LIMNOLOGICAL OBSERVATIONS IN THE UPPER MISSISSIPPI, 1921.

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CONTENTS.

INTRODUCTION.

The present paper deals with the results of the hydrobiological investigation of the section of the upper Mississippi between Hastings, Minn., and Alexandria, Mo., which is about 465 miles long if measured along the steamboat channel. At the extreme ends of this section the river forms two lakes—Lake Pepin and Lake Keokuk (fig. 3, p. 352). Lake Pepin, located 28 miles below Hastings, is a natural lake about 25 miles long and from 1 to 3 miles wide. Lake Keokuk is a recently formed basin that extends northward above the Keokuk Dam for about 60 miles. Between these two lakes, about 130 miles above the foot of Keokuk Lake and 240 miles below the foot of Lake Pepin, the river flows through the so-called Rock Island Rapids. The bed of the river here forms a series of steps causing rapids with a total fall of 21 feet in 16 miles. The character of the river above and below the

Rock Island Rapids is almost the same; the average slope from Minneapolis to Le Claire, at the head of the rapids, is about 0.35 foot per mile; from Rock Island, Ill., below the rapids, to the head of Keokuk Lake at Oquawka, Ill., 0.38 foot per mile. In Lake Pepin the river has a fall of less than 0.2 foot in 24 miles.

A peculiar characteristic of the river is the great number of islands. Between St. Paul and the mouth of the Missouri, 658 miles, there are about 540 big enough to be marked and enumerated on the map. Many of these are more than 10 miles long and of irregular shape. They split the river into many sloughs and form many bays and channels, most of which are too shallow to be reached even in a small flat-bottom river launch. The character of the river is clearly shown on the picture (fig. 1) taken from the top of Queens Bluff, 10 miles below Homer, Minn. Often the entrance to a slough is barred by sand deposits checking the flow of the water and forming a closed bay or a shallow temporary pond. Many lakes and ponds are found also on the islands, but in the warm season, when the river is at its lowest, usually in July and August, they almost entirely dry up. In many places the banks are covered with a soft dark-brown mud and a sparse aquatic vegetation is found along the river except in the section between Prairie du Chien and Homer, where beautiful water lilies grow here and there in great profusion along both sides of the river.

In the southern extremity of this section the flow of the river is obstructed by the Keokuk Dam. This dam, built in 1913, has been fully described in technical and in biological literature (R. E. Coker, 1914; Mississippi River Power Co., 1913) and it is unnecessary to repeat the descriptions here, although some data must be given. The dam extends from the Illinois side at Hamilton to the Iowa side at Keokuk. It is 4,278 feet long, and with abutments, power house, lock, and dry dock forms an uninterrupted barrier about 1 mile long. Its height is 53 feet. The water flows through 119 spillways, but ordinarily only a few of them are in use simultaneously. The difference between the water levels above and below the dam is about 35 feet at mean flow. Keokuk Lake extends about 60 miles northward from the dam and is from 1 to 2 miles wide. Its lower part covers the area where formerly the Des Moines Rapids existed. The formation of this artificial lake caused the submersion of about 25,000 acres of low-lying shore land and islands. In order to facilitate navigation not less than 5,000 acres of timber and brush near Fort Madison were cleared and burned. Dead trees cover many of the overflowed islands and rising above the water form a strange and desolate picture characteristic of the upper part of Lake Keokuk.

Even these introductory statements are sufficient to show that the upper Mississippi is of particular interest because of its hydrobiological conditions.

The first point we have to take into consideration is that a barrier, almost impassable (in an upward direction) for all water animals, divides the river into two parts; the second is that a new lake has been formed. An immense quantity of water is held in check, and consequently there arises the possibility of the development of a lake (or pond) fauna rather than a river fauna. The biological development of a new basin can be followed from the earliest stage of its existence; moreover, in a new lake, we have the opportunity to introduce the organisms that have the most practical value and by this means to control the natural process of the

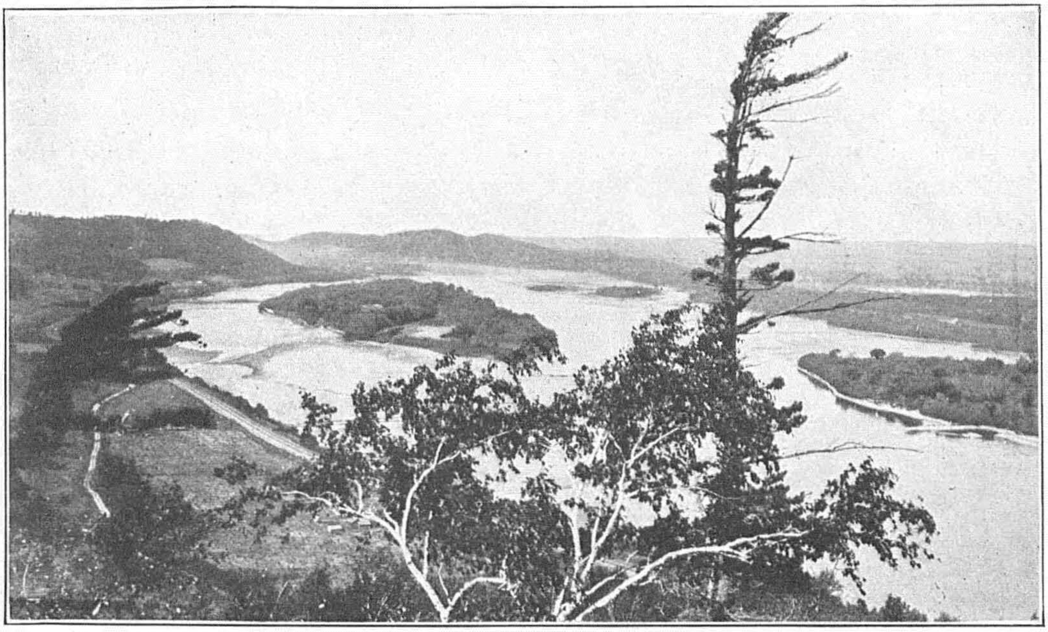

Fig. 1.—Mississippi River, looking upstream from Queens Bluff, 10 miles below Homer, Minn. September 11, 1921.

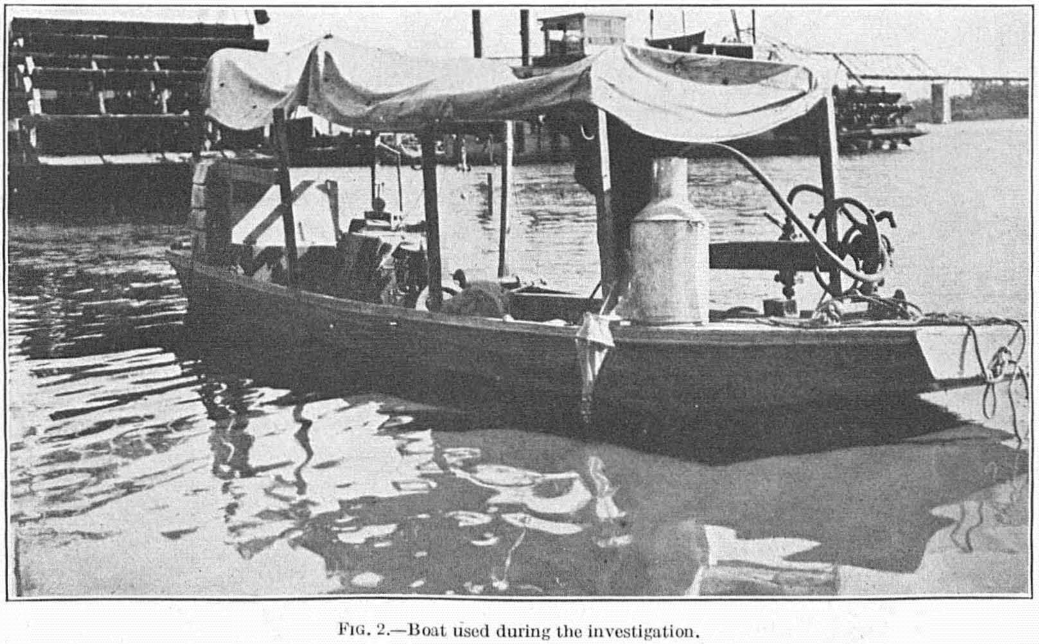

Fig. 2.—Boat used during the investigation.

formation of animal and plant communities. Of course, we should not forget the peculiar situation existing in Lake Keokuk, where a great quantity of old vegetation is now in a state of decomposition; therefore the conditions in the lake are unstable, and many changes will take place before the lake fauna and flora will be finally fixed.

The location of the lake as a part of the river is also worth considering, especially because there is no marked boundary between the river and the head of the lake; the river is gradually transformed into a lake, and every change in the river water immediately affects the whole body of the water in the lake. The presence of another lake, a natural one, also forming a part of the river and located 450 miles upstream and 240 miles to the north by direct line gives us the opportunity to compare the organic life of these two lakes one with the other and with that of the river.

The chief problem we have to investigate is how the organic life in the river has been affected by the new condition created by the dam and the consequent formation of a new lake. The solution of this problem requires many systematic and long-continued observations made at all seasons of the year. It is quite impossible to solve it completely after a short investigation, as such an investigation gives us only the general characteristics of the river and lake and may be used as a basis for further detailed study only.

The present investigation, made in the summer of 1921, is a study of the composition, amount, and distribution of plankton in various parts of the river and in the lakes. According to Hensen's (1887) principal work on plankton, the plankton organisms lie at the base of all the life in water. Hensen advanced the idea that the plankton is uniformly distributed in the sea and concluded that the determination of the amount of plankton under a unit of area of any part of the sea would afford a measure of the productive capacity of that part. This idea has been used very often as a basis in hydrobiological investigations of inland waters, especially for the determination of the productive capacities of ponds used for fish culture. Among the water organisms the planktonic forms are the most sensitive to the external conditions of existence. Every change in the surrounding medium affects these forms immediately, suppressing the reproduction of some and furthering that of the others. Therefore the composition of the plankton is characteristic for every type of basin, and its quantity may serve as an indicator of the productive capacity of a pond or lake because the number of higher animals, such as fishes and mussels, whether permanent inhabitants or only temporary visitors, depends directly or indirectly on the quantity of plankton existing in the basin.

The importance of plankton to other organisms living in water has been acknowledged by all scientists, but the question of the regularity of its distribution has been very much disputed. An especial interest in this question has arisen since Pütter's work (1907) on the nutrition of sea animals by organic matters dissolved in water. Hensen (1887), Lohman (1901, 1903, 1908), Gran (1912), and others pointed out that the distribution of the pelagic plants in the sea at any rate is extremely regular. Lohman has found that at certain seasons 10 to 15 $cm.^3$ of the sea water are sufficient to give a representative sample of the total plankton. At the same time Gran has shown that often in tropical waters dense masses of Trichodesmium collect as water bloom in certain areas and not in others, and that diatoms near the edge of the polar ice occur in more or less local swarms.

According to Gran the irregularities just mentioned do not invalidate the general statement but arise because the conditions of existence vary even in closely adjoining areas. The distribution of zooplankton is more irregular. The organisms may gather in certain areas in abundance and may be scarce in an adjacent area. This frequently occurs in the sea alongside currents and in bays. Moore, Edie, Whitley, and Dakin (1912), criticizing Pütter's ideas, have shown that in a comparatively small area of sea surface there may be no uniformity in distribution of the plankton. We may admit that the plankton is uniformly distributed in a definite area of sea or lake if the conditions of existence in said area are uniform, but this does not mean that there is a uniform distribution of plankton in the whole basin. When we are studying the productiveness of a definite part of sea, lake, or pond we are chiefly interested in finding out the quantity of organisms living in the whole body of water. As to their horizontal and vertical distribution these are quite different problems.

Many observations have been made on American and European lakes and ponds showing the irregularities in distribution of plankton (Huitfeld-Kaas, 1906; Skorikow, 1905; Galtsoff, 1914; Moberg, 1918). Bruno Hofer (1896), investigating the Bodensee Lake, came to the conclusion that the distribution of plankton may be called uniform when the difference between the volumes of plankton taken in two different parts of the lake does not exceed 25 per cent. The productive capacity of different parts of a lake may be different. Such a condition prevails when the form of the lake is irregular and there are many areas of shallow water covered with water plants. Thus Skorikow observed that the productiveness of Lake Pestovo (Russia) is greater near the banks and in shallow waters than in the pelagic region. Even in the pelagic region of a small and rounded lake the distribution of the plankton may be very irregular. In some cases observed by the writer in Kossino Lake near Moscow, Russia (Galtsoff, 1914), the difference in the volume of plankton in different parts observed simultaneously was more than 400 per cent. These conditions, however, were not stable and would change within 24 hours, the wind and the current apparently being the cause of such irregular distribution.

The estimation of the productive capacity of the basin must be based on many observations. A small number of catches obtained from the pelagic region is insufficient, and the conclusions drawn from such observations may be erroneous. The present investigation embodies a comparative study of the plankton of Lake Keokuk, Lake Pepin, and the Mississippi River between these two lakes, and is based on the examination of a large number of samples taken in various parts of the river and in the lakes. Some observations also were made in St. Croix Lake and in other tributaries of the Mississippi. All observations were made during the period from July 10 to September 24, 1921.

The author desires to express his gratitude to Dr. R. E. Coker, formerly in charge of the division of scientific inquiry, United States Bureau of Fisheries, for his many suggestions concerning the investigation; to R. L. Barney, director, and to H. L. Canfield, superintendent, United States Fisheries Biological Station, Fairport, Iowa, who so materially aided and facilitated the field investigation; to C. A. Sears, manager, Mississippi River Power Co., for information concerning the hydrography of the river and of Lake Keokuk; and to Dr. H. C. Frankenfield, United States Weather Bureau, who kindly furnished the data on river stages; and to express his indebtedness to Prof. T. H. Morgan, head of the department of zoology in Columbia University, for the courtesy of extending him the privileges of the laboratory where the examination of the plankton was made.

The author also wishes to make acknowledgment for valuable assistance in examination of plankton to Dr. Albert Mann, Smithsonian Institution, for identification of the diatoms in some samples of the collections; to H. K. Harring, United States Bureau of Standards, for his advice in identifying some of the species of Rotifera; to Dr. C. C. Curtis, Columbia University, for identifying the water plants collected in Lake Pepin and Lake Keokuk; and to Dr. T. E. Hazen, Barnard College, for identifying the blue-green algæ collected in St. Croix Lake.

METHOD OF INVESTIGATION.

SCHEDULE OF LOCALITIES.

It is very important in a comparative investigation to have the collections obtained and the observations made simultaneously, but as only one person was working in this case this was impossible. The first observations were made on July 11 at Fairport (fig. 3), where the headquarters of the expedition had been established. Lake Keokuk was visited twice, in June and at the end of September, the investigation of Lake Pepin was continued from August 18 until September 10, and the various parts of the river were visited during the periods August 1–18, September 1–5, and September 10–20. The details of this schedule are given in the following table:

TABLE 1.—*Schedule of investigation of Mississippi River between Hastings, Minn., and Alexandria, Mo., in the summer of 1921.*

Points visited.	Distance from St. Paul by steamboat channel, in miles.	July.	August.	September.	Points visited.	Distance from St. Paul by steamboat channel, in miles.	July.	August.	September.
Alexandria, Mo.	488¾	....	....	23	Between De Soto, Wis., and Lansing, Iowa	177	....	....	13
Des Moines River, Iowa	486⅝	....	....	23	Root River, Minn	148	....	....	12
Lake Keokuk between Keokuk, Iowa, and Burlington, Iowa	484–442	15–30	....	22–24	La Crosse, Wis	144⅛	....	....	11
Burlington, Iowa	441¾	14	....	....	Between Winona and Homer, Minn	119	....	....	11
New Boston, Ill	411⅝	13	....	20	Zumbro River, Minn	96¾	....	....	10
Fairport, Iowa	382½	11–12	9	....	One mile above Wabasha, Minn	81⅝	....	18	....
Rock River, Ill	362⅛	....	....	18	Reads Landing, Minn	77¼	....	30	10
Rock Islands Rapids, near Davenport, Iowa	359¼	....	11	17	Lake Pepin between Reads Landing and the head of the lake	77¼–55	....	18–29, 31	5–10
Six miles above Clinton, Iowa	320	....	12	17	Above the head of Lake Pepin	54¾	....	29	....
Four miles below Bellevue, Iowa	292	....	....	16	One mile above Red Wing, Minn	49	....	....	1
One mile below Cassville, Wis	237¾	....	....	15	Diamond Bluff, Wis	40½	....	....	1
Turky River, Iowa	233¼	....	....	14	St. Croix River and Lake, Wis	32	....	....	2
Wisconsin River, Wis	211¾	....	14	14	Prescott, Wis	30	....	....	2
Prairie du Chien, Wis	207½	....	15	14	Between Prescott, Wis., and Hastings, Minn	28	....	....	2
One mile below Lansing, Iowa	180¼	....	15	....					

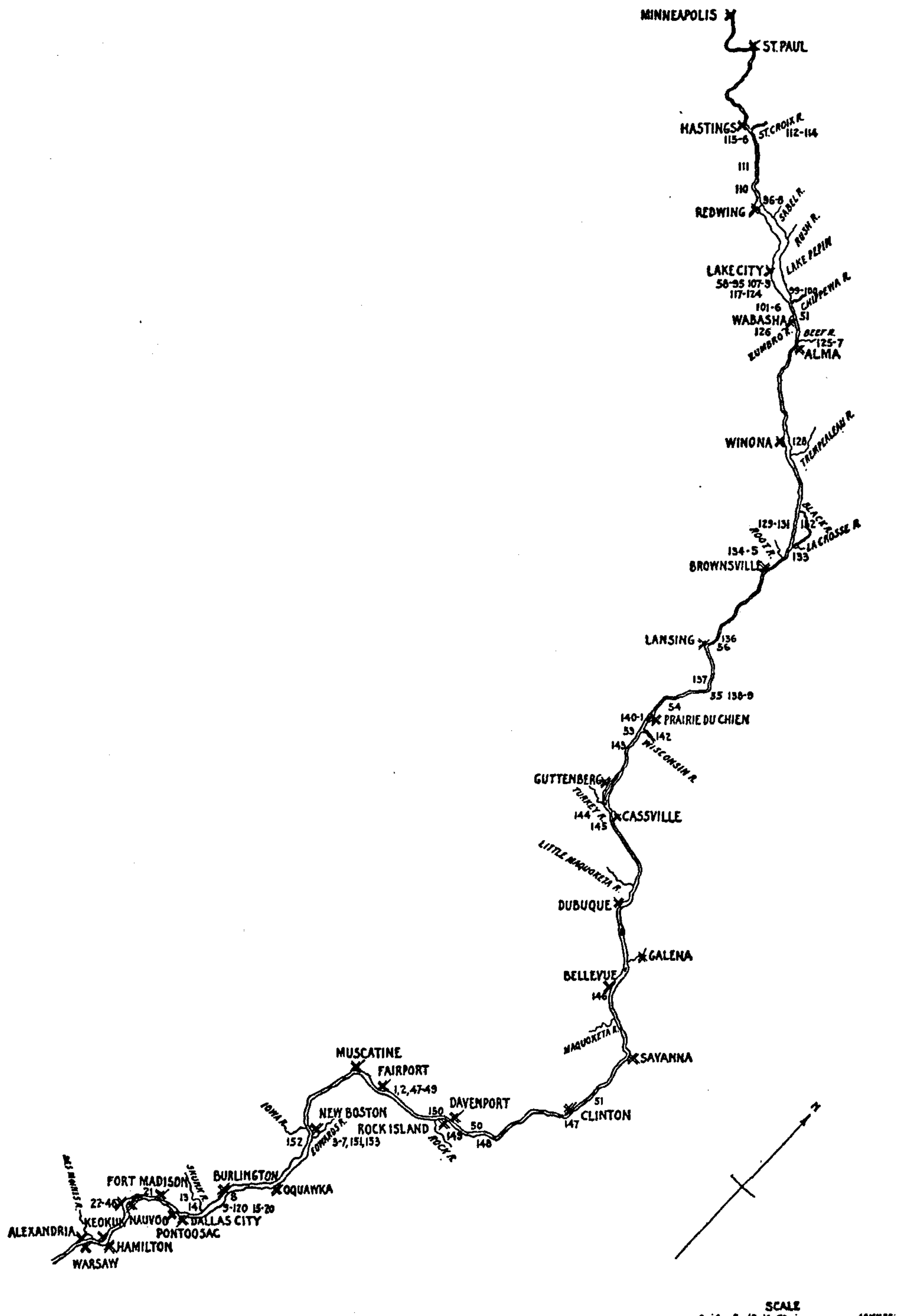

FIG. 3.—Mississippi River from Minneapolis, Minn., to Alexandria, Mo. (The figures indicate the serial numbers of stations.)

BOAT AND EQUIPMENT.

The question of a boat for hydrobiological work is of great importance, as the success of the exploration very often depends upon its suitability. Many difficulties arise when one has to work with one boat and has to visit different places on the river, parts of which are shallow, with sloughs and bays, while other parts widen into large lakes. During my investigation an ordinary fishermen's flat-bottom launch, 22 feet long, was used. All equipment and laboratory instruments, including a microscope, were placed in three specially constructed field chests and the chests were fixed on the stern, which in a short time could be transformed into a small field laboratory (fig. 2). An awning protected the instruments from showers. A pump with hose and a graduated tank were fixed on the bow.

Fully loaded and with two men aboard the boat drew 25 inches of water. It was convenient to have all instruments at hand and to be prepared to start the observations at any time or place, yet difficulties arose and many serious troubles even were encountered when it was attempted to reach the shallow parts of the river. In July and August the river was so low that even our boat was too deep to reach many of the sloughs and lateral channels. This was a great handicap to the whole work, because the observations in sloughs and bays are sometimes of greater importance than those in the main channel of the river. It was especially difficult to make observations on the overflowed area of Lake Keokuk, where branches of trees and bushes rising above the surface of the water form impassable thickets. Attempts to collect the material on foot here were also unsuccessful, for the bottom was covered with a thin brown mud incapable of supporting the weight of a human body. A small rowboat would be more suitable in such places if the equipment were not too heavy.

On windy days the water in Lake Keokuk and in Lake Pepin may become too rough for the safety of a flat-bottomed river launch. We had two accidents with our boat during storms on Lake Keokuk, and once the boat sank. Fortunately this happened near shore, but of course it caused considerable delay in the work. On Lake Pepin the weather was still less favorable, and the launch was changed for a keel boat (fig. 5).

Instruments.—For measuring temperature two reversing Negretti and Zambra (Richter) thermometers Nos. 281 and 283 were used, both of them having previously been tested by the United States Bureau of Standards (certificates No. Ttt–31154), and the data of observations have been corrected accordingly. The rate of current was measured with Price's electric water current meter, No. 970, manufactured by W. & L. E. Gurley (for description see Hoyt and Grover, 1916, pp. 9–12), this instrument also having been tested by the United States Bureau of Standards (test No. 31795). The current meter was not received until after the 15th of August, and during the first weeks of the investigations a simplified method of floats was used. A bottle filled with water until it nearly submerged was allowed to drift beside the boat; a distance of 20 feet had previously been measured on the gunwale of the boat and marked by two horizontally fixed sticks; time was taken first when the bottle passed under the forward stick and again when it passed beneath the second stick. The observation required two men, one on the bow to start the bottle some feet above the first mark and the other on the stern to hold the stop watch. The difference in data obtained by this method and by Price's current meter did not exceed 8 per cent. The float method can be used only if the position of the boat is exactly parallel to the direction of the current. If the current is slow and the wind blows across the river, the observation can not be made. During calm days on Lake Pepin the author often observed the drift of the plankton algæ alongside the boat when the current meter indicated no movement; evidently the drift was not strong enough to move the cups of the wheel. The Price current meter is more suitable for river observation than for lake observation. It seems that the instrument works only when the velocity of current is more than 0.2 foot per second.

The transparency of the water was measured with a round white disk, 25 cm. in diameter, attached to a long graduated metal rod. The results of the observations are expressed in centimeters, representing the depth at which the plate disappears from view.

Pump.—The greater part of the plankton collections was made with a pump. The water was pumped from different depths, usually at intervals of 5 feet, and then filtered through the plankton net made of No. 20 bolting silk. An iron double-acting oscillating force pump, No. 0 (manufactured by the Goulds Co., Seneca Falls, N. Y.), was used with a rubber hose 1 inch in diameter. The pump and the graduated tank of 50 liters capacity were fastened on the bow.

The galvanized-iron tank was cylindrical in form, with a long neck on the top and a pipe close to the bottom. In the neck was a graduated glass window. The total height of the tank was 28⅞ inches, the diameter of the bottom being 13¾ inches, the diameter of the neck 6 inches and its height 7⅜ inches, and the outlet pipe 10 inches long and 1 inch in diameter. The tank had a capacity of about 13 gallons, the mark on the neck corresponding to 50 liters having been made after many careful measurements. The same kind of tank was used in previous work on Lake Kossino near Moscow and has been already described (Galtsoff, 1914).

The hose was suspended on a line. At the river stations where the current was swift a weight of about 30 or more pounds was attached to the end to keep the line straight. It took about three minutes to fill the tank; the same amount of time was required to filter the water through the plankton net. Special care was taken to reduce the pressure on the filtering surface, the best method being to keep about three-fourths of the net in the water. The flow of water when emptying the tank was also regulated. The same net, Apstein's small vertical net, 13½ inches long, with an upper ring 4¾ inches in diameter, was used for the vertical plankton hauls. All collections were preserved in 3 per cent formalin.

DETERMINATION OF PLANKTON.

Two methods were used for volumetric determination of plankton: (*a*) settling in graduated tubes during 24 hours; (*b*) centrifuging for 2 minutes at the rate of 1,000 revolutions per minute. The first method has been strongly criticized

(Ward, 1900; Kofoid, 1897), and the author can only confirm the conclusions of these men. The inaccuracy of this method is so great that it must be abandoned entirely. More exact results are obtainable with the centrifuge method. A small hand centrifuge was used, 50 revolutions of its handle corresponding to 1,000 revolutions of the test tubes. During the observations 50 revolutions of the handle were made in 1 minute. The movement was controlled by counting the revolutions and simultaneously observing the stop-watch hand. After 2 minutes of centrifuging the volume of plankton settling on the bottom of the test tubes was read; from this the volume of plankton per cubic meter of water was calculated.

A complete quantitative study of the plankton was not undertaken. However, the number of Copepoda and Cladocera was counted because these two groups form the most important part of the food of plankton-eating fishes. In order to separate the Crustacea from other organisms, the plankton sample was filtered through No. 12 bolting silk and the remainder placed in a Petri dish 8 cm. in diameter with 1 cm. squares ruled on the bottom, a type of counting chamber used in quantitative bacteriological investigations. The uniform distribution of organisms was secured by shaking. If the number of Crustacea was less than 200 in a catch, all were counted; if greater, only 20 squares were examined and the average was taken, from which the number of organisms in a catch was calculated. The results of all the observations, including the number of Copepoda and Cladocera per 1 $cm.^3$ of water, are given in Table 29 (pp. 422 to 433), arranged in chronological order. The distances of stations from St. Paul are given in miles, the depths in meters. The distances were taken from the official publication of the Bureau of Lighthouses (Department of Commerce) "Light List, Upper Mississippi River and Tributaries, 13th Lighthouse District, 1914."

STATIONS.

Each point where observations were made is called a "station," and the location of the stations is shown in Figure 3. The number of each station on the map corresponds to its number in the tables. The stations were chosen after a careful examination of the map of the Mississippi River and on the basis of the information obtained from local men familiar with the river. The principal purpose was to make observations at every point where a substantial change in the river conditions could be expected. Therefore, the samples of plankton were collected and the observations made above and below the principal tributaries, in the main channel as well as in the sloughs and in the bayous. Usually in a section across the river or lake three stations were made, but if only one station was made it was in the main channel. The lake stations are shown in Figures 4 and 7. There being no intention to study the pollution of the river, no observations were made at cities where the river was polluted. More attention was paid to the lakes (Pepin and Keokuk), and therefore the number of stations on these lakes is considerably greater than on the river. In all, 171 stations were occupied, from which 673 samples were obtained after pumping and filtering a total of 25,800 liters of water through bolting silk.

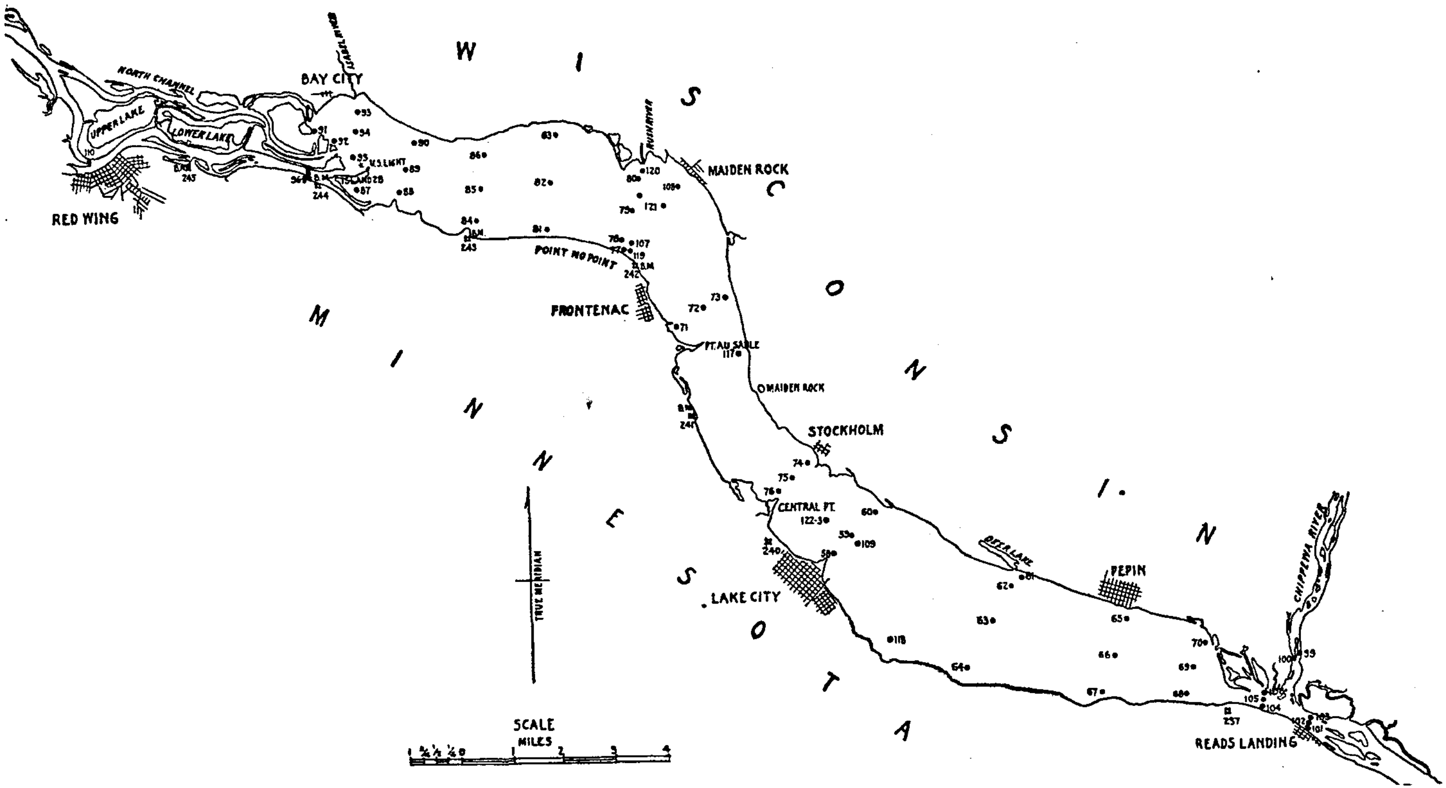

FIG. 4.—Lake Pepin. Location of stations, biological investigation, 1921. (Figures represent serial numbers of stations. B. M., bench mark.)

TABLE 2.—*Stations and number of samples collected during investigation of upper Mississippi River, 1921.*

Location.	Number of stations.	Samples collected.			
		Pump.	Vertical plankton net.	Dip net.	Total.
Mississippi River (main channel, sloughs, bays, and abandoned channels)	52	143	19	3	165
Tributaries of the Mississippi	19	45	6	5	56
Lake Keokuk	51	167	53	17	237
Lake Pepin	49	161	40	14	215
Total	171	516	118	39	673

PHYSIOGRAPHY.

THE RIVER.

The source of the Mississippi River has long been the subject of controversy. Lake Itasca, Minn., has been regarded as the head of this greatest American river, but according to an accurate map of Itasca State Park, issued by the Mississippi River Commission about 1910, Little Elk Lake, in northern Minnesota, latitude 47° 69′ N., longitude 95° 13′ W., is the real source of the "Father of Waters." The long history of the discovery of the Mississippi is fully described by Chambers (1910). The so-called Itasca State Park set aside by the State of Minnesota now covers 35 square miles of a basin containing the many glacial lakes forming the headwaters of the Mississippi. In scientific literature the upper Mississippi is considered rather a tributary of the lower Mississippi than a main stream. It drains 173,000 square miles, its total length is 1,293 miles, and its discharge into the lower Mississippi varies from 25,000 to 550,000 cubic feet per second. Similar data for the Missouri River are as follows: The length from the headwaters to the mouth of the Mississippi is about 3,000 miles, drainage area 541,000 square miles, and the discharge from 25,000 to 600,000 cubic feet per second. The annual rainfall over the upper Mississippi Basin averages 35.2 inches and over that of the Missouri 20.9 inches.

In respect to navigation the upper Mississippi can be divided into two sections—from the headwaters to St. Paul, head of navigation, 534 miles, and from St. Paul to the mouth of the Missouri, 659 miles. Only the latter is navigable by steamboats. The present investigation has covered 465 miles of the navigable part of the river; that is, about one-third of the total length of the river or about three-quarters of its navigable part. In its course the river forms many rapids and falls, the following being the principal ones: St. Anthony Falls, above Minneapolis, Minn.; Rock Island Rapids, between Le Claire, Iowa, and Rock Island, Ill., where the fall of the waters is about 21 feet in 16 miles; and Keokuk Dam, which has raised the water level at mean flow below the dam by 35.3 feet above the standard low water. The elevations of the water level at various points of the river, taken from the Mississippi River Commission charts, are shown in Table 3.

TABLE 3.—*Elevations of water level of the upper Mississippi River from Lake Itasca, Minn., to Alexandria, Mo.*

[Elevations, in feet, above Memphis datum, which is approximately 8.13 feet below mean Gulf level at Biloxi, Miss. The data refer to the condition before the construction of Keokuk Dam.]

Station.	Miles from St. Paul, Minn.	Water level (feet) above Memphis datum.	Mean stage at the days of sounding (feet).	Highest water known prior to survey (feet) above Memphis datum.
	Above.			
Little Elk Lake	534	1,578.6	...	1,579.9
Above St. Anthony Falls	...	809	...	...
Below St. Anthony Falls	...	732	...	...
St. Paul, Minn	...	696.2	4.6	711
	Below.			
Hastings, Minn	27⅛	681.9	4.2	695.7
Red Wing, Minn	50	675.8	4.9	...
Lake Pepin:				
Frontenac, Minn	61½	675.1	4.6	...
Lake City, Minn	68	674.7	4.1	677.7
Reads Landing, Minn	77½	674.6	3.9	...
Alma, Wis	88⅛	663.3	3.7	...
Winona, Minn	115⅞	650.6	3.3	664.1
La Crosse, Wis	144⅛	637.2	3.7	...
Prairie du Chien, Wis	207⅜	613	.9	633.8
Guttenberg, Iowa	228¼	606	1.9	614.2
Dubuque, Iowa	264⅞	594.4	1.9	...
Clinton, Iowa	326¾	574.2	.5	...
Le Claire, Iowa	347½	570.4	.9	...
Rock Island, Ill	363¾	550.2	1.4	568.6
Fairport, Iowa	383	542.9	.8	...
New Boston, Ill	411⅝	531.7	.2	...
Keithsburg, Ill	417⅛	529.7	1.1	...
Oquawka, Ill	429¼	525.1	1.0	...
Burlington, Iowa	441¼	519.5	1.2	535.8
Dallas, Ill	455⅛	514.1	1.6	...
Fort Madison, Iowa	462⅝	510.7	1.8	...
Nauvoo, Ill	469⅞	508.8	2.3	...
Lake Keokuk, head of the canal, opposite Galland	476	504.7	2.2	...
Keokuk, Iowa, foot of the canal	484	486.7	2.2	...
Alexandria, Mo	488¾	483.2	2.3	...

When leaving Itasca Lake the river is only 30 feet wide. In the Wisconsin section its width varies from 725 feet at Clayton to 2,400 feet near La Crosse. At Rock Island Rapids the narrow part of the river is about 800 feet wide, at Fairport, Iowa, it is about 2,600 feet wide, and at Keokuk, below the dam, about 2,000 feet. These data, based on the Mississippi River Commission charts, are only roughly comparable because they represent different stages of water. Between St. Anthony Falls and the mouth of the Ohio, 888 miles below, the Mississippi flows on the narrow flood plain between steeps and bluffs forming its gorge and its bed occupies a comparatively narrow part of it, varying from 8 per cent of the width of the flood plain at Clayton to 27 per cent at North Dubuque (Martin, 1916). In this portion the Mississippi flows through the western edge of the so-called "Driftless Area," world-famous on account of its geological peculiarity. Here the steep bluffs, rising 230 to 650 feet above the flood plain, form the most picturesque scenery of the Mississippi Valley. The river winds from one side of the flood plain to the other, numerous islands dividing its channel and forming many sloughs and bays which often are transformed by the sand bars into pools of stagnant water. A characteristic feature of the Mississippi flood plain is the many shallow lakes or pools, which seldom exceed 1½ miles in diameter. When the water is high the river floods the whole area, covering these lakes and the spaces between, but in summer many of them become almost dry.

