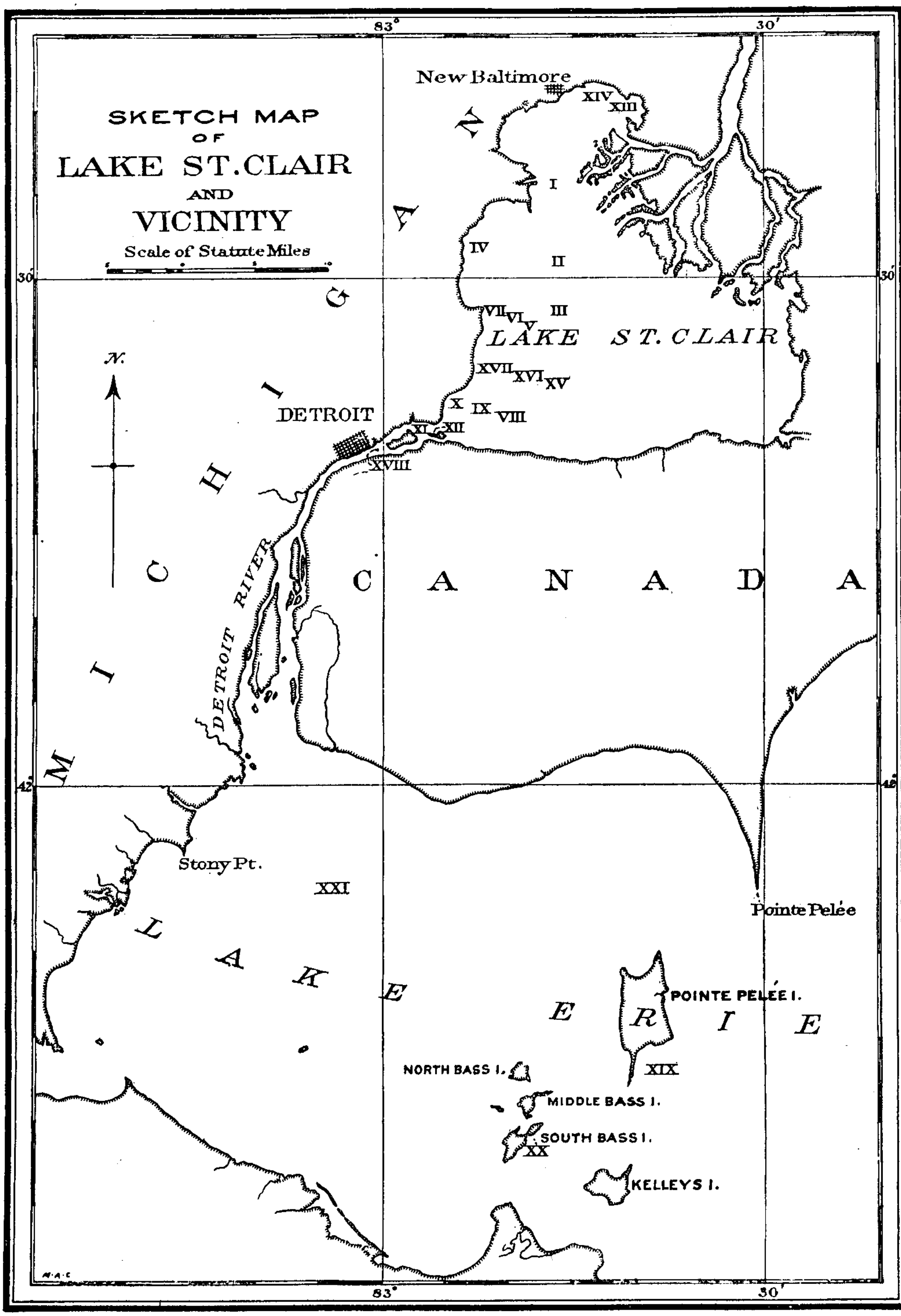
SKETCH MAP
OF
LAKE ST. CLAIR
AND
VICINITY
Scale of Statute Miles
83°
30′
30′
42°
New Baltimore
XIV
XIII
I
II
IV
III
VII VI V
LAKE ST. CLAIR
XVII XVI XV
X IX VIII
XI XII
XVIII
DETROIT
DETROIT RIVER
N.
MICHIGAN
CANADA
Stony Pt.
XXI
Pointe Pelée
LAKE ERIE
POINTE PELEE I.
XIX
NORTH BASS I.
MIDDLE BASS I.
SOUTH BASS I.
XX
KELLEYS I.

17.—SOME PLANKTON STUDIES IN THE GREAT LAKES.

BY JACOB E. REIGHARD,
Professor of Animal Morphology, University of Michigan.

The history of the whitefish industry of the Great Lakes is well known to the members of this conference. It is presumably the history of a diminishing production in spite of a very large annual outlay for artificial propagation. The enthusiasm with which the fish-culturists of twenty years back undertook the restocking of the Great Lakes was born of success in many similar enterprises. Trout and shad had been made to swarm in depleted waters. Similar results were, therefore, to be expected from the application of similar methods to the Great Lakes. These expectations have not been realized, and fish-culturists are casting about for an explanation.

On the one hand it is asserted that the expected increase in the yield of whitefish has not been realized because of the destructive methods of fishing. The ravages of the pound net are thought to be more than sufficient to wipe out the gain due to artificial propagation. It is said that if fishing methods were properly regulated the results of artificial breeding would at once make themselves felt, and that, while the planting of whitefish has not resulted in increasing the supply of adult fish, it has prevented any large reduction in that supply, so that many grounds, which now pay for the fishing, would have been utterly exhausted but for artificial propagation. The remedy for the present condition of things is believed to lie both in legislation controlling fishing methods and in a still greater extension of artificial propagation.

On the other hand it is claimed that if the artificial propagation of whitefish were successful it should result in an increasing yield in spite of existing methods of fishing. The remedy does not lie in restrictive legislation; it lies rather in greater effectiveness of methods of artificial propagation, and perhaps also in an increase of the annual output of artificially hatched fish.

The first view is held for the most part by fish-culturists, who favor restrictive legislation and increased facilities for artificial propagation. The second view is held for the most part by fishermen, many of whom are not yet convinced of the value of artificial propagation. When one who is neither fish-culturist nor fisherman attempts to discover the facts upon which the various opinions are based he very soon finds that there are but few recorded facts.

