GASES DISSOLVED IN THE WATERS OF WISCONSIN LAKES

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Secretary Wisconsin Commission of Fisheries

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In the following paper I propose to sketch briefly a small part of the work on lakes which the Wisconsin Geological and Natural History Survey has been carrying on during the past four seasons. During 1907 and 1908 our investigations have been aided by a grant of money from the United States Bureau of Fisheries, which has enabled us to extend our field work much more than would have been possible without this assistance.

LAKE DISTRICTS OF WISCONSIN.

The accompanying sketch map (fig. 1) roughly indicates the position of the lakes that have been studied. Wisconsin contains many hundreds of small lakes, most of them lying in the moraines and found in hollows occasioned by the melting of blocks of ice left during the glacial period. They occur in three pretty well-defined districts, in the southeastern, the northeastern, and the northwestern parts of the state. The water of the lakes in each district, though varying much, shows a very definite general character, especially in the matter of dissolved carbonates.

The southeastern lake district, as studied by us, extends from Waupaca on the north to Lake Geneva on the south, and from the lakes at Madison to Lake Michigan. Nearly 50 lakes in this district have been studied by our survey, and almost without exception they contain considerable quantities of dissolved carbonates, represented by 30 cubic centimeters to 50 cubic centimeters or more of carbon dioxide. Most of the work has been done upon these lakes. Very numerous observations have been made upon Lake Mendota at Madison, the headquarters of the survey, and some hundreds of series of determinations have been made on this lake at all seasons of the year. Much less frequent observations have been made on a dozen or more other lakes in the same region, giving a general picture of the annual cycle of gas changes of these lakes, though not in the same detail as for Lake Mendota.[a]

[a] The diagrams accompanying this paper have been selected from a great number which have resulted from the work of this survey, and are intended to illustrate some points in the distribution of temperature, of the various gases, and of dissolved carbonates of lime and magnesium in the waters of Wisconsin lakes. In all diagrams the vertical spaces represent the depth in meters. The horizontal spaces represent either degrees centigrade in the case of temperature, or cubic centimeters of gas per liter. The line marked "T" indicates the temperature; oxygen is marked "O"; nitrogen, "N"; carbon dioxide, "C"; and carbonates, "Cb." In the diagrams which show nitrogen, both this gas and oxygen were determined by boiling. In those without nitrogen, the oxygen was determined by titrating according to Winkler's method. The alkalinity or acidity of the water were determined by titrating

In the northeastern part of the state is a district somewhat triangular in shape, measuring roughly some 30 miles on each side, and containing several

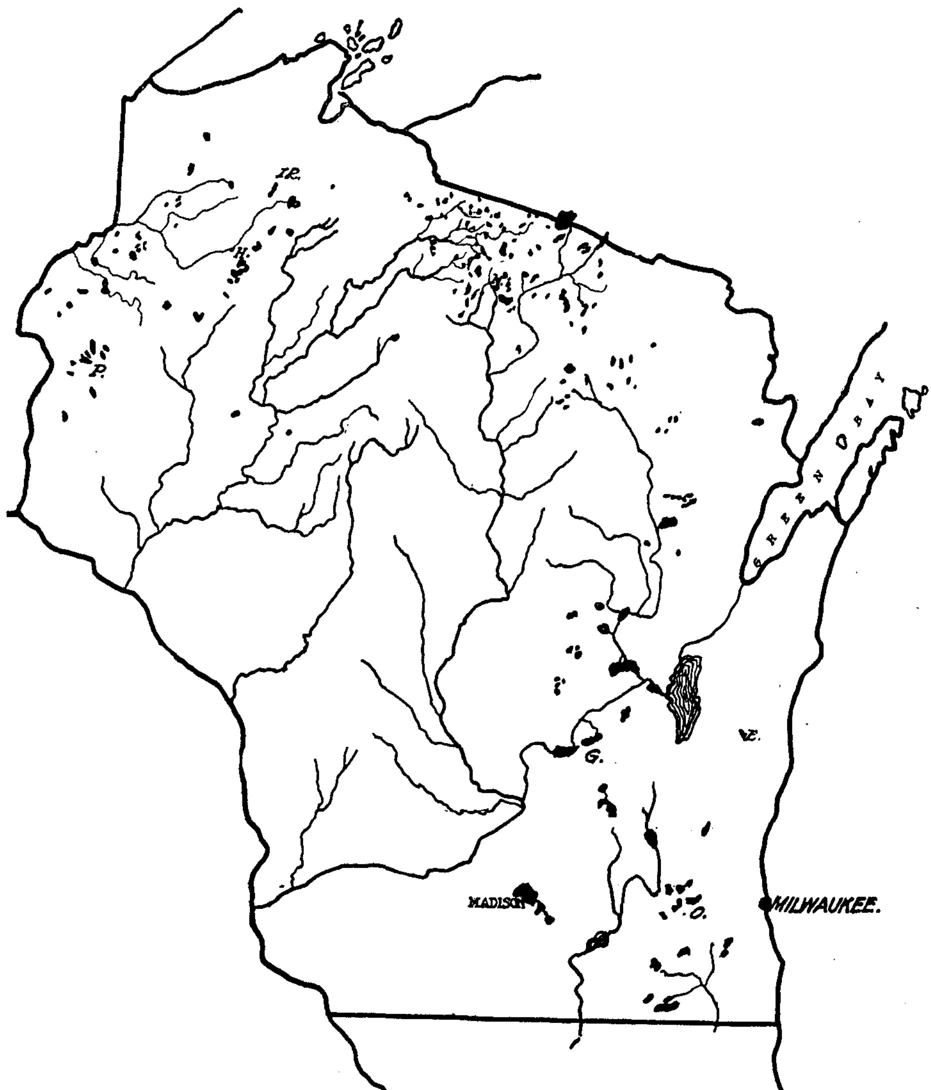

FIG. 1.—Sketch map of Wisconsin, showing lake districts. Scale about 1 inch=66 miles, or $\frac{1}{4,000,000}$. Green Lake lies directly north of "G". The Oconomowoc district is marked "O". Lake Geneva lies close to the southern boundary. Hammills Lake in northwestern Wisconsin is marked "H".

with standard solutions of HCl or Na_2CO_3, with phenolphthalein as an indicator. The result is expressed in the diagrams in cubic centimeters of CO_2 per liter, acidity being shown as free CO_2, while alkalinity is represented by platting the number of cubic centimeters of CO_2 that would be required to bring about a neutral reaction. Where the line indicating the CO_2 passes to the left of the zero line, it indicates that the water is alkaline.

The amount of dissolved carbonates was determined by titrating with HCl, with methyl orange as an indicator. It is represented in the diagrams by the number of cubic centimeters per liter of CO_2 set hundred small lakes. About 60 of the more important and deeper lakes in this region have been studied during the summer. The survey has found that the month of August and the early part of September represent the critical period for the distribution of gas in lakes, and that from observations made at this time the general history of a lake may be inferred when the cycle is known in detail from a number of lakes which may serve as standards. The lakes of northeastern Wisconsin contain, in general, soft water, the carbonates being much lower than in the southeastern lakes—frequently not more than one-sixth as great and not infrequently less than one-tenth.

The lakes in the northwestern district are scattered in two somewhat ill-defined elongated series extending north and south for a distance of 70 miles or more. Between 50 and 60 of these lakes also have been examined. Their water is intermediate in character between that of the two other districts, the content in carbonates averaging nearly one-half as great as that of the southeastern lakes.