FIG. 5.—Lake Pepin. Observations on a calm day.

FIG. 6.—Lake Pepin, looking upstream from Silver Fox Farm, August, 1921.

There are a great many of these lakes. Martin (1916) counted over 200 of them in an area of about 20 square miles in the Wisconsin section between Lynxville and De Soto, only the lakes that had no connection with the river being counted, the sloughs and bays being excluded. It seems that the number of lakes in other parts of the river is not less than in this section. Many of them have a rich aquatic vegetation, and as they slowly become filled with detritus they gradually become swamps. All stages of this process can easily be observed in many points of the Mississippi flood plain.

The depth of the Mississippi River between St. Paul, Minn., and Alexandria, Mo., in the main channel varies from 5 to 37 feet, though the depth at any given place is subject to many fluctuations, depending on the stage of the water. The deepest points found during the present investigation were 27 feet in the main channel near Prairie du Chien, Wis., on August 14, and 25 feet above the mouth of the Chippewa River on August 30. The depth found at most of the river stations varied from 9 to 15 feet.

LAKE PEPIN.

In the northern part, about 50 miles below St. Paul, the river fills out its gorge, covering the whole flood plain from bluff to bluff, and forming the so-called Lake Pepin (figs. 5 and 6), which covers an area of 38½ square miles and has a depth of about 35 feet. The maximum depth of 56 feet, shown on Mississippi River Commission chart No. 180, occurs at the very foot of the lake and covers only a small area. Lake Pepin owes its origin to the Chippewa River, a small tributary entering the Mississippi from the east. The delta of the Chippewa extending into the main stream lies at the southeastern end of the lake and is now covered with modern flood-plain deposits. It has dammed the Mississippi River, leaving a narrow outflow opposite Reads Landing, and the river above the delta has overflowed its banks and has filled out the whole gorge. Owing to the slope of the Chippewa, which is considerably greater than that of the Mississippi, it has been able to deposit more material than even the great Mississippi could carry away, hence the formation of the delta. The elevation at the source of the Chippewa River is about 1,500 feet above sea level. At Chippewa Falls, 62 miles above its mouth, it is 806 feet, 141 feet higher than at its mouth (Herron, 1917), making a slope of about 2.3 feet per mile. On the other hand, the fall of the Mississippi in the section from St. Paul to Reads Landing, Minn., 77½ miles, is about 21 feet, or 0.27 foot per mile. Thus the fall of the Chippewa River is about ten times that of the Mississippi River, and as a result the Chippewa River has formed a sand bar which acts as a dam almost 3 miles wide and which the Mississippi could not break.

At the northern end of Lake Pepin the Mississippi has built its own delta, which is still growing. Apparently the lake originally extended as far north as Red Wing, about 5 miles upstream from the present head of the lake. The northern part of the lake near Bay City, Wis., is now very shallow and almost entirely filled with silt and sand; the former northern channel (see fig. 4) has been reduced to a depth not exceeding 1.5 feet. Below Red Wing there are three large lakes and several small ones, all between the channels in the delta. In August, 1921, they were partially dry and covered with water plants, and the northern channel was impassable. The delta of the Mississippi River has reduced the inlet of the lake to a narrow stream less than 1,000 feet wide. The outlet above the mouth of the Chippewa River is 1,400 feet wide. There are also two small deltas in Lake Pepin, one formed by the Rush River near Maiden Rock, the other by the Isabel River near Bay City.

Bluffs and terraces form the shores of the lake (fig. 6). On the low shore lines, especially on the Minnesota side, the waves and currents have deposited sand and formed spits, some of them inclosing triangular swampy areas (see fig. 4). These capes (Point au Sable, Central Point, point at Lake City, and others) reach far out into the water and form a very characteristic feature of the lake.

The fall from Red Wing, 5 miles above the head of the lake, to Reads Landing on the outlet 28 miles below, is only 0.5 foot, about 0.02 foot per mile. In the middle part of the lake there is no fall of the water at all. At the head of the lake 3 miles above island No. 28 (see fig. 4) the slope is 0.26 foot for 3 miles; between island No. 28 and Wacouta Point it is only 0.07 foot for 3 miles. At the foot of the lake above the mouth of the Chippewa River (bench mark No. 237) the slope is 0.25 foot per 3 miles, and just below Reads Landing it is 1.65 feet per 3 miles.

The shore line of Lake Pepin is comparatively straight and there are few sloughs and bayous favorable for aquatic vegetation. Most of the banks are rocky or covered with sand. Water plants are found very close to the sandy spits where they are protected from waves (Point au Sable, Central Point), and in the lower shallow part near Pepin Village and the delta of the Chippewa River. Here *Potamogeton crispus* and *americanus*, *Ruppia occidentalis*, and *Vallisneria spiralis* grow in great profusion. A large, shallow area near Bay City in the northern part of the lake has very sparse vegetation. At the rocky shore line all stones are covered with sponges (*Spongilla fragilis*).

LAKE ST. CROIX.

Lake St. Croix, 21 miles above Red Wing, is similar to Lake Pepin and of the same origin. The only difference is that instead of the main stream a tributary was dammed. The deposits of the Mississippi obstructed the mouth of the St. Croix River, which filled out its valley and formed a lake 23 miles long and from one quarter to 1½ miles wide.

LAKE KEOKUK.

Lake Keokuk, as has already been said, is a newly formed lake spreading from the Keokuk Dam northward as far as Burlington or Oquawka and covering the area of the former Des Moines Rapids. According to the contract between the United States Government and the Mississippi River Power Co. the level of Lake Keokuk must be maintained at 515–525 feet above Memphis datum. Consequently the influence of the dam disappears at Oquawka, where the natural mean stage is about 525 feet above Memphis datum. (See Table 3.)

According to information received from the Mississippi River Power Co. the rise of water level above the dam at the mean flow of 50,000 c. f. s. caused by Keokuk Dam is as follows:

	Feet.
Keokuk Dam	35.3
Fort Madison	12.7
Burlington	4.4
Oquawka	1.0
Keithsburg	0.0

FIG. 7.—Lake Keokuk and the adjacent parts of the Mississippi River. (Above dam areas formerly submerged, but shallow, are defined by dotted outlines; areas form above water but now submerged and relatively shallow are indicated by close stippling. Below dam shallow areas are indicated by stippling. Boat channels, 1 indicated thus, . . . ; 1904 thus, ...; old wing dams indicated ———. Reduced from blue print furnished by Chief of Engineers, War Department.)

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Backwater entirely disappears at a flow of 50,000 c. f. s. a few miles above Oquawka. At flood stages backwater from the dam does not reach Keithsburg. Thus the head of the lake is approximately near Burlington.

A characteristic feature of Lake Keokuk is that it has no real head, the river being transformed gradually into a lake (fig. 7), and the overflowed islands below Burlington being the first noticeable signs of its existence. This lake can be divided into two parts, the upper extending from Burlington down to the Nauvoo-Montrose line and the lower extending from this line to the dam. Large areas of submerged forested islands and low-lying shore lands are found in the upper part. Here the lake is divided into many bayous, channels, and sloughs and passes among wooded islands and former agricultural lands which are now under several feet of water. The dead vegetation rising above the water forms a very characteristic peculiarity of this part of the lake (fig. 8).

The body of the lower part of Lake Keokuk has a comparatively straight shore, in several places bordered by bluffs, and compared with the upper part has fewer sloughs and bayous favorable for aquatic vegetation. The depth of the lake gradually increases from Burlington to Keokuk, attaining 37 feet near the dam. During the investigation on July 30 the maximum depth was found to be at station No. 45. The bottom is covered with soft brown mud.

In spite of favorable conditions, aquatic vegetation has not yet developed materially in the lake. It is almost entirely absent in the lower part, but more is found in the upper part, where the shallows and the protected areas on the submerged wooded islands are very favorable for the development of water-plant associations. Evidently the period of eight years since the dam has been constructed has not been long enough for a full development of aquatic vegetation. At the present time only one form (*Sagittaria longifolia*) seems to grow in profusion along the shore and on the overflowed islands (fig. 9). One can find also many *Ceratophyllum demersum* on the shallows and long filaments of Lyngbya sp., which cover the trunks of the trees and other objects under the water. A characteristic of this section is the rich development of duckweed (Lemna), which is found in such abundance that sometimes it covers several acres of water surface with a dense green layer. When the water rises Lemna is washed away from the submerged areas and is carried down to the dam, forming small floating islands.

The velocity of the current in Lake Keokuk at the mean stage decreases from 2.3 feet per second at Keithsburg to 0.3 foot per second near the dam. At intermediate points the velocity is as follows: 1.90 f. s. at Burlington, 1 f. s. at Dallas, 0.58 f. s. just below Nauvoo, and 0.34 f. s. 2 miles above the dam. It can be seen that in regard to the current also there is a great difference between the lower and upper parts of the lake. In the lower part, where the water is almost stagnant, the conditions are more stable than in the upper part, where the lake is more like the river. The conditions just mentioned exist only at the average and low stages of the river; at time of overflow they disappear almost entirely.

There is a marked difference between Lake Keokuk and Lake Pepin. There is no boundary between the river and the head of Lake Keokuk, while in Lake Pepin the inflow is reduced to a comparatively narrow stream. Probably when Lake Pepin extended as far northward as Red Wing and the Mississippi had not

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yet formed the delta that now separates the body of the lake from the river the conditions in Lake Pepin were similar to the present conditions in Lake Keokuk. As a result of the physiographical relations the river exerts more influence on Lake Keokuk than on Lake Pepin, the latter being more definitely separated from the river. This is of great importance to all organic life of both lakes.

STAGES.

The stages of the river are subject to considerable fluctuation. Usually the river is at its lowest in the warmest season (July to August) and in winter (December to January), when it is covered with ice; the highest stages occur in spring and fall. The heaviest rainfall over the upper Mississippi Basin occurs in May and June, and the highest stages often coincide with these months, but the time and duration of high water are subject to much variation. The fluctuations of the stages of the upper Mississippi during 10 years (1911–1920) are shown in Table 4, where the highest and the lowest gauge readings and the dates on which they occurred are given for 8 points from St. Paul, Minn., to Keokuk, Iowa. (The data are taken from "Stages of the Mississippi River," Mississippi River Commission, 1911–1920.) The greatest difference between the lowest and highest stage is about 17 feet (Prairie du Chien, 1920).

The stages of the river during the present investigation are given in Table 5, which contains the daily data for 14 points from St. Paul, Minn., to Warsaw, Ill. (5 miles below Keokuk), obtained from the United States Weather Bureau. The only considerable rise of water during the three-month period of investigation occurred in the latter part of September (beginning the 16th) in the lower part of the river below Le Claire.

The stages at Lake Keokuk are subject to daily fluctuations, depending on the operation of the dam. Sudden rises and falls, ranging from 12 to 18 inches, brought many complaints from the local population against the Mississippi River Power Co., and the question was even investigated by a special committee of Congress (see Rivers and Harbors Committee, Impounding of water above Keokuk Dam, hearings on the subject of House Resolution 468, 1917). From a biological point of view the daily fluctuations of the water level in the lake are of importance because every fall and subsequent rise of water causes a decrease in plankton. The water running into the lake is considerably poorer in plankton than that in the lake, and therefore every sudden rise diminishes the quantity of plankton in the lake. During September 16 to 26, when the river was rising, the plankton of Lake Keokuk disappeared almost entirely.

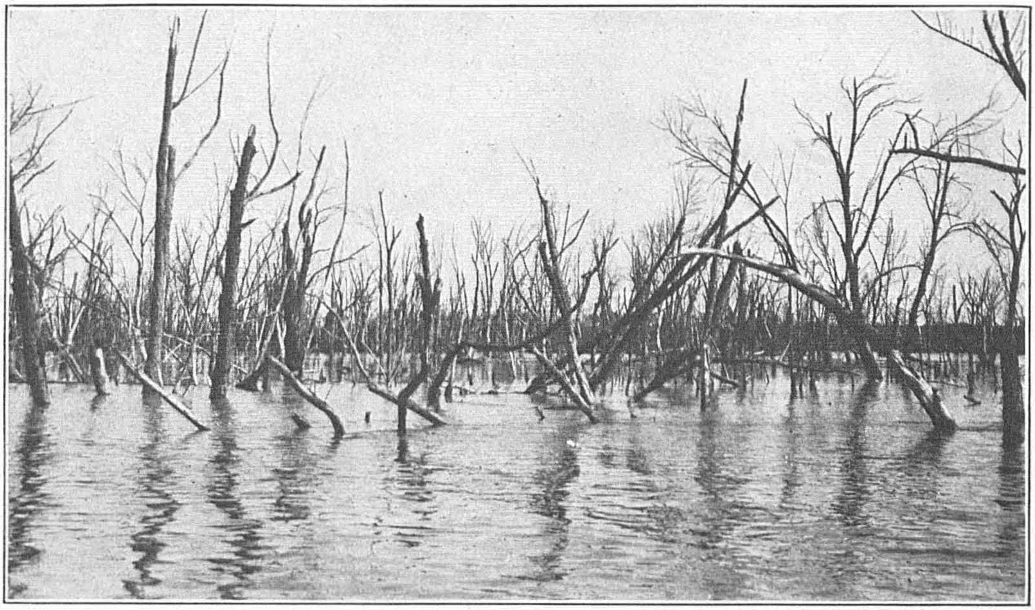

Fig. 8.—Lake Keokuk. Overflowed island near Dallas, Ill., July, 1921.

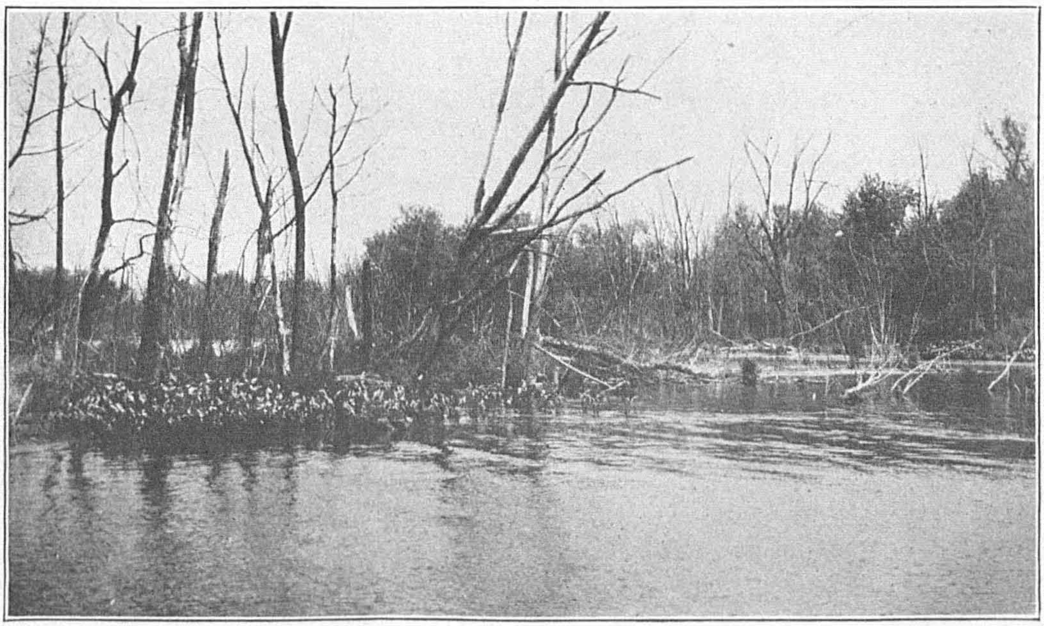

Fig. 9.—Lake Keokuk. Sagittaria associations in the upper part of the lake, July, 1921.

TABLE 4.—*Stages of the upper Mississippi River, 1911–1920, at eight points from St. Paul, Minn., to Keokuk, Iowa.*

HIGHEST GAUGE READINGS.

	Elevation of gauge zero above mean Gulf level.	1911		1912		1913		1914		1915	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Oct. 8	4.8	May 10	11.2	May 27, 28	6.1	July 3, 4	12.2	Apr. 5	10.5
Hastings, Minn.	670.36	Oct. 10, 20	4.9	...do	12.5	May 27	7.3	July 2–4	12.7	Apr. 7	9.8
Winona, Minn.	639.9	Oct. 12	9.9	May 13	11.7	Apr. 8, 9	9.2	July 3–5	12.5	Apr. 15–17	9.8
Prairie du Chien, Wis.	605.16	Oct. 17	13.5	May 18, 19	10.9	Apr. 14	11.5	July 8–10	13.3	Apr. 20, 21	11.2
Rock Island, Ill.	541.94	Oct. 22, 23	11.2	Mar. 30	12.2	Mar. 27, 28	12.8	July 14, 15	10.65	June 3–5, 7	9.5
Burlington, Iowa	518.82	Feb. 20	10.2	Apr. 5, 6	13.35	Mar. 29, 30	11.7	June 23	9.32	June 8	10.41
Fort Madison, Iowa	502.23					Mar. 30 July 23	10.8 12.7	Jan. 16–17, 19–20, 24–28	13.4	Dec. 29	14.42
Keokuk, Iowa	477.35					Mar. 30	13.5	June 24	11.2	June 6	13.75

	Elevation of gauge zero above mean Gulf level.	1916		1917		1918		1919		1920	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Apr. 6–9	16.6	Apr. 8	16.0	Mar. 24, 25	7.5	Apr. 22	13.8	Mar. 29	13.6
Hastings, Minn.	670.36	Apr. 8	15.3	Apr. 9	14.9	June 6	7.8	Apr. 23	13.0	...do	14.1
Winona, Minn.	639.9	Apr. 27	16.2	Apr. 12	13.2	...do	10.5	Apr. 16, 17	12.7	Mar. 31 Apr. 1	15.9
Prairie du Chien, Wis.	605.16	May 1	18.3	Apr. 15, 16	14.2	June 10	12.5	Apr. 20, 21	15.1	Apr. 4, 5	19.6
Rock Island, Ill.	541.94	May 5	15.9	Apr. 21	12.35	June 14	10.3	Apr. 25	13.7	Apr. 8, 9	17.00
Burlington, Iowa	518.82	May 9	14.2	June 17	11.62	June 12	12.9	May 8	13.79	Apr. 11	14.79
Fort Madison, Iowa	502.23	Feb. 1–3 May 9, 10	15.9	June 17, 18	15.05	Dec. 29	15.9	May 7, 8	16.65	Apr. 10	16.80
Keokuk, Iowa	477.35	May 14	16.7	June 13	14.9	June 12	16.7	...do	17.15	Apr. 21	16.70

LOWEST GAUGE READINGS.

	Elevation of gauge zero above mean Gulf level.	1911		1912		1913		1914		1915	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Feb. 24 Aug. 28	−0.7 .4	Dec. 7	−0.1	Feb. 1 Mar. 6	−0.2	Mar. 16, 17	0.3	Feb. 21	1.6
Hastings, Minn.	670.36	Mar. 10 Aug. 30, 31	.0 .1	Dec. 2, 5, 10	.0	Jan. 4, 21–29	.5	Jan. 7	.07	Jan. 31	1.1
Winona, Minn.	639.90	Jan. 5, 6 July 27–30	.6 .8	Dec. 12	.2	Feb. 2 Dec. 30, 31	1.9	Jan. 8–12	1.3	Jan. 29	2.3
Prairie du Chien, Wis.	605.16	July 31	.5	Nov. 16, 27–30 Dec. 1–8	2.1	Dec. 21	1.2	Nov. 22	2.0	Sept. 7–9	3.3
Rock Island, Ill.	541.94	July 28	.65	Dec. 16	1.7	Dec. 31	.95	Jan. 1–3	.8	Dec. 21	1.75
Burlington, Iowa	518.82	July 25	.05	Dec. 14	.5	Feb. 23	.45	Dec. 20	2.7	Jan. 1	4.4
Fort Madison, Iowa	502.23					Jan. 4	1.0	Mar. 25	[1] 10.6	May 31	10.7
Keokuk, Iowa[1]	477.35					Feb. 24	−1.5	Jan. 3	−1.4	Jan. 11	1.00

	Elevation of gauge zero above mean Gulf level.	1916		1917		1918		1919		1920	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Nov. 26	1.7	Dec. 5	−1.0	Oct. 21	−0.7	Mar. 8	0.3	Dec. 18	−0.2
Hastings, Minn.	670.36	Dec. 14	2.0	Dec. 4, 8	.0	Oct. 21, 22	−.3	Mar. 7	1.0	Dec. 19–20	.7
Winona, Minn.	639.90	Dec. 1–5	2.3	Dec. 7, 8	1.2	Oct. 19, 20	.3	Feb. 23–25	1.6	Dec. 20	1.0
Prairie du Chien, Wis.	605.16	Dec. 9–11	3.6	Oct. 11	2.3	Oct. 17, 27	1.9	Sept. 29	2.5	Oct. 1, 3, 14, 24	2.4
Rock Island, Ill.	541.94	Dec. 15	2.3	Dec. 9	1.2	Oct. 19	1.1	Mar. 2	.4	Dec. 21–22	.7
Burlington, Iowa	518.82	Dec. 24	4.2	Dec. 19	3.10	Feb. 10 Oct. 20	3.16 6.2	Jan. 10	5.06	Feb. 28–29	5.4
Fort Madison, Iowa	502.23	Dec. 24, 25	12.0	...do	10.6	Feb. 10	9.95	Jan. 10, 11 Dec. 13	13.0	Mar. 3, 4	12.20
Keokuk, Iowa[1]	477.35	Dec. 17	1.0	Dec. 20	.25	Oct. 20	.5	Mar. 9	.35	Dec. 28	−.80

[1] Keokuk Dam effective after May, 1913.

TABLE 5.—*United States Weather Bureau daily observations of stages of the Mississippi River during July–September, 1921, at 14 points, from St. Paul, Minn., to Warsaw, Ill.*

Day of month.	St. Paul, Minn.			Red Wing, Minn.			Reads, Minn.			Winona, Minn.			La Crosse, Wis.			Lansing, Iowa.			Prairie du Chien, Wis.		
	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.
1	2.5	1.4	0.2	2.4	1.2	0.1	2.8	1.3	0.1	3.4	1.7	0.7	3.8	1.9	0.9	5.1	3.1	2.2	4.9	2.5	1.9
2	2.4	1.3	.4	2.3	1.2	.1	2.6	1.2	.1	3.3	1.8	.7	3.6	2.0	.8	4.9	3.0	2.2	4.4	2.5	2.0
3	2.4	1.2	.2	2.1	1.2	.1	2.4	1.1	.1	3.1	1.8	.7	3.5	2.0	.8	4.8	3.1	2.0	4.3	2.4	1.9
4	2.5	1.0	−.2	1.9	1.1	.1	2.2	1.1	.1	3.0	1.7	.7	3.3	1.9	.8	4.5	3.1	2.2	3.8	2.4	1.7
5	2.2	1.2	−.3	1.7	1.0	.1	2.1	1.0	.0	2.9	1.6	.7	3.2	1.9	.9	4.3	3.0	3.5	3.9	2.4	2.3
6	2.5	1.0	−.3	1.6	.9	.0	1.9	1.0	−.1	2.6	1.6	.7	3.1	1.8	.9	4.2	2.9	3.3	3.7	2.4	2.8
7	2.4	.8	.1	1.5	.8	−.1	1.8	1.0	−.2	2.5	1.6	.6	2.9	1.8	.9	4.1	2.9	3.1	3.5	2.3	2.6
8	2.7	.2	−.1	1.4	.7	−.1	1.8	1.0	−.2	2.4	1.5	.5	2.8	1.8	.8	3.9	2.9	2.1	3.4	2.1	2.4
9	2.7	.6	.3	1.5	.7	−.1	1.9	.7	−.3	2.4	1.4	.5	2.7	1.6	.6	3.9	2.8	2.0	3.4	2.1	2.2
10	2.7	.4	.0	1.5	.6	.0	1.9	.5	−.3	2.4	1.3	.4	2.6	1.5	.6	3.7	2.6	2.0	3.3	2.0	2.1
11	2.5	.3	.1	1.5	.5	−.1	1.9	.5	−.2	2.3	1.2	.4	2.6	1.5	.6	3.6	2.6	2.0	3.2	2.3	2.0
12	2.5	.3	−.1	1.5	.4	−.2	1.9	.4	−.2	2.3	1.2	.4	2.6	1.4	.5	3.6	2.6	2.0	3.0	2.2	1.9
13	2.3	.3	−.1	1.5	.4	−.2	1.8	.6	−.4	2.3	1.1	.4	2.5	1.4	.5	3.6	2.5	2.0	2.9	2.2	1.8
14	2.3	.5	.5	1.5	.3	−.1	1.9	.5	−.3	2.5	1.0	.4	2.6	1.4	.6	3.6	2.4	2.0	2.9	2.1	1.7
15	2.5	.2	.4	1.5	.2	.0	1.9	.4	−.2	2.5	.9	.4	2.7	1.2	.6	3.6	2.4	1.9	2.9	2.0	1.7
16	2.3	.5	.9	1.5	.2	.1	1.8	.0	−.1	2.4	.9	.8	2.8	1.1	1.0	3.6	2.3	3.0	2.9	1.9	2.0
17	2.3	.8	1.3	1.4	.1	.2	1.8	.0	.0	2.4	.8	1.0	2.6	1.0	1.4	3.6	2.1	3.6	2.9	1.9	3.2
18	2.3	.5	1.5	1.4	.1	.2	1.8	.0	.1	2.3	.7	1.0	2.6	1.0	1.5	3.6	2.1	3.6	2.9	1.8	3.6
19	2.1	.8	1.0	1.4	.1	.3	1.8	−.1	.0	2.3	.6	1.0	2.5	.9	1.5	3.6	2.1	3.2	3.0	1.8	3.7
20	2.0	.7	1.1	1.4	.1	.4	1.7	.0	.1	2.3	.6	.8	2.5	.8	1.5	3.6	2.0	3.3	2.8	1.7	3.8
21	2.1	.6	1.9	1.3	.1	.4	1.7	−.1	.1	2.3	.6	.9	2.5	.8	1.4	3.5	1.9	3.2	2.8	1.6	3.7
22	2.0	.4	2.3	1.3	.1	.5	1.6	−.1	.3	2.2	.6	1.0	2.4	.7	1.4	3.5	1.9	3.1	2.8	1.6	3.6
23	2.0	.5	2.0	1.3	.0	.7	1.6	−.2	.4	2.2	.5	1.0	2.4	.7	1.3	3.5	1.9	2.8	2.8	1.6	3.4
24	1.6	.2	1.8	1.3	.0	.8	1.6	−.2	.7	2.2	.5	1.0	2.4	.7	1.3	3.5	1.9	2.7	2.8	1.5	3.1
25	1.6	.5	1.7	1.3	.0	.9	1.6	−.2	.9	2.1	.4	1.2	2.3	.6	1.4	3.5	1.9	2.7	2.8	1.5	3.0
26	1.5	1.3	1.6	1.3	.0	1.1	1.4	−.2	1.1	2.1	.4	1.4	2.3	.6	1.4	3.4	1.8	2.7	2.7	1.5	2.9
27	1.6	.6	1.5	1.4	.1	1.2	1.4	.1	1.2	2.0	.4	1.5	2.3	.6	1.6	3.3	1.8	2.7	2.7	1.4	2.8
28	1.9	.5	1.5	1.3	.2	1.3	1.4	.1	1.3	2.0	.5	1.7	2.2	.7	1.7	3.3	1.8	2.8	2.7	1.4	2.7
29	2.1	.2	1.4	1.3	.2	1.3	1.3	.1	1.5	2.0	.7	2.8	2.2	.8	1.8	3.3	1.8	2.8	2.7	1.3	2.7
30	2.0	.2	1.2	1.3	.1	1.3	1.3	.1	1.5	1.9	.8	2.0	2.1	.9	1.9	3.3	1.8	2.9	2.6	1.3	2.7
31	1.8	.3	......	1.2	.1	......	1.2	.0	......	1.9	.8	......	2.0	1.0	......	3.2	2.0	......	2.5	1.7	......
Mean	2.2	.6	.8	1.5	.4	.3	1.8	.4	.4	2.4	.6	.9	2.7	1.2	1.1	3.8	2.4	2.7	3.2	1.9	2.6

Day of month.	Dubuque, Iowa.			Clinton, Iowa.			Le Claire, Iowa.			Davenport, Iowa.			Muscatine, Iowa.			Keokuk, Iowa.			Warsaw, Ill.		
	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.
1	5.9	2.8	2.0	......	......	......	3.9	1.6	0.9	4.9	1.9	1.0	5.7	2.2	1.6	5.5	1.3	0.7	7.3	4.1	3.0
2	5.5	3.1	2.2	......	......	......	3.7	1.7	1.2	4.6	2.6	1.2	5.4	3.1	1.5	4.9	1.5	.4	8.1	5.2	3.0
3	5.3	3.1	2.4	......	......	......	3.5	1.7	1.3	4.4	2.2	1.3	5.0	2.9	1.7	5.1	3.1	.4	7.9	6.4	3.0
4	5.1	2.9	2.3	......	......	......	3.2	1.8	1.3	4.0	2.2	1.4	4.7	2.7	1.8	4.7	3.8	.4	7.5	7.0	3.2
5	4.8	2.8	2.9	......	......	......	3.0	1.7	1.4	3.8	2.0	1.7	4.5	2.6	1.9	4.0	3.8	1.4	7.1	5.8	3.8
6	4.6	2.8	2.9	......	......	......	2.9	1.7	1.8	3.6	2.2	2.1	4.3	2.4	2.0	3.9	2.4	1.5	7.0	5.7	4.8
7	4.3	2.7	3.0	......	......	......	2.7	1.6	1.9	3.4	2.0	2.3	4.1	2.5	2.5	4.0	2.4	1.5	7.0	5.4	5.0
8	4.2	2.6	3.0	......	......	......	2.5	1.5	1.8	3.2	2.0	2.3	3.8	2.4	2.7	3.6	2.2	1.8	7.0	5.1	5.2
9	4.0	2.5	2.8	......	......	......	2.4	1.5	1.8	3.0	1.7	2.2	3.6	2.4	2.7	3.6	2.2	2.2	6.3	5.4	5.3
10	3.9	2.4	2.6	2.1	......	2.7	2.3	1.4	1.8	2.8	1.6	2.4	3.4	2.1	3.0	3.1	1.9	2.3	6.1	5.4	5.4
11	3.8	2.6	2.6	2.0	......	......	2.2	1.4	1.7	2.8	1.4	2.5	3.3	2.0	3.0	2.9	1.8	3.6	6.0	5.0	6.7
12	3.7	3.2	2.6	2.5	......	......	2.2	1.4	1.7	2.7	1.4	2.5	3.2	2.0	3.0	2.5	1.8	4.5	5.6	5.0	7.5
13	3.5	3.1	2.3	2.5	......	......	2.1	1.5	1.7	2.5	1.5	2.2	3.1	2.0	2.9	2.6	1.5	4.0	5.8	4.7	7.1
14	3.4	2.7	2.6	2.9	......	......	2.0	1.7	1.7	2.4	1.8	2.3	3.0	2.1	2.9	2.4	1.3	3.2	5.1	4.6	6.8
15	3.4	2.6	2.4	2.3	......	......	1.9	1.7	1.9	2.3	2.0	2.4	2.9	2.2	2.8	2.2	1.7	3.1	5.1	4.6	6.5
16	3.4	2.4	2.4	2.3	......	3.3	1.8	1.5	2.6	2.3	[1]1.8	2.9	2.8	2.4	3.3	2.2	1.7	4.0	5.3	4.5	7.0
17	3.4	2.4	3.4	2.3	......	......	1.8	1.4	2.8	2.2	1.8	4.0	2.7	2.3	3.7	2.1	1.7	4.2	5.0	5.0	7.8
18	3.3	2.8	4.2	2.1	......	......	1.8	1.4	3.2	2.3	1.8	4.6	2.6	2.2	5.0	1.7	1.6	7.1	4.9	4.9	9.9
19	4.0	2.5	4.6	2.4	......	......	2.0	1.5	3.5	2.3	1.8	4.8	2.8	2.2	5.4	1.7	1.7	7.8	5.0	4.8	11.0
20	3.7	2.3	4.6	2.6	......	......	2.1	1.7	3.8	2.3	2.0	5.0	2.8	2.5	5.6	2.0	1.4	7.9	5.2	4.8	11.0
21	3.4	2.2	4.9	2.6	......	......	2.1	1.7	4.0	2.4	2.1	5.6	2.9	2.5	6.4	2.3	1.3	9.2	5.2	4.7	12.3
22	3.2	2.1	5.1	2.3	......	......	2.0	1.6	4.3	2.4	2.4	5.8	2.9	2.6	6.5	2.3	1.9	9.8	5.1	4.7	12.8
23	3.2	2.0	4.6	2.0	......	......	1.8	1.4	4.3	2.2	1.9	5.9	2.7	2.7	6.7	2.1	2.2	9.5	5.0	5.0	12.6
24	3.2	2.0	4.2	1.9	......	......	1.8	1.3	3.9	2.1	1.7	5.5	2.5	2.4	6.8	2.4	2.3	9.5	5.0	5.2	12.5
25	3.2	1.9	5.1	1.7	......	......	1.8	1.2	3.9	2.2	1.8	5.2	2.4	2.3	6.2	1.7	2.0	9.2	4.9	5.1	12.1
26	3.1	1.8	4.6	1.7	......	......	1.7	1.2	4.1	2.0	1.7	5.3	2.5	2.3	6.2	1.3	1.8	8.5	4.9	4.9	11.6
27	3.1	1.8	4.0	1.7	......	......	1.7	1.2	4.0	1.9	1.4	5.3	2.4	2.1	6.2	1.3	1.7	8.3	4.6	4.9	11.3
28	3.1	1.8	3.6	1.7	......	......	1.7	1.2	3.5	2.0	1.4	4.9	2.4	1.9	5.9	1.3	1.3	8.2	4.6	4.8	11.2
29	3.1	1.7	3.4	1.6	......	......	1.7	1.1	2.9	1.9	1.5	4.3	2.4	1.7	5.3	1.3	1.3	7.8	4.5	4.8	10.6
30	3.0	1.6	3.3	1.5	......	......	1.7	1.0	2.7	1.9	1.1	3.9	2.3	1.8	4.8	1.3	1.1	7.0	4.5	4.5	9.8
31	2.9	1.8	......	1.4	......	......	1.7	1.0	......	1.9	1.1	......	2.3	1.6	......	1.3	1.0	......	4.3	3.9	......
Mean	3.8	2.4	3.4	2.1	......	......	2.2	1.5	2.6	2.7	1.8	3.4	3.3	2.3	4.0	2.7	1.9	5.0	5.7	5.0	8.0

[1] 3 at 6 p. m.

VELOCITY OF CURRENT.

The velocity of the flowing water depends principally upon the surface slope of the stream, the roughness of the bed, and the hydraulic radius, the latter being the area of the cross section divided by the wetted perimeter. These relations are expressed by Chezy's formula, $V=c\sqrt{Rs}$, where V is the velocity, c is a coefficient combining the effects of roughness of the bed and of some other conditions affecting velocity, s is the slope, and R is the hydraulic radius.

Usually observations of the velocity of a stream are made to determine its discharge, but from a biological point of view the rate of motion of flowing water is of importance independently of the discharge. The greater the velocity of a stream the less the possibility for the development of organisms. For example, the water of very swift mountain creeks is, as a rule, almost entirely free from any organisms except those attached to the bottom or living under the stones. The mean velocity of a stream is the average rate of motion of all the filaments of water in cross section and can be determined by dividing the total discharge by the area of the cross section at a given stage. The mean velocity is generally used for purposes of comparison. Systematic studies of the flow of streams show that the mean velocity is, in general, a function of the stage and that the distribution of velocity through the cross section follows definite laws and, in the main, is independent of the stage. The velocity of a stream is usually less near the bottom and at the banks, the maximum velocity being found between the surface and one-third of the depth of the water. The vertical velocity curves have approximately the form of a parabola, and the velocities in a vertical line vary as its ordinates. From this it can be shown mathematically that at a point between 0.5 and 0.7 of the depth, measured from the surface, the velocity of a filament of water is as great as the mean of the velocities in that vertical line.

The mean velocities at different points on the Mississippi River are shown in Table 6. These data were obtained by the Mississippi River Power Co. They refer to the fall of 1914 and represent a mean velocity of the river at the average stage. The measured velocities were taken at bridge sections and probably represent velocities somewhat in excess of those in the open river. All data for Lake Keokuk were calculated.

TABLE 6.—*Mean velocity and discharge of the Mississippi River at different points from La Crosse, Wis., to Quincy, Ill.*

[Stations refer to distance above dam in hundreds of feet.]

Stations.	Date, 1914.	Mean velocity, feet per second.	Discharge, cubic feet per second.	Stations.	Date, 1914.	Mean velocity, feet per second.	Discharge, cubic feet per second.
Mississippi River:				Lake Keokuk—Continued.			
La Crosse	Sept. 30	[1]2.56	33,400	Station 800	Oct. 4	[2]0.50	55,000
Dubuque	Sept. 29	[1]2.81	47,800	Station 525 (just below Nauvoo)	...do....	[2].58	55,000
Clinton	Oct. 1	[1]2.03	46,900	Station 350	...do....	[2].52	55,000
Davenport	Oct. 2	[1]2.16	52,300	Station 200	...do....	[2].41	55,000
Muscatine	Oct. 3	[1]2.40	53,100	Station 125	...do....	[2].34	55,000
Keithsburg	Oct. 4	[2]2.30	54,000	Station 50	...do....	[2].30	55,000
Burlington	...do....	[2]1.90	55,000	Quincy (37 miles below Keokuk)	Oct. 5	[2]2.40	55,000
Lake Keokuk:							
Dallas City	...do....	[2]1.00	55,000				
Fort Madison	...do....	[2].72	55,000				

[1] Measured. [2] Computed.

