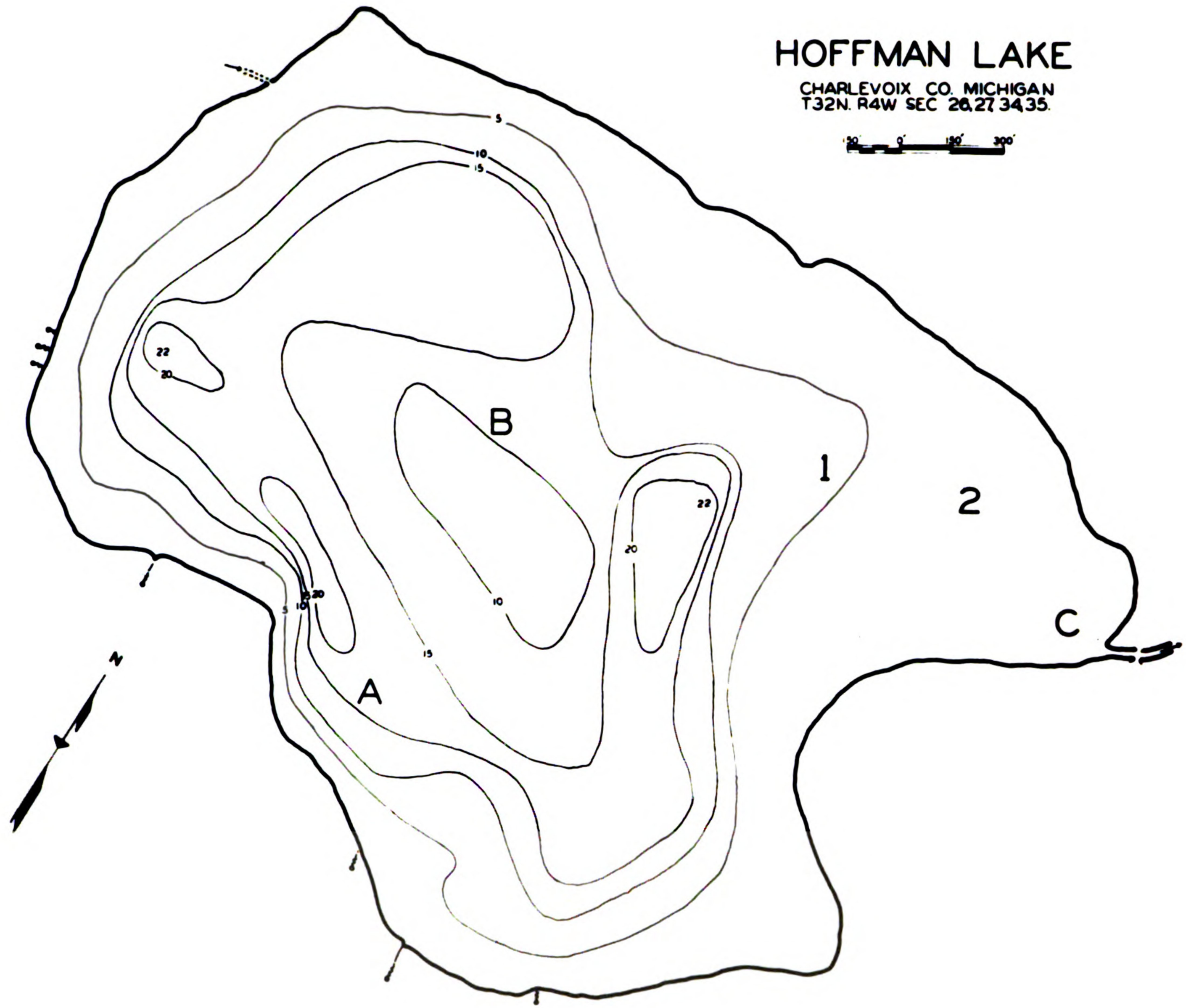
Sampling Stations

Five sampling stations were established in Hoffman Lake, designated as A, B, C, 1 and 2 (Fig. I). Stations A, B and C represent the points at which samples for chemical analyses were taken. Physical determinations were made from samples collected at stations A and B except for submarine photometer readings which were made in the area of

Table 1. Theoretical Concentration in P. P. M. of Chemicals in Hoffman Lake after Fertilization (1954 and 1955)

	First Application		Second Application		Annual Totals	
	1954 (3200 Lbs.)	1955 (6000 Lbs.)	1954 (2700 Lbs.)	1955 (4000 Lbs.)	1954 (5900 Lbs.)	1955 (10000 Lbs.)
Fertilizer	1.139	2.101	0.968	1.424	2.107	3.525
Nitrogen	0.1139	0.2521	0.968	0.1709	0.2107	0.4230
Ammonia	0.1464	0.3241	0.1244	0.2197	0.3708	0.5438
Sulfate	0.4026	0.6723	0.3421	0.5853	0.7447	1.2576
Phosphoric Acid	0.1139	0.2521	0.0968	0.1709	0.2107	0.4230
Phosphorus	0.0498	0.1084	0.0424	0.0735	0.0922	0.1819
Potassium Oxide	0.1139	0.2521	0.0968	0.1709	0.2107	0.4230
Potassium	0.0945	0.2092	0.0803	0.1418	0.1748	0.3510

Figure I. Map of Hoffman Lake, Showing Locations of Sampling Stations


HOFFMAN LAKE
CHARLEVOIX CO. MICHIGAN
T32N. R4W SEC 26,27,34,35.
150' 0' 150' 300'
N
A
B
C
1
2
5
10
15
20
22

greatest depth, just east of station B. Plankton and bottom organisms were sampled at stations 1 and 2.

The reason for selecting the chemical sampling stations A, B and C at the points shown (Fig. I) was to note how the chemical nutrients in the fertilizer were dispersed in the lake. Station A was located in the area of fertilizer application, near the south-west shore; station B in the center of the lake and station C at the outlet.

Stations 1 and 2 were the same as used the previous year (1954). Since similar sampling procedures were followed at these two stations for two consecutive years, a comparison of the data was possible.

Laboratory

All chemical and physical analyses were made as soon as possible after the water samples were collected. The laboratory was set up at the Pigeon River Trout Research Area headquarters located 15 miles east of Vanderbilt, Michigan, a total of 23 miles from Hoffman Lake.

The laboratory was well equipped with instruments, chemicals and glassware for making the various analyses. Colorimetric determinations of phosphorus, sulfates and ammonia nitrogen were made with a Klett-Summerson photoelectric colorimeter. The hydrogen-ion concentration was measured with an electric Beckman pH meter. Specific conductivity measurements were made with a portable, battery-operated conductivity bridge. A Hellige turbidimeter was employed for making turbidity measurements. Plankton and periphyton samples were concentrated by centrifugation with a Foerst centrifuge.

Sampling

PHYSICAL

Secchi disk. The secchi disk was used to determine the depth of visibility and gave a measure of transparency of the water. While a measurement of transparency is not a true measure of light penetration (Coker, 1954), it is useful for making comparisons. Secchi disk readings were made prior to, during, and following fertilization; the results made it possible to make comparable studies of the transparency of the water during the summer.

Submarine photometer. A submarine photometer was used to measure the percent of light transmitted through the water at various depths. The instrument consisted essentially of two Weston photronic cells, a subsurface unit and a deck unit, designed by Fred Schueler, Waltham, Massachusetts. A single galvonometer and a double-throw switch enabled readings to be made from each cell with a minimal lapse of time.

The percent of transmitted light was determined for each three-foot interval to a depth of 18 feet. The initial reading was taken 6 inches below the water surface. Since partly cloudy days do not give acceptable results (Greenbank, 1945), photometer readings were taken under uniform conditions at mid-day.

Turbidity. Water samples were analyzed for turbidity with a Hellige turbidimeter. All samples were taken at a depth of one foot from stations A and B. Enough samples were taken prior to and following fertilization to show the fluctuations in turbidity resulting from fertilization.

Temperature. A Taylor pocket thermometer was used for obtaining air and water temperatures. Temperatures were taken throughout the study period and recorded in degrees Centigrade. Since there was an indication that Hoffman Lake did not stratify, as will be explained later, each water temperature consisted of a single subsurface measurement.

CHEMICAL

Alkalinity. The method outlined by Ellis, Westfall and Ellis (1948) was followed for making alkalinity determinations. It was expected that the alkalinity would remain fairly constant throughout the summer and for this reason samples were taken at infrequent intervals, except for the period immediately following fertilization.

Hydrogen-ion concentration. The hydrogen-ion concentration (pH) was measured with a Beckman pH meter. Samples were taken at infrequent intervals throughout the study period for the same reason given under "Alkalinity".

Dissolved oxygen. Five dissolved oxygen determinations were made during the hottest period of the summer using the Winkler Method (Theroux, Eldridge and Mallman, 1943). Water samples were taken at the bottom of the deepest depression and just below the surface.

Specific conductivity. A portable, battery-operated conductivity bridge was used to determine the specific conductivity. Values are given in mhos at a standard temperature (18° C). These values gave an indication of the total concentration of the ionized constituents in the water and thus was a useful method for observing any changes in ion concentration.

Ammonia nitrogen. The direct Nesslerization method, outlined in Standard Methods (1955), was used for ammonia nitrogen determinations. The color development was measured in a colorimeter and the p.p.m. of ammonia nitrogen was obtained from a graph prepared from known ammonia standards.

Phosphorus. Water samples were analyzed for both soluble and total phosphorus. The procedure followed is outlined in Ellis, Westfall and Ellis (1948). The color development was measured in a colorimeter and readings in parts per billion were obtained from a graph prepared from known phosphorus standards.

Sulfates. Sulfates were determined by the turbidimetric method as outlined in Standard Methods (1955). The units obtained from a colorimeter were read in p.p.m. of sulfate from a graph prepared from solutions of known sulfate con-

centrations.

BIOLOGICAL

Plankton. Two 3-liter water samples were taken from each of the two stations 1 and 2 with a Juday water sampler. Each sample was centrifuged with a Foerst centrifuge shortly after the samples were taken. The concentrated material in the bowl was washed repeatedly with a 5 percent formalin solution and transferred to a graduated cylinder. When the bowl was thoroughly clean, enough 5 percent formalin was added to make 50 ml. This mixture was then poured into a two-ounce bottle and stored for later laboratory work.

Periphyton. The word periphyton has been used to describe a certain component of the aquatic biota but does not have a definite connatation. For this reason, periphyton as used in this thesis follows the definition of Young (1945). He states that periphyton is "that assemblage of organisms growing upon free surfaces of submerged objects in water, and covering them with a slimy coat. It is that slippery brown or green layer usually found adhering to the surface of water plants, wood, stones, or other objects immersed in water and may gradually develop from a few tiny gelatinous plants to culminate in a wooly, felted coat that may be slippery, or crusty with contained marl or sand". It can be said that periphyton occupies a position between the benthos and plankton since it has characteristics of both.

The importance of periphyton to the biology of a lake has only recently been recognized. It not only contains organisms, some of which are able to manufacture food, but is also an indicator of biological productivity. This realization has lead various workers to seek ways by which the production of periphyton might be measured.

Young (op. cit.) made quantitative counts upon measured sections of stones, logs and other objects. Newcombe (1950) found that the weight of attachment materials produced on standard microscope slides offered a plausible basis for measuring water productivity.

In the present study, periphyton was collected on 5 cinder bricks and 15 cedar shingles placed at station C. Each brick measured 7.9 X 3.7 X 2.3 inches. The shingles measured 12.0 X 3.0 X 0.3 inches.

Wire was used to suspend the bricks from suitable objects, such as submerged logs and overhanging trees. The shingles were nailed to submerged logs in such a manner as to expose the greatest possible surface to the surrounding water. Two sets of bricks and shingles were used; one set was in the water 30 days and was removed the day preceding the fertilization date. This set was replaced by other shingles and bricks on the day of fertilization. They were placed in the exact position occupied by the first set and allowed to remain in the water 30 days following the application of fertilizer.

After the two respective 30 day periods had elapsed, each brick was carefully removed and placed in a porcelain pan. The brick was then scraped with a nylon brush and washed so as to remove all of the attached material. The contents of the pan were then transferred to a quart jar for later laboratory treatment.

Instead of removing the attached material in the field, the shingles were placed directly into plastic bags. Attached material was removed in the laboratory. From this point on, bricks and shingles were treated similarly and each constituted a separate sample.

Further laboratory treatment consisted of removing the macro-benthic animals from each sample. These were preserved in a solution of 10 percent formalin and stored in 2-ounce bottles. The remaining material was then concentrated by centrifugation.

The next step consisted of extracting the chlorophyll pigments contained in the concentrated material. This was done by adding 95 percent ethyl alcohol to each centrifuged sample and stored in the dark in 2-ounce bottles.

The extraction of the chlorophyll pigments provided a method for measuring the production of periphyton. Harvey (1934) utilized this method and found a correlation between the production of chlorophyll and plankton counts from the same sample. Later work by Tucker (1949), working along similar lines, corroborated the findings of Harvey.

The method used was to measure the density of the extracted pigments in each sample in a Klett-Summerson photoelectric colorimeter. The Klett units thus obtained were then converted to "Harvey units". One Harvey unit consists of 25 mg. potassium chromate and 430 mg. nickel sulfate in one liter of water (Harvey, 1934). Harvey units were obtained from a graph prepared from known dilutions of an original solution consisting of 100 Harvey units. This constituted the arbitrary color standard for measuring the chlorophyll pigment density in each sample.

Bottom organisms. Twenty Ekman dredge samples were taken each week at stations 1 and 2, ten from each station. Each sample was washed in a 30-mesh screen and then transferred to a porcelain pan. All visible bottom organisms were picked at the site; these were preserved in a solution of 10 percent formalin and stored for later analyses.

In the laboratory, all organisms were identified and counted and the total volume of each sample was measured to the nearest five-hundredth of a milliliter. Since the burrowing mayfly, *Ephemera simulans*, showed up most frequently in the samples, the geometric rates of growth and mortality and the emergence date were determined for this species.

Fish. Determinations of age and growth and a study of the relationships between length and weight were made for five species of fish collected from Hoffman Lake. Fish were captured by trapping, seining and angling throughout the summer of 1955.

At the time of capture, fish were measured for total length in inches and weight in grams. The fish were also scale sampled, marked and released. The number of fish sampled, by species, were as follows:

Common sunfish	*Lepomis gibbosus*	103
White sucker	*Catostomus commersonnii*	84
Rock bass	*Ambloplites rupestris*	76
Largemouth bass	*Micropterus salmoides*	53
Yellow perch	*Perca flavescens*	66

Scales were permanently mounted on glass slides using a gelatin-glycerine preparation. A scale projection apparatus in conjunction with ruled scale cards facilitated age-growth studies. It was assumed that a straight-line relationship existed between the growth of the fish and that of the scale.

Mathematical relationships between length and weight were determined by the use of the following formula (Carlander, 1953):

$$W = cL^n$$

W = weight

L = length

c and n = constants

The values for c and n may be determined by fitting a straight line to the logarithms of L and W or by computation from normal equations (Lagler, 1952; Rounsefell and

Everhart, 1953). To facilitate computations, the length-weight formula may be expressed logarithmically:

$$\ln W = \ln c + n \ln L$$

where ln equals the natural logarithm.

RESULTS

Sampling

Following fertilization, there were temporary increases in certain of the physical and chemical characteristics of the lake. In most instances, after several days, conditions approached but did not equal those recorded prior to fertilization.

Macroscopic benthic organisms and fish respond much more slowly, if at all, to the addition of nutrients. Therefore, evidence of change in volume, number and growth rate was sought by comparing the present data with that of the previous year. This was possible since sampling procedures and handling of data were similar for the two years.

There was an increase in periphyton shortly after the addition of fertilizer. Strands of filamentous algae, which were not previously noted, began to appear in the shoal areas.

There was a noticeable increase in turbidity of the water following each application of fertilizer which reduced the transparency of the water. These increases were observed by secchi disk and submarine photometer readings.

PHYSICAL

<u>Secchi disk</u>. On July 25, five days prior to the first application of fertilizer, the secchi disk disappeared at a depth of 75 inches. On August 2, two days following the initial application, the depth at which the secchi disk disappeared was 56 inches.

There was a similar reduction in the transparency following the second application of fertilizer. The secchi disk disappeared at 62 inches on August 4 and at 47 inches on August 8. A list of the mean secchi disk readings for each sampling date is shown in Table 2. It can be seen that at no time after fertilization had readings returned to those observed prior to fertilization. A graphical representation of the mean secchi disk readings is shown in Figure II.

<u>Submarine photometer</u>. Figure II shows the percent of transmitted light which reached each three-foot interval and shows close correlation with secchi disk readings. These correlations are especially evident during the fertilization period and show that transmitted light was reduced at all levels.