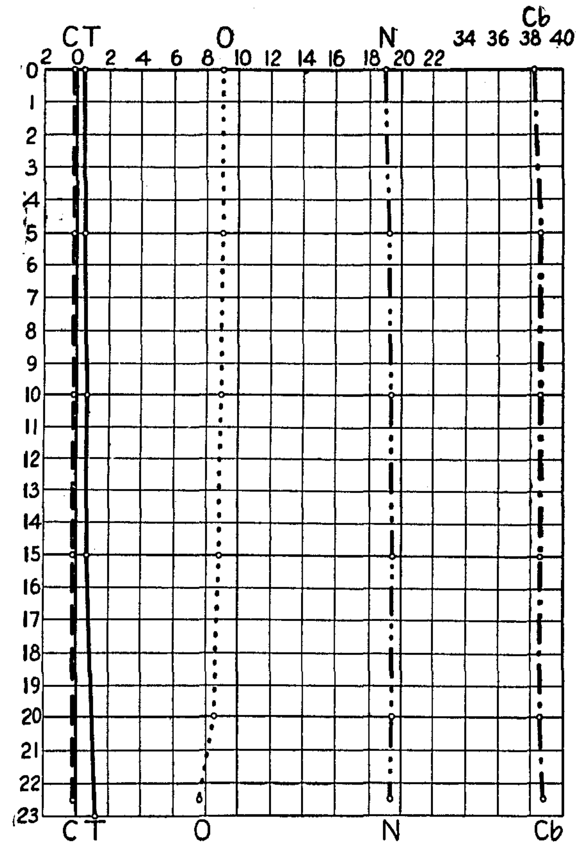

FIG. 2.—Lake Mendota. Vertical distribution of gases, carbonates, and temperature, January 26, 1906. C, carbon dioxide; Cb, carbonates of lime and magnesia; N, nitrogen; O, oxygen; T, temperature. See footnote.

GASEOUS CHANGES IN LAKE MENDOTA.

WINTER.

Let me begin my account by a short sketch of the cycle of changes in Lake Mendota. Figure 2 shows the condition under the ice in early winter. The

free from the monocarbonates. Since, in the lakes of southeastern Wisconsin, the amount of dissolved carbonates is considerable, the numeration of the horizontal scale is interrupted in order not to make the diagram too large. For instance, the numbers at the top of figure 2 change abruptly from 22 to 34. The larger numbers refer solely to the line Cb, indicating the number of cubic centimeters of CO_2 represented in the monocarbonates. A similar arrangement will be seen in other diagrams.

The points at which observations were taken are indicated by small circles in the lines of the diagrams. The lines are drawn directly from one point of observation to the next, no attempt being made to round off the curves.

temperature is nearly the same at all depths, rising from less than one degree just below the ice to something over one degree at the bottom. The water contains about 9 cubic centimeters of oxygen per liter, except in the bottom, where it has begun to disappear under the action of decomposition. Nitrogen is present to about the amount required to saturate water at the given temperature. The reaction of the water is neutral or slightly alkaline at all depths. Carbonates are present to an amount represented by about 38 cubic centimeters of carbon dioxide per liter.

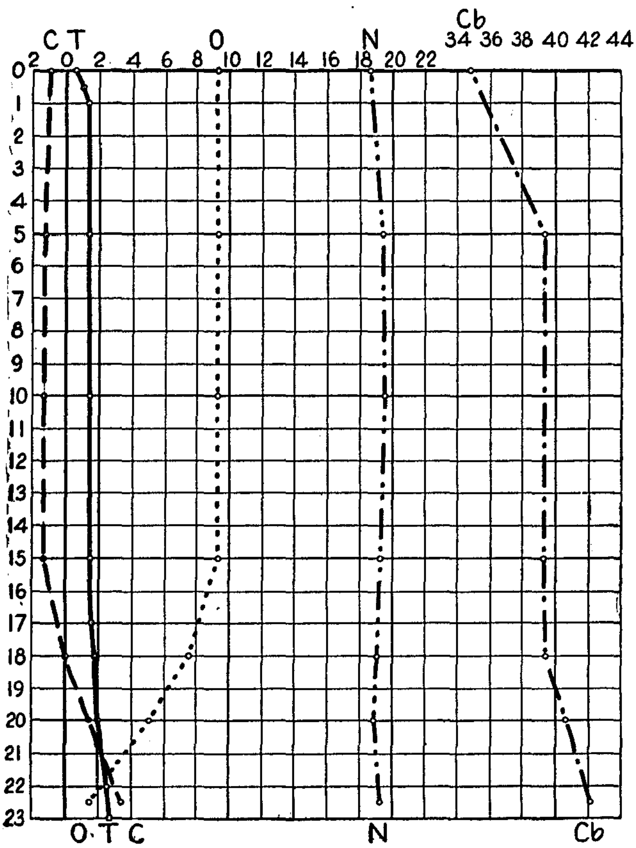

FIG. 3.—Lake Mendota, February 25, 1906.

As the winter advances (fig. 3) some changes occur under the ice. The temperature rises slowly at all depths, but most rapidly at the bottom. Slow decomposition goes on in the deeper water, where also the greater part of the fish are found. There thus results a reduction of the amount of oxygen, which may nearly or quite disappear at the bottom, and a corresponding development of carbon dioxide, so that as winter advances the bottom water may contain considerable quantities of free carbon dioxide. The reaction of the upper water becomes much more markedly alkaline than in the early winter, a change probably due to the influence of the growing plants. The carbonates may or may not decrease in the water immediately below the ice. If a diminution is found (and such decrease may be very pronounced, as in fig. 4), the change is due to the accumulation beneath the ice of water resulting from the melting of the ice or snow and containing, therefore, less dissolved matter than the water of the lake usually holds. As the season advances a rapid growth of algæ may take place beneath the ice, resulting in a considerable increase of the oxygen, which may carry it beyond the point of saturation. This increase is usually accompanied by a considerable increase in the alkalinity of the water (fig. 4).

SPRING AND SUMMER.

When the ice has disappeared in the spring (fig. 5), the water is once more mixed throughout the entire depth, and uniform conditions are again established. The reaction becomes almost or quite neutral. Oxygen is present to about the point of saturation, although, in figure 5, some trace of the winter's diminution of oxygen is still present at the bottom. Carbonates and nitrogen are distributed about uniformly at all depths. As the spring advances and the algæ begin their spring growth, the reaction of the water becomes increasingly

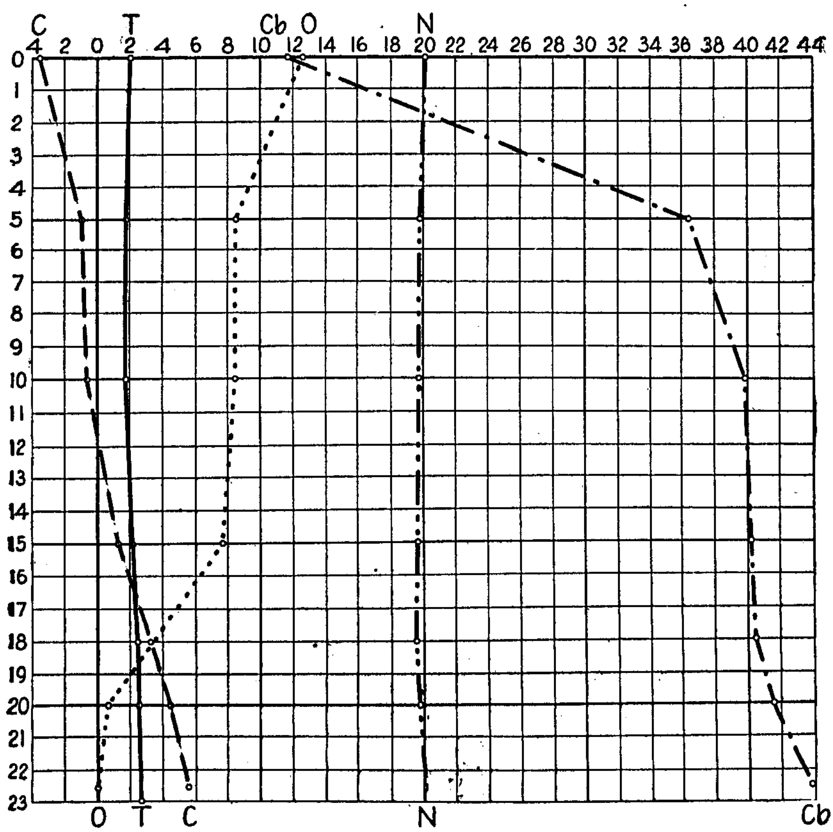

FIG. 4.—Lake Mendota, March 29, 1906.