In order to know whether the number of whitefish is increasing or diminishing for any locality or for all localities it is necessary to have statistics extending over a term of years. Statements based on statistics which are taken in two years separated by an interval of five or ten years are nearly valueless for purposes of comparison, for the reason that such statistics do not and can not take into account the climatic conditions which make one year favorable and another year unfavorable. The fact that in the year 1880 the number of whitefish marketed was greater than in 1890 does not prove that the number of whitefish has diminished in this interval; it proves only that the number caught in 1890 was less than the number caught in 1880. This may have been due to a diminution in the number of fish, but it may also have been due to storms during the fishing season of 1890. Statistics, to be conclusive, should enable us to compare the average yield for the ten years 1870 to 1880 with the average yield for the years 1880 to 1890.

No such continuous series of statistics is in existence for the United States, so that the assertions concerning a diminishing yield of whitefish rest either on a comparison of the statistics of isolated years or on the statements of fishermen concerning certain localities.

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 in 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 a still 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 of one of the elements in this problem, namely, the whitefish, we know but little.

What, then, do we know of the other element 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 the 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 native to 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,

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* This appears by adding the number of fry planted in 1888 by the U. S. Commission and by the commissions of Canada, Michigan, New York, Ohio, and Pennsylvania, as shown in the reports of those commissions.

† Forbes, S. A., The First Food of the Common Whitefish. Bulletin No. 6, Illinois State Laboratory of Natural History, May, 1882.

marketable whitefish. Should we not pursue our object more intelligently by first determining the characteristics of the materials with which we have to work? It was with this object in view that the Michigan Fish Commission, in the summer of 1893, established a scientific laboratory on Lake St. Clair. This lake is readily accessible from the Detroit hatchery at the season when whitefish are planted. Whitefish are caught in certain parts of the lake in considerable numbers in the spawning season, so that it is probable that spawning-grounds of this fish are found along the west shore of the lake near its outlet. In establishing a laboratory on the lake the Michigan Fish Commission hoped, therefore, to accomplish two things:

(1) To study carefully, and in the broadest possible way, the life of the lake. After examining the physical characteristics of the lake, such as the color, transparency, and chemistry of the water, such a study should include a determination of the kinds of animals and plants in the lake. Every species should be sought out, carefully described and figured, and a specimen of it preserved. Then the habits of each species should be known, its habitat, its food, its enemies, and its parasites. The numbers of animals and plants of each species in a given volume of water should be determined, and the variations in these numbers in different parts of the lake and at different seasons of the year. Such a collection of data would form a complete picture of the biology of the lake.

(2) It was hoped that young whitefish might be captured in the lake by suitably arranged nets and that it might thus be possible to determine the food habits of the young fish and the other conditions under which they are found in nature.

Should both these objects be accomplished we should be in a position to determine where in the Great Lakes are to be found the conditions favorable to the whitefish fry.

The materials collected have not been all worked up at this time, so that it is possible to give only a brief survey of the plan of work together with some of the more immediate results.

The laboratory was located at New Baltimore, near the head of Anchor Bay, which is the northeastern portion of Lake St. Clair. Here the second story of a large warehouse, situated on a dock, was transformed, by the use of temporary sheathing, into a commodious laboratory room about 20 by 40 feet. There were four large and very rigid laboratory tables, designed especially for their portability and intended each for two workers. The vacant places on the walls were filled with temporary shelves, and two large work tables were provided for general purposes. At one of the windows was placed a table arranged to hold a dozen small aquaria, to which running water was supplied from a tank outside the building. On the wharf without was erected a temporary shed which sheltered three large aquaria supplied with water from a special tank. In these aquaria the largest fish of the lakes could be kept under observation.

The laboratory was supplied with a sail and row boat. For more extended trips and for use with the heavier collecting apparatus there was a small steamer, the *Ben Hur*, of Detroit, a boat of about 10 tons burden, and with a very roomy cabin. She was found to serve every purpose admirably.

A considerable collection of pertinent literature as well as microscopes and the other usual laboratory apparatus were loaned by the University of Michigan. A liberal supply of the usual glassware and reagents and of the minor apparatus was provided by the fish commission. The collecting apparatus included the usual hand nets, tow nets, and dredges. Besides these there were some forms of nets not in common use. The ordinary form of deep-sea dredge was found to slip over the hard clay bottom or over the thick matting of characeæ which covers this bottom, so that it usually came up empty. In its place was used a dredge made as follows: An iron band 2 inches broad, ⅜ of an inch thick, and 4 feet 6 inches long, is cut along one edge into a row of triangular teeth, each an inch broad and an inch high. These teeth are sharpened and bent so as to form an angle of about 15 degrees with the rest of the band, which is provided with holes into which a net may be laced. The band is then bent on the broad side into the form of an equilateral triangle, with the teeth inclined outward. To each angle is welded a stout ring for the dredge rope, and also an iron rod, 2½ feet long, which projects at right angles to the plane of the triangle and from the edge of the band opposite the teeth. A flat net of inch mesh is suspended from the triangle, and its bottom is lined for about a foot with coarse cotton cloth. The whole net frame has thus the form of a triangular prism and when dragged along the bottom always rests upon one side, so that the teeth at the edge of the frame act with great effectiveness in loosening objects imbedded in the hard clay bottom. This net is modeled from one exhibited among the apparatus of the plankton expedition in the German University exhibit at the World's Fair.

Another piece of apparatus of great value is the net designed by Prof. E. A. Birge for collecting cladocera, and described in Trans. Wis. Acad., vol. VIII, 1891. It is indispensable on weedy bottom or shores.

The ordinary tow net when weighted to be used on the bottom is apt either to run at an unknown distance from the bottom, or, if it reaches the bottom, to foul in the weeds or fill with mud and sand. We therefore made use of a tow net supported on four flat iron runners which are welded to the iron net ring. These runners extend for about 30 inches at right angles to the plane of net ring and are then bent toward one another and riveted together at a point opposite the center of the net ring and 3 feet from it. The net thus hangs within the frame formed by the runners, and its mouth is held about 2 inches from the bottom. This proved an excellent device for collecting bottom forms free from weeds or mud.

For quantitative work we used a vertical net which is more fully described in another place.

Six persons worked in the laboratory from July 15 to September 15. They were—

Prof. J. E. Reighard, director; quantitative work, crustacea, and vertebrates.

Dr. H. B. Ward, associate professor of biology, University of Nebraska, Lincoln, Nebr.; worms.

