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THE BIOLOGICAL EFFECTS OF
FERTILIZER ON A NATURAL LAKE

Thesis for the Degree of M. S.
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Howard Allen Tanner
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This is to certify that the
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The Biological Effects of Fertilizer
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THE BIOLOGICAL EFFECTS OF
FERTILIZER ON A NATURAL LAKE

By

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I

INTRODUCTION

In the short history of our country we have passed through several phases of our relationships to our natural resources. Fish and game, taken as needed, were important items in the diet of the original inhabitants and the early settlers. With the rapid increase in the population our resources were exploited without regard to replacement potentials until what appeared to be drastic curbs were placed on numbers taken. The population of our country has increased in relation to the number of fish and game animals until we are now in a phase where the fish of our smaller lakes and streams are no longer of importance as a food source, but must be considered primarily as a recreational asset.

The number of people removing fish from our waters has increased many fold but the amount of water producing fish has remained constant, or because of pollution, removal of cover, drainage, and similar man-made factors has actually been reduced.

With this ratio of fewer fish to more men has arisen the problem of management of our fishery resources to produce more fish in the existing waters. New management practices are continually being tried, retained, modified or discarded. Fertilization is a comparatively new practice, its value remaining to be properly evaluated.

The early success of Swingle and Smith in increasing fish yields (Swingle and Smith 1939) has done much to spread

the popularity of fertilizers throughout this country and Canada. Their success and the success of others warrants a thorough attempt by Michigan to adapt fertilization to the conditions and problems of our state.

The waters, soils, climate and needs of the public in Michigan are factors that are basically different from most areas of the southern states. With these important differences it is recognized that, in order to successfully use fertilizer on Michigan waters, modifications of techniques and materials will be required. It is with this in mind that the Institute for Fisheries Research of the Michigan Conservation Department in cooperation with Michigan State College has undertaken an extensive research program.

Included under this program are studies involving the application of fertilizer to farm ponds, trout lakes and warm water lakes. The portion of this program involving warm water lakes which is reported upon in this thesis was conducted under the auspices of a research fellowship awarded by The Institute for Fisheries Research.

How fertilizers increase fish production should be clearly understood. Several biologists (Hogan 1933; Meehean 1934; Swingle and Smith 1939 and Smith 1945) working with small ponds have shown that the basic result of the application of inorganic fertilizers was to stimulate the growth of microscopic plants. Smith, E. V. and Swingle, H. S. (1939) showed that the production of bluegills varied directly with the production of the phytoplankton. It is recognized that

relatively few fishes are able to utilize phytoplankton directly but it appears that an increase in growth rate of fish may result from fertilizer stimulating the growth of phytoplankton, the stimulus traveling from this basic stratum of the food chain to the ultimate fish food organism.

Lake Description

North Twin Lake lies in Cheboygan County near the northern tip of Michigan's lower peninsula and is a natural lake with a surface area of 27.5 acres. It occupies an oval shaped basin, regular in outline and reaches a maximum depth of 15 feet. There is no inlet or outlet. The lake is entirely within the state owned Black Lake Forest. The surrounding region is a gently rolling plain draining south and west to the Little Sturgeon River. The dominate soil type is designated as Rubican sand with small areas at the north and south ends of the lake being Newton sand. These soils have a very low inherent fertility and are strongly acid. In appearance the soil is light grey, rather fine, overlaid by varying thicknesses of forest humus. The original forest cover was red pine and white pine. These pines were lumbered off 60 years ago and the area has since been burned over a number of times. At present, the cover consists largely of aspen and cherry with some young red and jack pine. On a very small area at the north end of the lake, swamp conifers predominate.

There are three bottom types present, the first extending from the shore margin to a depth of 30 inches is firm sand. In this area there is very little vegetation and forest

debris is present in varying amounts. It is here that the only important bottom fauna population exists. This sandy shoal is present around the perimeter of the lake except for a limited area on the north and south ends where fibrous peat extends to shore. Fibrous peat is present elsewhere in the lake from the deep margin of the shoal outward to a depth of 6 to 8 feet. Here the third bottom type, pulpy peat, begins and extends to the deep portions of the lake.

Prior to fertilization the turbidity of the lake was low and the water nearly colorless. Surface temperatures of the lake were high, reaching about 28.5 C. degrees during August. The water was relatively soft, having a total hardness ranging from 42 to 47 p.p.m. The pH of the water varied from 7.6 to 7.9. There was no thermal stratification of the lake at any time during the summer.

The aquatic vegetation consisted of sparse beds of the white water lily Nymphaea odorata, Eleocharis spp., Potamogetan natans, Potamogetan crispus, Polygonum amphibium and Chara spp.

The fish population of North Twin Lake was studied in the summer of 1946 (Crowe, unpublished report*). The following species were present: pumpkinseed sunfish Lepomis gibbosus, bluegill Lepomis m. macrochirus, yellow perch Perca flavescens, and northern yellow bullhead Ameiurus n. natalis. The pumpkinseed and the bluegill hybridize freely in North Twin Lake and these hybrids were present. Also present, but

*Crowe, Walter R., 1946. Inst. for Fish. Res. Report 1090.

very rare, was the northern smallmouth black bass Micropterus d. dolomieu. The forage species present included the black-nose shiner Notropis herterolepis, bluntnose minnow Hyborhynchus notatus, common shiner Notropis cornutus and the Iowa darter Peocillichthys exilis.

METHODS AND EQUIPMENT

Field Program

Application of Fertilizer

Preliminary soil and water analyses of the lake and the lake bottom revealed the more important nutrient deficiencies of the lake. An inorganic fertilizer containing 10 per cent nitrogen, 6 per cent available phosphoric acid, and 4 per cent potassium, was found to supply these nutrient needs and to be available in quantities for use in this investigation.

Fertilizer was applied every three weeks from early May until mid-September of 1946 and 1947. The fertilizer was distributed from a motor boat around the perimeter of the lake at the rate of 100 pounds to the acre. Swingle and Smith (1939) during their investigations in Alabama discovered that they achieved the most satisfactory results when application was made at a depth of 1 to 6 feet. In the case of North Twin Lake it was believed that the nutrients might be lost to the food chain by sinking into the flocculant pulpy peat if they were applied in the deep water zone.

Bottom Fauna Collections

All sampling was done with an Ekman dredge. During the summer of 1947, 412 samples were taken, The dredged bottom

material was first placed in a tub and by portions sifted through a 30 mesh screen. The residue was distributed to white enameled trays, covered with clear water, the organisms removed with forceps and preserved in 80 per cent alcohol.

Test sampling conducted at the beginning of the summer indicated the sandy shoal area to be the only bottom type supporting an appreciable population of fish food organisms. Almost no organisms were found in the areas of fibrous and pulpy peat. The two groups that were present there were the midges Chironomus spp. and the water mite Hydracarina. On the basis of this preliminary sampling it was decided to concentrate on the sandy shoal since large samples from this area would be of more value than scattered sampling of the whole lake bottom.

Fish Food Sampling

A program of fish-food sampling was undertaken to more properly establish food relationships of the fish population. All fish, except young-of-the-year, to be utilized for stomach analyses were taken by hook and line. The term young-of-the-year fish will be applied only to those fish that were hatched during the spawning season of 1947.

Young-of-the-year fish were taken by seining in the shallow areas and preserved whole in 40 per cent formalin.

Immediately upon capture the adult fish were weighed, measured, sex determined, a scale sample taken, and the stomach removed and preserved in 80 per cent alcohol. It was discovered that when the stomachs were placed in the alcohol there was a contraction of the stomach walls and in cases where

considerable food material was present much of it tended to be extruded. To make individual stomach content counts accurate, each stomach was preserved in an individual container.

Collecting fish by hook and line makes possible immediate preservation of the stomach and has the advantage of leaving the contents in better condition and results in fewer empty stomachs than is true with netted fish. Collection of adult fish by seining was impossible because of soft bottom.

Scale Sampling

Scale samples and their accompanying data were collected from North Twin Lake fish during the summer and fall of 1946 and 1947 and April 1948.

