Mary J. Rathbun

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
W. O. HOTCHKISS, Director and State Geologist

BULLETIN NO. 64 SCIENTIFIC SERIES NO. 13

The Inland Lakes of Wisconsin

The Plankton

I. Its Quantity and Chemical Composition

By
EDWARD A. BIRGE and CHANCEY JUDAY

MADISON, WISCONSIN
PUBLISHED BY THE STATE
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Wisconsin Geological and Natural History Survey

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PREFACE

The present bulletin is the third issued by the Wisconsin Survey under the general title of "The Inland Lakes of Wisconsin". The first bulletin of this series, No. XXII, was published in 1911. It was based upon results obtained in a quantitative study of the dissolved gases in about 150 lakes situated in different parts of the state; mineral and sanitary analyses of the waters of a few of these lakes were made also. In addition to the chemical studies, temperature obesrvations were made at different depths in the various lakes when the samples for the determination of the dissolved gases were secured. This investigation, therefore, comprised a general study of the thermal and chemical conditions which existed in these lakes at different seasons of the year, especially in the summer, together with a consideration of the biological significance of these conditions.

The second bulletin of the series, No. XXVII, was published in 1914. It deals with the physiography, hydrography and morphometry of 54 lakes in southeastern Wisconsin, on which complete hydrographic surveys have been made; it also contains data regarding 185 other lakes in the state, chiefly their length, breadth, and maximum depth.

The present report presents the results of quantitative and chemical studies of the plankton of four Wisconsin lakes, by far the greater part of the work being confined to Lake Mendota. Only a single observation, in fact, was made on one of these lakes, namely Lake Kegonsa. So far, these studies have not been extended to any other lakes of the state because large samples of water had to be strained or centrifuged in order to obtain enough plankton material for the chemical analysis. This made it necessary to use large pumping and centrifuging outfits which could not be readily transported from lake to lake. In fact, a permanent lakeside laboratory had to be established in order to carry on these studies. Recently, however, a portable type of continuous acting centrifuge has been constructed and this instrument can be used to ascertain the quantity of organic matter in the plankton of many other lakes of the state. With this small machine, enough plankton material may also be obtained for some chemical determinations.

The authors wish to acknowledge their great indebtedness to Dr. H. A. Schuette, assistant professor of chemistry in the University of

Wisconsin, who has had direct charge of all of the chemical work during this investigation. He has made substantially all of the nitrogen determinations, as well as many of the other organic analyses. Some idea of the magnitude of the chemical work may be obtained from the tables accompanying this report. The results given for nitrogen, ether extract, pentosans, and crude fiber in these tables are based on 1,249 separate chemical determinations; there are 425 quantitative results for ash and 519 different determinations of inorganic constituents of the ash. This represents a total of 2,193 separate determinations, many of which were made in duplicate. In addition to this number, many analyses were made which are not shown in the tables, such as ascertaining the quantity of nitrogen in the bowl water and in the filter papers of the centrifuge as well as more complete analyses of the water remaining in the bowl of the centrifuge at the end of a run; the chemical results presented in this bulletin, therefore, are based upon a total of not less than 2,500 separate determinations, excluding the duplicates.

During the period covered by these studies Dr. Schuette has received assistance in the chemical work from a number of individuals. Mr. N. A. Bailey, Mr. Geo. M. Bishop, the late Mr. A. J. Duggan, Mr. E. A. Hentzen, Mrs. Ethel Hoverson Miller, and Mr. G. G. Town may be mentioned in this connection; other persons have also given assistance for varying periods of time.

While engaged in this work Dr. Schuette analyzed some special catches of plankton and his results were embodied in a paper which appeared in the Transactions of the Wisconsin Academy of Sciences, Arts, and Letters, Vol. XIX, 1918, pp. 594-613, under the title of "A biochemical study of the plankton of Lake Mendota".

In the collection of plankton material Mr. W. S. Fusch, Mr. E. H. Toole, and several other individuals rendered efficient assistance.

The arduous task of counting the organisms in the net plankton was done chiefly by Mrs. Henrietta Achtenberg Ryall and Miss Dorothy von Toerne. The nannoplankton organisms were enumerated by C. Juday.

The junior author is responsible for the preparation of the tables and diagrams and for the writing of the report, but the work was reviewed in all stages by the senior author.

The numerical results relating to the net plankton of Lake Mendota, shown in figures 22 to 26 and discussed in the latter part of Chapter II, are not presented in detail because they represent only a part of the material of this character which has been secured during the past few years. In the various investigations that have been made on Wisconsin lakes since 1905, approximately 10,000 catches of net plankton have been taken for the purpose of ascertaining the number and distribution of the organisms therein. So far the planktonts in about half of these samples have been enumerated; when the counting is completed, a bulletin dealing with this phase of the work in greater detail will be prepared.

The United States Bureau of Fisheries granted financial assistance toward this investigation and grateful acknowledgment is extended for this valuable aid. A more thorough study of the various problems was made possible through this assistance. The results are published with the permission of the Commissioner of Fisheries.

INTRODUCTION

The following bulletin is based upon data obtained in an extensive quantitative and chemical study of the plankton of four lakes situated in the vicinity of Madison, Wisconsin. (See map, fig. 6.) The investigation dealt chiefly with the plankton of Lake Mendota, while the observations on the other three lakes were made for purposes of comparison.

The investigation was undertaken for the purpose of securing definite gravimetric data relating to the size of the plankton crop at different seasons of the year and also for the purpose of obtaining some notion of the food value of this plankton material. Such data were desired not only for the larger organisms which can be readily secured with a plankton net but also for the small organisms which easily escape through the meshes of the net. These two groups of organisms constitute the total plankton and it is very important to know just what part of the total each group contributes; some of the data presented in this report show this relation very clearly.

The annual cycle of physico-chemical changes which take place in the waters of these lakes has a very important bearing upon the crop of plankton. This cycle is separated into four phases which correspond closely to the four seasons of the year. The disappearance of the ice in the spring is followed by an overturning and complete circulation of the water. The temperature of the water rises as the season advances and the vernal period of complete circulation is finally terminated by the rapid warming of the upper water; that is, the upper stratum becomes so much warmer, hence lighter, than the lower water that the wind can no longer force the former down and mix it with the latter. This results in a thermal stratification of the water; evidences of this phenomenon appear in the latter part of May, but the strata are not very clearly defined until late June or early July.

Two of these lakes, namely Waubesa and Kegonsa, are so shallow that the water is not permanently stratified during the summer. During the summer period of stratification in Lakes Mendota and Monona there is a warm upper stratum, the epilimnion, which is kept in circulation by the wind and a cool lower stratum, the hypolimnion; between these two there is a relatively thin stratum, the mesolimnion or thermocline, in which the temperature of the water changes rapidly from that of the warm epilimnion to that of the cool hypolimnion. As the temperature of the epilimnion falls in the autumn the mesolimnion descends to greater and greater depths and this finally results in the autumnal overturning of the entire body of water. Complete circulation of the water is again established and it continues until the lakes become covered with ice. The ice prevents further circulation of the water and this results in indirect stratification; that is, the coldest water is at the surface and the warmest at the bottom. Direct stratification is found in the summer when the warmest water is at the surface and the coolest is at the bottom.

During the two periods of complete circulation the substances that are dissolved in the water are uniformly distributed from surface to bottom, but in the intervening periods of stratification the chemical conditions in the lower water become very different from those in the upper stratum. These differences are especially marked in late summer. The hypolimnion, for example, is cut off from contact with the air by the epilimnion and the mesolimnion so that its supply of dissolved oxygen is limited to the amount which is held in solution by this water at the time stratification takes place. For a certain time this stratum is populated by many animals which use up some of the dissolved oxygen in their respiratory processes. Decomposition is a still more important factor in exhausting the supply of oxygen in the hypolimnion. Through these two agencies, therefore, practically all of the free oxygen in this lower stratum is used up by the first of August, and a further supply is not obtained by this water until the autumnal overturn takes place. During the winter period of stratification, also, the oxygen may be exhausted from a bottom stratum of varying thickness.

Respiration and decomposition not only make inroads upon the supply of dissolved oxygen, but they also contribute certain products to the water, such as carbon dioxide and nitrogen compounds, for example; the latter remain in the lower strata until an overturning of the water takes place. These products may then be taken up by chlorophyl bearing organisms and again play an important rôle in life processes.

The following discussion regarding seasonal changes in the crop of plankton refers to the results obtained on Lake Mendota because no observations were made on the other lakes during the winter and early spring. During the vernal period of complete circulation the water becomes well aerated at all depths, the dissolved substances are evenly distributed, and the temperature of the water gradually rises; the plankton organisms respond to these favorable conditions by producing a large crop of material at this time. The vernal crop, in fact, proved to be the largest one of the year.

When the water is in complete circulation conditions are favorable for the growth of the various organisms at all depths, but as soon as the bottom stratum in the deeper water ceases to take part in the general circulation the chlorophyllaceous organisms are at a disadvantage because the light is insufficient at these depths for photosynthesis. When stratification is finally completed the entire hypolimnion becomes unsuitable for these organisms owing to the scarcity of light in this stratum; these forms, therefore, are restricted to the epilimnion, or in some instances they may extend into the mesolimnion also.

The disappearance of the dissolved oxygen from the lower stratum also restricts the volume of water that can be occupied by some of the plankton organisms, such as the rotifers and the crustacea. Substantially all of the water of the hypolimnion is without free oxygen in the month of August so that only those forms which are able to live under anaerobic conditions can occupy this region of the lake at that time. The hypolimnion, therefore, yields a relatively small amount of plankton material during this month because the scarcity of light excludes the chlorophyllaceous organisms and a lack of oxygen excludes the rotifers and crustacea; the hypolimnion is about twelve meters thick at this time so that these organisms are absent from about half of the maximum depth of the lake. Following the spring maximum there is a gradual decrease in the total quantity of plankton which is correlated in time with the thermal stratification and the subsequent disappearance of the oxygen in the hypolimnion; the minimum amount for this season is usually found in August.

The autumnal overturning and circulation of the water again release the decomposition products which have accumulated in the hypolimnion during the summer and the entire body of water becomes aerated, thus making the conditions favorable for the various planktonts at all depths. These changes are accompanied by an increase in the quantity of plankton which culminates in an autumn maximum in late September or in October. Following this maximum there is a gradual decline to a winter minimum which is reached in February or in March; the winter minimum is somewhat smaller than the summer minimum. Among the various constituents of the plankton the diatoms seem to respond most vigorously to the favorable conditions that obtain in the spring and in the autumn; consequently they are the chief forms concerned in the production of the vernal and the autumnal maxima.

Computations based on the area and the total volume of Lake Mendota show that the largest crop of spring plankton yielded 404 kilograms of dry organic matter per hectare of surface (360 pounds per acre), while the largest autumn crop gave 363 kilograms per hectare (324 pounds per acre). The smallest summer minimum amounted to 139 kilograms of organic matter per hectare (124 pounds per acre) and the smallest winter minimum to 110 kilograms per hectare (98 pounds per acre). The average amount of organic matter yielded by the entire series of plankton catches from Lake Mendota was 240 kilograms per hectare (214 pounds per acre) and those from Monona gave 267 kilograms per hectare (238 pounds per acre). Lake Waubesa yielded substantially the same average as Lake Mendota. These figures represent the weight of the dry organic matter in the plankton; the weight of the organic matter in the living state would be approximately ten times as large because water constitutes about 90 per cent of the live weight of these organisms, excluding the ash.

The quantities indicated above represent only the standing crop of plankton and not the amount of this material that is produced annually. A quantitative determination of the annual production of plankton is a very complex problem because the factors involved are so numerous and so diverse. The plankton itself is an assemblage of many different kinds of organisms, ranging from the more simple forms such as bacteria, protophyta, and protozoa to the more complex individuals such as crustacea and insect larvae; a single catch, for example, may contain as many as fifty or more different kinds of organisms. It is a very difficult matter, therefore, to determine the relative importance of the different forms in this plankton complex.

The various organisms multiply at very different rates also; under favorable conditions the bacteria may pass through several generations in the course of a single day, the protophyta and protozoa perhaps not more than one or two, while the crustacea may require two weeks or longer to pass from one generation to the next. These organisms differ enormously in size, ranging from the minute bacteria to forms that are approximately two centimeters in length.

Another complexity is introduced into the problem through the food relations of the various plankton constituents. The greater part of these organisms possess chlorophyl so that, with the aid of sunlight, they are able to manufacture their own food materials out of the substances dissolved in the water. Therefore these forms constitute, either directly or indirectly, the main source of the food for the other plankton constituents; the chlorophyl bearing forms also constitute a large part of the food of some non-plankton forms, such as the bivalve mollusks. The rotifers and the crustacea are the chief plankton forms which feed upon the chlorophyllaceous constituents and they, in turn, are fed upon by fishes; also certain crustacea prey upon others. Computations based upon the numerical results and upon the average weights of the various forms of rotifers and crustacea show that the other plankton constituents furnish an abundant supply of food for these two groups of organisms; that is, the material which can be used as food by them weighs from twelve to eighteen times as much as they do. In making an assessment of the annual crop of plankton, therefore, it is necessary to take the destructive processes into account as well as the productive processes.

In order to estimate the annual production of plankton it would be necessary to determine the approximate rate of turnover in this material, but the present data show only the actual quantity of organic matter yielded by the plankton at the time the various observations were made. The results show, however, that the greater part of the material was derived from the protophyta and the protozoa; these two groups of organisms reproduce at a rather rapid rate so that the turnover in that part of the stock which they contribute would be equally as rapid.

Numerical data were also obtained for the entire series of plankton catches, but they can be given only a general consideration at present. The average weight per individual has been ascertained for only a few of the characteristic plankton forms so that an assessment of the relative values of the different constituents cannot be made until further determinations of this kind have been made. If the average weight per individual were known for all of the different kinds of organisms that make up the plankton, the numerical results would make it possible to determine roughly, at least, the relative importance of the different forms which make up the plankton complex.

The chemical analyses show that, on an average, the crude protein constitutes from a little more than 44 per cent to more than 57 per cent of the dry organic matter in this fresh-water plankton; in this respect the material compares very favorably with some of the meats that are used for human food. Crude protein constitutes about 47 per cent of the dry organic matter in the edible portion of the hind quarter of beef, for example, and about 37 per cent of that in the hind quarter of mutton. This plankton material, therefore, must be given a high rank as a source of protein food for other organisms. The edible portion of fish, however, contains a higher percentage of protein than either beef, mutton, or plankton; in the black bass, for example, the crude protein makes up about 92 per cent of the dry organic matter of the edible portion and in the brook trout about 90 per cent.

The plankton yields a relatively small amount of fat or ether extract, averaging from about five per cent to somewhat more than seven per cent. This is comparable to the percentages in black bass and brook trout, for example, which are, respectively, eight per cent and ten per cent of the dry organic matter in the edible portions. The percentage of fat is much larger in beef and mutton; it amounts to 53 per cent of the dry organic matter in the edible portion of the hind quarter of beef and to 63 per cent in the hind quarter of mutton. On a fat free basis, then, the beef and mutton would yield a much larger percentage of crude protein than the plankton.

While this investigation has involved a rather large series of plankton observations and a fairly detailed quantitative and chemical study of the material that was secured, yet it can scarcely be regarded as more than an introduction to this fertile field of research. Not only should such studies be extended to other types of lakes for purposes of comparison, but it should also be the aim to secure data that would eventually make it possible to estimate the annual production of plankton material with some degree of exactness. The first problem presents no special difficulties, but the second one is very complicated. The latter involves a study of the rate of reproduction and the length of life of the various plankton constituents in their natural environment; such studies would also include investigations relating to the effect of the physical and chemical factors of the environment upon these organisms. The food relations among the plankton organisms themselves are included in this question, as well as those between the plankton and non-plankton forms. It is necessary, also, to ascertain the average weight of the different kinds of planktonts in order to determine the relative values of the different forms. Numerous factors, therefore, are involved in this problem; some of them are physical, some chemical, and some are biological in character.

CHAPTER I

APPARATUS, METHODS AND PURPOSES OF THE INVESTIGATION

Historical

The plants and animals that inhabit the open waters of ponds, lakes, streams, and the oceans constitute what is known collectively as the plankton. A multitude of organisms is included under this term, ranging, in fresh water, from forms as simple as the bacteria to forms as complex in structure as crustacea and insect larvae. The fresh-water planktonts vary in size from minute bacteria to organisms that are 15 millimeters or more in length, but the vast majority of them are microscopic in size. The plants float freely in the water and are subject to the action of waves and currents. Most of the animals, on the other hand, are more or less active swimmers, but they are not powerful enough to be independent of the waves and currents so that their distribution is also governed chiefly by the general movements of the water.

The insect larvae and some of the plankton crustacea have been known to scientists for two and a half centuries, but the smaller plankton organisms had to await the development of the compound microscope. Exception must be made of some of the smaller forms, more especially some of the algae, since they became familiar to the layman as well as to the scientist without the aid of the microscope because they frequently appear in great abundance. In the quiet waters of lakes these algae may become abundant enough at certain times of the year to form a thick scum on the surface of the water; this is the so-called "water bloom."

In spite of the fact that biologists became familiar with many of these forms at a comparatively early date, no attempt was made to study the plankton from a quantitative standpoint until 1882 when Hensen [1] undertook such investigations on the Baltic and North seas, and on the Atlantic ocean. His studies extended from 1882 to 1886 and the publication of his results in the latter part of 1887 stimulated a great interest in both marine and fresh-water investigations of this character. As a result a voluminous literature upon this subject has appeared in the last three decades.

[1] Fünf. Ber. Kom. zur wissen. Untersuch. d. deut. Meere, 1887, pp. 1-107.

In obtaining this plankton material Hensen used nets which had straining surfaces made of bolting cloth and, in the various nets, bolting cloth with different sizes of mesh was used, the finest being the No. 20. These nets were lowered into the water to the desired depth and were then hauled to the surface at as uniform a speed as possible, thus passing through a definite column of water. This is known as the vertical haul method. The whole column of water through which the net passes is not strained, however, since the straining part of the net offers some resistance to the passage of the water and a certain portion of it is pushed aside and not strained. This makes it necessary to determine the efficiency of the net, or the coefficient, which serves as a factor for calculating the total number of organisms in the column of water. This method is subject to a serious error in that this coefficient varies with the age of the net and with the abundance of the plankton. The silk bolting cloth is subject to a certain amount of shrinkage and its meshes also become more or less clogged with organisms which adhere to the net permanently in spite of careful washing. During the progress of the haul, the meshes become temporarily blocked with organisms, especially when the plankton is abundant, so that the efficiency of the net decreases as it approaches the surface.

Hensen determined the quantity of plankton in his net catches in three ways, namely, (a) by allowing it to settle, (b) by enumeration, and (c) by evaporating an aliquot part of the catch to dryness, weighing it, and then igniting it to ascertain the organic matter. In the settling method the material was placed in a graduated cylinder and, after standing a definite number of hours, a reading of the volume was taken. Such readings, however, have little value since the different organisms do not settle with the same degree of compactness. In the enumeration method a definite portion of the material was placed in a suitable counting tray and the organisms in a certain number of definitely marked off squares were counted. From the results thus obtained the total number of the various organisms in the catch was estimated. The numerical method is still extensively used by planktologists and it yields very valuable data concerning the abundance and distribution of the various plankton constituents. The method of drying, weighing, and igniting is also a valuable one since it gives important data respecting the proportion of organic material in the catch.

As work in this field of science has progressed new types of nets have been devised and new methods have been employed for the purpose of obtaining more accurate results. In order to ascertain more accurately the quantity of water that is strained for a catch the pump method was introduced. By means of a pump and hose a definite amount of water may be obtained from different depths and strained through a plankton net for a catch. In addition to yielding a definite quantity of water this method also enables one to study the vertical distribution of the organisms. The chief objection to it is that the currents produced in the water at the intake end of the hose tend to drive away the more active planktonts that are negatively rheotropic. Several sets of experiments made with a plankton trap and the power pumps showed an advantage in favor of the trap of 16 per cent in Diaptomus and of 15 per cent in the Daphnias; on the other hand, there was a numerical advantage in favor of the power pumps amounting to 12 per cent in Cyclops and 27 per cent in the nauplii. While the latter forms are smaller than the former, they are usually more numerous so that the gains and losses probably just about balance each other in so far as the weight of the net plankton is concerned. In addition to this objection the pump method is not practicable beyond a depth of about 75 meters.

At a comparatively early stage in the development of quantitative plankton studies it was found that even the finest meshed nets did not retain all of the organisms, but the extent of this loss was not fully appreciated until Lohmann [2] completed extensive investigations along this line and published his results in 1908. In studies on marine plankton he was able to show, by the use of the centrifuge and various filtration methods, that many organisms which were present in enormous numbers were not represented at all in the net catches. It has since been found that the same is true of the fresh-water plankton as well; in fact, results presented in this report show that the organic matter of the material which is retained by the net is frequently only a small percentage of the organic matter in the material which readily passes through the meshes of the net. A very important problem in this investigation, then, has been to ascertain the relation between the quantity of plankton material that is retained by the net and that which is lost through its meshes.

In addition to these gravimetric data, some chemical analyses of the material were desired. For the latter it was necessary to obtain rather large samples of dry material, at least five grams whenever such amounts could be secured. It was soon found that this large a sample of net plankton made it necessary to strain fairly large amounts of water, such as several thousand liters in some instances, and the apparatus employed had to meet these requirements.

Pumps and Net

For the net plankton, in fact, the quantity of water that was strained for each sample varied from a minimum of 2,000 liters to a maximum

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[2] Wissenschaftliche Meeresuntersuchungen. Bd. 10, 1908, pp. 131-370. Kiel.

of 38,000 liters, depending upon the abundance of the organisms and the size of the sample desired. In the great majority of instances, however, the quantity was between 10,000 liters and 20,000 liters. The apparatus shown in figure 1 was used in securing these large quantities of water from various depths. Figure 1 shows the launch with the apparatus in place ready for a run, except that the large plankton net suspended in the bow of the launch is hung inside the large can during the run.

Figure 2 gives a more detailed view of the pumping outfit. It consists of two small vane pumps each having a capacity of about 30 liters per minute at a speed of 300 revolutions. These pumps are operated by a small gasoline engine, the kind used for the ordinary milk separator. The engine and pumps are mounted on a substantial metal base in order to hold them firm and rigid while in operation. The engine is attached to the base with bolts so that it may be readily removed for convenience in loading it into the launch.

The water is obtained from different depths by means of two pieces of hose, each 30 meters long and with an inside diameter of 2.5 centimeters. A calibrated line is attached to the intake end of each hose which enables one to lower the hose to the depth from which water is desired. The water delivered by the pumps is strained through the large plankton net that is suspended inside the large can shown in figures 1 and 2. The stream of water from the discharge hose is not allowed to strike the straining part of the net directly because this would result in many organisms being forced through the meshes. When only a net catch is desired the overflow water is discharged over the side of the launch through an outlet pipe that is attached near the bottom of the can to facilitate the straining process. By means of a pet cock attached to the can at about its mid-height samples of the strained water from the various depths can be obtained for a study of the organisms that escape through the meshes of the net.

The straining cone of the plankton net is made of No. 20 * bolting cloth; when thoroughly shrunken this silk gauze possesses more than 6,000 meshes per square centimeter, with the area of the openings varying from 0.001 sq. mm. to 0.003 sq. mm. The straining cone of the net is 30 centimeters in diameter at the upper end and it is 70 centimeters long, thus furnishing a large straining surface.

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* Lohmann states (Internat. Revue, Bd. IV, 1911, p. 38) that a new system of numbering was adopted by six Swiss manufacturers of bolting cloth in 1907, and that the old No. 20 was changed to the new No. 25. Two American dealers had not received notice of this change up to 1919, and a sample book of Schindler's "Genuine Swiss Silk" obtained in this year still shows the old system of numbering.

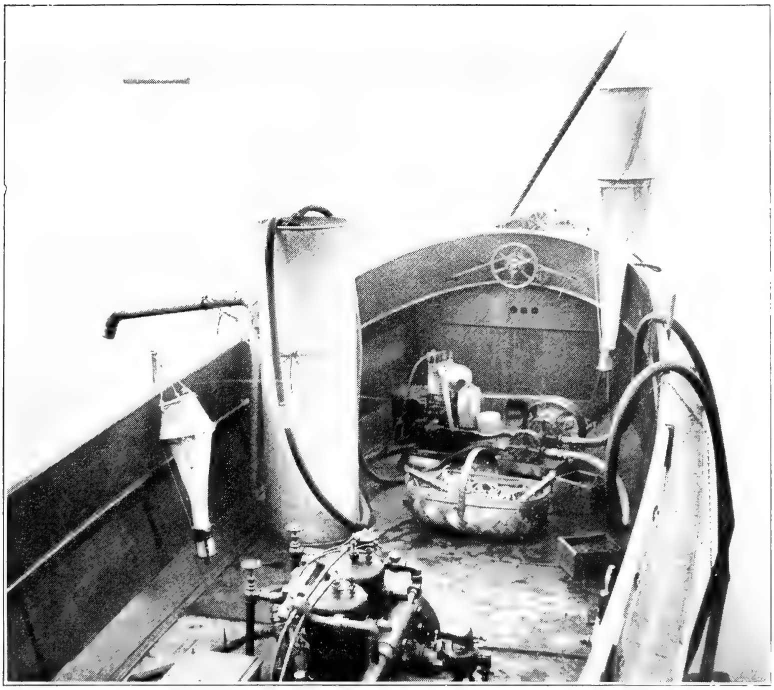

Fig. 1.—Launch and plankton apparatus.

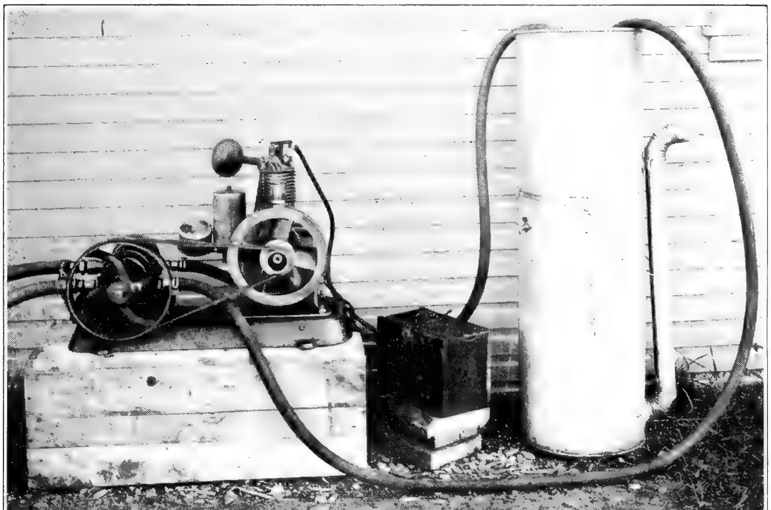

Fig. 2.—Pumping apparatus.

Work was begun on the net plankton in the latter part of May, 1911, and it was continued until July 1, 1914. During the first two winters no attempt was made to obtain material while the lake was covered with ice, but during the mild winter of 1913-14 catches were made each month. Owing to the late freezing of the lake the regular weekly observations were continued with the launch until December 24, 1913, and mild periods in the following months made it practicable to obtain one catch each in January and in February, 1914, and two in March. Following this the regular weekly observations were begun on April 18, 1914, and they were continued until July 1. In 1915 work was resumed on the net plankton on April 21 and was continued until June 1, 1917. In 1916 and 1917, however, only the relatively small amounts of water used for the centrifuge catches were strained for the net plankton.

The observations were made at a station where the water of Lake Mendota reaches a depth of 23.5 meters, a buoy being placed at this point each year to mark the place. Except in late summer the catch covered the entire depth of the lake down to 21 meters, either meter by meter or at two meter intervals. That is, the intake end of one hose was placed a few centimeters below the surface while that of the other hose was lowered to one meter. They were kept at these depths for a definite interval of time, usually ten to twenty minutes, while the pumps were in operation. Then they were lowered to two meters and three meters respectively for the same period of time, and so on to a depth of 21 meters. Attempts were made to get nearer the bottom than 21 meters, but bottom debris was found in the deeper catches so frequently that these attempts were finally abandoned. After the vernal and autumnal overturns the plankton was uniformly distributed throughout the entire depth of the lake for a while and at such times the depth was covered at two meter intervals.

In late summer the lower water, that is below 15 meters, contained so little net plankton that it was omitted from the catches. In all such catches, however, correction has been made for this and the results given in the tables are based on a depth of 21 meters. The pumps were calibrated frequently and their speed was taken during each run at the various depths, that is, during each ten to twenty minute period, so that the quantity of water strained was readily determined with a fair degree of accuracy.

In most instances the plankton was removed from the net at the end of each ten or twenty minute run in order to avoid undue clogging of the net and the consequent loss of organisms while the material was being concentrated in the bucket of the net. After filtering off as much of the lake water as possible the material was transferred from the plankton bucket to a jar with distilled water from a wash bottle. The material was then preserved with a few drops of chloroform and the catch, when completed, was placed in a porcelain dish and evaporated to dryness on a sand bath at a temperature of about 60° C. The dry material was carefully removed from the dish, ground up in a mortar, and transferred to a weighing dish. It was then kept in a desiccator for twenty-four to forty-eight hours, depending on the size of the sample, after which the weight of the entire sample was ascertained. Thereafter the material was transferred to a bottle and kept for further study.

At the end of the run made at each depth 10 liters of water were strained through a small plankton net and this catch was used for a numerical study of the various plankton constituents. Once each week these small catches were kept separate for the purpose of determining the vertical distribution of the organisms. At other times all of these small catches were combined into one sample. In order to obtain a check on this method of determining the total number of organisms in the large catch, samples for counting were taken from the large catch itself and the volume of the material was measured when the catch was placed in the porcelain dish for evaporation. With the exception of a few forms which were not well preserved by the chloroform, the two methods checked as closely as could be expected, the differences usually being well within the limits of error of the methods.

Centrifuge

As the work progressed on the net plankton it became increasingly evident that the material which was lost through the meshes of the net should be studied in a similar manner. It was a simple matter to take samples of the overflow water, centrifuge them, and enumerate the organisms therein, but this gave no results that could be compared directly with those obtained for the net plankton. What was desired was some method by which these minuter organisms could be obtained in sufficient quantities to ascertain their weight per unit volume of water, and to permit some studies relative to their chemical composition. Such data would thus permit direct comparisons with the results obtained for the net plankton.

Various filtration experiments made during the summer of 1914 showed that the problem could not be solved by such methods because the various substances used for the filtering process soon became clogged and thus permitted the use of only a small amount of water, not more than two or three liters, usually less. But these experiments served to stimulate a greater interest in the problem since the results showed that the organic matter in the organisms lost by the net was

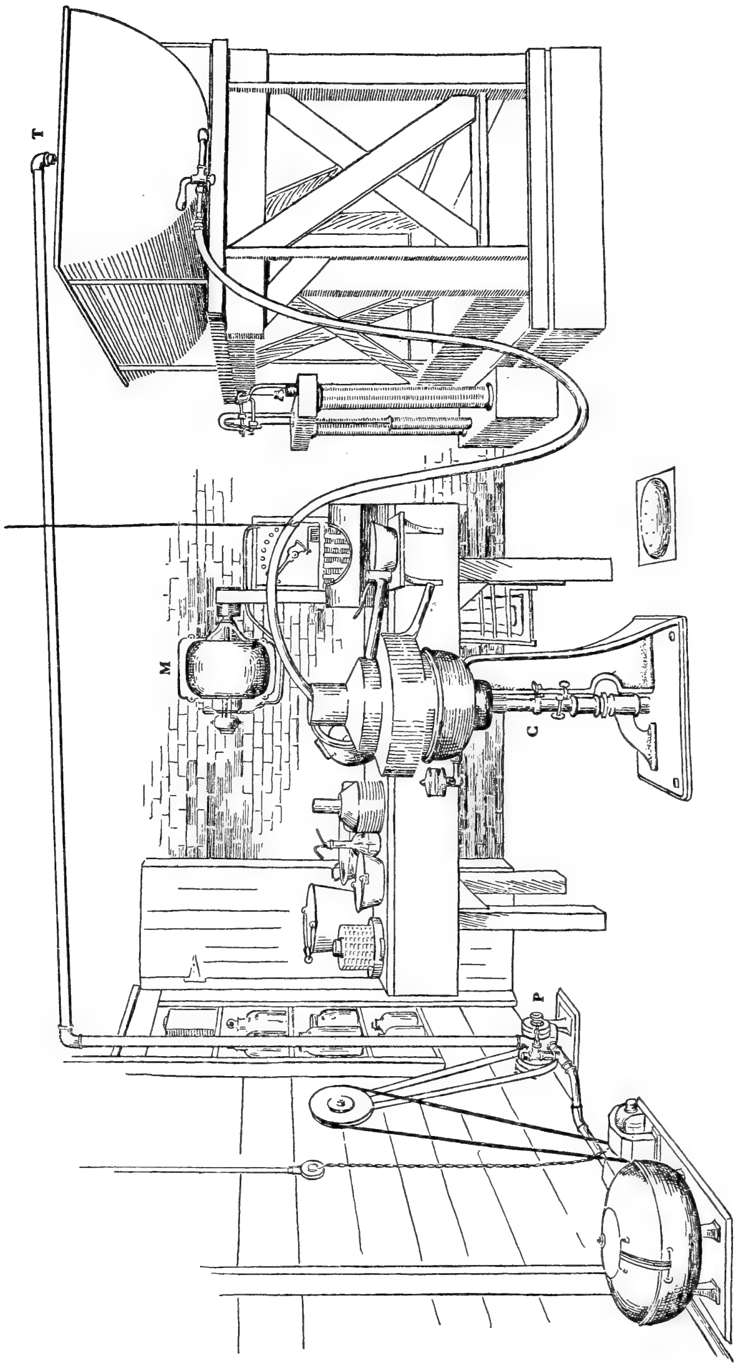

Fig. 3.—Sketch of lakeside laboratory showing centrifuge and tank mounted on a scale.

three to four times as great as that in the material retained by the net.

Following these experiments some tests were made with a milk clarifier and these proved to be very successful. While this machine did not remove all of the organisms, yet it removed such a large part of them that the experiments were continued with a larger and more powerful centrifuge which gave such satisfactory results that this type of machine was selected for the investigation. This centrifuge is the De Laval clarifier and filter which is intended for clarifying oils and varnishes; the belt style, size A, was used and in this machine the water is first subjected to a strong centrifugal action and then filtered through filter papers. During the progress of the investigation the effluent from this machine was tested frequently in order to ascertain what proportion of the organisms that were lost by the net, were being recovered by the centrifuge. These tests were made with the small centrifuge employed for the sedimentation of the material on which enumerations were made; the results obtained in these experiments indicated that the large centrifuge recovered substantially 98 per cent of the algae and protozoa lost by the net. In addition to these organisms, plate cultures made on gelatine and agar showed that between 25 per cent and 50 per cent of the bacteria were also removed in the centrifuging process. This efficiency is maintained for quantities of water up to 1,500 liters, or for as much as 10 grams of dry plankton material.

Figure 3 is a sketch drawing of the laboratory showing the equipment used in making these studies. In this sketch C is the centrifuge; M is the electric motor by which the centrifuge is driven through an intermediate; T is the tank into which the water is pumped from the dock by a pump marked P in the figure.

Figure 4 shows a sectional view of the bowl of the centrifuge. The water enters the bowl at A and passes down to the clarifying compartment, B, where some of the material is deposited. Then it passes out to the periphery of this compartment, C, where the centrifugal force is at a maximum. By far the greater portion is deposited here. The water next flows upward and toward the center of the bowl between conical discs which divide it into thin layers and subject it to further centrifugal action. This removes the last portion of material that is obtained in the centrifuging process. This material is deposited on the under side of the discs and most of it passes down and out to the pocket at C.

The centrifuged water passes to the center of the bowl and is then forced upward and outward to chamber D from which it passes on to the filter compartment. The latter is filled with a series of horizontal corrugated plates, F, nineteen in number, which possess perforated retaining rings at their outer and inner margins. The filter papers,

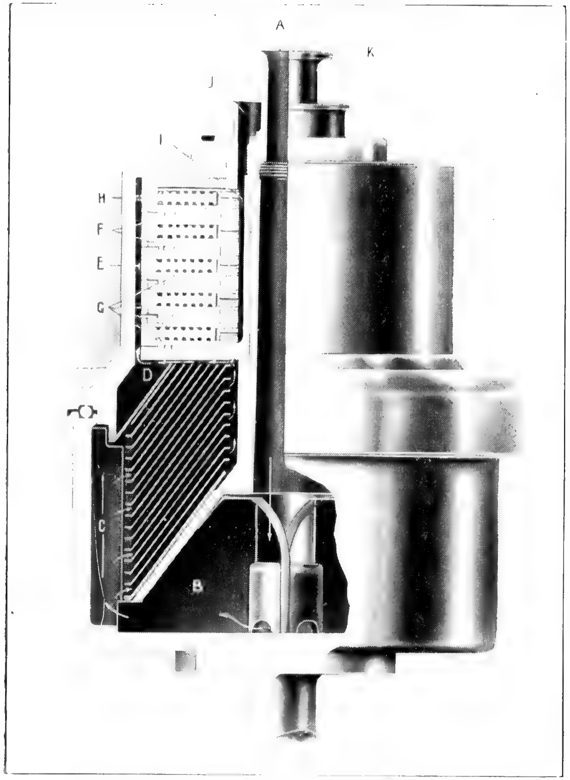

Fig. 4.—Sectional view of bowl of centrifuge.


Fig. 5.—Launch with a cargo of water.

G, are placed between the corrugated plates and the perforations in the plates are so arranged that the water passes through the filter papers in its course through this chamber. The water then flows upward through the passage indicated at I and is discharged from the bowl at the point marked J.

About 5.5 liters of water remain in the bowl at the end of a run and this is siphoned off and used to wash off the material that is deposited on the conical discs and on the sides of the bowl. A little chloroform is added and the whole is then evaporated in porcelain dishes at a temperature of about 60° C. About three quarters of the evaporation is done on a sand bath after which the dishes are transferred to a Hearson electric evaporating oven for the completion of the process. The dry material is then carefully removed from the porcelain dishes, ground, and placed in a weighing dish. After standing in a desiccator for forty-eight hours it is weighed and transferred to a bottle to await the chemical analyses.

The water used for the centrifuge was obtained from the regular station in the deep portion of Lake Mendota and it consisted of a certain quantity from each meter down to a depth of 20 meters. It was strained through the large plankton net and was caught in containers (milk cans) as it flowed from the large can in which the net was suspended. It was then conveyed to the laboratory dock in the launch where it was pumped into the large tank shown in figure 3. This tank is made of galvanized iron and has a capacity of about 1,200 liters. It is mounted on a framework which rests on a platform scale so that the quantity of water used for each run is readily ascertained by weighing. The scale also enables one to determine the rate at which the water is centrifuged, the usual rate being about 10 liters per minute. The framework elevates the tank to such a height above the centrifuge that the water flows from the former to the latter through a hose, the rate of flow being regulated by a valve.

By far the greater portion of the work done on the centrifuge plankton, or nannoplankton, as well as on the net plankton, was done on Lake Mendota; but for purposes of comparison some observations were also made on Lakes Monona and Waubesa. The quantity of water centrifuged at each run varied from about 1,100 liters to a little over 1,500 liters on Lake Mendota, but from the other two lakes it varied from about 700 liters to a little over 1,500 liters. Figure 5 shows the launch at the laboratory dock with a cargo of about 500 liters of water.

During the open season, that is, from April to December, both in 1915 and in 1916, two centrifuge runs per week were made on Lake Mendota when the weather was favorable. In most instances the material obtained in the two runs was combined into one sample for the chemical analyses. In 1917 only one run per week was made. On Lakes Monona and Waubesa observations were not made at regular intervals in 1915, but in 1916 they were made approximately every two weeks.

Chemical Methods

The various methods employed in the chemical analyses have been described by Schuette[3] so that they need not be considered in detail here. In all instances the samples used for the analyses were dried in an electric oven at a temperature of 60° C. for a period of twelve hours. After cooling in a desiccator the weights of the samples were taken and these constitute the dry weights used in the calculation of the percentages of the different substances determined. The material is more or less hygroscopic and the moisture lost in this drying process varied from a minimum of about 1 per cent to a maximum of almost 7 per cent; in most cases, however, the loss was between 2 per cent and 4 per cent. The material was not dried at a higher temperature because it was feared that some of the oils might be lost by volatilization at higher temperatures. Usually from half a gram to a gram of material was used for an analysis and a number of experiments showed that this amount came to a constant weight under the conditions described above, thus showing that it was thoroughly dry.

In determining the ash the sample was first carbonized at a low temperature, after which it was placed in an electric furnace heated to a temperature of 500° to 600°. It usually required from 15 minutes to 20 minutes to complete the ashing process at this temperature. That portion of the material that is consumed may be regarded as the organic matter, but a correction is necessary where a considerable amount of magnesium carbonate is present, since this substance gives off its carbon dioxide at a temperature of 250° to 300°. The regular methods were employed in making the quantitative determinations of the various constituents of the ash.

All nitrogen determinations were made by the Kjeldahl-Gunning-Arnold method.

The ether extract was determined in the Soxhlet extraction apparatus and the extraction process was continued for a period of 24 hours. In addition to the oils and fats, chlorophyl is also extracted by the ether but the quantity of this substance is regarded as too small to affect the results materially.

In determining the pentosans the material was distilled with hydrochloric acid, specific gravity 1.06, and the furfurol in the filtered distillate was precipitated with phloroglucinol solution. After standing

[3] Trans. Wis. Acad. Sci. Arts, and Let., Vol. XIX, 1918, p. 594.

24 hours the precipitate was filtered off, dried, and weighed; the results were then calculated to pentosans.

The amount of crude fiber was determined by digesting the material for half-hour periods with sulphuric acid and sodium hydroxide solution having a specific gravity of 1.25. The undigested material was filtered in a tared Gooch crucible, washed, thoroughly dried at 100°, weighed, and then ignited. In the pure crustacean material the crude fiber has been regarded as chitin.

The plankton which was deposited on the filter papers of the centrifuge could not be removed for direct estimation since it adhered too closely to the papers. So it was necessary to determine the quantity of this plankton by an indirect method; that is, the filter papers were dried and the total nitrogen in them was determined. One-eighth of each filter paper in the set of nineteen was used for this analysis and the nitrogen in excess of that obtained from a corresponding set of blanks was regarded as belonging to the plankton. The quantity of organic matter in this material was then estimated by multiplying the excess nitrogen by the factor representing the ratio of the nitrogen to the organic matter in the regular centrifuge catch. This estimated organic matter was then added to that obtained from the bowl of the centrifuge and the sum of these two constitutes the total organic matter in the catch. The quantitative results are based on this total. In most instances the nitrogen in the filter papers constituted between five per cent and ten per cent of that in the material from the bowl of the centrifuge.

Purposes of the Investigation

These studies were undertaken with a twofold purpose in view; first to obtain data on the annual plankton production of a lake with special reference to the quantity of organic matter involved as well as the chemical composition of this material; second, to obtain similar data with respect to the various kinds of organisms making up the plankton.

Concerning the first problem it may be said that it has been the aim to secure results which are comparable in a general way to those that have been obtained for the land. The agriculturist knows either exactly or approximately the amount of his crops each year in terms of some standard unit and he also knows approximately the area of land from which these crops have been harvested; thus he can state his season's results quantitatively per unit area of land. Furthermore numerous chemical analyses enable one to obtain some idea of the food value of the various agricultural products. But we have substantially no information of this character with respect to the productivity of our fresh waters; only estimates based on wholly insufficient data are available. Also, with the exception of the fishes, our knowledge of the chemical composition of the various fresh-water organisms is very scant indeed.

Thus the present investigation is a step in the direction of supplying this much needed information; but it can be regarded only as a beginning since it will require similar investigations on a considerable number of different types of lakes. Also, it applies to only a single element of this aquatic life, namely, the plankton. The larger organisms must receive similar treatment. Much more work, therefore, both of a numerical and of a chemical nature, must be done, not only on the plankton but also on the larger aquatic organisms, before we shall have sufficient data for drawing any general conclusions as to the productivity of our fresh-water lakes.

The problem of aquatic productiveness involves complexities which are not encountered in studies on the productivity of the land. In a lake, for example, the productive soil, so to speak, is coextensive in depth with the depth of the lake and also includes the bottom to a certain depth because many organisms, such as insect larvae and oligochaets, inhabit the bottom mud. On land the various crops are easily kept separate and they mature at a definite time so that they may be harvested and their total quantity ascertained. But in a lake the plankton crop alone, for example, comprises a considerable number of forms of which many are present at the same time. Thus the plankton crop, in general, consists of a mixture of forms and only rarely is it possible to obtain a pure catch of any form except the larger crustacea, which may be sorted out by means of nets having different sizes of mesh. The various forms reach their maximum numbers at different times of the year, some even in winter, so that there is no definite harvest time at which this material may be collected and the annual production of it thereby ascertained. The plankton, therefore, must be considered as a "standing crop" since it is present at all seasons of the year and since it does not possess any definite period of maturity; in other words, it constitutes a continuous stream of life which presents different degrees of abundance during the course of its annual cycle. The same is true also of many of the larger aquatic organisms.

Certain forms of algae frequently appear in a practically pure state in the summer as the socalled "water-bloom" and at such times they can be obtained in sufficient abundance for a chemical analysis. The smaller forms, however, more especially those found in the nannoplankton, present a more difficult problem since they do not seem to thrive well in laboratory cultures and they rarely appear in the lake in sufficient abundance and purity for one to obtain enough material of the different forms for an analysis. But the problem is not insoluble and the final results will justify the expenditure of much time and energy in its solution.

When several analyses of the various forms, representing the different seasons of the year and as many lakes as possible, have been obtained, the planktologist can then strike an average and obtain, with a reasonable degree of accuracy, a factor, a food-value factor if you will, for each form. This will serve as an index of the rôle played by the different organisms in the annual crop of organic matter produced by the plankton of a body of water. When such factors are established for the various planktonts, not only will it be possible to study the productivity of a lake by the numerical method, but it will also enable one to consider all numerical studies that have been made in the past from this same standpoint, which will add very greatly to the value of such studies. In brief, it will put the problem of plankton production on a chemical and gravimetric basis; that is, on the same basis as the modern investigations with respect to the crop production of the land.

CHAPTER II

THE NET PLANKTON OF LAKE MENDOTA

The material for the investigations relating to the quantity and chemical composition of the net plankton was obtained from four lakes, namely, Mendota, Monona, Waubesa, and Kegonsa. These lakes are situated in the Yahara river basin; they occupy local enlargements of this valley and they are named in order beginning with the one nearest the headwaters of this stream. (See map, fig. 6, p. 21). They have a northwest-southeast trend, the general course of the Yahara river being southeast. Detailed descriptions of these lakes are given in bulletins No. VIII (Second Edition) and No. XXVII of the Wisconsin Survey and they need not be repeated here.

The areas, volumes, and the maximum and mean depths of these lakes are given in table 1 (p. 181). Lake Mendota is by far the largest and the deepest member of the group. While the maximum depth of Lake Monona is only about 12 per cent less than that of Lake Mendota, the mean depth of the former is only two-thirds as great, thus showing that the basin occupied by the former is relatively much shallower. Lakes Waubesa and Kegonsa occupy very shallow basins; their maximum depths are distinctly less than half that of Lake Mendota, while their mean depths are but little more than a third as great.

Thermal Stratification

Lakes Mendota and Monona have sufficient depth to become thermally stratified in summer; that is, they become separated into three distinct strata for a period of three to three and a half months each season, or from late June or early July to late September or early October. The upper stratum comprises the warm water and is known as the epilimnion. It is kept in circulation by the wind and is thus freely exposed to the air so that its supply of dissolved oxygen may be replenished should this gas fall below the saturation point at any time. This stratum also receives by far the greater portion of the sun's energy that is delivered to the surface of the lake, and it is, therefore, the most favorable region for chlorophyl-bearing organisms. These two factors, an abundance of oxygen and light, make this the most favorable region for the major portion of the net plankton, and it is here that the great

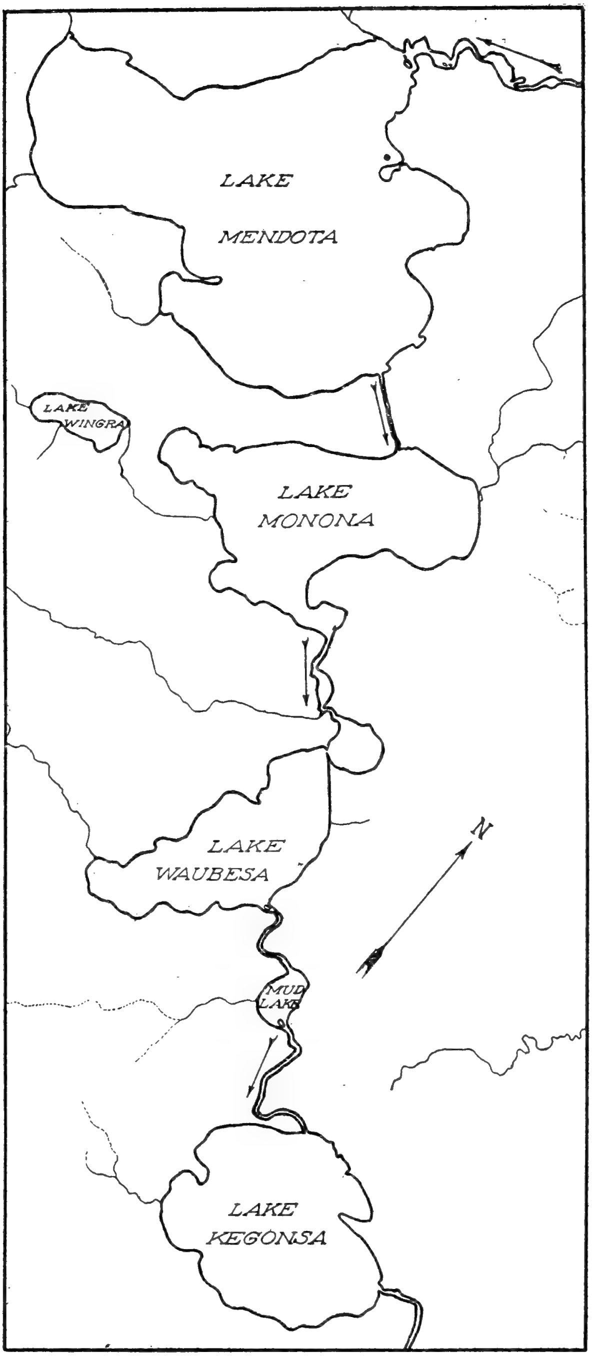

Fig. 6.—Outline map of the four lakes on which plankton observations were made.

majority of the organisms are found most abundantly. The epilimnion in these two lakes varies in thickness from five meters to seven meters when it is first formed, but it gradually increases in thickness as the season advances, extending to a depth of 10 meters to 12 meters by the middle of September.

There is a bottom stratum of cool water which may be regarded as stagnant during this period; that is, it is not kept in circulation by the wind and is not exposed to the air. Since light does not penetrate to this stratum in sufficient amount to permit much activity on the part of chlorophyl-bearing organisms, it is cut off from the two sources of oxygen supply, namely, the air and photosynthesis, and the quantity of this gas is limited to the amount held in solution at the time that stratification takes place. This supply of oxygen is drawn upon through respiration of the organisms which occupy this region and through the decomposition which takes place there, so that, by late July, substantially the entire hypolimnion of these two lakes is devoid of free oxygen. The dissolved gases bave been fully discussed in Bulletin No. XXII of this Survey and the reader is referred to that publication for a more detailed account.

The absence of oxygen makes the hypolimnion uninhabitable for the plankton crustacea, and those which occupy this region when there is a sufficient supply of this gas withdraw when the amount falls below the minimum required by the various forms. But this stratum is by no means entirely deserted during the period that it possesses no free oxygen because various forms of protozoa and some insect larvae thrive here even in the absence of oxygen. In fact, one ciliated protozoan has been noted which appeared in this stratum only when the oxygen was substantially or entirely absent, the largest numbers having been found under complete anaerobic conditions. (Juday, Biol. Bul., Vol. 36, 1919, pp. 92-95.)

Between the two strata mentioned above there is a definitely marked transition zone in which the conditions change from those of the warm water above to those of the cool water below. This is the mesolimnion or thermocline and it is relatively thin, usually not exceeding three or four meters in thickness and frequently not more than two meters. In the mesolimnion the temperature of the water rapidly changes from that of the warm water of the epilimnion above to that of the hypolimnion below and this decrease in temperature is accompanied by a decrease in the quantity of dissolved oxygen from that of the well aerated epilimnion to only a trace or none at all in the hypolimnion. These changes do not make this stratum uninhabitable, however, because the mesolimnion is generally well populated by various forms, some of which, in fact, are more abundant here than at any other depth.

The area of Lake Kegonsa is so great in proportion to its depth that the wind keeps the entire body of water in circulation during the summer. Lake Waubesa, while only slightly deeper than Lake Kegonsa, is only about a quarter as large, so that the wind is less effective in keeping the water in circulation. As a result, the deeper portion of this lake, which comprises a relatively small part of its total area, possesses a thin bottom stratum of cooler water until about the middle of August; but after this date the lake is substantially homothermous.

The maximum temperature of the upper water in these four lakes during the summer ranges between 25° and 30° C. The bottom temperatures in Lakes Mendota and Monona in summer vary from about 9° to 14°. In winter all of the lakes are covered with ice for a period of three to three and a half months, sometimes even longer. Usually the ice reaches a thickness of about three-quarters of a meter.

The region in which the lakes are situated is an agricultural district so that the dissolved substances carried by the drainage water of this basin are subject to the modifications usually found in such an area. During the period of these investigations also, Lake Monona received some raw sewage from the city of Madison as well as the effluent from its sewage disposal plant. This additional material in suspension and in solution also affected the waters of Lakes Waubesa and Kegonsa to a certain extent, since the Yahara river supplies water from Lake Monona to these two lakes.

The major portion of the work was done on Lake Mendota, on the south shore of which the laboratory is situated; but for purposes of comparison observations were also made on the other three members of this chain of lakes. Lake Kegonsa was visited only once because the river between it and Lake Waubesa has not been dredged and is not navigable for launches except at an unusually high stage of the water and then only with considerable difficulty. The river between Lake Mendota and Lakes Monona and Waubesa has been canalized so that they can be reached easily by launch from the laboratory.

Quantity of Water and of Plankton

Table 2 (p. 181) shows the quantity of water that was strained in each of the lakes and the amount of net plankton obtained therefrom. In all 481 catches were made and a little over two million liters of water were strained. Slightly more than 90 per cent of the total quantity of water was secured from Lake Mendota. The total volume of water yielded a little more than 1,292 grams of dry net plankton, or an average of approximately 600 milligrams per cubic meter. The average yield of net plankton was much smaller in Lake Mendota than in the other lakes; for 415 catches in this lake the average was 491 milligrams per cubic meter of water. For 47 catches in Lake Monona the yield was 1,499 milligrams; for 18 catches in Lake Waubesa it was 2,182 milligrams, while in the one catch in Lake Kegonsa the amount was 6,112 milligrams per cubic meter. The sample from Lake Kegonsa exceeded even the maxima of the other lakes. The largest amount found in Lake Mendota was only about 1,700 milligrams per cubic meter of water, while that of Lake Monona was 3,820 milligrams and that of Lake Waubesa 4,600 milligrams.

Table 3 shows the amount of water that was centrifuged for the nannoplankton, together with the quantity of dry material obtained therefrom.

Table 4 (p. 182) gives in detail the quantity of water used for the various samples of net plankton and nannoplankton, as well as the amount of dry material obtained in each instance. The quantitative results shown in the general tables (numbers 43 to 48) are based upon the quantities indicated in this table. In computing the amount of dry organic matter per cubic meter of water during the period from July to September, it was necessary to introduce a correction; that is, during these months the hypolimnion of Lakes Mendota and Monona is almost or quite devoid of free oxygen and, as a result, the net plankton organisms are unable to occupy this stratum. From 1911 to 1914, therefore, the net samples covered only the inhabited stratum of the lake so that it was necessary to apportion the total catch to the entire depth in order to get a general average for the whole lake. From 1915 to 1917 the corrections were very much smaller because material was secured regularly down to a depth of 20 meters in Lake Mendota and down to 18 meters in Lake Monona.

Some of the net plankton catches made in 1915 have been omitted because two series of such catches were taken in that year; only those are shown which have been subjected to the most complete analysis. Attention may be called to the fact that the quantity of water is the same for a net plankton catch as for the corresponding sample of nannoplankton, the same sample of water being used for both.

The studies on the net plankton were begun on June 1, 1911, and were continued regularly until June 1, 1917, with the exception of the period from July, 1914 to April, 1915. During the investigations nine sets of observations were made on Lake Mendota in the winter season, that is, while the lake was covered with ice. No attempt was made to secure winter catches on the other lakes. Work was begun as promptly as possible after the ice disappeared from the lake in the spring and it was continued until fairly thick ice formed along the shore of the lake in early winter and prevented further use of the launch. The latest date on which observations were made with the launch was December

24, 1913; regular trips were usually continued until the first or the second week in December.

Table 5 (p. 186) shows the general distribution of the net plankton during the different months of the year. The first column under each month indicates the number of runs or catches made during the month and the second column gives the average amount of dry net plankton per cubic meter of water that was secured in these catches; the latter shows, therefore, the monthly average of this matrial. The results for 1916 and 1917 are based on material obtained from much smaller quantities of water than in the previous years because net plankton was taken only from the water which was centrifuged for the smaller organisms. In these instances the quantity of water averaged about 1,200 liters per catch.

The 415 catches from Lake Mendota were combined in such a way as to make 184 samples for chemical analyses. Thirty-eight of these samples consist of single catches while the others are combinations of two to five catches each. In general it was the plan to make two or more catches each week during the open season in order to obtain a better average of material as well as a sufficient amount for analysis; usually all of the material obtained during a week was combined into one sample. Two of the samples from Lake Monona consist of two catches each while the others from this lake as well as all of those from Lake Waubesa contain but a single catch each.

Table 5 serves to show only the more general variations in the quantity of net plankton during the different months of the year; the time period is too long a unit to bring out the details. This general table indicates that there are marked differences in the amount of net plankton in the different years and also that the maximum and minimum amounts are not found in the same months from year to year. The results on the various lakes will now be taken up in greater detail.

LAKE MENDOTA

Organic Matter in Net Plankton

The organic matter of the net plankton consists of that portion of the material which is consumed in the ashing process. In general the amount of magnesium carbonate in the ash is so small that it is not necessary to make a correction for the carbon dioxide removed from it during the ashing process. During the greater part of the year from 70 per cent to 90 per cent or more, of the dry weight of the net plankton consists of organic matter; but during periods in which the diatoms predominate the organic and inorganic constituents may be almost equal in amount.

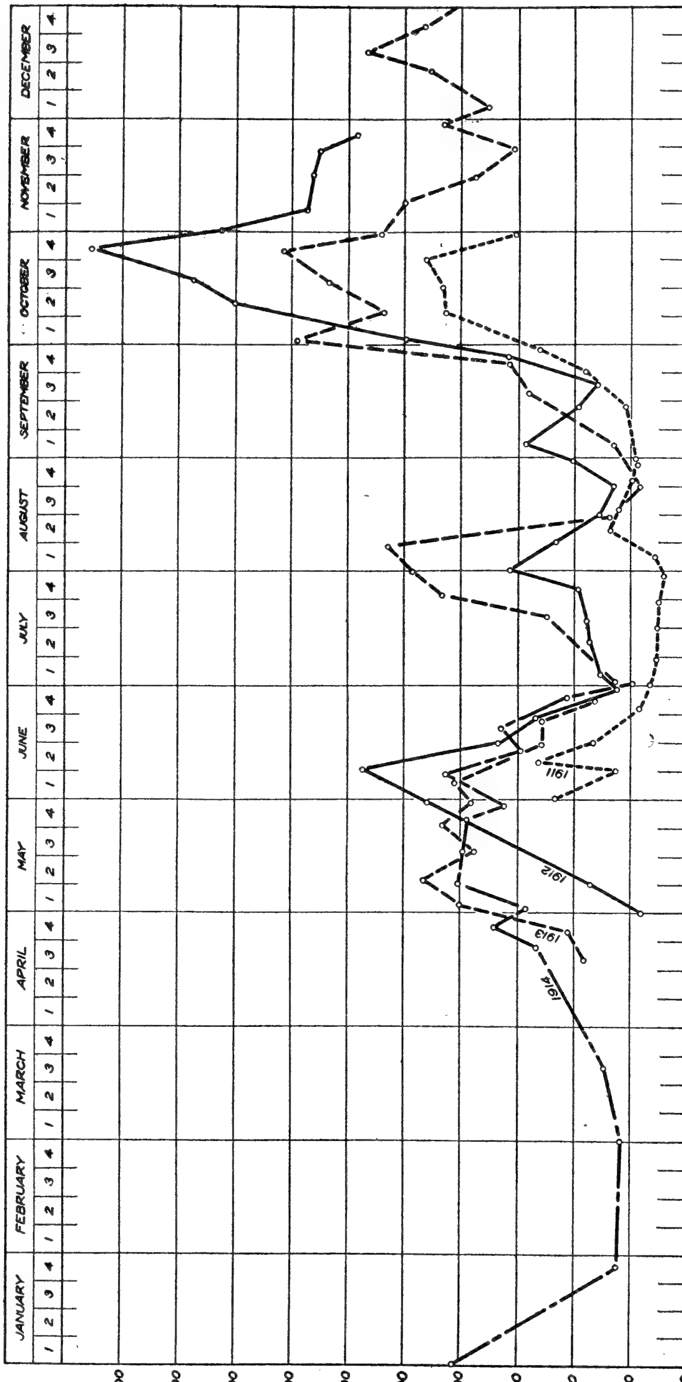

Fig. 7.—The amount of organic matter in the net plankton of Lake Mendota from 1911 to 1914. The vertical spaces represent the number of milligrams of dry organic matter per cubic meter of water. The curves are based upon the results shown in table 43.

The results obtained for the organic matter in the net plankton of Lake Mendota are summarized in table 6 (p. 187) in which the maximum, minimum, and mean quantities are indicated for the different years. The data are given in detail in the general table, No. 43, p. 202. During the period of these observations the amount of dry organic matter was smallest in 1911; the mean for this year was only 175 milligrams per cubic meter of water, or about half as much as in the other full years. Next in order come 1914 and 1917, but in these years the observations were discontinued respectively on July 2 and June 1, so that data are available for only the first half of these years. The results for these two years, therefore, are not comparable with those covering a full year. Adding the catches obtained between July and December, 1913, to the 14 secured during the first half of 1914 gives a mean of 363 milligrams of organic matter per cubic meter of water, while the catches taken between June 1, 1916, and June 1, 1917, give an average of 324 milligrams. Both of these averages are comparable in amount with those obtained during the full-year periods of 1912, 1913, 1915, and 1916, in which the means range from 343 milligrams to 393 milligrams per cubic meter of water. Thus, for the four full-year periods the largest mean exceeded the smallest by less than 15.0 per cent.

The seasonal changes in the amount of organic matter in the net plankton are shown in two diagrams, figures 7 and 8. The curves for 1913-14 (fig. 7) and for 1916-17 (fig. 8) cover all four seasons of the year; since they cover the complete annual cycle, they will be considered in some detail here. In these diagrams the vertical spaces represent the number of milligrams of organic matter per cubic meter of water, the scale being indicated in the left margin. The horizontal spaces represent the months of the year, each month being divided into four equal parts. In the curves the results obtained in the various observations are shown by the circles; the curves themselves have been constructed simply by connecting these points without attempting to round them off into more symmetrical diagrams. These diagrams are based on the data given in table 43.

The first sample obtained in 1913, namely, on April 16-18, yielded 185.1 milligrams of organic matter per cubic meter of water. Following this the amount rose rapidly to a maximum of 462.3 milligrams on May 7-9 and it then remained high until June 2-6. A marked decrease followed, a minimum of 126.9 milligrams being found on June 30-July 3. This was succeeded by a decided rise in July and early August, the amount reaching a maximum of 534.0 milligrams on August 4-7. This summer maximum was 71.7 milligrams larger than the vernal maximum. A very marked and rapid decrease to 87.2 milligrams on August 19-22 came next; this amount proved to be the minimum of the year.

The autumnal increase began early in September and reached its highest point on October 22-25, namely, 714.1 milligrams per cubic meter, which was the maximum for the year. A marked decrease followed in late October and in early November, while the sample of December 16-17 showed a secondary rise to 575.2 milligrams; the sample for the following week, however, contained a distinctly smaller amount of organic matter.

This decrease continued during the month of January, 1914, and reached a minimum of 123.7 milligrams by the latter part of this month. The February sample showed a similar amount, while that for March 14-21 contained a larger quantity of organic matter, namely, 146.6 milligrams. The first sample obtained after the disappearance of the ice in April showed a further increase and the organic matter continued to rise until it reached 401.8 milligrams on May 5-9. The amount then remained high until after a vernal maximum of 426.0 milligrams was reached on June 2-6. A decrease during the rest of June brought the quantity down to 98.8 milligrams on June 30-July 2, after which time the catches were discontinued.

The series of net catches for 1916-17 (fig. 8) began on February 11, 1916, and continued until June 1, 1917. The sample obtained on the former date contained 213.2 milligrams of organic matter per cubic meter, while that of March 8, 1916, had only 172.1 milligrams and that of April 15, 175.8 milligrams. The curve shows a small secondary peak during the last week in April which is followed by a decline to 176.9 milligrams on May 8-10. It will be noted that the latter amount was only a little larger than that of April 15. This was succeeded by the regular vernal rise which reached 395.6 milligrams on May 18-19 and a maximum of 418.1 milligrams on June 5-10. A rapid decline was noted during the next two weeks, which was followed by a slight rise during the last week in June; after this a further decrease brought the amount of organic matter in the net plankton down to the general summer minimum during the second week in July. Between this date and the third week in September the quantity of organic matter varied between 73.3 milligrams and 134.5 milligrams. The smallest amount was found in the sample obtained on August 22-25. The autumnal increase began during the last week in September and, through a series of secondary peaks, it rose to the maximum for the year, that is, 1,135.4 milligrams, on December 12, 1916.

By January 18, 1917, the organic matter had fallen to 866.2 milligrams and by February 14 to 187.3 milligrams. It declined still further during March and the first half of April, reaching a minimum of 92.4 milligrams on April 18. The latter was less than one-twelfth as much as that of December 12, 1916. During the latter part of April, 1917,

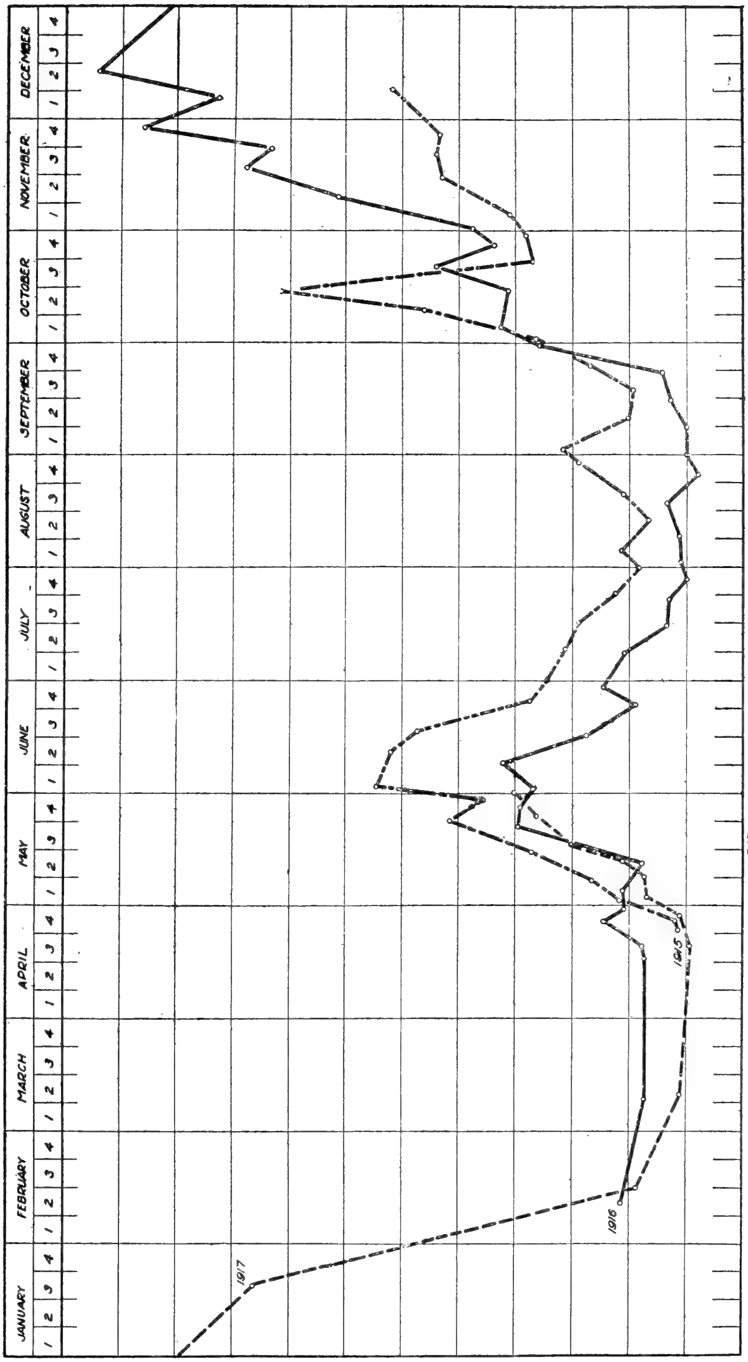

Fig. 8.—The amount of organic matter in the net plankton of Lake Mendota from 1915 to 1917. The curves show the number of milligrams of dry organic matter per cubic meter of water. See table 43.

and through the month of May there was a steady increase in the amount of organic matter which culminated in a maximum of 400.2 milligrams on June 1, 1917; after this date the observations were discontinued.

While the various curves show that there are considerable variations in the organic matter of the net plankton from year to year, yet they all agree in bringing out the fact that the annual cycle consists of four phases which correspond more or less closely to the four seasons of the year. Beginning in the spring, there is an increase during the latter part of April or early in May, at which time the organic matter rises more or less rapidly to a vernal maximum in late May or early June. There are considerable variations in the amount and in the duration of this increase from year to year. In two of the five years for which complete records were obtained, that is, in 1912 and 1915, the quantity of organic matter rose to maxima of 574.4 milligrams and 647.1 milligrams per cubic meter of water respectively. In the other three years the maxima lay between 400.0 and 462.0 milligrams. The period during which the organic matter remains near the maximum amount varies from a few days, as in 1912, to four weeks, as in 1913 and 1914. That part of the curve covering the vernal period in 1912 consists of a sharp peak; those for 1915 and 1916 have fairly broad apexes, while those for 1913 and 1914 have a more or less irregular plateau covering a period of about four weeks.

