# INVESTIGATIONS ON PLANKTON PRODUCTION IN FISH PONDS [1]

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## CONTENTS

| | Page |
|---|---|
| Introduction | 137 |
| Purpose of this investigation | 137 |
| Literature | 140 |
| Methods of analysis and expression of results | 141 |
| Acknowledgments | 142 |
| C pond experiments | 142 |
| Description of ponds | 142 |
| Purpose of this experiment | 142 |
| Limnological data | 144 |
| Organic matter | 151 |
| Plankton | 153 |
| Summary | 157 |
| D pond experiments | 158 |
| Description of ponds | 158 |
| Purpose of this experiment | 158 |
| D pond experiments—Continued. | |
| Pond D 4 | 158 |
| Notes on vegetation | 158 |
| Limnological data | 159 |
| Plankton | 159 |
| Pond D 5 | 161 |
| Notes on vegetation | 161 |
| Limnological data | 161 |
| Plankton | 163 |
| Pond D 9 | 163 |
| Notes on vegetation | 164 |
| Limnological data | 164 |
| Plankton | 166 |
| Summary of D ponds | 168 |
| General summary and conclusions | 168 |
| Literature cited | 175 |

## INTRODUCTION

### PURPOSE OF THIS INVESTIGATION

While the pond culture of fresh-water fishes is an art of many years' standing in certain European countries, notably Germany, in this country pond-fish culture is a relatively recent development. Hence, very little accurate knowledge applying to pond-fish culture in this country is at present available. With the depletion of the native fish stock in our natural waters and with the growing demand for game fish to stock inland waters, the need for more exact knowledge as to how to rear fish in ponds has become apparent. During the last few years the Bureau of Fisheries, through its division of scientific inquiry, has attempted to solve some of the problems pertaining to the rearing of game fish in ponds to the fingerling stage rather than to distribute them as fry. One of the chief problems has been that of increasing the food supply for the fish.

The amount of available fish food may be increased either directly or indirectly: Directly through artificial feeding, indirectly through increasing the natural food supply. It is the policy of the bureau in its pond-culture work with warm-water fishes to increase fish production by the indirect method of using fertilizers to increase the natural food supply rather than to resort to artificial feeding.

[1] This report is based on a doctor's thesis submitted before the graduate faculty of the University of Wisconsin. It was submitted to the Bureau of Fisheries for publication Mar. 13, 1930.

The question may arise as to how the addition of fertilizers increases fish production. The effect is, as already indicated, indirect. In general, the first step is through the plant life of the pond. The production of animal matter anywhere depends in the last analysis on photosynthesis or, in other words, on plant growth. The plant growth in turn depends on the energy derived from the sun, the carbon dioxide of either the atmosphere or of the water, and the presence in solution of suitable forms of nitrogen, phosphorus, potassium, etc. In other words, the amount of plant growth is limited by the amount of sunshine and the availability of those elements that go into the making of plant tissue, and also by the presence of those elements which, although they do not appear as constitutents of plants, are yet necessary to bring about proper growth. Whenever one or the other of these factors—that is, sunshine, carbon dioxide, nitrogen, phosphorus, etc.—becomes exhausted, plant growth ceases. The element that becomes exhausted and thus causes a cessation of plant growth is called a limiting factor, for it is those elements that either become exhausted completely or become reduced to concentrations too low to be effective that determine the amount of growth. Through the use of proper fertilizers all the elements, except sunshine, that enter into the process of plant growth may be intensified; and, provided enough sunshine is present, an increase in plant growth may be expected. This increase in plant growth should in the end mean an increase in fish production. The second step is through the organisms that feed on the plants and which, in turn, are consumed by the game fish. Among these intermediate organisms may be mentioned certain small crustacea like copepods and cladocera, the immature stages of some aquatic insects, and herbivorous forage fish.

In the case of fish ponds, one difficulty arises; namely, that certain plants may grow that are not available for fish food except in so far as they eventually die and decay and become fertilizer. In the fish ponds we are, therefore, more particularly interested in the algæ, and the production of fish may be expected to be more closely related to the production of algæ than to the total plant growth.

In the practice of pond fertilization, the assumption has quite generally been made (see review of literature, p. 140) that phosphorus and nitrogen are the only elements that have to be supplied by the fertilizer, and that the other necessary elements are present in sufficient quantities. In a few instances the assertion has even been made that only phosphorus becomes exhausted and that this element is the limiting factor.

One object of this paper is to present data to show that the addition of various fertilizers to the pond water increases the growth of the plankton algæ (phytoplankton) and likewise increases the production of copepods, cladocera, and rotifers (zooplankton)—organisms that feed directly or indirectly on phytoplankton. Hence, there are presented in this paper the results of quantitative studies on the plankton of ponds that were fertilized and also of control ponds that were not fertilized. Along with the data on plankton counts and volumes (in the case of the net plankton) are presented data showing the amount of organic matter in the water—the organic matter in the bodies of the plankton organisms as well as the unorganized organic matter suspended in the water—that can be removed with an electric centrifuge (see section on methods). Both sets of data show that the addition of fertilizer has a beneficial effect.

Another object of this paper is to present the results of a series of chemical determinations that have been made on the pond water. The reason for making these determinations is obviously as follows: If we are going to fertilize ponds intelligently, we must first of all have some idea as to what elements necessary to photosynthesis are becoming exhausted. In other words, which are the limiting factors? In an attempt to answer this question, the following chemical determinations were made quantitatively: Organic nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, dissolved phosphorus, organic phosphorus, chloride, free carbon dioxide, phenolphthalein alkalinity, pH, and dissolved oxygen. It is important that all the four forms of nitrogen and the two forms of phosphorus be determined, because an element must not only be present but it must be in an available form. In the case of nitrogen, for instance, the nitrate alone is immediately available to a majority of algæ. Some of the blue-green appear to utilize compounds of ammonia, but the nitrate seems to be preferred by most. The organic nitrogen and the nitrite nitrogen are not immediately available to any of the algæ. Hence, to determine total nitrogen or even total inorganic nitrogen would be misleading. The same is also true of the phosphorus, for it is only the dissolved phosphorus that is immediately available for plant growth. A major object of these chemical determinations was to find out if the inorganic nitrogen or the dissolved phosphorus ever became completely exhausted. The data presented in this report show that nitrate and ammonia nitrogen were always present, even in the unfertilized ponds. The dissolved phosphorus, however, becomes at times completely exhausted.

The determinations of pH and phenolphthalein alkalinity were made for the purpose of finding out whether or not the hydrogen-ion concentration may be a controlling factor in the growth of plankton. The results seem to show that within fairly wide limits the hydrogen-ion is not the controlling factor. The high values for alkalinity and for pH seem to be the direct result of photosynthesis. In fact, it looks very much as if the rate of photosynthesis controls alkalinity rather than the reverse. Another reason for making these determinations was to see just how great these variations really are.

That pH and alkalinity in these ponds would be governed very largely by the rate of photosynthesis would probably be expected, for carbonic acid is undoubtedly the chief acid in these pond waters. Now photosynthesis uses not only the free carbonic acid but some of that in loose combination with the metals calcium and magnesium. The withdrawal of carbonic acid would tend to make the water alkaline.

The determinations of free $CO_2$ were made for several reasons. In the first place, we wanted to know how close the correlation is between pH and $CO_2$. If the hydrogen-ion concentration in these pond waters is due largely to $CO_2$, then the pH values and the values for $CO_2$ should be in an inverse ratio; that is, as the $CO_2$ goes up the pH should go down. This assumption is borne out by the results. Another reason for making determinations of free $CO_2$ was to see if this acid might ever be present in sufficiently large quantities to become detrimental to fish life. Still a third reason is that since $CO_2$ is one of the raw materials for photosynthesis it may become a limiting factor.

The dissolved oxygen determinations are important for two reasons. In the first place, it seemed worth while to determine just how abundant this element is and to what extent it varies in amount. Another reason was to see if the dissolved oxygen would ever become low enough to endanger fish life. This was of especial importance in those cases where organic fertilizers were added to the water. Apparently the amount of fertilizers used in our pond work did not seriously affect the oxygen supply.

The chloride determinations were made to discover any relationship between the available chloride and the amount of plankton. The results suggest that a plentiful supply of chloride was always available, and that chloride was not a limiting factor.

Along with these chemical determinations there were also made observations on temperatures and on turbidity. Turbidity, since it determines the extent to which sunlight can penetrate the lower strata of water, may have an important influence on photosynthesis.

To attempt to analyze all the data that are presented in this report at the present time would seem premature to the writer. Although the data may seem impressive in volume, it is manifestly inadequate to explain and to correlate the physical, chemical, and biological processes that are taking place in a fish pond. An explanation which may hold true for one pond may not fare so well when the data from another pond are examined. The writer has, therefore, purposely refrained from drawing many hard and fast conclusions. A few conclusions that seemed warranted by the data presented in this report, as well as by other unpublished data, are given at the end of this paper. The writer hopes, however, that while this paper fails to solve the life processes of a fish pond, it may act as a stimulus for further work along this line.

## LITERATURE

Various attempts have been made to link up the productivity of the sea and of bodies of fresh water with certain definite chemical elements. The dissolved phosphorus has been designated as a limiting factor by Atkins and Harris (1924). They found that one pond which they studied contained 0.055 p. p. m. of dissolved phosphorus in spring, and another pond contained 0.04 p. p. m. During the summer no phosphorus at all or only very small amounts were found. They concluded that the further growth of algæ had been prevented by the exhaustion of the dissolved phosphorus early in spring.

Fisher (1924) reported that at the Bavarian Pond Fishery Experiment Station an increase in carp production was obtained when superphosphate or basic slag were used as fertilizers. Fertilizers rich in nitrogen and potassium but containing no phosphorus also increased carp production, but to a very much lesser degree. Fisher concluded from these experiments that the available phosphorus was the limiting factor and that nitrogen and potassium were generally present in sufficient amounts and did not have to be added through the fertilizer.

Brandt (1919) reported that the amount of soluble phosphorus in the surface water of the North Sea was smallest in May and June and largest in November and February. Atkins (1926) found that the dissolved phosphorus at various places off the coast of England reached a minimum in summer and a maximum in winter. The decrease in the soluble phosphorus in spring was proportionate to the increase in phytoplankton.

Harvey (1926) found that the nitrate nitrogen was completely exhausted in the English Channel during August of 1925. In 1927 in summarizing our present knowledge of the productivity of the ocean this author concludes "There is an excess supply of the requirements for photosynthesis with the exception of phosphate and nitrate," and "The fertility of an ocean will depend for the most part on two factors; namely, the length of time taken by the corpses of marine organisms and excreta to decay, and the length of time taken by the phosphate and nitrate so formed to come again within the range of algal growth."

Juday et al (1928), who studied 88 lakes situated in northeastern Wisconsin, state, "No definite evidence was found to indicate that soluble phosphorus is a limiting factor in the production of phytoplankton in those lakes." Again, "In some lakes which support a relatively large crop of plankton there is no decrease in the amount of soluble phosphorus, or only a very slight one, in the upper water from May to July or August." They therefore failed to confirm Atkins's theory at least in as far as the 88 lakes studied are concerned.

Data will be presented in this paper that tend to show that soluble phosphorus may be a limiting factor in fish ponds, but it will also be shown that phosphorus is not the only limiting factor. Evidence will also be presented to show that inorganic nitrogen was not a limiting factor.

Czensny (1919) calls attention to the fact that the free $CO_2$ may directly limit the production of algæ and indirectly the production of those organisms that feed on algæ. Birge and Juday (1927) have shown that the soft-water lakes in northeastern Wisconsin that are extremely low in fixed $CO_2$ do as a rule contain considerable quantities of free $CO_2$. In the hard-water lakes studied by Birge and Juday there is generally enough of what has been called the half-bound $CO_2$ to make up for any deficiency in free $CO_2$. The algæ can make use of the half-bound as well as of the free. The data that will be presented in this paper confirm the conclusions of Birge and Juday as far as the hard waters are concerned.

That the addition of fertilizer to the pond water has an effect on plankton production has been shown by Von Alten (1919). In Von Alten's experiments, the effect of fertilizer was specially noticeable in the case of diatoms. He observed an increase in the number of species, the number of individuals, and an increase in size. Pauly (1919) noticed that inorganic fertilizers exerted a beneficial effect upon Volvox, rotifers, Cladocera, and copepods, but the number of diatoms was decreased.

## METHODS OF ANALYSIS AND EXPRESSION OF RESULTS

The different forms of nitrogen and the chlorides were determined according to the procedures outlined by the American Public Health Association in Standard Methods of Water Analysis (1926). The free $CO_2$, the phenolphthalein alkalinity, and the dissolved oxygen were determined as outlined by Juday (1911). The soluble phosphorus was determined by Denige's method (1921). The total phosphorus was determined by a method outlined by Juday et al. (1928). The difference between the total and the soluble phosphorus has been designated as the organic phosphorus. All phosphorous determinations were made on centrifuged water. For the determination of hydrogen-ion a La Motte colorimetric outfit was employed. Transparencies were determined by means of Secchi disk. The organic matter in the plankton was determined as described by Juday (1926). The net plankton was determined volumetrically by straining a definite volume of water through a Wisconsin plankton net. The concentrated sample obtained in this way was then transferred from the plankton bucket to a graduated tube of an electric centrifuge and was centrifuged at a moderately high speed for two minutes. The volume in cubic centimeters was then read off directly from the tube. It might be stated here that volumetric determinations of net plankton are not always a very good index of productivity.

In the first place many of the smaller organisms will not be retained by the plankton net, and in the second place some organisms pack much more closely in the centrifuge tube than others. For the centrifuge plankton counts, half a liter of water was run through the Foerst centrifuge. The algæ in the centrifuge plankton were enumerated in the usual manner.

Most of the chemical results are expressed in parts per million (p. p. m.) in the text. The organic matter of the net plankton also called the organic matter or in some cases the net loss on ignition has been expressed in milligrams per liter. In the tables the expression milligrams per liter alone has been used. The hydrogen-ion concentrations are as a matter of convenience expressed in terms of pH values rather than in terms of the actual hydrogen-ion concentration. According to this notation the maximum hydrogen-ion concentration corresponds to the minimum pH value. The transparency is expressed in inches.

The volumetric net plankton determinations are expressed in cubic centimeters per 10 liters of water. The algæ of the centrifuge plankton are expressed in numbers per liter of water.

The expressions ammonia-nitrogen, nitrate-nitrogen, and nitrite-nitrogen when used in this paper have the same meaning as they have in Standard Methods of Water Analysis. The values for phosphorus are stated in terms of the element rather than in terms of $PO_4$ or $P_2O_5$.

### ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Prof. C. Juday, of the University of Wisconsin, and to Dr. H. S. Davis, of the United States Bureau of Fisheries, for helpful advice and criticism. The writer wishes also to acknowledge his indebtedness to those members of the staff at Fairport who have cooperated in the carrying out of this investigation.

## C POND EXPERIMENTS

### DESCRIPTION OF PONDS

The C ponds are a series of six small cement ponds, all of the same size and shape. Their arrangement with respect to one another is shown in Figure 1. These ponds are 50 feet long and 8 feet wide and each has an area of 378 square feet. The ends are in the form of a semihexagon, which accounts for the reduced area. The depth of the water in these ponds was 14 inches at the upper end and 20 inches at the lower end. This would give each pond a volume of water of approximately 530 cubic feet.

### PURPOSE OF THIS EXPERIMENT

The series of experiments in the C ponds was carried on to determine the effectiveness of soybean meal, shrimp bran, and superphosphate as pond fertilizers. Accordingly C 1 was fertilized with superphosphate, C 2 with soybean meal, and C 3 with shrimp bran. C 4 was used as a control without any fertilizer. An analysis of the soybean meal gave the following results: Total phosphorus 1.2 per cent, nitrogen (exclusive of nitrate nitrogen) 24 per cent, and total organic matter 60.9 per cent. A similar analysis of shrimp bran gave the following results: Total phosphorus 1.9 per cent, nitrogen (exclusive of nitrate nitrogen) 7.1 per cent, and total organic matter 52.6 per cent. The superphosphate is the 16 per cent acid phosphate.

The amounts of fertilizer used and the dates on which it was applied are shown in Table 1.

