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The Food Supply of the Fish in the Great Lakes

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When the early settlers made their homes along the shores of the Great Lakes, the waters of these inland seas teemed with fish. A cheap and apparently inexhaustible supply of food lay within easy reach, and they drew from it unstinted, nor was it strange that, with the increasing population and ever-widening means of communication, delicacies so tempting as the whitefish and lake trout were eagerly sought after in the markets of the neighboring cities, and that the ingenuity of generations of fishing folk was taxed to invent means of securing the fish—until finally, in the face of a growing demand and of improved apparatus for trapping the fish, natural methods of increase did not keep pace with the draft on the supply, and lake fish began to grow scarcer year by year. Artificial propagation had been tried in Europe, had proved a successful means of restocking depleted streams and ponds, and the newly founded fish boards of various states, charged in at least one case, Michigan, with the especial care of the whitefish, sought to perfect methods for hatching whitefish eggs. They were confident that therein lay the remedy for a great national calamity that seemed fast approaching—the loss of a food supply which, on the one hand, in its capture and distribution, gave employment to hundreds of men and vessels, and on the other furnished a cheap and agreeable supply of food to a large part of the central United States. But the methods which were so eminently successful in other instances have failed of final success in the Great Lakes. The annual catch of whitefish seems to be on the decline in spite of large sums spent by State and national fish commissions in hatching the fry and distributing them in the waters of the lakes. It has been a keen disappointment to all interested in fish culture that more immediate and pronounced results have not followed the extensive yearly plants of the fry; and some have attempted to explain the apparent failure on the ground that the present destructive methods of fishing effectually forbid any increase in the number of fish. They have, therefore, called for more stringent legislative regulations concerning methods of fishing, and for increased activity and artificial propagation. On the other hand it is evident that existing methods of fish culture may be open to criticism, and that the remedy as well as the fault must be sought here.

In an address before the World's Fishery Congress at Chicago in 1893, Professor J. E. Reighard says on this point:

"If we inquire into the facts concerning the sufficiency of the present methods of artificial propagation, we find that so far as concerns the whitefish there is no question as to the success of the earlier stages of the process. Several hundred million ova are taken annually and placed in the hatcheries, and of these usually from 80 to 90 per cent are hatched and placed in the waters of the Great Lakes—165,000,000 in Lake Erie alone in 1888.

"This is very nearly all that is known about these young whitefish. About their food habits we know only that in captivity they eat certain species of Crustacea. Whether in their natural habitat they eat other animals in addition to these Crustacea, or in preference to them, we do not know. It is uncertain at what age they begin to take food or how much they require. We do not know their natural enemies. We do not know whether they thrive best in running water or standing water, in shallow water or in deep water, whether at the surface or near the bottom. What changes of habitat or of food habits the fish undergo as they grow older is still a deeper mystery.

"Our problem is to place young whitefish in the Great Lakes under such conditions that as large a number as possible of them shall grow into adult fish. It is clear that one of these elements in this problem, namely, the whitefish, we know but little.

"What, then, do we know of the other elements of the problem, the Great Lakes themselves? Individual naturalists have made efforts from time to time to study one or another of the groups of animals living in the lakes. These efforts have been always circumscribed by the facilities at hand, by the time that could be devoted to the subject, by the small area examined, or by the small number of animals taken into account. Although much excellent work has resulted from these efforts, it remains true that there has been thus far no attempt to secure an accurate knowledge of all the conditions existing in any one locality, and no attempt to study exhaustively a single group of animals and plants of the lakes. We are still at the beginning so far as concerns a knowledge of life conditions in these lakes, the conditions with which we surround our young whitefish. If we could assume that the conditions are uniform over the whole area of the Great Lakes, then since the young whitefish are natives of these lakes, it might be a safe conclusion that they will find the conditions in one locality as well for them as in another. But there are no facts which support the view that the conditions are uniform over the lakes.

"We are thus in the position of bringing together under unknown conditions two things, both of unknown character, and we expect as a result to get a third thing—marketable whitefish. Should we not pursue our object more intelligently by first determining the characteristics of the materials with which we have to work?"

For ten years the Michigan Fish Commission had been carrying out a systematic investigation of the inland lakes of that State and had collected most valuable evidence on the biological conditions in these smaller bodies of water. The results of this survey, even as yet incomplete, have been immediate and invaluable, and it was a natural step when, under the advice of Professor Reighard, it was decided to extend operations to the Great Lakes themselves. In the summer of 1893 a scientific laboratory was maintained on Lake St. Clair, and, under the guidance of the director, Professor J. E. Reighard of the University of Michigan, a party of six specialists devoted two months to the study of the life in the lake. In 1894 Charlevoix, on the northeastern shore of Lake Michigan, was selected as a site for work, and owing to the absence of Professor Reighard in Europe, the writer was placed in charge.