This vernal pulse is followed by a decrease during June to a general summer minimum about the first of July. From this time to the middle of September the organic matter may remain uniformly low as in 1911 and in 1916, or it may show a more or less marked summer increase as in 1912, 1913, and 1915. This summer increase was most marked in 1913; in fact, the organic matter rose to a higher point at this time than it did during the vernal maximum. The curve for 1912 shows two secondary peaks during the summer, one the first of August and the other the first of September; that for 1915 also shows a secondary peak about the first of September. On the whole, however, the period from July 1 to September 15 may be regarded as one in which the average amount of net plankton is relatively low.

The third phase of the annual cycle comprises the autumn of the year, during which there is a rather rapid increase, beginning about the third week in September. This rise terminates in a maximum usually about the middle or last of October, but the different years show important differences both with respect to the rapidity and the extent of the increase. In 1916, for example, the autumnal rise was much more gradual than in the other years and did not reach its maximum height until almost the middle of December; this maximum was the largest found during these observations. It exceeded the next in rank, namely, the autumnal maximum of 1912 by 80.0 milligrams per cubic meter of water.

The autumnal period is succeeded by a decline to a winter minimum which is reached in late January, as in 1914, or by the middle of February, as in 1917. In 1913, however, the autumnal maximum was followed by a secondary rise which reached its highest point during the third week in December; this was then followed by a decline to the winter minimum. After reaching the winter minimum the quantity of organic matter remains fairly constant until about the middle of April and soon after this date the vernal increase begins.

CHEMICAL RESULTS

Nitrogen and Crude Protein

The detailed results for the nitrogen determinations on the net plankton of Lake Mendota are shown in table 43 (p. 202). There are five columns in the general table pertaining to the nitrogen. The first one shows the percentage of the total nitrogen in the dry sample; the second gives the percentage of nitrogen in the organic matter exclusive of that found in the crude fiber; the third indicates the number of milligrams of nitrogen per cubic meter of water; the fourth shows the quantity of crude protein, that is, the milligrams of nitrogen multiplied by the protein factor 6.25; the fifth column indicates the ratio of the organic matter to the nitrogen. The curves marked B in figures 11 to 14 show the number of milligrams of crude protein per cubic meter of water in the net plankton.

A certain portion of the total nitrogen is found in the chitin of the shells of the plankton crustacea; since these shells pass through the alimentary tract of fishes without being affected, apparently, by the digestive processes, it is assumed that this nitrogen compound has no food value. It was necessary, therefore, to make a correction for the nitrogen in the chitin since one of the purposes of this investigation was to secure data regarding the food value of the plankton. Schuette[1] found that the crude fiber derived from the plankton crustacea yielded from 5.9 per cent to 6.2 per cent of nitrogen, or substantially the same percentage as reported for chitin by several investigators. So the correction was made by determining the percentage of nitrogen in the crude fiber of the plankton material and then deducting this amount from the total nitrogen. It has been reported that chitin exists in the walls of many blue-green algae also, but later investigations do not confirm the earlier results; thus its presence in these forms is still an open question.

[1] Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 610.

In the general table, then, column one under nitrogen shows the percentage of the total nitrogen, including that in the crude fiber; but the nitrogen of the crude fiber was deducted from the total nitrogen before calculating the percentage on an ash free basis. In other words, the results given in column two under nitrogen in the general table represent the crude protein nitrogen in the organic matter. This same correction applies to the next two columns, but the last column for nitrogen shows the ratio of the organic matter to the *total* nitrogen.

Table 7 (p. 187) shows the variations in the percentage of nitrogen in the net plankton in the various years. Only about two-thirds of the samples obtained in 1916 and 1917 contained enough material for a nitrogen determination. In the total nitrogen there was approximately a twofold variation in the percentage each year; the ratio of maximum to minimum is greater than two for the first three years and less than two for the other four years. The greatest difference between maximum and minimum was noted in 1913, namely, slightly more than five per cent. The minimum percentage was found in August in each of the complete years except in 1913 when it was noted in the month of December. In 1914 and 1917 the observations did not cover the latter half of the year. In 1913 and 1914 the material which yielded the largest percentage of nitrogen was obtained in the month of April; in 1915 and 1917 it was obtained in May; in 1912 in June, in 1916 in July, and in 1911 it came in September. Thus in four of the five complete years the maximum percentage of nitrogen was found either in the spring or in the early summer.

The second part of table 7 shows the variations in the crude protein nitrogen when stated on an ash free basis. The ratio of maximum to minimum each year is distinctly less than two; the greatest difference, almost five per cent, was noted in 1913, while the smallest differences were found in 1915 and 1916, excluding 1917 which was not a complete year. The maximum percentage of crude protein nitrogen was found in 1913 and the minimum in 1916. The mean percentage was smallest in 1911 and largest in 1917. Excluding the partial years 1914 and 1917, the largest mean percentage was found in 1915, but the smallest mean, that of 1911, was a little less than one per cent below the maximum. Taken as a whole, then, the results for the five complete years show a rather striking uniformity in the mean percentage of crude protein nitrogen in view of the composite character of the net plankton and of the changes in the relative abundance of the various forms during the different seasons of the year.

The third column under nitrogen in table 43 shows the number of milligrams of crude protein nitrogen per cubic meter of water. In the various net samples on which nitrogen determinations were made, the quantity of crude protein nitrogen varied from a minimum of 3.4 milligrams per cubic meter of water in one sample collected in 1911 to a maximum of 93.0 milligrams in one of the 1916 samples; a minimum of 5.2 milligrams was noted in one of the 1916 catches, thus giving an eighteenfold variation in amount during that year. In 1911 the quantity varied from 3.4 milligrams to 40.8 milligrams, which represents a twelvefold variation in amount.

The quantity of nitrogen, like that of organic matter, showed vernal and autumnal maxima separated by summer and winter minima. The autumnal maximum always exceeded the vernal maximum of the same year; the greatest difference between the two was noted in 1912 when the vernal nitrogen rose to 49.3 milligrams per cubic meter of water and the autumnal to 85.0 milligrams, the difference being 35.7 milligrams. In 1911 the difference between these two maxima was 22.7 milligrams and in 1913 it was 19.4 milligrams, while in 1915 it was only 13.0 milligrams.

Figures 9 and 10 are graphical representations of the quantitative results obtained for nitrogen; they show the number of milligrams of crude protein nitrogen per cubic meter of water. These curves serve

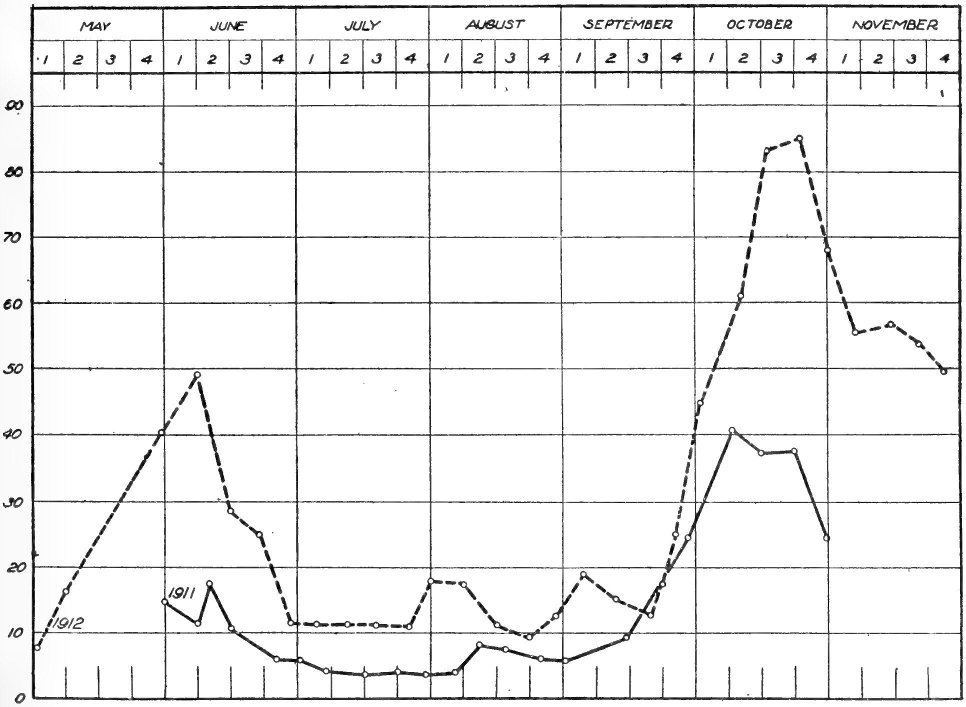

Fig. 9.—The quantity of nitrogen in the net plankton of Lake Mendota in 1911 and 1912. The vertical spaces show the number of milligrams of nitrogen per cubic meter of water.

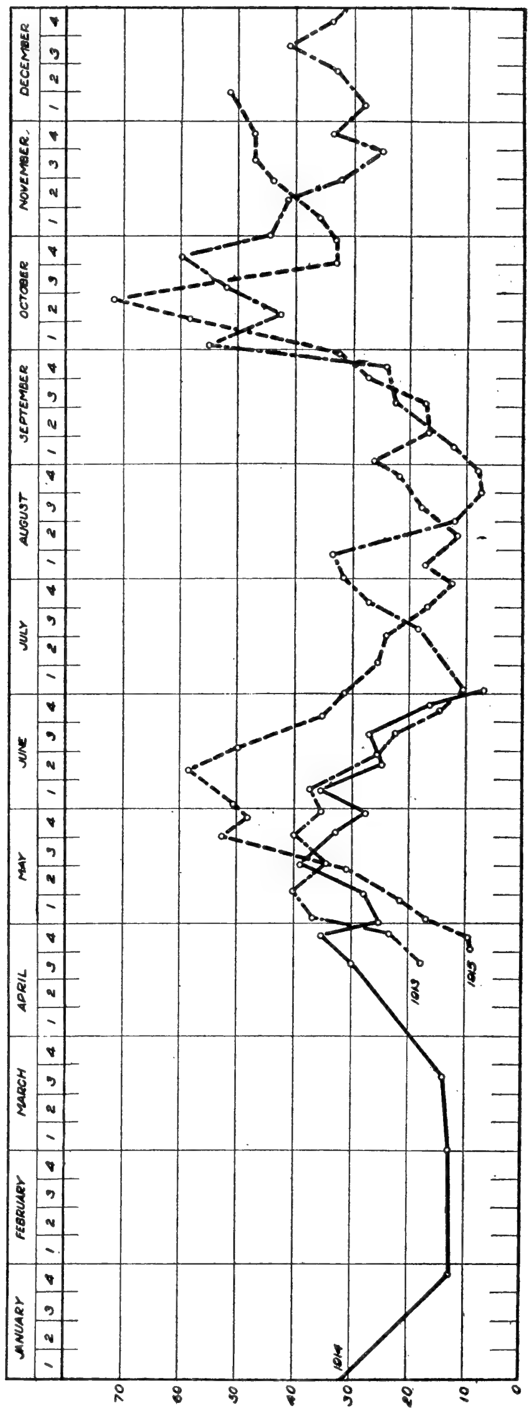

Fig. 10.—The quantity of nitrogen in the net plankton of Lake Mendota from 1913 to 1915. The curves show the number of milligrams of nitrogen per cubic meter of water. Compare with figure 9.

to bring out more clearly the vernal and autumnal maxima of nitrogen as well as the summer and winter minima. Many of the net catches that were made in 1916 and 1917 did not contain enough material for a nitrogen determination so that the data for these years are not complete enough for the construction of curves covering this period. Thus, only one winter season is covered in these curves, namely that of 1913-14 (fig. 10), but it furnishes a good illustration of the winter minimum which extended from late January, 1914, to the latter part of March.

The various curves reach their greatest heights in the spring in the months of May and June, while the summer minima are found in July and August. The autumnal maximum in the four years covered by these observations was attained in the month of October. These curves show clearly that the quantity of crude protein nitrogen was smallest in 1911, less than 10.0 milligrams per cubic meter of water being found from the middle of June to the middle of September. The quantity of nitrogen remained well above 10.0 milligrams per cubic meter of water during the summer of 1915; it fell below this amount only once in the summer of 1912 and twice in the summer of 1913.

Column four under nitrogen in table 43 (p. 202) shows the quantity of crude protein per cubic meter of water; that is, it gives the results obtained by multiplying the quantity of nitrogen shown in column three by the protein factor 6.25. The various proteins do not all possess the same percentage of nitrogen, the amount ranging from a minimum of about 15.0 per cent to a maximum of 19.0 per cent, but this factor is the one generally used by food chemists for calculating their nitrogen determinations into terms of protein. Thus, the results given in this column are more or less conventional, but they serve to give a general idea of the quantity of crude protein.

The range of variation in the quantity of crude protein in the various years is shown in the second part of table 8 (p. 188) in which the maximum, minimum, and mean amounts are stated in milligrams per cubic meter of water; the ratio of the maximum to the minimum is also indicated in the last column of this table.

The smallest maximum was noted in 1914, but this was due, no doubt to the fact that the observations were discontinued on the first of July so that the autumn maximum was not obtained. The largest maximum was found in 1912, while that of 1911 was somewhat less than half as large. The maxima of the other years fell between these two. The smallest minimum was noted in 1911 and the largest in 1915. Likewise, the smallest mean was found in 1911; it was only about 45.0 per cent as large as that for 1913 which was the next smallest of the four complete years. The mean for 1915 was the largest, the amount for this year being almost two and a half times as large as that for 1911.

The first part of table 8 indicates some of the general relations of the quantity of crude protein to the quantity of organic matter. It shows the maximum, minimum, and mean percentages of the former in the latter. It will be noted that the amount of crude protein fell as low as 34.5 per cent of the organic matter and it reached a maximum of 70.0 per cent, thus giving slightly more than a twofold variation. The seven maxima range from 56.2 per cent to 70.0 per cent, a difference of 13.8 per cent, while the minima vary from 34.5 per cent to 52.6 per cent, a difference of 18.1 per cent; the mean percentages show a variation of 15.1 per cent. The organic matter contained the lowest percentage of crude protein in 1912 and the highest in 1913; the highest mean percentage was found in 1915. The high mean percentage of 1915 is accounted for by the fact that the crude protein fell below 50.0 per cent of the organic matter in only four of the 34 samples obtained in this year.

Nitrogen determinations were made on 166 samples and, in this number, the crude protein constituted from 45.0 per cent to 60.0 per cent of the organic matter in 123 samples; that is, the proportion of crude protein in the organic matter does not vary more than 15.0 per cent in about three-quarters of the samples. Lowering the minimum to 40.0 per cent adds 16 more samples to this list.

The ratio of the crude protein to the organic matter is shown graphically in figures 11 to 14, inclusive. The curves marked A in these diagrams represent the organic matter and those marked B the crude pro-

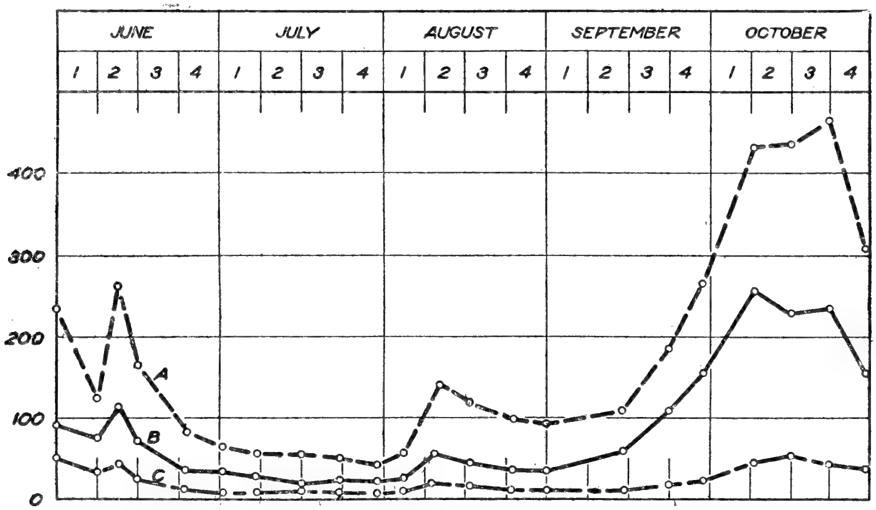

Fig. 11.—The amount of dry organic matter, of crude protein and of ether extract in the net plankton of Lake Mendota in 1911. Curve A represents the organic matter, curve B the crude protein and curve C the ether extract. The curves show the number of milligrams per cubic meter of water.

tein. The space between the base line, that is, the zero line, and the curve B in each case indicates that portion of the organic matter which the crude protein comprises, while the area between the two curves shows the remainder of the organic matter, such as the chitin, the carbohydrates, and the fats.

In general these curves show that a marked increase or decrease in the organic matter is accompanied by a similar change in the crude protein. Thus during corresponding periods, the curves representing

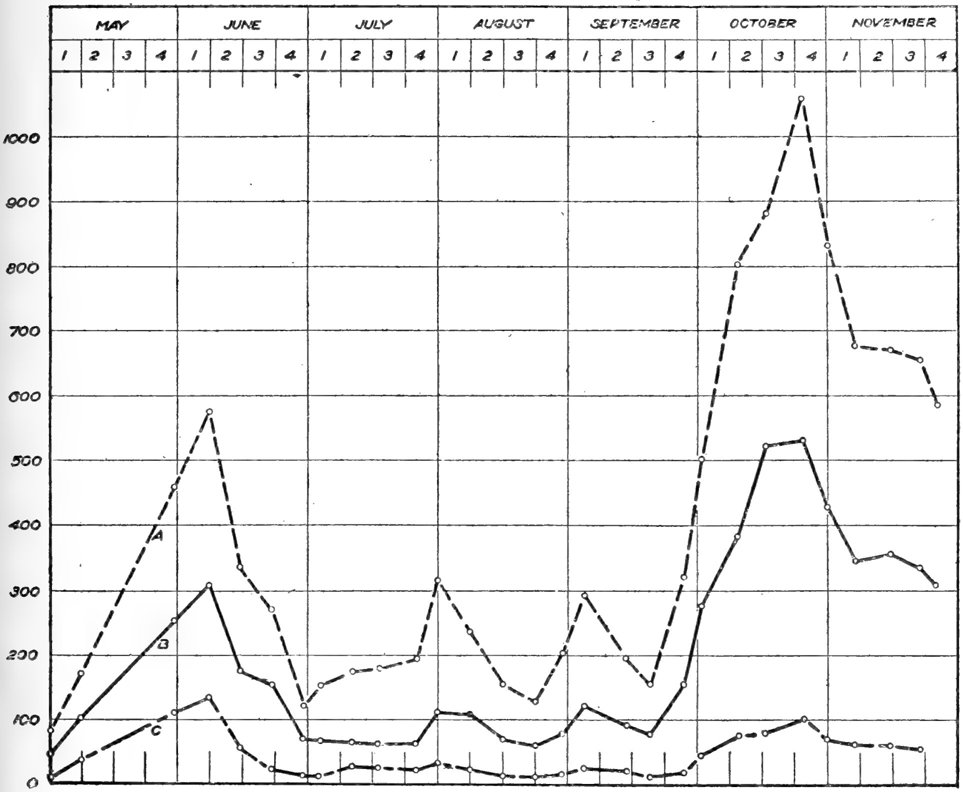

Fig. 12.—The amount of dry organic matter, of crude protein, and of ether extract in the net plankton of Lake Mendota in 1912. Curve A represents the organic matter, curve B the crude protein and curve C the ether extract. The curves show the number of milligrams per cubic meter of water.

the latter possess the same general form as those for the organic matter. In some instances, however, there are minor differences between the two sets of curves. In 1912, for example (fig. 12), there was a perceptible increase in the organic matter between the last week in June and the last week in July, but the crude protein remained almost constant in amount during this time; in fact, it showed a slight de-

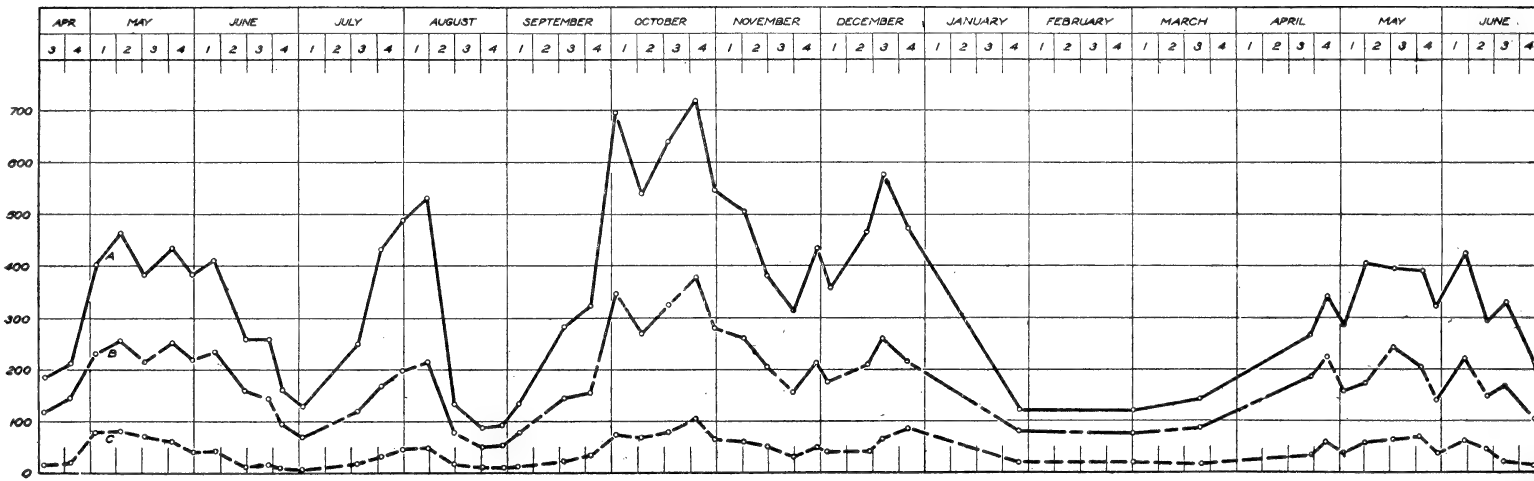

Fig. 13.—The amount of dry organic matter, of crude protein and of ether extract in the net plankton of Lake Mendota in 1913 and 1914. Curve A represents the organic matter, curve B the crude protein and curve C the ether extract. The curves show the number of milligrams per cubic meter of water. See table 43.

crease. The secondary peak in the curve for organic matter appearing the first of August, 1912, has a sharp apex while that of the protein curve at this time is broad. The same difference between the two curves also appears during the autumnal maximum. In the vernal peaks of 1915 (fig. 14) the protein reached its highest point about a week later than the organic matter so that the former curve has a distinctly broader summit. With the exception of these few minor differences, however, the curves for organic matter and crude protein show a close correlation during the period of time covered by these observations.

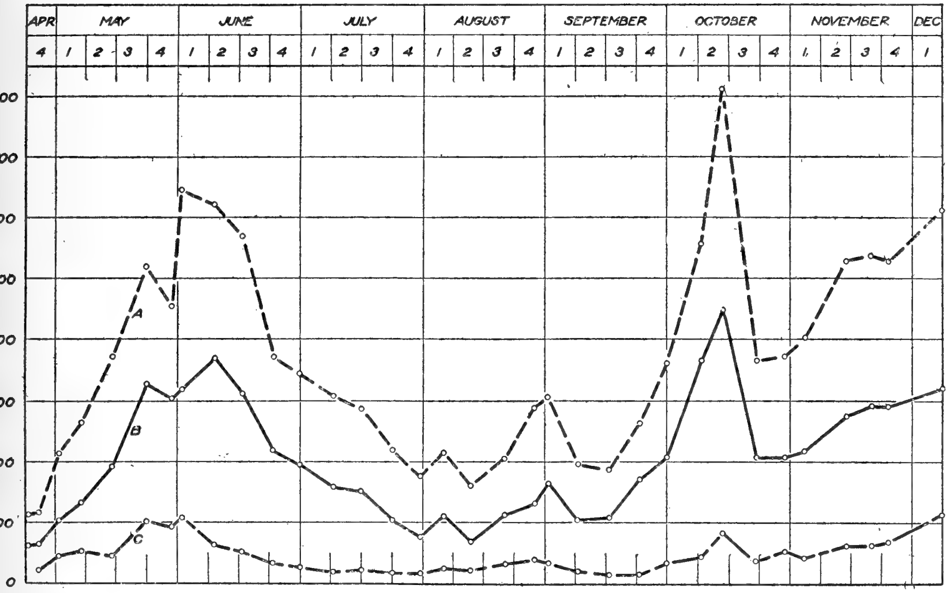

Fig. 14.—The amount of dry organic matter, of crude protein and of ether extract in the net plankton of Lake Mendota in 1915. Curve A represents the organic matter, curve B the crude protein and curve C the ether extract. The curves show the number of milligrams per cubic meter of water.

Column five under nitrogen in the general table (No. 43, p. 202) shows the ratio of the organic matter in the net plankton to the total nitrogen; that is, it is a numerical expression of the relation of the former to the latter. As might be expected from the results given for the percentage of total nitrogen in column one, this ratio is subject to a twofold variation and it is relatively low because the percentage of nitrogen is fairly high. In 91 out of 134 samples the ratio falls between 9 and 12; that is, in these samples the nitrogen constitutes from one-ninth to one-twelfth of the dry organic matter. In two samples the ratio falls below 9 and in 41 samples above 12, the highest being 17.4 and the lowest 8.7.

Quantitative determinations of four forms of nitrogen were made by Schuette[2] on five samples of plankton; the results of his analyses are shown in table 9 (p. 188). With respect to the material which he used for these analyses it may be said that it was collected in 1913, the first four samples in October and November of that year, and the fifth in December. A and B were regular pump catches so that they contained the same organisms as the net plankton of this period; that is, diatoms and crustacea were the chief constituents. The material in C and D was obtained with tow nets so that only the larger organisms were secured, hence it contained a larger proportion of plankton crustacea. Sample E consisted almost entirely of two algae, namely, Aphanizomenon and Anabaena.

It will be noted that by far the greater portion of the total nitrogen in these samples was found in the form of mono-amino nitrogen, while di-amino nitrogen was next in importance. These two forms of nitrogen constituted from 77.0 per cent to 85.0 per cent of the total nitrogen in these samples. From 9.0 per cent to 12.0 per cent of the total was found in the form of ammonia nitrogen and about half as much in the form of "humic" nitrogen. The highest percentage of "humic" nitrogen was found in sample E which consisted of the two blue-green algae.

Ether Extract

The ether extract from the net plankton contains the fats, more or less chlorophyl according to the relative abundance of the algae in the sample, and probably other substances, such as lecithin, which are widely distributed in plant and animal material and which are soluble in ether. The presence of chlorophyl is clearly indicated by the green color which it imparts to the extract, but no attempt has been made to ascertain the quantity of the various substances, in addition to the fat, which are extracted by the ether. It is believed, however, that such materials constitute only a very small part of the whole extract.

There are marked differences in the percentage of ether extract obtained from the different organisms as well as differences in the same organism at different seasons of the year. In general the extract from the algae varies from slightly more than one per cent to about 4.5 per cent of the dry weight. On the other hand a much larger percentage is obtained from the crustacea, ranging from a minimum of about 4.0 per cent to a maximum of approximately 40.0 per cent. The highest percentage was obtained from the copepod Limnocalanus which usually contains a large globule of oil in the thoracic region of the body. Another copepod, Cyclops, yielded 20.0 per cent of fat. There is a rather

[2] Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 604.

wide range in the percentage of fat in Daphnia; this variation appears to be more or less closely correlated with their stage of development. Those which are in an active stage of reproduction and are carrying many embryos in their brood chambers, contain the largest amount of fat; immature individuals or adults with few embryos yield a smaller percentage of extract. In the former individuals the amount of fat may exceed 21.0 per cent of the dry weight while in the latter it may fall as low as 3.9 per cent.

Thus the percentage of ether extract in the net plankton depends upon three factors, namely, (a) the relative proportion of plant and animal material present, (b) the predominant form of crustacean, and (c) the developmental stage of the Daphnias present.

The range of the variation in the percentage of the ether extract is shown in the first part of table 10 (p. 188) where the results are stated on an ash free basis; the second part of this table gives the variations in terms of milligrams per cubic meter of water. The maximum percentage in the net plankton was found in 1911; in one sample obtained this year, the ether extract constituted 26.58 per cent of the total organic matter. The minimum for this year was also higher than in any of the other years; the maximum percentage for 1911 was only about three and a half times as much as the minimum. The lowest maximum percentage was noted in 1914 and the lowest minimum in 1913. The maximum percentage in the latter year was nearly seven times as large as the minimum; in the other years the maxima were from three to four times as large as the minima. The highest mean percentage was found in 1914 and the lowest in 1913.

When stated in terms of milligrams per cubic meter of water, as in the second part of the table, the largest amount of ether extract was found in 1912 and the next largest in 1915. A sample obtained in 1913 showed the smallest amount per cubic meter and the maximum quantity for this year was a little more than twenty-five times as large as the minimum; this was the largest annual difference noted during the period of these observations. In the other instances, the maxima were from eight to twelve times as large as the minima of the corresponding years. The mean amount for 1911 was far below those of the other years, being only about half as large as three of the others. The largest average amount for a whole year was found in 1915, namely, 46.6 milligrams per cubic meter of water.

The curves marked C in figures 11 to 14, inclusive, show graphically the quantities of ether extract in milligrams per cubic meter of water for the different years; they also indicate the relative proportion of this material in the organic matter as well as the relation of the amount of ether extract to that of crude protein.

In general the curves for ether extract exhibit the four annual phases that have been noted for the organic matter and the crude protein, that is, spring and autumn maxima and summer and winter minima. Thus the form of these curves is similar to that of the curves representing the organic matter and crude protein. Attention may be called to some minor differences, however; in two of the four series of observations covering the open season of the lake, the curves for ether extract reach their highest points for the year during the vernal maxima, while in one year, namely, 1913, the highest point of the year is reached during the autumn maximum. In 1915 the maximum height of the curve is found at the end of the first week in December. On the other hand, the curves for organic matter and crude protein reach their highest points during the autumnal periods in all four years.

Some idea of the character of the ether extract of net plankton which consists chiefly or entirely of crustacea, may be obtained from table 11 (p. 189). Samples C and D were tow net catches from Lake Mendota and both contained mainly crustacean material. By far the greater part of the former consisted of Daphnia, Diaptomus, and Cyclops, with a smaller portion of algal material, chiefly the diatom Fragilaria; the major portion of the latter consisted of Daphnia, only a few copepods and very little plant material being present. Sample No. 403 was a tow net catch from Lake Monona and contained nothing but Daphnia, chiefly *Daphnia pulex.* The extracts possessed a fishy odor, especially that of No. 403; the physical and chemical constants indicate also that they should be classed with the fish oils. Upon standing for twelve hours crystals of glycerides were deposited and the extract from No. 403 solidified upon exposure to the air.

Carbohydrates

Quantitative determinations indicated that only small amounts of sugars were present in the net plankton and no systematic study of them was undertaken because it was not practical to obtain sufficient material in the regular catches for such determinations. The results obtained by Schuette[3] are summarized in the following statements.

1. Aqueous and alcohol extracts of the crustacean samples did not show the presence of reducing sugars.
2. Material in which the algae greatly predominated possessed reducing sugars that were soluble in 50.0 per cent alcohol.
3. A sample of blue-green algae and one consisting of a mixture of diatoms and crustacea contained carbohydrates that were soluble in hot water. No pentoses were present but the extracts showed a slight reducing action toward Fehling's solution.

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[3] Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 605.

4. The aqueous extract of the sample consisting of diatoms and crustacea gave an amorphous brown precipitate when treated with phenylhydrazine hydrochloride and sodium acetate. This precipitate did not contain an osazone that was soluble in hot 60.0 per cent alcohol or in pyridine. Neither did it contain disaccharides or glucosides.

5. No substance comparable to the algin of marine algae was found.

The samples of net plankton yielded measurable amounts of furfurol when distilled with hydrochloric acid; the furfurol was collected as the phloroglucide, weighed, and the result calculated to pentosans. Such quantitative determinations were made on 95 of the 134 net samples that were collected between 1911 and 1915. Table 12 gives a summary of the results obtained on the material from 1912 to 1915; only three determinations were made on the material collected in 1911 and none at all on that of 1916 and 1917, so that these three years do not appear in this table. All of the analyses are shown in the general table, however (No. 43, p. 202). The pentosans constitute a relatively small proportion of the organic matter in the net plankton. In only two samples out of the 95 that were analyzed did the pentosans amount to as much as 5.0 per cent of the organic matter, while the annual means range from a minimum of 1.7 per cent in 1914 to a maximum of 3.4 per cent in 1915.

The total quantity of the pentosans was relatively small; it exceeded 30 milligrams per cubic meter of water in only two of the samples on which determinations were made. One sample collected in 1912 yielded 36.1 milligrams and another obtained in 1915 gave 33.6 milligrams per cubic meter of water; both of these amounts were found during the autumnal maxima of organic matter. The annual means for the pentosans range from a minimum of 5.4 milligrams in 1914 to a maximum of 15.3 milligrams per cubic meter of water in 1912, almost a threefold variation. Since the observations were discontinued on July 2, 1914, the results cover only the first half of this year; therefore, it can not be compared fairly with the full years. The minimum of the complete years is 10.9 milligrams which is two-thirds as large as the maximum of 1912, thus showing a very much smaller range of variation when the three complete years only are considered.

Crude Fiber

The term "crude fiber" is applied to the organic material which remains undissolved after the plankton is digested for half-hour periods with sulphuric acid and sodium hydroxide solutions having a specific gravity of 1.25. In the mixed plant and animal material of the net plankton, the crude fiber consists of carbohydrates derived chiefly from the former and of chitin from the shells of the crustacea. A certain part of the crude fiber of forage crops is digested by the ruminants, but no data are available to indicate whether any portion of the carbohydrates in the plankton crude fiber is utilized by the organisms which feed upon this material or not. The chitinous portion of the crustacean shells passes through the alimentary canal of fishes without being affected by the digestive processes, so that this part of the plankton crude fiber may be regarded as having no food value, and it constitutes a considerable portion of the total crude fiber at times. Since the crude fiber constitutes a relatively small part of the organic matter in most instances, and since the chitinous part of it has no food value, it appears that the crude fiber of the net plankton plays a comparatively unimportant rôle from the food standpoint, even if some of the carbohydrates in it are utilized by the organisms which consume the various planktonts.

In table 13 (p. 189) it will be noted that the crude fiber of the net plankton varied from a minimum of 2.6 per cent of the organic matter in one sample obtained in 1913 to a maximum of 20.2 per cent in a sample collected in 1912. Thus, in one sample out of the 119 on which determinations were made the crude fiber amounted to as much as one-fifth of the organic matter, while in three-quarters of the samples it was 10.0 per cent or less. The mean percentage for the different years varied from 6.3 per cent in 1915 to 10.6 per cent in 1911.

In terms of milligrams per cubic meter of water the amount of crude fiber ranged from a minimum of 3.7 milligrams in 1911 to a maximum of 67.0 milligrams in 1912, an eighteenfold difference. The greatest difference for a single year was found in 1911 in which the maximum amount was fourteen times as large as the minimum. The mean quantity for the different years fell between 17.5 milligrams in 1914 and 30.8 milligrams in 1912.

Nitrogen Free Extract

The various constituents which have been considered thus far, such as the crude protein, the ether extract, the crude fiber, and the ash, do not comprise the whole of the net plankton; that is, if expressed in percentages of the dry sample they do not constitute 100.0 per cent of the material. In some instances, in fact, these four items account for only about two-thirds of the dry matter. This is due to the fact that there are various carbohydrates present which are not included in these items. More or less carbohydrate material is found in the crude fiber, especially in samples containing large numbers of algae, but, in general, only a relatively small proportion of the total amount of carbohydrates appears in the crude fiber. It is customary to designate all of the carbohydrates not included in the crude fiber as nitrogen free extract and the quantity of this extract is determined by difference; that is, the percentages of crude protein, ether extract, crude fiber and ash are deducted from 100 and the remainder constitutes the percentage of nitrogen free extract.

There is a wide variation in the percentage of this extract in the net plankton of Lake Mendota, ranging from a minimum of about 5.0 per cent to a maximum of 35.0 per cent; in the great majority of the samples, however, it falls between 10.0 per cent and 25.0 per cent. The average for the entire series of net samples is a little more than 20.0 per cent of the dry weight of the material.

Analyses of substantially pure catches show that the nitrogen free extract in ten samples of blue-green algae constitutes from 25.0 per cent to 52.0 per cent of the dry weight of the material; in most of the samples it falls between 30.0 per cent and 40.0 per cent. Two samples of diatoms show approximately 23.0 per cent and 34.0 per cent, respectively.

Table 49 shows that the crude protein, ether extract, crude fiber, and ash constitute from 75.0 per cent to 95.0 per cent of the dry weight of the plankton crustacea; the former was noted for a sample containing *Daphnia pulex* and the latter in one consisting of Cyclops. These four items, therefore, account for a much greater proportion of the crustacean material than they do of the algal material.

A quantitative study of only one of the carbohydrate compounds of the net plankton was made, namely, of the pentosans. The analyses show that the pentosans constitute but a relatively small part of the carbohydrate material that is present in the samples. The average for all of the pentosan determinations, for example, is about 2.6 per cent, while that of the nitrogen free extract is 20.8 per cent, the former being only about one-tenth as large as the latter.

Ash

The ash content of the net plankton was relatively large, more especially when diatoms were abundant. In only 12 samples out of a total of 184 did the ash fall below 10.0 per cent of the dry weight and in only 79, or less than half of the total number, did it fall below 20.0 per cent. In 68 out of 100 samples obtained from Lake Mendota between 1911 and 1914 the ash fell below 20.0 per cent, while only 11 out of 84 secured between 1915 and 1917 fell below this percentage. Table 14 gives a summary of the ash and silica determinations of the different years, while all of the determinations are indicated in the general table (No. 43, p. 202). The differences between maximum and minimum percentages of ash in the various years range from less than twofold to almost sevenfold. The former was noted in 1914, in which year the observations were discontinued on July 1, so that a full season was not represented; the latter was found in 1912. The highest maximum percentage, nearly half of the dry weight, was noted in 1915 and the lowest in 1914. The maximum percentage of ash each year was correlated with the appearance of large numbers of diatoms; in four of the years in which the observations continued from spring until late autumn or early winter, the highest percentage of ash was found in September and October, but in 1911 it came in August, being correlated with a crop of diatoms which flourished during this month. The very low maximum in 1914 was due to the scarcity of diatoms during the vernal period of that year and the observations did not cover the other diatom season, namely, the autumn.

Thus the mean percentage for 1914 is by far the lowest of all, but that for 1917, in which year the observations also covered only the

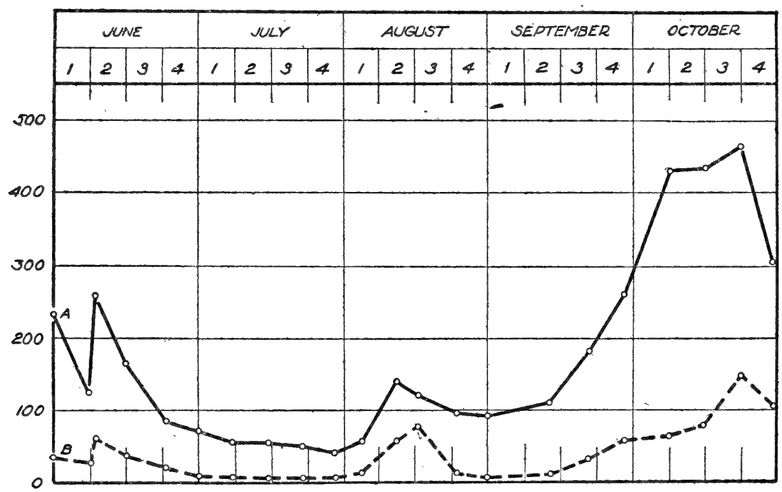

Fig. 15.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota in 1911. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water.

vernal period, is exceeded by only two other years. Excluding the two parts of years, the mean percentage of ash shows a gradual increase from 1911, the lowest, to 1915 and 1916, the highest, the last two years being substantially the same. This is in accordance with the fact already pointed out that most of the samples having less than 20.0 per cent of ash were collected during the period 1911 to 1914. The mean percentage of ash for the entire series of 184 net samples is 23.5 per cent of the dry material.

The relative amounts of organic matter and of ash or inorganic matter in the net plankton of the various years are shown graphically in figures 15 to 20, inclusive. Both are indicated in milligrams per cubic meter of water and the space between the two curves represents the excess of organic matter over the inorganic matter. In these diagrams the curves for the former are marked A and those for the latter B.

The curves representing the ash possess, in a general way, the same configuration as those of the organic matter; that is, they show spring and autumn periods of maxima and summer and winter periods of

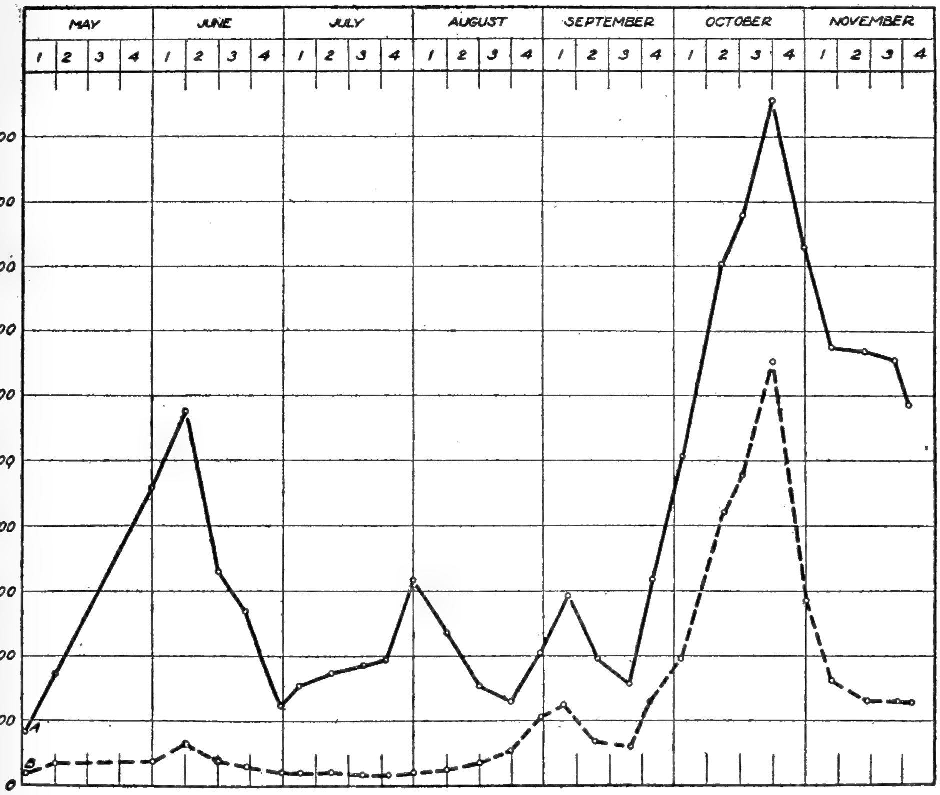

Fig. 16.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota in 1912. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water.

minima, which have already been noted for the organic matter. The ash is subject to certain irregularities in summer, however, just as noted in the organic matter. A closer comparison of the curves for the various years shows that more or less marked differences exist. In 1911, for example (fig. 15), the curve for ash does not reach its highest point in August until nearly a week after the organic matter reaches its maximum. Likewise in early October of that year the rise in the ash was not proportionately as rapid as in the organic matter.

The marked vernal rise in the organic matter in 1912 (fig. 16) was not accompanied by an equally marked increase in the ash. Between the first of May and the end of the first week in June, the former rose from 83.6 milligrams per cubic meter of water to 574.4 milligrams, almost a sevenfold increase, while the ash, during the same interval of time, increased from 18.1 milligrams to 63.7 milligrams, the latter being only three and a half times the former. The increase in organic matter at this time was due largely to an increase in the number of copepods and usually these organisms possess a low percentage of ash. During the last week of July in this year there was also a distinct rise in the

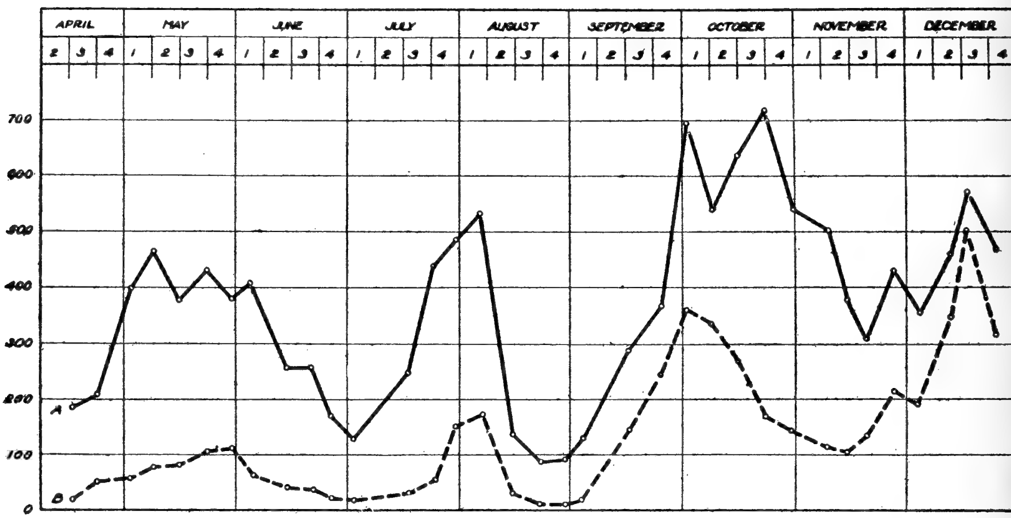

Fig. 17.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota in 1913. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water.

organic matter which was not accompanied by a corresponding increase in the ash; in this case, the rise of the former was due chiefly to a crop of Ceratium and the percentage of ash in this organism is low. The rise in organic matter in late August and early September was due to diatoms and it was accompanied by a similar rise in the ash. During the remainder of this year the two curves are similar, but the ash showed a proportionately greater decrease in November than the organic matter.

The vernal increase of ash in 1913 (fig. 17) did not begin as early as that of the organic matter and the curve for the former does not reach its maximum height until the last of May, while the latter reaches its highest point about three weeks earlier. Between the last week in August and the first of October, there was a thirty-fivefold increase in the ash while the organic matter on the latter date was only a little more then seven and a half times as much as that on the former date. During the rest of October the ash showed a decline; the organic matter showed a decline at the end of the first week in October and then rose to the highest point for 1913 at the end of the third week in October before it began to decline in amount. Thus, the curve for organic matter shows two peaks for the autumnal period of this year, while that for the ash shows only one. During the latter half of November and the first half of December, the ash showed approximately a fivefold increase while the change in organic matter during this interval was less than twofold.

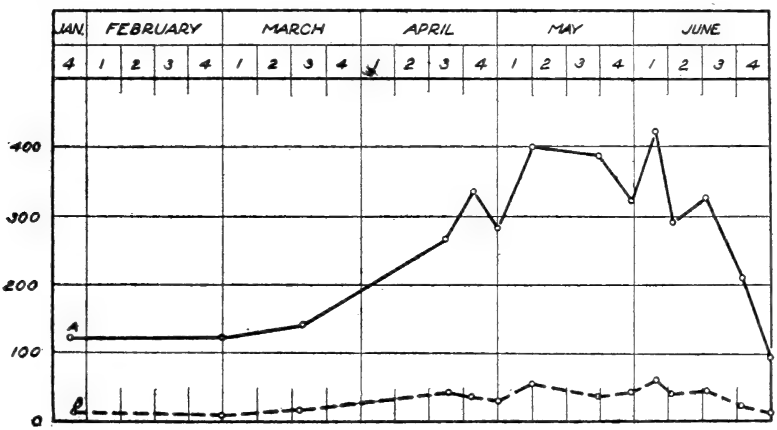

Fig. 18.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota in 1914. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water.

In 1915 (fig. 19) the vernal increase of ash did not begin as early as that of the organic matter and it declined more promptly following the maximum; as a result the curve for ash possesses a sharp-pointed peak and that for the organic matter has a peak with a much broader outline as well as a small secondary peak in the middle of May. Up to the middle of May the increase in organic matter was due largely to copepods and this was followed by a marked rise in the number of diatoms with a consequent increase in ash. Following this the diatoms declined while the organic matter remained high as a result of the increase in the number of crustacea.

During the latter part of April, 1916 (fig. 20), there was a small increase in the organic matter which was accompanied by a decrease in ash. This increase in the organic matter was due to a rise in the number of Cyclops and Microcystis, both of which possess a relatively low percentage of ash. The ash and organic matter rose simultaneously about the middle of May and the former declined rapidly during the latter part of the month, thus making a sharp peak in this curve; but the organic matter remained high during this time and rose to a maximum at the end of the first week in June, so that this curve is characterized by a broad apex covering this period. One other difference may be noted here; there was a marked decline in the ash during the second week of October to which no similar decrease in organic matter corresponded.

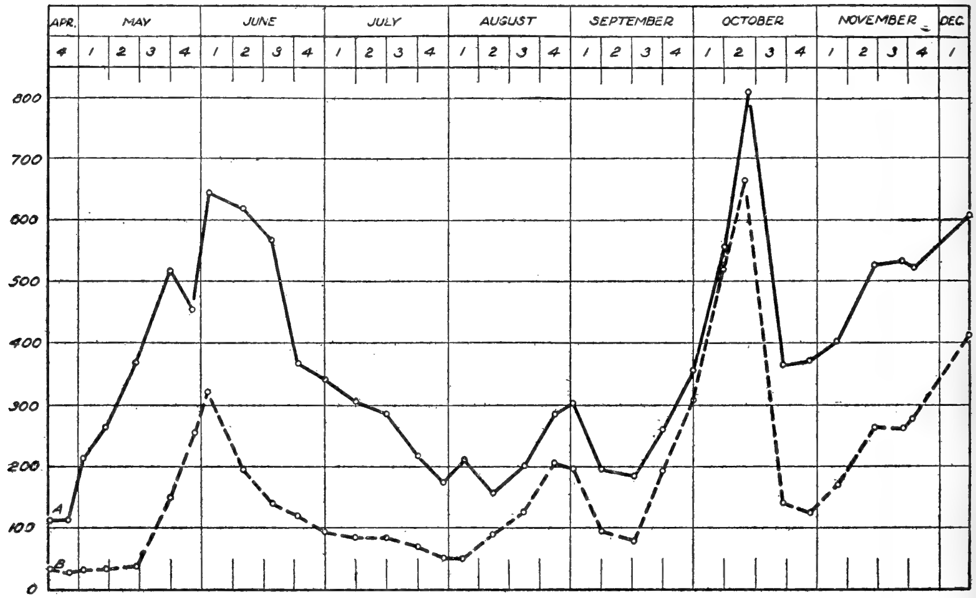

Fig. 19.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota in 1915. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water.

In 1917, the curve for ash shows a prominent peak about the first of May, but the organic matter shows a steady increase following this date instead of a decline similar to the ash. The increase in the organic matter during May was due chiefly to an increase in the crustacea and Aphanizomenon; these forms yield a much smaller percentage of ash than the diatoms which produced the rise in late April and early May.

In general, then, whenever the increase in organic matter is due to the crustacea, the rotifers, and the algae, exclusive of the diatoms, the accompanying rise in the ash is relatively small; but when the diatoms

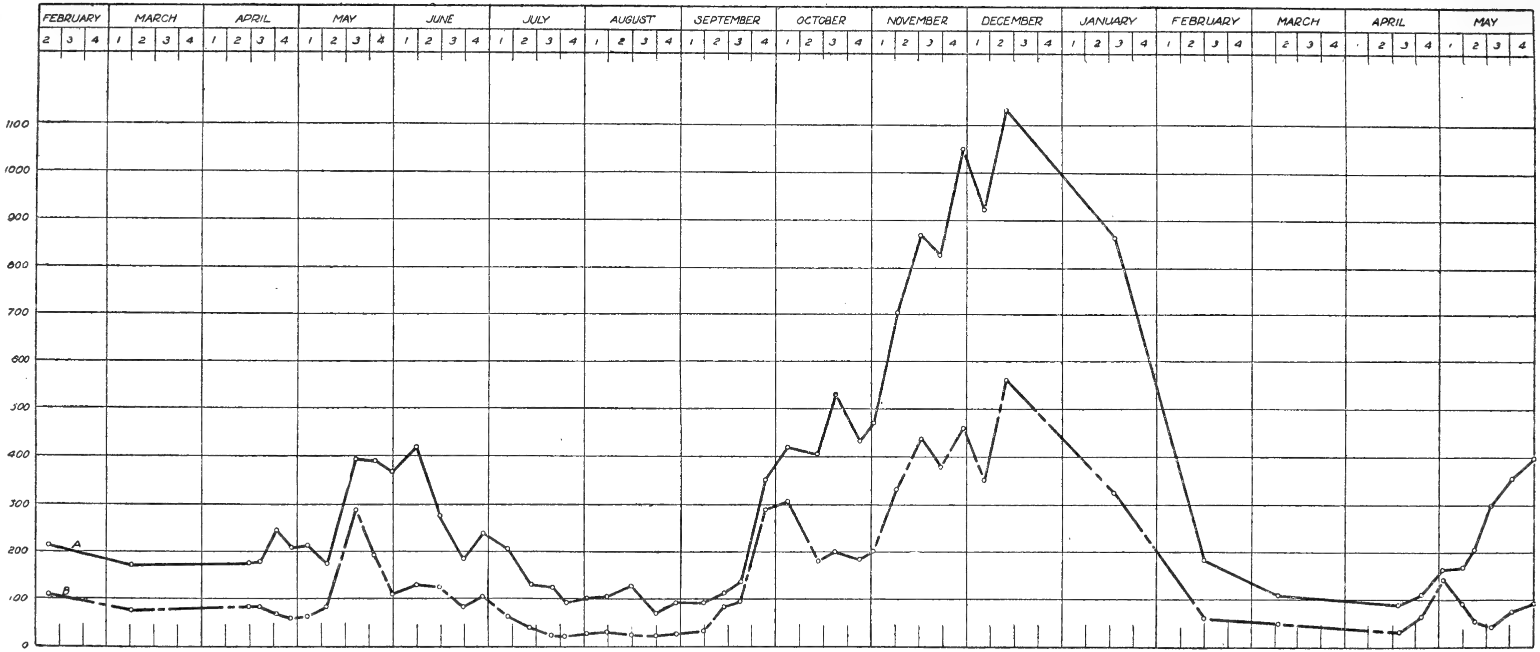

Fig. 20.—The quantity of dry organic matter and of ash in the net plankton of Lake Mendota from February, 1916, to May, 1917. Curve A represents the organic matter and curve B the ash. The amounts are indicated in milligrams per cubic meter of water. See table 43.

play the predominant rôle, the increase in ash is correspondingly marked because their silicious shells make a very substantial contribution to the ash.

Constituents of the Ash

Silica (SiO_2). Quantitative determinations of the silica were made for substantially all of the samples and the results are indicated in the general table (No. 43, p. 202); a summary of the results is given in table 14 (p. 190). The latter table shows that the maximum percentages of silica for the five full years ranged from 31.6 per cent of the dry weight of the sample in some material collected in 1912 to 37.2 per cent in another sample secured in 1915; that is, in three of the five complete years samples were obtained in which the silica constituted more than a third of the dry weight of the net plankton, while in the other two years the maximum percentages fell only a little below one-third. In 1911 the highest percentage of silica was found in August, at which time a crop of diatoms predominated; in 1912 and in 1915 the highest percentage was found in material collected in October, while in 1913 it was noted in December and in 1916 in September. The smallest percentage of silica noted for the entire series of net catches from Lake Mendota was found in sample No. 314 which was collected on June 30-July 3, 1913. The mean percentage for the complete years was lowest in 1911 and highest in 1915.

In 1914 and in 1917 the observations were discontinued on July 2 and June 1, respectively, and they show much smaller maximum percentages of silica than the complete years, more especially the former. This is accounted for by the fact that the largest crops of diatoms come in late summer as in 1911, or in the autumn or early winter as in the other four full years. The mean percentage of silica for 1914 is very much lower than those of the complete years, but that of the part year 1917 is somewhat higher than that of 1911, but distinctly lower than those of the other four full years.

A comparison of the mean percentages of ash and silica for the complete years shows that the latter is the most important constituent of the ash. In general the mean percentage of the silica comprises about half or more of the mean percentage of ash. This does not hold true for the individual samples, however, because there is a wide variation in the proportion of silica in the ash; that is, the former comprised as little as one twenty-fifth of the ash in one sample and more than four-fifths in another. It is derived mainly from the diatoms of the net plankton so that the amount is smallest when the diatoms are scarcest and largest when they are most abundant. The silica, in fact, serves as a good index of the relative abundance of diatoms in the samples. Thus, with the exception of 1911 when the maximum amount of silica was found in

August, the highest percentages of this substance were found in spring and in autumn, the latter always exceeding the former, and the lowest percentages were noted in summer and in winter.

The difference between the mean percentage of ash and the mean percentage of silica for the various years is shown in the last column of table 14. This difference represents the other inorganic constituents of the ash; it was smallest in 1912 and largest in 1917. The maximum range of variation was from 3.7 per cent in one sample of 1914 to 27.0 per cent in one sample of 1915. The general range, however, was much smaller; in only four samples out of 184 did the difference between the percentage of ash and the percentage of silica fall below 5.0 per cent and in only 23 did it go above 15.0 per cent. Of the latter, 12 were found in 1916 and 7 in 1917.

Further analyses were made on the ash of 27 samples of net plankton and the results of these analyses are shown in table 15, p. 190.

Iron and Alumina (Fe_2O_3 and Al_2O_3). Quantitative determinations of the iron and alumina were made on the ash of 16 samples. An attempt was made to obtain quantitative results for them separately but their amounts were so small in the material available for the work that the analyses did not yield concordant results; hence this effort was discontinued and they have been recorded together in the table. The iron and alumina constituted a minimum of 0.26 per cent of the dry weight of the sample in one instance and a maximum of 2.18 per cent in another sample. In 10 samples the amount did not exceed one per cent while the mean for the 16 analyses is a little less than one per cent.

Manganese (Mn_3O_4). The manganese was determined in the ash of 12 samples for the purpose of ascertaining how extensively the plankton organisms make use of this element. Bradley[4] found that the tissues of fresh-water mollusks belonging to the genera Anodonta and Unio contain, on an average, slightly more than one per cent of manganese. Since some of the plankton organisms included in these net catches serve as food for these bivalves a few analyses were made in order to determine the relative importance of this material as a source of this element. No measurable amount was found in 5 of the samples; in 5 others the amount of Mn_3O_4 ranged from 0.30 to 0.39 per cent of the dry weight of the material, while in the other two it was larger, namely, 0.75 and 0.77 per cent. Some of the net plankton, therefore, may serve as a source of manganese for other organisms, but the amount available in this material is relatively small.

Phosphorus (P_2O_5). The phosphorus was determined in 21 samples of ash. It was present in all of them and varied in amount from a minimum of 0.25 per cent of the dry weight of the material to a maxi-

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[4] Jour. Biol. Chem., Vol. 3, pp. 151-157; Vol. 8, 1910-11, pp. 237-249.

mum of 2.54 per cent, when calculated as P_2O_5. The average percentage for the 21 determinations is 1.44 per cent. Schuette[5] reported the elementary phosphorus as varying from 0.91 to 1.57 per cent in 6 samples of plankton which he analyzed.

Sulphur. The quantity of sulphur was determined by Schuette in 8 samples of plankton; 5 of these samples consisted of a mixture of plant and animal material, two were blue-green algae, and one was the crustacean *Daphnia pulex.* One of the mixed samples contained only 0.42 per cent of sulphur, while the other 7 samples possessed substantially the same percentage, namely, from 0.60 per cent to 0.64 per cent.

Calcium (CaO). Calcium determinations were made on the ash of 23 samples. The amount varied from a minimum of 1.03 per cent to a maximum of 6.8 per cent; the average for the 23 samples was 3.2 per cent. The plankton crustacea, more particularly the Daphnias, show a rather large variation in the amount of calcium which they possess and this probably accounts for the marked differences in the net plankton.

Magnesium (MgO). The analyses of 24 samples show that the magnesium is smaller in amount than the calcium. The magnesium in these samples varied from a minimum of 0.17 per cent to a maximum of 1.95 per cent. The average for the series was 0.81 per cent, or only about a quarter as large as the calcium.

Results of Other Investigators

Apstein[6] made ash determinations on the net plankton of several fresh-water lakes. In the material from Dobersdorfersee he found a marked variation in the percentage of ash during the different months of the year; it ranged from a minimum of 6.9 per cent of the dry material in a catch which was obtained on August 31, 1891, to a maximum of 45.0 per cent in a catch taken on October 4, 1891. In Plöner See a minimum of 7.1 per cent was found on September 25, 1891, while on November 6 a net catch yielded 66.6 per cent of ash. The lowest percentage of ash was found in net material collected in Molfsee on August 18, 1895, namely, 2.9 per cent.

The variations in the percentage of ash in the net plankton of Lake Mendota were of about the same order of magnitude as those noted by Apstein for Dobersdorfersee, that is, from a minimum of 5.6 per cent to a maximum of 48.3 per cent. The net plankton of Molfsee yielded a smaller percentage of ash than that of Lake Mendota and the material from Plöner See gave a larger percentage.

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[5] Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 602-3.

[6] Das Suesswasserplankton. Kiel und Leipzig, 1896, p. 200.

In some samples of marine net plankton which were obtained during the winter months when diatoms were abundant, Hensen[7] found that the ash constituted from 52.1 per cent to 54.7 per cent of the dry material. The ash of Ceratium amounted to 3.9 per cent of the dry weight; one sample of copepods contained only 0.45 per cent of ash and another consisting of Calanus yielded 3.78 per cent. *Salpa runcinata* gave 14.6 per cent of ash.

Brandt[8] gives results for the chemical analyses of nine samples of marine net plankton obtained in Kiel bay between September 21, 1892, and September 28, 1893. His data are given in table 51 (p. 218) in the series marked II to X. The nitrogen in these samples varied from a minimum of 1.8 per cent to a maximum of 5.6 per cent of the dry material; thus, the crude protein ranged from 11.2 per cent to 35.0 per cent, representing a little more than a threefold variation in percentage. This marine material yielded from 1.5 per cent to 8.7 per cent of ether extract and from 8.5 per cent to 61.4 per cent of ash; the ash contained from 4.5 per cent to 51.2 per cent of silica.

In the net samples from Lake Mendota the minimum percentage of nitrogen was 3.9 per cent of the dry sample (table 43) and the maximum was 9.9 per cent. In terms of crude protein these results represent 24.5 per cent and 62.3 per cent respectively. The minimum for nitrogen and crude protein, therefore, is more than twice as large in the Mendota material as in the marine catches recorded by Brandt, while the maximum in the former is nearly twice as large as that in the latter. The ether extract in the net samples from Lake Mendota ranged from 2.7 per cent to 20.0 per cent; both of these percentages are larger than the minimum and maximum given by Brandt. The minimum and maximum percentages of both ash and silica were larger in the marine material than in the Mendota net samples.

On the basis of these chemical analyses, then, the net plankton of Lake Mendota represents a better class of food material than the marine net plankton, in so far as protein and fat are concerned, because the former contains a larger percentage of these two excellent food substances; in addition also, the percentage of ash is not as large in the fresh-water as in the marine net plankton.

Organisms Responsible for Periodic Increase

During the five years of these obesrvations the vernal increase in the organic matter of the net plankton was due to a rise in the number of diatoms. In three of these years all of the limnetic forms, namely, Melosira, Tabellaria, Fragilaria, and Asterionella, showed a distinct

[7] Fünf. Ber. Kom. z. wissen. Untersuch. d. d. Meere, 1887, pp. 1-107.

[8] Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, pp. 45-90.

increase in number at this season; but in the other two years the rise was due chiefly to a single form, such as Tabellaria in 1913 and Asterionella in 1914, while the other forms showed only a relatively small increase at this time.

Following the vernal period the green and blue-green algae become the predominant phytoplanktonts and they usually hold this position until autumn. In 1913, however, the marked rise in the organic matter in late July and early August (fig. 7) was due to two organisms, one of which was a diatom; both Ceratium and Melosira began to increase in numbers during the first week in July. The former reached a maximum of 25,800,000 per cubic meter of water on July 21 and the latter rose to 29,900,000 filaments per cubic meter on August 4. After the latter date both declined rapidly in numbers, corresponding to the decline in the organic matter.

In the curve for 1912, Ceratium was responsible for the peak which appeared in late July (fig. 7). Its average number in the upper 10 meters was 15,665,000 individuals per cubic meter of water on July 30. The peak shown for the first week in September was produced by an increase in the diatoms, Melosira being the chief form while Fragilaria was second in importance. The former rose from 1,077,000 per cubic meter on July 30 to 17,639,000 on September 2 and the latter increased from 74,000 to 4,548,000 filaments per cubic meter during the same period. The secondary peak shown in the first week of September, 1915, was produced by an increase of two diatoms, namely, Fragilaria and Tabellaria, the former being the more important factor.

The five autumnal maxima shown in figures 7 and 8 were due chiefly or wholly to marked increases of the diatoms. In 1911 there was a large increase of Melosira in late September and of Fragilaria in October corresponding to the rise in the quantity of organic matter. Among the blue-green algae also there was a distinct rise in the number of colonies of Microcystis from the last of September to the middle of October. The Cyclops population was also larger during the latter half of October.

In 1912 increases in Melosira, Tabellaria, and Fragilaria were correlated with the autumn rise of the curve for organic matter. Coelosphaerium also increased in numbers during the second half of September and the number remained fairly high until the last of October. The first peak in the autumnal increase of organic matter in 1913 was correlated with an increase in the numbers of Fragilaria and Melosira, but the second peak came at a time when these two forms were declining in numbers. In fact, it is difficult to account for the second peak in October by means of the numerical data because the only increases in numbers at that time were relatively small ones in Microcystis, Coelosphaerium, and *Daphnia hyalina.* The December peak of 1913 was correlated with a rise in Fragilaria.

In 1915 the peak noted in October was correlated with a rise in Fragilaria, while the increase in organic matter during November and December corresponded to a gradual increase in the numbers of Tabellaria and Stephanodiscus. Asterionella and Stephanodiscus were responsible for the October peak in the curve for 1916.

The summer and winter minima correspond to relatively small numbers of the various organisms in the net plankton. In late spring or early summer the diatoms decline to a minimum number and the green and blue-green algae then become the predominant phytoplanktonts. While the light and temperature conditions are favorable for these forms during the summer, yet they do not develop in sufficient abundance in Lake Mendota to produce a maximum comparable to the maxima of the diatoms in the spring and in the autumn. In winter both temperature and light conditions are unfavorable for the growth of the phytoplankton; the latter is especially unfavorable after the lake becomes covered with ice and snow. As a result the numbers of these organisms decline as the winter season advances.

The numerical results obtained in this investigation show more or less pronounced maxima of crustacea and rotifers in spring and autumn and Birge [9] also noted these two periods of maxima, with an additional one in July, in his studies on the crustacea of Lake Mendota. Just how prominent a part these two groups of organisms play in increasing the quantity of organic matter in the net plankton is difficult to determine. When allowed to settle, the net samples taken during the spring and autumn maxima show a distinct preponderance of algal material; consequently these maxima have been attributed chiefly to the latter forms. Thus, the large growths of phytoplankton at such times tend to mask the increases shown by crustacea and rotifers.

Numerically, of course, the phytoplanktonts are more abundant, but a comparatively small increase in the number of the larger crustacea is equivalent to a very marked increase in the algae so far as weight is concerned. Several determinations show that it takes 225 individuals of Cyclops of mixed sizes to yield one milligram of dry material; of the other plankton crustacea it takes 135 Diaptomi, 140 *Daphnia retrocurva,* and 75 *Daphnia hyalina* to yield this amount of dry material. Among the rotifers it takes about 125 colonies averaging one hundred individuals each, or 12,500 individuals of *Conochilus volvox,* to yield one milligram of dry material, while it requires only about one-tenth as many, or 1,250, large specimens of Asplanchna for this amount. About 650 colonies of Volvox of mixed sizes yield a milligram of dry

[9] Trans. Wis. Acad. Sci., Arts, and Let., Vol. XI, 1898, pp. 274-448.

material, but it requires about one million individuals of Euglena. One milligram of dry material contains about 30 million cells of Microcystis, while Whipple and Jackson[10] found that it takes about 2.8 million cells of Asterionella to weigh this amount. These results show clearly that a relatively small rise in the number of crustacea is equivalent to a very marked increase in numbers in the smaller forms so far as the yield of dry material is concerned.

The numerical results show a wide variation in the numbers of the different forms, ranging from two or three individuals per liter of water in some forms to several thousand in others, or even to more than 30 million in one of the members of the nannoplankton. Such a wide range in numbers makes it impossible to construct diagrams by the usual methods for the purpose of illustrating the distribution of the various organisms, so that it has been necessary to use the spherical type of curve in order to get all of the forms on the same diagram. Lohmann[11] used this type of curve for the graphical expression of some of his results on marine plankton and he has discussed the method of constructing such curves. He prepared a table, based on a value of $1 = 0.25$ mm., showing the radii of spheres by half millimeters, which represent numbers from 32 individuals up to 864 million individuals; his table is incorporated in this report as table No. 52 (p. 219). The formula for determining the radius in a given instance is $R = \sqrt[3]{\frac{V}{4.19}}$ in which V equals the volume of the sphere, or in this case the number of individuals to be represented by the sphere. In order to simplify the formula, Lohmann has used 4 as a denominator instead of 4.19 since the omission of the fraction 0.19 makes only a very small difference, amounting to but 1.5 per cent in a number as large as 800 million.

Lohmann's diagram illustrating the method of construction of the spherical curve is shown in figure 21. The time element is platted along the abscissa, which also serves as the equatorial plane of the series of spheres. The radii of the spheres representing the various numbers of a given form are platted as ordinates at the proper time intervals so that the central point of each sphere is situated at the intersection of the radius and the abscissa. A circle of proper radius drawn around this point of intersection represents a cross section of the sphere. In order to complete the curve the outer ends of the radii representing ordinates are connected by lines. Only the radii above the abscissa may be used in constructing a curve, or both those above and those below are connected if a symmetrical figure is desired.

[10] Jour. N. E. Waterworks Assoc., Vol. 14, 1899, pp.1-25.

[11] Wissensch. Meeresuntersuch. K. Kom., Abt. Kiel, Bd. 10, 1908, pp. 192-194.

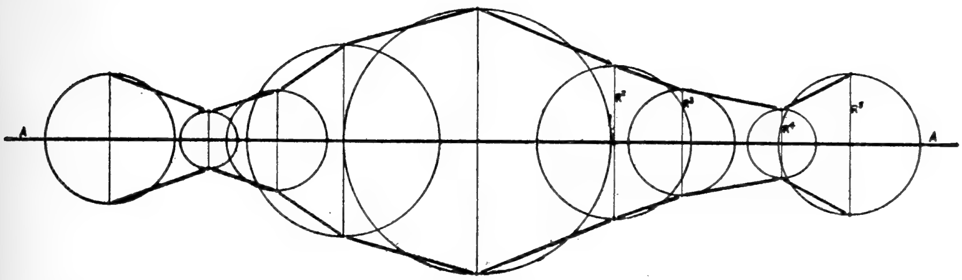

Fig. 21.—Diagram illustrating the construction of the spherical type of curve.