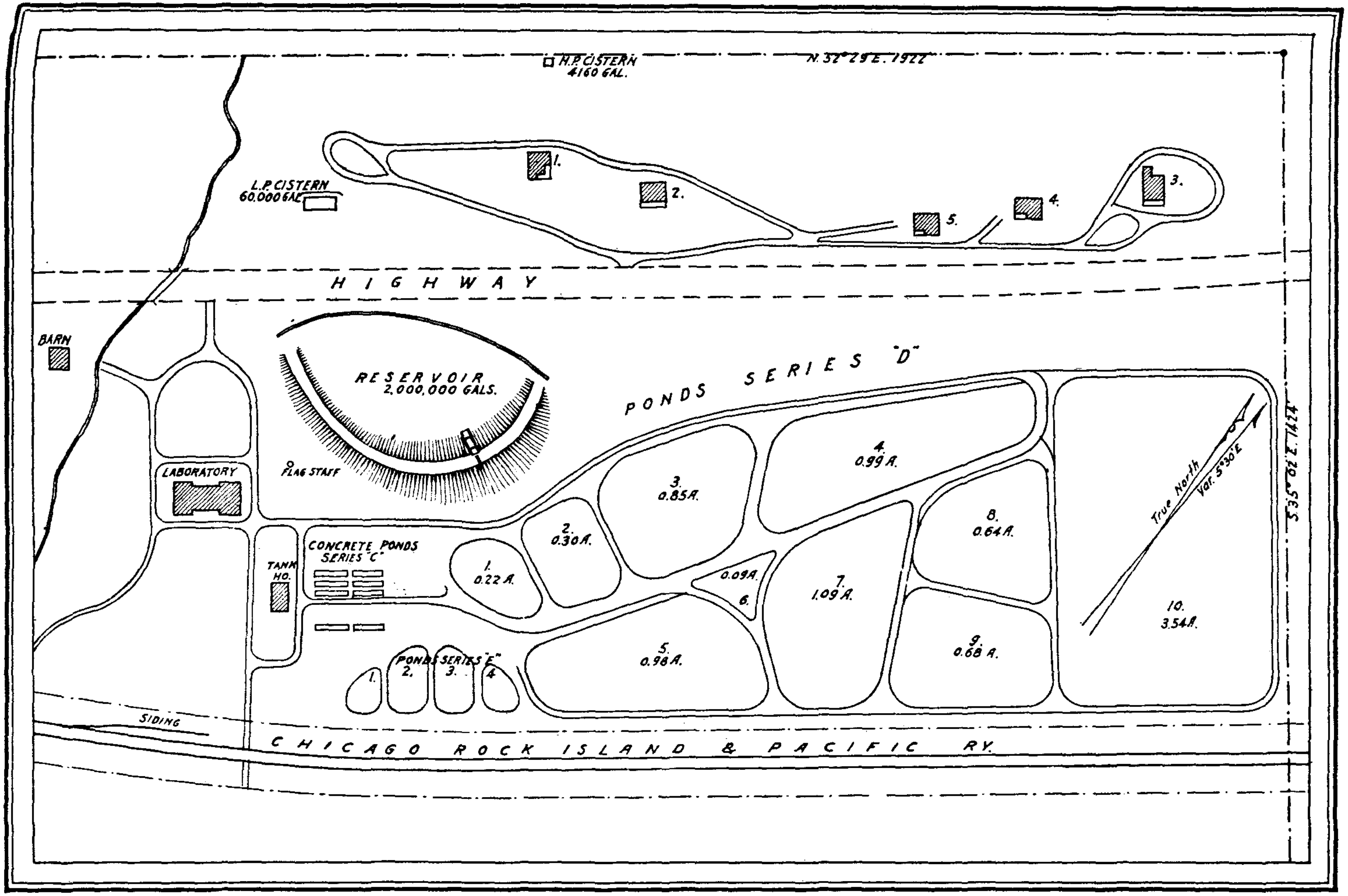


FIGURE 1.—Partial view of the station grounds at Fairport, Iowa, showing positions of the D and E series of ponds

No fish were kept in these ponds during the course of the experiment. The effects of the fertilizers are determined by the amount of plankton and the weight of the organic matter per unit volume of water.

## LIMNOLOGICAL DATA

The original plan for these experiments had been to take net plankton samples only, but it was later decided to make a complete series of limnological observations. The first plankton samples were taken on June 7. Then from June 13 to September 6 they were taken regularly several times a week—sometimes daily. From September 15 to 20 they were again taken daily. The other limnological observations made on this series of ponds cover the period from June 27 to September 19, 1928. The results discussed below are tabulated in Tables 2 to 5, and the variations are shown graphically in Figures 2 and 3.

*Temperature.*—Tests made at the beginning of the experiment and at intervals during the experiment showed that the maximum variation in the temperatures for this series of ponds did not exceed ½° C. at any one time. Therefore, the temperature of one pond was assumed to hold good for the series. I might repeat here that the C ponds are all of the same size and depth, have the same exposure, and are all free from any kind of rooted vegetation.

Table 3 shows that the minimum temperature of 18.3° C. occurred on June 27. The maximum of 25° C. occurred on July 7 and on August 9. Temperature does not seem to be a limiting factor in this experiment.

*Transparency.*—No measurements of transparency were made on these ponds. They were practically water-tight, and very little water had to be added during the season. This made it possible for the suspended silt to settle. Any differences in the transparency were due, therefore, to differences in the amount of plankton and the dust-fine detritus resulting from the decomposition of the dead plankton. In the control pond, C 4, the bottom was plainly visible throughout the season. In C 1 the bottom was visible until the plankton became very abundant. C 3 was very turbid early in the season, but as the plankton, especially the phyto-plankton, decreased, the water became more transparent, so that at the end of the season the bottom was visible. C 2 was always very turbid. This is correlated with the large amount of organic matter present throughout the season. It appears that at least as far as the C ponds are concerned productivity is not governed by transparency, but rather that the reverse is the case.

*Hydrogen-ion concentration.*—The results of pH determinations are shown in Table 2. In C 1 the pH value in samples taken at 8 a. m. ranged from 8.5 on June 27 to 9.0 on July 30. In samples taken later in the day the pH varied from 8.8 to 9.1. These figures show that the water in this pond was at all times distinctly alkaline in reaction to phenolphthalein. The variations in pH and temperature are shown in Figure 2. In C 2 the pH of 8 a. m. samples ranged from 7.55 on August 9 to 9.0 on July 30. In the afternoon samples it ranged from a maximum of 8.75 on September 13 to a minimum of 8.5 on September 19. The minimum of 7.55 occurred at the same time as the maxima for free $CO_2$ and ammonia nitrogen. One of the maxima for temperature occurs on the same date. The variations of temperature and pH are shown in Figure 2. In C 3 the pH in the morning samples varies from 7.6 on August 20 to 9.3 on July 7. In the afternoon samples it varies from 8.7 on August 9 to 9.1 on September 13 and 19. The maximum pH value occurs here after an enormous decrease in the net loss on ignition. The minimum comes after a slight decrease in the net loss on ignition while the latter is on a low level already. The minimum pH is correlated also with a decrease in dissolved oxygen and a large increase in ammonia nitrogen. With a subsequent rise in the organic matter, a decrease in ammonia nitrogen and an increase in dissolved oxygen, the pH goes up again. The variations in pH and temperature in C 3 are shown in Figure 3. In C 4 the pH ranges from 7.7 to 8.8 in the morning samples and from 8.9 to 9.05 in the afternoon samples. The minimum and the maximum occur here at the beginning and at the end of the season, respectively. Figure 3 shows the variations in these values in C 4.

On the whole it may be stated that with very few exceptions the water in these ponds was alkaline with respect to phenolphthalein. Also it may be stated that as a general rule the pH maxima correspond to the minima for free $CO_2$ and conversely the free $CO_2$ maxima correspond to the minima for pH. This would suggest that the acidity or hydrogen-ion concentration is controlled by the free $CO_2$.

*Free $CO_2$.*—Table 2 shows that free $CO_2$ was never present in C 1. In fact there existed always a $CO_2$ deficiency or a phenolphthalein alkalinity. This alkalinity varied from a minimum of 10.10 p. p. m. on June 27 to a maximum of 68.76 p. p. m. on July 30. From this date on the phenolphthalein alkalinity decreases, at first rapidly and then more slowly, until by September 19 it is down to 11.72 p. p. m. again. The great change in the phenolphthalein alkalinity or the free $CO_2$ deficiency from July 19 to August 9 is associated with a rapid rise and decline in the net loss on ignition, also by an increase in pH. The dissolved oxygen increases during this interval from 6.62 p. p. m. to 12.21 p. p. m. and decreases again to 8.74 p. p. m. An examination of Table 6 shows that the net plankton increased from 0.1 cubic centimeter per 10 liters of water on July 19 to 3.5 cubic centimeters on July 30, and to a maximum of 9.0 cubic centimeters per 10 liters of water on August 1. On August 9 it was down to 3.8 cubic centimeters again. These plankton samples were composed almost exclusively of algæ. This, of course, would mean a very rapid rate of photosynthesis and hence the great free $CO_2$ deficiency and the large increase in dissolved oxygen. The variations in pH and the free $CO_2$ deficiency or the phenolphthalein alkalinity is shown in Figure 2.

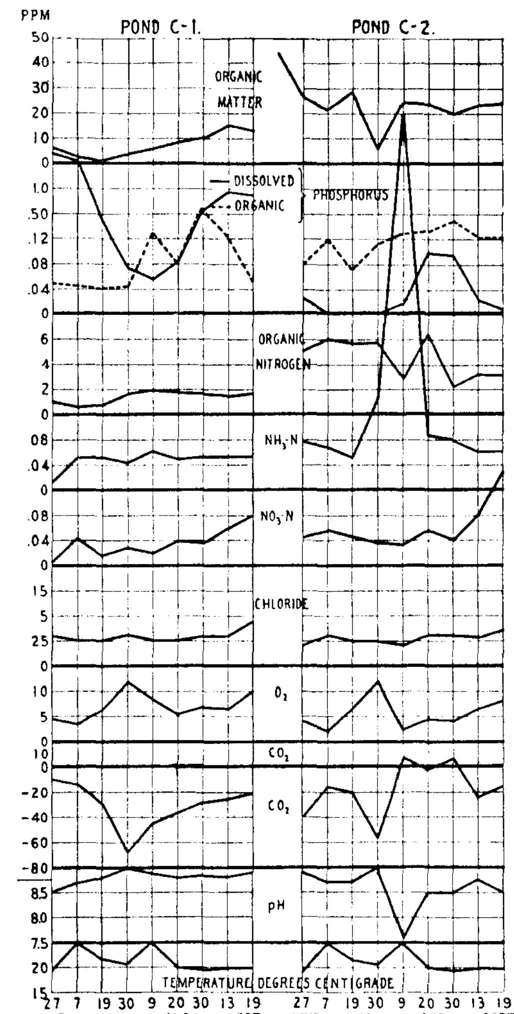


FIGURE 2.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperature in degrees C. for ponds C 1 and C 2

Table 2 shows that free $CO_2$ occurred only twice in pond C 2. The remainder of the time the water was alkaline to phenolphthalein, that is, a free $CO_2$ deficiency existed. The maximum free $CO_2$ deficiency amounted to 57.60 p. p. m. and the maximum free $CO_2$ was 7.58 p. p. m. The first occurrence of free $CO_2$ is associated with a rapid decrease in organic matter and the dissolved oxygen, and a very marked rise in the ammonia nitrogen. The second occurrence of free $CO_2$ is marked by a less-pronounced decrease in the organic matter and the dissolved oxygen, but there is a slight decrease in the ammonia nitrogen. The maximum $CO_2$ deficiency is accompanied by an increase in the organic matter and the volume of net plankton. The variations in free $CO_2$ are shown in Figure 2.

According to Table 2, free $CO_2$ appeared only once in C 3; namely, on August 20 when 6.06 p. p. m. were found. For the rest of the season, with one exception on July 30, when the water was neutral to phenolphthalein, there existed a free $CO_2$ deficiency. This $CO_2$ deficiency was at its height early in the season. The maximum of 85.94 p. p. m. occurred on July 7. Although this is associated with a large decrease in organic matter, the number of algæ that were present (Table 8) indicates that photosynthesis was still going on actively. However, Tables 2 and 9 show that the maximum alkalinity is not correlated with the maximum number of algæ. Later in the season the alkalinity was greatly reduced: From July 19 to August 30 it never exceeded 30.34 p. p. m. In September, however, the alkalinity increased rapidly again so that by September 19 it had reached 65.72 p. p. m. again. This rise in alkalinity in September is correlated with a rise in the number of algæ per liter of water. Figure 3 shows the variations in free $CO_2$.

In pond C 4 as in C 1 free $CO_2$ was never encountered. Table 2 shows that the phenolphthalein alkalinity here varied from a minimum of 8.08 p. p. m. on June 27 to a maximum of 45.50 p. p. m. on September 19. The minimum and the maximum phenolphthalein alkalinities correspond to the minimum and the maximum pH values. The minimum alkalinity corresponds also to the maximum for the net loss on ignition. The fact that the maximum alkalinity occurs simultaneously with the minimum for the net loss on ignition is due to the appearance of some filamentous algæ on the bottom. These algæ would not appear in the samples, yet they use up $CO_2$. Figure 3 shows the variations in free $CO_2$.

Table 2 shows that two sets of determinations of pH and free $CO_2$ were made on August 9. The first sample was taken at 8 a. m. and the second at 3 p. m. This was done in order to obtain some idea as to the amount of variations that may occur during a relatively short interval of time. This test was carried out on a bright day. The table shows that in C 1 the phenolphthalein alkalinity increased from 44.50 p. p. m. to 72.80 p. p. m., and the pH rose from 8.9 to 9.1. These changes are correlated with the presence of 216,000 colonies of Pleodorina and 748,800 colonies of Pandorina per liter of water. (Table 8.) These algæ used up more $CO_2$ for photosynthesis than they produced through respiration. Hence the increase in pH and in alkalinity. In C 2 the free $CO_2$ decreased from 7.58 p. p. m. to −23.34 p. p. m. and the pH rose from 7.55 to 8.7. These changes in C 2 are likewise correlated with fairly high counts for the algæ Oocystis and Chroococcus. (Table 8.) In C 3 the changes were: Phenolphthalein alkalinity from 5.06 p. p. m. to 13.14 p. p. m. and pH from 8.0 to 8.7. The changes in alkalinity are smaller in C 3 than in C 1 and C 2, but the change in pH is greater than in C 1. These changes in C 3 are correlated with fairly high counts for the algæ, Scenedesmus, Chroococcus, and Aphanizomenon.

(Table 8.) In C 4 the phenolphthalein alkalinity increased from 24.26 to 26.28 p. p. m. and the pH from 8.7 to 8.9. The changes in pH are equal to that in C 1, but are much less than in C 2 or 3. The change in alkalinity is less here than in either of the other three ponds of this series. The change in temperature between 8 a. m. and 3 p. m. was 5° C.; namely, from 25° C. to 30° C.

*Dissolved oxygen.*—The dissolved oxygen data are shown in Table 3. This table shows that in C 1 the dissolved oxygen varied from 4.36 p. p. m. on June 27 to a minimum of 3.43 p. p. m. on July 7. On July 30 it reached a maximum of 12.01 p. p. m. After this date it gradually decreases to 5.53 p. p. m. on August 20. By September 19 the dissolved oxygen is up to 10.25 p. p. m. again. The maximum of 12.21 p. p. m. when the temperature was 21.1° C. is amply accounted for by the plankton data Table 6 and is discussed more fully in that connection. The relationship between dissolved oxygen and temperature is shown in Figure 2. The variations in dissolved oxygen are shown in Figure 2.

In pond C 2 the dissolved oxygen reached a minimum of 2.14 p. p. m. on July 7. Then it rose to a maximum of 11.97 p. p. m. on July 30. Ten days later it had dropped to 2.59 p. p. m. On September 19 it was up to 8.18 p. p. m. The two minimal values for dissolved oxygen are associated with decreases in the loss on ignition and the volume of net plankton. Figure 2 shows the relationship between dissolved oxygen and temperature. The variations in dissolved oxygen are shown in Figure 2.

Table 3 shows that the dissolved oxygen in C 3 behaved somewhat differently than it did in C 1 and C 2. In this pond the minimum of 1.66 p. p. m. occurred simultaneously with a considerable increase in the net loss on ignition. Also the midsummer maximum of 6.91 p. p. m. is correlated with a sharp decline in the net loss on ignition. In C 1 and C 2 the reverse of this is true. The maximum for the season occurred on September 19 and amounted to 9.67 p. p. m. Figure 3 shows the variations in dissolved oxygen.

In C 4 the dissolved oxygen, as shown in Table 3, amounted to 6.29 p. p.m. on June 27. This figure is much higher than the corresponding figure for the other ponds of this series. The minimum of 3.53 p. p. m. is likewise higher than the minimum for C 1, C 2, and C 3. Both the season's minimum and the midsummer maximum are correlated with a decrease in the amount of organic matter. The amount of dissolved oxygen in C 1 and C 4 parallel each other fairly closely and are on the average somewhat higher than those in C 2 and C 3. The lower values for dissolved oxygen in C 2 and C 3 as compared with those in C 1 and C 4 are correlated with higher values for the average amount of organic matter. The variation in the dissolved oxygen in C 3 is shown in Figure 5.

*Chlorides.*—Table 3 shows that the amounts of chloride in solution in the water of C 1, C 2, and C 4 are comparable. The same is also true of their variations. In C 1 it ranges from 2.5 p. p. m. to 4.5 p. p. m. and the average for nine determinations is 2.94 p. p. m. In C 2 and C 4 it ranges from 2.0 p. p. m. to 3.5 p. p. m., but the average of nine determinations for C 2 is 2.7 p. p. m., while the average for an equal number of determinations in C 4 is 3.11 p. p. m.; that is, the unfertilized pond had on the average more chloride in solution than a pond fertilized with either superphosphate or soybean meal. In C 3 the amount of chloride in solution is much greater than that in C 1, C 2, and C 4. It ranges from 16.0 p. p. m. to 21.0 p. p. m. The average for nine determinations is 18.2 p. p. m. The higher values for dissolved chlorides in C 3 must be due to the type of fertilizers (shrimp bran) used. The fact that the average amount of chloride in C 1 and C 2 is less than that in C 4 probably does not mean that the superphosphate and the soybean meal contain no chloride, but rather that more chloride was consumed in the production of a relatively much larger crop of plankton. The variations in the dissolved chloride in C 1, C 2, C 3, and C 4 are shown in Figures 2 and 3, respectively. There is nothing in this chloride data that would point toward it as a limiting factor.

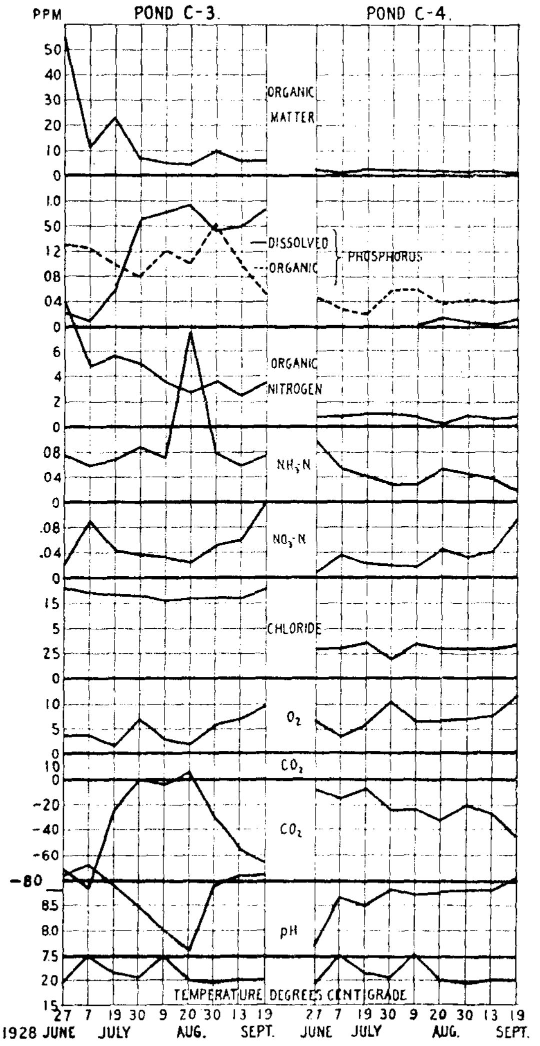


FIGURE 3.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for ponds C 3 and C 4

*Nitrogen.*—All the nitrogen data are combined in Table 4. The variations in the different forms of nitrogen are shown for C 1 in Figure 2, for C 2 in Figure 2, for C 3 in Figure 3, and for C 4 in Figure 3.