The mean velocity varies with change of river stage. Data received from the Mississippi River Power Co. as to variations of mean velocity, observed at Muscatine, Iowa, are as follows:

TABLE 7.—*Mean velocity and discharge of Mississippi River at different stages, Muscatine, Iowa.*

Date.	Discharge, cubic feet per second.	Mean velocity, feet per second.	Date.	Discharge, cubic feet per second.	Mean velocity, feet per second.
Aug. 16. 1916	41,900	1.91	May 11, 1914	81,200	2.87
Oct. 3, 1914	53,100	2.40	Mar. 30, 1916	154,800	3.58

During the present investigation measurements of velocity were made only in the upper layer of water. The results of observations on the main channel of the river are given in Table 8. The velocities observed at low stages of water vary from 1.23 feet per second at Red Wing to 2.8 at Fairport. Probably the velocity at Rock Island Rapids is considerably greater than was observed, as it was impossible to make observations in the swiftest part of the rapids. In the latter part of September when the river was rising its flow was swifter; the maximum velocity, 4.37 f. s., was observed at New Boston (September 20). The current just below Lake Pepin is rather swift, reaching 3.29 f. s. on September 10; another measurement made 10 days before this showed only 2.05 f. s. at the same station. Since there was no considerable change in the stage of the river during these days, the disparity may be due to the fact that the section where the current of the outflow of Lake Pepin is swiftest is very short, and on the occasion of the two observations the boat was not anchored each time at the same point. Only one-third mile upstream the velocity of the current observed on the same day, September 10, was 0.77 f. s. (See stations 124 and 124*a*, Table 29, p. 431.)

TABLE 8.—*Velocity of current measured at different points on the Mississippi River.*

Station.	Miles from St. Paul.	Date, 1921.	Stage of river on the day of observation.	Velocity, feet per second.
Between Prescott, Wis., and Hastings, Minn	28	Sept. 2	0.4	1.57
Below Prescott, Wis	30	...do.....	.4	1.57
Diamond Bluff, Wis	40½	Sept. 1	.1	1.38
One mile above Red Wing, Minn	49	...do.....	.1	1.23
One mile above the head of Lake Pepin	54¾	Aug. 29	.1	1.38
Lake Pepin	54–77	...do.....	.1	....
Reads Landing, Minn	77¼	Aug. 30	.1	2.05
		Sept. 10	.3	3.29
Opposite mouth of Zumbro River	96¾	Sept. 10	.4	3.14
Between Winona, Minn., and Homer, Minn	119	Sept. 11	.4	2.42
Four miles above La Crosse, Wis	140⅛	...do.....	.6	2.20
Opposite mouth of Root River	148	...do.....	.6	2.57
Between De Soto, Wis., and Lansing, Iowa	177	Sept. 13	2.0	1.92
Three miles above Prairie du Chien, Wis	204⅝	...do.....	1.8	2.49
Prairie du Chien, Wis., east channel	207½	Sept. 14	1.7	1.83
Prairie du Chien, Wis., main channel	207½	...do.....	1.7	1.46
Opposite mouth of Wisconsin River	211¼	...do.....	1.7	2.20
One mile below Cassville, Wis	237¾	Sept. 15	2.4	1.57
Four miles below Bellevue, Iowa	292	Sept. 16	2.4	1.83
Three miles below Clinton, Iowa	329¾	Sept. 17	3.3	3.14
Rock Island Rapids, near Day Mark Pier No. 2	359¼	...do.....	....	[1] 1.46
One mile below mouth of Rock River	....	Sept. 18	3.2	2.20
Fairport, Iowa	378½	July 12	3.2	2.8
Near New Boston, Ill	411⅝	July 13	3.1	2.5
		Sept. 20	5.6	4.37
Near Burlington, Iowa	443	July 14	3.0	1.4
		Sept. 20	5.6	2.20
Six miles above Dallas, Ill	449⅛	July 20	2.8	1.25
Six miles above lateral channel	449⅛	...do.....	2.8	.9
Four miles above Dallas, Ill., Shokokon Slough	451⅛	July 21	2.9	1.0
Dallas, Ill	455⅛	July 15	2.9	.8
		Sept. 22	[2] 6.5	2.18
Fort Madison, Iowa	462⅝	Sept. 24	[2] 9.5	1.99
Nauvoo, Ill	469⅞	...do.....	[2] 9.5	1.57
Three and a half miles below Galland, Iowa	479½	...do.....	[2] 9.5	1.13
Three miles above the Keokuk drawbridge	480⅜	...do.....	[2] 9.5	.68
Near the Keokuk dam	483⅜	July 15	[2] 2.2	....
		Sept. 23	[2] 9.5	.92
Alexandria, Mo	488¾	July 30	[2] 1.3	....
		Sept. 23	[3] 12.5	2.75

[1] Strong south wind. [2] At Keokuk, Iowa. [3] At Warsaw, Mo.

There was a striking difference in the velocities of current in Lake Keokuk in July and September. In July there was a drop in the rate of current from 1.4 foot per second at Burlington to 0.3 at Dallas. In September the river was rising and the difference between the two points became very slight, the figures being 2.2 at Burlington and 2.18 at Dallas. Near the dam, where the current in July was very slow, in September its velocity reached 1 foot per second.

It would be very interesting to know how the rise of the river affects the body of water in Lake Pepin, but unfortunately information for this comparison is lacking. Even the fluctuations of the water level in this lake are unkown, because there have been no stage observations made, the nearest stations being the regular gauges at Red Wing, above the lake, and at Reads Landing, below the mouth of the Chippewa River.

The velocity of the current is less near the shore and greater in the main channel. Many dikes built to improve navigation and to keep the water running faster in a narrow channel have great influence on the currents, the water between the dikes being often almost stagnant, especially when the dikes are located at very close intervals. The current in the sloughs is usually slower than in the main channel, whereas many of the tributaries are very swift streams. Velocities of the current measured almost simultaneously at different points across the river, those measured in different sloughs of the upper part of Lake Keokuk, and those measured near the mouths of certain tributaries of the Mississippi, are given in Table 9. Most of the observations on the tributaries were made in September, when heavy showers caused a considerable rise of water in the Mississippi. The velocity of 4.38 feet per second in the Des Moines River was the greatest observed during the investigation.

TABLE 9.—*Variations in velocities of current measured at various points, Mississippi River, 1921.*

Locality.	Date.	Velocity, feet per second.	Locality.	Date.	Velocity, feet per second.
SIMULTANEOUSLY AT DIFFERENT POINTS ACROSS THE RIVER.					
Stations 4 and 5, New Boston, Ill.:			Stations 101 to 103, Reads Landing:		
Main channel	July 13	2.8	Left shore	Aug. 30	0.92
Midstream	...do	2.5	Midstream	...do	2.05
Stations 96 to 98, above Lake Pepin:			Right shore (main channel)	...do	3.14
Left shore	Aug. 29	.91	Stations 104 to 106, above mouth of Chippewa River:		
Midstream (main channel)	...do	1.38	Left shore	...do	0
Right shore	...do	0	Midstream	...do	.77
			Right shore	...do	.77
DIFFERENT SLOUGHS, UPPER PART OF LAKE KEOKUK.					
Stations 9, 10, 12, Dallas:			Station 18, Turkey Chute	July 21	0.37
Right channel	July 15	.8	Station 19, Shokokon Slough	...do	1.0
Left channel	...do	.32			
Chute	...do	.8			
NEAR MOUTHS OF CERTAIN TRIBUTARIES.					
Stations 99 and 100, Chippewa River, 1 mile above mouth:			Station 134, Root River	Sept. 12	1.23
			Station 142, Wisconsin River	Sept. 14	2.42
Left shore	Aug. 30	3.13	Station 144, Turkey River	...do	1.83
Right shore	...do	2.42	Station 149, Rock River	Sept. 18	2.20
Station 132, Black River above the railroad bridge	Sept. 12	.34	Station 152, Iowa River	Sept. 20	3.14
			Station 158, Des Moines River	Sept. 23	4.38

Observations of the current were made at every station on Lake Pepin, but movement of the water from the river down the lake was observed only at stations 88 and 89 opposite Wacouta Light, about 2 miles below the mouth of the Mississippi. The velocity at these stations ranged from 0.9 f. s., close to the right shore, to 0.34 f. s., in mid lake. The velocity observed at various other stations on the lake ranged from 0.11 to 0.83 f. s., but the directions of the currents fluctuated, depending exclusively on the direction of the wind. The maximum velocity, 0.83 f. s., was observed on a very windy day. When the water was rough, it was impossible to work with the current meter because the vertical movements of the boat revolved the wheel of the instrument. The measures of velocity less than 0.2 foot per second are probably not exact, because the Price current meter does not work well at low velocities. On calm days the drift of Aphanizomenon clumps along the boat often could be observed, and the velocity of this movement could even be calculated, but the wheel of the current meter was motionless, as the flow of the water was not strong enough to turn the cups of the instrument.

DISCHARGE.

The quantity of water flowing in a stream is usually expressed in units of discharge. By the discharge of a stream we mean the quantity of water flowing through a given cross section in a unit of time, the most common unit of discharge being the so-called second-foot, which is the average number of cubic feet flowing in each second of a definite period of time (day, week, month, or year). The discharge is obtained as the product of two factors—the area of cross section of the stream, which depends on the shape and the dimensions of the bed and banks, and the mean velocity. As both factors are controlled by the stage, the discharge may be considered as a function of the stage.

The discharge of the Mississippi is exceedingly variable, the minimum varying from about 2,000 c. f. s., between Minneapolis and St. Paul, to 20,000 c. f. s., at Keokuk. Probably the minimum discharge at Keokuk in winter is even less, reaching only 12,000 c. f. s. (See Rivers and Harbors Committee, Impounding of water above Keokuk Dam, etc., 1917, pp. 78–79.)

The maximum and minimum discharges in the Wisconsin section of the river, according to Martin (1916), expressed in cubic feet per second, are as follows: Near Prescott, 134,000 and 3,000; outlet of Lake Pepin, East Winona and La Crosse, 127,000 and 8,000; Prairie du Chien, 179,000 and 16,000; and Clayton, 179,000 and 16,000.

The mean annual discharge is also subject to great fluctuations. Thus, for example, the mean annual discharges between Minneapolis and St. Paul for the years 1905–1912, according to Meyer (1914), are as follows:

	Cubic feet per second.		Cubic feet per second.
1905	12, 920	1909	6, 965
1906	13, 390	1910	4, 630
1907	10, 250	1911	3, 240
1908	8, 710	1912	5, 260

For four months during these eight years the mean monthly flow was below 2,000 feet per second.

The average annual flow at Keokuk estimated for a stage of 4.9 feet is approximately 55,000 c. f. s. The maximum flow at Keokuk is approximately 260,000 c. f. s. (See statement of D. C. Kingman, Chief of Engineers, U. S. A. Rivers and Harbors Committee, Impounding of water above Keokuk Dam, etc., 1917.) The average discharge of the river above Lake Keokuk increases from La Crosse, 33,400 c. f. s., to Keithsburg, 54,000 c. f. s. (see Table 6). During the course of the present investigation the discharge probably averaged 40,000 c. f. s. in the upper part of the river between Reads Landing and Le Claire, and 55,000 c. f. s. in the lower part between Le Claire and Keokuk.

FLOW OF SEDIMENT.

The flow of sediment suspended in the water and rolled along the bed of the river is of great importance in the Mississippi, as its annual discharge of sediment into the Gulf is expressed in the enormous figure of 7,459,267,200 cubic feet of solid material. Our knowledge of the matter is based chiefly on many valuable investigations made by Humphrey and Abbot (1876). Series of observations were made also by the Board of Engineers, United States Army, by the Mississippi River Commission, and by the United States Geological Survey.

The material carried down a river may be in solution, in suspension, or rolled along the bed. In the upper Mississippi the amount of material dissolved in the water is greater than that in suspension. The mean of the observations made at Minneapolis shows that 200 parts of material per 1,000,000 parts of water are in solution and only 7.9 parts per 1,000,000 in suspension (Townsend, 1915). The quantity of material suspended in water in the lower Mississippi is considerably greater, reaching the ratio of 280 parts per million. The amount of sediment in the lower Mississippi depends almost exclusively on the proportion of water from the Missouri. In comparison with the Missouri, the upper Mississippi is a clear stream and the amount of sediment carried by it is insignificant.

Observations on the Missouri near St. Charles, Mo., indicate that the so-called degree of saturation—that is, the amount of sediment per unit of volume of water—depends on the stage of the river. This rule can not be applied to the upper Mississippi, where there is no such relation between the degree of saturation and the stage. An important part in the upper Mississippi is being played by Lake Pepin, in which is deposited a considerable part of the sediment brought to the Mississippi from the Minnesota River. The amount of sediment in suspension at Winona, below Lake Pepin, is about one-third or one-quarter of that at Prescott above the lake.

The degree of saturation at the same stage may be very different, depending on the source of the flood. The maximum degree of saturation in the lower part of the upper Mississippi at Hannibal, Mo., is only one-sixth of that in the Missouri at St. Charles. The amount of sediment carried in the upper strata is usually less than at the depths. This is clearly shown in the following table, the data for which are taken from Hooker's paper (1897). Only the observations at Clayton show an amount of sediment at the bottom less than at mid depth.

TABLE 10.—*Sediment carried in various strata in Mississippi and Missouri Rivers.*

Locality and date.	Parts of sediment in 1,000,000 parts of water.		
	Surface.	Mid depth.	1 foot above bottom.
Mississippi River (1880–81):			
Prescott	123	157	159
Winona	34	32	36
Clayton	40	42	41
Hannibal	165	208	224
St. Louis	686	906	995
Missouri River (1879):			
St. Charles	2,418	2,473	2,548

CHEMICAL CONSTITUENTS OF WATER.

The water of the Mississippi River is mainly a calcium carbonate water and is poor in chlorides and sulphates; the chlorides tend to accumulate in the lower stream. Table 11 gives the results of the chemical analyses of Mississippi water taken at Minneapolis and at Memphis. The figures are taken from Clarke's work, "The Data of Geochemistry," 1908. The data for Minneapolis represent an average of 23 samples, each formed by 10-day collections between September, 1906, and May, 1907; those for Memphis represent an average of 17 10-day composites formed between October 29, 1906, and May 10, 1907.

TABLE 11.—*Chemical analyses of Mississippi water at Minneapolis, Minn., and Memphis, Tenn.*

	CO_3.	SO_4.	Cl.	NO_3.	Ca.	Mg.	Na, K.	SiO_2.	Fe_2O_3.	Salinity, parts per million.
Minneapolis	47.04	9.61	0.85	0.85	20.59	7.67	5.33	8.01	0.05	200
Memphis	32.02	11.31	5.72	0.10	17.45	6.98	6.19	19.45	.78	197

TRANSPARENCY OF WATER.

The water of the Mississippi River is muddy even at its lowest stage; it is clearer in the upper part of the river and becomes more opaque down the stream. The transparency in the main channel above Lake Pepin is about 80 cm., in Lake Pepin it varies from 28 cm. at the shallow places to 102 cm. in the outlet, and in the river between Wabasha and Burlington it varies from 22 to 79 cm. The lowest transparency, 22 cm. (Station 18) for July and August, was observed at Fairport.

At the time of flood the river carries a great quantity of silt, and the turbidity of water increases with the rise of the stage. This was observed in September, when heavy showers caused a considerable rise of water in the latter part of the month. The rise started about the 16th and the water became very turbid, as shown in Table 12.

The tributaries emptying into the Mississippi carry much sediment, and the transparency of their dirty, yellow water is sometimes only 2 cm. Observations made in the tributaries, most of them during the rise of the rivers when the turbidity of the water was greater than at low stages, are shown in Table 12. The amount of sediment in suspension in the mouth of Turkey River was as great as 9 $cm.^3$ per liter, or 9,000 $cm.^3$ per cubic meter. The volume of plankton and detritus suspended at this time in the Mississippi water was about 20 $cm.^3$ per cubic meter.

TABLE 12.—*Transparency of Mississippi River and various tributaries during rise of water, September, 1921.*

Locality.	Date.	Transparency.	Locality.	Date.	Transparency.
Stations:		*Cm.*	Tributaries:		*Cm.*
Reads Landing	Sept. 10	79	Beef Slough	Sept. 10	27
Winona	Sept. 11	50	Black River	Sept. 12	43
La Crosse	...do....	46	La Crosse River	...do....	20
Near Lansing	Sept. 13	28	Root River	...do....	10
Prairie du Chien	Sept. 14	17	Wisconsin River	Sept. 14	29
Near Cassville	Sept. 15	23	Turkey River	...do....	2
Near Bellevue	Sept. 16	12	Rock River	Sept. 18	8
Near Clinton	Sept. 17	12	Iowa River	Sept. 20	6
Rock Island Rapids	...do....	8	Des Moines River	Sept. 23	5
Near Davenport	Sept. 18	6			
New Boston	Sept. 20	12			
Burlington	...do....	10			
Alexandria	Sept. 23	9			

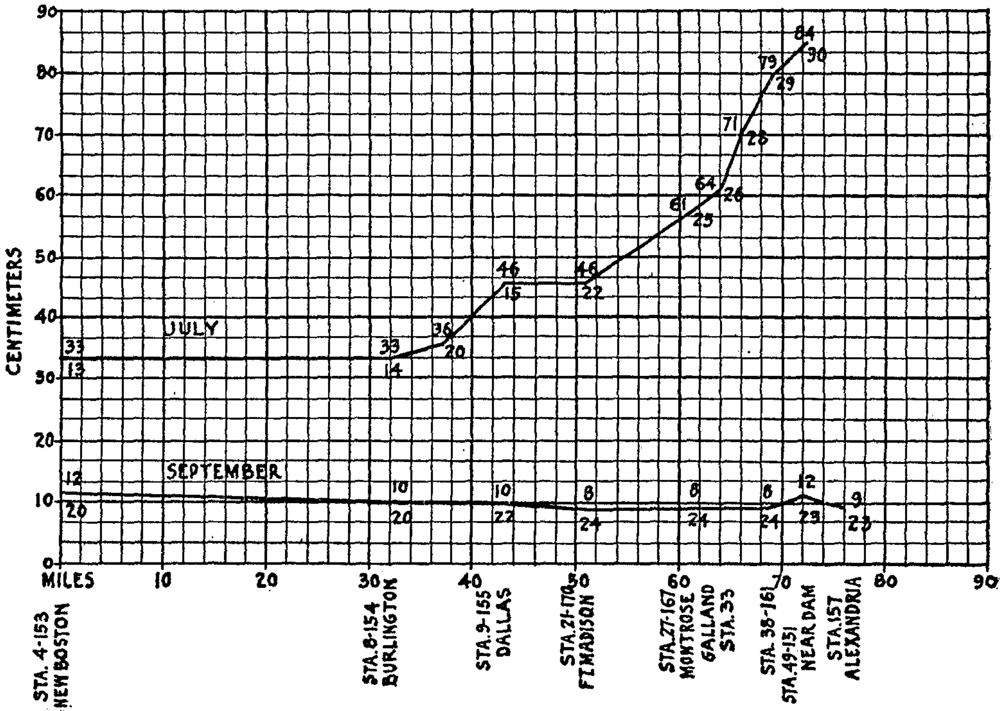

FIG. 10.—Transparency of water in the Mississippi River and Lake Keokuk, between New Boston, Ill., and Alexandria, Mo. (The figures on the lines represent the transparency in centimeters; the figures under the lines represent the day of observation.)

The transparency of the water may depend on the quantity of detritus or silt in suspension, as well as on the quantity of plankton. It has often been observed that the fluctuations in the transparency of water in lakes have closely followed fluctuations in the quantity of plankton (Apstein 1896, Le Roux 1899, Galtsoff 1913–14). In the Mississippi River the transparency of water depends principally on the amount of sediment in suspension. When the river is dammed and its flow becomes slower, a part of the sediment is deposited and the water becomes clearer, provided that the decrease in the amount of sediment is not compensated by the increase of plankton.

Such an increase of transparency of water can easily be observed in Lake Keokuk, where the water near the dam is more than twice as transparent as at Burlington at the head of the lake. This gradual increase of transparency from 33 cm. in the upper part of the lake to 84 cm. near the dam is graphically represented by Figure 10. Attention should be called to the fact that such relation exists only when there is no considerable change in the stage of the river. At the end of September, when the river was rising, the water near Burlington was as muddy as that near the dam (fig. 10, lower line).

In Lake Pepin fluctuations of transparency of water are not so evident as in Lake Keokuk. The water of the river above the lake is nearly as transparent as in the lake, although the most transparent water was found in the lower part of the lake. In the upper part of Lake Pepin the transparency of water varied from 46 to 61 cm. (Opposite Wacouta and Point No Point.) In the middle part of the lake opposite Point au Sable and Lake City and in the lower part of the lake the transparency was 76 to 87 cm. The maximum transparency, 102 cm., was found in the outlet of the lake opposite Reads Landing. The transparency of water in the northern shallow part of the lake, near Bay City, was 28 to 46 cm. and even less, 19 cm., opposite the mouth of Isabel River. The water of St. Croix Lake was considerably clearer, its transparency on September 2 being 150 cm.

TEMPERATURE OF WATER.

The water of the Mississippi River in July and August was exceedingly warm. The highest temperature noted in the main channel, 33.3° C. (91.9° F.), was observed on July 13, at 5 p. m. Probably the temperature in bayous and sloughs was even higher, because other observations show that the water just below the dikes and in sloughs with a slow current was usually 1 to 2 degrees higher than in the main channel. The highest temperature observed in Lake Keokuk was 31.1° C. (station 22); at most of the lake stations the temperature at the surface varied from 27 to 29° C.; at the end of September it was 20° C. In Lake Pepin the temperature of the upper stratum of water during the period from August 15 to September 10 varied from 22.1 to 28.9° C. The highest temperature observed was in the shallow places in the northern part of the lake; in the middle part of the lake on calm days the temperature of the upper stratum sometimes reached 27.8° C. (station 76). The surface temperature in Lake St. Croix on September 2 was 23.3° C. There was no great difference between the temperatures of tributaries and that of the main stream.

With regard to the vertical distribution of temperature both Lake Keokuk and Lake Pepin belong to the type of lake that is characterized by the absence of a thermocline. The uniform distribution of temperature at different depths facilitates the vertical circulation of water during a warm season, and therefore has great influence on the distribution of plankton. The maximum difference between surface and bottom temperature in Lake Keokuk at the time of the investigation was only 3.5° C. (Table 13), and on windy days the distribution of temperature became more uniform. The greatest difference between the surface and bottom temperatures observed in Lake Pepin was 6.5° C. (Table 13, station 76), but the difference between the temperature at the 1.5 m. stratum and at the bottom was only 0.9°. The greatest difference usually occurred at the afternoon observations.

TABLE 13.—*Differences in surface and bottom temperatures observed in Lakes Keokuk and Pepin, July and August, 1921.*

LAKE KEOKUK.

Station.	Date.	Time.	Depth.	Difference in temperature.
			Meters.	°*C.*
16	July 20	2-3 p. m.	2.7	0.2
17	..do....	3-4 p. m.	5.2	.1
18	July 21	8-9 a. m.	3.0	1.0
19	..do....	10-11 a. m.	4.3	.7
22	July 22	3-4 p. m.	6.1	3.0
23	July 23	9-10 a. m.	1.5	.1
24	..do....	10-11 a. m.	3.0	
25	..do....	11-12 a. m.	6.1	.5
26	July 25	10-11 a. m.	6.1	.8
27	..do....	11-12 a. m.	6.7	1.8
28	..do....	2-4 p. m.	4.6	3.5
29	July 26	9-10 a. m.	4.3	.8
30	..do....	10-11 a. m.	6.1	.7
31	..do....	12 noon-1 p. m.	6.1	1.7
32	July 28	9-10 a. m.	3.0	.7
33	..do....	10.30-11.30 a. m.	7.6	.8
34	..do....	12 noon-1 p. m.	7.6	1.6
36	July 29	10-11 a. m.	7.6	1.9
37	..do....	11.30 a. m.-1 p. m.	6.1	1.9
38	..do....	3-4 p. m.	6.1	.2
39	..do....	4-5 p. m.	7.6	.8
40	July 30	9.45-10.30 a. m.	6.1	.7
41	..do....	10.45-12 a. m.	9.1	1.8
42	..do....	11 a. m.-1.30 p. m.	9.1	2.2
43	..do....	2-3 p. m.	7.6	2.1
44	..do....	3-4.30 p. m.	13.4	3.5

LAKE PEPIN.

Station.	Date.	Time.	Depth.	Difference in temperature.
58	Aug. 18	3.30-4.30 p. m.	9.1	3.6
59	Aug. 22	9-11 a. m.	7.6	4.0
60	..do....	11-12 a. m.	6.1	1.1
63	..do....	3-4 p. m.	6.1	.3
64	..do....	4.30-5.40 p. m.	9.1	.7
65	Aug. 23	9.45-10.30 a. m.	4.6	.3
66	..do....	10.30-11.30 a. m.	6.1	1.1
67	..do....	11.45 a. m.-12.40 p. m.	10.7	1.9
68	..do....	1.40-2.45 p. m.	13.0	1.4
69	..do....	2.50-3.10 p. m.	1.2	2.0
70	..do....	3.15-4. p. m.	.6	1.2
72	Aug. 24	10-11 a. m.	7.0	1.3
73	..do....	11-12 a. m.	5.5	3.2
74	..do....	1.10-1.40 p. m.	4.0	3.8
75	..do....	1.50-2.30 p. m.	7.6	4.8
76	..do....	2.40-3.20 p. m.	9.1	6.5
78	Aug. 25	11-11.30 a. m.	7.3	1.9
79	..do....	11.45 a. m.-12.10 p. m.	5.5	2.7
80	..do....	12.15-12.45 p. m.	.9	.5
81	..do....	1.50-2.25 p. m.	6.1	2.3
82	..do....	2.40-3 p. m.	4.6	2.3
83	..do....	3.15-3.45 p. m.	2.7	1.5
84	Aug. 26	12.30-1.15 p. m.	5.2	.7
85	..do....	1.30-2 p. m.	4.3	1.5
86	..do....	3-4 p. m.	3.0	2.6
87	Aug. 27	11.30 a. m.-12 noon	.9	3.1
88	..do....	12 noon-12.30 p. m.	1.5	.4
89	..do....	1-1.30 p. m.	1.5	2.9
90	..do....	1.40-2.30 p. m.	3.6	4.4
117	Aug. 29	9.30-10.45 a. m.	7.6	.4
119	..do....	4-4.30 p. m.	6.1	2.0

The vertical distribution of temperature in the river is more uniform. The difference between the surface and bottom temperatures was usually less than 1°. The swifter the current the more uniform the temperature in different levels. For example, at station 96 on August 29 between 2 and 2.30 p. m., at a depth of 10 feet, when the velocity was 0.91 foot per second, the difference in surface and bottom temperatures was 2.4°, whereas at station 97 on August 29 between 2.30 and 3 p. m., at a depth of 14 feet, when the velocity was 1.38 feet per second, the difference was only 0.9°.

PLANKTON AND DETRITUS.

VOLUME.

As has been stated above, two methods were employed for volumetric determination of plankton, and the data obtained by each method are given in the tables. It is very well known to all limnologists that the volume of plankton measured by the settling method (sometimes called the gravimetric method) depends not only on the amount of organisms in the sample but also on the kind of plankton. For example, the plankton rich in diatoms, or Dinoflagellata, after 24 hours of settling, forms a compact mass on the bottom of the tube. If the catch contains many crustaceans, and especially if some big water fleas with long spines and appendices, such as Leptodora or Bytotrephes, are present, the mass settles on the bottom loosely. Therefore when one deals with different kinds of plankton, taken from different lakes for instance, comparable data can be obtained only by the centrifuge method, for, when comparing the data secured by the two methods (Table 29, p. 422), it will be noted that the figures representing volumes of plankton obtained by the settling method vary greatly and are not in accord with the figures secured by the centrifuge method. (See stations 13, 28, 30, 110, and others, Table 29, p. 422.) For example, when examining the amounts of plankton from different depths by the settling method, an increase would be found, where the centrifuge method would show a decrease, and vice versa.

No definite ratio of the data obtained by the gravimetric method to the data of the centrifuge method could be established. In most cases, as one would expect, the volume of plankton read on a settling tube is greater than that obtained after two minutes of centrifuging, and this difference in volume varies widely. Kofoid (1903) found that it ranged from 8 to 76 per cent. In the present investigation there were instances where no difference at all between the data obtained by the two methods was found. This usually happened when the samples contained much silt and detritus or when the amount of plankton was very small. (See stations 156, 158, Table 29, p. 433.) In most cases, however, the volume of plankton measured by the centrifuge method was from 30 to 70 per cent less than when determined by the settling method. These results apparently are in accord with those obtained by Kofoid. It may be concluded, therefore, that the possible error of the gravimetric method varies from 0 to 70 per cent. We are unable to control the density of plankton material when it is left to settle on the bottom of the tube by gravity only. The results obtained are too inaccurate, and this method ought to be abandoned entirely. In this paper, therefore, we shall discuss only the results arrived at by the centrifuge method.

In discussing the plankton attention should first be called to the fact that the material suspended in water, which we find in our plankton net or on the filters, consists not only of organisms but also of organic detritus and mineral particles. These different constituents of the plankton sample can not be separated one from another, and therefore, in speaking of the volume of plankton, we must keep in mind that a part of this volume is formed by the mineral particles or by the products of decomposition of organisms, the so-called detritus.

The different terms, such as euplankton, pseudoplankton, and detritus, have long been a subject of controversy. According to Hensen's (1887) original definition the word plankton denotes all that is floating in the water: "Alles was in Wasser treibt." The plankton-net catch contains, however, not only live organisms suspended in the water but also a certain quantity of inorganic matter such as sand and clay, as well as the products of decomposition of water plants and animals. In large and deep lakes the amount of inorganic matter and detritus is insignificant, but in shallow ponds and especially in rivers a great part of "plankton" samples consists of sand, silt, and detritus. Therefore when the productiveness of a basin is studied on the basis of volumetric determinations the examination of the detritus ought not to be omitted.

The terms detritus and pseudoplankton have been used sometimes with the same meaning, while in other cases the term pseudoplankton has been applied to the bottom organisms that occasionally occurred in the pelagic region of a lake or sea. The term detritus also has been used with different meanings. In some papers it denotes the material of organic origin suspended in water, while in others it means all material suspended in water, with the exception of live organisms only. In 1917 Wilhelmi tried to set in order this terminology. He suggested the use of the term plankton strictly in accord with Kolkwitz's definition of plankton as the natural community of those organisms that are normally living in water and are passively carried along by currents. Kolkwitz's (1912) exact definition of plankton is as follows: "Die natürliche Gemeinschaft derjenigen Organismen welche in freiem Wasser, bei Strömung willenlos treibend, freilebend normale Existenzbedingungen haben." As to the bottom and shore organisms that are only incidentally found in the pelagic region, these, according to Wilhelmi (1917), form pseudoplankton. All other material suspended in water, such as silt, sand, and particles of decomposed organisms, is called detritus, which, with regard to its origin, may be called inorganic or organic detritus. For this group of suspended substances Wilhelmi (1917) suggested a new term, "tripton." The creation of a new term does not seem to help, and the old term "detritus" is as good as the new one, but of course the terms "plankton" and "pseudoplankton" must be applied to denote only the organisms and the term "*detritus*" must be used when speaking of all other material suspended in water.

The water of the Mississippi River carries a great amount of loose brown detritus which forms a great part of the material collected by filtering the river water through bolting silk. The amount of detritus depends chiefly on the stage of the river, increasing with the rise of the river and decreasing with the fall. Although the present observations have not been made simultaneously, still we are able to compare the results obtained in different parts of the river because most of the observations have been made at low stages of the river. Fortunately there was no considerable change in hydrographic conditions during the course of the investigation. This stability permits us to make a comparison of the productive capacity of the different sections of the river. Only at the end of September during the rise of the water the data showed such an extensive decrease in the amount of plankton that they could not be used for estimating the productive capacity of the river.

The composition of the plankton is discussed on page 396. We will now analyze the results of the volumetric determinations of plankton only, regardless of its components. The remark, however, must be made here that the plankton samples of the Mississippi, and especially of the part between Rock Island Rapids and Burlington, Iowa, contain much detritus. From July to September the amount of plankton in the Mississippi River, excluding lakes, averaged 14.5 $cm.^3$ per cubic meter of water. This figure represents the average of the 142 samples collected at 51 stations. With regard to the amount of plankton a striking difference exists between the upper and lower parts of the river. In the lower part, between Rock Island Rapids and Burlington, the volume of plankton varied from 3.3 to 6.75 $cm.^3$ per cubic meter; the fluctuations in volumes of plankton in the upper part, between Hastings and Le Claire, at the head of Rock Island Rapids, ranged from 12.3 to 33 $cm.^3$ The data of the volume of plankton measured in different parts of the river are given in Table 14. The averages of volumes of plankton in each part of the river, expressed in cubic centimeters of plankton per cubic meter of water, were as follows: Upper part from Hastings to Le Claire (excluding Lake Pepin), July to August 21.3, September 16.2; lower part from Le Claire to Alexandria (excluding Lake Keokuk), July to August 5.16, and September 4.8. The average was calculated for the upper part from the data obtained at 18 stations in July and August and 17 stations in September; the corresponding number of stations for the lower part are 10 and 6, respectively.

The amount of plankton in the upper part of the river gradually increases from Hastings (station 116), where its volume is 12.3 $cm.^3$ per cubic meter, to Diamond Bluff, where the volume reaches 22.7 $cm.^3$ and Red Wing (station 110), 21.5 $cm.^3$; but 5 miles below, just above the head of Lake Pepin (stations 96–98), it decreases again, and the average plankton content of water flowing into the lake is only 16.6 $cm.^3$ per cubic meter.

The water flowing out of Lake Pepin is richer in plankton. The average volume of plankton measured in samples taken opposite Reads Landing (stations 101–103) in the outlet of the lake reached 21.8 $cm.^3$

Below Lake Pepin a considerable increase of plankton has been observed near Prairie du Chien. This part of the river apparently presents more favorable conditions for the development of plankton than any other, on August 15 the average amount of plankton observed here reaching 32 $cm.^3$ (station 54). One month later the volume of plankton here was only 17.3 $cm.^3$ per cubic meter (station 138), but 60 miles above, opposite the mouth of Root River (station 135), it was about twice that much (30.3 $cm.^3$). It is evident, then, that even during the time when hydrographic conditions are stable there are considerable fluctuations in the production of plankton in different parts of the river.

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In the lower part of the river the fluctuations in the amount of plankton are insignificant, and samples taken there contain detritus almost exclusively. The waters of the tributaries of the Mississippi River carry a great quantity of detritus, and the amount of the material suspended in them sometimes is exceedingly great, as it was, for instance, in Turkey River, where the volume of sediment in suspension reached 0.9 cm.^{3} per 100 cm.^{3} of water or 9,000 cm.^{3} per cubic meter. This observation was made on September 14, when the river was rising. The results of the determination of the amount of plankton found in the tributaries are given in Table 24.

TABLE 14.—*Volume of plankton—Mississippi River between Hastings, Minn., and Alexandria, Mo.*

Station.	Serial number of station.	Date.	Volume of plankton, cubic centimeters per cubic meter of water.	Serial number of station.	Date.	Volume of plankton, cubic centimeters per cubic meter of water.
Near Hastings	116	Sept. 1	12.3			
Near Prescott	115	...do....	16.3			
Diamond Bluff	111	...do....	22.7			
Near Red Wing	110	...do....	21.5			
One mile above head of Lake Pepin:						
Right bank	98	Aug. 29	17.0			
Main channel	97	...do....	17.5			
Left bank	96	...do....	15.3			
Above mouth of Chippewa River:						
Right bank	104	Aug. 30	21.5			
Midstream	105	...do....	18.0			
Left bank	106	...do....	33.0			
Reads Landing:						
Right bank	101	...do....	22.5	124	Sept. 10	14.6
Midstream	102	...do....	24.0			
Left bank	103	...do....	19.0			
One mile above Wabasha, main channel	57	Aug. 9	18.5			
Beef Slough				125	Sept. 10	10.0
Opposite mouth of Zumbro River				127	...do....	11.7
Between Winona, and Homer, main channel				128	Sept. 11	21.5
Four miles above La Crosse:						
Main channel				129	...do....	21.0
Right bank				131	...do....	18.0
Slough near Light No. 98				130	...do....	17.5
Opposite mouth of Root River, main channel				135	Sept. 12	30.3
Between De Soto and Lansing, main channel				136	Sept. 13	20.0
Three miles above Prairie du Chien, main channel	55	Aug. 15	28.7	137	...do....	17.0
Prairie du Chien:						
East channel, midstream	54	...do....	32.0	138	Sept. 14	17.3
East channel, left bank				139	...do....	11.0
McGregor, main channel				141	...do....	16.7
Opposite mouth of Wisconsin River, main channel	53	Aug. 14	25.8	143	...do....	16.5
One mile below Cassville, main channel				145	Sept. 15	14.7
Four miles below Bellevue, main channel				146	Sept. 16	10.7
Six miles above Clinton, main channel	51	Aug. 12	15.7			
Three miles below Clinton, main channel				147	Sept. 17	7.3
Rock Island Rapids	50	Aug. 11	6.0	148	...do....	6.0
One mile below mouth of Rock River, main channel				150	Sept. 18	7.0
Fairport:						
Main channel	2	July 12	6.0			
Andalusia Slough	1	July 11	4.0			
Do	47	Aug. 9	6.6			
Main channel	48	...do....	4.3			
Below the dike	49	...do....	3.3			
New Boston:						
Main channel	4	July 13	6.75			
Sturgeon Bay	3	...do....	5.0	151	Sept. 20	3.0
Midstream	5	...do....	3.7			
One mile below mouth of Edwards River:						
Midstream	7	...do....	6.0			
Main channel				153	Sept. 20	6.3
Two miles below Burlington, main channel				154	...do....	3.75
Alexandria, main channel				157	Sept. 23	3.0

HORIZONTAL DISTRIBUTION IN RIVER.