Mr. Frank Smith, instructor in zoölogy, University of Illinois, Champaign, Ill.; protozoa and mollusca.

Dr. Robert Wolcott, Ann Arbor, Mich.; insecta and hydrachnida.

Mr. H. S. Jennings, assistant in animal morphology, University of Michigan; rotifera, sponges, and bryozoa.

Mr. A. J. Pieters, assistant in botany, University of Michigan; plants.

Each had charge of that portion of the subject set opposite his name. These gentlemen worked enthusiastically, and without compensation, in the interest of science, so that whatever results have been reached are largely due to their unselfish devotion.

Two employés of the fish commission, Mr. Dwight Lydell and Mr. Jesse Marks, rendered valuable service in collecting, fishing, and otherwise furthering the interests of the laboratory.

The first six weeks were spent in qualitative work, that is in making a list of the animals and plants of the lake, in noting the way in which they were associated, their habits, and in preserving specimens, drawings, and records of observations. Every morning, and frequently again in the afternoon, a man was sent out into the bay, with the different sorts of nets. With the tow nets were obtained the smaller animals and plants floating in the water, at the surface, in mid-water and near the bottom. The forms attached to the bottom or concealed among the water plants were collected by means of the toothed dredge and by the Birge net. Collections were also made near the shore with the same apparatus. All the materials were brought to the laboratory and were ready for examination upon the arrival of the laboratory force. Each worker then sorted out from the collection the materials belonging to him. This method of working was kept up until it was felt that all the inhabitants of the lake, except possibly a few rare or occasional ones, had become familiar. The living specimens were studied in all cases and material was preserved for future use. Final identifications were attempted only in the cases where the original literature in the laboratory was ample for the purpose.

At the same time that collections were being made of the smaller inhabitants of the lake, gill nets were set every day for the capture of fish, while other fish were purchased from the fyke-net fishermen who landed their catch at the laboratory dock. The stomachs of several hundred of these fish were examined and the contents preserved, with the purpose of determining the food habits of the fish. At the same time the fish were systematically searched for parasites, and many important biological data were collected concerning the parasites. A more detailed report on these parasites is in preparation by Dr. Ward.*

In order to make a continuous and systematic record of the forms examined, use was made of blanks in which each person entered the forms observed by him. The blanks were of two kinds, one intended to give the important data concerning the individual animals and plants and the other intended to show how these animals and plants are associated under different conditions. The following is a sample of what may be called the individual blank:

NAME Sida† crystallina O. F. M.
No. ——— DRAWING ——— SPECIMEN ——— NOTES 117, 124.
LOCALITY middle of Anchor Bay
HABITAT
PELAGIC ——— DEPTH ———
LITTORAL ——— " ——— BOTTOM ——— VEGETATION ———
BOTTOM x " *13 ft.* " *Clay* " *Characeæ.*
FOOD dinobryon; diatoms; shells of both found in excreta.
ABUNDANCE moderate.
BREEDING HABITS { ♀♀ with embryos & larvae in brood sac. ♂♂ not found.
REMARKS greenish transparent color is noteworthy. The grinding surfaces of mandibles suggest the crushing of diatoms.
DATE Aug 11, 1893 **HOUR** 7 a. m. **SIGNT.** J. E. Reighard.

This blank gives the results of the observations of a single day on a single species of *Sida*, the name of which appears at the top of the card. Whenever this species was observed under different circumstances a new card was made for it. By sorting all the cards referring to a single species one has at hand in condensed form all the facts recorded concerning it.

* This report will appear as a bulletin of the Michigan Fish Commission.

† The words in this light-face type were added with the pen.

These blanks did not take the place of note books but were meant merely to condense and systematize the records made in the note books.

The other form of blank may be called the *collective* blank. A sample of it appears below. It is a modification of a form used at Mr. Agassiz's Newport laboratory.

No. ______ RECORD OF COLLECTIONS.

Made at ______

Tow at ______ *Dredged at* ______ *ft. on* ______ *bottom*

With ______ *net, along* ______ *shore* ______

Jan. Feb. Mar. Apr. May. June. July. Aug. Sept. Oct. Nov. Dec. ______ A.M.

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20,

21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31. 189 ______ ______ P.M.

Water: ______, *Wind:* ______, *Sky:* ______

Temp. air: ______, *Temp. water:* ______, *Barometer:* ______

Remarks: ______

______ *Observer.*

Name.	Very many.	Many.	Scarce.	Name.	Very many.	Many.	Scarce.

Blanks of this form were passed from one worker to another, and each person entered in them the forms which he had found as taken in a certain net at a certain time and in a certain location. The blanks thus serve to show the way in which the forms are associated and their relative numbers under different conditions at different times. To properly fill one of these blanks was usually the work of six observers for the greater part of a day.

For the records of parasites there was a third form of blank, designed by Dr. Ward and shown in the accompanying copy. It is intended to bring together certain data concerning the animal infected and the numbers and kinds of parasites.

No. ______

Name ______

Size ______ *Age* ______

Locality. ______

Examined by ______ ______ *189*__

PARASITES FOUND.

Name.	No.	Organ inhabited.	Condition.	Remarks.

Notes:

A similar record was kept of the contents of the fish stomachs, but no special blank was used for this purpose. It is desirable to use such a blank.

Reports are now in preparation by the various members of the laboratory staff, and as these are soon to be published as bulletins of the Michigan Fish Commission, detailed statements will be reserved for such publication. The following statements as to the biological conditions existing in the lake may prove of interest.

As to the lake itself, it has nearly the form of an equilateral triangle with rounded angles and with sides, each of which measures 25 to 30 miles. The southern and shortest side of the triangle runs nearly east and west, its western side inclines toward the east as it extends northward, while the third and longest side looks directly toward the northeast, and may be called the northeastern shore.

In the middle of this northeastern shore the lake receives the waters of the St. Clair River, which carries the overflow of the three upper lakes. At its entrance into Lake St. Clair the river breaks up into several channels, each of which again divides once or twice, so that the water of the river enters the lake through nine well-defined mouths of various sizes. These mouths are scattered for a distance of 20 miles along the northeast shore and discharge their waters into the lake at a considerable velocity. Between the channels which diverge from the main river to these mouths is swampy, shifting ground, which forms an enormous delta overgrown with rushes and covered usually by a foot or more of water. These are the celebrated St. Clair flats. The banks of the channels only are usually formed of moderately firm ground, and it is upon them that numerous summer residences and hotels have been built.