*Nitrate nitrogen.*—Table 4 shows that nitrate nitrogen in C 1 varied from a minimum of 0.008 p. p. m. at the beginning of the experiment to a maximum of 0.080 p. p. m. at the end of the experiment. In C 2 the minimum nitrate nitrogen of 0.032 p. p. m. occurred on August 9. The maximum of 0.150 p. p. m. was present on September 19. The minimum for the nitrate nitrogen corresponds to the maximum for ammonia nitrogen. Since this maximum for ammonia nitrogen occurs after a large decrease in the organic matter, the assumption seems warranted that this ammonia nitrogen is due rather to the bacterial decomposition of the organic matter than to the action of denitrifying bacteria. This conclusion seems justified also in view of the fact that there has not been a correspondingly large decrease in the nitrate nitrogen. The nitrogen as nitrate in C 3 is at a minimum of 0.023 p. p. m. and a maximum of 0.120 p. p. m. at the beginning and at the end of the experiment, respectively. In C 4 this form of nitrogen varied from a minimum of 0.009 p. p. m. to a maximum of 0.095 p. p. m. The minimum and the maximum occur here at the same time as the corresponding maxima and minima for C 1 and C 3. C 2 and C 3 contain on the average more nitrate nitrogen than C 1 and C 4. The average for nine determinations are: C 1, 0.036 p. p. m.; C 2, 0.059 p. p. m.; C 3, 0.053 p. p. m.; and C 4, 0.035 p. p. m. C 2 and C 4 differ from each other only by 0.001 p. p. m. and C 2 and C 3 differ from each other by 0.006 p. p. m. As in the case of the ammonia nitrogen the ponds fertilized with organic fertilizers yield the higher values for nitrogen.

*Ammonia nitrogen.*—Table 4 shows that in C 1 the ammonia nitrogen varied from a minimum of 0.012 p. p. m. to a maximum of 0.060 p. p. m. Except for the minimum value the variations are rather small; 0.044 p. p. m. to 0.060 p. p. m. In C 2 the ammonia nitrogen exhibits a far wider range of variations; namely, from 0.052 p. p. m. to 0.60 p. p. m. Only once does the ammonia nitrogen in C 1 equal that in C 2. The maximum for ammonia nitrogen in C 2 occurs simultaneously with a decrease in the net loss on ignition and the dissolved oxygen and an increase in the free $CO_2$. In C 3 the variation is from 0.060 p. p. m. (the maximum for C 1) to a maximum of 0.252 p. p. m. The maximum occurs here somewhat later than in C 1 and C 2, but is associated with similar changes in the net loss on ignition, dissolved oxygen, and free $CO_2$. In C 4 the maximum of 0.096 p. p. m. occurred on June 27 when the first observation was made. The minimum of 0.020 p. p. m. was present on September 19 when the last observation was made. Since the maximum occurs at the beginning of the experiment, it can not be determined whether or not it is associated with a decrease in organic matter.

The averages for nine determinations of ammonia nitrogen are as follows: C 1, 0.047 p. p. m.; C 2, 0.127 p. p. m.; C 3, 0.094 p. p. m.; and C 4, 0.044 p. p. m.

*Organic nitrogen.*—The results of organic nitrogen determinations show that this form of nitrogen varied in C 1 from a minimum of 0.608 p. p. m. to a maximum of 2.0 p. p. m. Figure 2 shows the variations in the organic nitrogen. In C 2 the organic nitrogen ranged from a minimum of 2.24 p. p. m. to a maximum of 6.43 p. p. m. For the variations in organic nitrogen see Figure 3. In C 3 the minimum was 2.56 p. p. m. and the maximum 10.08 p. p. m. The variations in the organic nitrogen are shown in Figure 4. This last maximum is the largest amount of organic nitrogen that was ever encountered in this series of ponds. It coincides with the appearance of the maximum amount of organic matter of 58.8 milligrams per liter; 55.80 milligrams of organic matter is not only the maximum for C 3 but the maximum for the series. In C 4 the organic nitrogen varied from a minimum of 0.240 p. p. m. to a maximum of 1.00 p. p. m. This pond has the smallest amount of organic nitrogen. It has also the smallest amount of organic matter. (Table 4.)

The average for nine determinations of organic nitrogen are: C 1, 1.304 p. p. m.; C 2, 4.43 p. p. m.; C 3, 4.403 p. p. m.; and C 4, 0.704 p. p. m. These values for organic nitrogen would represent the following amounts of proteins: 8.150 p. p. m., 27.687 p. p. m., 27.518 p. p. m., and 4.400 p. p. m. Nitrite nitrogen was never encountered in this series of ponds.

*Phosphorus.*—The data on phosphorous determinations in Table 5 show that the determinations of soluble phosphorus were begun earlier than the other determinations except the net plankton. In C 1 the dissolved phosphorus was 1.28 p. p. m. on June 19. On the 22d it was up to 1.50 p. p. m. and on June 27 it had increased to 1.80 p. p. m. This was the maximum for this pond. The rise in dissolved phosphorus from June 16 to 27 is undoubtedly due to a diffusion of the phosphorus of the superphosphate which had been added on June 7 and 16. After June 27 the soluble phosphorus decreased gradually until on August 6 only 0.045 p. p. m. was left. From August 6 there is an increase from 0.045 p. p. m. to 0.055 p. p. m. The big rise between August 9 and 20 is due in part to the addition of superphosphate (Table 1) and in part to the regeneration of dissolved phosphorus from the organic (fig. 2). On August 30 the dissolved phosphorus was lower than on August 20 in spite of the fact that some more superphosphate was added on August 25 and that the increase in the net loss on ignition had not been any greater than during the interval from August 9 to 20. The large increase in the organic phosphorus, however, suggests that more phosphorus had been used than would have been expected from the increase in the organic matter. The increase after August 30 occurs at the expense of the organic phosphorus. The first decline in dissolved phosphorus occurred simultaneously with an abundant growth of the blue-green alga, *Sphaerozyga.* This alga is attached to the bottoms and does not appear in the water samples on which the organic matter is determined. After this alga disappeared, the plankton and the organic matter increased and the soluble phosphorus decreased to a minimum. The dissolved phosphorus did not increase again until the organic matter decreased. A marked increase in dissolved phosphorus did not occur until after additional superphosphate had been added. The organic phosphorus remained uniformly low until after the first sharp decline in the amount of organic matter on August 9. The maximum of 0.50 p. p. m. occurred on August 30 and is correlated with a rise in organic matter and a decrease in the dissolved phosphorus. Two weeks later the organic phosphorus was down to 0.140 p. p. m. again, but the soluble phosphorus had increased from 0.550 to 0.960 p. p. m. The variations in the organic and the dissolved phosphorus are illustrated in Figure 2.

In C 2 the dissolved phosphorus ranged from none at all to as much as 0.096 p. p. m. Except for the maximum on August 20 and a near maximum value for August 30 the dissolved phosphorus was uniformly low. On several occasions no soluble phosphorus was present. The rise in August is largely, if not altogether, due to the addition of fertilizer. (Through an error on the part of an assistant, 5 ounces of superphosphate were added to this pond along with the soybean meal on August 14.) It is not likely that much of this increase had come from the decomposing plankton. (Fig. 2.) The organic phosphorus ranges from a minimum of 0.070 p. p. m. to a maximum of 0.410 p. p. m. Figure 2 gives little evidence that points toward the regeneration of dissolved phosphorus from the organic. The latter seems to accumulate gradually until the maximum is reached. There is nothing in the rest of the data to account for the decrease in the organic phosphorus between August 30 and September 13. (The assumption might be made that on August 30 a very considerable amount of organic matter, rich in phosphorus, was colloidally dispersed in such fine particles that the centrifuge did not remove it.)

In C 3 the dissolved phosphorous varied from a minimum of 0.005 p. p. m. on June 19 to a maximum of 0.90 p. p. m. on August 20. Table 5 and Figure 3 show that the lower values for the dissolved phosphorus correspond to the higher values for organic matter. The simultaneous rise in dissolved phosphorus and the organic matter between July 7 and 19 may be due either to the addition of fertilizer on July 11 or to the degeneration of organic phosphorus. The increase in soluble phosphorus between July 19 and August 9 must have come from the decaying organic matter. The decrease between August 20 and 30 is accompanied by increases in organic matter and in the organic phosphorus. As soon as the organic matter begins to decline the soluble phosphorus goes up again. The organic phosphorus ranges from a minimum of 0.050 p. p. m. to a maximum of 0.550 p. p. m. The minimum for organic phosphorus corresponds to the maximum for the soluble phosphorus. Figure 3 shows the variations in organic matter, the dissolved phosphorus, and the organic phosphorus. Some degree of relationship between the soluble phosphorus and the organic matter is suggested by Figure 3. Yet one could not draw the conclusion that the soluble phosphorus is the limiting factor, for at no time was it completely exhausted. Moreover, the accumulation of a very considerable amount of soluble phosphorus was not followed by a correspondingly large increase in the organic matter.

Table 5 shows that the dissolved phosphorus was, as a rule, rather low in C 4. Several times it was present only in traces. At other times it was absent altogether. The maximum of 0.012 p. p. m. occurred on August 20 and is correlated with a slight

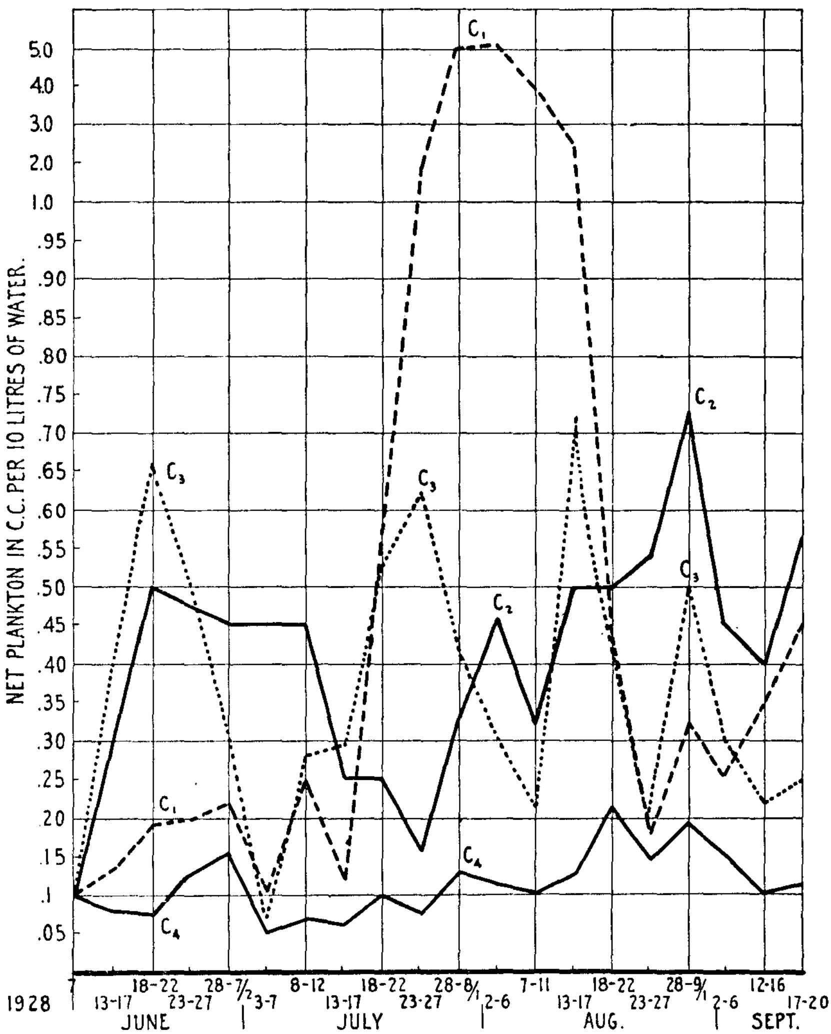


FIGURE 4.—The variation in the volume of net plankton in the C ponds

decrease in organic matter. The organic phosphorus varied from a minimum of 0.015 p. p. m. on July 19 to a maximum of 0.058 p. p. m. on July 30 and on August 9. The variations in the dissolved phosphorus and the organic phosphorus are shown in Figure 3.

## ORGANIC MATTER

The data on the organic matter in the centrifuge plankton are given in Table 4. This table shows that the organic matter in C 1 varied from a minimum of 1.35 milligrams per liter on July 19 to a maximum of 14.43 milligrams per liter of water on

September 13. The low values early in the season are associated with small numbers of algæ in the centrifuge plankton. (Table 8.) The increase in organic matter from July 19 to August 2 is due to a very rapid rise in the phytoplankton, due almost entirely to the growth of green algæ, especially the flagellates Pleodorina and Pandorina. Table 8 shows that on July 28 each liter of water contained 960,000 colonies of Pleodorina and on July 30 each liter of water contained 115,200 colonies of Pleodorina and 756,000 colonies of Pandorina. The net loss on ignition on July 30, August 2, and August 9 is not as great as might be expected from the volume of net plankton (Table 6), but this is probably due to the fact that the major portion of the net plankton was made up of hollow spherical colonies. From August 20 on the organic matter increases again, even though the volume of net plankton is far below the figure for the interval from July 31 to August 17. This is due to a change in the make up of the plankton. As Table 8 shows, the plankton is now dominated by the smaller algæ: Scenedesmus, Oocystis, Chroococcus, etc. The changes in the amount of organic matter are shown in Figure 2. The relationship of organic matter to phosphorus has already been discussed.

In C 2 the maximum amount of organic matter was found when the first determination was made on June 27. This maximum of 44.64 milligrams per liter of water is correlated with the maximum numbers for the algæ Scenedesmus and Aphanizomenon. (Table 8.) From June 27 to August 9 the tendency is downward except for the rise on July 30. This rise on July 30 occurs in spite of a decrease in the number of algæ. On August 9 the minimum of 5.19 milligrams per liter of water was reached. This minimum is correlated with the minimum for algæ counts. (Table 8.) The temporary rise on July 30 is accompanied by an increase in the dissolved oxygen from 6.76 to 11.97 p. p. m., an increase in pH from 8.7 to 9.0, and an increase in the alkalinity from 20.22 to 57.62 p. p. m. The large decrease in organic matter from 27.99 milligrams per liter on July 30 to 5.19 milligrams per liter on August 9 is accompanied by an increase in ammonia nitrogen (Table 4) from 0.144 to 0.60 p. p. m., a decrease in the dissolved oxygen from 11.97 to 2.59 p. p. m., and an increase in free $CO_2$ from −57.62 to 7.58 p. p. m., also a decrease in pH from 9.0 to 7.55. (Table 2.) There is also a slight increase in the dissolved phosphorus. (Fig. 2.) (The dissolved phosphorous was rather low until after the minimum for organic matter had been reached.) On August 20 the organic matter had increased to 24.74 milligrams per liter. The increase is accompanied by a large increase in the algæ Scenedesmus, Oocystis, and Chroococcus. (Table 8.) After August 20 the organic matter remained fairly constant until the end of the experiment. The variations in the organic matter are shown in Figure 2.

In C 3, as in C 2, the maximum for organic matter, namely, 55.80 milligrams per liter, occurred on June 27, when the first determination was made. This maximum is associated with the maximum number of algæ in the plankton. (Table 8.) After that the organic matter decreases very rapidly, so that on July 7 it is down to 11.41 milligrams per liter. Table 8 shows that the number of algæ in the plankton has also decreased enormously. This rapid decline in the organic matter is, however, not accompanied by an increase in the ammonia nitrogen, but there has been some increase in the nitrate nitrogen. (Fig. 3.) The dissolved oxygen has remained practically the same, and the alkalinity and the pH have increased. (Fig. 3.) All of which suggests that decomposition was not taking place at a very rapid rate and that the dead plankton had merely settled on the bottom. On July 19 the organic matter had increased to 23.30 milligrams per liter again. This rise is associated with large increases in the algæ Scenedesmus, Chroococcus, and Aphanizomenon. Still it is associated with a decrease in dissolved oxygen from 3.52 to 1.66 p. p. m., a slight increase in ammonia nitrogen, and a decrease in alkalinity from 85.94 to 23.42 p. p. m. The low oxygen and low alkalinity may be due to the fact that decomposition is going on more rapidly than photosynthesis. However, since there is a big increase in the algæ, it seems more logical to assume that the low oxygen and low alkalinity were due to the fact that during the night respiratory changes in the algæ had been using up the oxygen and at the same time produced the free $CO_2$ that reduced the alkalinity. Had the samples been taken at 3 p. m. instead of at 8 a. m., the dissolved oxygen and the alkalinity would probably both have been higher. After July 19 the organic matter is always relatively low. The minimum of 4.33 milligrams per liter was obtained on August 20. This minimum is accompanied by a low dissolved oxygen, 2.30 p. p. m.; a minimum pH value, 7.6; a maximum for free $CO_2$, 6.06 p. p. m.; and a maximum for soluble phosphorus of 0.90 p. p. m. The number of algæ, however, is not at a minimum on August 20. The rise in organic matter on August 30 is accompanied by big increases in the numbers of algæ Scenedesmus, Oocystis, and Chroococcus.