As swift streams do not afford favorable conditions for the development of plankton organisms we may expect an increase of plankton where water flows slowly or is stagnant. The velocity of current is greater in the main channel than near the banks and just below the dikes the water is often almost stagnant. Therefore one may expect plankton organisms to be more abundant near the banks and between the dikes.

The determinations of the volume of plankton made at different points across the river show, however, that such relations do not always exist. The volume of suspended material is sometimes greater in the main channel than near the banks. Evidently this occurs most often when the material in suspension consists largely of detritus and not of plankton. Such a case, for example, was observed at Fairport (stations 48, 49), where it was found that the volume of material suspended in the stagnant water below the dike was less than that in the main channel. There were very few organisms in the samples that contained detritus almost exclusively. The places below the dikes where the water is almost stagnant are evidently unfavorable for the development of plankton, as is shown by the fact that samples collected there usually contain fewer organisms than can be found in the main channel where the current is swift.

Sometimes, however, the amount of plankton in the shallows close to the banks is greater than in the main channel. Thus in the very outlet of Lake Pepin the amount of plankton near the left shore was greater than in the other parts of the stream (stations 104–106). As shown in Table 14, the amount of plankton near the left bank was 33 $cm.^3$ per cubic meter, whereas in midstream it was 18 and near the right bank 21.5 $cm.^3$ The water near the left bank was stagnant, and the increase of plankton was due to the great abundance of copepods forming the greater part of the total mass in this sample.

The amount of plankton in the bays is greater than in the main channel of the river, although the total volume of material taken in the plankton net in these bays was sometimes less than that taken in the river. Such a case, for example, was observed at stations 3 to 5 near New Boston, Ill.; the volume of plankton in Sturgeon Bay was 5 $cm.^3$ per cubic meter, and that in the main channel 6.75 $cm.^3$, but the first consisted exclusively of organisms, and most of the second was formed of detritus.

VERTICAL DISTRIBUTION IN RIVER.

Plankton organisms are passively carried by running water; therefore their vertical distribution in the river depends entirely on the current. Results of the determination of the volume of plankton taken from different strata show that sometimes the amount of plankton taken in the deeper strata is greater than that in the surface water, while sometimes the vertical distribution of plankton in the river is the same as that usually found in the lakes during the warm season; that is, the surface layers are richer in plankton than the deeper layers. At many stations it was found that the vertical distribution of plankton is uniform. This condition occurs especially where the current is swift, as, for instance, at the rapids. The vertical distribution of plankton in the river is, however, very variable.

The following (Table 15) are examples of the determinations of plankton taken from different depths in August and September at one of the deepest points of the upper Mississippi River, opposite the mouth of the Wisconsin River. The increase of volume at depths of from 3 to 6 m., observed on August 14, was due to the greater abundance of organisms, not to the increase of detritus. The results of other observations concerning the vertical distribution made during the course of the investigation are given in Table 29.

TABLE 15.—*Vertical distribution of plankton at stations 53 and 143.*

Depth, meters.	Plankton (cubic centimeters per cubic meter).		Depth, meters.	Plankton (cubic centimeters per cubic meter).	
	Station 53, Aug. 14.	Station 143, Sept. 14.		Station 53, Aug. 14.	Station 143, Sept. 14.
0	16	20	4.6	32	15
1.5	17	17	6.1	36	15
3.0	26	17	7.6	28	15

LAKE KEOKUK.

There is more plankton in Lake Keokuk than in the adjacent parts of the river. In July the mean volume of plankton in the lake, calculated as the average of 143 samples collected at 30 different stations, was 7.25 cm.^{3} per cubic meter. As to the richness in plankton there was a marked difference between the upper and the lower parts of the lake. The mean volume of plankton in the upper part, between Burlington and Nauvoo, was 5.28 cm.^{3} per cubic meter; in the lower part, 7.7 cm.^{3}

The total volume of the material in suspension observed in the river above Burlington (station 8) was 3 cm.^{3} per cubic meter; 9 miles downstream in the upper part of the lake (station 16) it was 4.25. Moreover, the upper part of the lake was considerably richer in plankton than was the river, because in the lake a great part of the detritus is replaced by live organisms. In this case volumetric observations are inadequate to determine accurately the increase in the production of plankton, and the gradual changes occurring in the river as it widens into a large lake can be recognized only by enumeration of the organisms. The distribution of plankton in the lower part of the lake was almost uniform (see fig. 11); the volume of plankton per cubic meter varied here from 6 to 9.6 cm.^{3} There was no increase of plankton from Nauvoo down to the dam. In the shallow parts the vertical distribution of the plankton was uniform. Near the dam, where the lake is deepest, the amount of plankton was considerably greater in the upper strata than in the depths. An example of the distribution of plankton as found on July 30 at stations 40, 41, and 45 follows:

TABLE 16.—*Vertical distribution of plankton at stations, 41, 45, and 40.*

Depth, meters.	Plankton (cubic centimeters per cubic meter).			Depth, meters.	Plankton (cubic centimeters per cubic meter).		
	Station 41.	Station 45.	Station 40.		Station 41.	Station 45.	Station 40.
0	14	12	10	6.1	8	5	8
1.5	10	10	8	7.6	7	6	(1)
3.0	10	7	8	9.1	6	5	....
4.6	6	7	10	10.7	(1)	6	....

[1] Bottom.

On windy days the stratification of plankton disappears and it becomes distributed uniformly. (See Table 29, p. 423. Stations 26, 28, 32, 34.) The stratification of plankton during calm weather and its uniform distribution from the surface to the bottom on windy days show that the wind causes the circulation of the whole body of water in the lake. This circulation is possible because there is no great difference in the temperature and density of water at the different levels.

Of the tributaries emptying into Lake Keokuk the most important is Skunk River, on the Iowa side of the lake. The mouth of this river is now submerged and its water flows slowly. The plankton of the Skunk River is considerably

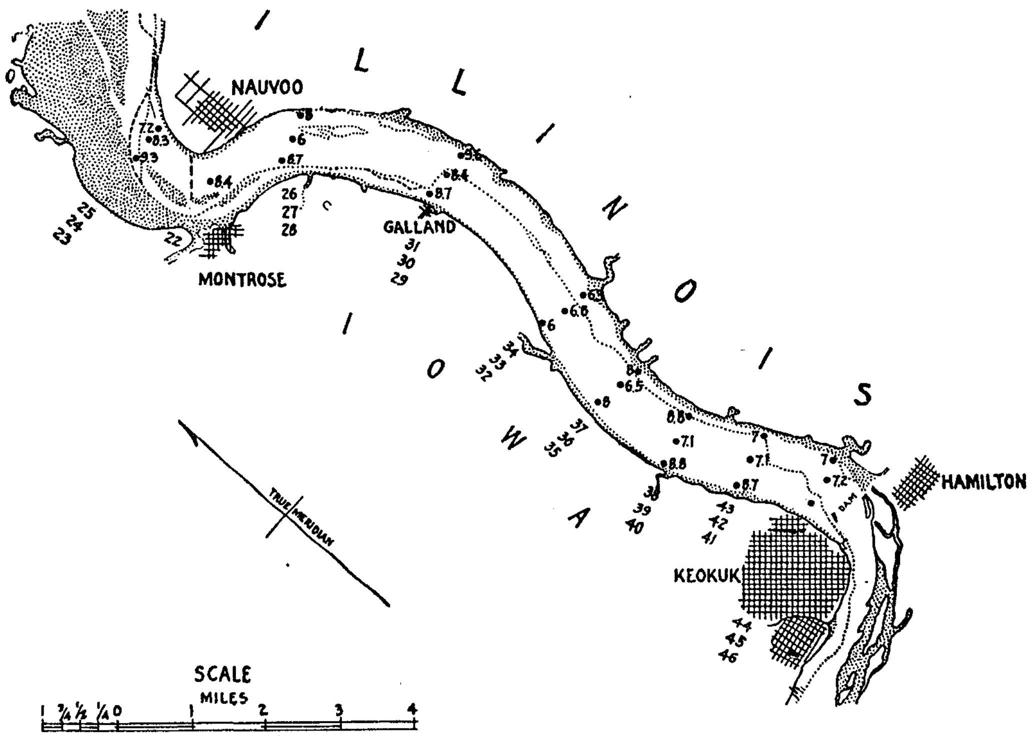

FIG. 11.—Distribution of plankton in Lake Keokuk, July, 1921. (Figures on the chart indicate the mean volume of plankton per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

richer than that of Lake Keokuk. On July 20 its average volume, measured in two different channels of the river, was 17.5 cm.[3] (station 14) and 26.5 cm.[3] (station 13) per cubic meter.

The overflowed islands with submerged vegetation are of particular importance for Lake Keokuk. It would be especially interesting to study in a detailed manner the microscopical fauna and flora of those parts of the lake where a great quantity of old vegetation is now in a state of decomposition. Unfortunately the writer was unable to collect the material for quantitative plankton investigation in these places, and therefore the question of whether the overflowed lands possess a greater productive capacity than the adjacent channels with running water remains open.

Fluctuations in hydrographic conditions immediately affect the plankton in Lake Keokuk. A rising level causes a sharp decline in plankton content, because storm waters mingle with and replace plankton rich backwaters. In September, when the river was rising, there was no difference in plankton content of the lower and the upper parts of the lake; moreover, no difference at all could be found between the river and the lake. All plankton that had been developed during the period of stability of hydrographic conditions was washed away with the rise of the river. The volume of material suspended in the water at this time varied from 2 to 4 $cm.^3$ and consisted almost exclusively of detritus. (See stations 156–171, Table 29, p. 433.)

LAKE PEPIN.

The mean volume of plankton in Lake Pepin, computed from the results of observations made during the 18-day period (August 18 to September 5), is 16.6 $cm.^3$ per cubic meter of water. The figure is the average of 140 samples collected at 36 different stations.

The lower part of the lake, below Lake City, is richer in plankton than the upper part. The mean volume of plankton in the lower part averaged 22.1 $cm.^3$; in the upper part 13.3 $cm.^3$ If we exclude from the upper part the shallow area near Bay City, its mean content of plankton would be 15.7 $cm.^3$ The increase of plankton in the lower part as compared with that in the upper is 8.8 $cm.^3$ per cubic meter of water. Compared with the mean content of plankton in the whole lake the amount of plankton is 33.1 per cent greater in the lower part and 19.9 per cent less in the upper part. The distribution of plankton in the lake is shown graphically on Figure 12, which is, of course, only schematic, because the observations were not made simultaneously.

The possible error due to nonsimultaneousness of observations seems, however, not to be great because there were no considerable changes in weather or hydrographic conditions during the period in question. The results obtained at stations 72, 75, and 76 on August 24 are very close to those obtained on September 5 at station 117, located in the same region. Unfortunately the samples collected on September 5 at stations 118 and 119 with the intention of comparing the results with those of previous observations made in August were lost before the volume of plankton was measured. Only one sample obtained with the plankton net at station 118 near Lake City has been saved. The amount of plankton in this sample agrees closely with that obtained with the net at station 58 (9.4 $cm.^3$ of plankton per cubic meter observed at station 118, September 5, and 9.5 $cm.^3$ at station 58 August 18). The amount of plankton obtained with a net differs greatly from that obtained with a pump. Therefore it is absolutely impossible to compare the results obtained by these two different methods, but the results of the net method, especially when referred to the same depth, may be compared. The question of the adequacy of the plankton net for quantitative investigation and a comparison of the pump and net methods is discussed on page 385.

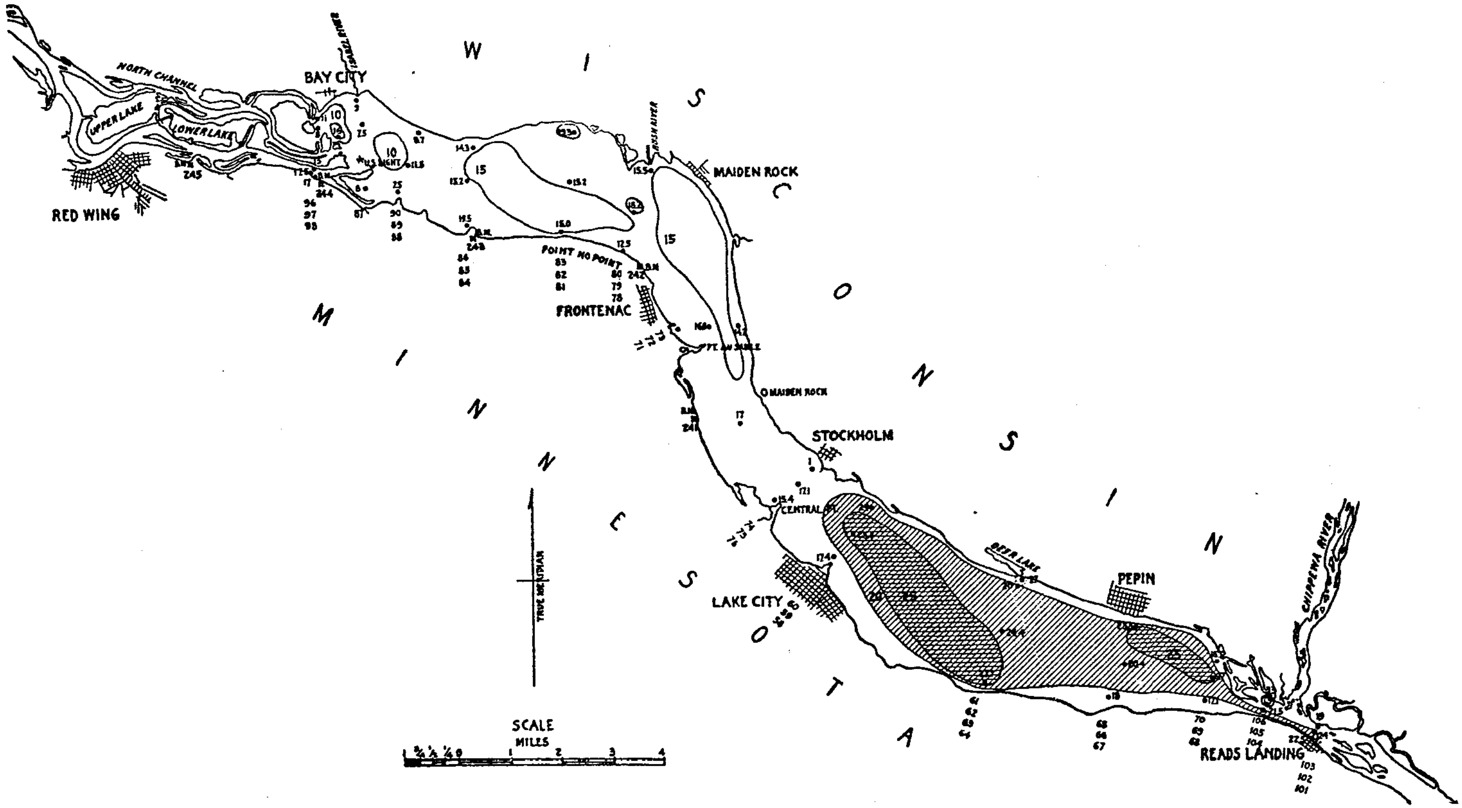

FIG. 12.—Distribution of plankton in Lake Pepin, July, 1921. (Figures on the chart indicate the mean volume of plankton per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

The figures on Figure 12 indicate the average volume of plankton in cubic centimeters per 1 cubic meter calculated for each station from the data obtained by pump collections. The curves are drawn between the points of equal content of plankton. The difference in the amount of plankton in each of the two parts of the lake is presented on this map in a vivid manner. The maximum volume of plankton, 25.8 and 27 cm.^{3}, is found in midlake in the lower part; the minimum amount, 7.5 cm.^{3}, is found in the northern shallow part of the lake near Bay City.

In the shallow water of the lower part of the lake between Pepin Village and the Chippewa Delta the amount of plankton is very great, ranging from 20 to 27 cm.^{3} per cubic meter. This area is covered with water plants, *Potamogeton crispus*, *P. americanus*, *Vallisneria spiralis*, and *Ruppia occidentalis*, forming large associations.

It is interesting to compare the content of plankton in the water running into the lake with that in the outflow. For this purpose we may use the observations made August 29 at stations 96 to 98, 1 mile above the head of the lake, and August 30 at stations 101 to 103, opposite Reads Landing, below the foot of the lake. The average amount of plankton above the lake was 16.6 cm.^{3} per cubic meter, while that in the outflow was 21.8 cm.^{3} The increase in plankton in the lake then was 5.2 cm.^{3} per cubic meter, or 31.3 per cent. It is noteworthy that the increase in plankton occurred only in the lower part of the lake (see fig. 12). The mean amount of plankton in the upper part, excluding the northern shallow section, as has been shown, averaged 15.7 cm.^{3}, or 0.9 cm.^{3} less than that in the Mississippi above the lake.

The vertical distribution of plankton in Lake Pepin is the same as in Lake Keokuk. On calm days the surface water sometimes contained more plankton than the lower layers, but after the wind had been blowing for a long time the whole body of water would be stirred up, and the distribution of plankton would become uniform. The results of the observations are presented in Table 29 (p. 426, stations 58 to 95). The uniformity of the distribution of plankton in a lake, so far as its volume is concerned, depends principally on the uniformity of temperature distribution. Of course the different organisms may be distributed differently in the vertical line, and, even if the amounts of plankton in the upper stratum and at depths are the same, they may consist of different components. In Lake Pepin the greatest difference in the distribution of plankton was due to the blue-green algæ, which were most abundant at the surface of the lake and very scarce in the depths.

LAKE ST. CROIX.

The average volume of plankton observed at Lake St. Croix September 2 was 29.3 cm.^{3} The observation was made on a calm morning. The vertical distribution of plankton at three stations located across the lake is shown in Table 17. Apparently the decrease in plankton occurs on the levels where the fall of temperature is the greatest (7.6 to 9.1 m., station 112; and 6.1 to 7. 6 m., station 113).

TABLE 17.—*Vertical distribution of plankton at stations 112, 113, 114.*

Depth, meters.	Station 112.		Station 113.		Station 114.	
	Plankton, cubic centimeters per cubic meter.	C°.	Plankton, cubic centimeters per cubic meter.	C°.	Plankton, cubic centimeters per cubic meter.	C°.
0	35	23.3	32	23.3	43	23.9
1.5	37	23.2	34	23.2	22	23.6
3	31	23.2	43	23.2	(1)	
4.6	37	23.1	36	23.1		
6.1	28	23.1	34	22.7		
7.6	36	23.0	24	21.4		
9.1	13	22.0	19	21.2		
10.6	9	21.0	9	20.6		
11.3	(1)	20.3	11	19.8		

1 Bottom.

PUMP AND NET COLLECTIONS.

At every station on the lakes the plankton samples were obtained both with the pump and with the vertical plankton net. Although in the present investigation only the results of the pumping method are taken into consideration, it is interesting to compare the two methods. Up to the present time the plankton net remains the chief instrument of limnological investigation, and the results obtained by this means are used for quantitative investigations and for estimates of the productiveness of basins. The source of error in this method lies in the determination of the so-called coefficient of the net. The meaning of the coefficient of the net and how it is found can be seen from the following:

The volume of water (M) filtered through the net drawn straight from the bottom to the surface of the lake is usually less than that computed by the formula $M = CH$, where C is the area of the net opening and H is the depth of water. For more accurate results the formula $M = qCtv$ is applied, where t is the time in seconds required to lift the net from bottom to surface, v is the velocity of vertical movement of the net in meters per second, q is the reciprocal of the coefficient of the net (K), and C, as before, is the area of the net opening. The resistance of the net causes a certain quantity of water to be pushed aside and q is the factor of correction, which varies, depending on several conditions. The coefficient of the net (K) can be computed, using Hensen's formula which has been found on the basis of experiments made with filtered water, and it can be applied to a net of known silk of definite dimensions and drawn at given velocities. The other methods consist in comparing the quantities of organisms or Lobelia seeds added to water (Reighard, 1894) caught in the net with the quantities obtained by filtering an exact volume of the same water. According to Amberg (1900) the filtering capacity of the net, and therefore the coefficient of the net, depends on the size of the meshes, the area of the net opening, the area of the filtering cone, the form of the net, the velocity of the lifting, the depth to which the net has been lowered, and the composition and the amount of plankton. Burckhardt (1900) pointed out that the net coefficient depends also on the length of time the net has been used. Kofoid (1903) came to the same conclusions, to wit:

A uniform coefficient, and, moreover, one founded on the operation of the net in filtered water, would not adequately correct the error, since it takes no account of the seasonal changes in the quantity and kind of plankton, and does not recognize the effect of the progressive clogging of the net by the catch, or the change of the net with use.

It would follow from these considerations that the net coefficient can not be accurately determined. It varies even during the same haul and becomes greater toward the end of the haul than at its beginning, because the net becomes progressively clogged.

The coefficient of the net used in our investigation was determined by comparing the amount of plankton taken by the net with that taken by the pump. The experiment was made on a small pond of stagnant water 2 m. deep and with a plankton content of about 15 $cm.^3$ per cubic meter. The coefficient computed for a new net was 1.40. The volume of plankton per cubic meter of water has been calculated from the actual data, using the formula $M=qCtv$, where for all observations q was supposed to be equal to the reciprocal of 1.40, 0.714, and the velocity v was one-half meter per second. The data obtained simultaneously with net and pumping methods are given in Table 18. The data of the pumping method represent the average volume of plankton at each station calculated from the determinations of the volume of plankton at various depths from surface to the bottom. The comparison of the average volume of plankton thus calculated with that obtained by continuously lifting the hose of the pump from the bottom to the surface and pumping 50 liters showed an insignificant difference between the results of the two methods, not to exceed +3 per cent. The table shows that in most cases the amount of plankton obtained by the pumping method is greatly in excess of that taken by the net.

The differences between the data vary from +1.25 per cent to −70.5 per cent of the pump data. All cases where the amount of plankton taken with the net is greater than that obtained with the pump occur in shallow water (Table 18, stations 35 and 114). This wide range of fluctuation indicates that in most cases the net coefficient ought to be greater than 1.40, but that in the shallow water (stations 35 and 114) it must be less. Since the filtering capacity of the net depends not only on the depth to which the net has been lowered and the amount of plankton, but also on the kind of plankton, it seems very difficult to find a definite relation between the net coefficient and the condition at which the haul is made. That the coefficient varies with different depths is apparent in Table 18.

The most instructive case may be found at stations 112 to 114, where the difference between the net and pump data in the cases of deep hauls varies from −61.4 to −70.5 per cent, whereas in the case of shallow water the difference is only +1.2 per cent. In order to avoid the error resulting from the adoption of one coefficient irrespective of the age of the net and of seasonal, local, quantitative, and qualitative differences in the catch, Kofoid (1903) decided to assign an empirical coefficient to each catch. This coefficient was decided upon after an analysis of the plankton and in view of its quantity, the basis for such an estimation being the coefficient test by the pumping method made under conditions most nearly approaching those of the catch in question. Obviously, this method, depending on a personal estimation, involves a source of error of uncertain extent. Consequently, it is impossible to determine the coefficient of the net without comparison with the results of the pumping method. Therefore it would be more practical to use the plankton net only for qualitative collections and to abandon this method entirely in all quantitative investigations of inland waters. The correct quantitative data can be obtained only by the pump method.

TABLE 18.—*Volumes of plankton collected simultaneously with pump and with vertical plankton net.*

Station number.	Depth in meters.	Plankton, cubic centimeters per cubic meter.		Difference, per cent of pump datum.	Station number.	Depth in meters.	Plankton, cubic centimeters per cubic meter.		Difference, per cent of pump datum.
		Pump.	Net.				Pump.	Net.	
LAKE KEOKUK.									
22	6.1	8.4	5.8	−30.9	36	7.6	6.5	5.6	−13.8
25	6.1	7.2	4.1	−43.1	37	6.1	8.0	6.1	−23.8
26	6.1	8.0	6.1	−23.8	38	6.1	8.8	7.0	−20.4
27	6.1	6	5.1	−15.0	39	7.6	7.1	4.9	−31.0
28	4.6	8.75	7.7	−11.4	40	6.1	8.8	6.0	−31.8
29	4.3	8.75	6.2	−29.2	41	9.1	8.7	7.6	−12.6
30	6.1	8.4	4.0	−47.6	42	9.1	7.1	5.5	−22.6
31	6.1	9.6	6.2	−35.4	43	7.6	7.0	6.1	−12.9
32	3.0	6.0	5.8	−3.3	44	9.1	7.0	4.9	−30.0
33	7.6	6.8	5.6	−17.6	45	10.7	7.25	3.8	−46.9
34	7.6	6.3	4.3	−31.8					
35	3.0	8.0	8.1	+1.25					
LAKE PEPIN.									
58	9.1	17.4	9.5	−45.4	68	13.1	17.1	11.2	−34.5
59	7.6	25.8	16.0	−34.8	72	7.0	16.0	14.0	−12.5
60	6.1	24.0	14.7	−38.8	75	7.6	17.1	12.5	−26.8
63	6.1	24.4	18.5	−24.2	79	6.1	18.2	16.9	−7.0
64	9.1	27.1	10.9	−59.8	81	6.1	15.0	10.9	−20.6
65	4.6	25.5	18.6	−27.0	82	4.6	15.2	12.6	−17.1
66	6.1	20.4	18.5	−7.3	84	5.2	19.5	17.8	−11.5
67	10.7	18.0	11.2	−37.8	85	4.3	15.2	11.2	−26.4
LAKE ST. CROIX.									
112	11.3	28.2	8.3	−70.5	114	1.5	32.5	32.9	+1.2
113	12.2	26.9	8.4	−61.4					

DISTRIBUTION OF COPEPODA AND CLADOCERA.

THE RIVER.

The crustacean population of the river consists principally of copepods (Diaptomus and Cyclops), the Cladocera comprising only an insignificant part of the plankton. In that part of the river between Rock Island Rapids and Burlington Crustacea are scarce. (See Table 19.) In this region the average number of Copepoda in July and August did not exceed 60 individuals per cubic meter, and Cladocera were almost entirely absent. In the latter part of September an unexpected increase of crustacean population was found in Sturgeon Bay near New Boston (station 151), where the number of Copepoda reached 3,520 and that of Cladocera 2,170 per cubic meter. In the adjacent parts of the main channel they were absent. Ninety per cent of the water fleas found in Sturgeon Bay was represented by *Moina rectirostris,* and *Diaphanosoma leuchtenbergianum* formed the remainder. In July the number of crustaceans at the same locality was 60 Copepoda and 20 Cladocera.

Above Rock Island Rapids the number of crustaceans gradually increased upstream (Table 19); near Prairie du Chien the number of Copepoda reached 29,000 per cubic meter (September 14); between Prairie du Chien and Reads Landing their numbers varied from 6,800 (opposite Root River) to 35,660 per cubic meter at Reads Landing in the outlet of Lake Pepin (stations 124 to 135, September 10, 12). In the main channel of the river, just below Lake Pepin, the number of Copepoda was even greater, reaching 44,000 to 46,000 per cubic meter (stations 101, 104, August 30).

TABLE 19.—*Number of Copepoda and Cladocera in the Mississippi River between Hastings, Minn., and Alexandria, Mo.*

Station.	Serial number of station.	Date.	Number of Copepoda per cubic meter.	Number of Cladocera per cubic meter.	Serial number of station.	Date.	Number of Copepoda per cubic meter.	Number of Cladocera per cubic meter.
Near Hastings	116	Sept. 1	1,053	160				
Near Prescott	115	...do...	1,133	120				
Diamond Bluff	111	...do...	2,320	187				
Near Red Wing	110	...do...	2,905	260				
One mile above head of Lake Pepin:								
Left bank	96	Aug. 29	7,810	1,240				
Midstream	97	...do...	1,650	505				
Right bank	98	...do...	640	280				
Above mouth of Chippewa River below Lake Pepin, main channel:								
Right bank	104	Aug. 30	46,223	190				
Midstream	105	...do...	21,550	340				
Left bank	106	...do...	125,660	0				
Reads Landing, main channel:								
Right bank	101	...do...	44,010	175	124	Sept. 10	35,660	405
Midstream	102	...do...	15,980	380				
Left bank	103	...do...	1,300	120				
One mile above Wabasha, main channel	57	Aug. 9	20,985	250				
Beef Slough					125	Sept. 10	1,840	120
Opposite mouth of Zumbro River					127	...do...	14,581	280
Between Winona and Homer, main channel					128	Sept. 11	20,340	100
One mile above La Crosse, main channel					129	...do...	16,290	390
Slough near light No. 98					130	...do...	15,520	460
Four miles above La Crosse, right bank					131	...do...	9,920	180
Opposite mouth of Root River, main channel					135	Sept. 12	6,813	247
Between De Soto and Lansing, main channel					136	Sept. 13	14,900	327
Three miles above Prairie du Chien, main channel	55	Aug. 15	19,253	207	137	...do...	27,047	267
Prairie du Chien, east channel:								
Midstream	54	...do...	20,970	170	138	Sept. 14	29,000	187
Left bank					139	...do...		
McGregor, main channel					141	...do...	17,966	153
Opposite mouth of Wisconsin River, main channel	53		18,257	127	143	...do...	18,307	80
One mile below Cassville, main channel					145	Sept. 15	7,453	17
One-half mile below Bellevue, main channel					146	Sept. 16	5,806	27
Six miles above Clinton, main channel	51	Aug. 12	5,467	40				
Three miles below Clinton, main channel					147	Sept. 17	2,120	0
Rock Island Rapids	50	Aug. 11	7	0	148	...do...	400	0
One mile below mouth of Rock River, main channel					150	Sept. 18	200	0
Fairport:								
Main channel	2	July 12	0	0				
Andalusia slough	1	July 11	0	0				
Do	47	Aug. 9	0	0				
Main channel	48	...do...	13	0				
Below the dike	49	...do...	0	0				
New Boston:								
Main channel	4	July 13	0	0				
Sturgeon Bay	3	...do...	60	20	151	Sept. 20	3,520	2,170
Midstream	5	...do...	0	0				
One mile below mouth of Edwards River:								
Midstream	7	...do...	0	0				
Main channel					153	Sept. 20	0	0
Two miles below Burlington, main channel					154	...do...	20	0
Alexandria, main channel					157	Sept. 23	40	0

The increase in the crustacean population was due mainly to an increase of Copepoda, the Cladocera being many times less abundant. A peculiar gathering of Copepods was observed at the left bank of the river near the Chippewa Delta (Table 19, station 106), where in shallow stagnant water the number reached 125,660 per cubic meter. No water fleas were found at this station, and the swarm of copepods consisted exclusively of Diaptomus and Cyclops.

The number of crustaceans gradually decreased from the head of Lake Pepin upstream as far as Hastings. The copepod population at station 116 (September 1) near Hastings was 1,053 per cubic meter, that of Cladocera 160, while just above Lake Pepin (station 96, August 29) the Copepoda content in the main channel reached 7,840 and that of Cladocera 1,270 per cubic meter.

The distribution of crustaceans across the river was very variable. In many cases it was observed that they were more numerous in the main channel than close to the banks or in the shallows. (See Table 19, statons 96 to 98 and 129 to 131. Both Stations 96 and 97 are located on the main channel.) As was shown at station 106, however, where the water was almost stagnant, the copepods were three times as numerous as in the main channel (station 104). Among the water lilies that form large zones along both banks of the river above Prairie du Chien crustaceans were very scarce (station 56).

The number of Copepoda in Lake St. Croix, as observed on September 2, varied from 12,460 per cubic meter near the shore to 18,315 in mid lake. The corresponding figures for Cladocera were 680 and 1,955.

The crustacean population was very scarce in most of the tributaries of the Mississippi River. A considerable quantity of copepods was found only in Zumbro River (station 126, September 10, 27,200 per cubic meter), in Black River (station 132, September 12, 5,960 per cubic meter), and in Wisconsin River (station 142, September 14, 2,120 per cubic meter). Only occasional copepods or water fleas can be found in the samples collected in other tributaries emptying into the Mississippi. (See Table 24.)

LAKE KEOKUK.

Crustaceans were more abundant in Lake Keokuk than in the adjacent part of the river. The distribution of the Copepoda and Cladocera population in the lake is presented graphically in Figures 13 and 14, where the figures at each station indicate the average number, in hundreds, of organisms per cubic meter of water. The lines on the maps are drawn between the points with equal content of organisms.

Crustacea were scarce in the upper part of the lake between Burlington and Nauvoo, where their number at different stations varied from 0 to 400 per cubic meter. In the lower part of the lake they were more abundant. Here the average number of Copepoda at different stations varied from 600 to 23,500 per cubic meter and of Cladocera from 100 to 14,500. The mean number of Copepoda in the lower part of the lake, computed as the average of 25 stations, was 5,400; that of Cladocera, 2,720. The mean number of Crustacea in the upper part of the lake could not be computed because of the small number of stations and the very different ecological conditions existing here.

In the lower part of the lake the crustacean population gradually increased from a line between Nauvoo and Montrose down toward the dam. This increase can be noticed on Figures 13 and 14, but it is more obviously demonstrated in Figure 15 which represents the mean number of Copepoda and Cladocera at eight cross sections of the lake. The ordinates of this figure represent the mean number, in hundreds, of individuals at each cross section; the abscissæ, the distances in miles between the line connecting Nauvoo and Montrose and the dam. The continuous line represents the fluctuations in the number of Copepoda; the dotted line, in that of the Cladocera. The maximum content of Copepoda occurs about 2½ miles above the dam; that of the Cladocera, at 1½ miles above the dam. Each of the two groups shows a decline in the section close to the dam, yet they are more abundant there than near Nauvoo.

The distribution of the Copepoda along the lake is shown on Figure 13. It is remarkable that they are more numerous near the shores than in the mid-lake region. All stations in the lower part of the lake are located in the pelagic region; therefore the differences in the abundance of organisms refer to one ecological area. The distribution of Cladocera in this lake is, in general, the same as that of Copepoda and differs only in details (fig. 14).

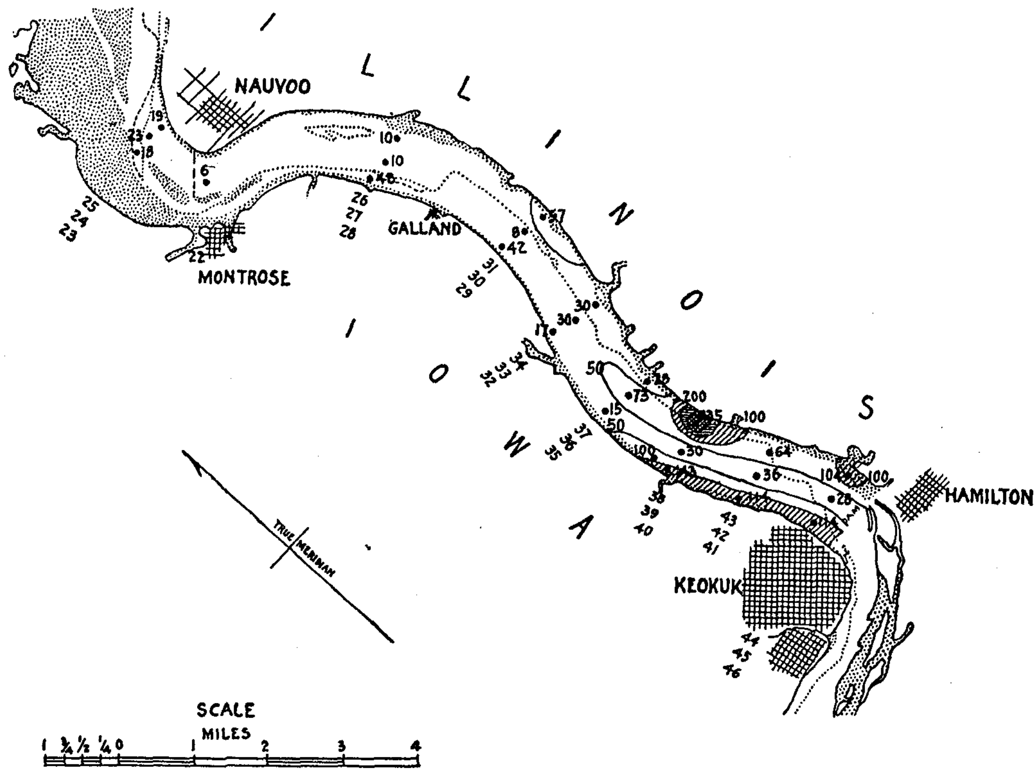

FIG. 13.—Distribution of Copepoda in Lake Keokuk, July, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

As has been stated above, the distribution of the total amount of plankton in the lower part of Lake Keokuk was almost uniform. The mean quantities of plankton for each cross section of the lake, computed in the same way as the mean number of Crustacea, varied from 6.4 to 8.3 cm.^{3} per cubic meter, but there was no increase in the lower sections near the dam. The volume of the plankton at the two sections nearest to the dam was even less than in the section opposite Nauvoo (Table 20 and fig. 15). Evidently Crustacea, which were about five times more numerous in the lower sections than in the upper, replaced there some other constituents of the plankton.