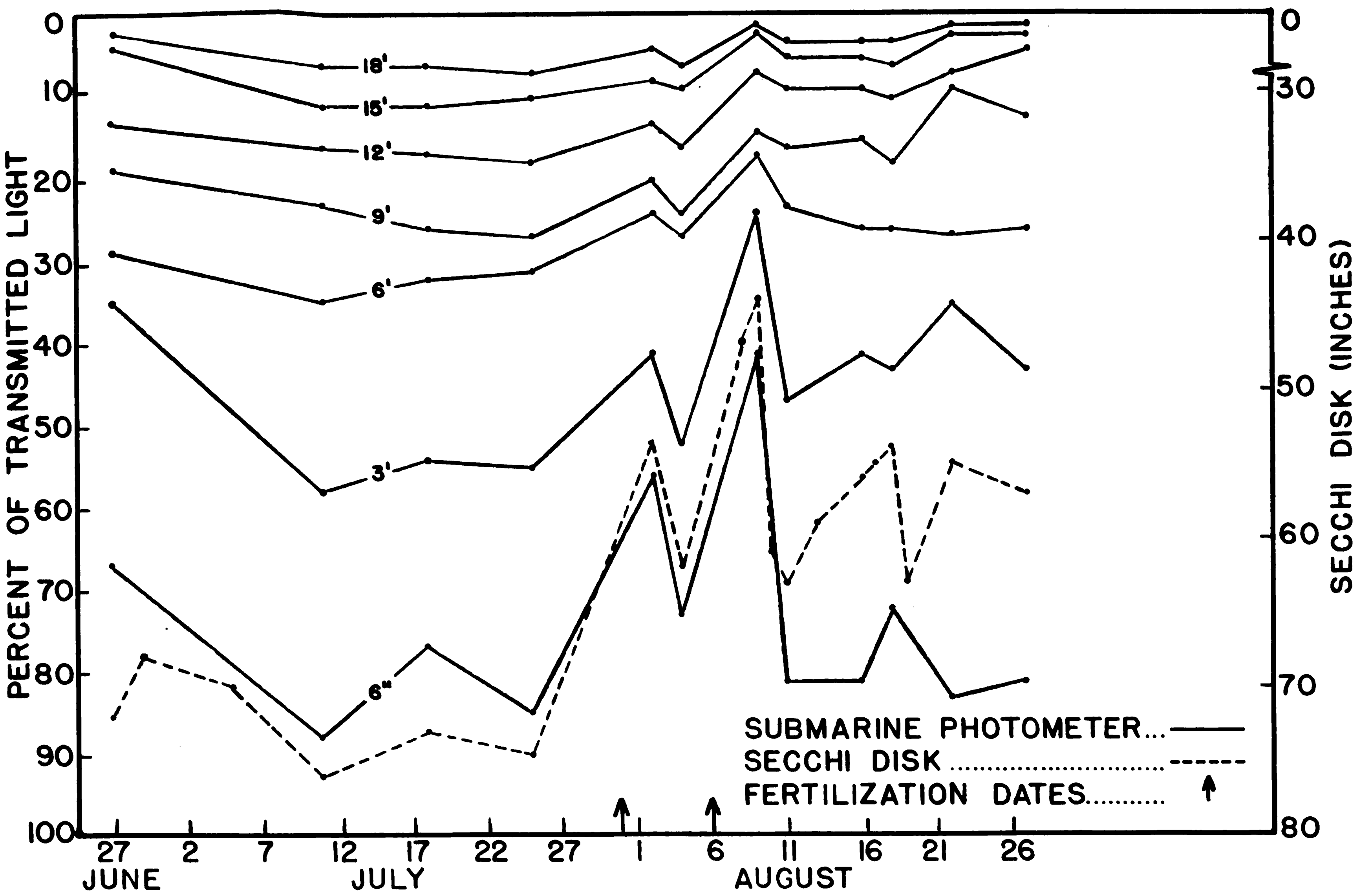
Both submarine photometer and secchi disk readings showed a greater reduction in transparency following the second application of fertilizer. It is presumed that this was due in part to the accumulated effects of the two appli-

Table 2. Mean Secchi Disk and Photometer Readings during Summer of 1955

Date	Secchi Disk (inches)	Photometer Readings Percent of transmitted light reaching various depths (feet)						
		S*	3	6	9	12	15	18
June								
27	72	67	35	29	19	13	04	02
29	68	..	..	..	..	..	..	..
July								
5	70	..	..	..	..	..	..	..
11	76	88	58	35	23	16	11	06
18	73	77	54	32	26	17	11	06
25	75	85	55	31	27	18	10	07
31**								
August								
2	56	56	41	24	20	13	08	04
4	62	73	52	27	24	16	09	06
6**								
8	47	..	..	..	..	..	..	..
9	44	41	24	17	14	07	02	01
10	61	..	..	..	..	..	..	..
11	63	81	47	23	16	09	05	03
13	59	..	..	..	..	..	..	..
16	56	81	41	26	15	09	05	03
17	55	..	..	..	..	..	..	..
18	54	72	43	26	18	10	06	03
19	63	..	..	..	..	..	..	..
22	55	83	35	22	09	07	02	01
27	57	81	43	26	12	04	02	01

* 6" below surface
**Fertilization dates

Figure II. Mean Secchi Disk Readings (inches) and the Percent of Transmitted Light at various Depths


PERCENT OF TRANSMITTED LIGHT
SECCHI DISK (INCHES)
0
10
20
30
40
50
60
70
80
90
100
0
30
40
50
60
70
80
18'
15'
12'
9'
6'
3'
6"
27
2
7
12
17
22
27
1
6
11
16
21
26
JUNE
JULY
AUGUST
SUBMARINE PHOTOMETER
SECCHI DISK
FERTILIZATION DATES

cations. At no time after fertilization had photometer readings returned to prefertilization levels (Table 2 and Fig.II).

Light penetration had been reduced as a result of an increase of some suspended material in the water. Other workers who carried out fertilization experiments invariably concluded that the reduction of light penetration concomitant with increased turbidity was the result of a plankton "bloom" (Hogan, 1933; Smith, 1934; Meehean, 1934; Swingle and Smith, 1939; Ball, 1949; Ball and Tanner, 1951; Nelson and Edmondson, 1955). Much of the previous work, however, has been carried out on farm ponds and other than marl lakes in which plankton blooms are known to occur following the addition of nutrients. There was no such increase of plankton in Hoffman Lake and, as will be discussed under "Plankton", the increase in turbidity was due to an inorganic flocculent material.

Temperature. Air and water temperatures taken from June 20 to August 26 during the summer of 1955 are recorded in Table 3. These values represent the means from all the sampling stations since the variation was slight from station to station. Mean air and water temperatures are shown graphically in Figure III.

It was believed that thermal stratification did not exist in Hoffman Lake and for this reason water temperatures consisted of a single subsurface measurement at each sampling station. This belief was substantiated from the results of oxygen determinations made from water samples taken at the surface and greatest depth in the lake (see "Dissolved oxygen", page 28).

Table 3. Mean Air and Water Temperatures (C.°) during the Summer of 1955

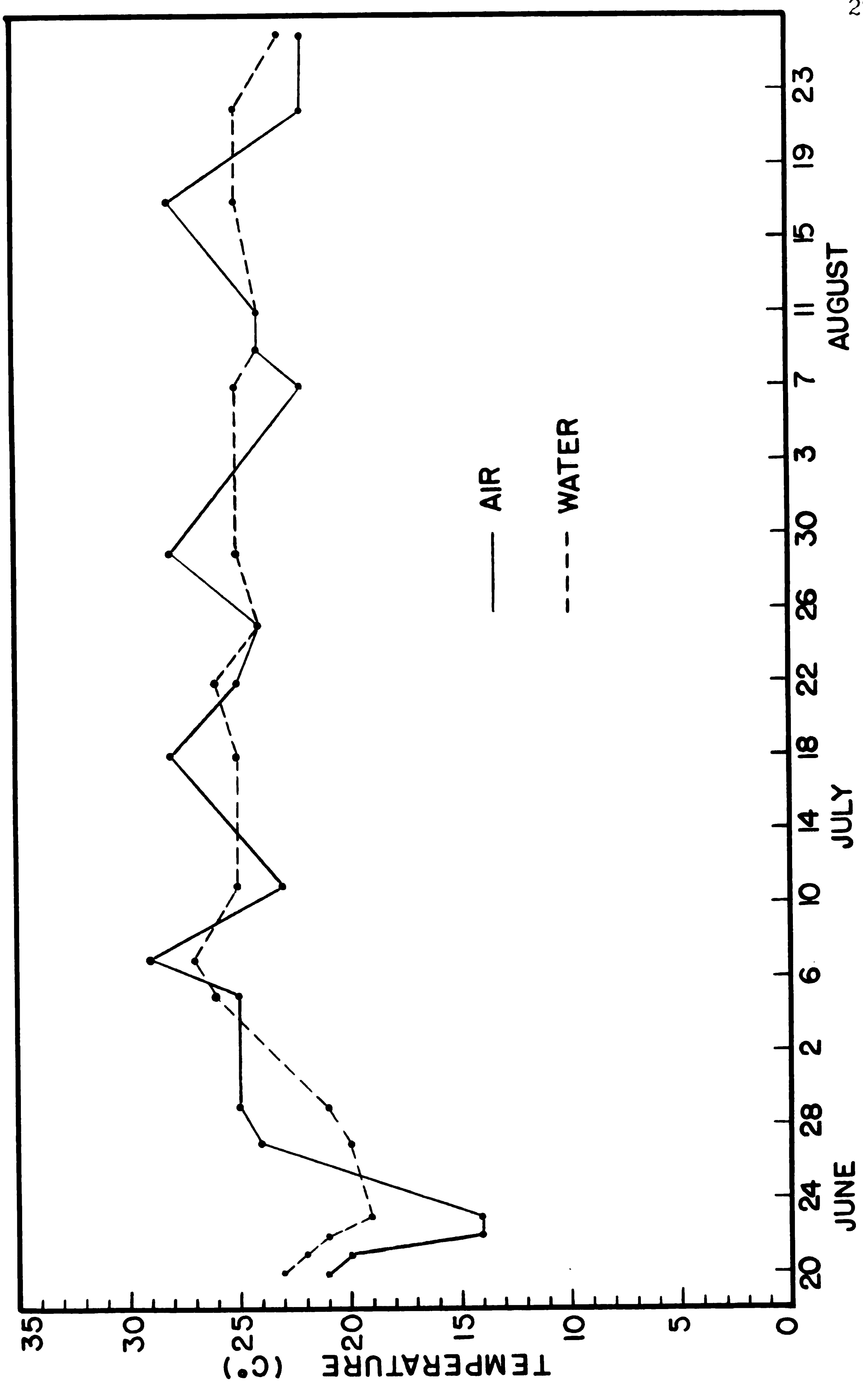
Date	Air Temperature	Water Temperature	Date	Air Temperature	Water Temperature
June			July		
20	21	23	22	25	26
21	20	22	25	24	24
22	14	21	29	28	25
23	14	19			
27	24	20	August		
29	25	21	7	22	25
			9	24	24
July			11	24	24
5	25	26	17	28	25
7	29	27	22	22	25
11	23	25	26	22	23
18	28	25			

Maximum air and water temperatures occurred during July and August with the lowest being recorded during June. Water temperatures, unlike air temperatures, varied slightly during the latter part of the summer.

CHEMICAL

Alkalinity. The addition of fertilizer had no noticeable effect upon the alkalinity of the water. Variations were slight throughout the summer and ranged from 135 to

Figure III. Graphical Representation of mean Air and Water Temperatures, Hoffman Lake, 1955



TEMPERATURE (C°)
0
5
10
15
20
25
30
35
20
24
28
2
6
10
14
18
22
26
30
3
7
11
15
19
23
JUNE
JULY
AUGUST
AIR
WATER

140 p.p.m. These values agreed closely with those obtained by Roelofs (mimeographed report).

The fact that the alkalinity did not change following fertilization indicates that Hoffman Lake is well buffered. The buffering effect in natural waters is due to substances which react in such a way as to maintain an equilibrium. Since there is a relationship between alkalinity and acidity in the same water, it is possible to express the buffering effect in terms of the hydrogen-ion concentration.

Hydrogen-ion concentration. The pH did not vary more than two-tenths of a unit throughout the summer. Values ranged from 8.1 to 8.3 and there was no indication that fertilization affected the pH.

It is believed that the concentration of calcium and magnesium carbonates in the water made it an efficient buffer system. Tack (personal communication) noted a change in pH after he added fertilizer to a small pond. Such a change is known to occur in waters low in buffer substances (Welch, 1952).

Dissolved oxygen. Water samples taken from the surface and in the deepest depression in the lake were analyzed for dissolved oxygen. This was done to see if differences in the oxygen content existed from top to bottom. Oxygen determinations were made during the warmest period of the summer. A difference at the two depths would indicate the presence of thermal stratification in the lake.

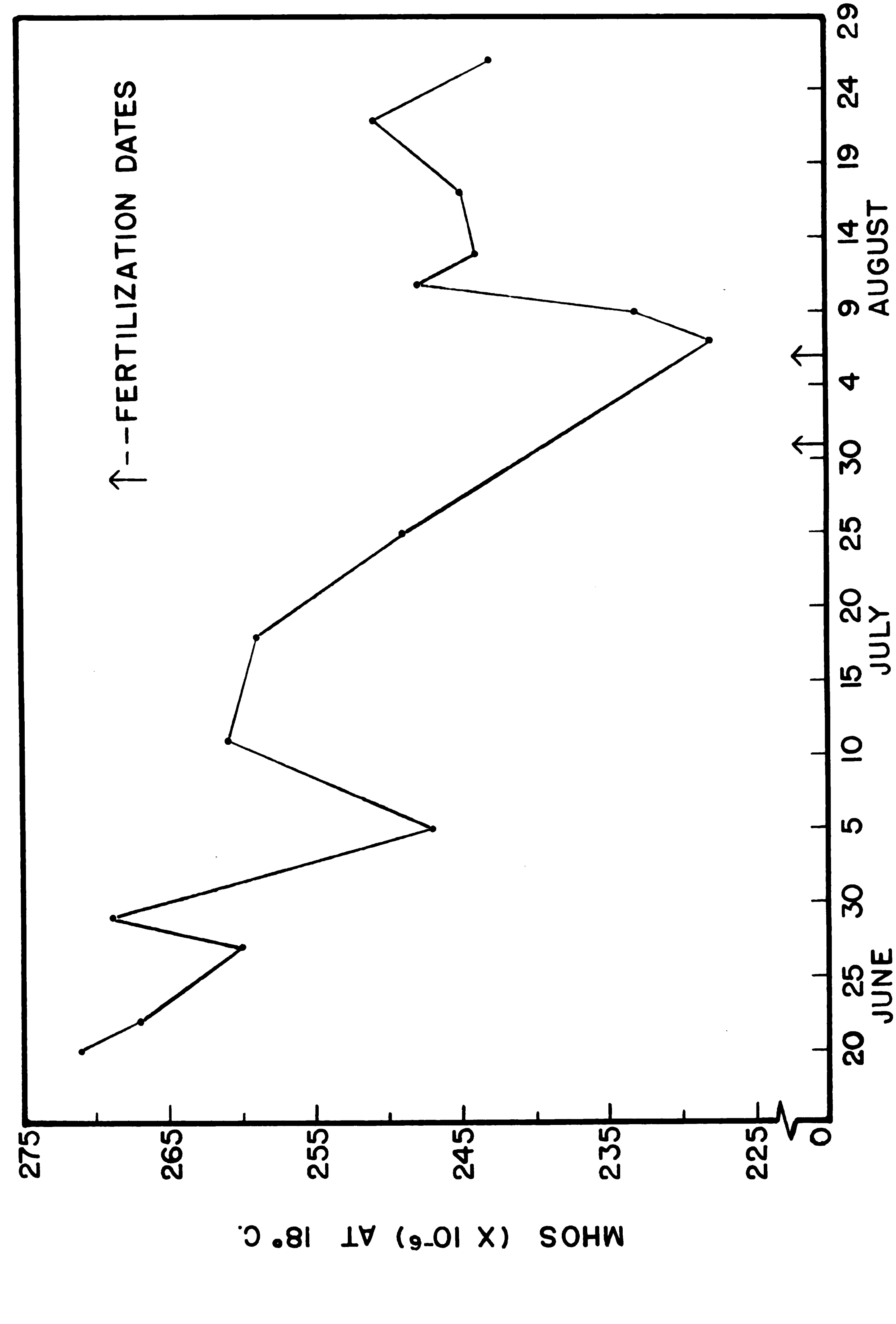
The results indicate that very little or no stratification existed. The values obtained for dissolved oxygen in p.p.m. were as follows:

	July				Aug.
	7	15	22	29	10
Water Temp. (C.°)	27	25	26	25	24
P.P.M. O_2 (Surface)	7.1	7.6	7.5	6.7	7.2
P.P.M. O_2 (Bottom)	7.1	7.5	7.4	6.7	7.1

Specific conductivity. The results of conductivity measurements show that there was an increase in the concentration of the ionized constituents in the water following fertilization (Fig. IV). This is indicated by the low reading observed on August 7, the first day following the second application. The higher readings observed prior to fertilization were probably due to late spring and early summer rainfall, which tended to reduce the concentration of ions by dilution. Values representing the means of data from stations A and B ranged from a high of 271 X 10^{-6} to a low of 228 X 10^{-6} mhos at 18° C. (Table 4).

As was stated elsewhere, there was an increase in turbidity following each application of fertilizer, which had the characteristics of a flocculent material. This material could conceivably be brought about by the combination of sulfates and phosphorus in the fertilizer with the

Figure IV. Specific Conductivity in Mhos ($X 10^{-6}$),
Hoffman Lake, 1955


←--FERTILIZATION DATES
MHOS (X 10-6) AT 18° C.
275
265
255
245
235
225
0
20
25
30
5
10
15
20
25
30
4
9
14
19
24
29
JUNE
JULY
AUGUST

calcium and magnesium ions present in the water. Neess (1949) found that in alkaline water where there is an excess of calcium, phosphorus may precipitate as tricalcium phosphate. The sulfate in the fertilizer may have precipitated as

Table 4. The Mean Specific Conductivity in Mhos at 18° C. from Stations A and B

Date	Mhos (X 10^{-6}) at 18° C.	Date	Mhos (X 10^{-6}) at 18° C.
June		July	
20	271	31*	...
22	267		
27	260	August	
29	269	6*	...
		7	228
July		9	233
5	247	11	248
11	261	13	244
18	259	17	245
25	249	22	251
		26	243

* Fertilization dates

calcium or magnesium sulfate. That such an occurrence had taken place is evidenced by the reduction in transparency following fertilization, as shown by secchi disk and submarine photometer readings. As the transparency of the water approached conditions which were present prior to fertilization, the specific conductivity also increased, indicating that the precipitation reaction reduced the concentration of ions in the water (see Tables 2 and 4).

Ammonia nitrogen. Surface waters at stations A, B and C showed increases of ammonia nitrogen following each application of fertilizer. These increases were only temporary, and only a trace amount was noted toward the latter part of August, as shown by the bar graphs in Figure V. Values ranged from a low of 0.01 to a high of 0.23 p.p.m. (Table 5).

At no time did concentrations of ammonia compounds approach levels which are considered as toxic to fish and other organisms. In areas of the Mississippi River receiving domestic sewage, values as high as 3 p.p.m. dissolved ammonia had little effect on the fish fauna (Ellis, 1937), depending on the pH of the water. Ellis found that ammonium salts become more toxic in more alkaline media. He further stated that in unpolluted natural waters having a pH range of 7.4 to 8.5, 1.5 p.p.m. dissolved ammonia was considered the maximal amount not suggestive of specific organic pollution.

Values which were obtained for ammonia nitrogen throughout the summer indicates that organic production in Hoffman Lake was low. The highest reading recorded was 0.23 p.p.m. at station C on August 3, three days after the first application of fertilizer (Table 5).

A slight rise in the concentration of ammonia nitrogen was recorded on July 18 following a windy period (Fig. V). This comparatively high reading during the pre-fertilization period was most evident from a water sample taken in the

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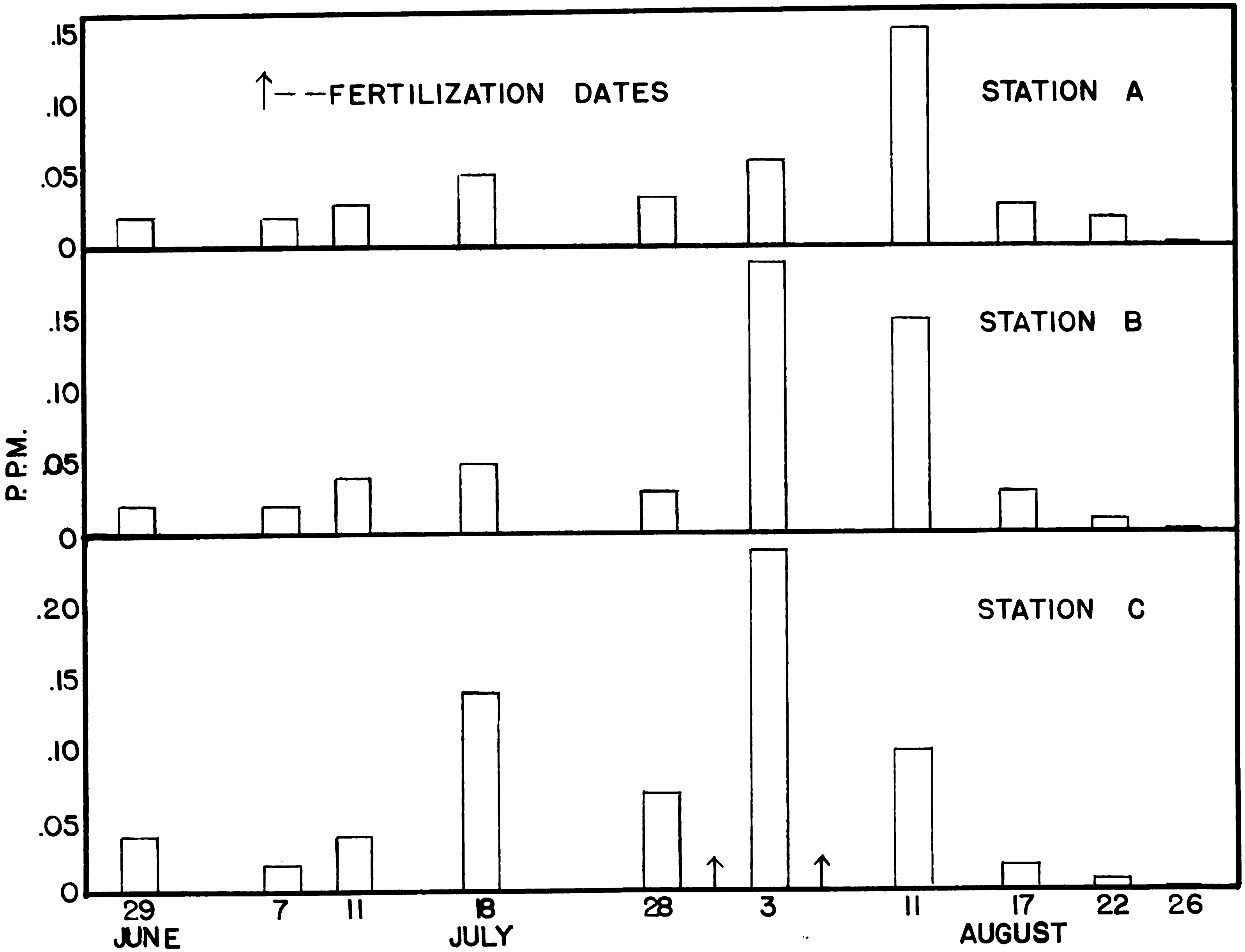
Figure V. Ammonia Nitrogen in P.P.M. at Stations A, B, and C,
Hoffman Lake, 1955



↑--FERTILIZATION DATES
STATION A
STATION B
STATION C
P.P.M.
.15
.10
.05
0
.20
29
JUNE
7
11
18
JULY
28
3
11
17
22
26
AUGUST

35

shallow area at station C. It was postulated that the water sample contained bottom detritus which was thrown into suspension by wave action caused by strong, westerly winds on that date.