The northwest corner of the triangle receives the greater part of the discharge of the northern fork of the river (North Channel) and is partly cut off by a projecting point of the west shore, so that there is formed a bay, Anchor Bay, upon which is situated the town of New Baltimore. From the southwest corner of the triangle the Detroit River leaves the lake and flows at first toward the west. The water poured into the triangular lake by numerous mouths along nearly the whole of one side, thus converges to the angle opposite this side, where it flows out. The lake is but little more than an enormous expansion of the river, so that almost everywhere there is a current, usually slight, but in some places near the mouths of channels reaching a velocity of 3 or 4 miles an hour. The lake is shallow. Over a large central area the bottom is quite level and the water has a nearly uniform depth of 20 feet. From this central area the depth diminishes toward the shores in every direction. The shores, so far as we examined them, are made by a clay bluff, which varies in height from 1 or 2 feet to perhaps 10 or 20 feet. Mixed with the blue clay which forms the bluff, there is more or less gravel or sand, and the action of the waves has in many places washed this free from the clay and left it in the form of little stretches of gravelly or sandy beach. The bottom of the lake is everywhere composed of the same mixture of blue clay with sand or gravel. On the bottom also the finer clay particles have been washed away from the superficial layer of the bottom, so that there is left everywhere a thin layer of fine sand or gravel which separates the hard clay bottom from the overlying water. This layer of sand is in some places so fine that it is known popularly as mud.

The water of the lake is not clear. No measure of its transparency has yet been made, but it lacks the great transparency of the water of the northern lakes. The shallow water near the shore is always much roiled by even moderate waves, apparently by reason of fine particles of clay suspended in it. A zone of this roiled water extends for perhaps a quarter of a mile from the shore and disappears only in very quiet weather. The temperature of the water in August and September was 65° or 66° F. There was but little difference between the bottom and top temperatures. In the deepest water the difference was about 1°.

The entire bottom of the lake is clothed with vegetation. The plants are, for the most part, stoneworts of several kinds. There are also some flowering plants and algæ, all of them enumerated in the report of the botanist.* Together they make a dense green carpet which appears to vary in thickness from 2 or 3 to 6 or 8 inches. It harbors a rich bottom fauna and should be good pasture ground for such bottom-feeding fish as the carp.

As for the smaller animals and plants found in the lake the following summary is sufficient. The net drawn at the surface showed usually 8 or 10 species of protozoa, about 15 species of pelagic rotifers, 5 or 6 species of crustacea (cladocera and copepoda), and about 20 species of diatoms and other algæ. A few fish larvæ of unknown species were taken, and occasionally there occurred a hydra, some insect larvæ or pupa skins, a snail or a worm, all evidently wanderers from the bottom. Algæ, rotifers, cladocera, copepoda, and protozoa make up nearly the whole of the surface life.

If the net be run in midwater or near the bottom, but in such a way as not to stir up the bottom vegetation, very nearly the same result is obtained. The algæ, the protozoa, and the rotifers are, with few exceptions, of the same species as those living in the surface water. A few ostracoda are now added to the crustacea taken, and occasionally an amphipod, both probably caught by the net as they left, for a moment, their hiding-place among the plants of the bottom. An occasional annelid also appears.

If a dredge be used which stirs up the water plants and harrows up the bottom the result is far different. All the forms previously noted are of course brought up, but in addition there are many that are peculiar to the bottom. The larger plants growing on the bottom in deep water have already been mentioned. They are mostly characeæ, with some elodea, naias, and valisneria. A larger list of algæ is found and includes several filamentous forms. The number of protozoa is greater and the list of rotifers grows from 15 to about 60. It includes many fixed forms. Among the crustacea there is now a preponderance of ostracoda and amphipoda, though the other groups are still well represented. The dredge brings up several sorts of animals never found in the free water above. First are the mollusks, mussels which are partly imbedded in the bottom, and many species of snails which are crawling about over the plants on the bottom. Secondly, many sorts of insect larvæ, especially those of the dragon-flies and may-flies are dragged from their hiding-places on the bottom. A third sort of animal found only in the bottom dredge are the water spiders or hydrachnids. There are probably 36 sorts of these voracious little cannibals, and they are very numerous in individuals. In the fourth place, many worms are found, some nematodes, many small oligochæta, and a few leeches. A few hydras and an occasional sponge or bryozoon complete the list of the bottom fauna. Its striking elements are the mollusca, the insect larvæ, the water spiders, the worms, the amphipod and ostracod crustacea.

*To be published in the Botanical Gazette and also as a bulletin of the Michigan Fish Commission.

The fish which occur in the lake are the usual and well-known inhabitants of these waters and need not be enumerated here. A few frogs and turtles and many gulls and terns complete the list of the fauna. The roily water of the lake, especially near the shore, is probably not favorable to the existence of many species of protozoa, sponges, bryozoa, or littoral crustacea. The total number of species found in the lake can not be stated until the collections have been more exhaustively studied. So far as studied the collections show species distributed as follows:

Plants:	
Phanerogams (17 of these are littoral, 1 to 6 feet of water)	52
Of these, but 3 (*Elodea*, *Naias*, and *Valisneria*) occur on the bottom usually in deep water; the others are in shallow water (5 to 12 feet) and reach the surface or extend above it.	
Characeæ	5
Algæ, filamentous: 2 (*Vaucheria*, *Cladophora*) on the bottom in deep water; 2 (*Spyrogyræ*) floating in shallow water	4
Algæ, other: 31 pelagic; 65 attached to or associated with larger plants	96
	157
Animals:	
Protozoa	14
Sponges	1
Hydroids (Hydra)	2
Rotifers: pelagic 18, on bottom in deep water 42, near shore 57	117
Bryozoa	1
Annelida, estimated at about	15
Platyhelminthes and Nemathelminthes (including parasites): 166 vials of material were preserved; the number of species cannot be stated.	
Crustacea, at least	36
Hydrachnids	36
Insects and insect larvæ	75
Mollusca	35
Fishes: Ganoids, 3; Teleosts, 22	25

The total is not less than 500 species and may reach 600.

Many of the species above recorded are now known to be new, and the study of the collection will doubtless discover a still larger number of undescribed species. The new forms are, for the most part, among the rotifers, hydrachnids, and parasitic worms, though there are a few new crustacea, annelids, and protozoa.