TABLE 20.—*Mean content of plankton and mean numbers of Copepoda and Cladocera in cross sections of the lower part of Lake Keokuk, July 15 to 30, 1921.*

Station number.	Distance from the dam, in miles.	Copepoda, mean number per cubic meter.	Cladocera, mean number per cubic meter.	Mean volume of plankton, cubic centimeters per cubic meter.
23 to 25	11.5	2,000	2,400	8.3
26 to 28	8.5	2,300	1,900	7.6
29 to 31	6.5	3,600	1,500	8.9
32 to 34	4.5	2,600	1,300	6.4
35 to 37	3.5	3,900	600	7.5
38 to 40	2.5	13,600	2,600	8.2
41 to 43	1.5	7,100	8,100	7.6
44 to 46	0.5	8,200	3,400	7.1

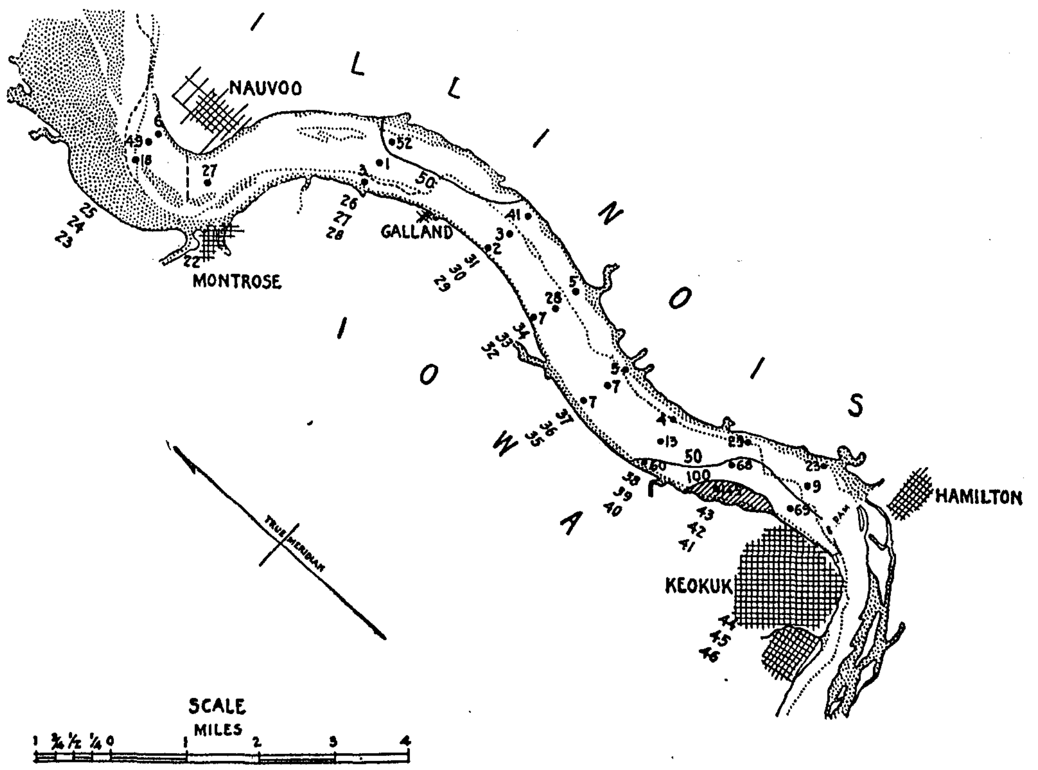

FIG. 14.—Distribution of Cladocera in Lake Keokuk, July, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

The vertical distribution of plankton Crustacea in Lake Keokuk varied greatly, as is evident from Table 29 (p. 422), in which the numbers of Copepoda and Cladocera observed at different depths are given for each station. These organisms can gather in great abundance at any depth from the bottom to the surface of the lake. The difference in the vertical distribution was sometimes very great even between neighboring stations. At some localities Copepoda were most abundant at the bottom, as at station 38, where the quantity just above the bottom was about 30 times as great as at the surface (3,320 at the surface, 94,500 at the bottom, a depth of 6 m.). This gathering of Copepoda at the bottom was observed only at this station; at the nearest stations no indication was found of any increase of these forms in the lower strata.

It is quite possible that in this case we are dealing with a so-called "swarm" of plankton organisms. Such swarms of Cladocera and Copepoda have been

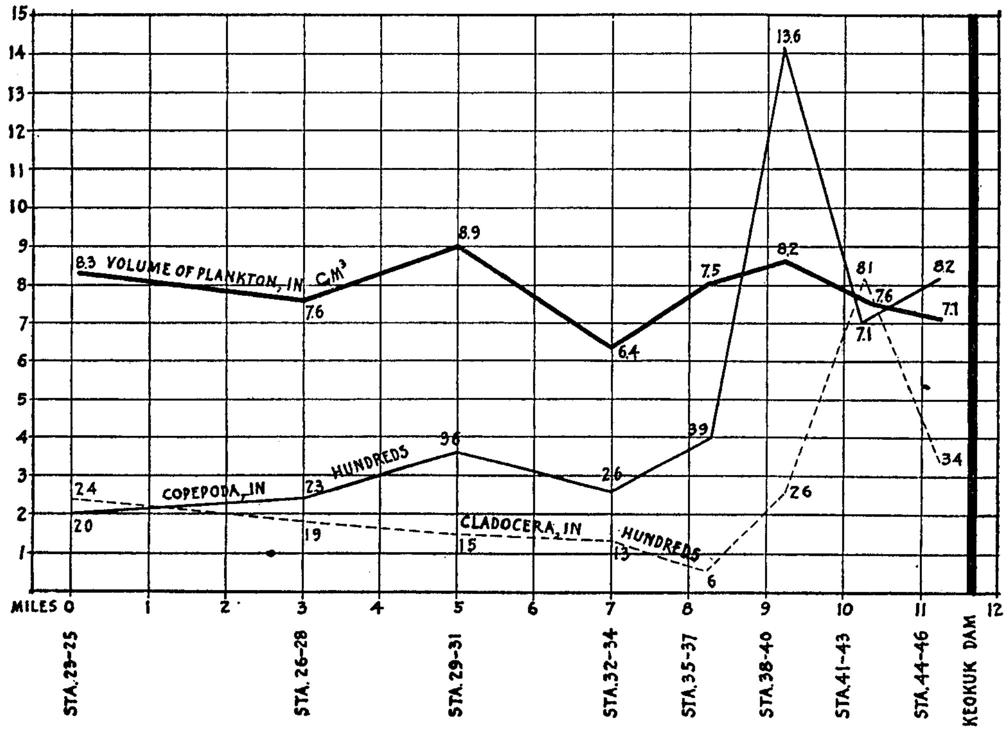

FIG. 15.—Distribution of Crustacea in Lake Keokuk. (The mean content of plankton and the mean numbers of Copepoda and Cladocera in cross sections of the lower part of Lake Keokuk, July 15–30, 1921. Stations 23–25 are located opposite Nauvoo, Ill. Heavy line, ▬▬, represents the mean volume of plankton per cubic meter of water; plain line, ———, the number of Copepoda per cubic meter of water; dotted line, ..., the number of Cladocera per cubic meter of water. The figures on the lines are the averages computed from the data of three stations on the given cross section of the lake. The serial numbers of stations are given under the abscissæ. Scale: One division of the abscissa—1 mile; one division of the ordinata—1 cm.³ of plankton for heavy line; 100 Copepoda and Cladocera for plain and dotted lines.)

described often in limnological literature, but nothing definite is known of the real cause of such gatherings. E. G. Moberg (1918), investigating the horizontal distribution of plankton in Devils Lake, N. Dak., describes swarms of plankton animals, which "are at times visible, even at considerable distances, to the naked eye." He found also that the zooplankton in Devils Lake shows a great irregularity in horizontal distribution and suggested that this irregularity "is due to the habit of swarming among plankton animals, due perhaps to a social instinct, similar to that found in many other groups of the animal kingdom."

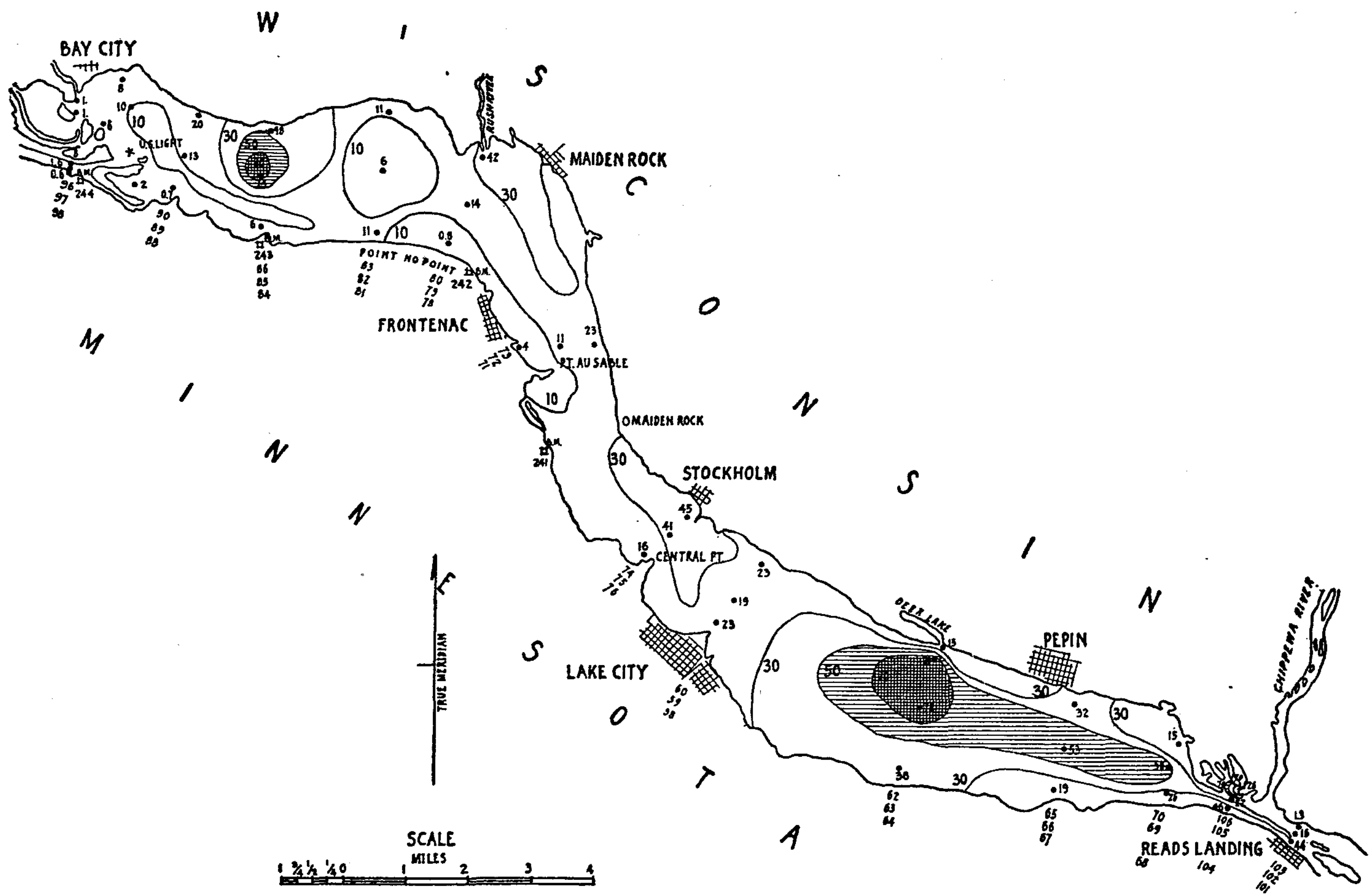

FIG. 16.—Distribution of Copepoda in Lake Pepin, August 18 to September 10, 1921. (Figures on the chart indicate the average number of individuals, in thousands, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

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This suggestion carries no weight, because the origin of the "habit of swarming" remains unexplained. We know, however, that the diurnal migrations of many plankton Crustacea depend on light conditions, and Steuer (1910) has suggested that the gathering of plankton animals may be caused also by wind and current.

There are probably various tropisms that cause the migrations of the plankton animals and their gathering on the surface or at a definite depth of the lake. The problem requires an experimental investigation, and a descriptive examination is insufficient to solve it. The explanation of the behavior of the animals, if one intends to explain it, ought to be based on exact data and not on purely speculative suggestions.

LAKE PEPIN.

Copepoda are very numerous in Lake Pepin and form a considerable part of its plankton. The mean number in this lake, computed from observations made at 36 stations, reached 25,800 per cubic meter. In the Mississippi River, just above the head of the lake, the mean number, as computed from the results of the observations made at three stations across the river, was 3,000 per cubic meter. Below the lake, at Reads Landing, their number averaged 20,000. If we take into consideration only the results obtained in the main channel of the river above and below the lake and omit the observations near the banks where the water runs slowly or is stagnant, we find that the water flowing into the lake carried about 8,000 copepods in each cubic meter and that running out carried from 44,000 to 46,000 per cubic meter (stations 96, 101, 104, Table 29, p. 429). The density of the copepod population in the different parts of the lake is shown in Figure 16, which is plotted in the same way as Figures 13 and 14. The figures on the lines and on the stations indicate the average number of Copepoda, in thousands of organisms, per cubic meter.

It is easy to see that the Copepoda were more abundant in the lower part of the lake, where a large area with the maximum content of 70,000 per cubic meter could be found midway across the lake. The same number of Copepoda per cubic meter (about 70,000) occurred in the upper part of the lake, but the area was small. In the northern shallow part of the lake there were only a few copepods, their average ranging from 1,000 to 10,000 per cubic meter.

The fluctuations in abundance of copepods from the head to the foot of the lake are shown in Figure 17. The figures on the ordinates indicate the average number of copepods for different cross sections of the lake, each figure representing the average of three stations across it. The first figure refers to stations 96 to 98 (fig. 12, p. 383), located just above the head of the lake. The abscissæ give the distances in miles from this point. The results of the observations made in the northern shallow part are omitted. The increase of Copepoda in the lower part of the lake is clearly indicated. Their average frequence there is evidently greater than in the upper part, where only a local increase is found at stations 85 to 86.

The distribution of copepods in general coincides with the distribution of the total amount of plankton in the lake, as is evident from Figure 17 and Table 21, and also by comparing Figures 12 and 16.

TABLE 21.—*Mean amount of plankton and mean number of Copepoda and Cladocera in cross sections of Lake Pepin, August to September, 1921.*

Station number.	Distance from the head of the lake.	Copepoda, mean number per cubic meter.	Cladocera, mean number per cubic meter.	Mean volume of plankton, cubic centimeters per cubic meter.
96 to 98	0	3,000	600	16.5
88 to 90	1.5	11,200	600	9
84 to 86	3	42,000	4,300	16
81 to 83	4.75	9,000	1,500	16
78 to 80	6	19,000	500	15
71 to 73	9	13,000	500	15.1
74 to 76	13.5	34,000	700	16.2
58 to 60	15	22,000	1,000	22.6
62 to 64	18.5	60,000	1,100	23.5
65 to 67	20.5	35,000	400	21.3
68 to 70	22.25	30,000	120	22.2
101 to 103	24.5	20,000	200	18.5

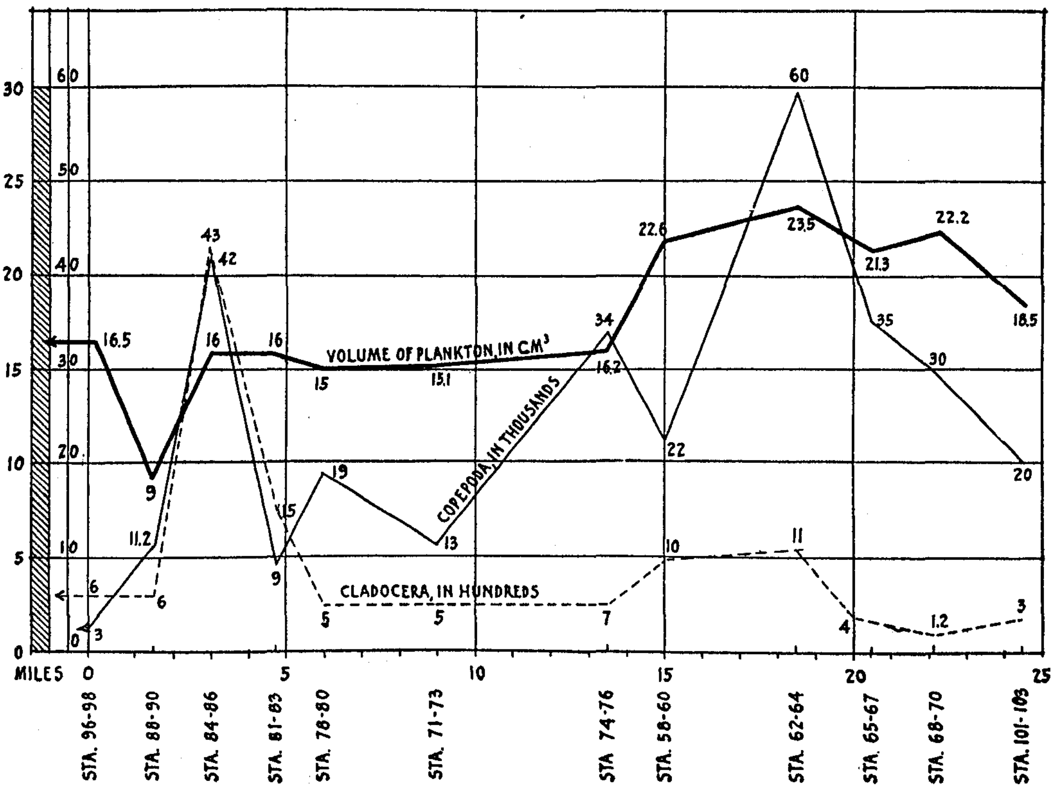

FIG. 17.—Distribution of Crustacea in Lake Pepin. (The mean content of plankton and the mean numbers of Copepoda and Cladocera in cross sections of Lake Pepin, August–September, 1921, from head of lake down to the foot. Stations 96–98 are located at the inflow of the Mississippi River; stations 101–103 at the outflow of the lake. Heavy line, ▬▬, represents the mean volume of plankton per cubic meter of water; plain line, ——, number of Copepoda per cubic meter of water; dotted line, ..., number of Cladocera per cubic meter of water. The figures on the lines are the averages computed from the data of three stations on the given cross section of the lake. The serial numbers of stations are given under the abscissæ. Scale: One division of the abscissa—1 mile; one division of the ordinata—5 cm.³ of plankton for heavy line, 10,000 individuals of Copepoda for plain line, and 1,000 individuals of Cladocera for dotted line.)

With regard to the distribution of Copepoda in the different parts of the lake, it is interesting to note that they are more numerous in the mid-lake region and less abundant near the shores. As we have seen, the reverse condition was found in Lake Keokuk.

The quantity of Cladocera in Lake Pepin was considerably less than that of Copepoda, the mean number per cubic meter being only 1,020, or about one twenty-fifth that of Copepoda. Each cubic meter of water running into the lake carries approximately the same average number of water fleas as can be found in 1 $cm.^3$ of lake water. The number of Cladocera in the outflow was only 230 per cubic meter. The maximum quantity of Cladocera, 11,200 per cubic meter, was found in the upper part of the lake close to the shore (station 86). The fluctuations in abundance of Cladocera in the different parts of the lake, represented in Figure 17 and in Table 21 show a decrease from the head to the foot of the lake. They are more abundant near the shores than in the mid lake. This can easily be seen on Figure 18, which is drawn in the same way as previously.

As compared with Lake Keokuk, Lake Pepin is considerably richer in Crustacea, especially in Copepoda, the mean number in Lake Pepin being 4.7 times greater than in Lake Keokuk. Cladocera, however, are more abundant in Lake Keokuk than in Lake Pepin, the mean number being 2.6 times as great in Lake Keokuk as in Lake Pepin.

In each of the lakes copepods are more abundant than cladocerans. The ratio between the mean number of Cladocera and the mean number of Copepoda is: In Lake Keokuk, 1:2; in Lake Pepin, 1:25. These relations are presented in the following table:

TABLE 22.—*Comparison of Copepoda and Cladocera in Lakes Keokuk and Pepin.*

	Mean number of Cladocera per cubic meter.	Mean number of Copepoda per cubic meter.	Ratio of Cladocera to Copepoda.
Lake Keokuk	2,720	5,400	1:2
Lake Pepin	1,020	25,800	1:25

Ratio of Crustacea in Lake Keokuk to that in Lake Pepin: Cladocera, 2.7: 1; Copepoda 1: 4.8.

COMPOSITION OF THE PLANKTON.

The examination of 673 samples collected by different methods in the river, lakes, and mouths of the principal tributaries makes it possible for us to describe the composition of the plankton of the upper Mississippi with a certain accuracy. One of the problems of the present investigation consists in the comparison of the plankton of the river itself with that of Lake Keokuk and Lake Pepin, which form parts of the same river.

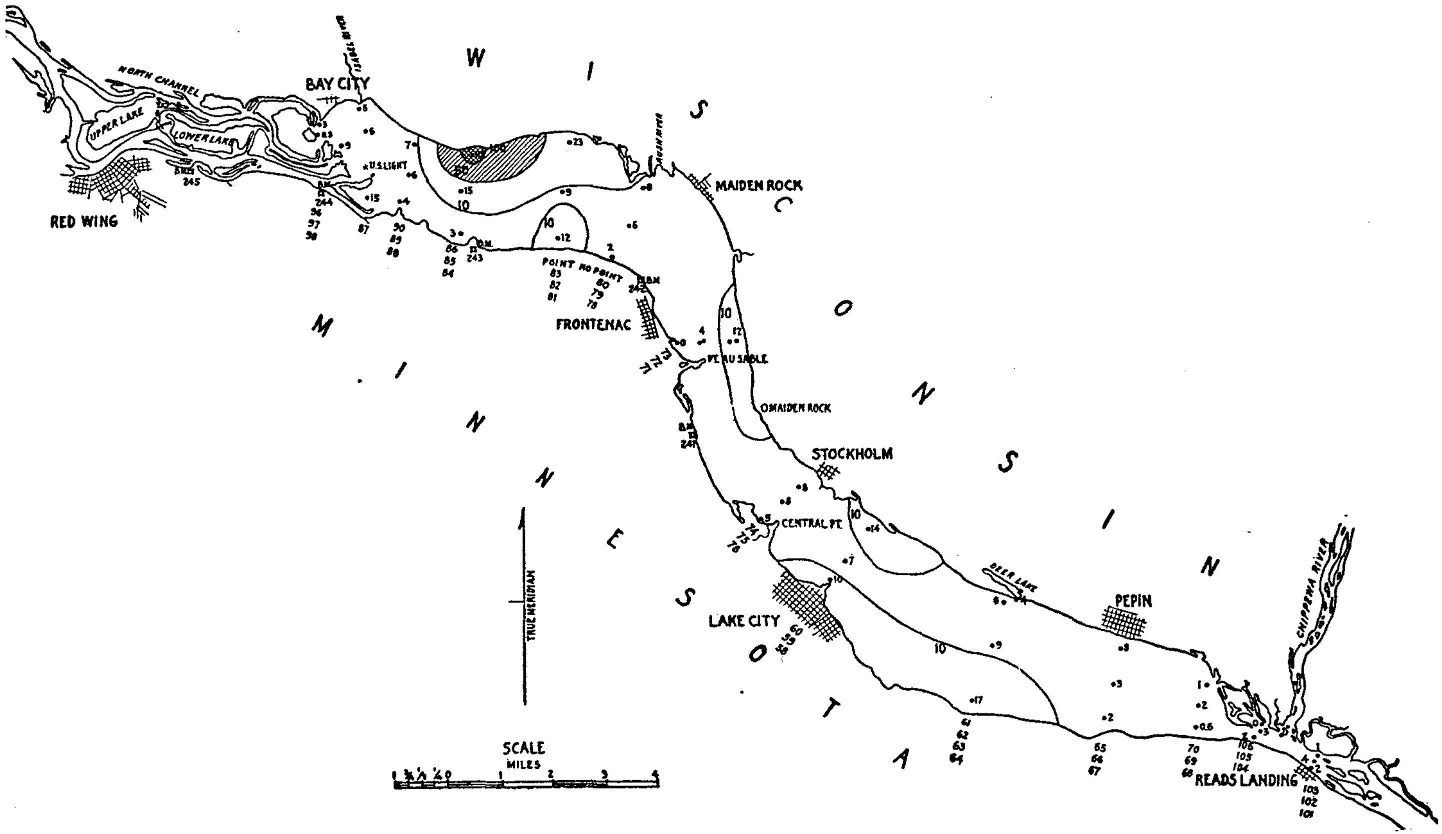

FIG. 18.—Distribution of Cladocera in Lake Pepin, August 18 to September 18, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cu bi meter of water. Figures beneath the chart correspond to serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

Where currents are found, the water, generally speaking, presents conditions adverse to the development of microscopical fauna and flora. The plankton organisms are therefore usually more abundant in slow-flowing streams and in stagnant places than in swift waters. The velocity of current is the principal factor that affects the organic life in the river. If the current becomes too swift, as at rapids or water falls, the amount of plankton decreases considerably. Such a condition is found in the Mississippi River above Rock Island Rapids, where the amount of plankton carried is four times as great as below the rapids. Sixteen miles of rapids destroy three-fourths of the microscopical population.

The stage of the river has the same effect on the river plankton, although the reason is different. At a high stage the river water mingles with barren storm waters and the plankton is washed away. Therefore, every sudden rise of the river carries away its plankton population. The instability of the hydrographic conditions, so characteristic of river regimen, strongly affects the productiveness of the river in plankton. The greater the instability of the river conditions the less the amount of plankton. Conversely, when a period of low water lasts for a long time the plankton may become very abundant.

The results obtained in the investigation made during a comparatively short time in summer are not sufficient to show what relations exist between the different parts of the river in other seasons. The present data refer only to the warm season and the low stage of the river. During the course of the investigation some points were visited twice; this makes the conclusions concerning the plankton resources in those parts of the river more reliable.

It does not seem necessary to publish here all the records of the examination of each plankton sample. The results of this study are presented in Tables 23 and 24, composed of these original records. The plankton data presented in these tables have been summarized and are given in different columns corresponding to the following subdivisions of the river: (*a*) The river from Burlington, Iowa, to Rock Island Rapids; (*b*) above Rock Island Rapids, from Le Claire, Iowa, at the head of the rapids, to Reads Landing, Minn., just below Lake Pepin; (*c*) above Lake Pepin, from the head of the lake to Hastings, Minn. The composition of the plankton of Lake Keokuk is given in two columns, because there was a difference between the upper and lower parts of the lake. All the data refer to the main stream of the river. The composition of the plankton collected in the sloughs, bayous, and among the water plants, and the data obtained at the end of September during the rise of the river, are presented separately.

The symbols in the columns indicate the relative frequency of the organisms, as follows: ●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; --, absent.

TABLE 23.—*Composition of the plankton of the Mississippi River, and Lakes Pepin, Keokuk, and St. Croix.*

	Mississippi River.					Lake Pepin, Aug. 15 to Sept. 10.	Lake Keokuk.		Lake St. Croix, September.
	Lower part, between Rock Island Rapids and Burlington.		Upper part, between Reads Landing and Rock Island Rapids.		Above Lake Pepin.		Upper part, July.	Lower part, July.	
	July.	August.	July.	September.					
Cyanophyceæ:									
Merismopedia sp	..	○	..	..	○	..	..	..	..
Clathrocystis æruginosa Henf	..	⊕	◑	◑	●	●	⊕	◑	●
Microcystis sp	..	..	..	..	●	⊕	⊕	○	..
flos-aquæ (W) K	..	..	..	..	..	..	..	..	●
Oscillatoria princeps V	..	..	..	..	⊙	..	..	..	..
sp	..	..	..	○	..	○	..	○	..
Lyngbya sp	..	○	..	..	..	..	⊙	..	..
Anabæna flos-aquæ Bréb	..	○	⊙	◑	●	◑	⊕	◑	●
circinalis Rab	..	..	..	..	..	◑	⊙	◑	..
spiroides Kl	..	..	..	..	..	◑	○	⊕	●
spiroides KC	..	⊙	⊙	◑	●	..	..	..	..
planktonica B	..	○	○	..	..	..	..	..	..
Aphanizomenon flos-aquæ R	..	○	⊙	◑	●	◑	⊙	⊕	●
Bacillariaceæ:									
Melosira granulata (E) R	..	..	..	..	..	..	..	..	●
spiralis E	..	..	..	..	..	..	..	..	⊕
crenulata K	⊙	◑	●	●	●	●	⊕	◑	..
Cyclotella menenghiniana Bréb	⊙	⊕	◑	◑	◑	⦶	⊙	⊕	..
Stephanodiscus niagaræ E	○	⊙	⊙	⊕	⊙	◑	○	⊙	⊕
Synedra delicatissima W. S	○	⊙	⊕	◑	◑	◑	○	⦶	◑
Fragilaria crotonensis K	..	○	○	○	○	●	⊙	◑	●
Navicula confervacea (K) Gr	..	..	..	..	..	..	⊙	○	..
Asterionella gracillima H	..	..	..	..	○	..	..	..	○
Chlorophyceæ:									
Desmidium sp	..	..	..	..	○	..	..	..	..
Closterium sp	..	○	..	○	○	○	○	..	..
moniliferum E	..	..	..	..	..	..	..	..	..
Staurastrum gracile R	..	○	○	..	○	..	..	..	..
sp	..	○	⊙	..	⊕	○	○	○	○
Cosmarium sp	..	○	..	..	..	⊙	..	○	..
Spirogyra sp	..	○	..	○	○	○	○	..	..
Actinastrum hantzchii Lag	⊙	⊕	⊕	⊕	⊕	◑	⊕	◑	⊙
Scenedesmus quadricauda Bréb	..	⊙	⊙	○	⊙	⊕	⊕	⊕	○
acuminatus Ch	..	..	..	..	..	⊙	○	○	..
minutus Ch	..	○	..	○	..	..	..	..	..
sp	..	..	..	..	..	○	..	..	..
Pediastrum duplex M	⊙	⊙	⊙	⊕	⊙	⊕	⊕	⊕	⊕
simplex R	○	○	⊙	○	..	⊕	⊙	⊙	⊙
Sarcodina:									
Arcella vulgaris E	○	..	○	..	..	○	○	○	..
sp	○	..	..	○	..	..	..	..	..
Centropyxis aculeata St	○	○	○	..	..	..	..	⊙	..
Difflugia pyriformis P	○	○	○	..	○	..	..	⊙	..
corona W	..	○	..	..	..	..	○	..	..
lebes P	..	..	..	..	..	..	○	..	..
Mastigophora:									
Euglena ehrenbergii K	..	..	..	..	..	○	..	..	..
spirogyra E	○	..	○	..	○	○	..	○	..
acus E	○	..	..	○	..	○	○	..	..
sp	○	○	..	○	○	○	○	..	..
Trachelomonas shauinslandii L	○	○	..	○	..	○	⊕	⊙	..
Phacus longicaudus E	..	○	○	○	..	○	○	○	..
Eudorina elegans E	○	..	○	○	⊙	⊙	⊕	⊕	..
Platydorina caudata K	○	⊙	⊙	⊙	⊙	⊙	⊙	⊕	..
Plæodorina illinoisensis K	..	○	⊙	⊙	⊙	⊙	⊙	⊕	○
Volvox spermatosphara P	○	○	..	○	..	○	⊙	⊙	..
Peridinium sp	○	○	○	○	○	○	..	○	○
Ceratium hirundinella Sch	..	..	○	⊙	○	⊙	..	○	○
Infusoria:									
Codonella lacustris E	..	..	○	..	○	⊙	○	○	○
Stentor coeruleus E	..	..	..	..	..	○	..	..	..
Zoothamnium sp. (Adamsi S.)	..	..	..	..	..	..	○	..	..

TABLE 23.—*Composition of the plankton of the Mississippi River, and Lakes Pepin, Keokuk, and St. Croix*—Continued.

	Mississippi River.					Lake Pepin, Aug. 15 to Sept. 10.	Lake Keokuk.		Lake St. Croix, September.
	Lower part, between Rock Island Rapids and Burlington.		Upper part, between Reads Landing and Rock Island Rapids.		Above Lake Pepin.		Upper part, July.	Lower part, July.	
	July.	August.	July.	September.					
Rotatoria:									
Asplanchna amphora H	○	○	..	..	..	⊙	⊕	⊙	..
priodonta G	..	..	..	..	..	..	⊙	..	..
Synchæta stylata Wierz	..	..	..	..	..	⊕	..	..	..
Triarthra longiseta E	..	○	○	○	○	⊙	⊙	⊙	○
Polyarthra platyptera E. v. euryptera W	..	○	⊙	⊙	○	⊙	○	⊙	○
Notops brachionus spinosus R	..	..	..	..	..	⊙	⊕	⊙	○
Rattulus rattus M	..	..	..	..	..	○	○	○	○
pusillus L	..	..	..	..	..	○	○	..	..
stylatus G	..	..	..	..	..	○	○	○	..
sp	..	○	○	..	..	..	..	..	..
Diurella stylata E	..	○	○	○	..	○	○	○	○
Dinocharis paupera E	..	..	..	..	..	..	○	..	..
Euchlanis dilatata E	..	..	..	..	..	⊙	⊙	..	..
Cathypna luna O. F. M	..	..	..	..	..	..	○	..	..
Monostyla cornuta O. F. M	..	..	..	..	..	○	..	..	..
lunaris E	..	..	..	..	..	○	○	..	..
bulla G	..	..	..	○	..	○	○	..	..
Brachionus angularis G	○	○	⊙	○	⊙	○	⊕	⊙	○
angularis caudatus B & D	○	○	○	○	○	⊙	⊕	⊙	..
pala f. amphiceros E	○	..	○	○	○	⊙	◐	◐	○
pala E	..	..	..	..	..	○	◐	◐	..
pala E. ♂	..	..	..	..	..	..	⊙	..	..
pala v. dorcas G	..	..	○	..	..	⊙	⊕	⊕	..
pala v. dorcas f. spinosus W	○	○	..	..	..	..	⊙	⊙	..
bakeri O. F. M. v. brevispinus E	..	..	..	..	○	○	⊙	..	..
bakeri O. F. M. v. cluniorbicularis S	..	○	○	○	○	○	⊙	..	○
bakeri O. F. M. v. entzii F	..	..	..	..	..	○	○	○	..
urceolaris O. F. M	..	..	..	..	..	⊙	○	○	..
budapestinensis v. D	..	..	..	..	..	⊙	..	..	..
Noteus militaris E	..	..	..	..	..	○	⊕	○	..
Schizocerca diversicornis v. D	..	..	○	⊙	..	○	..	..	..
Anuræa cochlearis G	○	⊙	⊙	⊙	○	⊕	⊕	⊙	..
cochlearis v. tecta g	○	⊙	○	○	○	⊙	⊙	⊕	..
Anuræopsis hypelasma G	..	..	..	..	..	⊕	..	⊙	..
Pedalion mirum H	..	..	..	..	..	..	..	⊕	..
Cladocera:									
Sida crystallina O. F. M	..	..	..	○	○	⊙	..	○	○
Diaphanosoma leuchtenbergianum F	..	..	○	○	○	⊙	○	⊙	○
Daphnia pulex v. pulicaria F	..	..	○	○	○	○	..	..	○
retrocurva F	..	..	⊙	⊙	⊙	⊙	..	..	⊙
arcuata F	..	..	○	○	○	⊙	..	..	..
longispina O. F. M	..	..	..	..	..	○	..	○	..
Scapholeberis mucronata O. F. M	..	..	..	..	..	..	○	..	..
Moina rectirostris L	..	..	○	..	..	○	⊕	⊙	..
brachiata J	..	..	..	..	..	..	..	⊙	..
macrocopa S	..	..	○	○	..	..	..	⊕	..
Bosmina longirostris O. F. M	..	..	..	..	..	..	..	○	..
Alona sp	..	..	..	..	..	..	..	○	..
Leydigia quadrangularis L	..	..	..	..	..	○	..	..	..
Dunhevedia setigera B	..	..	○	..	..	..	..	..	..
Leptodora kindtii Lill	..	..	○	⊙	⊙	⊙	..	⊙	○
Copepoda (Cyclops and Diaptomus)	○	○	⊕	⊙	⊙	◐	⊙	⊕	⊙
Nauplii	○	○	○	⊙	⊙	◐	⊙	◐	○
Corethra sp	..	..	..	..	..	⊕	..	○	..
Chironomus larvæ	..	..	..	..	..	..	⊙	⊙	○
Hydra sp	..	..	..	..	..	○	..	○	..
Glochidium	○	○	..	..	..	..	..	..	..
Mayflies (larvæ)	○	○	..	..	..	..	..	..	..
Mosquito larvæ	○	○	○	○	○	..	..	..	..
Detritus	●	●	●	●	●	⊙	⊕	⊙	○

The plankton collected in different parts of the river, in the lakes, and in the tributaries can be characterized as very uniform. The samples taken from different localities differ mainly in the amounts of plankton they contain, or in variations in the abundance of, or even in the absence of several forms; but there is not a single form present in plankton of the main channel of the river that could not be found in the lakes or in the tributaries.

The plankton consisted principally of diatoms and blue-green algæ. These two groups together in most samples made up more than 75 per cent of the total mass. Next to them were Chlorophyceæ, which occurred in almost every sample, and Rotifera, which were especially abundant in the upper part of Lake Keokuk. The Copepoda were also present in abundance and were very numerous in Lake Pepin.