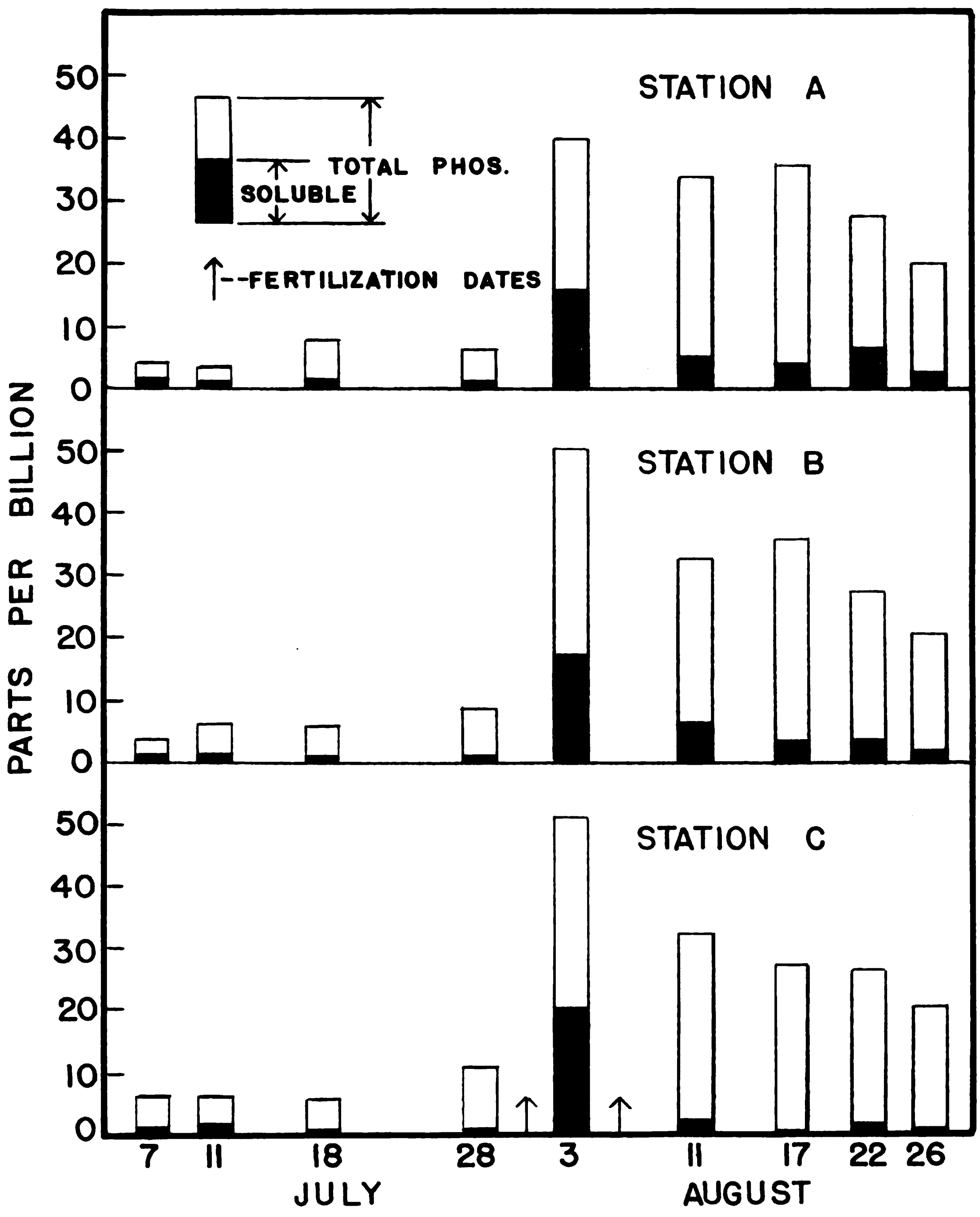
Table 5. Concentrations of Ammonia Nitrogen in P.P.M. from Stations A, B and C, Hoffman Lake, 1955

	Stations		
Date	A	B	C
June			
29	0.02	0.02	0.04
July			
7	0.02	0.02	0.02
11	0.03	0.04	0.04
18	0.05	0.05	0.04
28	0.03	0.03	0.07
31*	..	..	..
August			
3	0.06	0.19	0.23
6*	..	..	..
7	0.08	0.16	0.16
11	0.15	0.15	0.10
17	0.03	0.03	0.02
22	0.02	0.01	0.01
26	0.01	0.01	0.01

* Fertilization dates

Phosphorus. Increases were noted in both soluble and total phosphorus on the third day following the first application of fertilizer. It can be seen (Fig.VI) that on this date (August 3), there was a gradation in the concen-

Figure VI. Total and Soluble Phosphorus in Parts per Billion at Stations A, B and C, Hoffman Lake, 1955


STATION A
TOTAL PHOS.
SOLUBLE
--FERTILIZATION DATES
STATION B
STATION C
PARTS PER BILLION
0
10
20
30
40
50
7
11
18
28
3
11
17
22
26
JULY
AUGUST

tration of phosphorus from stations A to C with the greatest concentration at station C. This is more evident in the soluble fraction and shows the dispersal of phosphorus from west to east (see map, Fig. I and Table 6). This may have been due to the combined effects of the prevailing westerly winds and the natural flow of water from west to east.

Table 6. Concentrations of Total and Soluble Phosphorus in Parts per Billion at Stations A, B and C, Hoffman Lake, 1955

	Station A		Station B		Station C	
Date	Total	Soluble	Total	Soluble	Total	Soluble
July						
7	04	01	04	01	06	01
11	03	01	06	01	06	02
18	08	01	06	01	07	01
28	06	01	09	01	11	01
31*	..	..	..	..	..	..
August						
3	40	15	50	17	51	21
6*	..	..	..	..	..	..
7	32	13	31	11	22	10
11	34	05	33	06	33	03
17	36	04	36	04	28	01
22	28	06	28	04	26	02
26	20	02	21	02	21	01

* Fertilization dates

After an initial rise, following the second application of fertilizer, there was a gradual decrease in total phosphorus at all three stations. The soluble fraction at stations A and B showed an initial rapid decrease and then tapered off to pre-fertilization values. Concentrations of soluble phosphorus at station C quickly approached levels obtained prior to fertilization.

A decrease in soluble phosphorus is a common occurrence in natural waters due to the rapid uptake of this element by bottom muds and growing organisms and by chemical combination with other substances (Wiebe, 1931; Smith, 1948; Welch, 1952; Ruttner, 1953; Coker, 1954; Nelson and Edmondson, 1955). If this is true, it explains why the soluble phosphorus at station C dwindled to pre-fertilization levels if it is reasoned that: a. most of the aquatic vegetation is located in that area, b. the large shoal area adjacent to station C contains a greater proportion of bottom organisms and c. the shallow water enabled the bottom muds to quickly absorb the excess phosphorus. It is assumed that little loss occurred via the outlet because of the small volume of water leaving the lake.

It is probable that some of the soluble phosphorus entered into combination with calcium to form insoluble phosphate compounds. Barrett (1953) noted that the disappearance of added phosphorus from epilimnial waters was related to alkalinity. He found that in alkalitrophic waters (excess calcium) in which sediments were low in organic matter and high in marl, as in Hoffman Lake, the phosphorus became fixed in insoluble precipitates. It is believed that some of these precipitates remained in suspension in Hoffman Lake due to the turbulance of the water caused by wave action and underwater currents. This may explain why total phosphorus analyses showed a more gradual reduction during the remainder of the study period.

Sulfate. There was little variation in the concentration of sulfates throughout the summer, except for a noticeable rise three days after the first application of fertilizer. There was just a slight increase three days after the second application. The values obtained for sulfates (Table 7) are in general agreement with those obtained for waters of similar chemical characteristics (Coker, 1954).

Table 7 shows not only slight variation in sulfate values from June 21 to August 26, but also slight variation among the three chemical sampling stations. For this reason, the mean value for each sampling date was plotted and presented as a line graph (Fig. VII).

The distribution of sulfates in natural waters varies considerably. Data obtained from sulfate determinations are presented here to show the concentration of sulfates in Hoffman Lake during the study period.

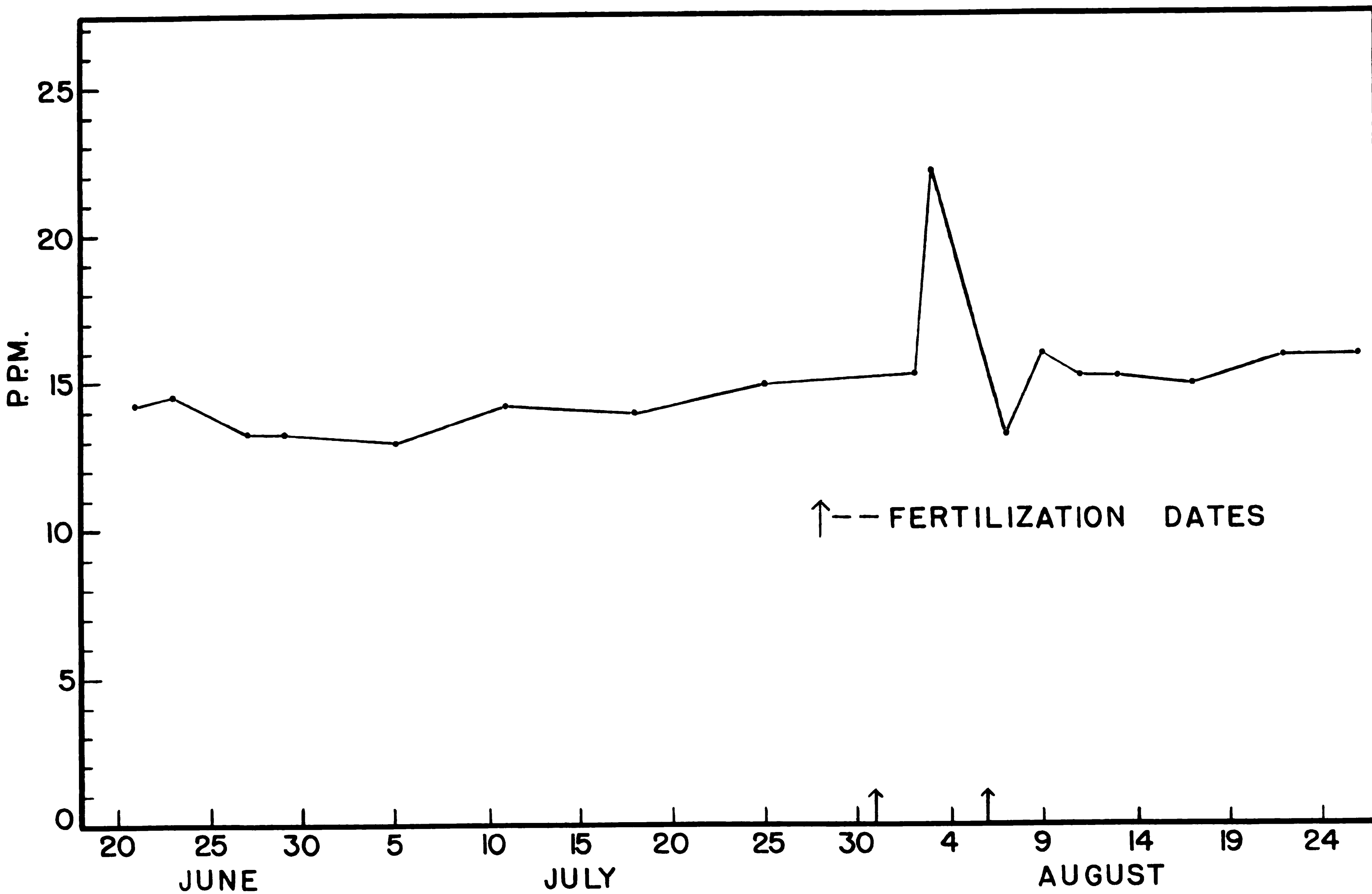
The value of sulfate determinations lies not only as a means for following the dispersal of the fertilizer of which sulfate was one constituent, but also gives an indication of the productivity of the lake. Moyle (1949) found a relationship of sulfate salts to the distribution and survival of larger aquatic plants. Working on Minnesota lakes, he found a paucity of aquatic vegetation in waters having a sulfate-ion concentration below 50.0 p.p.m.

Table 7. Concentration of Sulfates in P.P.M. at Stations A, B and C, Hoffman Lake, 1955

Date	Station A	Station B	Station C
June			
21	15	14	14
23	14	15	15
27	13	14	13
29	13	13	14
July			
5	13	13	13
11	14	15	14
18	13	15	14
25	16	15	14
31*	..	..	..
August			
2	15	15	16
3	26	23	18
6*	..	..	..
7	13	14	13
9	15	16	17
11	15	16	17
13	16	15	15
17	15	16	14
22	16	16	16
26	16	16	16

* Fertilization dates

Figure VII. Mean Concentrations of Sulfates from Stations A, B and C, Hoffman Lake, 1955


P.P.M.
25
20
15
10
5
0
↑-- FERTILIZATION DATES
20
25
30
5
10
15
20
25
30
4
9
14
19
24
JUNE
JULY
AUGUST

BIOLOGICAL

Plankton. It was previously stated that the initial effect of each application of fertilizer to Hoffman Lake was to increase the turbidity of the water. The turbid condition had the characteristics of a plankton bloom. Microscopic examinations of water samples failed to reveal, however, that such a bloom had taken place. To make certain that this was true, samples were selected which coincided with low and high turbidity, photometer and secchi disk readings, i.e., plankton samples which were taken before, during and following fertilization. After failing to find any changes in the number of planktonic organisms, it became evident that the increase in turbidity was due to other causes. Naumann (1932), referred to by Barrett (1953), believed that low phytoplankton production in marl lakes was due to phosphorus deficiency caused by the immobilization of this element by excessive quantities of calcium.

In an effort to determine the nature of the flocculent material in the plankton samples and to see whether there was an increase in organic material following fertilization, it became necessary to treat the samples by chemical means. This was done by analyzing the flocculent material in selected plankton samples for total suspended solids, volatile fraction, carbonate fraction and the organic fraction. Results of the preceding determinations substantiated the findings of Alexander (1956) who made similar determinations the previous year.

There was an increase in the total suspended solids following each application of fertilizer. After igniting in a muffle furnace, the volatile fraction or ash-free dry weight showed a direct relationship in p.p.m. to the total suspended solids (Fig. VIII). The volatile fraction represents that portion of the total suspended solids consisting of carbonates and organic matter. The loss in weight is due to the release of carbon dioxide on heating.

In order to determine what portion of the volatile fraction was due to organic matter, an aliquot of the same plankton sample was treated with hydrochloric acid to dissolve acid soluble material. A total suspended solids determination on this acid treated sample gave the p.p.m. of organic matter plus inorganic material. The volatile fraction of this portion of the sample gave an estimate in p.p.m. of organic matter (Fig. VIII). The actual values obtained from the preceding determinations are tabulated in Table 8.

It must be realized that the preceding gives only a rough estimate of the organic matter present. Plankton samples were centrifuged and concentrated from three liters to 50 ml. and some loss could easily have occurred. This method does, however, give an indication of the relative concentration of organic matter present and the final results show that fertilization had little or no effect on organic production in the surface waters of Hoffman Lake.

Figure VIII. Total and Acid Insoluble Suspended Solids and their Volatile Fraction in P.P.M.

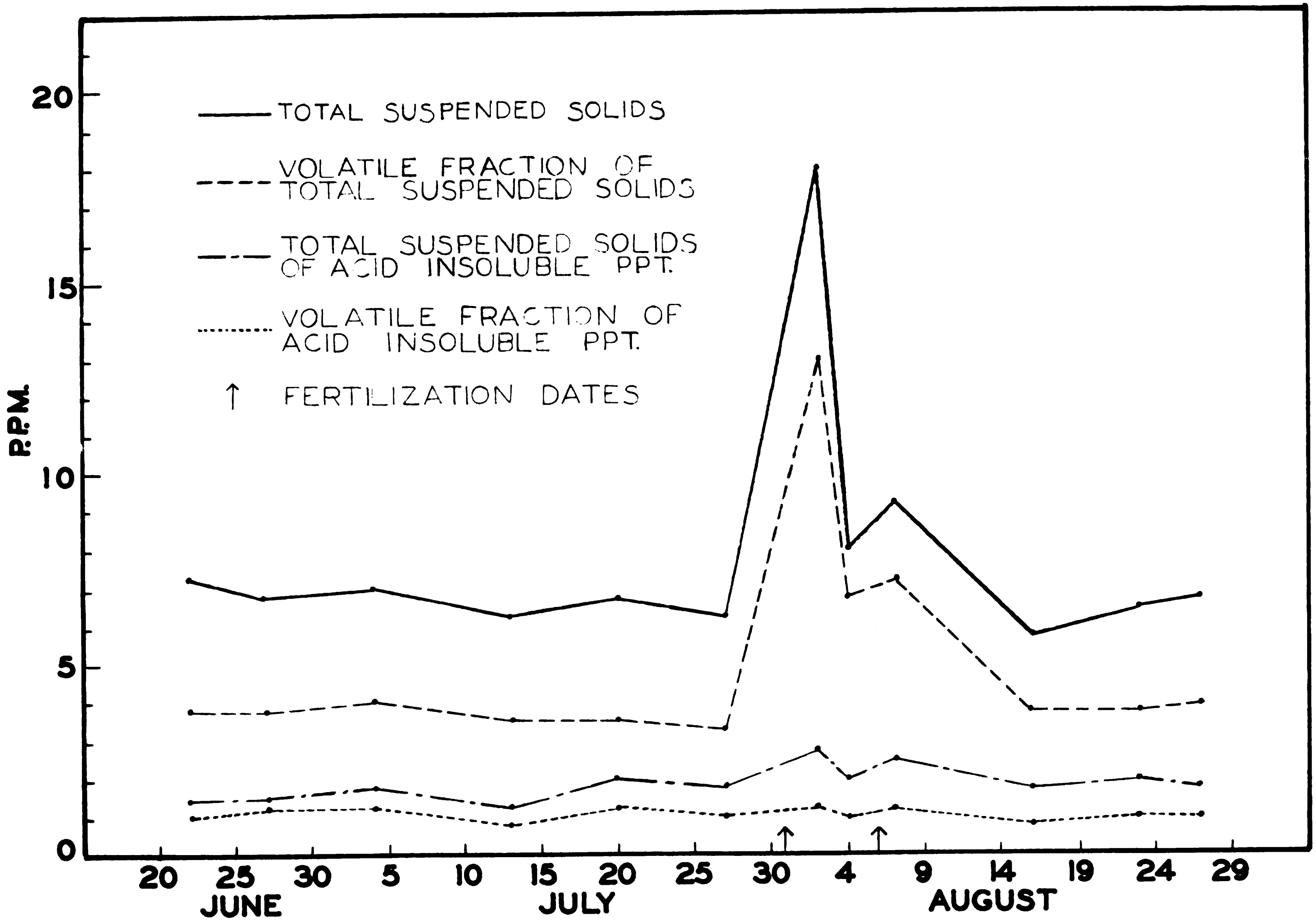

TOTAL SUSPENDED SOLIDS
VOLATILE FRACTION OF TOTAL SUSPENDED SOLIDS
TOTAL SUSPENDED SOLIDS OF ACID INSOLUBLE PPT.
VOLATILE FRACTION OF ACID INSOLUBLE PPT.
FERTILIZATION DATES
P.P.M.
0
5
10
15
20
20 25 30 5 10 15 20 25 30 4 9 14 19 24 29
JUNE
JULY
AUGUST

Table 8. Total and Acid Insoluble Suspended Solids, their Volatile Fraction, and the Carbonate Fraction (P. P. M.)

