DANIEL S. PLOSILA M. S. 1958

AN EVALUATION OF LAKE PRODUCTION FOLLOWING ARTIFICIAL ENRICHMENT

Thesis for the Degree of M. S.

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Daniel S. Plosila

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AN EVALUATION OF LAKE PRODUCTION FOLLOWING ARTIFICIAL ENRICHMENT

By

DANIEL S. PLOSILA

AN ABSTRACT

Submitted to the College 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

1958

Approved ______________________________

ABSTRACT

Twice each summer for three consecutive summers, 1954-56, inorganic fertilizers were applied to Hoffman Lake, a 120 acre marl lake in northern Michigan.

Temporary and prolonged changes were detected in some of the physical, chemical, and biological characteristics of the lake following fertilizer applications.

Water transparency and light transmission decreased temporarily after fertilizer applications and seemed to be decreasing in general as the study progressed. The temporary decreases were apparently related to the presence of a flocculent material after fertilizer applications.

A temporary decrease in specific conductance seemed to correspond with the appearance of the flocculent material. Concentrations of ammonia nitrogen and total phosphorus increased temporarily following fertilizer applications, but returned to equilibrium by the following summer.

Indications were obtained the final year that phytoplankton may have increased as a result of fertilization. Statistical analyses indicated that periphyton increases following fertilization each year were statistically significant. No discernible effects of fertilization were shown by benthic organism samples.

Fertilization of Hoffman Lake appears to have been reflected in the fish population through increase of growth rate. Instantaneous rates of growth for five species of fish improved as the study progressed.

Statistically significant changes in the length-weight relationships of two species of fish were maintained during the last two years of the study period. The changes were gains in weight per given length.

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I wish to express my gratitude to: Dr. Thomas F. Waters and Gerald F. Myers of the Pigeon River Trout Research Area for their cooperation during the field work; Gaylord Alexander, Nickolas Anton, Alfred Grzenda, Peter Colby, and Morris Brehmer for their many helpful suggestions; and my wife, Belva, for her assistance, especially in the typing of this thesis.

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INTRODUCTION

The history of fisheries management has been one of efforts to retain and improve sport and commercial fishing in our ponds, lakes, and streams. Recently the increasing demand on our natural waters by an increasing angler population has emphasized the need for greater fish production. This thesis is concerned with an experimental project designed to contribute information on a method of increasing fish production by artificial fertilization of natural waters.

Increased production through fertilization has been practiced extensively on land, but in aquatic environments fertilization, with both organic and inorganic nutrients, has been restricted primarily to ponds and small lakes. The principle of fertilization appears to be simply a matter of furnishing more available nutrients for the aquatic food chains; however, due to the complex physical, chemical, and biological relationships in our different waters, each body of water is a separate complicated unit. Ideally, these added nutrients will enter aquatic food chains and be converted by algae and higher plants into plant protoplasm. This in turn will be utilized directly or indirectly at the various consumer levels by zooplankton, benthic organisms, and fish. The desired end product, increased fish production, could result in one of three ways: a greater number of individuals, larger size of individuals, or both increased numbers and size.

Summaries of early European experiments in the late nineteenth century have been compiled by Davis and Wiebe (1930), Smith (1934), and Neess (1949). Early European work, as described in these summaries, was related to plankton production and later the procedure was applied to carp culture. Early American work in the twentieth century has been of a similar nature (Embody, 1921; Wiebe, 1929, 1930). Increased productivity resulting from organic and inorganic fertilization has been successful to varying degrees in ponds as shown by many workers (Maciolek, 1954).

Successful attempts on lake fertilization includes work by Juday, Schloemer, and Livingston (1938), Smith (1948), Ball (1950), Ball and Tanner (1951), Langford (1950), Nelson and Edmondson (1955), and Weatherley and Nicholls (1955). Huntsman (1948) reported success in increasing the numbers of plants and fish in a stream by the application of inorganic fertilizers. Maciolek (1954) in reviewing lake and pond fertilization experiments observed that early experiments were concerned only with fish or fish-food production. Some of the more recent investigators have been concerned also with the fundamental physical, chemical, and biological factors which may influence enrichment and resulting changes in productivity.

This three year study of Hoffman Lake was designed to evaluate those physical, chemical, and biological changes resulting from inorganic fertilizer applications to an unproductive marl lake. Two important characteristics of Hoffman Lake separate this study from most of the previous lake fertilization projects: first, the high calcium carbonate content of Hoffman Lake and secondly, its comparatively large surface area of 120 acres. This thesis contains the work performed on Hoffman Lake during the third and final summer of the project, 1956, and evaluations of the data for the entire three years. The data for the two preceding years, 1954 and 1955, were collected and presented originally by Alexander (1956) and Anton (1957), respectively. A simultaneous study of a similar nature was made on the West Branch of the Sturgeon River, an effluent stream from Hoffman Lake* (Grzenda, 1956; Colby, 1957; Carr, M. S.).

DESCRIPTION OF THE STUDY AREA

Hoffman Lake, Charlevoix county, is located in the northern lower peninsula of Michigan (T. 32 N., R. 4 W., Sec. 26, 27, 34, 35). The lake surface area of 120 acres covers a shallow basin containing three small depressions with maximum depths of 22 feet. The mean water depth is 10 feet; 25 per cent of the total surface area is water less than 5 feet in depth. Hoffman Lake approaches being ovoid in shape and has a shoreline development of 1.2. It has a maximum width of 2610 feet and a maximum length of 3330 feet.

The lake water temperature conditions during the study periods were nearly homothermous except for occasional trends towards thermal stratification following calm weather. Alkalinity averaged 130 p. p. m. and pH ranged from 7.9 to 8.5. The main water supply of this hardwater lake appears to be numerous springs and an intermittent stream draining a smaller neighboring lake. The high alkalinity of Hoffman Lake is believed to be due to the high concentration of calcium and magnesium salts in its water supply. The characteristic blue-green color of a marl lake is exhibited. This apparent color results from the high light reflecting properties of calcium carbonate.

The lake bottom types based on Roelofs's (1944) classification are marl, sand, and fibrous peat. The principal bottom type, marl, consists of shell and amorphous marls. The sand and fibrous peat types are represented by small deposits along portions of the shoreline.

The topography of the drainage of Hoffman Lake is rolling to hilly morainic land. The dominant soils are well-drained soils originating from sand to sandy loam parent materials (Whiteside, Schneider, and Cook, 1956). The original hardwood forests, primarily sugar maple, have been replaced by second growths of sugar maple and aspen. Portions of the lake shoreline and other low lying lands of the area are covered by cedar swamps. Land utilization consists of pasturage, limited farming, and pulpwood operations. Cottage sites are being developed along portions of the lake shoreline.

Under Odum's (1953) classification, Hoffman Lake can be described as a morphometrically eutrophic type lake. This type of lake has a shallow basin and low concentrations of nutrients. The low productivity of Hoffman Lake appears to be due to a high concentration of calcium carbonate and a lack of organic matter. Sparse vegetation, little evidence of plankton, scant bottom fauna, and generally poor fish growth rates as observed by Alexander (1956) are indicative of the low production in Hoffman Lake.

The submerged aquatic vegetation occurring in the lake are stoneworts (<u>Chara sp.</u>), bladderwort (<u>Utrichularia sp.</u>), bushy pondweed (<u>Najas sp.</u>), and pondweeds (<u>Potamogeton sp.</u>). Floating vegetation consists of a small patch of white water lilies (*Nuphar sp.*) located along the western shoreline. The most abundant vegetation appeared to be the bulrush (*Scirpus sp.*) in the shallower waters of the lake. The most numerous benthic organisms are members of the families Ephemeridae and Tendipedidae. Phytoplankton, which is very limited, is of the cyanophyte-diatom flora type, characteristic of some hard water lakes (Prescott, 1951).

Five species of game fish and one coarse species are known to occur in Hoffman Lake; these are:

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

Forage fish species present in Hoffman Lake as listed by Roelofs (1941) were:

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

METHODS

Fertilization

Twice each summer for three consecutive summers commercial inorganic fertilizers were applied to Hoffman Lake. The fertilizers contained nitrogen as ammonium sulfate, potassium as potassium chloride, and phosphorus as super-phosphate. Fertilization consisted of slowly emptying the fertilizer sack contents into the wake of a moving boat. The applications were restricted primarily to water under five feet in depth in order that wave action and propeller agitation would facilitate solution of chemicals.

Application dates were during a similar time period each summer of the project. A different concentration of fertilizer was applied each summer in order to secure varying annual results for evaluation. In 1954 the applications totaled 5900 pounds of 10-10-10 (N-K-P) fertilizer, the following summer 10,000 pounds of 12-12-12 were applied, and the final summer 4960 pounds of 12-12-12 were used.

Table 1 lists the theoretical concentrations for each year based upon complete solution of the fertilizers in a lake volume of 45,000,000 cubic feet. The calculated volume of Hoffman Lake was determined by Alexander (1956).

Sampling Stations

Eight sampling stations were established on Hoffman Lake during the entire study. Figure I illustrates the locations of the stations on a hydrographic map of Hoffman Lake. Stations A, B, C, D, and E were used to secure chemical samples.

Physical data were gathered primarily over the depression at station G. Stations 1 and 2 served as sampling areas for bottom organisms. In 1954 and 1955 plankton samples were also taken at stations 1 and 2. Plankton samples during 1956 were taken at station B.

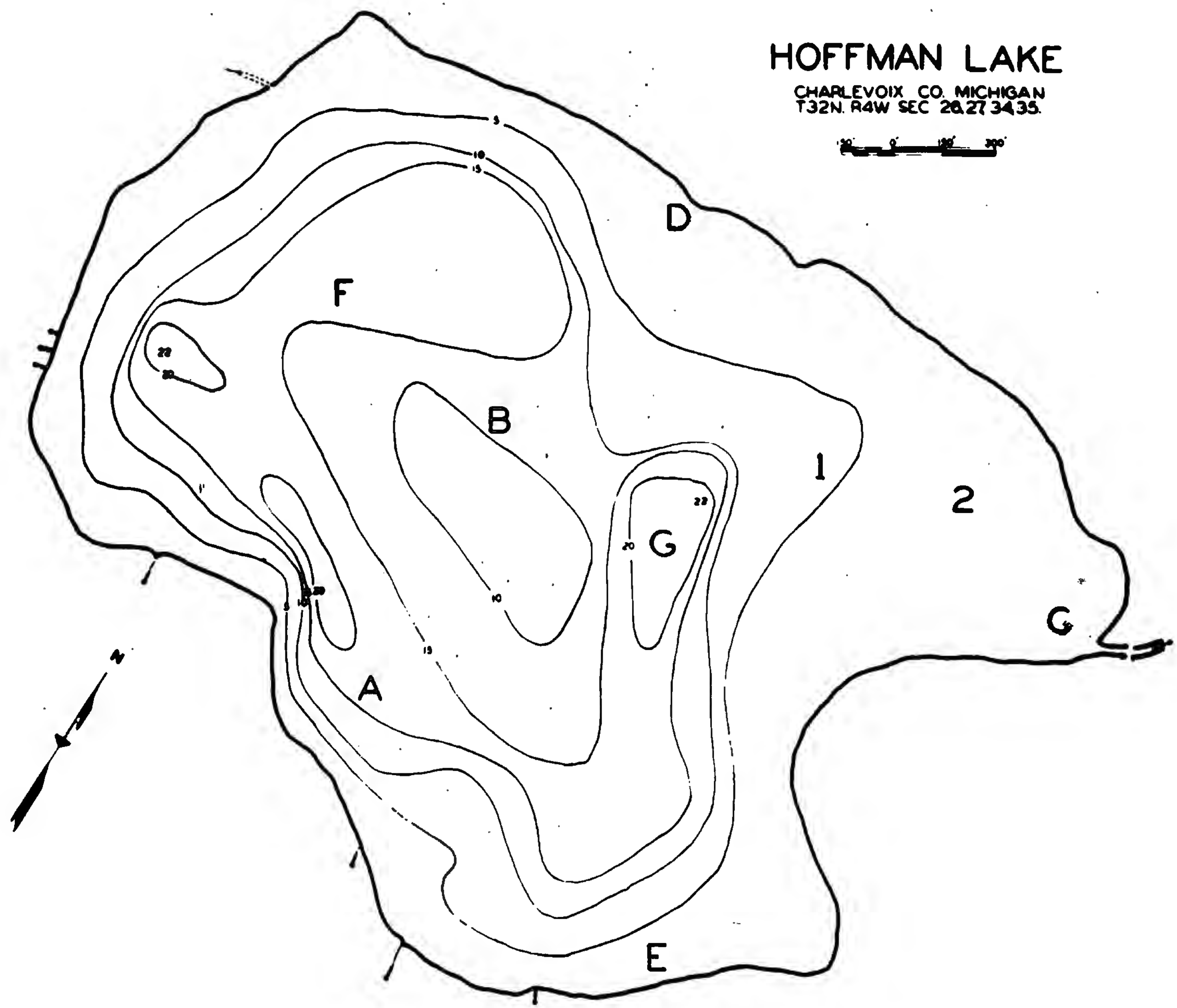
Station C, the lake outlet, was also the site of a series of

Table 1. Theoretical concentrations in parts per million of chemicals in Hoffman Lake after fertilization in 1954, 1955, and 1956

	1954* (5900 Lbs.) (10-10-10)	1955** (10,000 Lbs.) (12-12-12)	1956*** (4960 Lbs.) (12-12-12)
Fertilizer	2.107	3.525	1.748
Nitrogen	0.2107	0.4230	0.2098
Ammonia	0.3708	0.5438	0.2697
Sulfate	0.7447	1.2576	0.6238
Phosphoric Acid	0.2107	0.4230	0.2098
Phosphorus	0.0922	0.1819	0.0902
Potassium Oxide	0.2107	0.4230	0.2098
Potassium	0.1748	0.3510	0.1741

* 3200 lbs. on July 30 and 2700 lbs. on August 9 (Alexander, 1956)
** 6000 lbs. on July 31 and 4000 lbs. on August 6 (Anton, 1957)
*** 2480 lbs. on July 30 and 2480 lbs. on August 3

Figure I. Map of Hoffman Lake, showing locations of sampling stations used in 1956


HOFFMAN LAKE
CHARLEVOIX CO. MICHIGAN
T32N. R4W SEC 26,27,34,35.
D
F
B
1
2
G
G
A
E
5
10
15
20
22

artificial substrates for periphyton sampling. In 1956 an additional periphyton sampling station was established at the western end of the lake as station F. A spring remote from Hoffman Lake was the site of a control station.

Sampling

PHYSICAL

Secchi disk. This instrument was used to obtain measurements of water transparency. The limit of visibility in feet was the mean of two depth readings. These readings were the depth of disappearance upon lowering the disk and its depth of reappearance when raised again. In order to secure standard conditions, the disk was operated by the same individual at a set time of day from the protected side of the boat. Although the Secchi disk is not a measure of actual light penetration, it can be used for comparisons of the same water at various dates (Welch, 1948).

Submarine photometer. In addition to the measurement of water transparency, a submarine photometer was operated to determine the per cent of light transmission at increasing depths. The equipment consisted of a deck unit, a submarine unit, and a microammeter with a double-throw switch. The deck and submarine units were matched Weston photronic cells whose separate readings could be secured in rapid succession by use of the double-throw switch.

The initial measurement was made at the one foot depth followed by successive measurements at three feet intervals from three through eighteen feet. Weekly photometer measurements were made immediately following the Secchi disk measurements in order that a comparison of data might be performed.

Temperature. Air and water temperatures were taken throughout the summer. An electric-resistance thermometer was used for the measurements. It consisted of a cable equipped terminal, galvanometer, and Wheatstone bridge. Water temperatures were taken at a series of depths for evidence of thermal stratification. Supplemental notes were taken concerning wind activity.

CHEMICAL

Alkalinity. Total alkalinity was determined weekly by the titration method described in Ellis, Westfall, and Ellis (1948). Phenolphthalein and Fleisher's methyl purple were used as indicators.

Hydrogen-ion concentration. Weekly water samples were measured with a Beckman pH meter for hydrogen-ion concentration (pH).

Dissolved oxygen. A series of dissolved oxygen determinations were made at various depths during a warm period of the summer. The Winkler Method described in Theroux, Eldridge, and Mallman (1943) was used for these tests.

Specific conductance. Specific resistance in ohms was determined with a battery-operated conductivity bridge. These values were converted to specific conductance in reciprocal megohms (mho) at 18° C.

Ammonia nitrogen. Direct Nesslerization was used to determine ammonia nitrogen (Standard Methods, 1955). A Klett-Summerson photoelectric colorimeter was used to determine maximum color development. Ammonia nitrogen in p. p. m. was read from a graph based on known ammonia standards.

Phosphorus. The total phosphorus concentrations were obtained following the method in Ellis, Westfall, and Ellis (1948). Maximum color development was determined with a Klett-Summerson photoelectric colorimeter. Total phosphorus in p. p. b. was obtained from a graph based on known phosphorus standards.

BIOLOGICAL

Plankton. During the summer of 1956, a one-quart subsurface water sample was taken weekly at station B. Formalin was added to insure preservation of any organisms present. These samples were labeled, sealed, and stored for future laboratory analysis. Laboratory work included concentrating each sample by filtration through a millipore filter.

The sampling procedure of the two preceding years differed somewhat from the method described above. Previously the samples were taken at station 1 and station 2; however, due to the nearly constant wind action and the resulting uniform mixing of water, any effects of the station change were minimized.

A second difference was in the concentration of the samples. Instead of filtration, the 1954 and 1955 samples had been centrifuged. The use of a millipore filter in 1956 seemed warranted since it was felt that the efficiency of the Foerst centrifuge was not sufficient to retain the finer suspended solids.

The laboratory analyses of the plankton samples were basically the same each year. Since the concentrations of plankton were very low, qualitative and quantitative counts were not practical. However, in 1956 a uniform volume of the precipitate from each filtered sample was examined qualitatively for plankton.

Analyses for the total suspended solids and their carbonate and organic fractions were made on the concentrated plankton samples. The methods essentially followed Theroux, Eldridge, and Mallman (1943), except that samples were dried at 60° C. An aliquot of each weekly concentrated sample was dried and weighed to determine the total suspended solids in parts per million. This aliquot was then ashed and weighed. The reduction in weight due to ignition represented the loss of the organic fraction and the CO_2 portion of the carbonate fraction. This weight loss was known as the total volatile fraction.

A second aliquot was treated with dilute hydrochloric acid to dissolve acid soluble salts constituting the carbonate fraction. The aliquot was then centrifuged to remove these soluble salts. The residue, the acid insoluble fraction, was dried and weighed, then ashed and re-weighed. This weight loss, after ignition, was due to the organic fraction lost through oxidation. An estimate of the carbonate fraction as CO_2 was obtained by subtracting the organic fraction from the total volatile fraction obtained from the first aliquot. All these values were computed in parts per million.

Periphyton. The use of the term periphyton has been applied somewhat differently by various workers in referring to a group of sessile microorganisms (Cooke, 1956). Generally the term included bacteria, algae, protozoans, and some higher organisms which grow attached to submerged objects. Periphyton has some characteristics of both benthos and plankton being normally on a substrate like benthos, but has a position up in the water like plankton. In the study of Hoffman Lake, the use of the word periphyton by Young (1945) was selected (Alexander, 1956).

Young (op. cit.) described periphyton as "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".

Previous workers have used periphyton as a measure of biological productivity. Young (op. cit.) performed numerical counts on Scirpus sp., stones, and submerged brush. Patrick (1949) made numerical counts on submerged glass slides. Gumtow (1955) used stones for sampling periphyton in a stream.

Many periphytic organisms possess the ability to manufacture chlorophylls and other pigments. Harvey (1934) in pigment extractions from phytoplankton found in general a correlation between the colorimetric determination of pigments and the numerical count of organisms. He used an arbitrary color standard for comparing extracted pigments. This standard, the "Harvey Unit", consisted of 25 mg. of potassium chromate and 430 mg. of nickel sulphate dissolved in one liter of water.

Tucker (1949) performed a statistical analysis to test the reliability of the pigment extraction method for quantitative work. He found the extraction method satisfactory for showing general trends in quantity of organisms when a number of samples are analyzed. Tucker (op. cit.) mentioned the simplicity and rapidity of pigment extraction over quantitative counts. In the light of this work by these earlier workers, the pigment extraction method was selected for Hoffman Lake.

In the Hoffman Lake study two types of artificial substrates were used for periphyton sampling. These substrates were wooden shingles measuring 12.0 x 3.0 x 0.3 inches and cinder bricks measuring 7.9 x 3.7 x 2.3 inches. The shingles were nailed in a horizontal position on to submerged logs, while the submerged bricks were suspended by wire from logs and overhanging brush.

At station C, the lake outlet, one series of bricks and shingles was submerged for the 30 days preceding fertilization. A second series was submerged for the 30-day period following fertilization. These samples furnished data for the 30-day periods before and after fertilization. In 1956 the 30-day substrates at station C were supplemented with a series of ten weekly shingles which were submerged and replaced at 7-day intervals throughout the summer. An additional series of weekly shingles were added in the summer of 1956 at station F. This station was located in the open area of the lake. Ten shingles were nailed to an anchored circular plywood disk, which was maintained at a depth of four feet below the water surface.

The field collecting of the periphyton substrates differed somewhat between the bricks and shingles. The bricks were removed from the water by means of the suspension wires and placed directly into an enameled pan. A stiff nylon brush and a wash bottle were used to remove attached material. The material and wash water were poured into quart jars for laboratory treatment. The shingles were placed directly into individual plastic bags for transport to the laboratory where the washing operation was performed.

Immediately following the field collections, the laboratory phase of pigment extraction was undertaken. Each sample of periphyton wash water was processed through a Foerst centrifuge to concentrate this mixture of algae, marl, sand, and debris. Previous to the centrifuging each sample had been picked-over for macro-invertebrates, which were preserved in 10 per cent formalin. The concentrated periphyton samples were washed from the centrifuge bowl with 95 per cent ethyl alcohol which acted as a solvent upon the cell pigments. The extracted pigment sample and its solid matter were stored in 2-ounce jars with 95 per cent ethyl alcohol.

Final laboratory work consisted of filtering each extracted pigment sample and bringing the filtrate up to a uniform volume of 50 ml. with 95 per cent ethyl alcohol. The density of each pigment sample was determined in a Klett-Summerson photoelectric colorimeter using a number 66 red filter. The values in Klett units were converted to Harvey units by the use of a graph based on known Harvey standards.