TABLE 24.—*The composition of the plankton of the Mississippi River tributaries.*

[●, very abundant; ◐, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Des Moines River, station 158, Sept. 23.	Iowa River, station 152, Sept. 20.	Edwards River, station 6, July 13.	Rock River, station 149, Sept. 18.	Turkey River, station 144, Sept. 14.	Wisconsin River, station 142, Sept. 14.	Root River, station 134, Sept. 12.	La Crosse River, station 133, Sept. 12.	Black River, station 132, Sept. 12.	Zumbro River, station 126, Sept. 11.	Chippewa River, stations 99 to 100 Aug. 30.
Volume of plankton and detritus, cubic centimeters per cubic meter of water	12.0	11.5	12.0	11.5	9,000	20.0	16.0	38.0	7.5	15.0	23.0
Cyanophyceæ:											
Clathrocystis æruginosa H	..	..	⊕	..	..	◐	..	..	⊙	◐	●
Microcystis sp	..	..	..	..	..	⊕	..	..	○	○	●
Anabæna circinalis Rab	..	..	..	..	..	..	..	..	⊙	⊙	⊕
flos-aquæ Brèb	..	..	..	..	..	..	..	..	..	⊙	⊙
Aphanizomenon flos-aquæ R	..	..	..	..	..	..	..	..	..	..	⊙
Bacillariaceæ:											
Melosira crenulata K	○	..	..	○	..	●	..	⊙	●	●	⊕
Stephanodiscus niagaræ E	..	..	..	..	..	..	..	..	⊙	○	..
Synedra delicatissima W. S.	○	..	..	..	..	..	..	..	⊙	⊕	⊙
Fragiliaria crotenensis K	..	..	..	..	..	⊙	..	..	⊙	..	⊙
Chlorophyceæ:											
Staurastrum sp	..	..	..	..	..	..	..	..	○	⊕	○
Actinastrum hantzschii L	..	..	○	..	..	..	..	..	⊙	⊕	⊕
Scenedesmus quadricauda Brèb	..	..	○	..	..	○	..	..	..	⊙	○
Pediastrum duplex M	..	..	○	..	..	○	..	..	⊙	⊕	⊙
simplex R	..	..	..	..	..	..	..	..	○	⊙	..
Hydrodictyon reticulatum R	..	..	..	..	..	..	..	..	..	..	○
Draparnaldia sp	..	..	..	..	..	..	..	..	..	..	○
Sarcodina:											
Arcella sp	..	..	○	..	..	..	..	..	..	..	○
Difflugia corona W	..	..	○	..	..	..	..	..	..	..	○
Mastigophora:											
Euglena spirogyra E	..	..	○	..	..	..	..	..	○	..	..
Platydorina caudata K	..	..	..	..	..	..	..	..	..	..	⊙
Eudorina elegans E	..	..	..	..	..	○	..	..	..	..	..
Volvox aureus E	..	..	..	..	..	..	..	..	○	..	..
Ceratium hirundinella Sch	..	..	..	..	..	..	..	..	..	⊙	..
Infusoria: Codonella lacustris E	..	○	..	○	..	○	..	..	..	..	○
Rotatoria:											
Polyarthra platyptera E. v. euryptera W	..	..	..	..	..	○	..	..	○	⊙	..
Brachionus pala f. amphiceros E	..	..	..	..	..	..	..	..	○	..	..
Noteus militaris E	..	..	..	..	..	..	..	..	..	..	○
Anuræa cochlearis G	..	..	..	..	..	○	..	..	○	⊙	○
cochlearis v. tecta G	..	..	..	..	..	..	..	..	○	○	..
cochlearis v. hispida L	..	..	..	..	..	..	..	..	..	..	○
Cladocera:											
Daphnia retrocurva F	..	..	..	..	..	..	..	..	[1] 80	[1] 120	..
Moina rectirostris L	..	[1] 80	..	..	..	..	..	..	..	..	..
Leptodora kindtii L	..	..	..	..	..	..	..	..	[1] 10	[1] 40	..
Copepoda (Cyclops and Diaptomus)	..	[1] 180	..	[1] 240	..	[1] 2,120	..	..	[1] 5,960	[1] 27,200	[1] 120
Nauplii	..	..	..	..	..	..	..	..	○	⊙	⊙
Detritus	●	●	●	●	●	●	●	●	⊕	⊕	●

[1] Individuals per cubic meter of water.

Among the diatoms, *Melosira crenulata* (E) K. is the most common form. It has been found at all stations on the river and on the lakes except Lake St. Croix, where it is wholly replaced by *Melosira granulata* (E) Ralfs. Another species, *Fragilaria crotonensis* K., is also widely spread. It was very abundant in the upper part of the river between Hastings and Red Wing, in Lake Pepin, in Lake St. Croix, and in the lower part of Lake Keokuk, but very scarce in the river below Rock Island Rapids. In July it was entirely absent in the section between Davenport and Burlington. In some catches Melosira and Fragilaria make up more than 80 per cent of the total amount of plankton *Synedra delicatissima* W. S., *Stephanodiscus niagaræ* E., and *Cyclotella menenghiniana* Bréb. can be found in nearly all the samples, but do not constitute any considerable part of the total amount of plankton.

Dr. Albert Mann, who has examined the diatoms in some samples of the collections from different parts of the river, has come to the following conclusions:

It is noteworthy that the range of species in all the gatherings is small as compared with the usual fresh-water diatom flora; also that they have a close resemblance to each other, although their geographical range is considerable. It is interesting to find that several almost cosmopolitan fresh-water forms are absent; for example *Navicula* (*Stauroneis*) *phoenicenteron*, *N. major*, such as Surirellæ as *S. biseriata* (E) Bréb., *S. splendida* (E) K., *S. cardinalis* Kitt., and the almost universal *Melosira varians* Ag., unless the *M. subflexilis* K., sparingly found in Lake Keokuk, can be taken as a variety of that species. On the other hand, *Melosira crenulata* and its too close relative, *M. granulata*, are very abundant in nearly all samples. Neither of these species is at all frequent east of the Mississippi but appear from that river westward, and the latter of the two, *M. granulata*, formed vast beds of new fossil diatoms extending over the northwest part of the United States and running into Canada around Deadmans River, British Columbia.

The blue-green algæ form a great part of the plankton in Lake Pepin, in Lake St. Croix, and in the Mississippi River between Hastings and Rock Island Rapids. They were less abundant in Lake Keokuk and scarce in the river below Rock Island Rapids, where they were almost entirely absent during July. The principal forms of Cyanophyceæ found were as follows: *Microcystis flos-aquæ* (Wittr.) Kirchn., *Clathrocystis æruginosa* (Kutz.) Henfrey, *Aphanizomenen flos-aquæ* (L) Ralfs., *Anabæna flos-aquæ* (Lyngb.) Bréb., *Anabæna spiroides* Klebahn. In some samples these forms were as abundant as Melosira and Fragilaria; in others they were scarce. In Lake Keokuk in July there was only a little blue-green algæ, except Lyngbya; in Lake Pepin, in Lake St. Croix, and in the river above Rock Island they were in excess in August and in September. *Actinastrum hantzchii* L., *Pediastrum duplex* M., *P. simplex* R., *Scenedesmus quadricauda* B., and *S. acuminatus* Ch. were found in every sample, but were never numerous. *Pediastrum duplex* was usually more abundant than *P. simplex*.

The Flagellata are chiefly represented by *Platydorina caudata* K., *Plæodorina illinoisensis* K., *Eudorina elegans* E., and *Trachelmonas schauinslandii* Lemm. The latter is more abundant in Lake Keokuk than in other parts of the river. Various species of Euglena—*E. spirogyra*, *E. acus*, and some others that could not be identified in the preserved material—occasionally occur in the samples. They are more abundant in the bays and sloughs than in the main channel.

A few *Volvox spermatosphara* P. were found in many of the samples taken in the river and in the lakes. It is interesting to note that in the water-supply reservoir of the Fairport Biological Station Volvox occurred in such great abundance that in July a sample of water from the faucet in the laboratory room looked like a pure culture of this organism. The water in the reservoir is supplied from the Mississippi River, yet in the samples taken at the same time in the river one could hardly find more than two or three colonies of Volvox.

Other rather common Protozoa are the following: *Arcella vulgaris* E., *Difflugia pyriformis* P., and *Codonella lacustris* E. *Codonella lacustris*, which has a great resemblance to *Difflugia pyriformis*, is more abundant in the lakes, but the latter is found more often in the river samples, especially when taken near the bottom. This list of the planktonic Protozoa should be longer, but as preserved material chiefly has been available for study, many Ciliata and Flagellata could not be identified.

The Rotifera are scarce in the river and become more abundant in the lakes, the upper part of Lake Keokuk being especially rich in these organisms. In the main channel of the river the most common forms found at nearly every station are the following: *Anuræa cochlearis* G., *Brachionus pala* E., *Br. pala amphiceros* E., *Br. angularis* G., *Br. angularis caudatus* B. and D., *Diurella stylata* E., and *Polyarthra euryptera* W. The same species occur in excess in the lakes where the rotifer population is more varied, and some species, absent in the river samples, are found in great abundance.

The plankton crustaceans are very scarce in the lower part of the river and more abundant in the upper part and in the lakes. The cladoceran population in Lake Pepin is mainly represented by *Daphnia retrocurva* F.; that in Lake Keokuk by *Moina rectirostris* L. and *M. brachiata* J. The relative frequency of these and other cladoceran species will be discussed later.

The plankton of the Mississippi River, in comparison with that of Lake Pepin and Lake Keokuk, is characterized by the absence of several forms abundant in the lakes, and a great part of its volume is composed of organic and inorganic detritus. There has been found no form in the running waters of the Mississippi that was not present in the samples taken in the lakes, which is quite natural, because both lakes are but reservoirs of the river water, and the plankton organisms carried by the latter rapidly multiply and become more abundant in the stagnant water of the lakes.

THE RIVER.

It has been stated above that with regard to the richness of plankton there is a great difference between two main sections of the river, below and above the Rock Island Rapids. The river below the rapids, from Davenport to Burlington, is very poor in plankton, the samples taken in this section consisting of detritus, silt, a little sand, and few organisms. The plankton here was especially poor in July. An analysis of some of the samples taken near Fairport on July 11 and 12 is given in Table 25.

It is noteworthy that the plankton crustaceans, both Copepoda and Cladocera, were entirely absent. There was no considerable difference between the main channel of the river and the Andalusia Slough. Andalusia Slough is a long and shallow lateral channel of the Mississippi, but passable by boat. It is about 10 miles long, and during the time of observation was from 2 to 3 feet deep. The current was slower than in the main channel. One would naturally expect to find more organisms in the samples taken in the slough, but the analysis of the July sample shows that they are scarcer in the slough than in the main channel. (See Table 25.) One month later, however, on August 9, the plankton collected at the same localities was generally richer, and in Andalusia Slough it was more abundant than in the main channel. The composition of the plankton collected on August 9 is given in Table 25.

TABLE 25.—*Plankton of the Mississippi River at Fairport, Iowa, in July and August.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

JULY.

	Main channel.	Andalusia Slough.
Volume, cubic centimeters per cubic meter of water	6	4
Species:		
Melosira crenulata K	⊙	⊙
Cyclotella menenghiniana B	○	○
Stephanodiscus niagaræ E	○	⊙
Pediastrum duplex M	⊙	⊙
simplex R	○	..
Actinastrum hantzchii L	○	..
Difflugia pyriformis P	○	..
Arcella sp	..	○
Species—Continued.		
Brachionus backeri v. cluniorbicularis S	○	○
Brachionus pala v. amphiceros E	..	○
Anuræa cochlearis typ. G	○	○
cochlearis forma tecta G	○	○
Glochidium sp	○	○
Mayfly larvæ	○	○
Mosquito larvæ	○	○
Detritus	●	●
Sand	⊕	⊕

AUGUST.

	Main channel.	Main channel just below dike.	Andalusia Slough.
Volume, cubic centimeters per cubic meter of water	4.3	3.3	6.6
Species:			
Clathrocystis æruginosa H	⊙	⊙	⊙
Microcystis sp	..	..	⊙
Oscillaria sp	..	..	○
Anabæna spiroides K	..	..	⊕
Melosira crenulata K	⊕	⊕	⊕
Synedra delicatissima W. S	⊙	⊕	⊕
Fragilaria crotenensis K	⊕	○	○
Stephanodiscus niagaræ E	⊙	○	⊙
Cyclotella menenghiniana B	⊙	○	⊙
Pediastrum duplex M	○	○	⊕
simplex R	..	○	⊙
Scenedesmus quadricauda B	○	..	⊙
Actinastrum hantzchii L	○	○	⊕
Staurastrum gracile R	..	○	⊙
Peridinium sp	..	..	○
Species—Continued.			
Phacus longicaudus E	..	○	○
Platydorina caudata K	○	⊙	⊙
Plaedorina illinoisensis K	⊙	..	○
Eudorina elegans E	○	..	⊙
Difflugia pyriformis P	○	..	○
corona W	○	..	○
Brachionus angularis C	..	○	○
Polyarthra platyptera W	○	..	○
Conochilus unicornis R	○	..	○
Rattulus sp	○	○	○
Anuræa cochlearis typ. G	○	○	○
cochlearis forma tecta G	○	○	○
Moina rectirostris L	..	..	○
Nauplii	..	..	○
Detritus	●	●	●
Sand	⊕	⊕	⊙

It can be seen from the table that the plankton in Andalusia Slough in August was richer qualitatively as well as quantitatively than that in the main channel. Besides that, the samples taken in the almost stagnant water just below the dikes in the main channel were the poorest, containing even less plankton than in mid river. The composition and the average amount of plankton at the other points in the lower section of the Mississippi is almost the same as at Fairport. The samples taken in the main stream consist mainly of detritus and contain very few organisms.

A considerable increase in plankton population was observed only in Sturgeon Bay near New Boston, Ill. Sturgeon Bay is a narrow and shallow bayou extending about 7 miles northward from the river. The observations were made only about half a mile above the mouth of the bay, because the water was only 18 inches deep and it was impossible to go farther. The water was stagnant, but a very slight drift of the plankton, caused by the wind, was observed. The surface of the water was covered with large groups of water beetles and with empty skins of mayflies, the larvæ of which were very numerous near the bottom. The amount of plankton in Sturgeon Bay was only 5 $cm.^3$ per cubic meter, which is 1.75 $cm.^3$ less than in the adjacent part of the river, but the analysis of plankton (see Table 26) shows that it was composed of Flagellata, Rotifera, and other plankton organisms, whereas in the river it consisted mainly of detritus.

TABLE 26.—*Plankton of the Mississippi River near New Boston, Ill., July 13, 1921.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Sturgeon Bay.	Main channel.		Sturgeon Bay.	Main channel.
Volume, cubic centimeters per cubic meter of water	5.0	6.75	Species—Continued.		
Species:			Triarthra longiseta E	○	..
Anabæna spiroides Kl	○	..	Brachionus backeri v. cluniorbicularis S	⊙	..
Melosira crenulata K	○	⊙	pala v. amphiceros E	◑	○
Cyclotella menenghiniana B	○	..	pala v. dorcas f. spinosa W	◑	..
Pleurosigma spenceri W. S	○	..	angularis caudatus B and D	◑	○
Stephanodiscus niagaræ E	○	..	Notops clavulatus E	○	..
Scenedesmus quadricauda Bréb	○	..	Asplanchna amphora H	◑	○
Pediastrum duplex M	..	⊙	Sida crystallina O. F. M	[1] 20	..
Eudorina elegans E	⊕	○	Cyclops sp	[1] 60	..
Platydorina caudata K	◑	..	Detritus	⊙	●
Trachelmonas schauinslandii L	◑	○	Sand	○	⊙
Euglena spirogyra E	◑	..			
acus E	◑	..			

[1] Individuals per cubic meter of water.

The composition and the amount of plankton in the river near Burlington at the head of Lake Keokuk are the same as in the main channel at New Boston. Rock Island Rapids divide the river into two sections, different as regards their plankton contents. Below the rapids the Mississippi carries a little plankton; above the rapids the production of plankton in the river is about three times greater. This can easily be seen from an examination of Table 27, in which are presented the results of the observations made on August 11 and 12 at stations 50 and 51, the first of which is located 12 miles below the head of the rapids and the latter 27 miles above the head of the rapids.

TABLE 27.—*The composition of the plankton of the Mississippi River at stations 50 and 51, August 11 and 12.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Rock Island Rapids, station 50.	Six miles above Clinton, station 51.		Rock Island Rapids, station 50.	Six mile above Clinton, station 51.
Volume of plankton, cubic centimeters per cubic meter of water	6.0	15.7	Species—Continued.		
Species:			Difflugia pyriformis P	○	..
Clathrocystis æruginosa H	○	⊕	Arcella sp	○	○
Anabæna flos-aquæ Bréb	⊙	⊕	Brachionus angularis G	○	⊙
planktonica Bréb	..	○	Anuræa cochlearis G	○	○
Melosira crenulata K	⊕	◑	cochlearis tecta G	○	⊙
Fragilaria crotonensis K	○	⊕	Daphnia longispina O. F. M	..	[1] 40
Stephanodiscus niagaræ E	○	⊙	Bosmina longirostris O. F. M	..	[1] 4
Actinastrum hantzchii Lag	○	⊙	Diaphanosoma leuchtenbergianum F.	..	[1] 6
Scenedesmus quadricauda Bréb	..	○	Copepoda	[1] 7	[1] 5,467
Pediastrum duplex M	○	○	Nauplii	○	⊕
Staurastrum sp	○	○	Detritus	●	⊕

[1] Individuals per cubic meter of water.

Although the composition of the plankton taken at the two stations was essentially the same, there was considerable difference in the quantity of organisms, especially of the diatoms and copepods, which were abundant in the river above the rapids and scarce below the rapids. The composition of the plankton in the upper part of the river was almost the same as at station 51. The amount of plankton, however, increased progressively up the river and near Prairie du Chien, Wis., 182 miles above, was about twice as great as at Clinton (station 51), reaching 32 cm.^{3} per cubic meter. This increase in the total amount of plankton was due to the great abundance of diatoms (*Melosira crenulata* K.; *Fragilaria crotonensis* K.), blue-green algæ (*Anabæna spiroides* Kl.), and copepods. The Rotifera were scarce and were represented by *Polyarthra euryptera* W., *Anuræa cochlearis* G., and *Brachionus angularis* G. The Cladocera were represented by *Daphnia retrocurva* F., which formed almost 99 per cent of the Cladocera population; other forms, such as *Moina rectirostris* L. and *Dunhevedia setigera* B., were also occasionally noticed in some of the samples.

The plankton collected among the water lilies, which grew here in profusion along the banks of the river, had almost the same composition as in the main channel except that the Cladocera were represented by *Moina rectirostris* L., which was found here in hundreds of individuals per cubic meter, while *Daphnia retrocurva* L. was very scarce. As to the Rotifera, some specimens of *Asplanchna brightwelli* G have been found, but this organism was not noted in the stream.

In the section from Prairie du Chien to Reads Landing, a distance of 130 miles, the river plankton is very uniform and has a great resemblance to that in Lake Pepin. The observations made here in August and September showed a considerable increase in blue-green algæ during the latter month, when *Aphanizomenon flos-aquæ* R., *Anabæna spiroides* Kl., *A. flos-aquæ* Bréb., *A. circinalis* Rab., *Clathrocystis æruginosa* K., and Microcystis made up a greater part of the plankton. *Leptodora kindtii* L., which is very common in Lake Pepin, was also found in this part of the river. The last point below Lake Pepin where this big cladoceran was observed is a little below Prairie du Chien opposite the mouth of the Wisconsin River. It did not occur farther downstream. Other Cladocera were represented mainly by *Daphnia retrocurva* F., found in nearly all the samples, and by occasional *D. arcuata* F., *D. pulex* F., *Diaphanosoma leuchtenbergianum* F., and *Sida crystallina* O. F. M. There was a gradual decline in the number of *Daphnia retrocurva* from the foot of Lake Pepin to Prairie du Chien, and above the mouth of the Wisconsin River it disappeared entirely.

The composition of the plankton of the Mississippi River above Lake Pepin is, in general, the same as below the lake except that *Ceratium hirundinella* Sch. was more abundant above the lake and that *Asterionella gracillima* H. was occasionally found at Hastings and Prescott. The Cladocera are less numerous than below the lake and are represented by the same species as in Lake Pepin: *Diaphanosoma leuchtenbergianum* F., *Sida crystallina* O. F. M., *Daphnia retrocurva* F., *D. arcuata* F., *D. pulex* v. *pulicaria* F., *Simocephalus vetulus* O. F. M., and *Leptodora kindtii* L. *Daphnia retrocurva* is the most abundant form among the water fleas collected in this part of the river. *Leptodora kindtii*, found in some samples, was represented by both the young and the adult organisms, while in the part below Lake Pepin only adult Leptodora occurred.

LAKES.

The distribution and the composition of the plankton of Lake Pepin has been discussed above. Only a few facts can be added now concerning the distribution of different plankton forms in the lake. A slight difference can be noticed in the composition of plankton taken at different points of the pelagic part of the lake. It was observed that *Fragilaria crotonensis* was most abundant in the upper part

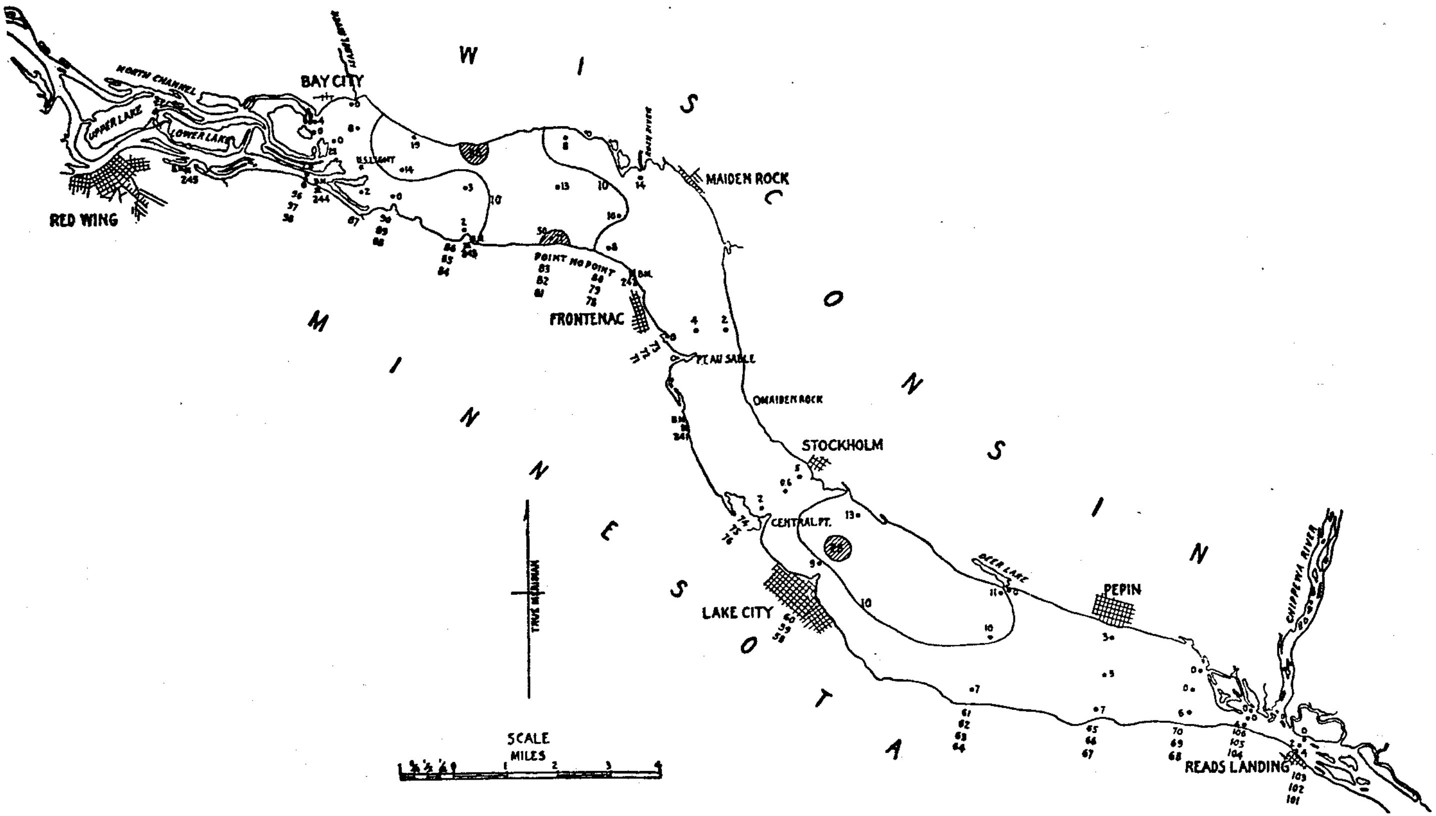

FIG. 19.—Distribution of *Leptodora kindtii* in Lake Pepin, August 18 to September 10, 1921. (Figures on the chart indicate the average number of individuals, in tens, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

(stations 81 to 88), and that *Synchæta stylata* W., absent in the lower part, was very common at all stations above Point au Sable. The eggs of this species occurred very often also in the upper part of the lake and were not found at all in the part below Lake City.

Special attention was given to the distribution of *Leptodora kindtii*. This organism was especially numerous in the upper part of the lake and in mid lake opposite Lake City. The distribution of Leptodora in the lake is shown on Figure 19. The maximum abundance, 710 per cubic meter, was found at station 81, close to the shore. Many young Leptodora have been found in the upper part of the lake, whereas in the lower part only adults occurred.

The behavior of Leptodora in lakes has attracted the attention of many investigators. It is generally known that at twilight this organism appears near the surface and during the day keeps in the lower strata. In Lake Pepin, at the stations where Leptodora was most abundant (stations 81 and 86), its maximum during the daytime was found at the depth of 4 to 7 meters, but several specimens of it occurred also in the top water, especially in the shallow parts of the lake and near the shores. The writer has found in previous investigations in Lake Kossino (Russia) that the diurnal migrations of Leptodora are rather complicated. At nightfall the Leptodora in that lake move up to the surface water and toward the shores; at sunrise they return, but some remain near the shore in the top water. There was no opportunity to study the dirunal movement of Leptodora in Lake Pepin because all observations were made between 8 a. m. and 5 p. m., but it was often noted that near the shores these forms occurred at the surface layer, while in mid lake the maximum occurrence was in deeper strata.

The plankton collected amid the aquatic vegetation differs from that of the pelagic region mainly by a greater variety of diatom flora. The principal plankton forms are, however, the same as in other parts of the lake. Water plants grow in profusion in the lower shallow part of the lake close to the shores, beginning from Pepin village down to the delta of the Chippewa River. The bottom of the lake is covered here with *Potomogeton crispus*, *P. americanus*, *Vallisneria spiralis*, and *Ruppia occidentalis*, each of them forming separate associations.

The most abundant diatom flora has been found among the Potamogeton associations. The following is the list of diatoms collected here and identified by Dr. Albert Mann:

Cocconeis distans Greg.	○	Navicula amphigomphus E.	○
placentula E.	⊕	Reinhardtii Grun.	○
Cyclotella menenghiniana Bréb.	⊕	scutelloides W. S.	⊕
Cymatopleura elliptica W. S.	○	Nitzschia palia (E) W. S.	○
Cymbella, caespitosa K.	⊕	Pleurosigma Spenceri K.	⊕
cistula (Hemp.) Kirch.	○	Stephanodiscus niagaræ E.	○
Epithemia gibba (E) K.	⊕	Surirella minuta Bréb.	⊙
sorex K.	◑	Synedra delicatissima W. S.	⊕
Gomphonema affine K.	⊕	splendens K.	⊙
lanceolatum E.	○	ulna v. capitata E.	⊙
Melosira crenulata K.	◑		

Among the other water plants the diatom flora was the same as the foregoing except for one new form, *Navicula radiosa* K., which was rather abundant.

The stems of the water plants were covered with many filamentous algæ, such as Œdogonium, Spirogyra, and Stigeoclonium. The Copepoda were abundant here, but the Cladocera scarce. All stems of Potamogeton were covered with Hydra sp. Besides the Rotifera that usually occurred in plankton samples, the following species were found amid water plants:

Monostyla cornuta O. F. M.	○	Colurus uncinatus E.	○
lunaris E.	○	deflexus G.	⊙
quadridentata E.	○	Diaschiza gibba E.	⊙
pyriformis D.	○	Diglena forcipata E.	○
Euchlanis dilatata E.	⊕	Lecane arcula.	○
Metopidia acuminata E.	⊕		

The plankton of Lake St. Croix is the same as in Lake Pepin (Table 23), excepting that *Cyclotella menenghiniana* Bl., generally present at other stations, here disappears and *Melosira crenulata* K. is replaced by *M. granulata* (E) R. and *M. spiralis* E.

The plankton of Lake Keokuk is not so uniform as that in Lake Pepin, the upper and lower parts of the lake differing one from another not only in the amount of plankton, but in its composition. (See Table 23.) Roughly speaking, the upper part of the lake is richer in Rotifera, whereas in the lower part the diatoms and the blue-green algæ are more abundant.

In July the blue-green algæ were not so abundant in Lake Keokuk as were diatoms. During this time *Melosira crenulata* K. was the principal form found in the plankton, and in the lower part of the lake it made up almost 80 per cent of the total mass in the sample at some stations. Among the blue-green algæ the filaments of Lyngbya very often occurred in the samples. This alga was very common in the upper part of the lake, where all trunks of the submerged trees on the islands were covered with a thick layer of this organism. Lyngbya was also very often found between the leaves of Lemna and was carried downstream by the drifting Lemna groups.

The Rotifera were very numerous in Lake Keokuk, especially in its upper part, and consisted of representatives of Brachionus, Asplanchna, Noteus, Notops, Anuræa, and Pedalion. Among the species of Brachionus, *B. pala* E. was the most numerous and was represented by the varieties *amphiceros*, *dorcas*, and *spinosus*. *Brachionus pala amphiceros* E. was represented by various forms, beginning from the almost spineless organisms to the forms with extremely long spines. At many stations there were found also the males of Brachionus.

Both forms of *Brachionus angularis*, the typical spineless Brachionus and *B. angularis caudatus* B. and D., were also present. The caudal spines of this species are subject to wide fluctuation, and all variations between the two extreme forms were observed in the samples taken from Keokuk Lake. A great part of *B. pala* E. and *B. angularis* G. was infected with a sporozoon, *Ascosporidium asperosporum* Zach.

Pedalion mirum H. was found at nearly all stations in the lower part of the lake but did not occur in the upper part.

The Cladocera population was mainly represented by *Moina rectirostris* L. and *M. brachiata* I. Both species were more numerous in the lower part of the lake,

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where they constituted almost 95 per cent of the total number of Cladocera, than in the upper, where they were rather scarce. The other species, such as *Moina macrocopa* S., *Diaphanosoma leuchtenbergianum* F., *Bosmina longirostris* O. F. M., *Sida crystallina* O. F. M., and *Leptodora kindtii* L., were scarce.

The plankton of Lake Keokuk, in comparison with that of Lake Pepin, is characterized by the abundance of Rotifera and by the presence of *Pedalion mirum* H., which does not occur in other parts of the river; the blue-green algæ are less abundant here than in Lake Pepin; Cladocera are more numerous in Lake Keokuk, and are represented mainly by *Moina rectirostris* L. and *M. brachiata* J., whereas *Daphnia retrocurva* F., so common in Lake Pepin, is absent in Lake Keokuk.

At the rise of water the plankton in Lake Keokuk is almost entirely washed away, and the difference between the river and the lake with regard to the amount and the composition of plankton disappears. This can be seen in Table 28.

TABLE 28.—*Plankton of the Mississippi and Lake Keokuk, September 20 to 23.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Station 153, Miss. River, near New Boston, Sept. 20.	Station 155, Lake Keokuk at Dallas City, Sept. 22.	Station 156, Lake Keokuk near the dam, Sept. 23.	Station 157, Miss. River, at Alexandria, Mo.
Volume, cubic centimeters per cubic meter of water	6.3	6.2	4.0	3.0
Species:				
Clathrocystis aeruginosa H.	..	○	..	..
Melosira crenulata K.	○	○	○	○
Stephanodiscus niagaræ E.	○	○	..	..
Synedra delicatissima W. S.	○	○	○	○
Fragilaria crotonensis K.	..	○	..	..
Pediastrum duplex M.	○	○	○	..
Codonella lacustris E.	..	○	..	..
Triarthra longiseta E.	..	..	○	..
Polyarthra euryptera W.	..	○	..	..
Copepoda	..	..	..	[1]12
Cladocera	..	..	..	..
Lemna	..	⊙	⊙	..
Detritus	●	●	●	●

1 Individuals per cubic meter of water.

TRIBUTARIES.

The tributaries of the Mississippi River carry less plankton than the main stream. Only the Skunk River is an exception, and the plankton content of its waters emptying into the upper part of Lake Keokuk is from 16.5 to 27.5 cm.^{3} per cubic meter, or about four or six times more than the plankton content in the adjacent part of the lake. The plankton of this river consists almost exclusively of Rotifera. Its composition is as follows:

Stations 13 and 14, Skunk River, July 20, 1921:

Asplanchna amphora H.	●
Brachionus pala E.	⊕
pala amphiceros E.	⊕
pala dorcas	⊙
pala spinosus	⊙
angularis G.	⊙
Brachionus angularis caudatus B. and D.	⊙
Notops brachionus R.	⊙
Clycops (young)	[1]10
Detritus	⊙

1 Individuals per cubic meter.

The composition of the plankton in other tributaries is given in Table 24. It is evident from this table that, in comparison with other rivers emptying into the Mississippi, Zumbro and Black Rivers are the richest in plankton. The number of Copepoda observed in the mouth of Zumbro River reached a considerable figure—23,200 per cubic meter—exceeding even the content of Copepoda in the adjacent part of the Mississippi River, where their number was 14,500 per cubic meter (station 127). *Leptodora kindtii* and *Daphnia retrocurva* occurred also in those rivers.

Swift streams, such as the Chippewa and Wisconsin Rivers, are very poor in plankton. The material suspended in their waters consisted almost exclusively of sand and detritus which was deposited immediately below their mouths, forming large sand bars in the Mississippi River.

The observations in other rivers, except Edwards River, were made during the rise of the water at the end of September, and therefore their results are not comparable with those at a low stage. The samples taken from these rivers contained nothing but silt, sand, and occasional Melosira and Codonella.

DISCUSSION AND CONCLUSION.

POTAMOPLANKTON.

As can be seen from the foregoing sections, the plankton of the upper Mississippi River is mainly composed of diatoms, blue-green algæ, and Rotifera. This agrees with the results of many other observations made of different American and European rivers; the river plankton or, using Zacharias's term, potamoplankton, is generally composed mainly of diatoms and Rotifera, whereas the greatest part of plankton in the lakes and ponds is formed of crustaceans. It is noteworthy that in spite of the difference in relative abundance of the various forms, the organisms forming the plankton of the streams are the same as found in the plankton of stagnant water. Therefore the term potamoplankton does not express the idea that there exists a special community of organisms adapted to live in the running water. Among the microscopical organisms there have been found only some species of Schizomycetes (*Micrococcus rhenanus*, *Sarcina alba*, and *Microspira danubica*), which apparently occur exclusively in the streams. All other plankton forms in the river can be found also in the lakes, ponds, and pools. According to Steuer (1910) the potamoplankton can be characterized as an ecological group (Biocoenose) of organisms living and breeding in running water. This group consists principally of diatoms (Melosira, Asterionella, Synedra, Fragilaria, Stephanodiscus) and Rotifera (Asplanchna, Brachionus, Anuræa, Gastropus, Polyarthra, and Synchæta). As one can notice from this list of organisms, which are regarded by Steuer as typical for river plankton, each of them can be found in stagnant water, and, as every limnologist knows, they all are very common in lakes and ponds. Their predominance in the river, however, may be taken as characteristic of the potamoplankton, because such a combination of organisms has been observed in almost all rivers.

It is obvious that the list of microorganisms that occur in the river plankton is not limited to the above-mentioned forms. Several observations have shown that some rivers carry exclusively zooplankton, but not phytoplankton, as is generally admitted. Thus Sernow (1901) observed that the Shoshma River, a tributary of the Viatka River in the Volga Basin (Russia) carries exclusively zooplankton. It has been shown in the present investigation that the plankton of the Skunk River in July was composed of Rotifera only, no algæ being present. We do not know, however, that this composition is permanent. The very characteristic peculiarities of river plankton are the inconstancy of its composition and a great proportion of mineral particles, silt, and various kinds of detritus.

It has been pointed out by many investigators (Kofoid, 1908; Allen, 1920; and others) that river plankton is subject to extreme fluctuations in quantity and constitution. Therefore the data concerning the production of plankton obtained in different rivers are comparable one with another only when they represent the results of long-continued observations.

The more stable conditions obtaining during low water stages afford an opportunity for more abundant development of plankton organisms. Every rise of the water level and the consequent increase in the velocity of the current is accompanied by a decrease in the plankton population, which is washed away. The river waters that contain rich plankton mingle with barren storm water. At the same time new forms from ponds, lakes, and other basins connected at the high stage with the main stream are brought into the main channel. Therefore the river plankton may be characterized as a polymixic plankton with a great proportion of littoral and benthal forms.

The question of the origin of the river plankton has often been discussed in scientific literature. Schütt (1892), on the ground of his observations on the Amazon, pointed out that the plankton organisms of that river come from the upper tributaries and have not been developed in the main stream itself. Other investigators—for example, Schmidle (1898)—thought that the river plankton develop in the slow-running parts of the stream, in the bayous, and in the lakes forming parts of or otherwise connected with the main river. Kofoid (1908), as a result of his long-continued observations on the Illinois River, came to the conclusion "that the plankton of the channel is not immediately derived from the tributaries, but comes in large part from the impounding backwaters, and at low-water stages is almost exclusively indigenous in the channel itself."

We have seen in the foregoing sections that in the upper Mississippi the total amount of plankton is greater in Lake Pepin and in Lake Keokuk than in the adjacent parts of the river. We can not say, however, that in all parts of the river the plankton is poorer than in the lakes. Thus, for instance, the amount of plankton observed on September 12 opposite the mouth of the Root River (station 135) —30.3 $cm.^3$ per cubic meter—was more than twice as great as 70 miles above, just below Lake Pepin, where the average amount of plankton on September 10 at Reads Landing (station 124) was only 14.6 $cm.^3$ per cubic meter. The observations made in the river above Lake Pepin show also that there is a considerable increase of plankton in the main channel from Hastings down to Red Wing. On September 2 the amount of plankton near Hastings (station 116) was 12.3 $cm.^3$ per cubic meter, and on September 1, 21 miles downstream near Red Wing (station 110), the amount of plankton was 21.5 $cm.^3$. At the intermediate station (111) 9 miles above Red Wing the amount of plankton observed on the same day was even greater, reaching 22.7 $cm.^3$ per cubic meter.

It follows from these observations that a considerable difference in the production of plankton sometimes occurs within a comparatively short distance, which may not exceed 10 or 15 miles. Therefore the increase of plankton in some parts of the main channel of the Mississippi is due to the greater productive capacity of that part of the river, not to the mixing with the waters of its tributaries.