The amount of organic matter in the control pond, C 4, was on the average much lower than in the ponds C 1, C 2, and C 3. (Table 4.) The maximum of 2.51 milligrams per liter occurred on June 27. The minimum of 0.56 milligram per liter occurred on September 19, when the last determination was made. From July 19 to September 13 the amount of organic matter was practically stationary, ranging from 1.76 milligrams per liter to 1.5 milligrams per liter. Figure 3 shows that the dissolved phosphorus was also uniformly low and suggests that in this case the soluble phosphorus might have been a limiting factor. That inorganic nitrogen was not a limiting factor has been shown on pages 148 and 149. It is pointed out there that the average for ammonia nitrogen in C 1 was 0.047 and 0.044 p. p. m. for C 4, and that the average amount of nitrate nitrogen was 0.036 p. p. m. for C 1 and 0.035 p. p. m. for C 4. The low values for organic matter in C 4 are correlated with relatively small numbers of algæ. (Table 8.)

The average amount of organic matter present in 10 samples from C 1 was 7.22 milligrams per liter, the averages for 9 determinations for C 2, C 3, and C 4 were 23.86, 14.24, and 1.65 milligrams per liter, respectively.

## PLANKTON

*Net plankton.*—The taking of net plankton samples was begun on June 7 and was continued until September 20. A total of 68 samples was taken from each pond. The dates on which samples were taken and the volumes of the samples are shown in Table 6. In Figure 4 the averages for 5-day intervals are plotted. These averages were obtained by dividing the sum of the volumes of plankton taken during the 5-day period by the number of samples taken during the period.

Table 6 shows that the net plankton in C 1 remained low until July 23, when suddenly it increased to 3.0 cubic centimeters per 10 liters of water. On August 1 the maximum of 9.0 cubic centimeters per 10 liters of water was reached. Then it dropped to 4.0 cubic centimeters per 10 liters of water on August 3 and 4, but on August 6 it was again up to 8.6 cubic centimeters per 10 liters of water. On August 18 it is down to less than a cubic centimeter per 10 liters of water, but on the average the volume of plankton after August 18 remains higher than it was before July 25. In the discussion of the free $CO_2$ (p. 145) it has already been pointed out that the enormous increase in the volume of net plankton during the latter part of July and the early part of August was due to the production in large numbers of the flagellates—Pleodorina and Pandorina. It has also been mentioned (p. 145) that the rise in the phytoplankton is associated with a high phenolphthalein alkalinity; namely, 68.76 p. p. m. at 8 a. m. on July 30 and of 72.80 p. p. m. at 3 p. m. on August 9. In discussing the dissolved oxygen it has been mentioned that the maximum of 12.21 p. p. m. occurred on July 30; that is, during the period when the net plankton ran high. Plankton counts show that on July 29 a liter of water contained 960,000 colonies of Pleodorina and on July 30, 115,200 colonies of Pleodorina and 756,000 colonies of Pandorina. (Table 8.) (The figures for the net plankton in this pond along with those for the phenolphthalein alkalinity and the dissolved oxygen give some idea as to the magnitude of the changes that may take place when everything is favorable for photosynthesis.) The average amount of net plankton for 68 samples was 1.22 cubic centimeters per 10 liters of water.

Table 6 shows that the behavior of the net plankton in C 2 was less striking than was the case in C 1. As the tables show the variation here was from 0.10 to 1.0 cubic centimeters per 10 liters of water, the total amount of net plankton produced in this pond is far less than that in C 1. The average for 68 samples from C 2 was 0.43 cubic centimeter; the average for an equal number of samples from C 1 was 1.22. This is a ratio of very nearly 1:2.3. This apparently contradicts the fact that the net loss on ignition in C 2 was slightly more than three times as large as that in C 1. However, it serves to emphasize the fact, already referred to in the introduction, that the volume of net plankton is not always an absolute standard whereby the productivity can be measured. This is well illustrated by the fact that even in C 1 the maximum for the net plankton does not correspond to the maximum for the loss on ignition. Again, on July 30, when the net plankton in C 1 and C 2 amounted to 3.5 and 0.48 cubic centimeters per 10 liters of water, respectively, the loss on ignition in C 1 was 3.69 milligrams per liter, and in C 2 it was 27.99 milligrams per liter of water. Plankton counts made on the centrifuge plankton of that date show that in C 1 each liter of water contained 115,200 colonies of Pleodorina and 756,600 colonies of Pandorina and that each liter of water in C 2 contained 40,200,000 filaments of Aphanizomenon and 480,000 filaments of Anabaena. The reason why the loss on ignition and the volume of net plankton do not always agree is due to the fact that the centrifuge removes small organisms and fine detritus that would pass through the net.

In pond C 3 the volume of net plankton varies from a minimum of 0.10 cubic centimeter per 10 liters of water to a maximum of 0.92 cubic centimeter per 10 liters of water. The average for 68 determinations was 0.36 cubic centimeter. The average amounts of net plankton for C 3 and C 2 do not differ very much. As Table 6 shows, there are brief intervals when the production in C 3 exceeds that in C 2, but on the average C 2 keeps somewhat ahead of C 3.

In control pond C 4 the volume of net plankton from 10 liters of water ranged from a minimum of 0.03 cubic centimeter to a maximum of 0.40 cubic centimeter. The average for 68 determinations was 0.12 cubic centimeter. This is exactly a third of the average for C 3, a little better than one-fourth the average for C 2 and approximately a tenth of the average for C 1. The same thing, therefore, that holds true for the organic matter is also true of the net plankton; namely, that the three ponds which were fertilized produced more plankton than did the control pond that was not fertilized.

In Table 7 there is given a brief summary of the results of enumerating the animals in the net plankton samples. Only the most important genera are listed. For a more complete tabulation of these results the reader is referred to another paper

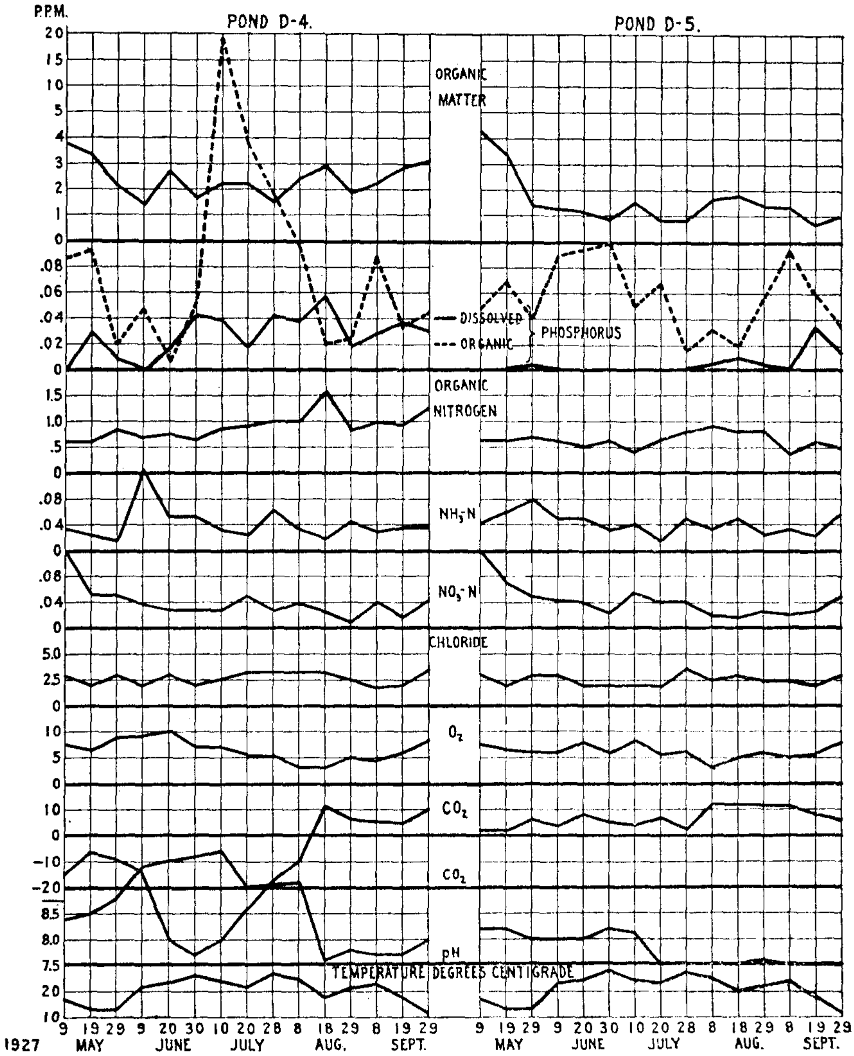


FIGURE 5.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for ponds D 4 and D 5

(Wiebe et al., 1929). The results show that Cyclops, Bosmina, the copepod nauplii, and the rotifers of the genus Anuraea were by far the most important constituents of the zooplankton. The table reveals a large discrepancy between the number of Cyclops and the number of nauplii. Since other copepods were present in very small numbers only, this discrepancy may be referred to as existing between nauplii and Cyclops. The table also shows that Anuraea was more abundant in the control pond and in the pond that was fertilized with inorganic fertilizer than in those ponds that were fertilized with organic fertilizer.

The average number of all crustacea, exclusive of nauplii, per liter of water was as follows: C 1, 484.41; C 2, 1812.21; C 3, 621.4; and C 4, 265.72.

This brief summary of the zooplankton counts again shows quite definitely that the addition of fertilizer had a beneficial effect on plankton production.

*Centrifuge plankton.*—The algæ in the centrifuge plankton have been enumerated in all of the samples collected between June 27 and August 30, 1928. The results are tabulated in Tables 8 to 12.

C 1. Table 8 shows that Chroococcus was the only member of the Myxophyceæ that was present in large numbers. A maximum of 1,800,000 cells per liter occurred on August 30. Aphanizomenon was the only other blue-green alga that occurred in this pond. Among the Chlorophyceæ (exclusive of the flagellates) Oocystis, Pediastrum, Scenedesmus, and Staurastrum appeared in fairly large numbers. Oocystis reached a maximum on August 20, when 536,200 single cells and 960,000 colonies of this alga were present per liter of water. Pediastrum, Scenedesmus, and Staurastrum all reached a maximum on August 30. Of the flagellates, Pandorina and Pleodorina should be mentioned. These two colonial flagellates are the dominant forms in the plankton from July 28 to August 9. Pleodorina reaches a maximum of 960,000 colonies per liter on July 28 and Pandorina a maximum of 749,800 colonies on August 9. Eudorina and Volvox also occurred in the plankton, but only in small numbers. Stephanodiscus and Synedra were the only diatoms found in this pond and they occurred in small numbers only.

C 2. Table 8 shows that Aphanizomenon and Chroococcus were the principal Myxophyceæ that occurred in this pond. Of these the former reached a maximum of 205,500,000 filaments per liter on June 27, the latter a maximum of 8,032,000 single cells and 9,728,000 colonies on August 30. A third blue-green, Anabaena, occurred once in considerable numbers. The principal Chlorophyceæ were Oocystis and Scenedesmus. Both of these algæ attained a maximum on June 27, when each liter of water contained 240,000 single cells and 840,000 colonies of Oocystis and 8,550,000 colonies of Scenedesmus. Other green algæ present in appreciable numbers were Actinastrum, Closterium, Kirchneriella, Merismopedia, Pediastrum, and Tetrædron. Synedra was the only diatom that was found. The plankton of this pond was characterized by the total absence of the flagellates that were so abundant in C 1.

C 3. A comparison shows that the same algæ that were most abundant in C 2 are likewise the most abundant in C 3. Aphanizomenon reached a maximum of 101,700,000 on July 19. In the case of Chroococcus the single cells were most abundant on June 27, whereas the palmella stage was most abundant on August 30. Of the Chlorophyceæ, Oocystis reached a maximum of 1,219,720 single cells and 234,360 palmelloid colonies on August 30. The other leading green alga, Scenedesmus, attained a maximum of 3,840,000 colonies on June 27. It, however, was almost equally abundant on August 30. Other green algæ that occurred in considerable numbers were Actinastrum and Pediastrum. As in C 2, Synedra was the only diatom that occurred in the plankton from this pond. It was present in large numbers only once; namely, on June 27, when each liter of water contained 7,040,000 cells of this alga. The colonial flagellates that were so abundant in C 1 were absent altogether from the plankton of this pond.

C 4. Table 8 shows that the control pond, C 4, contained a greater variety of algæ than either C 2 or C 3, but that none of the algæ that were present in C 4 occurred in very large numbers. Scenedesmus was present in all but one sample from this pond, but the maximum number of colonies per liter of water was only 123,000. This is in marked contrast to the maxima for C 1, C 2, and C 3, as shown in Table 8. Single cells of Chroococcus occurred regularly, but here again the maximum was only 210,000 cells per liter. Aphanizomenon was more abundant in C 4 than in C 1, but it was far less abundant than in C 2 and C 3. Oocystis was present in all samples except the first, but the numbers per liter are not comparable to those for C 2 and C 3. The rest of the algæ that were found were present in small numbers only. It may be mentioned here that Eudorina occurred once in this pond. This is the only instance in which colonial flagellates were found in this series of ponds, outside of C 1.

In Table 9 there is given a summary of the dominant algæ in the centrifuge plankton for the four C ponds. This table shows a marked contrast in the abundance of algæ in the fertilized ponds as compared with their abundance in the control pond. It emphasizes, likewise, the difference in the types of algæ that are dominant in C 2, C 3, and C 4, and those that are dominant in C 1. The table shows that the dominant algæ in C 1 were colonial flagellates, whereas the dominant algæ in the other three ponds were the blue-greens, Aphanizomenon and Chroococcus; the greens, Oocystis and Scenedesmus; and the diatom, Synedra.

The relationship between the fluctuations in the number of algæ and the amount of organic matter has been referred to in the discussion of the latter.

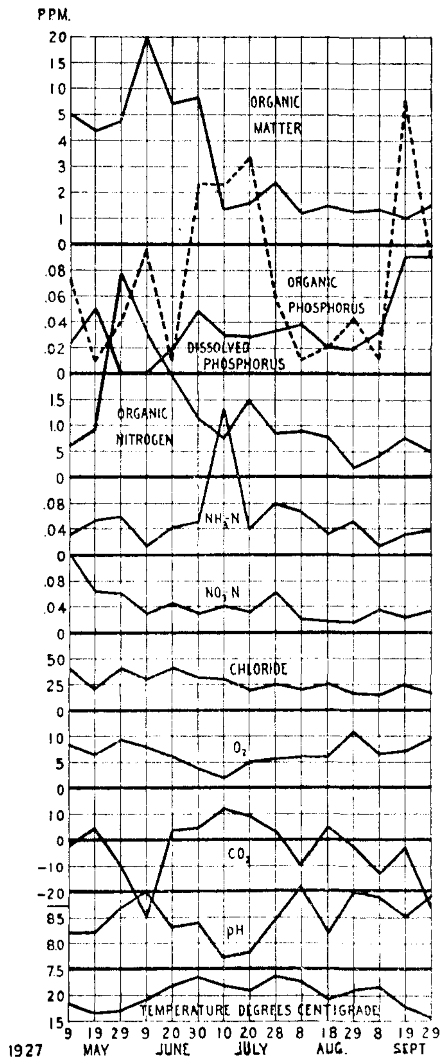


FIGURE 6.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for pond D 9

## SUMMARY

It was stated at the beginning of this section that the object of the experiments in the C ponds was to determine the effectiveness of soybean meal, shrimp bran, and superphosphate as pond fertilizers. The results, as presented in Tables 4, 6, 8, and 9, show that each one of these fertilizers had a beneficial effect on plankton production. This is evidenced by the larger amount of organic matter in the centrifuge plankton, the larger volume of net plankton, and the greater number of algæ in the centrifuge plankton from the fertilized ponds as compared with the control pond. Which one of the three fertilizers used was the most effective it is difficult to say. The amount of organic matter and the number of algæ in the centrifuge plankton would rank the fertilizers in the following order: First, soybean meal; second, shrimp bran; and third, superphosphate. On the other hand, if the volume of net plankton is used the order would be: First, superphosphate; second, soybean meal; and third, shrimp bran. It has already been mentioned that the volume of net plankton is not an absolute index of productivity. This fact taken into consideration along with the data given in the tables, seems to warrant the conclusion that soybean meal was the most effective fertilizer.

## D POND EXPERIMENTS

### DESCRIPTION OF PONDS

The D ponds studied in this investigation constitute Nos. 4, 5, and 9, of a series of 10 dirt ponds. The position and the shape of these ponds are shown in chart 1. D 4 has an area of approximately 42,920 square feet, or 0.99 acre. Its maximum depth is 4.35 feet and it average depth is 2.47 feet. That gives the pond a volume of approximately 106,012 cubic feet. D 5 has practically the same area as D 4, namely, 42,860 square feet, or 0.98 acre. Its maximum depth is 4.5 feet and its average depth 2.21 feet. The volume of this pond is, therefore, approximately 94,720 cubic feet. D 9 has an area considerably smaller than either D 4 or D 5. Its area equals 29,700 square feet, or 0.66 acre. Its maximum depth is 4.8 feet and its average depth is 3.61 feet. This gives the pond a volume of 107,217 cubic feet.

### PURPOSE OF THIS EXPERIMENT

The object of the limnological observation on the D ponds was to determine the behavior of the plankton, the phosphorus, the carbon dioxide, dissolved oxygen, hydrogen-ion, chlorides, and the different forms of nitrogen in dirt ponds in which fish were being raised. The effect of fertilizer was also considered. (See below.)

The observations on the D ponds cover the period from May 9, 1927, to September 29 of the same year. The observations were made at approximately 10-day intervals. All samples were taken from the surface. All samples were taken between 6.30 and 7.30 a. m.

### POND D 4

This pond had been wintered wet. It was drained during the last week in April. On April 30 it was refilled with water and stocked with fish.

The pond was fertilized with a 3:1 mixture of sheep manure and superphosphate. On May 9 and June 18, 118 pounds of this mixture were added to the pond. Then from July 2 until August 23, 39 pounds of fertilizer were added every five days.