The curves in figures 22 to 26 represent the number of individuals or colonies of the various organisms in the net plankton per cubic meter of water; this is a rather large unit of volume, but a smaller one would make it difficult to show some of the forms which are present in relatively smaller numbers, such as Diaptomus and Daphnia, for example. The scale used in these curves is the same as that employed by Lohmann, namely, 1 = 0.25 mm., and his table has been used to ascertain the lengths of the radii. For purposes of comparison with the enumerations of the net planktonts, the results obtained for the organic matter are also shown by this type of curve; it was necessary to make use of a larger volume of water for the organic matter in order to bring out more clearly the various changes in quantity. These curves for the organic matter, therefore, show the number of milligrams of dry organic matter per 10,000 cubic meters. Figures 7 and 8 indicate the variations in the quantity of the organic matter much better and these diagrams should be considered along with figures 22 to 26. The printed figures showing the numerical results for the net plankton are approximately one-fourth as large as the original diagrams.

In 1911 (fig. 22) numerical work was begun on the net plankton in April but the gravimetric and chemical study did not begin until the first of June. The increase of organic matter in the second week of June was correlated with an increase in Ceratium and slight increases in the number of diatoms, while the August rise of the organic matter corresponded to marked increases in Ceratium and Melosira. In the autumn of 1911, there was a marked rise in the number of diatoms, especially Melosira and Fragilaria, with an increase in the organic matter at this time.

In 1912 (fig. 23) there was no marked rise in any one form correlated with the increase in organic matter during the month of April, but several forms were present in considerable abundance at this time. A rise in the organic matter about the first of June accompanied an increase in the numbers of Ceratium and Melosira, and a second rise during the first week of August corresponded to increases of Melosira and Fragilaria. The September rise of organic matter accompanied a marked increase in the diatoms as well as a distinct rise in the number of Coelosphaerium.

The diagram for 1913 (fig. 24) shows that a large crop of Tabellaria in May yielded a large amount of organic matter, while increases in Ceratium and Melosira during the last week in July and the first week in August correspond to an expansion in the curve for organic matter at this time. Fragilaria was the chief organism responsible for the autumnal rise.

Increases in the numbers of diatoms and of Microcystis in May, 1915 (fig. 25), were accompanied by an increase in the organic matter, while a large increase of Aphanizomenon was found in June, which helped to keep the organic matter high when the other two forms declined in numbers. The October maximum of this year corresponded to a rise in Fragilaria. In 1916 (fig. 26) the peak during the last half of May and the first half of June was accounted for largely by the increase in the diatoms during this interval. The rise in the amount of organic matter in the autumn of 1916 was correlated in time with increases in the numbers of the various diatoms; some of these forms together with Aphanizomenon prolonged the increased quantity of organic matter until the middle of December.

Explanation of the Net Plankton Diagrams

Figures 22 to 26 show the numerical results obtained for the samples of net plankton; the spherical type of curve has been used in these diagrams. The curves show the number of individuals or colonies per cubic meter of water. In order to bring out the variations in the quantity of organic matter more clearly by this type of diagram, that curve was platted on a different scale; it shows the number of milligrams of dry organic matter in 10,000 cubic meters of water.

The species of Cladocera and Rotifera were enumerated separately, but it was not practicable to indicate each species in the diagrams. The following abbreviations have been used for the different forms:

DI = Diaptomus, CY = Cyclops, NA = nauplii, DA = Daphnia, RO = Rotifera, CE = Ceratium, MI = Microcystis, CO = Coelosphaerium, AP = Aphanizomenon, AN = Anabaena, LY = Lyngbya, SM = Staurastrum, ME = Melosira, TA = Tabellaria, FR = Fragilaria, AS = Asterionella, ST = Stephanodiscus, OM = organic matter.

APR			MAY				JUNE				JULY				AUG				SEPT				OCT			
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

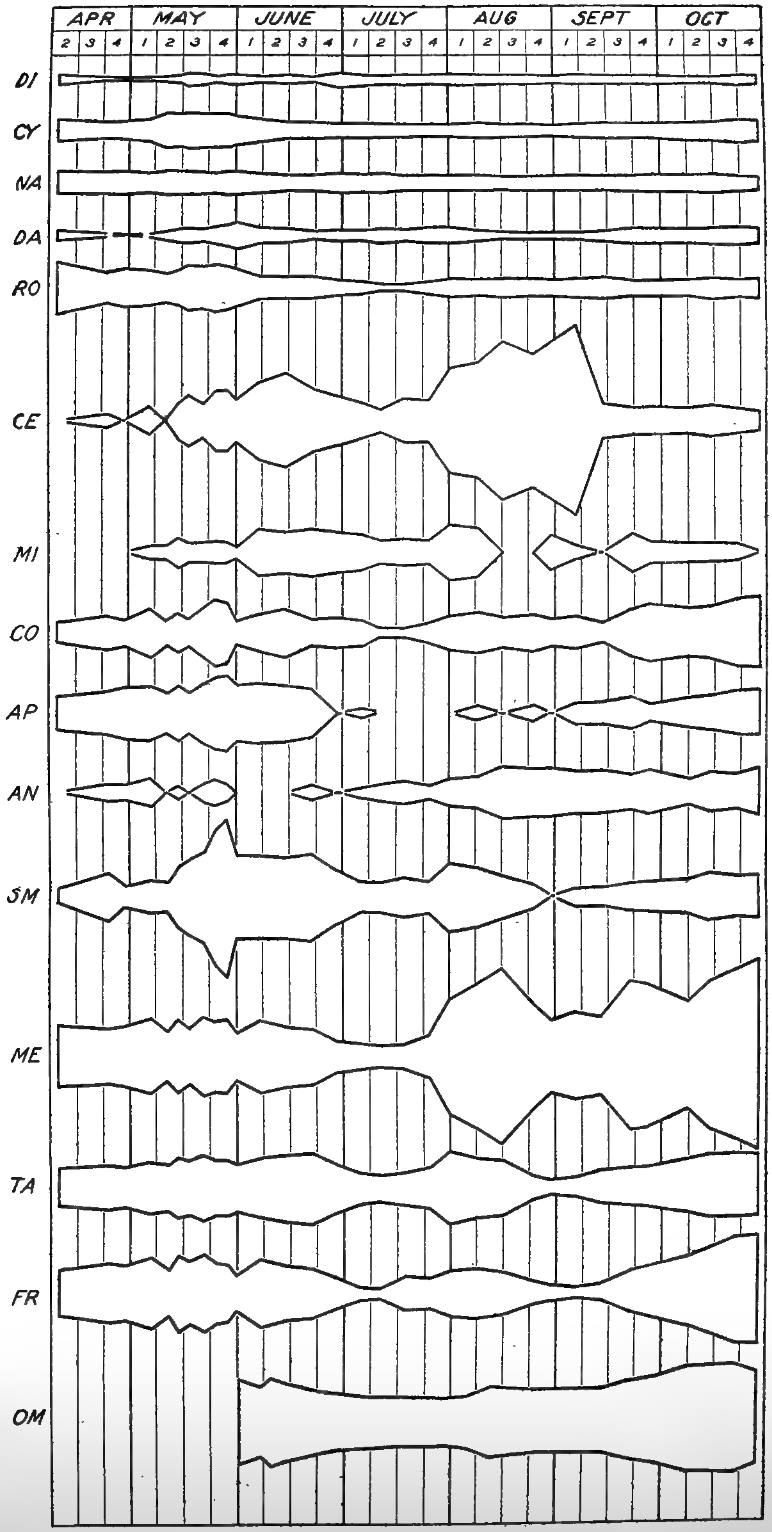

Fig. 22.—Diagram showing the numerical results for the net plankton of Lake Mendota in 1911. The various planktonts are indicated in the explanation on page 60.

APR				MAY				JUNE				JULY				AUG				SEPT				OCT			
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

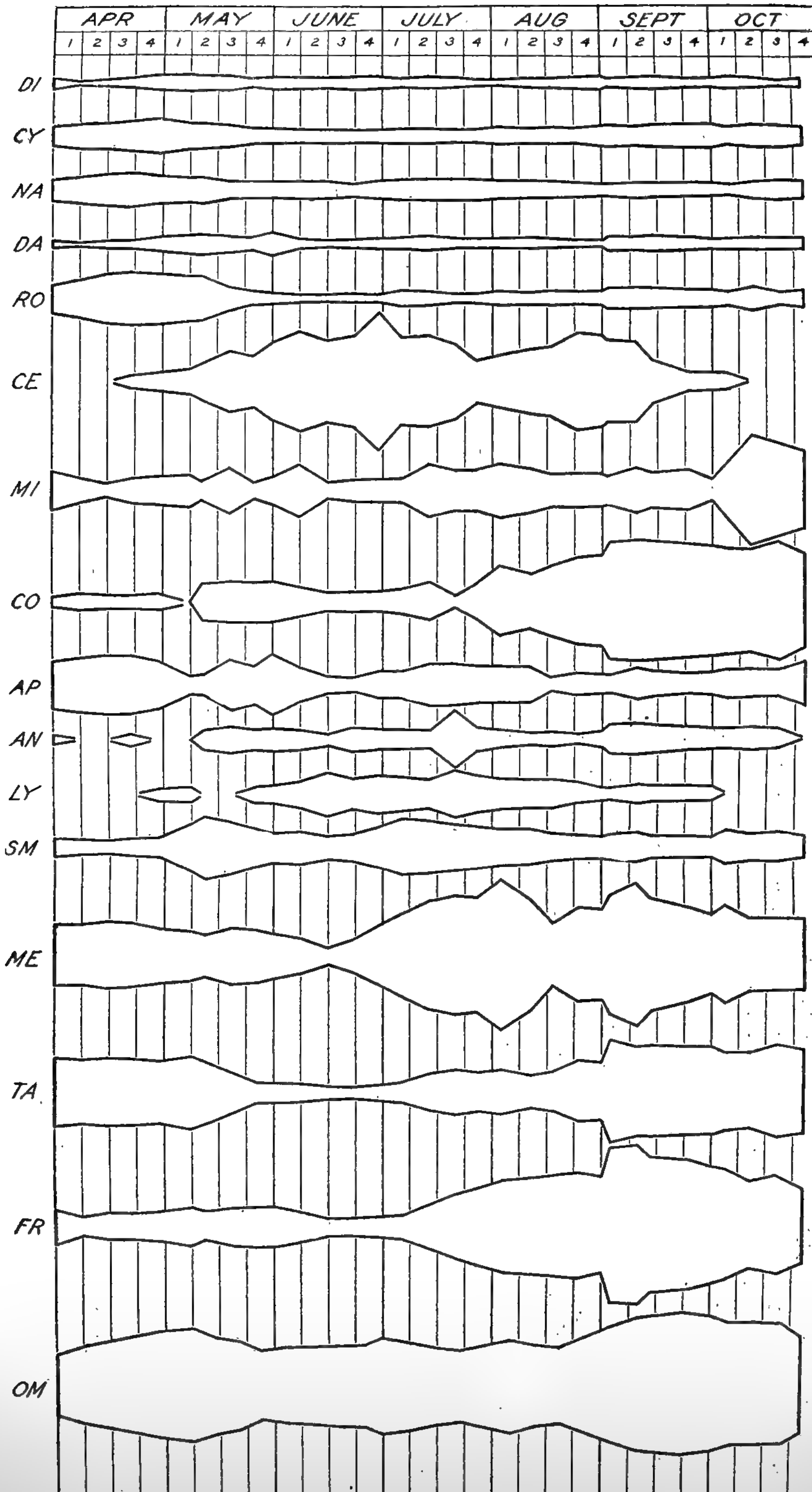

Fig. 23.—Diagram showing the numerical results for the net plankton of Lake Mendota in 1912. The various forms of plankton organisms are indicated in the explanation on page 60.

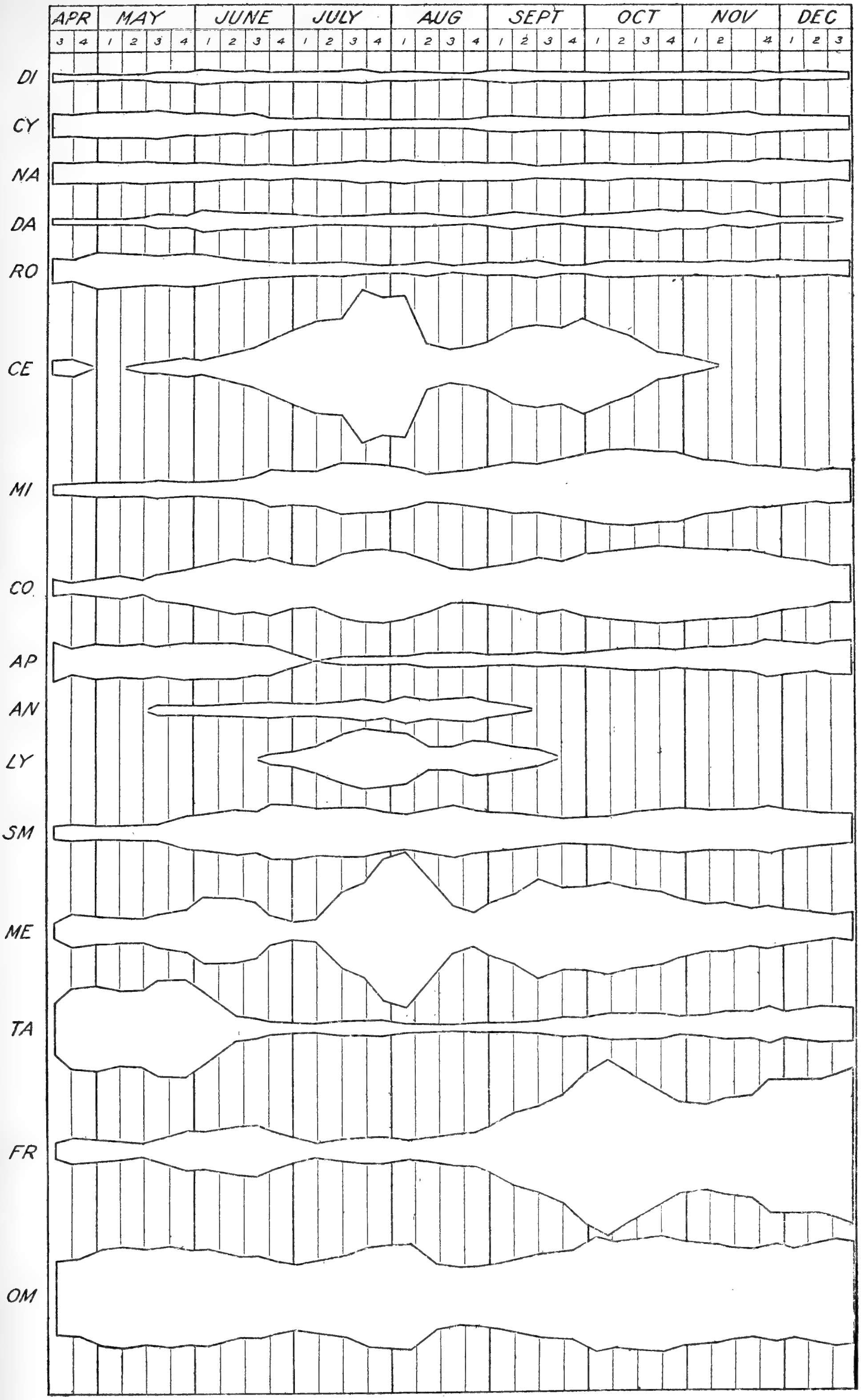

Fig. 24.—Diagram showing the numerical results for the net plankton of Lake Mendota in 1913. The various forms of plankton organisms are indicated in the explanation on page 60.

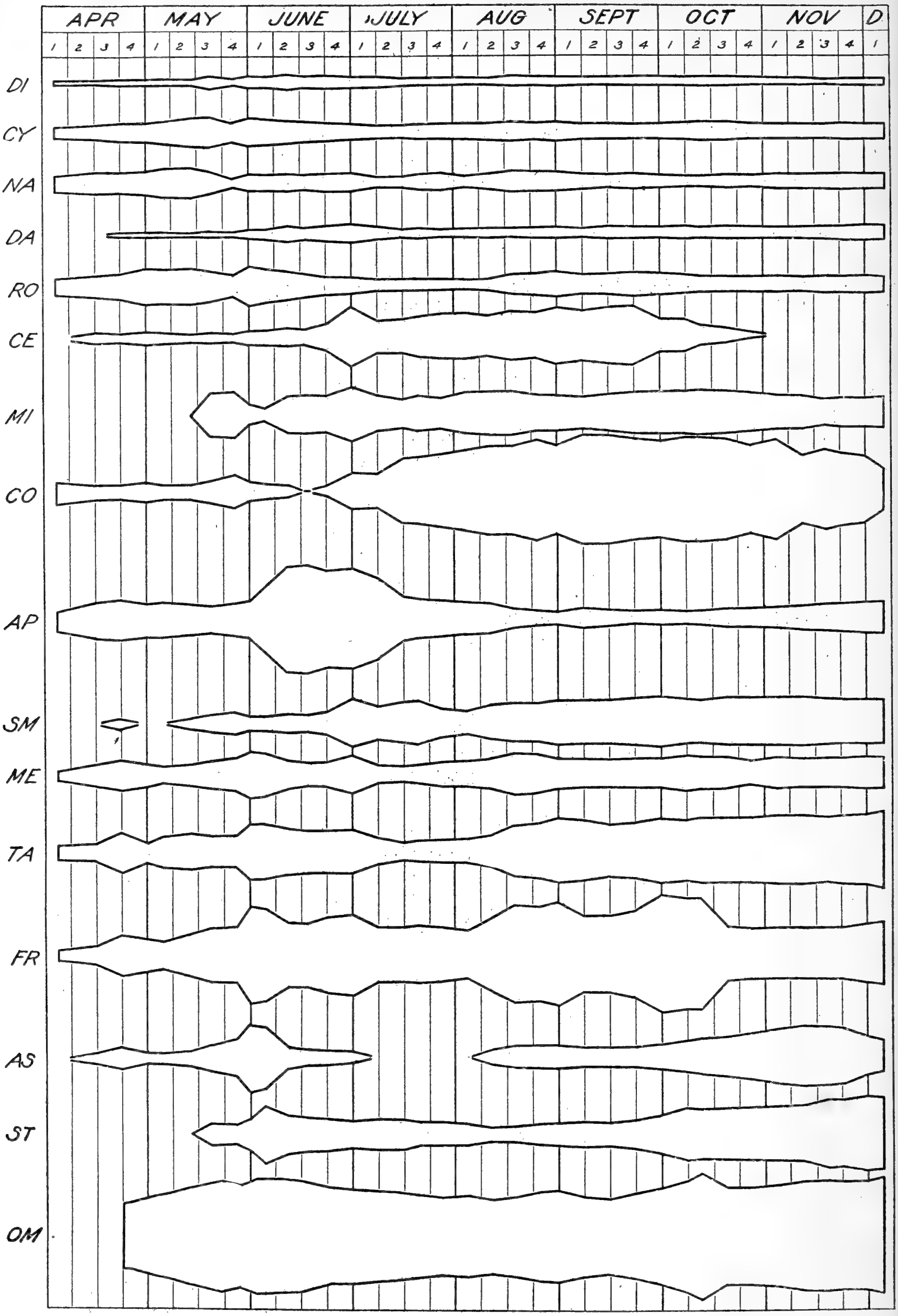

Fig. 25.—Diagram showing the numerical results for the net plankton of Lake Mendota in 1915. The various forms of plankton organisms are indicated in the explanation on page 60.

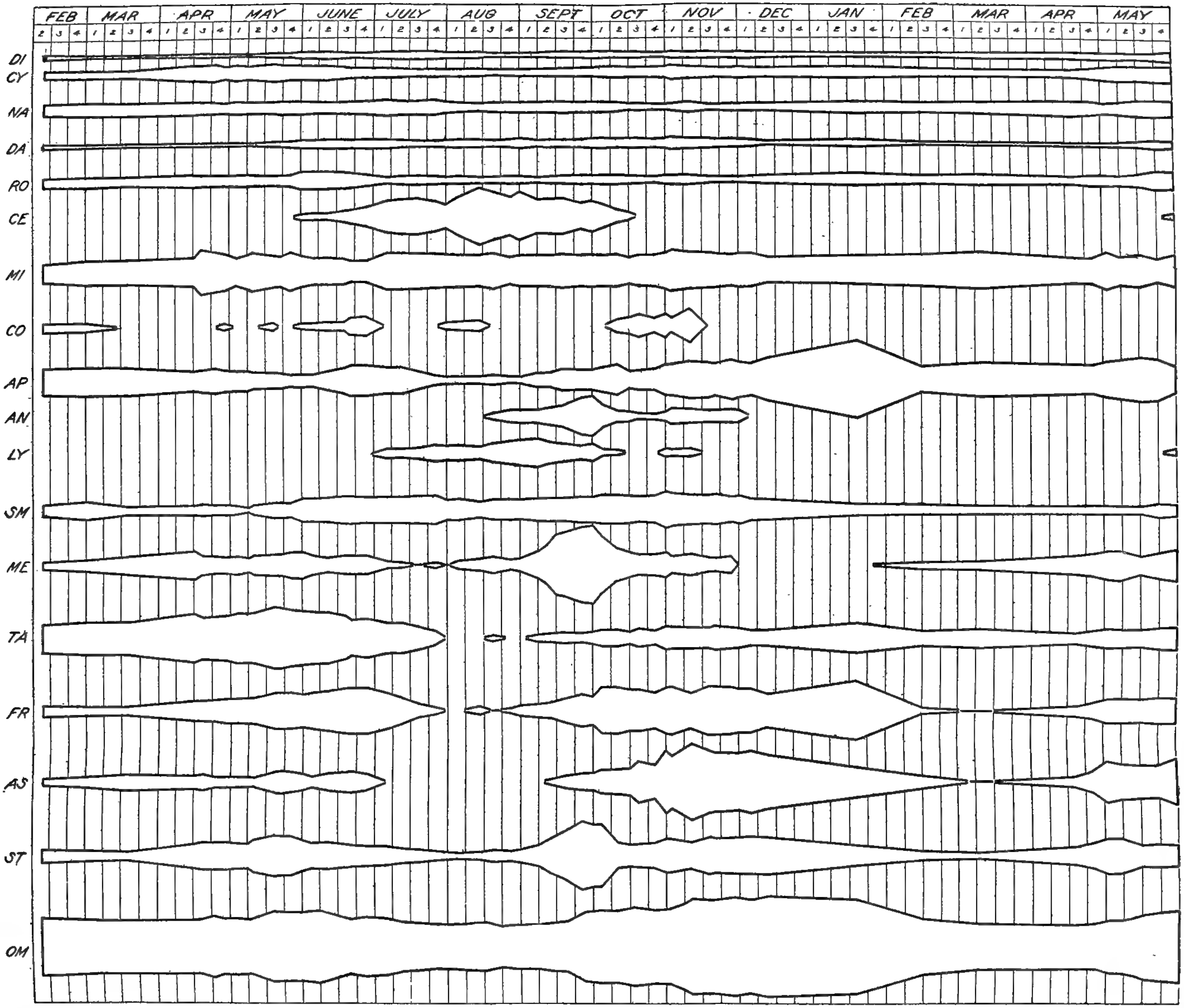

Fig. 26.—Diagram showing the numerical results for the net plankton of Lake Mendota in 1916 and 1917. The various planktonts are indicated in the explanation on page 60.

CHAPTER III

THE NANNOPLANKTON OF LAKE MENDOTA

The term nannoplankton, meaning *dwarf* plankton, was employed by Lohmann [1] in 1911 to designate the very minute plankton organisms. He set an arbitrary maximum diameter of 25μ for the members of this group. Many of the fresh-water organisms which are so small that they readily pass through the meshes of the finest bolting cloth, exceed this dimension, so that the usefulness of the term would be very greatly restricted if it should be applied only to forms whose maximum diameter is not greater than 25μ. Therefore, since these organisms are grouped together on a purely artificial and arbitrary basis, a broader meaning is applied to the term nannoplankton in this report in order to make it more useful to planktologists. As used here, it is applied to the assemblage of plankton organisms which are so small that they readily pass through the meshes of the finest silk bolting cloth and are thus lost regularly by the net. Such an extension of the meaning makes the term much more useful and gives, at the same time, a practical basis for the separation of the total plankton into two definite classes, namely, the net plankton and the nannoplankton. As used in this report, the term nannoplankton is the equivalent of what has been called the centrifuge plankton, but the word nannoplankton is a more convenient term as well as a more euphonious one.

In the Wisconsin lakes that have been investigated so far, the assemblage of organisms which passes through the meshes of the net is made up of rhizopods, flagellates, and ciliates among the animals, and of various algae, such as Ankistrodesums, Oocystis, Sphaerocystis, Aphanocapsa, and species of diatoms belonging to the genera Stephanodiscus, Cyclotella, and Cocconeis. Certain forms are lost by the net accidentally, such as rod-shaped organisms which strike the net endwise and so are enabled to pass through, young individuals or colonies, and fragments of the colonial forms. In general, however, the great bulk of the material which was obtained with the centrifuge in these investigations consisted of the minute individuals that were small enough to be lost regularly by the net.

Quantitative studies on the nannoplankton of Lake Mendota were begun with the large De Laval centrifuge on April 21, 1915, and were

[1] Internat. Revue, Bd. IV, 1911, pp. 1-38.

continued until June 1, 1917. With the exception of January, 1916, observations were made every month during this period, and runs or catches were made twice a week in most instances during the time that the lake was free of ice, i. e., from April to December. In 1915 the centrifuge runs totaled 65 in number, in 1916 there were 69, and in 1917 there were 11 up to June 1 when the observations were discontinued. The number of runs and the amount of water centrifuged each year are shown in table 3 (p. 182). The total for Lake Mendota for the three years was 145 runs in which 179,506 liters of water were centrifuged, an average of about 1,240 liters for each run.

Effect of Centrifuging

The centrifuge bowl has an inside diameter of 24 centimeters and the maximum speed at which it can be run with safety is 6,000 revolutions per minute. For all of the runs made in these investigations the speed was kept a little below the maximum so that it ranged from 5,600 to 5,800. Experiments showed that this high speed was necessary to remove the organisms effectively; only about 70.0 per cent as much material was obtained at 4,000 revolutions as at 5,800. Taking 5,700 revolutions per minute as the average speed of the centrifuge, the inner surface of the bowl, on which most of the material was deposited, moved at a rate of about 4,300 meters per minute, or 71.6 meters per second.

The material was frequently examined with a microscope in order to ascertain whether the various organisms showed any signs of serious injury as the result of being centrifuged. In general those forms which possess a fairly firm cell wall did not show any evidences of serious injury. Colonies of Pandorina were found intact, for example, and they promptly renewed their normal activities after being centrifuged; while Euglena showed no signs of physical injury, it remained in a contracted state for about an hour before it became active. None of the algae showed any evidences of injury to the cells.

The more delicate forms, such as Amoeba and the monads, appeared in the material in good condition but their numbers were not as large as expected from enumerations made previous to centrifuging. It seems probable, therefore, that some of these organisms suffered more or less damage, but it is not believed that this was sufficient to affect appreciably the total quantity of the centrifuge material nor its chemical composition. Such an injury might result in the loss of some of the cell fluids which have about the same density as water, but the protoplasmic portion would be retained in the centrifuge. A slight loss as the result of more or less injury to these forms, however, would have little significance in the final results because they constitute a relatively small part of the bulk of the centrifuged material.

Three sets of experiments were made in 1915 to determine what effect the centrifuging process had on the chemical composition of the material. The results of these tests are shown in table 16, p. 191. Net plankton, consisting largely of algae, was used for the experiments. A fairly large catch of plankton was obtained by means of a net and the material was placed in about two liters of water. The catch was then stirred thoroughly in order to distribute the organisms as evenly as possible and it was divided into two equal parts. One portion was evaporated to dryness directly and used as a standard sample. The other portion was put into about 900 liters of centrifuged water and the material was then recovered with the centrifuge; its subsequent treatment was the same as that given to the regular centrifuge catches.

In samples No. 5108 and No. 5109 Coelosphaerium was the predominant form with Ceratium second; a relatively small portion of the material consisted of Microcystis and several other algae. In samples No. 5120 and 5121 Coelosphaerium was also the most abundant form but there was a very large element of Lyngbya and Microcystis. The bulk of the material in samples No. 5154 and No. 5155 consisted of diatoms, chiefly Melosira and Stephanodiscus. In these catches the blue-green algae were represented mainly by Microcystis with an occasional filament of Lyngbya. These catches also contained a larger proportion of zooplankton than the other two sets; Chydorus and *Anuraea cochlearis* were the leading representatives of this group.

In total organic matter the uncentrifuged material in sample No. 5109 exceeded that in the centrifuged half of the catch by 311.6 milligrams. This difference in favor of the uncentrifuged portion was due to two factors. With such a large amount of material, namely, about 22 grams dry weight, concentrated into a little less than two liters of water, it was difficult to distribute the organisms evenly so that the catch could be divided into two equal portions; experiments have shown also that there is danger of a slight loss of material from the centrifuge whenever the catch exceeds about 10 grams in dry weight. In spite of these unfavorable factors, however, it will be noted that the difference is less than three per cent. In samples No. 5120 and No. 5121 there was a small difference, less than two per cent, in favor of the centrifuged portion of the catch. Sample No. 5154, the centrifuged portion, yielded just 34.0 milligrams less than No. 5155, a difference of less than one-half of one per cent in favor of the uncentrifuged material.

In table 16 the nitrogen and ether extract are indicated in percentages of the dry organic matter in the various samples. The centrifuged and uncentrifuged portions of each set of experiments show substantially the same percentages of these two substances; the differences in each case are no greater than those usually shown by duplicate determinations on a single sample. These results indicate, then, that the proteins and fats in these organisms are not affected quantitatively by the centrifuging process.

Quantity of Material

The amount of material obtained in the various centrifuge catches in 1917 is shown in figure 27. After the samples were evaporated to dryness and the residues were ground up in a mortar, they were placed in vials until needed for the chemical analyses. When arranged in a series these catches illustrated, in a very interesting manner, the changes in the quantity of nannoplankton during the vernal pulse of this year and a photograph of them was taken. Since these vials were of approximately the same diameter, the height to which they were filled by the different samples indicated roughly these changes in quantity. The samples in the first two vials were obtained from 904 and 909 liters of water respectively, while all of the others were obtained from a larger quantity of water, namely, from 1,168 liters to 1,183 liters; the former, therefore, ought to be a little more than 25.0 per cent larger than they are for a direct comparison with the other samples.

Attention may also be called to the fact that this material contains a large proportion of ash, ranging from a minimum of 51.7 per cent in sample No. 718 to a maximum of 64.2 per cent in sample No. 708; that is, somewhat less than half of the dry material consists of organic matter.

For the purpose of indicating more clearly the differences in height two scales marked off in centimeters were included in the photograph. The samples are arranged in chronological order beginning with sample No. 704 (vial No. 1) obtained on February 14, 1917, and ending with sample No. 722 (vial No. 10) secured on June 1, 1917; the intervening numbers and dates are shown in the general table for the nannoplankton catches, No. 44, p. 207. The series includes all of the centrifuge samples collected in 1917, except No. 702 and this one was omitted because some of it had already been used for a chemical analysis when the photograph was taken.

Vial No. 2, containing sample No. 706 collected on March 9, 1917, shows the smallest quantity of material and increasing its volume 25.0 per cent would not make it as large as that of vial No. 3 (sample No. 708), so that there was a distinct increase in material by the latter date, namely, April 18. There followed, then, a substantial increase during the succeeding week, but the most marked increase came between April 25 (vial No. 4) and May 2 (vial No. 5); the material in the

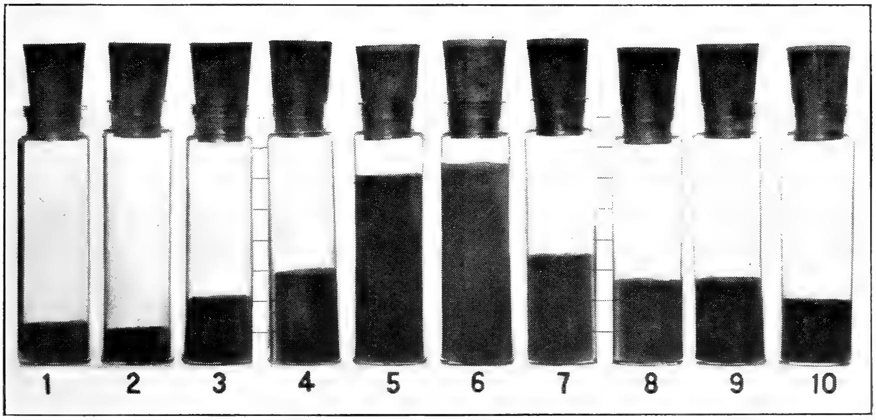

Fig. 27.—Photograph of dry nannoplankton material obtained from Lake Mendota in 1917. Nannoplankton catches 704 to 722, inclusive, table 44.

former reached a height of about 3 centimeters and in the latter about 6 centimeters. The maximum height, fully 6.5 centimeters, was attained in vial No. 6 (sample No. 714); this was succeeded by a rapid decline to a height of only about 3.5 centimeters in vial No. 7 (sample No. 716) during the following week. By the first of June (vial No. 10, sample No. 722) the amount of material was substantially the same as that obtained on April 18 (vial No. 3, sample No. 708).

Organic Matter in the Nannoplankton

In the regular observations on Lake Mendota the material obtained from the two runs of the same week were usually combined into one sample for the chemical analyses. In all there were 35 samples of centrifuge material in 1915 and 41 in 1916; only one run per week was made in 1917, or 11 in all, and these were not combined so that the total number of centrifuge samples amounted to 87. The results of the chemical analyses of the various samples are shown in detail in table 44, p. 207.

The variations in the amount of dry organic matter in the centrifuge plankton are shown in table 17, p. 192. The largest amount, 3,151.5 milligrams of dry organic matter per cubic meter of water, was obtained in sample No. 604 on April 15, 1916, and the smallest amount, 795.2 milligrams, in No. 706 on March 9, 1917. It will be noted that this minimum is distinctly below the minima of the other two years, but the mean amount for the three years shows a striking uniformity, the differences being only a little more than one per cent.

The results for the dry organic matter are shown graphically in figure 28 in which the curves represent the number of milligrams per cubic meter of water that were obtained from the various samples. The first sample obtained in 1915 contained the largest amount of organic matter for that year. It is uncertain whether a larger amount was present before this date or not, but the first sample consisted of two runs, one made on April 21 and the other on April 23, 1915, and the latter produced a larger amount than the former, which indicates that the first sample covered the highest point attained by the nannoplankton in 1915.

A sharp decline in the amount of organic matter was noted during the last week in April and the first week in May, 1915, and the quantity thereafter remained fairly uniform until the middle of June. During the last half of June there was a marked decrease, which was followed by a distinct rise in July. The increase culminated in a peak about the end of the first week in August after which the amount fell rapidly, reaching the lowest point of the year about the middle of August. During the succeeding two months there was a gradual increase and there-

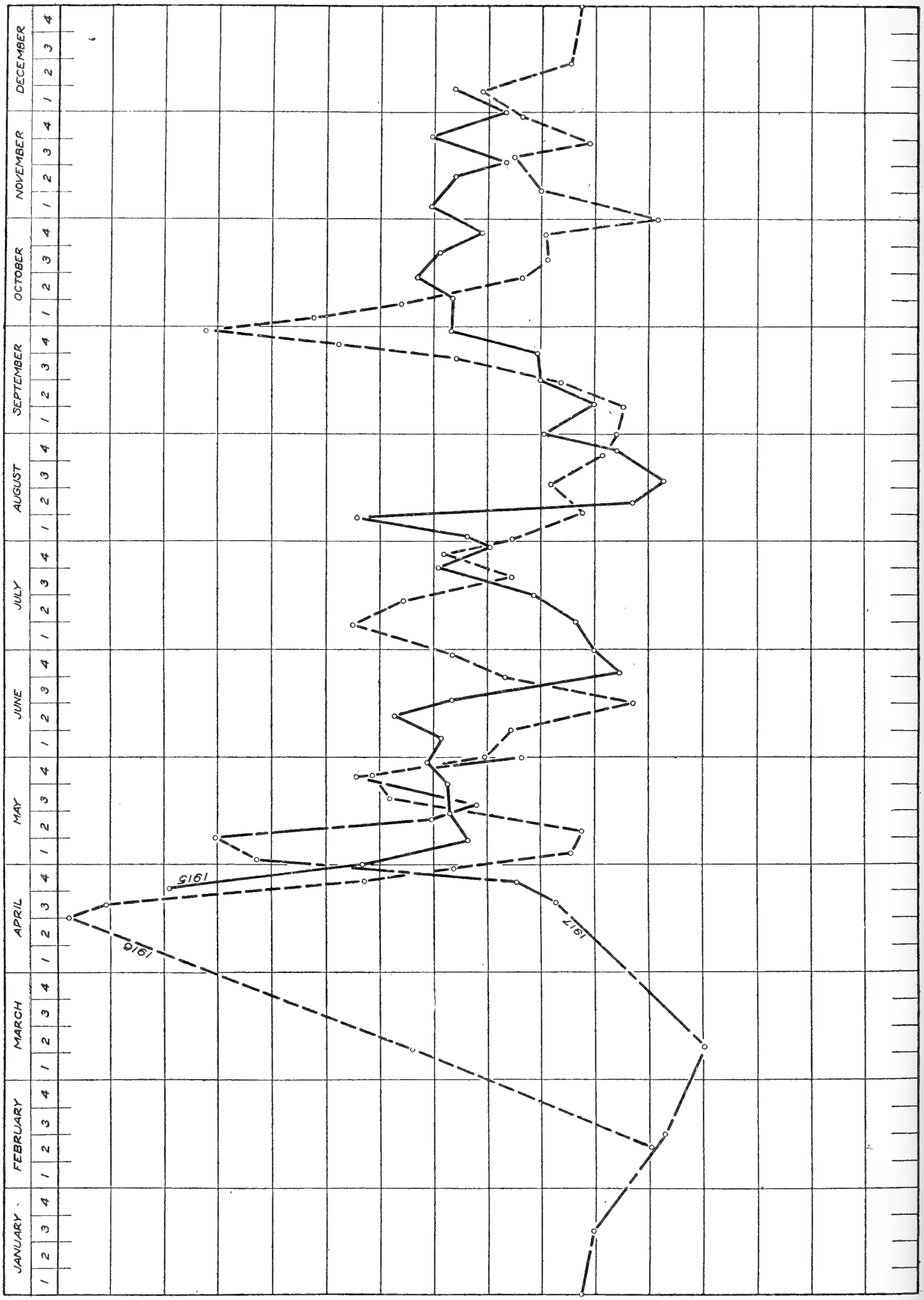

Fig. 28.—The quantity of dry organic matter in the nannoplankton of Lake Mendota, 1915 to 1917. The curves show the number of milligrams of organic matter per cubic meter of water.

after the quantity of organic matter showed considerable variation, but remained relatively high until the last run was made on December 6, 1915.

Between December 6, 1915, and February 11, 1916, the organic matter decreased from 1,719.0 milligrams to approximately 995.0 milligrams per cubic meter of water, a decline of 43.0 per cent. By March 8, 1916, the amount was almost double what it was on February 11, and it rose to more than treble the amount on the latter date by April 15. During the succeeding three weeks there was a marked decline so that the vernal peak in the curve for this year is a very prominent one and reaches the highest point of the entire series.

A secondary peak covers the period from the second week in May to the middle of June, 1916, and another reaches its maximum height about the end of the first week in July. Following this a gradual decline continued until the end of the first week in September; during the remainder of this month there was a rapid rise which was followed by an equally rapid decline in October. Thus, the curve for this period possesses a sharp and prominent peak which gives it a very different appearance from the curve of 1915. This decline continued in 1916 until the minimum amount of the year was reached on November 1. The following six weeks were characterized by two minor increases in the organic matter which were succeeded by relatively small decreases, so that the curve presents two small peaks covering this period of time.

A decrease of about 8.0 per cent in the organic matter of the nannoplankton was noted between December 12, 1916, and January 18, 1917; this decline continued until March 9, 1917, when the minimum of the entire series was found. By April 18 the organic matter had nearly doubled in amount and the increase continued until the vernal maximum was reached on May 7; this maximum was a little more than three times as much as the minimum of March 9. There was a marked decline between May 7 and May 16 so that the curve presents a well defined vernal peak; this decline was followed by a prominent increase on May 23 and this was followed by a decrease on June 1, 1917, when the observations were discontinued.

In a general way the curves in figure 28 show that the annual cycle of the nannoplankton is separated more or less definitely into four phases corresponding to the four seasons of the year; the same fact has been noted for the net plankton. It will be observed, however, that the autumnal phase may not be as prominent in the nannoplankton in some years, such as 1915 for example, as it was each year in the net plankton. A distinct vernal maximum was noted for each of the three years covered by these observations and it proved to be the maximum of the year in both of the complete years, namely, 1915 and 1916.

The curves for 1916 and 1917 show that there are considerable variations in the extent and duration of the vernal pulse of nannoplankton. The highest point of the former, for example, is almost 20.0 per cent above that of the latter. In the former year also a marked increase of organic matter took place during the latter part of February and early in March, while in 1917 it was decreasing at this time; the late April samples of 1917, in fact, contained a smaller amount than that of March 8, 1916. Thus, the vernal peak of 1916 represents very much more organic matter than that of 1917. Following the vernal maximum the curves for both 1915 and 1916 show two secondary peaks during the summer period with an extended minimal region in August and September.

In the autumn the organic matter rose to a decided maximum in 1916, but in 1915 it rose only to a median level and then remained fairly uniform in amount during this season. The winter season was characterized by a decline in the amount of organic matter. The relation of the various organisms to the changes in the quantity of organic matter is discussed on a subsequent page of this chapter.

On August 7, 1915, two samples were obtained for the purpose of studying the vertical distribution of the nannoplankton material. One sample was taken from the lower water of Lake Mendota, or from the 14-20 meter stratum, and the other from the upper water, or the 0-13 meter stratum. The sample of nannoplankton from the upper stratum yielded 1,837.0 milligrams of dry organic matter per cubic meter of water, while the one from the lower stratum contained only 854.0 milligrams; that is, the former yielded a little more than twice as much organic matter per cubic meter of water as the latter.

CHEMICAL ANALYSES OF THE NANNOPLANKTON

Nitrogen and Crude Protein

Owing to the presence of a large amount of inorganic matter in the centrifuge material, the percentage of nitrogen in the dry sample was relatively low. It varied from a minimum of 1.27 per cent in one sample obtained in 1916 to a maximum of 5.18 per cent in one sample secured in 1915. (See general table, No. 44, p. 207). The mean percentages ranged from 2.37 per cent in 1916 to 3.63 per cent in 1917.

Calculated on an ash free basis, the maximum percentages of the different years vary from 8.77 per cent of nitrogen to 10.66 per cent, while the minima are about half as much, namely, from 4.24 per cent to 5.91 per cent. The results for the different years are summarized in table 18, p. 192. The mean percentage was lowest in 1916, namely, 6.27 per cent and highest in 1917, or 8.27 per cent, the difference being just two per cent. While the average amount of organic matter was somewhat higher in the nannoplankton of 1916 than in that of the other two years, it contained a smaller percentage of nitrogen.

A comparison of the percentage of nitrogen in the net plankton (table 7, p. 187) with that in the nannoplankton shows that the latter is much lower in the dry sample, but when both are calculated to an ash free basis the difference is relatively small, although the nitrogen in the nannoplankton material is appreciably smaller than in the net plankton. In 1915 when the observations covered all seasons of the year, the mean percentage of nitrogen in the nannoplankton was less than half of one per cent below that in the net plankton of 1911, but it was almost one and a half per cent below that of the net plankton of 1915. The mean percentage of nitrogen in the nannoplankton in 1916 was almost two and a half per cent below that in the net plankton of 1915.

The annual variations in the quantity of nitrogen in the nannoplankton of Lake Mendota are shown in figure 29; the curves in this diagram indicate the number of milligrams of nitrogen per cubic meter of water. It will be noted that the general form of these curves is similar to that of the curves representing the organic matter of the corresponding years in figure 28; they show vernal and autumnal maxima with summer and winter minima. In 1915, however, there was an August maximum in both the organic matter and the nitrogen which exceeded the autumnal maximum of that year. The curves for organic matter and nitrogen are very similar in configuration in 1915, but the curves for the other years show more or less marked differences. In 1916, for example, the nitrogen did not rise to its maximum height in April until a few days after the organic matter had passed its maximum point; in the rise which took place during the latter half of June and in early July the nitrogen reached its highest point during the last week in June while the organic matter reached its highest point a week later. The nitrogen curve has a well rounded form during November and Dcember, 1916, while the curve for organic matter presents two well defined peaks at this period. In 1917 the nitrogen curve possesses two equally prominent peaks in the month of May, but in the curve for organic matter the second peak is much lower than the first.

In 1915 the ratio of the organic matter to the total nitrogen in the nannoplankton of Lake Mendota varied from 9.1 to 18.8, thus showing slightly more than a twofold difference. (See table 44.) In 1916 the range was from 11.4 to 23.5, indicating a smaller proportion of nitrogen in the organic matter obtained this year than in the previous year; the material collected in 1917 showed the smallest range of variation, namely, from 9.4 to 16.9. For the entire series of nannoplankton sam-

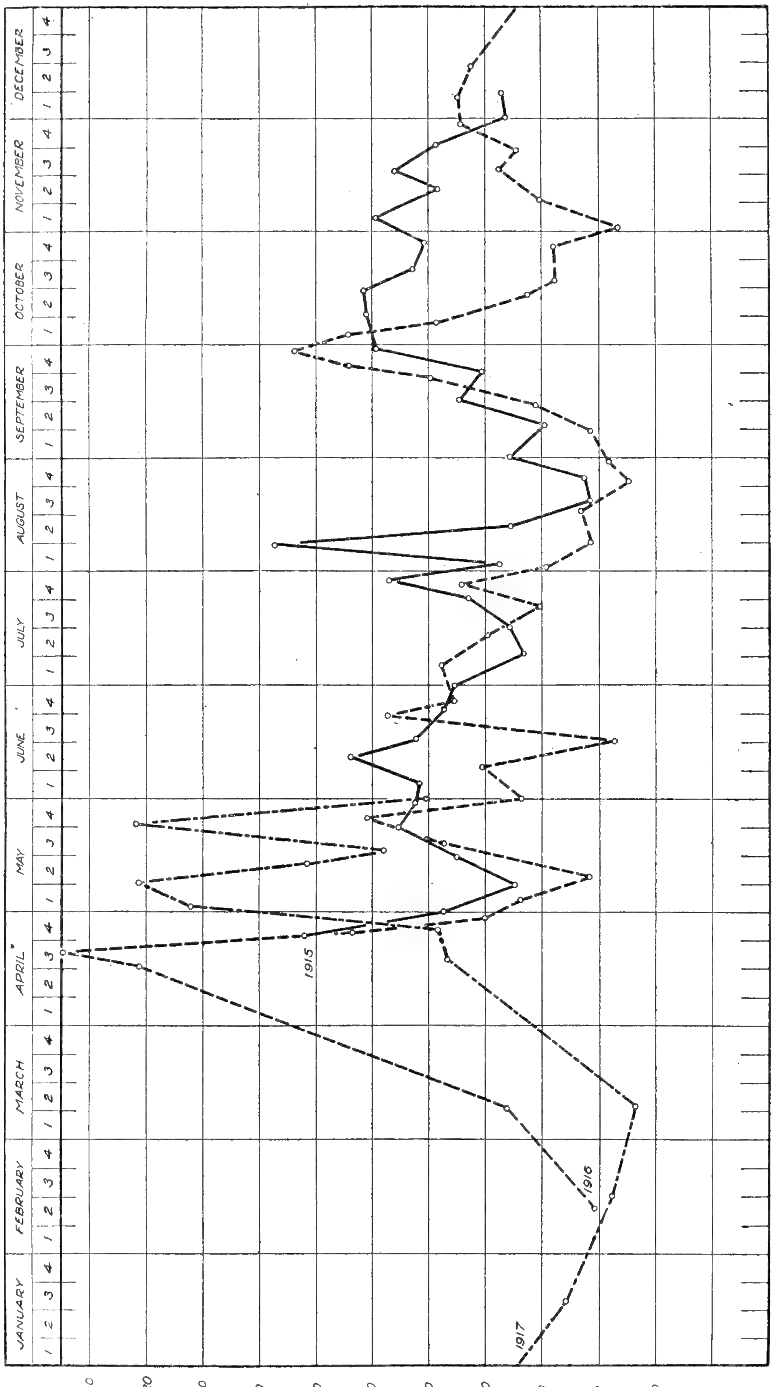

Fig. 29.—The quantity of nitrogen in the nannoplankton of Lake Mendota, 1915 to 1917. The curves show the number of milligrams of nitrogen per cubic meter of water.

ples from Lake Mendota, the ratios varied from 9.1 to 23.5; that is, the nitrogen constituted from one-ninth to about one-twenty-third of the organic matter in the centrifuge material. This was a larger variation than was found in the net plankton of Lake Mendota in which the extremes were 8.7 and 17.4.

In 1915 several determinations of the nitrogen content of the water, both before and after being centrifuged, were made for the purpose of ascertaining how closely the loss of nitrogen during the centrifuging process corresponded with the amount of nitrogen in the nannoplankton recovered by the centrifuge. It was found that the individual determinations showed considerable variation; in some instances the loss of nitrogen by the water was in excess of that recovered in the nannoplankton and in other samples the reverse was true. These differences were due, apparently, to slight inaccuracies in the method of determining the quantity of nitrogen in the water when it is present in such relatively small amounts. These variations are about evenly balanced, however, so that the differences become comparatively small in the averages for a number of determinations.

In twelve analyses, for example, the average quantity of nitrogen lost by the water in the centrifuging process was 106.3 milligrams per cubic meter of water, and the nannoplankton material recovered from this water yielded 103.5 milligrams per cubic meter; the two amounts correspond as closely as could be expected when the two very different methods of treatment are taken into consideration. That is, the discrepancy is only 2.8 milligrams, or a difference of 2.6 per cent. A larger number of determinations would, doubtless, have reduced this difference materially.

In these twelve analyses the average quantity of organic nitrogen in the water after it was centrifuged was 758.0 milligrams per cubic meter; in comparison with this the nannoplankton yielded 103.5 milligrams and the net plankton 21.5 milligrams, thus making a total of 125.0 milligrams of organic nitrogen per cubic meter of water for the total plankton. On this basis the water of Lake Mendota contained somewhat more than six times as much organic nitrogen as the total plankton. In addition to this the water contained an average of 4.0 milligrams of nitrite and 392.0 milligrams of nitrate so that the total nitrogen amounted to 1,154.0 milligrams per cubic meter of water, all of which would be available for the nitrogenous element in the food of the various plants of the lake. According to these results, then, the water contained a little more than nine times as much nitrogen as the total plankton.

In view of the abundance of the dissolved nitrogen compounds, Pütter's theory regarding the nutrition of aquatic animals may be considered here. Through computations based on data obtained by himself and by others, Pütter[2] became convinced that there is not enough organized food present in most bodies of water to support the animal population; he concluded, therefore, that the animals are able to make use of the organic compounds that are held in solution by the water, as well as of the organized food. Pütter thought he obtained confirmatory evidence for his theory in a series of experiments on several kinds of aquatic animals, including plankton crustacea and fishes; in spite of these results, however, his theory is not generally accepted by other investigators.

The quantitative results obtained on Lake Mendota show that there was always an abundance of food for the rotifers and crustacea and these two groups of animals are the chief consumers of the other plankton forms. Computations based upon numerical data and upon the average weight of the different kinds of rotifers and crustacea indicate that from twelve to eighteen times their own weight of available food was present in the plankton of Lake Mendota at the time of this investigation; it must be concluded, therefore, that these two groups of animals always had an ample supply of organized food. Pütter's conclusion regarding the lack of food for plankton crustacea was based upon data obtained from net catches only; all of the nannoplankton, however, may be used for food by the crustacea and the quantity of nannoplankton in Lake Mendota was several times as large as the available crustacean food in the net plankton.

The results for crude protein (N $\times$ 6.25) are summarized in table 19. The largest percentage of crude protein was found in a sample collected in 1917, while the maximum, minimum, and mean percentages were lower in 1916 than in the other two years. On the other hand, the largest quantity of crude protein per cubic meter of water was found in 1916, namely, 1,560.0 milligrams; this was more than 43.0 per cent higher than the maximum amount of 1915. The largest minimum amount was found in 1915 and the smallest in 1917, the latter being just a little more than 75.0 per cent of the former. The maximum quantity of crude protein in 1915 was less than three times as large as the minimum of that year, but in 1916 there was a fivefold difference, with more than a fourfold difference in 1917. The mean quantity was smallest in 1916 and largest in 1917, the former amounting to about 77.0 per cent of the latter. The average amount of crude protein in the nannoplankton was three times as large as that in the net plankton in 1916, three and a half times as large in 1915, and a little more than five times as large in the 1917 samples. (Compare tables 8 and 19.)

[2] Die Ernährung der Wassertiere, p. 168. Jena, 1909.

The crude protein constituted 45.0 per cent of the organic matter, or more, in three-quarters of the net plankton samples, but in only 30 of the 87 centrifuge samples, or about a third of them, did it reach this large a proportion; in only 50 samples did the crude protein equal 40.0 per cent or more of the organic matter in the nannoplankton.

The details of the relation of the crude protein to the organic matter are shown in figures 30 and 31. In these diagrams the quantities are indicated in milligrams per cubic meter of water. In 1915 the curve representing the crude protein, marked B in the diagram, possesses an outline similar to that representing the organic matter, curve A, but attention may be called to two minor differences. The small peak in the former which appears in the last week of July has a valley corresponding to it in the latter, the organic matter having reached a small maximum during the previous week. Also during the latter half of November and the first week in December the changes in the quantity of crude protein were not closly correlated in time with similar changes in the organic matter.

In 1916 the vernal maximum for crude protein came a few days later than that of the organic matter and a rise of the latter during the first part of July was correlated in time with a decrease in the former. The curve for crude protein in November and December, 1916, presents a rounded form while that for the organic matter shows two peaks at this time. In 1917 the second peak in the curve for organic matter during April is much lower than the first, while the two peaks in the curve for crude protein at this time are substantially equal in altitude.

Column 5 under nitrogen in the general table (No. 44) gives the ratio of the organic matter to the total nitrogen in the various samples. In 60 of the 87 samples of nannoplankton this ratio varies between 12 and 18; that is, the nitrogen constituted from one-twelfth to one-eighteenth of the organic matter in these samples. The ratio fell below 12 in 10 samples and above 18 in 18 samples. The sample containing the largest proportion of nitrogen gave a ratio of 9.1 and the one having the smallest proportion 23.5. These figures again serve to show that the proportion of nitrogen in the nannoplankton, in general, was distinctly smaller than in the net plankton. In a little more than two-thirds of the net plankton samples, for example, the ratio fell between 9 and 12, while in the nannoplankton samples only about one-ninth of them gave a ratio as low as 12 or less.

Ether Extract

A summary of the results of the determinations of the ether extract in the nannoplankton is given in table 20, p. 192; the figures indicate the percentage of the organic matter and the number of milligrams per

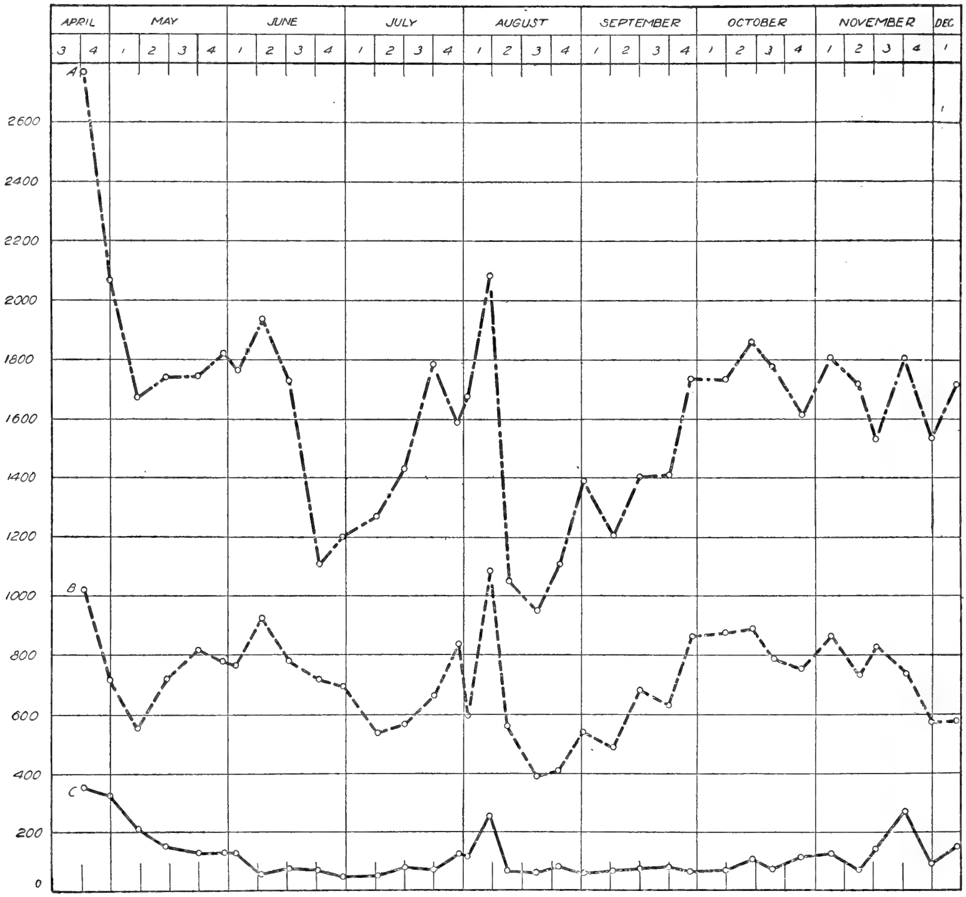

Fig. 30.—The quantity of organic matter, of crude protein and of ether extract in the nannoplankton of Lake Mendota in 1915. Curve A shows the amount of dry organic matter, curve B the crude protein and curve C the amount of ether extract in milligrams per cubic meter of water. Compare with figure 14. See table 44.

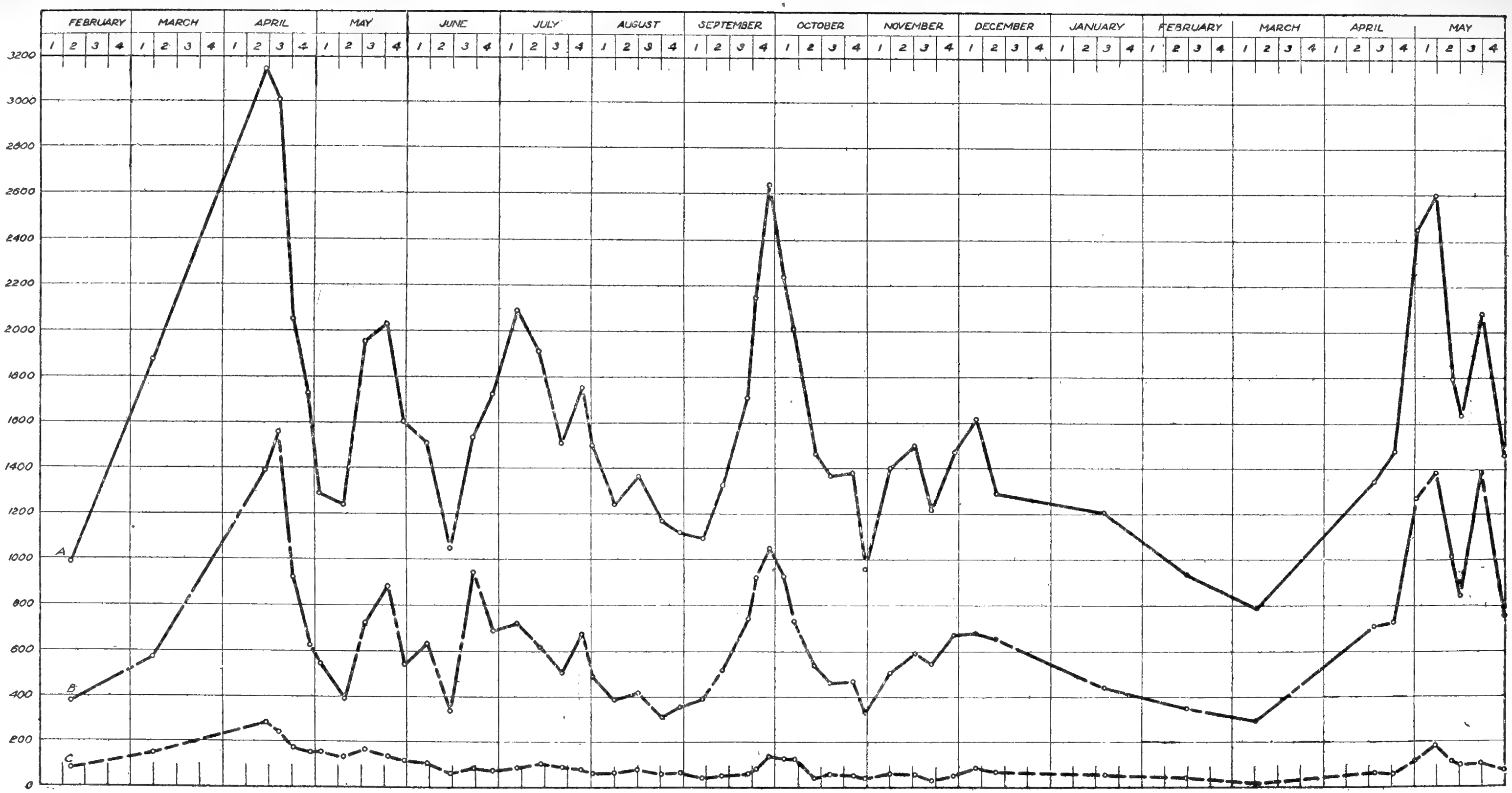

Fig. 31.—The quantity of organic matter, of crude protein and of ether extract in the nannoplankton of Lake Mendota in 1916 and 1917. Curve A shows the quantity of dry organic matter, curve B the crude protein, and curve C the ether extract in milligrams per cubic meter of water.

cubic meter of water. The details of the analyses are shown in the general table, No. 44, p. 207.

The highest percentage of ether extract, calculated on an ash free basis, was found in a sample obtained in 1915, namely, 15.77 per cent. In 1917 the maximum was only 7.07 per cent, less than half of the preceding maximum, but the latter is not representative of an entire year since the observations were discontinued on June 1, 1917. The minimum percentage was highest in 1915 and lowest in 1917 and the same was true of the mean percentage. There was slightly more than a fivefold difference between the maximum and minimum of 1915, almost sixfold in 1916, and more than threefold in 1917.

When stated in terms of milligrams per cubic meter of water, as indicated in the second part of this table, the largest quantity of ether extract was found in 1915 and the smallest in 1917. The mean quantity was lowest in 1917 and highest in 1915, the latter being about 40.0 per cent higher than the former.

The curves marked C in figures 30 and 31 give a graphic representation of the quantity of ether extract in the various samples. These curves show that, in general, the extract constituted a relatively small proportion of the organic matter. The largest amount was found during the vernal pulse of the nannoplankton, after which there was a gradual decline to the summer level, which was reached about the first week in June. Thus, the decrease was more gradual than in either the organic matter or the crude protein. With two exceptions the quantity remained well below 100 milligrams per cubic meter of water during the summer season. In 1915 the curve shows a distinct peak during the early part of August which is correlated with similar peaks in the organic matter and the crude protein at this time. In 1916 the quantity rose slightly above 100 milligrams about the middle of July, and again during the autumnal rise in late September and early October. In the latter part of 1915 there is no marked rise corresponding to the early autumnal increase of organic matter, but a prominent peak covers the second part of November which is correlated with a peak in the organic matter.

In comparison with the net plankton (table 43) the nannoplankton shows a distinctly lower percentage of ether extract; the mean of the latter averages only about a half to two-thirds as high as the former. This is probably due to the larger proportion of fat in the crustacea of the net plankton. Owing to the presence of a larger quantity of nannoplankton, however, the total amount of ether extract in it is markedly greater than that in the net plankton. In 1915, for example, the mean percentage of ether extract in the net plankton is one and seven-tenths times as much as that in the nannoplankton, yet the mean quantity of the latter is two and a half times that of the former.

Pentosans

The pentosans were determined in 32 nannoplankton samples which were collected in 1915. The amount in them varied from a minimum of 2.84 per cent of the organic matter to a maximum of 7.35 per cent; the mean percentage for these samples was 4.94 per cent. (Table 21, p. 193.) This represented a distinctly larger amount than was found in the net plankton of this year, the mean percentage of the latter being 3.41 per cent. With a larger amount of organic matter and a higher percentage of pentosans in the nannoplankton than in the net plankton the differences in favor of the former are still more striking when the amounts are expressed in terms of milligrams per cubic meter of water. In 1915, for example, the average quantity of the pentosans in the nannoplankton was a little more than six times as much as that in the net plankton. The maximum quantity in the former was about three and a half times as large as the maximum of the net plankton, while the minimum of the nannoplankton was more than fourteen times as large as the minimum of the net plankton.

Only eight determinations were made on the samples collected in 1916 and but two on those of 1917. The samples of 1916 yielded a higher mean percentage of pentosans than those of 1915, but the two of 1917 were both lower than the mean of 1915. When stated in milligrams per cubic meter of water the mean quantity in 1916 was about 10.0 per cent higher and that of 1917 about 8.0 per cent lower than the mean of 1915.

Crude Fiber

The percentage of crude fiber in the organic matter of the nannoplankton showed considerable variation during the period of these observations. The largest percentage was found in 1917 and the smallest in 1915. (See table 22, p. 193.) The mean percentage for 1917 was a little larger than that of 1916, while that of 1915 was less than half as much as that of 1916. Crude fiber determinations were made on only 17 of the 41 samples obtained in 1916 and on only 4 of the 11 samples of 1917, and this fact must be taken into account with reference to the mean percentages. The differences between the mean quantities are of similar magnitude when the results are expressed in terms of milligrams per cubic meter of water.

The mean percentage of the crude fiber in the nannoplankton in 1916 and 1917 was substantially the same as that of the net plankton for 1913 to 1915 inclusive, but it was much higher in the latter in 1911 and 1912. (See table 13, p. 189 for net plankton.) In 1915 the mean percentage of crude fiber in the net plankton was a little more than twice as large as that of the nannoplankton; in this year also the mean quantity was 49.0 milligrams per cubic meter of water in the latter and 22.0 milligrams in the former, somewhat more than a twofold difference. The mean quantity of crude fiber in the samples of net plankton obtained between 1911 and 1915 was only about a quarter to a sixth as much as that of the nannoplankton material collected in 1916 and 1917. This difference was due mainly to the presence of a larger quantity of nannoplankton than of net plankton.

The crude fiber of 20 samples of nannoplankton were analyzed for their nitrogen content, but it was found that the fiber contained at most only a trace of nitrogen. This indicates that the organisms in this material are practically free from chitin.

Nitrogen Free Extract

The nitrogen free extract, or that part of the organic matter which is left after deducting the crude protein, the ether extract, the crude fiber, and the ash, ranges from a minimum of a little less than 10.0 per cent to a maximum of about 32.0 per cent of the dry weight of the nannoplankton; that is, it shows a little more than a threefold variation as compared with sevenfold in the net plankton. The largest percentage of nitrogen free extract was found in a nannoplankton sample collected in 1915 and the smallest percentage was noted in a sample obtained in 1916. The mean percentage for the 87 samples of nannoplankton from Lake Mendota is approximately 19.0 per cent, or just a little less than the mean for the net plankton. In the nannoplankton the mean percentage of the pentosans is only a little more than one-tenth as large as the mean of the nitrogen free extract and this is substantially the same as noted for the net plankton.

Ash

The centrifuge material from Lake Mendota yielded a very high percentage of ash, the range being from a minimum of about 35.0 per cent to a maximum of about 75.0 per cent of the dry sample. In the corresponding samples of net plankton the ash varied from about 9.0 per cent to a little more than 48.0 per cent of the dry material. Thus the minimum of the nannoplankton was about four times as large as the minimum of the net plankton, while the maximum of the former was somewhat less than twice as large as that of the latter.

The inorganic constituents of the nannoplankton were derived from three sources, namely, (1) the nannoplankton organisms, (2) the silt removed from the lake water by the centrifuge, and (3) the water remaining in the bowl of the centrifuge at the end of a run. In the latter instance about 5.5 liters of lake water are involved; that is, at the end of each run this quantity of water remains in the bowl of the centrifuge and large numbers of organisms are suspended in it. During 1915 all but about 250 cubic centimeters of this water was siphoned out of the bowl and kept separate from the material which was deposited on the side of the bowl. The amount of organic matter represented by the organisms suspended in the bowl water was estimated by making a quantitative determination of the organic nitrogen in this water. The quantity of nitrogen was then multiplied by the factor representing the ratio of the organic matter to the nitrogen in the sample. By this method of treatment only about a quarter of a liter of lake water was added to the sample, distilled water being used to wash the catch from the bowl; this small quantity of lake water did not add materially to the ash of the sample.

In 1916 and 1917, on the other hand, all of the bowl water was added to the sample and the entire quantity was evaporated; this made a very substantial addition to the ash. Several determinations showed that an average of 119.0 milligrams of inorganic material was obtained from a liter of lake water, so that the 5.5 liters contributed about 655.0 milligrams of ash to the sample. Ash determinations on aliquot portions of 18 bowl waters in 1915 gave an average of 652.0 milligrams of inorganic material for 5.5 liters, thus corresponding closely with the former amount which was ascertained by another method. On the basis of these results it has been assumed that the bowl water contributes 655.0 milligrams of ash to the sample, or twice this amount where two runs are combined into one sample.

The percentage of ash in the various organisms of the nannoplankton, with the exception of Euglena, has not been determined, but such results have been obtained for various constituents of the net plankton and these may be used as a basis for estimating the ash of the nannoplankton. In some of the blue-green algae the ash varied from 4.3 per cent to 7.8 per cent of the dry weight, while in Euglena it amounted to 5.1 per cent. In the diatoms, of course, there is a much larger proportion of ash, ranging from 40.0 per cent to approximately 50.0 per cent. Since the diatoms constitute a relatively small portion of the centrifuge material, except in the spring and in the autumn, the ash derived from the organisms in the summer and winter catches may be estimated as about 10.0 per cent; that is, the organic matter constitutes 90.0 per cent of the dry material in these organisms. On this basis, then, the ash derived from the nannoplankton organisms ranged from a minimum of about 100.0 milligrams to a maximum of approximately 250.0 milligrams per cubic meter of water during June, July, and August, while in January, February, and March the amount varied from 90.0 milligrams to about 158.0 milligrams per cubic meter. In the spring and in the autumn small diatoms and the fragments of the larger forms are more plentiful in the centrifuge material so that it is impossible to give a fair estimate of the percentage of ash in the nannoplankton organisms during these seasons.