Benthic organisms. Each summer twenty Ekman dredge bottom samples were taken per week. Ten samples each were taken at station 1 and station 2. Station 1 was located in 7 feet of water, while station 2 was located in water 4 feet deep. A 30-mesh screen was used to wash each dredge sample before transfer into a white enameled pan for picking. Picked organisms were preserved in 10 per cent formalin for further laboratory work.

In 1956 the procedure was altered due to the lack of time necessary for the lengthy hunt-and-pick method. The bottom samples of the first two weeks were hand picked as in the other years, but the remaining weekly samples were processed by the flotation method. A sugar solution with a specific gravity of 1.110 was used to float organisms, which were removed from the surface with a fine-mesh wire scoop (Anderson, unpublished).

This technique proved ideal for Hoffman Lake due to the low organic content of its marl bottom type. The bottom type at station 1 and station 2 was composed mainly of shell and amorphous marls with very limited particles of organic matter. The finer materials appeared to be somewhat clay-like in texture.

Further laboratory work consisted of identification of all organisms, numerical counts of organisms, and volumetric measurements of each sample to the nearest five-hundredth milliliter. A burrowing mayfly naiad, Ephemera simulans, was the most representative of all samples. These individuals were measured for length in millimeters upon a Bogusch measuring slide. These linear measurements and the numbers of naiads were used to estimate instantaneous rates of growth and mortality for two separate generations of Ephemera simulans.

Fish. Fish traps and seines were operated each summer to secure fish samples for growth studies. Data on five species of fish were gathered throughout the study. Captured fish were measured for weight in grams and total length in inches. Scale samples were taken and each fish was fin clipped to avoid duplicate data in case of recapture the same summer.

Laboratory work involved mounting the scales on glass slides in a gelatin-glycerine medium. A scale projector and ruled scale cards were used to determine and record annuli for age-growth computations. The length-weight relationship, calculated lengths and weights at the last complete annulus, and the instantaneous rates of linear and gravimetric growth were computed from the scale card data.

The relationship between length and weight was obtained by use of the formula below (Carlander, 1953):

$$W = cL^n$$

W = weight

L = length

c and n = constants

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

ln = natural logarithm

The logarithmic form of the formula was used for computations.

The body scale relationship for each species was tested mathematically using the regression method to solve the equation:

$$Y = \underline{a} + bX$$

Y = total body length

X = scale radius

$\underline{a}$ and b = constants

The value of $\underline{a}$, the intercept of the regression line, was found to be negligible for all five species of fish sampled. This near zero intercept justified the use of the direct-proportion method of length determination, which is based on the assumption that a straight-line relationship exists between body and scale growth. A nomograph and ruled scale cards were used to back calculate the total lengths at the last complete annulus. Back calculations of lengths were determined for age groups on the nomograph using the direct-proportion formula (Lagler, 1952; Rounsefell and Everhart, 1953):

$$l = \frac{s}{S} L$$

l = body length at annulus x

s = length of scale radius at annulus x

L = body length at capture

S = length of scale radius at capture

The instantaneous growth rates for age groups were computed as follows (Anton, 1957):

$$\ln \frac{L_2}{L_1} = \text{instantaneous rate of linear growth}$$

$$\ln \frac{L_2}{L_1} \times n = \text{instantaneous rate of gravimetric growth}$$

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, $W = cL^n$

RESULTS

Sampling

Inorganic fertilizer applications to Hoffman Lake appear to have been the cause of two types of changes as shown in the physical and chemical data. These changes consisted of sudden temporary responses and other less obvious, but apparently more prolonged responses. These latter changes of a more permanent nature probably were direct or indirect reflections of the more pronounced temporary changes.

Periphyton seems to have responded noticeably to fertilizer applications each year of the study. Indications of an increase in phytoplankton after fertilization were detected only the final year. This detection may be due to a refinement in methods of plankton analysis in 1956. Thus, a favorable response by plankton during 1954 and 1955 may have occurred without detection. Two species of fish showed statistically sound evidence of favorable changes in their length-weight relationships after fertilization.

PHYSICAL

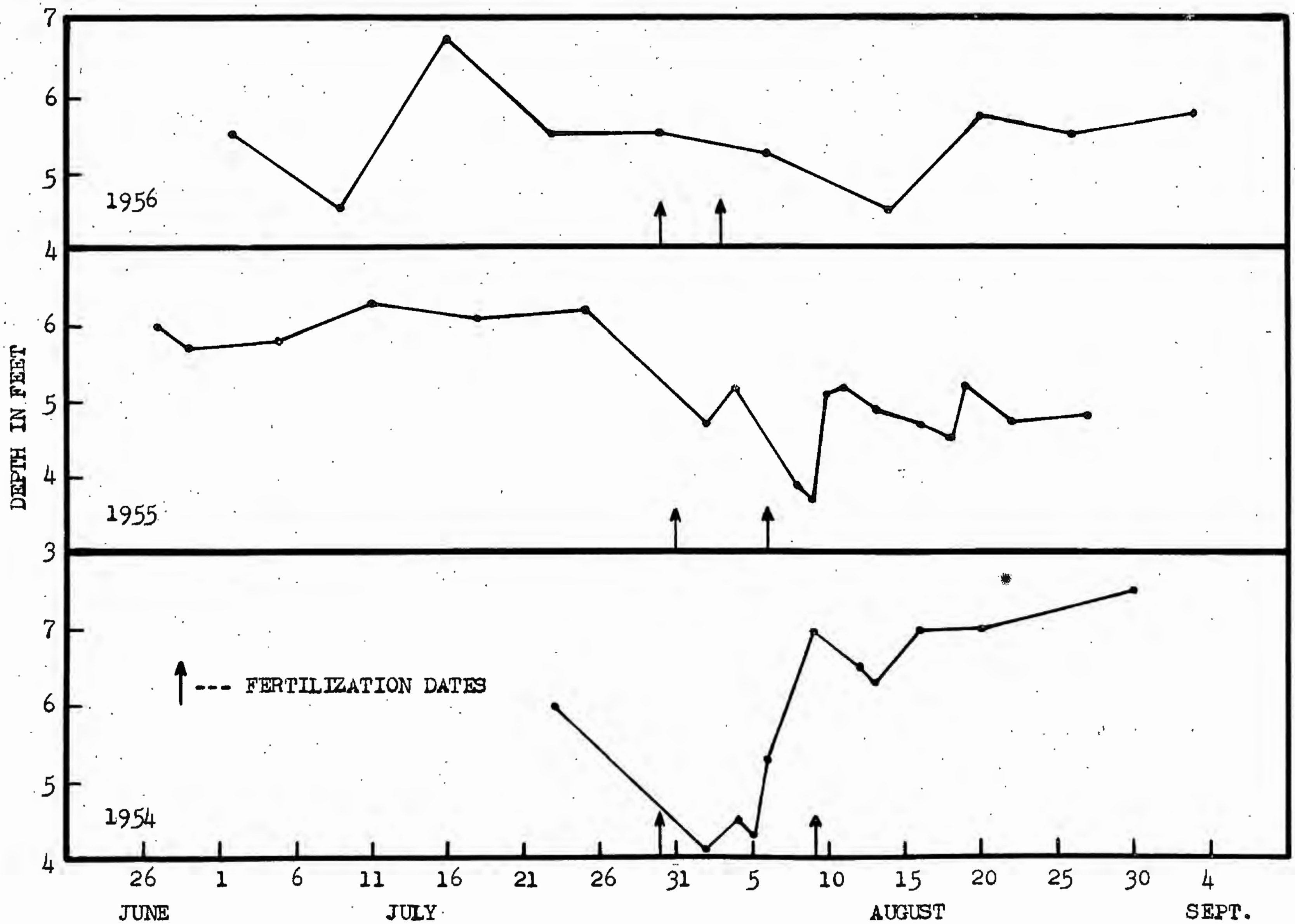
Secchi disk. The Secchi disk readings for the summer of 1956 are shown in Table 2. A graphical comparison of the data for all three years of the study is presented in Figure II (Alexander, 1956; Anton, 1957).

Figure II illustrates two trends regarding water transparency during

Table 2. Mean Secchi disk and photometer readings during summer of 1956

Date	Secchi Disk (feet)	Photometer readings showing per cent of surface light reaching following depths						
		1'	3'	6'	9'	12'	15'	18'
July								
2	5.5	52.8	33.0	17.6	10.2	6.0	3.7	1.8
9	4.5	31.7	19.7	12.3	8.3	6.4	5.1	2.6
16	6.75	55.0	18.8	13.2	7.7	5.8	2.9	1.7
23	5.5	81.8	27.8	14.4	9.0	5.9	3.3	1.9
30	5.5	54.5	29.7	15.0	12.7	7.6	4.5	2.3
August								
3	...	56.1	34.3	21.6	7.5	5.6	3.5	3.0
6	5.25	42.8	21.6	12.0	8.3	4.4	2.6	1.7
14	4.5	46.7	30.0	12.5	7.3	4.2	2.3	1.2
20	5.75	45.0	20.3	14.2	9.2	5.8	3.3	1.9
26	5.5	40.0	25.8	17.2	10.6	6.2	3.5	2.0
September								
3	5.75	53.6	32.1	16.7	10.3	6.4	3.9	2.4

Figure II. Mean Secchi disk readings in feet recorded in Hoffman Lake during the summers of 1954, 1955, and 1956


DEPTH IN FEET
1956
1955
1954
FERTILIZATION DATES
7
6
5
4
6
5
4
3
7
6
5
4
26
1
6
11
16
21
26
31
5
10
15
20
25
30
4
JUNE
JULY
AUGUST
SEPT.

the entire study. First, there are indications that the general water transparency, excluding the fertilization periods, decreased more each year of the study. Disregarding the application periods, the higher readings averaged near 7 feet in 1954, 6 feet in 1955, and 5½ feet in 1956.

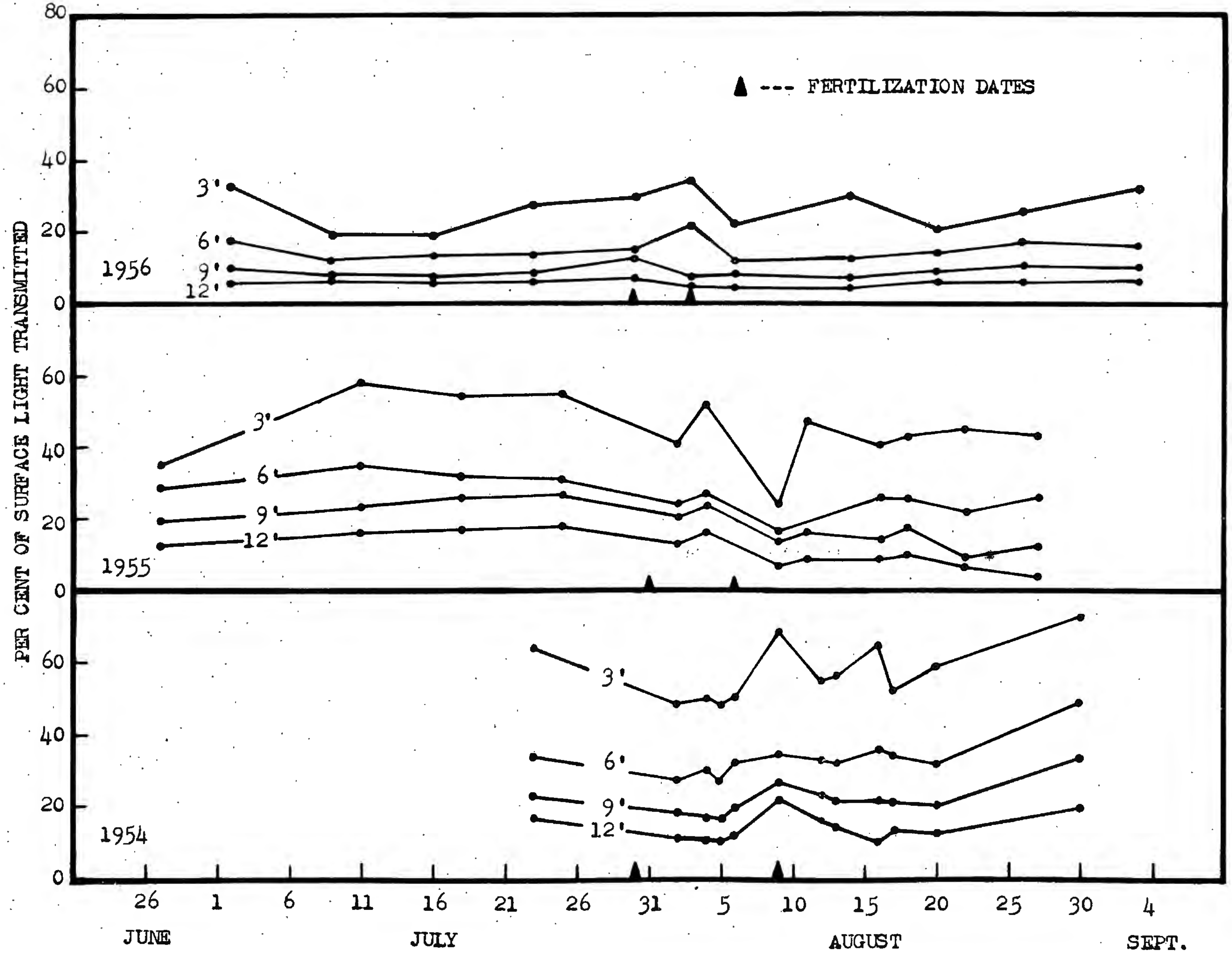
Secondly, the temporary reduction in transparency after fertilizer applications was less pronounced each year. This was especially noticeable the final summer, 1956, which did not exhibit a definite reduction in transparency after fertilization. The increased water transparency following the temporary reduction was also less pronounced each year.

The data suggest that the normal water transparency in Hoffman Lake decreased as the study progressed. It also appears that the temporary reductions in transparency after fertilizer applications were less pronounced each year of the study.

Submarine photometer. The submarine photometer reading closely supported the Secchi disk readings throughout the study period. Table 2 includes a list of the submarine photometer readings for 1956. A comparison of the annual readings are shown in Figure III (Alexander, 1956; Anton, 1957).

Light penetration was less each ensuing year of the study. Reduced light penetration was observed at all depths as shown by Figure III. The per cent of surface light transmitted annually to the 3 foot level ranged around 60 per cent in 1954, 50 per cent in 1955, and 30 per cent in 1956 (Figure III). Similar patterns in annual reductions at the other levels are illustrated in the graph also.

Figure III. Percentages of transmitted light recorded at 3, 6, 9, and 12 feet in Hoffman Lake during the summers of 1954-56



▲ --- FERTILIZATION DATES
PER CENT OF SURFACE LIGHT TRANSMITTED
80
60
40
20
0
1956
3'
6'
9'
12'
60
40
20
0
1955
3'
6'
9'
12'
60
40
20
0
1954
3'
6'
9'
12'
26
1
6
11
16
21
26
31
5
10
15
20
25
30
4
JUNE
JULY
AUGUST
SEPT.

Corresponding to the declining effect of successive fertilizer applications to reduce water transparency was a similar effect upon light penetration. An abrupt reduction in light penetration followed the 1954 fertilizer applications. In 1955 a similar response to fertilization occurred.

The final year, 1956, showed a slight increase in light penetration on August 3 and a similar decrease on August 6. The August 3 increase was noted only at the 3 and 6 feet levels and was not supported by definite similar or inverse trends at deeper levels. The data for August 3, 1956, seemed to imply that the photometer readings were aberrant at least in part.

The possibility of suspended material reducing the light penetration between the 6 and 9 feet levels on August 3 seemed remote. If an abnormal amount of light was lost between those levels, a marked reduction in percentage of light transmitted was observed only at the 12 foot level (Figure III). Since no water samples were collected between 6 and 9 feet, the presence of increased suspended material between those levels can not be definitely established or denied.

The correlation between the Secchi disk readings and submarine photometer readings indicates that light transmission and water transparency were affected by fertilizer applications directly. There is evidence also that a more prolonged effect was occurring throughout the study period. Possible causes of these effects will be discussed fully in the results concerning "Plankton".

Temperature. The air and water temperatures recorded during the summer of 1956 are listed in Table 3. The water and air temperatures for 1956 appeared to flucuate in harmony with each other. The trends in air temperature were more pronounced than those in water temperature. Generally the water temperatures throughout the study period were of a homothermous nature. Occasional tendencies towards thermal stratification were recorded in depressions during calm weather. Normally wind action on Hoffman Lake with its resultant mixing of the shallow lake waters maintained a nearly constant homothermous condition.

Figure IV presents a graphical comparison of the air and surface water temperatures for the entire three year study period. The graphs indicate that lower air and water temperatures were recorded the initial and final years. Temperatures during the initial summer had a tendency to decrease throughout the summer (Alexander, 1956). The temperature the final summer, 1956, averaged very close to that of 1954, but varied less frequently. In the intermediate year, 1955, higher temperatures were recorded in July and August. The mean surface water temperatures recorded were 21° C. in 1954, 24° C. in 1955, and 20° C. in 1956 (Alexander, 1956; Anton, 1957).

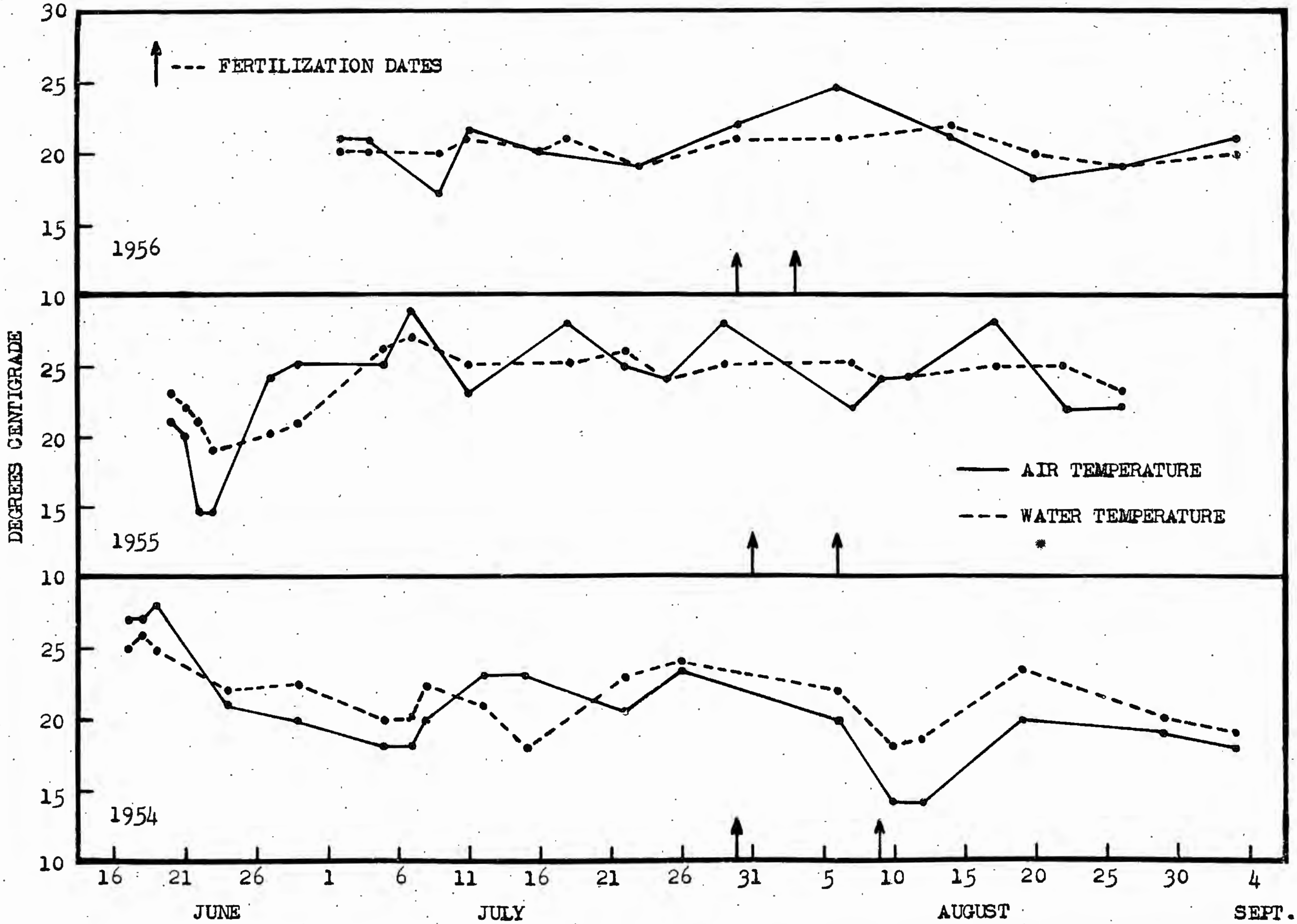
These temperatures and their indications are supported by comparisons with the mean monthly air temperatures recorded by three United States Weather Bureau Stations located within a 20 mile radius of Hoffman Lake. These were the Boyne Falls State Nursery, Gaylord Conservation Department, and Vanderbilt Trout Station. The Weather Bureau data indicate that the total summer precipitation was also very similar in 1954 and 1956, while in 1955 precipitation was noticeably lower (United States Department of Commerce, Weather Bureau, 1955, 1956, 1957.

Table 3. Air and water temperatures ($^{o}F.$) recorded during the summer of 1956

Date	Air Temp.	1'	5'	10'	15'	16'	17'	18'	19'	20'	Notes
July											
2	70.0	68.0	..	..	..	..	..	..	..	..	....
4	69.0	68.5	68.5	66.2	64.5	..	..	..	..	62.0	Wind**
9	62.5	67.5	68.0	67.5	65.5	..	..	..	..	61.0	Calm
11	72.5	69.5	69.5	69.5	67.2	66.5	66.0	65.2	64.0	63.0	Wind*
16	67.5	68.5	68.5	68.0	67.5	67.0	66.0	65.0	63.2	62.2	Calm
18	..	70.0	..	..	..	..	..	..	..	..	Calm
23	67.0	66.8	67.0	67.0	67.0	66.0	65.5	65.0	64.0	63.5	Wind
30	71.5	70.0	69.0	68.5	67.5	..	..	..	..	66.0	Wind
August											
6	76.0	69.0	68.5	68.0	67.5	..	..	..	..	66.5	Wind
14	70.5	71.0	70.5	70.0	68.0	67.5	66.5	65.5	65.0	64.0	Wind*
20	64.0	67.5	68.5	68.0	67.5	67.0	66.5	66.0	66.0	66.0	Wind**
26	67.0	65.5	65.2	65.2	65.0	..	..	..	..	64.0	Wind
Sept.											
3	70.0	68.0	67.8	67.8	67.5	..	..	..	..	66.8	Wind

* Moderate wind
** Strong wind

Figure IV. Mean air and surface water temperatures recorded at Hoffman Lake during the summers of 1954-56


FERTILIZATION DATES
DEGREES CENTIGRADE
30
25
20
15
10
1956
1955
1954
AIR TEMPERATURE
WATER TEMPERATURE
16
21
26
1
6
11
16
21
26
31
5
10
15
20
25
30
4
JUNE
JULY
AUGUST
SEPT.