alkaline. (Fig. 6.) The temperature rises, and soon the surface gains so rapidly in warmth that the wind is unable to distribute the surface water throughout all depths; the circulation becomes increasingly restricted, and summer conditions begin to develop. The temperature curve (fig. 7) shows a marked difference between surface and bottom temperatures, and indicates a temporary thermocline at the depth of 10 meters or more. Corresponding to this stratification of the water and consequent shutting off of the lower water with direct contact with the air, the oxygen in the lower water begins to decline and free carbon dioxide begins to appear there. This process is accentuated as summer approaches. (Fig. 7 and 8.) The amount of free carbon dioxide increases, the thickness of the stratum of the water whose reaction is acid increases also, and the oxygen steadily and rapidly declines in the lower water. By the early part of July the permanent summer conditions of temperature are found. (Fig. 8.) The regular summer thermocline is found lying, in general, between 5 meters and 10 meters. Oxygen has disappeared wholly from the bottom waters, and is rapidly going from all parts of the lake below the thermocline. The water has divided into an upper warm stratum containing an abundance of oxygen and with an alkaline reaction, and a lower, colder layer with free carbon dioxide, and little or no oxygen except in the extreme upper part.

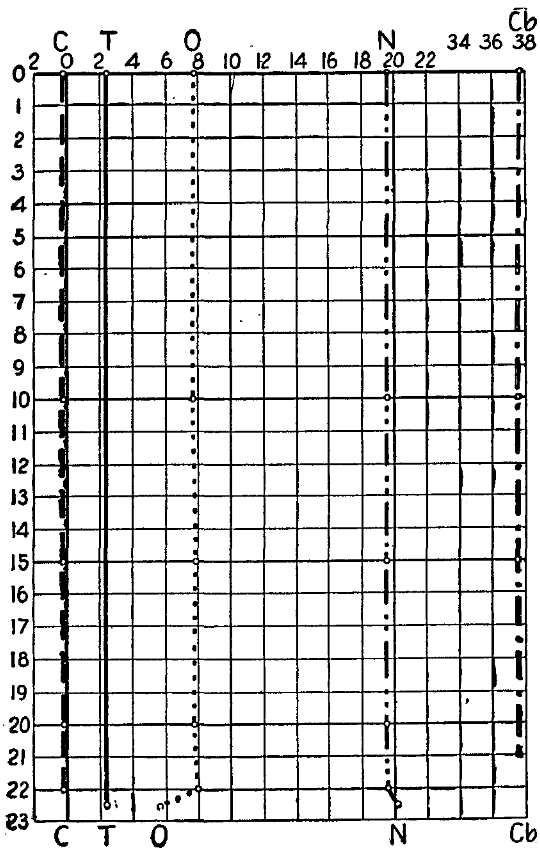

FIG. 5.—Lake Mendota, April 8, 1906.

LATE SUMMER AND AUTUMN.

By the first of August this condition has reached its maximum. (Fig. 9). The lake contains no oxygen below a depth of 10 meters. Above that level, in the warm water and in the uppermost part of the thermocline, there is abundance of oxygen for animal life. Beneath that depth no active animal life is found in the water,[a] though the inhabitants of the mud remain alive through this period, some of them in an inactive condition and some in a partially active state. The carbonates show the characteristic summer condition, in which the upper water contains a smaller amount than the lower, the transition coming in rapidly at the thermocline. This condition persists through August and early September for a period varying with the warmth of the season. As the temperature of the water begins to fall, the thermocline moves downward under the action of the wind, and this process increases the extent of circulating water and in like degree the thickness of the layer containing oxygen. Figure 10 illustrates this condition in early October. The cold weather and winds which are apt to occur at about this time soon bring about a complete mixture of the

[a] Except *Corethra* larvæ, whose presence is an apparent rather than a real exception.

water (fig. 11); and with it returns the condition of uniformity which we found at the opening of winter. From this time until the lake freezes the temperature declines almost uniformly at all depths; the amount of oxygen increases as the capacity of the water to hold it rises with the fall in temperature; and the water becomes almost or quite neutral as the vigor of the growing algæ declines and as decomposition becomes slower in the cooling water.

From this brief account it is plain that the cycle of gas changes in Lake Mendota is a very important factor in determining the conditions and possibilities of life in that lake. Here is an inland lake, one of the largest in Wisconsin,

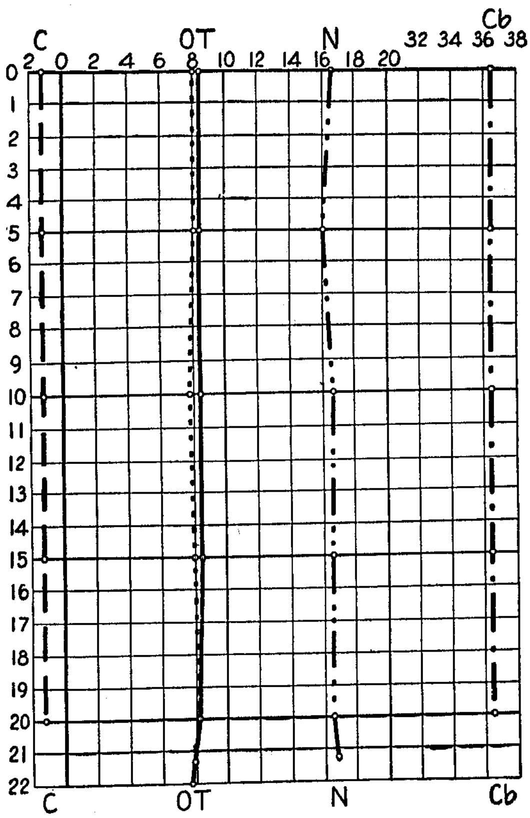

FIG. 6.—Lake Mendota, May 4, 1906.