In addition to the work which has been done in the identification of these forms by the laboratory staff, the following gentlemen have undertaken to work up the groups set opposite their names.

Dr. R. Blanchard, Paris, France; the leeches.

Dr. E. A. Birge, University of Wisconsin; the cladocera.

Dr. G. Eisen, San Francisco; the oligochæta.

Prof. C. D. Marsh, Ripon, Wis.; copepoda.

Dr. W. McM. Woodworth, Harvard College; the turbellaria.

Aid has also been received in the identification of the mollusca from Mr. Bryant Walker, of Detroit; in the characeæ from Dr. T. F. Allen, of New York City; and in the desmidaceæ and unicellular algæ from Mr. L. N. Johnson of the botanical department of Michigan University.

After six weeks spent in determining the composition of the lake fauna and flora, the attention of the laboratory staff was turned toward the question of the distribution of these forms and toward measurements of the total volume of living forms found in a given volume of water and of the numbers of each species in a given volume of water. For this purpose twenty-one stations were selected. Fifteen of these were in Lake St. Clair. Since the time was limited, these fifteen stations were located on the American half of the lake and were more numerous in the neighborhood of the fishing-grounds. Their distribution is shown on the accompanying chart. It will be noticed that while they are not scattered over the entire lake, they represent all the conditions of bottom, shore, and depth that are to be found in the lake. Any conclusions concerning them probably hold for the entire lake. Three stations were located near the head of the Detroit River, while for the purpose of comparison three others were located in the western end of Lake Erie.

At each station the various forms of nets described were used and the collections made were preserved. Their study will determine the distribution of the animals and plants.

An attempt was also made to measure at each station the quantity of animals and plants floating free in the water under each square meter of surface. No methods have yet been devised for determining the quantity of the animals or plants that are attached to the bottom or that live upon it. Measurements are, therefore, to be made only upon those forms that are found floating free in the water. There is reason to believe that whitefish fry (and probably the fry of many other young fish) feed for a time upon minute animals (crustacea) floating free in the water. If this is true, it becomes at once a question of great practical importance to know where these crustacea are to be found in greatest numbers, so that the whitefish fry may be planted in such localities. Such measurements have also a very high scientific interest.

Quantitative determinations of the living forms in the water have not been previously undertaken in this country and its methods are almost unknown among us. They have been conducted on a large scale by Prof. Victor Hensen, of the University of Kiel, in Germany. Hensen has examined the waters of the North Sea and more recently those of the Atlantic Ocean, and has perfected very ingenious apparatus for the purpose. Apstein,* a pupil of Hensen, has adapted this apparatus for use in fresh water, and has made a careful study of several fresh-water lakes in the neighborhood of Kiel.

As it was found necessary for work in the Great Lakes to modify the apparatus and methods used by Hensen and Apstein, I give here a somewhat detailed account of our procedure.

The name *plankton* has been given by Hensen to all those animals and plants which are found floating free in the water and subjected to the action of the waves, currents, or tides. Thus adult fish do not belong to the plankton, since they are able to move about independently of waves or currents. Fish eggs and young fish fry are

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*Das Plankton des Süsswassers und seine quantitative Bestimmung. Schriften d. Naturw. Ver. f. Schleswig-Holstein. Bd. IX. Hft. 2. 1892.

Quantitative Plankton-Studien in Süsswasser, Biologisches Centralblatt. Bd. XII. 1892.