CHEMICAL

Alkalinity. The total alkalinity values for Hoffman Lake during the summer of 1956 are listed in Table 4. Nearly all of the alkalinity in Hoffman Lake was due to bicarbonates. The titration method employed failed to show any phenolphthalein alkalinity present in these samples. Moore's nomograph was utilized to secure a measure of the carbonate alkalinity present in the samples (Moore, 1939). By plotting the total alkalinity and pH data for an individual sample, a measure of its carbonate alkalinity was determined from the nomograph.

The calculated carbonate alkalinities ranged from 1.0 - 5.0 p. p. m. with a summer average of 2.0 p. p. m. According to Standard Methods (1955), the accuracy of the titration method is plus or minus 2.0 p. p. m. between 10 and 500 p. p. m. Thus, the calculated average carbonate value of 2.0 p. p. m. was within the error of the method.

Fertilization appeared to have no measurable effect on alkalinity during the summer of 1956. The alkalinity in 1956 varied from 113-138 p. p. m. with a mean of 126 p. p. m. during the summer. The extreme values were recorded early in the summer. This stable alkalinity was also observed the preceding two summers. In 1954 Alexander (1956) recorded an alkalinity range of 128 to 133 p. p. m., while in 1955 Anton (1957) recorded 135 to 140 p. p. m.

Hydrogen-ion concentration. The pH readings recorded from water samples taken during the summer of 1956 are listed in Table 5. Hydrogen-ion concentration, like the alkalinity, failed to show any measurable effects from fertilization. The 1956 range of 7.9 to 8.5 was slightly

Table 4. Total alkalinity in parts per million from station B, Hoffman Lake, 1956

Date	Phenolphthalein Alkalinity**	Methyl-orange Alkalinity	Total Alkalinity
July			
2	0	138.	138.
9	0	135.	135.
16	0	113.	113.
23	0	123.	123.
30*	0	130.	130.
August			
3*	...	....	....
6	0	126.	126.
14	0	126.	126.
20	0	125.	125.
26	0	126.	126.
September			
3	0	126.	126.

* Fertilization dates
** Carbonate values below accuracy of method

Table 5. Hydrogen-ion concentration (pH) from station B, Hoffman Lake, 1956

Date	pH	Date	pH
		August	
July		3*	...
2	8.0	6	8.3
9	7.9	14	8.5
16	8.0	20	8.3
23	8.1	26	8.1
30*	8.2	September	
		3	8.2

* Fertilization dates

wider than the 1954 values of 8.2 to 8.5 and the 1955 values of 8.1 to 8.3.

The fact that the pH of Hoffman Lake did not show a measurable response to fertilization is no doubt due to its highly buffered waters. In natural waters the amount of buffering action against pH changes depends on the bicarbonate content (Ruttner, 1953). The high bicarbonates of magnesium and calcium, especially calcium bicarbonate, in Hoffman Lake were shown by the high methyl orange alkalinity.

<u>Dissolved oxygen</u>. Dissolved oxygen determinations were made during a calm period in the summer of 1956. On August 20 with a surface temperature of 20° C. dissolved oxygen was as follows:

Depth (feet)	O_2 (p. p. m.)
10	6.5
15	6.4
17	5.8
19	5.8
20	5.5

No evidence of definite chemical stratification was indicated by these dissolved oxygen concentrations. Determinations made in 1955 also showed no evidence of a chemocline.

<u>Specific conductance</u>. The specific conductances recorded during the summer of 1956 are listed in Table 6. These readings did not show any changes contributable to the fertilizer applications that summer. Except for the initial summer readings, the alkalinity and conductivity readings seem to be in agreement. An initial disagreement between conductivity and alkalinity appears to be due to inaccurate analyses

Table 6. Mean specific conductance in mhos at 18° C. from Hoffman Lake during the summer 1956

Date	Mhos ($X 10^{-6}$) at 18° C.
July	
2	303.
9	253.
16	294.
23	263.
30*	274.
August	
3*	....
6	269.
14	278.
20	241.
26	256.
September	
3	250.

* Fertilization dates

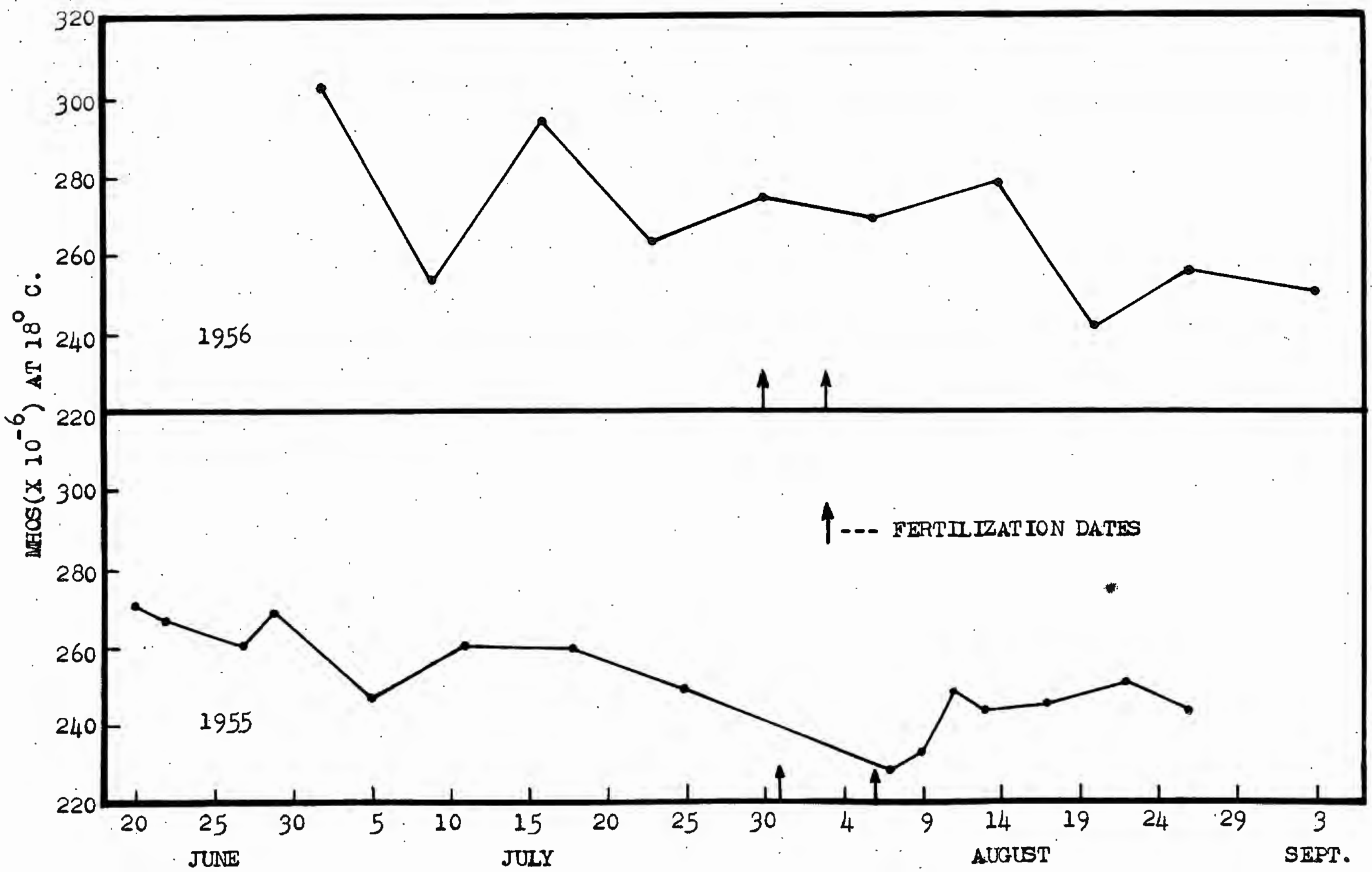
rather than of a chemical origin in the samples since a control station also had a corresponding disagreement.

Since the alkalinity and total conductivity for the remainder of the summer exhibited similar trends, it was suspected that the bicarbonate conductivity would follow likewise. Using graphical data furnished by Ruttner (1953), the amount of bicarbonate conductivity was approximated. By converting a methyl orange alkalinity reading into equivalent parts per million, an approximate calcium bicarbonate conductivity value for that sample was obtained. These conductivity values for calcium bicarbonate followed the total conductivity values uniformly except for the early summer disagreement. The uniform agreement between calcium bicarbonate and total conductivity indicated that other electrolytes did not vary measurably during the summer of 1956. Other electrolytes would include sulfates, chlorides, and certain organic matter.

Figure V is a graphical illustration of the conductivity readings for 1955 (Anton, 1957) and 1956. Both years suggest a slight decline in conductivity through the summer periods. This decline may be an annual occurrence in Hoffman Lake.

The 1955 graph indicates a temporary decrease in conductivity following fertilization. Anton (1957) believed that a flocculent precipitation of phosphates and sulfates after fertilization was responsible for a temporary reduction in ions in 1955. The data of 1956 did not exhibit either a definite reduction in conductance or physical evidence of precipitate formation after fertilization. The mean specific conductance for the summer of 1955 and 1956 were 252×10^{-6} mhos and 268×10^{-6} mhos respectively.

Figure V. Specific conductance in mhos ($X\ 10^{-6}$), Hoffman Lake, 1955 and 1956



MHOS(X 10^{-6}) AT 18^{o} C.
320
300
280
260
240
220
1956
1955
--- FERTILIZATION DATES
20
25
30
5
10
15
20
25
30
4
9
14
19
24
29
3
JUNE
JULY
AUGUST
SEPT.

Interpretations of the higher mean conductance in 1956 must be made with caution since there are numerous factors affecting conductivity of a solution. Ellis, Westfall, and Ellis (1948) list variability in conductivity due to particular compounds, concentration, degree of ionization, and temperature. A comparison of conductivity readings from the control station in 1955 and 1956 showed a similar increment of increase in 1956. This suggested that the differences in annual readings may have resulted from errors in analyses rather than from true differences..

Ammonia nitrogen. The ammonia values recorded from five sampling stations during the summer of 1956 are presented in Table 7. These values were based on single samples; however, the general agreement between stations indicated that the figures were representative. There were no significant changes in ammonia values other than temporary increases at station C and D after the second fertilizer application on August 3.

Similar temporary increases in ammonia nitrogen were also recorded the two previous summers. The ammonia concentrations recorded annually at station C, the lake outlet, are presented graphically in Figure VI. Each year ammonia dropped to prefertilization levels after temporary increases resulting from fertilization.

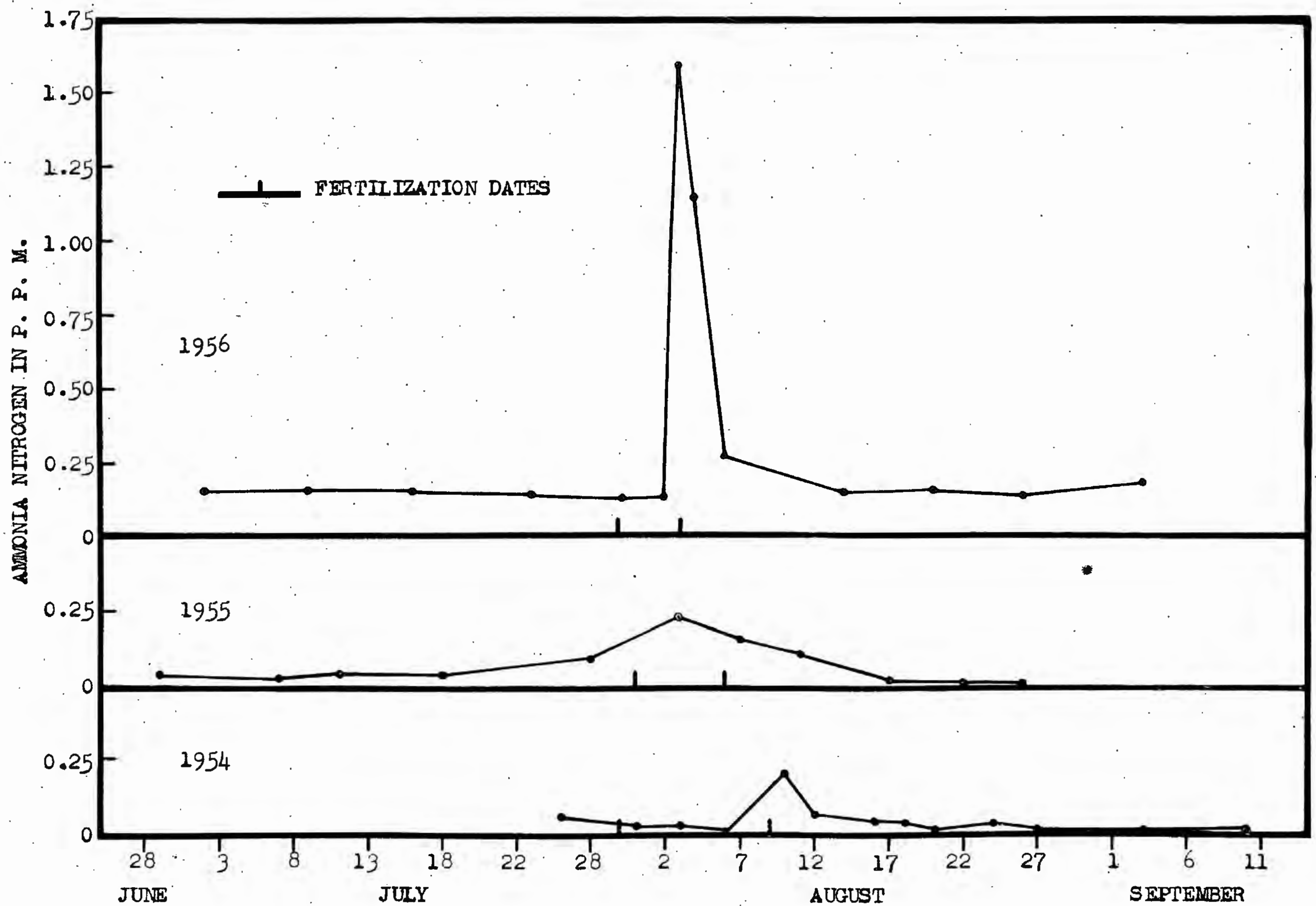
Figure VI illustrates a higher mean value of ammonia in 1956 than during the two preceding summers. The analyses of water samples from the control station also showed a similar higher mean value in 1956. This evidence suggested that the differences in annual mean values may have been due to analysis variability rather than actual differences.

Table 7. Concentrations of ammonia nitrogen in parts per million from stations A through E, Hoffman Lake, 1956

Date	Stations A	B	C	D	E
July					
2	....	0.16	0.16	....	....
9	....	0.16	0.16	....	....
16	....	0.14	0.15	....	....
23	....	0.13	0.14	....	....
30*	....	0.12	0.13	....	....
August					
2	0.18	0.13	0.14	0.15	....
3*	0.15	....	1.58	0.29	0.16
4	0.18	....	1.14	0.20	0.14
6	....	0.14	0.27	....	....
14	....	0.16	0.15	....	....
20	....	0.16	0.16	....	....
26	....	0.14	0.14	....	....
September					
3	....	0.18	0.19	....	....

* Fertilization dates, samples taken after applications

Figure VI. Ammonia nitrogen in parts per million from station C, outlet of Hoffman Lake, during the summers of 1954-56


FERTILIZATION DATES
AMMONIA NITROGEN IN P. P. M.
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
1956
1955
1954
28
3
8
13
18
22
28
2
7
12
17
22
27
1
6
11
JUNE
JULY
AUGUST
SEPTEMBER

The comparatively high mean values in 1956 approached those of very fertile or polluted waters (Moyle, 1956). This suggests that the 1956 analyses were probably the most abberant. The values obtained during the first two years were probably nearer the actual ammonia values. These evident variable results indicate that ammonia analysis and its reagents should be the responsibility of one analyst if discrete comparisons are desired.

According to Hutchinson (1957), ammonia in waters is "mainly as NH_4^+ and as undissociated NH_4OH". The temporary increases in ammonia in Hoffman Lake were mainly due to dissociated ions in solution. The annual decreases in ammonia to prefertilization levels seem natural since ammonia is converted by bacteria to nitrites and nitrates in the presence of oxygen. The dissolved oxygen in Hoffman Lake was determined to be plentiful even at maximum depths. Direct utilization of ammonia by higher plants (Moyle, 1956) and dilution through mixing may have contributed to re-establishing the ammonia equilibrium in Hoffman Lake.

Phosphorus. The concentrations of total phosphorus for 1956 are listed in Table 8. Temporary increases in total phosphorus values were recorded at all stations except station B following fertilization. The few samples from station B and its location in deep water did not allow for a complete evaluation of its data.

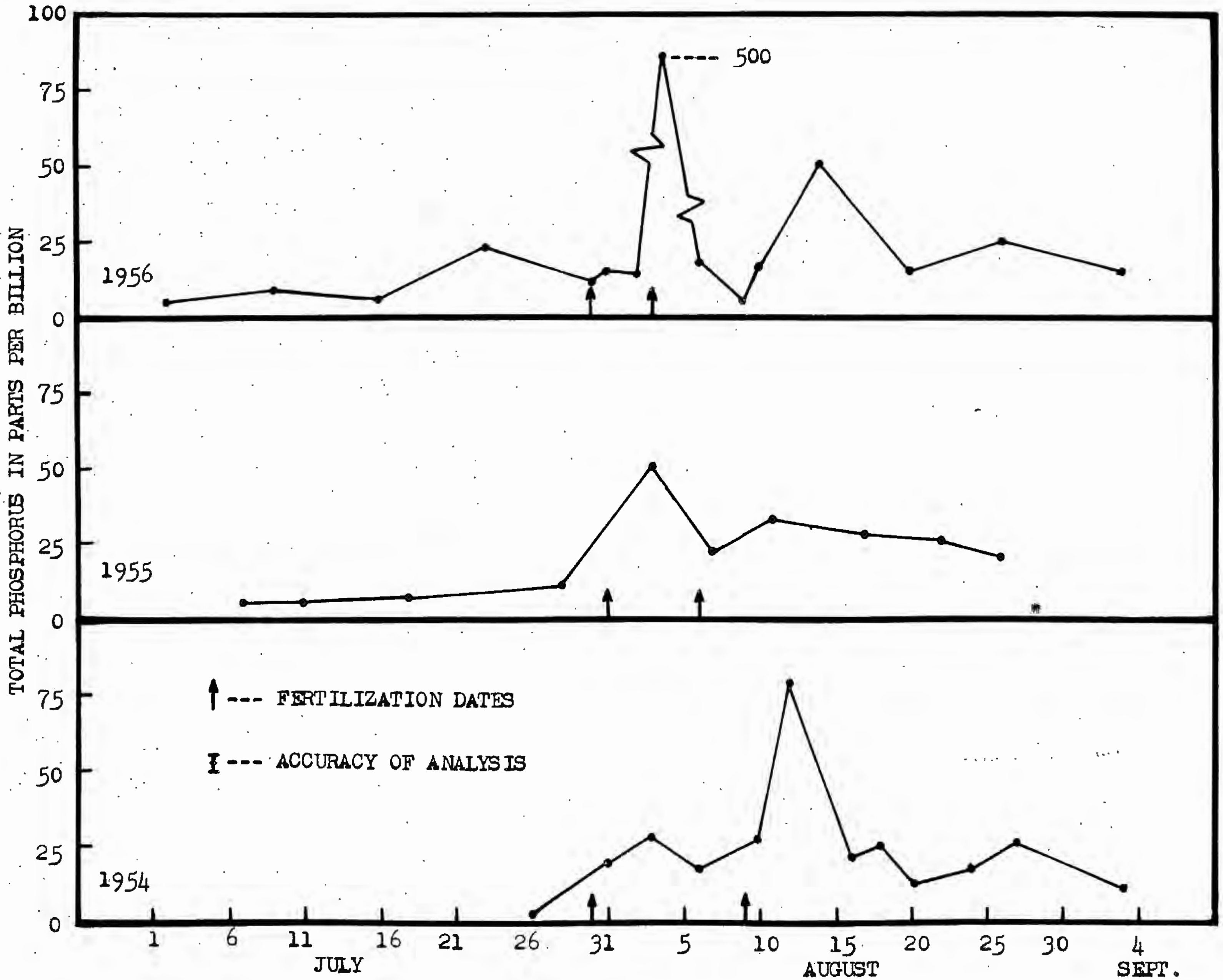
The total phosphorus values obtained at station C, the lake outlet, throughout the study are graphed in Figure VII. A temporary increase after fertilization was recorded each summer of the study. The very high pulse of 500 p. p. b. recorded in 1956 may have resulted in part

Table 8. Concentrations of total phosphorus in parts per billion from stations A through E, Hoffman Lake, 1956

	Stations				
Date	A	B	C	D	E
July					
2	....	2.6	4.4	....	....
9	....	10.0	8.8	....	....
16	....	9.7	6.3	....	....
23	....	28.5	23.0	....	....
30*	....	8.8	11.0	....	....
31	42.0	....	15.0	27.5	18.0
August					
1	16.5	....	....	19.0	18.5
2	....	24.0	14.0	46.0	18.0
3*	21.0	....	500.0**	31.0	15.0
4	35.0	....	256.0	64.5	34.5
6	....	8.2	17.8	....	....
9	15.0	....	5.0	....	....
10	....	....	16.5	....	7.5
14	....	22.5	50.5	....	....
20	....	12.2	15.5	....	....
26	....	8.5	25.5	....	....
September					
3	....	3.0	15.0	....	....