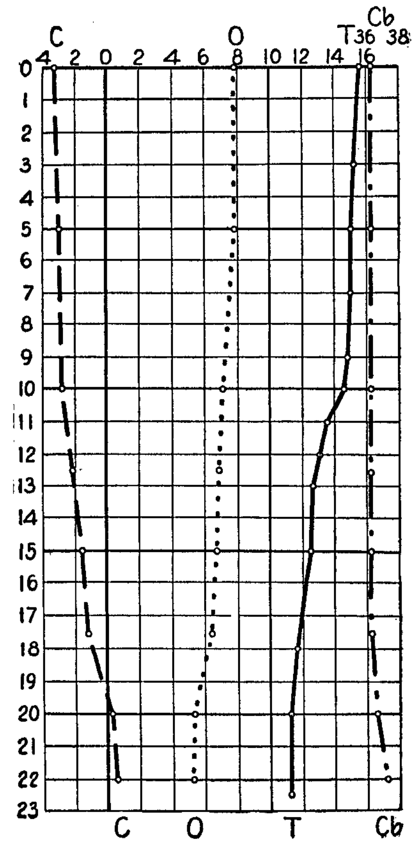

FIG. 7.—Lake Mendota, May 22, 1906.

about 9 kilometers in length and 6 kilometers in breadth, with a maximum depth of 24 meters and an average depth of about 12 meters, the lower half of whose water is wholly uninhabitable during middle and late summer and early fall. This water in the early spring is saturated with oxygen, as is the lower water of all lakes, but the supply is not great enough to meet the demands which are made upon it. The lake is peculiarly rich in plankton, and the decomposition of the great amount of animal and vegetable débris which is showered down from the upper waters into the lower soon exhausts the oxygen supply and renders the lower water unfit for the maintenance of higher life.

Thus the vital conditions in one part of the lake very sharply limit the possibilities of life in another portion. None of those fish which demand a refuge in the cold bottom water during the summer can live in Lake Mendota, nor is it possible to find there those members of the plankton which belong only in the deeper and colder water.

It is perhaps unfortunate for some reasons that Lake Mendota was necessarily the lake on which the most numerous observations were made, since this lake offers an extreme case in the matter of loss of oxygen from the lower water. The oxygen disappears more quickly and fully than in any other Wisconsin lake

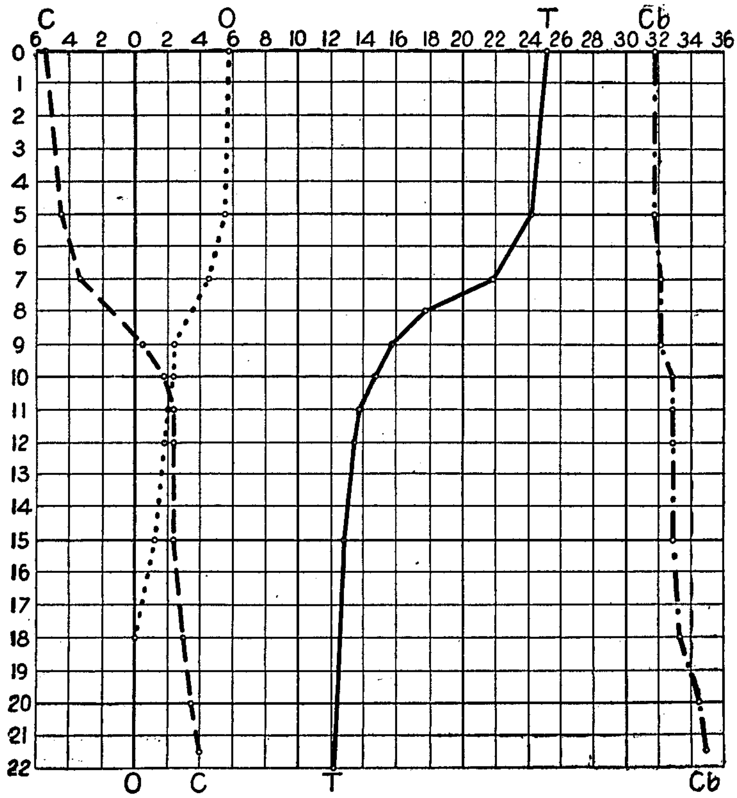

FIG. 8.—Lake Mendota, July 2, 1906.

of approximately equal size and depth. The area of the lake is so large that the bottom water has necessarily a relatively high temperature, and the plankton is so abundant that the lower water is continually receiving great quantities of decomposable matter. Moreover, the thermocline lies comparatively deep because of the large size of the lake, so that the volume of the cooler water is correspondingly reduced. All of these causes combine to make the disappearance of the oxygen very complete and unusually rapid. This lake therefore affords less opportunity than do other bodies of water for the study of the process in its details.

GASES AND CARBONATES OF OTHER LAKES IN SOUTHEASTERN WISCONSIN.

We may contrast the summer conditions in Lake Mendota with those that obtain in the deepest inland body of water in Wisconsin, Green Lake. This has a maximum depth of 72 meters, with length of about 12 kilometers and a breadth of 4 kilometers. Figure 12 shows the conditions found in Green Lake on October 4, 1906. The volume of water is so great that summer conditions of temperature still remain, and cooling has proceeded to no great depth. The water shows the characteristic summer condition of an alkaline upper stratum,

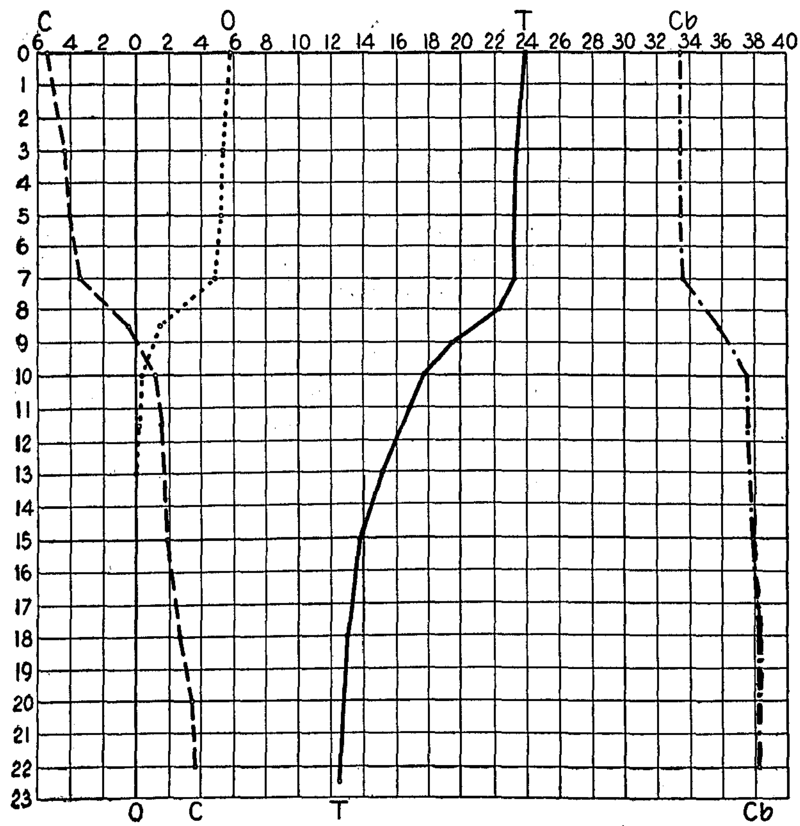

FIG. 9.—Lake Mendota, August 1, 1906.

with the cooler water acid. The dissolved carbonates are low in the warmer waters, rapidly increasing at the thermocline, and then remaining nearly constant till the bottom of the lake is almost reached, where there is again an increase. The oxygen shows a marked diminution in the thermocline (11 meters to 16 meters); it then slowly increases in quantity with the depth until a maximum is reached at about 40 meters, which remains for some 10 meters; and the amount of the gas then declines until it is nearly or quite exhausted at the bottom. The diagram shows plainly the effect of life and death on the oxygen where it is found in abundance in a large volume of water. The oxygen curve shows that two of the regions where chemical action is going on most vigorously are the thermocline and the bottom water. The accumulation and decomposition of the plankton in the lower water is a sufficient explanation for the changes which take place there. The reduction at the thermocline is apparently due to the fact that the algæ, as they begin to die and sink, often remain for some time at the thermocline. The cool water apparently causes their life to be prolonged, and while certain parts of the filaments are dead and decomposing, others still retain sufficient vitality to keep the plant from sinking. When this period is passed, the plant sinks steadily and rather rapidly to the bottom, thus consuming comparatively little oxygen on the journey. Many forms of plankton animals also accumulate in the thermocline, finding there more food than in any other part of the cool water. Both these causes, then, lead to a diminution of the oxygen at this point. It must not be supposed that there has been no loss of oxygen in the lower water where it is at a maximum. In early spring this water would have contained between 8 cubic centimeters and 9 cubic centimeters per liter, so that at least one-third of the original stock has been consumed.