#### NOTES ON VEGETATION

May 15: Patches of cattails (*Typha latifolia*) along north bank.

May 26:

- Patches of cattails (*Typha latifolia*) along north bank.
- Blanket algæ (mostly Hydrodictyon) common.

June 16:

- Blanket algæ (mostly Hydrodictyon) cover 10 to 15 per cent of area (estimate).
- Elodea, common, covers about 10 per cent of area.
- Typha, cover about 5 per cent of area.
- Sagittaria, cover about 2 per cent of area.
- Various grasses, pond lilies and narrow-leafed Potamogeton present.

June 30:

Blanket algæ (Hydrodictyon) covers about 20 per cent of area.
Elodea cover about 15 per cent of area.
Sagittaria cover about 3 per cent of area.
Cattails (Typha) cover about 1 per cent of area.
Narrow-leafed Potamogeton present.

July 23:

Elodea cover about 10 per cent of area.
Cattails (Typha) cover about 3 per cent of area.
Sagittaria cover about 2 per cent of area.
Blanket algæ cover about 5 per cent of area.
Broad-leafed Potamogeton present.

August 16:

Elodea cover about 10 per cent of area.
Sagittaria cover about 2 per cent of area.
Blanket algæ cover about 8 per cent of area.
Cattails (Typha) cover about 1 per cent of area.

### LIMNOLOGICAL DATA

Table 10 shows that the temperature was 17.2° C. on May 9, when the first observations were made. On May 19 the temperature had gone down to 13.3° C. The maximum temperature of 26.7° C. occurred on June 30 and July 28.

A study of Table 10 shows that the transparency of the water in D 4 was relatively high. Transparency, or the depth at which a 4-inch white disk disappears from view varied from 2 to 4 feet. The lower values for transparency were due to silt.

Table 10 shows that the minimum pH value of 7.6 occurred on August 18 and the maximum of 9.7 on July 10. Figure 5 shows that in a measure the higher pH values correspond to the higher temperatures. The correlation, however, is not close enough to warrant the conclusion that the hydrogen-ion concentration varies inversely as the temperature.

Free $CO_2$ did not occur in this pond until August 18, when 12.64 p. p. m. of the gas were present. This is the maximum of free $CO_2$ observed in this pond. After August 18 free $CO_2$ was present regularly. From May 9 to August 8 the water always showed a free $CO_2$ deficiency or a phenolphthalein alkalinity. This alkalinity ranged from a minimum of 6.08 p. p. m. on May 19 to a maximum of 46.5 p. p. m. on June 30. Table 10 shows that the maximum alkalinity corresponds to practically the maximum pH value. The variations in $CO_2$ are shown graphically in Figure 5.

The dissolved oxygen varied from a minimum of 2.86 p. p. m. on August 18 to a maximum of 10.46 p. p. m. on June 9. The low values for dissolved oxygen on August 8 and 18 are probably due to the decaying of blanket algæ. The notes on vegetation show that there had been a marked decrease in blanket algæ since June 20. Figure 5 shows the variations in dissolved oxygen.

The dissolved chlorides ranged from 1.8 to 3.5 p. p. m. There is no correlation between the variations in the chlorides and those in the organic matter that points toward the soluble chloride as a limiting factor. The variations in chlorides are shown in Table 10.

All nitrogen data are shown in Table 10. This table shows that the ammonia nitrogen varied from a minimum of 0.016 p. p. m. on May 29 to a maximum of 0.128 p. p. m. on June 9. This increase in ammonia nitrogen is associated with a decrease in organic matter. The decrease in ammonia nitrogen after June 9 is due to the growth of blanket algæ. The fact that there were 0.052 p. p. m. of ammonia nitrogen on June 30 is due to the addition of fertilizer. Nitrate nitrogen ranged from a maximum of 0.120 p. p. m. on May 9 to a minimum of 0.010 p. p. m. on August 29. On September 29 the nitrate nitrogen was up to 0.047 p. p. m. again. Nitrite nitrogen was present only once; namely, on September 29, when 0.002 p. p. m. was present. The organic nitrogen ranged from a minimum of 0.602 p. p. m. on May 19 to a maximum of 1.60 p. p. m. on August 18. This maximum value for organic nitrogen is probably due to the decomposition of blanket algæ. It occurs simultaneously with the minimum for dissolved oxygen and the maximum for free $CO_2$. Total nitrogen ranges from a minimum of 0.704 to 1.65 p. p. m. The variations in the different forms of nitrogen are shown in Figure 5.

Table 10 shows that on May 9, when the first observation was made, no dissolved phosphorus was present. After that date dissolved phosphorus was always present, although on June 9 it was down to a trace. After June 9 it was always present in considerable quantities. This is due, no doubt, to the addition of fertilizer at regular intervals. The organic phosphorus varied from a minimum of 0.005 milligram on June 20 to a maximum of 0.257 milligram on July 10. The variations in the soluble and the organic phosphorus are shown in Figure 5.

The organic matter or the net loss on ignition is rather uniform throughout the summer and is uniformly low. The minimum of 1.39 milligrams per liter occurred on June 9. This occurs simultaneously with the maximum for ammonia nitrogen. The maximum of 3.83 milligrams per liter occurred on May 9, when the soluble phosphorus was exhausted. On the whole, the relationship between the dissolved phosphorus and the organic matter is not very clear in this case. This is probably due to the fact that the pond was fertilized at short intervals and to the abundant growth of blanket algæ and rooted vegetation such as cattails and Elodea.

## PLANKTON

*Net plankton.*—Table 10 shows that the volume of net plankton varied from a minimum of 0.05 cubic centimeter per 10 liters of water to a maximum of 0.45 cubic centimeter. The average for 15 determinations was 0.18 cubic centimeter per 10 liters. The animals in the net plankton have been enumerated. The results are here given very briefly. Cyclops was always present in appreciable numbers. The maximum of 177.0 individuals per liter occurred on June 9. Diaptomus occurred for the first time on August 29. It was present in all September samples. The maximum of 15 per liter occurred on September 29. Nauplii were always present. They reached their maximum development in the latter part of May and during June. The maximum of 1,245 nauplii per liter was found on June 9. Of the Cladocera occurring in the net plankton, Bosmina was the most common. It was present in all samples except in two of the May samples. Bosmina was most abundant during the last few days in June and during July. It was still fairly abundant during the greater part of August. A maximum of 975 Bosmina per liter was found on July 20. Ceriodaphuia was present in all samples except one after June 20. The maximum of 95.2 per liter occurred on August 29. Chydorus occurred regularly from May 9 to June 9. After that it occurred only twice and then in small numbers. The maximum of 37.8 per liter was found on May 29. Daphnia was present in small numbers from May 29 to June 20, and again on July 20, the maximum number being 9.0 per liter. Scapholeberis occurred once in small numbers. Moina occurred twice in very small numbers. Among the

Rotifera, Anuraea, Asplanchna, Brachionus, Polyarthra, and Triarthra were the most common. Anuraea was present in two-thirds of the samples and reached a maximum of 465.0 per liter on June 9. Asplanchna occurred only in one-third of the samples, but attained a maximum of 651 per liter on May 29. Brachionus occurred in three samples having a maximum of 25.5 per liter on May 19. Polyarthra was found regularly during June and September. It was present, also, in one sample for July and in one for August. The maximum of 65.2 individuals per liter occurred on June 30. Triarthra occurred three times—twice in May and once in June. The maximum number of 28.5 per liter occurred on May 19. The genera Monostyla, Rotifer, Noteus, and Rattulus were at different times represented by a few individuals.

*Centrifuge plankton.*—All the algæ in the centrifuge plankton have been enumerated, but only the principal ones are taken up here. The number of algæ, on the whole, is very low. Among the Myxophyceæ, Aphanizomenon was the most important one. But even it did not occur in anything like the numbers that are given below for D 9. The maximum for Aphanizomenon in D 4 is 14,400 filaments per liter. Of the Chlorophyceæ, Oocystis and Gloeocystis were by far the most abundant. Oocystis occurred in a majority of the samples, but only in relatively small numbers, the maximum being 10,400 cells per liter. This number was present on June 20. Synedra is the only diatom that occurred in considerable numbers. The maximum for this alga was 48,100 cells per liter. This number was present on May 9. None of the Peridiniæ occurred in significant numbers.

## POND D 5

The pond D 5 had not been in use for several years and, therefore, was in a sense a new pond. It had been wintered dry and was not fertilized. The water was turned into this pond during the last week of April.

### NOTES ON VEGETATION

May 15: Cattails (*Typha latifolia*) abundant all over the pond.
May 26: Cattails (*Typha latifolia*) abundant all over the pond.
June 16: Cattails covered approximately 80 per cent of area. Various grasses cover large area of bottom.
June 30: Cattails cover about 85 per cent of area. Land plant and spear grass present.
July 23: Cattails cover about 50 per cent of area. Elodea, blanket, algæ, land plants and grasses present.
August 16: Cattails cover about 60 per cent of area; grasses and land plants, 25 per cent of area. Some blanket algæ (Hydrodictyon).

### LIMNOLOGICAL DATA

The limnological data are shown in Table 10.

The range in temperature is very similar to that recorded for D 4. The minimum spring temperature of 13.3° C. occurred on May 19. The maximum summer temperature of 27.8° C., occurred on June 30. By September 29 the temperature was down to 11.1° C.

A study of Table 10 shows that the water in pond D 5 was more transparent than in D 4 and D 9. The minimum transparency was 3 feet. When the transparency reached a maximum, the bottom was visible. The greater transparency of the water in this pond is due, at least in part, to the small amount of plankton.

The pH in this pond varied from a maximum of 8.2 to a minimum of 7.5. This minimum value was obtained 6 times in 14 determinations. Figure 5 shows these variations in pH.

Table 14 shows that free $CO_2$ was always present and varied from a minimum of 2.02 p. p. m. on May 19 to a maximum of 12.64 p. p. m. on August 8 and 18. The higher values for free $CO_2$ correspond, as a rule, to the lower pH values. (Table 10.) The variations are shown graphically in Figure 5.

The dissolved oxygen ranges from a maximum of 8.14 p. p. m. on July 10 to a minimum of 3.33 p. p. m. on August 8. This minimum for dissolved oxygen occurred on the same date as one of the maxima for free $CO_2$. The variations in the dissolved oxygen are shown in Figure 5.

Dissolved chloride was always present. Table 10 shows that it varied from 2.0 to 3.5 p. p. m. There is nothing in Table 10 that points toward chlorides as a limiting factor.

The data on nitrogen determinations are given in Table 10. The ammonia nitrogen reached a maximum of 0.080 p. p. m. on May 29. The minimum of 0.016 p. p. m. was reached on July 20. The nitrate nitrogen was at its highest point on May 9, when the first determination was made. At that time 0.120 p. p. m. was present. It decreased gradually until on June 30 only 0.025 p. p. m. was found. On July 10 it was up to 0.055 p. p. m. again. The minimum of 0.015 p. p. m. occurred on August 18. Figure 5 shows that at times the ammonia and the nitrate nitrogen increase or decrease simultaneously; at other times they vary in opposite direction. Nitrite nitrogen occurred only once; namely, on May 19, when 0.002 p. p. m. of this form of nitrogen were present. The organic nitrogen ranged from a minimum of 0.360 p. p. m. on September 9 to a maximum of 0.920 p. p. m. on August 8. Since most of the nitrogen present is in the form of organic nitrogen, the values for total nitrogen follow the values for organic nitrogen rather closely. The minimum for total nitrogen was 0.411 p. p. m., the maximum was 0.972 p. p. m.; and they occurred on the same dates, respectively, as the minimum and the maximum for organic nitrogen. The variations in the different forms of nitrogen are shown in Figure 8.

Table 10 shows that the dissolved phosphorus varied from none at all on May 9 to as much as 0.032 p. p. m. on September 19. The absence of soluble phosphorus on May 9 is correlated with the maximum amount of organic matter. The high values of 0.028 p. p. m. on July 7 and of 0.032 p. p. m. on September 19 are associated with a decrease in the organic matter and the organic phosphorus. (Fig. 5.) It may, therefore, be assumed that this soluble phosphorus had been derived from the organic phosphorus. The small amount of dissolved phosphorus present from May 29 to July 10, in spite of the small amount of organic matter, is perhaps due to the rapid growth of cattails. The notes on vegetation show that on June 30 the area estimated to be covered by cattails amounted to 85 per cent of the entire pond area. Organic phosphorus was always present in considerable quantities. It ranged from a minimum of 0.013 milligram per liter to a maximum of 0.095 milligram per liter of water.

The organic matter ranged from a minimum of 0.57 milligram per liter to a maximum of 4.24 milligrams per liter of water. The relationship of the organic matter to the soluble phosphorus has been discussed above.

The data presented here would seem to suggest that, at times, the dissolved phosphorus may have been a limiting factor that determined the productivity of the surface waters of this pond.

## PLANKTON

*Net plankton*.—The net plankton was usually low. The maximum amount present in 10 liters of water was 0.25 cubic centimeter. The average for 15 determinations was 0.11 cubic centimeter per 10 liters of water. The zooplankton counts made on the net plankton samples are here summarized very briefly. Cyclops was present in all save 2 samples. The maximum of 64.7 individuals occurred on May 9. On the average Cyclops were most abundant in August. Diaptomus was present in small numbers 5.25 per liter on June 20. Then it was present regularly from July 28 to September 29. The maximum number per liter was 9.0. This number was present on August 29. Nauplii were always present. They were most abundant in August. The maximum of 142.5 per liter occurred on August 8. Bosmina was present fairly regularly. The maximum of 212.5 individuals per liter occurred on June 9. Ceriodaphnia was present at four different times, but only in very small numbers. Chydorous occurred in 1 sample each for the months of June, July, and August and in 2 samples in September. The maximum of 13.6 per liter was reached in June. From May 29 on, Daphnia occurred more or less regularly. The maximum of 115.5 individuals per liter occurred on May 29. Diaphanasoma was present several times, but only in very small numbers. Of the Rotifera, the genus Anuraea was always present. The maximum of 155.2 per liter occurred on June 20. Brachionus was present twice in small numbers. Asplanchna occurred in 5 samples, reaching a maximum of 33 per liter on May 29. Cathypna occurred at six different times in small numbers. Polyarthra was also present in 6 samples, the maximum of 11.4 per liter coming in September. Triarthra occurred twice in May and once in June. In the June sample 17.0 individuals per liter occurred. The genera Rotifer, Noteus, and Monostyla occurred each once in insignificant numbers.

*Centrifuge plankton*.—All the algæ in the centrifuge plankton have been enumerated, but only the numerically important ones are discussed here. Among the Myxophyceae, Aphanizomenon may be mentioned. This alga was present fairly regularly after June 9, but it never occurred in large numbers, the maximum being 16,400 filaments to the liter. This number occurred in the sample for July 20. These small numbers are in marked contrast to the large numbers for Aphanizomenon in D 9. Anabaena, which also was very abundant in D 9, was absent altogether from D 5. Of the Chlorophyceae, Gloeocystis and Pandorina may be mentioned. Gloeocystis occurred in insignificant numbers on June 20. On August 29 and September 8, 18,000 and 72,000 cells per liter, respectively, were present. Pandorina occurred in a majority of the samples after June 20. The maximum of 28,800 colonies per liter occurred on June 30. Synedra, the only diatom that needs to be mentioned, was present in relatively small numbers in all samples save one. The maximum of 104,400 cells per liter occurred on August 8. On May 9, 66,300 cells per liter were present. Of the Flagellata, Euglena was present in 6 samples. The maximum of 20,700 was found in the sample for August 8.

## POND D 9

D 9 had been stocked with fish in the fall of 1926 and was not drained in the spring of 1927. Like D 4, it was fertilized with a 3:1 mixture of sheep manure and superphosphate. On April 26 and on June 17, 81 pounds of this mixture were added to the pond. Then from July 2 until August 23, 27 pounds were added at 5-day intervals.

NOTES ON VEGETATION

May 15:
- A few cattails along north side.
- Aphanizomenon approaching water bloom stage.

May 26: Cattails northwest corner. Some Elodea.

June 16:
- A few cattails along northwest corner.
- Some Elodea scattered. Ranunculus rare.

June 30:
- Elodea cover about 5 per cent of area.
- Blanket algæ cover about 25 per cent of area.
- Cattails present.

June 23:
- Elodea cover about 2 per cent of area.
- Blanket algæ cover about 2 per cent of area.
- Cattails present.

August 16: Blanket algæ cover about 25 per cent of area.

LIMNOLOGICAL DATA

The samples from D 9 were taken on the same days as those from D 4 and D 5 and at 10-day intervals. The limnological data are given in Table 10.

Table 10 shows that the temperature range in D 9 was practically the same as that in D 4 and D 5. The minimum temperature observed is that of 11.1° C. on September 29. The maximum of 27.2° C. occurred on June 30 and on July 28.

The transparency of the water in D 9 was lower than that in D 4 and D 5 until July 20. From July 28 on, however, it was more transparent than the water in D 4 and compared favorably with that in D 5. The minimum transparency of 6 inches on June 9 is due, at least, in part to the water bloom caused by the blue-green algæ Aphanizomenon and Anabaena. Table 10 shows that the organic matter on this date amounted to 20.24 milligrams per liter of water. Phytoplankton counts for that date show that there were present per liter of water 4,635,000 filaments of Aphanizomenon and 6,345,000 filaments of Anabaena.

The reaction of the water varied from a minimum pH of 7.7 to a maximum of 9.1. The pH values of 9.0 on June 9 and August 29 correspond to the second greatest and the greatest alkalinity, respectively. The low pH values of 7.7 and 7.8 on July 10 and 20, respectively, correspond to the disappearance of the blanket algæ from the surface and to a decrease in the organic matter from 8.57 milligrams per liter to 1.30 milligrams per liter. The variations in pH are shown in Figure 6.