* Fertilization dates, samples taken after applications
** Approximation of a value beyond range of colorimeter

Figure VII. Total phosphorus in parts per billion from station C, outlet of Hoffman Lake, during the summers of 1954-56


TOTAL PHOSPHORUS IN PARTS PER BILLION
100
75
50
25
0
500
1956
1955
1954
FERTILIZATION DATES
ACCURACY OF ANALYSIS
1
6
11
16
21
26
31
5
10
15
20
25
30
4
JULY
AUGUST
SEPT.

from fertilizer applied near the outlet area. Each summer the decrease in total phosphorus after fertilization was a gradual decline. These declines did not drop to prefertilization levels during the remainder of the summer periods, but they appear to have done so by the beginning of the following summer.

A complete comparison of annual prefertilization total phosphorus levels is difficult due to the lack of sufficient data in 1954. A comparison of prefertilization levels is further complicated by the natural variation within the water, in sampling, and in analysis (Moyle, 1956). Assuming that the annual variations were uniform, there is no evidence of a general increase in total phosphorus in the lake waters. According to Hayes's (1951) equilibrium theory, a detectable increase in phosphorus would be noted only for a period of a few weeks after fertilization.

The fate of added inorganic phosphorus after fertilization has been postulated upon by many workers (Maciolek, 1954). Combination with excessive calcium into insoluble tricalcium phosphate has often been suspected. Barrett (1952) studied the precipitation of phosphorus by calcium with laboratory experiments. He obtained evidence that "supported the assumption that precipitation of phosphorus by calcium may be an adsorption mechanism, rather than simply a molecular formation of tri-calcium phosphate".

Alexander (1956) and Anton (1957) obtained evidence of precipitate formation after fertilization in Hoffman Lake during 1954 and 1955. They postulated that this precipitate may have been tricalcium phosphate.

Little evidence of a precipitate or "floc" formation was obtainable from data in 1956. No doubt some of the soluble phosphorus was utilized by phytoplankton, periphyton, and higher aquatic plants throughout the study. Planktonic algae have been known to store more than ten times their normal store of phosphorus (Ruttner, 1953).

BIOLOGICAL

Plankton. The first two years of the study, plankton was very sparse in plankton samples. Table 9 is a qualitative list of the genera of plankton observed in weekly plankton samples in 1956. The flora was predominately of the cyanophyta-diatom type. Results of a "t" test (Snedecor, 1956) indicated that the difference between mean numbers of genera observed weekly before and after fertilization was not statistically significant.

The total suspended solids and their volatile, carbonate, and organic fractions in 1956 are listed in Table 10. The total suspended solids and their organic fractions were somewhat higher in 1956 than in 1954 and 1955 (Figure VIII). The carbonate fractions were of similar magnitude each year, except no abrupt increase in carbonates after fertilization was apparent in 1956.

Following fertilization in 1954 and 1955, abrupt increases in total suspended solids were recorded (Figure VIII). These increases were accompanied by increases of similar magnitude for the carbonate fractions. Alexander (1956) and Anton (1957) postulated that the increases were due to a flocculent formation of calcium, sulphates, and phosphates. A flocculent material believed to be tricalcium phosphate was observed at

Table 9. Qualitative list of plankton indentified in weekly plankton samples from Hoffman Lake, summer, 1956

Collection Date	July					August				September
	2	9	16	23	30	6*	14*	20*	26*	3*
Cyanophyta										
Aphanocapsa sp.	0	0	0	0	0	0	0	X	X	0
Chroococcus sp.	X	X	X	X	X	0	X	X	X	X
Gloeocapsa sp.	0	0	0	0	0	0	0	0	X	0
Merismopedia sp.	0	0	0	0	0	0	X	0	0	0
Microcystis sp.	0	0	0	0	X	X	0	X	X	X
Chlorophyta										
Cosmarium sp.	0	0	0	0	0	0	X	X	0	0
Gonium sp.	0	0	0	0	0	0	X	0	0	0
Scenedesmus sp.	0	0	0	X	0	0	X	0	0	0
Tetraedron sp.	0	0	0	0	0	0	0	0	X	0
Chrysophyta										
Characiopsis sp.	0	0	0	X	0	0	0	0	0	0
Cocconeis sp.	X	X	0	X	0	0	X	X	X	X
Coscinodiscus sp.	X	X	X	X	X	X	0	X	X	X
Gomphonema sp.	0	0	0	0	0	0	0	0	0	X
Navicula sp.	0	0	0	0	0	0	0	0	X	0
Stephanodiscus sp.	0	X	X	X	X	0	X	0	X	0
Synura sp.	0	X	0	X	0	X	X	X	0	0
Colonial Flagellate	0	0	0	0	0	0	X	0	0	0
Total Varieties	3	5	3	7	4	3*	9*	7*	9*	5*

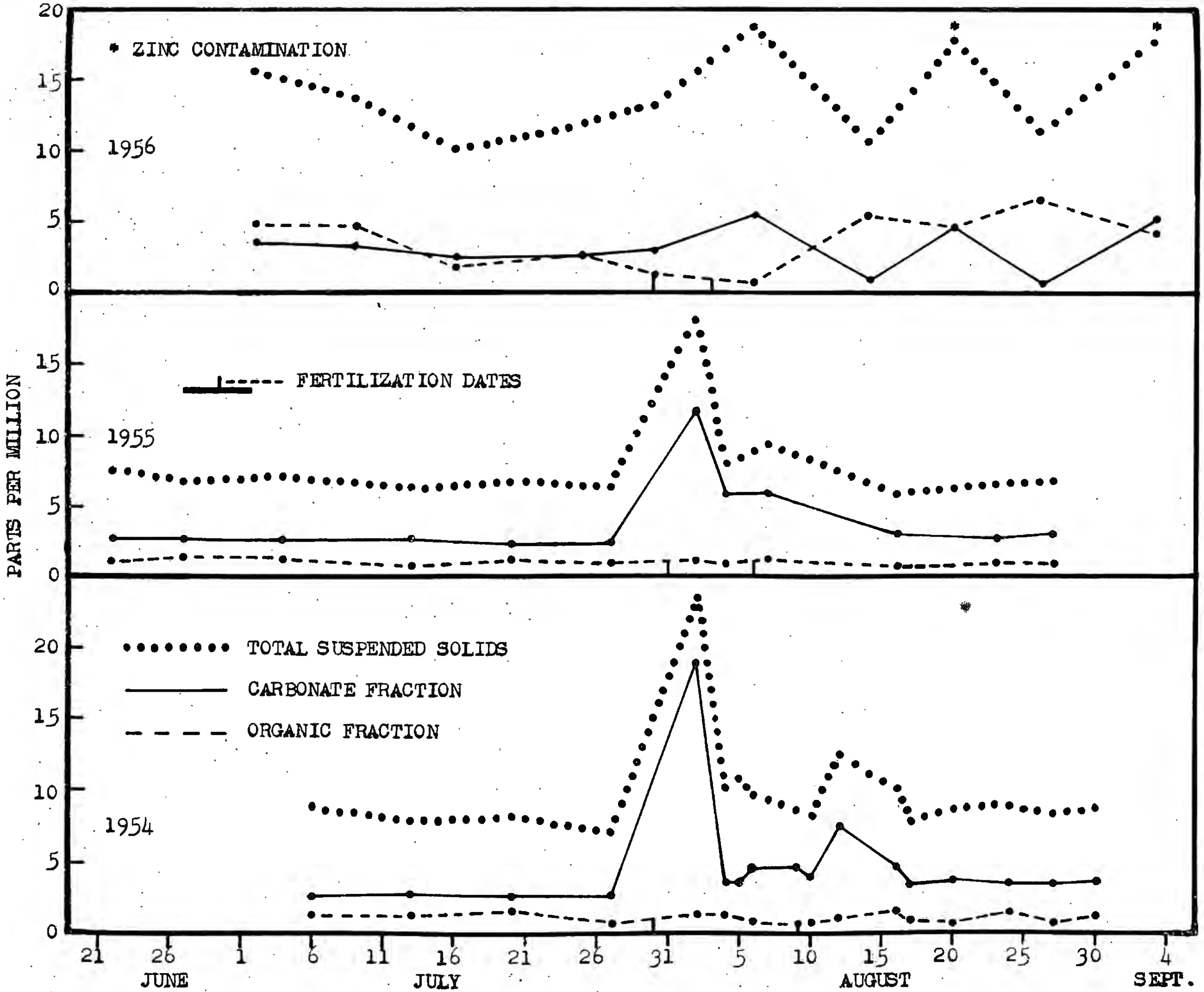
* After fertilization
X Denotes at least one individual observed

Table 10. Total suspended solids, volatile fractions, organic fractions, and carbonate fractions in water samples from station B, Hoffman Lake, 1956. Data in parts per million

Date	Total Suspended Solids	Volatile Fraction of Total	Organic Fraction	Carbonate Fraction (as CO_2)
July				
2	15.5	8.5	4.9	3.6
9	13.7	8.0	4.7	3.3
16	10.0	4.1	1.8	2.3
25	11.9	5.1	2.6	2.5
30*	13.2	4.2	1.2	3.0
August				
3*	....	...	...	...
6	18.7	6.2	0.8	5.4
14	10.5	6.2	5.3	0.9
20**	17.7	9.2	4.6	4.6
26	11.1	7.5	6.7	0.8
September				
3**	17.7	9.2	4.1	5.1

* Fertilization dates
** High values due in part to zinc contamination

Figure VIII. Total suspended solids, organic fractions, and carbonate fractions for the summers of 1954-56



* ZINC CONTAMINATION
1956
FERTILIZATION DATES
1955
TOTAL SUSPENDED SOLIDS
CARBONATE FRACTION
ORGANIC FRACTION
1954
PARTS PER MILLION
JUNE
JULY
AUGUST
SEPT.

this period by Alexander (1956). These postulations were supported by decreases in photometer and Secchi disk readings after fertilization.

The nonvolatile residues obtained during these pulses in suspended solids were abnormally low compared with other periods of the two summers. Alexander (1956) found a decrease in total hardness and calcium occurring at the same time. These data suggest that the "floc" formed may have been an adsorption of excess phosphate ions upon calcium ions. Barrett (1952), as mentioned earlier, found evidence of adsorption of phosphate rather than simply molecular formation with calcium. If sudden adsorption of many phosphate ions by calcium did occur in 1954 and 1955, this might account for the extremely high carbonate fraction and low nonvolatile residue at fertilization. In 1956 there was little evidence of a "floc" or precipitate formation.

The variations in total suspended solids in 1956 appeared to be due to normal flucuations in carbonates and flucuations in the organic fraction. The high increases in total suspended solids on August 20 and September 3 were probably due to zinc contamination from the lids of water storage jars. High amounts of zinc were detected in these two samples.

Part of the higher values in 1956 may reflect the higher efficiency of the Millipore filter over the Foerst centrifuge used in 1954 and 1955. This may be true particularly in regard to plankton and bacteria retention. Creity and Richards (1955) compared both methods with aliquot samples of sea water. They found the Millipore filter significantly more efficient in retaining plankton. The high efficiency of Millipore filters in retaining bacteria is illustrated by their use in bacteriology (Lovell Chemical Company, undated). However, lower photometer and Secchi disk readings throughout 1956 imply that the suspended solids may have actually been higher than in previous years.

The higher organic fractions from Hoffman Lake samples in 1956 represents a measure five times larger than the 1954 and 1955 values (Figure VIII). This large increase from 1 p. p. m. to 5 p. p. m. in 1956 suggests a truly higher organic fraction rather than increased efficiency of separation. This increase of 4 p. p. m. in the organic fraction is responsible for most of the higher total suspended solids in 1956. Figure VIII not only illustrates a higher organic fraction in 1956, but also shows the increase in this fraction after fertilization. It is believed that the suggested increase after fertilization in 1956 consisted mainly of phytoplankton since evidence of zooplankton was negligible in qualatative samples (Table 9).

<u>Periphyton</u>. As described under "Methods", artificial substrates were submerged in Hoffman Lake for two different time periods. Those shingles submerged and collected at 7-day intervals are referred to as weekly shingles and were located at both stations C and F. Other shingles and bricks were submerged at station C for 30 days before fertilization and 30 days after fertilization. These substrates are referred to as 30-day shingles and as bricks.

Post-fertilization increases in the density of extracted pigments were noted from both the weekly and 30-day artificial substrates in 1956. Tables 11-14 are records of the densities of extracted pigments collected from substrates at stations C and F.

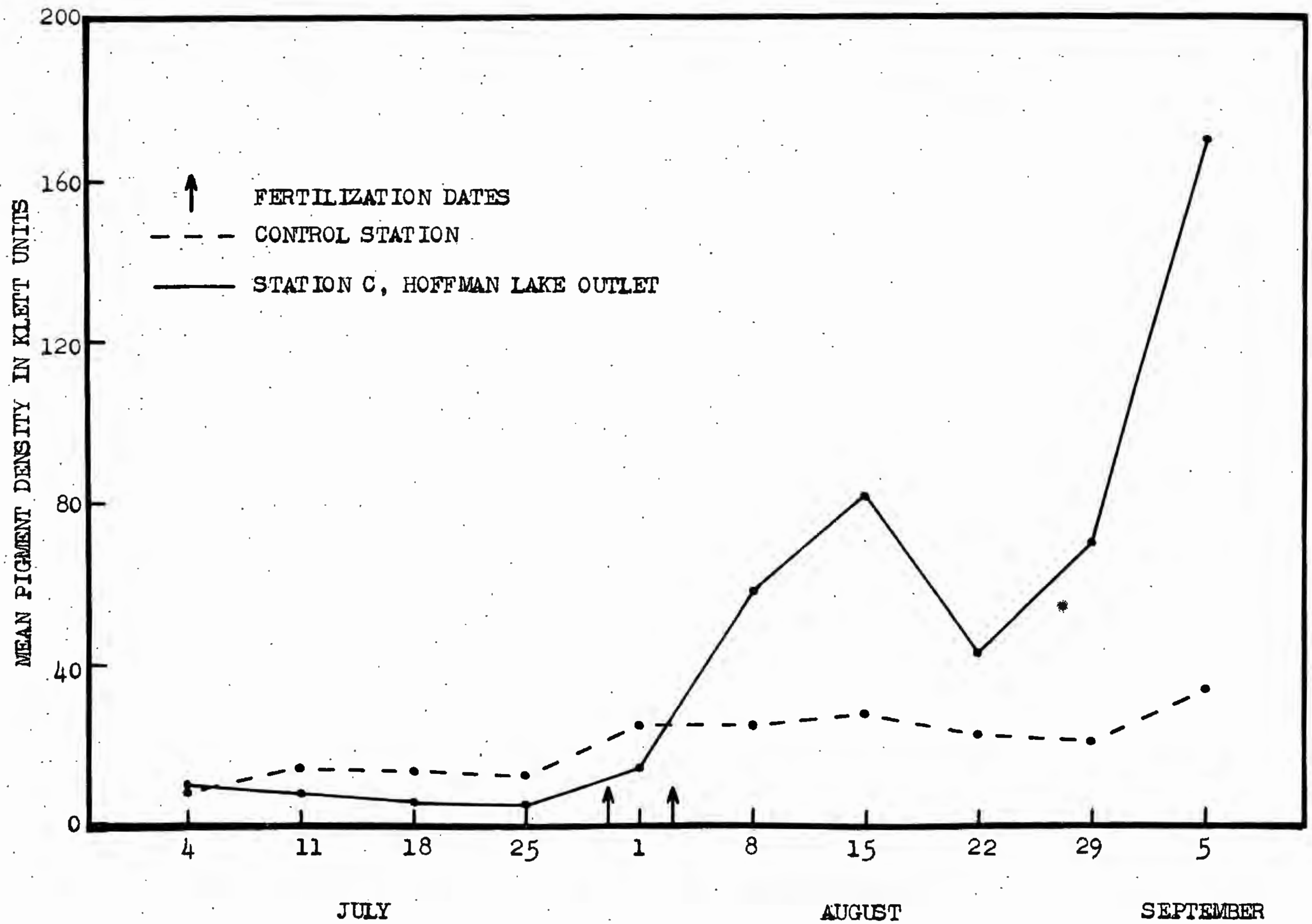
In Tables 11 and 12 a noticeable increase in mean pigment densities after fertilization is apparent upon weekly shingles from stations C and F. An analysis of variance determined that statistically a highly significant difference existed between weekly samples. Individual samples within weeks did not differ significantly (Table 15). These tests indicated that the weekly differences in pigment densities were the result of more than simply chance of sampling 99 per cent of the time.

Figure IX is a graphical comparison of weekly mean pigment densities at station C and the control station. A rapid increase in pigments is apparent at station C after fertilization, while at the unfertilized control station, the pigment density remained constant.

In Tables 13 and 14 large increases in pigment densities of 30-day shingles and bricks following fertilization are apparent. Mean increases of 193.3 and 119.4 Klett units were recorded for shingles and bricks, respectively. An analysis of variance determined that statistically a highly significant difference existed between pairs of substrates before and after fertilization (Table 16).

The data and statistical analyses indicated that increases in pigment densities had occurred after fertilization in 1956. As stated previously under "Methods", earlier workers have shown that pigment densities can be used to indicate trends in the abundance of periphyton. Evidence that fertilization may increase periphyton was illustrated in Figure IX where the control periphyton remained constant. The absence

Figure IX. Mean density of pigments extracted from shingles located at the lake outlet, station C, for 7-day periods compared with shingles from the control (unfertilized) station


MEAN PIGMENT DENSITY IN KLETT UNITS
0
40
80
120
160
200
FERTILIZATION DATES
CONTROL STATION
STATION C, HOFFMAN LAKE OUTLET
4
11
18
25
1
8
15
22
29
5
JULY
AUGUST
SEPTEMBER

of a change in the pigment level at the control station indicates that changes in light and temperatures were not significant factors in bringing about the increase of periphyton in the lake during the post-fertilization period. Water and air temperatures during the entire summer were quite constant (Table 3; Figure II).

Alexander (1956) and Anton (1957) also found statistically sound evidence of increases in periphyton upon 30-day bricks and shingles in Hoffman Lake after fertilization. Figure X is a graphical comparison of mean pigment densities from 30-day bricks each summer of the study. The increases after fertilization were similar in 1954 and 1956 being 10 times and 11 times greater, respectively, than before fertilization. Fertilizer concentrations, temperatures, and precipitation were similar both years. In 1955 an increase in mean pigment density of only 4 times the prefertilization mean was obtained.

Post-fertilization increases in periphyton upon the 30-day shingles corresponded to the increases obtained each summer upon the bricks. Alexander (1956) and Anton (1957) obtained 30 times and 2 times more periphyton, respectively on 30-day shingles after fertilization, while in 1956 thirteen times more periphyton was obtained after fertilization.

Although twice as much fertilizer was applied in 1955, the temperatures were higher and precipitation was lower than the other two years. There is a possibility that the suggested lower lake level and outflow in 1955 may have made less nutrients available for periphyton located in the outlet area, station C, than in 1954 and 1956.

Figure X. Mean pigment densities in Harvey units from 30-day bricks, 1954-56

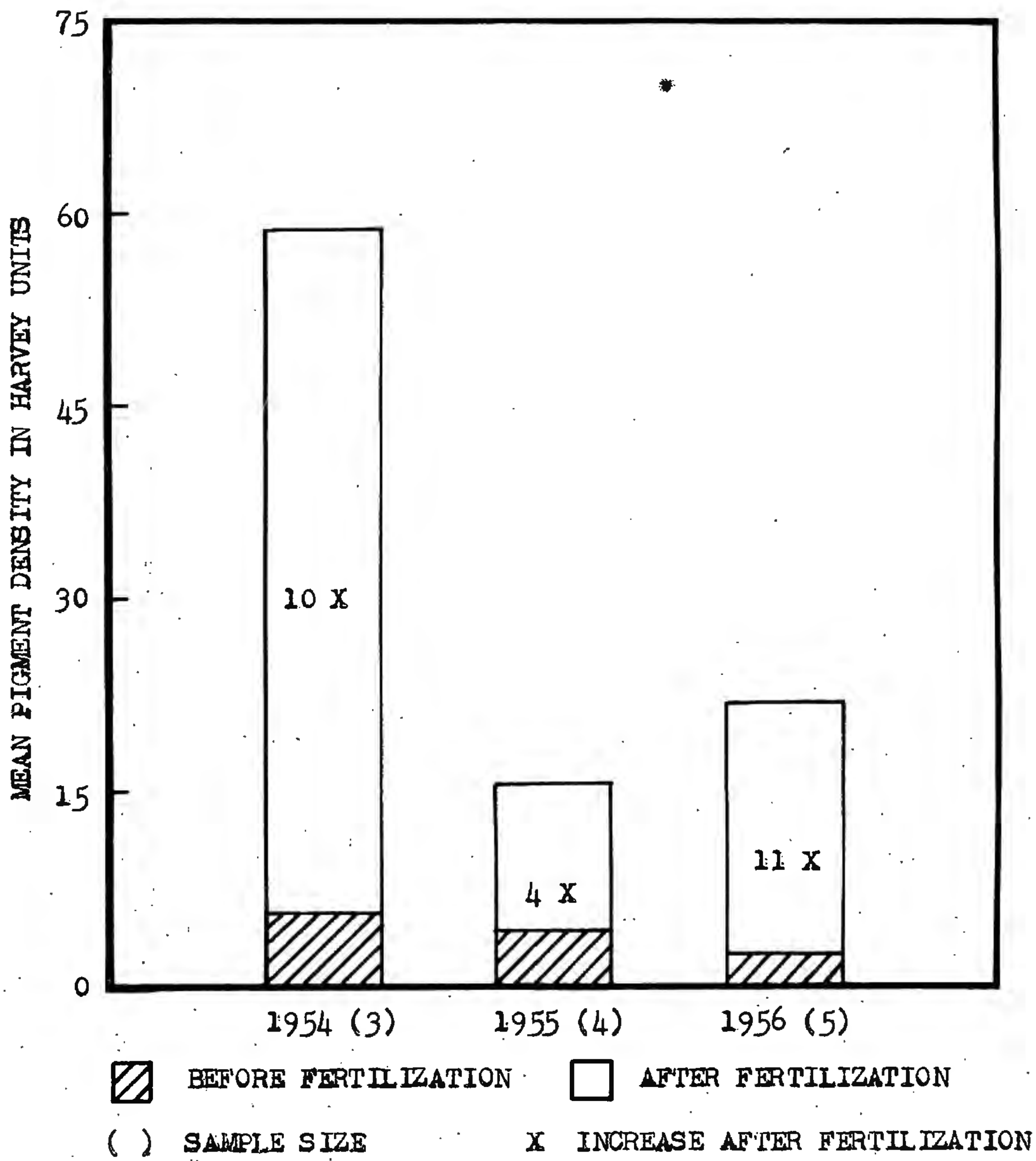

MEAN PIGMENT DENSITY IN HARVEY UNITS
75
60
45
30
15
0
10 X
4 X
11 X
1954 (3)
1955 (4)
1956 (5)
BEFORE FERTILIZATION
AFTER FERTILIZATION
( ) SAMPLE SIZE
X INCREASE AFTER FERTILIZATION