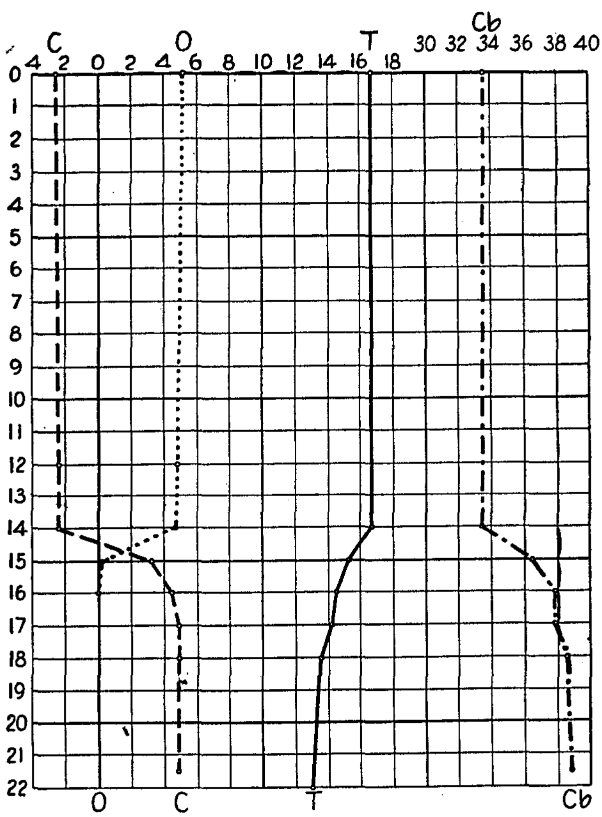

FIG. 10.—Lake Mendota, October 8, 1906.

Green Lake is the only lake in Wisconsin that shows so small a reduction of the oxygen of the lower water. Lake Geneva, near the southern boundary of the state, has about the same dimensions as Green Lake; it is the second deepest lake in the State, having a depth of 41 meters. The late summer conditions are shown in figure 13, where the same general facts are visible as in Green Lake; but the oxygen is much more reduced and shows only a trace, or is altogether absent, from the depth of 33 meters to the bottom. In North Lake, one of the Oconomowoc group, consumption of oxygen at the thermocline goes on more rapidly, and sometimes leads, as is shown in figure 14, to the disappearance of the oxygen from that stratum, while some of the gas still remains at a greater depth.

This lake has an area of about 51 hectares (126 acres) and a depth of about 22 meters. It contains an abundance of oxygen in the water above the thermocline; then follows a stratum in which the gas has almost or quite disappeared; then comes one containing a small amount, but sufficient for the maintenance of a large number of plankton animals; and beneath this to the bottom the water contains no oxygen. A little later, in September, all of the oxygen will have disappeared from the lower water, and the region beneath the thermocline will become uninhabitable by animal life.

LAKES OF NORTHEASTERN WISCONSIN.

All of these illustrations are taken from the lakes of southeastern Wisconsin, where, as shown by the diagrams, the dissolved carbonates are present in large quantities, and where the plankton life is correspondingly abundant. In the lakes of northeastern Wisconsin, where the carbonates are low, the average quantity of plankton is much less than in the hard-water lakes. It is not true that the plankton of every soft-water lake is smaller than that of every hard-water lake. The lakes of both types differ among themselves very greatly, but on the average the statement is entirely correct. European observers have found the same thing for the fish in the lakes of Switzerland that we have found for the plankton in Wisconsin. We have also found that there are fewer fish in the northern lakes than in the southern, hard-water lakes. In these northern lakes, therefore, with their poorer plankton, the oxygen persists longer than in the southern ones. It may disappear entirely, but it usually lingers late, and in the deeper lakes it is apt to remain throughout the season.

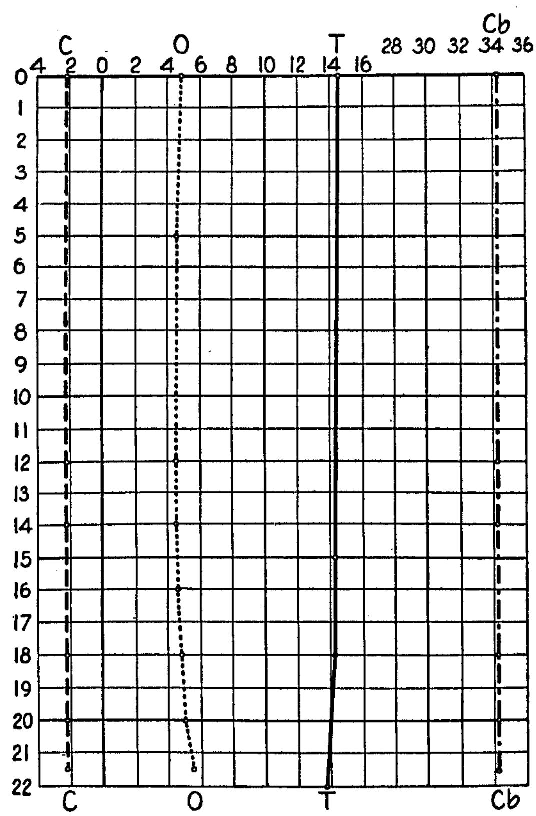

FIG. 11.—Lake Mendota, October 11, 1906.

The diagrams of Thousand Island Lake and Stone Lake (fig. 15, 16) show the summer condition in two of the larger and deeper lakes of this type. The carbonates in both are low, representing about 9 centimeters and 3 cubic centimeters of carbon dioxide, respectively. The upper water is acid, or nearly neutral, the acidity increasing below the thermocline. The oxygen curve of Thousand Island Lake closely resembles that of Green Lake, having a depression at the thermocline, and an increase in the deeper waters, followed by a gradual decrease to the bottom, where the oxygen is nearly or quite exhausted. This Thousand Island Lake is one of the lakes in northeastern Wisconsin that contain lake trout (*Cristivomer namaycush*). The fish inhabits the bottom water during the summer, and seems to be found native only in lakes which carry an abundance of oxygen to the bottom. The oxygen curve of Stone Lake (fig. 16) shows another interesting fact which is observable in many inland lakes, namely, an increase of oxygen in the upper part of the thermocline. This is due to the presence of algæ at this depth, which still receive sufficient light to manufacture starch, and liberate oxygen in that process. This phenomenon is very commonly found in our lakes, but by no means universally. The crops of algæ, which produce oxygen, are not necessarily continuous; nor is oxygen produced in quantities beyond consumption at all periods of their growth. The thermocline may lie so deep or the water may be so opaque that algæ in the cool water do not get light enough to enable them to produce starch. Neighboring lakes, therefore, which seem quite similar, may or may not show this rise of the oxygen. In the same lake it may appear and disappear during the season, and although usually present at a corresponding time in successive seasons may vary greatly in amount. One common result of this process is the using up, at this point, of the carbon dioxide, the fact being shown by a reduction of the acidity, or an increase in the alkalinity, of the water. The contrast between the carbon dioxide curves in Thousand Island and Stone lakes is sufficiently noteworthy, and this difference is apparently due to the activity of the algæ at a depth of 9 meters