Scales were taken from 573 fish: 287 were pumpkinseed sunfish; 110 yellow perch; 92 bluegills and 84 hybrids.

Laboratory Examinations

Bottom Fauna

Volumetrical analyses were made of the bottom collections. The organisms were removed to a white enameled tray, sorted, identified, counted, separated into taxonomic groups and the total number recorded. Using the method of liquid displacement, the volume was taken of each group.

Fish Stomachs

Because of differences in procedure, the examination of adult stomachs will be described separately from those of young-of-the-year.

The content of each adult stomach was placed in a pan, the recognizable organisms and plant material sorted out and the debris discarded. The work of Leonard (Leonard, 1939) indicates that in stomach analyses the percentage composition of the recognizable stomach contents will be the same as the percentage composition of the unrecognizable debris, hence, nothing is to be gained by retaining the debris. The volume of each taxonomic group was determined by liquid displacement and the number recorded. To facilitate comparisons the groupings of bottom fauna organisms appearing as fish food were held the same as in the examination of the bottom samples.

The young-of-the-year fish to be utilized for stomach analysis were preserved whole in 40 per cent formalin. The stomachs were opened and the organisms counted under a binocular microscope. It was not possible to measure the volumes directly. Instead, the most important organisms present were accumulated until a large number of each group was available. The group volumes were taken several times, the averages determined and this number used to calculate the volume of an individual organism and finally the volume of these organisms present in each stomach. This was done for only the three most important groups.

Scales

The scales were examined using a scale projecting machine. From the scales, age and growth was determined. Occasionally it was not possible to determine with any reasonable accuracy the age of the fish from the scales. In these few cases the

sample was discarded. Growth rates were charted by use of a nomograph.

EVALUATION OF FERTILIZATION

The observed effects of fertilizer on all phases of the food chain and the relationships of these changes to fish production are discussed in this section.

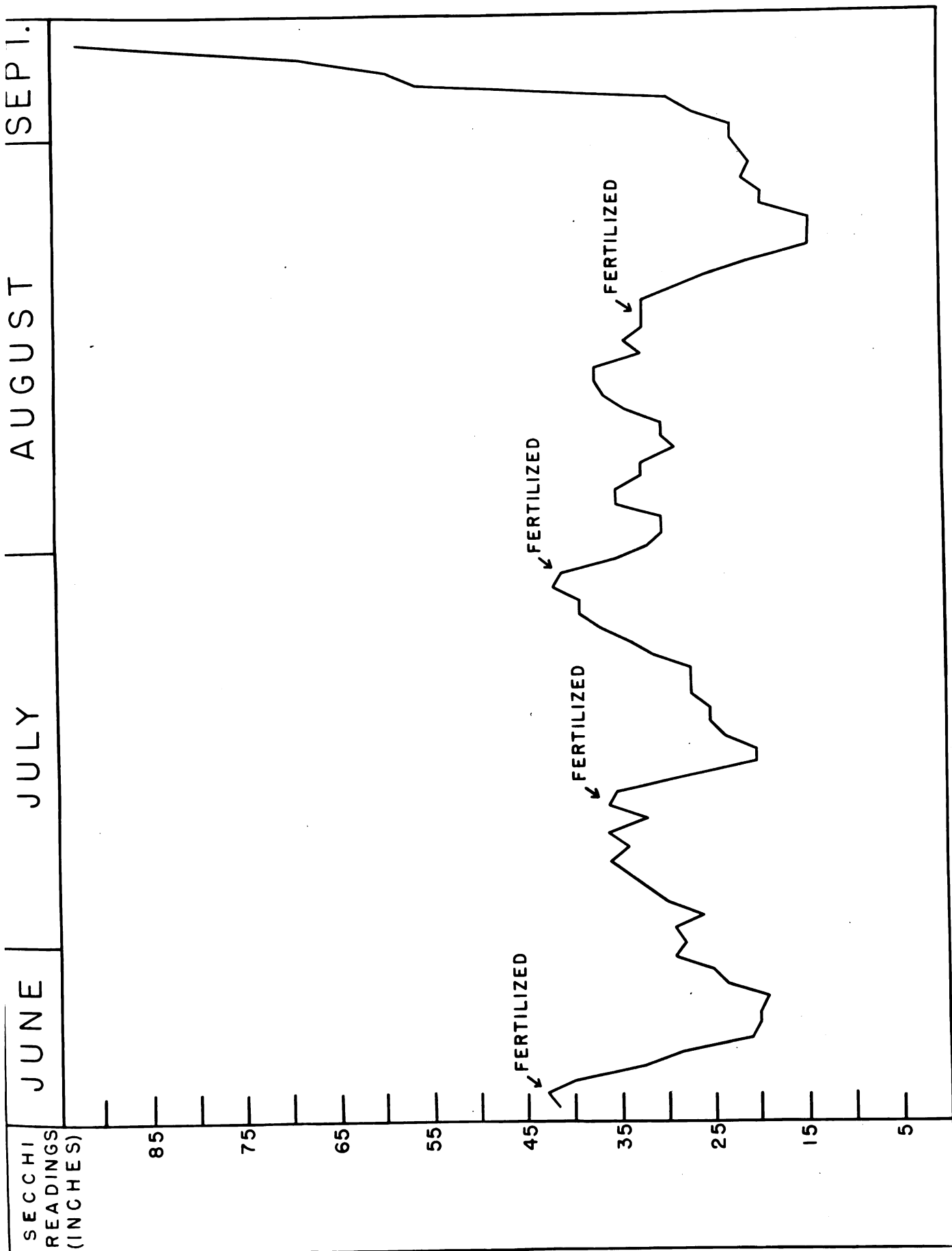
Plankton

Van Deusen (unpublished data) in a comparison of plankton counting methods found that Secchi readings gave accuracy comparable with direct counts, photoelectric colorimeter, and quantitative determinations of total particulate organic matter. The daily record of Secchi readings kept throughout the summer of 1947 recorded the fluctuations in the quantity of plankton present.

Secchi readings taken on North Twin Lake soon after fertilization begun during 1946 by Dr. R. C. Ball averaged 5-6 feet. Readings taken nearly daily throughout the summer of 1947 are presented. (Figure 1.) The summer average was between 25-30 inches. A clear indication of an increase in plankton is shown by a lowering of the Secchi reading following each application of fertilizer. This bloom was then followed by a gradual clearing of the water until the next application, when the turbidity again increased.

Upon examining Figure 1. it will be observed that the fluctuations in the turbidity are uniform throughout the summer. The one important deviation in the pattern occurred

Figure 1. Turbidity record of North Twin Lake
Summer of 1947



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between July 29 and August 9. Between these dates the algal bloom which, judging by the blooms following preceding applications of fertilizer, should have developed, failed to materialize. Instead, the filamentous algae abundant in shoal areas since the large application of fertilizer on June 18, 1947 made a further increase. It is believed that during this period the filamentous algae competed successfully with the phytoplankton for the added nutrients. The filamentous algae was particularly successful at this time because of the hot weather and little wind.

Filamentous Algae

A heavy growth of filamentous algae following the application of fertilizer has been reported by several workers. It is not desirable as it ties up the nutrients of the fertilizer in a form that is not immediately available by the upper levels of the food chain and may cause an undesirable appearance and odor.

In North Twin Lake the filamentous algae did not appear during the first summer, 1946. Neither was it present following the first applications of the summer of 1947. However, on May 29 only 1400 pounds of the usual 2700 pounds of fertilizer were available. In order to catch up to the schedule of 100 pounds to the acre every three weeks, the omitted 1300 pounds of fertilizer were added on June 18 together with the regular 2700 pounds or a total of 4000 pounds.