Table 11. Density of extracted pigments from weekly shingles at station F, Hoffman Lake, summer of 1956, in Klett units

	Unfertilized Period					Fertilized Period				
	July					August				Sept.
	4	11	18	25	1	8*	15*	22*	29*	5*
	T	3.0	T	T	1.0	T	6.0	1.0	2.0	4.0
	T	T	T	T	3.0	T	4.0	2.0	1.0	3.0
	T	T	T	T	T	T	1.0	5.0	5.0	4.0
	T	T	T	T	2.0	T	4.0	1.0	9.0	4.0
	4.0	4.0	T	T	T	T	5.0	3.0	3.0	3.0
	1.0	T	T	T	1.0	T	4.0	1.0	7.0	T
	T	T	T	T	T	T	2.0	0.5	3.0	2.0
	T	T	T	T	T	T	4.0	2.0	2.0	5.0
	T	T	T	T	4.0	T	6.0	T	4.0	4.0
	T	5.0	T	T	T	...	...	5.0	9.0	T
Total	5.0	12.0	T	T	11.0	T	36.0	20.5	45.0	29.0
Mean	0.5	1.2	T	T	1.1	T	4.0	2.0	4.5	2.9

T Denotes values below accuracy of colorimeter
... Denotes missing shingles
* Weeks when shingles were exposed to one complete week of fertilized conditions
Fertilizer applied on July 30 and August 3

Table 12. Density of extracted pigments from weekly shingles at station C, Hoffman Lake, summer of 1956, in Klett units

	Unfertilized Period					Fertilized Period				
	July					August				September
Shingle	4	11	18	25	1	8*	15*	22*	29*	5*
1	13.0	1.0	10.0	....	9.0	91.0	119.0	49.0	61.0	34.0
2	....	3.0	T	....	12.0	81.0	182.0	70.0	127.0	40.0
3	....	7.0	10.0	9.0	16.0	70.0	123.0	23.0	79.0	50.0
4	3.0	5.0	....	3.0	19.0	80.0	73.0	28.0	35.0	40.0
5	9.0	5.0	2.0	7.0	22.0	64.0	78.0	56.0	42.0	28.0
6	18.0	11.0	5.0	5.0	10.0	97.0	58.0	81.0	30.0	636.0
7	9.0	15.0	5.0	4.0	7.0	25.0	32.0	44.0	95.0	246.0
8	5.0	10.0	4.0	T	26.0	29.0	81.0	43.0	113.0	166.0
9	12.0	15.0	6.0	4.0	9.0	12.0	28.0	19.0	95.0	282.0
10	13.0	10.0	4.0	4.0	7.0	28.0	42.0	16.0	22.0	174.0
Total	82.0	82.0	46.0	36.0	137.0	577.0	816.0	429.0	699.0	1696.0
Mean	10.2	8.2	5.1	4.5	13.7	57.7	81.6	42.9	69.9	169.6

T Denotes values below accuracy of colorimeter
.... Denotes missing shingles
* Weeks when shingles were exposed to one complete week of fertilized conditions
Fertilizer applied on July 30 and August 3

Table 13. Density of extracted pigments from 30-day shingles at station C, Hoffman Lake, summer of 1956, in Klett units

Shingle	Before Fertilization	After Fertilization	Increase
1	9.0	176.0	167.0
2	13.0	247.0	234.0
3	22.0	206.0	184.0
4	21.0	149.0	128.0
5	34.0	59.0	25.0
6	19.0	153.0	134.0
7	11.0	103.0	92.0
8	26.0	596.0	570.0
9	14.0	253.0	239.0
10	8.0	114.0	106.0
11	9.0	440.0	431.0
12	14.0	189.0	175.0
13	21.0	217.0	196.0
14	20.0	107.0	87.0
15	5.0	137.0	132.0
Total	246.0	3146.0	2900.0
Mean	16.4	209.7	193.3

Table 14. Density of extracted pigments from 30-day bricks at station C, Hoffman Lake, summer of 1956, in Klett units

Brick	Before Fertilization	After Fertilization	Increase
1-A	5.0	142.0	137.0
1-B	30.0	117.0	87.0
1-C	17.0	128.0	111.0
1-D	9.0	154.0	145.0
1-E	1.0	118.0	117.0
Total	62.0	659.0	597.0
Mean	12.4	131.8	119.4

Table 15. Analysis of variance test to determine if statistically significant differences in pigment densities existed between and among weekly shingles, summer, 1956

Source of Variability	Degrees of Freedom	Sum of Squares	Mean Square	"F" Ratio
		Station C		
Total	59	537,490.6		
Between weeks	9	306,660.4	34,073.4	7.6**
Among weeks	5	27,184.3	5,436.9	1.2
Error	45	203,645.9	4,525.5	
		Station F		
Total	99	473.0		
Between weeks	9	236.0	26.2	9.7**
Among weeks	9	16.1	1.8	0.7
Error	81	220.9	2.7	

** Difference highly significant

Table 16. Analysis of variance test to determine if statistically significant differences in pigment densities existed between and among pairs of 30-day shingles and bricks at station C, summer, 1956

Source of Variability	Degrees of Freedom	Sum of Squares	Mean Square	"F" Ratio
		Shingles		
Total	29	554,339.9		
Between pairs	1	280,333.3	280,333.3	28.8**
Among pairs	14	137,848.9	9,846.4	1.0
Error	14	136,157.7	9,725.6	
		Bricks		
Total	9	37,188.9		
Between pairs	1	35,640.9	35,640.9	136.4**
Among pairs	4	502.4	125.6	0.5
Error	4	1,045.6	261.4	

** Difference highly significant

<u>Benthic organisms</u>. Quantitative and qualitative results of analyses of Ekman dredge samples taken at two stations during the summer of 1956 are listed in Tables 17 and 18. Both stations were located in the littoral zone of Hoffman Lake and qualitatively the bottom fauna was very similar. Station 1 (Table 17) was located in 7 feet of water, while station 2 (Table 18) was in water 4 feet deep. Shell and amorphous marls constituted the bottom types at both sampling stations. There were indications of slightly more organic matter mixed with the marl at station 2.

Numerically the most important organisms were members of the Ephemeridae, Tendipedidae, Trichoptera, Amphipoda, and Oligochaeta. Total numbers of organisms collected at stations 1 and 2 were 3314 and 5015, respectively. The shallower waters at station 2 exhibited a 51 per cent higher mean standing crop of individuals than station 1. Volumetrically the mean standing crop was 16 per cent higher at station 2. These values indicated that a higher standing crop of benthic organisms had been present in the shallower waters.

This may not have been true for production of benthic organisms, since "the standing crop does not necessarily reflect the productivity of a particular fauna" (Hayne and Ball, 1956). Predation by a fish population can lower a standing crop and increase the rate of production of fish food organisms. The magnitude of fish predation upon the benthic organisms at the two Hoffman Lake sampling stations was not known, and no attempt was made to determine the rates of production from the standing crop data. Other factors responsible for the higher standing crop

Table 17. Quantitative and qualitative evaluation of Ekman dredge samples from station 1, 1956

Sampling Date	June 29	July 6	13	20	29	August 10	17	24	31	September 7	Total
<u>Ephemera simulans</u>	5	3	3	4	37	82	103	79	72	42	430
<u>Hexagenia limbata</u>	..	2	6	6	14	35	42	53	34	52	244
Odonata	1	4	6	4	2	...	1	1	5	2	26
Sialidae	..	1	...	9	5	3	3	1	2	3	27
Tendipedidae	29	34	228	359	396	357	200	228	250	147	2228
Trichoptera	1	1	...	7	9	15	12	7	11	1	64
Other Diptera	2	2	13	6	12	8	8	8	12	15	86
Other Ephemeroptera	2	..	...	2	1	1	2	1	2	2	13
Miscellaneous Insects	..	..	1	...	...	...	...	1	...	...	2
Amphipoda	..	..	20	11	14	3	5	21	24	15	113
Oligochaeta	5	1	4	2	1	1	2	6	4	2	28
Other Non-insects	5	7	6	3	6	8	2	11	4	1	53
Number of samples	10	10	10	10	10	10	10	10	10	10	100
Total area (sq. ft.)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25
Total no. organisms	50	55	287	413	497	513	380	417	420	282	3314
Number per sq. ft.	20.0	22.0	114.8	165.2	198.8	205.2	152.0	166.8	168.0	112.8	132.6*
Total vol. organisms (milliliters)	0.65	0.40	0.85	0.65	0.70	0.65	0.90	0.95	0.85	1.20	7.8
Volume per sq. ft. (milliliters)	0.26	0.16	0.34	0.26	0.28	0.26	0.36	0.38	0.34	0.48	0.31*

*Mean

Table 18. Quantitative and qualitative evaluation of Ekman dredge samples from station 2, 1956

Sampling Date	June 29	July 6	July 13	July 20	July 29	August 10	August 17	August 24	August 31	September 7	Total
<u>Ephemera simulans</u>	6	2	8	10	140	194	149	140	54	58	761
<u>Hexagenia limbata</u>	4	1	...	...	1	2	10	10	8	5	41
Odonata	5	..	...	...	1	2	2	2	4	2	18
Sialidae	1	..	...	1	...	2	...	...	...	2	6
Tendipedidae	23	96	326	504	689	646	396	374	358	224	3636
Trichoptera	..	1	4	4	12	28	29	17	10	10	115
Other Diptera	1	7	8	13	13	9	6	13	15	12	97
Other Ephemeroptera	..	2	3	2	2	...	...	3	4	9	25
Miscellaneous Insects	..	1	...	1	...	...	...	1	1	...	4
Amphipoda	..	3	5	2	...	2	6	16	...	5	39
Oligochaeta	..	24	44	22	24	30	16	10	38	15	223
Other Non-insects	5	8	6	2	4	6	10	5	2	2	50
Number of samples	10	10	10	10	10	10	10	10	10	10	100
Total area (sq. ft.)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25
Total no. organisms	45	145	404	561	886	921	624	591	494	344	5015
Number per sq. ft.	18.0	58.0	161.6	224.4	354.4	368.4	249.6	236.4	197.6	137.6	200.6*
Total vol. organisms (milliliters)	0.45	0.45	0.40	0.30	0.60	1.25	1.05	1.25	1.55	1.70	9.0
Volume per sq. ft. (milliliters)	0.18	0.18	0.16	0.12	0.24	0.50	0.42	0.50	0.62	0.68	0.36*

*Mean

at station 2 may have been associated with its shallowness. Unknown factors may have been the influences of water currents and wave action upon each sampling station.

Volumetric measurements of the individual Ekman dredge samples are presented in Table 19. A combination of total numbers and volumes from stations 1 and 2 are shown in Table 20 and Figure XI. The number of organisms began the summer with low values for June 29 and July 6. After these low values, the number of organisms increased to a peak of 1434 per week or 286.8 per square foot on August 10. The remainder of the summer total number of organisms decreased weekly.

The family Tendipedidae contributed a high proportion of the total number of organisms during the summer (Figure XI). This group reached a peak on July 27. The strong influence of the Tendipedids upon the total number of organisms is illustrated in Figure XI where very similar numerical flucuations are exhibited throughout the summer.

The initial low numerical values recorded for the first two weeks illustrate the differences in results obtained from two methods of sorting bottom organisms (Figure XI). The samples of the first two weeks were hand picked, while those the remainder of the summer were processed by flotation. The high number of Tendipedids and the resulting high total number of organisms is apparently a result of the increased efficiency of flotation over the "hunt-and-pick" method.

Volumes of organisms appeared to be independent of the number of individuals (Figure XI). Volumes showed a general increase throughout the summer of 1956. The Tendipedids had a negligible influence upon

Table 19. Volumetric measurements in milliliters of bottom organisms per Ekman dredge sample, 1956

Sampling Date	June	July				August				September
	29	6	13	20	29	10	17	24	31	7
Station 1										
Sample Number										
1	0.05	0.05	0.05	0.05	0.05	0.10	0.05	0.10	0.05	0.20
2	T	0.05	0.30	0.05	0.05	0.05	0.10	0.10	0.15	0.05
3	T	0.05	0.05	0.10	0.15	0.05	0.10	0.05	0.10	0.05
4	T	0.05	0.20	T	0.10	0.05	0.10	0.10	0.10	0.05
5	0.05	0.05	0.05	0.05	0.10	0.05	0.05	0.20	0.05	0.10
6	T	T	0.05	0.05	0.05	0.05	0.05	0.15	0.10	0.10
7	0.50	0.05	T	0.10	0.05	0.10	0.10	0.05	0.10	0.10
8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10	0.10
9	T	0.05	0.05	0.10	0.05	0.10	0.25	0.05	0.05	0.40
10	T	T	0.05	0.10	0.05	0.05	0.05	0.05	0.05	0.05
Total	0.65	0.40	0.85	0.65	0.70	0.65	0.90	0.95	0.85	1.20
Station 2										
Sample Number										
1	0.05	0.05	0.05	T	0.05	0.10	0.10	0.10	0.45	0.55
2	0.05	0.05	T	0.05	0.05	0.10	0.10	0.15	0.10	0.55
3	T	0.05	0.05	T	0.05	0.10	0.05	0.15	0.40	0.05
4	T	0.05	0.05	T	0.05	0.05	0.05	0.10	0.10	0.10
5	0.05	0.05	0.05	0.05	T	0.45	0.15	0.15	0.10	0.15
6	0.05	0.10	0.05	0.05	0.05	0.10	0.15	0.10	0.05	0.05
7	0.10	T	0.05	0.05	0.05	0.10	0.10	0.15	0.10	0.10
8	0.05	T	0.05	0.10	0.05	0.05	0.10	0.10	0.15	0.05
9	0.05	0.05	T	T	0.10	0.10	0.10	0.10	0.05	0.05
10	0.05	0.05	0.05	T	0.15	0.10	0.15	0.15	0.05	0.05
Total	0.45	0.45	0.40	0.30	0.60	1.25	1.05	1.25	1.55	1.70

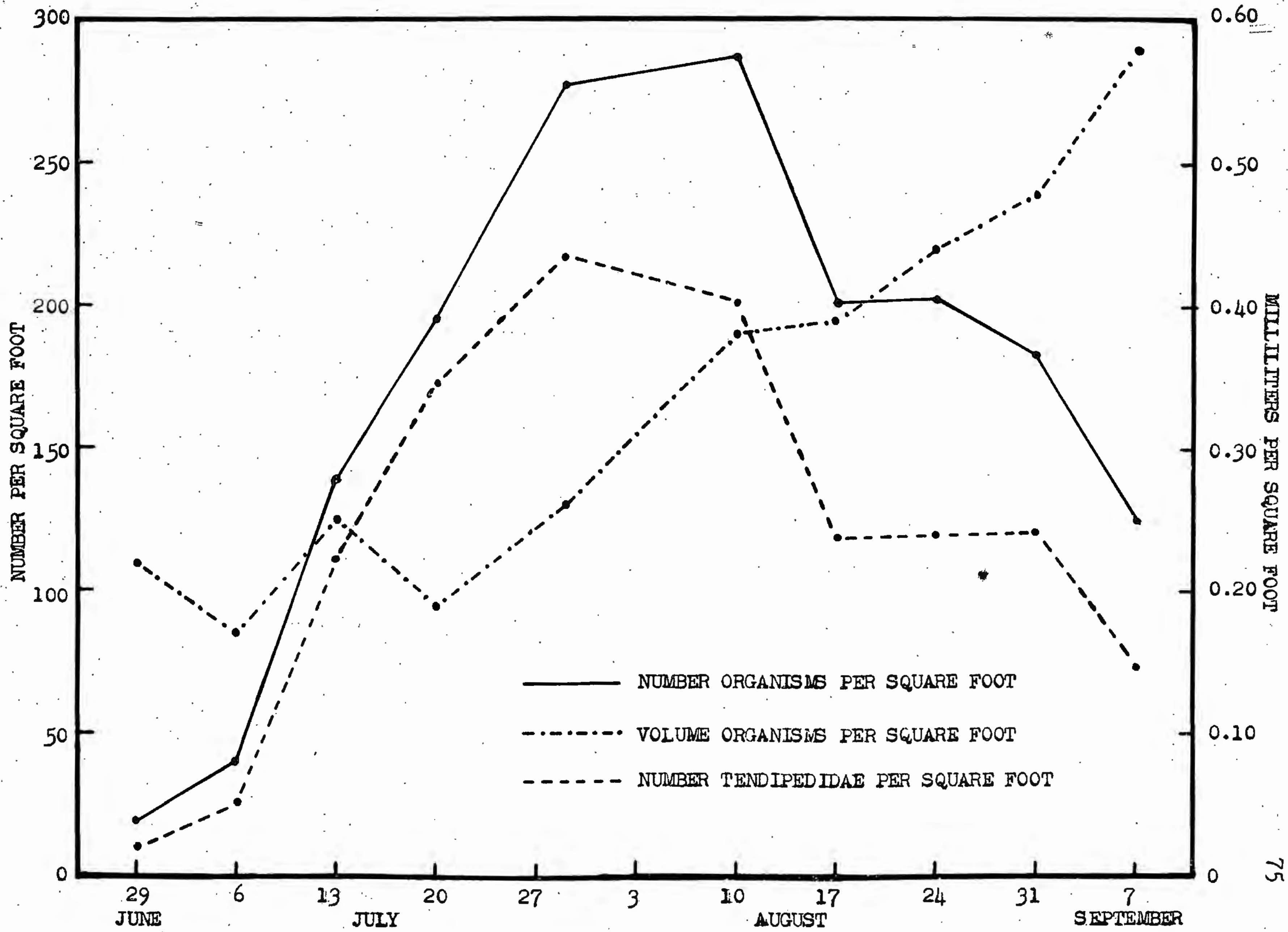
T Denotes an unmeasurable trace below .025 milliliters

Table 20. Total number and volume of bottom organisms from stations 1 and 2, 1956

Date	Total Number of Organisms	Number per Square Foot	Total Volume of Organisms (ml.)	Volume per Square Foot (ml.)
June				
29	95	19.0	1.10	0.22
July				
6	200	40.0	0.85	0.17
13	691	138.2	1.25	0.25
20	974	194.8	0.95	0.19
29	1383	276.6	1.30	0.26
August				
10	1434	286.8	1.90	0.38
17	1004	200.8	1.95	0.39
24	1008	201.6	2.20	0.44
31	914	182.8	2.40	0.48
September				
7	626	125.2	2.90	0.58
Total	8329	166.6*	16.80	0.34*

* Mean

Figure XI. Numbers and volume of benthic organisms per square foot at stations 1 and 2, Hoffman Lake, 1956


NUMBER PER SQUARE FOOT
MILLILITERS PER SQUARE FOOT
300
250
200
150
100
50
0
0.60
0.50
0.40
0.30
0.20
0.10
0
29
JUNE
6
13
20
27
JULY
3
10
17
24
AUGUST
31
7
SEPTEMBER
NUMBER ORGANISMS PER SQUARE FOOT
VOLUME ORGANISMS PER SQUARE FOOT
NUMBER TENDIPEDIDAE PER SQUARE FOOT

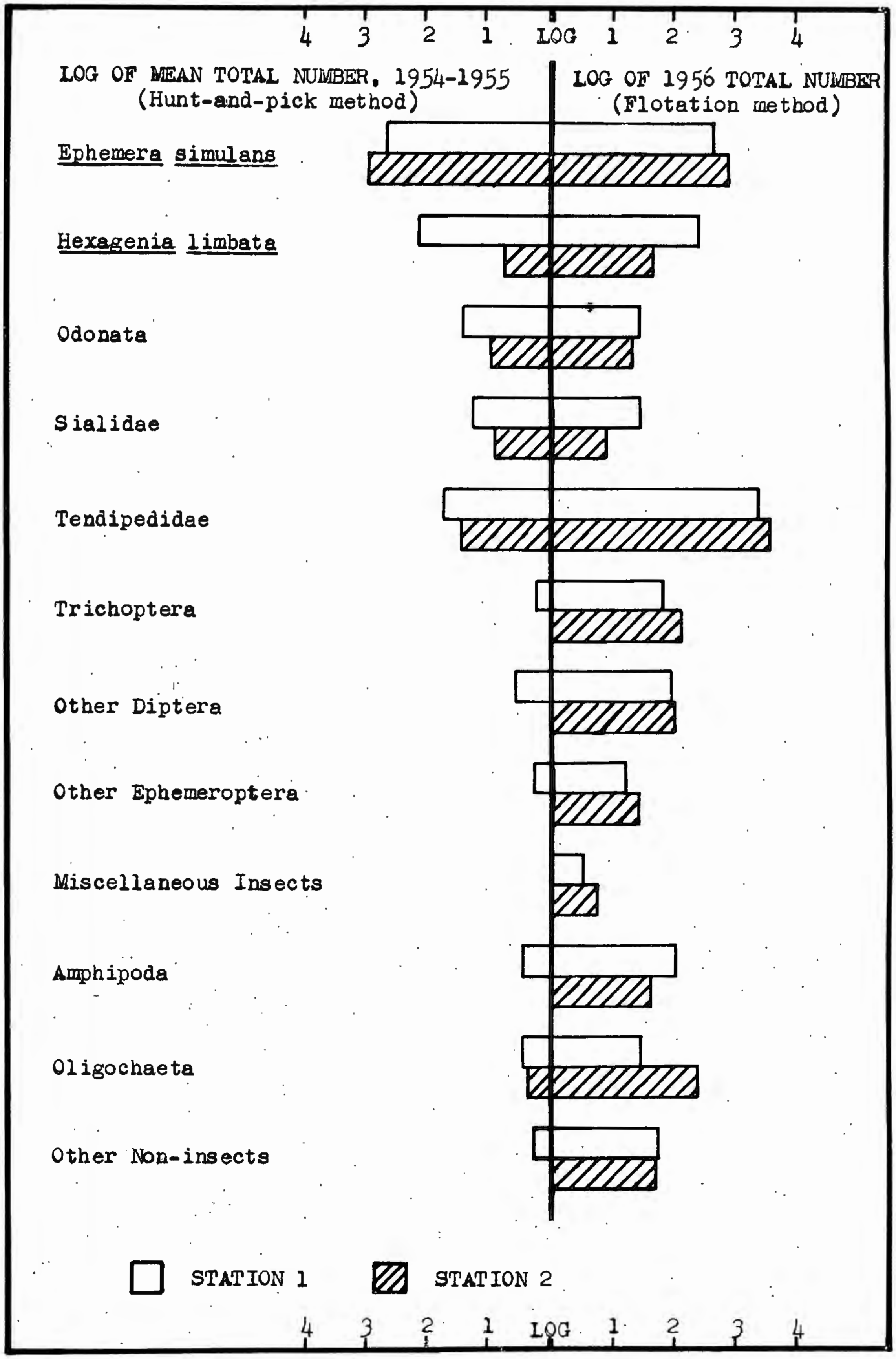
the total volume. The Odonata were an important group influencing volumetric measurements. Unusually high individual sample volumes were observed to be due to naiads of the families Gomphidae and Libellulidae (Table 19).