Date	Total Suspended Solids	(X) Volatile Fraction	Acid Insoluble Suspended Solids	(Y) Volatile Fraction	Carbonate Fraction**
June					
22	7.25	3.75	1.50	1.00	2.75
27	6.75	3.75	1.50	1.25	2.50
July					
4	7.00	4.00	1.75	1.25	2.75
13	6.25	3.50	1.25	0.75	2.75
20	6.75	3.50	2.00	1.25	2.25
27	6.25	3.25	1.75	1.00	2.25
31*	....	....	....	....	....
August					
2	18.00	13.00	2.75	1.25	11.75
4	8.00	6.75	2.00	1.00	5.75
6*	....	....	....	....	....
7	9.25	7.25	2.50	1.25	6.00
16	5.75	3.75	1.75	0.75	3.00
23	6.50	3.75	2.00	1.00	2.75
27	6.75	4.00	1.75	1.00	3.00

* Fertilization dates
** Differences between values in columns (X) and (Y)

The question which now presents itself is: What caused the increase in turbidity of the water following fertilization? The answer to this question involves a knowledge of the chemistry of Hoffman Lake and the chemical nutrients which were added to it.

Barrett (1953) found that the rate of disappearance of added phosphorus from epilimnial waters was related to alkalinity. He referred to waters as being alkalitrophic if these had an excess of calcium and M. O. alkalinity between 120 and 160 p.p.m. Barrett postulated that in waters low in organic matter and high in marl, i.e., Hoffman Lake, the phosphorus entered into combination with calcium ions to form insoluble precipitates.

This writer believes that Hoffman Lake may be regarded as lying above the lower limit of alkalitrophy. The fertilizer which was added to the lake contained a high concentration of phosphorus; this element, in the presence of excess calcium ions in the lake (which was deficient in organic matter) combined with the calcium to precipitate as an insoluble "floc". This belief is supported by the findings of Schloesing (1900) and Gessner (1939), referred to by Barrett (1953), who demonstrated in laboratory experiments the precipitation of phosphorus in solutions containing an excess of calcium and believed the precipitate to be tricalcium phosphate. Benne, Perkins and King (1936), working with farm soils, found a maximum precipitation of phosphorus in the presence of calcium ions at a pH value of 7.5 and over.

The phosphorus results lend support to the preceding explanations. Following the addition of fertilizer, the soluble phosphorus first increased and then rapidly decreased to approach pre-fertilization values. This suggests that the phosphorus and calcium ions combined to form a flocculent compound resulting in an increase in turbidity. The total phosphorus, however, decreased more gradually since this determination included that of the original soluble form which combined with the calcium.

Periphyton. There was an increase in the production of periphyton following the addition of fertilizer to Hoffman Lake. This increase was observed both visually and by quantitative measurements. It was assumed that the increase was a direct result of the added nutrients contained in the fertilizer since rapid growth of periphyton was noted three days after the first application.

Prior to fertilization, filamentous algae were extremely scarce and were observed only in widely scattered patches on the shoal areas. Within a few days following the first application, long strands had developed on a variety of submerged objects and were especially conspicuous in the vicinity of the outlet. This may indicate that some of the nutrient material had been carried down the West Branch of the Sturgeon River.

In terms of mean "Harvey units", the development of chlorophyll within the periphyton complex showed a twofold and threefold increase on the shingles and bricks, respectively, following fertilization. To see whether these differences were significant, an analysis of variance determination was made to test the null hypothesis that fertilization had no effect on the production of chlorophyll. Due to losses, 12 pairs of shingles and 4 pairs of bricks were used for making the final analyses. Table 9 shows the results obtained from the analyses of variance determinations for both shingles and bricks.

Table 9. Analysis of Variance to determine whether Significant Differences in the Concentration of Chlorophyll existed Between and Among Pairs of Shingles and Bricks

Source of Variability	Degrees of Freedom	Sum of Squares	Mean Square	"F" Ratio
		Shingles		
Total	23	2229.5		
Between pairs	1	376.1	376.1	5.9*
Among pairs	11	1156.0	105.1	1.7
Error	11	697.4	63.4	
		Bricks		
Total	7	708.7		
Between pairs	1	586.5	586.5	27.2*
Among pairs	3	57.3	19.1	0.9
Error	3	64.8	21.6	

* Difference significant

The final analyses show that there were significant statistical differences between pairs of shingles and bricks. This means that there was an increase in the amount of measureable chlorophyll pigments following fertilization and thus lends support to the theory that the addition of fertilizer increased the production of periphyton in Hoffman Lake. The analyses also show that there was no evidence of differences among pairs of shingles and bricks which indicates a uniform increase in periphyton following fertilization.

Gumtow (1955) found that an increase in periphyton may be correlated with maximum water temperatures and low turbidity. The fact that water temperatures in Hoffman Lake remained nearly constant during each 30 day period during which time periphyton was sampled eliminated this factor as being responsible for the increase in periphyton following fertilization. The effects of turbidity must be disregarded since increases in periphyton were noted at a time when turbidity increased due to fertilization; actually, the increase in turbidity was probably negligible in reducing radiant energy in the shallow water at station C.

These findings may be interpreted as being further evidence that the increase in periphyton was the direct result of fertilization. Just what constituents in the fertilizer were responsible for the increase is not known.

Bottom organisms. In contrast to other non-marl, warm-water lakes, the bottom fauna in Hoffman Lake consisted of relatively few species which were present in limited numbers. Two species of burrowing mayflies, (*Ephemera simulans* and *Hexagenia limbata*) belonging to the family Ephemeridae, showed up most frequently in the samples. The combined number of these two species collected at stations 1 and 2 comprised 93 percent of the total (Fig. IX). Midge larvae (Tendipedidae) were next in order of abundance while the remainder consisted of dragonfly nymphs, alderfly larvae and one biting midge larva. The quantitative and qualitative results from Ekman dredge samples during the summer of 1955 are tabulated in Table 10. The results show that benthic animals are more numerous in the shallower waters at station 2 (3 feet) as compared to the deeper water at station 1 (5 feet).

It can be seen from the graph (Fig. IX) that of the two sampling stations, *H. limbata* mayflies were almost entirely restricted to the deeper water at station 1. Lyman (1943) noted that lake dwelling species of *Hexagenia* nymphs are inhabitors of soft substrates and are limited to the deeper-water areas in which wave action is minimized. It was not known whether the substrates at stations 1 and 2 differed but environmental conditions at station 1 seemed more favorable to *H. limbata* nymphs. The substrate at station 2 was under the influence of considerable wave action which favored the distribution of *E. simulans* (Burks, 1953).

Volumetric determinations were made for each Ekman

Table IX. The Percentage Composition of Bottom Organisms at Stations 1 and 2, Hoffman Lake, 1955

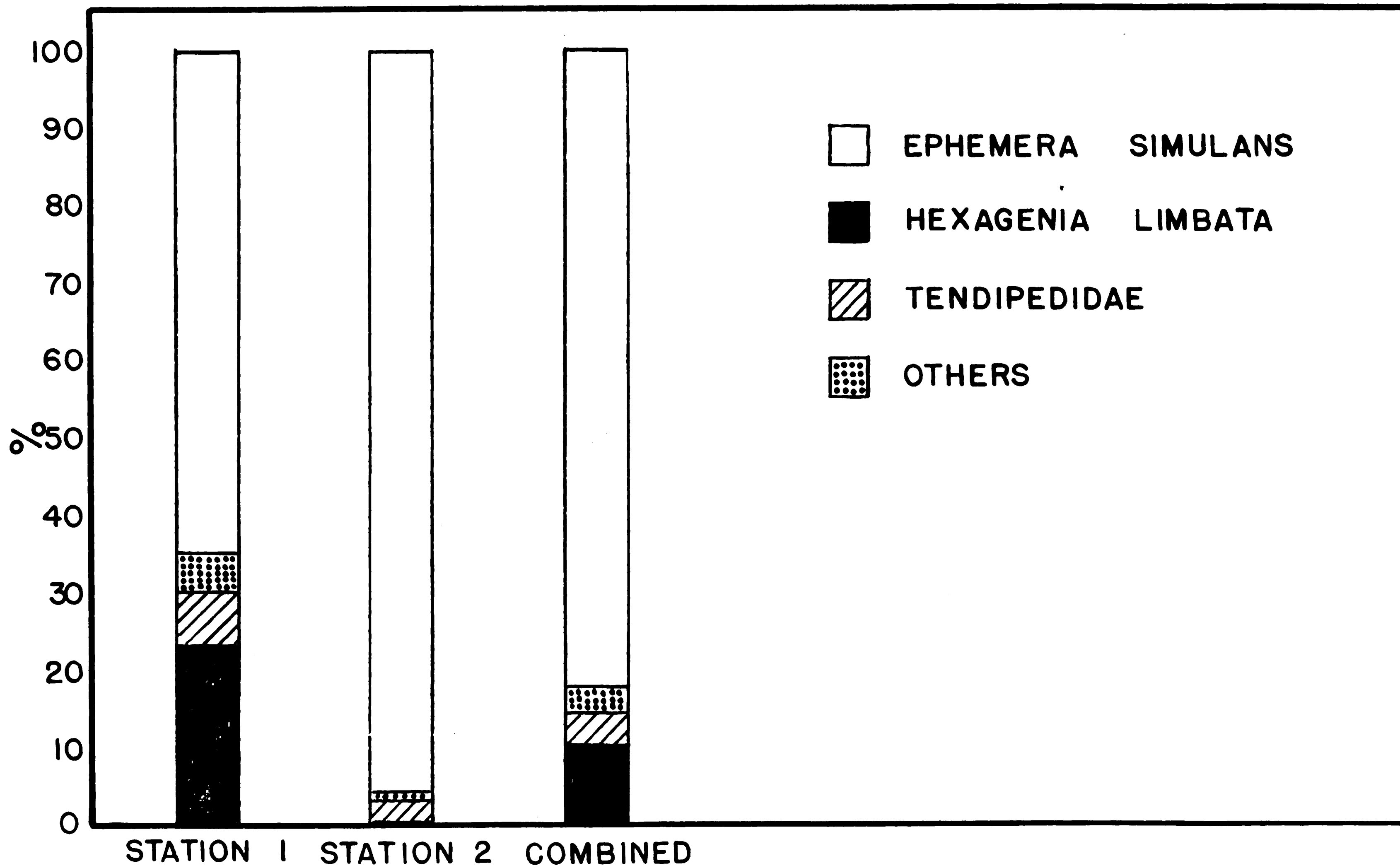

100
90
80
70
60
%50
40
30
20
10
0
STATION 1
STATION 2
COMBINED
EPHEMERA SIMULANS
HEXAGENIA LIMBATA
TENDIPEDIDAE
OTHERS

Table 10. **Quantitative and Qualitative Results from Ekman Dredge Samples**

	June 24	July 1	8	15	22	29	August 5	12	19	26	Total
Station 1											
No. of Samples	10	10	10	10	10	10	10	10	10	10	100
E. simulans	8	16	29	4	51	74	85	114	77	41	498
H. limbata	9	10	3	14	3	32	18	23	33	34	179
Tendipedidae	13	..	4	2	7	14	5	2	4	2	53
Gomphus sp.	..	2	1	1	2	..	1	..	1	..	8
Sialis sp.	..	1	..	2	1	3	4	3	2	5	21
Macromia sp.	..	..	2	2	2	3	3	2	..	2	12
Heleidae	..	..	..	..	..	1	..	..	..	..	1
Total	30	29	39	22	64	127	116	144	117	84	772
Station 2											
No. of Samples	10	10	10	10	10	10	10	10	10	10	100
E. simulans	36	39	48	43	23	152	172	177	147	136	973
H. limbata	..	..	..	..	..	1	..	2	..	..	3
Tendipedidae	1	1	1	2	2	6	5	3	4	1	26
Gomphus sp.	..	..	..	..	..	3	1	1	..	2	7
Sialis sp.	..	1	..	1	..	..	1	..	2	..	5
Macromia sp.	..	..	..	..	1	1	..	..	..	1	3
Heleidae	..	..	..	..	..	..	..	..	..	..	0
Total	37	41	49	46	26	163	179	183	153	140	1017*

*Total No. of Organisms: 1789

dredge sample and recorded to the nearest five-hundredth of a milliliter (Table 11). In some of the samples, organisms were so few in numbers that their volumes were not measurable. For this reason, the combined total number and volume collected at stations 1 and 2 was utilized to determine the number and volume per square foot of area sampled (Table 12).

The data presented in the preceding table indicates that the emergence of mayfly nymphs had occurred prior to July 15. The evidence for this reasoning is indicated by a drop in volume and a corresponding drop in numbers between July 8 and July 15. As the numbers began to increase between July 15 and July 22, the volume continued to decrease which suggests that newly hatched nymphs began to appear. The fact that these newly hatched nymphs contributed little to the volume explains why an increase in number did not show a corresponding increase in volume. According to Hunt (1951), burrowing mayfly eggs will hatch in 11 to 14 days at temperatures ranging from 75° to 95° Fahrenheit, following egg fertilization. Since the water temperature in Hoffman Lake fell within this range, the first emergence date was estimated to be around July 4. Figure X is presented to give a clearer picture of the weekly variations in number and volume per square foot.

A knowledge of the approximate emergence date is necessary in order to distinguish between the two yearly generations and to determine the instantaneous rates of growth and

Table 11. Volumetric Results, in Milliliters, of Bottom Organisms Per Ekman Dredge Sample During 1955

Sample Number	June 24	July 1	July 8	July 15	July 22	July 29	August 5	August 12	August 19	August 26
					Station 1					
1	0.00	0.05	0.00	0.05	0.15	0.05	0.10	0.25	0.25	0.10
2	0.05	0.10	0.20	0.00	0.10	0.10	0.05	0.20	0.20	0.10
3	0.05	0.10	0.10	0.10	0.10	0.05	0.15	0.20	0.35	0.10
4	0.05	0.10	0.10	0.20	0.05	0.15	0.20	0.15	0.20	0.20
5	0.00	0.30	0.10	0.00	0.00	0.05	0.05	0.40	0.10	0.40
6	0.00	0.05	0.10	0.10	0.00	0.10	0.20	0.20	0.10	0.10
7	0.00	0.00	0.20	0.15	0.05	0.10	0.10	0.20	0.20	0.20
8	0.00	0.00	0.05	0.00	0.10	0.05	0.05	0.15	0.30	0.35
9	0.00	0.30	0.10	0.00	0.10	0.10	0.15	0.20	0.20	0.15
10	0.10	0.05	0.10	0.00	0.15	0.10	0.05	0.15	0.30	0.35
Total	0.25	1.05	1.05	0.60	0.80	0.85	1.10	2.10	2.20	2.05
Sample Number					Station 2					
1	0.10	0.10	0.10	0.20	0.10	0.35	0.15	0.40	0.20	0.30
2	0.10	0.10	0.05	0.10	0.00	0.25	0.15	0.20	0.30	0.30
3	0.10	0.15	0.10	0.15	0.00	0.20	0.20	0.30	0.30	0.30
4	0.20	0.10	0.20	0.20	0.05	0.20	0.25	0.30	0.30	0.35
5	0.10	0.15	0.10	0.20	0.10	0.20	0.30	0.30	0.30	0.20
6	0.10	0.00	0.20	0.25	0.05	0.10	0.20	0.30	0.20	0.30
7	0.05	0.00	0.10	0.10	0.05	0.10	0.15	0.10	0.20	0.20
8	0.10	0.00	0.25	0.10	0.10	0.10	0.20	0.20	0.20	0.20
9	0.10	0.20	0.05	0.00	0.05	0.10	0.15	0.20	0.20	0.30
10	0.00	0.05	0.10	0.00	0.05	0.10	0.10	0.30	0.40	0.20
Total	0.95	0.85	1.25	1.30	0.55	1.70	1.85	2.60	2.60	2.65

mortality for a given species. To determine the natural instantaneous rates of growth and mortality with any degree