Lake St. Clair has long been famous as the spawning ground for the whitefish; it is comparatively shallow, having a maximum depth of but a little more than six meters, and is of limited area. Both inflow and outflow are very large, and in fact the lake constitutes hardly more than a slight enlargement in the course of the stream connecting Lakes Huron and Erie.

In the waters of the Charlevoix region whitefish are caught the year round, and Lake Michigan has an area of more than 23,000 square miles and a maximum depth of 870 feet. It is estimated to contain at least one-tenth of all the fresh water of the globe. On the other hand the inflow and outflow are so inconsiderable in comparison that the volume may be said to be stable. Furthermore, the amount of shallow water is meagre, the area included between the shore and the ten-fathom line constituting hardly an appreciable amount on the chart of the lake; and yet this depth is more than two and one-half times the maximum of Lake St. Clair. The shallow area being thus limited, there is a relative scarcity of the larger plants which are found only in areas of limited depth; and the development of the strictly littoral forms is further hindered by the storms which subject the shore to constant change and prohibit on it any permanent plant growth.

It must also be remembered that light and temperature decrease rapidly with increase in depth while at the same time the pressure to which organisms are subjected increases with equal rapidity. Hence, the considerable depth of the major part of the lake affects very markedly the conditions for existence. In these respects Lake Michigan affords a strong contrast to the ordinary inland lake, while it is on the other hand a typical representative of the great inland seas. Similar conditions hardly exist elsewhere in the civilized world. It should be remembered that the work of European investigators has been carried on in lakes of comparatively limited area and depth, and that results characteristic of such conditions cannot, without further evidence, be extended to the larger bodies of water.

It must be noted that the question of food supply for the fish is peculiarly unlike the similar problems in agriculture. The food animals which come under our immediate attention are almost without exception herbivorous. The supply of food is drawn directly from the inorganic material in earth, air, and water, through the single intermediate step of the grasses, grains, and various forage plants. The chain of biological relations in this case is short and simple in its main features. Furthermore, constant and careful study by many workers in scientific institutions and on experimental fields has done much to explain the details of the process. The preparation and enrichment of the soil, the development of the seed, the growth of the plant, the dangers that threaten it, the diseases and pests that attack it, its protection and improvement, are all subjects of continued investigation. On the other hand, the pisciculturist has had no such aid, and, worse than that, often does not know even the immediate food of the fish or its amount and distribution, while concerning the more remote questions he has hardly thought to ask for their solution. In fresh water there are few large plants, in the Great Lakes a still scantier amount. Among all the fish there are none that depend on these plants for food supply; they are purely carnivorous.

In the light of the universal dependence of animal life upon plant life, one of the most fundamental questions for the fish culturist is the primitive food supply of the lakes in its character, amount, and distribution, since on this evidently depend the possibilities of fish culture, and with variations in it are connected necessarily variations in the number of fish. Unless the primitive food supply be abundant at the present time, all efforts to increase the number of fish will be only partially successful, and, unless the food of the fry is to be found in sufficient quantities in that locality when the fry are planted, the maximum number can never attain to the adult condition. The subject is too large for the limits of one paper or of a single series of investigations. Here I desire to present some results drawn from the work on Lake St. Clair and Lake Michigan with reference to the general question of the source of the food supply, its character, amount, and distribution. The more particular question with reference to the whitefish has been discussed elsewhere.

The source of food supply is not to be sought in the streams flowing into the lake. The amount brought in this way constitutes not only a very small part of the total volume, far too insignificant to be an important factor in the question, but it is furthermore chiefly inorganic matter in suspension or solution which is contributed from this source. The very limited development of bottom flora precludes the possibility of considering it the source of food supply, and the barren character of the littoral zone shows that from it is derived only inorganic matter by wave action. From the atmosphere comes in the rain much valuable material, but here exclusively inorganic. It is clear, then, that the primitive organic food material does not reach the Great Lakes from some source or other apart from them; it must be sought in the water itself.