Patriarche and Ball (1949) obtained greater production of bottom organisms in fertilized ponds as compared to unfertilized ponds. However, in the study of a single body of water, such as Hoffman Lake, evaluation of bottom fauna is difficult due to natural and induced variations. Annual and seasonal variations of bottom organisms make evaluation of data within and between years difficult. Anderson and Hooper (1956) found, in an untreated Michigan lake, approximately a three times higher volume during one year, as compared with a similar period the following year.

Other variables preventing accurate comparisons between years were the differences in numbers apparently due to the higher efficiency of the flotation method employed in 1956, and the variation in annual volumetric measurements by different individuals. Figure XII is a comparison of the common logarithms of numbers of organisms between years. In Figure XII the increased numbers of individuals, especially Tendipedids, resulting from flotation is apparent if one is cognizant that these values represent common logarithms of numbers. Nearly all groups of organisms in 1956 showed increased numbers of individuals over 1954-55.

It is possible that the Tendipedids were numerically low in the 1954 and 1955 samples because their small size and light coloration made visual detection difficult. However, there remains the possibility that

Figure XII. Common logarithms for total numbers of benthic organism groups sampled in 1954-56


4 3 2 1 LOG 1 2 3 4
LOG OF MEAN TOTAL NUMBER, 1954-1955
(Hunt-and-pick method)
LOG OF 1956 TOTAL NUMBER
(Flotation method)
Ephemera simulans
Hexagenia limbata
Odonata
Sialidae
Tendipedidae
Trichoptera
Other Diptera
Other Ephemeroptera
Miscellaneous Insects
Amphipoda
Oligochaeta
Other Non-insects
STATION 1
STATION 2
4 3 2 1 LOG 1 2 3 4

the Tendipedids may not have exhibited a response to fertilization until 1956. Ball (1949) found indications that the Tendipedids respond rapidly to pond fertilization. Whether or not this occurred in Hoffman Lake can not be determined due to the change in methods of picking organisms.

Variations in volumetric measurements recorded by different individuals were apparent from a comparison of the total annual volumes. Figure XII suggests that the volumes in 1956 should have been at least similar to the previous two years, since volumetrically important groups in 1956 were similar or higher numerically than previously. However, a comparison of annual total volumes showed that the 1956 figure of 16.8 milliliters was only slightly over one-half of the 1954-55 mean total volume of 30.3 milliliters.

A species of burrowing mayfly, Ephemera simulans, did offer a comparison of data between years. Alexander (1956) selected this species for estimations of instantaneous rates of gravimetric growth and mortality. Ephemera simulans naiads were believed to be quite free from fish predation due to their deep burrowing habits. Thus, rates of growth and mortality estimated for this species were thought to reflect little fish predation. Data from both sampling stations were combined for this phase of the study.

Two generations of Ephemera simulans were known to be present in the series of bottom samples from Hoffman Lake (Alexander, 1956; Anton, 1957). In order to separate these two generations, each naiad was measured for length in millimeters. The measurement was made by placing the naiad upon a Bogusch measuring slide and recording the distance from the tip of the tusks to the posterior of the last abdominal segment. These values were recorded in a frequency distribution for size classes (Table 21). Weekly histograms of the frequency distribution for size classes of naiads were made to facilitate separation of the two generations (Figure XIII).

The emerging 1955-56 generation and the hatching 1956-57 generation were separated by visual inspection of Figure XIII. The appearance of naiads 3-4 millimeters long on July 13 was the entrance of the 1956-57 generation in the bottom samples. Actually the naiads of this generation were present earlier in the summer, but due to their small size escapement during the screening process had occurred. The low numbers resulting from escapement are represented by the broken line or ascending arm of the catch curve in Figure XIV.

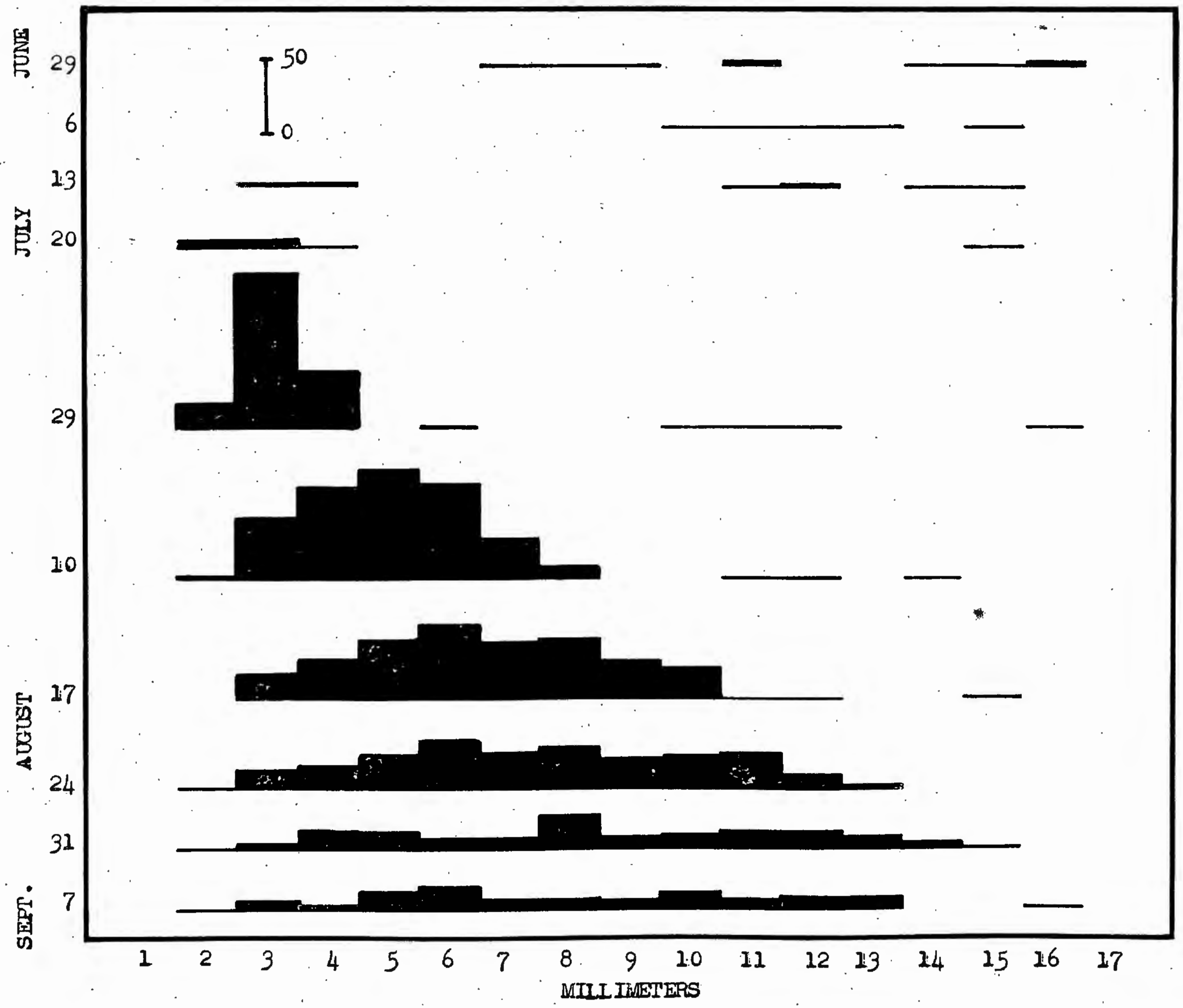
The emergence of the 1955-56 generation represented by the larger size classes continued through August 17. Table 22 is a listing of the numbers and mean lengths of the two generations of Ephemera simulans present during the summer of 1956. These values were plotted on semi-logarithm paper for estimation of the instantaneous rates of growth and mortality per week (Figure XIV).

A weekly rate of instantaneous mortality was determined by dividing the number of naiads present one week by the number of naiads present the previous week. The natural logarithm of this ratio represented the instantaneous rate of mortality per week. This rate for the 1956-57 generation was based on the descending right arm of the catch curve (Figure XIV). The instantaneous rates of mortality were estimated to

Table 21. Frequency distribution for size classes of *Ephemera simulans* naiads, Hoffman Lake, 1956

Date	Millimeters															Total
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
June																
29	..	...	..	..	..	1	1	1	..	2	..	..	1	1	3	10
July																
6	..	...	..	..	..	..	..	..	1	1	1	1	..	1	..	5
13	..	3	3	..	..	..	..	..	..	1	2	..	1	1	..	11
20	5	6	1	..	..	..	..	..	..	..	..	..	..	1	..	13
29	16	107	37	..	2	..	..	..	2	1	1	..	..	..	1	167
August																
10	4	39	60	73	63	26	8	..	..	1	1	..	1	..	..	276
17	..	17	25	38	49	37	38	25	19	1	1	..	..	2	..	252
24	1	13	17	26	33	22	27	19	21	23	9	2	..	..	..	213
31	1	4	14	13	9	7	21	9	10	11	9	8	5	2	..	123
September																
7	1	6	5	12	17	9	8	7	10	6	8	8	..	..	2	99

Figure XIII. Histograms of weekly size (length) distributions of *Ephemera simulans* naiads in millimeters, Hoffman Lake, 1956

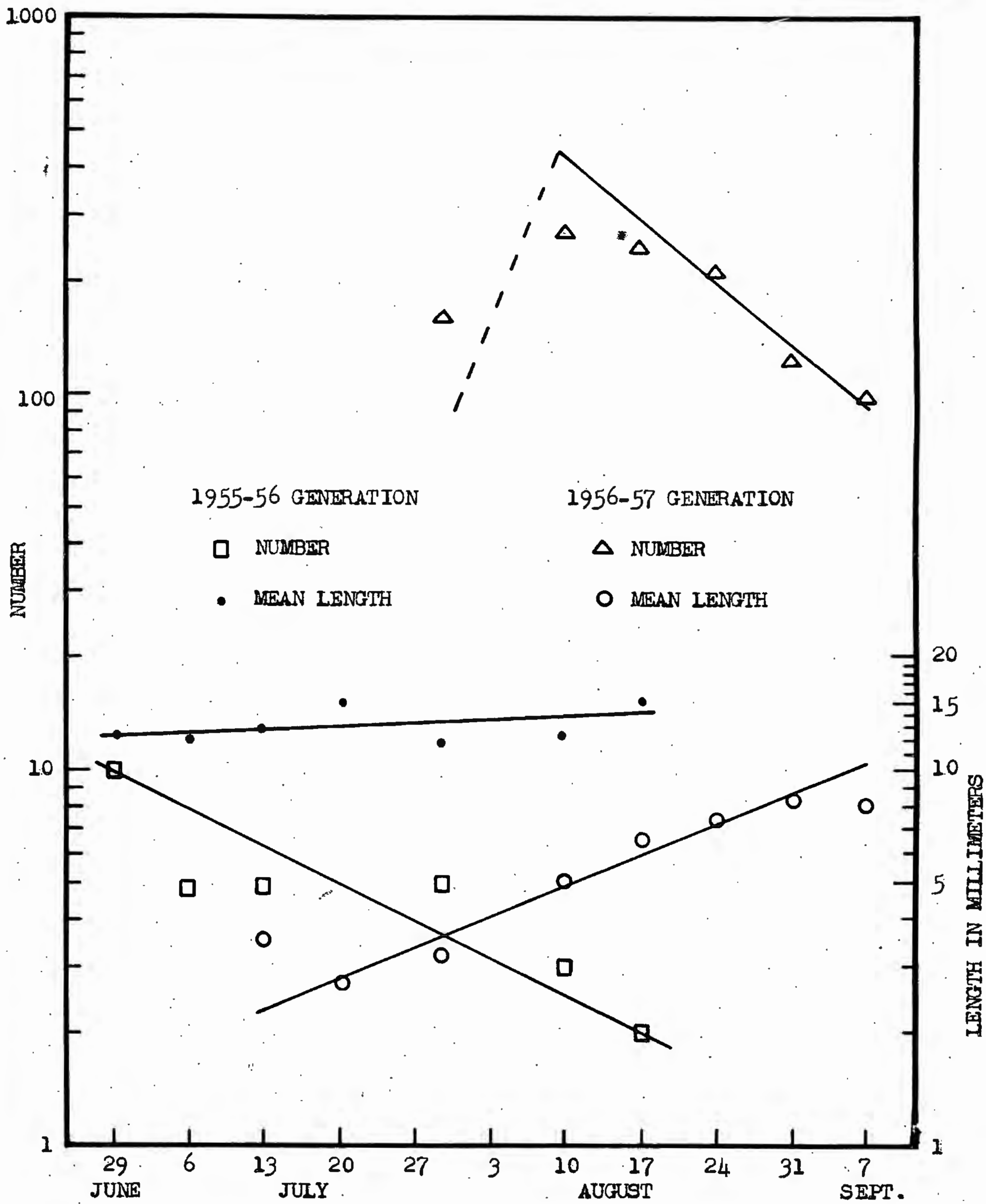


JUNE
29
6
13
JULY
20
29
10
17
AUGUST
24
31
SEPT.
7
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
MILLIMETERS

Table 22. Number and mean length of <u>Ephemera</u> <u>simulans</u> naiads for determining instantaneous rates of mortality and growth

	1955-56 Generation		1956-57 Generation	
Date	Number	Mean Length (mm.)	Number	Mean Length (mm.)
June				
29	10	12.3	...	....
July				
6	5	12.2	...	....
13	5	12.8	6	3.5
20	1	15.0	12	2.7
29	5	11.8	162	3.2
August				
10	3	12.3	273	5.0
17	2	15.0	250	6.5
24	..	....	213	7.4
31	..	....	123	8.3
September				
7	..	....	99	8.0

Figure XIV. Numbers and mean lengths for generations of *Ephemera simulans*, Hoffman Lake, 1956


1000
100
10
1
NUMBER
20
15
10
5
1
LENGTH IN MILLIMETERS
1955-56 GENERATION
NUMBER
MEAN LENGTH
1956-57 GENERATION
NUMBER
MEAN LENGTH
29
JUNE
6
13
20
27
JULY
3
10
17
24
AUGUST
31
7
SEPT.

be -0.374 and -0.230 for the 1955-56 and 1956-57 generations, respectively.

The weekly rate of instantaneous gravimetric growth was estimated by dividing the mean length of one week by the mean length of the previous week. The natural logarithm of this ratio represented a rate of linear growth and was multiplied by 3 to obtain the instantaneous rate of gravimetric growth. This latter operation is based on the cube law relationship between length and weight. The instantaneous rates of gravimetric growth were estimated to be +0.566 and +0.059 for the 1955-56 and 1956-57 generations, respectively.

Table 23 is a comparison of the instantaneous rates obtainable for four different generations of _Ephemera simulans_ during the Hoffman Lake study. Rates for both the first and second summers of the life cycle were obtainable for the 1954-55 and 1955-56 generations. Prefertilization rates were available for only the maturing 1953-54 generation, while all other rates are for generations exposed to fertilization.

Evaluation of the instantaneous rates in Table 23 does not show any indications of effects contributable to fertilization. The 1954-55 generation exhibited a comparatively high rate of growth its second summer as compared to the rate of the 1953-54 generation the previous summer. However, the 1955-56 generation exhibited a comparatively low rate of growth its second summer. The data appear to show merely natural fluctuations in mortality and growth for _Ephemera simulans_. Thus, no discernible evidence of fertilization effects was shown by the total benthic organisms or by _Ephemera simulans_ naiads.

Table 23. Instantaneous rates of gravimetric growth and mortality for *Ephemera simulans*, 1954-56*

Generation	First Summer of Life: Sample Size	First Summer of Life: Instantaneous Rates: Grav. Growth	First Summer of Life: Instantaneous Rates: Mortality	Second Summer of Life: Sample Size	Second Summer of Life: Instantaneous Rates: Grav. Growth	Second Summer of Life: Instantaneous Rates: Mortality
1953-54	....	.....	.....	217	+0.073**	-0.187**
1954-55	944	+0.519	-0.192	292	+0.117	-0.174
1955-56	1079	+0.495	-0.189	31	+0.059	-0.230
1956-57	1138	+0.566	-0.374	...	.....	.....

* Data in part from Alexander (1956) and Anton (1957)
** Not exposed to fertilization

__Fish.__ During the study, data were collected on five species of fish: rock bass, common sunfish, largemouth bass, yellow perch, and common sucker. Calculated mean lengths and weights at the last complete annulus and mean instantaneous rates of growth were computed for age groups of each species. Fish samples of questionable age were excluded from these computations, but were included in determining a length-weight relationship for each species. The above growth computations have been described earlier under "Methods".

The results of these annual computations permitted growth comparisons for the entire study period. The calculated sizes and instantaneous rates of growth obtained for fish sampled during a summer were actually based on sizes at or before the last complete annulus. Thus, the growth rates calculated from the 1954 samples were actually rates for a growth period that had occurred partly in 1953. Since fertilizer was applied initially during the mid-summer of 1954, it is probable that the computed growth rates of fish sampled in 1954 represented a growth period at least partially before fertilization. The sizes and growth rates of the intermediate year, 1955, reflected a growth period more completely exposed to the effects of fertilization. The sizes and growth rates for 1956 reflected a complete growth period exposed to effects of fertilization.

Length-weight relationships each year were based on data at capture. Thus, the 1954 length-weight relationships were basically before fertilization, while those of 1955 and 1956 were potentially able to reflect effects of one and two years of fertilizer, respectively. Since a population study was not performed, possible changes in the number of individuals were undetectable.

Alexander (1956) observed that fish sampled the first summer, 1954, generally exhibited below average or average growth when compared to values given in Carlander (1953) and Beckman (1949). The yellow perch appeared to be a stunted population. A few old, large perch were captured, while the majority of the samples contained numerous smaller, slower growing fish. Alexander described the suckers as being "in poor condition, they had a thin body which narrowed abruptly behind a head that was disproportionately large for the body size". Everhart (1950) mentioned a somewhat similar situation in Maine lakes where he believed the small average size of the sucker was probably a result of the scarcity of bottom fauna. Evidence from the first year of study, 1954, indicated that at least the yellow perch and common sucker were in poor physical condition. The growth status of the three Centrarchids was not as clear as for the other two species sampled. An occasional brook trout was captured during the study, but the sample sizes were too low for adequate growth rate evaluations.

The calculated mean lengths and weights for fish sampled during 1955 and 1956 are presented in Tables 24, 25, 26, 27, and 28. Unfortunately the initial year, 1954, could not be included due to the unavailability of necessary data. Generally all age groups of four of the species exhibited similar sizes and increments of growth, while the rock bass showed a longer mean total length in 1956 than in 1955. Both sets of data were from periods of growth exposed to fertilizer effects;

however, the 1955 data were from a growth period not exposed to fertilizer effects throughout.

Table 29, 30, 31, 32, and 33 are comparisons of the annual mean instantaneous growth rates obtained each year of the study. The rock bass, yellow perch, and common suckers showed progressively increasing rates of growth as the study evolved (Tables 29, 32, and 33). These increased rates were especially noticeable in the younger age groups, while the differences in older age groups were less pronounced. The growth rates for the common sunfish and the largemouth bass showed a decrease in 1955 as compared with the 1954 samples. In 1956 the rates for both the sunfish and largemouth bass were generally higher than those of either 1954 or 1955. As with the other species, the increases in 1956 were especially evident in the younger age groups of the sunfish and largemouth bass.

The length-weight relationship ($W = cL^n$) of each species of fish sampled was computed annually as described under "Methods". The values and number of samples obtained in 1956 were as follows:

Species	Sample Size	ln c (intercept)*	n value (slope)
Rock bass	116	-0.4365	2.5694
Common sunfish	115	-1.2998	3.1121
Largemouth bass	26	-1.9679	3.2205
Yellow perch	124	-1.4810	2.7831
Common sucker	73	-1.4658	2.8318

* ln = natural logarithm

The log-log transformations of the annual length-weight relationships of each species are shown in Figures XV, XVI, XVII, XVIII, and XIX.

To evaluate the length-weight relationships ($W = cL^n$) of each species during the study, a covariance analysis (regression analysis) was performed (Snedecor, 1956). These analyses tested whether a statistically significant change or changes in the length-weight relationship of a species had taken place during the study. A length-weight relationship is the result of two factors; one is the slope of the regression line and the other is the position (elevation or mean value) of the line (Figure XV). The slope or "n" value indicates the proportional increase in weight when an increase in length occurs, while the position indicates the weight at a given length.

A covariance analysis tests if a statistically significant difference in slope or in position exists between separate regression lines. The test first determines if the lines differ significantly. If the lines do differ, the test then determines whether there is a significant difference between slopes. Finally, if there is no difference between slopes, is the difference in position? The three parts of the test are answered by the results of calculated "F" values.

Results of the covariances analyses testing the length-weight relationships of each fish species throughout the study are shown in Tables 34, 35, 36, 37, and 38. Figures XV, XVI, XVII, XVIII, and XIX illustrate the tested lines. These figures must be viewed with caution, however, since an apparent visual difference may be statistically unsound. Figure XV, for example, suggests that the 1956 regression line for the rock bass differed from the other two years. Statistically this was proven untrue since one regression line could be used for all the observations. A check of the deviations of the observations about the separate regression lines showed a comparatively high deviation in 1956. This is apparently the reason for the somewhat misleading picture presented in Figure XV.

When a significant difference was detected within the three-year study period, separate covariance analyses were performed by the present writer between 1954 and 1956, and between 1955 and 1956. Anton had tested the 1954 and 1955 relationships by covariance analyses in an earlier study. These two year analyses between all combinations of three years served to locate where the difference or differences occurred within the three-year study period. Results of these tests within pairs of years are given as footnotes under the tables testing the entire three years.