Following this latter application, filamentous algae appeared and was abundantly present for the remainder of the

summer. It matted on the surface of the shoal area and clung to the emergent vegetation along the margins and formed so heavily on a deep-water bed of potamogeton as to reduce it to a point where it was no longer visible from the surface. Observations indicated that the amount of filamentous algae increased with each application of fertilizer then decreased slowly until the next application. However, it was much more conspicuous during a period from August 1-10 when there was a prolonged period of hot, quiet weather. On the basis of the preceding observations, it appears that the growth of filamentous algae was due to the one massive application of fertilizer of June 18 and that, once present, the usual applications of fertilizer were sufficient to maintain it. Checks during the summer of 1948, the year following fertilization, revealed filamentous algae to be present in small amounts in the lake.

Higher Aquatic Plants

In the discussion of filamentous algae it was mentioned that the combined reduction in light penetration and the burden of the filamentous algae all but destroyed the Chara and potamogetons. These were the only important submerged aquatic plants in the lake. The other aquatic vegetation was either emergent or floating and there was no detrimental effect of the fertilizer noted, rather the floating plants seemed to benefit by it. The white water lily present in one bed only became more extensive and smaller groups of lilies extended in all directions along the west shore from the orig-

inal patch. By August 1948, a year following fertilization, Chara and the submerged potamogetons had attained approximately their former abundance.

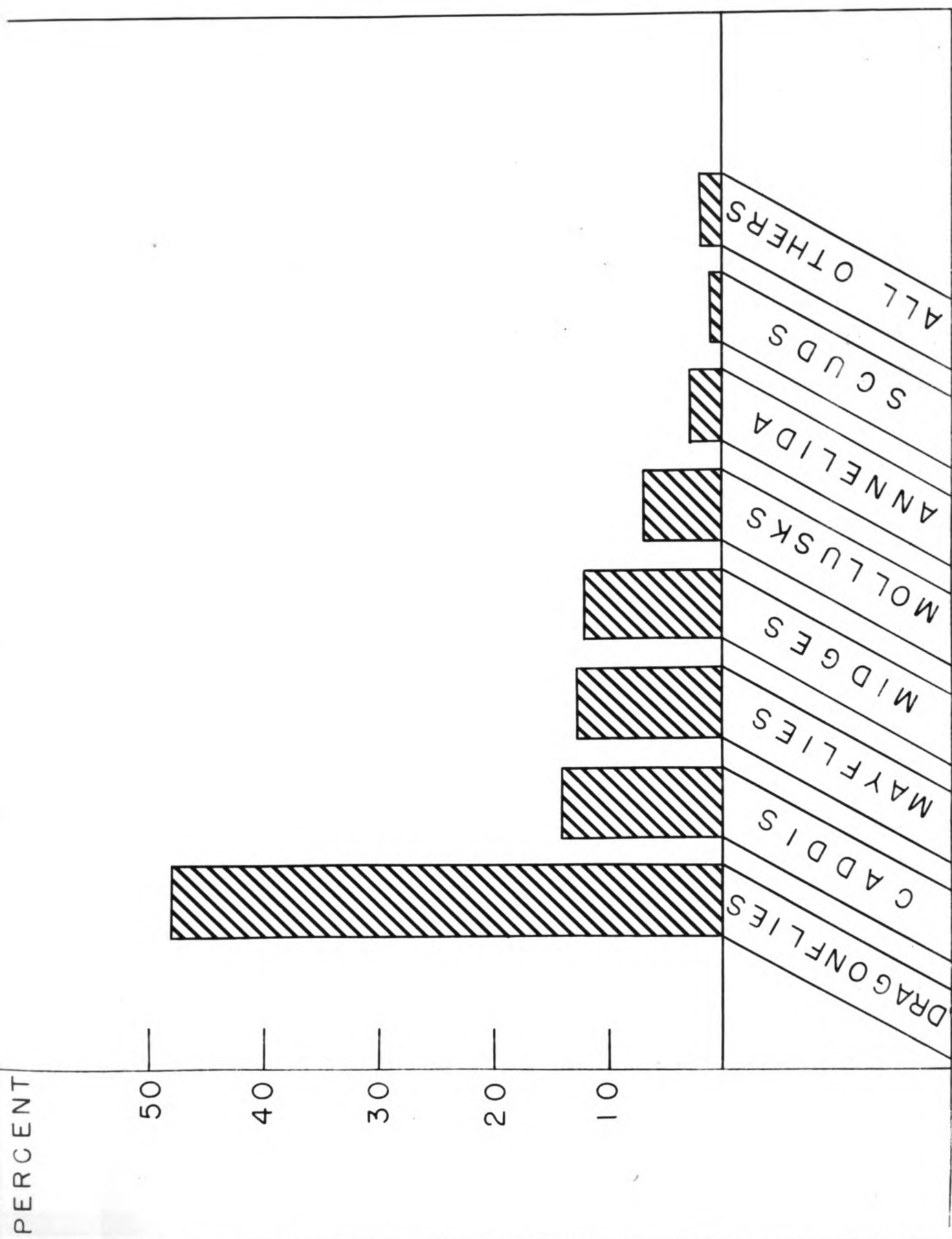
Bottom Fauna

The sampling methods for the bottom fauna collections have been described under methods and equipment. The sampling was confined to the shoal areas of the lake where nearly all of the bottom fauna were found.

The 412 bottom samples were taken from the last week in June through the first week in September. The bottom organisms were examined and tabulated on a volumetric and numerical basis. As indicated in Table 1, the organisms, in order of numerical importance, were midges, mayflies, mollusks, caddis, dragonflies, and scuds. In order of importance volumetrically were dragonflies, caddis, mayflies and midges. Figure 2 indicates the composition of the bottom fauna by volume. Some groups were prominent temporarily but scarce at other times. Among these was the creeping mayfly Caenis which was important until large hatches which occurred July 5-10 and on the 13th reduced their numbers. Table 1 shows the collection data on a two week basis.

Lack of comparative data makes it impossible to show directly an increase in bottom fauna. That an increase did occur, is supported by less direct evidence. Small numbers of bottom samples were taken by Dr. R. C. Ball from North Twin Lake during the summer of 1946 soon after the beginning of

Figure 2. Percentage Composition of Bottom
Fauna by Volume



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Table 1. Bottom Fauna Sampled

Collection Dates	June 15-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	Totals
Number of Samples	36.	56.	108.	96.	88.	28.	412.
Area of Samples (sq. ft.)	9.	14.	27.	24.	22.	7.	103.
Total Number of Organisms	773.	3452.	3371.	4205.	2510.	300.	14,611.
Number of Organisms per sq. ft.	86.	247.	125.	181.	147.	43.	(ave.) 150.
Total Volume of Organisms (c.c.)	10.9	26.1	35.0	20.2	19.6	5.9	118.5
Volume (c.c. per sq. ft.)	1.2	1.9	1.3	.9	.9	.8	(ave.) 1.2
	A	A	A	A	A	A	A
	B	B	B	B	B	B	B
Dragonflies	4.1	5.5	14.9	13.2	14.9	4.6	57.1
Caddis	2.1	5.3	8.0	.9	.3	.2	16.9
Mayflies	1.5	7.6	4.7	1.0	.1	T	14.9
Midges	.6	3.0	3.1	4.0	3.6	.5	14.7
Mollusks	1.7	1.8	2.5	1.3	.5	.3	8.0
Annelida	.6	1.6	.8	T	T	T	3.1
Hyalrella	.3	.5	.6	T	.1	T	1.5
All Others	.6	.8	.7	T	T	.2	2.4
	5.3	3.1	2.0	....	.1	3.4	2.0

A = Volume in cubic centimeters
 B = Per cent of total volume
 T = trace

fertilization. From these samples it was determined that the bottom fauna population was very low. This was in agreement with other observations which indicated a general low productivity. Samples taken throughout the summer of 1947 from the shoal area of North Twin Lake averaged 150 organisms per square foot with an average volume of 1.2 cc. Ball (1948 and 1949) in reporting on natural lakes considered of average productivity, recorded bottom fauna populations not significantly in excess of this. Bottom organisms, particularly those important as fish food, have been shown to increase rapidly following fertilization (Swingle and Smith 1941) (Surber 1943) (Smith, M. W. 1948) (Patriarche and Ball 1949). Further evidence of an increase in bottom fauna production is the statistically highly significant increase in growth rate of the centrarchids and yellow perch, fishes dependent directly and indirectly on the bottom fauna for a very large per cent of their food supply.