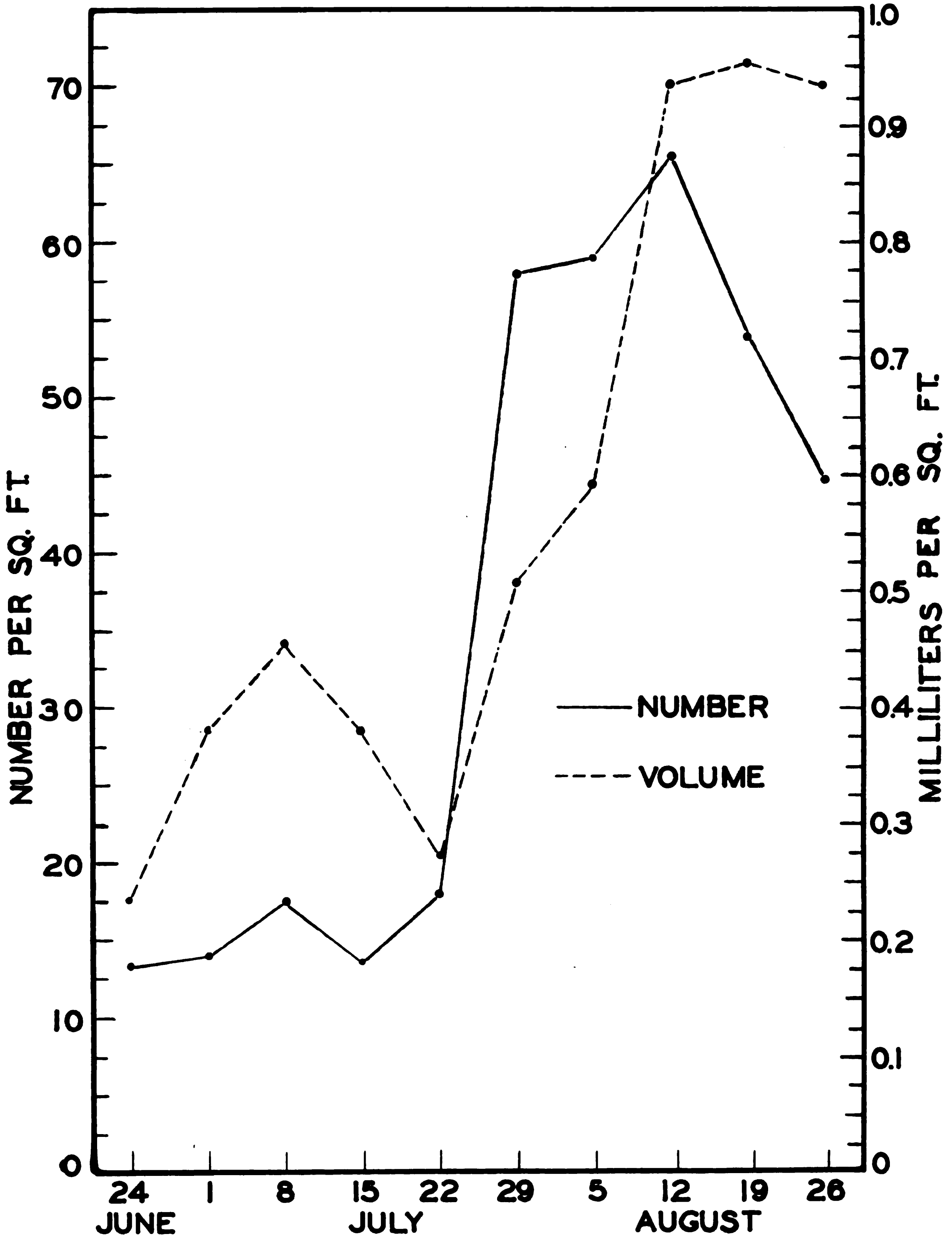
Table 12. Total Number and Volume of Bottom Organisms from Stations 1 and 2

Date	Total Number of Organisms	Number per Square Foot	Total Volume of Organisms (ml.)	Volume (ml. per Square Foot)
June				
24	67	13.4	1.20	0.24
July				
1	70	14.0	1.90	0.38
8	88	17.6	2.30	0.46
15	68	13.6	1.90	0.38
22	90	18.0	1.35	0.27
29	290	58.0	2.55	0.51
August				
5	295	59.0	2.95	0.59
12	327	65.4	4.70	0.94
19	270	54.0	4.80	0.96
26	224	44.8	4.70	0.95
Total	1789	35.8*	28.35	0.57*

* Average

of accuracy, it is necessary that predation on that species be at a minimum. Leonard (1947) pointed out that the comparatively deep burrowing activities of *Ephemera simulans* nymphs to a large degree prevented this species from falling prey to predation. For this reason, and also because of the fact that *E. simulans* nymphs made up over 80 percent of the total number of bottom organisms sampled, yearly life cycles

Figure X. Weekly Variations in Number and Volume of Bottom Organisms per Square Foot at Stations 1 and 2, Hoffman Lake, 1955



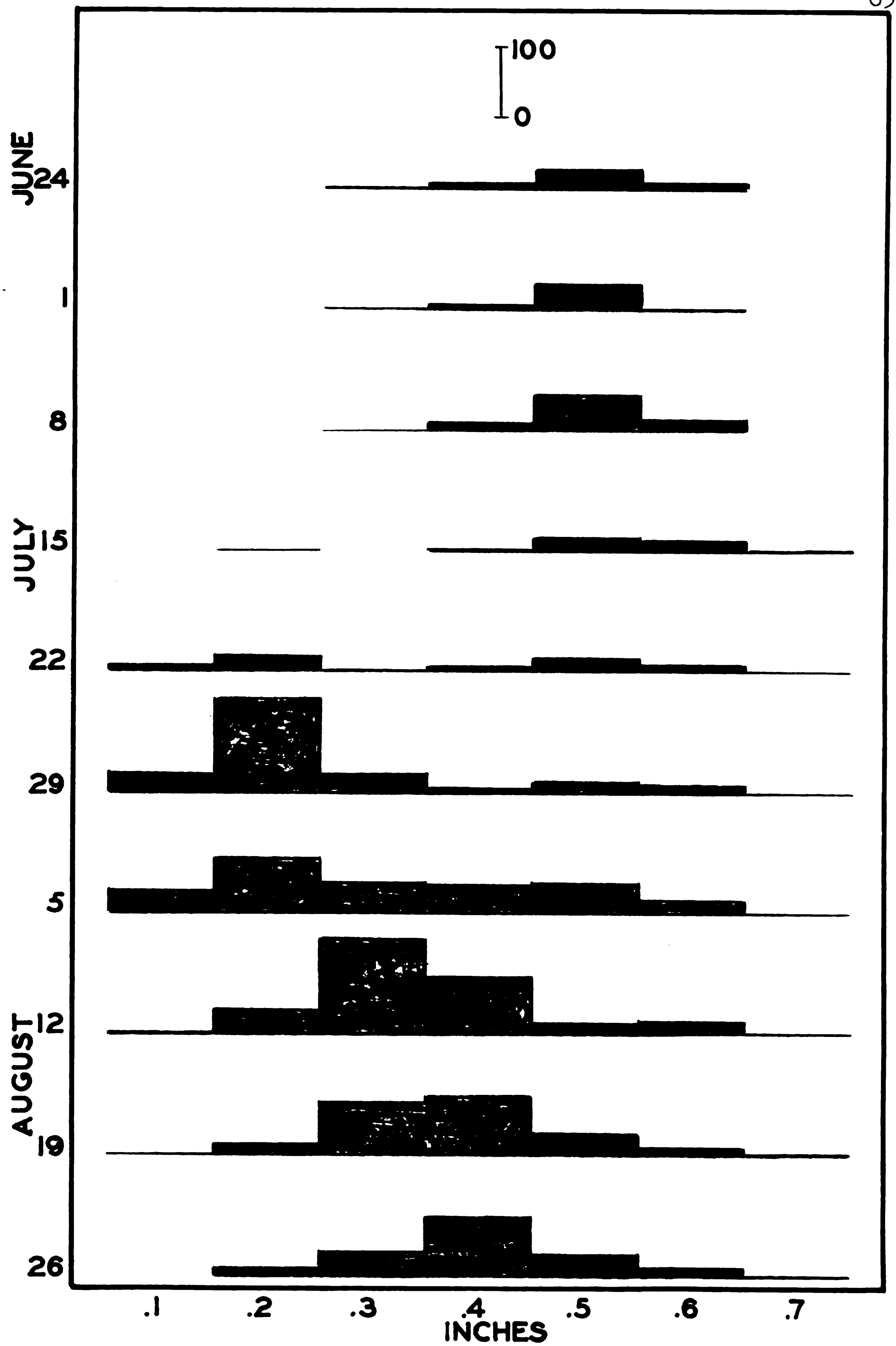
NUMBER PER SQ. FT.
MILLILITERS PER SQ. FT.
0
10
20
30
40
50
60
70
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
NUMBER
VOLUME
24
1
8
15
22
29
5
12
19
26
JUNE
JULY
AUGUST

(generations) and the instantaneous rates of growth and mortality were determined for this species.

Two generations of E. simulans were observed during the summer of 1955. All those sampled prior to July 15 belonged to the 1954-55 generation. The first appearance of the 1955-56 generation was noted on July 15. Since E. simulans has an annual life cycle (Leonard, op. cit.), it was estimated that the emergence period continued until August 12 and nymphs which appeared after that date represented the 1955-56 generation. Figure XI, which shows the weekly size distribution of E. simulans nymphs in the form of histograms, was the basis for determining the occurrence of the two generations. Instantaneous rates of growth and mortality were determined from weekly size and frequency distributions (Fig. XI and Table 13).

For the 1954-55 generation, the instantaneous rate of mortality was -0.174 per week. This value represents the natural logarithm of the ratio of the number of E. simulans present at a particular time to those present a week previously (Fig. XII). The natural logarithm of the mean length for one week to the mean length observed the previous week gave the linear instantaneous rate of growth per week. This growth rate was determined from mean lengths plotted on semi-logarithm paper (Fig. XII) and had a value of +0.039. Multiplying this value by 3 (cube law relationship between length and weight) gives +0.117, which constitutes the

Figure XI. Histograms showing Weekly Size (Length) Distributions of *Ephemera simulans* Nymphs in Tenths of an Inch


100
0
JUNE
24
1
8
JULY
15
22
29
5
AUGUST
12
19
26
.1
.2
.3
.4
.5
.6
.7
INCHES

gravimetric instantaneous growth rate per week for the 1954-55 generation.

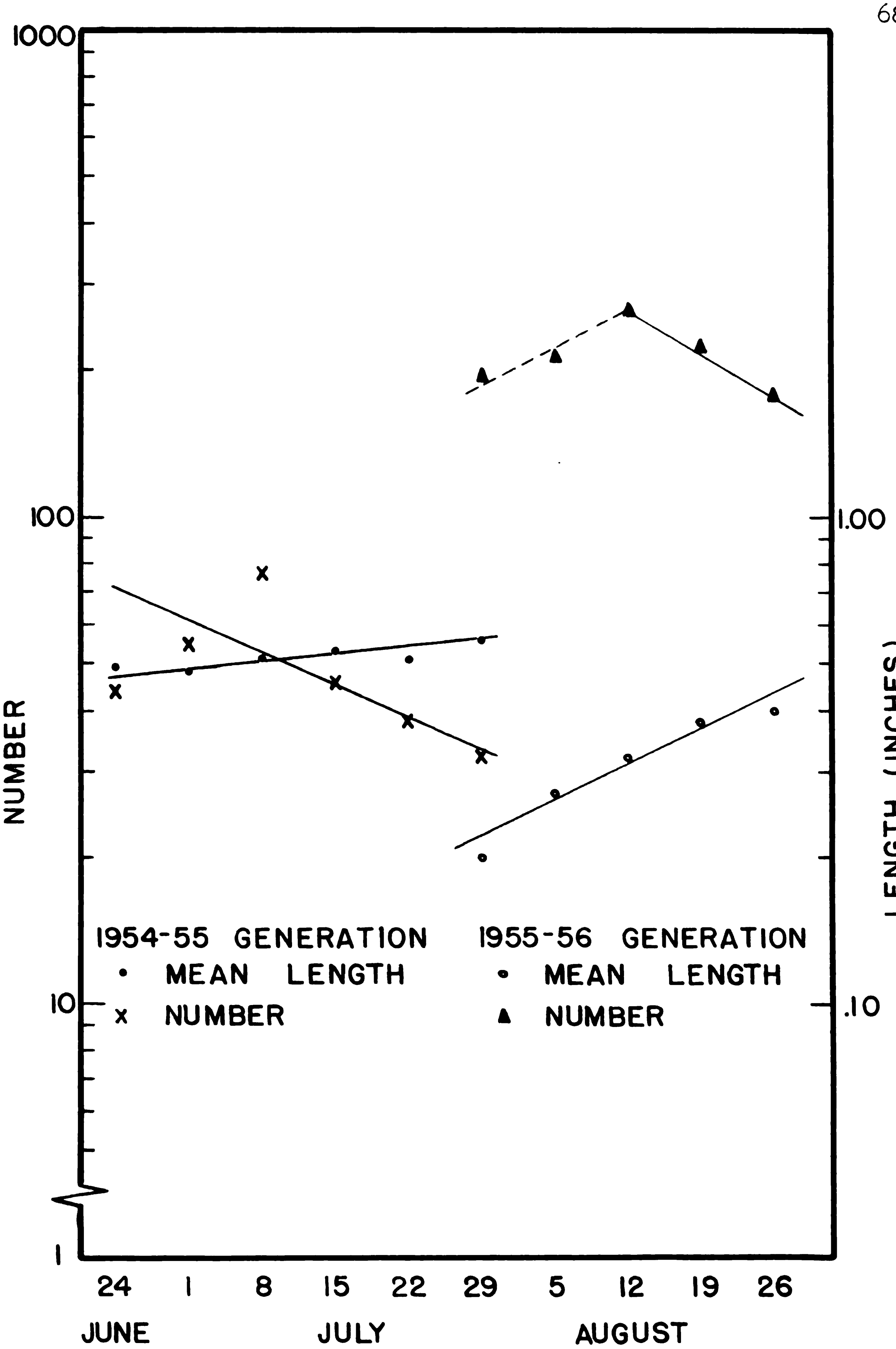
Similar procedures were followed for obtaining instantaneous rates of mortality and growth for the 1955-56 generation. These were -0.189 and +0.495 per week, respectively; the latter figure being the gravimetric growth rate. The rate

Table 13. The Number and Mean Length of *Ephemera simulans* Nymphs used for determining Instantaneous Rates of Mortality and Growth

Date	1954-55 Generation		1955-56 Generation	
	Number	Mean length (inches)	Number	Mean length (inches)
June				
24	44	0.49	...	....
July				
1	55	0.48	...	....
8	77	0.51	...	....
15	46	0.53	...	....
22	38	0.51	...	....
29	32	0.56	193	0.20
August				
5	..	....	216	0.27
12	..	....	268	0.32
19	..	....	224	0.38
26	..	....	178	0.40

of mortality was determined from the descending right limb of the catch curve (Fig. XII). The dotted line represents the ascending left limb which is a typical characteristic of

Figure XII. The Number and Mean Length for two Generations of *Ephemera simulans*, Hoffman Lake, 1955



1000
100
10
1
1.00
.10
NUMBER
LENGTH (INCHES)
1954-55 GENERATION
• MEAN LENGTH
x NUMBER
1955-56 GENERATION
∘ MEAN LENGTH
▲ NUMBER
24
1
8
15
22
29
5
12
19
26
JUNE
JULY
AUGUST

a catch curve. It indicates the escapement of extremely small individuals, probably during the screening process. The frequency distribution for each size class of _E. simulans_ nymphs and the weekly totals are shown in Table 14.

Table 14. Frequency Distribution for each Size Class of _E. simulans_ nymphs, Hoffman Lake, 1955

	Tenths of an inch							
Date	0.1	0.2	0.3	0.4	0.5	0.6	0.7	Total
June								
24	...	...	2	6	28	8	...	44
July								
1	...	...	3	9	37	6	...	55
8	...	...	1	10	50	16	...	77
15	...	1	...	5	20	18	3	47
22	9	24	3	8	19	10	1	74
29	28	134	27	4	16	15	1	225
August								
5	30	79	45	41	43	19	1	258
12	2	36	134	82	14	19	4	291
19	1	15	77	85	31	12	3	224
26	...	12	35	84	32	13	2	178

Instantaneous rates of mortality and growth gave rough estimates since it was necessary to arbitrarily select the dividing line between the two generations. This was done by comparing the frequency of the weekly size distributions, as shown by the histograms in Figure XI and the actual numbers recorded in Table 14. For example, on July 15, all but one out of a total of 47 specimens were placed in the 1954-

55 generation. The one exception measured 0.2 inches and the occurrence of this small size class undoubtedly represented the new (1955-56) generation. Using this procedure, the number and mean lengths for each generation were determined.

The use of instantaneous rates in the present study provides a means for noting what effects, if any, the addition of nutrients had on the growth of a particular species. To facilitate studies of instantaneous rates, the preceding determinations are grouped as follows:

	Generations	
	1954-55	1955-56
Gravimetric instantaneous rate of growth	+0.117	+0.495
Instantaneous rate of mortality	-0.174	-0.189

It can be seen that the rate of growth for the 1955-56 generation increased considerably over that of the 1954-55 generation. Since the 1955-56 generation was sampled after fertilization, it would seem that the addition of nutrients accelerated the growth rate. However, it is known that a faster growth rate is common for the young of most animals and for this reason the effects of the fertilizer added in 1955 was not known. In order to determine if fertilization had any effect on the growth rate, it was necessary to compare the growth rates of two identical generations, one of which had not been exposed to added nutrients. Identical here means generations which occur during a specific part of a season, such as E. simulans nymphs prior to emergence. Comparisons of two identical generations was possible since data was available from the previous year's study of instantaneous rates of growth.

Alexander (1956) determined instantaneous rates of growth from samples collected in 1954. The gravimetric instantaneous growth rate for the 1953-54 generation, as determined by Alexander, was +0.073 per week. This generation was sampled prior to any fertilization of Hoffman Lake. By comparing +0.073 to +0.117, it can be seen that the growth rate almost doubled the second year. The significance of this finding lies in the fact that the higher instantaneous growth rate was observed after Hoffman Lake was fertilized for the first time. It seems justifiable to conclude that the increase in the growth rate was due to fertilization since all other measured factors remained relatively constant.

An increase in the rate of growth was also indicated by the earlier emergence period of E. simulans during 1955. Newly hatched nymphs first appeared on July 15, whereas in 1954 they were first observed on August 6 (Alexander, 1956). These dates show that emergence had occurred 22 days earlier in 1955 as compared to 1954. If it is assumed that the one-year-effects of fertilization enhanced the growth rate of E. simulans nymphs from one year to the next, the earlier emergence in 1955 may have been due to the shorter period required to reach "emergence size". The mean size at emergence was essentially the same both years. The effects of water temperatures were disregarded because they were nearly the same both years.

If it is true that fertilization enhanced the growth rate of E. simulans nymphs, just what ingredients within the fertilizer initiated the increased growth rate are not known. The very low concentration of phosphorus in the surface waters and the immobilization of this element by calcium suggests that phosphorus was the limiting factor in Hoffman Lake. A knowledge of bottom muds as regards the exchange of phosphorus ions may explain to what extent this element is available for organic production. Hooper and Elliott (1953) suggest that a regeneration of phosphorus takes place at the surface of bottom muds and involves the action of bacteria. This is significant because it was thought that phosphorus added to Hoffman Lake was precipitated to the bottom by the action of calcium.

The fact that there was no plankton bloom in Hoffman Lake following fertilization does not necessarily mean that organic production did not increase. Meehean (1933) and Wiebe (1935) found that phytoplankton production was not absolutely essential to the food cycle in an aquatic environment. They found evidences which indicated that many microorganisms, such as bacteria and microcrustaceans, utilize phosphorus directly. These microorganisms are then fed on by zooplankton which in turn are fed on by bottom organisms and fingerling fish, completing the food cycle in the absence of phytoplankton organisms. These latter conclusions are only hypotheses which have yet to be proven, but they offer an explanation of how increased production could take place, as was indicated by instantaneous growth rate studies.

Fish. Four species of game and pan fish and one coarse species were sampled during the summer of 1955. The primary objectives were to study the growth attained by fish of the different age groups and also to gain some information of the length-weight relationship for each species. The effects of fertilization on growth and the length-weight relationship were sought on the basis of data compiled for two consecutive years (1954 and 1955) since not much information was expected during the short interval of time following the 1955 application. This enabled comparable studies to be made following one full year's effects of fertilization to Hoffman Lake. The initial application of fertilizer to the lake was made in 1954 (Alexander, 1956).

The five species of fish sampled were rock bass, largemouth bass, common sucker, common sunfish and yellow perch. No studies were made of the total number present for any of the species but it is believed that these population densities were below normal. Age determinations were made from scale samples. Each fish was measured for total length (inches) and weighed (grams) at time of capture. All fish were marked by removing the anal fin, then released. Mean lengths and weights of the five species of fish are shown in Tables 15, 17, 19, 21 and 23; instantaneous rates of growth for each species are shown in Tables 16, 18, 20, 22 and 24.