This can be seen clearly from the following: The plankton content of St. Croix River, as compared with that of the Mississippi River, is very high, averaging 29.2 cm.^{3} per cubic meter, whereas the amount of plankton of the Mississippi River observed simultaneously at station 116, just above the mouth of the St. Croix River, is only 12.3 cm.^{3} per cubic meter. The amount of plankton of the Mississippi River at station 115, 1 mile below the mouth of the St. Croix River, is 16.3 cm.^{3}, or only 4 cm.^{3} greater than above the mouth, whereas 10 miles downstream the content of plankton increases to 22.7 cm.^{3} per cubic meter. There are no other tributaries in this section of the river and the increase of plankton evidently is due to a greater productive capacity of this part of the main river.

There arises a question: What is the cause of the higher or lower productivity of the different parts of the river? The writer is unable to answer this satisfactorily because the solution of this problem requires many special local investigations and observations as to the chemical composition of water, which could not be made during the course of the present investigation.

It has been observed by many investigators that the amount of plankton in the river depends mainly on the hydrographic conditions, and especially on the velocity of current. Allen (1920), on the basis of a statistical study of the plankton of the San Joaquin River, Calif., came to the conclusion that "water currents above a very moderate speed are distinctly inimical to plankton development." The same idea has been expressed more precisely by Schröder (1899) in his paper on the phytoplankton of the Oder River (Germany). He says that the amount of plankton in the running water of the river is in inverse proportion to the slope of the river. In Steuer's textbooks on limnology this statement is called "Schröder's law" (Steuer, 1910, p. 107). There is no sufficient reason for designating as a "law" such a statement, which is made mainly to describe the phenomenon and which can be applied only to a limited number of cases.

The amount of plankton in a given part of the river depends not only on the slope of the river, and consequently on the velocity of the current, but also on the hydrographic conditions in the upper parts of the river. We have seen that the slope of the Mississippi River above Rock Island Rapids (0.35 foot per mile) is almost the same as below the rapids (0.38 foot per mile). The distance, 16 miles, where the river passes through the rapids with a total fall of 21 feet, divides the river into two sections, distinct from each other in their plankton content. The rich plankton of the upper part of the river, averaging 21.3 cm.^{3} per cubic meter, is evidently destroyed in the rapids, as the plankton content in the lower part of the river averages only 5.16 cm.^{3}, although from Davenport, just below the rapids, to Burlington, about 100 miles down, the slope is the same as in the upper section of the river, its plankton resource is not restored, and an increase in plankton occurs only in the backwaters of Lake Keokuk.

Swift currents are, of course, unfavorable for the development of zooplankton. In comparison with the velocity of current the movements of plankton animals are so slow that they are unable to obtain a sufficient quantity of food where the current is swift. The plankton algæ, feeding on salts and gases dissolved in water, are in more favorable condition. When a filament of Melosira or a band of Fragilaria is drifting many miles with a stream, the processes of assimilation and photosynthesis going on in its cells are not interrupted. That is why the algæ form the larger part of the potamoplankton.

We have seen that the amount of plankton decreases in swift-running water. Thus, below Rock Island Rapids the river carries only about 0.4 as much plankton as above the rapids. (Table 27, p. 405, stations 50 and 51). If we suppose the average rate of flow in the rapids to be 3 feet per second, or 1 mile in 29 minutes, it would require about 8 hours to pass the rapids, drifting with the current. In this time a greater part of the plankton disappears. It may be assumed that the plankton organisms are destroyed, not directly by the water running with a great velocity, but by the friction against the particles of sand that are suspended in the water. Then it becomes probable that the devastating influence of the rapids depends not only on the velocity of the stream, but also on the character and the degree of roughness of the river bed. Unfortunately we have no direct observations to that effect made at different parts of the rapids, and the question remains open. It is certain, however, that the amount of detritus is greater below the rapids than above, whereas the reverse is the case with the amount of plankton.

When the water becomes stagnant, or at least flows slowly, the plankton crustaceans grow more numerous. This has been observed in both Lake Pepin and Lake Keokuk. The increase of Copepoda and Cladocera is especially noticeable in the backwaters of Lake Keokuk, where the crustacean population progressively increases from the upper part of the lake to the dam (Fig. 15).

The stagnant water of Lake Pepin apparently affords more favorable conditions for Copepoda, which form a considerable part of the plankton of this lake. The number of copepods in the river plankton below Lake Pepin, from Reads Landing down to Prairie du Chien, is as great as in the lake itself, but above Lake Pepin they are less abundant. The water fleas (*Daphnia retrocurva* and *Leptodora kindtii*) also occur in the section of the river between Lake Pepin and Prairie du Chien, but their quantities progressively decline from the lake down to Prairie du Chien, and below this point these organisms have not been noticed at all. It is interesting to note that only adult Leptodora and *Daphnia retrocurva* occurred below Lake Pepin, while both above and in the lake adult as well as young organisms occurred frequently.

Daphnia retrocurva is a very variable organism, the various forms differing from one another in the shape and length of the head. In Lake Pepin this species was represented mainly by forms with an extremely extended crest of the head (*D. retrocurva* proper). In the river below the lake only forms with a short and straight crest have been found.

The plankton of Lake Keokuk, as shown above, differs quantitatively as well as qualitatively from that of Lake Pepin. The mean content of plankton in the water of Lake Pepin is 2.3 times greater than that in Lake Keokuk. The comparative poorness of Lake Keokuk in plankton is due to several causes. First, the water of the Mississippi River running into Lake Keokuk carries less plankton than the water of the inflow into Lake Pepin. Second, the hydrographic conditions are more unstable in Lake Keokuk than in Lake Pepin, both because of the operation of the dam, which causes fluctuations in the water level, and because of the fact that although both lakes are interpolated in the course of the river, Lake Keokuk is more intimately connected with the river than Lake Pepin. Due to the delta that the Mississippi River has built in the northern upper part of Lake Pepin, the inflow of the river into the lake is limited to a relatively narrow canal, while in Lake Keokuk the whole body of the river water is held in check and the river is progressively transformed into the lake. Therefore, every change of the river conditions immediately affects the whole body of water in the lake.

In each of the two lakes the conditions surrounding the plankton and other ecological communities may differ from that in a typical lake. The most important peculiarity consists in a constant renewal of water which affects, of course, the whole organic life in these so-called "river lakes." The last term has been proposed by Coker (1914). It very clearly expresses the profound difference that exists between a typical lake and such a body of relatively still water as is intimately connected with the river and where the water is constantly renewed.

A sudden decrease of plankton may occur in the river lakes, where, due to the rise of the water level, the whole plankton resource can be washed away and replaced by silt and detritus. Such a case has been observed in Lake Keokuk when, at the end of September, the rise of the river caused the total disappearance of relatively rich plankton developed in the lake during the low stage. It is probable that Lake Pepin is affected in a smaller degree by the changes in the river stage, and therefore affords more favorable conditions for plankton development. The present observations on Lake Pepin were completed on the 10th of September when the river was still at a low stage, and therefore this question remains open.

Obviously the complete cycle of life in the "river lakes," the plankton pulses, the appearance and disappearance of plankton forms, the seasonal fluctuations in the amount and composition of plankton, and even the distribution of plankton and bottom organisms is different from that in typical lakes. Lake Pepin and Lake Keokuk afford a rare opportunity for making a comparative study of the life in two river lakes, one of which is a natural lake, the other an artificial lake not as yet completely developed. One could expect that the study of the organic life in these two lakes carried on during the whole year should solve many interesting problems concerning the biology of the river plankton and its relation to the plankton of the river lakes.

PLANKTON AND THE FISHERIES.

Many attempts have been made to use the results of the quantitative investigations of plankton as a basis for estimating the productiveness of ponds or lakes in fishes. From a practical point of view the problem is of great importance, especially in connection with the artificial propagation of fishes. The question as to whether there is a sufficient quantity of natural fish food in the pond in which the fishes are to be raised is the first one to be answered by the fish-culturist before stocking the waters. Therefore, measurements of the total amount of plankton have often been applied to determine the food resource in the pond where propagation of carp and other fishes was under consideration.

Many such determinations of the productive capacity of ponds were made in Germany and in the western part of European Russia, where the propagation of carp was very common. Consequently, the great part of the observations in the matter pertain to carp ponds. A special scale for estimating the productive capacity of ponds has been worked out by Walter (1905). According to his scheme the estimation of the productive capacity of a pond must be based on the determination of the volume of zooplankton. Walter recognizes the three following types of ponds: (1) Ponds of low productive capacity, in which the amount of zooplankton does not exceed 5 $cm.^3$ per cubic meter. (2) Ponds of medium productive capacity, in which the amount of zooplankton varies from 5 to 15 $cm.^3$ per cubic meter. (3) Ponds of high productive capacity, with zooplankton content from 15 to 50 $cm.^3$ per cubic meter.

It has been observed that the Rotifera and Copepoda are more abundant in ponds of low productive capacity, whereas the Cladocera are more numerous in ponds rich in plankton.

The practical experience of fish-culturists dealing with the artificial propagation of fish in ponds has discovered various methods which may be used to increase the productive capacity of ponds. It has been found that the production of plankton can be considerably increased if the pond is drained and its bottom allowed to overgrow with vegetation. When several months later the pond is again filled with water the zooplankton develops in greater abundance. Another method, successfully applied to increase the production of zooplankton, consists in throwing various kinds of soil fertilizers into the ponds. Knauthe and Zuntz (see Knauthe, 1907) have made many laboratory experiments and field observations in studying this question and have proved that the amount of plankton in the ponds considerably increases after adding to the water a certain quantity of different fertilizers.

The determination of the amount of plankton has thus been applied as a basis for estimating the productive capacity of ponds. Obviously the problem is comparatively simple when one deals with a small pond where the fish population consists of one species. All the factors, such as the number of fishes, their feeding habits, their average size, the amount of plankton, and other conditions, can be easily observed and taken into consideration.

In a natural lake, however, we are dealing with many factors that can not be accurately determined. First, the fish population consists of various species with different feeding habits, some of them being carnivorous while others feed largely upon vegetable matter. Second, all features of the lake, such as depth and character of bottom and shores, exert a great influence on the organic life of the lake. Therefore the determination of the productive capacity of a natural lake is a more complicated problem than the estimation of the productivity of a small pond.

There arises the question: To what degree may the amount of plankton in the lake be used as an indicator of its productive capacity? This topic has been discussed for a long time in the limnological literature. Some limnologists—as, for example, Schiemenz (1905) and Zander (1903)—are of the opinion that plankton is of little value as food for fishes. Most fishes feed upon littoral crustaceans, mosquito larvæ, worms, and other shore or bottom animals. Therefore, according to Schiemenz and Zander, the estimation of the fitness of a lake or pond for fish culture ought to be made on the basis of an examination of shore and bottom fauna rather than on the study of plankton. The examination of the composition of plankton is useless for estimating the productive capacity of a lake, and only the determination of nitrates dissolved in water is of importance for that purpose.

Schiemenz (1902-1905) pointed out that if the fishes in a pond change their food and become plankton eaters it indicates that the conditions in the pond are unfavorable for fish culture. With regard to the nutrition of carp Schiemenz discovered some very interesting facts. In carp ponds the number feeding on shore and bottom organisms progressively increases from midsummer to fall. The ratio between the plankton-eating carp and those consuming bottom animals and plants was, in July, 1 : 2; in August, 1 : 5; and in October, 1 : 13. Schiemenz's interesting observations have been much criticized. His opponents have pointed out that he gives no information concerning the average productivity of the ponds in which the observations were made and says nothing about the character of the ponds in question, and that therefore a different conclusion might be arrived at if all the factors were taken into consideration.

The estimation of the productive capacity of a lake, based on the determination of the total amount of plankton, does not mean that the plankton is regarded as the principal food of fishes, mussels, and other edible or useful animals. From numerous investigations made in America and in Europe—Pearse (1921), Schiemenz (1902-1905), Walter (1905), Arnold (1902), and Geineman (1902)—we know that the food of most of the commercial fishes consists of other fishes or shore and bottom inhabitants. There are but few fishes living on a pure plankton diet, and even these plankton eaters do not consume plankton without regard to its composition. Thus Hofer (1896) found that 75 per cent of the total amount of food of the whitefish in Bodensee Lake was composed of a planktonic cladoceran, *Bytotrephes longimanus*. The whitefish in this lake evidently are able to choose their food among the small planktonic crustaceans, and Hofer affirms that their gathering at different depths depends on the vertical distribution of Bytotrephes. Regardless of whether this interpretation is justified or not it seems certain that the fishes occur in greater abundance at the depths where Bytotrephes is most numerous.

Similar observations made in various countries show that there are many fishes that feed on definite plankton crustaceans. For example, *Osmerus eperlanus*, in the Russian lakes, feeds in summer on Leptodora and Hyalodaphnia and on Bosmina and Cyclops in winter. *Coregonus shinsii*, in Neuenburgersee Lake, according to Fuhrman's (1905) observations, consumes exclusively *Bytotrephes longimanus*. Juday (1907) described the food of a trout in Twin Lakes, Colo., as consisting of an immense quantity of water fleas—4,500 Daphnia were found in the stomach of a small specimen only 30 cm. long.

Some fishes are known to change their diet with the season. For instance, *Alburnus lucidus* in summer feeds almost exclusively on Cladocera, although in winter its food consists mainly of diatoms (Arnold, 1902). Some fishes (*Abramis brama* and *Leuciscus rutilus*) become plankton eaters when there is a lack of food on the bottom or near the shores (Arnold; Schiemenz, l. c.).

Many of the observations just mentioned refer to European rivers and lakes. They show, however, that the question of the food of fishes must be studied separately for each species. Besides, the various constituents of the plankton, even that belonging to one taxonomic group, differ greatly in their nutritive value. Brandt (1898) determined that the dried substance of Copepoda contains protein, 59 per cent; chitin, 4.7 per cent; fat, 7 per cent; carbohydrates, 20 per cent; and ash, 9.3 per cent. Knauthe (1907) analyzed two common water fleas—Sida and Bosmina—and found their dried substance to have the following composition: Sida, 53.3 per cent protein, 7.6 per cent fat, and 21.5 per cent ash; Bosmina, 72.4 per cent protein, 8.2 per cent fat, and 17.4 per cent ash.

The recent investigation of C. Juday (1922) shows that crude protein constitutes more than 50 per cent of the dry weight of plankton algæ, whereas in large aquatic plants its amount varies from 10 to 20 per cent. In animals the crude protein constitutes from 36 to 64 per cent of the dry weight of the plankton Crustacea and from 35 to 69 per cent in the larger forms, the maximum percentage being noted in the leeches.

It is obvious that the value of the various plankton constituents as nutritive material is very different. If the estimation of the productive capacity of a given lake should be based on the determination of its resources of food available for fishes and other animals of commercial importance, the solution of the problem would require extensive special investigations. The amount of food material required for each separate species of fish should be determined, as well as the chemical composition of various plankton and bottom organisms. Evidently such an estimation is next to impossible at the present stage of our knowledge.

The average content of plankton in the water, however, may be regarded as an indicator of the productive capacity of a lake or pond even if the plankton-eating fishes are entirely absent. Phytoplankton and zooplankton form the middle links of the chain of food relations existing in the water. At one end of this chain are gases and mineral salts dissolved in water and at the other end are found fishes, mussels, and other organisms forming the food for carnivorous aquatic animals. Even if the plankton in a given case is not consumed by the adult fishes it constitutes the principal food of bottom organisms, and consequently the fish resource in that lake depends, though indirectly, on the amount of plankton. Moreover, the food of young fish as a rule is composed of plankton.

A possible error in using the quantitative study of plankton for determining the productive capacity lies in the method itself. The plankton samples collected by filtering the water through bolting silk do not represent the total amount of organisms suspended in water. A considerable part is lost by leakage through the silk. Kofoid (1903) found that catches made by filtering the water through filter paper show the presence of an average amount of plankton 3.3 times greater than the volume of the catches taken by the silk net. The use of filter paper instead of bolting silk, does not provide a satisfactory volumetric method because of the great increase in the proportion and quantity of silt found in filter-paper catches. The collecting of plankton by centrifuging can be applied to the study of the microplankton only and is invalid for collecting Rotifera and Crustacea because of the small volume of water that can be studied. Therefore, up to the present time filtering through bolting silk remains the best method, and in spite of its defects is widely used in limnological investigations.

When considering the data obtained by this method one has to remember that the figures representing the amount of plankton do not represent the total quantity of organisms living in the water, although they may be used in a comparative study of the productive capacities of various lakes. But a great mistake will be made if, on the basis of these data, one attempts to compute the absolute quantities of the living material in the inland waters.

One of the purposes of the present investigation of the upper Mississippi River was to find out how the life in the river has been affected by the construction of the Keokuk Dam. It is shown above that there is an increase of plankton, especially in the copepod and cladoceran population, in the newly formed Keokuk Lake. This increase in plankton production occurs only at low stages of water and disappears during the rise of the river. It means that from a biological point of view the difference between the river and lake exists only at a low stage and can disappear at every sudden rise of water. These conditions are probably peculiar to all river lakes, and of course they are of great importance to the organic life in the lakes.

The productive capacity of such river lakes as Lake Keokuk is lessened by the instability of the hydrographic conditions. Nevertheless, the increase of plankton in Lake Keokuk during low stages of water indicates the increase of its general productive capacity. Therefore it would be very interesting to know if there can be found any indications of the increase of fish resources in this lake since the dam was built. Such information is found in the analysis of the statistics of the commercial fisheries in Lake Keokuk and in Lake Pepin made by R. E. Coker and E. S. Stringham (1921). The authors, having analyzed the statistical data of fisheries in 1914 and 1917, came to the conclusion that the total catch of fish in Lake Pepin in 1917 was 60 per cent greater than in 1914, whereas the catch in Lake Keokuk had increased 172 per cent. It must be born in mind, however, that according to the authors "between the years 1914 and 1917 the prices of fishery products had risen substantially and doubtless proved a stimulus to the fisheries; but it does not appear at all probable that the stimulation due to price could have had so pronounced an effect as to create an appearance of abundance where actual scarcity prevailed."

It is interesting to note that the total increase in catch of fish in Lake Keokuk was nearly three times greater than the increase in Lake Pepin. As Keokuk Dam was completed in 1913 this appears to be due to the increased productive capacity of the lake. The following fishes in Lake Keokuk show substantial increases: Buffalofish, catfish, fresh-water drum, and German carp. Three show a decrease: Eels, sturgeon, and suckers. The buffalofish is the most valuable commercial fish in both lakes, and the catch of this fish in Lake Keokuk increased from 249,900 pounds in 1914 to 696,543 pounds in 1917. It appears that the new conditions in a recently formed lake have afforded the opportunity for a substantial development of buffalofish as a natural resource. The commercial statistics refer, of course, to a limited number of fishes, but the statistics of the capture of game fish (black bass, crappie, pike, and suckers) also suggest an increased abundance of these fishes.

The deductions from the fisheries statistics agree with the results obtained from the present investigation. The body of water held in check by the Keokuk Dam obviously affords more favorable conditions for the development of organic life in the new lake. The increase in the amount of plankton in the lake as compared with that in the adjacent part of the river indicates an increase in productive capacity, and a confirmation of this statement is found in the fisheries statistics. The peculiar conditions existing in Lake Keokuk require more detailed and long-continued observations. From the biological point of view the formation of the lake is not yet complete and the natural process of the formation of various ecological communities can easily be controlled by introducing into the lake such fishes, mussels, and water plants as are of greatest practical value.

SUMMARY.

The present limnological investigation of the upper Mississippi between Hastings, Minn., and Alexandria, Mo., covered a period of three months (July to September) in 1921. The following conclusions are made on the basis of the examination of 673 plankton samples collected at 171 stations:

1. The mean content of plankton in the river, excluding Lake Pepin and Lake Keokuk, averaged 14.5 $cm.^3$ per cubic meter of water (the plankton was collected with pump and its volume determined by the centrifuge method). The production of plankton in the upper part of the river between Hastings and Rock Island Rapids, excluding Lake Pepin, averaged in August 21.3 $cm.^3$ and in September 16.2 $cm.^3$ per cubic meter. The production of plankton in the lower part of the river, between Rock Island Rapids and Burlington (head of Lake Keokuk), averaged in July 5.16 $cm.^3$ and in September 4.8 $cm.^3$ per cubic meter.

2. The river below Rock Island Rapids carried less than 40 per cent of the amount of plankton found above the rapids. This is possibly due to the destruction of the plankton organisms when passing the rapids.

3. The mean plankton content in Lake Pepin averaged 16.6 $cm.^3$ per cubic meter of water (August 18 to September 10). In the upper half of the lake the average was 13.3 $cm.^3$ per cubic meter. Excluding the shallow northern part, the mean content of plankton in the upper half of the lake reached 15.7 $cm.^3$ per cubic meter. The mean plankton content in the lower half of the lake averaged 22.1 $cm.^3$ per cubic meter. The plankton resource of the lake is greater than that of the river just above the lake. The water running into the lake contained 16.6 $cm.^3$ of plankton (August 29) and leaving the lake it contained 21.8 $cm.^3$ of plankton (August 30) per cubic meter.

4. The mean plankton content in Lake Keokuk averaged 7.25 $cm.^3$ per cubic meter (July). The mean plankton content in the upper part between Burlington and Nauvoo averaged 5.28 $cm.^3$ and that in the lower part, between Nauvoo and the dam, 7.7 $cm.^3$ per cubic meter.

5. The crustacean population was very scarce in the lower part of the river, where the number did not exceed 60 per cubic meter, and was richer in the upper part, varying there from 1,000 to 46,000 per cubic meter.

6. The mean number of Copepoda in Lake Pepin averaged 25,800 and in Lake Keokuk 5,400 per cubic meter. The mean number of Cladocera in Lake Pepin averaged 1,020, and in Lake Keokuk 2,720 per cubic meter.

7. In Lake Pepin the Copepoda were more numerous in the lower part and the Cladocera in the upper part.

8. The plankton of the river is subject to great fluctuations, depending on the stage of water. During the rise of the water the plankton is replaced almost entirely by detritus and silt. In Lake Keokuk, at the rise of the river, the plankton is washed away and plankton samples taken during this period contain detritus almost exclusively.

9. The composition of the plankton of the river may be described as monotonic. The plankton of Lake Pepin and Lake Keokuk, as compared with that of adjacent parts of the river, may be characterized as richer in Crustacea and Rotifera. There has been no organism found in the river plankton that could not be found in the lakes.

10. At low-water stages the production of plankton in both Lake Pepin and Lake Keokuk is greater than in the adjacent parts of the river.

11. The increase in the production of fishes in Lake Keokuk since the erection of the Keokuk Dam, as recorded by the official statistics, can be correlated with the increased production of plankton in this lake.

TABLE 29.—*Limnological observations in the upper Mississippi River.*

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter. Pump: Settling method.	Pump: Centrifuge method. Each sample.	Pump: Centrifuge method. Average.	Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda per cubic meter. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera per cubic meter. Mean.	Current velocity per second. Meters.	Current velocity per second. Feet.	Transparency, cubic meters.	Remarks.
1. Mississippi River near Fairport, Iowa, Andalusia Slough.	378⅜	July 11	3–5 p. m.	1.0	Mud	0	31.1	4	4	4		0	0	0	0				
2. Mississippi River near Fairport, Iowa, main channel.	378½	July 12	9–11 a. m.	4.6	...do...	0	30.55	8	6	6		0	0	0	0	0.85	2.8	27	
						1.5	30.23	4	4			0		0					
						3.0	30.23	4	10			0		0					
						4.5	30.23	20				0		0					
3. Mississippi River near New Boston, Ill., Sturgeon Bay.	411⅝	July 13	9–10 a. m.	.25	...do...	0	32.22	6	5	5		60	60	20		.05	.18	11	
4. Mississippi River near New Boston, Ill., main channel (near left shore).	411⅝	...do...	10–11 a. m.	.3	...do...	0	31.11	8	6	6.75		0	0	0	0	.85	2.8	33	
						.9	31.11	6	5			0		0					
						1.8	31.11	10	8			0		0					
						.3	31.03	8	8			0		0					
5. Mississippi River near New Boston, Ill., midstream.	411⅝	...do...	11–12 a. m.	2.1	...do...	0	31.11	6	3	3.7		0	0	0	0	.76	2.5	30	
						.9	31.23	4	5			0		0					
						1.8	31.19	0	3			0		0					
6. The mouth of the Edwards River, near New Boston, Ill.	413½	...do...	3–4 p. m.	.6	Sand	0	33.33												
							33.53	12	12	12		0	0	0	0			20	Current very swift and irregular.
7. Mississippi River near New Boston, Ill., 1 mile below the mouth of Edwards River, mid river.	414½	...do...	4–5 p. m.	.6	Sand and gravel.	0	33.33	8	6	6		0	0	0	0	.39	1.3	27	
8. Mississippi River, 1 mile above Burlington, Iowa, main channel.	440¾	July 14	1.30–2 p. m.			0	31.11	4	3			40	40	0	0	.42	1.4	33	
9. Lake Keokuk, near Dallas City, Ill., between Dallas Island and right shore, midstream.	455⅛	July 15	9.30–10 a. m.	5.2	Mud	0	31.11	6	4	4.5		100	85	120	150	.24	.8	46	
						1.5	30.63	8	6			80		240					
						3.0	30.58	4	4			40		160					
						4.6	30.43	2	4			120		80					
10. Lake Keokuk, near Dallas City, Ill., between Dallas Island and right shore, near the shore.	455⅛	...do...	11.30–12	.3	...do...	0	33.33	Mud.				0	0	0	0		0	18	
11. Lake Keokuk, between Dallas Island and left shore.	455⅛	...do...	2–3.30 p. m.	3.0	...do...	0	32.2	12	10	6		0		100		.1	.32	27	
						1.5	32.0	2	2			0		20					
						3.0													
12. Lake Keokuk, ½ mile above Dallas City, Ill., Dallas Chute.	455⅛	...do...	4–5 p. m.	4.6	...do...	0	31.1				2.9	0		340		.24	.8	43	
						1.5	31.0												
						3.0	31.0												
						4.6	31.0												
13. 5¾ miles above Dallas City, Ill., the slough of the Skunk River.	449⅞	July 20	9.30–11 a. m.	4.6	...do...	0	28.9	36	36	26.5		0	10	0	0	.1	.33	36	
						1.5	28.8	40	32			40		0					
						3.0	28.6	28	22			0		0					
						4.6	28.6	20	16			0		0					
14. Skunk River, 5¾ miles above Dallas, City, Ill.	449⅞	...do...	11 a. m.–1.30 p. m.	4.0	...do...	0	29.4	18	16	17.5	12.6	0	10	0	0			46	
						1.5	28.8	18	14			0		0					
						3.0	28.6	22	22			20		0					
						4.0	28.5	22	18			20		0					
15. Skunk River, right shore	449¼	...do...	2–2.30 p. m.	.3	...do...														
16. Lake Keokuk, 6 miles above Dallas City, Ill., the channel between Twin-Island and right shore.	449¼	...do...	2–3 p. m.	3.0	...do...	0	28.9	4	3	4.25		140	270	0	70	.27	.9	36	
						.9	28.8	6	6			340		100					
						1.8	28.8	4	4			480		60					
						27	28.7	6	4			120		120					
17. Lake Keokuk, 6 miles above Dallas City, Ill., main channel, between Burlington Island and Twin Island.	449⅛	...do...	3–4 p. m.	5.2	...do...	0	28.9	6	6	5.6		740	425	40	50	.38	1.25	36	
						1.5	28.9	4	4			440		120					
						3.0	28.9	2	4			320		0					
						4.6	28.9	8	6			200		40					
						5.2	28.9												
18. Lake Keokuk, 4 miles above Dallas City, Ill., Turkey Chute.	451⅛	July 21	8–9 a. m.	3.7	...do...	0	28.3	8	6	6.6	5.8	300	293	220	360	.11	.37	30	
						1.5	27.5	8	6			140		480					
						3.0	27.3	8	8			140		380					
19. Lake Keokuk, 4⅛ miles above Dallas City, Ill., Shokokon Slough.	450⅝	...do...	10–11 a. m.	4.3	...do...	0	28.3	10	4	4.75	4.5	60	310	0	20	.3	1.0	36	
						1.5	27.7	6	5			320		0					
						3.0	27.7	10	4			340		80					
						4.3	27.6	8	6			520		0					
20. Lake Keokuk, near Dallas City, Ill., Ill., Thomson Slough.	454⅞	...do...	12–1 p. m.	4.6	...do...						12.3								
21. Lake Keokuk, opposite Fort Madison, Iowa, main channel.	462⅝	July 22	11–11.30 a. m.	6.1	...do...						6.2	0		0				46	
22. Lake Keokuk, between Montrose, Iowa, and Nauvoo, Ill., mid lake.	470	...do...	3–4.30 p. m.	6.4	...do...	0	31.1	4	6	8.4	5.8	1,380	562	300	2,865			73	
						1.5	29.8	4	10			520		2,360					
						3.0	28.1	2	6			300		3,100					
						4.6	28.1	10	10										
						6.1	28.1	22	10			0		5,700					
23. Lake Keokuk, 1½ miles above Montrose, Iowa, right shore.	471	July 23	9–10 a. m.	1.5	...do...	0	28.3	12	10	9.3		1,080	1,827	184	1,801			48	
						.9	28.2	12	10			1,520		2,560					
						1.5	28.2	10	8			2,880		2,660					
24. Lake Keokuk, 1½ miles above Montrose, Iowa, mid lake.	471	...do...	10–11 a. m.	3.3	...do...	0	27.8	10	7	8.3		2,880	2,333	960	4,873			47	
						1.5	27.8	10	10			1,520		4,280					
						3.0	27.8	8	8			2,600		9,380					
25. Lake Keokuk, 1½ miles above Montrose, Iowa, left shore (main channel).	471	...do...	11–12 a. m.	6.4	...do...	0	27.8	10	6	7.2	4.1	1,080	1,928	920	652			53	
						1.5	27.7	10	7			1,640		560					
						3.0	27.6	9	7			2,600		1,240					
						4.6	27.6	6	6			1,440		540					
						6.1	27.3	10	10			2,880		0					
26. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, left shore.	472½	July 25	10–11 a. m.	6.7	...do...	0	27.8	12	8	8	6.1	280	964	0	5,188			61	Strong wind.
						1.5	27.2	12	8			620		1,274					
						3.0	27.1	12	8			480		2,880					
						4.6	27.0	8	8			1,320		3,640					
						6.1	27.0	10	8			2,120		6,680					
27. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, mid lake.	472½	...do...	11–12 a. m.	6.7	...do...	0	28.9	8	6	6	6.1	960	960	60	132			61	
						1.5	27.4	10	6			440		280					
						3.0	27.1	6	4			80		0					
						4.6	27.1	12	8			1,480		200					
						6.1	27.1	8	6			1,840		120					
28. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, right shore.	472½	...do...	2–4 p. m.	4.6	...do...	0	30.5	8	10	8.75	7.7	3,320	4,800	620	270			61	
						1.5	29.2	10	10			11,960		240					
						3.0	29.2	11	8			1,840		0					
						4.6	27.0	10	7			2,080		80					
29. Lake Keokuk, opposite Galland, Iowa, right shore.	476	July 26	9–10 a. m.	4.3	...do...	0	27.8	8	7	8.75	6.2	2,160	4,240	140	190			61	
						1.5	26.9	8	6			3,360		380					
						3.0	27.0	10	8			5,240		0					
						4.3	27.0	14	14			6,200		240					
30. Lake Keokuk, opposite Galland, Iowa, mid lake.	476	...do...	10–11.30 a. m.	0	...do...	0	27.8	8	6	8.4	4.0	740	780	0	272			64	
						1.5	27.3	10	8			920		860					
						3.0	27.2	14	8			600		120					
						4.6	27.2	12	12			960		160					
						6.1	27.1	12	8			680		220					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter: Pump: Settling method.	Pump: Centrifuge method: Each sample.	Pump: Centrifuge method: Average.	Vertical net.	Number of Copepoda per cubic meter: Each sample.	Number of Copepoda per cubic meter: Mean.	Number of Cladocera per cubic meter: Each sample.	Number of Cladocera per cubic meter: Mean.	Current velocity per second: Meters.	Current velocity per second: Feet.	Transparency, cubic meters.	Remarks.
31. Lake Keokuk, opposite Galland, Iowa, left shore.	476	July 26	11.45 a.m.-1.15 p.m.	7	Mud	0	28.9	16	10	9.6	6.2	5,600	5,664	3,820	4,104			64	Strong wind and rough; the boat was damaged.
						1.5	28.1	16	10			4,800		7,300					
						3.0	28.1	22	12			8,780		6,980					
						4.6	27.8	12	8			1,760		500					
						6.1	27.2	10	8			7,380		2,420					
32. Lake Keokuk, 2 miles below Galland, Iowa, right shore.	478	July 28	9.30-10.15 a. m.	3.3	...do	0	28.3	6	6	6	5.8	2,480	1,720	880	666			76	
						1.5	27.7	6	6			1,840		640					
						3.0	27.6	6	6			840		480					
33. Lake Keokuk, 2 miles below Galland, Iowa, mid lake.	478	...do	10.30-11.30 a. m.	7.6	...do	0	28.3	10	8	6.8	5.6	2,020	2,960	680	2,800			71	
						1.5	27.8	10	8			6,740		7,120					
						3.0	27.6	14	7			5,720		7,240					
						4.6	27.5	10	6			920		1,000					
						6.1	27.5	14	6			880		320					
						7.6	27.5	14	6			1,480		1,440					
34. Lake Keokuk, 2 miles below Galland, Iowa, left shore.	478	...do	11.45 a.m.-1.15 p.m.	7.0	...do	0	28.9	10	7	6.3	4.3	3,040	3,033	560	533			71	
						1.5	27.7	10	7			4,800		400					
						3.0	27.7	12	6			1,880		800					
						4.6	27.6	12	6			4,480		480					
						6.1	27.6	12	6			2,960		680					
						7.0	27.5	10	6			1,040		280					
						7.6	27.3												
35. Lake Keokuk, 3½ miles below Galland, Iowa, right shore.	479½	...do	2-3 p. m.	5.5	...do	0	27.8	14	8	8	8.1	1,820	1,553	440	707			77	Storm at 2.45 p. m., rain, rough; boat was damaged.
						1.5	27.7	12	8			1,360		1,040					
						3.0		16	8			1,480		640					
36. Lake Keokuk, 3½ miles below Galland, Iowa, mid lake.	479½	July 29	10-11 a. m.	7.6	...do	0	28.9	12	7	6.5	5.6	1,640	7,290	1,000	690			81	
						1.5	27.3	10	8			3,280		1,760					
						3.0	27.1	8	6			1,800		800					
						4.6	27.1	6	6			4,220		320					
						6.1	27.0	10	5			13,080		140					
						7.6	27.0	6	7			19,720		120					
37. Lake Keokuk, 3½ miles below Galland, Iowa, left shore.	479½	...do	11.30 a. m-1.15 p.m.	6.4	...do	0	28.9	18	10	8	6.1	1,960	2,788	280	544			77	
						1.5	27.1	12	8			880		500					
						3.0	27.1	12	8			1,840		500					
						4.6	27.1	8	6			2,060		680					
						6.1	27.0	10	8			7,200		760					
38. Lake Keokuk, 3 miles above Keokuk drawbridge, left shore.	480⅜	...do	3-4 p. m.	6.4	...do	0	27.2	14	8	8.8	7.0	3,320	23,492	400	448			79	
						1.5	27.1	10	7			1,600		640					
						3.0	27.0	8	5			4,560		440					
						4.6	27.0	10	8			13,480		220					
						6.1	27.0	22	16			94,500		540					
39. Lake Keokuk, 3 miles above Keokuk drawbridge, mid lake.	480⅜	...do	4-5.15 p.m.	8.2	...do	0	27.8	12	8	7.1	4.9	4,120	3,027	320	1,280			77	
						1.5	27.6	6	6			4,360		2,800					
						3.0	27.1	10	6			9,560		940					
						4.6	27.1	6	7			2,640		1,760					
						6.1	27.1	10	8			2,560		1,320					
						7.6	27.0	14	8			1,920		540					
40. Lake Keokuk, 3 miles above Keokuk drawbridge, right shore.	480⅜	July 30	9.45-10.30 a. m.	6.4	...do	0	27.8	20	10	8.8	6.0	13,360	14,372	840	5,980			76	
						1.5	27.2	16	8			24,040		7,760					
						3.0	27.1	16	8			12,340		2,800					
						4.6	27.1	20	10			14,620		13,600					
						6.1	27.1	14	8			7,500		1,900					
41. Lake Keokuk, 2 miles above Keokuk drawbridge, right shore.	481⅜	...do	10.45-12 a. m.	9.4	...do	0	28.9	26	14	8.7	7.6	9,160	11,360	20,360	14,494			76	
						1.5	27.2	14	10			24,940		39,920					
						3.0	27.1	18	10			12,720		17,800					
						4.6	27.1	12	6			6,240		6,760					
						6.1	27.1	16	8			6,360		6,860					
						7.6	27.1	14	7			10,300		4,960					
						9.1	27.1	10	6			9,800		4,800					
42. Lake Keokuk, 2 miles above Keokuk drawbridge, mid lake.	481⅜	...do	12-1.30 p. m.	9.4	...do	0	28.9	14	10	7.1	5.5	5,720	3,589	6,060	6,814			79	
						1.5	28.2	18	10			5,860		13,520					
						3.0	26.9	12	8			6,620		11,960					
						4.6	26.8	10	6			3,560		9,660					
						6.1	26.8	16	6			840		3,560					
						7.6	26.7	10	6			1,600		2,220					
						9.1	26.7	6	4			920		720					
43. Lake Keokuk, 2 miles above Keokuk drawbridge, left shore.	481⅜	...do	1.45-3 p. m.	8.2	...do	0	28.9	24	9	7	6.1	3,180	6,360	3,440	2,910			76	
						1.5	28.1	16	6			10,040		4,200					
						3.0	27.2	20	10			10,040		6,100					
						4.6	27.2	18	6			9,820		3,200					
						6.1	26.8	12	7			840		120					
						7.6	26.8	6	4			4,240		400					
44. Lake Keokuk, 1 mile above Keokuk drawbridge, left shore.	483⅜	...do	3-4.30 p. m.	9.4	...do	0	30.5	22	10	7	4.9	10,300	10,434	4,840	2,331			84	
						1.5	29.6	16	8			14,000		3,960					
						3.0	29.5	16	8			9,800		2,600					
						4.6	28.2	16	6			5,600		1,820					
						6.1	27.2	10	5			8,520		520					
						7.6	27.1	10	5			12,120		1,660					
						9.1	27.0	14	7			12,600		1,520					
45. Lake Keokuk, 1 mile above Keokuk drawbridge, mid lake.	483⅜	...do	4.30-5.45 p. m.	11.3	...do	0	28.9	18	12	7.25	3.8	6,360	2,830	1,780	900			74	Rough.
						1.5	29.2	16	10										
						3.0		14	7			4,060		1,600					
						4.6		14	7										
						6.1		16	5			1,040		1,000					
						7.6		14	6			1,520		680					
						9.1		8	5			2,320		180					
						10.7		12	6			1,680		160					
46. Lake Keokuk, 1 mile above Keokuk drawbridge, right shore.	483⅜	...do	5.45-6.15 p. m.	10.7	...do	0	28.9	18	10		4.9	11,440		6,860				76	
47. Mississippi River near Fairport, Iowa, Andalusia Slough.	382⅛	Aug. 9	3-4 p. m.	1.8	...do	0	25.5	8	6	6.6		0	0	0	0			25	Current swift.
						.9		12	8			0		0					
						1.5		8	6			0		0					
48. Mississippi River near Fairport, Iowa, main channel, opposite biological station.	382⅛	...do	4.10-5.15 p. m.	3.3	...do	0	25.5	8	5	4.3		20	13	0	0			22	Do.
						1.5		4	3			20		0					
						3.0		4	5			0		0					
49. Mississippi River near the Fairport, Iowa, right shore just below dike.	382⅛	...do	5.30-6.15 p. m.	1.5	...do	0	26.6	4	4	3.3		0	0	0	0			19	No current.
						1.5		4	4			0							
						3.0		4	2			0							
50. Mississippi River above Davenport, Iowa, Rock Island Rapids, pier daymark 2.	359¼	Aug. 11	11-12 a. m.	3.3	Sand	0	25.6	12	6	6		0	7	0	0			28	Current very swift.
						.6		12	6			20		0					
						.9		12	6										
51. Mississippi River, 6 miles above Clinton, Iowa, opposite Iowa Slough head light.	320	Aug. 12	9.30-10.30 a. m.	3.7	Mud	0	25.0	18	15	15.7		2,480	5,467	20	40			28	Do.
						1.5		26	16			7,440		20					
						3.0		26	16			6,480		80					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter: Pump, Settling method.	Pump, Centrifuge method: Each sample.	Pump, Centrifuge method: Average.	Vertical net.	Number of Copepoda per cubic meter: Each sample.	Number of Copepoda: Mean.	Number of Cladocera per cubic meter: Each sample.	Number of Cladocera: Mean.	Current velocity per second: Meters.	Current velocity: Feet.	Transparency, cubic meters.	Remarks.
52. Wisconsin River, ½ mile above the mouth.	211¾	Aug. 14	3-4 p. m.	1.2	Sand	0													Current swift.
53. Mississippi River, ½ mile below the mouth of the Wisconsin River, main channel.	211⅜	do	4.30-6 p. m.	8.2	Mud and sand.	0	25.5	22	16	25.8		14,240	18,257	0	127			29	Do.
						1.5		20	17			17,300		100					
						3.0		42	26			20,860		120					
						4.6		46	32			11,700		240					
						6.1		60	36			18,320		20					
						7.6		40	28			21,120		280					
54. Mississippi River, near Prairie du Chien, Wis. (above the town), east channel.	207⅜	Aug. 15	8.30-9 a. m.	1.5	Mud	0	23.3	44	32	32		17,520	20,970	160	170			29	Current slow.
						.9		42	32			24,420		180					
55. Mississippi River, above Prairie du Chien, Wis., opposite Scrogum Island Light, main channel.	206⅜	do	9.15 - 9.45 a. m.	3.7	do	0	23.3	32	28	28.7		20,600	19,253	180	207			35	Current swift.
						1.5		32	26			16,800		160					
						3.0		40	32			20,360		280					
56. Mississippi River, 1 mile below Lansing, Iowa, left shore among water lilies.	180¼	do	2.30 - 3.30 p. m.	.9	do	0						520		40					
57. Mississippi River, 1 mile above Wabash, Minn., main channel.	81⅝	Aug. 18	8.30 - 9.30 a. m.	5.2	do	0	21.7	24	16	18.5		18,580	20,985	200	250			79	Do.
						1.5		24	16			25,440		40					
						3.0		26	16			30,000		480					
						4.6		36	26			9,920		280					
58. Lake Pepin, near Lake City, Minn., right shore.	68	do	3.30 - 4.30 p. m.	9.75	do	0	25.5	22	14	17.4	9.5	19,840	22,871	780	1,020			84	
						1.5	22.8	38	16			51,900		1,260					
						3.0	22.2	52	20			23,260		1,080					
						4.6	22.1	46	14			21,620		900					
						6.1	22.1	38	14			24,420		280					
						7.6	22.1	50	20			12,200		680					
						9.1	21.9	56	24			6,860		2,160					
59. Lake Pepin, near Lake City, Minn., mid lake.	68	Aug. 22	9-11 a. m.	7.9	do	0	25.5	54	27	25.8	16.0	19,080	17,783	400	660			79	
						1.5	21.8	86	25			14,500		600					
						3.0	21.8	40	20			15,000		720					
						4.6	21.8	48	27			16,920		1,080					
						6.1	21.8	76	34			22,120		460					
						7.6	21.5	94	22			19,080		700					
60. Lake Pepin, near Lake City, Minn., left shore.	68	do	10.45 a. m. to 12.10 p. m.	6.1	Sand	0	23.9	60	28	24	14.7	30,520	23,292	1,700	1,400		0.61	71	
						1.5	22.8	32	22			30,520		2,400					
						3.0	22.8	26	22			22,100		1,960					
						4.6	22.8	26	22			20,600		540					
						6.1	22.8	30	26			12,720		400					
61. Lake Pepin, 3½ miles below Lake City, Minn., left shore, opposite Deer Lake.	71	do	2-2.30 p. m.	.9	Mud	0	23.4	20	24	24		27,720	15,280	780	430		0.58	49	
						.9	23.4					2,840		80					
62. Lake Pepin, 3½ miles below Lake City, Minn., left shore.	71	do	2.30-3 p. m.	1.5	do	0	23.9	34	18	20		68,180	71,240	1,100	830		0.58	64	
						1.5	23.5	38	22			74,300		560					
64. Lake Pepin, 3½ miles below Lake City, Minn., mid lake.	71	do	3-4.15 p. m.	6.7	do	0	22.2	48	28	24.4	18.5	77,340	72,032	400	884		0.83	76	Rough; strong wind.
						1.5	22.1	50	26			100,740		1,860					
						3.0	22.0	22	16			63,040		1,000					
						4.6	22.0	60	28			68,160		420					
						6.1	21.9	50	24			50,880		740					
64. Lake Pepin, 3½ miles below Lake City, Minn., right shore.	71	do	4.30 - 5.40 p. m.	9.1	do	0	22.2	58	28	27.1	10.9	37,140	37,958	280	1,708		0	76	
						1.5	21.9	22	18			51,910		220					
						3.0	21.8	68	26			49,660		440					
						4.6	21.8	56	18			34,340		400					
						6.1	21.7	80	34			14,000		680					
						7.6	21.5	80	32			26,000		3,640					
						9.1	21.5	60	34			52,660		6,300					
65. Lake Pepin, opposite Pepin, Wis., left shore.	73½	Aug. 23	9.45-10.30 a. m.	4.9	do	0	21.7	80	40	25.5	18.6	14,520	31,610	1,560	870		.11	84	
						1.5	21.6	80	30			24,160		1,080					
						3.0	21.5	34	16			40,700		220					
						4.6	21.4	30	16			47,060		480					
66. Lake Pepin, opposite Pepin, Wis., mid lake.	73½	do	10.30-11.30 a. m.	6.7	do	0	22.8	60	22	20.4	18.5	41,200	53,280	280	276		0	74	
						1.5	21.8	70	30			59,160		60					
						3.0	21.8	48	16			50,880		320					
						4.6	21.8	52	14			61,060		240					
						6.1	21.7	56	20			61,100		480					
67. Lake Pepin, opposite Pepin, Wis., right shore.	73½	do	11.45-12.40 p. m.	10.7	Sand	0	23.3	46	14	18	11.2	10,160	19,100	240	210		0	76	
						1.5	21.6	68	20			30,520		320					
						3.0	21.5	18	12			25,920		200					
						4.6	21.5	76	30			17,800		40					
						6.1	21.5	24	16			24,940		160					
						7.6	21.5	28	18			25,460		300					
						9.1	21.4	48	12										
						10.7	21.4	36	22			38,660		100					
68. Lake Pepin, opposite Lake Pepin footlight, right shore.	75⅜	do	1.40 - 2.45 p. m.	13.1	Mud	0	22.8	16	12	17.1	11.2	24,160	26,007	0	60		0	87	
						1.5	21.6	42	20			9,920		60					
						3.0	21.5	24	16			20,860		0					
						4.6	21.5	20	16			12,980		100					
						6.1	21.5	16	14			28,740		80					
						7.6	21.5	64	20			23,920		180					
						9.1	21.5	20	18			21,220		100					
						10.7	21.5	50	18			48,600		120					
						12.2	21.5	30	20			37,660		80					
						13.1	21.4												
69. Lake Pepin, opposite Lake Pepin, footlight, mid lake.	75⅜	do	2.50 - 3.10 p. m.	1.2	do	0	23.9	72	30	27		61,060	50,370	0	240		0	50	
						1.0	23.9	64	24			39,680		480					
70. Lake Pepin, opposite Lake Pepin footlight, left shore.	75⅜	do	3.15 - 3.40 p. m.	0.76	do	0	24.4	42	16	16.5		14,000	15,540	0	140		0	71	
						.6	23.2	32	17			17,080		280					
71. Lake Pepin, near Point au Sable, right shore, among water plants.	63	Aug. 24	9.30-10 a. m.	.6	do	0	22.8	50	40	40		4,060	4,060	40	40		0	53	
72. Lake Pepin, opposite Point au Sable, mid lake.	63	do	10-11 a. m.	7.0	do	0	23.3	42	18	16	14.4	640	10,880	0	376		0	81	
						1.5	22.0	30	17			5,080		280					
						3.0	21.8	30	13			18,060		480					
						4.6	21.8	20	14			16,800		600					
						6.1	21.7	44	18			13,760		520					
						7.0	22.0												
73. Lake Pepin, opposite Point au Sable, left shore.	63	do	11.10-12 a. m.	5.5	do	0	24.4	30	16	14.2		15,280	22,560	400	1,190		0	76	
						1.5	22.0	28	18			24,260		800					
						3.0	21.4	26	11			24,040		1,360					
						4.6	21.3	18	12			26,660		2,200					
						5.5	21.2												