While the water of Lake Mendota does not show any turbidity due to silt, except after unusually heavy rains, yet it contains regularly a larger or smaller amount of such material in suspension; without exception, silt was noted in all of the centrifuge samples that were used for the enumeration of the organisms. No attempt was made to measure the quantity of this silt directly, but the amount removed from the lake water by the large centrifuge is represented roughly by the quantity of inorganic matter left after the ash of the bowl water and that of the organisms are deducted from the total ash of the sample. The results obtained in this way are indicated for a number of samples in table 23, p. 194. The samples represented in this table include only those in which the diatoms constitute but a relatively small part of the material as shown by the enumerations. Where these organisms are abundant in the centrifuge material the ash of the nannoplankton would exceed 10.0 per cent of the dry weight and the samples given in the table have been selected with a view of keeping the ash content within the 10.0 per cent limit.

No bowl ash is shown for the samples of 1915 because the bowl water was not added to the samples of that year. The sixth column of table 23, shows the amount of dry silt in milligrams per cubic meter of water. During the summer months, the quantity of silt varies from about 370.0 milligrams (sample No. 5124-26) to 1,349.0 milligrams (sample No. 579-81) per cubic meter of water, representing almost a fourfold variation. Expressed in other terms, these quantities are 0.37 and 1.35 parts per million, respectively. The particles of silt have not been measured, but they are so minute that even these surprisingly small amounts represent an enormous number of individuals.

The specific gravity of the more common rock-forming minerals averages about 2.6, so that this may be assumed as approximately the specific gravity of the silt also. On this basis the volume of 370.0 milligrams of silt is about 140 cubic millimeters and that of 1,349.0 milligrams equals 520 cubic millimeters, thus giving a range of 0.14 cubic millimeters to 0.52 cubic millimeters of this material per liter of water.

The last two samples given in the table show the results for the January and March catches of 1917. In both of these samples the amount of silt obtained by difference, namely, 235.5 milligrams and 112.5 milligrams, is well below the summer minimum; the March catch, in fact, shows only about a third as much as the summer minimum. The January sample was taken about a month after the lake became covered with ice and the comparatively small amount of silt found on that date seems to indicate that some of the suspended material gradually settles out of the water under these conditions because the ice keeps the water from being disturbed by the wind. The results obtained on March 9 show a further decrease in the quantity of silt thus indicating that the process of settling continued during the intervening period of time. In some winters, however, there is a very substantial contribution to the amount of silt during this season.

Thaws accompanied by rain sometimes occur in late January or in February and much drainage water, well laden with silt, may reach the lake at such times. This drainage water contains very little dissolved material so that its specific gravity is less than that of the lake water. For this reason the drainage water does not mix readily with the lake water, but tends to spread out and form a layer of turbid water just under the ice. The thickness of this stratum ranges from half a meter to a meter, or perhaps a little more at times. In some years the spreading continues until the entire lake becomes covered with this stratum of turbid water, which results in a wide distribution of the suspended silt.

The second part of table 23 gives the results of some analyses of the ash of the centrifuge material. It will be noted that the addition of the bowl water to the samples in 1916 and 1917 increased the percentages of CaO and MgO very materially, but that this made practically no difference in the percentage of silica nor in that of iron and alumina. Analyses of the solids of 14 samples of bowl water in 1915 showed that CaO constituted from 16.2 per cent to 19.5 per cent of the total solids, while MgO ranged from 10.7 per cent to 17.4 per cent. The percentage of silica in the solids of the bowl water, as well as that of iron and alumina, was relatively low; the former varied from 1.8 per cent to 3.4 per cent with one sample unusually high, namely, about 9.0 per cent, and the latter ranged from 1.1 per cent to 1.7 per cent. These results indicate that the diatoms and silt are pretty thoroughly removed from the bowl water in the centrifuging process. Since the ash of the centrifuge catches had a complex origin, any further discussion of its chemical composition would not be profitable from a biological standpoint.

The Number of Organisms

After being pumped into the tank, the water used for a centrifuge run was thoroughly stirred and a representative sample of about two liters was taken out for a numerical study of the organisms; about 75 cubic centimeters of this sample were used for the enumerations and the remainder was then returned to the tank. A few of the forms were usually present in sufficient numbers to be counted directly without any concentration; for the enumeration of the others it was necessary to concentrate the material with a centrifuge. An electric centrifuge carrying two 15 cubic centimeter tubes and having a speed of about 4,000 revolutions per minute was used. The enumerations were made in the usual manner and, in general, they were made in duplicate; in most instances it was found that the two counts checked very closely for most of the organisms, but whenever the differences for the common forms seemed too large, a third count was made. In the more abundant forms also, the counts were frequently checked by counting them in the centrifuged as well as in the uncentrifuged material. The mean of the different counts has been regarded as representing the number of the various organisms.

Samples of water were also obtained at different depths of the lake for a study of the vertical distribution of the various forms noted in the nannoplankton, but the data secured in the enumerations will not be discussed here.

The results of the counts made on the samples of water taken from the tank are shown graphically in figures 32 and 33. As already indicated for the net plankton, the numbers of the various organisms differ so widely that it has been necessary to use the spherical type of curve for the nannoplanktonts also, in order to show all of them on the same diagram. The curves in these two figures indicate the number of individuals in 10 liters of water. The number of individuals per unit volume of water is so much larger in the nannoplankton forms than in the net plankton forms, that a much smaller volume of water has been used for the diagrams of the former than for those of the latter; that is, 10 liters in the nannoplankton as compared with one cubic meter in the net plankton. The organic matter of the nannoplankton has been platted on the same basis as in the net plankton, namely, the number of milligrams of dry material per 10,000 cubic meters of water. In spite of being based on a much larger volume of water, this type of curve does not show the results for the organic matter nearly as well as the curves in figure 28. It will be best to compare the two types of diagrams in this connection.

The various forms of organisms appearing in the nannoplankton of Lake Mendota are shown in figures 32 and 33. The rhizopods were represented by four different forms. One of them was a small Amoeba which was irregular in its seasonal distribution; large numbers were found at all depths in some instances. An average of 255,000 individuals per liter of water was noted in a sample obtained in August, 1916; in most of the samples in which this form was found, the numbers ranged from 1,000 to 6,000 per liter. Three unidentified rhizopods were noted; they were present much more frequently than Amoeba, but the number rarely exceeded 1,000 to 2,000 per liter of water.

Minute flagellates were found in the nannoplankton of Lake Mendota at all seasons of the year. Most of them, perhaps all of them, belonged to the form described by Lewis[3] in 1913 under the name of *Chlorochromonas minuta.* Lewis' description is based on material obtained from Lake Mendota, but the form has been noted in lakes in Iowa and New York as well, which indicates that this flagellate is rather widely distributed. In Lake Mendota it was found in very considerable numbers at times, especially during the month of May. During the third week in May, 1916, the number reached two and a quarter million per liter of water in two sets of observations. The average number for 137 samples in which this form was found, was 237,000 per liter.

Cryptomonas was found pretty regularly in the various counts, but the breaks in the curves show that it was not found at certain periods both in winter and in summer. It was most abundant in November, 1915, when more than 300,000 individuals per liter of water were noted in two samples. The average for 112 samples in which this form was noted, was 45,000 individuals per liter of water. Another flagellate, Euglena, was found in 1915; it appeared chiefly during the months of September and October, but the numbers were relatively small, ranging from about 1,000 to 13,000 individuals per liter of water.

Ciliated protozoa of various sizes were found in the majority of the catches, but they were rather irregular in their distribution as indicated by the breaks in the curve representing them. A fairly large anaerobic ciliate appeared in the lower water each year during the latter part of the summer.[4]

Several genera of the blue-green algae (Cyanophyceae or Myxophyceae) and of green algae (Chlorophyceae) were represented in the material as indicated in the diagrams. A few other forms appeared from time to time, but they were found in such small numbers and so irregularly that they have not been shown in the figures.

The most important alga belonging to the blue-green or green group of forms is an Aphanocapsa with very minute cells, probably *Aphanocapsa delicatissima* West. It was found at all seasons of the year and at all depths of the lake. This alga was obtained at a depth of 170 meters (558 feet) in Seneca Lake, New York, and it seems to have a wide range geographically, since it has been noted in the nannoplankton of various Wisconsin lakes, in Seneca and Cayuga Lakes, New York, and in West Okoboji Lake, Iowa. Usually the colonies are rather small, having only 15 to 50 cells, but sometimes a colony is found which has 100 cells or more. This Aphanocapsa was most abundant in Lake Mendota in April and May, but the numbers were fairly large during

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[3] Archiv für Protistenkunde, Bd. 32, 1913, pp. 249-256, 1 pl.

[4] See Juday, Biological Bulletin, Vol. 36, 1919, pp. 92-95.

the other months of the year also. In one set of observations in April, 1915, a maximum of somewhat more than 8 million colonies per liter was noted.

The other forms of blue-green and green algae were found chiefly in the summer and autumn. Coelosphaerium and Oocystis were the most regular in their appearance, but breaks in the curves representing them show that they were not found at times. With respect to the breaks in the various curves it may be said that a break does not mean, necessarily, that this particular form had disappeared entirely for the period covered by the break in the curve, but it does mean that the form was so scarce that it was not noted in the samples for this period of time; by centrifuging a larger sample of water for the enumeration, say 100 or perhaps 200 cubic centimeters, some of the breaks might have been eliminated, but in all probability not many of them. Coelosphaerium was more abundant as well as more regular in its appearance than Oocystis; the other forms of blue-green and green algae were still more irregular in their appearance in samples as indicated by the more numerous breaks in the curves representing them.

Three genera of diatoms were found in the nannoplankton, namely, Cocconeis, Cyclotella, and Stephanodiscus. Cocconeis appeared at irregular intervals during the period from March to December, 1916, but the number was relatively small. A small form of Cyclotella was found in all of the 1915 samples and it was present in the 1916 catches from February to October with the exception of one set of observations during the latter part of August. In November and December it was noted as irregular and it was not observed in any of the samples between the middle of January and the last week of April, 1917.

Stephanodiscus astraea * showed a most interesting periodicity during this series of observations as indicated in the diagrams. This disc-shaped diatom is very small, the diameter ranging from 6.5μ to 9.0μ with an average of approximately 8.0μ. It appeared about the middle of April in 1915, rose to a maximum during the second week in May, and then declined in numbers, rather rapidly at first and then more gradually until it finally disappeared about the first of July. In 1916 this diatom was found during the latter part of March, increased rapidly in numbers in early April, and reached its maximum point in the third week of this month. There was a rapid decrease in the last week of April and a more gradual decline in May, the form disappearing entirely by the first of June. In 1917 this diatom again made its appearance in the latter part of March, but the number rose more slowly so that the maximum was not reached until the end of the first week in May. This was followed by a rapid decrease in numbers, but

* We are indebted to Dr. Albert Mann for the identification of this diatom.

the form was still present in considerable numbers when the observations were discontinued on the first of June. *S. astraea* yielded a larger number of individuals per liter of water than any other organism that was found in the nannoplankton. The mean of two counts made on a sample taken from the tank on April 18, 1916, was approximately 35 million individuals per liter of water. In 1917 the maximum number of *S. astraea* was a little more than 27 million per liter, while in 1915 it was only about 8.5 million.

Another species of Stephanodiscus, a distinctly larger form than the preceding, was found each year in the spring and in the autumn. It was never present in very large numbers, however; the largest number was observed in the first week of October, 1916.

Fragments of the colonial diatoms, such as Asterionella, Fragilaria, and Tabellaria, were found in the centrifuge material and they were enumerated. As indicated in the diagrams, these fragments were most abundant in spring and in autumn.

Filaments of the blue-green alga Aphanizomenon were found in most of the samples, but usually relatively small numbers of them were noted.

The vernal increases in the organic matter of the nannoplankton were correlated in time with the increase in the numbers of certain forms; in 1915, for example, the maximum for organic matter was found at the same time that Aphanocapsa reached its maximum point for the entire series of observations. *Stephanodiscus astraea* was also increasing in numbers at this time, but its increase was not sufficient to counterbalance the decline of Aphanocapsa in the last week of April and the first week of May. Thus, there was a decrease in the organic matter at this time corresponding to an increase of this diatom, but its maximum number this year was only about a quarter as large as in 1917.

The vernal maxima of organic matter in 1916 and in 1917 were both correlated in time with the maximum number of *Stephanodiscus astraea*. There was also a marked increase in Cyclotella and in Aphanocapsa at this period in the former year and a distinct rise in the number of monads was noted at this time in the spring of 1917.

The marked rise in the organic matter in the latter part of July and during the first week of August, 1915, was correlated in time with increases in the numbers of monads and of Coelosphaerium. In September there was an increase in Aphanocapsa and in Coelosphaerium at the time of the rise in the organic matter, but there was no well marked maximum of the latter during this autumn and neither was there any unusual rise in the number of organisms. A fairly well defined increase in the monads in late October and in November was accompanied by a decrease in Aphanocapsa and Coelosphaerium, the two changes just about balancing each other according to the results for organic matter.

In 1916 the rise in organic matter in late June and in early July corresponded to increases in the numbers of monads, Coelosphaerium, Aphanocapsa, and Oocystis. The prominent September peak in the curve for organic matter in 1916 was correlated in time with a marked rise in Cryptomonas, Stephanodiscus, and the fragments of diatom colonies.

Rôle of Bacteria in the Nannoplankton

No quantitative observations were made on the bacteria of Lake Mendota during this plankton investigation, except to ascertain by means of several series of plate cultures that the centrifuge removed about one-third of the bacteria normally present in the lake water. A quantitative study was begun in July, 1919, and the work is still being continued, March 1, 1922. The results obtained during this interval of time furnish enough data for a fair estimate of the rôle of the bacteria in the plankton complex of the lake.

In this quantitative study the number of bacteria has been determined both by direct counts and by plate cultures. For the plate method Nährstoff-Heyden agar was selected for the culture medium because it gave the highest counts and apparently the largest number of different types of colonies. Several series of direct counts have yielded an average of ten times as many bacteria as the plate cultures, so that it is necessary to multiply the plate counts by the factor ten in order to ascertain approximately the number of bacteria per cubic centimeter of water by the plate method.

On the basis of the direct counts, the total number of bacteria in Lake Mendota from July to October, 1919, averaged about 3,000 per cubic centimeter of water from surface to bottom in 23.5 meters of water. In late autumn and early winter the number decreased to a minimum average of 1,500 per cubic centimeter. In the spring and early summer of 1920 the number rose steadily to a maximum average of 30,000 per cubic centimeter; the number remained near the maximum until the latter part of August, after which there was a gradual decline to a winter minimum of 2,000 bacteria per cubic centimeter of water in January, 1921. In the following spring and summer, the number averaged from 3,000 to 5,000 per cubic centimeter, but in September the number rose rapidly. A maximum of 60,000 individuals per cubic centimeter was obtained at a depth of 10 meters on September 22, 1921. Following this the number declined to a winter minimum of about 3,000.

The direct counts also show that about two-thirds of the total number of bacteria in Lake Mendota are rod-shaped forms and one-third spherical or coccus forms. The rods range in length from 1.2μ to 10.0μ and their diameters vary from 0.2μ to 2.75μ. The shorter individuals are more abundant than the longer ones, so that a large number of measurements gave an average length of 2.5μ and a mean diameter of 0.9μ. The coccus forms vary from 0.22μ to 0.75μ in diameter, with a mean of 0.44μ.

These results, together with those obtained by other investigators, constitute a basis for the computation of the live weight and the quantity of dry organic matter in this crop of bacteria. The volume of a rod-shaped individual of mean size, that is 2.5μ long and 0.9μ in diameter, is 1.5904 cubic micra, or 0.0000000015904 cubic millimeter. The volume of a spherical individual with a diameter of 0.44μ is 0.0446 cubic micron, or 0.0000000000446 cubic millimeter.

The maximum summer average in 1920 was 30,000 bacteria per cubic centimeter, or 30 billion per cubic meter of water. Two-thirds of them, or 20 billion, were rod-shaped individuals and one-third, or 10 billion, were spherical forms. On the basis of the mean size the volume of the rod-shaped bacteria in a cubic meter of water at that time was 31.808 cubic millimeters and of the spheres 0.446 cubic millimeter, making a total of 32.254 cubic millimeters for the two groups. Rubner [5] found that the specific gravity of water bacteria averaged about 1.05 so that the live weight of the bacteria in a cubic meter of Mendota water during the summer maximum of 1920 was approximately 33.9 milligrams.

Rubner [6] and Nishimura [7] state that about 84.0 per cent of the live weight of aquatic bacteria consists of water; on this basis the maximum crop of bacteria in Lake Mendota in 1920 represented 5.4 milligrams of dry material per cubic meter of water. Nishimura also found 11.2 per cent of ash in a water bacillus which he analyzed; deducting this percentage of ash from the Mendota material leaves 4.8 milligrams of dry organic matter per cubic meter of water for the maximum summer crop of bacteria in 1920. The average number from July to October, 1919, was 3,000 bacteria per cubic centimeter, or one-tenth as many as the summer maximum of 1920; the crop of the former year, therefore, represented only about 0.48 milligram of dry organic matter per cubic meter of water. The winter minimum of 1,500 bacteria per cubic centimeter was only one-twentieth as large as the summer maximum of 1920, so that it amounted to 0.24 milligram per cubic meter.

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[5] Archiv für Hygiene, Bd. 11, 1890, pp. 365-395.
[6] Archiv für Hygiene, Bd. 46, 1903, pp. 1-63.
[7] Archiv für Hygiene, Bd. 18, 1893, pp. 318-333.

The maximum number of 60,000 per cubic centimeter noted at 10 meters on September 22, 1921, represented twice as much material as the maximum of 1920: that is, wet weight 67.8 milligrams per cubic meter of water, dry weight 10.8 milligrams, and organic matter 9.6 milligrams. The 1921 maximum, however, is not the average for all depths, but the number at 10 meters; the numbers noted at other depths on this date were considerably smaller, but they would still give an average above that of 1920.

On the basis of their ability to produce living matter in the course of the year, Lohmann [8] estimated that one volume of bacteria is equal to six volumes of protista (protophyta and protozoa) and to three hundred volumes of metazoa. These results obtained on Lake Mendota show a very much larger proportion of protista to bacteria. The nannoplankton alone, exclusive of the protophyta and protozoa of the net plankton, yielded an average of 1,472.0 milligrams of dry organic matter per cubic meter of water during the three summer months of June, July, and August in 1915, and 1,507.0 milligrams during the same months in 1916. For the same periods the net plankton averaged 337.0 milligrams of organic matter per cubic meter in 1915 and 181.0 milligrams in 1916. Computations based upon numerical data show that the crustacea and rotifers contribute an average of one-third of the organic matter in the net plankton; thus, it seems safe to estimate that about half of the net plankton during the summers of 1915 and 1916 was derived from the protista. Adding half of the organic matter of the net plankton to that of the nannoplankton gives an average of about 1,640.0 milligrams of dry organic matter in the protista in the summer of 1915 and of 1,589.0 milligrams per cubic meter in 1916. These amounts represent more than three hundred thirty times as much organic matter as the maximum crop of bacteria in 1920 and more than one hundred sixty times as much as the maximum number of bacteria noted at 10 meters on September 22, 1921. They represent more than three thousand times as much organic matter as the late summer crop of bacteria in 1919.

The value of the bacteria in the plankton economy of Lake Mendota is by no means as small as these figures seem to indicate, because they multiply at a much faster rate than the protista; the bacteria may pass through a number of generations in the course of a day under favorable food and temperature conditions, while the protista may not average more than one or perhaps two divisions per day under similar conditions. In spite of this marked difference in reproductive capacity, it appears from the foregoing results that the bacteria do not play nearly as important a rôle in the plankton complex of Lake Mendota as Lohmann's estimate might lead one to expect.

[8] Internationale Revue, Bd. 4, 1911, pp. 1-38.

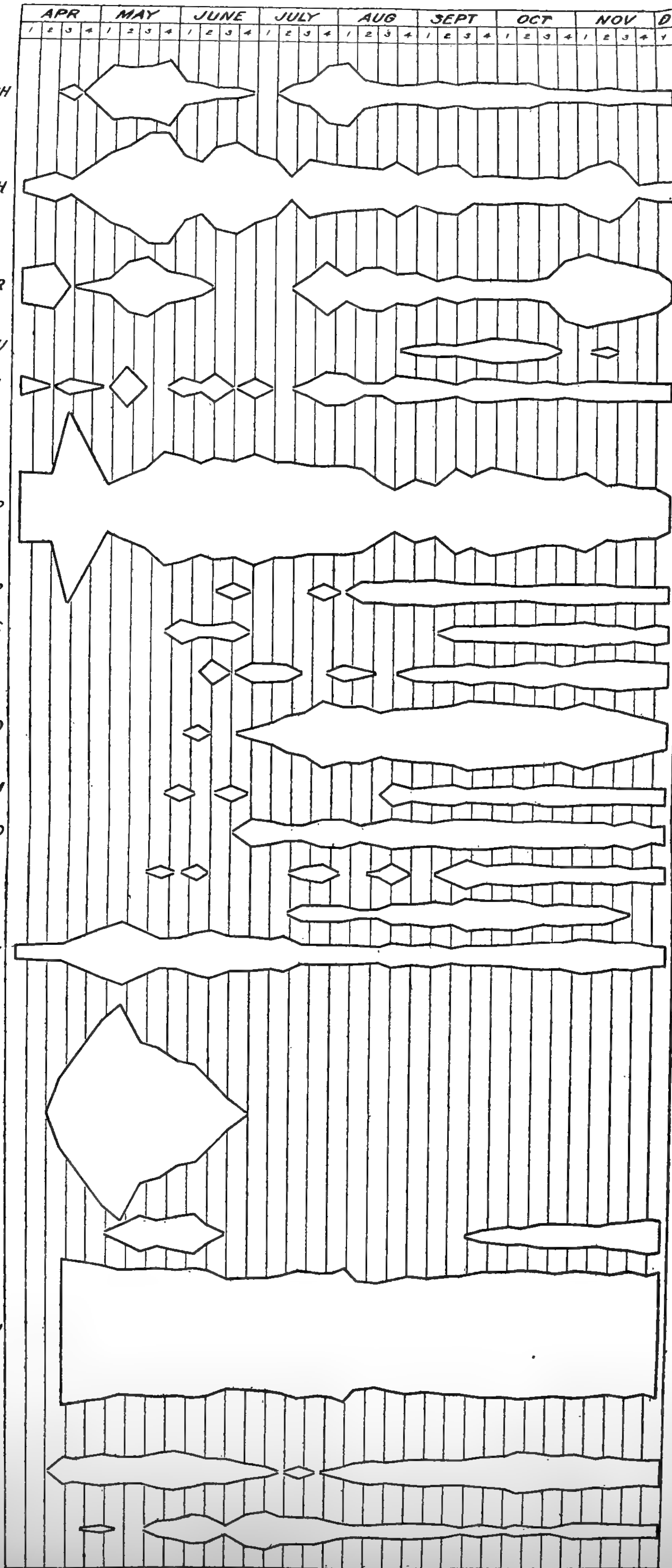

Fig. 32.—Diagram showing the numerical results obtained for the various organisms in the nannoplankton of Lake Mendota in 1915. The different forms are indicated in the explanation on page 91. Compare with figure 25.

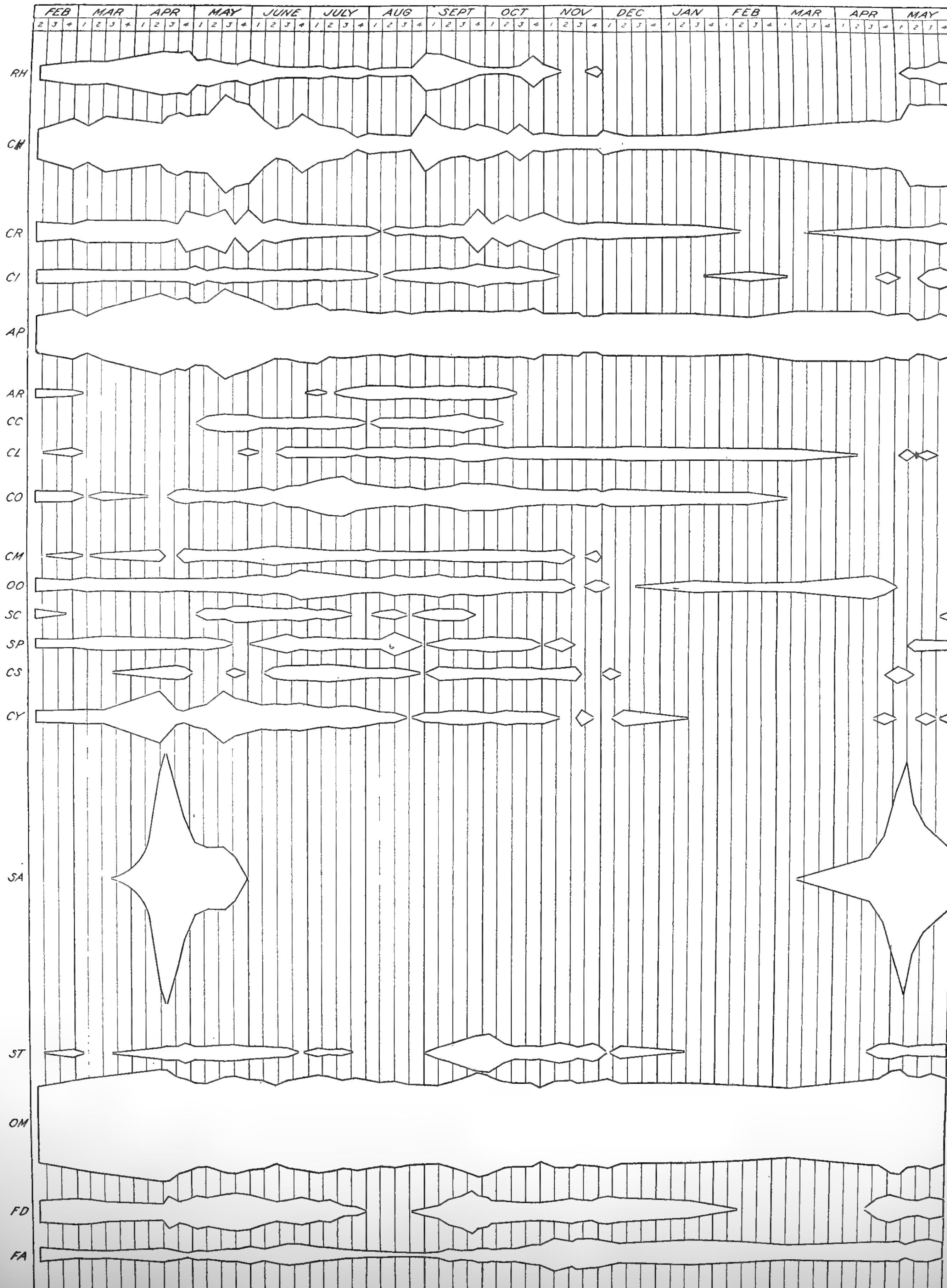

Fig. 33.—Diagram showing the numerical results obtained for the various organisms in the nannoplankton of Lake Mendota in 1916 and 1917. The different forms are indicated in the explanation on page 91. Compare with figure 26.

Explanation of the Nannoplankton Diagrams

Figures 32 and 33 show the numerical results obtained for the samples of nannoplankton from Lake Mendota; the spherical type of curve has been used. The curves show the number of individuals or colonies in 10 liters of water. In order to bring out the variations in the quantity of organic matter more clearly by this type of diagram, that curve was platted on a different scale; it shows the number of milligrams of dry organic matter in 10,000 cubic meters of water.

The following abbreviations have been used for the different organisms: RH=Rhizopoda, CH=Chlorochromonas, CR=Cryptomonas, EU=Euglena, CI=Ciliates, AP=Aphanocapsa, AR=Arthrospira, CC =Chroococcus, CL=Closterium, CO=Coelosphaerium, CM=Cosmarium, OO=Oocystis, SC=Scenedesmus, SP=Sphaerocystis, CS=Cocconeis, CY=Cyclotella, SA=Stephanodiscus astraea, ST=Stephanodiscus, OM=organic matter, FD=fragments of diatoms, FA=fragments of Aphanizomenon.

CHAPTER IV

THE TOTAL PLANKTON OF LAKE MENDOTA

The term total plankton is used here to designate the sum of the net plankton and the nannoplankton. Since the ash of the centrifuge material contains a certain amount of silt, and is therefore abnormally high, the discussion of the results is necessarily limited to the organic matter of the net plankton and of the nannoplankton. Only those catches of the former which correspond to the samples of nannoplankton are taken into consideration in this chapter. That is, the results given for net plankton in this chapter cover only those samples which were obtained between April 21, 1915, and June 1, 1917.

Variations in the Quantity

The distribution of the dry organic matter of the net plankton and of the nannoplankton of Lake Mendota by months for the different years is shown in table 24, in which the average amount of each is indicated for the different months as well as the sum of the two, or the organic matter of the total plankton. The months of January and February are represented by single catches, but the results for the other months are averages of two to eight or more catches per month.

The large crop of Aphanizomenon which developed late in 1916 held over into January, 1917, and gave a large catch of net plankton in this month. By February the net plankton had decreased to less than a quarter of the January amount, even being below that of February, 1916. In both years the March samples were smaller than those of the previous month. The average of April, 1917, was about 10.0 per cent below March, but in 1916 there was an increase in the net plankton during this period. The average for May showed an increase in all three years; June yielded a distinctly larger average than May in two years, but it was somewhat smaller than May in 1916. July and August were characterized by declines in the amount of net plankton, but September ushered in the autumnal rise both in 1915 and in 1916; the maximum point was reached in December of both years.

The difference in the amount of organic matter in the two February samples of nannoplankton was only a little over 5.0 per cent, the quantity being somewhat larger in 1916 than in 1917. The catch in February, 1917, showed a decrease of somewhat more than 20.0 per cent over that of January of this year. In 1916 the amount of organic matter in the nannoplankton was almost twice as large in March as in February, but in 1917 the quantity was smaller in March than in February. April showed the maximum average of the year both in 1915 and in 1916, but the maximum of 1917 was not reached until May. The average amount of organic matter for June showed a variation of only about 8.0 per cent in the three years covered by these observations, but there was a much greater difference in July. The summer minimum was reached in August and the averages were substantially the same in 1915 and in 1916. The September averages were higher than those of August and the amount remained at this level or somewhat higher during the last three months of the year.

In the total plankton, that is the net plankton plus the nannoplankton, the smallest amount of organic matter was found in February or March and the largest average in April or May. The average for December, 1916, was higher than that of May, 1917. From June until September the monthly averages of organic matter in the total plankton ranged from a little more than 1,350 milligrams to about 2,000 milligrams per cubic meter of water; October fell within these limits in 1916, but for October, 1917, and for the last two months of both years the amount varied from about 2,200 milligrams to substantially 2,500 milligrams.

The smallest amount of organic matter in the total plankton was found in March, 1917, and the largest amount for the entire series was noted in April, 1916; the latter was approximately three times as large as the former.

Figures 34 and 35 show graphically, in more detail, the relations between the quantity of organic matter in the net plankton and that in the nannoplankton; they also show the total organic matter or the sum of the two. The amounts are indicated in milligrams per cubic meter of water. The curve marked A in the diagrams represents the organic matter of the total plankton; the one marked B indicates that of the nannoplankton, while C represents the organic matter of the net plankton. The nannoplankton curve, B, is distinctly higher than the one for net plankton, C, for the entire series of observations, thus showing clearly that the organic matter in the former always exceeds that in the latter. The two curves are most widely separated in April, 1915, and 1916, and in May, 1917; they approach each other most closely in December, 1916.

The fact that the curve for total plankton, A, is, in general, very similar in form to that for the nannoplankton, B, is further evidence of the predominance of the latter over the net plankton. The most prominent difference between these two curves is shown in October, 1915,

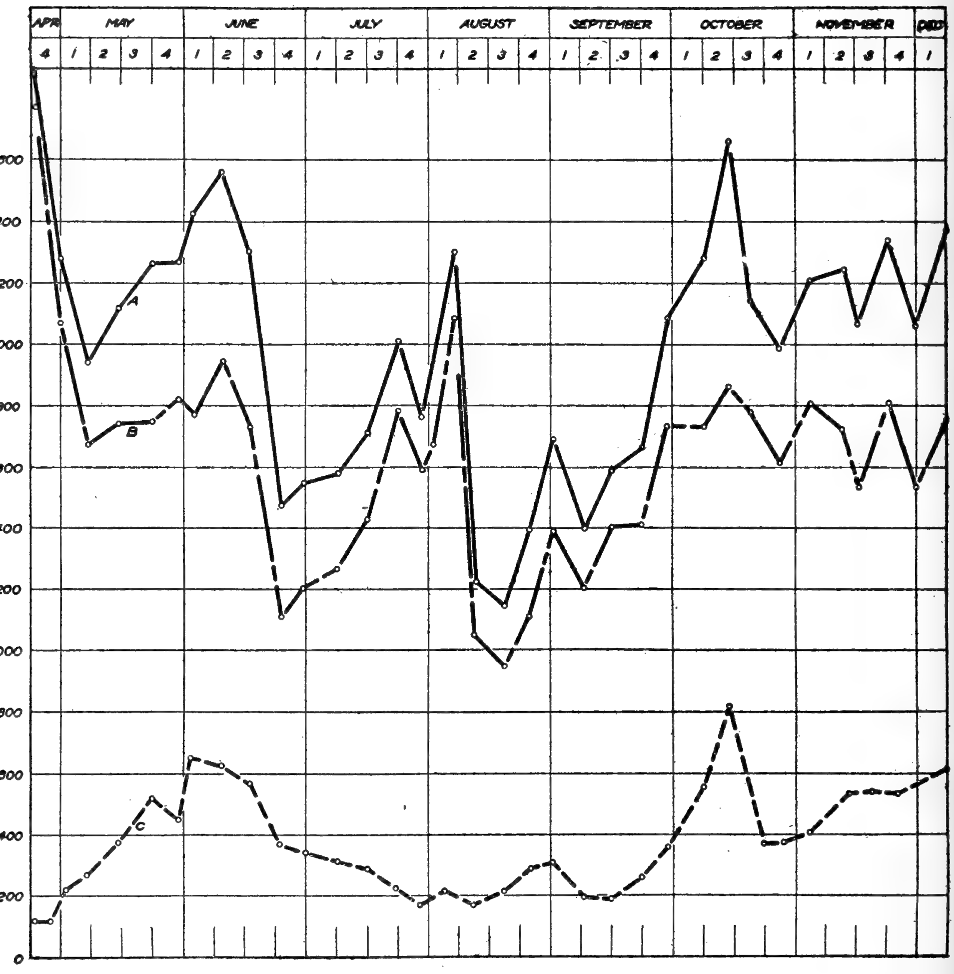

Fig. 34.—The amount of dry organic matter in the net plankton, the nannoplankton and the total plankton of Lake Mendota in 1915. Curve A represents the total plankton, curve B the nannoplankton, and curve C the net plankton. The curves show the number of milligrams per cubic meter of water.

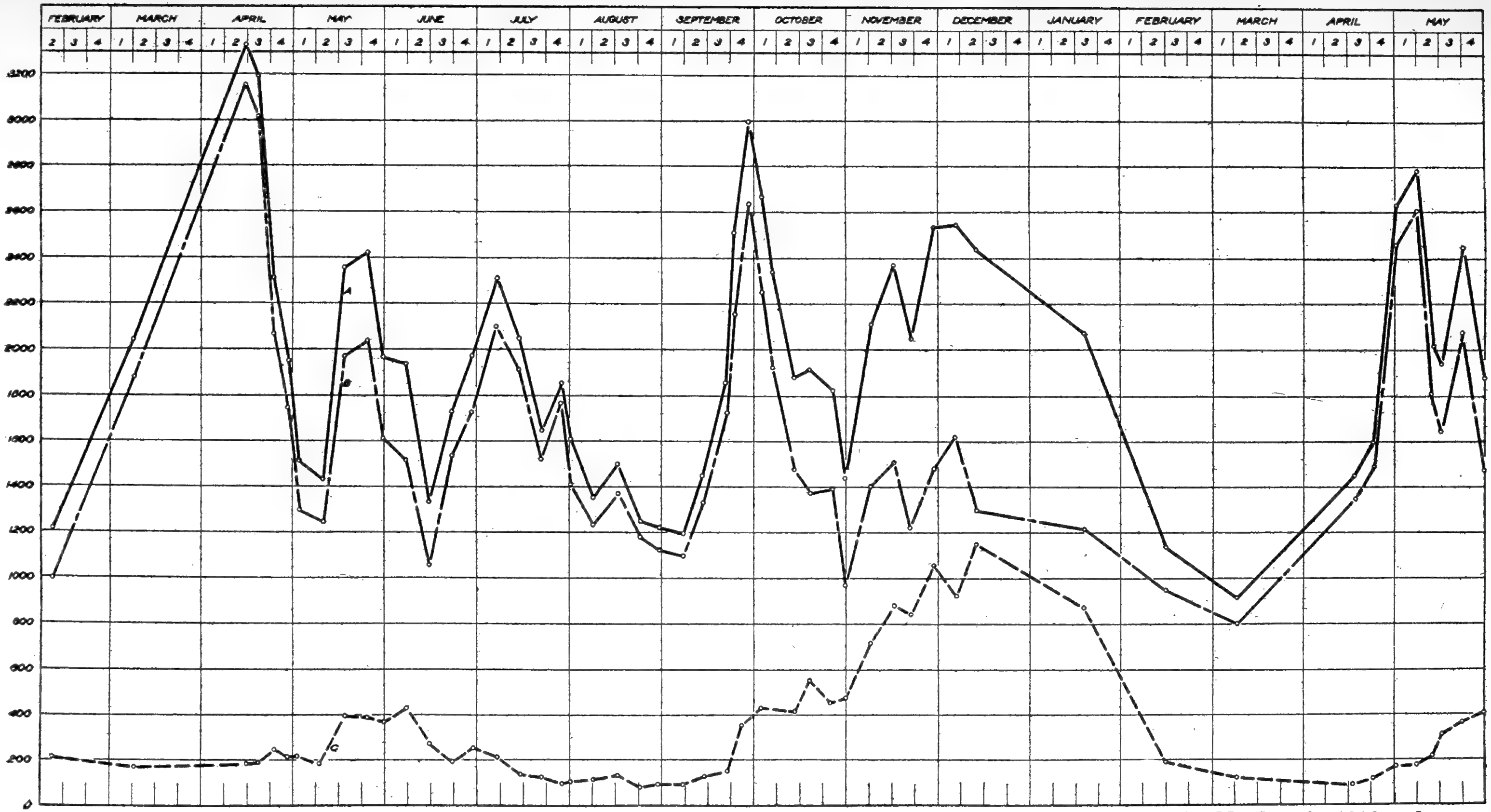

Fig. 35.—The amount of dry organic matter in the net plankton, the nannoplankton and the total plankton of Lake Mendota in 1916 and 1917. Curve A represents the total plankton, curve B the nannoplankton and curve C the net plankton. The curves show the number of milligrams per cubic meter of water.

and in November-December, 1916. In the former year, curve A presents a conspicuous peak in October corresponding to a similar peak in C, but which is not represented in B; in the latter year, curve A possesses a broad, prominent peak in November-December, 1916, and in January, 1917, which more closely resembles the one found in C at this time.

Expressing the relation of the amount of organic matter in the net plankton to that in the corresponding sample of nannoplankton in the form of a ratio also serves to bring out more clearly some of these quantitative differences. Taking the samples collected on December 12, 1916, in which the organic matter of the two is most nearly equal in amount, the following ratio is obtained, net plankton: nannoplankton=1:1.1; on the other hand, the samples which show the greatest difference, those collected on April 21-23, 1915, give a ratio of 1:24.6. Each year the largest differences were found during the vernal maximum of the nannoplankton; the nannoplanktonts thus appear to respond more promptly to the more favorable conditions which obtain after the ice disappears than the organisms in the net plankton. That is, the small forms multiply and develop more rapidly than the larger ones.

The ratios of the mean quantities of organic matter in the net plankton and in the nannoplankton are the same for 1915 and 1916, namely, 1:4.8, while that for the samples collected in 1917 is somewhat higher, that is, 1:5.9. The latter year, however, is incomplete; if the January samples, in which the net plankton is unusually large, are omitted, the ratio then becomes 1:7.8. In comparison with this, the samples obtained between February and June, 1916, give a ratio of 1:7.7, or substantially the same as that of the same period in 1917. Thus, it appears that, with the exception of the January samples, the normal ratio of the organic matter in the net plankton to that in the nannoplankton is shown by the material collected in 1917. In general, then, it may be said that, for the entire year, the nannoplankton of Lake Mendota yields an average of about five times as much organic matter as the net plankton; but, at certain times, the amounts may be almost equal, while at other times the nannoplankton may yield about twenty-five times as much organic matter as the net plankton.

Moore, Edie, Whitney, and Dakin[1] obtained from three to six times as much organic matter from sea water with a Chamberland filter as with No. 20 silk bolting cloth.

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[1] Biochemical Journal, Vol. 6, 1912, pp. 255-296.

Mean Quantity and Chemical Composition of Total Plankton

Table 25 gives a general summary of the results obtained for all of the samples of net plankton and of nannoplankton from Lake Mendota, as well as those from Lakes Monona, Waubesa, and Kegonsa, which are discussed in subsequent chapters. The results obtained by combining the net plankton and the nannoplankton into what has been called the total plankton are also indicated in this table.

The average amount of organic matter in the 184 samples of net plankton from Lake Mendota secured between 1911 and 1917 was 332.5 milligrams per cubic meter of water; in the various samples the quantity ranged from a minimum of 42.0 milligrams to a maximum of 1,135.0 milligrams per cubic meter of water. The average of 332.5 milligrams of organic matter contained 28.7 milligrams of nitrogen which was equivalent to about 180.0 milligrams of crude protein, 39.8 milligrams of ether extract, 11.4 milligrams of pentosans, and 22.8 milligrams of crude fiber. These four items account for 76.2 per cent of the organic matter. Since some of the pentosans may be derived from carbohydrates in the crude fiber and thus duplicate a certain amount of the latter, the pentosans may be omitted from this computation. The crude protein, ether extract, and crude fiber together give an average of 242.6 milligrams per cubic meter of water which is approximately 73.0 per cent of the organic matter; this leaves 27.0 per cent of the average quantity of the organic matter in the net plankton as nitrogen free extract.

For direct comparison with the nannoplankton samples, a summary of the corresponding samples of net plankton is included in the table. In making the computations for the total plankton, only the 84 samples of net plankton which cover the same period of time as the nannoplankton observations have been used, and not those of the entire series of net catches, namely, 184 samples. The average amount of organic matter in the 84 samples of net plankton collected between 1915 and 1917 is somewhat larger than that of the entire series of net catches, or 343.5 milligrams per cubic meter of water as compared with 332.5 milligrams; this represents a difference of only 11.0 milligrams, or slightly more than 3 per cent. The nitrogen, ether extract, pentosans, and crude fiber were slightly larger in the average of the 84 samples than in the whole series, the difference ranging from a fraction of a milligram to 2 milligrams per cubic meter of water. The crude protein, ether extract, and crude fiber constituted 70.1 per cent of the organic matter of these samples of net plankton; this is about 3 per cent below the average for the entire series of net catches. Approximately 30.0 per cent of the organic matter in these samples, therefore, consisted of nitrogen free extract.

The average quantity of dry organic matter in the entire series of nannoplankton samples from Lake Mendota is 1,630.5 milligrams per cubic meter of water, or about four and three-quarters times as much as that in the net plankton. The amount varied from a minimum of about 795.0 milligrams to a maximum of 3,151.0 milligrams per cubic meter of water. The average quantity contained 111.5 milligrams of nitrogen (equivalent to 697.0 milligrams of crude protein), 106.5 milligrams of ether extract, 78.6 milligrams of pentosans, and 84.6 milligrams of crude fiber. The crude protein, ether extract, and crude fiber together constituted 888.4 milligrams, or 54.5 per cent of the average quantity of organic matter. The remainder, 45.5 per cent, consisted of nitrogen free extract; the latter, therefore, was 15.5 per cent larger in the nannoplankton than in the net plankton.

The total plankton, that is, the net plankton plus the nannoplankton, yielded an average of 1,974.0 milligrams of dry organic matter per cubic meter of water from April, 1915, to June, 1917. In this material there were 878.2 milligrams of crude protein, 148.7 milligrams of ether extract, 90.2 milligrams of pentosans, and 105.0 milligrams of crude fiber. The crude protein, the ether extract, and the crude fiber amounted to 1,131.9 milligrams, or 57.3 per cent of the average quantity of organic matter, leaving 42.7 per cent as nitrogen free extract.

Total Plankton Per Unit Area

The total plankton may now be considered from the standpoint of the quantity per unit of area; the averages for the deep water are presented first and those for the entire lake later. Since the observations were made in the deeper part of Lake Mendota and extended to a depth of 20 meters, the results apply more particularly to this portion of the lake. For this part of the discussion, then, the 20 meter contour line may be taken as the boundary of the particular portion of the lake under consideration. This comprises an area of 6,641,000 square meters, or 16.8 per cent of the total area of the lake. The volume of water in this area down to a depth of 20 meters is 132,820,000 cubic meters and below this depth it is 13,449,000 cubic meters, giving a total of 146,269,000 cubic meters within this area, or 30.6 per cent of the total volume of the lake. The quantitative computations for the plankton of the deep water are thus based on this area and on this volume.

Total Plankton in Deep Water

The monthly averages for the entire set of observations on the total plankton have been ascertained from table 24 and these averages have been used to compute the quantity of organic matter per unit of surface. The results for the deep water are given in the first part of table 26 in which the quantities found for the different months of the year are expressed in kilograms per hectare and in pounds per acre. The average quantity of dry organic matter in the total plankton varies from a minimum of 257.7 kilograms per hectare (230 pounds per acre) in February to a maximum of 521.5 kilograms (465 pounds per acre) in December. While the largest single catches were obtained in April

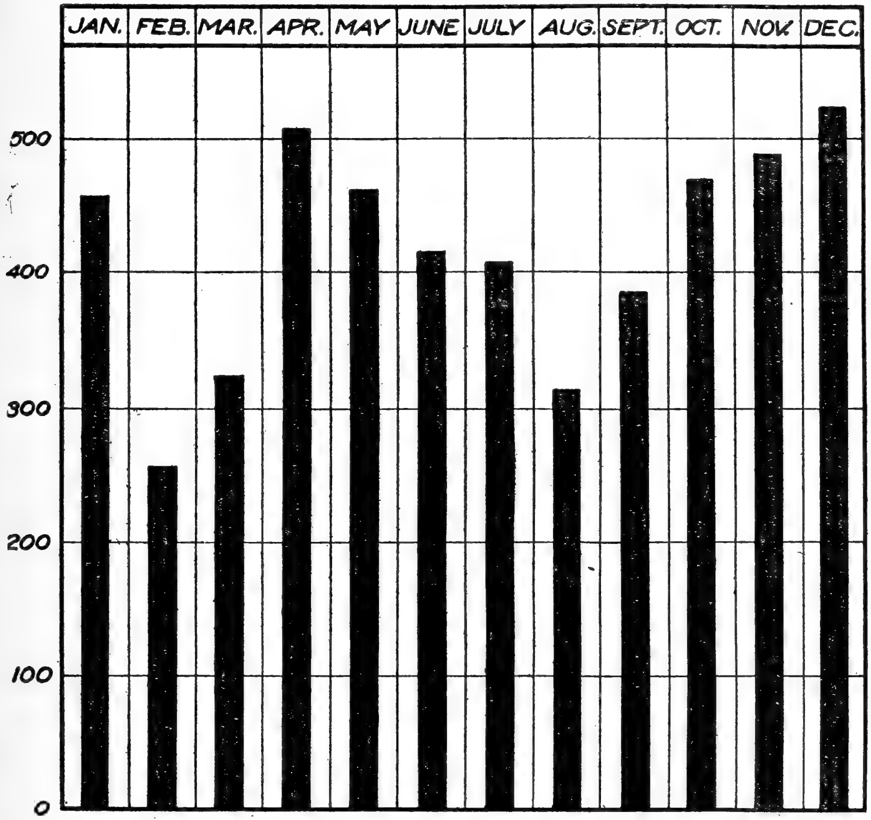

Fig. 36.—Diagram showing the monthly distribution of the total plankton in the deep part of Lake Mendota, 1915 to 1917. This diagram is based on the results given in table 24; it shows the average number of kilograms of dry organic matter per hectare of surface for the area bounded by the twenty meter contour line.

in 1915 and in 1916 and in May, 1917, the averages for these two months fall below that of December; this is especially true of the month of May.

The averages for the different months of the year are shown graphically in figure 36 in which the various columns indicate the average quantity of organic matter in the total plankton in kilograms per hectare of surface. The shortest column appears in February, while the next in length is found in August, and the third in March. The longest column is found in December, with April second and November third. Only two columns rise above the 500 kilogram line, namely, December and April, while February-March and August-September fall well below the 400 kilogram line, more especially the February average.

The figures given in table 26 and the columns indicated in diagram 36 show only the amount of dry organic matter per unit of area. In the living state, this material weighs about ten times as much as shown here because most of the organisms found in this material contain at least 90.0 per cent of water when alive, some of them in fact as much as 97.0 per cent. On this basis, then, the quantity of living organic matter in the total plankton in this portion of Lake Mendota ranges from a minimum of 2,577 kilograms per hectare (2,300 pounds per acre) in February to a maximum of 5,215 kilograms per hectare (4,652 pounds per acre) in December. An additional 10.0 per cent to 15.0 per cent of the dry weight would be contributed to this total by the ash of the various organisms.

Attention may be again called to the fact that these figures show only what has been referred to as the standing or permanent crop, that is, the amount of material that is present constantly during the different months of the year. Therefore, they do not show how large a quantity of organic matter is produced in the course of a year. Each plankton form that appears during the year plays its particular rôle in the production of this material; each comes on, passes through its regular cycle when conditions are most favorable for it, and then declines to a minimum number or disappears entirely for a certain portion of the year. When some forms are on the wane, others are usually ready to take their places to a greater or less extent, so that, while there are marked variations in quantity during the year, there is no period during which all forms are absent. This results in a complex overlapping of the crops of the various planktonts which continues throughout all seasons of the year.

The problem of ascertaining the amount of plankton material produced by the lake annually is made extremely difficult by this overlapping of the various forms and also by the fact that production is a continuous process. There are no definite breaks in the stream of plankton life which might serve to mark off one season's or one year's production from another. Concomitant with the process of production, also, is the process of destruction; some of the planktonts are constantly being consumed as food by other organisms. Even some members of the group, such as the plankton crustacea, feed upon others, such as the algae and flagellates. The crustacea, in turn, are preyed upon by the larger forms. In addition to these losses, a certain portion of the plankton is constantly dying and sinking to the bottom. Thus, the quantity of plankton material maintained by the lake is the resultant of the productive processes and of the various destructive processes. In spite of the various changes in quantity in the course of the year, the amount of material found during a particular month does not differ so very greatly from year to year.

In the spring the water is kept in fairly complete circulation by the wind from the time of the disappearance of the ice, which usually takes place about the first week in April, until early June; the same is true for the autumn and early winter, or from the autumnal overturn about the first week in October until the lake becomes covered with ice, usually in December. As a result of this extensive circulation of the water at these seasons, the plankton becomes fairly uniformly distributed from surface to bottom for about four to five months each year. Since the mean depth of the water within the 20 meter contour is 22 meters, the quantity of plankton in the upper 11 meters would be half as large as that shown in table 26 during these periods of general circulation and one-quarter as great in the upper 5.5 meters.

In summer and in winter, however, the plankton organisms do not have such a uniform distribution; the upper strata in summer are more densely populated than the lower, while in winter after the lake becomes covered with ice there is a tendency for the chlorophyl-bearing organisms to come nearer the surface where light conditions are more favorable and for the crustacea to be more numerous in the lower strata where the water is somewhat warmer.

Two special runs made on August 7, 1915, will serve to illustrate the unequal distribution of the plankton at this time of the year. The results for organic matter are shown in table 27. Samples No. 593 and No. 594 represent the organic matter in the nannoplankton and in the net plankton respectively, from the 0-13 meter stratum; this stratum included the epilimnion and the mesolimnion at this time. Samples No. 591 and No. 592 are the catches of nannoplankton and net plankton from the 14-20 meter stratum and they represent the hypolimnion. The nannoplankton obtained from the 0-13 meter stratum yielded nearly two and a half times as much organic matter per cubic meter of water as that from the 14-20 meter stratum. The difference was still more striking in the net plankton; the upper stratum yielded almost twelve times as much organic matter per cubic meter as the lower stratum.

Enumerations were made for the purpose of ascertaining the vertical distribution of the various plankton organisms at the time these catches were secured and, on the basis of these counts, the amount of organic matter in the 0-5 meter and in the 0-10 meter strata have been estimated. These estimates together with the results obtained in the observations are given in table 28; they are indicated in kilograms per hectare and in pounds per acre. According to the estimates nearly 37.0 per cent of the organic matter in the total plankton came from the upper 5 meters, while a little more than two-thirds of it was obtained from the 0-10 meter stratum. The catches show that 79.5 per cent of the total quantity of organic matter came from the 0-13 meter stratum, leaving only 20.5 per cent for the 14-23 meter stratum.

Some data were obtained on the horizontal distribution of the plankton by taking one of the two catches of a week about four kilometers (2.5 miles) west of the regular station. The total plankton obtained at the regular station on July 10, 1916, yielded 1,968.7 milligrams of organic matter per cubic meter of water, while the catch taken in the western part of the lake on July 14, 1916, gave 1,972.9 milligrams. The difference is only 4.2 milligrams per cubic meter which indicates a pretty uniform horizontal distribution of the material.

Plankton of Entire Lake Per Unit of Area

The monthly averages for organic matter may now be considered on the basis of the amount per unit area when the surface of the whole lake is taken into account. In general, the amount of plankton under a unit of surface is dependent upon the depth of the water since the volume of water occupied by the organisms is proportional to the depth. Unfavorable factors, such as the absence of dissolved oxygen, insufficient light, and low temperature, may exclude many organisms from the deeper strata, still certain forms occupy the lower water even when such conditions exist. The population of this region may be scant in comparison with the upper strata, as shown in table 27, yet those forms which occupy the lower strata contribute their quota to the total quantity of plankton under a unit of surface. Thus, while the increase in plankton would not be directly proportional to an increase in depth during periods of unequal vertical distribution, still an increase in depth at such times would show a well marked increase in some of the organisms.

It must be borne in mind, therefore, that, in stating the results in averages for the entire lake, a larger quantity of plankton than is actually present there, is attributed to the water which is shallower than the mean depth of the lake, while, on the other hand, the amount assigned to the deeper water is smaller than it should be. For example, the mean depth of Lake Mendota is 12.14 meters, so that the average quantities give results that are too high for areas with a smaller depth than this and too low for the areas with a greater depth of water. This method of stating the results would show the actual conditions only in a lake with straight sides and a uniform depth. Taking the variations in depth into account would complicate the problem too much and the discussion is confined, therefore, to the averages for the total area of the lake.

In computing the results for the entire area of the lake, the monthly averages per cubic meter of water were ascertained from table 24 and these averages were then multiplied by the mean depth of the lake (volume÷area=mean depth). The results of these computations are shown in the second part of table 26 in which the amounts of organic matter are indicated in kilograms per hectare and in pounds per acre. The quantity per unit of area, when the total surface of the lake is considered, is a little more than 55.0 per cent of that found in the deep water as shown in the first part of this table; that is, by this method of calculating the results, approximately 45.0 per cent of the material noted in the deep water is attributed to the shallower water. On this basis the amount of dry organic matter in the total plankton varies from a minimum of 141.4 kilograms per hectare (126 pounds per acre) in February to a maximum of 287.5 kilograms (256 pounds per acre) in December, or slightly more than a twofold variation. The living material, on the other hand, would weigh at least ten times as much as this.

CHAPTER V

THE PLANKTON OF LAKE MONONA

Samples of net plankton were obtained from Lake Monona each year from 1911 to 1916, inclusive, with the exception of 1914. This material was secured chiefly for the purpose of making qualitative and quantitative comparisons with the results obtained on Lake Mendota. No winter observations were made on Lake Monona and it was not practicable to begin the work very promptly in the spring nor to continue it very late in the autumn, so that the catches cover only the period from late May to late October or early November.

The area, volume, and mean depth of Lake Monona are much smaller than those of Lake Mendota, but the maximum depth of the former is only about three meters less than that of the latter. (Table 1, p. 181). Lake Monona receives the water from the outlet of Lake Mendota as well as that from two other streams. The water of Lake Monona is subject to considerable pollution, which is a matter of much importance both from a biological and from a chemical standpoint. It receives (a) the effluent of the sewage disposal plant of Madison, (b) the greater part of the storm water drainage of this city, (c) the effluent from a small private sewage disposal plant at South Madison, and (d) some trade wastes consisting principally of the effluent from a large beet sugar factory. Just what effect this pollution has upon the plankton crop of the lake is not definitely known, but these polluted waters carry an abundance of material which may be utilized by various plankton organisms.

The Net Plankton

Table 2 (p. 181) shows the number of samples of net plankton procured each year, as well as the volume of water strained and the total quantity of dry plankton. Only four samples were taken in 1911 and but six in 1912. In 1913 and in 1916 catches were obtained at more frequent intervals so that the data are sufficient to construct curves for the results of these two years. In general the net plankton of Lake Monona contained a larger proportion of algal material than that of Lake Mendota.

Organic matter. The organic matter constituted from 68.9 per cent to 97.7 per cent of the total dry weight of the net plankton, with an average of 85.4 per cent for the whole series of 47 samples. The variations in the amount are summarized in table 29, in which the quantities are given in milligrams per cubic meter of water. Details for the organic matter and the chemical analyses are given in the general table, No. 45, p. 210. The maximum quantities in the different years ranged from 519.3 milligrams of organic matter in 1911 to 3,303.6 milligrams per cubic meter of water in 1912. The smallest minimum was found in 1916 and the largest in 1915. The smallest mean was noted in 1911 and the largest in 1915. The average amount of organic matter yielded by the 47 samples of net plankton was 850.2 milligrams per cubic meter of water as compared with 332.5 milligrams in Lake Mendota.

Curves indicating the number of milligrams of dry organic matter per cubic meter of water are shown in figure 37 for the summer and autumn of 1913 and 1916. The curve marked A represents the results for the net plankton in 1913 and the one marked B those of 1916. In the former there was a comparatively small rise in the quantity of organic matter during the month of June but this was followed by a marked rise in July. The amount remained high during the early part of August so that the curve shows a conspicuous peak covering this period of time. This was followed by a minimum during the early part of September; following this came the autumnal rise which reached its maximum point about the middle of October.

In 1916 there was a slight decrease in the amount of organic matter in the net plankton between the middle of May and the middle of June, but there was a marked increase during the third week in June, followed by a gradual decline during the first half of July. This forms a prominent peak in the curve extending from the middle of June to about the middle of the third week in July. The quantity then remained fairly uniform until the middle of August, after which time it declined to a minimum covering the latter part of August and the first half of September. There was a gradual rise after this time but there was no autumn maximum this year comparable to that of 1913.

Nitrogen. Quantitative determinations of the nitrogen were made on 41 samples of the net plankton from Lake Monona; the results of these analyses are summarized in table 30. The highest percentage of nitrogen was noted in material obtained in 1915 and the lowest in 1911. The mean percentage was lowest in 1916, namely, 8.37 per cent, and highest in 1915, namely, 10.71 per cent, thus showing a difference of 2.34 per cent.

When stated in milligrams per cubic meter of water, the largest amount of nitrogen was found in 1912, namely, 302.2 milligrams, and the smallest in 1911, that is, 13.2 milligrams. The mean quantity was highest in 1915 and lowest in 1911.

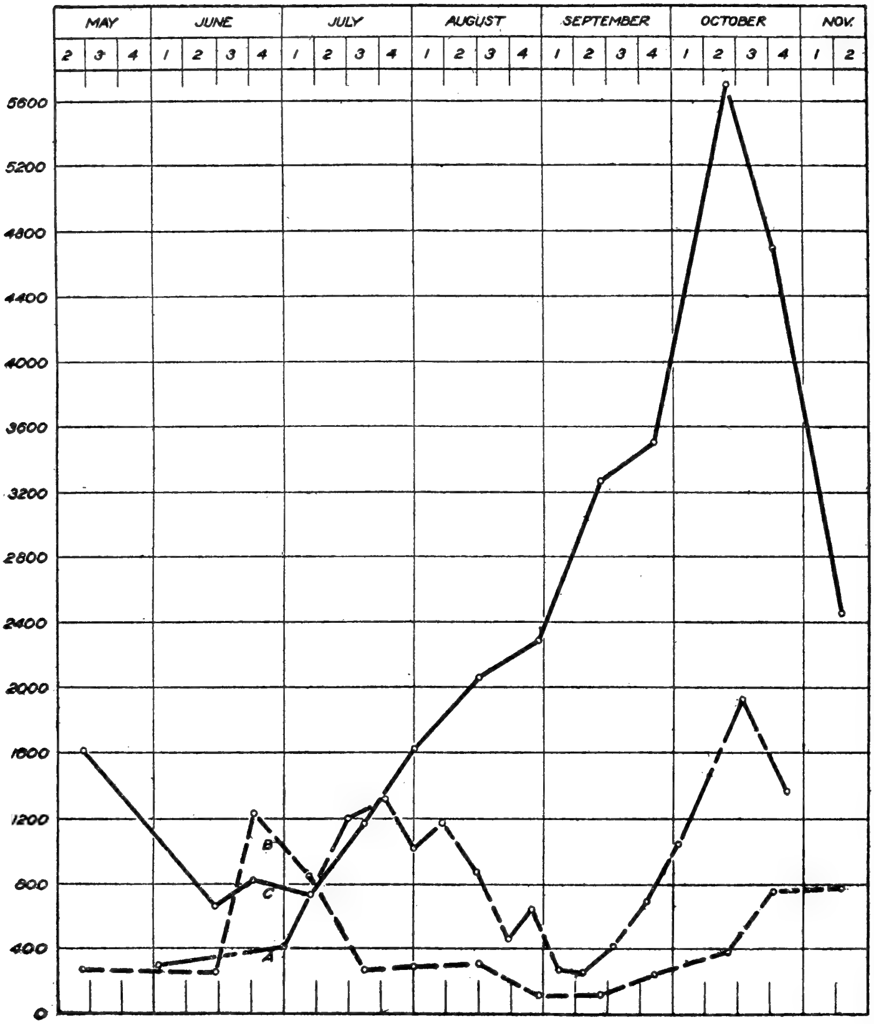

Fig. 37.—The quantity of dry organic matter in the net plankton of Lake Monona in 1913 and 1916, and in the nannoplankton in 1916. Curve A represents the net plankton in 1913, curve B the net plankton in 1916 and curve C the nannoplankton in 1916. The amounts are indicated in milligrams per cubic meter of water. See tables 45 and 46.

The ratio of the organic matter to the total nitrogen in the net plankton of Lake Monona varied from 8.5 to 14.6. (See table 45.) In three-quarters of the samples upon which nitrogen determinations were made, however, the ratio fell between 9 and 12, thus showing a fairly constant proportion of nitrogen in the organic matter. The proportion was larger in the samples collected in 1915 than in those of any other year; in only one sample obtained in this year did the nitrogen fall below 10.0 per cent of the organic matter, while it reached or exceeded this percentage in but one sample collected in the other years.

Crude protein. The results for crude protein are shown in table 31, p. 198. The highest percentages for the different years varied from 60.4 per cent in 1912 to 73.2 per cent in 1915, a difference of approximately 13.0 per cent; the minima ranged from 42.7 per cent in 1911 to 62.6 per cent in 1915, a difference of almost 20.0 per cent. With the exception of 1915 the range of variation in the mean is less than 5.0 per cent; the mean percentage of 1915, however, is from 9.5 per cent to 13.1 per cent higher than those of the other years. This is a smaller range of variation than in the net plankton from Lake Mendota where there is a difference of 15.1 per cent in the mean percentages of the different years. In general the net plankton of Lake Monona has a distinctly higher percentage of crude protein than that of Lake Mendota. Only three of the annual means for Lake Mendota exceed the minimum for Lake Monona. (See table 7, p. 187.) The mean percentage of crude protein in the 41 samples from Lake Monona, on which nitrogen determinations were made, is 56.4 per cent, while that for 166 samples from Lake Mendota is 52.4 per cent, just 4.0 per cent smaller.

The largest amount of crude protein was found in 1912, namely, 1,888.7 milligrams per cubic meter of water and the smallest amount in 1911, or 112.5 milligrams. The latter year also yielded the smallest mean of the five years in which observations were made on Lake Monona.

Ether extract. The percentage of ether extract in the net plankton ranged from a minimum of 2.79 per cent in sample No. 330, July 30, 1913, to a maximum of 11.16 per cent of the organic matter in sample No. 659, June 23, 1916. (Table 45.) The mean percentages for the different years fall between 4.77 per cent and 9.62 per cent. The mean for the 35 determinations is 7.23 per cent. This percentage is much lower than that of the net plankton of Lake Mendota; the highest mean of Lake Monona, 9.62 per cent, is distinctly lower than the lowest mean for the various years on Lake Mendota, namely, 11.27 per cent. (See table 32, p. 199.)

The amount of ether extract per cubic meter of water varied from a minimum of 12.6 milligrams in sample No. 114, July 27, 1911, to a maximum of 171.8 milligrams in sample No. 5167, October 15, 1915. The mean quantities for the different years ranged from 27.5 milligrams in 1911 to 105.6 milligrams in 1916. Only two determinations were made on the samples collected in 1916 and they were made on samples which contained a large amount of organic matter, so that they cannot be regarded as representative of the whole series of net catches obtained in 1916. The mean quantity for the 35 determinations on

Lake Monona material is 61.5 milligrams per cubic meter of water. This average is about one and a half times as large as that of the net plankton of Lake Mendota; while the percentage of ether extract averages lower in the material from the former than in that from the latter lake, the amount per cubic meter of water is greater in Lake Monona because the quantity of organic matter is much larger than in Lake Mendota.

Pentosans. The pentosans were determined for only 20 samples of net plankton from Lake Monona and 13 of these were on material collected in 1913; therefore, no comparisons of the different years can be made. (See general table No. 45). In the 20 samples on which determinations were made the percentage of the pentosans varied from a minimum of 3.07 per cent to a maximum of 10.6 per cent. The latter was found in sample No. 345, August 27, 1913, which contained a large amount of Microcystis; this form, in fact, constituted by far the greater part of the net material. The average percentage for the 20 samples on which determinations were made, amounted to 8.23 per cent of the organic matter as compared with an average of 3.5 per cent for 92 analyses of material from Lake Mendota.

The quantity of pentosans varied from a minimum of 11.2 milligrams per cubic meter of water to a maximum of 228.3 milligrams. The latter was found in sample No. 238, October 15, 1912; this sample contained a larger amount of organic matter than usual and it contained very large numbers of Microcystis and Melosira. The 20 analyses of material from Lake Monona yielded an average of 70.0 milligrams per cubic meter of water, while the material from Lake Mendota gave an average of 11.7 milligrams for 92 samples, a sixfold difference.

Crude Fiber. The crude fiber was determined for 26 samples of net plankton from Lake Monona; 16 of the catches belonged to the series obtained in 1913. In general the percentage of crude fiber was comparatively low; it ranged from a minimum of 1.56 per cent of the organic matter in sample No. 340, August 20, 1913, to a maximum of 9.74 per cent in No. 308, May 30 and June 4, 1913. The average for all of the analyses was 5.0 per cent as compared with an average of 6.82 per cent for the net plankton of Lake Mendota.

The quantity of crude fiber in the net plankton of Lake Monona varied from 7.2 milligrams per cubic meter of water to 92.5 milligrams. The 26 analyses yielded an average of 42.6 milligrams, or almost twice as much as the net plankton of Lake Mendota; while the percentage was lower in the former lake, the total yield was larger because the quantity of organic matter was larger than in Lake Mendota.

Nitrogen Free Extract. The crude protein, ether extract, crude fiber, and ash were all determined on 27 of the 41 samples of net plankton from Lake Monona so that the nitrogen free extract can be computed for this number of catches. Together these four items constituted a minimum of only about 51.0 per cent of the dry material in sample No. 345, thus leaving 49.0 per cent for the nitrogen free extract consisting of the carbohydrates that were not included in the crude fiber.

The maximum percentage of crude protein, ether extract, crude fiber, and ash was found in sample No. 5167 in which they constituted almost 85.0 per cent of the dry weight of the sample, so that substantially only 15.0 per cent consisted of nitrogen free extract. These results show that the nitrogen free extract in the net plankton of Lake Monona ranges from a minimum of about 15.0 per cent of the dry material to a maximum of 49.0 per cent, or somewhat more than a threefold variation.

Ash. The lowest percentage of ash found in the 47 samples of net plankton from Lake Monona amounted to 2.28 per cent of the dry weight of the material in sample No. 345, August 27, 1913, and the highest was 33.19 per cent in sample No. 6111, August 15, 1916; thus, there was almost a fifteenfold difference between the maximum and the minimum. Table 33 (p. 199) gives a summary of the ash determinations and the complete data are given in the general table, No. 45. The lowest percentages were found from late July to early September, 1913, and the highest ones in the year 1916. Of the 13 samples obtained in 1916 the percentage of ash amounted to 20.0 per cent or more in 8 of them, while in the other 34 samples of the series only 5 contained 20.0 per cent of ash or more. In general, the net plankton of Lake Monona contained a distinctly smaller percentage of ash than that of Lake Mendota.

The net plankton of Lake Monona showed a considerable variation in the maximum and minimum percentages of ash from year to year, but the general result was a marked increase in the mean percentage of ash from 1911 to 1916; each year showed an appreciable increase over the previous one. The mean for 1916, for example, is more than two and a half times as much as that of 1911, the difference amounting to 13.51 per cent. A similar rise in the mean percentage of ash in the net plankton of Lake Mendota was noted between 1911 and 1915, with the exception of 1914; the mean for 1915 was 11.44 per cent higher than that of 1911. (See table 14, p. 190).

Silica. The percentage of silica was determined for all but two of the net catches from Lake Monona; in these two instances the material was accidentally lost before the determination was completed. The results are summarized in the second part of table 33. Silica is present in largest amounts when diatoms are most abundant, usually in spring and in autumn. A high percentage of silica was found on August 15, 1916, which was due to a large crop of diatoms at that time.

The silica varied from a minimum of 0.12 per cent of the dry weight of the sample in one catch obtained in 1913 to a maximum of 27.05 per cent in one of the catches of 1916. The mean percentage was lowest in 1911 and highest in 1916, but there was no regular increase between these dates as already indicated for the ash. In general the mean percentage of silica was much lower in the net plankton of Lake Monona than in that for the corresponding years from Lake Mendota.

The difference between the mean percentage of ash and the mean percentage of silica of the same year represents the average of the other inorganic constituents of the ash. This difference is shown in the last column of table 33. The smallest difference is indicated for 1912 and the largest for 1916, the latter being more than twice as large as the former. There is the same marked increase in this difference in the later years over the earlier ones corresponding more or less closely to the increase in ash. In 1913 and in 1916 the differences were substantially the same for Lake Monona as for Lake Mendota, but in the other years they were lower in the former lake.