Instantaneous rates of growth were determined for the last complete year's growth for each species. The computations were as follows:

Instantaneous rate of growth (linear): $\ln \frac{L_2}{L_1}$

Instantaneous rate of growth (gravimetric): $\ln \frac{L_2}{L_1} \times n$

where,

ln = natural logarithm

L_2 = length of fish at last annulus

L_1 = length of fish at next to last annulus

n = a constant, derived as the exponent of the length-weight relationship, $W = cL^n$

Studies made for 76 rock bass revealed that growth was extremely slow. Rock bass which had entered their ninth growing season had a mean length and weight of 7.6 inches and 142.3 grams, respectively, as compared to the Michigan average of 9.9 inches and 312 grams (Beckman, 1949). The sizes attained by the different age groups and the annual increment growths of rock bass sampled during the summers of 1954 and 1955 are tabulated in Table 15 and the instantaneous

Table 15. Growth Attained by Rock Bass sampled from Hoffman Lake during 1954 and 1955

Age Group	Number of fish		Mean total size Length (inches)		Mean total size Weight (grams)		Increment growth Length (inches)		Increment growth Weight (grams)	
	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
I	8	10	2.1*	2.1*	4.2**	4.0++	2.1	2.1	4.2**	4.0++
II	8	10	3.0*	3.0*	10.8**	10.4++	0.9	0.9	6.6**	6.4++
III	8	10	3.9*	3.9*	21.8**	21.2++	0.9	0.9	11.0**	10.8++
IV	2	4	4.7	4.9	34.0	40.4	0.8	1.0	12.2	19.2
V	15	10	5.3	5.3	50.8	49.6	0.6	0.4	16.8	9.2
VI	32	16	5.7	5.9	60.7	64.2	0.4	0.6	9.9	14.6
VII	26	22	6.1	6.3	72.8	77.8	0.4	0.4	12.1	13.6
VIII	10	16	6.8	6.9	107.7	96.5	0.7	0.6	34.9	18.7
IX	10	8	7.7	7.6	125.9	142.3	0.6	0.8	18.2	45.8

* Back calculated from scales
** Calculated from $\ln W = -0.5341 + 2.6558 \ln L$
++ Calculated from $\ln W = -0.6367 + 2.7113 \ln L$

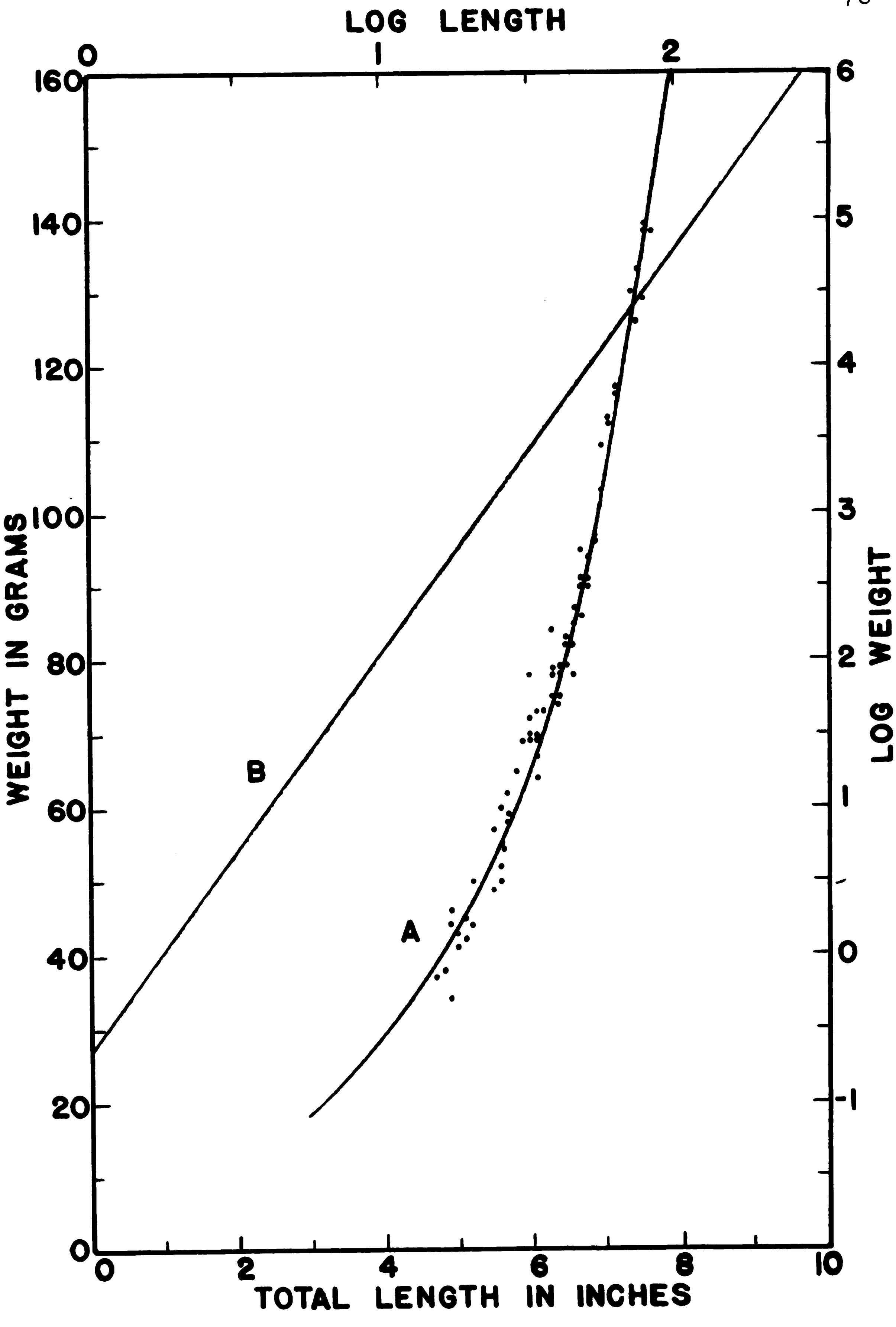
rates of growth in Table 16. There appears to be small but consistent increases in instantaneous growth rates the second year (1955). The computed length-weight relationship was $\ln W = -0.6367 + 2.7113 \ln L$ (ln = natural logarithm), the graphical representation of which appears in Figure XIII.

Table 16. Mean Instantaneous Rates of Growth for Rock Bass, 1954 and 1955

Age Group	Number of fish		Rate of growth (linear)		Rate of growth (gravimetric)			
	1954	1955	1954	1955	1954	± Standard deviation	1955	± Standard deviation
IV	2	4	0.29	0.36	0.78	0.120	0.91	0.109
V	15	10	0.21	0.25	0.56	0.132	0.66	0.176
VI	32	16	0.12	0.22	0.33	0.085	0.58	0.177
VII	26	22	0.10	0.16	0.27	0.066	0.43	0.133
VIII	10	16	0.09	0.12	0.24	0.077	0.28	0.107
IX	10	8	0.08	0.10	0.22	0.050	0.26	0.102
X	3	..	0.08	....	0.20	0.033	....	.....

Largemouth bass in Hoffman Lake were in excellent condition, as judged from age and growth studies. Comparable data compiled by Beckman (1949) and Carlander (1953) showed growth here to be slightly above the averages exhibited by these authors for each age group. A total of 53 bass were captured during the summer and scale samples disclosed that Age Groups II, III, IV and VI were represented. Lengths and weights which were attained by the various age groups and

Figure XIII. The Length-weight Relationship of the Rock Bass. Curve A represents Actual Values; Curve B represents the Log-log Transformation



LOG LENGTH
0
1
2
160
140
120
100
80
60
40
20
0
6
5
4
3
2
1
0
-1
WEIGHT IN GRAMS
LOG WEIGHT
B
A
0
2
4
6
8
10
TOTAL LENGTH IN INCHES

annual increment growths of bass captured during 1954 and 1955 are shown in Table 17. Instantaneous rates of growth are shown in Table 18. While the Age Group II fish seem to have grown faster the second year, the older fish show no evidence of increased growth rate. The computed length-weight relationship was $\ln W = -1.7215 + 3.1020 \ln L$ and is shown graphically in Figure XIV.

The common sucker showed the poorest growth of the five species sampled. Comparable weight data were not available for this species but fish of the different age groups were consistently shorter than those of identical age groups in tables compiled by Carlander (1953). Eighty-four suckers were captured during the study period and successful capture was obtained only by setting traps in the deepest depressions in the lake. It was not known to what extent suckers remained in these depressions although it is believed that they must have ventured to shallower areas at night in search of food.

Almost every sucker taken from Hoffman Lake had a head which was disproportionate to the rest of its body. Immediately posterior to the head region, there was an abrupt narrowness which extended backwards to the unusually slender peduncle. The outward appearance of these fish was indicative of the effects of undernourishment. This condition may have been the result of : 1. A scarce food supply, 2. An unavailable food supply, due to the hard, marl substrate, 3. Un-

Table 17. Growth Attained by Largemouth Bass sampled from Hoffman Lake during 1954 and 1955

Age Group	Number of fish		Mean total size Length (inches)		Mean total size Weight (grams)		Increment growth Length (inches)		Increment growth Weight (grams)	
	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
I	21	18	4.8*	4.9*	21.5**	14.0++	4.8	4.9	21.5**	14.0++
II	23	9	8.6	8.9	151.7	148.2	3.8	4.0	130.2**	134.2++
III	15	30	11.4	10.9	380.0	322.3	2.8	1.0	228.3	174.1
IV	7	2	13.7	12.5	672.5	453.5	2.3	1.6	292.5	131.2
V	8	..	14.6	....	830.8	.....	0.9	...	158.3	.....
VI	2	3	15.9	15.3	1064.0	898.6	1.3	...	233.2	.....

* Back calculated from scales
** Calculated from $\ln W = -2.0813 + 3.2765 \ln L$
++ Calculated from $\ln W = -1.7215 + 3.1020 \ln L$

favorable environmental conditions, such as an extremely long winter and 4. A combination of these factors.

Table 18. Mean Instantaneous Rates of Growth for Largemouth Bass, 1954 and 1955

Age Group	Number of fish		Rate of growth (linear)		Rate of growth (gravimetric)			
	1954	1955	1954	1955	1954	± Standard deviation	1955	± Standard deviation
II	23	9	0.74	1.08	2.41	0.469	3.36	0.432
III	15	30	0.40	0.37	1.32	0.190	1.22	0.384
IV	7	2	0.20	0.19	0.65	0.076	0.56	0.106
V	8	..	0.17	....	0.56	0.125	....	.....
VI	2	3	0.15	0.13	0.48	0.017	0.40	0.336
VII	1	..	0.10	....	0.33	.....	....	.....
VIII	1	..	0.08	....	0.26	.....	....	.....

Table 19 shows the lengths and weights and annual increments for each age group of suckers from Hoffman Lake captured in 1954 and 1955. The data show a peculiar situation in that fish of the same age in the younger, 1955 age groups were lighter, wheras fish of the same age in the older age groups were heavier than those sampled in 1954. The instantaneous rates of growth (Table 20) show an increased rate of growth for all ages of suckers sampled in 1955 as compared to those of 1954. These increased rates of growth are especially evident in the younger age groups.

The computed length-weight relationship for suckers

Figure XIV. The Length-weight Relationship of the Largemouth Bass. Curve A represents Actual Values; Curve B represents the Log-log Transformation

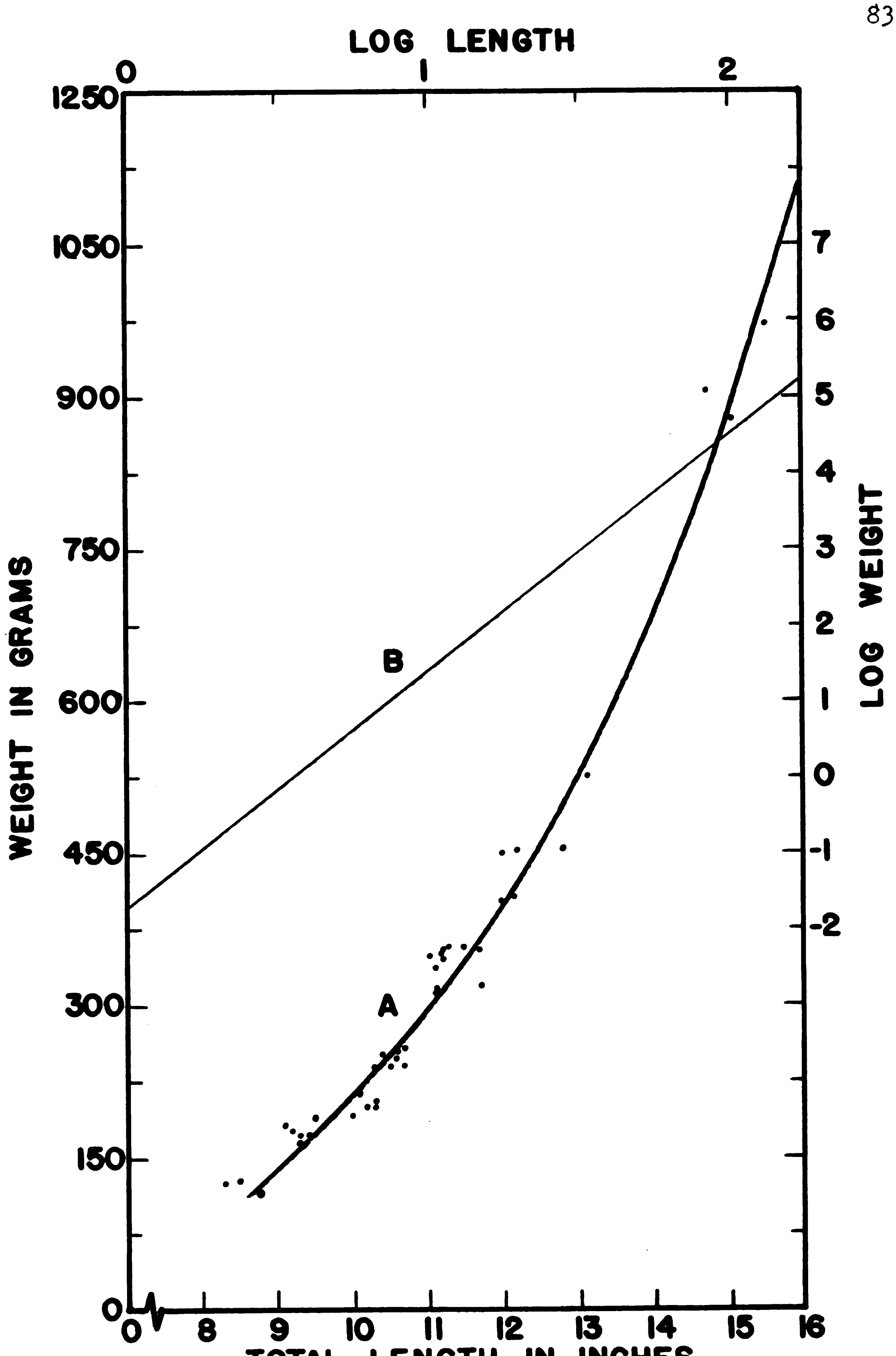

LOG LENGTH
0
1
2
1250
1050
900
750
600
450
300
150
0
WEIGHT IN GRAMS
7
6
5
4
3
2
1
0
-1
-2
LOG WEIGHT
B
A
0
8
9
10
11
12
13
14
15
16
TOTAL LENGTH IN INCHES

Table 19. Growth Attained by Common Suckers sampled from Hoffman Lake during 1954 and 1955

Age Group	Number of fish		Mean total size Length (inches)		Mean total size Weight (grams)		Increment growth Length (inches)		Increment growth Weight (grams)	
	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
I	18	10	4.8*	4.9*	27.0**	19.0++	4.8	4.9	27.0**	19.0++
II	18	10	7.8*	7.9*	86.0**	76.1++	3.0	3.0	59.9**	57.1++
III	7	21	9.9	10.1	175.7	187.8	2.1	2.2	89.7**	111.7++
IV	13	25	11.0	11.4	199.7	225.3	1.1	1.3	24.0	37.5
V	38	21	11.8	12.6	250.8	295.5	0.8	1.2	51.1	70.2
VI	8	11	12.7	13.6	307.0	372.3	0.9	1.0	56.2	76.8
VII	4	5	13.5	14.5	334.0	412.8	0.8	0.9	27.0	40.5

* Back calculated from scales
** Calculated from $\ln W = -0.4388 + 2.3852 \ln L$
++ Calculated from $\ln W = -1.6995 + 2.9183 \ln L$

sampled in 1955 was $\ln W = -1.6995 + 2.9183 \ln L$ and is shown graphically in Figure XV.

Table 20. Mean Instantaneous Rates of Growth for Common Suckers, 1954 and 1955

Age Group	Number of fish		Rate of growth (linear)		Rate of growth (gravimetric)			
	1954	1955	1954	1955	1954	± Standard deviation	1955	± Standard deviation
III	7	21	0.34	0.43	0.81	0.167	1.23	0.323
IV	13	25	0.20	0.26	0.47	0.115	0.74	0.127
V	38	21	0.16	0.18	0.38	0.069	0.52	0.103
VI	8	11	0.11	0.12	0.26	0.047	0.36	0.069
VII	4	5	0.10	0.10	0.25	0.029	0.30	0.085

The species which occurred most frequently during sampling operations was the common sunfish. It is believed that this was a disproportionate representation due to the wide ranging habit of this species since recaptures were a common occurrence. Age Groups II through VIII were represented in the samples and comparable data revealed that growth was near average for Michigan lakes (Beckman, 1949). Growths attained by the various age groups and annual increment growths of sunfish sampled during 1954 and 1955 are listed in Table 21. Variations in lengths and weights for the two years were slight for all age groups.