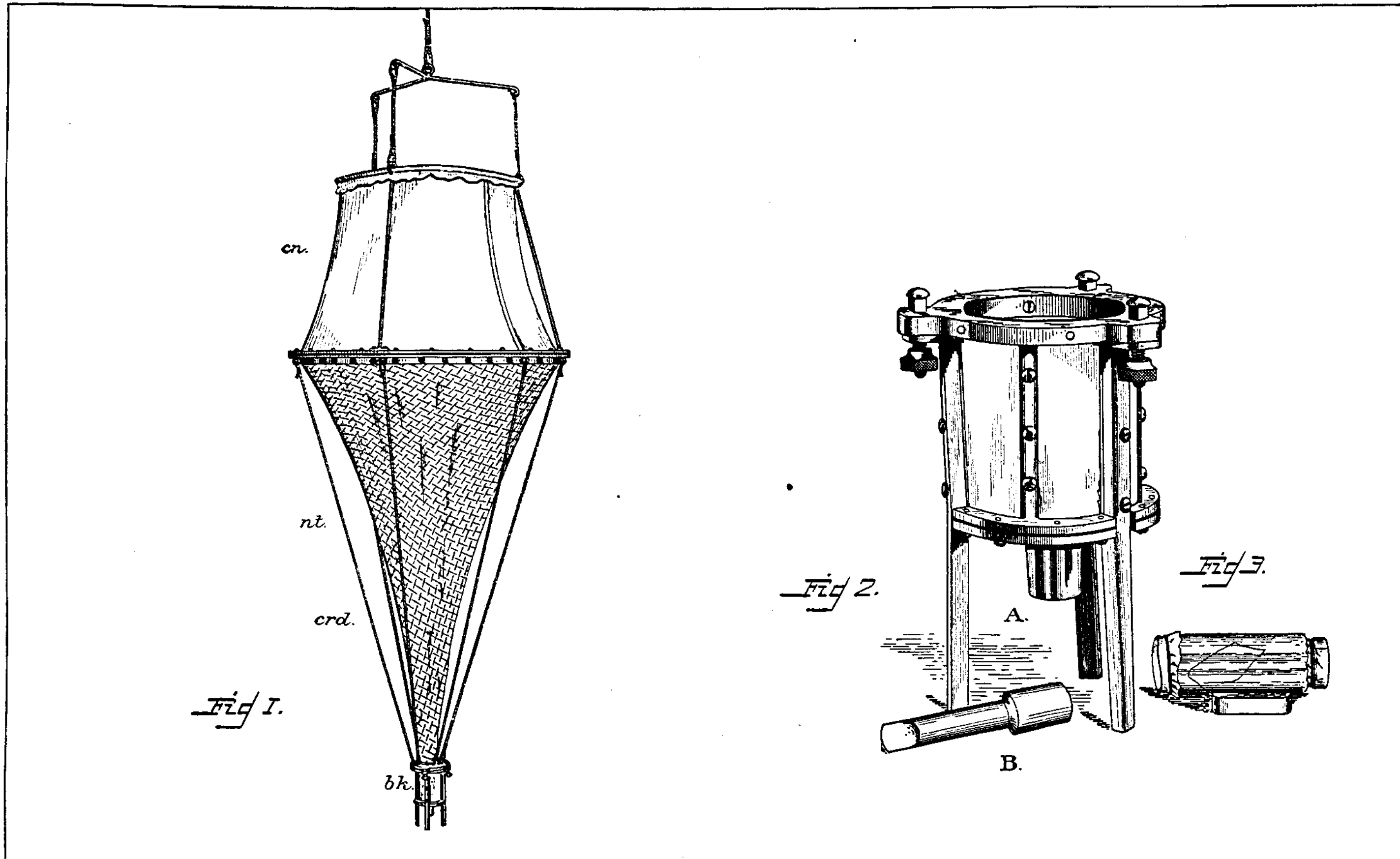

Fig. 1. Vertical net, ready for use. When the net is out of the water its mathematical form is somewhat distorted by its own weight.
Fig. 2. The bucket removed from the net and shown on a larger scale. The bucket is shown at A ; the plug, removed from the inside, is shown at B.
Fig. 3. One of the tubes containing plankton.

reckoned as a part of the plankton. The constitution of the plankton varies, since occasionally forms which belong on the shore or bottom wander into the free water and become a part of the plankton.

In order to measure the quantity of plankton contained in a lake, or in any portion of a lake, it is necessary to strain a certain volume of the water through a fine net and to weigh or measure the material thus obtained. The volume of the water taken should be a representative one; that is, it should consist of water taken at all depths. In other words, it is necessary to strain a vertical column of water extending from the bottom to the surface. The only practical way of doing this seems to be to draw a fine net through the water vertically from the bottom to the surface. Such a net strains a column of water of known height and with a base equal in area to the net opening. It collects at a single haul all the plankton under an area of lake surface equal to the area of the net opening, and by measuring the plankton thus taken under a small area it is possible to calculate the total plankton contained in the lake, or under any desired area of the lake.

The net used for this purpose is shown in the accompanying plate, fig. 1. The upper part of the net consists of a truncated canvas cone (*cn*) supported on an iron framework. This cone is about 40 cm. high; the smaller end has a diameter of 40 cm. and the larger end a diameter of 60 cm. It is impervious to water and serves two purposes. When the net is let to the bottom it prevents the mud which may be upon the bottom from getting into the net, and when the net is being drawn up it prevents its contents from spilling over the edge, a thing which might otherwise happen with a boat pitching in a heavy sea.

From the iron ring which supports the broader end of the cone depends the net proper (*nt*). The net is a cone with a slant height of about 100 cm. It consists of No. 20 silk bolting cloth, a very strong fabric, which contains many very small openings of uniform size. This cloth or gauze has the further advantage of not undergoing changes in water and of not yielding any lint to contaminate the plankton. The outside of the gauze net is protected by a twine net of inch mesh, which serves to take up the strain on the gauze net when it is being drawn through the water.

The lower end of the gauze net does not run to a point, but is truncated and attached to a flat metal ring. To this ring there is attached a bucket (*bk*), which is shown separated from the net in fig. 2, A. In order that the weight of the bucket may not be borne by the net, six stout cords (*crd*) run from the upper net ring to the lower net ring, and are made of such length that they support the weight of the bucket. The bucket is essentially a metal cylinder about 6 cm. in diameter inside and 6 cm. deep. It is supported on three legs. At the top it is arranged to be attached to the bottom ring of the net by means of three binding screws. The sides of the bucket are cut away as much as possible, so as to leave only six narrow strips of metal, and the windows thus formed are filled with gauze like that of the net. The bottom of the bucket is conical and has at its middle an outlet tube, closed by an accurately fitted plug, which may be removed from the inside. This plug is shown separately at fig. 2, B.

The whole net is suspended by means of three cords from a support consisting of three radiating arms. At the junction of the three arms is a strong iron ring, from which runs a rope, by means of which the net is drawn up. The rope is graduated in feet, or fractions of a meter, so that one may read off the depth to which the net descends. By holding in the hand the tri-radiate support from which the net hangs the latter may be kept from twisting on the supporting rope.

In working, a spar is lashed to the upper deck of the steamer, so that its end extends about 4 feet beyond the side of the vessel. To the end of the spar is lashed a pulley, through which the net rope runs. The net is then allowed to sink. In going down it takes in no water except that which is filtered through the gauze. It is sometimes let to the bottom and sometimes to a depth of only 2, 4, or 6 meters. It is then drawn up by hauling in the rope hand over hand. The net is always hauled up by the same person and note is made of the number of seconds between the time it leaves the bottom and the time the top of the canvas cone reaches the surface. From this time the velocity of the net is determined. The net is then drawn out of the water and allowed to hang at the end of the spar while the water drains out of it. At the same time a stream of water from a hose is turned upon the outside of the net. This water is filtered in passing through the net gauze to the inside, so that it does not add anything to the material captured in the net. The stream washes all the plankton into the bucket beneath.

After the water has partly drained out of the bucket, the binding screws are loosened and the bucket is removed and taken into the cabin. Here nearly all the water is allowed to drain out through the gauze sides of the bucket and the plankton adhering to the inside is washed down into the conical bottom by means of a stream of filtered water from a wash bottle. All the material taken in the net is thus collected into the conical bottom of the bucket. A small glass beaker is then placed beneath the tube in the bottom of the bucket, the plug is removed, and the plankton falls into the beaker. The inside of the bucket and the plug are then rinsed several times in filtered water and the rinsing water is added to the material in the beaker. The small quantities of material obtained necessitates great care in handling lest some of it be lost. The substitution of a plug in the bottom of the bucket for the stopcock used by Apstein is believed to be an advantage, in that it allows the inside of the tube to be rinsed with greater thoroughness.