Table 10 shows that free $CO_2$ was present in varying amounts on seven different dates. At other times there existed a phenolphthalein alkalinity. The free $CO_2$ reached a maximum of 12.64 p. p. m. on July 10. The maximum phenolphthalein alkalinity of 38.42 p. p. m. occurred on August 29. The maximum of 12.64 p. p. m. of free $CO_2$ corresponds to the minimum pH of 7.7. The latter, as has already been pointed out, corresponds to a decrease in the organic matter and the disappearance of the blanket algæ. The alkalinity of 30.34 p. p. m. on June 9 corresponds to the water-bloom stage of Aphanizomenon and Anabaena. The alkalinities of 38.42 and 28.32 on August 29 and September 29, respectively, correspond to an abundant growth of blanket algæ. (No formal observations on the vegetation were made after August 16, but blanket algæ and some vegetation had to be removed before the pond was drained.) The variations in free $CO_2$ are shown in Figure 6.

Table 10 shows that the dissolved oxygen ranged from a minimum of 2.17 p. p. m. to a maximum of 11.34 p. p. m. The low value of 3.63 p. p. m. on June 30 and of 2.17 p. p. m. on July 10 follow the disappearance of the water bloom caused by the blue-greens and the temporary disappearance of the blanket algæ from the surface. The minimum for dissolved oxygen occurs on the same date as the maxima for free $CO_2$ and the hydrogen-ion concentration. The high values for dissolved oxygen of 9.47 p. p. m. (91.0 per cent saturation) on May 29, 11.34 p. p. m. (129.0 per cent saturation) on August 29, and 9.75 p. p. m. (88.1 per cent saturation) on September 29, correspond to pH values of 8.7, 9.0, and 8.9, and to the phenolphthalein alkalinities of 10.12 p. p. m., 38.42 p. p. m., and 28.32 p. p. m., respectively. The high oxygen values for May 29 and September 29 are due to the lower temperatures of the water. The degree of saturation shows that the water was capable of absorbing still more oxygen from the atmosphere. The difference between the minimum and the maximum amounts of dissolved oxygen can not be explained on a temperature basis, for the temperature on July 10, when the minimum 2.17 p. p. m. (24.2 per cent saturation) occurred, was 23.9° C.; the temperature on August 29, when the maximum 11.34 p. p. m. (129.0 per cent saturation) occurred, was 22.2° C.—a difference in temperature of 1.7° C. but a difference of 104.8 per cent in the degree of saturation. It has already been mentioned that the minimum was associated with the disappearance of the water bloom and is, therefore, in all probability caused by a decay of organic matter. The maximum, since the water is 129 per cent saturated with oxygen may be the result of photosynthetic activity. The variations in dissolved oxygen are shown in Figure 6.

The amount of chloride in solution ranges from 1.5 p. p. m. to 4.0 p. p. m. (Table 10.) The generally lower values for chlorides during the latter part of the season, when the plankton was low is due, probably, to the abundant growth of blanket algæ already referred to. There is no evidence, however, that chloride is a limiting factor.

The results of the nitrogen determinations are given in Table 10. This table shows that the ammonia nitrogen varied from a minimum of 0.016 p. p. m. on June 9 and September 8 to a maximum of 0.224 p. p. m. on July 10. The minimum of 0.016 p. p. m. corresponds to the maximum for organic matter. The maximum of 0.224 p. p. m. is associated with a decrease in organic matter. The nitrate nitrogen ranged from 0.120 p. p. m. on May 9 to 0.015 p. p. m. on August 18 and 29. Nitrite nitrogen was never present even in traces. The organic nitrogen varied from a minimum of 0.169 p. p. m. on August 29 to a maximum of 3.92 p. p. m. on May 29. As Table 10 shows the maximum for organic nitrogen does not correspond to the maximum for organic matter. This discrepancy is probably due to the fact that the sample on May 29 was centrifuged only once, while that on June 9 was centrifuged twice. Plankton counts made on the May 29 sample show that every liter of water contained 3,025,000 filaments of Aphanizomenon and 4,680,000 filaments of Anabaena. Now Juday (1926) has pointed out the fact that by centrifuging the water once only a small proportion of Aphanizomenon is removed. Hence, it seems permissible to assume that the value for organic matter on May 29 as given in Table 10 is far below the true value. The total nitrogen follows the organic nitrogen very closely. The minimum for the total nitrogen is 0.235 p. p. m. and the maximum is 4.04 p. p. m. The maxima for the organic and the total nitrogen occur when the blue-green plankton algæ are at the height of production. The minima occur when the plankton algæ are at a minimum and the blanket alga, Hydrodictyon, is at its height of development. The variations in the different forms of nitrogen are shown in Figure 6.

Table 10 shows that on May 9 the dissolved phosphorus amounted to 0.023 p. p. m. On May 19 this had increased to 0.048 p. p. m. This increase might have taken place at the expense of the organic phosphorus, since the latter had decreased very considerably. On May 29, however, the dissolved phosphorus had disappeared completely. On June 9 a trace only was present. The rapid decline in the soluble phosphorus is accompanied with a rapid growth of plankton algæ. After June 9 dissolved phosphorus is present regularly. That is does not become exhausted in spite of the abundant growth of Hydrodictyon is due to the addition of fertilizer. The relatively large amount of dissolved phosphorus on September 9 and 29 is due, no doubt, to the decay of organic matter that had accumulated on the bottom during the summer. The organic phosphorus ranges from a minimum of 0.010 p. p. m. to a maximum of 0.205 p. p. m. If it had been possible to estimate quantitatively the amount of blanket algæ each time a sample of water was taken the variation in the organic phosphorus would become more intelligible. The variations in the phosphorus are shown in Figure 6.

Table 10 and Figure 6 show that the organic matter was relatively much more abundant during the early part of the season than later. (A comparison of Table 10 with the notes on vegetation seems to indicate that the blanket algæ are displacing the plankton algæ in the surface waters. They accomplish this by depriving the latter of sunlight.) A maximum of 20.24 milligrams per liter of organic matter was present on June 9. A minimum of 1.09 milligrams per liter occurred on September 19. It has already been pointed out that the maximum of 20.24 milligrams corresponds to very high counts for Aphanizomenon and Anabaena. It is also associated with a high degree of alkalinity as is evidenced by a pH of 9.0 and a phenolphthalein alkalinity of 30.34 p. p. m. The low value for organic matter in the centrifuge plankton during July, August, and September is due, perhaps, to the very abundant growth of Hydrodictyon and not to the exhaustion of either the soluble phosphorus or the inorganic nitrogen, for Table 10 shows that soluble phosphorus, ammonia nitrogen, and nitrate nitrogen were always present during these months. The variations in organic matter are shown in Figure 6.

That phosphorus may, temporarily, become a limiting factor when a pond is not fertilized is suggested by the disappearance of the soluble phosphorus as shown by the determinations for May 29 and June 9. That the disappearance of the dissolved phosphorus is correlated with a maximum production of blue-green algæ has already been referred to.

## PLANKTON

*Net plankton.*—Table 10 shows that the volume of net plankton varied from 0.05 cubic centimeter to 0.92 cubic centimeter per 10 liters of water. Only the animals of the net plankton have been counted and the results are as follows: Cyclops was present throughout the entire season; the maximum of 52 per liter occurred in July. Diaptomus occurred for the first time on July 29 and after that date was present regularly with a maximum of 44 per liter occurring on August 8. Nauplii were always present except on September 29 and were most abundant in June with the maximum of 216 per liter occurring on June 9. The following Cladocera occurred in the net plankton: Bosmina, Ceriodaphnia, Chydorus, Daphnia, and Diaphanasoma. Of these Bosmina was the most abundant and was present in all the samples.

It was more abundant in June than during any other month, with the maximum of 904 individuals per liter occurring on June 9. Ceriodaphnia was present once in May, once in June, once in July, and once in August. In September it occurred in 2 samples. The maximum of 48 per liter occurred on September 29. Chydorus was present throughout May and September. It was present also in the first June sample and in one of the August samples. The maximum of 66 per liter occurred on June 9. Daphnia did not occur until June 9, but after that date it was always present save for the one exception on September 9. It was more abundant during July and August than during June and September. The maximum of 297.5 per liter occurred on August 18. Diaphanasoma occurred once in May and July. During June it was absent and during August and September it was always present. The maximum of 13 individuals per liter occurred on September 19. The Rotifers were represented by the following genera: Anuraea, Asplanchna, Brachionus, Cathypna, Polyarthra, Rotifer, and Triarthra. Of these Anuraea was present the greatest number of times. It was most abundant in May and June and was absent during September. The maximum number per liter was 134.2, which were found in the sample taken on May 29. Asplanchua occurred twice; namely, on May 9 and May 29. On this latter date 365.2 individuals per liter were present. Brachionus occurred once in small numbers. Cathypna was present in small numbers at three different times—in May, June, and in September. Polyarthra occurred regularly in May and in the first June sample, and after that it occurred in the August 29 samples. Thirty-three individuals per liter was the maximum for this genus. Rotifer was present in 4 samples scattered over the entire season. The maximum number per liter was only 1.7. Triarthra occurred in small numbers in 2 of the May samples. In the first June sample 38 individuals per liter were present, but it was absent from the rest of the samples.

*Centrifuge plankton.*—In the centrifuge plankton all the algæ have been enumerated, but only the genera that were fairly common will be mentioned here. Of the Myxophyceæ, Anabaena and Aphanizomenon deserve mention. Anabaena was present in the 3 samples from May 29 to June 30, inclusive. The numbers of filaments per liter present were as follows: May 29, 4,680,000; June 9, 6,345,000; and June 20, 3,600. Aphanizomenon made its first appearance on May 19, when 6,500 filaments per liter of water were present. On May 19 this number had risen to 3,025,000 and on June 9 to 4,635,000. On June 20 it was down to 396,000 per liter, but it rose again to 1,670,400 on June 30. After this date it occurred in small numbers only. Among the Chlorophyceæ, Gloeocystis, and Oocystis may be mentioned. Gloeocystis occurred in small numbers in 2 of the June samples. It was present regularly from July 20 to September 8, the maximum of 93,600 per liter occurring on the last-mentioned date. Oocystis was present to the extent of 252,000 individuals on May 29 and 409,600 on June 9. After that it occurred fairly regularly but only in insignificant numbers. Of the diatoms, Synedra is the only form that occurred with any degree of regularity and was most abundant during May, with the maximum of 122,200 cells per liter occurring on May 9. Of the Peridiniæ, the genus Ceratium was the most common. This form was, except for 1 sample, always present after the end of June. The maximum for Ceratium was 28,800 cells per liter and occurred on August 29.

### SUMMARY OF D PONDS

The data for the D ponds recorded in the preceding pages show that in each of these 3 ponds there occurred at least one instance when the soluble phosphorus was completely exhausted. This fact would seem to point toward the soluble phosphorus as a limiting factor. However, since there was an abundance of soluble phosphorus in D 4 and D 9 after June 9, and still the organic matter and the plankton remained low, it becomes very apparent that some other factor besides the soluble phosphorus plays a part in limiting productivity. The data also show that inorganic nitrogen (free ammonia and nitrates) was never completely exhausted and that the amounts of inorganic nitrogen present in the water of the unfertilized pond D 5 compared favorably with the amounts of inorganic nitrogen in D 4 and D 9, which were fertilized. The data on organic matter and on the volume of net plankton show that D 4 and D 9, which were fertilized, were more productive than D 5, which was not fertilized. The differences in the productivity of D 4 and D 5 becomes much more apparent when the fish production is taken into consideration. D 4 produced much more fish than did D 5. The fish production will be considered in a separate report.

## GENERAL SUMMARY AND CONCLUSIONS

The discussion in the preceding pages has been limited to the data obtained from the C ponds and the D ponds. A series of observations similar to those made on the C ponds in 1928 was made on the A series of cement ponds in 1927. Observations similar to those made on the D ponds in 1927 were made on F 1 and on the E ponds in 1927. The observations on the E ponds were repeated in 1928. The data obtained from the A and the E ponds in the main confirm the data obtained on the C ponds and the D ponds but are too voluminous to include in the present paper. The following conclusions apply to all series alike:

(1) Although temperature is a very important factor and may govern the seasonal distribution of plants and animals, it can not be considered as a limiting factor in the course of this experiment. The differences in the temperatures from the different ponds as shown in Tables 3 and 10 are too small to account for the differences in the amount of plankton.

(2) Transparency also did not act as a limiting factor in the surface water of these ponds.

(3) The data on pH determinations do not point toward the hydrogen-ion as a limiting factor. In fact, they rather suggest that the hydrogen-ion concentration is controlled by productivity; that is, in any one pond when photosynthesis is going on at a high rate the pH is high also. When the rate of photosynthesis decreases and the amount of $CO_2$ resulting from respiration or from the decomposition of organic matter exceeds the $CO_2$ used in photosynthesis, the pH is low. The data suggest also that the variations in the concentration of the hydrogen-ion are due largely, if not altogether, to the variations in the amount of free $CO_2$.

(4) If the algæ were dependent on the free $CO_2$ in the water only, then $CO_2$ might be considered a limiting factor, for free $CO_2$ was often absent from the surface waters of these ponds. The algæ, however, can make use of a large proportion of the $CO_2$ present as the half-bound $CO_2$. Juday (1911) reports that certain algæ used as much as 83 per cent of the half-bound $CO_2$. In the course of this investigation it was found that plankton algæ, principally Pandorina and Pleodorina,

used up as much as 92 per cent of the half-bound $CO_2$. The results show that the half-bound $CO_2$ (unpublished data) was never completely exhausted, although in the 3 p. m. sample from C 1 August 9 only 5.06 p. p. m. were left. This suggests the possibility that on unusually bright days the available $CO_2$ may temporarily become exhausted. The data on $CO_2$ show that this occurred very rarely, if ever. In D 5 free $CO_2$ was always present when samples were taken in the morning, yet the production in this pond was poor.

(5) Dissolved oxygen was probably not a limiting factor. In the ponds that had fish in them there was always enough oxygen to meet the requirements of these fish. In the C ponds the lowest value for dissolved oxygen was 1.66 p. p. m. This should have been sufficient to supply the respiratory needs of the plankton organisms. Moreover, this minimum value for oxygen occurred when the algæ were very abundant in that pond (C 3), and the dissolved oxygen was undoubtedly much higher during the day than it was in the morning when the samples were taken. (That the amount of dissolved oxygen varies during the day was shown by some observations made in 1928 on 3 of the D ponds. Samples were taken at 6 a. m. and again at 3 p. m. During this interval the amount of dissolved oxygen increased in D 3 from 6.0 to 8.6 p. p. m., in D 9 from 4.68 to 15.90 p. p. m., and in D 10 from 6.57 to 7.83 p. p. m. The increase in the amount of dissolved oxygen in these ponds was roughly proportional to the amount of algæ present. D 9 had a water bloom of Anabaena.)

(6) There is, on the whole, very little correlation in the variations in the dissolved chloride and the amount of organic matter in the centrifuge plankton. This, taken together with the fact that chloride was always present in relatively large quantities—that is, as compared with the quantities of inorganic nitrogen or dissolved phosphorus—suggest very strongly that there was at all times an adequate supply of chloride available. Whether the unusually high concentrations of dissolved chloride in C 3 had any detrimental effect has not been determined. The high counts for algæ (Table 8) would tend to show that as much as 21.0 p. p. m. of chloride did not have an inhibitory effect on the algæ.

(7) That inorganic nitrogen was not a limiting factor is shown by the fact that nitrogen as free ammonia and as nitrates was always present. Moreover, the amounts of nitrogen as free ammonia and as nitrates in the unfertilized ponds compared favorably, in most instances, with the amounts of these substances present in the fertilized ponds. In D 5, which was not fertilized, the average amount of free ammonia present equaled the average amount present in D 4. The average amount of nitrate nitrogen in D 5 exceeds that in D 4 and D 9, both of which were fertilized. The data for the C series show that the averages for free ammonia nitrogen and nitrate nitrogen in C 1 and C 4 differ but slightly. Yet C 1 produced 4.37 times as much centrifuge plankton as C 4 did.

(8) That the soluble phosphorus may be a limiting factor is shown by the data presented in this paper. In all of the D pond studies, as well as in F 1, C 2, and C 4, the soluble phosphorus became completely exhausted for short periods of time. That the soluble phosphorus is not the only limiting factor is suggested by the behavior of the C ponds. In C 1 the dissolved phosphorus never fell below 0.045 p. p. m. and in C 3 not below 0.005 p. p. m. Still plankton production dropped markedly at that point. Again, in C 3, a subsequent rise in the dissolved phosphorus was not followed by a proportionately large increase in the amount of organic

matter in the centrifuge plankton. The facts presented in this paper do show that Harvey's (1927) statement to the effect that the productivity of the sea depends only on the amount of available nitrates and phosphates does not apply to these fish ponds. The data on phosphorus are only partially in agreement with the conclusions arrived at by Atkins and which have been reviewed in the introduction. However, they are more nearly in agreement with Atkins's theory than with the results obtained by Juday et al. on the lakes of Wisconsin.

(9) That the addition of various fertilizers increases the production of plankton in a pond is shown by the data for the C ponds. (Tables 4, 6, and 8.) It is also shown by the fish production in the D and the E ponds (data to be published in a separate paper). The large number of algæ in C 1, C 2, and C 3, as compared with the small numbers for C 4, are in agreement with the results obtained by Jaernefelt (1926) and those of Von Alten (1919). Jaernefelt used various combinations of inorganic salts and cellulose in half barrels and in glass aquaria. Gaerder and Gran (1927) and Gran (1927) in cultural experiments with raw sea water at times obtained an increase in the production of algæ when either nitrates or phosphates or a mixture of the two were added to the culture flasks. At other times the increase in the number of algæ in the treated flasks was no greater than in the untreated flasks. Gran concludes that when no additional increase was obtained in the treated flasks "That the occurrence of nutritive salts at that time was not yet the limiting factor for the nourishment of algæ." If in the experiments reported here the dates on which the ponds were fertilized are placed on the curves for the organic matter, the result is that often there is no immediate response to the addition of fertilizer. At times the plankton will keep on decreasing through several applications of fertilizer. Finally, however, when the necessary nutrient materials have accumulated and the conditions are physiologically right, the plankton goes up. That the naturally occurring plankton maxima are augmented through the addition of fertilizer would seem to follow from the fact that the average amount of plankton produced is increased.