Instantaneous rates of growth for sunfish, by age

Figure XV. The Length-weight Relationship of the Common Sucker. Curve A represents Actual Values; Curve B represents the Log-log Transformation

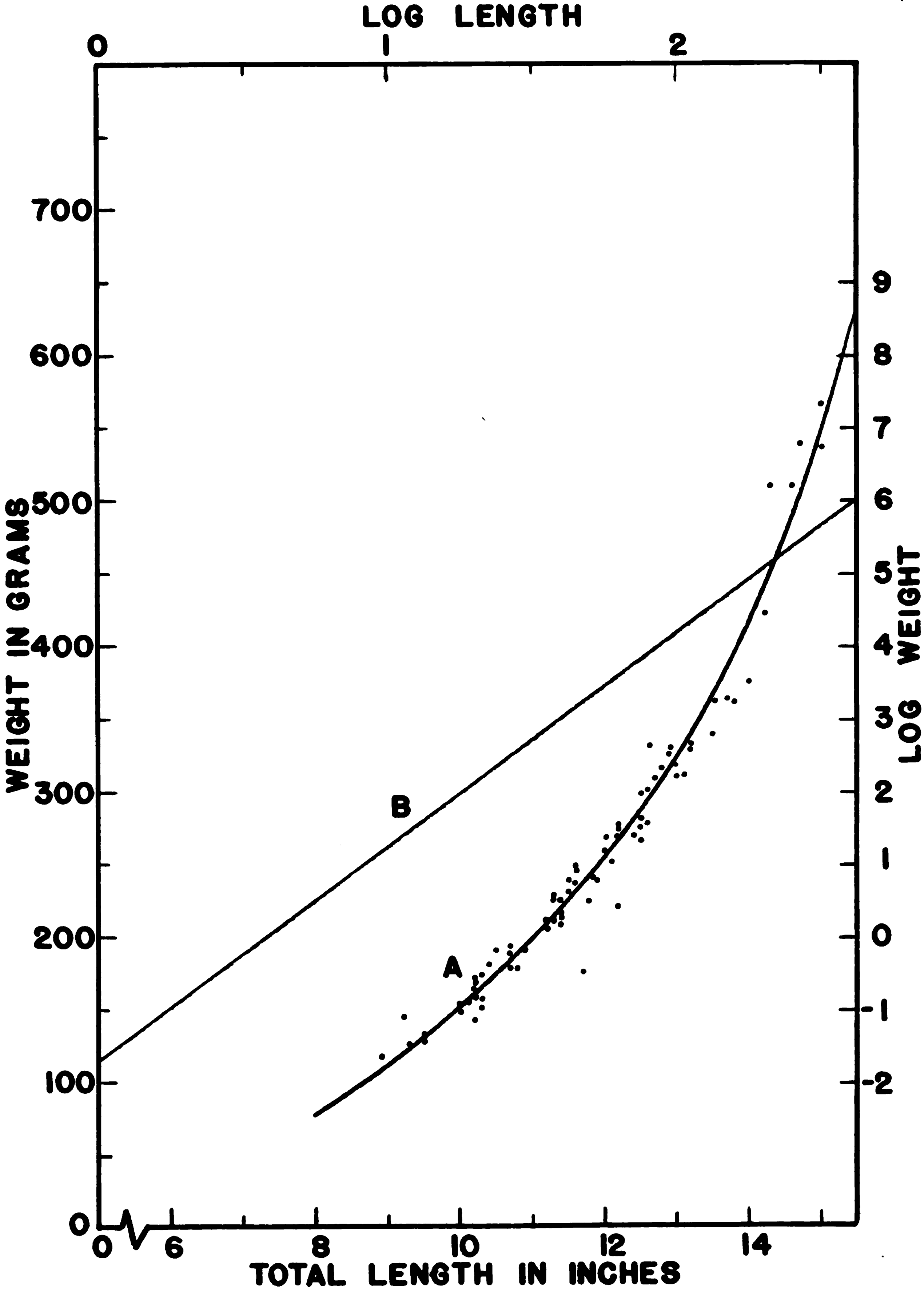

LOG LENGTH
0
1
2
700
600
500
400
300
200
100
0
WEIGHT IN GRAMS
9
8
7
6
5
4
3
2
1
0
-1
-2
LOG WEIGHT
B
A
0
6
8
10
12
14
TOTAL LENGTH IN INCHES

Table 21. Growth Attained by Common Sunfish sampled from Hoffman Lake during 1954 and 1955

Age Group	Number of fish		Mean total size Length (inches)		Mean total size Weight (grams)		Increment growth Length (inches)		Increment growth Weight (grams)	
	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
I	24	15	2.4*	2.4*	4.2**	3.7++	2.4	2.4	4.2**	3.7++
II	24	8	3.5*	3.4	13.6**	12.2	1.1	1.0	9.4**	8.5++
III	8	13	4.7	4.5	35.1	33.0	1.2	1.1	21.5**	20.8
IV	12	13	5.6	5.4	61.7	55.4	0.9	0.9	26.6	22.4
V	38	29	5.8	5.9	65.5	64.3	0.2	0.5	3.8	8.9
VI	37	28	6.3	6.3	85.8	82.9	0.5	0.4	20.3	18.6
VII	7	10	6.9	6.8	118.3	102.2	0.6	0.5	32.5	19.3
VIII	..	2	...	7.5	....	136.5	...	0.7	...	34.3

* Back calculated from scales
** Calculated from $\ln W = -1.3224 + 3.1270 \ln L$
++ Calculated from $\ln W = -1.5133 + 3.2238 \ln L$

groups, for 1954 and 1955 are shown in Table 22. The data reveal that for all ages there was a decrease in the rate of growth the second year (1955) as compared to the previous year.

Table 22. Mean Instantaneous Rates of Growth for Common Sunfish, 1954 and 1955

Age Group	Number of fish		Rate of growth (linear)		Rate of growth (gravimetric)			
	1954	1955	1954	1955	1954	± Standard deviation	1955	± Standard deviation
II	..	8	....	0.51	....	.....	1.64	0.169
III	8	13	0.39	0.28	1.22	0.393	0.90	0.266
IV	12	13	0.18	0.17	0.55	0.132	0.54	0.083
V	38	29	0.16	0.12	0.49	0.103	0.39	0.071
VI	37	28	0.13	0.09	0.41	0.074	0.28	0.060
VII	7	10	0.09	0.05	0.27	0.047	0.17	0.034
VIII	..	2	....	0.05	....	.....	0.16	0.000

The length-weight relationship for the 1955 samples was computed to be $\ln W = -1.5133 + 3.2238 \ln L$ and is shown graphically in Figure XVI.

There were 66 yellow perch sampled during the summer of 1955. Compared to data compiled by Carlander (1953), the absolute growths of the younger age groups of yellow perch taken from Hoffman Lake (Table 23) indicate that growth was slow. A typical example is shown by Age Group III. The average length and weight of this age group from Hoffman Lake

Figure XVI. The Length-weight Relationship of the Common Sunfish. Curve A represents Actual Values; Curve B represents the Log-log Transformation

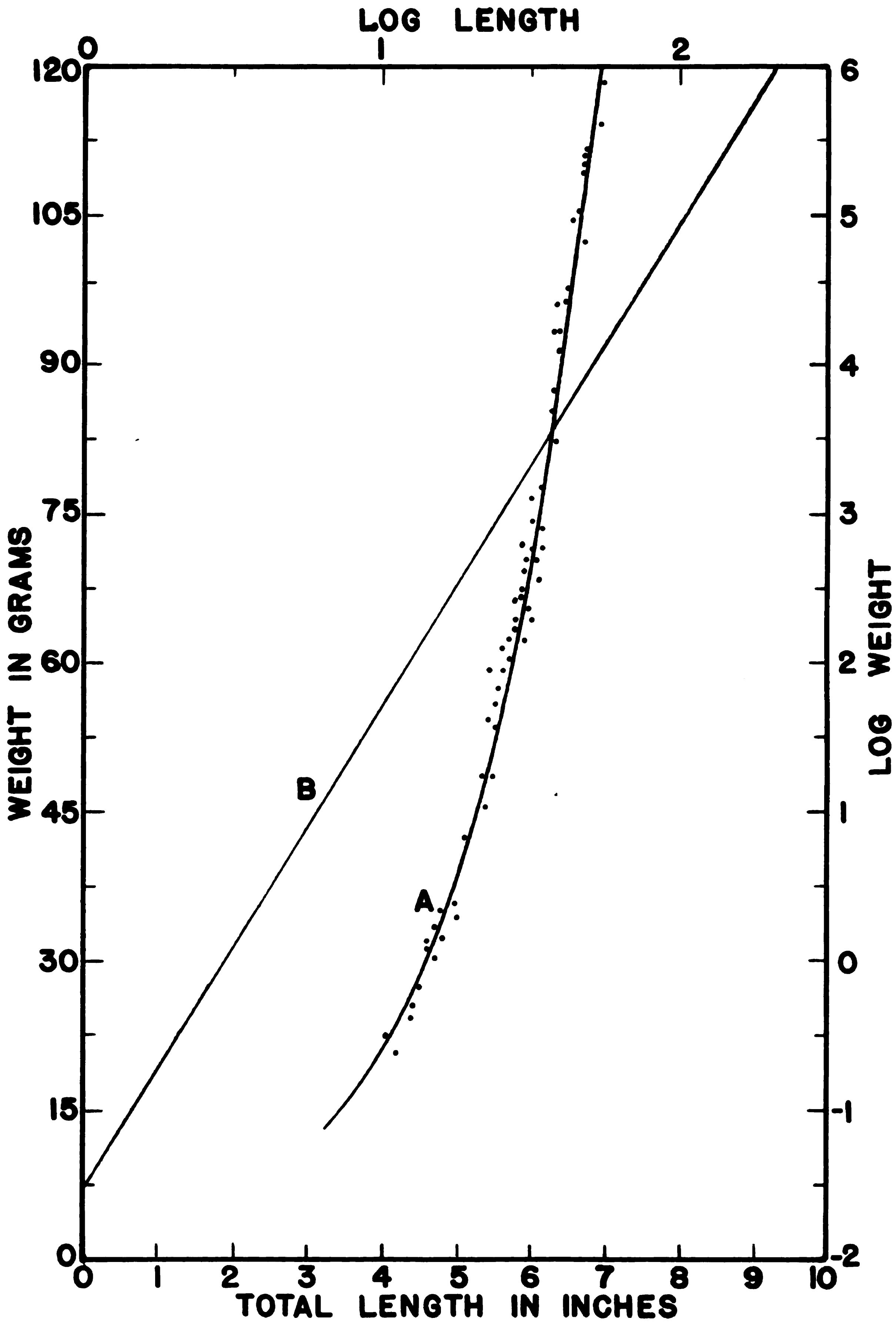

LOG LENGTH
0
1
2
120
105
90
75
60
45
30
15
0
6
5
4
3
2
1
0
-1
-2
WEIGHT IN GRAMS
LOG WEIGHT
A
B
0
1
2
3
4
5
6
7
8
9
10
TOTAL LENGTH IN INCHES

Table 23. Growth Attained by Yellow Perch sampled from Hoffman Lake during 1954 and 1955

Age Group	Number of fish		Mean total size Length (inches)		Mean total size Weight (grams)		Increment growth Length (inches)		Increment growth Weight (grams)	
	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
I	8	9	3.8	3.9*	7.3	9.5**	3.8	3.9	7.3	9.5**
II	46	23	4.6	4.6	13.6	16.5	0.8	0.7	6.3	7.0**
III	28	24	5.0	5.1	20.4	21.2	C.4	0.5	6.8	11.7
IV	13	13	5.5	6.0	27.9	37.2	0.5	0.9	7.5	9.0
V	4	5	8.0	7.8	91.0	97.2	2.5	1.8	63.1	60.0

* Back calculated from scales
** Calculated from $\ln W = -1.9729 + 3.0829 \ln L$

was 5.1 inches and 21.2 grams, respectively. Carlander (op. cit.) found that similar lengths and weights were attained by Age Group II but Beckman (1949) observed that yellow perch in Michigan exhibited slower growth when compared to those sampled from neighboring states.

Perch of Age Group V had attained a size which was considered normal for Michigan lakes (Beckman, op. cit.), but only five out of a total of 66 perch sampled fell within this age group. It is believed that once these fish had attained a size which enabled them to compete successfully with largemouth bass for forage fish, growth proceeded at a normal rate.

Instantaneous rates of growth (Table 24) seems to indicate a slight increased rate of growth the second year (1955)

Table 24. Mean Instantaneous Rates of Growth for Yellow Perch, 1954 and 1955

Age Group	Number of fish		Rate of growth (linear)		Rate of growth (gravimetric)			
	1954	1955	1954	1955	1954	± Standard deviation	1955	± Standard deviation
II	46	23	0.43	0.45	1.32	0.317	1.38	0.381
III	28	24	0.26	0.29	0.79	0.197	0.91	0.153
IV	13	13	0.21	0.18	0.64	0.116	0.54	0.109
V	4	5	0.19	0.13	0.58	0.095	0.40	0.095
VI	1	1	0.17	0.10	0.52	.....	0.32	.....

for perch of Age Groups II and III, whereas for Age Groups IV through VI there was a slight decrease in the rate of growth.

The computed length-weight relationship of yellow perch sampled in 1955 was $\ln W = -1.9729 + 3.0829 \ln L$. This relationship is shown graphically in Figure XVII.

In order to gain a better understanding of the length-weight relationship for each species, a covariance analysis (regression analysis) following Snedecor (1956) was carried out to test whether changes in the length-weight relationship ($W = cL^n$) occurred from year to year. Comparisons based on the length-weight relationship are complicated by the fact that the relationship is based on two different kinds of measurement of growth : 1. The exponent n (the slope in the logarithmic form of $W = cL^n$) measures the proportional increase in weight with an increase in length and 2. The position of the line measures the relative weight at a given length.

In essence, the test is a method for determining if a real difference, either in slope or in position (elevation or mean value), existed between the relationships for the two years (1954 and 1955) for each species. Figure XVIII, for example, shows the plotted (natural) logarithmic length-weight relationships for the yellow perch sampled during 1954 and 1955. A covariance analysis (Table 29) tests first, whether the two lines differ to a statistically important

Figure XVII. The Length-weight Relationship of the Yellow Perch. Curve A represents Actual Values; Curve B represents the Log-log Transformation

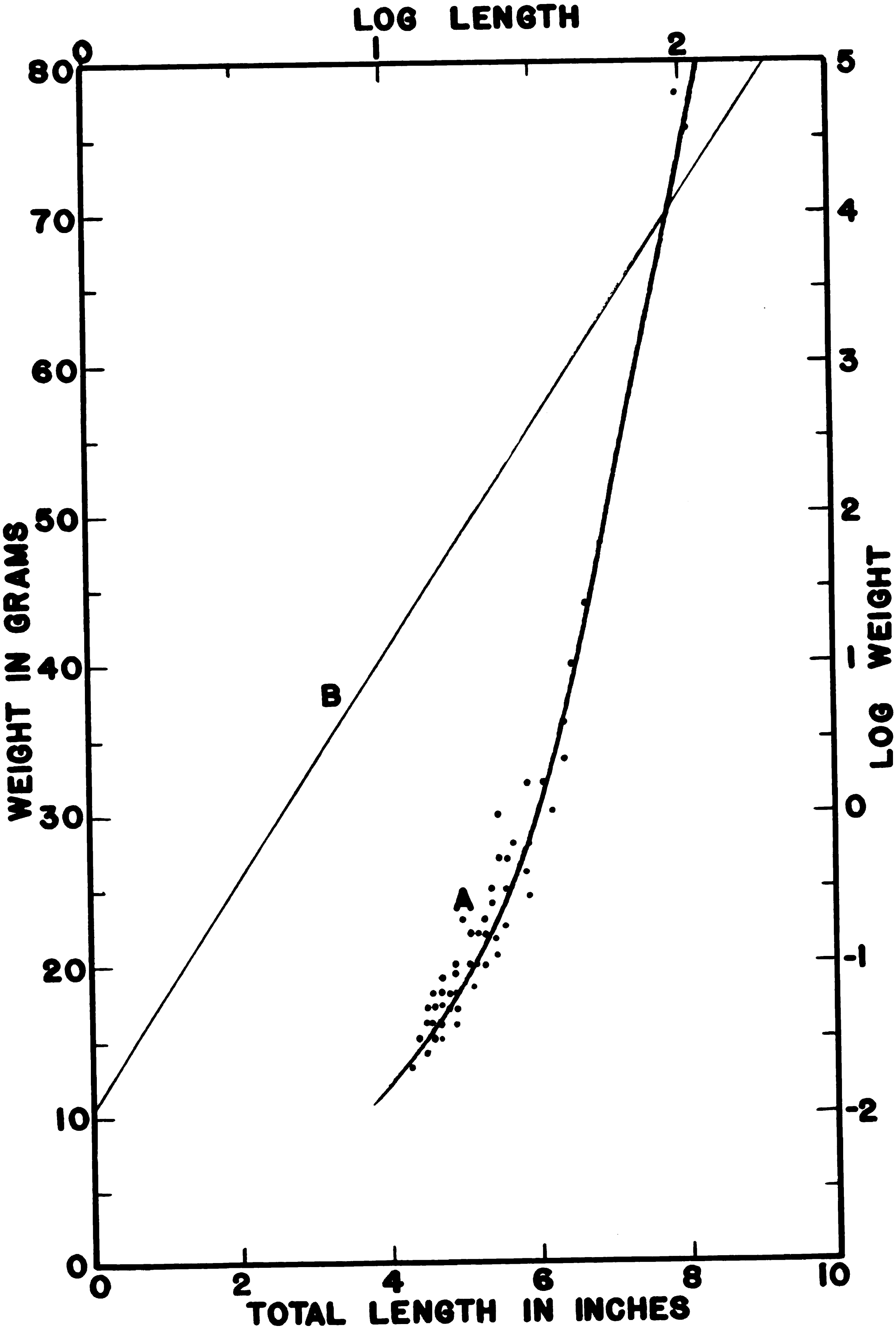
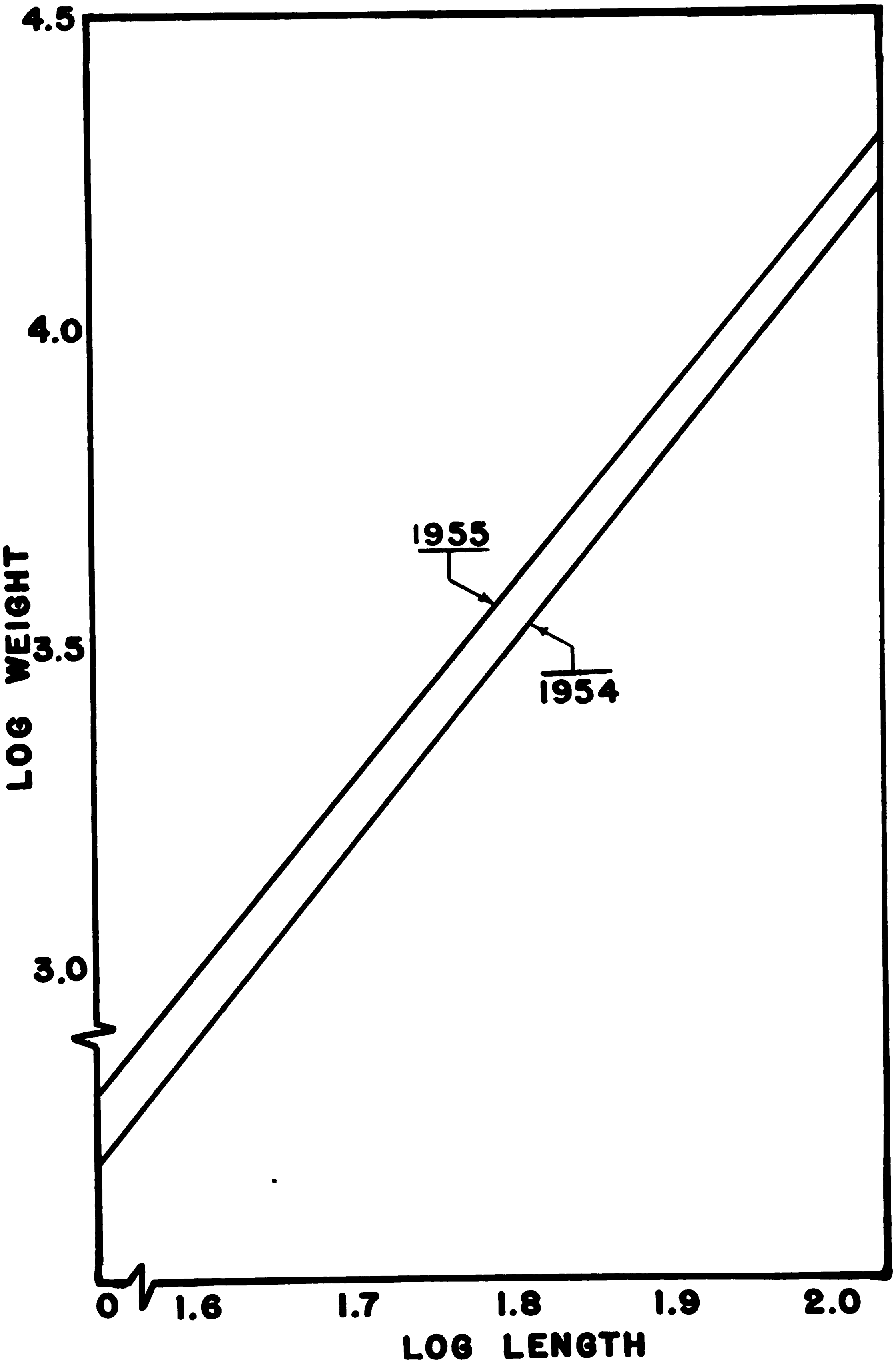

LOG LENGTH
0
1
2
80
70
60
50
40
30
20
10
0
5
4
3
2
1
0
-1
-2
WEIGHT IN GRAMS
LOG WEIGHT
B
A
0
2
4
6
8
10
TOTAL LENGTH IN INCHES

Figure XVIII. Relationship between Lengths and Weights of Yellow Perch from Hoffman Lake, 1954 and 1955


4.5
4.0
3.5
3.0
LOG WEIGHT
1955
1954
0
1.6
1.7
1.8
1.9
2.0
LOG LENGTH

degree, second, if they do differ, whether the difference is in the slopes of the lines regardless of positions, and third, if there is no appreciable difference in slope, whether the difference is in position. Each part of the test poses a question, the answer to which is dependent on the outcome of the "F" value.