The ash of two samples of net plankton from Lake Monona was subjected to a further analysis and the results are shown in table 15, p. 190. Both of these samples were collected in 1913, one on July 30 (No. 330) and the other on September 24 (No. 354). The ash amounted to 6.20 per cent of the dry sample in the former catch and to 12.16 per cent in the latter. The marked difference was due mainly to a difference in the amount of silica in the two samples. The latter sample also contained a distinctly larger proportion of Fe_2O_3 and Al_2O_3 than the former. Deducting the percentage of silica and the percentage of iron and alumina from the percentage of ash in each sample reduces the difference between the two to only 0.71 per cent. Of the remaining constituents, P_2O_5 and CaO are the most important. It will be noted, also, that the percentage of MgO in sample No. 330 is four times as large as that of No. 354. The variations in the percentages of the different constituents of these two ashes, however, come within the range of those noted in the ash analyses of the net plankton of Lake Mendota.

Organisms of the Net Plankton

The crustacea were well represented in the net plankton of Lake Monona. The copepods included species of Diaptomus and Cyclops together with their nauplii; there were five forms of Cladocera, namely, *Daphnia pulex, D. hyalina, D. retrocurva,* Chydorus, and Leptodora.

Half a dozen kinds of rotifers were noted, but only one, *Anuraea cochlearis,* appeared regularly in the catches. The flagellates were represented by Ceratium and Volvox.

The green and blue-green algae consisted of representatives of Microcystis, Coelosphaerium, Aphanizomenon, Anabaena, Lyngbya, Staurastrum, and Pediastrum, while the diatoms included forms belonging to Melosira, Tabellaria, Fragilaria, Asterionella, Synedra, and Stephanodiscus.

The largest net catch of the entire series of observations was obtained on October 15, 1912. (See sample No. 238, table 45). The chief constituents of this material were two algal forms, namely, Microcystis and Melosira. The former yielded nearly three million colonies per cubic meter of water and the latter two and a half million filaments per cubic meter. Fragilaria was also fairly abundant at this time, the number being approximately three-quarters of a million per cubic meter.

The samples collected in 1913 yielded two maxima of organic matter, one on July 24 (sample No. 326) and another on October 18 (No. 360). The former was due mainly to a rise in the amount of Lyngbya and Microcystis; a cladoceran, Chydorus, also showed a sixfold increase in number between July 15 and July 24. The October maximum was produced by a very large crop of the diatom Melosira. (See figure 37, curve A.)

Two maxima of organic matter were also found in 1915, one on June 23 (sample No. 554, table 45) and another on October 15 (sample No. 5167). The catch obtained on June 23 consisted mainly of Aphanizomenon, an enormous crop of which was present in the upper water at this time. The chief constituents of the net plankton during the October maximum were Microcystis and Melosira.

In 1916 there was almost a fivefold increase in the organic matter of the net plankton between June 14 and June 23 (sample No. 649 and No. 659); this was due to a marked increase in the number of *Daphnia pulex.* By far the greater portion of the material in sample No. 659 consisted of this cladoceran, while only a minor part was furnished by the algae; this is the only instance in any of the lakes wherein a marked rise of the organic matter of the net plankton could be attributed directly and solely to any organism other than an alga. The scarcity of the algae in the net plankton at this time was due, undoubtedly, to the fact that the large Daphnia population was feeding extensively on them. (See figure 37, curve B.)

Following the Daphnia maximum a very large crop of Volvox was found in the upper water of Lake Monona on July 6, 1916. Colonies of this flagellate were present in enormous numbers at a depth of three meters on this date so that a substantially pure catch, amounting to a little more than 22 grams of dry material, was obtained for a chemical analysis. The results of this analysis are given in table 49, p. 215. This material was obtained about 10 a. m. on a bright, calm day and the colonies of Volvox were concentrated in a relatively narrow stratum about three meters below the surface of the water, thus showing a definite negative reaction to the sunlight. Their subsequent behavior was studied by Smith[1] and the results of his investigation have already been published.

The autumn maximum of organic matter in the net plankton of 1916 was noted on November 9 (sample No. 6183) and it was due chiefly to a large crop of Melosira. Stephanodiscus also showed a fairly large increase in numbers at this time.

The Nannoplankton

Quantitative studies of the nannoplankton of Lake Monona were made in 1915 and in 1916; 8 samples were obtained in the former year between June 23 and October 29, and 13 samples in the latter year between May 12 and November 9. The amount of water centrifuged in 1915 was 9,777 liters and 12,510 liters in 1916, making a total of 22,287 liters for the two years. (See table 3, p. 182.)

Organic Matter. The results of the determinations of the organic matter in the nannoplankton material from Lake Monona are shown in table 29, p. 198. In 1915 the largest amount of organic matter was found in sample No. 5166, October 15, and the smallest amount in No. 563, July 13; the former sample yielded 3,746.5 milligrams per cubic meter of water and the latter 723.0 milligrams, a little more than a fivefold difference. In 1916 the maximum amount was noted in sample No. 6158 on October 12, namely, 5,696.2 milligrams and the minimum amount in No. 648 on June 14, namely, 672.1 milligrams; the former quantity is approximately eight and a half times as much as the latter. (Table 46.) While the maximum was very much higher in 1916 than in 1915, the mean of the two years was substantially the same, namely, 2,355.6 milligrams and 2,339.5 milligrams, respectively, the average amount for 1915 being only 16.1 milligrams smaller than that for 1916.

The maximum amounts of dry organic matter in the nannoplankton of Lake Monona were appreciably higher than those noted for Lake Mendota; in the latter lake, for example, the maximum for 1915 was 2,776.3 milligrams per cubic meter of water, 3,151.5 milligrams in 1916, and 2,603.4 milligrams in 1917. In 1915 a summer minimum of 944.2 milligrams was noted in August in Lake Mendota, while in the summer of 1916 the smallest amount of organic matter, 1,053.5 milligrams per

[1] Amer. Jour. Botany, Vol. 5, 1917, pp. 178-185.

cubic meter, was found about the middle of June. Thus, the summer minima were much higher in Lake Mendota in both years than in Lake Monona; the minimum in the former lake which came nearest to the summer minima of the latter was the one obtained on March 9, 1917, when the nannoplankton of Lake Mendota yielded only 795.2 milligrams of dry organic matter per cubic meter of water. The range of variation in the amount of organic matter in the nannoplankton of Lake Monona is much greater, therefore, than in that of Lake Mendota.

The results for organic matter in the nannoplankton of Lake Monona can not be indicated by a diagram for the year 1915 because the observations were not made frequently enough in that year for this purpose, but the collections were made with sufficient regularity in 1916 for the construction of a curve showing the results. The curve marked C in figure 37 indicates the number of milligrams of dry organic matter per cubic meter of water in the nannoplankton samples obtained in 1916. This diagram shows that there was a decline in the organic matter between May 12 and June 14, with only a slight rise between the latter date and July 6. By July 18, however, there was an appreciable increase in the quantity and this rise continued thereafter until it reached a maximum point on October 12. A very marked decrease followed on October 29 and on November 9, so that the curve shows a sharp peak covering the autumnal period. Attention should be called to the fact here that, in late June and early July, curve C falls below curve B in this diagram; the former curve (C) represents the organic matter in the nannoplankton and the latter (B) that in the net plankton. That is, during this period of time the nannoplankton yielded a smaller amount of organic matter per cubic meter than the net plankton. This phenomenon was noted in two samples obtained in 1915 and in two collected in 1916.

According to curve C the story of the organic matter in the nannoplankton of Lake Monona was comparatively simple in 1916. The first observation of that year served to show that there was a more or less marked vernal maximum; this was followed by a decline to a summer minimum in late June and early July. Thereafter the organic matter steadily increased in amount until an autumnal maximum was reached on October 12; a marked decrease was noted during the following month and this decline continued, doubtless, until a winter minimum was attained. The annual cycle, therefore, consisted of four phases, namely, summer and winter minima separated by spring and autumn maxima, just as has been noted for Lake Mendota. A comparison of curve C of this diagram with curve B in figure 35 shows, though, that the various changes were much less complex in Lake Monona than in Lake Mendota during the same period of time in 1916, so that the curve is much simpler for the former lake than for the latter.

Nitrogen. The nitrogen content of all of the nannoplankton samples obtained on Lake Monona in 1915 and in 1916 was determined. A summary of the results is given in table 34. On an ash free basis the nitrogen ranged from a maximum of 11.28 per cent to a minimum of 5.92 per cent in the former year and from 10.08 per cent to 3.58 per cent in the latter year. The difference for 1915 was about twofold and for 1916 almost threefold. Both maximum and minimum were higher in 1915 than in 1916, and the mean percentage, likewise, was almost two per cent higher in the former year.

The maximum percentage of nitrogen in the net plankton was somewhat higher in 1915 than in the corresponding nannoplankton catches, but it was lower in the net plankton in 1916 than in the nannoplankton. (Compare tables 30 and 34.) The minimum for nannoplankton was below that of the net plankton both in 1915 and in 1916; the mean percentages also show small differences in favor of the former.

A rise in the percentage of nitrogen in the nannoplankton of Lake Monona accompanied the increase in the quantity of organic matter in 1915 as well as in 1916. (See general table, No. 46.) In the former year the largest percentage was found in sample No. 5144, collected on September 24, in which the quantity of organic matter was within 15.0 per cent of the maximum for the year, and in 1916 it was noted in sample No. 6158, October 12, which yielded the largest quantity of organic matter in that year. In Lake Mendota, on the other hand, the maximum percentage of nitrogen in the nannoplankton was found during the third week in June both in 1915 and in 1916 and at this time the quantity of organic matter was distinctly below the annual mean. In 1917 the maximum was noted on May 23, which was about two weeks after the organic matter had reached its highest point; the quantity of organic matter at this time was 80.0 per cent of the amount obtained two weeks earlier.

When expressed in terms of milligrams per cubic meter of water the largest quantity of nitrogen was found in sample No. 6158 obtained from Lake Monona on October 12, 1916; but the minimum for 1916 as well as the mean for this year fell below those of the year 1915.

The ratio of the organic matter to the total nitrogen in the nannoplankton of Lake Monona varied from 8.1 to 27.9, more than a threefold difference. (See table 46.) This is a much greater variation than in the net plankton; in the latter three quarters of the ratios fall between 9 and 12, while in the nannoplankton material only half of them are within these limits. In eight of the nannoplankton samples, also, the proportion of nitrogen falls below the minimum of the net samples.

Crude Protein. The nitrogen results have been expressed in terms of crude protein in table 35; the first part of the table shows the percentage of crude protein in the organic matter and the second part the amount per cubic meter of water. As might be expected from the nitrogen results the maximum and minimum percentages were higher in 1915 than in 1916 and the mean percentage was nearly 12.0 per cent higher in the former year. In 1915 the crude protein fell below 50.0 per cent of the organic matter in only two of the eight samples, but in 1916 it fell below this figure in eight of the thirteen samples; in one instance, namely, sample No. 620, it fell as low as 22.4 per cent. The maximum was noted in one sample obtained in 1915 which contained 70.4 per cent of crude protein in the organic matter.

The mean percentage of crude protein was higher in the nannoplankton material from Lake Monona than in that from Lake Mendota. (See table 19, p. 192.) The difference in favor of the former lake was 18.9 per cent in 1915 and 12.7 per cent in 1916. The mean for the samples obtained from Lake Mendota in 1917 was substantially the same as that of Lake Monona in 1916; the samples collected from the former lake in 1917, however, were all obtained by June 1 of that year and the material was, therefore, not representative of a complete year. As a whole the nannoplankton of Lake Mendota contained a smaller percentage of crude protein than that of Lake Monona.

In 1915 the mean quantity of crude protein in the nannoplankton material from Lake Monona was a little more than twice as large as that in the nannoplankton from Lake Mendota, while in 1916 it was a little less than twice as large in the former lake. (Compare tables 19 and 35.)

Attention may also be called to the fact that the increase in the quantity of organic matter in the nannoplankton in Lake Monona was accompanied by a rise in the percentage of crude protein both in 1915 and in 1916; in both years the maximum percentage was found when the organic matter had nearly or quite reached its maximum quantity. (See table 46.)

The relation between the organic matter and the crude protein in the nannoplankton of Lake Monona for the year 1916 is shown in figure 38, in which the amounts of each are given in milligrams per cubic meter of water. In this figure the space between the zero line and the curve marked B represents the crude protein, while the space between B and A, the latter being the curve for the organic matter, represents the other organic constituents of the nannoplankton. The smallest proportion of protein was found on May 12, that is, in the first sample obtained in this year, and the largest proportion was noted for the sample obtained on October 12, when the organic matter reached the highest point of the year. Between May 12 and June 14 the organic matter decreased in amount relatively more than the crude protein, but beyond the latter date the two curves are very similar in outline.

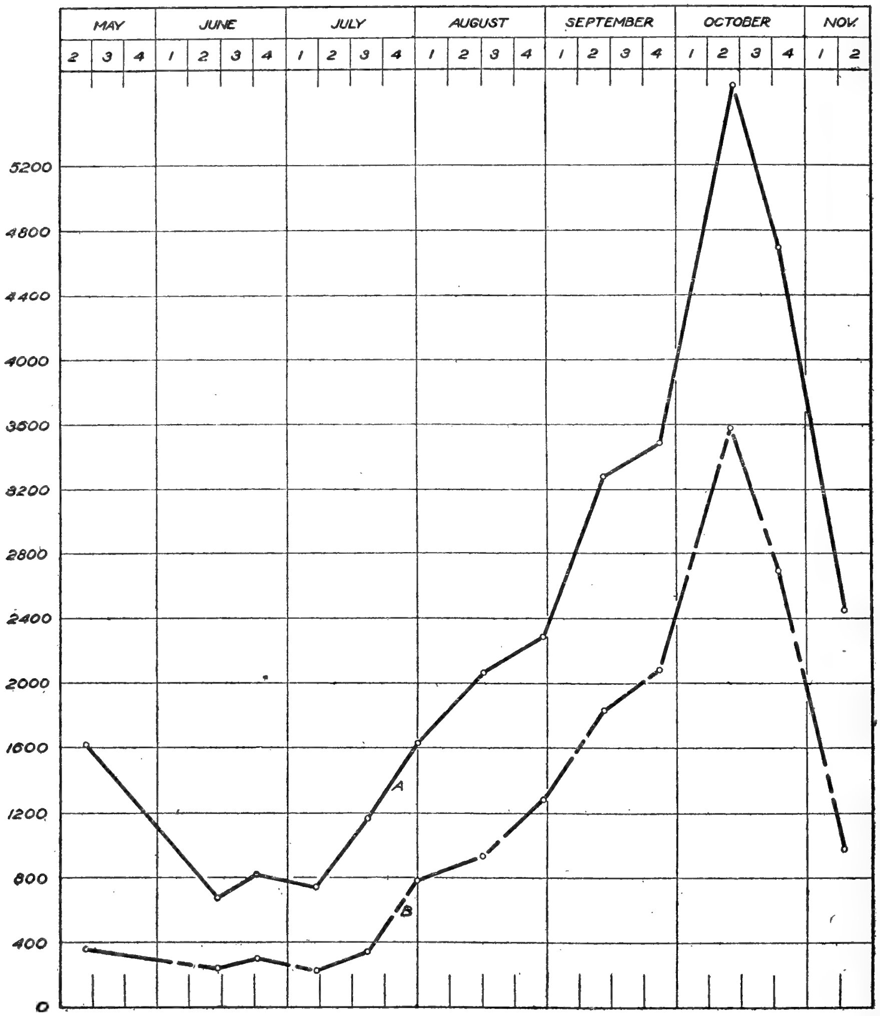

Fig. 38.—The quantity of organic matter and of crude protein in the nannoplankton of Lake Monona in 1916. Curve A represents the dry organic matter and curve B the crude protein. The amounts are indicated in milligrams per cubic meter of water.

Ether Extract. Determinations of the ether extract were made on seven of the eight samples collected in 1915 and on nine of those obtained in 1916. In the former year the percentage of the extract varied from 3.34 per cent to 6.27 per cent of the organic matter, with a mean of 4.90 per cent. (See table 36, p. 200.) In 1916 there was a greater range of variation in percentage, namely, from 2.00 per cent to 9.50 per cent, but the mean was substantially the same as that in the previous year, that is, 4.75 per cent.

When stated in terms of milligrams per cubic meter of water, the amount of the ether extract varied from 47.9 miligrams to 201.5 milligrams in 1915, with a mean of 125.9 milligrams, and from 51.8 milligrams to 154.2 milligrams in 1916, with a mean of 95.5 milligrams. Thus, the average amount was slightly more than 30.0 milligrams per cubic meter of water larger in 1915 than in 1916.

Pentosans. Only four samples were analyzed for the pentosans, all collected in 1915. (See table 46, p. 212.) The average amount in these four samples was 140.4 milligrams per cubic meter of water, which was 4.36 per cent of the organic matter in these samples.

Crude Fiber. Quantitative determinations of the crude fiber were made on six samples collected in 1915 and on five obtained in 1916. In the former year the average amount was 57.2 milligrams per cubic meter of water, which was 2.23 per cent of the organic matter in these samples. (See table 46.) The five samples of 1916 yielded an average of 126.7 milligrams of crude fiber per cubic meter of water, or a little more than twice as much as was found in 1915; this was 10.0 per cent of the organic matter in these five samples.

Nitrogen Free Extract. The crude protein, ether extract, crude fiber, and ash were all determined for only 11 of the 21 samples of nannoplankton from Lake Monona. In these samples the four items constituted from 77.0 per cent to almost 86.0 per cent of the dry weight of the material, leaving only 14.0 per cent to 23.0 per cent for the nitrogen free extract. This is a much smaller range of variation than was noted for the net plankton, in which the maximum percentage of nitrogen free extract was approximately 49.0 per cent, with a minimum of about 15.0 per cent.

Ash. In general the percentage of ash was not as high in the centrifuge material from Lake Monona as in that from Lake Mendota. In the former lake the ash averaged about 49.0 per cent of the dry material which was obtained with the centrifuge, while in the latter lake the average was about 56.0 per cent. In Lake Monona the ash varied from a minimum of slightly less than 29.0 per cent to a maximum of almost 67.0 per cent. (See table 46.) Both of these percentages are smaller than the maximum and minimum of Lake Mendota (table 44). The average percentage of ash was somewhat smaller in the catches obtained from Lake Monona in 1915 than in those collected in 1916, because the bowl water was added to the samples of the latter year. Thus, in the former year, the ash was derived from the plankton organisms and from the silt which was removed from the water by the centrifuge, while in the latter year there was an additional source, namely, the bowl water.

Allowing 10.0 per cent for the ash of the organisms when the diatoms were least abundant, the amount of ash coming from this source varied from 80.0 milligrams to 200.0 milligrams per cubic meter of water in 1915 and from 83.0 milligrams to 228.0 milligrams in 1916.

In 1915 the silt, as determined by difference (see p. 81), ranged from 251.0 milligrams to 878.0 milligrams per cubic meter of water in June and July. This represents somewhat more than a threefold variation; the smallest amount was noted in sample No. 563 and the largest in sample No. 583. In estimating the silt in the 1916 catches, the ash of the bowl water has been regarded as 655.0 milligrams, just as in Lake Mendota (p. 81). On this basis the amount of silt ranged from about 200.0 milligrams in sample No. 648 to 950.0 milligrams per cubic meter of water in sample No. 696. Thus, all of the samples which have been regarded as falling within the 10.0 per cent limit of ash in the organisms, show less than one part of silt per million parts of water. Both the minimum and maximum amounts of silt in Lake Monona are smaller than those of Lake Mendota.

Organisms of the Nannoplankton

The centrifuge material from Lake Monona was made up largely of the same kinds of organisms that were noted in Lake Mendota (p. 84). The ciliates were represented by Vorticella, Halteria, and some unidentified forms that were present in a few of the catches. The flagellates consisted of Chlorochromonas, Cryptomonas, Euglena, a disc-like flagellate which was not identified, and, rarely, Peridinium. The monads and the disc-shaped form were most abundant. The rhizopods were represented by Amoeba and two unidentified forms belonging to this group.

Representatives of several genera of algae were noted, namely, Ankistrodesmus, Aphanocapsa, Arthrospira, Closterium, Chroococcus, Oocystis, Oscillatoria, Scenedesmus, Schroederia, and Sphaerocystis. Small colonies and fragments of the algae belonging regularly to the net plankton were more plentiful in this material than in the centrifuge samples from Lake Mendota. The smaller colonies of Microcystis were especially abundant in some of the samples obtained in 1915, while fragments of the chains of Anabaena were numerous in some of the catches both in 1915 and in 1916. The diatoms consisted of Cocconeis, Navicula, Stephanodiscus, and a good many fragments of Melosira.

In the centrifuge material secured in 1915, the most abundant forms were the monads, the disc-shaped flagellate, *Aphanocapsa delicatissima,* and Oscillatoria. The monads reached a maximum number of 819,200 per liter on July 13 and 409,600 individuals per liter were also noted on August 31. The disc-shaped flagellate numbered 102,400 individuals per liter on July 30 and also on August 31. The largest numbers of Aphanocapsa were found on June 23 and on August 31, namely, 645,100 and 716,800 individuals per liter, respectively. A minute Oscillatoria rose to a maximum of 409,600 filaments per liter on September 24. Fragments of the strands of Anabaena and filaments of Melosira were most abundant in September and October.

The minimum amounts of material obtained in the two catches of July corresponded to relatively small numbers of the various forms with the exception of the monads. In addition to this a much smaller variety of organisms was noted in June and July than in the later months. The marked rise in the quantity of organic matter in August was due chiefly to an increase in the variety of organisms rather than to any unusual rise in the number of any particular form. On June 23 but four forms of organisms were noted; this number rose to six on July 13, to nine on July 30, to seventeen on August 31, and to nineteen on September 15. The latter represented the greatest variety for this year. The small colonies of Coelosphaerium and the diatoms showed an increase in numbers corresponding to a rise of the organic matter to a maximum on October 15. (Table 46.)

In 1916 Schroederia and Aphanocapsa were the most abundant forms in the material obtained on May 12; the former numbered 2,867,000 per liter and the latter 409,600. By June 14 these two forms had decreased very much in numbers, the latter, in fact, was not found after this date. The monads had increased somewhat in numbers but not sufficiently to counterbalance the decrease in the other forms, so that the minimum amount of organic matter obtained in 1916 was noted on June 14.

In 1916, also, a smaller variety of organisms was found early in the season than later; the largest number of forms, namely, twenty-one, was obtained on August 29, while up to the first of August the number ranged from seven to ten. The distinct rise in the organic matter in the latter half of July was correlated in time with an increase in the variety of the organisms. (See figure 38, curve A.) The maximum on October 12 corresponded to a rise in the monads, in Aphanocapsa and in the diatoms, as well as a larger number of fragments of Anabaena. After this date there was a decrease in the number of most forms and also a decrease in the number of forms present, corresponding to a marked decline in the amount of organic matter.

The Total Plankton of Lake Monona

Since the ash of the centrifuge material contains inorganic substances derived from other sources than the nannoplankton organisms, it is best to consider the total plankton (the net plankton plus the nannoplankton) only on an ash free basis. In this connection also, it is necessary to confine the discussion of the net plankton to those samples which were obtained at the same time as the samples of nannoplankton; that is, only those collected in 1915 and in 1916 are considered here.

In 1915 the quantity of dry organic matter in the net plankton varied from a minimum of 404.0 milligrams per cubic meter of water in sample No. 564 to a maximum of 2,161.8 milligrams in sample No. 5167 (table 45). In 1916 the minimum and maximum amounts were 109.3 milligrams and 1,226.1 milligrams, respectively, in samples No. 6123 and No. 659. In the former year the variation was somewhat more than fivefold, while in the latter year it was a little more than elevenfold.

The dry organic matter in the nannoplankton of Lake Monona ranged from 723.0 milligrams in sample No. 563 to 3,746.5 milligrams per cubic meter of water in sample No. 5166 (table 46). In 1916 the minimum amount was 672.1 milligrams, noted in sample No. 648, and the maximum was 5,696.2 milligrams per cubic meter of water in sample No. 6158. In the former year the maximum was just a little more than five times as large as the minimum, while in the latter year it was about eight and a half times as large.

A comparison of the organic matter in the net plankton with that in the corresponding samples of nannoplankton shows that the latter was smaller in amount than the former in four samples. These nannoplankton samples are Nos. 543, 583, 658, and 672 and the corresponding net samples are Nos. 544, 584, 659, and 673; in the other seventeen samples of nannoplankton the organic matter was larger in amount than in the corresponding net samples. (Tables 45 and 46.) The minimum ratio is shown by samples No. 658 and No. 659 in which the quantity of organic matter in the nannoplankton is only two-thirds as large as that of the net plankton, the ratio being 1 : 0.66; in the other three of these samples the nannoplankton yielded somewhat more than four-fifths as much organic matter as the corresponding net catches. In seventeen of the samples the quantity of organic matter was larger in the nannoplankton catches than in the corresponding net plankton catches; in four of these samples the nannoplankton yielded somewhat less than twice as much organic matter as the net plankton, while sample No. 6134 contained approximately twenty-eight times as much organic matter as the corresponding net sample, No. 6135, and sample No. 6122 almost twenty-three times as much as No. 6123. These results differ from those obtained on Lake Mendota in two respects, namely, all of the nannoplankton samples from Lake Mendota yielded a larger amount of organic matter than the corresponding catches of net plankton, but the maximum excess of the former over the latter was not quite as large, being only about twenty-five times as large instead of about twenty-eight times.

In 1915 the organic matter of the total plankton of Lake Monona ranged from a minimum of 1,127.0 milligrams per cubic meter of water in samples No. 563 and No. 564 to a maximum of 5,908.3 milligrams in samples No. 5166 and No. 5167. (Tables 45 and 46.) In 1916 the minimum amount of organic matter in the total plankton was 926.2 milligrams per cubic meter of water in samples No. 648 and No. 649 and the maximum quantity was 6,088.8 milligrams in samples No. 6158 and No. 6159. In the former year the variation in quantity was somewhat more than fivefold and it was almost sevenfold in the latter year. The minimum amount of organic matter in the total plankton was much smaller in 1916 than in 1915, but the maximum quantity was somewhat larger in the former year.

The above quantities indicate only the dry weight of the organic matter; the live weight would be approximately ten times as much. Thus, the live weight of the organic matter in the total plankton obtained on October 12, 1916, samples No. 6158 and No. 6159, for example, was approximately 61 grams per cubic meter of water. The total live weight of these organisms would include the ash also.

Table 25 shows the mean quantity and the chemical composition of the net plankton and the nannoplankton of Lake Monona. The 47 samples of net plankton yielded an average of 850.2 milligrams of dry organic matter per cubic meter of water. This material contained 497.5 milligrams of crude protein, 51.2 milligrams of ether extract, 48.7 milligrams of pentosans, and 30.8 milligrams of crude fiber. The crude protein, ether extract, and crude fiber made up 579.5 milligrams, or 68.2 per cent, of the organic matter. The remainder of the organic matter, 31.8 per cent, constituted the nitrogen free extract.

The 21 samples of net plankton obtained in 1915 and in 1916, which correspond to the nannoplankton catches, yielded a smaller mean quantity of dry organic matter than the whole series of samples, namely, only 813.8 milligrams per cubic meter. The proportion of crude protein, ether extract, and pentosans was somewhat larger in these 21 samples than in the complete series; the crude protein, ether extract, and crude fiber amounted to 594.0 milligrams in the former, or substantially 73.0 per cent of the mean quantity of organic matter in these catches. These three items, therefore, constituted 4.8 per cent more of the organic matter in the 21 samples of net plankton than they did in the 47 samples. Thus, the nitrogen free extract in the former amounted to 27.0 per cent of the organic matter as compared with 31.8 per cent in the latter.

The nannoplankton material gave an average of 2,350.0 milligrams of dry organic matter per cubic meter of water and this contained 1,310.0 milligrams of crude protein, 113.3 milligrams of ether extract, 102.5 milligrams of pentosans, and 111.8 milligrams of crude fiber. Together the crude protein, ether extract, and crude fiber make up 1,535.1 milligrams, or 65.3 per cent of the organic matter in the nannoplankton material. This leaves 34.7 per cent of the organic matter to be classed as nitrogen free extract, which is a larger percentage than that noted in the net plankton.

The total plankton yielded 3,163.8 milligrams of dry organic matter per cubic meter of water in Lake Monona. This material contained an average of 1,821.2 milligrams of crude protein, 170.3 milligrams of ether extract, 150.1 milligrams of pentosans, and 137.6 milligrams of crude fiber. The crude protein, ether extract, and crude fiber made up 2,129.1 milligrams of the organic matter, or 67.3 per cent, thus leaving 32.7 per cent of the organic matter as nitrogen free extract.

Organic Matter per Unit of Area

The plankton material from Lake Monona was obtained regularly from the deeper portion of the lake, that is, where the water reaches a depth of 20 meters to 22.5 meters, the latter being the maximum depth, and the samples of water from which the material was secured covered the lake down to a depth of 18 meters to 20 meters each time. This plankton material, then, represents the deeper part of the lake and the results may, therefore, be compared with similar ones obtained on Lake Mendota.

The 20 meter contour line of Lake Monona bounds an area of 56,700 square meters and the volume of water down to this depth is 1,134,000 cubic meters; between 20 meters and 22.5 meters the volume is 59,000 cubic meters, thus making a total of 1,193,000 cubic meters. From this volume and the monthly averages of the organic matter in the total plankton for the two years 1915 and 1916 combined, the results shown in the first part of table 37 (p. 200) have been obtained. The results given for the months of May and November are based on a single set of observations in each of these months, but the other months indicated in the table are represented by three or four sets of observations.

This table shows a smaller quantity of organic matter in the total plankton in May than in June, while the smallest average was found in July. The August and September averages show a marked increase leading up to the maximum quantity in October. The single set of observations taken in November yielded only a little more than half as much organic matter as the average for October. The October maximum is almost four times as large as the July minimum.

The amount of organic matter in the total plankton of Lake Monona was smaller in the months of May and July than in the corresponding months in Lake Mendota, but it was larger in the other months. The maximum difference appears in October when the amount in Lake Monona is two and a half times as large as that of Lake Mendota. (See table 26.)

The second part of table 37 shows the quantity of dry organic matter in the total plankton per unit of area of Lake Monona when the entire body of water is taken into account. The mean depth of the lake is 8.43 meters. As noted in the discussion of the results on Lake Mendota (p. 102), the amount of material attributed to areas shallower than the mean depth is larger than is actually present there, and that assigned to areas that are deeper than the mean is too small when computations are made on this basis. On the other hand, such results give some idea of the general abundance of the plankton material when the whole lake is taken into account, and for this reason they are well worth considering.

Taking the entire body of water into account, the amount of dry organic matter in the total plankton of Lake Monona varied from a minimum of 124 kilograms per hectare (111 pounds per acre) in July to a maximum of 478 kilograms per hectare (426 pounds per acre) in October. The minimum of Lake Monona is below that of Lake Mendota (table 26), but the maximum of the former lake is more than one and a half times as large as that of the latter.

The average amount for the whole of Lake Monona is a little more than 40.0 per cent of the quantity noted for the deep water in the first part of table 37; this is due to the fact that the mean depth of the whole lake is only slightly more than 40.0 per cent of the mean depth of the area bounded by the 20 meter contour line. In Mendota the mean depth of the entire lake is about 55.0 per cent of the mean depth within the 20 meter contour line, so that the average quantity of organic matter in the total plankton when the whole body of water is taken into account is about 55.0 per cent of the amount found in the deep water.

It should be noted that the results given for Lake Monona in table 37 are stated in terms of dry organic matter; the weight of the living organic matter would be about ten times as large as these amounts. Thus, within the 20 meter contour line, the live weight of the organic matter in the total plankton would range from a minimum of 3,100 kilograms per hectare of surface (2,760 pounds per acre) in July to a maximum of 11,920 kilograms per hectare (10,630 pounds per acre) in October. When the whole body of water is taken into account, the amounts vary from 1,240 kilograms per hectare (1,110 pounds per acre) in July to 4,780 kilograms per hectare (4,260 pounds per acre) in October. To obtain the total live weight of these organisms, it would be necessary to add to these amounts from 10 per cent to perhaps 15 per cent of the dry weight of the organic matter for the inorganic matter or ash that they contain.

CHAPTER VI

THE PLANKTON OF LAKES WAUBESA AND KEGONSA

LAKE WAUBESA

Net Plankton

Material for a quantitative study of the net plankton of Lake Waubesa was obtained in 1913, in 1915, and in 1916; the number of samples each year was two, four, and twelve, respectively. The quantity of water strained for each catch and the amount of dry plankton obtained therefrom are given in table 2, p. 181. No samples were taken during the winter season and the catches for the first two years were made at irregular intervals in the summer and autumn; they were secured at fairly regular intervals in 1916, being taken at approximately two week periods from May 24 to October 30.

The largest quantity of net plankton per cubic meter of water was found in 1915, while the catches taken in 1916 yielded the smallest amount of dry material; the average for the former year was a little more than three times as large as that of the latter year. The mean quantity in the two samples of 1913 was a little larger than the average for the entire series of samples of net plankton from this lake.

Organic Matter. The results for organic matter are summarized in table 29, p. 198. The quantity varied from a minimum of 471.1 milligrams per cubic meter of water in one sample collected in 1916 to a maximum of 4,232.5 milligrams in one secured in 1915. The two catches made in 1913 yielded about the same amount of material per cubic meter, but there was nearly a threefold difference between the maximum and minimum amounts of organic matter in the 1915 samples and more than a fivefold difference in those of 1916. The mean quantity of organic matter in the four samples of 1915 was about three times as large as the mean for 1916 and almost twice as large as that for 1913. The eighteen samples yielded an average of 1,665.8 milligrams of organic matter per cubic meter of water. This quantity is nearly twice as large as the organic matter in the net plankton of Lake Monona and approximately five times as large as that of Lake Mendota. The percentage of organic matter in the net plankton of Lake Waubesa varied from a minimum of 69.3 per cent to a maximum of 93.3 per cent of the

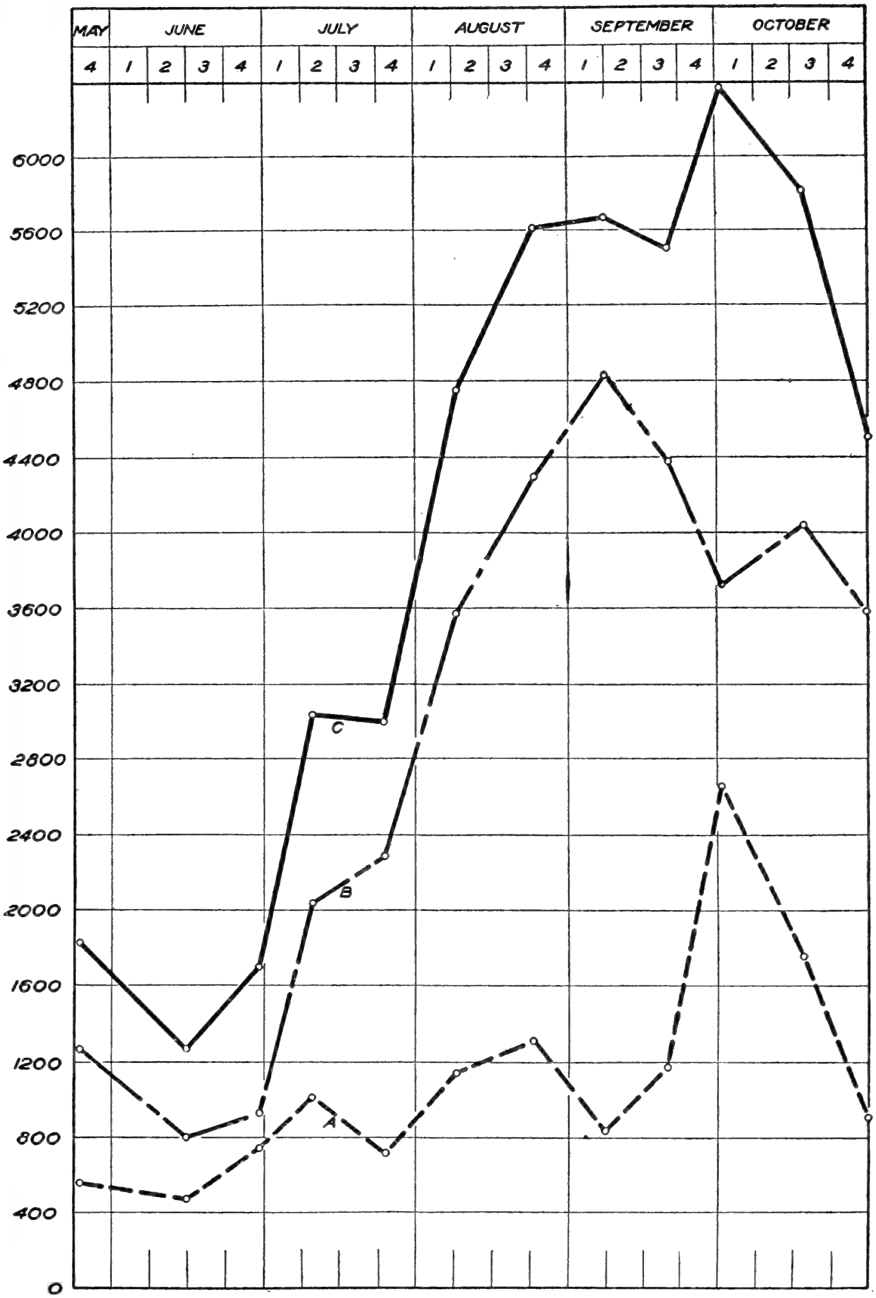

Fig. 39.—The quantity of dry organic matter in the net plankton, in the nannoplankton and in the total plankton of Lake Waubesa in 1916. Curve A represents the net plankton, curve B the nannoplankton and curve C the total plankton. The amounts are indicated in milligrams per cubic meter of water. See tables 47 and 48.

dry material, with an average of 89.2 per cent for the eighteen samples.

The results for organic matter in 1916 are shown in figure 39, in which the curve marked A indicates the quantity per cubic meter of water in the various samples. This curve shows that there was a slight decrease in the organic matter between May 24 and June 15; the amount noted on the latter date was the smallest obtained in the various samples from this lake. A small peak in July and another in August represent moderate increases at these times, but the large increase came during the latter part of September. The maximum point was reached in the sample collected on October 2. The two samples collected later in October showed a marked decline in the quantity of organic matter so that the autumnal peak is sharp and prominent; the amount was only about 12.0 per cent larger on October 30 than on September 7.

Nitrogen. The quantity of nitrogen was determined in all of the samples of net plankton from Lake Waubesa. The percentage varied from a minimum of 5.82 per cent in one sample collected in 1916 to a maximum of 8.57 per cent in a catch obtained in 1913. The mean percentages were substantially the same in 1915 and 1916, but that of 1913 was somewhat higher than the other two. (See table 38, p. 200.)

A maximum of 343.7 milligrams of nitrogen per cubic meter of water was noted in one of the 1915 samples and a minimum of 36.1 milligrams in a 1916 catch. The smallest mean was found in the material collected in 1916 and the largest in that of 1915, the latter being almost three times as large as the former.

The ratio of the quantity of organic matter to the quantity of total nitrogen in the net plankton of Lake Waubesa ranged from 10.2 to 16.3, these extremes being found in two samples collected in 1916, namely, No. 6141 and No. 6117. (Table 47, p. 213.) These results show that the net plankton of Lake Waubesa contained a smaller proportion of nitrogen than that of Lake Monona, in which the ratio ranged from 8.5 to 14.6; in the net plankton of Lake Mendota the ratios showed a wider variation, ranging from 8.7 to 17.4.

Crude Protein. The nitrogen results are given in terms of crude protein in table 39, p. 201; the first part of this table shows the variations in the percentage of crude protein in the organic matter, while the second part gives the maximum and minimum quantities. The maximum percentage, namely, 53.6 per cent of the organic matter, was found in one of the samples collected in 1913, while the minimum was noted in a sample collected on October 23, 1915, which contained 32.1 per cent of crude protein.

The quantity of crude protein ranged from a minimum of 225.6 milligrams per cubic meter of water to a maximum of 2,148.1 milligrams; the former was found in 1916 in sample No. 663 and the latter in 1915 in sample No. 5129. The latter is almost ten times as large as the former. The mean quantity for the entire series of eighteen samples is 785.6 milligrams, which is 47.1 per cent of the average amount of organic matter. This percentage of crude protein is much lower than the means for the net plankton of Lakes Mendota and Monona; the mean for the former is 52.3 per cent and for the latter 58.5 per cent. (See table 25.) This indicates that the net plankton of Lake Waubesa contains a smaller proportion of nitrogenous material than either of the other lakes. Both the maximum and the minimum percentages of crude protein are smaller in Waubesa also than in the other two lakes. (Tables 8 and 31.)

Ether Extract. The ether extract was determined in twelve of the net plankton samples from Lake Waubesa, namely, the two obtained in 1913, four in 1915, and six in 1916. (See table 47.) The extract varied from a minimum of 2.81 per cent of the organic matter to a maximum of 8.82 per cent, with a mean of 4.64 per cent. The quantity of the extract ranged from 50.0 milligrams to 295.2 milligrams per cubic meter of water, almost a sixfold difference. The average for the twelve determinations is 115.8 milligrams per cubic meter of water.

Pentosans. The pentosans were determined in six samples of the net plankton from Lake Waubesa. The percentage ranged from 4.05 per cent to 6.77 per cent of the organic matter in these samples; the mean is 5.90 per cent. The quantity varied from 75.9 milligrams to 264.5 milligrams per cubic meter of water, representing more than a threefold variation. The mean quantity for the six determinations is 163.5 milligrams.

Crude Fiber. The amount of crude fiber was ascertained in ten samples. In these catches the crude fiber varied from a minimum of 1.82 per cent to a maximum of 10.18 per cent of the organic matter, the mean being 4.70 per cent. The quantity ranged from 17.9 milligrams to 189.6 milligrams per cubic meter of water, thus showing more than a tenfold difference.

Nitrogen Free Extract. The crude protein, ether extract, crude fiber, and ash were all determined for ten of the eighteen samples of net plankton from Lake Waubesa and together these four items constituted from 53.8 per cent of the dry material in sample No. 691 to 73.5 per cent in sample No. 6175. Deducting these percentages from 100 leaves a minimum of 26.5 per cent and a maximum of 46.2 per cent for the nitrogen free extract; this is less than a twofold variation in the percentage of the nitrogen free extract. The range of variation in the nitrogen free extract in the net plankton of Lake Monona was much greater, ranging from 15.0 per cent to 49.0 per cent.

Ash. The ash constituted from 6.68 per cent to 30.73 per cent of the material in the various samples, with a mean of 10.86 per cent. The percentage was highest in spring and in autumn when the diatoms were most abundant and lowest in the summer when the green and blue-green algae predominated. (Table 47.)

In most of the catches silica was the most important constituent of the ash, varying in amount from 1.04 per cent to 23.52 per cent of the dry material. The silica was notably high in those samples containing a large percentage of ash, thus indicating the presence of diatoms in such samples.

Deducting the percentage of silica from the percentage of ash leaves from 4.85 per cent to 14.87 per cent of the dry sample for the other inorganic constituents of the ash. The samples obtained in 1913 and in 1915 yielded a smaller amount of such constituents than those collected in 1916. The first sample taken in 1916, No. 633, gave the maximum difference, 14.87 per cent; the two samples following this one showed a slight decline in the percentage of the other inorganic constituents. The most marked decrease was noted between samples No. 667 and No. 679, taken on June 29 and July 11, in which the difference fell from 12.15 per cent in the former to 7.91 per cent in the latter. Thereafter the decline continued until the difference between the percentage of ash and the percentage of silica amounted to only 5.21 per cent on August 23, or but little more than a third as much as the maximum of May 24. In September and October of this year the difference ranged from 7.21 per cent to 9.60 per cent.

The ash of one sample, No. 352, was subjected to a further analysis and the following results are stated in terms of percentages of the dry plankton material: ash 22.78 per cent, silica 16.37, Fe_2O_3 and Al_2O_3 1.35, P_2O_5 0.67, CaO 2.20, and MgO 1.28 per cent. This sample was obtained on September 19, 1913, when the diatoms were fairly abundant and the silica derived from their shells constituted more than two-thirds of the ash, leaving only 6.41 per cent for the other inorganic constituents.

Organisms of the Net Plankton

The net plankton of Lake Waubesa was made up of crustacea, a very few rotifers, some protozoa, and various forms of algae. The crustacea were represented by species of Diaptomus, Cyclops, Daphnia, and Chydorus. The rotifers included a few individuals belonging to the genera Asplanchna and Triarthra, and two species of Anuraea. The flagellate Ceratium was noted in all of the material.

The algae were represented by a rather large variety of forms. Among the blue-greens the most important forms were species of Anabaena, Aphanizomenon, Lyngbya, and Microcystis, while the most important diatoms were Melosira, Fragilaria, and Stephanodiscus.

The largest quantity of organic matter noted in the net plankton of 1915 was found in the catch taken on October 2 (No. 5153). In this maximum catch, only two crustacea appeared in considerable numbers, namely, 17,100 Cyclops per cubic meter of water and 44,000 Chydorus per cubic meter. The rotifer *Anuraea cochlearis* averaged 26,200 individuals per cubic meter, while Ceratium numbered 905,000. There were 614,000 colonies of Microcystis per cubic meter of water in this catch and slightly more than a million masses of Anabaena per cubic meter. The most abundant forms at this time, however, were the diatoms Melosira and Stephanodiscus, the numbers being, respectively, 4,123,000 and 4,500,000 per cubic meter.

In 1916 the crustacea showed a June maximum and an October maximum, with a more or less pronounced minimum during the intervening months. Diaptomus, for example, numbered 3,500 individuals per cubic meter of water on June 15 and 4,200 on October 2, with a minimum of 800 on August 8. Cyclops gave a maximum of 8,000 per cubic meter on June 29 and another of 13,100 on October 2, with a minimum of 1,500 on July 25. The copepod nauplii ranged from a minimum of 4,300 per cubic meter of water on July 25 to a maximum of 19,500 on October 30; a secondary maximum of 18,500 was noted on July 11. *Daphnia pulex* was most abundant on June 29, namely, 3,000 per cubic meter and its numbers were negligible in the catches taken after July 11. *Daphnia hyalina* yielded a maximum of 13,700 individuals per cubic meter on June 29 and one of 11,200 on October 2, with an intervening minimum of 900 on August 8. Chydorus, on the other hand, showed no distinct maximum during the early part of the season, but the number rose to 40,500 individuals per cubic meter on September 19 and again to 52,000 on October 30.

Anuraea cochlearis was the only rotifer found in considerable numbers; 223,200 individuals per cubic meter were obtained in the catch secured on October 2, 1916. Ceratium attained a maximum of 2,200,000 per cubic meter on August 23 and it stood a little above two million on October 2.

Microcystis was found in greatest abundance on September 19 when 2,734,000 colonies per cubic meter of water were obtained. The number of masses of Anabaena rose slightly above one million per cubic meter on September 7, while Lyngbya was rather scarce during the entire season, the largest number being 490,000 filaments per cubic meter on July 25. The diatom Melosira rose to a maximum of 3,286,000 filaments per cubic meter on October 18, while Stephanodiscus reached a maximum of 2,914,000 individuals per cubic meter on the same date.

NANNOPLANKTON

Four samples of centrifuge material were obtained from Lake Waubesa in 1915 and a dozen samples in 1916. In the former year the catches were made between August 11 and October 23, inclusive, but in the latter year samples were taken about every two weeks from May 24 to October 30. The amount of water centrifuged in 1915 was 5,732 liters and 11,641 liters in 1916, making a total of 17,373 liters for the two years. (Table 2.)

Organic Matter. The results obtained for the organic matter in the sixteen samples of nannoplankton are summarized in table 29, p. 198, and the analyses are given in detail in table 48, p. 214. In 1915 the minimum quantity of dry organic matter was 2,871.2 milligrams per cubic meter of water and the maximum was 6,143.2 milligrams, the latter being more than twice as large as the former; the mean quantity for the four catches of this year was 4,260.2 milligrams. In 1916 the amount was much smaller, the minimum falling to 801.0 milligrams and the maximum reaching only 4,830.0 milligrams, a sixfold difference. The mean for 1916 was also much smaller than that of 1915, being only 2,977.5 milligrams. In both years, however, the amount of organic matter in the nannoplankton of Lake Waubesa was larger than in Lake Mendota or in Lake Monona.

The curve marked B in figure 39 gives the story of the organic matter in the nannoplankton of Lake Waubesa in 1916. There was a decline in the amount in late May and early June reaching a summer minimum on June 15. This period was succeeded by one in which there was a regular increase lasting from early July to September 7, the highest point in the curve being attained on the latter date. A period of decrease was noted for the rest of September, but there was a moderate increase during the first half of October followed by a further decline during the remainder of this month.

A comparison of this curve with the one marked C in figure 37 shows that the story of the nannoplankton of Lake Waubesa in 1916 was substantially the same as that of the nannoplankton of Lake Monona in this year. There are slight differences, however; the rise in Lake Waubesa was more rapid in the earlier stages and the decline more gradual so that the autumn peak of the curve has a broader aspect than that of Lake Monona. Another difference is that the small secondary peak in October shown in the curve for Lake Waubesa is not represented in the curve for Lake Monona. In general, though, the curves for the organic matter of the nannoplankton of these two lakes are very similar in outline and they both differ markedly from that of Lake Mendota for this year as shown in curve A, figure 31.

Curves A and B in figure 39 represent the organic matter in the net plankton and in the nannoplankton, respectively, of Lake Waubesa; they show that the former was always smaller than the latter in 1916. In 1915, on the other hand, the net plankton gave a larger yield of dry organic matter than the corresponding nannoplankton catches in two instances. (See samples No. 597-598 and No. 5128-5129, tables 47 and 48.) Thus, in half a dozen catches out of 37 from Lakes Monona and Waubesa, the net plankton yielded a larger amount of organic matter than the nannoplankton, but in all of the samples from Lake Mendota the net plankton gave a smaller amount of organic matter than the nannoplankton.

These two curves (A and B in figure 39) do not indicate any definite correlation between the quantity of organic matter in the net plankton and that in the nannoplankton. There was a moderate rise in the former in late June and early July corresponding to a rise in the latter, but beyond this point the net plankton changed independently of the nannoplankton. In fact, the former showed a decline at the time that the latter reached its maximum point and the maximum of the net plankton was not reached for fully three weeks after the nannoplankton had passed its maximum.

Curve C in figure 39 shows the amount of dry organic matter in the total plankton of Lake Waubesa, that is, the net plankton plus the nannoplankton. The autumnal peak of the total organic matter presents a different outline from that of either curve A or curve B. The maximum point in the total organic matter is correlated in time, however, with the maximum of the net plankton instead of the nannoplankton and the small secondary peak is found on the September side of the main peak as in the net plankton instead of on the October side as in the nannoplankton. These two facts show clearly that the quantity of net plankton in this lake is large enough to affect materially the form of the curve representing the organic matter of the total plankton. The dry organic matter in the total plankton amounted to 6,378.3 milligrams per cubic meter on October 2, 1916, as compared with 1,271.7 milligrams on June 15; the latter was the minimum for the year and the October maximum was five times as large as this minimum.

Nitrogen. Quantitative determinations of the nitrogen were made on all of the samples of nannoplankton taken from Lake Waubesa. A summary of these results is given in table 40, p. 201, and all of the determinations are shown in table 48. The material obtained in 1915 contained a higher percentage of nitrogen than that secured in 1916. The mean for the former year was 9.03 per cent, while that of the latter was 7.41 per cent. Both the maximum and the minimum were higher in 1915 than in 1916. The difference between the maximum and the minimum in the former year was 2.90 per cent and in the latter year 3.91 per cent, so that there was not as large a variation in the percentage of nitrogen in the centrifuge material from Lake Waubesa as in that from Lakes Mendota and Monona. (See table 18, p. 192 and table 34, p. 199.)

When expressed in terms of milligrams per cubic meter of water, the quantities of nitrogen were much higher in 1915 than in 1916; the mean for the former year was more than one and a half times as large as that for the latter. In 1915 the maximum quantity of nitrogen was two and a half times as large as the minimum, but in 1916 there was an eightfold difference between the maximum and the minimum amounts.

The nannoplankton of Lake Waubesa showed almost a twofold variation in the ratio of the organic matter to the total nitrogen, ranging from 9.9 to 18.7; this range was larger than that noted for the net plankton. (See table 47.) It is a smaller difference than that noted for the nannoplankton of Lake Monona in which the limits were 8.1 and 27.9; it is smaller, also, than in the nannoplankton material from Lake Mendota which varied from 9.1 to 23.5. These results also show that the proportion of nitrogen in the organic matter had the widest range of variation in the net plankton of Lake Mendota, while the material from Lakes Monona and Waubesa possessed the same range, with a larger proportion of nitrogen in the former lake. In the nannoplankton, however, the proportion was much more constant in the material from Lake Waubesa than in that from the other two lakes; the largest variation was noted in the nannoplankton of Lake Monona.

Crude Protein. The nitrogen results are summarized in terms of crude protein in table 41; the first part of this table shows the variations in the percentage and the second part the changes in the quantity. There was a much larger proportion of crude protein in the material collected in 1915 than in that secured in 1916; in the former year the percentage of crude protein in the nannoplankton ranged from a minimum of 44.4 per cent of the organic matter to a maximum of 62.5 per cent, with a mean of 56.4 per cent for the four catches obtained in this year. In 1916 the extremes were 33.5 per cent and 57.9 per cent, with a mean of 46.3 per cent for the twelve samples of this year; thus, the mean for 1916 was 10.0 per cent below that of 1915. The crude protein fell below 50.0 per cent of the organic matter in only one of the four samples of 1915, but it reached or exceeded this amount in only one of the dozen catches made in 1916. In two samples secured in 1916 the crude protein fell below 40.0 per cent of the dry organic matter.

The quantity of crude protein varied from a minimum of 1,361.9 milligrams per cubic meter of water to a maximum of 3,471.9 milligrams in the 1915 samples of nannoplankton from Lake Waubesa, while in

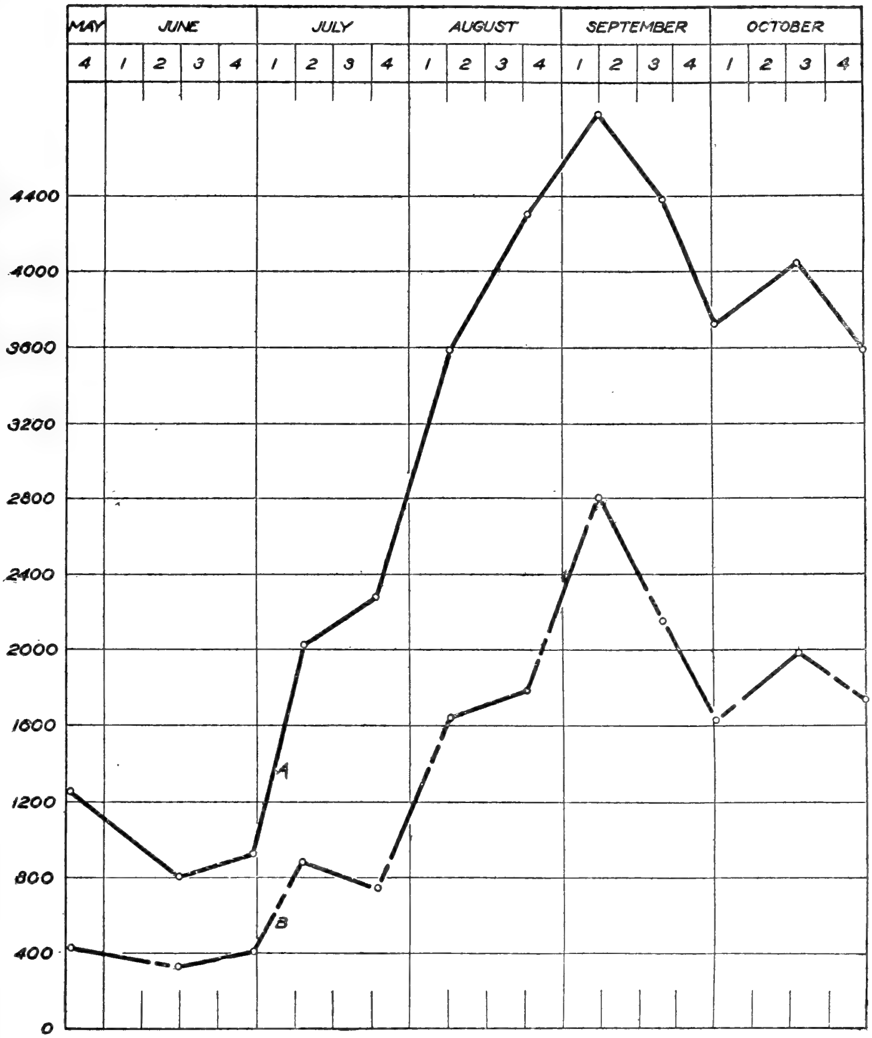

Fig. 40.—The quantity of organic matter and of crude protein in the nannoplankton of Lake Waubesa in 1916. Curve A represents the dry organic matter and curve B the crude protein. The amounts are indicated in milligrams per cubic meter of water. See table 48.

1916 the extremes were 341.2 milligrams and 2,800.0 milligrams. In the former year the mean quantity was 2,404.4 milligrams per cubic meter of water and in the latter year 1,378.1 milligrams, so that the mean for 1916 was only a little more than half as large as that of 1915.

Figure 40 shows graphically the relation of the crude protein to the organic matter in the nannoplankton material collected from Lake Waubesa in 1916. The curve marked A represents the quantity of organic matter in milligrams per cubic meter of water in the various samples and curve B indicates the amount of crude protein in this material. That is, the space between the zero line and curve B shows the proportion of crude protein, while the space between B and A represents the other constituents of the organic matter. With one exception the two curves possess a similar outline; during the second and third weeks in July there is a decrease in the crude protein which is correlated in time with a moderate increase in the organic matter.

Ether Extract. The quantity of ether extract was determined in twelve of the sixteen samples of nannoplankton from Lake Waubesa. The percentage of extract varied from a minimum of 1.48 per cent to a maximum of 8.13 per cent of the dry organic matter, almost a sixfold difference. Both of these percentages were found in material collected in 1916. (Table 42.) A much smaller range of variation was found in the 1915 samples, the difference between maximum and minimum being less than two per cent. The mean for the twelve samples on which determinations were made, amounts to substantially four per cent of the organic matter in these samples.

The quantity of ether extract varied from 61.5 milligrams to 308.0 milligrams per cubic meter of water, with a mean of 121.0 milligrams for the twelve samples. The mean quantity in the 1915 catches was more than twice as large as that in the 1916 material.

Pentosans. The pentosans were determined in the four samples collected in 1915, but not in any of the catches made in 1916. In these four samples the pentosans varied from 4.55 per cent to 6.72 per cent of the dry organic matter. (See table 48, p. 214.) The quantity of pentosans in this material ranged from a minimum of 193.0 milligrams to a maximum of 346.0 milligrams per cubic meter of water; the mean for the four samples was 237.0 milligrams.

Crude Fiber. Twelve samples of nannoplankton were analyzed for the crude fiber. The percentage of this material in these samples varied from a minimum of 0.83 per cent to a maximum of 10.43 per cent of the organic matter; the mean for all determinations was 4.45 per cent. (Tables 25 and 48.)

Quantitatively the amount ranged from 49.7 milligrams to 332.6 milligrams per cubic meter of water, with a mean of 135.5 milligrams. The smallest quantity was found in sample No. 597 and the largest in No. 6150.

Nitrogen Free Extract. The chemical analyses were complete enough to ascertain the percentage of nitrogen free extract in a dozen samples of nannoplankton from Lake Waubesa. In these catches it ranged from a minimum of 15.0 per cent in sample No. 666 to a maximum of 29.0 per cent of the dry weight of the material in sample No. 597, representing almost a twofold variation. The percentage was somewhat larger in the nannoplankton material from Lake Waubesa than in that from Lake Monona where the minimum was 14.0 per cent and the maximum 23.0 per cent.

On an ash free basis the nitrogen free extract constituted 42.8 per cent of the dry organic matter in sample No. 666 and 50.7 per cent in sample No. 597. From 30.7 per cent to 52.7 per cent of the organic matter in the twelve samples from Lake Waubesa consisted of nitrogen free extract. The minimum was found in samples No. 5128 and No. 5174 and the maximum in sample No. 690.

Ash. The ash in the centrifuge catches from Lake Waubesa ranged from a minimum of 33.44 per cent to a maximum of 65.35 per cent of the dry material. (Table 48.) The average for the entire series amounted to 49.38 per cent, or substantially the same as that noted for the centrifuge samples from Lake Monona.

The diatoms were fairly abundant in all of the nannoplankton samples from Lake Waubesa except four and these four were probably the only ones in which the ash of the organisms fell within the 10.0 per cent limit; two of these samples were obtained in June, 1916, No. 650 and No. 666, and two in July, 1916, No. 678 and No. 690. Allowing 10.0 per cent for the ash, the organisms in these four samples contributed from 89.0 milligrams to 253.0 milligrams per cubic meter of water to the total ash of the samples. When the ash derived from the organisms and that derived from the bowl water are deducted from the total ash, the remainder, which may be attributed to silt, varies from 368.0 milligrams in sample No. 650 to 1,135.0 milligrams per cubic meter of water in sample No. 678; this means from 0.37 to 1.13 parts of silt per million parts of water. These results show that silt is a little more abundant in the water of Lake Waubesa than in that of Lake Monona, but it is substantially the same as that in Lake Mendota.

Organisms of the Nannoplankton

The protozoan population in the nannoplankton of Lake Waubesa consisted of essentially the same forms that were found in Lake Monona. There was a somewhat greater variety of algal forms, however, than in Lakes Mendota and Monona. The more abundant algae were *Aphanocapsa delicatissima,* Oocystis, and the young colonies and fragments of Microcystis and Anabaena; several other forms were obtained from time to time in the various catches, but they were never found in any considerable numbers. The chief diatoms were Melosira and Stephanodiscus.

Chlorochromonas was abundant in the four catches which were obtained in 1915; it ranged from a minimum of 135,000 per liter of water on August 11, to a maximum of 768,000 per liter on October 23. Cryptomonas reached a maximum of about 65,000 per liter on the latter date, while the same maximum was noted for the disc-shaped flagellate on August 11. *Aphanocapsa delicatissima* yielded a maximum of 444,-000 colonies per liter on August 11, while another blue-green alga, Oscillatoria, rose to 477,500 per liter on October 23. In fifteen other forms of algae, exclusive of the diatoms, the numbers varied from 2,000 to 75,000 per liter of water. The diatom Melosira numbered 307,000 filaments per liter on October 2, while Stephanodiscus rose to 20,000 per liter on this date.

In the series of catches obtained in 1916, Chlorochromonas showed two maxima; the first one was noted on June 25 when the number rose to 665,500 per liter and a second maximum of 512,000 was found on September 7. The minimum number for the entire series of catches collected in this year was found on July 25, namely, 10,000 per liter. The maximum for the disc-shaped flagellate was 204,000 per liter on September 7. Seven other forms of protozoa were noted from time to time, but none of them appeared regularly in the various catches; the most abundant one was Cryptomonas, of which 105,000 individuals per liter were found on October 2.

Aphanocapsa delicatissima gave a maximum of 512,000 per liter on October 2, while the maximum for Oscillatoria was 768,000 per liter on August 23. It may be noted here that Oscillatoria was found in considerable abundance both in Lake Monona and in Lake Waubesa, but it was not present in any of the centrifuge material from Lake Mendota. Small colonies of Microcystis were present in all of the nannoplankton collected in Lake Waubesa after the middle of July; they numbered 205,000 per liter in both of the August samples in 1916. With the exception of the first sample (No. 632) portions of the filaments of Anabaena were more or less abundant in all of the catches of this year; the number ranged from a minimum of 3,400 per liter to a maximum of 410,000 per liter, the latter number being noted on September 7. Fourteen other forms of algae, exclusive of the diatoms, were found in the various catches, but all of them were irregular in their appearance; their numbers varied from about 1,000 to 102,000 per liter of water.

The most important diatom was Melosira; it was present in all of the catches obtained after the middle of July. The largest number, 375,000 per liter, was noted on September 19. Half a dozen other diatoms were found in the material but they did not appear regularly in the various catches; of these forms Stephanodiscus, Coscinodiscus, and Cocconeis were obtained most frequently.

Only one form, Aphanocapsa, gave a maximum number on October 2 when the largest quantity of organic matter was obtained in the centrifuge catch; several other forms, however, showed a marked increase in number at this time and these increases together with that of Aphanocapsa were sufficient to yield a maximum of organic matter.

The number of forms represented in the centrifuge material from Lake Waubesa in 1916 increased as the season advanced, just as noted in Lake Monona. On May 24, for example, ten different forms were present in the centrifuge catch, and the number varied from seven to ten until July 25, when it rose to fifteen. In the catch taken on September 19, the various forms number twenty and a maximum of twenty-five was found on October 30.

Total Plankton of Lake Waubesa

In the 18 samples of net plankton from Lake Waubesa, the dry organic matter varied from a minimum of 471.1 milligrams to a maximum of 4,232.5 milligrams per cubic meter of water, almost a tenfold variation in quantity. The whole series of net catches yielded an average of 1,665.8 milligrams of organic matter per cubic meter of water, of which 785.0 milligrams consisted of crude protein, 115.8 milligrams of ether extract, 98.3 milligrams of pentosans, and 78.3 milligrams of crude fiber. (Table 25.) The crude protein, ether extract, and crude fiber amounted to 979.1 milligrams per cubic meter of water, or 58.7 per cent of the organic matter. This leaves an average of 41.3 per cent of the organic matter as nitrogen free extract.

In the 16 samples of net plankton corresponding to the same number of samples of nannoplankton, the mean quantity of organic matter was somewhat smaller than in the entire series of net catches, namely 1,639.2 milligrams per cubic meter of water. In this material the crude protein, ether extract, and crude fiber made up 56.9 per cent of the organic matter, leaving 43.1 per cent of nitrogen free extract. The latter is nearly two per cent larger in these samples than in the complete series.

The organic matter of the nannoplankton varied from a minimum of 801.0 milligrams to a maximum of 6,143.2 milligrams per cubic meter of water. The mean quantity for the 16 samples was 3,299.1 milligrams, of which 1,635.0 consisted of crude protein, 132.0 milligrams of ether extract, 183.1 milligrams of pentosans, and 146.8 milligrams of crude fiber. The crude protein, ether extract, and crude fiber accounted for 1,913.8 milligrams, or 58.0 per cent of the organic matter; this leaves 42.0 per cent of the organic matter in the nannoplankton of Lake Waubesa as nitrogen free extract. The percentage of extract is a little larger in the net plankton than in the nannoplankton.

The quantity of dry organic matter in two net samples from Lake Waubesa, No. 598 and No. 5129, was larger than that in the corresponding samples of nannoplankton, No. 597 and No. 5128. (Tables 47 and

48.) In net sample No. 598 the organic matter was about 17.0 per cent larger than in nannoplankton sample No. 597, while nannoplankton sample No. 5129 yielded only about two-thirds as much organic matter as net sample No. 5128. Four net samples from Lake Monona also yielded a larger amount of organic matter than the corresponding nannoplankton samples, which makes a total of six sets of catches showing this phenomenon. All of the nannoplankton samples from Lake Mendota yielded a larger amount of organic matter than the corresponding net samples.

In the four sets of samples that were obtained in Lake Waubesa in 1915, the dry organic matter of the total plankton ranged between a minimum of 6,538.0 milligrams in samples No. 5174 and No. 5175 and a maximum of 9,489.7 milligrams in samples No. 5152 and No. 5153. (Tables 47 and 48.) In 1916 the quantity varied from 1,272.1 milligrams in samples No. 650 and No. 651 to 6,378.3 milligrams per cubic meter of water in samples No. 6150 and No. 6151; this represents a fivefold variation in the quantity of organic matter obtained in the samples of this year. The maximum amount was found on the same date in both years, October 2, but the maximum for 1915 was almost one and a half times as large as that of 1916. The dry organic matter constitutes only about one-tenth of the weight of the living organic matter because most of the organisms in the plankton contain at least 90.0 per cent of water in the living state; the 1915 maximum, therefore, represents approximately 95 grams of living organic material per cubic meter of water.

The Waubesa maximum of dry organic matter in the total plankton noted in 1915 was not only the largest for this lake, but it was also much larger than the maxima for Lakes Mendota and Monona. It was a little more than one and a half times the maximum of Lake Monona, 6,088.8 milligrams per cubic meter of water, and almost three times as large as that of Lake Mendota, which was 3,327.3 milligrams per cubic meter. The minimum amount of organic matter in the total plankton of Lake Waubesa, 1,272.1 milligrams per cubic meter of water, was about one-third larger than the minimum of Lake Mendota, 906.0 milligrams, and also about a third larger than the minimum of Lake Monona, 926.2 milligrams.

The mean quantity of organic matter in the total plankton of Lake Waubesa amounted to 4,938.3 milligrams per cubic meter of water. (Table 25.) This material contained 2,401.2 milligrams of crude protein, 227.5 milligrams of ether extract, 284.7 milligrams of pentosans, and 218.1 milligrams of crude fiber. The crude protein, ether extract, and crude fiber amounted to 2,846.8 milligrams, or 57.6 per cent of the organic matter; this leaves 42.4 per cent of the organic matter as nitrogen free extract.

Total Organic Matter per Unit Area. The plankton material was obtained in the deepest portion of Lake Waubesa, that is, in the region where the water reaches a maximum depth of a little more than 11 meters. The 10 meter contour line bounds an area of 101.2 hectares and the volume of water within this boundary line is 10,306,000 cubic meters. In this region of the lake, then, the maximum crop of total plankton in 1915, namely, 9,489.7 milligrams per cubic meter of water, amounted to 966 kilograms of dry organic matter per hectare, or about 862 pounds per acre. The living organic matter would represent about 9,660 kilograms per hectare, or 8,620 pounds per acre.

The mean quantity of organic matter for the 16 samples of total plankton is 4,938.3 milligrams per cubic meter of water, which represents 499 kilograms of dry organic matter per hectare of surface, or 445 pounds per acre.

For the entire lake the maximum crop of total plankton in 1915 represented 465 kilograms of dry organic matter per hectare, or 415 pounds per acre, and the mean of the 16 samples amounted to 242 kilograms per hectare, or 216 pounds per acre. The quantity per unit area for the entire lake was somewhat less than half as large as that for the deep water.

LAKE KEGONSA

The material from Lake Kegonsa consisted of a single sample of net plankton which was obtained on July 29, 1913. This catch gave the largest yield of net plankton per cubic meter of water that was secured during the entire investigation (see table 2, p. 181); it was almost one-third larger than its nearest competitor. Owing to the high percentage of ash in this material, namely, 38.85 per cent of the dry sample, with the silica amounting to 32.38 per cent of the dry material, the quantity of organic matter per cubic meter fell below that of a net sample taken in Lake Waubesa on September 10, 1915. (See table 47, p. 213, sample No. 5129 and table 25, p. 196.) In this net catch from Lake Kegonsa the phytoplankton was much more abundant than the zooplankton and the chief constituent of the former was Melosira. The ash content of this diatom was high, as indicated by the high percentage of silica, and this served to reduce the proportion of organic material in the sample.