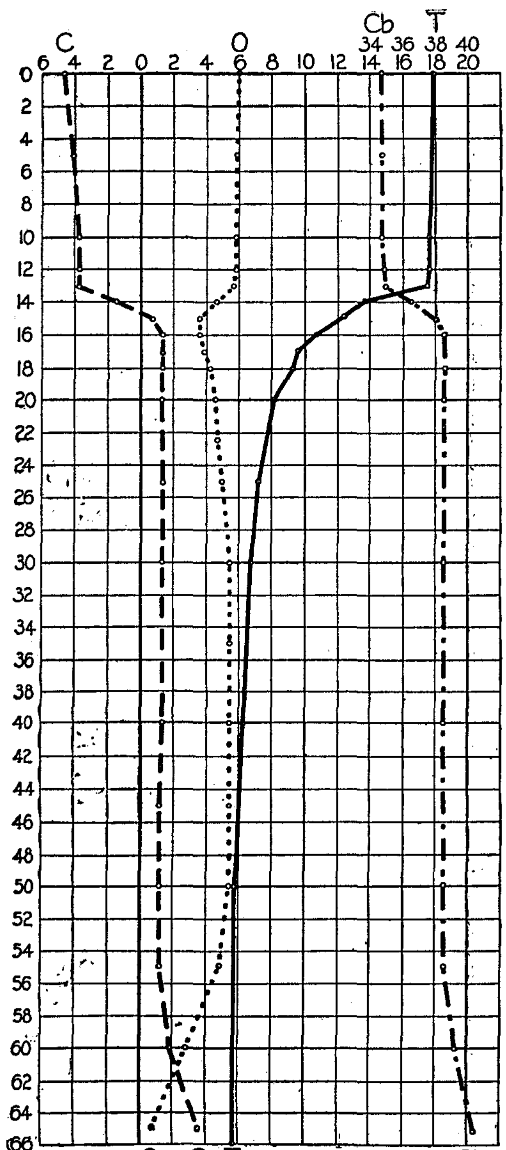

FIG. 12.—Green Lake, October 4, 1906.

and 10 meters in Stone Lake, and the consequent using up of the supply of free carbon dioxide.

MANUFACTURED OXYGEN.

In other lakes this process goes on much more vigorously than it did in Stone Lake. An illustration may be given from Beasley Lake, a little body of water in the Waupaca chain (fig. 17), where the oxygen at the thermocline rises to the maximum of about 15 cubic centimeters, and where its presence is accompanied by a marked increase of the alkalinity of the water.

It must be remembered that both the amount of oxygen and of alkalinity represent the algebraic sum of numerous complicated processes. The amount of oxygen is determined not only by the quantity manufactured, but also by that consumed, and the quantity or deficiency of carbon dioxide depends on the relation of the rate of the manufacture of starch to the rate of the decomposition of the plankton. The two processes are not necessarily parallel, and we not infrequently find, as is shown in figure 18, a great excess of oxygen, while the carbon dioxide curve shows no traces of the process which has manufactured it. In the soft-water lakes whose reaction is usually acid, the manufacture of oxygen in the cooler water may cause a change in the reaction of the water. This is illustrated by Silver Lake (fig. 19), a small pond in northeastern Wisconsin, where the oxygen maximum occurs at 7 meters, and at the same depth the reaction changes from a positive acid to an equally positive alkaline one. It returns to a slight acidity at 9 meters, and from this point the amount of free carbon dioxide rapidly increases.

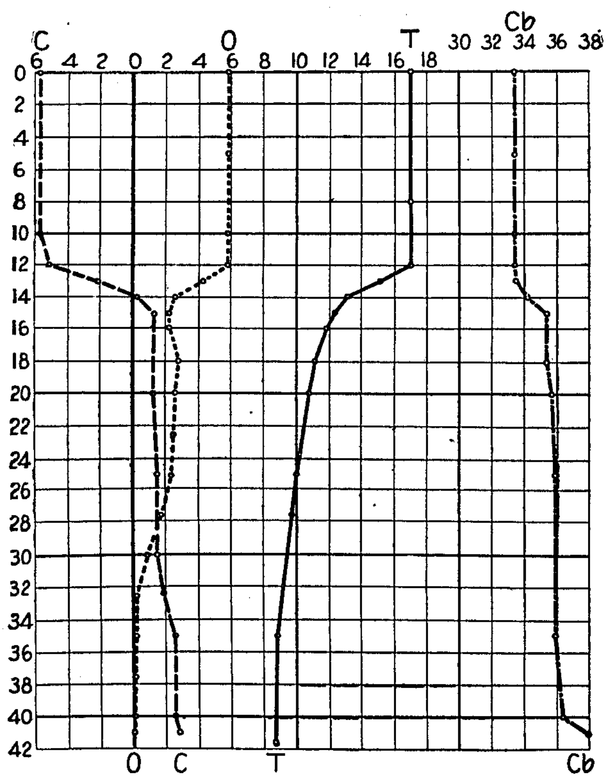

FIG. 13.—Lake Geneva, September 26, 1907.

In the smaller and shallower lakes the presence of this manufactured oxygen at the thermocline region is often of great importance in extending the inhabitable region. Beasley Lake is perhaps the best illustration of this fact. The lake contains a great amount of fermentable material, and the oxygen disappears from the bottom water early in the spring. The lake is so small that the thermocline lies very close to the surface, remaining at 4 meters or above until late in the summer. Were it not for the manufactured oxygen, the entire body of water below the thermocline would be uninhabitable. The maintenance of the stock of this gas by the presence of the algæ doubles the thickness of the habitable stratum during the summer and the early part of the autumn. Figure 17 also shows the effect of the manufacture of oxygen on the dissolved carbonates; but that matter is too complex to be discussed here.

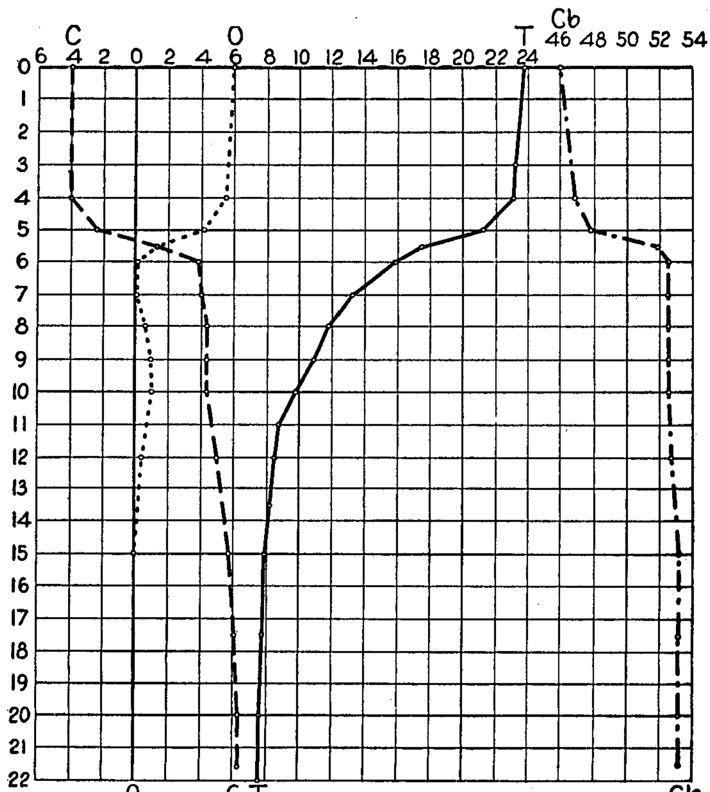

FIG. 14.—North Lake, east part, July 30, 1906.