If at any point in the clear, free water of the lake a net of finest miller's gauze be lowered to a depth of a few meters or more, and raised so as to strain the water and collect whatever may be present, it will be found on subsequent examination to contain numerous minute organisms, plant and animal, in varying quantity. It matters not whether the place of the experiment be near the shore or distant from it, in shallow or deep water, or whether the net be lowered only a short distance or to the bottom; there will always be obtained a certain quantity of life from the water, varying in amount with different circumstances. All the organisms obtained, both plant and animal; are characterized by their minute size, and are evidently unable by their own powers of locomotion to influence materially their position in the water. The environment to which they are subject is the result of external agencies and cannot be modified by their own efforts. They do not seek the bottom or the shore for rest, but remain always floating in the open water. All such forms together constitute what is called the *plankton*. Near the shore the plankton is corrupted by the addition of migrants from the littoral fauna and flora, and in proximity to the bottom some additions come to it from the bathybic (bottom-living) forms; but throughout by far the greater part of the water the plankton is found unmixed with other elements. Although present in small lakes and ponds it is more characteristic of larger bodies of water, both fresh and salt. In fresh water the fish alone invade its territory, and yet there are few fish that depend upon it directly for food. But the biological relations will be clearer after a consideration of some of the widely different forms of life included under the term plankton.

Four elements constitute the plankton of the Great Lakes, the unicellular plants and animals, or the Protophyta and Protozoa, the Rotifera, and the Crustacea. The number of species of each which are found in the plankton of the Great Lakes is limited, in fact not more than half as many as can be had from smaller bodies of water, but each species is present in an enormous number of individuals. Kellicott has calculated that of a single protophyte *(Stephanodiscus)* eight tons pass daily from Lake Erie into the Niagara river.

These forms together constitute the primitive food supply of the water, and the Protophyta are the fundamental element. They float in a nutritive fluid, the water of the lake which holds in solution inorganic substances obtained from the air, water, and shore, and brought down by various streams. In common with other green plants, they are able to manufacture out of this inorganic matter living material. Leuckart was the first to point out that since chemical action proceeds most rapidly where the proportion of surface to volume is the greatest, these organisms are peculiarly adapted to rapid growth. And since with them reproduction is clearly growth beyond the limits of the individual and consequent division into two organisms, under favorable conditions of light, temperature, and so forth, generation follows generation, with extraordinary rapidity, myriads are produced and are destroyed in every moment. These Protophyta of the plankton are then the actual elementary food supply, and all other forms of the plankton as well as all higher forms are in last analysis dependent upon them.

With them, however, may be included in the primitive food supply the other elements of the plankton. The Protozoa subsist in general on the Protophyta, the Rotifera are dependent upon both, and the Crustacea make way with whatever falls in their way. This last group usually predominates in the plankton, constituting in most cases by far the larger part of the entire volume. It is also the immediate source of fish food, serving directly as the food of the fry and rarely of the adult fish also, as in the case of the lake herring. Of the adult food fish the trout are piscivorous, subsisting on the herring and smaller forms, while the food of the various species of whitefish consists of bottom forms, such as *mollusks, insect larvæ, and crustaceans of medium size,* all of which are dependent upon the plankton for their food supply.

The fundamental position occupied by the plankton in the series of food relations in the Great Lakes renders it in the highest degree advisable that its quality, quantity, and distribution be accurately determined. The method employed in obtaining material for this determination is peculiar. In the case of ordinary collecting a net is towed behind the boat for an indefinite distance and only such part of the "catch" is utilized as may be convenient. Here the exact amount, and the volume of

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water from which it is taken are necessary factors in estimating the relative fertility of the water. The boat is brought to anchor, a net of peculiar construction is lowered to the bottom, and after a moment hauled vertically to the surface. The time consumed in the haul is recorded, as are also the depth, temperatures of air top and bottom, and if possible the character of the bottom, the condition of the sky and surface of the water, and the amount of current, if any, that exists at this point. At each point a number of hauls are made from varying depths, and the total amount of material obtained in each haul is preserved and bottled so carefully that the loss is very small. The error is always negative, however, and the amount obtained can be greater than is present only if foreign matter be included, and this is easily detected by the microscope. The material thus collected and preserved is retained in alcohol-filled vials for future study.

The ordinary method of estimating the volume is to place all the material from a single haul in a long graduated tube closed at the lower end, and after twenty-four hours of settling to read the volume in the tube as exactly as possible. It is evident that a very loose flocculent plankton will settle less rapidly than a denser mass, and that both will show irregularities rendering the reading hardly more than an approximation. This volumetric method is thus somewhat inexact, but probably correct within reasonable limits. It has the advantage of comparative rapidity, and since the material remains under alcohol during the entire process it suffers no injury. The gravimetric method, advocated by some investigators, consists in drying and weighing the entire mass of a plankton haul, and this is held to be more exact than the previous method. Great difficulty is found in weighing just at the time when all the external water is driven off, but when that which enters into structure is retained. The fatal objection to the method is, however, that the material when once dried is useless for further study. I have proposed a combination of the two methods which will be valuable in certain cases, but in general the volumetric is no doubt sufficiently accurate.