Fish

Feeding Habits

Data on fish used in food study.- The data for the 255 adult fish taken by hook and line between June 20 and September 9 for the food study are shown on the following page.

Table 2. Numbers, size and species of fishes utilized in stomach analysis of adult fish.

Fish Group	Number of Fish	Average Total Length (Inches)	Average Weight (Grams)
Pumpkinseed sunfish	96	5.5	52
Hybrids	69	7.1	115
Bluegills	28	7.6	135
Yellow perch	62	7.4	62

The foods of each of these fishes have been tabulated in order of their importance (Table 3) by numbers and volume.

In Table 3, micro-caddis have been separated from other caddis because of ecological differences. The micro-caddis were small, with cases entirely of their own secretion and found in enormous numbers in the algal mats and rarely on higher aquatic plants. It was only after the great increase in the filamentous algae that they became important as food for the fish. The other caddis present were large bottom dwellers with cases of sand. Prominent among these were the families Mollannidae and Limnophilidae.

The "aquatic plants" include both rooted aquatic vegetation and filamentous algae. It is believed that the algae was taken incidental to the capturing of the micro-caddis. Under terrestrial insects are included a variety of forms, the most important being flying ants. The ants were present on the lake surface only on the days of September 3 and 4. Other terrestrial insects eaten were adult beetles, bees, wasps and grasshoppers. Terrestrial insects were unimportant to the yellow

**Table 3. Food of Adult Bluegills, Pumpkinseed
sunfish, Perch and Hybrids**

		Pumpkin-seed Sunfish	Hybrids	Bluegills	Yellow Perch	Totals
Number of stomachs		96.	69.	28.	62.	255.
Number empty		9.	3.	2.	28.	42.
Per cent stomachs empty		9.4	4.4	7.1	45.1	Average 16.5
Total number organisms		2385.	5851.	1842.	569.	10647.
Organisms per stomach		27.	89.	71.	17.	Average 51.
Food Groupings						Averages
Wedges	A.	52.8	54.9	41.6	75.5	56.2
	B.	25.0	18.0	24.5	8.3	19.0
	C.	67.9	69.9	65.4	35.8	59.7
Dragonflies	A.	2.0	.9	.5	1.2	1.2
	B.	34.5	16.1	7.5	2.5	15.1
	C.	20.7	27.4	3.9	8.8	15.2
Mayflies	A.	2.3	16.4	35.2	15.3	17.3
	B.	1.0	11.3	22.4	2.8	9.4
	C.	12.7	21.3	46.2	23.5	25.9
Terrestrial Insects	A.	7.8	5.7	.6	....	3.5
	B.	9.7	15.6	5.2	....	7.6
	C.	15.0	44.1	23.1	....	20.5
Aquatic Plants	A.	....	....	....	....	....
	B.	3.7	18.1	20.2	....	10.5
	C.	18.4	56.2	57.7	....	33.1
Fish	A.	....	....	.5	6.0	1.6
	B.	....	....	11.9	86.4	24.6
	C.	....	....	3.9	64.7	17.1
Micro-caddis	A.	20.3	9.3	2.9	1.8	8.6
	B.	8.4	6.8	1.6	.3	4.3
	C.	40.3	18.2	11.5	8.3	19.6
Caddis (other than micro)	A.	8.4	2.3	2.2	.2	3.2
	B.	10.1	3.9	2.8	..	4.2
	C.	28.8	47.1	46.2	2.9	31.2
Zooplankton	A.	.2	8.4	6.9	....	3.9
	B.	..	3.6	2.2	....	1.4
	C.	1.0	11.4	14.3	....	6.2
Mollusks	A.	4.4	1.5	.3	....	1.6
	B.	4.3	1.3	..	....	1.4
	C.	31.1	18.2	11.5	....	15.2
Coleoptera Larvae	A.	1.0	.2	.5	....	.4
	B.	2.7	.8	.1	....	.9
	C.	8.1	12.2	7.7	....	7.0
Hydrocarnia	A.	.5	.2	8.3	.2	2.3
	B.	..	..	2.0	..	.5
	C.	5.2	10.2	35.7	2.9	13.5
Scuds	A.	.3	.3	.4	....	.2
	B.	.1	.1	..	....	..
	C.	6.3	8.7	10.9	....	6.5
A = per cent of food by numbers						
B = per cent of food by volume						
C = per cent of fish eating this food						
.. = trace						

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perch but made up nearly 10 per cent by volume of the food of the centrarchids. All mayflies were of the single genus Caenis. These small, single-winged mayflies were present in large numbers in the bottom and stomach samples until hatches on nights of July 5 - 10 and 13 reduced their numbers to a level where they were unimportant as fish food. Under the heading mollusks are both snails and clams. The snails were slightly more important numerically and volumetrically. Of the dragonflies, the Gomphinae predominated, representing 60 per cent of the total by number, Libellulidae 30 per cent and Aeschinanae 10 per cent. The zooplankters taken by adult fish were chiefly ostracods which are normally found near the bottom and usually would not show up in plankton net collections. The small fish taken as food, as near as could be determined, were yellow perch. The heading all others includes hydrocarina, coleoptera, biting diptera and leeches.

Yellow perch.- Yellow perch are well recognized as being carnivorous in their feeding habits. Their own young made up 83 per cent by volume of the food of the adult yellow perch in North Twin Lake. Other organisms utilized by the perch as food were midges, dragonflies and mayflies. Forty-five per cent of the yellow perch stomachs were empty compared to 4 - 9 per cent for the centrarchids.

Bluegills and pumpkinseed sunfish.- Certain important differences between the feeding habits of bluegills and pumpkinseed sunfish in the same waters have been noted elsewhere. The pumpkinseeds characteristically select a larger proportion

of mollusks and hard-bodied insects than do the bluegills. (Baker 1916) (Ball 1948) The bluegills, on the other hand, eat a larger proportion of aquatic plants than do the pumpkinseed sunfish. (McCormick 1940) These findings were generally born out in the study of the feeding habits of these species in North Twin Lake. The importance of mollusks as food, even to the pumpkinseeds, was small. The pumpkinseeds did eat mollusks to a greater extent than the bluegills, 4.3 per cent of total food volume for pumpkinseed sunfish and only a trace in the bluegills. Thirty one per cent of the pumpkinseeds and 11 per cent of the bluegills contained mollusks. However, the pumpkinseeds selected more hard-bodied insects, chiefly dragonflies, which made up 34.5 per cent by volume of their food and accounted for only 7.5 per cent of the bluegill food. Aquatic plants made up 20 per cent by volume of the bluegill food and only 3 per cent for the pumpkinseeds. The importance of small fish as a food of the bluegills is the result of too small a sample since all of the small fish were taken by one very large bluegill.

Hybrids.- The hybrids selected nearly all major food groups at an intermediate rate. They ate fewer dragonflies, mollusks, caddis and micro-caddis than did the pumpkinseeds but ate more of these organisms than did the bluegills. The hybrids selected less aquatic plants and fewer mayflies than the bluegills but more than the pumpkinseeds. They ate a greater proportion of terrestrial insects than did either of the parent species and a slightly smaller portion of midges

than either the bluegills or pumpkinseeds. These differences in per cent of total volume of food are shown in the following table.

Table 4. Food choice of hybrids compared to food choice of parent species.

	Pumpkinseed sunfish	Hybrids	Bluegills
Midges	25	18	24.5
Dragonflies	34.5	16	7.5
Terrestrial insects	9.7	15.6	5.2
Aquatic plants	3	18.1	20.2
Mayflies	1	11.3	22.4
Micro-caddis	8.4	6.8	1.6
Other caddis	10.1	4.0	2.8
Mollusks	4.3	1.3	T

There is only indirect evidence of any change in foods due to fertilization. In North Twin Lake there was observed an apparent large increase in dragonflies. Dragonflies in the summer of 1947 made up 48.3 per cent by volume of the bottom fauna sampled while the usually important pumpkinseed food, mollusks, made up only 6.8 per cent by volume of the bottom fauna. On this evidence, it is probable that there was a shift on the part of the pumpkinseeds from scarce mollusks to abundant dragonflies. Dragonflies made up 34.5 per cent of the pumpkinseed food and the mollusks made up 4.3 per cent of their food. The increase in the numbers of the micro-caddis following the formation of the algal mats was undoubt-

edly a new source of food and was utilized most by the pumpkinseeds.