Due to the increased probability of locating a significant difference between two years, these tests were performed only when a difference was detected within the three-year study period. The probability of finding a significant difference within three years was 0.95 x 0.95 x 0.95 or only 0.85, while for two years the probability was 0.95 x 0.95 or 0.90. One species, the common sunfish, showed a significant difference between 1954 and 1955 that was undetectable in the three-year analysis. This difference can be called spurious since it was not detectable within the three-year analysis (Table 35).

Results of covariance analyses did not show a significant difference in the length-weight relationships of the rock bass or the common sunfish during the three-year period. The analyses indicated that one regression line could be used for data from all three years (Tables 34 and 35; Figures XV and XVI). Table 36 shows a significant difference in means or positions for the regression lines of the largemouth bass during the three years. Results of analyses within pairs* of years showed that the difference in positions was between 1954 and 1955 (Table 36). These differences for the largemouth bass were barely significant and probably reflect merely natural annual variations in the length-weight relationship (Figure XVII).

The yellow perch showed a highly significant difference in means or positions of the regression lines during the study (Table 37; Figure XVIII). Analyses within pairs of years indicated that the means of both 1955 and 1956 were highly significant from the mean of 1954. The relationships for 1955 and 1956 did not differ statistically since one regression line could be used for both years (Table 37). These tests indicated that the weights of the yellow perch in 1955 and 1956 were similar, while the weights both years were highly significant from weights in 1954.

Analysis showed that there was a highly significant difference in the slope of the length-weight regression line for the common sucker (Table 38). Analyses within pairs of years indicated that the slopes of 1955 and 1956 were highly significant from the slope of 1954. The regression lines for 1955 and 1956 were found not to differ statistically. These tests indicated that a highly significant statistical change in the length-weight relationship of the common sucker had occurred in 1955, and this change remained in the 1956 samples (Figure XIX). The change, as indicated by Figure XIX, was a gain in weight after fertilization. The gain was more pronounced in the longer fish. The higher intercept of the regression line for 1956 suggested that the younger fish that year may have been improving in weight over 1955 also (Figure XIX).

Table 39 is a comparison of mean ln weights, mean ln lengths, and "n" (slope) values obtained annually throughout the fish study. Use of data from Table 39 permitted computation of an annual relative weight by fish species for comparative purposes. The difference in relative weights between two regression lines (years) possessing the same slope is a measure of the relative weight change of the species concerned (Snedecor, 1953). These relative or adjusted mean ln weights were computed as follows:

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

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

$$\text{Adjusted mean ln weight (1956)} = \bar{Y}_{1956} - b(\bar{X}_{1956} - \bar{X}_{Total})$$

where,

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

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

$\bar{Y}_{1956}$ = mean ln weight of 1956 samples

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

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

$\bar{X}_{1956}$ = mean ln length of 1956 samples

$\bar{X}_{Total}$ = mean ln length of 1954 + 1955 + 1956 samples

b = common slope (n) of 1954 + 1955 + 1956 samples

The computed adjusted mean ln weights and their differences within pairs of years are shown in Table 40. The differences in the three Centrarchids, while statistically significant for two species between 1954 and 1955, did not prove true throughout the study. The rock bass, common sunfish, and largemouth bass appear to reflect changes which approach being spurious. This suggests that these variations may be natural flucuations within the three species.

The yellow perch (Table 40) shows a 14.5 per cent and 11.1 per cent weight increases in 1955 and 1956, respectively over 1954. A comparison of weights of the common sucker between 1954 and the other two years was not possible due to a change in the slopes of the regression lines. Relative differences in weight at a given length would change due to the change in slope.

Fertilization of Hoffman Lake appears to have been reflected in the fish population through increase of growth rate. Each species sampled exhibited increasing instantaneous growth rates as the study progressed. Two species, the yellow perch and the common sucker, showed statistically significant changes in their length-weight relationships after fertilization. The yellow perch maintained over a 10 per cent weight increase at a given length after fertilization. The common sucker maintained a favorable change in weight after fertilization with the older fish showing higher weight gains than the younger fish.

Table 24. Calculated mean lengths and weights of rock bass sampled during 1955 and 1956

Age Group	Number of fish		Mean total size: Length (inches)		Mean total size: Weight (grams)		Increment growth: Length (inches)		Increment growth: Weight (grams)	
	1955	1956[a]	1955	1956	1955[b]	1956[c]	1955	1956	1955	1956
I	..	3	..	1.4	..	1.5	..	1.4	..	1.5
II	..	2	..	2.2	..	4.9	..	0.8	..	3.4
III	..	4	..	3.6	..	17.4	..	1.4	..	12.5
IV	4	20	4.0	4.4	22.7	29.1	..	0.8	..	11.7
V	10	36	4.7	5.1	35.1	42.5	0.7	0.7	12.4	13.4
VI	16	7	5.3	5.8	49.7	59.2	0.6	0.7	14.6	16.7
VII	22	21	5.8	6.1	62.8	67.3	0.5	0.3	13.1	8.1
VIII	16	9	6.4	6.3	81.2	73.2	0.6	0.2	18.4	5.9
IX	8	3	7.3	7.6	115.9	118.5	0.9	1.3	34.7	45.3

[a] 11 samples rejected in 1956 due to questionable age
[b] $\ln W = -0.6367 + 2.7113 \ln L$
[c] $\ln W = -0.4365 + 2.5694 \ln L$

Table 25. Calculated mean lengths and weights of common sunfish sampled during 1955 and 1956

Age Group	Number of fish		Mean total size: Length (inches)		Mean total size: Weight (grams)		Increment growth: Length (inches)		Increment growth: Weight (grams)	
	1955[a]	1956[b]	1955	1956	1955[c]	1956[d]	1955	1956	1955	1956
I	...	3	..	1.4	..	0.8	..	1.4	..	0.8
II	8	..	3.7	..	14.9	..	..	..	..	..
III	13	3	4.3	3.9	24.3	18.8	0.6	..	9.4	..
IV	13	44	5.0	5.1	39.5	43.4	0.7	1.2	15.2	24.6
V	29	13	5.4	5.6	50.6	58.1	0.4	0.5	11.1	14.7
VI	28	4	5.9	5.7	67.3	61.4	0.5	0.1	16.7	3.3

[a] Age groups VII and VIII not shown (see Anton, 1957)
[b] 48 samples rejected in 1956 due to questionable age
[c] $\ln W = -1.5133 + 3.2238 \ln L$
[d] $\ln W = -1.2998 + 3.1121 \ln L$

Table 26. Calculated mean lengths and weights of largemouth bass sampled during 1955 and 1956

Age Group	Number of fish		Mean total size: Length (inches)		Mean total size: Weight (grams)		Increment growth: Length (inches)		Increment growth: Weight (grams)	
	1955	1956[a]	1955	1956	1955[b]	1956[c]	1955	1956	1955	1956
I	9	2	3.0	3.3	5.4	6.5	3.0	3.3	5.4	6.5
II	9	14	6.8	7.2	68.4	80.6	3.8	3.9	63.0	74.1
III	30	6	9.2	9.2	174.6	177.5	2.4	2.0	106.2	96.9
IV	2	2	11.2	11.8	321.4	395.7	2.0	2.6	146.8	218.2
V	..	1	..	12.3	..	452.3	..	0.5	..	56.6
VI	3	1	14.5	13.2	716.0	567.8	..	0.9	..	115.5

[a] 2 samples rejected in 1956 due to questionable age
[b] $\ln W = -1.7215 + 3.1020 \ln L$
[c] $\ln W = -1.9679 + 3.2205 \ln L$

Table 27. Calculated mean lengths and weights of yellow perch sampled during 1955 and 1956

Age Group	Number of fish		Mean total size: Length (inches)		Mean total size: Weight (grams)		Increment growth: Length (inches)		Increment growth: Weight (grams)	
	1955[a]	1956[b]	1955	1956	1955[c]	1956[d]	1955	1956	1955	1956
I	..	7	..	2.6	..	6.0	..	2.6	..	6.0
II	23	20	3.7	3.8	7.8	9.3	..	1.2	..	3.3
III	24	39	4.4	4.3	13.4	13.2	0.7	0.5	5.6	3.9
IV	13	13	5.3	5.1	23.8	21.2	0.9	0.8	10.4	8.0

[a] Age group V not shown (see Anton, 1957)
[b] 45 samples rejected in 1956 due to questionable age
[c] $\ln W = -1.9729 + 3.0829 \ln L$
[d] $\ln W = -1.4810 + 2.7831 \ln L$

Table 28. Calculated mean lengths and weights of common suckers sampled during 1955 and 1956

Age Group	Number of fish		Mean total size: Length (inches)		Mean total size: Weight (grams)		Increment growth: Length (inches)		Increment growth: Weight (grams)	
	1955	1956[a]	1955	1956	1955[b]	1956[c]	1955	1956	1955	1956
II	1	..	7.4	..	62.9	..	..	..	..	..
III	21	17	8.5	8.8	94.2	109.1	1.1	..	31.3	..
IV	25	27	10.2	10.2	160.4	165.8	1.7	1.4	66.2	56.7
V	21	12	11.4	11.5	222.0	232.9	1.2	1.3	61.6	67.1
VI	11	7	12.6	11.0	297.3	205.3	1.2	-0.5	75.3	-27.6
VII	5	3	13.6	12.4	371.5	288.2	1.0	1.4	74.2	82.9

[a] 7 samples rejected in 1956 due to questionable age
[b] $\ln W = -1.6995 + 2.9183 \ln L$
[c] $\ln W = -1.4658 + 2.8318 \ln L$

Table 29. Mean instantaneous rates of growth of rock bass, 1954-56

Age Group	Number of fish			Rate of linear growth			Rate of gravimetric growth					
	1954[a]	1955	1956[b]	1954	1955	1956	1954	± Standard deviation	1955	± Standard deviation	1956	± Standard deviation
II	..	..	2	..	..	0.65	..	...	..	...	1.67	0.141
III	..	..	4	..	..	0.54	..	...	..	...	1.39	0.111
IV	2	4	20	0.29	0.36	0.49	0.78	0.120	0.91	0.109	1.26	0.185
V	15	10	36	0.21	0.25	0.31	0.56	0.132	0.66	0.176	0.80	0.206
VI	32	16	7	0.12	0.22	0.27	0.33	0.085	0.58	0.177	0.69	0.175
VII	26	22	21	0.10	0.16	0.18	0.27	0.066	0.43	0.133	0.46	0.126
VIII	10	16	9	0.09	0.12	0.14	0.24	0.077	0.28	0.107	0.36	0.082
IX	10	8	3	0.08	0.10	0.09	0.22	0.050	0.26	0.102	0.23	0.036
X	3	..	..	0.08	..	..	0.20	0.033	..	...	..	...

[a] Age groups XI and XII not shown (see Alexander, 1956)
[b] 11 samples rejected in 1956 due to questionable age

Table 30. Mean instantaneous rates of growth of common sunfish, 1954-56

Age Group	Number of fish			Rate of linear growth			Rate of gravimetric growth					
	1954[a]	1955[b]	1956[c]	1954	1955	1956	1954	± Standard deviation	1955	± Standard deviation	1956	± Standard deviation
II	..	8	..	..	0.51	..	..	...	1.64	0.169	..	...
III	8	13	3	0.39	0.28	0.50	1.22	0.393	0.90	0.266	1.56	0.417
IV	12	13	44	0.18	0.17	0.42	0.55	0.132	0.54	0.083	1.31	0.177
V	38	29	13	0.16	0.12	0.25	0.49	0.103	0.39	0.071	0.78	0.140
VI	37	28	4	0.13	0.09	0.17	0.41	0.074	0.28	0.060	0.53	0.112

[a]Age group VII not shown (see Alexander, 1956)
[b]Age groups VII and VIII not shown (see Anton, 1957)
[c]48 samples rejected in 1956 due to questionable age

Table 31. Mean instantaneous rates of growth of largemouth bass, 1954-56

Age Group	Number of fish			Rate of linear growth			Rate of gravimetric growth					
	1954[a]	1955	1956[b]	1954	1955	1956	1954	± Standard deviation	1955	± Standard deviation	1956	± Standard deviation
II	23	9	14	0.74	1.08	1.15	2.41	0.469	3.36	0.432	3.69	0.736
III	15	30	6	0.40	0.37	0.47	1.32	0.190	1.22	0.384	1.52	0.326
IV	7	2	2	0.20	0.19	0.34	0.65	0.076	0.56	0.106	1.11	0.097
V	8	..	1	0.17	..	0.16	0.56	0.125	..	...	0.51	0.0
VI	2	3	1	0.15	0.13	0.07	0.48	0.017	0.40	0.336	0.22	0.0

[a]Age groups VII and VIII not shown (see Alexander, 1956)
[b]2 samples rejected in 1956 due to questionable age

Table 32. Mean instantaneous rates of growth of yellow perch, 1954-56

Age Group	Number of fish			Rate of linear growth			Rate of gravimetric growth					
	1954[a]	1955[b]	1956[c]	1954	1955	1956	1954	± Standard deviation	1955	± Standard deviation	1956	± Standard deviation
II	46	23	20	0.43	0.45	0.66	1.32	0.317	1.38	0.381	1.83	0.322
III	28	24	39	0.26	0.29	0.35	0.79	0.197	0.91	0.153	0.97	0.178
IV	13	13	13	0.21	0.18	0.21	0.64	0.116	0.54	0.109	0.59	0.142

[a]Age groups V and VIII not shown (see Alexander, 1956)
[b]Age group V not shown (see Anton, 1957)
[c]45 samples rejected in 1956 due to questionable age

Table 33. Mean instantaneous rates of growth of common suckers, 1954-56

Age Group	Number of fish			Rate of linear growth			Rate of gravimetric growth					
	1954[a]	1955	1956[b]	1954	1955	1956	1954	± Standard deviation	1955	± Standard deviation	1956	± Standard deviation
III	7	21	17	0.34	0.43	0.43	0.81	0.167	1.23	0.323	1.22	0.263
IV	13	25	27	0.20	0.26	0.29	0.47	0.115	0.74	0.127	0.81	0.303
V	38	21	12	0.16	0.18	0.18	0.38	0.069	0.52	0.103	0.52	0.125
VI	8	11	7	0.11	0.12	0.15	0.26	0.047	0.36	0.069	0.43	0.108
VII	4	5	3	0.10	0.10	0.14	0.25	0.029	0.30	0.085	0.40	0.037

[a]Age group VIII not shown (see Alexander, 1956)
[b]7 samples rejected in 1956 due to questionable age

Figure XV. Log-log transformations of length-weight relationships of rock bass sampled from Hoffman Lake, 1954, 1955, and 1956

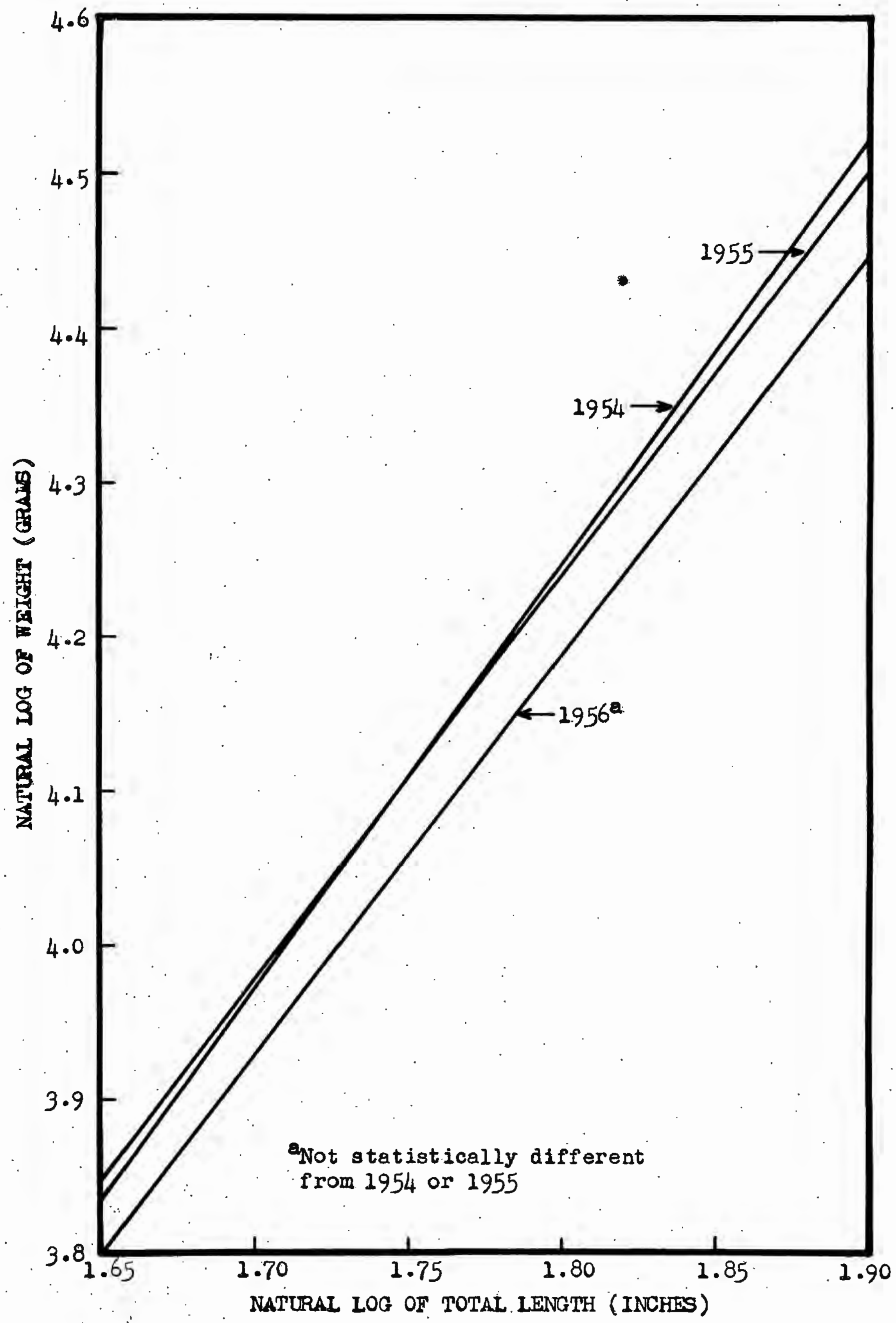

NATURAL LOG OF WEIGHT (GRAMS)
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
1955
1954
1956[a]
[a]Not statistically different from 1954 or 1955
1.65
1.70
1.75
1.80
1.85
1.90
NATURAL LOG OF TOTAL LENGTH (INCHES)

Table 34. Covariance analysis of ln[a] length-ln weight relationship of rock bass from Hoffman Lake, 1954, 1955, and 1956

Source of Variation	Degrees of Freedon	Sum of Squares	Mean Square
Total	290	75.3420	
Due to general regression	1	65.0340	65.0340
Deviations from general regression	289	10.3080	0.0357
1. Can one regression line be used for all observations?			
Gain from three separate regressions over general regression	4	0.2675	0.0669
Deviations from separate regressions	285	10.0405	0.0352
("F" = 1.89, answer is yes)			

[a]Denotes natural logarithm

Figure XVI. Log-log transformations of length-weight relationships of common sunfish sampled from Hoffman Lake, 1954, 1955, and 1956

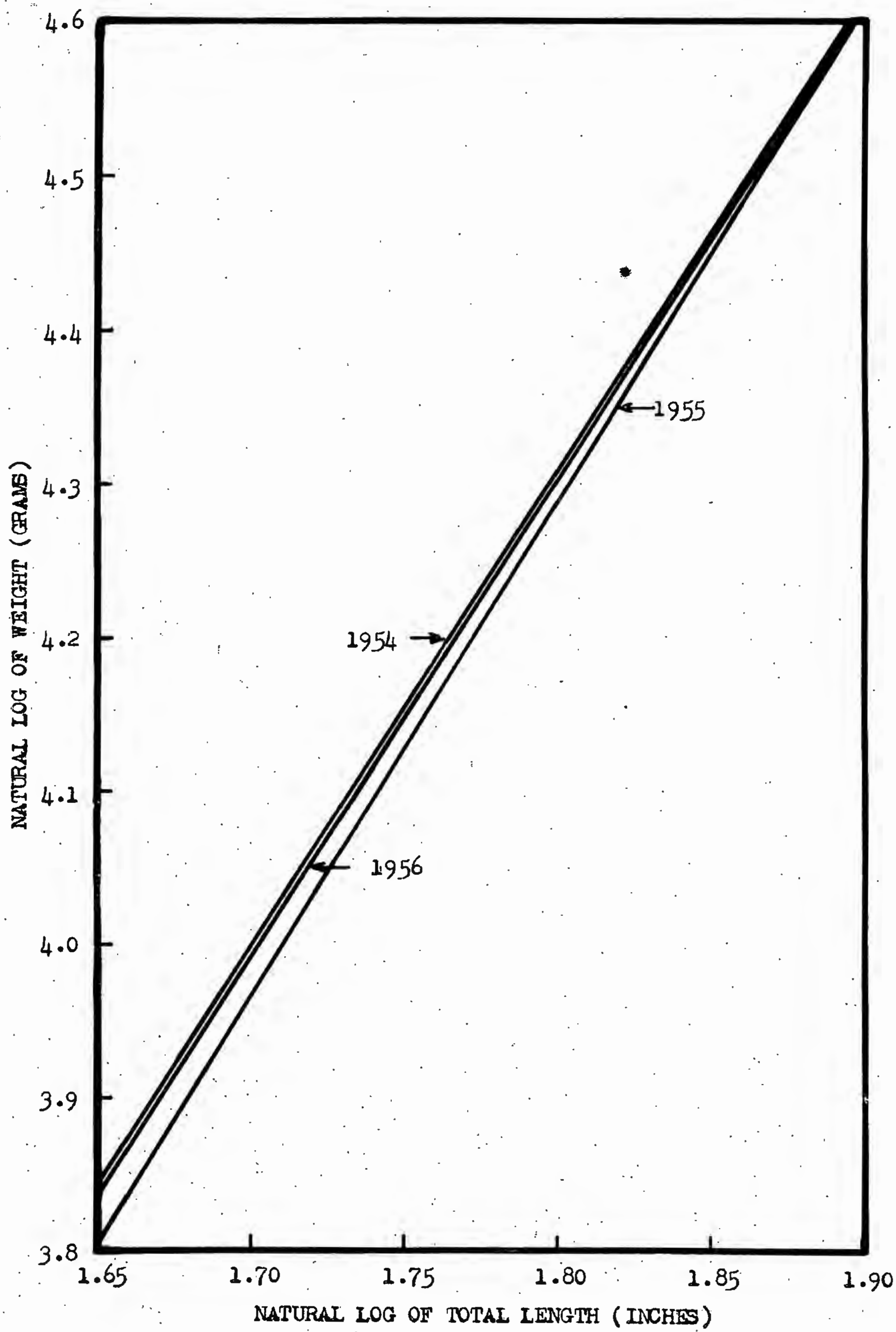

NATURAL LOG OF WEIGHT (GRAMS)
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
1.65
1.70
1.75
1.80
1.85
1.90
1955
1954
1956
NATURAL LOG OF TOTAL LENGTH (INCHES)