The qualitative determination of a haul may be made by a method of approximation or by enumeration. In the first case the plankton is poured into a very shallow dish, and the observer estimates the percentage of each species present. Such a procedure gives but a very general idea and evidently depends entirely upon the judgment of the observer. In the other method the total amount of a haul is diluted with alcohol to a fixed volume, then thoroughly shaken up and three small tests, of 1 cc., for instance, removed at random, spread upon a ruled plate, and the number of each species actually counted under the microscope. By averaging the three sample tests and by multiplying the result the total number of the species found in the haul is estimated. The amount of labor involved in laboriously counting for each of the twenty to one hundred species in each plankton haul is enormous, and yet for the determination of the relative importance of the various elements it seems to be necessary. For the plankton of Lake St. Clair and Lake Michigan this part of the work has not yet been done.

One further process is necessary. The results of the calculations just described are characteristic only for the particular net used and at the actual velocity, and it is necessary to express them in some more general terms. This may be done by multiplying by a correction such as to give the amount of plankton under one square meter of surface; the result will be the total amount contained in a column of water one meter square with a height equal to the depth of the haul. If, now, this be divided by the depth of the haul, the result will be the average amount of plankton per cubic meter of water, or the relative amount at the place and time of making the haul.

In Lake St. Clair there were made twenty-seven bottom hauls, two from each station except the first; the amount of plankton per cubic meter of water obtained in each haul is in the following table:

NO. OF STATION.	I	II	III	IV	V	VI	VII	VIII	IX	X	XIII	XIV	XV	XVI	AV.
Volume of plankton in cubic centimeters per cubic meter of water.	4.97	1.44 2.68	2.76 3.89	2.01 2.01	2.74 3.62	2.29 3.08	3.69 3.69	2.70 3.01	2.54 2.39	4.15 4.15	4.79 3.97	3.60 3.31	1.80 2.42	1.90 2.33	3.03

From Lake Michigan, near Charlevoix, eighteen bottom hauls show the following results:

NO. OF STATION.	I	II	III	IV	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XX	XXI	XXII	AV.
Volume of plankton in cubic centimeters per cubic meter of water....	1.64	3.82 3.20	2.70	4.91	4.46	2.01	1.52	5.68	4.77	8.16	5.34	5.38	1.23	2.49	2.68	4.03	2.41	3.69

In Round and Pine lakes, two connecting inland lakes which have immediate and free connection with Lake Michigan at Charlevoix, the following amounts were obtained in nine bottom hauls:

NO. OF STATION.	V	VI	VII	VIII	XXIII	XXIV	XXV	XXVI	AV.
Volume of plankton in cubic centimeters per cubic meter of waters..........................	2.88	2.28	3.14	5.84 5.27	3.96	6.88	3.17	2.34	3.97

In comparison with other lakes which have been measured in Germany, all of these are very poor in plankton, Dobersdorfer See, containing, for example, as much as 62.1 cc. of plankton per cubic meter of water. And yet the small amount which is present constitutes *in toto* a tremendous mass. The estimated volume of Lake Michigan is about 7,434 millions of cubic meters, and if the average of the lake contain an amount of plankton only equal to the least amount in any bottom haul at Charlevoix, it would make a solid mass of plankton in the entire lake of over *eleven thousand cubic meters.*

The distribution of this mass is of the greatest practical moment in fish culture, and here are contained in fact three problems: (1) seasonal, (2) areal, (3) vertical distribution. It is evident that only long continued observations in the same region can throw light on the question of seasonable distribution. Studies on lakes in Holstein are the source of our present knowledge; they show a minimum in February and a maximum in September, connected by a variable line of increase and decrease. The results of consecutive years exhibit marked differences in the extremes, both as to time and amount, and yet there is a general agreement in the increase of life with rising temperature and decrease with the lowering of the same.