Forage ratios.- Other workers (Hess and Swartz 1940) (Allen 1941) considered the ratio between the availability of a food (position in the bottom fauna by number or volume) and the rate it is selected by the fish as a food. This factor has been termed "forage ratio". Such a ratio has been determined between the foods of the centrarchids and bottom organisms important as food. The percentage of total volume of the bottom organism has been recalculated for the dragonflies, caddis, midges, mollusks and mayflies on the basis of these organisms representing one hundred per cent of the bottom samples by volume. The stomach samples were recalculated in the same manner. In the test table below (Table 5), the per cent of total volume of bottom samples is divided into the per cent of total volume of the stomach samples and the resulting number (C) is the forage ratio.

Table 5. Comparison of food available to food utilized by the centrarchids.

		Pumpkinseed sunfish	Hybrids	Bluegills
Dragonflies	A	51.	51.	51.
	B	46.	32.	13.
	C	.90	.63	.26
Caddis	A	15.	15.	15.
	B	14.	8.	5.
	C	.93	.53	.33
Midges	A	13.	13.	13.
	B	34.	36.	43.
	C	2.61	2.77	3.30
Mollusks	A	7.	7.	7.
	B	6.	3.	-
	C	.86	.43	-
Mayflies	A	13.	13.	13.
	B	6.	23.	39.
	C	.46	1.77	3.

- A - per cent in bottom samples by volume
- B - per cent in stomach samples by volume
- C - forage ratio

It will be noted that the midges were the only food having a forage ratio of more than 1.0 for all species which agrees with Ball (1948). Mayflies had a forage ratio of more than 1.0 for the bluegills and hybrids but not for the sunfish. Comparing this table of forage ratios with the table on page 17 where the differences of diet between the three centrarchids were compared, it will be noted that agreement is complete. The pumpkinseeds show a distinct preference for dragonflies and mollusks and the bluegills select the midges and mayflies. For every one of the five major bottom organisms compared here, the position of food habits of the hybrids is intermediate between the parent species.

Young-of-the-year fish.- The presence of the small hybrids among young-of-the-year centrarchids made accurate separations difficult. Therefore, hybrids, bluegills and pumpkinseeds are all grouped under "centrarchids".

A total of 237 fish stomachs of young-of-the-year were examined of which 127 were yellow perch and 110 centrarchids. The yellow perch in this region spawn very early, probably during the month of April. When the field work was begun on June 19, the young-of-the-year perch were present and large enough to be clearly recognized as perch. Weekly collections of stomach samples were made from June 20 until September 9. The spawning activities were just beginning by June 20 and the young-of-the-year centrarchids were first collected during the last week in July. A late fall collection

of young-of-the-year was made on October 11.

The results of the stomach examinations of young-of-the-year fish (Table 6) show that in the yellow perch, the food by volume was approximately 50 per cent zooplankters, 25 per cent midges, 25 per cent mayflies. In the centrarchids approximately 75 per cent of the food was zooplankters while mayflies constituted approximately 4 per cent. In the centrarchid stomachs the water mites were present in considerable numbers. The heading "All Others" includes small numbers of caddis, Coleoptera larvae, snails, clams and scuds. Spawning activities.

The hard sandy bottom on the west side of the lake was the area selected by the bluegills for spawning beds. There also were 70 per cent of the pumpkinseed sunfish beds. The remaining 30 per cent were scattered around the perimeter of the lake. Hybrids were observed and some were removed by fishing from spawning beds.

Following the massive application of 4,000 pounds of fertilizer on May 29, the filamentous algae became prominent. The spawning activity on the part of the centrarchids did not get underway until after the 15th of June due to a late spring. By that date, the filamentous algae had temporarily subsided. Frequent tallies of spawning beds were made after June 20. Following the application of fertilizer on June 18, the filamentous algae appeared in large quantities all around the lake including the areas previously occupied by the spawning beds. The fish were unable to keep the nests clear and

Table 6. Results of Young-of-the-year
Stomach Sampling

		Centrarchids		Yellow Perch	
Number of stomachs		110.		127.	
Number empty		4.		14.	
Per cent stomachs empty		3.6		11.	
Average length (mm.)		30.7		43.5	
Total number organisms		12,070.		10,888.	
Organisms per stomach		114.		96.	
Zooplankters	A	11279	92.4	10030	92.1
	B	2.4	73.2	1.7	50.4
	C	96	90.5	92	80.7
Midges	A	588	4.9	641	5.9
	B	.8	22.8	.8	24.6
	C	76	71.7	81	71.0
Mayflies (Caenis)	A	3	0.1	207	1.9
	B	0.1	3.6	.8	24.9
	C	3	2.8	40	35.1
Hydrocarnia	A	179	1.5	....	....
	B	....	....	....	....
	C	29	27.4	....	....
All others	A	21	1.8	10	.1
	B	....	....	....	....
	C	16	14.5	13	10.2

A = Number of organisms and per cent of all organisms by number
 B = Volume of organisms in c.c. and per cent of all organisms by volume
 C = Number of fish and percentage of fish selecting this food

63,455 51

the beds were abandoned. Bluegills were observed guarding nests in deeper water on the areas of fibrous peat and beyond the spread of the filamentous algae. It is doubtful whether the spawning on the softer bottoms was very successful. Spawning activity on the part of pumpkinseed sunfish was observed up to the second week in August and they were probably more successful because of this prolonged spawning activity. It appears that the filamentous algae reduced the success of the bluegills and possibly that of the sunfish. Whether or not this result of fertilization would be considered desirable or undesirable would depend on the condition of the fish population concerned.

Age and Growth

A growth analysis was conducted in order to determine if an increase in growth rate of the fish population occurred during and following fertilization. The growth analysis revealed increases in growth rate of the game species present that were statistically highly significant. In this phase of the problem direct comparison of pre-fertilization growth rates to growth rates during the two years following the first application of fertilizer is presented.

In making this growth study, 573 scale samples from 287 pumpkinseed sunfish, 110 yellow perch, 92 bluegills, and 84 hybrids were collected, aged, and lengths at different ages calculated. These fish were collected between July 25, 1946 and April 11, 1948 by means of hook and line, trap nets, or were picked up following winter kill. The trap nets resembled

commercial fyke nets but were smaller. Using the population estimate of North Twin Lake in 1946 (Crowe, unpublished data) and the numbers of scale samples collected for this problem, a comparison was drawn indicating the per cent of population sampled. It should be noted that, since his net mesh was too large to retain perch, Crowe made no estimate of their numbers. However, the perch are by far the most important species present and, based on the rate of capture with both small trap nets and hook and line, are present in numbers several times that of all the Centrarchids combined. The large perch population is a factor that must be considered when any part of the biology of the lake is being studied.

Table 7. Per cent of estimated total population included in age and growth studies.

Fish Group	Estimated Number of Fish	Number of Scale Samples	Per Cent of Total Estimated Population
Pumpkinseed sunfish	2,800	287	10%+
Bluegills	290	92	32%
Hybrids	950	84	9%
Yellow perch	No estimate	110	-

These numbers are based on "catchable fish", that is, fish large enough to be retained by the mesh of the fyke nets being used.

Table 8. The composition of the North Twin Lake fish population by year groups on basis of the scale samples.