(10) The results on the C ponds show that the organic fertilizers, soybean meal, and shrimp bran, which in addition to containing phosphorus also contain large amounts of nitrogen, give better results than superphosphate which contains phosphorus mainly. This is contrary to the conclusion reached by Fisher (1924) and to which reference has been made in the introduction. It seems also to contradict the conclusion arrived at in (7) that inorganic nitrogen was not a limiting factor. This latter contradiction may, however, be more apparent than real. It may be that the soybean meal and the shrimp bran contain along with the nitrogen some other substance that makes a greater utilization of nitrogen possible. Allen and Nelson (1908–9), who tried to rear marine algæ in artificial sea water made up of highly purified salts, report that the algæ would not grow in this culture medium. When, however, extracts of ulva or of fish tissue were added to the artificial sea water good growths were obtained.

Whatever the explanation may be, the fact that the addition of fertilizers increases the productivity of fish ponds seems to be fairly well established.

TABLE 1.—*Dates in 1928 on which the C ponds were fertilized and the kind and amount in pounds of fertilizer used*

| Pond | Fertilizer | June 7 | June 16 | June 11 | August 14 | August 25 | September 14 |
|---|---|---|---|---|---|---|---|
| C 1 | Superphosphate | 1 | 1 | 0 | ½ | ½ | 0 |
| C 2 | Soybean meal | 3 | 3 | 1 | 1 | 1 | 2 |
| C 3 | Shrimp bran | 3 | 3 | 1 | 1 | 1 | 2 |
| C 4 | Control | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE 2.—*Quantities of free $CO_2$ and phenolphthalein alkalinity in the C ponds in 1928 expressed in milligrams per liter of water. pH values are also given in this table*

| Date and time | Free $CO_2$ | | Alkalinity | | | | pH | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C 2 | C 3 | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 |
| June 27, 8 a. m. | | | 10.10 | 40.46 | 71.80 | 8.08 | 8.5 | 8.9 | 9.1 | 7.7 |
| July 7, 8 a. m. | | | 14.16 | 16.18 | 85.94 | 15.16 | 8.7 | 8.7 | 9.3 | 8.65 |
| July 19, 8 a. m. | | | 27.70 | 20.22 | 23.42 | 9.10 | 8.8 | 8.7 | 8.9 | 8.5 |
| July 30, 8 a. m. | | 0 | 68.76 | 57.62 | | 23.26 | 9.0 | 9.0 | 8.5 | 8.8 |
| Aug. 9, 8 a. m. | 7.58 | | 44.50 | | 5.06 | 24.26 | 8.9 | 7.55 | 8.0 | 8.7 |
| Aug. 9, 3 p. m. | | | 72.80 | 23.24 | 13.14 | 26.28 | 9.1 | 8.7 | 8.7 | 8.9 |
| Aug. 20, 8 a. m. | | 6.06 | 35.40 | 1.12 | | 32.36 | 8.8 | 8.5 | 7.6 | 8.75 |
| Aug. 30, 8 a. m. | 5.56 | | 28.32 | | 30.34 | 20.22 | 8.85 | 8.5 | 8.9 | 8.8 |
| Sept. 13, 1 p. m. | | | 25.28 | 24.26 | 55.60 | 27.30 | 8.8 | 8.75 | 9.1 | 8.8 |
| Sept. 19, 12 m. | | | 21.72 | 15.16 | 65.72 | 45.50 | 8.9 | 8.5 | 9.1 | 9.05 |

TABLE 3.—*Amounts of chlorides and of dissolved oxygen in the C ponds in 1928 in milligrams per liter. Also the temperatures in degrees centigrade*

| Date | Chloride | | | | Dissolved oxygen | | | | Temperature all ponds |
|---|---|---|---|---|---|---|---|---|---|
| | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 | |
| June 27 | 3.0 | 2.0 | 21.0 | 3.0 | 4.36 | 3.90 | 3.53 | 6.29 | 18.3 |
| July 7 | 2.5 | 3.0 | 19.0 | 3.0 | 3.43 | 2.14 | 3.52 | 3.53 | 25.0 |
| July 19 | 2.5 | 2.5 | 18.0 | 3.5 | 6.62 | 6.76 | 1.66 | 5.79 | 23.8 |
| July 30 | 3.0 | 2.5 | 18.0 | 2.0 | 12.21 | 11.87 | 6.91 | 10.80 | 21.1 |
| Aug. 9 | 2.5 | 2.0 | 16.0 | 3.5 | 8.74 | 2.59 | 3.10 | 6.41 | 25.0 |
| Aug. 20 | 2.5 | 3.0 | 16.5 | 3.0 | 5.53 | 4.55 | 2.30 | 6.51 | 20.5 |
| Aug. 30 | 3.0 | 3.0 | 17.5 | 3.0 | 6.85 | 3.99 | 5.52 | 6.99 | 19.4 |
| Sept. 13 | 3.0 | 2.8 | 17.0 | 3.0 | 6.81 | 6.61 | 7.12 | 7.59 | 20.0 |
| Sept. 19 | 4.5 | 3.5 | 21.0 | 3.5 | 10.25 | 8.18 | 9.67 | 11.79 | 20.0 |

TABLE 4.—*Organic matter in centrifuge plankton and nitrogen in the C ponds in 1928. The results are stated in milligrams per liter of water*

| Date | Organic matter | | | | Organic nitrogen | | | | $NH_3$—nitrogen | | | | $NO_3$—nitrogen | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 |
| June 27 | 3.63 | 44.64 | 55.80 | 2.51 | 0.992 | 5.02 | 10.08 | 0.840 | 0.012 | 0.076 | 0.076 | 0.096 | 0.008 | 0.045 | 0.023 | 0.009 |
| July 7 | 1.38 | 26.15 | 11.41 | 1.17 | .608 | 6.04 | 4.80 | | .052 | .068 | .060 | .052 | .045 | .055 | .090 | .035 |
| July 19 | 1.35 | 21.81 | 23.30 | 2.45 | .760 | 5.48 | 5.73 | 1.00 | .052 | .052 | .068 | .040 | .017 | .045 | .045 | .022 |
| July 30 | 3.69 | 27.99 | 6.98 | 1.70 | 1.60 | 5.80 | 5.08 | 1.00 | .044 | .144 | .088 | .028 | .029 | .035 | .036 | .019 |
| Aug. 2 | 10.70 | | | | | | | | | | | | | | | |
| Aug. 9 | 6.47 | 5.19 | 4.86 | 1.76 | 2.00 | 2.76 | 3.56 | .784 | .060 | .600 | .072 | .028 | .020 | .032 | .032 | .018 |
| Aug. 20 | 8.02 | 24.74 | 4.33 | 1.53 | 1.88 | 6.43 | 2.76 | .240 | .048 | .104 | .272 | .052 | .037 | .055 | .024 | .045 |
| Aug. 30 | 9.86 | 23.34 | 9.80 | 1.65 | 1.66 | 2.24 | 3.60 | .912 | .052 | .080 | .076 | .044 | .035 | .040 | .050 | .033 |
| Sept. 13 | 14.43 | 18.89 | 5.96 | 1.50 | 1.36 | 3.12 | 2.56 | .640 | .052 | .060 | .060 | .036 | .060 | .080 | .060 | .043 |
| Sept. 19 | 12.75 | 22.02 | 5.75 | 0.56 | 1.64 | 3.04 | 3.52 | .928 | .052 | .060 | .076 | .020 | .080 | .150 | .120 | .095 |
| Av. | 7.22 | 23.86 | 14.24 | 1.65 | 1.304 | 4.43 | 4.40 | .704 | .047 | .127 | .094 | .044 | .036 | .059 | .053 | .035 |

TABLE 5.—*Data on phosphorous determinations in milligrams per liter of water in the C ponds in 1928*

| Date | Total | | | | Dissolved | | | | Organic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 | C 1 | C 2 | C 3 | C 4 |
| June 19 | | | | | 1.28 | Nil. | 0.005 | Nil. | | | | |
| June 22 | | | | | 1.50 | Nil. | .010 | Nil. | | | | |
| June 27 | 1.850 | 0.095 | 0.250 | 0.045 | 1.80 | 0.025 | .025 | Trace. | 0.050 | 0.072 | 0.225 | 0.045 |
| June 28 | | | | | 1.60 | .010 | .025 | Nil. | | | | |
| July 7 | | .120 | .170 | .025 | 1.60 | Nil. | .008 | Nil. | | .120 | .162 | .025 |
| July 14 | | | | | .640 | .022 | .012 | Trace. | | | | |
| July 19 | .400 | .070 | .150 | .015 | .360 | Trace. | .055 | Trace. | .040 | .070 | .095 | .015 |
| July 24 | | | | | .240 | Nil. | .220 | Nil. | | | | |
| July 25 | | | | | .165 | Nil. | .360 | Nil. | | | | |
| July 30 | .120 | .110 | .700 | .058 | .075 | Trace. | .620 | Nil. | .045 | .110 | .080 | .058 |
| Aug. 2 | | | | | .050 | | | | | | | |
| Aug. 3 | | | | | .048 | Nil. | .620 | Nil. | | | | |
| Aug. 6 | | | | | .045 | | | | | | | |
| Aug. 9 | .225 | .175 | .880 | .058 | .055 | .015 | .750 | Trace. | .175 | .160 | .130 | .058 |
| Aug. 20 | .880 | .280 | .960 | .045 | .80 | .096 | .900 | 0.012 | .080 | .184 | .060 | .033 |
| Aug. 30 | 1.120 | .500 | 1.00 | .045 | .550 | .090 | .450 | .003 | .570 | .410 | .550 | .042 |
| Sept. 13 | 1.10 | .150 | .620 | .038 | .960 | .020 | .520 | Nil. | .140 | .130 | .100 | .038 |
| Sept. 19 | .900 | .128 | .900 | .050 | .850 | .003 | .850 | .010 | .050 | .125 | .050 | .040 |

TABLE 6.—*Net plankton in cubic centimeters per 10 liters of water in the C ponds in 1928*

| Date | C 1 | C 2 | C 3 | C 4 | Date | C 1 | C 2 | C 3 | C 4 | Date | C 1 | C 2 | C 3 | C 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| June 7 | 0.10 | 0.10 | 0.10 | 0.10 | July 14 | 0.05 | 0.20 | 0.25 | 0.10 | Aug. 17 | 1.15 | 0.60 | 0.55 | 0.10 |
| June 13 | .12 | .20 | .35 | .10 | July 16 | .25 | .27 | .30 | .03 | Aug. 18 | .60 | .65 | .70 | .15 |
| June 15 | .12 | .40 | .50 | .05 | July 18 | .15 | .20 | .35 | .10 | Aug. 20 | .40 | .70 | .35 | .30 |
| June 16 | .15 | .30 | .35 | .10 | July 19 | .03 | .12 | .60 | .10 | Aug. 21 | .40 | .60 | .28 | .12 |
| June 19 | .20 | .70 | .65 | .05 | July 21 | .10 | .45 | .65 | .12 | Aug. 22 | .35 | .70 | .32 | .30 |
| June 20 | .20 | .40 | .40 | .05 | July 23 | .35 | .18 | .60 | .10 | Aug. 23 | .12 | .48 | .30 | .12 |
| June 21 | .15 | .45 | .50 | .10 | July 25 | 3.00 | .15 | .65 | .07 | Aug. 24 | .15 | .55 | .18 | .15 |
| June 22 | .20 | .45 | .95 | .10 | July 28 | .85 | .22 | .38 | .06 | Aug. 27 | .25 | .55 | .28 | .12 |
| June 23 | .35 | .43 | .41 | .12 | July 30 | 3.50 | .48 | .28 | .07 | Aug. 28 | .20 | 1.0 | .18 | .13 |
| June 24 | .15 | .75 | .65 | .10 | July 31 | 4.0 | .40 | .40 | .25 | Aug. 29 | .30 | .90 | .70 | .18 |
| June 25 | .14 | .60 | .85 | .28 | Aug. 1 | 9.0 | .18 | .35 | .13 | Aug. 30 | .33 | .63 | .55 | .22 |
| June 26 | .18 | .32 | .35 | .15 | Aug. 2 | 4.4 | .45 | .40 | .08 | Aug. 31 | .22 | .48 | .50 | .15 |
| June 27 | .10 | .39 | .29 | .10 | Aug. 3 | 4.0 | .32 | .30 | .15 | Sept. 1 | .50 | .60 | .50 | .30 |
| June 28 | .18 | .70 | .50 | .40 | Aug. 4 | 4.0 | .40 | .30 | .12 | Sept. 4 | .25 | .55 | .35 | .10 |
| June 30 | .30 | .45 | .18 | .12 | Aug. 6 | 8.6 | .70 | .20 | .16 | Sept. 5 | .25 | .40 | .35 | .18 |
| July 2 | .20 | .30 | .15 | .05 | Aug. 7 | 6.8 | .28 | .20 | .18 | Sept. 6 | .28 | .40 | .20 | .15 |
| July 5 | .10 | .32 | .10 | .05 | Aug. 8 | 3.5 | .28 | .22 | .10 | Sept. 14 | .40 | .45 | .25 | .10 |
| July 6 | .10 | .40 | .03 | .05 | Aug. 9 | 3.8 | .30 | .18 | .10 | Sept. 15 | .20 | .60 | .20 | .10 |
| July 9 | .15 | .50 | .20 | .10 | Aug. 10 | 2.8 | .26 | .28 | .06 | Sept. 16 | .35 | .40 | .22 | .10 |
| July 10 | .10 | .50 | .10 | .05 | Aug. 11 | 3.2 | .48 | .28 | .04 | Sept. 17 | .60 | .60 | .25 | .12 |
| July 11 | .50 | .10 | .25 | .03 | Aug. 13 | 2.3 | .38 | .50 | .08 | Sept. 19 | .40 | .60 | .20 | .10 |
| July 12 | .30 | .30 | .60 | .10 | Aug. 15 | 3.7 | .30 | .92 | .10 | Sept. 20 | .35 | .50 | .30 | .15 |
| July 13 | .05 | .30 | .30 | .07 | Aug. 16 | 2.3 | .70 | .75 | .25 | | | | | |

TABLE 7.—*Animals in the net plankton in the C ponds in 1928*

| Organism | Pond | Number of samples | Average number per liter | Organism | Pond | Number of samples | Average number per liter |
|---|---|---|---|---|---|---|---|
| Cyclops | C 1 | 68 | 70.38 | Ceriodaphnia | C 1 | 68 | 69.61 |
| | C 2 | 69 | 505.14 | | C 2 | 69 | 5.9 |
| | C 3 | 70 | 503.73 | | C 3 | 70 | 0.76 |
| | C 4 | 68 | 31.53 | | C 4 | 68 | 13.8 |
| Bosmina | C 1 | 68 | 325.19 | Diaphanosoma | C 1 | 68 | 8.06 |
| | C 2 | 69 | 1,216.39 | | C 2 | 69 | 0.54 |
| | C 3 | 70 | 26.36 | | C 3 | 70 | 0.15 |
| | C 4 | 68 | 208.12 | | C 4 | 68 | 2.01 |
| Moina | C 1 | 68 | 4.89 | Nauplii | C 1 | 68 | 3,649.68 |
| | C 2 | 69 | 80.27 | | C 2 | 69 | 511.16 |
| | C 3 | 70 | 52.30 | | C 3 | 70 | 493.98 |
| | C 4 | 68 | 7.07 | | C 4 | 68 | 622.95 |
| Daphnia | C 1 | 68 | 4.37 | Anuraea | C 1 | 68 | 691.17 |
| | C 2 | 69 | 3.65 | | C 2 | 69 | 92.46 |
| | C 3 | 70 | 37.94 | | C 3 | 70 | 130.18 |
| | C 4 | 68 | 1.30 | | C 4 | 68 | 277.44 |

TABLE 8.—*Number of algæ per liter of water in the centrifuge plankton in the C ponds in 1928*

POND C 1

| Organism | June 27 | July 7 | July 19 | July 28 | July 30 | Aug. 9 | Aug. 20 | Aug. 30 |
|---|---|---|---|---|---|---|---|---|
| Aphanizomenon | 14,000 | 9,000 | 9,000 | | | | | |
| Botryococcus | | | 9,000 | | | | | |
| Botryococcus, compound colony | | | | | | | 32,000 | 24,000 |
| Chroococcus, single | | 9,000 | | | | | | 1,800,000 |
| Chroococcus, colony | | | 22,500 | | | | | |
| Closteirum | | | | | | | 6,400 | |
| Cosmarium | | 3,000 | 9,000 | | | | 89,600 | |
| Eudorina | | | | 24,000 | 21,600 | 7,200 | 12,800 | |
| Merismopedia | | | | | | | 12,800 | |
| Oocystis, single | | | 31,500 | 36,000 | 21,600 | 93,600 | 563,200 | 1,920,000 |
| Oocystis, colony | | | | | | | 960,000 | |
| Pandorina | | | 4,500 | 24,000 | 756,000 | 748,800 | | |
| Pediastrum | | | 4,500 | | | | 76,800 | 133,000 |
| Pleodorina | | | | 960,000 | 115,200 | 216,000 | | |
| Scenedesmus | | | 4,500 | | | 7,200 | 1,843,200 | 7,680,000 |
| Staurastrum | | | | | | | | 170,000 |
| Stephanodiscus | | | | | | | | 24,000 |
| Synedra | 14,400 | | | | | | 6,400 | |
| Tetraspora | | | | | | | 12,800 | |
| Volvox | | | | 24,000 | | | | |