Table 35. Covariance analysis of ln[a] length-ln weight relationship of common sunfish from Hoffman Lake, 1954, 1955, and 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	317	60.3576	
Due to general regression	1	57.9441	57.9441
Deviations from general regression	316	2.4135	0.0076
1. Can one regression line be used for all observations?			
Gain from three separate regressions over general regression	4	0.0624	0.0156
Deviations from separate regressions	312	2.3511	0.0075
("F" = 2.08, answer is yes)[b]			

[a]Denotes natural logarithm

[b]A difference in position between 1954 and 1955 was obtained by Anton (1957)

Figure XVII. Log-log transformations of length-weight relationships of largemouth bass sampled from Hoffman Lake, 1954, 1955, and 1956

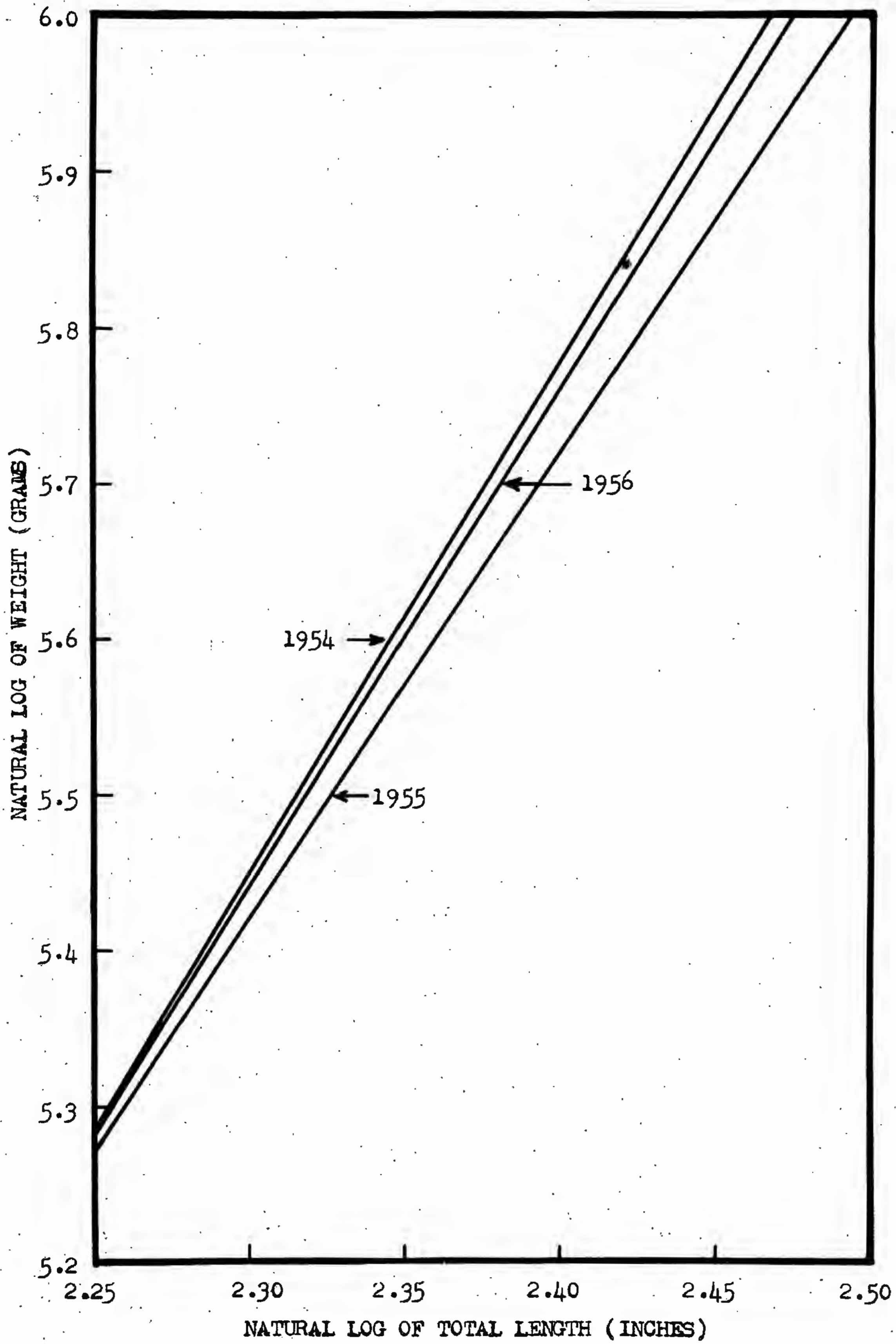

6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
NATURAL LOG OF WEIGHT (GRAMS)
1956
1954
1955
2.25
2.30
2.35
2.40
2.45
2.50
NATURAL LOG OF TOTAL LENGTH (INCHES)

Table 36. Covariance analysis of ln[a] length-ln weight relationship of largemouth bass from Hoffman Lake, 1954, 1955, and 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	135	76.5412	
Due to general regression	1	74.6666	74.6666
Deviations from general regression	134	1.8746	0.0140
1. Can one regression line be used for all observations?			
Gain from three separate regressions over general regression	4	0.1404	0.0351
Deviations from separate regressions	130	1.7342	0.0133
("F" = 2.64*, answer is no)[b]			
2. 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	132	1.7762	0.0134
Further gains from fitting separate regressions (difference between slopes)	2	0.0420	0.0210
Deviations about separate regressions	130	1.7342	0.0133
("F" = 1.58, answer is yes)			
3. Can one mean be used for the separate regression lines?			
Gains from lines through each mean, with common slope, compared to general regression	2	0.0984	0.0492
Deviations about lines with common slope	132	1.7762	0.0134
("F" = 3.67*, answer is no)[c]			

[a]Denotes natural logarithm

[b]Yes was obtained for question No. 1 in analyses of 1954 and 1956, and 1955 and 1956

[c]No was also obtained for question No. 3 in analysis of 1954 and 1955 (Anton, 1957).

Figure XVIII. Log-log transformations of length-weight relationships of yellow perch sampled from Hoffman Lake, 1954, 1955, and 1956

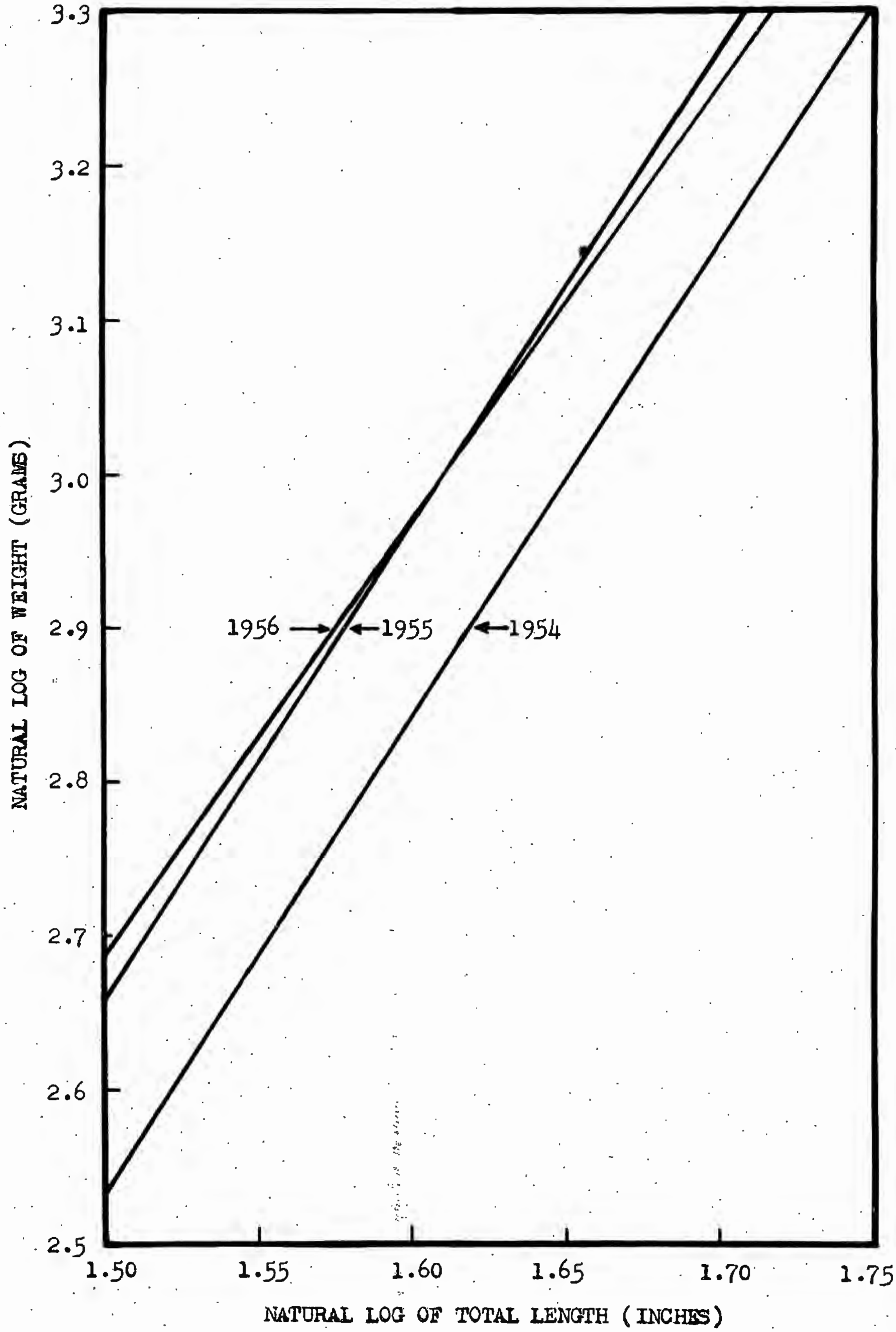

3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
NATURAL LOG OF WEIGHT (GRAMS)
1956
1955
1954
1.50
1.55
1.60
1.65
1.70
1.75
NATURAL LOG OF TOTAL LENGTH (INCHES)

Table 37. Covariance analysis of ln[a] length-ln weight relationship of yellow perch from Hoffman Lake, 1954, 1955, and 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	289	98.3613	
Due to general regression	1	91.3074	91.3074
Deviations from general regression	288	7.0539	0.0245
1. Can one regression line be used for all observations?			
Gain from three separate regressions over general regression	4	0.8243	0.2061
Deviations from separate regressions	284	6.2296	0.0219
("F" = 9.41**, answer is no)[b]			
2. 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	286	6.2454	0.0218
Further gains from fitting separate regressions (difference between slopes)	2	0.0158	0.0079
Deviations about separate regressions	284	6.2296	0.0219
("F" = 0.36, answer is yes)			
3. Can one mean be used for the separate regression lines?			
Gains from lines through each mean, with common slope, compared to general regression	2	0.8085	0.4042
Deviations about lines with common slope	286	6.2454	0.0218
("F" = 18.54**, answer is no)[c]			

[a]Denotes natural logarithm
[b]Yes was obtained for question No. 1 in analysis of 1955 and 1956
[c]No was also obtained for question No. 3 in analyses of 1954 and 1955 (Anton, 1957), and 1954 and 1956

Figure XIX. Log-log transformations of length-weight relationships of common suckers sampled from Hoffman Lake 1954, 1955, and 1956

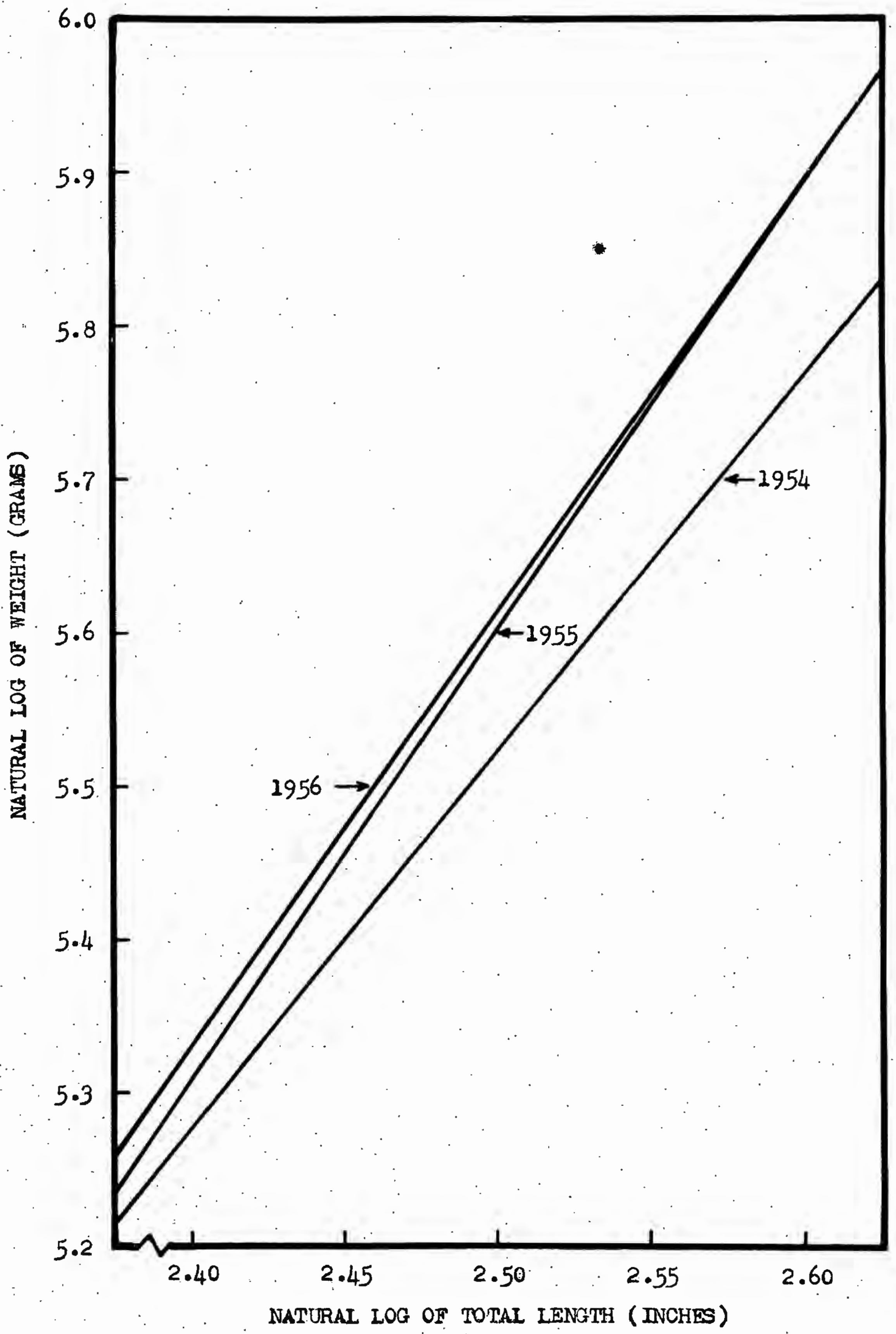

6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
NATURAL LOG OF WEIGHT (GRAMS)
1954
1955
1956
2.40
2.45
2.50
2.55
2.60
NATURAL LOG OF TOTAL LENGTH (INCHES)

Table 38. Covariance analysis of ln[a] length-ln weight relationship of common suckers from Hoffman Lake, 1954, 1955, and 1956

Source of Variation	Degrees of Freedom*	Sum of Squares	Mean Square
Total	206	21.3795	
Due to general regression	1	19.8980	19.8980
Deviations from general regression	205	1.4815	0.0072
1. Can one regression line be used for all observations?			
Gain from three separate regressions over general regression	4	0.1727	0.0432
Deviations from separate regressions	201	1.3088	0.0065
("F" = 6.65**, answer is no)[b]			
2. 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	203	1.4413	0.0071
Further gains from fitting separate regressions (difference between slopes)	2	0.1325	0.0662
Deviations about separate regressions	201	1.3088	0.0065
("F" = 10.2**, answer is no)[c]			

[a]Denotes natural logarithm
[b]Yes was obtained for question No. 1 in analysis of 1955 and 1956
[c]No was also obtained for question No. 2 in analyses of 1954 and 1955 (Anton, 1957), and 1956 and 1956

Table 39. Comparisons of mean ln[a] weights and lengths and "n" values for species of fish sampled from Hoffman Lake, 1954, 1955, and 1956

Species	Mean ln weights			Mean ln lengths			Slope ("n" value)		
	1954	1955	1956	1954	1955	1956	1954	1955	1956
Rock bass	4.26	4.31	4.12	1.81	1.83	1.77	2.66	2.71	2.57
Common sunfish	4.26	4.15	4.26	1.78	1.76	1.79	3.13	3.22	3.11
Largemouth bass	5.82	5.42	5.30	2.41	2.30	2.26	3.28	3.10	3.22
Yellow perch	2.80	3.16	3.31	1.59	1.66	1.72	3.08*	3.08	2.78
Common sucker	5.49	5.49	5.67	2.47	2.46	2.52	2.39	2.92**	2.83**

[a]Denotes natural logarithm
**Difference with 1954 value is highly significant, see Table 38

Table 40. Adjusted mean ln[a] weights of fish from Hoffman Lake, 1954, 1955, and 1956

Species	Adjusted mean ln weights			Difference between Mean ln weights (1954 and 1955)	Difference between Mean ln weights (1954 and 1956)	Difference between Mean ln weights (1955 and 1956)
	1954	1955	1956			
Rock bass	4.234	4.231	4.199	-0.003	-0.035	-0.032
Common sunfish	4.261	4.210	4.227	-0.051**	-0.034	+0.017
Largemouth bass	5.594	5.549	5.558	-0.045*	+0.009	-0.036
Yellow perch	3.015	3.160	3.126	+0.145**	+0.111**	-0.034
Common sucker	5.514[b]	5.577	5.583	...	...	+0.006

[a]Denotes natural logarithm
[b]Based on slope (n) of 1954 length-weight relationship only
*Difference significant (Anton, 1957)
**Difference highly significant, see Tables 35 and 37, and Anton (1957)

CONCLUSION

Results of this study have shown that certain physical, chemical, and biological responses occurred after inorganic fertilization of Hoffman Lake. The physical and chemical responses were generally more pronounced and ephemeral, while the biological responses were more subtle and prolonged.

Indication of a possible increase in phytoplankton production the final summer was suggested by a pronounced increase in the organic fraction of the total suspended solids. Each summer periphyton production showed a definite increase following fertilization. The standing crop of benthic organisms did not appear to change during the study period; however, benthic production, which was not determined, may have benefited from fertilization.

Progressively higher rates of instantaneous growth for five species of fish were obtained as the study advanced. The yellow perch maintained over a 10 per cent increase in weight the second and third summers. The common sucker also maintained a weight gain those two summers. These maintained weight gains for both species were proven to be highly significant statistically from values obtained the first summer, which were basically prefertilization values. Both the yellow perch and common sucker were observed to be in poor physical condition before fertilization. Thus, it seems that these two species would benefit the most from any favorable changes in their environment. Visually the yellow perch still appeared to be a stunted population the final year;

however, the common sucker showed visible physical evidence of improved condition.

The increased growth rates for five species of fish and the marked increases in weights for two of those species imply that more fish food was available after fertilization. Possible effects of seasonal and climatic conditions appear to be minor since the intermediate year differed noticeably from the other years. Periphyton in Hoffman Lake, which could have been utilized by at least the common sucker (Stewart, 1926), is known to have increased annually after fertilizer applications. Juday, Schloemer, and Livingston (1938) found indications that an increased yellow perch growth rate correlated with an increased plankton production following fertilization. Indications of an increase in phytoplankton, which may have been of benefit to the perch, fry of other species, and some forage species, were found the final summer in Hoffman Lake.

SUMMARY

1. Twice each summer for three consecutive summers, 1954-56, inorganic fertilizers were applied to Hoffman Lake, a 120 acre marl lake in northern Michigan.

2. Physical, chemical, and biological sampling detected prolonged changes, as well as, temporary changes in some characteristics of the lake following fertilizer applications.

3. Water transparency and light transmission decreased temporarily following fertilizer applications in 1954 and 1955, while in 1956 no definite decreases were detected after fertilization. The decreases were apparently due to the formation of a flocculent material after fertilization. The material seemed to consist of calcium and fertilizer components. No evidence of this material was obtained in 1956. There were indications that the normal water transparency and light transmission were decreasing more each year of the study.

4. Alkalinity and pH remained stable following fertilizer applications. Little evidence of a chemocline or thermocline was obtained during the study.

5. A temporary decrease in specific conductance was recorded following fertilization in 1955. This decrease appeared to result from a reduction in ions related to the formation of the flocculent material. No decrease in conductance was recorded in 1956.

6. Concentrations of ammonia nitrogen and total phosphorus increased temporarily following fertilizer applications, but returned to equilibrium by the following summer.

7. The final year, 1956, indications of increased phytoplankton were noted, as well as, an increase in phytoplankton after fertilization that year. Plankton water samples showed very abrupt increases in total suspended solids after fertilization in 1954 and 1955. These increases were due to the flocculent materials formed those years.

8. Periphyton increased each summer following fertilizer applications. Statistical analyses indicated that these post-fertilization increases were statistically significant each year.

9. No discernible evidence of fertilization effects was shown by the standing crop of benthic organisms. However, a change in the method of processing bottom samples did not permit discrete comparisons. A burrowing mayfly naiad, <u>Ephemera simulans</u>, appeared to exhibit only natural flucuations in growth and mortality.

10. Fertilization of Hoffman Lake appears to have been reflected in the fish population through increase of growth rate. Instantaneous rates of growth for five species of fish improved as the study progressed. Favorable changes in the length-weight relationships of the common sucker and yellow perch were detected first in 1955. These statistically significant changes, which were gains in weight per given length, were maintained in 1956 also. The three other species of fish sampled failed to show statistically sound changes in their length-weight relationships for the three-year period.

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