	1946	1945	1944	1943	1942	1941	1940
Bluegills	-	-	13% ¹ (12) ²	49% (44)	34% (31)	2% (2)	1% (1)
Hybrids	3% (2)	3% (2)	20% (17)	73% (61)	1% (1)	-	-
Pumpkinseed sunfish	42% (57)	18% (26)	12% (16)	21% (29)	6% (8)	-	-
Yellow perch	29% (32)	13% (14)	52% (58)	5% (6)	1% (1)	-	-

1/ percentage of sampled fish (by species) coming from that year group

2/ number of fish collected

As indicated by Table 8, the spawning and survival of 1943 was particularly successful for centrarchids and that most of the hybrids were produced that season. The yellow perch spawning was most successful in 1944 and the spawning or survival of the centrarchids was unsuccessful from that year until 1946 when the pumpkinseed sunfish seem to have been very successful.

Wherever possible the comparison of pre-fertilized growth rates to growth rates after the beginning of fertilization has been based on actual measurements using the total lengths of fish of the same age. Where data was insufficient to do this, namely in some age groups of the perch and sunfish, calculated total lengths at past annuli were included. The work of Creaser (1926) in his study of the pumpkinseed sunfish in a lake in this same general area wherein he indi-

cates maximum error of 2-3 mm. between calculated measurements and actual measurements will justify such a procedure. For the yellow perch, the inaccuracies are present but are only significant in the older age groups. To avoid these errors, the calculations of lengths utilized in the comparison of growth rate of yellow perch from fertilized and unfertilized waters were carried back no more than two growing seasons.

The scale samples from the hybrids were few in number and gaps in collection data made impossible a complete statistical analysis of the growth rate changes by year group. It is sufficient to say that during the growth study conducted in 1946, 50 hybrids in their fourth growing season averaged 154 mm. in length. These samples were collected about August 1. Sixteen hybrids collected during 1947 in their fourth growing season averaged 173 mm. in total length and the average date of capture was July 14. The average difference was 24 mm. and is highly significant statistically.

Comparison of bluegills growing before fertilization and after fertilization are made in Figure 3. The lengths of three and four year old fish at the end of the 1945 growing season, just prior to fertilization, are compared with the lengths of fish which were of equal age at the end of 1946 and 1947 the two seasons when fertilizer was applied. The five year old fish are compared for only 1946 and 1947 since no bluegills five years old at the end of the 1945 season were taken. Three, four and five year old bluegills were

Figure 3. Comparison of the average length of
three, four and five year old bluegills
for the years 1945, 1946 and 1947.

TOTAL
LENGTH
(M.M.)



- UNFERTILIZED



- END OF FIRST SEASON
OF FERTILIZATION



- END OF SECOND SEASON
OF FERTILIZATION

225

200

175

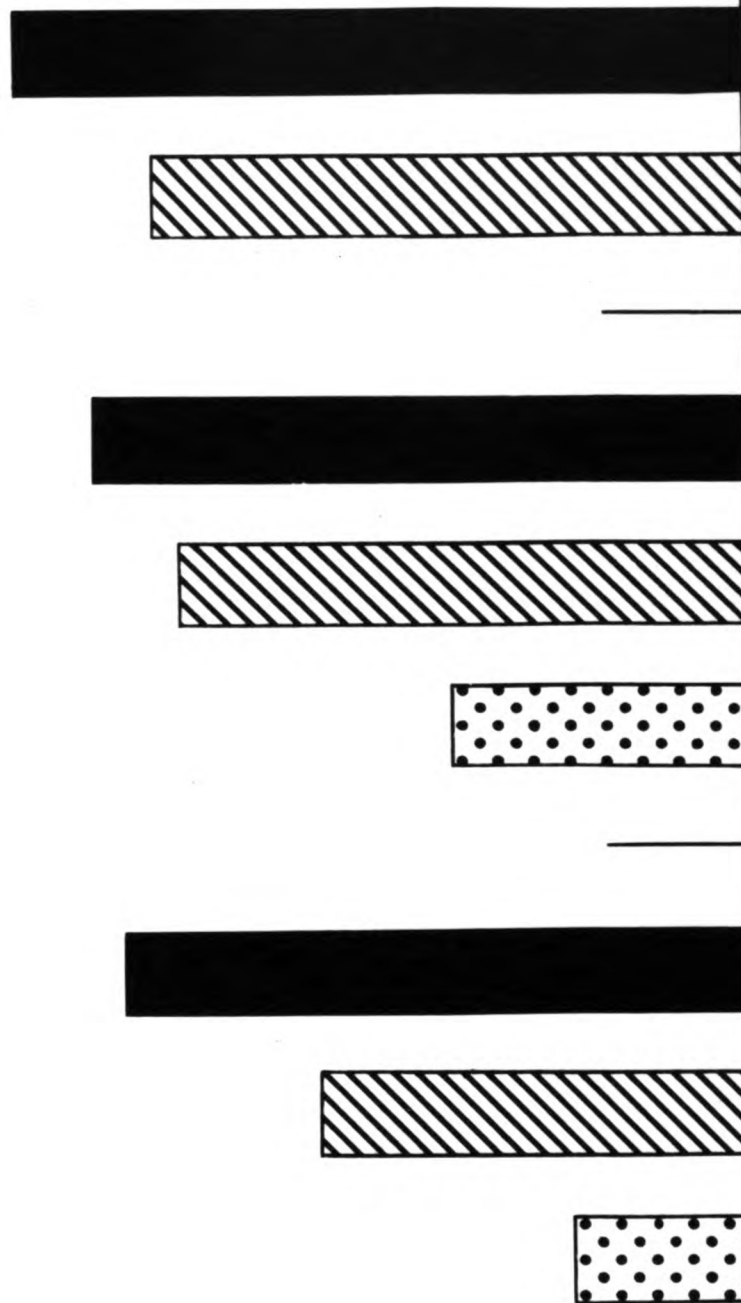
150

125

III

IV

V



selected for comparison because they were the only year groups where there were sufficient numbers on which to base a comparison.

The difference in size before and after fertilization was analyzed on a statistical basis in the table below and it will be seen that in each comparison there is a highly significant difference. Procedure for determination of "t" value was taken from Walker (1943).

Table 9. "t" test to determine the significance of growth rate changes of bluegills following fertilization.

Age	Last completed growing season	Number of fish	Average total length mm.	Standard deviation	"t"	Significance
III	1945	18	128.5	± 11.7	A. 2.77	Highly sig.
III	1946	9	166.0	± 20.7	B. 5.85	
III	1945	18	128.5	± 11.7	A. 2.80	Highly sig.
III	1947	6	195.6	± 12.8	B. 12.0	
IV	1945	15	147.8	± 9.0	A. 2.75	Highly sig.
IV	1946	15	183.6	± 9.4	B. 14.06	
IV	1945	15	147.8	± 9.0	A. 2.76	Highly sig.
IV	1947	14	199.3	± 12.5	B. 13.2	
V	1946	7	188.6	± 9.4	A. 2.90	Highly sig.
V	1947	10	210.5	± 13.4	B. 4.54	

A - "t" value necessary for significance at 1 per cent level.
B - "t" value for data.