The percentage of nitrogen in the organic matter of the net catch from Lake Kegonsa was somewhat lower than the average for the net material from the other lakes, namely, 6.88 per cent as compared with 7.54 per cent for Lake Waubesa and 9.36 per cent for Lake Monona. (Table 25.) Thus the crude protein constituted a proportionally smaller percentage of the organic matter. The large quantity of organic matter per cubic meter of water, on the other hand, gives a larger yield of nitrogen, and consequently of crude protein, than the averages for the other lakes when the results are stated in terms of milligrams per cubic meter of water. It will be noted that the amount of nitrogen is almost ten times as large in this net sample from Lake Kegonsa as the average for the various net catches of Lake Mendota and somewhat more than twice as large as the average of Lake Waubesa.

The percentage of ether extract is larger than the average for the net material of Lake Waubesa, but lower than the averages of Lakes Mendota and Monona. The percentage of pentosans is higher than the average for Lake Mendota, but lower than the averages of the other two lakes, while the order is reversed for the crude fiber. Owing to the fact that the organic matter in the net catch from Lake Kegonsa is much larger than the averages for the other lakes, the ether extract, pentosans, and crude fiber are distinctly larger in this sample than the averages for the other lakes when the results are given in terms of milligrams per cubic meter of water.

CHAPTER VII

GENERAL SUMMARY AND DISCUSSION

In previous chapters attention has been called to the fact that there are marked variations in the quantity of net plankton and of nannoplankton during the course of the year. This fact is shown graphically in figures 8, 9, 28, and 36. There are also more or less marked changes in the chemical composition of the plankton, which is illustrated by the variations in the percentages of nitrogen, ether extract, pentosans, and crude fiber. (Tables 43 to 48.) These variations in quantity and in chemical composition make it difficult to give a summary of the entire series of plankton samples. It is necessary to remember, therefore, in connection with the general data presented in table 25 (p. 196) that this plankton material is subject to such changes in order to guard against a wrong interpretation of these data. Furthermore, it should be noted that the data presented in this table do not represent the total amount of organic matter produced by the plankton; they show only the average standing crop maintained during the period of this investigation.

The mean quantity of dry organic matter indicated for the different lakes in table 25 represents the average amount for all of the plankton samples from each lake; this mean also represents the average amount for all depths in the deeper part of each lake. The plankton was more abundant in the epilimnion than in the hypolimnion during the summer period of stratification (see p. 101), but the water from all depths was combined into one sample in this investigation. In addition to the average for the complete series of net catches, the averages for the net samples corresponding to the nannoplankton samples are indicated also. The mean percentages of nitrogen, ether extract, pentosans, and crude fiber were ascertained by dividing the mean quantities of these substances in the various samples on which such determinations were made by the average amount of organic matter in the same samples. For example, the general table (No. 43) shows that nitrogen determinations were made on 166 samples of net plankton from Lake Mendota; these samples yielded an average of 28.6 milligrams of nitrogen per cubic meter of water, excluding the nitrogen of the crude fiber, and an average of 341.8 milligrams of dry organic matter. The nitrogen in this material, therefore, amounted to 8.37 per cent of the organic matter.

Multiplying the average quantity of organic matter in the 184 samples of net plankton, namely 332.5 milligrams per cubic meter of water, by the above percentage gives an average of 27.8 milligrams of nitrogen per cubic meter of water for the entire series of net catches in Lake Mendota. The other mean percentages and mean quantities were obtained in a similar manner. For the crude protein the results for nitrogen were multiplied by the factor 6.25.

In the following summary of the results, the fractions of milligrams have been omitted; they have been used, however, in computing the data into larger units. These fractions of milligrams are shown in table 25 and in tables 43 and 48.

Net Plankton

Lake Mendota. Table 25 shows that 184 samples of net plankton from Lake Mendota yielded an average of 332 milligrams of dry organic matter per cubic meter of water, while the 84 samples corresponding to the series of nannoplankton samples gave an average of 343 milligrams. In the former series the nitrogen made up 8.37 per cent of the organic matter (equivalent to 52.31 per cent of crude protein), the ether extract 11.78 per cent, the pentosans 2.88 per cent, and the crude fiber 6.54 per cent. In other words the crude protein, the ether extract, the pentosans, and the crude fiber constituted about 73.51 per cent of the average quantity of organic matter. The remaining portion consisted of nitrogen free extract or carbohydrates that are not included in the pentosans and the crude fiber. The percentage of nitrogen in the complete series of net catches is substantially the same as in the 84 samples corresponding to the nannoplankton samples, but the percentages of ether extract and of the pentosans are slightly higher and that for crude fiber is somewhat lower.

In the whole series of net catches from Lake Mendota, the organic matter varied from a minimum of 42 milligrams to a maximum of 1,135 milligrams per cubic meter of water. The regular station was located within the area bounded by the 20 meter contour line; when stated in terms of larger units for this area (see p. 98), the amount ranges from about 9 kilograms to 250 kilograms per hectare (8 pounds to 223 pounds per acre) for this portion of the lake, with an average of a little more than 72 kilograms per hectare (65 pounds per acre). These figures represent only the dry weight of the organic matter; the living organic material would weigh approximately ten times as much. For the 84 catches corresponding to the nannoplankton samples the average is somewhat higher, or approximately 76 kilograms per hectare of surface (68 pounds per acre).

Assuming that the net plankton is uniformly distributed over the whole lake, the mean quantity of organic matter (332 milligrams per cubic meter of water) multiplied by the total volume of the lake (table 1) gives an average standing crop of 159 metric tons of dry organic matter for the entire body of water. Since the lake has an area of 3,940 hectares, this crop amounts to a little more than 40 kilograms per hectare, or 36 pounds per acre, when expressed in terms of a unit of surface. The 84 net catches yield an average of just a little less than 42 kilograms of dry organic matter per hectare, or 37 pounds per acre.

Lake Monona. The 47 catches of net plankton from Lake Monona gave an average of 850 milligrams of organic matter per cubic meter of water, or a little more than two and a half times as much as those of Lake Mendota. In Lake Monona the amount ranged from a minimum of 109 milligrams to a maximum of 3,306 milligrams per cubic meter. No winter catches are included in this series so that the general average may be somewhat higher than it would be if some winter catches had been taken. On the other hand, it may be said that 111 net samples from Lake Mendota taken during the same months of the same years as the catches from Lake Monona yielded a smaller average than the complete series of samples, or only 309 milligrams as compared with 332 milligrams per cubic meter of water.

The nitrogen amounted to 9.36 per cent of the dry organic matter in the net plankton of Lake Monona, the ether extract 6.02 per cent, the pentosans 5.73 per cent, and the crude fiber 3.62 per cent. The percentages of nitrogen and pentosans are larger in the net material from Lake Monona than in that from Lake Mendota, but the reverse is true of the percentages of ether extract and crude fiber. The crude protein, ether extract, pentosans, and crude fiber constitute 73.87 per cent of the dry organic matter, leaving 26.13 per cent of undetermined nitrogen free extract. (Table 25.)

The 21 samples of net plankton from Lake Monona corresponding to the same number of nannoplankton catches yielded a somewhat smaller average amount of dry organic matter than the complete series of net catches, namely, 813 milligrams per cubic meter of water. The percentages of nitrogen, ether extract, and pentosans are larger in this material, but the percentage of crude fiber is smaller in the complete series of net samples.

The catches were taken in the deeper water of Lake Monona so that the results may be stated in larger units for the area within the 20 meter contour line (see p. 122). The average quantity of dry organic matter in the net plankton is 17.9 grams per square meter of surface for this part of the lake, or 179 kilograms per hectare (160 pounds per acre) for the whole series of net catches. The average is somewhat smaller for the 21 samples corresponding to the nannoplankton series, namely, 171 kilograms per hectare or 153 pounds per acre. The variations in the average for the complete series of net catches range from a minimum of 23 kilograms to a maximum of 695 kilograms per hectare (20 pounds to 620 pounds per acre) for the deep part of the lake.

When the area and the volume of the entire lake are taken into account, the amount of dry organic matter in the 47 net samples from Lake Monona varies from a minimum of 9 kilograms to a maximum of 278 kilograms per hectare of surface (8 pounds to 248 pounds per acre), with an average of about 72 kilograms per hectare (65 pounds per acre). For the whole lake the average standing crop of net plankton yields 101 metric tons of dry organic matter. The mean quantity of organic matter in the 21 samples of net plankton corresponding to the nannoplankton catches is a little less than 69 kilograms per hectare (61 pounds per acre).

Lake Waubesa. The 18 samples of net plankton from Lake Waubesa yielded an average of 1,665 milligrams of dry organic matter per cubic meter of water, or almost twice as much as the average for Lake Monona and five times as much as the mean of Lake Mendota. (Table 25.) The nitrogen constituted an average of 7.54 per cent of the dry organic matter, the ether extract 4.64 per cent, the pentosans 5.90 per cent, and the crude fiber 4.70 per cent. The percentages of nitrogen and of ether extract are appreciably below those of the net plankton from Lakes Monona and Mendota, but the percentage of the pentosans is higher. The percentage of crude fiber is higher than that noted in the material from Lake Monona, but lower than that of Lake Mendota. The average percentages of crude protein, ether extract, pentosans, and crude fiber account for 62.36 per cent of the organic matter, leaving 37.64 per cent of undetermined nitrogen free extract. In the net material from Lake Mendota the nitrogen free extract constituted an average of only 26.49 per cent of the organic matter and in that from Lake Monona only 26.13 per cent.

The quantity of dry organic matter in the complete series of net catches from Lake Waubesa varied from a minimum of 471 milligrams to a maximum of 4,232 milligrams per cubic meter of water. In that part of the lake having a depth of 10 meters or more (p. 139) the amount varied from about 48 kilograms to 427 kilograms per hectare (42 pounds to 381 pounds per acre). The average standing crop of dry organic matter in this region of the lake was 170 kilograms per hectare (151 pounds per acre). For the 16 samples of net plankton corresponding to the same number of nannoplankton catches, the average is somewhat smaller, namely, 1,639 milligrams per cubic meter of water, or 167 kilograms per hectare (149 pounds per acre) for the deep part of the lake.

Taking the entire lake into account the net plankton of Lake Waubesa gave an average of slightly more than 81 kilograms of dry organic matter per hectare of surface (72 pounds per acre) for the complete series of catches; the range is from a minimum of 23 kilograms to a maximum of 195 kilograms per hectare (20 pounds to 174 pounds per acre). The average for the 16 catches corresponding to the nannoplankton is 80 kilograms per hectare, or a little more than 71 pounds per acre.

A comparison of the results for the deep portions of the three lakes shows that the complete series of net catches from Lake Mendota yielded an average of somewhat more than 73 kilograms of dry organic matter per hectare, the series from Lake Monona a little more than 171 kilograms, and that from Lake Waubesa approximately 170 kilograms. Thus, the average amounts are substantially the same for Monona and Waubesa, with a slight advantage in favor of the former, while the average of Mendota is less than half as large as those of the other two lakes. Table 1 shows that the maximum depth of Waubesa is slightly less than half as much as the maxima of the other two lakes, yet it maintains substantially as large an average crop of net plankton in the deep water as Monona and a far larger amount than Mendota. Computed on the basis of the entire volume and area of each lake the average amounts of dry organic matter in the standing crop of net plankton per unit of surface are as follows, Mendota 42 kilograms per hectare (37 pounds per acre), Monona 72 kilograms per hectare (64 pounds per acre), Waubesa 81 kilograms per hectare (72 pounds per acre). Thus, for the entire lake the standing crop of net plankton of Lake Waubesa yields an average of almost twice as much organic matter per unit of surface as that of Lake Mendota and 12.5 per cent more than that of Lake Monona.

It should be noted again that the series of net catches from Lakes Monona and Waubesa cover only the period from late May to early November in the different years, so that the averages may be higher than they would be if catches had also been taken during the interval extending from the middle of November to the middle of May. On the other hand, it is shown on page 143 that the average for just those net samples from Mendota which correspond in time to those taken on Monona is about 8.0 per cent smaller than the average for the complete series of net catches from Mendota.

Lake Kegonsa. Only one sample of net plankton was obtained from Lake Kegonsa and that contained 3,378 milligrams of dry organic matter per cubic meter of water. (Table 25). For the entire lake this amount is equivalent to 174 kilograms per hectare (155 pounds per acre). The percentage of nitrogen in this material is smaller than the averages for the other three lakes, but the percentage of ether extract is a little larger than the average of Lake Waubesa. The percentage of the pentosans falls below the averages for the net material from Monona and Waubesa, but it is larger than the average of Mendota; the percentage of crude fiber, on the other hand, is larger than the averages of Monona and Waubesa, but smaller than the mean of Mendota. Together the crude protein, ether extract, and crude fiber constitute 53.36 per cent of the organic matter in the net catch from Lake Kegonsa, leaving 46.64 per cent as nitrogen free extract. The pentosans make up 4.36 per cent of the nitrogen free extract which leaves 42.28 per cent of the dry organic matter as undetermined carbohydrate material.

The Nannoplankton

Lake Mendota. The second part of table 25 gives a general summary of the nannoplankton for the three lakes from which such material was secured. A summary of the net samples corresponding to the nannoplankton catches is given also in order to show figures that are directly comparable for the two series of samples.

The dry organic matter of the nannoplankton of Lake Mendota varied in amount from a minimum of 795 milligrams to a maximum of 3,151 milligrams per cubic meter of water. (Table 17.) The average amount for the entire series of nannoplankton catches is 1,630 milligrams per cubic meter. (Table 25.) Nitrogen constituted 6.84 per cent of the mean quantity of organic matter (equivalent to 42.75 per cent of crude protein), ether extract 6.55 per cent, the pentosans 4.82 per cent, and the crude fiber 5.19 per cent. The percentages of nitrogen, ether extract, and crude fiber are smaller than those of the corresponding samples of net plankton, but the percentage of pentosans is larger. The crude protein, ether extract and crude fiber make up 54.49 per cent of the organic matter in the nannoplankton of Lake Mendota and the remainder consists of the carbohydrates which constitute the nitrogen free extract. Of the latter, the pentosans make up 4.82 per cent.

In the deep water of Lake Mendota the organic matter of the nannoplankton ranged from 175 kilograms to 694 kilograms per hectare (155 pounds to 619 pounds per acre), while the average quantity for the entire series of nannoplankton samples was 359 kilograms per hectare, or a little more than 320 pounds per acre. When the entire body of water is taken into account the mean quantity of dry organic matter becomes 198 kilograms per hectare of surface, or about 177 pounds per acre.

Lake Monona. The 21 samples of nannoplankton from Lake Monona gave an average of 2,350 milligrams of dry organic matter per cubic meter of water, with a minimum of 666 milligrams and a maximum of 5,696 milligrams. (Tables 25 and 29.) Of the mean quantity of organic matter 8.92 per cent consisted of nitrogen, 4.82 per cent of ether extract, 4.36 per cent of pentosans, and 4.76 per cent of crude fiber. With the exception of that for crude fiber, these percentages are smaller than those of the corresponding samples of net plankton. The crude protein, ether extract, and crude fiber constitute 65.33 per cent of the dry organic matter in the average crop of nannoplankton of Lake Monona; the remainder, 34.67 per cent, is represented by the nitrogen free extract, of which 4.36 per cent consists of pentosans. The percentage of nitrogen in the average standing crop of nannoplankton of Lake Monona is considerably larger than that in the nannoplankton of Lake Mendota, but the percentages of ether extract, pentosans, and crude fiber are larger in the material from the latter lake.

For the area bounded by the 20 meter contour line in Lake Monona, the average quantity of organic matter in the nannoplankton amounts to 494 kilograms per hectare (441 pounds per acre), with a variation ranging from 140 kilograms to 1,198 kilograms per hectare (125 pounds to 1,069 pounds per acre). For the entire body of water the mean quantity of organic matter is 198 kilograms per hectare (177 pounds per acre), with a minimum of 56 kilograms and a maximum of 480 kilograms per hectare (50 pounds to 428 pounds per acre).

Lake Waubesa. The average amount of dry organic matter in the 16 samples of nannoplankton from Lake Waubesa is 3,299 milligrams per cubic meter of water, of which 7.92 per cent consists of nitrogen (equivalent to 49.50 per cent of crude protein), 4.00 per cent of ether extract, 5.55 per cent of pentosans, and 4.45 per cent of crude fiber. (Table 25.) The crude protein, ether extract, and crude fiber constitute 57.95 per cent of the organic matter in the nannoplankton material, leaving 42.05 per cent to be classed as nitrogen free extract, of which 5.55 per cent consists of pentosans.

Unlike the material from the other two lakes the mean percentage of nitrogen is higher in the nannoplankton than in the net plankton of Lake Waubesa. The mean percentage of crude fiber is slightly larger in the nannoplankton, but the percentages of ether extract and of pentosans are larger in the net plankton. In comparison with the other two lakes the mean percentage of nitrogen in the nannoplankton material from Lake Waubesa is lower than that of Lake Monona and higher than that of Lake Mendota; the percentage of ether extract is lowest in the material from Waubesa, while the mean percentage of pentosans and of crude fiber is highest in the material from this lake.

Within the area bounded by the 10 meter contour line (p. 139) the mean quantity of dry organic matter in the nannoplankton amounts to 336 kilograms per hectare (300 pounds per acre). The range of variation is from a minimum of 81 kilograms to a maximum of 625 kilograms per hectare (73 pounds to 558 pounds per acre). For the entire lake the amount varies from about 39 kilograms to 300 kilograms per hectare (35 pounds to 268 pounds per acre), with an average of 161 kilograms per hectare of surface, or about 144 pounds per acre.

The mean quantity of dry organic matter in the nannoplankton is largest for the deep water area in Lake Monona, namely 494 kilograms per hectare (441 pounds per acre); Lake Mendota is second with 359 kilograms per hectare (320 pounds per acre), while Lake Waubesa comes last with 336 kilograms per hectare (300 pounds per acre). Computed on the basis of the entire body of water, the mean quantities are the same for Mendota and Monona, namely, 198 kilograms per hectare (177 pounds per acre), while the mean quantity for Waubesa is 161 kilograms per hectare (144 pounds per acre). Thus the mean quantity per unit of surface in Lake Waubesa is less than 20.0 per cent below that of the other two lakes in spite of the fact that it is a much shallower body of water.

The nannoplankton samples taken on Lake Mendota during the same intervals of time as those obtained from Lake Waubesa give a smaller mean quantity of organic matter than the complete series of catches from the former lake. That is 38 nannoplankton samples secured on Lake Mendota between August 10 and October 31, 1915, and between May 22 and November 1, 1916, give an average of 1,543 milligrams of dry organic matter per cubic meter of water as compared with 1,630 milligrams in the complete series of 87 samples. For the deep part of Lake Mendota this means a decrease to 340 kilograms per hectare (303 pounds per acre), and for the entire lake a decrease to 87 kilograms per hectare (167 pounds per acre). On the seasonal basis, then, the area within the 10 meter contour line in Lake Waubesa maintains almost as large a standing crop of nannoplankton as the area bounded by the 20 meter contour in Lake Mendota. When the entire lake is taken into account on this seasonal basis, the average quantity of dry organic matter in the standing crop of nannoplankton in Lake Mendota is considerably smaller during the two periods of time indicated above than in the complete series, but this amount is still about 16.0 per cent larger than the average for Lake Waubesa.

Total Plankton

Lake Mendota. The average yield of dry organic matter in the total plankton (net plankton plus nannoplankton) in the series of samples from Lake Mendota is 1,974 milligrams per cubic meter of water. (Table 25.) The various chemical analyses show that nitrogen constitutes an average of 7.11 per cent of this organic matter (equivalent to 44.49 per cent of crude protein), the ether extract 7.53 per cent, the pentosans 4.57 per cent, and the crude fiber 5.32 per cent. Using the crude protein value of the nitrogen these four substances account for 61.9 per cent of the organic matter, leaving 38.1 per cent as undetermined nitrogen free extract.

For the deep part of Lake Mendota the mean quantity of dry organic matter in the total plankton amounts to approximately 435 kilograms per hectare (338 pounds per acre); the monthly variations in the quantity of organic matter are shown graphically in figure 36. The amount varied from a minimum of 256 kilograms per hectare (228 pounds per acre) in February to a maximum of 522 kilograms per hectare (465 pounds per acre) in December.

When the volume and the area of the entire lake are taken into account the average amount of organic matter in the standing crop of total plankton is 240 kilograms per hectare (214 pounds per acre). Crude protein and ether extract make up a little more than 52.0 per cent of this organic material.

Lake Monona. The mean quantity of organic matter in the total plankton of Lake Monona is 3,163 milligrams per cubic meter of water, of which 9.21 per cent consists of nitrogen (57.56 per cent of crude protein), 5.36 per cent of ether extract, 4.74 per cent of pentosans, and 4.35 per cent of crude fiber. The crude protein and the three non-nitrogenous substances that were determined make up 72.01 per cent of the organic matter, while the remainder consists of undetermined nitrogen free extract.

In the deep water area of the lake the average amount of dry organic matter in the standing crop of total plankton is a little more than 665 kilograms per hectare (594 pounds per acre), while the yield of the whole lake is about 267 kilograms per hectare of surface (238 pounds per acre).

Lake Waubesa. The 16 samples of total plankton from Lake Waubesa gave an average of 4,398 milligrams of dry organic matter per cubic meter of water. The mean percentage of nitrogen in this material is 7.78 per cent, of ether extract 4.61 per cent, of pentosans 5.76 per cent, and of crude fiber 4.41 per cent. (Table 25.) By converting the nitrogen into crude protein these four substances account for 63.4 per cent of the organic matter, leaving 36.6 per cent as undetermined nitrogen free extract.

The average quantity of dry organic matter in the standing crop of total plankton is 503 kilograms per hectare (448 pounds per acre) for the area bounded by the 10 meter contour line, while the yield of the entire lake is 241 kilograms per hectare of surface (215 pounds per acre).

In what has been designated as the deep water portions of the three lakes the total plankton of Monona gives the largest average amount of dry organic matter per unit of area, namely, 665 kilograms per hectare (594 pounds per acre), while Waubesa is second in rank with 503 kilograms per hectare (448 pounds per acre) and Mendota is third with 435 kilograms per hectare (388 pounds per acre). When the results are computed on the basis of the volume and area of the entire lake, Monona is again first in rank with 267 kilograms per hectare (238 pounds per acre), Waubesa is second with 241 kilograms per hectare (215 pounds per acre), and Mendota is third with 240 kilograms per hectare (214 pounds per acre).

The mean percentage of nitrogen is largest in the total plankton of Lake Monona and smallest in that of Lake Mendota. The percentage of ether extract, on the other hand, is largest in the material from Lake Mendota and smallest in that obtained from Lake Waubesa; the latter lake has the highest mean percentage of pentosans and Lake Mendota the largest mean percentage of crude fiber.

Discussion of Results

For the sake of emphasis it may be worth while to repeat the statement that the data pertaining to the quantity of material per unit of volume or of area refer to the dry weight of the organic matter and that the living organic matter would weigh about ten times as much. The total weight of the living material would also include the inorganic constituents of the ash. Just how much the ash of the nannoplankton organisms would add to the weight of the living organic material in these organisms can not be determined from the present data because the centrifuge catches contained a certain amount of inorganic material derived from the silt in addition to the ash of the organisms. Since the quantity of inorganic material yielded by the nannoplankton organisms is not known, the amount of ash in the total plankton can not be indicated.

A number of determinations show that the ash content of the plankton algae ranges from about 3.0 per cent to almost 10.0 per cent of the dry weight in the green and blue-green forms, and from 40.0 per cent to more than 50.0 per cent in the diatoms. In Euglena and Volvox the ash constitutes from 4.0 per cent to 9.0 per cent of the dry weight. It seems probable, therefore, that the ash of most of the nannoplankton organisms does not constitute more than 10.0 per cent of the dry weight, but the diatoms yield a much larger percentage. When diatoms are abundant in the nannoplankton in the spring and in the autumn, the percentage of ash will be relatively high but when the diatoms are at a minimum in summer and in winter it will be comparatively low.

The mean quantity of ash in the 184 samples of net plankton from Lake Mendota amounts to 23.5 per cent of the dry weight of the material. This gives an average yield of 102 milligrams of ash per cubic meter of water for the entire series of samples. The 47 net samples from Lake Monona contain an average of 14.6 per cent of ash, or 145 milligrams per cubic meter of water. In the 18 net samples from Lake Waubesa the ash content averages 16.4 per cent of the dry weight of the material, which gives a yield of 331 milligrams per cubic meter of water.

The quantitative data presented in the various tables do not represent the total amount of plankton produced during any given period of time, but they show simply the standing crop of this material that was present at the time the observations were made. Neither do the mean quantities shown in table 25 refer to the problem of production, but they indicate the average amount of organic matter in the standing crop of plankton when the whole series of samples from each lake is considered as a unit. The seasonal or annual production of this material involves the question of the rate of the turnover in the plankton crop and this is a very complex problem.

The plankton of a lake may be regarded as analogous to a pool in a stream, with a current of water constantly flowing in on one side and a regular outflow on the other. The pool itself represents the standing crop of plankton, while the inflowing stream is analogous to the process of plankton production and the outflowing one typifies the losses of this material from various causes. The stream of water that is continually passing through the pool closely resembles the constant stream of plankton life which exists in a body of water. Since the standing crop of plankton shows marked variations in quantity during the year, it is necessary to regard the pool and stream as variable in size, expanding to several times their normal size in periods of flood and falling considerably below normal in periods of drought. In spite of these seasonal variations in quantity, however, a surprisingly close correlation in the size of the standing crop of plankton is found at corresponding periods of the different years. (Figures 34 and 35.)

In the foregoing illustration it would be a relatively simple problem to ascertain, with some degree of accuracy, the amount of water that passes through the pool annually, and this may be thought of as corresponding to the annual production of plankton. It is also a comparatively simple problem to ascertain the annual productivity of a given area of land because the crop can be limited to a single kind of grain or hay and because there are definite seasons for planting and harvesting the crop. But the problem of ascertaining the plankton productivity of a body of water is far more complex than the determination of the amount of water that passes through the pool in the foregoing illustration, or than determining the productivity of a piece of land.

One of the chief complexities involved in the question of plankton production is the variety of the organisms constituting the crop; that is, the standing crop of plankton is always made up of a number of different kinds of organisms. At certain times of the year perhaps not more than twelve or fifteen genera of organisms may be represented in the total plankton, while at other seasons the number may increase to thirty or forty genera, possibly more; the number depends partly upon the character of the lake and partly upon the season of the year. The various forms differ widely in character, also, ranging from one-celled plants and animals to organisms as complex in structure as the crustacea and the insect larvae.

There is no period of time during the year when one crop of plankton ceases and another begins, so that there is no definite starting point for the estimation of the annual crop of plankton, such as one finds for a land crop, for example. Neither is there any exact date of maturity, or harvest season, for the plankton crop as there is for the land crop. The crop of plankton, therefore, represents a continuous stream of life which flourishes at all seasons of the year and which passes on from year to year as long as favorable conditions obtain in a body of water.

Some of the plankton forms are present in varying degrees of abundance at all seasons of the year; others make their appearance from time to time when conditions are favorable for them, rise to a maximum, and then decline in numbers. The decline of one form may be accompanied by the rise of another, so that the developmental cycles of the two overlap in time, or two or more forms may rise to their maxima simultaneously; therefore, this overlapping may produce a great variety of complexities. These complications usually result, however, in a series of waves or pulses of plankton in the course of the year, with the largest crops generally coming in the spring and in the autumn.

In comparison with land productivity another marked difference is shown by the lake in that plankton production takes place at all depths in a body of water; the plankton soil of a lake, therefore, is coextensive with the depth of the water.

The various plankton organisms possess very different rates of reproduction. Under favorable conditions the aquatic bacteria may pass through several generations in the course of a single day, while the algae and protozoa may divide only once or perhaps twice in this interval of time and the plankton crustacea may require two weeks or longer to pass from one generation to the next. Temperature is a very important factor in determining the rate of reproduction in the various forms; that is, the reproductive process is most vigorous at the higher temperatures which prevail during the summer months and it is least vigorous during the winter period of low temperatures. A decrease of a few degrees in temperature is sufficient to cause a marked decline in the rate of reproduction; thus even in summer this process will proceed more vigorously in the warm water of the epilimnion than in the cooler water of the hypolimnion.

Another factor which helps to complicate the problem of determining the plankton productivity of a body of water is the great variation in the length of life of the different forms. In the unicellular plankton organisms, which multiply chiefly by fission, the lifetime of an individual covers the period from one cell division to the next; the lifetime of a bacterium, therefore, may be less than an hour under favorable temperature and food conditions, or it may be greatly prolonged, perhaps to several days, by a low temperature of the water. Among the algae and protozoa the span of life may be less than a day at summer temperatures or it may be prolonged to several days at lower temperatures.

In the higher plankton forms reproduction takes place by means of germ cells and the lifetime of the individual is much longer. Some of the crustacea, for example, may live for several weeks, or even for several months when the temperature of the water is low. The lifetime of the various planktonts, therefore, shows a great variation, ranging from a minimum of less than an hour in some forms to a maximum of several weeks or even months in others. Thus, the determination of the rate of reproduction and of the length of life of individuals belonging to the various forms in their natural environment will be a very important advance toward the solution of the problem in plankton productivity. In fact, very little progress can be made in answering this question until such data are obtained.

There is also a great diversity in the size of different planktonts. The coccus forms of bacteria, for example, are only 0.22μ to 0.75μ in diameter, while Leptodora among the plankton crustacea may reach a length of 18 millimeters.

The question of plankton productivity is complicated still further by the fact that the losses as well as the gains of material must be taken into account. These losses are sustained in two ways, namely, (1) through the consumption of some of the planktonts as food by various organisms, (2) through the death of some of the material. The losses, like the gains, continue throughout the year so that production and destruction are simultaneous processes and the quantity of plankton that is present at any given time during the year is the resultant or the algebraic sum of these two processes; this resultant constitutes what has been termed the standing crop of plankton. Whenever production takes place at a faster rate than destruction, there is an increase in the standing crop of plankton and the degree of increase depends upon the excess of the former over the latter. On the other hand, when the rate of destruction exceeds that of production there is a decrease in the standing crop of plankton which corresponds to the excess of the former over the latter; when these two processes just about balance each other the quantity remains fairly uniform. The variations in the quantity of organic matter in the standing crop of plankton in Lake Mendota are well illustrated in figures 34 and 35.

The present data do not enable one to make a definite assessment of the value of the plankton crop in the biologic economy of the lake, nevertheless it is well worth while to consider certain phases of this question. The larger zooplankton forms, such as the crustacea and the rotifers, and even the minute forms such as algae and protozoa, are eaten more or less extensively by fishes. The plankton crustacea are of special economic importance in this respect since most freshwater fishes at some period in their lives feed chiefly or exclusively upon these small organisms. Some fishes, in fact, are plankton feeders during the whole period of their existence. Among the crustacea the Cladocera are more important than the Copepoda because they are used for food more extensively by fishes; hundreds or even thousands of Daphnias may be found in a single fish stomach, while the smaller Cladocera may be eaten in much larger numbers. Some of the insect larvae prey upon the Cladocera and they, in turn, are fed upon by the fishes. Also midge larvae feed upon plankton algae and they, too, constitute an item in the menu of fishes.

The bivalve mollusks depend chiefly upon the bacteria, algae, and protozoa of the plankton for their food. Part of the plankton sinks to the bottom of the lake and this constitutes a source of food for the insect larvae, mollusks and worms which dwell upon the bottom; this material is especially important for the bottom dwellers which are found in the deeper portions of a lake.

In the assemblage of plankton organisms themselves those forms which do not bear chlorophyl are dependent, either directly or indirectly, upon those members which do possess this substance for their food. The crustacea are rather voracious feeders and their food consists chiefly of algae and protozoa; when the former are abundant, therefore, they consume large quantities of the latter organisms and at such times they are very important agents in reducing the stock of the organisms on which they feed. The rotifers also feed upon the algae and protozoa, while the protozoa that do not possess chlorophyl, in turn, feed upon the algae and the bacteria.

Just how much food a rotifer or a crustacean consumes each day is not known, but the following figures show how much water would have to be depleted of its population in order to furnish some of these forms with their own weight of organic matter for food. The average dry weight of some of the constituents of the plankton of Lake Mendota has been determined and the results are as follows: (1) A large Asplanchna weighs 0.000834 milligram, (2) a mature Cyclops 0.0041 milligram, (3) a Diaptomus 0.00858 milligram, (4) an adult *Daphnia longispina hyalina* 0.02172 milligram. Taking the average quantity of organic matter in the nannoplankton of Lake Mendota as a basis for the calculation, namely, 1,630 milligrams per cubic meter of water (table 25), each of these animals would have to remove all of the nannoplankton from the following quantity of water in order to obtain its own weight of dry organic matter for food; (1) An Asplanchna 0.5 cubic centimeter, (2) a Cyclops 2.5 cubic centimeters, (3) a Diaptomus 5.2 cubic centimeters, and (4) an adult *Daphnia hyalina* 13.3 cubic centimeters. These quantities of water seem very small, but when compared with the size of the organisms concerned they are very large. Disregarding temperature and assuming that one cubic centimeter of water weighs one gram, the above organisms would have to filter about 600,000 times their own dry weight of water in order to secure their own weight of dry organic matter in the form of nannoplankton. These animals may also feed upon some of the organisms in the net plankton and thereby reduce the above quantities of water proportionately.

Computations based on the numerical data indicate that the crustacea and the rotifers contribute from 25.0 per cent to 75.0 per cent of the organic matter in the net plankton; the maximum percentage is found in late winter and in early spring when the algae and protozoa reach their lowest points in the net material; the minimum percentage is found in the early summer and in the autumn when the protista flourish most abundantly. Since the maximum percentage of crustacea and rotifers is correlated in time with one of the minimum periods of the net plankton, it seems probable that these two groups or organisms furnish something like 30.0 per cent to 40.0 per cent, or about one-third, of the mean quantity of organic matter in the net plankton; that is, an average of about 115 milligrams out of 343 milligrams per cubic meter of water (table 25). If the protista of the net plankton are included in the computation, therefore, the quantity of water that a rotifer or a crustacean would have to strain to obtain its own weight of organic matter would be reduced about 12.0 per cent.

These quantities of water are based on the mean quantity of organic matter in the nannoplankton and in the protista of the net plankton. Whenever the quantity of organic matter in these two groups of organisms is above the mean, the quantities of water would be smaller than the amounts indicated and whenever it is below the mean, these amounts of water would be larger than indicated above.

Owing to the absence of free oxygen in the hypolimnion of Lake Mendota in July and August, the rotifers and crustacea are limited to the epilimnion and the mesolimnion during this time and the food supply in these two strata is about 12.5 per cent larger than the mean on which these computations are based.

The data presented in this report do not indicate the quantity of plankton material produced annually, but by far the greater part of the standing crop of plankton is contributed by organisms that multiply rather rapidly under favorable conditions of temperature and food; thus the turnover in this stock of material is proportionally rapid. As indicated in a previous paragraph only about 115 milligrams of organic matter out of a mean of 1,974 milligrams (table 25) per cubic meter of water in the total plankton is derived from the rotifers and crustacea, and these two forms have the slowest rate of reproduction among the various fresh-water planktonts. Substantially all of the other material is derived from organisms that reproduce much more rapidly; that is, from unicellular forms or from colonies consisting of groups of cells. The single cells of the various forms are capable of dividing once a day or oftener when the temperature of the water is 20° C. or higher; the bacteria, in fact, may divide oftener than once an hour. At a rate of one division per day the possible progeny of a single cell would amount to more than one billion in a period of thirty days, while one division every three days would result in the production of 1,024 descendants in the same length of time.

The epilimnion of Lake Mendota has a temperature of 20° or higher from about the middle of June until the middle of September and during this period the turnover in the stock of plankton will be rapid in this stratum. It will not be so rapid in the mesolimnion and in the hypolimnion because the temperature of the water is lower in these strata. The cooling of the water in the autumn and early winter will tend to decrease the rate of production. The temperature of the water rises slowly during the winter, but it does not reach a mean of 4° until after the ice disappears, or about the middle of April. This is followed by a period of vigorous production which culminates in the vernal maximum.

The foregoing discussion clearly brings out the fact that the problem of ascertaining the quantity of plankton that a body of water produces annually is a very complex one and its solution will require very extensive and detailed investigations; the present data show only the standing crop of plankton and its quantitative variations. A more complete knowledge of (1) the rate of reproduction of the various planktonts under natural conditions of light, temperature, and food, (2) the length of their life in the natural environment, and (3) the average weight of the different kinds of organisms per individual or colony, is of prime importance in the solution of this complex problem. Data regarding the first two questions will enable one to estimate, with some degree of accuracy, the annual turnover in the stock of plankton material, and therefore the annual production of this material, while data pertaining to the third question will make it possible to evaluate the relative importance of the different forms in the plankton complex of the lake.

While these data do not indicate the rate of turnover in the stock of plankton, yet some computations based wholly on estimates may be worthy of consideration at this point. The mean quantity of dry organic matter in the standing crop of total plankton of Lake Mendota amounted to approximately 945 metric tons during the period covered by these observations, or an average of 240 kilograms per hectare of surface (214 pounds per acre), when the entire lake is taken into account. A turnover in this mean quantity of plankton organic matter once a month would give an annual production of 2,880 kilograms per hectare, or 2,568 pounds per acre; a turnover twice a month would double this amount.

Since the planktonts which contribute by far the greater part of the organic matter multiply rapidly under favorable conditions, once a day or oftener, the turnover in this stock of plankton material may take place more frequently, perhaps as often as once a week, on an average. With a turnover of fifty times per year, the annual production would amount to 12,000 kilograms of dry organic matter per hectare of surface, or 10,700 pounds per acre. Which of the above amounts approaches the annual production most closely can not be determined with any degree of accuracy until more data are available relating to the rate of reproduction of the various plankton organisms in their natural environment. It seems most probable, however, that the time interval for the turnover in the mean quantity of plankton will be found to fall somewhere between one and two weeks during the greater part of the year.

CHAPTER VIII

CHEMICAL ANALYSES OF VARIOUS ORGANISMS

The purpose of this investigation was not only to obtain a general idea of the quantity and of the chemical composition of the plankton as a whole, but also to ascertain the chemical composition of the different constituents of the plankton whenever they could be secured in a pure or substantially pure state. Several plankton forms were obtained in sufficient abundance and purity to warrant analyses of them and the results of the analyses of these forms are shown in table 49 (p. 215). Since the general problem of the total productivity of a lake was kept in mind during this study, samples of the larger forms were secured from time to time and the results of the analyses of these samples are also given in table 49.

The analyses of fifty-two samples are shown in this table, of which thirty-four are results obtained on plankton organisms and eighteen on non-plankton forms. Nineteen of the fifty-two samples represent plant material and thirty-three animal material.

Among the plants the Myxophyceae or blue-green algae are represented by Microcystis, Anabaena, Coelosphaerium, Aphanizomenon, and Lyngbya; the Chlorophyceae or green algae include Ankistrodesmus, Volvox, Spirogyra, and Cladophora, while the diatoms or Bacillariaceae are represented by a sample containing both Fragilaria and Tabellaria. All of these algae except Spirogyra and Cladophora are regular plankton forms; very rarely Spirogyra and Cladophora may be found in the plankton but they are only accidental constituents. Samples of three of the large aquatic plants which grow in the shallow water and which represent the phanerogams, namely, Potamogeton, Vallisneria, and Myriophyllum, have been analyzed.

Of the thirty-three samples of animal material, nineteen represent plankton crustacea belonging to six genera; the Copepoda include three genera, namely, Diaptomus, Cylops, and Limnocalanus, and the Cladocera are represented by three species of Daphnia, by Holopedium, and Leptodora. Besides the plankton forms of crustacea two of the larger forms of this group are represented, namely, a crayfish belonging to the genus Cambarus and the amphipod Hyalella. The Oligochaeta are worms belonging to the genera Limnodrilus and Tubifex, while the Hirudinea are represented by a sample containing two or three species of leeches. The last ten items in the table represent aquatic insects, all except the last two being larvae; the sample of Gyrinids consisted of adults, while that of the Hemiptera contained both young and adults. The Corethra larvae are limnetic in habit and they are the only insect constituents of the plankton.

In part I of table 49 the results of the analyses are stated in percentages of the dry weight of the sample when the ash is included; in part II the percentages are given on an ash free basis. The percentage of ash varied so much in the different samples that it seemed worth while to state the results on an ash free basis also, so that the different components of the organic matter in the various samples might be more readily compared.

The chemical study of these samples included the usual determinations that are made in a food analysis, namely, a quantitative determination of the nitrogen, the ether extract, the crude fiber, and the ash. The nitrogen multiplied by the factor 6.25 gives the crude protein. These items do not account for all of the organic matter in a sample and the remainder is usually designated as the nitrogen free extract; that is, the sum of the percentages of crude protein, ether extract, crude fiber, and ash deducted from 100 gives the percentage of nitrogen free extract. This extract consists principally, if not entirely, of carbohydrate material, but in some instances small amounts of other substances may be present; it may contain, for example, a certain amount of fats which are not completely removed by ether from some of the compounds in which they occur. The pentosans are the only carbohydrates which have been studied in these samples and they were determined quantitatively in thirty-one samples as indicated in table 49. The other carbohydrate constituents of these samples remain as a problem for future chemical investigation.

Plants

Myxophyceae. Ten samples containing material derived from four genera of blue-green algae, namely, Microcystis, Anabaena, Aphanizomenon, and Lyngbya, are shown in table 49. With the exception of one sample they yielded a high percentage of nitrogen; a sample of Microcystis gave only 6.32 per cent of nitrogen when the ash is included in the dry weight of the sample, but in the other nine the nitrogen ranged from 8.21 per cent to 9.94 per cent. This high percentage of nitrogen represents a correspondingly large amount of crude protein; the latter, in fact, falls below 50.0 per cent of the dry weight in only one sample, while it exceeds 60.0 per cent in one instance. This large percentage of crude protein is not surprising in view of the fact that these forms contain only a relatively small amount of material besides the protoplasmic content of the cell; the cell walls are fairly delicate and the gelatinous covering yields but a small amount of dry matter. On an ash free basis, the crude protein makes up from 54.12 per cent to 66.45 per cent of the dry weight of the organic matter, if the one sample with a minimum of 41.60 per cent is omitted.

The ether extract constituted a relatively small percentage of the dry material in these ten samples of blue-green algae, ranging from a minimum of 1.11 per cent to a maximum of 5.02 per cent. On an ash free basis these percentages are somewhat higher. The green color of the ether extract indicated that it contained a certain amount of chlorophyl.

The percentage of crude fiber was small, with the exception of one sample of Lyngbya in which it amounted to 7.39 per cent of the dry weight of the sample; it was less than one per cent in four of the nine samples on which determinations were made.

Including the ash the nitrogen free extract ranged from a minimum of 25.72 per cent of the dry weight to a maximum of 52.09 per cent; it exceeded 40.0 per cent in only one of the nine samples of blue-green algae shown in table 49. No crude fiber determination was made on one of the samples of these algae so that the nitrogen free extract can not be indicated for this sample. Pentosan determinations were made on eight of these samples and they show percentages ranging from 2.04 per cent to 7.80 per cent of the dry weight of the sample.

On an ash free basis the nitrogen free extract constituted from 27.62 per cent to 54.82 per cent of the organic matter in the samples of blue-green algae, and the pentosans varied from 2.20 per cent to 8.46 per cent. The former is substantially a twofold variation and the latter almost fourfold.

The ash varied from a minimum of 4.31 per cent to a maximum of 7.81 per cent of the dry weight, so that it may be regarded as relatively small in amount. Quantitative determinations of the silica were made on nine samples; in seven instances the quantity of this substance was less than one per cent of the dry weight of the sample, while two were higher, one yielding a maximum of 1.62 per cent.

The various samples show not only that the different kinds of blue-green algae differ somewhat in their chemical composition, but also that the same form is subject to more or less marked variations in this respect. The specimens of Microcystis, for example, show considerable differences in their nitrogen content and smaller but distinct differences in the percentages of ether extract, crude fiber and ash. The two samples of Lyngbya from Lake Monona also differ appreciably in their organic constituents although the second one was collected only four days later than the first one; the ash, however, is about the same in both samples. These variations in the chemical composition of the same form are due, doubtless, to the fact that the samples represent different stages in the life cycle of the alga.

Hyams and Richards[1] found, for example, that young, green filaments of the blue-green alga *Oscillatoria prolifica* contained 9.0 per cent of nitrogen, while mature, brown colored specimens yielded only 7.9 per cent; the ash in the former amounted to only 4.5 per cent, while in the latter it ranged from 6.1 per cent to 6.7 per cent. (See table 51.) Most of the difference in the ash was due to a greater abundance of silica in the mature material; the silica in the young amounted to 1.46 per cent and in the mature to 2.90 per cent. This evidence seems to indicate that an alga collected during a period of rapid growth and vigorous reproduction differs somewhat in chemical composition from a sample of the same alga which is collected after the form has become fully mature.

In other analyses Hyams and Richards obtained 11.0 per cent of nitrogen in one sample of *Oscillatoria prolifica* and 10.3 per cent in another; both of these percentages are higher than the maximum of nitrogen in the samples of blue-green algae shown in table 49.

Turner[2] also analyzed samples of *Oscillatoria prolifica* and found that the air dried material contained 9.7 per cent of moisture, 7.4 per cent of nitrogen, 2.2 per cent of ether extract, and 6.4 per cent of ash. When recalculated on an oven dry basis, the nitrogen equals 8.2 per cent, the ether extract 2.4 per cent, and the ash 7.1 per cent. (Table 51.) His results for nitrogen, therefore, are substantially the same as those found in four samples of blue-green algae in this series of analyses, and his percentages of ether extract and ash are also similar to some of the results obtained on this Wisconsin material.

Whipple and Jackson[3] found 9.6 per cent of nitrogen in Anabaena and 8.3 per cent in Microcystis (Clathrocystis). (Table 51.) The former is higher than the percentage of nitrogen in the Anabaena material obtained from Lake Mendota on September 19, 1914, while the latter is substantially the same as the average of the four samples of Microcystis shown in table 49.

Chlorophyceae. The sample of Ankistrodesmus was grown in a culture containing Knop's solution; this nutrient solution yielded a precipitate which was removed from the water by the centrifuge along with the alga. This made the ash content of the sample too high, namely 41.61 per cent, so that the results for Ankistrodesmus are given only on an ash free basis. The percentage of nitrogen in this alga is a

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[1] Technology Quarterly, Vol. 15, 1902, pp. 308-315.

[2] Jour. Amer. Chem. Soc., Vol. 38, 1916, p. 1402.

[3] Jour. N. E. Waterworks Assoc., Vol. 14, 1899, pp. 1-25.

little below the mean of the blue-green algae, but the percentages of ether extract and of crude fiber are appreciably higher than in the latter. Only one sample of the blue-greens has a smaller percentage of nitrogen free extract than Ankistrodesmus and only one has a smaller percentage of pentosans.

On July 6, 1916, an abundant growth of the flagellate Volvox was found in Lake Monona and enough of this material was secured for a chemical analysis. This flagellate yielded a smaller amount of nitrogen than the blue-green algae; still the percentage of nitrogen is large enough to show that almost half of the dry material consists of crude protein. The percentages of ether extract and of crude fiber are somewhat larger in this Volvox material than the average for the blue-green algae, with the exception of the crude fiber in Lyngbya. The pentosans are smaller in Volvox than in the blue-greens, while the nitrogen free extract is about the same as the average for the latter group.

All of the percentages for Volvox are somewhat smaller than those for Ankistrodesmus except that of nitrogen free extract. (Table 49, p. 215.)

Brandt[4] records the results of a chemical analysis of some marine flagellates; his sample consisted of peridinians, chiefly the flagellate Ceratium. The crude protein in this material amounted to 12.68 per cent of the dry weight of the sample, the fat or ether extract 1.3 per cent, the crude fiber 41.5 per cent, the nitrogen free extract 39.0 per cent, and the ash 5.2 per cent. (Table 51.) A comparison shows that the percentage of crude protein in the sample of Volvox from Lake Monona is more than three times as large as that in the above sample of marine peridinians, while the percentage of ether extract is more than four times as large in the former as in the latter. The crude fiber in the peridinians is more than six times as large as that in Volvox and the nitrogen free extract is somewhat larger in the former; the percentage of ash is a little larger in Volvox than in the peridinians.

The two samples of green algae which do not belong to the regular plankton forms, namely Spirogyra and Cladophora, yielded different results from those obtained on the blue-green algae and also from those of the two green algae noted above. The percentage of nitrogen is less than half as large as the mean of the blue-greens and also less than half as large as the percentages in Ankistrodesmus and Volvox; this means correspondingly low percentages of crude protein in the two filamentous algae. Whipple and Jackson[5] found 4.5 per cent of nitrogen in the sample of Spirogyra which they analyzed. (Table 51.)

[4] Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, p. 88.

[5] Jour. N. E. Waterworks Assoc., Vol. 14, 1899, pp. 1-25.

The ether extract in Spirogyra and Cladophora is substantially the same as the mean of the blue-green algae, but it is smaller than in Ankistrodesmus and in Volvox. The percentage of pentosans is larger in Spirogyra and Cladophora than in any of the other algae included in this series of samples; on an ash free basis the percentages are substantially the same in these two filamentous algae, but they are more than five times as large as the minimum in the blue-green algae and more than eleven times as large as the percentage of the pentosans in Volvox. Cladophora yielded a large percentage of crude fiber, this item amounting to more than a quarter of the dry organic matter, but only a relatively small percentage was found in the sample of Spirogyra. In this respect the latter compares very favorably with about half of the samples of blue-green algae, but it is much smaller than the percentages in Ankistrodesmus and Volvox. The percentage of crude fiber in this sample of Cladophora is almost three times as large as the maximum of the other algae given in this table; in fact, it is the maximum obtained in this series of samples.

The sample of Cladophora yielded a large percentage of ash and silica; the material was obtained from rocks along the edge of the lake and was carefully washed when it was collected, but the large percentages of ash and silica seem to indicate that the sample contained some sand. The percentage of ash in Spirogyra is only about one-third as large as that in the Cladophora material, still it is appreciably larger than the percentages of ash in the samples of blue-green algae.

Part II of table 49 shows that nearly three-quarters of the organic matter of Spirogyra consisted of nitrogen free extract, the percentage being larger than in any other form given in the table. With the exception of one sample of Microcystis, the nitrogen free extract in the sample of Cladophora is larger than in all of the samples of blue-green algae listed in table 49.

Bacillariaceae. The sample of diatoms obtained from Lake Mendota contained several forms, but the most abundant one was Fragilaria, with Tabellaria ranking second in importance. This material yielded a large percentage of ash which consisted chiefly of silica derived from the silicious shells of these organisms. As a result of the presence of such a large amount of inorganic material, the percentages of the organic constituents are relatively small when the ash is included. The percentage of nitrogen in the diatoms, for example, is less than half as large as that in the various samples of blue-green algae, with the exception of one sample of Microcystis. On an ash free basis, however, the comparison is more favorable to the diatoms, but even then the percentage of nitrogen falls below the minimum of the blue-greens; it is only two-thirds as large in the diatom sample as in the samples of Ankistrodesmus and Volvox.

The diatom sample contained a larger percentage of ether extract than any other sample of plant material. The percentage of this extract in the diatoms is more than two and a half times as large as the maximum in the blue-green algae with the ash included, while it is more than four times as large as the latter on an ash free basis. The percentage of ether extract in the organic matter of the diatoms, in fact, is exceeded by that in only five samples of animal material as shown in part II of table 49. The large percentage of this extract in the diatoms is due to the fact that the reserve material in these forms consists of drops of oil instead of carbohydrate compounds.

The percentages of crude fiber and of pentosans are relatively small in this sample of diatoms, and the nitrogen free extract, on an ash free basis, is substantially the same as the mean for the nine samples of blue-green algae.

Whipple and Jackson[6] found 2.2 per cent of nitrogen in the diatom Asterionella, while the ash constituted 57.52 per cent of the dry material. The percentage of nitrogen in Asterionella is smaller than in the diatom material from Lake Mendota, while the ash is much larger; on an ash free basis the percentage of nitrogen in the former is 5.18 per cent as against 6.05 in the latter. (See table 51.) The ash of the sample containing Asterionella contained 49.48 per cent of silica, leaving only 8.04 per cent for the other constituents; deducting the silica from the ash of the diatoms secured in Lake Mendota leaves 8.72 per cent.

For marine diatoms Brandt[7] gives the following results on an ash free basis: crude protein 28.7 per cent, fat 9.0 per cent, and carbohydrate 63.2 per cent. (See table 51.) He regards the crude protein in his material as rather high, but it is more than 10.0 per cent below that found in the material from Lake Mendota; the percentage of fat in the marine material is only a little more than one-third as large as the ether extract in this sample of freshwater diatoms. In the marine diatoms the crude protein and the fat constitute only 36.7 per cent of the dry organic matter, while in the freshwater forms from Lake Mendota these two items make up 60.29 per cent of the organic matter.

On an ash free basis the nitrogen found in Asterionella by Whipple and Jackson is equivalent to 32.4 per cent of crude protein as compared with 28.7 per cent in the marine diatoms indicated by Brandt.

Phanerogams. Two samples of Potamogeton were analyzed; one contained mature plants whose leaves were dead and the other consisted of plants whose leaves were still bright green. The stems as well as the leaves of the plants were used for both samples, but not the roots. The

[6] Jour. N. E. Waterworks Assoc., Vol. 14, 1899, pp. 1-25.

[7] Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, p. 89.

sample consisting of green plants yielded a larger percentage of nitrogen and of ether extract than the one containing the mature plants, but the reverse was true of the pentosans, the crude fiber, and the ash. Small differences in the ash are not very significant, however, because the leaves are covered with a deposit of lime which comes off very readily when the plants are dry; it is very difficult to prevent a slight loss of this lime while the material is being dried and prepared for the analysis.

The percentage of nitrogen is smaller in these two samples of Potamogeton than in the other two samples of phanerogams, namely Vallisneria and Myriophyllum. In Vallisneria the percentage of nitrogen is substantially the same as it is in the sample of Cladophora, but it is smaller than that in the sample of Spirogyra. On an ash free basis the percentage of nitrogen is smaller in the sample of Vallisneria than in those of Cladophora, Spirogyra, or Myriophyllum; of these four samples the last one has the largest percentage of nitrogen, but even this maximum is much smaller than the percentages shown for the various samples of blue-green algae, or than those of Ankistrodesmus and Volvox.

The two samples of Potamogeton yielded a smaller amount of ether extract than those of Vallisneria and Myriophyllum; the latter rank with Spirogyra and Cladophora in this respect. The sample of mature Potamogeton gave a smaller percentage of ether extract than the one containing green plants.

On an ash free basis the crude fiber constituted from 16.52 per cent to 21.16 per cent of the dry organic matter in these four samples of phanerogamic plants. The maximum here is exceeded only by the percentage found in Cladophora. The percentages of pentosans are about the same in the samples of Potamogeton as in those of Spirogyra and Cladophora, but they are smaller in Vallisneria and Myriophyllum.

The percentage of ash is fairly large in the four samples of phanerogamic plants, being exceeded among the plants only by the sample of diatoms and that of Cladophora.

The nitrogen free extract is rather large in these four samples of the large aquatic plants also, ranging from 51.20 per cent of the dry organic matter in Myriophyllum to 65.55 per cent in the mature Potamogeton. The maximum percentage is exceeded by only one other sample of plant material, namely, that of Spirogyra. These percentages of nitrogen free extract are comparable to those that have been obtained for such land crops as alfalfa and timothy hay.

Animals

Samples of the more common forms of the plankton crustacea were secured for analysis. The Copepoda are represented by Diaptomus, Cyclops, and Limnocalanus, while the Cladocera comprise Holopedium, Leptodora, and three species of Daphnia.

The crustacea and the insects possess chitinous coverings which contain a certain amount of nitrogen. Since chitin is non-protein in character it is necessary to make a correction for this part of the total nitrogen in order to ascertain the amount of nitrogen that belongs to the crude protein. In making this correction the crude fiber has been regarded as chitin and the percentage of nitrogen in the crude fiber has been determined in most of these samples. The percentage of nitrogen in the fiber varied from a little less than 6.0 per cent to a little more than 7.0 per cent of the dry weight of the crude fiber; thus for the samples on which no determinations were made, an average of 6.5 per cent of the crude fiber has been deducted from the total nitrogen as a correction for the nitrogen of the chitin. In the samples on which determinations were made the actual amount of this nitrogen has been deducted from the total. The percentages of nitrogen shown in table 49, therefore, represent the amount in the crude protein and they do not include the nitrogen in the chitin.

Copepoda. The five samples of copepods yielded a high percentage of nitrogen, thus indicating a correspondingly large proportion of crude protein; the sample containing Limnocalanus gave the smallest percentage and that containing Diaptomus the largest. On an ash free basis only three other samples in this series yielded a larger percentage of nitrogen than Diaptomus and these three consisted of animal material; the maximum for the blue-green algae, however, is only four-tenths of one per cent below Diaptomus.

All of the copepod samples contained a relatively large amount of ether extract or fat; Diaptomus gave the smallest percentage and Limnocalanus the largest. In the latter the ether extract amounted to 41.6 per cent of the organic matter; this large yield is due to fairly large drops of oil which are present in the thoracic region of this animal. The crude protein and the ether extract combined constitute from 73.0 per cent to almost 85.0 per cent of the dry weight of these samples of copepods; this means that they are a source of very nutritious food for the organisms which feed on them.

The Cyclops material yielded the largest percentage of crude fiber or chitin and Limnocalanus the smallest.

The nitrogen free extract in these five samples of copepods varies from a minimum of 4.89 per cent of the dry organic matter in Cyclops to a maximum of 14.45 per cent in one of the samples containing both Cyclops and Diaptomus. In other words the crude protein, the ether extract, and the crude fiber constitute from 85.0 per cent to more than 95.0 per cent of the organic matter in these copepod samples.

The five samples of copepods listed in table 49 contained a relatively small percentage of ash and similar results have been obtained in more than forty other ash determinations on small samples of Diaptomus, Cyclops, Epischura, and Limnocalanus. A sample from Spring Lake, Wisconsin, containing Diaptomus yielded 17.07 per cent of ash and another from Silver Lake containing Cyclops gave 12.04 per cent of ash. These two samples of copepods are the only ones obtained from Wisconsin lakes which have contained more than 9.0 per cent of ash and the majority of them have yielded less than 6.0 per cent. Specimens of Cyclops[8] from Lake Okoboji, Iowa, gave 10.0 per cent of ash, while samples of Cyclops and of Diaptomus from some of the Finger lakes and from Lake George, New York, contained from 11.49 per cent to 15.38 per cent of ash.

Volk[9] records an analysis of another copepod, namely, Eurytemora. He states that 78.48 per cent of the dry weight of the material consisted of muscle and other tissue, 6.2 per cent fat, 11.08 per cent chitin, and 4.24 per cent ash. (See table 51.) Apparently he determined the ether extract, crude fiber, and ash, and then called the remainder "muscle and other tissue." The percentage of ether extract or fat is much smaller in Eurytemora than in the five samples of Wisconsin copepods, but the percentage of crude fiber or chitin is larger in the former; the percentage of ash in Eurytemora is substantially the same as that of Limnocalanus.

Brandt[10] gives an analysis of a sample of freshwater copepods; his material yielded 57.25 per cent of crude protein, 6.01 per cent of ether extract or fat, 4.54 per cent of crude fiber or chitin, and 9.21 per cent of ash. (See table 51.) A comparison of his results with those obtained for the samples of copepod material collected in Wisconsin lakes, shows that two of the latter yielded a smaller percentage of crude protein and three a larger percentage; four of the latter contained a larger percentage of chitin or crude fiber and all five gave a larger percentage of fat or ether extract. The percentage of ether extract shown for Limnocalanus is more than six times as large as that in Brandt's material. The percentage of ash recorded by Brandt is larger than that in the five copepod samples shown in table 49. The nitrogen free extract in his sample of freshwater copepods amounted to 22.99 per cent of the dry weight; this is nearly twice as large as the maximum percentage of nitrogen free extract in the five samples of Wisconsin copepods and five times as large as the minimum.

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[8] Birge and Juday, Univ. of Iowa Studies in Nat. Hist., Vol. 9, 1920, pp. 1-56.

[9] Verhand. d. Naturwis. Vereins in Hamburg, 3. Folge XV, 1907, p. 45.

[10] Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, p. 71.

Brandt also records an analysis of a sample of marine copepods which yielded substantially the same percentage of nitrogen as his sample of freshwater copepods, but the ether extract and ash were somewhat larger in the marine copepods.

Cladocera. Eight samples of *Daphnia pulex* var. *pulicaria* were collected from three different Wisconsin lakes. Those from Lake Monona were secured in different years, while different years as well as different seasons of the same year are represented in the material from Devils Lake. These samples thus afford a good opportunity to study the variations in the chemical composition of this form. (Table 49.)

The nitrogen ranged from a minimum of 5.82 per cent to a maximum of 8.63 per cent of the dry weight of the material, the latter being almost one and a half times as large as the former. The largest percentage was found in material from Devils Lake and the smallest in a sample from Lake Monona; the difference is nearly as great, however, if only the samples from the former lake are considered because a maximum of 8.27 per cent is recorded for one of the Devils Lake samples. The mean percentage of nitrogen in the five samples from Devils Lake is 7.13 per cent of the dry material, which is more than one per cent below the mean of the two samples of *Daphnia pulex* from Lake Monona, and it is smaller also than the percentage of nitrogen found in the sample from Lake Waubesa.

On an ash free basis the nitrogen varied from a minimum of 7.22 per cent to a maximum of 10.98 per cent. With the exception of one sample, considerably more than half of the organic matter in these eight catches of *Daphnia pulex* consisted of crude protein.

Similar variations were noted in the ether extract or fat, the range being from 2.82 per cent of the dry sample to 27.9 per cent. The sample of *Daphnia pulex* obtained from Lake Waubesa yielded the maximum percentage of extract and one of those from Devils Lake the minimum. On an ash free basis the maximum amount of ether extract constituted 31.75 per cent of the organic matter. The physical and chemical constants of the ether extract obtained from the Monona sample which was collected on April 4, 1914, were determined by Schuette[11]. The index of refraction at 25° C. is 1.4810, the iodine number 172.88, the saponification number 208.56, the Reichert-Meisel number 0.94, and the Polenske number 1.22. The odor from the extract was decidedly like that of a fish oil and it was noted also that this extract solidified upon exposure to the air.

The variations in the ether extract bear a fairly close relation to the age and the condition of the Daphnias. The developing embryos are well supplied with fat and the material will yield a high percentage of

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[11] Trans. Wis. Acad. Sci., Arts, and Let., Vol. 19, 1918, p. 599.

ether extract if the sample consists largely of adult females with many embryos in their brood chambers. On the other hand, if the sample contains a large proportion of immature individuals, or if it is made up of females carrying relatively few embryos, the yield of ether extract will be much smaller.

In these eight samples of *Daphnia pulex* the crude fiber or chitin varied from a minimum of 3.34 per cent to a maximum of 10.89 per cent of the dry weight of the material, a little more than a threefold difference; on an ash free basis the percentages range from 3.62 per cent to 13.08 per cent of the organic matter. The samples from Devils Lake show a larger percentage of crude fiber than those from Lakes Monona and Waubesa, the minimum of the former being larger than the maximum of the latter.

Three determinations showed that only small amounts of pentosans were present in the material, the maximum quantity being 1.92 per cent of the dry weight of the sample.

The nitrogen free extract ranged from a minimum of 8.25 per cent to a maximum of 25.19 per cent of the dry sample; on an ash free basis this extract constituted from 9.4 per cent to 31.34 per cent of the organic matter. In other words the crude protein, the ether extract, and the crude fiber account for approximately 70.0 per cent to 90.0 per cent of the organic matter in these eight samples of *Daphnia pulex.*

The percentage of ash also showed somewhat more than a threefold variation, ranging from 7.62 per cent of the dry material in one sample from Lake Monona to 25.85 per cent in one sample from Devils Lake. The minimum percentage of ash in the five samples from Devils Lake is 16.87 per cent and this is exceeded by one of the samples from Lake Monona; the other sample from Lake Monona as well as that from Lake Waubesa gave a much smaller percentage of ash. An ash determination on a small sample of *Daphnia pulex* obtained from Devils Lake on September 30, 1918, yielded 11.06 per cent; this is appreciably smaller than the minimum noted above.

The percentage of ash appears to bear some relation to the age of the specimens in *Daphnia pulex.* By means of small platinum crucibles and a sensitive assayer's balance the amounts of organic matter and of ash may be readily ascertained for small numbers of these organisms, from 100 to 500 individuals being used for such determinations. In a series of such samples taken from material collected in Lake Monona on May 16, 1918, the largest females, noted as adults carrying embryos, yielded 13.93 per cent of ash; medium sized individuals, estimated as one-fourth to one-third grown, contained 18.89 per cent of inorganic material, while the smallest size gave 23.6 per cent of ash. In two samples collected at Devils Lake, September 30, 1918, the ash amounted to

11.06 per cent of the dry weight of full grown females with eggs and to 14.15 per cent in medium sized individuals. Similar differences in ash corresponding to differences in age have been noted in specimens of *Daphnia hyalina.*

The various analyses of blue-green algae and of *Daphnia pulex* show clearly the necessity of analyzing a number of samples of each form if one wishes to obtain a general idea of the chemical composition. The number of analyses may be reduced, however, by making a composite sample: that is, one which contains material that has been collected at different periods in the development of the form in question.

The composite sample containing *Daphnia pulex* and *D. hyalina* collected in Lake Monona on August 5, 1913, and that of *D. hyalina* and *D. retrocurva* secured on Lake Mendota on August 28, 1917, yielded results similar to some of the samples of pure *D. pulex.* (Table 49.) It seems probable, therefore, that a series of catches of these two forms would give substantially the same results as those obtained for the various samples of *D. pulex.*

Another cladoceran, *Holopedium gibberum,* also has percentages which agree closely with some of those obtained for the Daphnia material, with the exception of the pentosans. The percentage of nitrogen, for example, is the same as that in the composite sample containing *D. pulex* and *D. hyalina,* and it is very close to that of three other samples of Daphnia. The ether extract, crude fiber, and ash are also within the range of the percentages noted for the Daphnia material; the pentosans constitute a much larger percentage of the dry weight of Holopedium than of any of the other animal material.

Quantitative determinations of the pentosans were made on fourteen samples of animal material as shown in table 49. With one exception the percentages are comparatively small in such samples and this exception is Holopedium. The latter sample is the only one of the fourteen which yielded more than two per cent of the dry weight in pentosans and eight of them contained less than one per cent, the smallest amount being found in the leeches.

The first determination of the pentosans in Holopedium was made on a sample collected in Kawaguesaga Lake at Minocqua, Wisconsin, in 1913; the pentosans in this material amounted to 6.17 per cent of the dry weight, which was regarded as surprisingly high. A second sample, therefore, was secured from this lake in 1917 and this gave a still larger percentage of pentosans, namely 9.62 per cent. This percentage is not only much larger than that in any of the other animal material included in this series of samples, but it is exceeded by the percentages in only two samples of plant material. In 1918 a third sample of Holopedium was secured from a neighboring lake and it yielded 4.35 per cent of pentosans. These three analyses, therefore, seem to establish the fact that Holopedium regularly possesses a much larger percentage of pentosans than the other animal forms represented in table 49; the percentage shown in the table is the mean of the three determinations. Holopedium differs from all of the other Cladocera in that its body is enclosed in a large transparent, gelatinous case and the large yield of pentosans suggests that this gelatinous covering may be the source of these carbohydrates.

The three samples of Leptodora showed a variation of more than two per cent in their nitrogen content; on an ash free basis the range is from 8.35 per cent to 11.09 per cent of the organic matter. The latter is the maximum percentage of nitrogen in the various samples of Cladocera and it is also a little larger than the maximum in the Copepoda. The percentages of ether extract, pentosans, nitrogen free extract, crude fiber, and ash fall within the range of variations shown by the various samples of Daphnia. The mean percentage of nitrogen free extract and of ash is smaller in the Leptodora material, however, than in the Daphnias.

The percentages obtained for the organic constituents of the fourteen samples of Cladocera are very similar to those noted in the five samples of Copepoda as shown in table 49; the most striking difference is the larger percentage of ether extract in Limnocalanus. As a whole the samples of Cladocera yielded a much larger proportion of ash than those of the Copepoda; the maximum percentage of ash in the former is more than four times as large as the maximum in the latter group of crustacea, while the minimum of the former is nearly one and a half times as large as the maximum percentage of ash in the latter.

Volk[12] records an analysis of another cladoceran, namely, Bosmina, in which he found that 77.83 per cent of the dry sample consisted of "muscle and other tissue," 10.66 per cent of fat or ether extract, 8.21 per cent of crude fiber or chitin, and 3.3 per cent of ash. (See table 51.) This result is similar to that shown by Volk for Eurytemora which is referred to on a previous page; that is, apparently he determined the ether extract, the crude fiber, and the ash, and then designated the remainder as "muscle and other tissue." The percentage of fat or ether extract in Bosmina is the same as that in Holopedium, while the percentage of crude fiber or chitin in the former is substantially the same as that noted in three of the Daphnia samples. The percentage of ash in Bosmina is much smaller than those noted for the various samples of Cladocera in table 49.

Cambarus. Forty-four specimens of crayfishes belonging to the genus Cambarus were collected and analyzed for the purpose of getting

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[12] Verhand. d. Naturwis. Vereins in Hamburg, 3. Folge XV, 1907, p. 45.

data for comparison with the results obtained on the plankton crustacea. These crayfishes ranged in age from about six months to two years and the whole animal was used for the sample. The crayfish material yielded a smaller percentage of nitrogen and of ether extract than most of the samples of plankton crustacea; only two samples of Daphnia gave a lower percentage of nitrogen than the crayfishes and all of the copepod material contained a larger amount. On an ash free basis, however, the percentage of nitrogen in the crayfishes is larger than it is in two samples of Copepoda and also larger than in eleven of the fourteen samples of Cladocera.

The ether extract in the crayfishes is smaller than in seven of the ten samples of Daphnia and very much smaller than in all of the copepod material; this statement holds true for the percentages which include the ash as well as for those which do not.

The percentage of crude fiber is slightly larger in one sample of Daphnia than in Cambarus, while the sample of Cyclops shows nearly as large a percentage as the latter; in all of the other samples of Copepoda and Cladocera the percentage of crude fiber or chitin is appreciably smaller than in the crayfish material with the ash included. On an ash free basis, the crude fiber is larger in Cambarus than in any of the samples of Copepoda or Cladocera in table 49.

With the ash included, the nitrogen free extract is smaller in the crayfish material than in all except two of the fourteen samples of Cladocera and it is also smaller than two of the five samples of Copepoda. On an ash free basis the percentage of nitrogen free extract in the crayfish sample is below those of nine samples of Cladocera, but it is larger than those in all of the copepod samples.

The percentage of ash is much larger in the crayfishes than in the various samples of Cladocera and Copepoda, being one-third larger than the maximum for Daphnia and from five to eight times as large as the percentage of ash in the five copepod samples.