POND C 2

| Organism | June 27 | July 7 | July 19 | July 30 | August 9 | August 20 | August 30 |
|---|---|---|---|---|---|---|---|
| Aphanizomenon | 205,500,000 | 11,160,000 | 58,320,000 | 40,200,000 | | | |
| Actinastrum | 120,000 | | | | | | |
| Anabaena | | | | 480,000 | | | |
| Chroococcus, single | 1,140,000 | 2,999,600 | 342,000 | 48,000 | 1,178,310 | 13,888,300 | 8,032,000 |
| Chroococcus, colony | | 195,300 | 54,000 | | 572,880 | 3,333,120 | 9,728,000 |
| Closterium | | | | | | | 60,000 |
| Kirchneriella | 60,000 | | | | | | |
| Merismopedia | | 39,060 | 36,000 | | | | |
| Oocystis, single | 240,000 | 442,680 | 90,000 | 18,000 | 91,140 | 729,120 | 720,000 |
| Oocystis, colony | 840,000 | | | | | | |
| Pediastrum | 60,000 | 13,020 | 30,000 | 6,000 | 6,510 | 34,720 | |
| Scenedesmus | 8,550,000 | 546,840 | 180,000 | | 39,060 | 2,430,400 | 5,568,000 |
| Synedra | 540,000 | 450,000 | 540,000 | | | | 48,000 |
| Tetraedron | | 13,020 | 18,000 | | | 34,720 | 96,000 |

POND C 3

| Organism | June 27 | July 7 | July 19 | July 30 | August 9 | August 20 | August 30 |
|---|---|---|---|---|---|---|---|
| Aphanizomenon | 48,000,000 | 252,000 | 101,700,000 | 868,050 | 693,000 | 1,368,000 | |
| Actinastrum | | | | 110,670 | | | |
| Chroococcus, single | 17,920,000 | 528,000 | 4,230,000 | 225,460 | 126,000 | 126,000 | 1,236,900 |
| Chroococcus, colony | | | | 234,360 | | 9,000 | 429,660 |
| Kirchneriella | | 36,000 | | | 54,500 | | |
| Merismopedia | 24,000 | | | | | | |
| Oocystis, single | 48,000 | 72,000 | | 91,140 | 36,000 | 126,000 | 1,219,720 |
| Oocystis, colony | | | | | | | 234,360 |
| Pediastrum | 192,000 | | | 37,550 | 13,500 | 58,500 | 13,020 |
| Scenedesmus | 3,840,000 | 780,000 | 1,260,000 | 313,735 | 63,000 | 337,500 | 3,176,880 |
| Synedra | 7,040,000 | | | | | 18,000 | |
| Tetraedron | | 12,000 | | | | | 13,020 |

POND C 4

| Organism | June 27 | July 7 | July 19 | July 30 | August 9 | August 20 | August 30 |
|---|---|---|---|---|---|---|---|
| Aphanizomenon | | 24,000 | 264,000 | | | 6,000 | |
| Botryococcus | | | 12,000 | | | 6,000 | |
| Ceratium | | | | | | | 3,000 |
| Chroococcus, single | 13,500 | 6,000 | 126,000 | 9,000 | 30,000 | 66,000 | 210,000 |
| Cosmarium | | | 9,000 | | | | 3,000 |
| Crucigenia | | | 3,000 | | | | |
| Eudorina | | | | 21,000 | | | |
| Fragilaria | | 3,000 | 3,000 | 3,000 | | 3,000 | |
| Melosira | | 3,000 | 12,000 | 3,000 | | | |
| Navicula | | 3,000 | 12,000 | | | | |
| Oocystis, single | | 3,000 | 24,000 | 3,000 | 12,000 | 9,000 | 24,000 |
| Oocystis, colony | | | 12,000 | | | 3,000 | 9,000 |
| Pediastrum | | | 15,000 | 3,000 | | 12,000 | 9,000 |
| Periodinium | | | 9,000 | | | | |
| Scenedesmus | | 3,000 | 123,000 | 12,000 | 3,000 | 63,000 | 78,000 |
| Staurastrum | | | 3,000 | 15,000 | 3,000 | | 6,000 |
| Stephanodiscus | 4,500 | | | | | | |
| Synedra | | | 3,000 | | | | |
| Tetraedron | | | | | | 3,000 | |

TABLE 9.—*Relative abundance in the different ponds of the C series in 1928 of the principal algæ in the centrifuge plankton*

| Pond | Organism | June 27 | July 7 | July 19 | July 28 | July 30 | Aug. 9 | Aug. 20 | Aug. 30 |
|---|---|---|---|---|---|---|---|---|---|
| C 1 | Scenedesmus | | | 4,500 | | | 7,200 | 1,843,200 | 7,680,000 |
| C 2 | | 8,550,000 | 546,840 | 180,000 | | | 39,060 | 2,430,400 | 5,568,000 |
| C 3 | | 3,840,000 | 780,000 | 1,260,000 | | 313,735 | 63,000 | 337,500 | 3,176,880 |
| C 4 | | | 3,000 | 123,000 | | 12,000 | 3,000 | 63,000 | 78,000 |
| C 1 | Chroococcus, single cells | | 9,000 | | | | | | 1,800,000 |
| C 2 | | 1,140,000 | 2,999,600 | 342,000 | | 48,000 | 1,178,310 | 13,888,300 | 8,032,000 |
| C 3 | | 17,920,000 | 528,000 | 4,230,000 | | 2,252,460 | 126,000 | 126,000 | 1,236,900 |
| C 4 | | 13,500 | 6,000 | 126,000 | | 9,000 | 30,000 | 66,000 | 210,000 |
| C 1 | Chroococcus, colony | | | 22,500 | | | | | |
| C 2 | | | 195,300 | 54,000 | | | 572,880 | 3,333,120 | 9,728,000 |
| C 3 | | | | | | 234,360 | | 9,000 | 429,660 |
| C 1 | Aphsizomenon | 14,000 | 9,000 | 9,000 | | | | | |
| C 2 | | 205,500,000 | 11,160,000 | 58,320,000 | | 40,200,000 | | | |
| C 3 | | 48,000,000 | 252,000 | 101,700,000 | | 868,050 | 693,000 | 1,368,000 | |
| C 4 | | | 24,000 | 264,000 | | | | 6,000 | |
| C 1 | Oocystis, single cells | | | 31,500 | 36,000 | 21,600 | 93,600 | 563,200 | 1,920,000 |
| C 2 | | 240,000 | 442,680 | 90,000 | | 18,000 | 91,140 | 729,120 | 720,000 |
| C 3 | | 48,000 | 72,000 | | | 91,140 | 36,000 | 126,000 | 1,219,720 |
| C 4 | | | 3,000 | 24,000 | | 3,000 | 12,000 | 9,000 | 24,000 |
| C 1 | Oocystis, colony | | | | | | | 960,000 | |
| C 2 | | 840,000 | | | | | | | |
| C 3 | | | | | | | | | 234,360 |
| C 4 | | | | 12,000 | | | | 3,000 | 9,000 |
| C 1 | Pleodorina | | | | 960,000 | 115,200 | 216,000 | | |
| C 1 | Pandorina | | | 4,500 | 24,000 | 756,000 | 748,800 | | |
| C 1 | Synedra | 14,400 | | | | | | 6,400 | |
| C 2 | | 540,000 | 450,000 | 540,000 | | | | | 48,000 |
| C 3 | | 7,040,000 | | | | | | 18,000 | |
| C 4 | | | | 3,000 | | | | | |

NOTE.—On July 28 no samples were taken from C 2, C 3, and C 4.

TABLE 10.—*Data on carbon dioxide, dissolved oxygen, chloride, phosphorus, nitrogen, and organic matter in milligrams per liter in 1927. Temperatures in degrees centigrade, turbidity in inches, net plankton in cubic centimeters per 10 liters of water. Also pH values*

POND D 4

| Date | Temperature | Turbidity | $O_2$ | pH | $CO_2$ free | Chloride | Phosphorus: Total | Phosphorus: Dissolved | Phosphorus: Organic | Nitrogen: $NH_3$ | Nitrogen: $NO_3$ | Nitrogen: $NO_2$ | Nitrogen: Organic | Organic matter | Net plankton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May 9 | 17.2 | 29 | 7.42 | 8.4 | −15.18 | 3.0 | 0.085 | Nil. | 0.085 | 0.032 | 0.120 | Nil. | 0.632 | 3.83 | 0.10 |
| May 19 | 13.3 | 30 | 6.59 | 8.5 | −6.08 | 2.0 | .095 | 0.030 | .092 | .025 | .050 | Nil. | .602 | 3.32 | .04 |
| May 29 | 13.3 | 38 | 9.18 | 8.8 | −9.10 | 3.0 | .027 | .008 | .019 | .016 | .050 | Nil. | .880 | 2.16 | .10 |
| June 9 | 22.2 | 46 | 9.55 | 9.4 | −14.16 | 2.0 | .095 | Trace. | .095 | .128 | .035 | Nil. | .720 | 1.39 | .45 |
| June 20 | 24.4 | 41 | 10.46 | 9.5 | −40.44 | 3.0 | .023 | .018 | .005 | .052 | .030 | Nil. | .768 | 2.68 | .12 |
| June 30 | 26.7 | 48 | 7.22 | 9.6 | −46.52 | 2.0 | .095 | .043 | .052 | .052 | .030 | Nil. | .664 | 1.65 | .28 |
| July 10 | 23.9 | 28 | 7.05 | 9.7 | −40.44 | 2.5 | .295 | .038 | .257 | .032 | .030 | Nil. | .856 | 2.21 | .16 |
| July 20 | 21.7 | 32 | 5.37 | 9.0 | −28.32 | 3.3 | .195 | .018 | .177 | .024 | .050 | Nil. | .912 | 2.17 | .50 |
| July 28 | 26.7 | 29 | 5.50 | | −18.20 | 3.3 | | .043 | | .064 | .030 | Nil. | 1.024 | 1.49 | .10 |
| Aug. 8 | 25.0 | 24 | 3.43 | 9.1 | −10.10 | 3.3 | .135 | .038 | .097 | .032 | .040 | Nil. | 1.024 | 2.39 | .12 |
| Aug. 18 | 18.2 | 28 | 2.86 | 7.6 | 12.64 | 3.3 | .078 | .058 | .020 | .020 | .030 | Nil. | 1.600 | 2.88 | .15 |
| Aug. 29 | 21.7 | 30 | 5.19 | 7.8 | 6.56 | 2.5 | .068 | .018 | .050 | .044 | .010 | Nil. | .880 | 1.81 | .20 |
| Sept. 8 | 23.3 | 24 | 4.70 | 7.7 | 5.56 | 1.8 | .115 | .028 | .087 | .032 | .042 | Nil. | 1.080 | 2.22 | .10 |
| Sept. 19 | 16.7 | 24 | 5.86 | 7.7 | 5.16 | 2.0 | .073 | .038 | .035 | .036 | .017 | Nil. | .960 | 2.83 | .05 |
| Sept. 29 | 11.1 | 27 | 8.21 | 8.0 | 10.10 | 3.5 | .073 | .030 | .043 | .036 | .047 | 0.002 | 1.260 | 3.07 | .30 |
| Average | | | | | | | | | | .041 | .033 | | .924 | 2.41 | .18 |

POND D 5

| Date | Temperature | Turbidity | $O_2$ | pH | $CO_2$ free | Chloride | Phosphorus: Total | Phosphorus: Dissolved | Phosphorus: Organic | Nitrogen: $NH_3$ | Nitrogen: $NO_3$ | Nitrogen: $NO_2$ | Nitrogen: Organic | Organic matter | Net plankton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May 9 | 17.22 | 41 | 7.79 | 8.2 | 2.12 | 3.0 | 0.048 | Nil. | 0.048 | 0.038 | 0.120 | Nil. | 0.632 | 4.24 | 0.20 |
| May 19 | 13.3 | 48 | 6.49 | 8.2 | 2.02 | 2.0 | .067 | Trace. | .067 | .060 | .070 | 0.002 | .601 | 3.33 | .05 |
| May 29 | 13.9 | 60 | 6.23 | 8.0 | 6.59 | 3.0 | .039 | 0.003 | .036 | .080 | .050 | Nil. | .720 | 1.31 | .25 |
| June 9 | 22.8 | 46 | 6.31 | 8.0 | 4.04 | 3.0 | .086 | Nil. | .086 | .048 | | Nil. | | 1.24 | .15 |
| June 20 | 24.4 | 50 | 7.84 | 8.0 | 8.03 | 2.0 | | Nil. | | .048 | .040 | Nil. | .528 | 1.10 | .09 |
| June 30 | 27.8 | 53 | 6.05 | 8.2 | 5.06 | 2.0 | .095 | Trace. | .095 | .032 | .025 | Nil. | .600 | .83 | .06 |
| July 10 | 24.4 | 51 | 8.14 | 8.1 | 4.56 | 2.0 | .048 | Trace. | .048 | .040 | .055 | Nil. | .424 | 1.46 | .05 |
| July 20 | 22.8 | 48 | 5.35 | 7.5 | 7.08 | 2.0 | .095 | .028 | .067 | .016 | .040 | Nil. | .672 | .77 | .04 |
| July 28 | 26.7 | 41 | 6.07 | | 3.54 | 3.5 | .013 | Trace. | .013 | .048 | .040 | Nil. | .864 | .79 | .07 |
| Aug. 8 | 25.0 | 36 | 3.33 | 7.5 | 12.64 | 2.5 | .038 | .008 | .030 | .032 | .020 | Nil. | .920 | 1.58 | .15 |
| Aug. 18 | 18.9 | 41 | 5.22 | 7.5 | 12.64 | 3.0 | .028 | .010 | .018 | .048 | .015 | Nil. | .800 | 1.73 | .20 |
| Aug. 29 | 22.2 | 48 | 6.28 | 7.6 | 11.12 | 2.5 | .058 | .003 | .055 | .024 | .025 | Nil. | .800 | 1.30 | .10 |
| Sept. 8 | 23.3 | 54 | 5.18 | 7.5 | 11.12 | 2.5 | .095 | Trace. | .095 | .032 | .019 | Nil. | .360 | 1.24 | .05 |
| Sept. 19 | 17.22 | 60 | 5.65 | 7.5 | 7.58 | 2.0 | .090 | .032 | .058 | .024 | .027 | Nil. | .600 | .57 | .10 |
| Sept. 29 | 11.1 | 60 | 7.86 | 7.5 | 6.06 | 3.0 | .043 | .013 | .030 | .060 | .050 | Nil | .460 | .96 | .15 |
| Average | | | | | | | | | | .041 | .042 | | .641 | 1.41 | .11 |

TABLE 10.—*Data on carbon dioxide, dissolved oxygen, chloride, phosphorus, nitrogen, and organic matter in milligrams per liter in 1927. Temperatures in degrees centigrade, turbidity in inches, net plankton in cubic centimeters per 10 liters of water. Also pH values*—Continued

POND D 9

| Date | Temperature | Turbidity | $O_2$ | pH | $CO_2$ free | Chloride | Phosphorus | | | Nitrogen | | | | Organic matter | Net plankton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total | Dissolved | Organic | $NH_3$ | $NO_3$ | $NO_2$ | Organic | | |
| May 9 | 17.2 | 24 | 7.89 | 8.2 | −2.02 | 4.0 | 0.095 | 0.023 | 0.072 | 0.032 | 0.120 | Nil. | 0.632 | 5.0 | 0.15 |
| May 19 | 13.3 | 22 | 6.81 | 8.2 | 5.06 | 2.0 | .058 | .048 | .010 | .052 | .060 | Nil. | .900 | 4.44 | .05 |
| May 29 | 13.9 | 12 | 9.47 | 8.7 | −10.12 | 4.0 | .038 | Nil. | .038 | .060 | .060 | Nil. | 3.920 | 4.76 | .60 |
| June 9 | 18.3 | 6 | 7.96 | 9.0 | −30.34 | 3.0 | .095 | Trace. | .095 | .016 | .030 | Nil. | 2.760 | 20.24 | .65 |
| June 20 | 24.4 | 12 | 6.26 | 8.3 | 4.54 | 4.0 | .028 | .018 | .010 | .044 | .045 | Nil. | ------ | 7.02 | .19 |
| June 30 | 27.2 | 24 | 3.63 | 8.4 | 5.06 | 3.0 | .195 | .048 | .147 | .048 | .030 | Nil. | 1.120 | 8.57 | .29 |
| July 10 | 23.9 | 24 | 2.17 | 7.7 | 12.64 | 3.0 | .175 | .029 | .146 | .224 | .040 | Nil. | .776 | 1.30 | .08 |
| July 20 | 21.7 | 40 | 5.16 | 7.8 | 9.78 | 2.0 | .195 | .029 | .166 | .040 | .030 | Nil. | 1,472 | 1.57 | .52 |
| July 28 | 27.2 | Bottom. | 5.66 | ------ | 3.54 | 2.5 | .095 | .033 | .062 | .080 | .060 | Nil. | .864 | 2.30 | .70 |
| Aug. 8 | 25.5 | Bottom. | 6.22 | 9.1 | −10.10 | 2.0 | .048 | .038 | .010 | .064 | .020 | Nil. | .920 | 1.24 | .22 |
| Aug. 18 | 19.4 | Bottom. | 5.76 | 8.2 | 5.06 | 2.5 | .038 | .019 | .019 | .032 | .015 | Nil. | .760 | 1.45 | .92 |
| Aug. 29 | 22.2 | 40 | 11.34 | 9.0 | −3.42 | 1.5 | .063 | .018 | .045 | .052 | .015 | Nil. | .169 | 1.19 | .12 |
| Sept. 8 | 22.8 | Bottom. | 6.75 | 8.9 | −13.16 | 1.5 | .043 | .033 | .010 | .016 | .035 | Nil. | .400 | 1.28 | .15 |
| Sept. 19 | 15.5 | Bottom. | 7.06 | 8.5 | −3.04 | 2.5 | .295 | .090 | .205 | .032 | .025 | Nil. | .760 | 1.09 | .20 |
| Sept. 29 | 11.1 | Bottom. | 9.75 | 8.9 | −28.32 | 1.5 | .180 | .090 | .090 | .036 | .033 | Nil. | .460 | 1.52 | .60 |
| Average | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | .055 | .041 | ------ | 1.136 | 4.13 | .36 |

NOTE.—A negative value for free $CO_2$ means a phenolphthalein alkalinity.

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