The small quantity of material now in the beaker contains very minute forms. If this material be turned into a bottle of some fixing or killing fluid, and if this fluid be afterward poured off and alcohol substituted for it, some part of the material is sure to be poured off and lost. After much experimenting we finally hit upon the following device for preserving the material:

A short 6-dram homeopathic vial has its bottom removed and edges annealed. The bottom is then closed by tying over it with fine silk thread a piece of the No. 20 gauze, such as is used for the net. The contents of the beaker are poured into this tube, and by gentle tapping the water is made to filter very rapidly through the gauze bottom, leaving the plankton in the tube. Before all the water has filtered away a label is placed in the tube and the open end is closed by tying over it a piece of the gauze. The tube (see fig. 3) is then placed with other tubes in a large bottle of fixing fluid. (We used alternately Flemming's solution and Kleinenberg's picro-sulphuric acid.) The tube is then passed through successive grades of alcohol (preceded by water in the case of the use of Flemming's solution), and is finally preserved in 82 per cent alcohol. In passing the tube from one fluid to another it may be emptied of its fluid by forcing air into it by means of a pipette held against the gauze at either end. When the tube, emptied of its fluid, is placed in the next fluid it may be filled by immersing it in the fluid and removing with a pipette the air previously forced in. This method prevents the loss of plankton in the manipulation, and it also saves much time and enables one to pack many tubes of plankton in a single large vessel.

When the plankton has been preserved in the tubes they must be taken to the laboratory in order to carry out the rest of the work. Here the contents of each plankton tube are measured in the following manner: The gauze is removed from one end of a tube and carefully rinsed free from any adhering plankton. The alcohol used in rinsing is placed in a beaker and the contents of the tube poured into the beaker. The tube and the other gauze are thoroughly rinsed and the rinsings placed in the beaker. The contents of the beaker are now turned into a tube graduated to tenths of a cubic centimeter. This tube is allowed to stand twenty-four hours in order that the lighter constituents of the plankton may settle, and the volume is then read off and recorded.

The volume thus obtained is the volume of plankton taken by the net in drawing it vertically through, let us say, a distance of 200 cm. The area of the opening into the net is about 1,250 sq. cm. Hence the net might be thought to have filtered a volume of water equal to the area of its opening multiplied by the distance through which it is drawn. On this assumption the net would have filtered, in this case, 1,250 by 200, which is 250,000 c. c. of water, and the volume of plankton taken (perhaps 1·5 c. c.) would be the volume contained in 250,000 c. c. of water. Since the gauze net offers considerable resistance to the water it is not true that the net filters the whole of the column of water through which it is drawn; on the contrary, a part of this column is forced aside while another part passes through the net. The proportion of water which passes through the net depends upon the velocity of the net. Let us suppose that it is one-half of the whole column; then the 1·5 c. c. of plankton taken represents not the amount in 250,000 c. c. of water, but the amount in 125,000 c. c. of water. To get the volume of plankton in 250,000 c. c. of water, we must multiply the volume taken by 2. Similarly, under whatever circumstances the net is drawn, if we wish to know the amount of plankton contained in the column of water through which it is drawn we must multiply the volume of plankton taken by some number which represents the relation of the volume of water strained to the whole column of water through which the net is drawn. This number is called the coefficient of the net.

In the case of our net the volume taken when multiplied by the net coefficient gives the total volume of plankton under an area of 1,250 sq. cm. of the lake surface. In order to get the area under one square meter of lake surface this number is multiplied by 8 (1,250 c. c. is one-eighth of a square meter). The coefficient of the net used is now being investigated, but has not yet been accurately determined, so that the reduction of the volume taken to the actual volume and to the volume under a square meter of surface can not be attempted at this time.

The following table shows the results obtained by measurements of the volumes taken at five of the stations. The volumes taken at the other stations, with the necessary reductions and a fuller discussion of the results, will appear in the forthcoming bulletin of the Michigan Fish Commission:

Schedule of the hauls of the vertical net.

Date, 1893. Month.	Day.	Hour.	Number of haul.	Depth of water in meters.	Depth of haul in meters.	Temperature of water in degrees centigrade. Top.	Bottom.	Temperature of air, degrees centigrade.	Wind.	Sky.	Water.	Volume taken in cubic centimeters.
IX	8	11:10 a. m ..	III q ..	5·94	5·54	17.2	17.2	19.2	NE. 1 ..	Cloudy	Slight waves..	·90
		11:30 a. m...	III ...	5·94	5·54	"	"	"	NE. 1 ..	....do	....do	1·27
		11:45 a. m...	III^2 ..	5·94	4·50	"	"	"	NE. 1 ..	....do	....do	·80
		1:15 p. m...	III^3 ..	5·94	3·00	"	"	19.8	NE. 2 ..	Cloudy and sunny ..	....do	·98
		1:30 p. m...	III^4 ..	5·94	1·50	"	"	"	NE. 1 ..	....do	....do	·87
	9	10:40 a. m...	V q ...	5·66	5·26	18.2	17.9	19.8	SE. 1...	....do	Moderate swell	·90
		11:00 a. m...	V	5·66	5·26	"	"	"	SE. 1...	....do	....do	1·19
		11:15 a. m...	V^2....	5·64	4·50	"	"	"	SE. 1...	....do	Swell and waves.	·83
		11:30 a. m...	V^3....	5·64	3·00	"	"	"	SE. 1...	....do	....do	·63
		11:45 a. m...	V^4....	5·64	1·50	"	"	"	SE. 1...	....do	Not so rough as V^3.	·54
	10	1:45 p. m...	IX q ..	4·69	4·28	18.4	18.1	25.	N. 1....	....do	Slight waves..	·66
		2:00 p. m..	IX....	4·69	4·28		"	"	N. 1....	....do	....do	·62
		2:10 p. m...	IX^2...	4·69	3·00	"	"	22.8	N. 1....	....do	Moderate waves.	·68
		2:30 p. m...	IX^3...	4·69	1·50	"	"	"	N. 1....	....do	Slight waves..	·42
	17	10:30 a. m...	XIX q	4·78	4·37	18.1	18.1	......	NW. 3 .	Clear	Rough	2·43
		10:45 a. m...	XIX..	4·78	4·37	"	"	......	NW. 3 .	....do	....do	4·50
		11:00 a. m...	XIX^2.	4·78	3·00	"	"	......	NW. 3 .	....do	....do	3·29
		11:45 a. m...	XIX^3.	4·78	1·50	"	"	......	NW. 3 .	....do	....do	2·66
		3:15 p. m...	XX...	8·84	8·43	18.9	18.6	17.7	N. 1....	Hazy	Smooth	2·47
		3:30 p. m...	XX q .	8·84	8·43	"	"	"	N. 1...	....do	....do	2·50
		4:00 p. m...	XX^2..	8·84	6·00	"	"	"	N. 1....	....do	....do	1·75
		4:15 p. m...	XX^3..	8·84	3·00	"	"	"	None ..	....do	....do	1·97
		4:30 p. m...	XX^4..	8·84	1·50	"	"	"	None ..	Foggy	....do	1·43

The fourth column contains the arbitrary number given to each haul of the net. The Roman numerals indicate the number of the station. Two hauls were always made from the bottom; one of these, distinguished by the letter q, is intended to be used for qualitative work, the other is indicated by the station number only. The small Arabic numerals affixed to the remaining station numbers serve to indicate the different hauls which do not reach the bottom, the number 2 indicating the haul made from the greatest depth. The fifth column gives the depth of water and the sixth the depth from which the net was hauled. When the net is hauled from the bottom the depth from which it is hauled is reckoned from the top of the canvas cone. It equals the depth of water minus the height of this cone. The remaining columns give the temperature of air and water in degrees centigrade, the direction and strength of the wind, and condition of the sky and water. The last column gives the volume taken.