Tables 25, 26, 27, 28 and 29 show the results of the covariance analyses for five species of fish sampled in Hoffman Lake during 1954 and 1955. Final results showed a highly significant difference in n values for only one species, the common sucker (Table 27). Since the mean values were approximately the same, there existed the interesting situation that shorter fish were lighter and longer fish heavier in 1955 than in 1954. Any attempt to correlate this difference with fertilization would be largely conjectural at present.

Of special interest is a comparison of relative weights for each species at a given length from one year to the next, based on the position of the two regression lines. The difference between these two weights at a given length gives the relative change in weight over all members of the species from one year to the next when the regression lines have the same slope. In order to make such a comparison, the adjusted mean log weights for each species must first be obtained, as follows :

Table 25. Covariance Analysis of ln[1] Length-ln Weight Relationship in Rock Bass from Hoffman Lake, 1954 and 1955

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	174	27.1978	
Due to general regression	1	25.4481	25.4481
Deviations from general regression	173	1.7497	0.0101
a. Can one regression line be used for all observations ?			
Gain from two separate regressions over general regression	2	0.0214	0.0107
Deviations from separate regressions	171	1.7283	0.0101
("F" = 1.06, answer is yes)			

[1] natural logarithm

Adjusted mean log weight (1954) = $\bar{Y}_{1954} - b(\bar{X}_{1954} - \bar{X}_{Total})$

Adjusted mean log weight (1955) = $\bar{Y}_{1955} - b(\bar{X}_{1955} - \bar{X}_{Total})$

where,

$\bar{Y}_{1954}$ = mean log weight of 1954 samples

$\bar{Y}_{1955}$ = mean log weight of 1955 samples

$\bar{X}_{1954}$ = mean log length of 1954 samples

$\bar{X}_{1955}$ = mean log length of 1955 samples

$\bar{X}_{Total}$ = mean log length of 1954 + 1955 samples

b = common slope (n) of 1954 + 1955 samples

Using the pertinent values from Table 30, the adjusted mean

Table 26. Covariance Analysis of ln[1] Length-ln Weight Relationship in Largemouth Bass from Hoffman Lake, 1954 and 1955

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	109	63.2280	
Due to general regression	1	61.4414	61.4414
Deviations from general regression	108	1.7866	0.0165
a. Can one regression line be used for all observations ?			
Gain from two separate regressions over general regression	2	0.1398	0.0699
Deviations from separate regressions	106	1.6468	0.0155
("F" = 4.51*, answer is no)			
b. Can a common slope be used for the separate regression lines ?			
Deviations about lines with common slope but fitted through mean of each set of data	107	1.6868	0.0157
Further gains from fitting separate regressions (difference between slopes)	1	0.0400	0.0400
Deviations about separate regressions	106	1.6468	0.0155
("F" = 2.58, answer is yes)			
c. Can one mean be used for the separate regression lines ?			
Gains from lines through each mean, with common slope, compared to general regression	1	0.0998	0.0998
Deviations about lines with common slope	107	1.6868	0.0157
("F" = 6.35*, answer is no)			

1 natural logarithm

Table 27. Covariance Analysis of ln[1] Length-ln Weight Relationship in Common Suckers from Hoffman Lake, 1954 and 1955

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	133	14.9083	
Due to general regression	1	13.7170	13.7170
Deviations from general regression	132	1.1913	0.0090
a. Can one regression line be used for all observations ?			
Gain from two separate regressions over general regression	2	0.1443	0.0722
Deviations from separate regressions	130	1.0470	0.0081
("F" = 8.91**, answer is no)			
b. Can a common slope be used for the separate regression lines ?			
Deviations about lines with common slope but fitted through mean of each set of data	131	1.1668	0.0089
Further gains from fitting separate regressions (difference between slopes)	1	0.1198	0.1198
Deviations about separate regressions	130	1.0470	0.0081
("F" = 14.79**, answer is no)			

[1] natural logarithm

Table 28. Covariance Analysis of ln[1] Length-ln Weight Relationship in Common Sunfish from Hoffman Lake, 1954 and 1955

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	202	30.4989	
Due to general regression	1	29.1167	29.1167
Deviations from general regression	201	1.3822	0.0068
a. Can one regression line be used for all observations ?			
Gain from two separate regressions over general regression	2	0.0510	0.0255
Deviations from separate regressions	199	1.3312	0.0067
("F" = 3.81*, answer is no)			
b. Can a common slope be used for the separate regression lines ?			
Deviations about lines with common slope but fitted through mean of each set of data	200	1.3362	0.0067
Further gains from fitting separate regressions (difference between slopes)	1	0.0050	0.0050
Deviations about separate regressions	199	1.3312	0.0067
("F" = 1.34, answer is yes)			
c. Can one mean be used for the separate regression lines ?			
Gains from lines through each mean, with common slope, compared to general regression	1	0.0460	0.0460
Deviations about lines with common slope	200	1.3362	0.0067
("F" = 6.86**, answer is no)			

[1] natural logarithm

Table 29. Covariance Analysis of ln[1] Length-ln Weight Relationship in Yellow Perch from Hoffman Lake, 1954 and 1955

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	165	62.4547	
Due to general regression	1	58.8613	58.8613
Deviations from general regression	164	3.7546	0.0229
a. Can one regression line be used for all observations ?			
Gain from two separate regressions over general regression	2	0.7071	0.3536
Deviations from separate regressions	162	3.0475	0.0188
("F" = 18.81**, answer is no)			
b. Can a common slope be used for the separate regression lines ?			
Deviations about lines with common slope but fitted through mean of each set of data	163	3.0481	0.0187
Further gains from fitting separate regressions (difference between slopes)	1	0.0006	0.0006
Deviations about separate regressions	162	3.0475	0.0188
("F" = 0.03, answer is yes)			
c. Can one mean be used for the separate regression lines ?			
Gains from lines through each mean, with common slope, compared to general regression	1	0.7065	0.7065
Deviations about lines with common slope	163	3.0481	0.0187
("F" = 37.78**, answer is no)			

1 natural logarithm

log weights for each species have been computed (Table 31) to derive the difference from 1954 to 1955. It can be seen in Table 31 that three species showed a loss in weight at a given length the second year, but only two of these differences were significant. The yellow perch showed a highly significant gain in 1955 over 1954. The value obtained for the common sucker has no meaning, for since in this species the two lines were shown to differ in slope, the relative difference in weight from year to year would vary with the length at which the comparison was made. The situation with the other species, however, is in contrast to that found for the sucker in that the relative change in weight was constant over all lengths.

The antilog of the difference yields the percentage loss or gain from one year to the next. For example, the antilog of the difference for the yellow perch (antilog + 0.10) was 1.10, meaning that there was a 10 percent increase in weight at any given length for this species in 1955 over 1954.

It is not known to what extent fertilization produced changes in the weight of the various species. It is interesting to note (Table 31) that a decrease in weight at a given length was noted for the three centrarchids in Hoffman Lake (although the decrease for the rock bass was not significant). On the other hand, the yellow perch showed a 10 percent increase in this weight over the same period. This suggests that here the yellow perch exhibited better physiological adjustments to certain environmental changes, but it

Table 30. Comparisons of Mean ln Weights and Lengths and n Values for Five Species of Fish from Hoffman Lake, 1954 and 1955

Species	Mean ln Weights		Mean ln Lengths		Slope (n value)	
	1954	1955	1954	1955	1954	1955
Rock bass	4.26	4.31	1.80	1.82	2.66	2.71
Large. bass	5.82	5.42	2.41	2.30	3.28	3.10
Sucker	5.48	5.49	2.46	2.46	2.39	2.92**
Sunfish	4.26	4.14	1.78	1.75	3.14	3.22
Perch	2.80	3.15	1.58	1.66	3.08	3.08

** Difference highly significant, see Table 27.

Table 31. Adjusted Mean ln Weights of Fish from Hoffman Lake, 1954 and 1955

Species	Adjusted Mean ln Weights		Difference Between Mean ln Weights (1954 and 1955)	Antilog Difference
	1954	1955		
Rock bass	4.29	4.28	-0.01	0.99
Large. bass	5.66	5.61	-0.05*	0.95
Sucker	5.51	5.52	....	....
Sunfish	4.20	4.17	-0.03**	0.97
Perch	2.89	2.99	+0.10**	1.10

* Difference significant, see Table 26.
** Difference highly significant, see Tables 28 and 29.

is not clear whether these changes were related to fertilization. If it is argued that fertilization increased the food supply in Hoffman Lake, an increase in the weight of yellow perch may have been due to some favorable balance in competition with other species for the available food supply.

CONCLUSION

The results of the present investigation showed increases in the growth of some organisms following fertilization. Increases in instantaneous rates of growth were observed for the burrowing mayfly, Ephemera simulans, and the common sucker, Catostomus commersonnii. A study of the length-weight relationship for the yellow perch disclosed that the one-year-effects of fertilization to Hoffman Lake apparently produced a 10 percent increase in weight at a given length for this species. The results of chlorophyll extractions from periphyton samples revealed that the addition of nutrients apparently accelerated the production of this component of the biota.

The difficulty of the present problem lies in trying to determine to what extent these observed changes in organic production were a direct result of fertilization. However, the fact that changes were noted in some of the physical and chemical, as well as biological, characteristics of the lake following fertilization is noteworthy.

The increased rate of growth observed for the common sucker probably was tied in with the increased production of periphyton. Stewart (1926) observed that part of the periphyton complex is utilized for food by the sucker. Thus, the sucker is able to subsist on organisms found nearer the base of the food chain.

The yellow perch exhibited a 10 percent increase in weight at a given length in 1955 over 1954. Why this species gained in weight but not in length is difficult to explain. During the summer of 1955, the greatest portion of the perch was sampled during the latter part of the summer and the possibility exists that at that period the deposition of fat occurred rather than an increase in length.

There was no change in the length-weight relationship for any of the fish species except the common sucker. Two species, the common sunfish and the largemouth bass, decreased in weight at a given length. It is hypothesized that the decrease in weight for these two species may have been due to 1. An increase in the size of the population with resulting increased competition for available food, 2. An increase in the size of food organisms, thus making them unavailable to the fish and 3. "Normal" fluctuations in the legth-weight relationship due to undetermined influences.

The failure of plankton organisms to increase following fertilization is believed to have been due to the excess calcium present in the water. Since very low concentrations of phosphorus existed in the surface waters of Hoffman Lake, it is believed that this element constituted an important factor which limited the production of plankton organisms.

The increased production of periphyton in the absence of a plankton bloom was probably due to complex chemical reactions. Active ingredients in the fertilizer became unavailable in the surface waters as a result of a precipitation reaction which continued to the bottom of the lake. The action of bacteria in the bottom muds on this flocculent material caused the release of inorganic phosphorus, which then became available to periphyton organisms (Hooper and Elliott, 1953). Meehean (1933) also found this to be true in pond fertilization experiments.

SUMMARY

1. Commercial, inorganic fertilizer was added in two applications to Hoffman Lake, a 120 acre marl lake in northern Michigan, during the summer of 1955.

2. Temporary increases were noted in certain physical and chemical characteristics of the lake immediately following each application of fertilizer. After fertilization, conditions returned to or approached those existing prior to fertilization.

3. Fertilization brought about an increase in turbidity which resulted in the reduction of light penetration at all depths. The turbid condition was due to the action of excess calcium in the water upon the components of the fertilizer.

4. The pH and alkalinity remained almost constant throughout the study period, indicating that the concentration of calcium and magnesium carbonates was such as to make the lake an efficient buffer system.

5. Analyses for ammonia nitrogen, total and soluble phosphorus and sulfates showed increases in surface water samples immediately following fertilization. Increases were only temporary, however, and after a few days returned to prefertilization levels.

6. Little or no difference existed in the concentration of oxygen found in surface waters and at the greatest depth, indicating that little or no stratification was present in Hoffman Lake during the summer of 1955.

7. There was no detectable increase in planktonic organisms following fertilization. Chemical analyses of material collected by concentration of lake water with a Foerst centrifuge revealed the presence of suspended matter consisting of calcium, phosphorus and carbonate compounds.

8. Fertilization brought about an increase in periphyton. Quantitative analyses showed that the increase was significant and was related to the increase of nutrients added to the lake.

9. The effects of fertilization on macroscopic benthic organisms were sought by noting changes in the rate of growth of the burrowing mayfly, *Ephemera simulans*. The results of growth rate studies for this species revealed that the rate of growth had increased.

10. Instantaneous rates of growth and studies of the length-weight relationship for five species of fish were made on the basis of data compiled during two consecutive years. A highly significant change in the length-weight relationship was observed for one species, the common sucker. Yellow perch showed a 10 percent increase in weight in 1955 as compared to those sampled in 1954. No changes were found in the length-weight relationships of the other species.

LITERATURE CITED

Alexander, Gaylord R.

1956. The fertilization of a marl lake. Master's thesis, Michigan State University.

American Public Health Association

1955. Standard methods for the examination of water, sewage, and industrial wastes. 10th. ed., New York, 522 pp.

Ball, Robert C.

1949. Experimental use of fertilizer in the production of fish-food organisms and fish. Mich. State Coll., Agric. Exper. Sta., Tech. Bull. 210., 28 pp.

1950. Fertilization of natural lakes in Michigan. Trans. Am. Fish. Soc., 1948, 78: 145-155.

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., 1952, 82: 78-90.

Beckman, William C.

1949. The rate of growth and sex ratio for seven Michigan fishes. Trans. Am. Fish. Soc., 1946, 76: 63-81.

Benne, E. J., A. T. Perkins and H. H. King

1936. The effect of calcium ions and reaction upon the solubility of phosphorus. Soil Science, Vol. 42, No. 1, July, 1936.

Burks, B. D.

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

Carlander, Kenneth D.

1953. Handbook of freshwater fishery biology with the first supplement. Wm. C. Brown Co., Dubuque, Iowa, 429 pp.

Coker, Robert E.

1954. Streams, lakes, ponds. The University of North Carolina Press. Chapel Hill, North Carolina, 327 pp.

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

1948. Determination of water quality. U. S. Dept. Inter., Fish. and Wild. Ser., Research Rept. No. 9.

Gessner, Fritz

1939. Die Phosphorarmut der Gewasser und ihre Beziehung zum Kalkgeholt. Internat. Rev. der gas. Hydrob. und Hydrogr., Bd. 38, S. 203-211.

Greenbank, John

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

Gumtow, Ronald B.

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

Grzenda, Alfred R.

1956. The biological response of a trout stream to headwater fertilization. Master's thesis, Michigan State University.

Harvey, H. W.

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

Hogan, Joe

1933. Experiments with commercial fertilizers in rearing largemouth black bass fingerlings. Trans. Am. Fish. Soc., 1933, 63: 110-119.

Hooper, Frank F. and Alfred M. Elliott

1953. Release of inorganic phosphorus from extracts of lake mud by protozoa. Trans. Am. Micros. Soc. 72 (3): 276-281.

Hunt, Burton P.

1951. Reproduction of the burrowing mayfly, Hexagenia limbata (Seville), in Michigan. The Florida Entomologist. 34 (2).

Lagler, Karl F.

1952. Freshwater 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., 1948, 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.

Lyman, Earle F.

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

Meehean, O. Lloyd

1933. The role of fertilizers in pondfish production. Trans. Am. Fish. Soc., 1933, 63: 103-109.

1934. The role of fertilizers in pondfish production, II. Some Ecological Aspects. Trans. Am. Fish. Soc., 1934, 64: 151-154.

Moyle, John B.

1949. Some indices of lake productivity. Trans. Am. Fish. Soc., 1946, 76: 322-334.

Naumann, E.

1932. Grundzuge der regionalen Limnologie. Die Binnengewasser, Bd. 11, 176 S.

Neess, John C.

1949. Development and status of pond fertilization in Central Europe. Trans. Am. Fish. Soc., 1946, 76: 335-358.

Nelson, Philip R. and W. T. Edmondson

1955. Limnological effects of fertilizing Bare Lake, Alaska. Fish. Bull. 102, Fish and Wild. Serv., Vol. 56.

Newcombe, Curtis L.

1950. A quantitative study of attachment materials in Sodon Lake, Michigan. Ecology, Vol. 31, No. 2, April, 1950.

Odum, Eugene P.

1953. Fundamentals of ecology. W. B. Saunders Co., Philadelphia, Pennsylvania, 384 pp.

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.

Roelofs, Eugene

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

Rounsefell, George A. and W. H. Everhart

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

Ruttner, Franz

1953. Fundamentals of limnology. (Translated by D. G. Frey and F. E. J. Fry). University of Toronto Press, 242 pp.

Schloesing, Th.

1900. L'acide phosphorique en presence des dissolutions saturees bicarbonate de chaux. C. R. Acad. Sci., Vol. 131, pp. 211-215.

Smith, M. W.

1934. The dissolved oxygen content of fertilized waters. Trans. Am. Fish. Soc., 1934, 64: 408-415.

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.

1956. Statistical methods. The Iowa State College Press., 5th. ed., 534 pp.

Stewart, Norman H.

1926. Development, growth, and food habits of the white sucker, Catostomus commersonnii (Lesuer). Department of Commerce; Bureau of Fisheries Document No. 1007., Vol. XLII.

Surber, Eugene W.

1945. The effects of various fertilizers on plant growths and their probable influence on the production of smallmouth black 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.

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

1939. Fertilizers for increasing the natural food for fish in ponds. Trans. Am. Fish. Soc., 1938, 68: 126-134.

1940. Fish production in terrace-water ponds in Alabama. Trans. Am. Fish. Soc., 1939, 69: 101-105.

Theroux, Frank R., E. F. Eldridge and W. L. Mallmann

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

Tucker, Allan

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

Welch, Paul S.

1952. Limnology. McGraw-Hill, New York, 538 pp.

Whiteside, E. P., I. F. Schneider and R. L. Cook

1956. Soils of Michigan. Michigan State University., Agric. Exp. Sta. Spec. Bull. 402, 52 pp.

Wiebe, A. H.

1931. Dissolved phosphorus and inorganic nitrogen in the water of the Mississippi River. Science, 73: 652.

1935. The pond culture of black bass. Game, Fish and Oyster Commission, Austin, Texas, Bull. No. 8, 58 pp.

Young, Orson W.

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

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