Areal or horizontal distribution must be determined by comparison of observations made within a limited time, since throughout the year there is, as already explained, a progressive variation due to other causes. The series of hauls made at St. Clair and Charlevoix are peculiarly adapted to throw light on this question, since each series falls within a period of less than two weeks and both were made also at about the same season of the year. The results of the work at Charlevoix, which covered the greater variety of conditions in depth, distance from shore, and number of hauls, are represented graphically on plates I. and II. Each vertical line represents a station, and on it are set off on plate I. the depth of the haul, the total volume, and the volume per cubic meter of water. By connecting similar points, lines are produced which represent the changes of these elements from station to station. The various stations are arranged in order of depth with the shallowest at the right so that the dotted line of depth (D) continually descends toward the left. Considering first the conditions in Lake Michigan (1 *A*) it is evident that the line of total volumes (T) shows a rapid increase at first, then a region of uncertain fluctuation in which the greatest variation (XIX) is undoubtedly due to the presence of foreign matter,* and finally a second decided increase with the sharp plunge downward of the line of depth. Compare these two lines; the total volume increases at first more rapidly and in the last half of its course less rapidly than the depth. The line of relative volume, *i. e.*, volume per cubic meter of water (R), steadily ascends towards the left. One station alone (XIX) excepted, it swerves but little from the fine dotted line which connects its two ends and which may be said to indicate the average tendency: Compared with the line of depth it is clear that the relative volume decreases steadily with increasing depth of water. On plate I. *B* are represented in the same way the results of a smaller number of hauls in the two inland lakes of the Charlevoix region already mentioned. An examination of the lines shows that the principles already demonstrated for the great lake hold true in general here also. It may be that the more limited environment of the smaller area and shallower water introduces other factors and gives rise in this way to the apparently greater irregularities in this case. Comparing the results from Round and Pine lakes with those from equal depths in Lake Michigan (I. *A*) it is evident that excepting the two shallowest stations, the great lake possesses a much larger amount of plankton. It is an interesting indication of the limited food supply in Pine lake, especially that very few fish are found in its waters while adjacent lakes are well populated.

The table of bottom hauls from Lake St. Clair, given on page 115, is strong evidence that at the same point the amount of plankton to be obtained at any time is comparatively uniform. Two bottom hauls were made at each station after the first. These two were separated by a considerable time interval. Now, if the plankton were massed in so called "swarms," it would be altogether probable that the two hauls would in a

* The fine dotted line from XVIII to XX represents more nearly the true volume.

number of cases be decidedly different in amount according as they included a swarm or only the more barren interspaces. But the table shows that many of the pairs agree exactly, and that ninety per cent of them do not differ from each other by so much as one-fifth. Again, among the hauls in Lake Michigan (Plate I. *A*) there is only one, XIX, which shows any considerable difference from those made at equal, or nearly equal, depths, and this one, XIX., owes its extreme volume, as already mentioned, to the presence of a quantity of foreign matter (sand) carried into the net by some accident. This evidence may fairly be regarded as establishing for the same body of water the principle of equal amounts of plankton at equal depths.

In determining the vertical distribution of plankton, two methods are possible. A closable net may be sunk to any depth, opened, drawn up a given distance, and then closed and brought to the surface. The amount of plankton included is, then, that which was in the part of the water through which the net passed while open. Such a method would be the most exact, but closable nets are more difficult to manipulate and sometimes unreliable, so that the method of subtraction is more often employed. At each station hauls are made from a series of depths; 2, 5, 10, 25, 50, and 100 meters were the artificial strata made in the Charlevoix work, each series being concluded or interrupted by a haul from the bottom to the next higher limit. By this means the following amounts were obtained from Lake Michigan. The figures represent in all the tables cubic centimeters of volume:

No. of station	IX	X	XI	XIII	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII
2 m.-surface	19.4	18.5	22.1	28.4	25.3	27.2	23.4	26.3	25.7	18.5	23.2	17.7
5 m.-surface	40.7	26.3	35.3	41.6	31.1	42.4	44.4	33.7	34.9	31.7	35.1	25.0
10 m.-surface	54.7	47.8	66.6	79.6	53.4	80.9	88.7	49.2	58.8	49.6	50.3	49.4
25 m.-surface	117.3	96.8	115.5	169.2	------	126.3	159.3	90.1	118.5	82.9	88.7	75.8
50 m.-surface	116.0	106.8	157.8	143.2	------	------	179.2	89.6	?	110.1	------	101.4
Bottom-surface	------	------	170.3	------	------	------	168.0	------	------	------	------	------
Depth of bottom haul in meters	26	53	111	30	10	23.5	130	36	36	41	22	42

By subtracting consecutive hauls at any station the amounts in the several artificial strata are secured.