The same net was used for all the hauls, and if we assume that it was drawn in each case with the same velocity, then the volumes taken in the different hauls may be directly compared with one another without applying the correction. It is not possible to compare the measurements shown in this schedule with those given by Apstein for European lakes, until the measurements here given have been reduced to show the volume under a square meter.

Stations III, V, and IX are in Lake St. Clair, while stations XIX and XX were in Lake Erie near the Put in Bay Islands. The following facts are evident from an inspection of the schedule:

1. There is about three times as much plankton at stations XIX and XX in Lake Erie in the month of September as at any of the stations in Lake St. Clair.

2. The hauls made by letting the net down but a little way from the surface contain nearly as much plankton as those made from the bottom at the same stations. Thus at station III the two hauls from the bottom yield an average of 1·09 c. c., while a haul (III, 4) made from a depth of but 1·5 meters contains 0·87 c. c. In the case of station V the amount falls from an average of 1·05 for the bottom haul to ·54 for the 1·5 meter haul. In the case of station IX the numbers are 0·64 c. c. and 0·42 c. c., respectively. It thus appears that one-half or more than one-half of all the plankton occurring in water 5 meters deep is in the upper 1½ meters of the water. A similar result was reached by Apstein. Whether the plankton maintains the same relation to the surface at night or at other seasons of the year requires further investigation.

After having determined the volume of plankton in any locality it is possible to count the number of animals and plants of each species occurring in the volume of plankton taken. The method of accomplishing this has been worked out by Hensen, and is essentially as follows: Let us suppose that 1 cubic centimeter of plankton has been taken. One-tenth or one-hundredth of this is spread on a glass plate upon which parallel lines have been ruled with a diamond. Hensen has devised means by which the one-tenth or one-hundredth part may be accurately measured. The glass plate is then placed upon the stage of a specially constructed microscope. This stage is provided with a suitable carriage actuated by micrometer screws, and upon this carriage the glass plate may be moved about, so that it is possible to examine all parts of it. The number of each species of animal and plant upon the plate is then counted, the lines serving to separate the forms counted from those still to be counted. By thus counting the forms contained in a tenth part or a hundredth part of the plankton taken the number contained in the whole plankton taken may be calculated. It is then possible to calculate the number of animals of any one species occurring under a square meter of surface. It is possible also to calculate the numbers of any species at any depth. Thus we may find that in a haul made from a depth of 3 meters there are 2,000 cyclops, and in a haul made at the same time and place, but from a depth of 1½ meters, there are but 500 cyclops. We have, then, the number of cyclops contained in the whole column of water (3 meters long) and the number contained in the upper half of this column (1.5 meters long). The difference between these two numbers must be the number of cyclops contained in the lower half of the column of water. In other words, then, 1,500 cyclops are living in a known volume of water, let us say 1 cubic meter, at a depth of from 1½ to 3 meters. By this method of counting the number of forms in each column of water and by subtracting the contents of one column from the contents of another we may know at what depth each form lives and in what numbers. We may also know what its migrations are at different hours of the day and at different seasons of the year.

The plankton taken in Lake St. Clair has not yet been counted, owing to delay in procuring apparatus, but it is hoped this will be accomplished during the year.

The fish-culturist and the fisherman will now wish to know what practical results have come from our work. The work was undertaken as a scientific problem, the determination of the biological conditions existing in the lake. This problem is very large and will necessarily, more especially if extended to the whole chain of lakes, involve the work of many investigators for many years. It is believed that the past summer's work is a step toward its solution. Any operation of practical fish-culture which involves Lake St. Clair is likely to be guided to some extent at least by the data which we have collected.

It must deal with a shallow, roily lake, poor in plankton and in littoral forms, but rich in bottom fauna and flora. Bottom-feeding fish which are adapted to roily water of this temperature will find here a rich pasturage. This is illustrated in the case of the carp, which seems to have made its way into the lake through the small tributary streams. This fish is multiplying rapidly and is of excellent quality.

It was hoped that we should find in the lake the young whitefish and that we might be able to determine the conditions under which this fish lives. In this we were disappointed. It is possible that a search begun earlier in the season and with more elaborate apparatus would succeed. It is manifestly not possible to say whether or not the lake is a suitable one in which to plant whitefish, until we know the habits of the fry. If the fry feed only upon the minute crustacea of the surface plankton, as Forbes found them to do in confinement, then they would find food much more abundant in the region of the Put in Bay Islands in Lake Erie than in Lake St. Clair. If they feed upon the many small animals which inhabit the bottom vegetation (this is the habit of the adult whitefish) then it would be hard to find a better place than Lake St. Clair.

The Michigan Fish Commission has made a beginning in the investigation of the biology of the Great Lakes. It has shown great foresight in instituting the work, has provided liberally for it, and has not hampered it by unwise restrictions. Such an investigation, carried out as a scientific enterprise, without restriction, is sure to yield results of the utmost value to the fisheries. This statement needs no other justification than is contained in the facts alluded to at the beginning of this paper, the fact that both the fish-culturist and the fisherman are dealing with a problem with but little knowledge of the nature of the materials involved. Let them study to understand the nature of these materials. Let us have a biology of the Great Lakes and we shall have both fish-culture and fishing on a surer basis.

To build up a knowledge of the biology of the Great Lakes must take the time of many men for many years, and must require the expenditure of large sums of money. It is an enterprise that should commend itself to every State which has an interest in fish-culture in the lakes. Especially should such an enterprise commend itself to the commercial fisherman, as he has much to gain by it.