Hyalella. Including the ash the sample composed of the amphipod *Hyalella knickerbockeri* yielded a larger percentage of nitrogen than the crayfish material, but on an ash free basis the two are very nearly the same. (Table 49.) The percentages of ether extract and of nitrogen free extract are larger in the former than in the latter sample, but the reverse is true of the crude fiber and of the ash.

In comparison with the plankton crustacea this sample of Hyalella, with the ash included, yielded a somewhat larger percentage of nitrogen than the minimum of the copepod samples, namely, that in Limnocalanus, but on an ash free basis the percentage in the former is much larger than that in the latter. In fact the organic matter of Hyalella contained a larger proportion of nitrogen than three of the copepod samples. The percentage of ether extract is smaller in Hyalella than in the five samples of copepods, while the crude fiber and the nitrogen free extract are larger in two of the latter samples. The percentage of ash in the Hyalella material is from four to seven times as large as that in these five samples of copepods.

Including the ash, only two of the fourteen samples of Cladocera yielded a smaller percentage of nitrogen than this sample of Hyalella, but on an ash free basis only three of the former samples exceeded the percentage of nitrogen in the latter. Including the ash seven samples of Cladocera contained a larger percentage of ether extract than Hyalella, but this number is reduced to five on an ash free basis. On the basis of dry material nine samples of Cladocera gave a larger percentage of crude fiber and twelve a larger amount of nitrogen free extract than Hyalella, but both of these numbers are reduced to eight on an ash free basis. The sample of Hyalella yielded a larger percentage of ash than those of the Cladocera.

Oligochaeta. The bottom mud in the deeper portions of Lake Mendota is inhabited by worms belonging to the genera Limnodrilus and Tubifex. Enough specimens of these two forms were secured to permit the determination of the nitrogen and of the ash. The nitrogen in this sample of Oligochaeta amounted to 7.76 per cent of the dry weight, which is equivalent to 48.5 per cent of crude protein; on an ash free basis these amounts become 8.1 per cent and 50.62 per cent respectively. These percentages are substantially the same as those noted in Volvox and in about half a dozen samples of plankton crustacea.

The percentage of ash is smaller in this sample of Oligochaeta than in the various samples of plankton crustacea with the exception of Limnocalanus.

Hirudinea. A sample consisting of 286 leeches was collected on August 28, 1915, in Lake Mendota. The specimens varied in length from about six centimeters to ten centimeters and they represented three different species. These leeches yielded a larger percentage of nitrogen than any other form given in table 49. With the ash included, 11.13 per cent of the dry weight of this sample consisted of nitrogen, or 69.56 per cent of crude protein; on an ash free basis these amounts become 11.82 per cent and 73.88 per cent respectively. The ether extract amounted to 11.33 per cent of the organic matter, so that the crude protein and the ether extract together constituted 85.21 per cent of the organic matter in the sample; this large percentage is exceeded only by that of the crude protein and ether extract in Limnocalanus, which constituted 88.35 per cent of the organic matter in this copepod.

The percentages of pentosans and crude fiber are very small in this sample of leeches; the ash is somewhat larger than that in the sample of Oligochaeta, but it is about the same as the percentages in most of the copepod material and in some of the insect larvae.

Insect Larvae. Eight samples of aquatic insect larvae, from Ephemerida to *Corethra plumicornis* inclusive in table 49, were analyzed. The specimens of *Sialis infumata* consisted of larvae that had migrated to the shore for the purpose of pupating; this material, therefore, represents the full grown larvae. The two samples of Corethra also were full grown larvae; the other five samples contained insect larvae of different sizes, thus representing different stages in the growth of these forms.

In these eight samples of insect larvae the nitrogen varied from a minimum of 7.36 per cent in *Chironomus tentans* to a maximum of 10.74 per cent of the dry weight of the material in *Corethra punctipennis;* on an ash free basis the range is from 7.76 per cent to 11.67 per cent of the organic matter in these two forms. The crude protein in these larvae, therefore, made up from 48.5 per cent to 72.94 per cent of the organic matter. The ether extract showed more than a twofold variation in percentage, ranging from a minimum of 8.0 per cent in *Chironomus tentans* to a maximum of 18.5 per cent of the dry sample in Sialis; on an ash free basis the former becomes 8.43 per cent and the latter 19.44 per cent of the organic matter. The Sialis larvae were provided with reserve food to carry them through the pupating period of two weeks or more and the high percentage of ether extract indicates that part of this reserve probably consisted of fat.

The percentage of crude fiber or chitin showed a little more than a threefold variation in these samples of insect larvae, with a minimum in Sialis and a maximum in the Anisoptera. The nitrogen free extract reached a minimum in the Zygoptera larvae and a maximum in *Chironomus tentans.* The latter, in fact, yielded a larger percentage of nitrogen free extract than any other sample of animal material. Small amounts of pentosans were found in three of the samples.

The ash varied from a minimum of 4.76 per cent in *Corethra plumicornis* to a maximum of 15.11 per cent of the dry weight in the Trichoptera larvae. Seven of the samples yielded less than one per cent of silica, while the eighth, consisting of Ephemerid larvae, possessed 3.85 per cent.

On an ash free basis the percentages of nitrogen in the samples of insect larvae show about the same range of variation as the various samples of plankton crustacea; also some of the former are substantially the same as the percentages of nitrogen in the other four samples of animal material, namely, the crayfishes, the amphipods, the worms, and the leeches. The leeches yielded a slightly larger percentage of nitrogen than the maximum of the insect larvae.

The five copepod samples, in general, yielded a larger percentage of ether extract than the insect larvae, the amount in Limnocalanus being a little more than twice as large as the maximum in the latter samples. In seven samples of Cladocera the percentage of ether extract fell below the minimum in the insect larvae and three contained a larger percentage than the maximum in the latter. The crayfish sample yielded a smaller amount of extract than the minimum of the insect larvae, while the amphipods and the leeches corresponded closely to the Anisoptera and Zygoptera respectively.

The crude fiber and the nitrogen free extract in the insect larvae came within the range of variation noted in the plankton crustacea, except that the percentage of nitrogen free extract in *Chironomus tentans* exceeded that in any of the other samples of animal material.

Three of the samples of insect larvae yielded about the same percentage of ash as the copepod samples, but the other five insect samples gave a larger percentage of ash than the copepod material. About half of the Daphnia samples, together with the crayfishes and the amphipods, contained a larger amount of ash than the maximum in the insect larvae, while the worms and leeches yielded about the same percentages of ash as those noted in *Corethra plumicornis* and *Chironomus tentans.*

Gyrinidae. This sample consisted of adult whirligig beetles that were obtained from the surface of the water. This material contained a much smaller percentage of nitrogen than the insect larvae, yielding only a little more than half as much as the maximum found in *Corethra punctipennis.* The percentage of nitrogen in these beetles, in fact, is smaller than in any other sample of animal material.

The percentage of ether extract is much larger in the Gyrinids than in the insect larvae, being from two to more than four times as large as the percentages in the latter; it is exceeded only by the large extract noted in Limnocalanus.

Whirligig beetles have relatively large and thick wing covers of chitinous material; as a result the percentage of crude fiber or chitin is much higher in them than in most of the insect larvae, that in Anisoptera being nearest to it. On an ash free basis the percentage of crude fiber in the Gyrinids is next to the largest obtained for the animal samples, being exceeded only by Cambarus.

The percentage of nitrogen free extract is relatively low in this sample of Gyrinids; only two samples of insect larvae and four of plankton crustacea have a lower percentage.

This beetle material yielded an unusually small percentage of ash; it is the smallest noted in any of the samples recorded in table 49. It is only a little more than one-third as large as the minimum percentage in the insect larvae.

Hemiptera. The sample of Hemiptera contained representatives of several genera; nearly half of the material consisted of young Belostoma, while about a quarter of it was made up of Notonecta and Corixa. The remainder consisted of Nepa, Naucoris, and Ranatra, with a few individuals belonging to still other genera. This sample yielded a much larger percentage of nitrogen than the Gyrinids; with the ash included, only four samples of animal material gave a larger percentage of nitrogen than these Hemiptera, but on an ash free basis the percentage of nitrogen in the latter is exceeded by that in seven other animal samples.

This sample of Hemiptera yielded a relatively small percentage of fat or ether extract; only one other insect sample shows a smaller percentage, namely, *Chironomus tentans,* while that of Sialis is more than twice as large and that of the Gyrinids is more than four times as large. The percentage of crude fiber is relatively high in the Hemiptera, being exceeded by only two other insect samples. The nitrogen free extract is smaller than in five of the other insect samples and larger than in three.

The percentage of ash in the Hemiptera material is nearly four times as large as that in the Gyrinids, but it is fairly low in comparison with the other insect samples.

McHargue[13] analyzed samples of grasshoppers (Melanoplus) and June bugs (Lachnosterna). He states that 75.28 per cent of the dry weight of the grasshopper material consisted of crude protein and that the percentage was somewhat larger in the June bugs, no definite percentage being given for the latter form. This author does not state, however, whether any correction was made in the total nitrogen for that part which enters into the composition of the chitinous coverings of these insects. If such a correction has not been made, the percentage of crude protein indicated by McHargue is larger than it should be; a little more than 6.0 per cent of the dry weight of chitin consists of nitrogen.

The percentage of crude protein in the grasshopper material as given by McHargue is more than twice as large as that in the Gyrinids and it is 8.16 per cent larger than the maximum in the aquatic insect samples shown in table 49. The grasshoppers yielded only 7.21 per cent of ether extract, or less than the minimum of these aquatic insects; the former contained 5.61 per cent of ash and only three of the ten insect samples analyzed in this series fell below this percentage. The main constituents of the grasshopper ash consisted of silica (0.6 per cent), potassium oxide (1.2 per cent), and phosphorus pentoxide (1.19 per cent).

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[13] Jour. Agric. Research, Vol. 10, 1917, pp. 633-637.

McHargue made quantitative determinations of the various kinds of nitrogen in the grasshopper and June bug material along with those in beef roast and breast of turkey; he found that the different kinds of nitrogen in these two insects were similar in amount to those noted for the beef and the white meat of turkey.

In the samples shown in table 49 the crude protein, the ether extract, the crude fiber, and the ash make up from 34.13 per cent in Spirogyra to 95.42 per cent of the dry weight of the material in Cyclops; in other words the nitrogen free extract ranges from a minimum of 4.58 per cent in Cyclops to a maximum of 65.88 per cent in Spirogyra. On an ash free basis from 4.89 per cent to 72.46 per cent of the organic matter in the various samples consisted of nitrogen free extract.

The samples of plant material, in general, contained a larger percentage of nitrogen free extract than the animal samples. In the former the largest percentages were found in the non-plankton forms, that is, in Spirogyra, Cladophora, Potamogeton, Vallisneria, and Myriophyllum. With the ash included the smallest percentage of nitrogen free extract is recorded for the diatom sample, but on an ash free basis it is a sample containing Aphanizomenon and Anabaena. In the non-plankton plant material from 47.85 per cent to 72.46 per cent of the organic matter consisted of the undetermined carbohydrates which made up the nitrogen free extract, while in the plankton algae these carbohydrates constituted from 27.62 per cent to 54.82 per cent of the organic matter.

In the thirty-three samples composed of animal material the sum of the percentages of crude protein, ether extract, crude fiber, and ash is smallest in *Chironomus tentans* (65.0 per cent) and largest in Cyclops (95.42 per cent), making the range of the nitrogen free extract in these samples from 4.58 per cent in Cyclops to 35.0 per cent in *Chironomus tentans.* With the exception of *Chironomus tentans* and one of the Daphnia samples, the nitrogen free extract constituted less than 25.0 per cent of the dry weight of the material in the animal samples.

No attempt has been made to ascertain the composition of the nitrogen free extract in these samples of animal material, but the greater part undoubtedly consists of carbohydrates. Some fatty compounds are not entirely extracted with ether, so that, in some instances, small amounts of fats may be included in the nitrogen free extract, and possibly other substances are present also. The nitrogen free extract amounts to more than 10.0 per cent of the dry material in twenty-four of these animal samples and to more than 20.0 per cent in eight of them; if this extract is regarded as chiefly carbohydrate in character, it means that these samples contain fairly large percentages of carbohydrates, especially the latter group. In various analyses carbohydrates are not listed as being present in such food materials as beef, mutton, and fish, except in the heart and the liver, but they are found in some of the aquatic organisms that are used as human food in percentages that are comparable to the nitrogen free extract in these samples of animal material. In oysters, for example, the carbohydrates constitute 28.2 per cent of the dry weight of the animal, exclusive of the shell, while mussels contain 26.25 per cent and scallops 17.26 per cent; the edible portion of the crayfish yields 4.35 per cent of carbohydrates.

Brandt[14] states that the carbohydrates may constitute from 20.0 per cent to 25.0 per cent of the dry weight of copepods, depending upon the amount of plant food that may be present in the alimentary canal of the specimens. The percentage of nitrogen free extract given for the various samples of plankton crustacea in table 49 exceeds Brandt's minimum in only five samples and only one exceeds his maximum.

While part of the carbohydrate material in some of the animal samples given in table 49 may be derived from plants that have been consumed as food, yet it does not seem probable that any large amount comes from this source because the food contained in the alimentary canal would constitute a relatively small part of the weight of the entire animal. In four of the Daphnia samples the nitrogen free extract constitutes from a quarter to nearly a third of the dry weight of the organic matter and but little more than one-third of the organic matter in the plankton algae consists of nitrogen free extract or carbohydrates. The fact that the nitrogen free extract is nearly as large in the four Daphnia samples as in the plankton algae indicates that a large part of the carbohydrate material in this extract is derived from the animals themselves rather than from plant food in the alimentary canal.

In the three samples of Leptodora, the nitrogen free extract constitutes from 9.25 per cent to 15.65 per cent of the organic matter and no part of the carbohydrate material in this extract comes from plants because this animal is predaceous, feeding upon other crustacea. In the leeches, also, which are not plant feeders, the nitrogen free extract constitutes 14.44 per cent of the organic matter and no part of the carbohydrates therein is of direct plant origin.

The results obtained in these analyses show that most of the forms represented in table 49 are excellent sources of food for other organisms bcause the major portion of most samples consisted of crude protein and ether extract. The smallest percentages of these two substances were found in the large aquatic plants. The plankton algae, on the other hand, yielded substantially as large a percentage of crude protein as the animal material, but the percentage of ether extract in the former

[14] Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, p. 77.

was smaller than in the latter; the largest amount of ether extract obtained from plant material was noted in the sample of diatoms.

Moore, Edie, Whitley, and Dakin[15] analyzed several marine forms, but their results are not comparable with those given in table 49 because they removed the skeletons from the organisms which they analyzed and used only the soft parts.

Ash Analysis

Some of the inorganic constituents of the ash were determined for a few of these samples as indicated in table 50. The results shown in this table are stated in percentages of the dry weight of the sample.

Silica (SiO_2). Quantitative determinations of the silica were made on the ash of most of these samples and the results are recorded in table 49. The diatoms yielded the largest percentage of silica, namely, 30.78 per cent of the dry weight of the sample. Cladophora ranks second with 7.1 per cent and the Ephemerid larvae are third with 3.85 per cent. One sample of *Daphnia pulex* contained 2.84 per cent of silica. Excluding these four samples, the silica in all of the other material amounted to less than two per cent of the dry weight, ranging from nothing in the Gyrinids to 1.96 per cent in Myriophyllum.

Iron and Alumina (Fe_2O_3 and Al_2O_3). The results for iron and alumina are shown in table 50. The sample of Myriophyllum contains the largest percentage of iron and alumina, namely, 4.35 per cent of the dry weight, while one of the samples of *Daphnia pulex* gives 2.94 per cent. In all of the other samples on which determinations were made, the percentage falls well below two per cent of the dry weight, varying from 0.1 per cent in Limnocalanus to 1.8 per cent in Cladophora.

Phosphorus (P_2O_5). The sample of Cladophora is the only one recorded in table 50 in which phosphorus pentoxide falls below one per cent. In the other plant material the amount is distinctly larger than one per cent of the dry weight. The maximum percentages are found in the Cladocera, namely, the three samples of *Daphnia pulex* and Leptodora. All of the crustacea, in fact, show relatively large percentages of phosphorus pentoxide; the Cladocera rank highest, the crayfish (Cambarus) and the amphipod (Hyalella) second, and the copepods (Cyclops and Limnocalanus) third. The leeches (Hirudinea) and the insects average about the same as the copepods.

Clarke and Salkover[16] state that phosphorus is an important constituent of the ash of two marine crustaceans; for the copepod *Temora longicornis* they record 2.77 per cent of the dry weight as calcium phosphate ($Ca_3P_2O_8$) and for the small shrimp *Thysanoessa inermis* 7.68

[15] Biochemical Journal, Vol. VI, 1912, p. 291.

[16] Jour. Washington Acad. Sci., Vol. 8, 1918, pp. 185-186.

per cent. In terms of phosphorus pentoxide these percentages are 1.27 per cent and 3.52 per cent respectively. The marine copepod shows a somewhat smaller percentage of phosphorus pentoxide than the two freshwater copepods included in table 50, while the marine shrimp shows the same percentage as the freshwater Cladocera.

Calcium (CaO). The largest percentage of calcium oxide or lime is recorded for the crayfish material, namely, 17.82 per cent of the dry weight, while the amphipod Hyalella comes second with 14.82 per cent and one sample of *Daphnia pulex* is third with 9.89 per cent. Calcium is a very important constituent of the shells of these crustacea. In two other samples of *Daphnia pulex* and in Leptodora, a much smaller amount of calcium oxide was found, ranging from 2.01 per cent to 3.22 per cent. The percentage is still smaller in the copepods and leeches as well as in the insects.

In the plant material the maximum percentage of calcium oxide is recorded for Myriophyllum, with Cladophora ranking second. The other plant samples show relatively small amounts.

Magnesium (MgO). Only three of the eighteen samples on which determinations were made yielded more than one per cent of magnesium oxide. In the samples of plant material the maximum percentage was found in Cladophora, while the maximum for the animal samples was found in the insect larva Sialis. These data indicate that magnesium is used only in rather small amounts by the various forms represented in table 50.

APPENDIX

Statistical Tables

Table 1. *This table shows the maximum length and the width, the area, the depth, and the volume of the four lakes on which the plankton studies were made.*

Lake	Length in Km.	Width in Km.	Area in Sq. Km.	Maximum Depth in Meters	Mean Depth in Meters	Volume in in Cubic Meters
Mendota...	9.50	7.40	39.40	25.6	12.1	478,370,000
Monona....	6.70	3.85	14.10	22.5	8.4	118,887,000
Waubesa...	6.75	2.25	8.24	11.1	4.9	40,252,000
Kegonsa....	4.83	3.62	12.70	9.6	4.6	59,060,000

Table 2. *The number of runs or catches made on the different lakes in the various years, the volume of water strained, and the dry weight of the net plankton obtained are given in this table.*

Lake	Year	Number of Catches	Volume of Water in Liters	Net Plankton	
				Dry Weight in Grams	Milligrams per Cubic Meter of Water
Mendota...........	1911	38	164,740	42.535	258
	1912	58	369,900	222.502	601
	1913	91	623,800	355.165	569
	1914	37	260,100	76.937	296
	1915	115	441,460	220.181	498
	1916	65	74,960	35.497	473
	1917	11	12,070	4.233	350
	Total	415	1,947,030	957.050	491
Monona............	1911	4	12,710	9.600	755
	1912	6	43,140	69.899	1,620
	1913	16	99,510	144.864	1,556
	1915	8	9,776	19.221	1,966
	1916	13	12,510	7.698	615
	Total	47	177,646	251.282	1,414
Waubesa...........	1913	2	11,800	26.729	2,265
	1915	4	5,732	22.426	3,912
	1916	12	11,641	14.499	1,245
	Total	18	29,173	63.654	2,182
Kegonsa............	1913	1	3,318	20.282	6,112
Grand Total........		481	2,157,167	1,292.268	

TABLE 3. *The number of centrifuge runs, the amount of water centrifuged in the different years, and the quantity of dry material obtained are indicated in this table.*

Lake	Year	Number of Runs	Volume of Water in Liters	Nannoplankton	
				Dry Weight in Grams	Milligrams per Cubic meter of Water
Mendota...........	1915	65	88,953	212.417	2,388
	1916	69	78,483	296.430	3,777
	1917	11	12,670	45.858	3,619
	Total	145	179,506	554.705	3,090
Monona............	1915	8	9,777	43.659	4,465
	1916	13	12,510	55.156	4,409
	Total	21	22,287	98.815	4,433
Waubesa...........	1915	4	5,732	36.002	6,280
	1916	12	11,641	62.423	5,362
	Total	16	17,373	98.425	5,665

TABLE 4. *The quantity of water, in liters, used for the various samples of net plankton and nannoplankton are given in this table as well as the dry weight of the plankton obtained therefrom. The quantitative results given in tables 43 to 48 are based upon the amounts indicated in this table; those samples secured in July, August, and September were subject to correction as indicated on page 24. In the series of sample numbers the first figure indicates the year in which the sample was taken; 102 for example, represents the second sample obtained in 1911, 215 the fifteenth sample of 1912, and so on.*

Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams	Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams
102	1,925	520	125	10,500	4,450
103	2,200	350	126	9,632	5,130
104	3,060	1,000	128	3,132	1,550
105	3,645	730	129	4,360	2,240
106	2,570	1,940	130	4,080	2,505
108	7,860	850	131	3,936	1,627
109	6,777	540	202	8,350	850
110	7,112	690	204	4,250	868
111	8,400	770	205	11,928	5,914
112	10,980	1,210	207	11,190	7,102
113	10,314	1,000	208	14,842	5,632
114	2,640	1,040	209	14,430	4,293
115	12,457	1,660	212	11,680	1,672
116	12,579	4,790	213	14,628	2,610
117	12,432	4,840	214	10,100	4,236
118	8,322	1,550	215	16,464	3,226
119	10,500	2,090	218	15,358	4,661
120	3,215	3,580	219	17,360	6,459
123	10,535	2,443	220	14,712	10,258
124	4,284	3,040	221	14,160	7,872

TABLE NO. 4—CONTINUED

Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams	Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams
222	14,094	5,568	355	16,260	22,036
223	7,340	6,220	356	5,820	7,483
224	14,094	5,320	357	14,330	12,593
225	13,030	7,066	359	15,630	14,229
227	13,090	9,658	360	5,150	14,398
228	13,028	6,121	361	15,840	14,027
229	14,850	5,676	362	6,600	12,140
230	14,540	10,711	363	16,000	11,120
231	5,735	7,140	364	12,380	7,696
232	13,045	11,576	365	26,400	12,792
233	6,665	15,313	366	38,000	17,119
236	13,950	17,087	367	18,530	12,017
237	11,860	16,128	368	24,740	13,562
238	7,060	27,004	369	22,540	18,259
242	12,000	20,527	370	12,590	13,605
243	11,220	12,535	371	8,760	6,949
245	11,855	9,941	401	20,340	2,764
246	6,240	9,986	402	26,250	4,242
247	11,430	9,166	404	11,760	3,686
248	10,680	8,403	405	14,600	5,491
249	7,835	5,637	406	21,100	6,770
301	12,500	2,573	407	16,510	7,618
302	14,590	3,805	408	25,260	11,405
303	13,580	6,225	409	15,590	6,680
304	13,300	7,182	410	13,900	5,203
305	13,000	5,957	411	15,000	7,332
306	12,400	6,712	412	20,650	7,000
307	12,000	5,940	413	19,620	7,379
308	14,300	5,353	414	18,800	4,503
309	15,500	7,329	415	20,735	2,361
310	15,096	4,503	500-1	2,223	9,232
311	15,390	4,550	502	2,223	338
312	17,340	3,295	503	14,400	2,096
314	18,840	2,721	505	1,100	2,895
315	5,800	5,480	506-7	15,032	2,291
320	5,350	10,942	508-10	2,204	4,115
322	6,330	19,346	509-11	2,204	660
324	22,720	10,346	513-16	2,632	5,532
325	17,700	15,288	514-17	2,632	1,076
326	3,130	10,060	519	1,143	3,157
328	17,310	19,501	520	1,143	763
329	3,318	20,282	522	1,143	3,250
330	5,400	13,112	523	1,143	808
332	16,340	20,405	525-27	2,311	5,127
333	3,020	8,340	526	1,183	1,150
337	24,800	7,427	529-31	2,343	5,860
338	5,430	11,089	530-32	2,343	1,914
339	26,016	4,475	535-37	2,324	5,283
340	8,300	8,891	536-38	2,324	1,657
341	34,986	6,855	540	13,176	6,470
345	5,472	6,529	541-45	2,328	3,361
346	25,872	7,649	542-46	2,328	922
347	9,588	5,213	543	869	1,512
349	8,520	4,726	544	869	2,109
350	19,130	15,732	548	12,842	5,638
351	13,970	11,499	549-51	3,009	4,902
352	6,450	15,787	550-52	3,009	1,488
353	16,250	11,712	553-57	3,042	5,654
354	7,000	6,557	554-58	3,042	1,202

TABLE NO. 4—CONTINUED

Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams	Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams
561-65	2,979	5,622	5181	1,176	2,687
562-66	2,979	1,110	5182-84	2,238	7,446
563	865	628	5183-85	2,238	1,401
564	865	574	5187	4,980	3,982
567-75	3,022	8,123	5188-90	2,294	6,704
568-76	3,022	996	5192	1,110	4,515
579-81	3,004	8,239	5194	5,480	4,383
580-82	3,004	785	5195	5,000	4,041
583	1,091	1,918	5196	1,120	5,240
584	1,091	1,909	5198	1,117	5,230
585	1,540	4,202	5200	1,190	4,211
586-90	3,117	946	5202	5,160	5,291
589	1,577	4,924	602	1,109	2,785
595-100	3,219	4,943	603	1,109	356
596-101	3,219	940	604	515	2,066
597	1,547	7,556	605	515	127
598	1,547	6,328	606	1,068	11,230
5102-6	3,253	3,711	607	1,068	274
5103-7	3,253	1,468	608	1,100	10,710
5104	14,330	7,358	609	1,100	290
5110-12	3,139	4,161	610	1,091	7,759
5111-13	3,139	1,788	611	1,091	339
5115	14,165	10,818	612	1,108	6,152
5116-22	3,201	5,689	613	1,108	292
5117-23	3,201	1,843	614	1,090	5,163
5118	1,441	8,010	615	1,090	296
5119	1,441	3,656	616-18	2,306	9,918
5124-26	3,123	4,439	617-19	2,306	602
5125-27	3,123	1,004	620	966	3,382
5128	1,525	7,439	621	966	375
5129	1,525	7,019	626-28	2,210	12,421
5130	11,790	3,995	627-29	2,210	1,514
5131	13,980	4,300	630-34	2,372	10,338
5132-36	3,079	5,848	631-35	2,372	1,380
5133-37	3,079	1,046	632	1,137	3,257
5134	1,472	9,382	633	1,137	885
5135	1,472	2,028	636-38	2,270	7,832
5139-43	14,850	7,792	637-39	2,270	1,076
5140-42	3,035	6,517	640-44	2,341	11,884
5144	1,523	8,169	641-45	2,341	1,283
5145	1,523	2,646	646-52	2,359	5,988
5146-48	3,135	8,591	647-53	2,359	938
5147-49	3,135	2,191	648	1,113	1,998
5150	13,986	10,752	649	1,113	383
5152	1,474	12,947	650	1,145	2,291
5153	1,474	6,827	651	1,145	657
5156-60	3,147	9,660	654-56	2,350	7,472
5158	10,780	11,603	657	1,182	325
5159	10,980	16,209	658	1,127	2,241
5162-64	2,985	10,536	659	1,127	1,735
5166	1,340	7,592	662-64	2,360	7,593
5167	1,340	3,613	663-65	2,360	814
5168-70	2,431	6,366	666	1,143	2,865
5172	7,360	3,645	667	1,143	1,024
5173-79	14,110	4,618	668-74	2,365	9,293
5174	1,186	8,060	669-75	2,365	605
5175	1,186	2,252	672	1,122	2,812
5176-78	2,470	6,914	673	1,122	1,309
5180	1,176	6,448	676-80	2,329	8,708

TABLE NO. 4—CONTINUED

Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams	Number of Sample	Quantity of Water, Liters	Dry Weight of Plankton, Milligrams
677-81	2,329	393	6156-60	2,352	8,595
678	1,141	4,689	6157-61	2,352	1,374
679	1,141	1,321	6158	741	7,303
682-86	2,351	8,543	6159	741	402
683-87	2,351	406	6162-66	2,350	8,297
684	1,138	3,237	6163-67	2,350	1,733
685	1,138	441	6164	745	6,346
688-92	2,357	8,495	6165	745	1,684
689-93	2,357	324	6168	728	6,336
690	1,145	4,804	6169	728	773
691	1,145	910	6170-72	2,343	8,030
694-98	2,356	7,155	6171-73	2,343	1,455
695-99	2,356	352	6174	744	4,828
696	1,145	4,145	6175	744	880
697	1,145	439	6176-78	2,343	6,581
6100-6	3,026	8,295	6177-79	2,343	1,573
6101	1,187	179	6180-84	2,327	8,035
6102	1,144	6,455	6181-85	2,327	2,420
6103	1,144	1,438	6182	726	3,289
6108-12	2,316	6,433	6183	726	707
6109-13	2,316	262	6186	1,177	3,369
6110	1,073	4,383	6187	1,177	1,552
6111	1,073	539	6188	1,183	3,320
6114-18	2,353	5,966	6189	1,183	1,429
6115-19	2,353	262	6190-92	2,132	7,234
6116	747	5,486	6191-93	2,132	3,217
6117	747	1,068	6194	1,066	3,885
6120-24	2,386	6,000	6195	1,066	1,355
6121-25	2,386	328	6196	735	2,550
6122	1,149	5,899	6197	735	1,249
6123	1,149	211	702	860	2,221
6126-30	2,367	6,432	703	860	1,036
6127-31	2,367	343	704	904	2,147
6128	1,091	8,290	705	904	231
6129	1,091	1,035	706	909	1,765
6132-36	2,361	7,941	707	909	146
6133-37	2,361	561	708	1,171	4,251
6134	745	4,622	709	1,171	150
6135	745	130	710	1,168	4,154
6138-42	2,367	10,881	711	1,168	202
6139-43	2,367	635	712	1,170	7,325
6140	724	7,086	713	1,170	366
6141	724	1,237	714	1,180	7,481
6144	1,182	6,149	715	1,180	315
6145-49	2,362	1,740	716	1,172	4,314
6146	737	5,514	717	1,172	308
6147	737	254	718	1,170	3,692
6148	1,180	4,834	719	1,170	407
6150	735	6,027	720	1,183	4,900
6151	735	2,361	721	1,183	518
6152	1,180	6,394	722	1,183	3,611
6153-55	2,355	1,719	723	1,183	584
6154	1,175	5,247			

TABLE 5. *The general variations in the quantity of dry net plankton during the different months of the year. The first column under each month shows the number of runs or catches made during the month and the second column indicates the average number of milligrams of dry net plankton per cubic meter of water that was secured in these catches.*

Lake	Year	Jan'y		Feb'y		March		April		May		June		July		August		Sept.		October		November		December	
Mendota	1911	...	...	...	...	...	...	...	...	...	...	7	185	9	62	9	138	7	192	4	507	...	...	...	...
	1912	...	...	...	...	...	...	...	...	5	311	8	358	9	211	9	255	9	406	9	1,215	8	791	...	...
	1913	...	...	...	...	...	...	5	310	9	509	9	310	8	387	12	270	8	552	9	885	13	520	11	763
	1914	1	135	1	135	2	161	5	348	13	392	13	333	...	...	...	...	...	...	...	...	...	...	...	...
	1915	...	...	...	...	...	...	5	160	12	301	16	480	21	278	18	471	18	488	16	884	11	700	3	995
	1916	...	...	1	302	1	246	4	274	8	457	9	432	9	181	8	148	7	358	9	663	6	1,122	3	1,484
	1917	1	1,205	1	253	1	159	2	149	5	325	1	490	...	...	...	...	...	...	...	...	...	...	...	...
Monona	1911	...	...	...	...	...	...	...	...	...	...	1	378	1	197	1	557	1	426	...	...	...	...	...	...
	1912	...	...	...	...	...	...	...	...	...	...	...	...	1	252	1	466	1	810	2	2,765	1	1,600	...	...
	1913	...	...	...	...	...	...	...	...	...	...	...	...	4	1,162	4	784	5	482	3	1,936	...	...	...	...
	1915	...	...	...	...	...	...	...	...	...	...	1	1,620	2	846	1	1,649	2	1,041	2	2,504	...	...	...	...
	1916	...	...	...	...	...	...	...	...	1	389	2	945	2	774	3	352	2	259	2	800	1	974	...	...
Waubesa	1913	...	...	...	...	...	...	...	...	...	...	...	...	1	2,045	...	...	1	2,447	...	...	...	...	...	...
	1915	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	4,090	1	4,602	1	1,899	...	...	...	...
	1916	...	...	...	...	...	...	...	...	1	779	2	734	2	976	2	1,343	2	1,328	3	2,218	...	...	...	...
Kegonsa	1913	...	...	...	...	...	...	...	...	...	...	...	...	1	6,113	...	...	...	...	...	...	...	...	...	...

Table 6. *The maximum, the minimum, and the mean amounts of organic matter in the net plankton of Lake Mendota for the different years are shown in this table. The results for 1914 and 1917 do not cover full years; in the former instance the observations extended only to the first of July and in the latter to the first of June. The results are stated in milligrams of organic matter per cubic meter of water.*

Year	Number of Samples	Maximum	Minimum	Mean
1911	22	464	42	175
1912	29	1,055	84	393
1913	35	697	87	373
1914	14	426	99	289
1915	34	810	113	367
1916	39	1,135	73	343
1917	11	866	92	271

Table 7. *The variations in the percentage of nitrogen in the net plankton and the mean percentage for the different years are indicated in this table. Nitrogen determinations were not made on all of the samples collected in 1916 and 1917. The mean annual percentages are based on the mean quantity of nitrogen and the mean quantity of organic matter in the samples on which nitrogen determinations were made. In the first part of the table the percentages of total nitrogen are indicated, but in the second part the percentages do not include the nitrogen of the chitinous shells of the crustacea.*

Year	Number of Analyses	Per Cent of Sample		Per Cent, Ash Free		
		Maximum	Minimum	Maximum	Minimum	Mean
1911	22	8.33	3.92	9.44	5.75	7.93
1912	29	8.95	4.47	9.55	5.61	8.11
1913	35	9.22	4.16	11.20	6.26	8.14
1914	14	9.96	6.60	11.10	6.95	8.65
1915	34	8.11	4.59	10.72	7.22	8.87
1916	26	7.02	3.95	9.00	5.50	8.16
1917	6	9.97	5.76	11.11	8.43	10.21

TABLE 8. *The maximum, minimum, and mean percentages and amounts of crude protein in the organic matter of the net plankton of Lake Mendota. This table is based on the second part of table 7. Crude protein equals N × 6.25.*

Year	Number of Analy-ses	Per Cent of Crude Protein in the Organic Matter			Crude Protein, Milligrams per Cubic Meter of Water			
		Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum ÷ Minimum
1911	22	59.0	37.1	49.6	255.0	21.2	87.0	12.0
1912	29	59.4	35.0	50.7	531.2	48.1	199.1	11.1
1913	35	70.0	39.1	50.9	374.4	49.4	189.8	7.6
1914	1[illegible]	69.3	43.4	54.1	244.3	43.7	156.2	5.6
1915	34	67.0	45.1	55.4	449.4	58.7	203.7	7.6
1916	26	56.2	34.5	51.0	581.3	32.5	2[illegible]0.0	17.8
1917	6	69.4	52.6	63.8	232.5	109.3	159.9	2.1

TABLE 9. *The percentages of four forms of nitrogen found by Schuette in some net plankton from Lake Mendota.* (Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 604.)

Sample	Total Nitrogen	Nitrogen as NH^3	Di-amino Nitrogen	Mono-amino Nitrogen	"Humic" Nitrogen
A	6.15	0.70	1.22	3.69	0.39
B	5.58	0.70	0.96	3.35	0.38
C	8.25	0.97	1.90	4.77	0.30
D	8.55	0.76	2.14	5.16	0.32
E	9.94	1.09	2.79	5.39	0.67

TABLE 10. *The variations in the percentage and in the quantity of ether extract in the net plankton of Lake Mendota are shown in this table.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1911	22	26.58	7.37	13.57	52.4	6.6	21.9
1912	28	24.3	5.93	11.70	135.8	11.1	43.5
1913	35	20.16	3.12	10.63	102.7	4.0	42.7
1914	13	18.06	6.23	13.00	70.7	6.4	37.9
1915	33	21.28	6.07	12.42	113.1	12.9	46.6
1916	7	14.48	7.55	11.17	60.5	16.9	38.1

TABLE 11. *Some of the physical and chemical constants of the ether extract of three samples of net plankton as determined by Schuette.* (Trans. Wis. Acad. Sci., Arts, and Let., Vol. XIX, 1918, p. 599.)

Sample	C	D	No. 403
Percent of ether extract in dry sample	8.01	13.47	21.25
Index of refraction at 25° C.	1.4777	1.4785	1.4810
Iodine Number	102.08	87.58	172.88
Saponification number		248.60	208.56
Reichert-Meissl number		1.16	0.94
Polenske number		1.55	1.22

TABLE 12. *The variations in the percentage and in the quantity of the pentosans in the net plankton of Lake Mendota are indicated in this table.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1912	17	4.08	1.38	3.06	36.1	5.0	15.3
1913	32	3.90	1.79	2.86	23.8	1.8	10.9
1914	12	3.65	1.18	1.71	10.7	3.6	5.4
1915	31	5.16	1.38	3.41	33.6	3.0	12.9

TABLE 13. *The changes in the percentage of crude fiber in the organic matter of the net plankton are shown for the different years in this table, as well as the variations in quantity per cubic meter of water. The mean percentage is based on the mean quantity of crude fiber and the mean quantity of organic matter in the samples on which crude fiber determinations were made.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1911	17	17.74	6.80	10.34	52.2	3.7	17.7
1912	21	20.21	3.54	6.86	67.0	10.8	30.4
1913	35	12.71	2.67	6.19	55.3	5.8	23.1
1914	13	12.11	3.68	6.12	28.3	6.4	17.5
1915	33	10.32	4.15	6.00	37.9	5.9	22.0

TABLE 14. *A summary of the ash and silica determinations for the net plankton of Lake Mendota, 1911 to 1917. The results are stated in percentages of the dry weight of the net plankton.*

Year	Number of Samples	Per Cent of Ash			Per Cent of Silica			Difference between Means of Ash and Silica
		Maximum	Minimum	Mean	Maximum	Minimum	Mean	
1911	22	40.67	7.54	17.65	32.66	1.97	9.22	8.43
1912	29	38.30	5.62	19.47	31.62	0.76	12.37	7.10
1913	35	43.78	10.08	22.70	36.42	0.50	14.45	8.25
1914	14	13.63	9.13	11.56	9.04	1.34	3.84	7.72
1915	34	48.30	9.40	29.09	37.25	2.84	17.37	11.72
1916	39	45.18	16.56	29.07	36.86	2.80	15.55	13.52
1917	11	46.66	13.40	27.44	21.32	3.79	10.04	17.40

TABLE 15. *Analyses of the ash of the net plankton. The results are stated in percentages of the dry weight of the net plankton.*

Lake	Number of Sample	Ash	SiO_2	$Fe_2O_3+Al_2O_3$	Mn_3O_4	P_2O_5	CaO	MgO
Mendota.	102	12.25	2.41	2.18	0.00	2.08	3.60	0.20
	108	19.87	10.36	....	....	....	3.83	1.95
	112	12.53	2.90	0.98	....	2.12	6.18	0.62
	116	28.38	21.50	1.12	0.00	1.43	2.97	0.51
	117	40.67	32.66	1.20	....	1.42	....	....
	118	12.25	4.92	....	0.00	1.82	2.75	0.86
	125	15.30	8.94	0.67	0.00	0.59	2.68	0.17
	130	24.40	16.93	1.44	0.00	1.17	3.29	0.40
	202	17.82	6.74	0.26	....	0.25	4.36	0.80
	207	9.90	3.45	1.02	....	1.58	2.23	0.24
	213	12.98	1.63	0.83	....	0.94	6.80	0.23
	220	5.62	1.38	0.84	....	0.76	1.63	0.35
	302	19.56	12.58	1.00	....	2.00	1.60	1.04
	307	22.82	15.57	1.17	....	1.78	2.65	1.16
	311	13.32	1.56	0.67	....	2.54	5.43	1.41
	325	11.01	6.06	0.45	....	1.48	1.03	1.24
	337	19.72	9.10	0.68	....	2.31	3.72	0.74
	350	33.60	25.58	0.88	....	1.45	2.50	0.87
	359	29.86	18.66	....	....	....	4.75	0.94
	363	21.21	7.86	....	0.34	....	2.01	0.90
	366	30.99	20.74	....	....	....	4.01	0.82
	367	33.35	25.36	....	0.38	1.22	....	....
	401	9.64	2.40	....	0.31	0.58	1.37	1.03
	404	13.63	5.14	....	0.30	1.30	....	....
	409	9.13	3.86	....	0.39	1.40	....	....
	502	24.72	10.76	....	....	....	2.98	1.53
	503	19.65	11.12	....	....	....	1.37	0.71
Monona..	330	6.20	0.38	0.40	....	1.28	1.56	0.81
	354	12.16	4.71	1.32	....	0.83	1.70	0.20

TABLE 16. *Results obtained from centrifuged and uncentrifuged plankton material. The nitrogen and ether extract are stated in percentages of the dry organic matter.*

Lake	Number		Date	Volume in cc.	Milligrams of Dry Organic Matter	Difference in Milligrams	Nitrogen, Per Cent Ash Free	Ether Extract, Per Cent Ash Free
Waubesa	5108	Centrifuged	Aug. 20, 1915	980	10,876.0	—311.6	6.39	4.23
	5109	Uncentrifuged	Aug. 20, 1915	980	11,187.6	....	6.42	3.77
Monona	5120	Centrifuged	Sept. 1, 1915	1,275	4,836.8	+ 76.0	8.96	2.65
	5121	Uncentrifuged	Sept. 1, 1915	1,275	4,760.8	....	8.88	2.30
Waubesa	5154	Centrifuged	Oct. 2, 1915	1,000	8,730.0	— 34.0	8.53	7.07
	5155	Uncentrifuged	Oct. 2, 1915	1,000	8,764.0	....	8.20	6.80

TABLE 17. *Maximum, minimum, and mean quantities of material in the nannoplankton of Lake Mendota expressed in milligrams of dry organic matter per cubic meter of water. Compare with the results given for the net plankton in table 6.*

Year	Number of Samples	Maximum	Minimum	Mean
1915	35	2,776.2	944.2	1,622.0
1916	41	3,151.5	962.3	1,640.7
1917	11	2,603.4	795.2	1,621.3

TABLE 18. *This table shows the maximum, minimum, and mean percentages of nitrogen on an ash free basis in the nannoplankton of Lake Mendota and also the quantity per cubic meter of water. Compare with the net plankton in table 7.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	35	10.44	5.32	7.07	174.2	63.2	114.7
1916	41	8.77	4.24	6.27	249.7	49.8	102.9
1917	11	10.66	5.91	8.27	222.5	47.8	134.1

TABLE 19. *The annual range of variations in the percentages and in the amounts of crude protein in the nannoplankton of Lake Mendota. These results are based on those given in table 18. Compare with the net plankton, table 8.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	35	65.25	33.25	44.19	1,088.7	395.0	716.6
1916	41	54.81	26.50	39.19	1,560.6	311.2	642.8
1917	11	66.62	36.93	51.68	1,390.6	298.8	838.0

TABLE 20. *The range of variation in the percentage and in the quantity of ether extract in the nannoplankton of Lake Mendota. Compare with the net plankton in table 10.*

Year	Number of Analyses	Ether Extract, Per Cent Ash Free			Ether Extract, Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	35	15.77	3.02	7.38	355.6	49.0	119.7
1916	41	12.50	2.56	6.17	287.7	31.2	101.2
1917	11	7.07	2.21	5.36	184.0	17.6	87.0

TABLE 21. *The variations in the percentages and in the amounts of the pentosans found in the nannoplankton material. Compare with the net plankton in table 12.*

Year	Number of Analyses	Pentosans, Per Cent Ash Free			Pentosans, Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	32	7.39	2.84	4.87	115.6	42.7	78.9
1916	8	7.61	3.64	5.28	144.0	53.7	86.6
1917	2	3.71	3.52	3.64	96.6	47.4	72.0

TABLE 22. *The range of the variations in the percentage and in the amount of crude fiber in the nannoplankton of Lake Mendota. Compare with the results for net plankton, table 13.*

Year	Number of Analyses	Crude Fiber, Per Cent Ash Free			Crude Fiber, Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	34	5.36	1.27	3.02	85.8	24.7	49.0
1916	17	9.27	4.20	6.46	215.7	57.2	106.0
1917	4	11.17	3.86	6.73	158.2	78.8	109.2

TABLE 23. *The amount of ash and silt in the nannoplankton of Lake Mendota given in terms of milligrams per cubic meter of water. The last part of the table shows four constituents of the ash stated in percentages of the dry weight of the nannoplankton.*

Number of Sample	Date	Total Ash, Mg. per Cu. M.	Bowl Ash, Mg. per Cu. M.	Ash of Nanno-plankton Mg. per Cu. M.	Silt, Mg. per Cu. M.	SiO_2, Per Cent	Fe_2O_3 + Al_2O_3 Per Cent	CaO, Per Cent	MgO, Per Cent
529–31	June 8-11, 1915	926.6	......	216.0	710.6	19.50	.....	.....	.....
535–37	June 14-17	964.7	......	192.3	772.4	20.91	.....	.....	.....
541–45	June 21-24	727.9	......	123.0	604.9	24.51	5.20	4.59	1.59
549–51	June 28–July 1	727.9	......	133.4	594.5	21.92	.....	.....	.....
553–57	July 6-9	921.6	......	141.0	780.6	19.70	.....	.....	.....
561–65	July 12-15	822.6	......	158.5	664.1	17.72	.....	.....	.....
567–75	July 19-22	1,260.8	......	198.5	1,062.3	10.44	3.80	6.97	1.47
579–81	July 26-29	1,525.7	......	176.7	1,349.0	6.35	.....	.....	.....
585	August 2	1,404.0	......	186.4	1,217.6	8.33	.....	.....	.....
589	August 6	1,342.6	......	232.0	1,110.6	11.32	.....	.....	.....
595–100	August 9-12	678.2	......	117.0	561.2	13.69	.....	.....	.....
5102–6	August 16-19	532.6	......	105.0	427.6	13.33	.....	.....	.....
5110–12	August 23-26	588.5	......	123.0	465.5	25.53	6.65	5.76	1.65
5116–22	Aug. 30-Sept. 2	741.0	......	154.2	586.8	17.04	.....	.....	.....
5124–26	September 7-9	503.0	......	133.4	369.6	14.71	.....	.....	.....
646–52	June 12-16, 1916	1,371.0	555.3	117.0	698.7	21.70	.....	.....	.....
654–56	June 19-22	1,577.7	557.4	164.6	855.7	18.49	6.97	8.13	5.17
668–74	July 5-7	1,696.2	554.0	248.1	894.1	11.41	5.77	13.76	5.12
688–92	July 24-28	1,767.8	555.6	204.0	1,008.2	8.25	.....	18.15	.....
694–98	July 31-Aug. 3	1,466.9	556.0	174.0	736.9	7.36	6.14	19.44	6.21
6100–6	August 7-9	1,454.7	649.3	138.3	667.1	10.19	.....	.....	.....
6108–12	August 14-18	1,320.6	566.0	161.4	593.2	9.53	7.55	10.05	6.25
6114–18	August 22-25	1,297.0	556.7	130.3	610.0	12.22	.....	.....	.....
6120–24	August 28-31	1,269.0	550.0	124.2	594.8	11.43	.....	.....	.....
702	Jan. 18, 1917	1,155.6	761.6	158.5	235.5	5.90	5.80	11.66	9.35
706	March 9	942.5	720.0	111.0	112.5	6.00	3.72	15.20	11.72

TABLE 24. *The average amount of organic matter in the net plankton and in the nannoplankton separately and the sum of the two are indictaed by months for the different years in this table. The results are stated in milligrams of dry material per cubic meter of water. January and February are represented by single catches, but the results for the other months are averages of two to eight or more catches. Compare with table 5.*

Year		January	February	March	April	May	June	July	August	Sept.	October	November	December
1915	Net	....	....	....	137.2	209.6	402.6	288.1	247.8	264.4	543.8	463.4	611.3
	Nanno.	....	....	....	2,540.5	1,735.5	1,588.6	1,482.9	1,262.4	1,431.0	1,747.7	1,729.2	1,626.1
	Sum	....	....	....	2,677.7	1,945.1	1,991.2	1,771.0	1,510.2	1,695.4	2,291.5	2,192.6	2,237.4
1916	Net	....	213.2	172.1	203.0	312.1	302.9	133.8	99.4	174.6	451.8	832.1	1,035.1
	Nanno.	....	994.9	1,881.9	2,488.4	1,674.0	1,473.5	1,784.5	1,256.8	1,633.1	1,507.8	1,398.8	1,463.4
	Sum	....	1,208.1	2,053.0	2,691.4	1,986.1	1,776.4	1,918.3	1,356.2	1,807.7	1,959.6	2,230.9	2,498.5
1917	Net	866.2	187.3	110.8	101.1	242.3	400.2	....	....	....	....	....	....
	Nanno.	1,206.5	943.9	795.2	1,415.0	2,118.2	1,467.9	....	....	....	....	....	....
	Sum	2,072.7	1.131.2	906.0	1,516.1	2,360.5	1,868.1	....	....	....	....	....	....

TABLE 25. *General summary of the various plankton catches from the four different lakes. The first four lines show the general results for all of the catches of net plankton from the different lakes. The rest of the table gives a summary of the net plankton catches corresponding to nannoplankton, of the nannoplankton samples, and also of the total plankton. The mean percentages indicated for the total plankton are based upon the mean quantity per cubic meter of water in each case.*

Lake	Plankton	Number of Samples	Organic Matter, Mg. per Cu. M.	Nitrogen		Crude Protein (N×6.25)		Ether Extract		Pentosans		Crude Fiber	
				Per Cent, Ash Free	Mg. per Cu. M.	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent, Ash Free	Mg. per Cu. M.
Mendota	Net	184	332.5	8.37	27.8	52.31	173.8	11.78	39.2	2.88	9.6	6.54	21.7
Monona	Net	47	850.2	9.36	79.6	58.50	497.5	6.02	51.2	5.73	48.7	3.62	30.8
Waubesa	Net	18	1,665.8	7.54	125.6	47.12	785.0	4.64	115.8	5.90	98.3	4.70	78.3
Kegonsa	Net	1	3,738.0	6.88	257.2	43.00	1,607.5	4.94	184.6	4.36	163.0	5.42	202.6
Mendota	Net	84	343.5	8.34	28.6	52.12	178.7	12.21	41.9	3.38	11.6	5.95	20.4
	Nanno.	87	1,630.5	6.84	111.5	42.75	697.0	6.55	106.8	4.82	78.6	5.19	84.6
	Total	....	1,974.0	7.11	140.5	44.48	878.2	7.53	148.7	4.57	90.2	5.32	105.0
Monona	Net	21	813.8	10.05	81.8	62.81	511.2	7.00	57.0	5.85	47.6	3.17	25.8
	Nanno.	21	2,350.0	8.92	209.6	55.75	1,310.0	4.82	113.3	4.36	102.5	4.76	111.8
	Total	....	3,163.8	9.21	291.4	57.56	1,821.2	5.36	170.3	4.74	150.1	4.35	137.6
Waubesa	Net	16	1,639.2	7.49	122.6	46.81	766.2	5.83	95.5	6.20	101.6	4.35	71.3
	Nanno.	16	3,299.1	7.92	261.6	49.50	1,635.0	4.00	132.0	5.55	183.1	4.45	146.8
	Total	....	4,938.3	7.78	384.2	48.62	2,401.2	4.61	227.5	5.76	284.7	4.41	218.1

TABLE 26. *The quantity of dry organic matter in the total plankton of Lake Mendota during the different months of the year. The figures indicate the averages for the different months and cover the period from April, 1915, to June, 1917. The first part of the table gives the results for the deep water, that is, the area within the 20 meter contour line, and the second part shows the amount when the entire area of the lake is taken into account. The live weight of this material would be approximately ten times as large as the dry weights shown in this table.*

Month	Deep Water		Entire Lake	
	Kilograms per Hectare	Pounds per Acre	Kilograms per Hectare	Pounds per Acre
January	456.5	407.3	251.6	224.4
February	257.7	230.1	141.4	126.1
March	325.8	290.8	179.6	160.2
April	505.5	451.0	278.7	248.6
May	462.0	412.1	254.6	227.1
June	414.0	369.3	228.0	203.4
July	406.3	362.4	223.9	199.7
August	315.6	281.5	174.0	155.2
September	385.8	344.1	212.6	189.6
October	468.2	417.6	258.0	230.1
November	487.2	434.6	268.5	239.5
December	521.5	465.2	287.5	256.4

TABLE 27. *This table shows the amount of organic matter in the net plankton and in the nannoplankton of Lake Mendota in the 0-13 meter stratum and in the 14-20 meter stratum on August 7, 1915. The amounts are given in milligrams per cubic meter of water.*

Sample	Stratum, Meters	Organic Matter, Mg. per Cu. M.
No. 593, Nannoplankton	0–13	1,686.4
No. 591, Nannoplankton	14–20	703.6
No. 594, Net plankton	0–13	264.2
No. 592, Net plankton	14–20	22.3

TABLE 28. *Quantity of organic matter in the total plankton (net plankton plus nannoplankton) of the different strata of Lake Mendota on August 7, 1915. These estimates are based on the results shown in table 27 and on the numerical data obtained in these catches.*

Stratum, Meters	Kilograms per Hectare	Pounds per Acre	Per Cent of Total Amount
0–5	117.1	104.5	36.7
0–10	214.6	191.4	67.3
0–13	253.6	226.2	79.5
14–23	65.3	58.3	20.5
0–23	318.9	284.5	100.0

TABLE 29. *The maximum, minimum, and mean amounts of dry organic matter obtained from the net plankton and from the nannoplankton of Lakes Monona and Waubesa. The results are stated in milligrams per cubic meter of water. Compare with Lake Mendota, table 6 and table 17.*

	Lake Monona				Lake Waubesa			
Year	Number of Samples	Maximum	Minimum	Mean	Number of Samples	Maximum	Minimum	Mean
NET PLANKTON								
1911	4	519.3	134.3	345.7	....	....	....	....
1912	6	3,303.6	213.3	1,344.0	....	....	....	....
1913	16	1,925.1	259.6	839.0	2	1,890.0	1,868.5	1,879.2
1915	8	2,161.8	404.0	1,404.0	4	4,232.5	1,580.0	3,214.2
1916	13	1,226.1	109.3	450.6	12	2,654.3	471.1	1,114.2
NANNOPLANKTON								
1915	8	3,746.5	723.0	2,339.5	4	6,143.2	2,871.2	4,260.2
1916	13	5,696.2	672.1	2,355.6	12	4,830.9	801.0	2,977.5

TABLE 30. *The range of variations in the percentage and in the quantity of nitrogen in the net plankton of Lake Monona. Compare with Lake Mendota, table 7.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1911	4	9.91	6.85	9.20	46.9	13.2	31.8
1912	6	9.67	8.83	9.20	302.2	20.0	123.6
1913	16	10.39	7.15	8.70	157.7	24.6	73.0
1915	8	11.71	8.09	10.71	237.6	40.5	150.5
1916	7	9.89	7.18	8.37	88.0	21.1	53.0

TABLE 31. *Variations in the percentage and in the quantity of crude protein in the net plankton of Lake Monona. Compare with Lake Mendota, table 8. (Crude protein equals N $\times$ 6.25.)*

Year	Number of Analyses	Per Cent of Organic Matter			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1911	4	61.9	42.7	57.5	293.1	112.5	198.8
1912	6	60.4	55.2	57.5	1,888.7	125.0	772.3
1913	16	65.0	44.7	54.4	985.6	153.7	456.2
1915	8	73.2	62.6	67.0	1,485.0	253.1	940.6
1916	7	61.8	44.9	52.3	550.0	131.9	331.2

Table 32. *Variations in the percentage and in the quantity of ether extract in the net plankton of Lake Monona. Compare with the net plankton of Lake Mendota, table 10.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1911	4	10.57	5.30	7.95	41.3	12.6	27.5
1912	6	8.81	3.12	4.77	156.4	18.8	64.2
1913	16	9.61	2.79	5.62	143.4	13.3	47.2
1915	7	7.95	4.20	6.38	171.8	37.2	98.8
1916	2	11.16	8.09	10.15	142.2	69.0	105.6

Table 33. *A summary of the variations in the percentages of ash and of silica in the net plankton of Lake Monona. Compare with Lake Mendota, table 14.*

Year	Number of Analyses	Per Cent of Ash			Per Cent of Silica			Difference between Means of Ash and Silica
		Maximum	Minimum	Mean	Maximum	Minimum	Mean	
1911	4	13.55	5.32	8.10	2.67	0.77	1.86	6.24
1912	6	20.46	5.15	10.75	13.82	1.15	4.96	5.79
1913	16	31.14	2.28	12.12	21.70	0.12	3.82	8.30
1915	8	19.82	8.40	14.00	14.17	1.47	5.06	8.94
1916	13	33.19	9.76	21.61	27.05	1.27	8.30	13.31

Table 34. *The range of the variations in the percentage and in the amount of nitrogen in the nannoplankton of Lake Monona. Compare with the net plankton, table 30, and with the nannoplankton of Lake Mendota, table 18.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	8	11.28	5.92	10.10	412.5	44.1	236.2
1916	13	10.08	3.58	8.21	574.2	35.4	193.3

Table 35. *The range of the variations in the percentage and in the amount of crude protein in the nannoplankton of Lake Monona. These results are based on those given in table 34. Compare with the net plankton, table 31, and with the nannoplankton of Lake Mendota, table 19.*

Year	Number of Samples	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	8	70.4	37.0	63.1	2,578.1	275.6	1,476.5
1916	13	63.0	22.4	51.3	3,588.8	221.2	1,208.2

TABLE 36. *The range of the variations in the percentage and in the amount of ether extract in the nannoplankton of Lake Monona. Compare with the net plankton, table 32, and with the nannoplankton of Lake Mendota, table 20.*

Year	Number of Analyses	Per Cent, Ash Free			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	7	6.27	3.34	4.90	201.5	47.9	125.9
1916	9	9.50	2.00	4.75	154.2	51.8	95.5

TABLE 37. *The quantity of dry organic matter in the total plankton of Lake Monona covering the period from May to November in 1915 and 1916. The averages for the different months are shown as well as the mean for the entire series of 16 catches. The first part of the table gives the results for the deep water, that is, the area within the 20 meter contour line, and the second part shows the amount per unit of surface when the entire lake is considered. Compare with Lake Mendota, table 26.*

Month	Deep Water		Entire Lake	
	Kilograms per Hectare	Pounds per Acre	Kilograms per Hectare	Pounds per Acre
May	398	355	160	143
June	483	431	194	173
July	310	276	124	111
August	563	502	226	202
September	798	712	320	285
October	1,192	1,063	478	426
November	678	605	272	243
Mean	666	594	267	238

TABLE 38. *The range of variation in the percentage and in the quantity of nitrogen in the net plankton of Lake Waubesa. Compare with Lake Mendota, table 7, and with Lake Monona, table 30.*

Year	Number of Analyses	Per Cent in Organic Matter			Milligrams per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1913	2	8.57	7.44	8.00	162.0	139.0	150.5
1915	4	8.12	5.14	7.45	343.7	81.2	239.6
1916	12	8.20	5.82	7.50	217.6	36.1	83.6

TABLE 39. *The range of variation in the percentage and in the quantity of crude protein in the net plankton of Lake Waubesa. Compare with Lake Mendota, table 8, and with Lake Monona, table 31.*

Year	Number of Analyses	Per Cent of Crude Protein in Organic Matter			Milligrams of Crude Protein per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1913	2	53.6	46.7	50.0	1,012.5	868.0	940.2
1915	4	50.7	32.1	46.6	2,148.1	507.5	1,497.8
1916	12	51.2	36.4	46.9	1,360.0	225,6	522.5

TABLE 40. *The range of variation in the percentage and in the quantity of nitrogen in the nannoplankton of Lake Waubesa. Compare with Lake Mendota, table 18, and with Lake Monona, table 34.*

Year	Number of Analyses	Per Cent of Nitrogen in Organic Matter			Milligrams of Nitrogen per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	4	10.00	7.10	9.03	555.5	217.9	384.7
1916	12	9.27	5.36	7.41	448.0	54.6	220.5

TABLE 41. *The range of variation in the percentage and in the quantity of crude protein in the nannoplankton of Lake Waubesa. Compare with Lake Mendota, table 19, and with Lake Monona, table 35.*

Year	Number of Analyses	Per Cent of Crude Protein in the Organic Matter			Milligrams of Crude Protein per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	4	62.5	44.4	56.4	3,471.9	1,361.9	2,404.4
1916	12	57.9	33.5	46.3	2,800.0	341.2	1,378.1

TABLE 42. *The range of variation in the percentage and in the quantity of ether extract in the nannoplankton of Lake Waubesa. Compare with Lake Mendota, table 20, and with Lake Monona, table 36.*

Year	Number of Analyses	Per Cent of Ether Extract in the Organic Matter			Milligrams of Ether Extract per Cubic Meter of Water		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
1915	4	5.28	3.35	4.61	308.0	102.7	193.0
1916	8	8.13	1.48	4.68	134.7	61.5	85.1

TABLE 43. *Results of the analyses of the samples of net plankton obtained from Lake Mendota between June 1, 1911, and June 1, 1917. The first figure in the sample number indicates the year; for example, No. 102 refers to the second sample taken in 1911 and No. 202 to the second one of 1912. The organic matter is stated in milligrams of dry material per cubic meter of water. The nitrogen, ether extract, pentosans, crude fiber, ash, and silica are stated in percentages of the dry sample; the first four items are also given on an ash free basis, while one column under each shows the amount per cubic meter of water. One column under nitrogen gives the quantity of crude protein (N × 6.25) per meter of water. The percentage of nitrogen in the dry sample represents the total nitrogen, but the percentages given on an ash free basis do not include the nitrogen in the chitinous shells of the crustacea.*

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent Ash Free	Mg. per Cu. M.		
102	June 1, 1911	237.0	5.87	6.23	14.8	92.5	14.7	18.77	21.39	50.7	...	...	...	...	...	...	12.25	2.41
103	June 7	126.6	7.60	8.88	11.2	75.0	10.4	20.07	25.21	31.9	...	...	...	11.16	14.02	17.7	20.39	8.01
104	June 9	264.2	5.96	6.85	18.1	113.1	13.5	12.90	15.96	42.7	...	...	...	...	...	...	18.98	7.82
105	June 14	165.3	5.74	6.48	10.7	66.9	14.3	12.44	15.07	24.9	...	...	...	...	...	...	17.45	8.45
108	June 21-26	86.6	5.78	6.70	5.8	36.2	13.8	10.82	13.50	11.7	...	...	...	9.38	11.70	10.1	19.87	10.36
109	June 28–July 3	69.5	7.86	8.37	5.8	36.2	11.1	9.01	10.32	7.2	...	...	...	7.69	8.81	6.1	12.72	2.81
110	July 5-7	53.7	7.44	8.15	4.4	27.5	11.4	11.60	13.65	6.7	...	...	...	6.56	7.72	4.1	15.04	3.88
111	July 11-15	52.2	6.18	6.60	3.4	21.2	14.0	23.20	26.58	13.9	...	...	...	6.56	7.52	3.9	12.77	3.27
112	July 18-21	50.3	7.67	8.15	4.1	25.6	11.4	15.00	17.15	8.6	...	...	...	6.56	7.50	3.7	12.53	2.90
113	July 25-29	42.5	7.13	7.90	3.4	21.2	11.7	12.86	15.34	6.5	...	...	...	9.00	10.73	4.5	16.10	7.06
115	August 1-5	55.7	6.33	7.18	4.0	25.0	12.6	11.80	14.71	8.2	...	...	...	10.66	13.28	7.4	19.77	12.94
116	August 8-12	142.4	4.65	6.14	8.7	54.4	15.4	8.60	11.98	17.0	2.40	3.35	4.7	7.83	10.93	15.5	28.38	21.50
117	August 15-17	120.5	3.92	6.30	7.6	47.5	15.1	6.50	10.95	13.2	2.92	4.92	5.9	10.53	17.74	21.4	40.67	32.66
118	August 23-26	99.5	5.43	5.91	5.9	36.9	16.1	8.97	10.22	8.7	...	...	...	11.30	12.88	11.0	12.25	4.92
119	Aug. 29–Sept. 1	96.0	5.60	5.75	5.5	35.9	17.4	6.81	7.37	7.0	...	...	...	...	...	...	7.54	1.97
123	September 12-15	108.6	8.04	8.57	9.3	58.1	11.1	8.18	9.10	10.0	...	...	...	8.59	9.56	10.4	10.14	3.60
125	September 19-22	187.3	8.33	9.38	17.6	110.0	10.1	6.87	8.10	15.1	2.60	3.07	5.7	...	...	...	15.30	8.94
126	September 26-29	265.3	8.00	9.22	24.5	153.1	10.2	7.29	8.91	23.6	...	...	...	6.09	7.44	19.7	18.16	12.24
128	October 8	432.0	8.88	9.44	40.8	255.0	9.1	8.54	9.77	42.2	...	...	...	5.94	6.80	29.4	12.69	6.10
129	October 14	435.5	8.06	8.59	37.4	233.7	10.5	10.20	12.03	52.4	...	...	...	9.15	10.80	47.0	15.23	8.75
130	October 21	464.2	6.93	8.35	37.8	236.2	10.9	6.54	8.64	40.1	...	...	...	8.50	11.24	52.2	24.40	16.93
131	October 28	306.5	6.53	8.03	24.6	153.7	11.3	9.38	12.65	38.8	...	...	...	8.87	11.95	36.6	25.83	15.37
202	April 30–May 4, 1912	83.6	8.08	9.25	7.7	48.1	10.1	10.89	13.25	11.1	...	...	...	...	...	...	17.82	6.74
204	May 7	173.5	8.54	9.45	16.4	102.5	10.0	18.23	21.44	37.2	...	...	...	...	...	...	15.00	5.25
205	May 29–June 1	458.4	8.61	8.77	40.2	251.2	10.7	22.48	24.31	111.4	...	...	...	5.37	5.81	26.6	7.54	2.14

207	June 5-8	574.4	8.23	8.59	49.3	308.1	10.9	21.32	23.65	135.8	1.18	1.31	7.5	...	...	...	9.90	3.45
208	June 11-15	335.7	8.38	8.57	28.8	180.0	10.5	14.76	16.68	56.0	1.31	1.48	5.0	...	...	...	11.54	1.76
209	June 18-21	268.9	8.96	9.28	25.0	156.2	10.0	8.45	9.35	25.1	...	...	...	8.83	9.77	26.3	9.61	1.44
212	June 24-28	123.0	8.73	9.55	11.7	73.1	9.8	11.04	12.84	15.8	...	...	...	13.21	15.36	18.9	14.03	2.83
213	July 1-5	155.2	6.70	7.32	11.4	71.2	12.9	8.13	9.34	14.5	2.89	3.17	5.2	9.64	11.07	17.2	12.98	1.63
215	July 8-12	174.8	6.08	6.48	11.3	70.6	14.6	16.28	18.26	31.9	2.94	3.30	5.7	...	...	...	10.84	0.84
218	July 14-19	183.6	6.03	6.23	11.4	71.2	15.3	13.04	14.05	25.8	...	...	...	12.90	13.90	25.5	7.18	0.76
219	July 22-26	196.1	5.43	5.61	11.0	68.7	17.1	9.22	9.88	19.4	...	...	...	18.85	20.21	39.6	6.72	1.42
220	July 30–Aug. 2	314.7	5.70	5.74	18.1	113.1	16.5	10.35	10.97	34.5	2.11	2.24	7.0	19.00	20.13	67.0	5.62	1.38
221	August 5-9	237.3	7.00	7.40	17.6	110.0	12.7	8.44	9.46	22.4	2.58	2.89	6.8	10.16	11.39	27.0	10.78	4.82
222	August 12-16	154.7	6.79	7.40	11.4	71.2	12.0	7.30	8.92	13.8	...	...	...	8.25	10.08	15.6	18.14	11.90
224	August 20-23	129.7	5.65	7.25	9.4	58.7	12.7	7.05	9.81	12.7	2.81	3.91	5.1	...	...	...	28.14	22.58
225	August 26-31	202.7	4.47	6.39	12.9	80.6	14.7	5.74	8.68	17.6	2.58	3.90	8.0	3.54	5.35	10.8	33.85	28.30
227	September 2-6	291.9	4.83	6.56	19.1	119.4	14.4	6.61	9.43	27.6	2.42	3.46	10.1	...	...	...	30.01	24.11
228	September 10-13	197.0	5.93	7.60	15.0	93.8	12.5	7.50	10.13	19.9	...	...	...	8.00	10.78	21.2	25.84	20.22
229	September 16-20	154.7	6.20	8.22	12.7	79.4	11.7	5.59	7.80	12.1	...	...	...	8.40	11.72	18.1	28.36	21.62
230	September 23-27	323.1	5.85	7.71	24.9	155.6	12.3	4.27	5.93	19.1	...	...	...	...	...	...	27.95	20.37
232	Sept. 30–Oct. 4	500.0	6.66	8.96	44.8	280.0	10.7	6.67	9.34	46.3	2.47	3.46	17.1	4.85	6.72	33.1	28.59	21.87
236	October 9-11	802.7	5.19	7.61	61.1	381.9	12.6	6.17	9.42	75.6	2.02	3.08	24.7	4.86	7.42	59.5	34.47	27.42
237	October 14-17	880.9	6.32	9.46	83.3	520.6	10.1	5.78	8.92	78.6	1.91	2.90	24.4	3.15	4.86	42.8	35.22	29.14
242	October 21-24	1,055.4	5.12	8.05	85.0	531.2	12.0	5.87	9.51	100.4	2.11	3.42	36.1	2.60	4.21	44.5	38.30	31.62
243	Oct. 28–Nov. 2	832.0	6.30	8.22	68.4	427.5	11.1	6.37	8.55	71.2	2.61	3.50	29.2	2.64	3.54	29.5	25.53	19.44
245	November 4-7	677.1	6.80	8.17	55.3	345.6	12.0	7.52	9.31	63.0	2.12	2.50	17.8	3.00	3.71	25.1	19.22	13.53
247	November 11-15	672.3	7.34	8.48	57.0	356.2	11.4	7.84	9.35	62.9	2.91	3.47	23.3	3.00	3.58	24.1	16.16	9.53
248	November 18-20	653.0	7.12	8.25	53.9	336.9	11.6	7.24	8.72	57.0	3.39	4.08	26.7	3.10	3.73	24.4	17.00	11.27
249	November 25	586.1	7.18	8.48	49.7	310.6	11.3	...	...	...	...	...	...	5.82	7.14	41.8	18.53	11.35
301	April 16-18, 1913	185.1	9.00	9.80	18.1	113.1	10.0	6.30	7.00	13.0	...	...	...	4.17	4.64	8.6	10.08	3.56
302	April 23-26	209.8	9.22	11.20	23.5	146.9	8.7	7.10	8.80	18.5	1.64	2.04	4.3	3.52	4.38	9.2	19.56	12.58
303	April 30–May 3	400.4	8.29	9.26	37.0	231.2	10.5	17.61	20.16	80.7	1.81	2.07	8.3	4.15	4.75	19.0	12.64	7.38
304	May 7-9	462.3	7.82	8.77	40.5	253.1	19.9	15.16	17.71	81.9	1.53	1.79	8.3	4.74	5.54	25.6	14.38	8.96
305	May 14-16	379.1	7.83	9.02	34.2	213.7	10.5	15.45	18.67	70.8	1.91	2.31	8.8	4.95	5.97	22.6	17.26	10.67
306	May 19-24	434.8	7.84	9.22	40.1	250.6	10.2	11.20	13.94	60.6	...	...	...	4.67	5.81	25.3	19.68	12.88
307	May 28-30	382.0	7.68	9.25	35.3	220.6	10.0	8.39	10.87	41.5	2.74	3.55	13.6	4.33	5.61	21.4	22.82	15.57
309	June 2-6	410.7	8.56	9.16	37.6	235.0	10.1	9.56	11.01	45.2	1.71	1.97	8.1	6.46	7.44	30.5	13.15	3.54
310	June 12-14	254.7	9.20	10.02	25.5	159.4	9.2	4.23	4.95	12.6	...	...	...	7.95	9.31	23.7	14.61	1.24
311	June 17-20	256.3	8.32	8.95	22.9	143.1	10.4	5.02	5.78	14.8	2.59	2.99	7.7	10.02	11.56	29.6	13.32	1.56
312	June 23-26	166.0	8.19	8.74	14.5	90.6	10.6	2.98	3.41	5.7	3.29	3.77	6.3	8.50	9.73	16.1	12.64	0.88
314	June 30–July 3	126.9	7.76	8.24	10.4	65.0	11.5	2.74	3.12	4.0	3.43	3.90	4.9	10.44	11.87	15.1	12.12	0.50
324	July 16-18	250.0	7.11	7.41	18.5	115.6	12.7	5.66	6.32	15.7	2.23	2.49	6.1	9.58	10.69	26.5	10.43	4.04
325	July 21-23	434.4	5.97	6.26	27.2	170.0	14.9	6.86	7.71	33.5	2.72	3.06	13.3	11.32	12.71	55.3	11.01	6.06
328	July 28-31	488.0	5.32	6.50	31.7	198.1	14.4	7.17	9.36	45.6	1.38	1.80	8.8	8.46	11.04	53.8	22.38	18.68
332	August 4-7	534.0	5.12	6.31	33.7	210.6	14.7	6.66	8.80	47.0	2.68	3.54	19.0	6.10	8.06	43.1	24.34	18.24
337	August 11-15	136.0	7.61	8.88	12.1	75.6	10.5	9.12	11.36	15.4	1.65	2.06	2.7	5.93	7.39	10.0	19.72	9.10
339	August 19-22	87.2	8.64	9.02	7.9	49.4	10.4	9.32	10.40	9.0	2.40	2.68	2.3	9.51	10.61	9.2	10.35	2.36
341	August 25 29	91.9	8.75	9.07	8.3	51.9	10.3	8.71	9.69	9.0	1.74	1.94	1.8	5.66	6.30	5.8	10.10	2.04
346	September 1-5	134.6	8.63	9.27	12.5	78.1	10.1	7.66	8.78	11.8	1.81	2.07	2.8	7.46	8.55	11.5	12.75	4.96
350	September 15-18	285.0	5.60	8.01	22.8	142.5	11.8	4.70	7.08	20.2	2.01	3.03	8.6	5.26	7.92	22.6	33.60	25.58
353	September 23-26	317.1	4.50	7.63	24.2	151.2	12.5	5.74	10.21	32.4	1.61	3.01	9.5	3.81	6.78	21.5	43.78	35.26
355	Sept. 29–Oct. 4	697.5	5.22	7.90	55.1	344.4	12.4	6.90	10.65	73.1	2.12	3.27	22.4	4.02	6.21	42.2	35.24	29.04
357	October 6-10	539.8	4.95	7.89	42.6	266.2	10.3	7.64	12.44	67.1	1.93	3.14	17.0	2.26	3.68	19.9	38.57	32.50
359	October 13-18	638.5	5.90	8.15	52.0	325.0	11.8	8.80	12.54	80.1	2.52	3.59	22.9	3.76	5.36	34.2	29.86	18.66

TABLE NO. 43—CONTINUED.