No. of station	IX	X	XI	XIII	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII
2 m.-surface	19.4	18.5	22.1	28.4	25.3	27.2	23.4	26.3	25.7	18.5	23.2	17.7
5 m.-2 m.	21.4	7.8	13.2	13.2	5.8	15.2	21.0	7.4	9.2	13.2	11.9	7.2
10 m.-5 m.	13.9	21.5	31.3	38.0	22.3	38.6	44.3	15.6	23.9	17.9	15.2	24.4
25 m -10 m.	62.6	49.1	48.9	89.6	------	45.4	70.6	40.9	59.7	33.3	38.4	26.4
50 m.-25 m.	-1.3	10.0	42.4	-26.1	------	------	19.9	-0.5	?	27.2	------	25.5
Bottom-50 m.	------	------	12.5	------	------	------	-18.8	------	------	------	------	------

Dividing the amount in each stratum by the thickness of the stratum in meters, the result will represent the amount of plankton per cubic meter of water in each of the artificial strata.

No. of station	IX	X	XI	XIII	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	AV.
2 m.-surface	9.7	9.2	11.0	14.2	12.7	13.6	11.7	13.1	12.9	9.2	11.6	8.9	11.5
5 m.-2 m.	7.1	2.6	4.4	4.4	1.9	5.1	7.0	2.5	3.1	4.4	4.0	2.4	4.8
10 m.-5 m.	2.8	4.3	6.3	7.6	4.5	7.7	8.9	3.1	4.8	3.6	3.0	4.9	5.1
25 m.-10 m.	4.2	3.3	3.3	6.0	......	3.0	4.7	2.7	4.0	2.2	2.6	1.8	3.2
50 m.-25 m.	-1.3	0.4	1.7	-5.2	......	......	0.8	0.0	?	1.7	......	1.5	-0.1
Bottom-50 m.	......	......	0.2	......	......	......	-0.2	......	......	......	......	......	0.0

These results for Lake Michigan are expressed graphically in Plate II. *A;* the other part of the plate (II. *B)* shows like results from Round and Pine lakes. The line of depth *(D)* is the same as on Plate I. The amount of plankton per cubic meter of water in the surface stratum, as shown by the line *S—S*, is far greater than that in any other stratum. The amount is variable; and its fluctuations seem on comparison of the lines to be independent: (1) of the depth, (2) of the total volume, (3) of the time of day,* (4) of the temperature of the water.*

It may be that the variations in the amount of plankton present in the surface stratum are due to the combination of two or more of the factors cited; but their independence of any one factor can easily be seen by noting the number of cases of opposite trend in the lines.

In the work in Lake St. Clair it was also shown that the surface stratum contained from one and one-quarter to two times as great a volume of plankton per cubic meter of water as any other part of the depth which was, to be sure, inconsiderable—not exceeding 5.5 meters. The same holds true for the lakes in Holstein, and may probably be regarded as a fundamental principle in the vertical distribution of the plankton. While the plankton is most closely massed in the superficial stratum of two meters, it is still not to be found at the immediate surface in the day time. A net of special construction was towed just at the surface of the water for hours during the trips of our boat at Charlevoix and never made a "catch" of appreciable volume during the hours of the day; but when towing was tried after nightfall at the same depth a large amount was taken. It is probable that a daily migration takes place which carries the mass of the surface plankton down a short distance in the day time and brings it back to the immediate surface with the coming of darkness.

The three intermediate strata, 2-5 m., 5-10 m., and 10-25 m., possess on the average about the same amount of plankton per cubic meter of water. The amount found in any one of them varies exceedingly, and each has at certain stations more than either of the others. Curiously the upper of the three strata (2-5 m.) has, for nearly all stations, less than the middle stratum, and only about the same as the lower (10-25 m.). It is perhaps true that the upper and the lower vary in accord with each other in general; their variations are apparently independent of the depth or other factors at hand. There is an interesting parallelism in the lines representing the surface stratum and that from 5 to 10 meters; but for this no cause can be assigned as yet. Only one of these lines is above the zero line of the plate, that is, indicates a quantity of plankton less than nothing! It is the 2-5 m. line at the shallowest station, where

*The last two points are not shown on the plates given in this article.

this is the bottom stratum. The apparent absurdity of a quantity of plankton with the minus sign is one of the minor disadvantages of the subtraction method; it is possible only when the minimum amount of plankton in a given stratum is less than the possible fluctuations in the amount of plankton contained in the superjacent water, and it indicates that the amount probably present in the stratum was insignificant.

The lines denoting the intermediate strata lie in all cases clearly below the lines of the deep strata, 50-25 m., and bottom—50 m.; the latter never equal to the former and in a large per cent of cases the amount of plankton seems to be a negative quantity. This is indicated by the position of the 25-50 m. line above the zero horizontal at IX., XIII., and XVIII. In the case of the deepest stratum, which was present in but two instances, the amount of plankton obtained was even more insignificant. The deep strata are practically without plankton so far as our observation extended.