I have spoken of Thousand Island Lake as a characteristic "lake-trout lake." So far as our observations go, the lake trout in northeastern Wisconsin is found only in lakes of this type; yet observations made in the summer of 1908 in northwestern Wisconsin show that the fish can exist in lakes of a type which would seem to be unfavorable to it. I give a diagram of the conditions in Hammill's Lake (fig. 20), a small body of water in northwestern Wisconsin, which contains a few lake trout that have been introduced. Their presence in the lake shows that they can exist in a body of water in which the oxygen extends some distance into the cooler stratum, although the bottom water is practically or wholly devoid of the gas. Their presence in small numbers shows that such a lake is not suited to the species, and that, while it can adjust itself and survive under these unfavorable conditions, it is unable to thrive. It is not known whether it spawns under these conditions. There can be little question that the continuance of the species in this lake is due to the fact that the cool water still retains a certain amount of oxygen throughout the season.

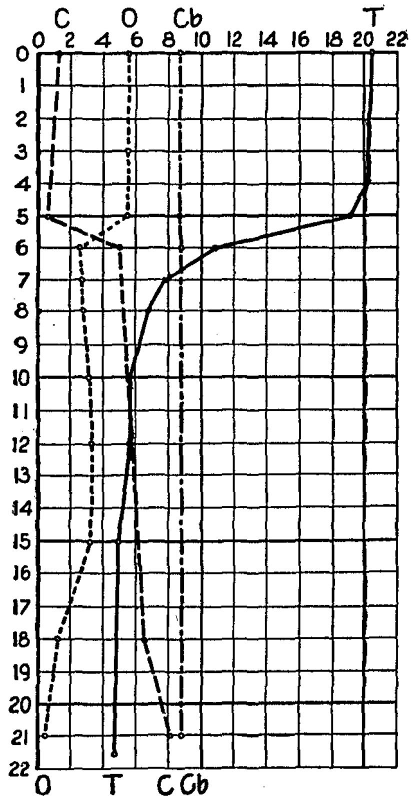

FIG. 15.—Thousand Island Lake, August 13, 1907.

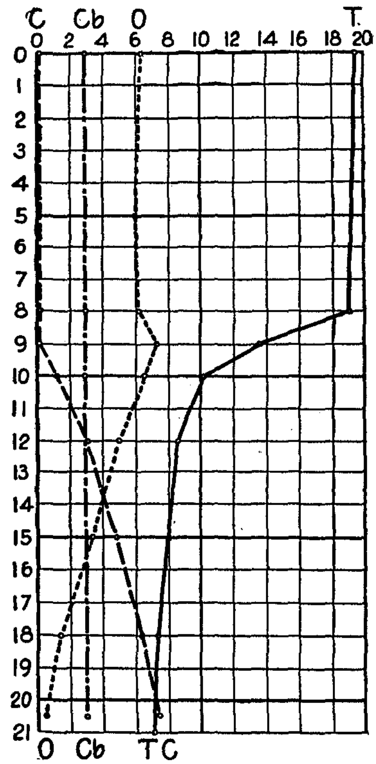

FIG. 16.—Stone Lake, August 22, 1907.

CONCLUSIONS.

I have selected for illustration these series from among the hundreds of similar observations that have been made by the Wisconsin Geological and Natural History Survey. I have not attemped to give any complete picture of the story of the gaseous changes in any lake, and many of the most important relations and results have been left unmentioned. I have brought these cases to your attention in order to illustrate two conclusions which are of importance. The first is that the cycle of the gaseous changes in a lake illustrates more readily and more conspicuously than perhaps any other facts could do what may be called the "annual life cycle" of the individual lake, showing both the underlying resemblances of that cycle as found in different lakes and also some small part of the infinite variation in its details. These diagrams from late summer represent the culminating point of an annually recurrent series of definite changes through which the lakes pass with the season as certainly as the season returns. These changes result from the interrelation of the living beings of the lake with an environment strictly limited in its space and containing only definite amounts of food and of oxygen, to which only small additions can be made from the outside. The story of these changes is legible to him who will closely follow it. Its details differ, indeed, in each lake from those found in a neighboring lake, but on the whole it always follows along certain great lines and shows that lakes can be grouped into classes according to its major variants. Only a little of this story is now known, and many years of detailed work will be needed before even its larger facts are fully ascertained and justly interpreted. But from the few diagrams which I have given one may see that lakes present to the student a vital story, as definite, as variable, and as complex as is that of a living organism; a story to be followed by means like those needed to work out biological life histories, and one whose interest is such as to claim far more attention from science than it has received.

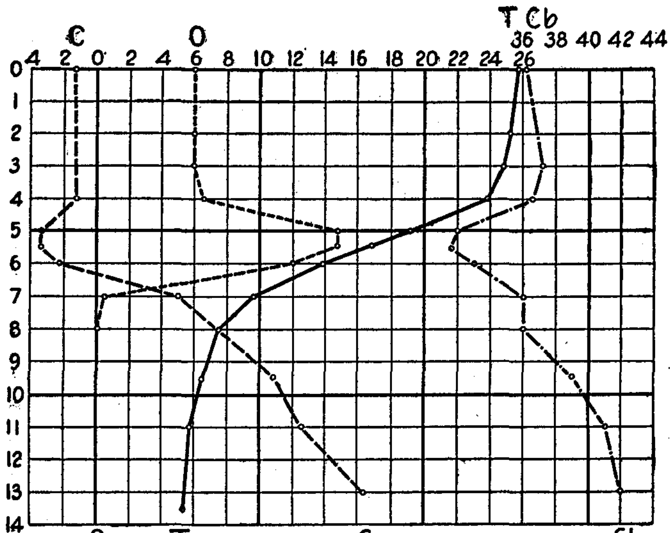

FIG. 17.—Beasley Lake, August 4, 1908.

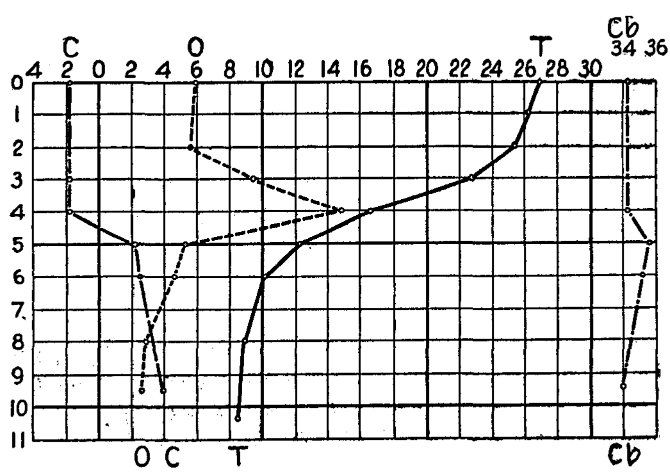

FIG. 18.—Otter Lake, August 4, 1908.

PRACTICAL IMPORTANCE OF THE SUBJECT.