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
361	October 22-25	714.1	7.05	8.39	59.9	374.4	11.4	11.60	14.38	102.7	2.69	3.34	23.8	4.58	5.68	40.6	19.36	8.45
363	October 28-31	547.6	6.70	8.17	44.7	279.4	11.7	9.44	11.98	65.6	2.84	3.60	19.7	4.44	5.64	30.9	21.21	7.86
364	November 6-11	501.6	6.98	8.31	41.7	260.6	11.5	10.87	11.98	60.1	2.88	3.18	16.0	4.16	4.59	23.0	19.30	8.78
365	November 12-14	379.5	7.00	8.63	32.7	204.4	11.2	10.36	13.23	50.2	2.40	3.06	11.6	4.10	5.23	19.9	21.68	13.84
366	November 17-22	310.9	5.71	8.00	24.9	155.6	12.0	6.80	9.85	30.6	2.17	3.14	9.8	3.71	5.38	16.7	30.99	20.74
367	November 24-29	432.2	5.44	7.90	34.0	212.5	12.2	7.64	11.46	49.6	1.58	2.37	10.2	3.12	4.68	20.2	33.35	25.36
368	December 1-5	354.3	5.26	7.93	28.1	175.6	12.3	7.34	11.35	40.2	1.83	2.83	10.0	2.52	3.90	13.8	35.36	29.10
369	December 11-13	460.4	4.20	7.20	33.1	206.9	13.2	4.97	8.74	40.2	1.16	2.04	9.4	1.73	3.04	14.0	43.16	34.99
370	December 16-17	575.2	4.16	7.22	41.5	259.4	13.5	5.72	10.17	61.8	1.72	3.06	18.6	1.59	2.83	17.2	43.77	36.42
371	December 22-24	471.8	4.42	7.26	34.2	213.7	13.4	10.70	17.99	84.9	1.64	2.76	13.0	1.59	2.67	12.6	40.53	34.24
401	Jan. 28–Feb. 28, 1914	123.7	9.49	10.21	12.6	78.7	9.5	14.25	15.77	19.5	......	......	......	4.67	5.17	6.4	9.64	2.40
402	March 14-21	146.6	8.89	9.53	14.0	87.5	10.2	10.66	11.75	17.2	......	......	......	7.74	8.53	12.5	9.28	1.76
404	April 18-21	270.7	9.96	11.10	30.0	187.5	8.7	11.55	13.37	36.2	1.56	1.81	4.9	3.18	3.68	10.0	13.63	5.14
405	April 22-25	339.1	9.86	10.45	35.4	221.2	9.2	15.44	17.12	58.1	1.06	1.18	4.0	3.51	3.89	13.2	9.84	3.16
406	April 27–May 2	285.8	8.22	8.82	25.2	157.5	10.9	12.62	14.07	40.2	3.33	3.71	10.6	4.07	4.54	13.0	10.32	4.00
407	May 5-9	401.8	6.68	7.00	28.1	175.6	13.1	12.64	14.45	58.0	1.53	1.75	7.0	5.07	5.79	23.3	12.52	5.08
408	May 13-16	396.5	9.22	9.86	39.1	244.3	9.5	......	......	......	1.20	1.37	5.4	4.95	5.64	22.4	12.19	5.92
409	May 20-23	391.3	8.03	8.40	32.9	205.6	11.3	16.41	18.06	70.7	1.39	1.53	6.0	4.52	4.97	19.5	9.13	3.86
410	May 27-30	325.6	6.60	6.95	22.6	141.2	13.1	10.42	11.95	38.9	2.87	3.29	10.7	4.94	5.67	18.5	12.83	9.04
411	June 2-6	426.0	7.88	8.36	35.6	222.5	11.1	14.22	16.31	62.8	1.28	1.47	6.3	5.79	6.64	28.3	12.84	4.06
412	June 8-13	295.4	7.69	8.09	23.9	149.3	10.9	14.19	16.29	48.1	1.76	2.02	6.0	7.81	8.96	26.5	12.87	3.88
413	June 16-18	329.8	7.85	8.30	27.4	171.2	11.2	6.13	6.99	23.0	1.72	1.96	6.5	......	......	......	12.30	2.55
414	June 23-25	212.5	7.34	7.66	16.3	101.8	12.0	5.53	6.23	13.2	1.95	2.20	4.7	10.75	12.11	25.8	11.26	1.34
415	June 30–July 2	98.8	6.68	7.07	7.0	43.7	13.0	5.60	6.45	6.4	3.17	3.65	3.6	7.77	8.95	8.8	13.17	1.59
502	April 21-23, 1915	112.7	6.62	8.34	9.4	58.7	11.3	......	......	......	......	......	......	......	......	......	24.72	10.76
503	April 24-25	116.9	7.01	8.27	9.7	60.6	11.6	13.79	17.16	20.0	2.14	2.66	3.1	4.05	5.04	5.9	19.65	11.12
506–7	April 30–May 4	214.2	6.95	7.89	16.9	105.6	12.4	18.14	21.28	45.6	3.24	3.75	8.0	3.59	4.15	8.9	13.57	4.61
509–11	May 5-7	264.9	7.29	8.07	21.4	133.7	12.1	17.12	19.32	51.1	......	......	......	4.16	4.69	12.4	11.38	3.18
514–17	May 12-14	370.3	7.74	8.37	31.0	193.7	11.7	11.29	12.47	46.2	......	......	......	4.11	4.54	16.8	9.40	2.84
520	May 21	517.0	8.11	10.24	52.9	330.6	9.5	15.18	19.59	101.3	1.91	2.46	12.7	4.18	5.39	27.8	22.54	9.98
523	May 28	452.2	7.06	10.72	48.5	303.1	9.0	13.11	20.49	92.6	2.36	3.69	16.7	3.64	5.69	25.7	36.03	22.12
526	June 2	647.1	5.43	7.84	50.7	316.9	12.2	11.03	16.57	107.2	1.80	2.70	17.5	2.96	4.45	28.8	33.45	26.96
530–32	June 8-11	621.8	7.52	9.48	58.9	368.1	10.1	7.65	10.05	62.5	1.61	2.11	13.1	4.52	5.94	36.9	23.88	14.11
536–38	June 14-17	570.6	7.30	8.75	49.9	311.9	11.0	7.10	8.87	50.6	1.11	1.38	7.9	2.89	3.61	20.6	19.97	8.36
540	June 22-25	370.5	7.53	9.49	35.2	220.0	10.0	7.32	9.69	35.9	1.48	1.96	7.3	5.20	6.89	25.5	24.57	14.33
548	June 28–July 2	342.9	7.45	9.14	31.7	198.1	10.4	6.47	8.28	28.4	2.08	2.66	9.1	5.26	6.73	23.1	21.89	10.34
554–58	July 6-9	309.4	6.72	8.27	25.6	160.0	11.7	4.84	6.18	19.1	2.45	3.13	9.7	5.49	7.01	21.7	21.71	7.85
562–66	July 12-15	287.1	6.88	8.52	24.4	152.5	11.2	6.74	8.75	25.1	2.01	2.61	7.5	6.32	8.20	23.5	22.96	12.66

568-76	July 19-22	222.0	6.32	7.64	17.0	106.2	12.2	7.13	9.21	20.4	2.35	3.03	6.7	6.28	8.11	18.0	22.57	11.46
580-82	July 26-29	177.4	6.11	7.22	12.8	80.0	11.3	8.05	10.31	18.3	2.78	3.56	6.3	7.92	10.15	18.0	21.96	11.02
586-90	August 2-6	214.0	7.01	8.18	17.5	109.4	11.5	10.29	12.69	27.1	2.13	2.62	5.6	8.37	10.32	22.1	18.94	9.75
596-101	August 9-12	161.6	5.31	7.26	11.7	73.1	12.0	10.58	15.28	24.7	1.30	1.87	3.0	5.52	7.97	12.9	30.77	19.79
5104	August 16-19	204.6	5.71	8.85	18.1	113.1	10.7	10.31	16.87	34.5	2.04	3.33	6.8	5.92	9.69	19.8	38.91	20.61
5111-13	August 23-26	288.8	4.59	7.56	21.8	136.2	12.7	8.08	13.85	40.0	3.01	5.16	14.9	4.76	8.16	23.6	41.69	14.64
5115	Aug. 29-Sept. 2	304.1	5.43	8.67	26.4	165.0	11.2	6.92	11.33	34.4	2.61	4.27	13.0	4.01	6.56	20.0	38.96	14.08
5130	September 7-9	197.6	5.72	8.33	16.5	103.1	11.7	6.84	10.19	20.1	2.71	4.04	8.0	5.01	7.46	14.7	32.91	21.88
5131	September 13-17	189.0	6.50	9.02	17.0	106.2	10.8	4.84	6.84	12.9	2.39	3.38	6.4	6.46	9.14	17.3	29.32	17.86
5139-43	September 21-22	260.7	6.13	10.55	27.5	171.9	9.3	3.47	6.07	15.8	2.87	5.02	13.1	3.98	6.96	18.1	42.84	29.13
5150	September 29-30	359.8	5.11	9.25	33.3	208.1	10.5	5.06	9.40	33.8	2.22	4.12	14.8	2.41	4.47	16.1	46.17	34.52
5158	October 6-9	556.5	5.59	10.54	58.6	366.2	9.2	4.30	8.31	46.2	2.07	4.00	22.2	2.57	4.97	27.6	48.30	37.25
5159	October 11-13	810.5	5.03	8.87	71.9	449.4	10.6	5.80	10.56	85.5	2.28	4.15	33.6	2.40	4.37	35.4	45.10	34.80
5172	October 19-22	364.5	6.73	9.10	33.2	207.5	10.6	7.90	11.06	40.2	2.93	4.10	14.9	4.90	6.86	25.0	28.60	18.89
5173-79	October 25-28	373.8	6.88	8.88	33.2	207.5	10.8	10.50	14.10	52.7	2.73	3.66	13.7	4.01	5.38	20.1	25.55	15.07
5183-85	November 3-5	401.5	6.40	8.84	35.5	221.9	10.9	7.25	10.37	41.6	2.92	4.17	16.7	4.02	5.75	23.1	30.08	18.36
5187	November 13	530.0	5.73	8.34	44.2	276.2	11.5	7.62	11.49	60.9	2.78	4.19	21.2	4.75	7.16	37.9	33.71	22.64
5194	November 18	535.8	6.21	8.81	47.2	295.0	10.9	7.80	11.47	61.5	2.46	3.62	19.4	3.57	5.25	28.1	32.00	22.52
5195	November 23	527.1	6.04	8.94	47.1	294.3	10.8	8.40	12.87	67.8	2.73	4.18	22.0	2.95	4.52	23.8	34.78	25.96
5202	December 7	611.3	5.22	8.44	51.6	322.5	11.4	11.04	18.51	113.1	2.46	4.12	25.2	2.71	4.54	27.7	40.38	31.14
603	February 11, 1916	213.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	34.41	17.68
605	March 8	172.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	29.99	10.30
607	April 15	175.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	31.50	13.60
609	April 18	181.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	31.13	14.49
611	April 24	247.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	21.26	9.45
613	April 28	207.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22.41	10.68
615	May 3	211.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22.75	10.67
617-19	May 8-10	176.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	32.22	19.02
627-29	May 18-19	395.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	42.27	24.26
631-35	May 22-26	387.5	5.76	8.35	32.3	201.8	11.5	7.31	13.58	52.6	...	...	...	4.57	6.86	26.6	33.40	23.65
637-39	May 30-June 2	364.9	...	...	...	...	...	9.05	11.75	42.9	...	...	...	...	...	...	23.01	11.78
641-45	June 5-10	418.1	6.71	8.53	35.7	223.1	11.3	11.05	14.48	60.5	...	...	...	5.67	7.43	31.0	23.69	13.32
647-53	June 12-16	274.1	5.33	7.43	20.4	127.5	12.9	7.85	11.38	31.2	...	...	...	...	...	...	31.05	19.47
657	June 22	188.5	3.95	5.50	10.4	65.0	17.3	...	...	...	...	...	...	...	...	...	31.48	17.70
663-65	June 26-28	242.7	5.65	7.74	18.8	117.5	12.4	5.32	7.55	18.3	...	...	...	...	...	...	29.58	17.13
669-75	July 5-7	203.5	5.58	7.01	14.3	89.3	13.7	6.39	8.32	16.9	...	...	...	...	...	...	23.28	8.36
677-81	July 10-14	131.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22.18	6.05
683-87	July 17-21	124.7	7.02	8.20	10.2	63.7	11.8	...	...	...	...	...	...	...	...	...	16.80	2.80
689-93	July 24-28	92.5	6.76	8.20	7.6	47.5	11.8	...	...	...	...	...	...	...	...	...	20.04	4.44
695-99	July 31-Aug. 3	100.6	5.96	7.44	7.5	46.8	12.9	...	...	...	...	...	...	...	...	...	22.61	4.63
6101	August 7	104.2	5.54	6.73	7.0	43.8	14.3	...	...	...	...	...	...	...	...	...	20.64	6.01
6109-13	August 14-18	128.0	5.56	6.42	8.2	51.3	15.0	...	...	...	...	...	...	...	...	...	16.56	4.04
6115-19	August 22-25	73.3	5.63	7.16	5.2	32.5	13.4	...	...	...	...	...	...	...	...	...	24.23	7.80
6121-25	August 28-31	94.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	21.41	5.09
6127-31	September 5-8	92.8	6.28	8.26	7.9	49.3	11.7	...	...	...	...	...	...	...	...	...	26.44	9.47
6133-37	September 11-15	120.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	41.83	23.42
6139-43	September 18-21	134.5	4.74	7.86	10.6	66.2	12.1	...	...	...	...	...	...	...	...	...	42.22	29.71
6145-49	September 25-28	351.1	4.28	7.44	26.1	163.1	12.8	...	...	...	...	...	...	...	...	...	45.18	36.86
6153-55	October 3-5	422.0	4.29	7.08	29.9	186.8	13.4	...	...	...	...	...	...	...	...	...	42.19	31.06
6157-61	October 10-14	404.7	5.47	7.61	30.8	192.5	12.6	...	...	...	...	...	...	...	...	...	30.80	16.80
6163-67	October 16-19	537.4	6.20	8.23	44.2	276.2	11.7	...	...	...	...	...	...	...	...	...	27.12	14.26

TABLE No. 43—CONTINUED.

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.		
6171-73	October 26-27	434.5	5.61	7.73	33.6	210.0	12.4										30.02	16.15
6177-79	Oct. 31-Nov. 2	469.2	5.90	8.00	37.6	235.0	11.8										30.10	18.52
6181-85	November 6-10	705.8	6.10	8.68	61.3	383.1	11.1										32.12	20.38
6187	November 17	870.5	6.03	8.78	76.4	477.5	11.0										33.58	22.27
6189	November 20	827.4	6.36	9.09	74.5	465.6	10.7										31.52	21.18
6191-93	Nov. 27-Dec 1	1,050.9	6.04	8.37	88.0	550.0	11.5										30.36	21.30
6195	December 5	919.0	6.76	9.00	82.7	516.8	10.7										27.70	20.14
6197	December 12	1,135.4	5.69	8.20	93.0	581.3	11.7										33.20	22.62
703	January 18, 1917	866.2	6.26	8.43	73.0	456.3	11.5										27.52	3.79
705	February 14	187.3															26.87	6.52
707	March 9	110.8															31.10	11.22
709	April 18	92.4															27.76	6.65
711	April 25	109.8															36.59	15.52
713	May 2	166.8	5.76	10.50	17.5	109.3	9.2										46.66	21.32
715	May 7	173.1	6.98	10.45	18.1	113.1	9.3										35.10	18.05
717	May 11	209.6	8.47	10.33	21.6	135.0	9.4										20.32	8.60
719	May 16	501.7	9.97	11.11	33.5	209.4	8.7										13.40	4.55
721	May 23	360.5															17.58	6.54
723	June 1	400.2	7.77	9.30	37.2	232.5	10.4										18.98	7.67

TABLE 44. *Results of analyses of the samples of nannoplankton obtained from Lake Mendota between April 21, 1915, and June 1, 1917. The quantity of nitrogen was so small in the crude fiber of the nannoplankton that no correction was made in computing the percentage to an ash free basis as indicated for the net plankton in table 43. See the heading of table 43 for further explanations.*

Number of Sample	Date	Organic Matter, Mg. per Cu M	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sampl	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	PerCent, Ash Free	Mg. per Cu. M.		
500–1	April 21-23, 1915 ..	2,776.3	3.28	5.89	163.5	1,022.0	17.0	7.09	12.81	355.6	1.69	3.03	84.1	1.72	3.09	85.8	44.28	30.38
505	April 30...........	2,069.0	3.36	5.59	115.6	722.5	17.8	9.50	15.77	326.3	2.34	3.88	80.3	1.41	2.34	48.4	39.79	21.93
508–10	May 5-7...........	1,679.7	3.26	5.32	89.3	558.1	18.8	7.71	12.57	211.2	2.88	4.69	78.8	2.15	3.50	58.8	38.68	18.48
513–16	May 12-14.........	1,744.4	4.02	6.61	115.3	720.6	15.1	5.35	8.80	153.5	2.32	3.81	66.4	1.19	1.95	34.0	39.18	19.83
519	May 21............	1,747.4	3.56	7.50	131.0	818.7	13.3	3.42	7.21	126.0	2.33	4.90	85.6	1.63	3.43	59.9	52.46	26.98
522	May 28............	1,817.3	3.20	6.88	125.0	781.2	14.5	4.04	8.67	129.5	1.70	3.65	66.3	1.21	2.60	47.2	53.40	30.78
525–27	June 2-4...........	1,770.1	3.96	6.96	123.3	770.6	14.3	4.06	7.13	126.2	2.32	4.08	72.2	1.16	2.04	36.1	43.06	26.36
529–31	June 8-11..........	1,943.3	4.79	7.61	147.9	924.4	13.1	1.90	3.02	58.7	2.34	3.72	72.3	0.80	1.27	24.7	37.05	19.50
535–37	June 14-17.........	1,730.5	4.16	7.22	125.0	781.2	13.8	2.48	4.31	74.5	2.30	3.99	69.0	1.16	2.02	34.9	42.44	20.91
541–45	June 21-24.........	1,104.5	5.18	10.44	115.3	720.6	9.1	3.25	6.55	72.4	1.92	3.87	42.7	1.62	3.27	36.1	50.41	24.51
549–51	June 28–July 1......	1,200.6	5.13	9.28	111.5	697.0	10.7	2.26	4.08	49.0	2.58	4.66	55.9	2.33	4.21	50.5	44.68	21.92
553–57	July 6-9...........	1,269.0	3.52	6.77	85.9	536.8	14.7	2.15	4.13	52.4	2.81	5.40	68.5	2.03	3.90	49.5	47.97	19.70
561–65	July 12-15.........	1,426.2	3.62	6.42	91.7	573.1	15.6	3.06	5.42	77.3	2.78	4.92	70.1	2.29	4.06	57.9	43.59	17.72
567–75	July 19-22.........	1,786.3	3.15	5.93	106.1	663.1	16.8	2.11	3.96	70.7	2.46	4.63	82.7	1.61	3.03	54.1	46.89	10.44
579–81	July 26-29.........	1,590.6	3.74	8.43	134.1	838.1	11.1	3.45	7.75	123.3	1.82	4.10	65.2	1.54	3.47	55.2	55.63	6.35
585	August 2...........	1,678.0	2.77	5.70	95.5	596.9	17.5	3.18	6.54	113.9	1.59	3.27	56.9	1.57	3.23	56.2	51.41	8.33
589	August 6...........	2,086.8	4.76	8.35	174.2	1,088.7	12.0	6.95	12.18	254.2	2.17	3.81	79.5	1.90	3.33	69.5	42.99	11.32
595–100	August 9-12........	1,052.3	4.83	8.65	91.1	569.3	11.5	3.74	6.70	70.5	3.37	6.03	63.4	2.08	3.72	39.1	44.17	13.69
5102–6	August 16-19.......	944.2	3.57	6.70	63.2	395.0	14.9	3.72	6.98	65.9	3.44	6.45	60.9	2.86	5.36	50.6	46.68	13.33
5110–12	August 23-26.......	1,108.2	3.28	5.90	65.4	408.7	16.9	4.20	7.55	83.7	3.73	6.71	74.3	2.77	4.98	55.2	44.40	25.53
5116–22	August 30–Sept. 2...	1,387.4	3.80	6.59	91.4	571.2	15.1	2.45	4.24	58.8	4.27	7.39	102.5	1.84	3.18	44.1	42.26	17.04
5124–26	September 7-9.......	1,200.4	4.23	6.56	78.8	492.5	15.2	3.81	5.89	70.7	......	......	......	2.71	4.19	50.3	35.39	14.71
5132–36	September 13-17....	1,400.1	4.38	7.79	109.1	681.9	12.8	3.09	5.49	76.9	3.40	6.05	84.7	1.29	2.29	32.0	43.80	20.70
5140–42	September 20-22....	1,411.6	3.52	7.18	101.4	633.5	13.9	2.96	6.04	85.2	3.41	6.96	98.2	1.74	3.55	50.1	51.02	22.90
5146–48	September 28-29....	1,733.7	3.97	8.00	138.8	867.5	12.5	1.87	3.77	65.3	3.31	6.67	115.6	1.28	2.58	44.7	50.41	22.34
5156–60	October 6-9.........	1,729.0	3.92	8.21	141.9	886.9	12.2	2.10	4.39	75.9	......	......	......	0.86	1.80	31.1	52.23	22.71
5162–64	October 11-13.......	1,862.2	3.37	7.65	142.6	891.2	13.0	2.46	5.59	104.0	2.68	6.09	113.4	1.06	2.41	44.9	56.00	29.78
5168–70	October 18-20.......	1,781.5	3.67	7.11	126.7	791.8	14.0	2.33	4.51	80.3	2.93	5.67	101.0	1.25	2.42	43.1	48.36	25.93
5176–78	October 25-27.......	1,618.1	3.69	7.50	121.4	758.7	13.3	3.47	7.04	113.9	3.06	6.21	100.5	1.21	2.45	39.6	50.74	25.87
5182–84	November 3-4.......	1,803.0	3.44	7.69	138.7	866.9	13.0	3.05	6.80	122.6	2.56	5.71	102.9	1.39	3.10	55.9	55.19	28.71
5188–90	November 10-13.....	1,717.1	3.16	6.79	116.7	729.4	14.7	2.08	4.46	76.6	2.49	5.34	91.7	1.02	2.19	37.6	53.43	28.03
5192	November 16.......	1,530.1	2.72	8.67	132.8	830.0	11.5	2.48	7.89	139.0	1.56	4.96	87.4	1.04	3.31	58.3	63.61	32.13

TABLE No. 44—CONTINUED.

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
5196	November 22	1,804.9	2.43	6.50	117.8	736.2	15.3	4.29	13.25	278.2	0.92	2.84	59.6	0.96	2.96	62.2	67.64	34.39
5198	December 1	1,533.3	1.58	6.06	92.9	580.6	16.5	1.62	6.22	95.4	1.24	4.76	73.0				73.98	37.67
5200	December 6	1,719.0	2.20	5.47	94.0	578.5	18.2	3.55	8.84	152.0				1.58	3.93	67.5	59.87	28.32
602	February 11, 1916	994.9	2.21	6.20	61.7	385.6	16.1	3.21	9.00	89.6				2.52	7.07	70.6	64.36	21.17
604	March 8	1,881.9	2.06	4.92	92.6	578.7	20.3	3.41	8.14	153.2				2.48	5.92	111.4	58.14	11.42
606	April 15	3,151.5	1.89	7.08	223.2	1,395.0	14.1	2.44	9.13	287.7	1.22	4.57	144.0	1.81	6.78	215.7	73.30	38.67
608	April 18	3,011.5	2.39	8.29	249.7	1,560.6	12.0	2.30	8.00	240.9				1.32	4.58	137.9	71.20	35.45
610	April 24	2,058.6	2.01	7.14	147.0	918.7	14.0	2.45	8.70	179.1							71.84	38.23
612	April 28	1,732.1	1.73	5.78	100.1	625.6	17.3	2.73	9.12	158.0							70.08	37.27
614	May 3	1,291.4	1.77	6.80	87.8	548.7	14.6	3.25	12.50	161.4				2.05	7.88	101.8	74.00	34.12
616–18	May 8-10	1,246.7	1.27	5.08	63.8	398.7	18.8	2.80	11.21	139.8							75.04	35.35
626–28	May 18-19	1,969.3	1.92	5.88	115.8	723.7	17.0	2.80	8.58	169.0	1.40	4.29	84.5				67.38	31.63
630–34	May 22-26	2,031.9	2.96	6.97	141.7	885.6	14.3	3.00	7.07	143.7				2.13	5.02	102.0	57.58	28.96
636–38	May 30–June 2	1,604.1	2.47	5.44	87.3	545.6	18.3	3.30	7.27	116.6							54.62	18.50
640–44	June 5-10	1,512.4	1.85	6.70	101.3	633.1	14.9	1.93	7.00	105.9							72.38	33.52
646–52	June 12-16	1,053.5	2.08	5.20	54.8	342.5	19.2	2.40	6.00	63.2	2.08	5.20	54.8	2.68	6.70	70.6	60.00	21.70
654–56	June 19-22	1,536.3	3.92	8.77	134.7	841.8	11.4	2.55	5.70	87.6							55.30	18.49
662–64	June 26-28	1,726.6	3.14	6.43	111.0	693.7	15.5	2.27	4.65	80.2				2.63	5.50	95.0	51.22	15.95
668–74	July 5-7	2,098.7	2.83	5.53	115.8	723.7	18.9	2.32	4.53	95.1				3.41	6.66	139.8	48.80	11.41
676–80	July 10-14	1,910.2	2.57	5.22	99.7	623.1	19.1	2.72	5.53	105.6							50.80	9.44
682–86	July 17-21	1,510.8	2.09	5.33	80.5	503.1	18.7	2.47	6.29	95.0	2.04	5.20	78.6	2.96	7.55	114.1	60.79	8.68
688–92	July 24-28	1,759.5	2.75	6.17	108.5	678.1	16.2	2.27	5.09	89.6							55.45	8.25
694–98	July 31–August 3	1,501.8	2.34	5.22	78.4	490.0	19.1	2.15	4.80	72.1				3.04	6.78	101.8	55.20	7.36
6100–6	August 7-9	1,244.7	2.08	5.18	62.5	390.6	19.3	2.32	5.78	71.9							59.87	10.19
6108–12	August 14–18	1,367.0	2.22	4.87	66.6	416.2	20.5	2.87	6.29	86.0	3.47	7.61	104.0	4.01	8.79	120.1	54.41	9.53
6114–18	August 22–25	1,173.1	1.78	4.24	49.8	311.2	23.5	2.46	5.85	68.6							58.00	12.22
6120–24	August 28–31	1,118.2	2.20	5.15	57.6	360.0	19.4	2.69	6.30	70.4				7.94	18.60	208.0	57.30	11.43
6126–30	September 5–8	1,097.0	2.18	5.77	63.3	395.6	17.3	1.43	3.78	41.5				3.50	9.27	101.7	62.23	14.26
6132–36	September 11–15	1,324.6	2.34	6.21	82.2	513.7	16.1	1.70	4.51	59.7							62.34	19.60
6138–42	September 18–21	1,715.4	2.51	6.96	119.4	745.6	14.3	1.39	3.85	66.0	2.38	6.60	113.2	6.47	17.93	307.6	63.93	25.61
6144	September 25	2,151.1	2.75	6.89	148.2	925.6	14.5	1.60	4.00	86.0							60.07	29.46
6148	September 28	2,639.8	3.23	6.37	168.2	1,051.2	15.6	2.67	5.27	139.1				5.32	10.50	277.2	49.34	32.60
6152	October 3	2,241,2	2.66	6.63	148.5	928.1	15.1	2.32	5.78	129.5				2.37	5.90	132.2	59.89	29.37
6154	October 5	1,915.3	2.50	6.12	117.3	733.1	16.3	2.73	6.69	128.1							59.19	24.92
6156–60	October 10–14	1,472.3	2.27	5.84	86.1	538.1	17.1	1.08	2.78	40.9							61.16	23.25
6162–66	October 16–19	1,370.3	2.07	5.68	75.7	473.1	18.1	1.63	4.48	61.4	1.59	4.37	60.0	1.86	5.11	70.0	63.60	23.10
6170–72	October 26–27	1,383.2	1.90	5.50	76.1	475.6	18.1	1.29	3.73	51.6							65.45	24.51
6176–78	Oct. 31–Nov. 2	962.3	2.07	5.53	53.1	331.9	18.5	1.73	4.62	44.4				2.23	5.95	57.2	62.55	20.17

6180-84	November 6-10	1,400.3	2.23	5.76	80.6	503.8	17.3	1.86	4.80	67.2	......	......	......	......	......	......	61.25	21.66
6186	November 17	1,500.3	2.62	6.36	95.4	596.2	15.7	1.66	4.03	60.4	......	......	......	1.73	4.20	63.0	58.84	18.68
6188	November 20	1,217.8	3.06	7.24	88.2	551.2	13.8	1.08	2.56	31.2	......	......	......	......	......	......	57.77	18.28
6190-92	Nov. 27-Dec. 1	1,475.2	2.73	7.36	108.4	677.5	13.7	1.28	3.45	50.9	1.35	3.64	53.7	......	......	......	62.94	19.37
6194	December 5	1,619.0	2.69	6.78	109.7	685.6	14.7	2.17	5.47	88.5	......	......	......	2.05	5.16	83.5	60.30	16.87
6196	December 12	1,296.0	2.86	8.10	105.0	656.2	12.3	1.96	5.55	71.9	......	......	......	2.57	7.25	94.0	64.70	16.17
702	January 18, 1917	1,206.5	2.66	5.91	71.3	445.6	16.9	2.21	4.91	59.2	......	......	......	7.16	15.91	191.9	54.98	5.90
704	February 14	943.9	2.23	5.93	56.1	350.6	16.8	1.83	4.87	46.0	......	......	......	6.25	16.64	156.7	62.45	11.42
706	March 9	795.2	2.32	6.01	47.8	298.8	16.6	0.84	2.21	17.6	......	......	......	4.45	11.54	91.7	61.44	6.00
708	April 18	1,345.7	3.01	8.41	113.2	707.5	11.9	1.86	5.20	70.0	1.26	3.52	47.4	......	......	......	64.21	19.55
710	April 25	1,484.2	3.08	7.89	117.0	731.2	12.7	1.70	4.35	64.6	......	......	......	2.76	7.07	104.6	60.95	21.28
712	May 2	2,458.2	3.08	8.32	204.6	1,278.7	12.0	1.82	4.92	120.9	......	......	......	1.43	3.86	94.9	63.00	31.32
714	May 7	2,603.4	3.38	8.53	222.2	1,388.8	11.7	2.80	7.07	184.0	1.47	3.71	96.6	......	......	......	60.39	32.60
716	May 11	1,802.3	4.17	9.04	163.1	1,019.4	11.0	2.90	6.29	113.4	......	......	......	......	......	......	53.90	21.68
718	May 16	1,638.8	4.00	8.29	135.9	849.4	12.0	2.96	6.11	100.1	......	......	......	2.32	4.81	78.8	51.75	16.91
720	May 23	2,088.3	5.04	10.66	222.5	1,390.6	9.4	2.30	4.86	101.5	......	......	......	......	......	......	52.71	19.34
722	June 1	1,467.9	3.61	8.26	121.3	758.1	12.1	2.38	5.45	80.0	......	......	......	4.88	11.17	158.2	56.31	16.82

TABLE 45. *Results of the analyses of the samples of net plankton obtained from Lake Monona between 1911 and 1916. See heading of table 43 for explanations.*

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
106	June 22, 1911	326.3	5.92	6.85	22.3	139.4	14.6	9.14	10.57	34.5	......	......	......	2.91	3.37	11.0	13.55	2.67
114	July 27	183.5	9.13	9.80	18.0	112.5	10.2	6.43	6.89	12.6	......	......	......	5.31	5.70	10.5	6.82	2.15
120	August 30	519.3	8.42	9.03	46.9	293.1	11.0	7.42	7.96	41.3	......	......	......	......	......	......	6.72	......
124	September 13	403.1	9.38	9.91	39.9	249.4	10.0	5.03	5.30	21.4	......	......	......	......	......	......	5.32	0.77
214	July 2, 1912	213.3	7.96	9.39	20.0	125.0	10.6	7.50	8.81	18.8	......	......	......	......	......	......	15.22	1.90
223	August 15	442.1	9.17	9.67	42.7	266.9	10.3	4.08	4.30	19.0	......	......	......	......	......	......	5.15	1.15
231	September 24	758.5	8.97	9.57	72.6	453.8	10.4	2.92	3.12	23.6	2.47	2.64	20.0	......	......	......	6.27	1.66
233	October 1	2,073.3	8.34	9.24	191.6	1,197.5	10.8	3.18	3.52	73.1	6.68	7.40	153.4	1.86	2.06	42.7	9.76	3.22
238	October 15	3,303.6	7.90	9.15	302.2	1,888.7	10.9	4.08	4.72	156.4	5.97	6.91	228.3	2.41	2.79	92.2	13.63	8.03
246	November 5	1,272.9	7.02	8.83	112.3	702.0	11.3	5.88	7.39	94.1	......	......	......	3.10	3.90	49.6	20.46	13.82
308	May 30–June 4, 1913	299.2	8.31	10.39	31.1	194.4	9.6	4.35	5.44	16.3	......	......	......	7.79	9.74	29.2	20.06	......
315	July 1	405.9	7.51	9.61	39.0	243.7	10.4	4.32	5.53	22.4	3.67	4.70	19.1	4.68	5.99	24.3	21.88	8.43
322	July 15	1,200,9	8.56	9.80	117.7	735.4	10.2	4.36	4.99	59.9	5.08	5.82	69.9	3.48	3.98	47.9	12.68	5.29
326	July 24	1,348.4	8.04	8.62	116.3	729.0	11.5	3.43	3.68	49.6	6.34	6.80	91.7	3.05	3.27	44.1	6.73	0.84
330	July 30	1,024.9	7.62	8.12	83.7	523.1	12.3	2.62	2.79	28.6	......	......	......	2.78	2.96	30.4	6.20	0.38
333	August 5	1,176.3	7.26	7.67	90.2	563.7	13.0	2.94	3.11	36.5	......	......	......	2.10	2.22	26.1	5.34	0.44
338	August 13	879.9	7.87	8.22	72.3	451.9	12.2	3.29	3.44	30.2	2.94	3.07	27.0	1.79	1.87	16.5	4.25	0.12
340	August 20	459.5	7.26	7.62	35.0	218.7	13.1	2.76	2.90	13.3	7.76	8.15	37.4	1.49	1.56	7.2	4.68	0.20
345	August 27	641.5	6.99	7.15	45.9	286.9	13.9	3.06	3.13	20.1	10.36	10.60	68.0	2.23	2.28	14.6	2.28	0.22
347	September 3	279.4	8.53	9.13	25.5	159.4	11.0	4.99	5.34	14.9	6.25	6.69	18.7	3.93	4.21	11.7	6.55	0.80
349	September 9	259.6	8.89	9.49	24.6	153.7	10.5	6.36	6.80	17.6	4.57	4.88	11.2	7.64	8.16	18.8	6.42	0.87
351	September 15-18	413.0	9.17	10.05	41.5	259.4	10.0	6.60	7.23	29.8	3.50	3.84	15.8	7.85	8.61	35.5	8.78	2.94
354	September 24	699.3	8.43	9.60	67.1	419.4	10.4	7.94	9.04	63.2	4.18	4.76	33.3	6.56	7.47	52.3	12.16	4.71
356	October 3	1,037.0	7.70	9.55	99.0	618.8	10.5	6.08	7.54	78.2	3.22	3.99	41.4	7.19	8.91	92.5	19.35	10.56
360	October 18	1,925.1	5.64	8.19	157.7	985.6	12.2	5.13	7.45	143.4	3.03	4.40	84.7	2.54	3.69	71.0	31.14	21.70
362	October 25	1,370.2	6.60	8.86	121.4	758.8	11.3	7.16	9.61	131.7	2.56	3.44	47.1	3.30	4.43	60.7	25.51	19.80
544	June 23, 1915	2,138.4	9.79	11.11	237.6	1,485.0	9.0	5.47	6.21	132.8	......	......	......	2.09	2.37	50.7	11.89	1.47
564	July 13	404.0	8.14	10.03	40.5	253.1	9.9	......	......	......	......	......	......	......	......	......	18.86	3.09
584	July 30	940.0	6.69	8.09	76.0	475.0	12.3	3.47	4.20	39.4	......	......	......	1.97	2.38	22.4	17.35	5.46
5119	August 31	1,471.2	10.45	11.71	172.3	1,076.8	8.5	4.75	5.32	78.3	5.75	6.44	94.7	2.61	2.92	43.0	10.79	3.88
5135	September 15	803.1	9.33	10.40	83.5	521.8	9.6	4.15	4.63	37.2	6.22	6.93	55.6	......	......	......	10.31	1.76
5145	September 24	1,352.6	10.55	11.52	155.8	993.7	8.7	5.65	6.17	83.4	4.87	5.32	71.9	3.83	4.18	56.5	8.40	1.92
5167	October 15	2,161.8	8.78	10.95	236.7	1,479.4	9.1	6.38	7.95	171.8	4.38	5.46	118.0	2.96	3.69	79.8	19.82	14.17
5181	October 29	1,961.2	8.84	10.34	202.0	1,262.5	9.6	6.51	7.61	149.2	4.98	5.82	114.1	2.87	3.35	65.7	14.53	8.76
621	May 21, 1916	272.6	......	......	......	......	......	......	......	......	......	......	......	......	......	......	29.85	6.63

649	June 14	254.1	6.13	8.30	21.1	131.9	12.0										26.18	3.14
659	June 23	1,226.1	5.72	7.18	88.0	550.0	13.9	8.89	11.16	142.2							20.35	2.50
673	July 6	853.6	6.43	7.18	61.3	383.1	13.9	7.30	8.09	69.0							9.76	1.27
685	July 18	276.1	7.31	8.71	24.0	150.0	11.4										16.09	1.37
697	August 1	285.3	8.31	9.49	27.1	169.4	10.5										12.48	2.33
6111	August 15	301.8															33.19	27.05
6123	August 29	109.3															16.92	6.55
6135	September 12	118.6															20.00	5.07
6147	September 26	235.9															19.60	7.29
6159	October 12	392.6															27.72	18.10
6169	October 24	757.2	6.86	9.62	72.8	455.0	10.4										28.69	19.06
6183	November 9	777.8	7.90	9.89	76.9	480.6	10.1										20.14	7.54

TABLE 46. *Results of the analyses of the nannoplankton samples obtained from Lake Monona in 1915 and 1916. See headings of tables 43 and 44 for explanations.*

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Crude Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sampe	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
543	June 23, 1915	1,782.3	7.56	10.59	188.7	1,179.4	9.4	2.39	3.34	59.5	......	......	......	2.41	3.37	60.0	28.62	8.35
563	July 13	723.0	3.32	6.10	44.1	275.6	16.3	......	......	......	......	......	......	......	......	......	45.61	15.47
583	July 30	764.1	2.68	5.92	45.2	282.5	16.8	2.84	6.27	47.9	......	......	......	2.24	4.95	37.8	54.77	17.37
5118	August 31	2,583.1	6.06	9.18	237.1	1,481.9	10.9	3.77	5.71	147.5	3.73	5.72	147.8	1.34	2.03	52.4	34.01	24.47
5134	September 15	2,580.9	6.07	10.74	277.2	1,732.5	9.3	2.87	5.08	131.1	......	......	......	......	......	......	43.49	21.54
5144	September 24	3,296.3	7.20	11.28	371.8	2,323.7	8.1	2.23	3.49	115.0	1.45	2.26	74.5	0.88	1.38	45.5	36.17	14.53
5166	October 15	3,746.5	6.77	11.01	412.5	2,578.1	9.1	2.93	4.77	178.7	2.88	4.70	176.1	0.81	1.31	49.0	38.54	19.35
5180	October 29	3,240.0	4.97	9.67	313.3	1,958.1	10.3	3.20	6.22	201.5	2.59	5.04	163.3	1.57	3.05	98.8	48.63	22.14
620	May 12, 1916	1,623.2	1.43	3.58	58.1	363.1	27.9	3.80	9.50	154.2	......	......	......	4.82	12.05	195.6	60.0	14.40
648	June 14	672.1	2.00	5.65	38.0	237.5	17.6	2.73	7.71	51.8	......	......	......	......	......	......	64.62	9.54
658	June 23	809.3	1.98	5.97	48.4	302.5	16.7	2.82	8.50	68.8	......	......	......	3.81	11.49	93.0	66.85	9.55
672	July 6	749.5	1.66	4.72	35.4	221.2	21.1	2.50	7.11	53.3	......	......	......	......	......	......	64.84	16.51
684	July 18	1,175.6	2.10	4.75	55.8	348.8	21.0	3.66	8.28	97.3	......	......	......	......	......	......	55.80	7.31
696	August 1	1,620.2	3.65	7.75	125.6	785.0	12.8	3.48	7.39	119.7	......	......	......	......	......	......	52.93	5.19
6110	August 15	2,055.6	3.90	7.30	150.0	937.5	13.7	......	......	......	......	......	......	......	......	......	46.60	11.43
6122	August 29	2,289.5	5.27	9.03	206.8	1,292.5	11.0	......	......	......	......	......	......	......	......	......	41.65	8.75
6134	September 12	3,278.6	5.23	8.94	293.2	1,832.5	11.1	1.97	3.37	110.5	......	......	......	6 45	11.02	361.3	41.52	6.65
6146	September 26	3,504.0	4.92	9.51	333.3	2,083.1	10.5	......	......	......	......	......	......	......	......	......	48.28	13.52
6158	October 12	5,696.2	5.79	10.08	574.2	3,588.8	9.9	1.14	2.00	113.9	......	......	......	1.65	2.87	163.5	42.60	14.98
6168	October 24	4,701.8	4.92	9.26	435.4	2,721.2	10.7	......	......	......	......	......	......	......	......	......	46.92	14.23
6182	November 9	2,447.5	2.63	6.46	158.3	989.4	15.4	1.50	3.69	90.3	......	......	......	4.01	9.85	241.0	59.30	17.10

TABLE 47. *Results of the analyses of the samples of net plankton obtained from Lake Waubesa between 1913 and 1916. See heading of table 43 for explanations.*

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
320	July 8, 1913	1,868.5	7.17	7.44	139.0	868.0	12.7	4.88	5.32	99.8	3.71	4.05	75.9	7.03	7.67	143.3	8.34	2.74
352	September 19	1,890.0	6.94	8.57	162.0	1,012.5	11.1	4.85	6.28	118.4	4.40	5.70	107.4	3.96	5.12	96.8	22.78	16.37
598	August 11, 1915	3,697.7	6.75	7.10	262.5	1,640.6	13.3	2.54	2.81	103.9	6.12	6.77	250.3	1.65	1.82	67.3	9.60	3.79
5129	September 10	4,232.5	7.86	8.12	343.7	2,148.1	11.7	5.02	5.45	230.7	5.75	6.25	264.5	4.12	4.48	189.6	8.04	3.10
5153	October 2	3,346.5	6.11	8.10	271.1	1,694.3	11.8	6.38	8.82	295.2	4.47	6.18	206.8	2.08	2.88	96.4	27.74	22.89
5175	October 23	1,580.0	4.48	5.14	81.2	507.2	18.5	4.89	5.87	92.7	4.02	4.83	76.3	5.24	6.30	99.5	16.80	11.55
633	May 24, 1916	566.6	4.87	6.37	36.1	225.6	14.9	...	...	...	...	...	...	...	...	...	27.24	12.37
651	June 15	471.1	6.67	7.72	36.4	227.5	12.3	...	...	...	...	...	...	...	...	...	17.85	3.41
667	June 29	754.9	6.83	7.72	58.3	364.3	12.3	7.08	8.40	63.4	...	...	...	...	...	...	15.73	3.58
679	July 11	1,008.0	6.55	7.16	72.2	451.2	13.3	5.78	6.63	66.8	...	...	...	3.62	4.15	41.8	12.91	5.00
691	July 25	723.0	6.02	6.30	45.5	284.3	15.1	6.80	7.47	54.0	...	...	...	2.25	2.47	17.9	9.00	2.53
6103	August 8	1,172.6	6.53	6.63	77.7	485.6	14.3	7.26	7.78	91.2	...	...	...	...	...	...	6.68	1.04
6117	August 23	1,315.6	5.62	5.82	76.6	478.7	16.3	...	...	...	...	...	...	...	...	...	8.00	2.79
6129	September 7	824.0	7.35	8.10	66.7	416.9	11.8	...	...	...	...	...	...	...	...	...	13.16	4.71
6141	September 19	1,183.1	5.87	8.17	96.7	604.4	10.2	...	...	...	...	...	...	...	...	...	30.73	23.52
6151	October 2	2,654.3	7.08	8.20	217.6	1,360.0	11.6	3.85	4.65	123.4	...	...	...	5.71	6.91	183.4	17.37	8.87
6165	October 18	1,776.9	6.67	8.15	144.8	905.0	11.7	...	...	...	...	...	...	...	...	...	21.39	12.79
6175	October 30	920.1	6.59	8.09	74.4	465.0	11.8	4.23	5.43	50.0	...	...	...	7.92	10.18	93.6	22.21	14.64

TABLE 48. *Results of the analyses of the samples of nannoplankton obtained from Lake Waubesa in 1915 and in 1916. See headings of tables 43 and 44 for explanations.*

Number of Sample	Date	Organic Matter, Mg. per Cu. M.	NITROGEN				Organic Matter ÷ Nitrogen	ETHER EXTRACT			PENTOSANS			CRUDE FIBER			Ash, Per Cent of Dry Sample	SiO_2, Per Cent of Dry Sample
			Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Crude Protein, (Nx6.25) Mg. per Cu. M.		Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.	Per Cent of Dry Sample	Per Cent, Ash Free	Mg. per Cu. M.		
597	August 11, 1915	3,068.5	4.06	7.10	217.9	1,361.9	14.0	1.92	3.35	102.7	3.77	6.59	202.2	0.93	1.62	49.7	42.82	16.75
5128	September 10	2,871.2	4.99	9.70	278.5	1,740.6	10.3	2.60	5.05	145.0	3.46	6.72	193.0	1.87	3.63	104.2	48.55	16.27
5152	October 2	6,143.2	6.11	9.04	555.5	3,471.9	10.8	3.51	5.28	308.0	3.94	5.93	346.0	0.55	0.83	51.0	33.58	17.55
5174	October 23	4,958.0	6.69	10.05	498.2	3,113.8	9.9	3.18	4.77	236.5	3.03	4.55	225.6	1.14	1.71	84.8	33.44	17.02
632	May 24, 1916	1,257.7	2.15	5.47	68.8	430.0	18.2	1.95	4.96	62.4	....	....	....	4.10	10.43	131.1	60.70	14.17
650	June 15	801.0	2.66	6.81	54.6	341.2	14.6	3.18	8.13	65.1	....	....	....	4.02	10.29	82.4	60.94	11.02
666	June 29	942.9	2.36	6.81	64.2	401.2	14.6	2.26	6.52	61.5	....	....	....	2.83	8.16	76.9	65.35	12.12
678	July 11	2,026.6	3.23	6.94	140.7	879.3	14.4	2.40	5.15	104.4	....	....	....	4.78	10.27	208.1	53.46	9.88
690	July 25	2,275.4	2.57	5.36	122.0	762.5	18.7	2.84	5.92	134.7	....	....	....	3.76	7.86	178.8	52.09	7.42
6102	August 8	3,584.3	4.28	7.28	261.0	1,631.2	13.7	....	....	....	....	....	....	....	....	....	41.26	5.12
6116	August 23	4,298.5	3.68	6.67	286.7	1,791.9	15.0	....	....	....	....	....	....	....	....	....	44.84	9.07
6128	September 7	4,830.9	5.62	9.27	448.0	2,800.0	10.7	0.90	1.48	68.1	....	....	....	2.65	4.37	211.1	39.41	11.88
6140	September 19	4,377.0	3.33	7.90	345.9	2,161.9	12.6	....	....	....	....	....	....	....	....	....	57.85	26.81
6150	October 2	3,724.0	3.09	6.97	259.6	1,622.5	14.3	1.16	2.61	94.9	....	....	....	4.06	9.15	340.7	55.67	21.72
6164	October 18	4,039.3	3.68	7.87	318.0	1,987.5	12.6	....	....	....	....	....	....	....	....	....	53.28	19.60
6174	October 30	3,587.8	4.10	7.77	278.8	1,742.5	12.8	1.39	2.63	94.3	....	....	....	2.86	5.41	194.1	47.18	15.20

TABLE 49. *Results of chemical analyses of various organisms made during this investigation. They are stated in percentages of the dry weight of the sample. Part I indicates the results with the ash included, while Part II gives the data on an ash free basis. (See Chapter VIII.)*

Lake	Date	Organism	PART I. ASH INCLUDED								PART II. ASH FREE					
			Nitrogen	Crude Protein (Nx6.25)	Ether Extract	Pentosans	Crude Fiber	Nitrogen Free Extract	Ash	SiO_2	Nitrogen	Crude Protein	Ether Extract	Pentosans	Crude Fiber	Nitrogen Free Extract
Mendota	IX 30, 1911	Microcystis	8.60	53.75	4.55	...	2.11	32.05	7.54	0.38	9.30	58.13	4.92	...	2.28	34.67
Monona	VII 11, 1914	Microcystis	9.27	57.94	2.67	4.97	0.26	34.82	4.31	0.13	9.68	60.55	2.79	5.19	0.27	36.39
Monona	X 17, 1917	Microcystis	6.32	39.50	2.75	...	0.65	52.09	5.01	...	6.65	41.60	2.90	...	0.68	54.82
Waubesa	VII 7, 1917	Chiefly Microcystis	8.35	52.19	5.02	7.80	...	...	7.81	1.62	9.05	56.61	5.44	8.46	...	...
Mendota	IX 19, 1914	Anabaena	8.27	51.69	1.11	4.81	0.63	39.40	7.17	0.95	8.91	55.68	1.20	5.18	0.68	42.44
Devils	X 8, 1913	Anabaena and Coelosphaerium	8.35	52.19	2.05	6.15	1.17	39.93	4.66	0.27	8.75	54.74	2.15	6.45	1.22	41.89
Mendota	VII 11, 1915	Aphanizomenon	9.30	58.12	3.72	2.04	0.53	30.12	7.51	1.16	10.05	62.83	4.02	2.20	0.57	32.58
Mendota	XII 3, 1913	Aphanizomenon and Anabaena	9.94	62.12	4.34	3.42	1.30	25.72	6.52	0.17	10.63	66.45	4.64	3.66	1.29	27.62
Monona	VII 20, 1915	Lyngbya	9.17	57.31	2.36	5.25	3.42	31.24	5.67	0.15	9.73	60.81	2.50	5.56	3.63	33.06
Monona	VII 24, 1915	Lyngbya	8.21	51.31	1.38	3.76	7.39	34.74	5.18	0.20	8.66	54.12	1.45	3.97	7.79	36.64
Culture	V 13, 1915	Ankistrodesmus	...	...	...	...	...	...	...	...	8.32	52.00	8.78	2.41	9.67	29.55
Mendota	VIII 28, 1915	Diatoms	3.66	22.87	13.60	2.87	1.43	22.60	39.50	30.78	6.05	37.81	22.48	4.74	2.36	37.35
Monona	VII 6, 1916	Volvox	7.61	47.56	5.54	1.00	6.32	34.30	6.28	0.24	8.12	50.75	5.91	1.06	6.74	36.60
Wingra	IX 28, 1917	Spirogyra	3.47	21.68	2.75	10.70	0.64	65.88	9.05	0.24	3.81	23.82	3.02	11.76	0.70	72.46
Mendota	VI 15, 1916	Cladophora	2.77	17.31	2.54	8.32	18.47	35.14	26.54	7.10	3.77	23.56	3.45	11.32	25.14	47.85
Mendota	VII 15, 1917	Potamogeton (mature)	1.47	9.19	0.94	9.80	16.10	49.86	23.91	1.36	1.93	12.06	1.23	12.88	21.16	65.55
Mendota	VII 15, 1917	Potamogeton (green)	1.80	11.25	1.83	8.46	13.55	46.64	26.73	1.39	2.45	15.31	2.50	11.54	18.49	63.70
Mendota	VII 15, 1917	Vallisneria	2.80	17.50	2.41	7.38	13.10	46.29	20.70	0.52	3.53	22.06	3.03	9.30	16.52	58.39
Mendota	VII 15, 1917	Myriophyllum	3.23	20.19	2.95	7.91	15.58	40.56	20.72	1.96	4.07	25.43	3.72	9.98	19.65	51.20
Fowler	IX 28, 1918	Diaptomus	10.38	64.87	8.01	...	8.58	12.60	5.94	...	11.03	68.93	8.51	...	9.12	13.44
Mendota	XII 10, 1918	Cyclops	9.57	59.81	19.80	...	10.07	4.58	5.74	...	10.15	63.43	21.00	...	10.68	4.89
Mendota	V 1, 1912	Diaptomus and Cyclops	9.27	57.93	16.74	...	5.92	13.59	5.82	0.36	9.84	61.50	17.77	...	6.28	14.45
Mendota	V 8, 1918	Diaptomus and Cyclops	9.87	61.69	17.68	...	5.58	9.47	5.58	0.01	10.45	65.31	18.72	...	5.91	10.06
Green	VIII 22, 1913	Limnocalanus	7.18	44.88	39.90	0.58	3.96	7.16	4.10	0.10	7.49	46.75	41.60	0.60	4.13	7.52
Devils	VII 2, 1913	Daphnia pulex	7.45	46.56	3.90	1.32	9.02	14.67	25.85	0.73	10.04	62.75	5.26	1.78	12.16	19.83
Devils	X 1, 1915	Daphnia pulex	8.27	51.69	2.82	1.92	8.51	12.25	24.73	1.16	10.98	68.62	3.74	2.55	11.30	16.34
Devils	V 15, 1916	Daphnia pulex	6.55	40.94	4.60	...	7.25	24.04	23.17	2.84	8.52	53.25	5.98	...	9.43	31.34
Devils	V 25, 1917	Daphnia pulex	5.82	36.38	12.07	...	6.96	25.19	19.40	1.46	7.22	45.12	14.97	...	8.63	31.28
Devils	VIII 30, 1917	Daphnia pulex	7.58	47.37	3.10	...	10.89	21.77	16.87	0.14	9.12	57.00	3.73	...	13.08	26.19
Monona	IV 4, 1914	Daphnia pulex	8.63	53.94	21.25	0.80	3.34	13.85	7.62	0.07	9.34	58.38	23.00	0.86	3.62	15.00
Monona	VI 17, 1916	Daphnia pulex	7.91	49.44	3.45	...	5.58	23.32	18.21	1.95	9.67	60.43	4.22	...	6.82	28.53

TABLE No. 49—CONTINUED.

Lake	Date	Organism	PART I. ASH INCLUDED								PART II. ASH FREE					
			Nitrogen	Crude Protein (Nx6.25)	Ether Extract	Pentosans	Crude Fiber	Nitrogen Free Extract	Ash	SiO_2	Nitrogen	Crude Protein	Ether Extract	Pentosans	Crude Fiber	Nitrogen Free Extract
Monona	VIII 5 1913	Daphnia pulex and D. hyalina	8.51	53.19	8.42	1.58	8.31	15.44	14.64	0.08	9.97	62.31	9.86	1.85	9.73	18.10
Waubesa	V 10, 1917	Daphnia pulex	7.55	47.19	27.90	...	4.53	8.25	12.13	1.02	8.59	53.70	31.75	...	5.15	9.40
Mendota	VIII 28, 1917	Daphnia hyalina and D. retrocurva	8.35	52.19	4.55	...	8.35	19.02	15.89	0.67	9.92	62.00	5.41	...	9.92	22.67
Kawaguesaga	VIII 14, 1913	Holopedium	8.35	52.19	10.65	6.71	5.80	23.72	7.64	0.28	9.04	56.50	11.53	7.26	6.28	25.69
Monona	VIII 8, 1912	Leptodora	7.69	48.06	25.93	1.03	9.55	8.46	8.00	0.20	8.35	52.19	28.18	1.12	10.38	9.25
Monona	VIII 5, 1913	Leptodora	9.28	58.00	8.70	0.72	4.60	13.20	15.50	0.22	10.98	68.62	10.29	0.85	5.44	15.65
Mendota	IX 3, 1917	Leptodora	9.84	61.50	5.88	...	8.80	12.51	11.31	0.23	11.09	69.31	6.63	...	9.92	14.14
Mendota	VIII 28, 1915	Cambarus	6.60	41.25	3.45	0.95	10.42	10.51	34.37	0.14	10.05	62.81	5.25	1.44	15.87	16.07
Mendota	IX 1, 1915	Hyallela	7.37	46.06	7.60	0.90	6.00	11.74	28.60	0.14	10.32	64.50	10.64	1.26	8.40	16.46
Mendota	VI 20, 1916	Oligochaeta	7.76	48.50	...	...	...	...	4.25	...	8.10	50.62	...	...	...	...
Mendota	VIII 28, 1915	Hirudinea	11.13	69.56	10.67	0.06	0.33	13.56	5.88	0.74	11.82	73.88	11.33	0.06	0.35	14.44
Mendota	VII-IX, 1914	Ephemerida	8.82	55.12	15.43	1.10	5.05	13.42	10.98	3.85	9.91	61.94	17.33	1.23	5.67	15.06
Mendota	VII-IX, 1914	Zygoptera	10.62	66.37	10.82	0.13	7.83	8.08	6.70	0.54	11.38	71.12	11.60	0.14	8.39	8.89
Mendota	VIII, 1914-15	Anisoptera	9.47	59.18	9.68	...	12.48	11.49	7.17	0.83	10.20	63.75	10.42	...	13.44	12.39
Mendota	IV 30, 1914	Sialis	8.07	50.44	18.50	...	3.77	22.43	4.86	0.33	8.48	53.00	19.44	...	3.96	23.60
Mendota	VII, 1914	Trichoptera	7.93	49.56	12.47	0.16	9.11	23.75	15.11	0.59	9.34	58.37	14.69	0.19	10.73	16.21
Mendota	VII-IX, 1916	Chironomus tentans	7.36	46.00	8.00	...	5.76	35.10	5.14	0.32	7.76	48.50	8.43	...	6.07	37.00
Mendota	VI-IX, 1916	Corethra punctipennis	10.74	67.12	9.45	...	6.15	9.32	7.96	0.16	11.67	72.94	10.26	...	6.68	10.12
Devils	V 15, 1916	Corethra plumicornis	9.73	60.81	...	...	...	...	4.76	0.22	10.22	63.87	...	...	...	...
Mendota	VI 15, 1914	Gyrinidae	5.74	35.88	37.65	...	14.47	10.30	1.70	0.00	5.84	36.50	38.30	...	14.72	10.48
Mendota	VII-VIII, 1914	Hemiptera	9.94	62.12	8.78	...	11.78	10.93	6.39	0.61	10.62	66.37	9.48	...	12.58	11.57

Table 50. *This table shows some of the inorganic constituents of the ash as determined for eighteen samples. The results are stated in percentages of the dry weight of the sample. See table 49 also.*

Lake	Date	Organism	Ash	SiO_2	Fe_2O_3 and Al_2O_3	P_2O_5	CaO	MgO
Monona..	VII 11, 1914	Microcystis	4.31	0.13	0.84	1.18	0.92	0.63
Mendota.	IX 19, 1914	Anabaena	7.17	0.95	1.27	1.21	1.42	0.70
Devils ...	X 8, 1913	Anabaena and Coelosphaerium	4.66	0.27	.....	.....	0.82	0.63
Monona..	VII 6, 1916	Volvox	6.28	0.24	0.80	2.50	1.10	0.93
Mendota.	VI 15, 1916	Cladophora	26.54	7.10	1.80	0.32	3.26	1.62
Mendota.	VII 15, 1917	Myriophyllum	20.72	1.96	4.35	1.18	4.28	1.34
Mendota.	XII 10, 1918	Cyclops	5.74	.....	1.43	2.32	0.78	0.75
Green....	VIII 22, 1913	Limnocalanus	4.10	0.10	0.10	1.78	0.53	0.42
Devils ...	V 15, 1916	Daphnia pulex	23.17	2.84	1.58	3.65	9.89	0.49
Monona..	IV 4, 1914	Daphnia pulex	7.62	0.07	0.98	3.50	2.25	0.89
Waubesa.	V 10, 1917	Daphnia pulex	12.13	1.02	2.94	3.37	2.01	0.47
Monona..	VIII 5, 1913	Leptodora	15.50	0.22	1.10	3.52	3.22	0.95
Mendota.	VIII 28, 1915	Cambarus	34.37	0.14	1.56	2.63	17.82	0.57
Mendota.	IX 1, 1915	Hyalella	28.60	0.14	0.75	2.73	14.82	0.35
Mendota.	VIII 28, 1915	Hirudinea	5.88	0.74	1.04	1.73	1.00	0.70
Mendota.	VII-IX, 1914	Zygoptera	6.70	0.54	1.48	1.50	0.84	0.03
Mendota.	IV 30, 1914	Sialis	4.86	0.33	0.46	1.46	0.16	1.12
Mendota.	VII-IX, 1916	Chironomus tentans	5.14	0.32	.....	2.10	1.30	0.46

TABLE 51. *Results of analyses of marine and fresh-water organisms as given by other investigators. The sources of the data are indicated in the first column of the table. The results are stated in percentages of the dry weight of the material. All of the samples taken from Brandt, except one, consisted of marine organisms; the series numbered II to X were catches of marine net plankton and contained various kinds of organisms. Brandt considered the amount of nitrogen in protein as 15.61 per cent and this gave him a protein factor of approximately 6.41 instead of 6.25; his data for crude protein, therefore, are somewhat higher than those given in this table.*

The other samples shown in table 51, as well as one of Brandt's, consisted of freshwater forms. Volk gives no data for nitrogen in the two analyses recorded by him; instead of protein he designates this material as "muscle and other tissue." Apparently he determined the ether extract, crude fiber, and ash, and listed the remainder as "muscle and other tissue." The latter, therefore, includes the crude protein and the nitrogen free extract; an asterisk has been used in the table to call attention to this fact.

Authority	Organism	Nitrogen	Crude Protein (N×6.25)	Ether Extract	Crude Fiber	Ash	Silica
Whipple and Jackson[1]	Microcystis (Clathrocystis)	8.30	51.87	......	......	......	.....
	Anabaena	9.60	60.00				
	Asterionella	2.20	13.75	......	......	57.52	49.48
	Spirogyra	4.50	28.12	......	......	......	.....
Hyams and Richards[2]	Oscillatoria, young	9.00	56.25	......	......	4.50	1.46
	Oscillatoria, fully grown	7.90	49.38	......	......	6.40	2.90
Turner[3]	Oscillatoria	8.19	51.19	2.43	......	7.09	.....
Brandt[4]	Peridinians (Chiefly Ceratium)	2.03	12.68	1.30	41.50	5.20	.....
	Diatoms (Chiefly Chaetoceros)	1.56	9.75	2.80	......	65.20	54.50
	Freshwater Copepoda	9.16	57.25	6.01	4.54	9.21	.....
	Marine Copepoda	9.18	57.37	7.40	......	10.92	.....
	Marine net plankton						
	II	3.41	20.06	2.12	......	9.94	4.95
	III	3.16	19.75	2.26	......	8.55	4.59
	IV	3.28	20.50	3.21	......	15.71	9.59
	V	3.14	19.62	4.31	......	29.68	16.33
	VI	1.80	11.25	2.21	......	60.08	47.16
	VII	2.43	15.18	4.24	......	61.41	51.26
	VIII	5.61	35.06	1.56	......	38.77	27.00
	IX	5.24	32.75	8.72	......	19.41	10.95
	X	3.19	19.94	3.08	......	36.14	26.40
Volk[5]	Eurytemora	......	78.47*	6.20	11.07	4.24	.....
	Bosmina	......	77.82*	10.66	8.21	3.30	.....

1. Jour. N. E. Waterworks Assoc., Vol. 14, 1899, pp. 17-18.
2. Technology Quarterly, Vol. 17, 1904, p. 275.
3. Jour. Amer. Chem. Soc., Vol. 38, 1916, p. 1402.
4. Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1898, pp. 45-90.
5. Verhand. d. Naturwis. Vereins in Hamburg, 3 Folge, XV, 1907, p. 45.

Table 52. *This table shows the length of radius required in the spherical type of curve to represent numbers ranging from one individual up to 864 million. The table is based on a value of one individual equals a radius length of 0.25 millimeter. The length of the radius for any number is determined by dividing the number by four, extracting the cube root of the quotient, and then multiplying the cube root by the value selected for one individual. Let the number be 6,912, for example; dividing it by four gives 1,728, of which the cube root is 12, and multiplying the latter by 0.25, the unit of value selected for this table, gives a radius of 3.0 millimeters. The construction of the curve is discussed on page 58. This table is taken from Lohmann's report on nannoplankton (Wissensch. Meeresuntersuch., Abt. Kiel, N. F., Bd. 3, 1908, p. 361).*

The original diagrams used for figures 22 to 26 and figures 32 and 33 are based on a value of one individual equals a radius length of 0.25 millimeter, but the original diagrams have been reduced to one quarter size in reproducing them.

Length of Radius	Number of Individuals	Length of Radius	Number of Individuals
0.25 mm.	1	16.0 mm.	1,048,576
0.5	32	17.0	1,257,728
1.0	256	18.0	1,492,992
1.5	864	19.0	1,755,904
2.0	2,048	20.0	2,048,000
2.5	4,000	25.0	4,000,000
3.0	6,912	30.0	6,912,000
3.5	10,976	35.0	10,976,000
4.0	16,384	40.0	16,384,000
4.5	23,328	45.0	23,328,000
5.0	32,000	50.0	32,000,000
5.5	42,592	55.0	42,592,000
6.0	55,296	60.0	55,296,000
6.5	70,304	65.0	70,304,000
7.0	87,808	70.0	87,808,000
7.5	108,000	75.0	108,000,000
8.0	131,072	80.0	131,072,000
8.5	157,216	85.0	157,216,000
9.0	186,624	90.0	186,624,000
9.5	219,488	95.0	219,488,000
10.0	256,000	100.0	256,000,000
11.0	340,736	110.0	340,736,000
12.0	442,368	120.0	442,368,000
13.0	562,432	130.0	562,432,000
14.0	702,464	140.0	702,464,000
15.0	864,000	150.0	864,000,000

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