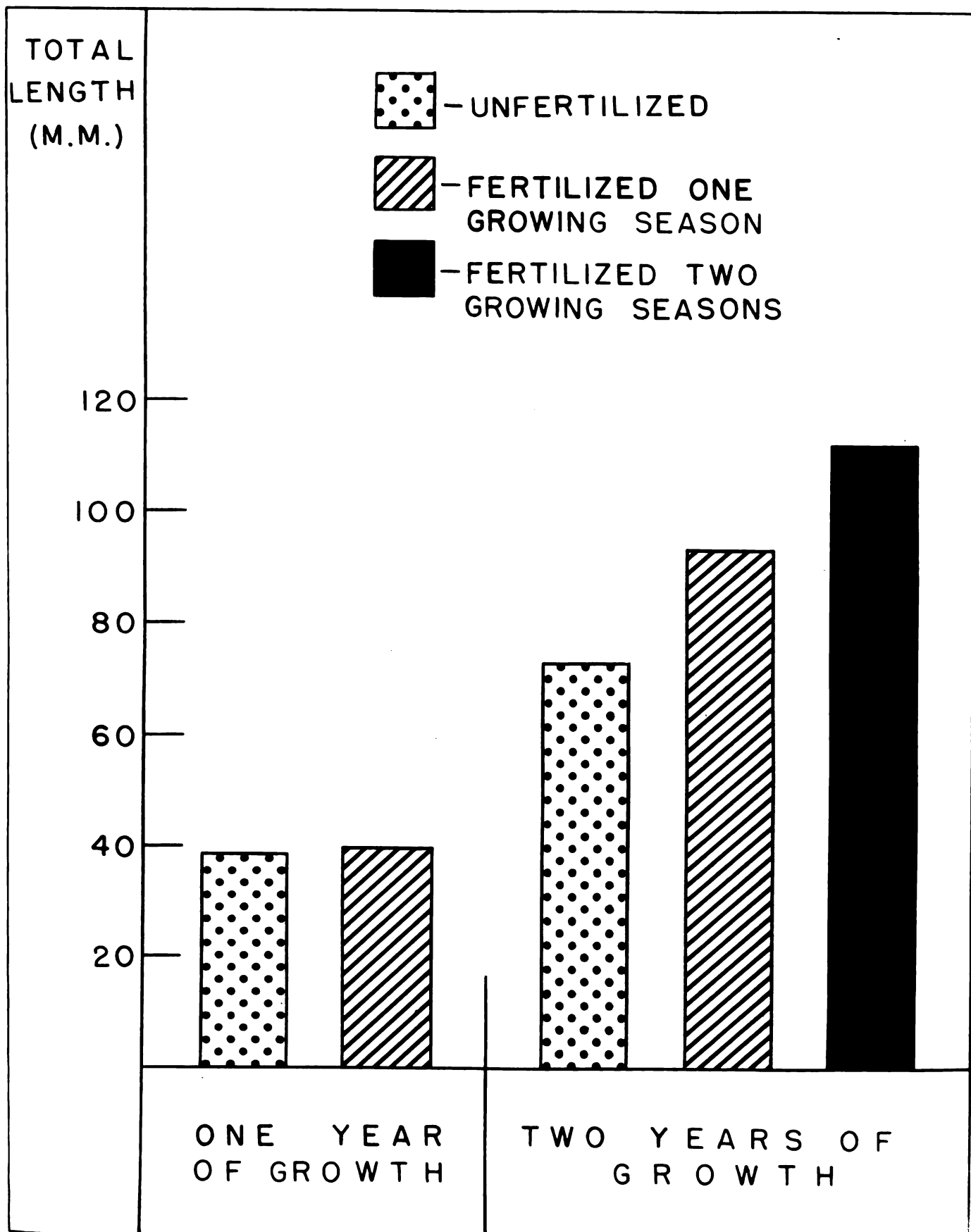
The average lengths of pumpkinseed sunfish before and

after fertilization are compared in Figure 4. The left column represents average length of the pumpkinseeds completing their first year prior to fertilization (1944-1945) and was calculated back one or two years. The second column represents fish that were spawned in 1946 whose first growing season was during the first year of the application of fertilizer. The difference between pre- and following fertilization average length of fish completing their first year of growth during fertilization is small. It is, however, significant at the 7 per cent level.

The second half of the chart represents fish completing two years of growth. The first column represents growth completed prior to fertilization. The second column represents fish completing two years of growth, the first year prior to fertilization and the second during fertilization. The third column represents fish completing two seasons of growth, both during fertilization. Comparing the three columns, it is clear that the pumpkinseed sunfish grew faster during fertilization than prior to fertilization. The change in growth rate was of much greater significance when the fish which had completed two seasons of growth were compared than for one season only.

Why there should be such a highly significant difference between the growth rates of two year old sunfish before and after fertilization and only a slight difference when one year olds were compared is not immediately apparent. A possible explanation might be suggested: Spawning of the sunfish was

Figure 4. Comparison of average total lengths of pumpkinseed sunfish completing first and second years of growth prior to fertilization to average total lengths of pumpkinseed sunfish completing first and second years of growth during fertilization.



very late in 1947 and this slow start would tend to offset any increase in food supply resulting from fertilizer. This would explain why there was a difference significant at only the 7 per cent level for the first year of growth and a very highly significant difference (above the .001 per cent level) the second year of growth. The statistical analysis is shown in the following table.

Table 10. "t" test to determine the significance of growth rate changes in pumpkinseed sunfish following fertilization.

Age	Number of fish	Average length mm.	Standard deviation	"t"	Significance
End of first season of growth.					Significant at 7 per cent level
Unfertilized	123	38.7	± 5.3	A. 2.60	
Fertilized	60	40.2	± 4.8	B. 1.93	
End of second season of growth					Highly sig.
Unfertilized	93	72.7	± 10.5	A. 2.62	
Fertilized*	31	93.2	± 7.6	B. 20.5	
Unfertilized	93	72.7	± 10.5	A. 2.61	Highly sig.
Fertilized	56	111.6	± 11.4	B. 68.2	

* - Pumpkinseeds completing two seasons of growth, the first season prior to fertilization, and the second season during fertilization.

A - "t" value necessary for significance at 1 per cent level.
B - "t" value of data.

The average lengths of yellow perch completing one and two growing seasons before fertilization are compared in Figure 5 with fish completing one and two seasons during fertiliza-

tion. In Figure 5 the two columns on the left represent fish at the end of their first growing season. The difference between the average length attained by the perch in one growing season prior to fertilization is not significantly smaller than perch completing the first year of growth during fertilization. The difference between two years of growth prior to fertilization and two years during fertilization for the yellow perch is highly significant. Since most of the one year old perch representing growth after fertilization made this growth during the 1946 growing season, the first season of fertilization, it is believed that the reason for the high significance of the two growing seasons compared to the null significance of just one year's growth is a lag between the application of fertilizer and an increase in fish food organisms. The carnivorous habits of the perch made for even greater lag than for the centrarchid species. Shown below is a statistical analysis of the data on Figure 5.

Table 11. "t" test to determine the significance of growth rate changes in yellow perch following fertilization.

Age	Number of fish	Average length mm.	Standard deviation	"t"	Significance
At end of first season of growth					
Unfertilized	71	62.6	± 8.3	A. 2.62	Not significant
Fertilized	30	63.3	± 6.5	B. .41	
At end of second season of growth					
Unfertilized	38	102.5	± 10.2	A. 2.66	Highly sig.
Fertilized	24	124.3	± 13.7	B. 8.3	

A - "t" value necessary for significance at 1 per cent leve.

B - "t" value of data.

Figure 5. Comparison of average lengths of yellow perch completing first and second years of growth prior to fertilization to the average lengths of yellow perch completing first and second years of growth during fertilization.

TOTAL
LENGTH
(M.M.)



UNFERTILIZED



FERTILIZED

140

120

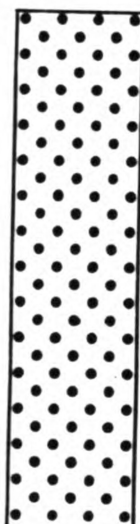
100

80

60

40

20



ONE YEAR
OF GROWTH



TWO YEARS
OF GROWTH

Results of growth analysis for the game species in North Twin Lake indicated that there was a highly significant increase in growth rate for all year groups on which data was available with the exception of the growth for the first year groups of pumpkinseed sunfish and yellow perch. The size of the samples in some of the comparisons are small but it is to be remembered that in testing for significance the size of the sample is considered and the limits of significance set accordingly.

Lake Appearance

North Twin Lake prior to fertilization was clear, had uncolored water and a limited amount of aquatic plants. Following fertilization, the turbidity was greatly increased by the plankton bloom. The filamentous algae mats clogged the shallow water, destroyed most submerged plants and burdened the emergent plants with their weight. The odor of the decomposing algae and plant material was very disagreeable. The clean shore line was obscured by the matted algae. As far as appearance alone was concerned, fertilization did not have a desirable effect.

Winter Kill

During the winter of 1946-47 chemical analysis indicated some oxygen depletion but not severe enough to cause mortality. However, during the latter part of February 1948, chemical examination showed oxygen so low as to be not accurately

measurable by our methods (less than .2 p.p.m.). The strong odor of decomposition noticeable as soon as the ice cover was penetrated was enough to indicate a mortality had occurred.