One question in the distribution of life in these waters which was not studied, is the possible existence of a deep fauna, not strictly planktonic in character, but dependent in fact upon the bottom, where it rests and reproduces, and frequently making short excursions into the superjacent water. It would thus be dependent for support on the plankton and would frequently be collected with the latter, but would be no proper portion of it.

If this be in rough outline the distribution of the plankton as a whole, it will be seen at a glance that this is merely the beginning of the problem. The distribution of the whole is no more than the sum of the distributions of its many species. In so far as the variations in the volume of the different strata, so clearly marked on the maps, are not produced by errors in apparatus and method, they are due, no doubt, to fluctuations in the location of certain species. Such changes are known to be brought about in isolated instances by change in temperature and light; how far these influences are operative in carrying an unknown species from one side to the other of the artificial limits we have placed in the water, and in thus modifying the qualitative and quantitative composition of the plankton in any particular stratum—these are but suggestions of the many questions awaiting a solution.

The investigation of plankton problems has only just begun; yet hand in hand with these studies goes the practical application of the results obtained. It would be impracticable to explain here the light that they throw on the probable life of the young fish and the precautions to be observed in planting the fry; the subject must be left with the mere hint. Already efforts have been made on a small scale at least to increase the primitive food supply, and in some small fish ponds in Europe it has met with moderate success. No one can predict the possibilities of the future; these studies have made one of its necessities evident and imperative. Aquaculture must be given the same sort of broad, scientific treatment that agriculture already receives; it must be studied from the scientific standpoint, its problems analyzed, its course marked out with definiteness. Not until then can it hope to render that service to the people which the unequalled opportunity of our inland seas makes possible in the way of a permanent supply of food at once cheap and agreeable.

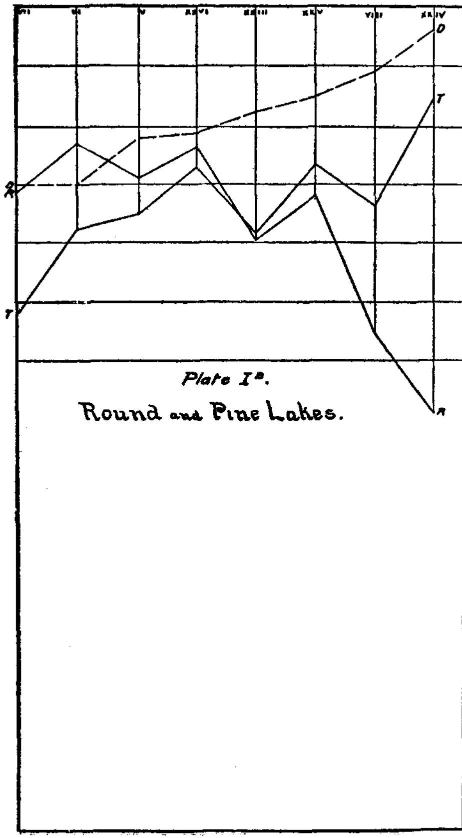

Plate I[b].

Round and Pine Lakes.