If this scientific interest were all that the story affords, however, I should not have brought it to the attention of this congress, whose interest rightly lies in the fisheries. But these changes, which go on in the water of the lake, affect not only the life of lower organisms but also that of the higher ones, including the fish. No facts of environment show more clearly than do these how life determines its own conditions. On the presence of a large or a small quantity of plankton in the upper waters may depend the conditions which make the lower water habitable or uninhabitable. The relation between the volume of the lower water and the quantity of decomposing matter discharged into it

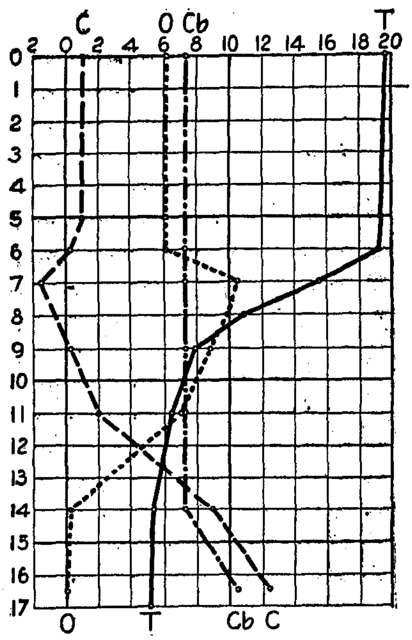

FIG. 19.—Silver Lake, August 21, 1907.

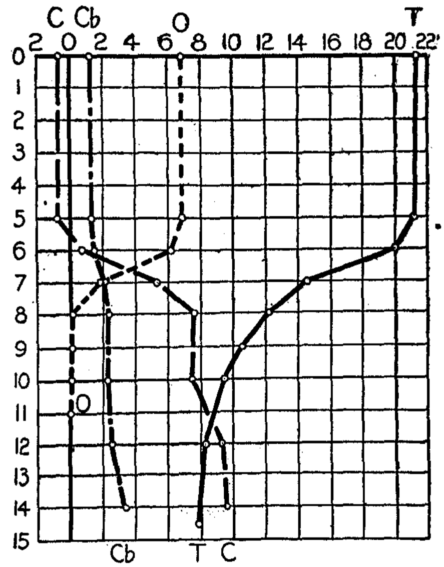

FIG. 20.—Hammills Lake, August 17, 1908.

determines whether this lower water shall be filled with animal life and support a relatively abundant population of lake trout and whitefish, or whether life of all kinds shall cease abruptly at the thermocline, or whether a scanty plankton shall indeed leave abundance of oxygen in the lower water but provide a supply of food for a scanty higher life. Thus the annual history of the lake discloses facts that are fundamentally important in determining the amount and kind of life which the lake may support and that which may wisely be introduced into it; and it becomes plain that a knowledge of them is indispensable to an intelligent use of the waters of the lake by those concerned in increasing the supply of fish.

In other words, it seems clear that a knowledge of lacustrine physics and chemistry is just as necessary to the best economic utilization of the waters of the lakes as a knowledge of soil physics and chemistry is to the best agricultural use of the land. The problems of the lakes are complex and are not easily solved, but they are far less complex and much more easily solved than are the corresponding problems of the soil. This nation and the several states are spending hundreds of thousands of dollars annually in studying the soil. This expenditure is fully justified, not only by its scientific results but also by its practical consequences. Little or no time or money is now devoted to the similar study of the waters of the lakes. Yet no one who has followed investigations of this kind can doubt that if the lakes could be studied on the same large scale and with the same careful methods as those applied to the study of soils, results of great economic value would be obtained. It was years before the study of physics and chemistry of soils promised large economic results. Valuable practical hints have already come from the brief and imperfect study of the lakes which our survey has made, and the present situation of our knowledge indicates that a wider and more systematic study than we have been able to undertake would ultimately lead to far larger and more important conclusions. Such a study is greatly needed. The culture of fish in the innumerable inland lakes of this country should rest on the basis of scientific knowledge at least as broad and as complete as that which underlies the cultivation of our farm products. We who have in charge the maintenance of a public interest so extensive and valuable as is that of the fisheries are most of all concerned in the acquisition of that knowledge which is the only true guide of practical affairs.

DISCUSSION.

Mr. J. J. STRANAHAN (U. S. Fisheries Station, Bullochville, Ga.). I would like to ask Professor Birge a question or two. It is not closely related to this subject, although not entirely foreign. I desire to ask if you have had any experience as to the plankton and the relative amount of crustaceans and other animal life that is in soft and hard waters.

Professor BIRGE. Yes; although the matter can not be finally settled. It is a condition well known to European investigators. The hard-water lakes are much richer in plankton on the average than the soft-water, but you can not make the statement that every hard-water lake has more plankton than any soft-water.

Mr. STRANAHAN. At Guilford, in England, south of London; at Castalia, in Ohio; I think at Northville, in Michigan, and wherever I have known of exceedingly hard water, full of lime and other salts, there has been an excess of plankton. I collected plankton at Castalia to take to the World's Fair at Chicago, and with pretty carefully conducted weights the amount of crustaceans exceeded the amount of mosses and aquatic plants in which they were congregated when taken from the water. That water is so rich in lime and magnesia that it makes stone of a shingle in a year, and that is probably the greatest trout preserve in the world. At Bullochville, Ga., where I am now, our water is practically aqua pura; we can use it in photographic processes; it is exceedingly soft. We have put mollusks in it, but the different little periwinkles and other shell-covered species die in a few months, and it is not conducive to fish culture. We took two carloads of cement and buried it in our spring, and we thought we could see a marked increase in the growth of some kinds of vegetation, to say nothing of small water animals that grow in it. So I am a great stickler for the idea that we ought not to put fish hatcheries where there is not a large amount of calcareous material in the water.

Professor BIRGE. I wanted to talk about that, but with the limitations on the time I could hardly get to that part of the subject.

Doctor NORDQVIST. Those investigations Professor Birge has made are of the greatest importance in fish culture in lakes. I am of the same opinion as Professor Birge, that many of the disappointments that we have in fish culture are due to lack of knowledge about the amount of oxygen and the biological conditions of the lakes.

I would only ask Professor Birge about some slight points here in his investigations. At what time in the day was the amount of oxygen determined?

Professor BIRGE. We have made a great many attempts to discover diurnal variations in oxygen, but it is a very rare thing to find any difference in the results obtained from tests made in early morning, late afternoon, and late evening. We have continued the tests throughout the twenty-four hours. We have found very small, hardly perceptible, diurnal differences. I have received, since I came to this congress, a letter from my assistant, Mr. Juday, to whom much of this work is due, telling me that he had found such a difference in Lake Mendota.

Doctor NORDQVIST. That is just what I mean with reference to the investigations; it ought to show a difference, and I think that the curve that you have given in many of your lakes at the depths of six, seven, to ten meters may perhaps——

Professor BIRGE [interrupting]. We have spent from two to three weeks hunting for diurnal changes right on that point. I put a party on those lakes—Otter Lakes—and we got negative results all the time; the curve remained substantially the same.

Doctor NORDQVIST. It is very interesting to hear that. Then I would be glad to learn in what way the oxygen was determined.

Professor BIRGE. In two ways: One diagram showed an oxygen line determined by boiling; and in the other it showed oxygen by Winkler's method of titration, or by one of the modifications of Winkler's method, which is a standard in the books.

Doctor NORDQVIST. Oxygen by the Winkler method?

Professor BIRGE. Yes, depending on the liberation of iodine and sodium at the end.

Doctor NORDQVIST. How was the water taken up?

Professor BIRGE. The water was taken up by a pump and hose, the latter being lowered to the proper depth, and the water brought up and kept completely out of contact with the air, so that where there was no oxygen we had like results always.

The PRESIDENT. Are there others who will contribute to the discussion of this most interesting paper?