No dead fish were found but an examination of the bottom material revealed many dead but no living bottom organisms except a few of large Chironomus sp. and these were very inactive. Chaborus or phantom midges were found present in large numbers just under the ice over the deep areas of the lake. These were mostly dead. A few were still alive but their presence in that area would seem to indicate that they were in distress.

The lake was visited again at the time of the spring breakup. Dead fish littered the bottom in shallow areas and on the shore. All species were present among the dead, including large numbers of bullheads. One small yellow perch was observed alive. Every indication was that the winter kill was very severe.

It is believed that this winter kill was a direct result of the application of fertilizer. Examination of South Twin Lake, the mate to the North Twin Lake, bears this out. While South Twin cannot strictly be termed a control lake, the fact that there was no mortality in a similar lake only 100 yards removed is important. Further, in a study conducted simultaneously with the one presented here by Dr. R. C. Ball on two trout lakes 20 miles removed, the result was the same. A severe winter kill occurred in the fertilized water and there

was no serious oxygen reduction in the control lake which, in this case, was very similar to the lake fertilized and could be properly termed a control lake.

Apparently, the additional organic matter provided by the addition of nutrients coupled with the speeded up decomposition and "digestion" of the bottom deposits by the action of the fertilizer brought about the near complete reduction of oxygen.

DISCUSSION

The data that have been presented are the results of a study of the biological effects of fertilizer on a natural warm water lake. This study is a portion of an extensive program to determine the place of fertilization in fisheries management in Michigan. An attempt was made through field collections to obtain data that would show the means by which fertilization results in increased growth in fishes, data that would trace the stimulus of the added nutrients throughout the food chain to the ultimate consumer, in this case the fish. While direct comparisons are not possible in each portion of the field collections, many changes in the lake were apparent as a result of fertilization and these changes proved and evaluated in terms of biological productivity.

The preliminary examination conducted prior to fertilization revealed the lake as unproductive, a condition more or less typical of the lakes lying in the sandy pine plains region of the north central portion of Michigan's lower penin-

sula. The turbidity was low indicating low plankton production. Small numbers of bottom samples revealed the bottom fauna population to be so meager as to be almost absent in many regions of the lake. Scale analysis revealed fish growth as generally poor. The pumpkinseed sunfish seldom reached legal size. Beckman in determining average growth rates of certain Michigan fishes (Beckman 1949) found that the yellow perch reached the six inch limit somewhere between their second and third growing seasons while the yellow perch of North Twin Lake prior to fertilization achieved the six inch limit only after nearly five complete growing seasons. Only the small population of bluegills seemed to be growing normally and they were in poor condition.

Secchi readings taken daily throughout the second summer of fertilization present an accurate record of fluctuations in amount of phytoplankton present. (Van Deusen unpublished.) The average secchi reading of 25-30 inches throughout the summer of 1947 compared to the readings of 5-6 feet of Dr. Ball in July of 1946 indicate a general increase in phytoplankton in the lake. The fluctuations (Figure 1.) of the turbidity during the period of daily secchi readings show that the phytoplankton increased following each application and had started to decrease by the time of the next application. The filamentous algae which appeared on the lake following and during fertilization was observed to follow much the same cyclic pattern. Spot checks taken during the summer of 1948, the summer following fertilization, gave secchi readings of from 4-6 feet.

The filamentous algae was present but no longer conspicuous. These observations would indicate little if any carry over effect of nutrients on the plankton population. However, the excellent growth of the largemouth bass and bluegills planted since the winter kill of February 1948 would indicate that there was a large population of bottom fauna present.

Lack of pre-fertilization data has prevented any demonstration of an increase in zooplankton by direct comparison. It was possible to show an increase in phytoplankton and an increase in the rate of growth for the game fish present. These facts plus the presence of large numbers of zooplankters in the stomachs of both adult and young-of-the-year fish support the probability of an increase in zooplankton. The fact that most of the zooplankters which appeared as fish food were ostracods and bottom or near bottom dwellers in habit would explain why few of them were present in the plankton samples.

The results of other workers show conclusively that an increase in bottom organisms usually follows the application of inorganic fertilizer to ponds and lakes. (Swingle and Smith 1941) (Surber 1943) (Ball 1949) The absence of pre-fertilization data on North Twin Lake precludes any direct comparison. However, small numbers of bottom samples taken before fertilization by Dr. Ball indicated a paucity of bottom organisms. Good but less direct evidence is furnished by examining the results of the stomach and scale analyses. In post-fertilization stomach samples the bottom fauna furnished 77 per cent

of the food of the centrarchids and directly or indirectly nearly 100 per cent of the food of the yellow perch. The age and growth study that was conducted using scale samples from the same individual fish showed, when analyzed statistically, a highly significant increase in growth rate following fertilization. Since no other phenonema that could account for as great a difference in growth rate was observed to have occured during the two years of observations on North Twin Lake, it can be assumed that the increase in growth rate occured as a result of an important increase in bottom fauna organisms, the major source of food to all species important in the lake.

The spawning of the centrarchids was affected adversely by the covering of the shoal areas by mats of filamentous algae. Depending on the condition of the fish population present, such an effect would be either desirable or undesirable, depending on whether or not the lake is overpopulated with centrarchids.

The appearance of the lake and the useability of the lake was adversely affected by the fertilizer. The sight of the matted green scum formed by the filamentous algae around the shore and festooning the marginal vegetation was very unsightly. Aside from this, the algal mats were also a hindrance to fishermen both in manoeuvering their boats and by the fouling of their baits. The odor of decaying algae was very unpleasant.

The winter kill that followed the second year of fertiili-

zation which was from every indication the direct result of the fertilization is a problem that anyone contemplating the use of fertilizers in fish production should be cognizant of. The greater amount of total organic matter produced by the adding of nutrients and perhaps the more rapid decomposition of this and other organic matter by the added nutrient material are the steps that increase the danger of winter kill. Until we are better able to predict the amount of increase in total organic matter produced by a given amount of fertilizer on any particular body of water, the danger of winter kill will be present in Michigan and areas of comparably severe winters.

SUMMARY

1. A definite increase in plankton followed each application of fertilizer.
2. Heavy mats of filamentous algae were a nuisance to fishermen, overburdened higher aquatic plants and had an unpleasant odor as they decayed.
3. It is very probable that an important increase in the bottom fauna occurred. Lack of pre-fertilization data precluded direct comparisons of bottom fauna before and after fertilization but a proved increase in plankton and a highly significant increase in the growth rate of fishes dependent on the bottom organisms for food are good indications that an important increase in the bottom fauna of the lake did occur. This would be in line with results of other workers using fertilizers to increase fish productivity. (Smith, M. W. 1945) (Patriarche and Ball 1949) (Ball 1949)

4. Stomach analyses of the game species present clearly showed a nearly complete dependence, directly or indirectly, on the bottom fauna for their food.
5. Comparisons of the feeding habits of the bluegills and pumpkinseed sunfish to their hybrids revealed that where major differences in food habits of the parent species existed the hybrids occupied an intermediate position.
6. The filamentous algae kept the centrarchids from their normal spawning areas and probably reduced their spawning success.
7. A statistical analysis of growth rates before and during fertilization showed a highly significant increase in growth following fertilization for all major game species and for all ages for which data was available.
8. No alteration in the alkalinity or pH of the lake was observed. No oxygen reduction was observed during the summer months.
9. Checks and observations on North Twin Lake during the summer of 1948, the summer following fertilization, to measure carry over effects of fertilizer revealed: (a) No plankton bloom was observed; (b) filamentous algae was no longer a problem; (c) the largemouth bass and bluegills with which the lake was restocked following the near complete winter kill of February 1948 were growing at a rapid rate which indicated an excellent food supply.
10. An almost complete winter kill followed the second summer of fertilization. The kill was complete for the centrarchid species and nearly so for the yellow perch. Bottom organisms

of all major groups were observed dead in large numbers.

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