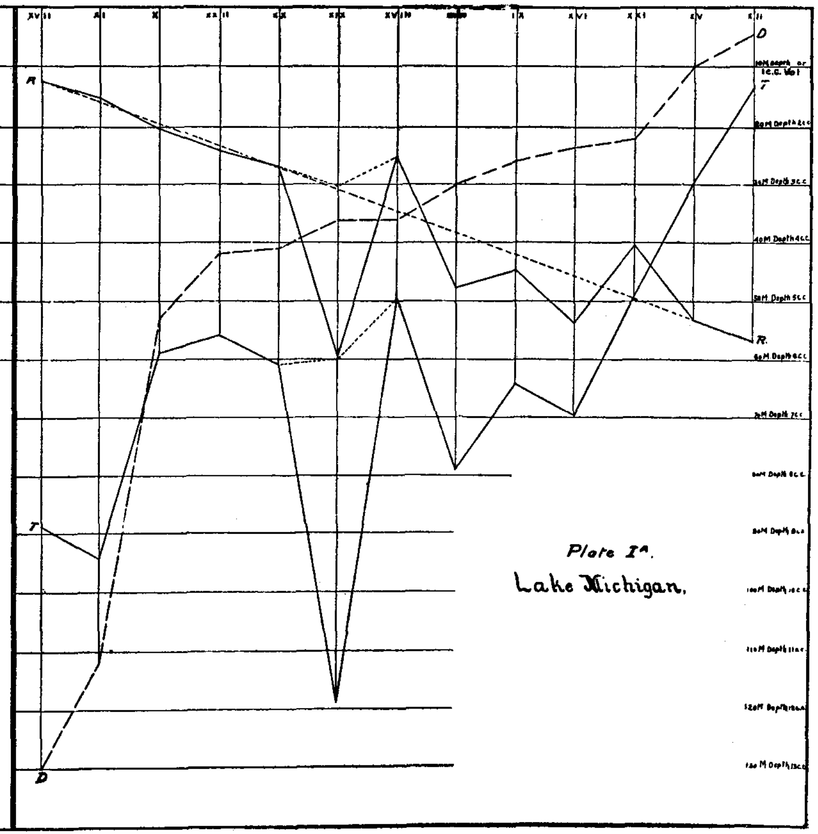

Plate I[a].

Lake Michigan.

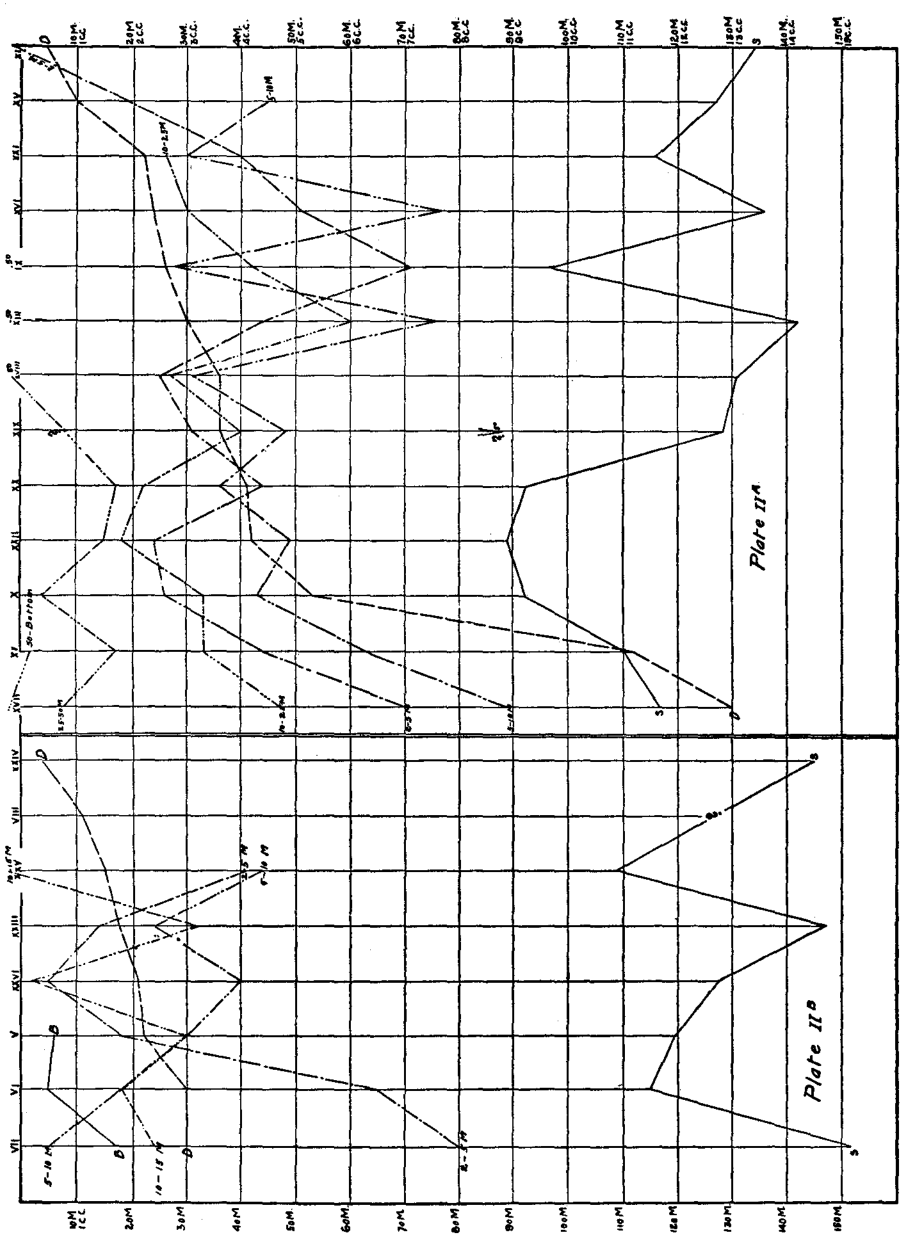

Plate IIᴬ

Plate IIᴮ