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter: Pump: Settling method.	Volume of plankton: Pump: Centrifuge method: Each sample.	Volume of plankton: Pump: Centrifuge method: Average.	Volume of plankton: Vertical net.	Number of Copepoda per cubic meter: Each sample.	Number of Copepoda per cubic meter: Mean.	Number of Cladocera per cubic meter: Each sample.	Number of Cladocera per cubic meter: Mean.	Current velocity per second: Meters.	Current velocity per second: Feet.	Transparency, cubic meters.	Remarks.
74. Lake Pepin, opposite Stockholm, Wis., left shore.	66¼	Aug. 24	1.10 - 1.40 p. m.	4.0		0	25.6						40,367		853		0.47	74	
						1.5	23.7					40,700		880					
						3.0	22.1					45,800		880					
						4.0	21.8					34,600		800					
75. Lake Pepin, opposite Stockholm, Wis., mid lake.	66¼	...do.....	1.50 - 2.30 p. m.	7.6		0	26.1	46	20	17.1	12.5	33,080	40,812	720	825		.55	66	
						1.5	22.4	30	20			86,500		1,660					
						3.0	21.5	24	16										
						4.6	21.2	18	8			43,760		840					
						6.1	21.2	34	17			30,280		240					
						7.6	21.3	62	22			10,440		680					
76. Lake Pepin, opposite Stockholm, Wis., right shore.	66¼	...do.....	2.40 - 3.20 p. m.	9.1		0	27.8	16	8	15.4	9.9	20,360	15,694	520	466		0	74	
						1.5	22.2	34	18			13,220		780					
						3.0	21.3	18	13			8,640		200					
						4.6	21.3	28	17			17,040		80					
						6.1	21.3	20	17			10,660		360					
						7.6	21.3	32	18			18,580		760					
						9.1	21.3	28	17			21,360		560					
77. Lake Pepin, Point No Point, Minn.		Aug. 25																	Sponges on the stones.
78. Lake Pepin, between Point No Point, Minn., and Rush River, Wis., right shore.	60½	...do.....	11-11.30 a. m.	7.3		0	23.3	26	14	12.5		240	880	80	226		.38	72	
						1.5	22.8	14	13			240		0					
						3.0	22.3	8	6			120		0					
						4.6	21.8	36	12			600		120					
						6.1	21.6	40	10			1,560		400					
						7.3	21.4	42	20			2,520		760					
79. Lake Pepin, between Point No Point, Minn., and Rush River, Wis., mid lake.	60½	...do.....	11.45 a.m. to 12.10 p.m.	5.5	Mud.....	0	23.9	24	22	18.2	16.9	4,320	13,635	360	585		.42	79	
						1.5	23.4	28	16			17,300		780					
						3.0	22.6	22	14			19,840		920					
						4.6	22.4	60	21			12,980		280					
						6.1	21.2												
80. Lake Pepin, opposite the mouth of the Rush River, Wis., left shore.	60½	...do.....	12.15-12.45 p. m.	.9	Sand.....	0	25.6	20	16	15.5		53,420	42,480	720	840			36	Rough.
						1.5	25.1	22	15			31,540		960					
81. Lake Pepin, 1½ miles above the mouth of the Rush River, right shore.	59	...do.....	1.50 - 2.25 p. m.	6.7	Mud.....	0	23.9	34	15	15	10.9	14,000	11,100	440	1,236		.46	53	Strong south-east wind; rough.
						1.5	23.4	28	15			16,540		300					
						3.0	23.0	20	13			7,640		360					
						4.6	22.1	46	18			14,640		2,320					
						6.1	21.6	38	14			2,630		2,760					
82. Lake Pepin, 1½ miles above the mouth of the Rush River, mid lake.	59	...do.....	2.40-3 p.m.	4.9	...do......	0	23.9	52	21	15.2	12.6	4,400	6,325	1,320	920		.5	64	Do.
						1.5	23.3	18	11			4,240		1,000					
						3.0	22.9	48	19			3,680		320					
						4.6	21.6	10	10			12,980		1,040					
83. Lake Pepin, 1½ miles above the mouth of the Rush River, left shore.	59	...do.....	3.15 - 3.45 p. m.	2.7	...do......	0	26.1	40	24	19.3		214,720	107,527	1,360	2,280		0	66	Do.
						1.5	25.7	28	18			58,000		4,440					
						2.7	24.6	26	16			49,860		1,000					
84. Lake Pepin, 1 mile below Wacouta Light, right shore.	57⅝	Aug. 26	12.30-1.15 p. m.	5.2		0	24.4	64	22	19.5	17.8	2,800	6,420	120	285		.42	46	Calm; fog.
						1.5	23.8	24	18			4,060		360					
						3.0	23.7	44	18			13,480		340					
						4.6	23.7	30	20			5,340		320					
						5.2	23.7												
85. Lake Pepin, 1 mile below Wacouta Light, mid lake.	57⅝	...do.....	1.30-2 p.m.	4.3		0	25.0	42	21	15.2	11.2	174,480	74,600	1,800	1,490		.2	46	Calm.
						1.5	24.0	38	14			73,260		2,360					
						3.0	23.6	34	13			25,720		440					
						4.3	23.5	32	13			24,940		1,360					
86. Lake Pepin, 1 mile below Wacouta light, left shore.	57⅝	...do.....	3-4 p. m...	3.0		0	26.1	25	16	14.3		53,940	48,247	4,220	11,227		.48	39	Do.
						1.5	24.6	26	14			49,600		22,620					
						3.0	23.5	20	13			41,200		6,840					
87. Lake Pepin, Bay of the Island No. 28.	55⅝	Aug. 27	11.30 - 12 a. m.	.9		0	26.7	18	7	8		2,720	2,160	1,880	1,540		0	43	Do.
						.9	23.6	13	9			1,600		1,200					
88. Lake Pepin, opposite Wacouta, Minn., right shore.	56	...do.....	12 - 12.30 p. m.	1.5		0	24.4	16	6	7.5		720	740	520	360		.9	66	Do.
						1.5	24.0	14	9			760		200					
89. Lake Pepin, opposite Wacouta, Minn., mid lake.	56	...do.....	1-1.30 p. m.	1.5		0	26.7	14	10	11.5		2,080	13,380	440	610		.34	46	Do.
						1.5	23.8	28	13					800					
90. Lake Pepin, opposite Wacouta, Minn., left shore.	56	...do.....	1.40 - 2.30 p. m.	3.7		0	27.8	16	9	8.7	8.5	11,200	19,593	980	753		0	61	Do.
						1.5	25.9	7	8			25,700		720					
						3.0	23.6	8	9			21,880		560					
						3.7	23.4												
91. Lake Pepin, north channel near Bay City Wis.	(1)	Aug. 29	11 - 11.30 a. m.	.6	Mud.....	0	26.7	18	11	11		1,280	1,280	360	360		0	33	Do.
92. Lake Pepin, north channel near Bay City, Wis.	(1)	...do.....	11.30 - 12 a. m.	.6	...do......	0	27.8	14	8	8		1,240	1,240	80	80		0	28	Do.
93. Lake Pepin, north channel opposite the mouth of the Isabel River, left shore.	(1)	...do.....	12 - 12.30 p. m.	.6	...do......	0	27.8	25	9	9		8,400	8,400	840	840		0	33	Do.
94. Lake Pepin, north channel opposite the mouth of the Isabel River, mid channel.	(1)	...do.....	12-1 p. m..	1.2	...do......	0	27.8	34	9	7.5		9,060	10,250	600	580		0	28	Do.
						1.3	27.5	10	6			11,440		560					
95. Lake Pepin, north channel opposite the mouth of the Isabel River, right shore.	(1)	...do.....	1-1.20 p.m.	.6	...do......	0	28.9	32	16	16		4,560	4,560	900	900		0	19	Do.
96. Mississippi River, 1 mile above Lake Pepin headlight, left shore.	54¾	...do.....	2-2.30 p. m.	3.0	...do......	0	27.8	32	12	15.3		7,880	7,907	560	1,246	.28	.91	71	
						1.5	25.4	28	17			7,640		840					
						3.0	25.4	21	17			8,400		2,380					
97. Mississippi River, 1 mile above Lake Pepin headlight, midstream.	54¾	...do.....	2.30-3 p. m.	4.3	...do......	0	26.1	24	16	17.5		3,060	1,650	680	565	.12	1.38	36	
						1.5	25.2	36	20			1,280		880					
						3.0	25.2	28	19			660		120					
						4.3	25.2	20	15			1,600		440					
98. Mississippi River, 1 mile above Lake Pepin headlight, right shore.	54¾	...do.....	3-3.20 p. m.	.6	...do......	0	27.8	32	17	17		640	640	280		0		36	
99. Chippewa River, Wis., 1 mile above the mouth, left shore.	78	Aug. 30	10 - 10.30 a. m.	.75	Sand.....	0	25.0	48	25	24.5		120	200	0	0	.95	3.13	76	
						.6		46	24			280		0					
100. Chippewa River, Wis., 1 mile above the mouth, right shore.	78	...do.....	10.40-11.20 a. m.	2.1	...do......	0	25.6	42	23	21.5		0	260	0	0	.74	2.42	66	
						1.5	25.0	40	20			520		0					
101. Mississippi River, opposite Reads Landing, Minn., right shore.	77¼	...do.....	11.30 - 12 a. m.	2.1	Mud.....	0	25.0	42	28	22.5		32,560	44,010	160	175	.96	3.14	102	
						1.5	24.6	38	17			55,460		180					
102. Mississippi River, opposite Reads Landing, Minn., midstream.	77¼	...do.....	12-1 p. m..	1.8	...do......	0	23.9	40	28	24		13,500	15,980	200	380	.62	2.05	91	
						1.5	23.8	44	20			18,460		560					
103. Mississippi River, opposite Reads Landing, Minn., left shore.	77¼	...do.....	1-1.20 p. m.	.6	Sand.....	0	26.7	33	19	19		1,300		120	120	.28	.92	38	
104. Mississippi River, above the mouth of the Chippewa River, right shore.	77¼	...do.....	1.30 - 2.15 p. m.	7.6	Mud.....	0	25.6	44	29	21.5		66,160	46,223	20	90	.23	.77	87	
						1.5	24.8	50	25			49,780		20					
						3.0	23.6	20	20			49,100		120					
						4.6	22.7	38	19			36,500		120					
						6.1	22.4	24	16			29,000		180					
						7.6	22.3	26	20			46,800		80					

[1] Head of the lake.

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water.		Volume of plankton, cubic centimeters per cubic meter.				Number of Copepoda per cubic meter.		Number of Cladocera per cubic meter.		Current velocity per second.		Transparency per cubic meters.	Remarks.
								Pump.											
									Centrifuge method.										
						Depth, meters.	°C.	Settling method.	Each sample.	Average.	Vertical net.	Each sample.	Mean.	Each sample.	Mean.	Meters.	Feet.		
105. Mississippi River, above the mouth of the Chippewa River, midstream.	77	Aug. 30	2.15 - 2.45 p. m.	1.2	Mud	0	26.1	26	14	18	...	9,280	21,550	440	340	0.23	0.77	87	
						1.2	23.8	23	22			33,820		240					
106. Mississippi River, above the mouth of the Chippewa River, left shore.	77	...do...	2.45 - 3.10 p. m.	.6	...do...	0	25.6	46	33	33	...	125,660	125,660	0	0		0	43	
107-109. Lake Pepin, opposite Lake City		...do...																	Qualitative vertical haul.
110. Mississippi River, 1 mile above Red Wing, Minn., main channel.	49	Sept. 1	1.30-2 p. m.	5.5	...do...	0	25.0	34	21	21.5	...	6,100	2,905	120	260	.37	1.23	87	
						1.5	25.0	52	18			1,200		80					
						3.0	25.0	38	24			3,060		360					
						4.6	25.0	44	23			1,260		480					
111. Mississippi River, opposite Diamond Bluff, Wis., main channel.	40½	...do...	4-4.30 p. m.	2.7	...do...	0	26.1	40	19	22.7	...	2,240	2,320	120	187	.42	1.38	79	
						1.5	25.7	36	20			2,200		100					
						2.7	25.4	56	29			2,320		340					
112. St. Croix River and Lake, Wis., 3 miles above the mouth, left shore.	32	Sept. 2	8-9 a. m.	11.3	...do...	0	23.3	40	35	28.2	8.3	18,580	16,476	1,760	1,955	0	0	150	Calm.
						1.5	23.2	46	37			8,640		3,080					
						3.0	23.2	34	31			10,420		2,900					
						4.6	23.1	38	37			38,160		2,400					
						6.1	23.1	32	28			30,460		1,980					
						7.6	23.0	29	36			17,040		960					
						9.1	22.0	18	13			4,060		1,120					
						10.6	21.0	26	9			3,440		1,440					
						11.3	20.3												
113. St. Croix River and Lake, Wis., 3 miles above the mouth, mid lake.	32	...do...	9-10 a. m.	12.2	...do...	0	23.3	48	32	26.9	8.4	28,740	18,315	500	1,523	0	0	150	
						1.5	23.2	64	34			35,100		1,080					
						3.0	23.2	45	43			34,600		780					
						4.6	23.1	70	36			30,580		420					
						6.1	22.7	44	34			25,440		440					
						7.6	21.4	30	24			8,400		500					
						9.1	21.2	15	19			1,120		1,440					
						10.6	20.6	9	9			720		1,640					
						12.1	19.8	12	11			140		6,900					
114. St. Croix River and Lake, Wis., 3 miles above the mouth, right shore.	32	...do...	10 - 10.30 a. m.	1.5	Sand	0	23.9	74	43	32.5	32.9	9,660	12,460	640	680	0	0	150	Do.
						1.5	23.6	34	22			15,260		720					
115. Mississippi River, below Prescott, Wis., main channel.	30	...do...	11-11.30 a. m.	3.0	Mud	.0	25.0	20	9	16.3	...	400	1,133	200	120	.48	1.57	84	
						1.5	24.4	36	21			1,120		100					
						3.0	24.4	46	19			1,880		60					
116. Mississippi River, between Prescott, Wis., and Hastings, Minn., main channel.	28	...do...	12.30-1 p. m.	4.0	...do...	0	25.6	22	9	12.3	...	1,120	1,053	280	160	.48	1.57	76	
						1.5	25.2	28	12			1,280		200					
						3.0	25.2	36	16			760		0					
117. Lake Pepin, opposite Maiden Rock, Wis., left shore.	62½	Sept. 5	9.30-10.45 a. m.	7.6		0	24.4	44	22	17.5	9.4	10,940	28,750	260	617		.31	46	
						1.5	24.2	30	17			41,720		140					
						3.0	24.2	42	14			24,940		200					
						4.6	24.2	36	17			38,160		520					
						6.1	24.1	28	18			21,120		904					
						7.6	24.0	28	17			35,620		1,680					
118. Lake Pepin, 2 miles below Lake City, Minn., right shore.	70	..do...	11.30-12.15 p. m.	7.9		0	25.6				9.4							66	
						1.5	23.8												
						3.0	23.3												
						4.6	23.2												
						6.1	23.1												
						7.6	23.3												
119. Lake Pepin, opposite Point No Point, Minn., right shore.	60½	...do...	4-4.30 p. m.	6.7		0	25.0										0	61	
						1.5	24.6												
						3.0	24.2												
						4.6	23.8												
						6.1	23.0											39	Rough; west wind.
120. Lake Pepin, opposite the mouth of the Rush River, near Maiden Rock City, Wis.	60½	...do...	5-5.15 p. m.	.9		0	24.4												
						.9	24.0												
121. Lake Pepin, opposite Maiden Rock City, Wis.	60½	...do...	5.45 p. m.	7.6															All samples lost during transportation.
122-123. Lake Pepin, opposite Lake City (only net samples).																			Do.
124. Mississippi River, opposite Reads Landing, Minn., main channel.	77½	Sept. 10	11-11.45 a. m.	5.8	Mud	0	22.8	18	12	14.6	...	62,060	35,660	400	405		.77	79	
						1.5	22.3	28	15			32,300		280					
						3.0	22.2	14	14			25,940		360					
						4.6	22.2	12	11			33,840		260					
						5.8	22.2	27	21			24,160		720					
124a. One-third mile below, opposite mouth of Chippewa River.																1.00	3.29		
125. Mississippi River, Beef Slough, Wis.	86¼	Sept. 10	12.30-1 p. m.	.6	Mud	0	25.0	16	10	10	...	1,840	1,840	120	120		0	27	
126. Mouth of the Zumbo River, Minn.	96¾	...do...	2-2.30 p. m.	.3	Sand	0	23.9	14	15	15	...	23,200	23,200	160	160				
127. Mississippi River, opposite mouth of the Zumbo River, Minn., main channel.	96¾	...do...	2.30 - 3.30 p. m.	3.3	Mud	0	22.8	14	10	11.7	...	7,880	14,587	40	280	.96	3.14	69	
						1.5	22.8	8	7			12,720		320					
						3.0	22.8	30	18			23,160		480					
128. Mississippi River, between Winona, Minn., and Homer, Minn., main channel.	119	Sept. 11	9-9.30 a. m.	1.8	...do...	0	21.7	26	23	21.5	...	21,120	20,340	120	100	.74	2.42	50	
						1.5	21.4	28	20			19,560		80					
129. Mississippi River, 4 miles above La Crosse, Wis., main channel.	140⅓	...do...	4-4.30 p. m.	2.1	...do...	0	21.7	26	23	21	...	15,760	16,290	400	390	.67	2.20	46	
						1.5	21.9	26	19			17,020		380					
130. Mississippi River, slough near Light No. 98.	140⅓	...do...	4.30-5 p. m.	.9	...do...	0	22.2	22	19	17.5	...	18,320	15,520	440	460		0	46	
						.9	22.4	22	16			12,720		480					
131. Mississippi River, 4 miles above La Crosse, Wis., right shore.	140⅓	...do...	5-5.30 p. m.	.6	...do...	0	22.2	26	18	18	...	9,920	9,920	180	180	.31	1.01	48	
132. Black River, near La Crosse, Wis., above railroad bridge.	144⅓	Sept. 12	9-9.30 a. m.	.9	...do...	0	19.4	10	8	7.5	...	7,880	5,970	80	100	.10	.34	43	
						9		8	7			4,060		120					
133. Mouth of La Crosse River, at La Crosse, Wis.	144⅓	...do...	10-10.30 a. m.	.3	...do...	0	18.3	48	38			0	0	0	0	.48	1.57	20	
134. Mouth of Root River, Minn.	148	...do...	11.30-12 a. m.	.3	...do...	0	18.3	18	16	16	...	0	0	0	0	.37	1.23	10	
135. Mississippi River, opposite mouth of Root River, main channel.	148	...do...	1-1.25 p. m.	2.7	...do...	0	20.5	36	27	30.3	...	360	6,813	40	247	.78	2.57	51	
						1.5	20.4	38	34			6,860		320					
						2.7	20.4	40	30			13,220		380					
136. Mississippi River, between De Soto, Wis., and Lansing, Iowa, main channel.	177	Sept. 13	8.30-9 a. m.	3.7	...do...	0	19.9	26	20	20	...	10,180	14,900	120	327	.58	1.92	28	
						1.5		20	18			13,400		400					
						3.0		24	22			21,120		460					
137. Mississippi River, 3 miles above Prairie du Chien, Wis., main channel.	204⅓	...do...	3.30-4 p. m.	2.7	...do...	0	21.7	20	17	17	...	18,560	27,047	320	267	.76	2.49	20	
						1.5		18	18			25,940		40					
						2.7		20	16			36,640		440					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter: Pump: Settling method.	Pump: Centrifuge method: Each sample.	Pump: Centrifuge method: Average.	Vertical net.	Number of Copepoda per cubic meter: Each sample.	Copepoda: Mean.	Number of Cladocera per cubic meter: Each sample.	Cladocera: Mean.	Current velocity per second: Meters.	Current velocity: Feet.	Transparency, cubic meters.	Remarks.
138. Mississippi River, near Prairie du Chien, Wis., east channel below railroad bridge, midstream.	207½	Sept. 14	10–10.30 a. m.	2.4	Mud	0	21.1	22	19	17.3		13,480	29,007	160	187	0.56	1.83	20	
						1.5	20.7	22	18			23,140		120					
						2.4	20.7	26	15			50,400		280					
139. Mississippi River, near Prairie du Chien, Wis., east channel below railroad bridge, left shore.	207½	...do...	10.30–11 a. m.	.3	...do...	0	21.1	16	11	11							0	17	
140. McGregor Lake, island near Prairie du Chien, Wis.	207½	...do...	11–12 a. m.	.4	...do...	0												28	
141. Mississippi River, opposite McGregor, Iowa, main channel.	208	...do...	12–1 p. m.	3.3	...do...	0	21.1	22	18	16.7		21,620	17,966	40	153	.44	1.46	27	
						1.5	20.7	18	15			11,200		160					
						3.0	20.7	22	17			21,080		200					
142. The mouth of the Wisconsin River, Wis.	211¾	...do...	1.30–2 p.m.	1.1	Sand	0	22.2	30	21	20		2,120	1,300	0	0	.74	2.42	29	
						1.1		20	19			480		0					
143. Mississippi River, opposite mouth of Wisconsin River, main channel.	211¾	...do...	2.15–3 p.m.	8.2	Mud	0	21.7	22	20	16.5		9,660	18,307	80	80	.67	2.20	28	
						1.5	21.4	18	17			21,880		0					
						3.0	21.4	18	17			21,620		40					
						4.6	21.3	16	15			23,680		120					
						6.1	21.3	16	15			23,200		200					
						7.6	21.2	16	15			17,800		40					
						6.1	21.1												
144. The mouth of the Turkey River, Iowa.	33½	...do...	6–6.20 p.m.	.6	...do...	0	20.0	14,000	9,000	9,000		60	60	0	0	.56	1.83	2	
145. Mississippi River, 1 mile below Cassville, Wis., main channel.	237¾	Sept. 15	8.30–9 a.m.	2.4	...do...	0	21.7	16	13	14.7		8,260	7,453	0	17	.48	1.57	23	
						1.5		16	14			5,080		0					
						3.0		18	17			9,020		40					
146. Mississippi River, 4 miles below Bellevue, Iowa, opposite light No. 659, main channel.	292	Sept. 16	9.30–10 a.m	4.3	...do...	0	21.1	14	10	10.7		4,700	5,806	0	27	.56	1.83	12	Rain; strong wind.
						1.5		14	10			6,360		80					
						3.0													
						4.3	21.5	12	12			6,360		0					
147. Mississippi River, 3 miles below Clinton, Iowa, main channel.	329¾	Sept. 17	9–9.30 a. m.	3.7	...do...	0	21.7	12	7	7.3		3,000	2,120	0	0	.96	3.14	12	
						1.5		10	7.5			1,560		0					
						3.0		10	7.5			1,800		0					
148. Mississippi River, Rock Islands Rapids near day mark pier No. 2, main channel.	359¼	...do...	3–3.45 p.m.	3.7	Sand	0	22.2	10	6	6			400			.32	1.46	8	
						1.5		10	6			320		0					
						3.0		12	6			480		0					
149. Rock River, Ill., 1 mile above the mouth.	362⅝	Sept. 18	9–10 a. m.	2.0	Mud	0	21.1	16	15	11.5		240	320	40	20	.67	2.20	8	
						3.0		10	8			400		0					
150. Mississippi River, 1 mile below the mouth of Rock River, main channel.	363⅝	...do...	10.15 - 11 a. m.	3.7	...do...	0	21.1	10	7	7		400	200	0	0	.67	2.20	6	
						1.5		10	6			120		0					
						3.0		10	8			80		0					

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water: Depth, meters.	Temperature of water: °C.	Volume of plankton, cubic centimeters per cubic meter: Pump: Settling method.	Pump: Centrifuge method: Each sample.	Pump: Centrifuge method: Average.	Vertical net.	Number of Copepoda per cubic meter: Each sample.	Copepoda: Mean.	Number of Cladocera per cubic meter: Each sample.	Cladocera: Mean.	Current velocity per second: Meters.	Current velocity: Feet.	Transparency, cubic meters.	Remarks.
151. Mississippi River, near Sturgeon Bay, opposite ice house, New Boston, Ill.	411⅝	Sept. 20	8–8.30 a.m.	1.8	...do...	0	20.5	2	3	3		3,480	3,520	2,200	2,170	0		15	
						1.5	20.2	6	3			3,560		2,140					
152. Iowa River, Iowa, near New Boston, Ill, ⅓ mile above the mouth.	411⅝	...do...	9–9.30 a.m.	2.9	...do...	0	20.0	10	8	11.5		500	193	480	160	1.11	3.4	6	
						1.5		16	15			20		0					
						2.9		52	42			0		0					
153. Mississippi River, 2 miles below New Boston, Ill.., main channel.	413⅝	...do...	10 - 10.30 a. m.	3.0	Sand	0	21.1	10	4	6.3		0	0	0	0	1.33	4.37	12	
						1.5		6	8			0		0					
						3.0		8	7			0		0					
154. Mississippi River, 2 miles below Burlington, Iowa, main channel.	443¾	...do...	3.30–4 p.m.	4.3	Mud	0	22.2	8	6	3.75		80	20	0	0	.67	2.20	10	
						1.5		4	3			0		0					
						3.0		4	3			0		0					
						4.3		4	3			0		0					
155. Lake Keokuk, near Dallas City, between Dallas Island and left shore, midstream.	455⅛	Sept. 22	8.30 - 9.30 a. m.	5.8	...do...	0	19.4	10	7	6.2		0	0	0	0	.66	2.18	10	Strong wind. rough.
						1.5	20.5	6	5			0		0					
						3.0	20.3	10	7			0		0					
						4.6	20.3	6	6			0		0					
						6.1	19.9	12	6			0		0					
156. Lake Keokuk, 1 mile above Keokuk drawbridge, mid lake.	340⅞	Sept. 23	9–10 a. m.	11.3	...do...	0	20.0	6	6	4	1.3	0	5	0	2	.28	.92	12	
						1.5	20.8	4	4			40		0					
						3.0	20.8	11	10			0		0					
						4.6	20.8	6	3			0		0					
						6.1	20.7	4	2			0		20					
						7.6	20.6	4	2			0		0					
						9.1	20.5	4	2			0		0					
						10.7	20.4	4	3			0		0					
157. Mississippi River, opposite Alexandria, Iowa, main channel.	488¾	...do...	11.30–12.30 p. m.	7.3	...do...	0	21.1	4	3	3		60	40	0	0	.83	2.75	9	Storm, rain, strong wind.
						1.5						60		0					
						3.0						0		0					
						6.1						0		0					
158. Mouth of the Des Moines River	486⅝	...do...	1–1.30 p.m.		...do...	0	20.6	14	12	12		0	0	0	0	1.34	4.38	5	Rain.
159. Lake Keokuk, 1 mile above the Keokuk drawbridge, left shore.	483⅜	Sept. 24	8.45–9.15 a. m.	9.4	...do...	0	21.1										0	10	Calm.
160. Lake Keokuk, 3 miles above the Keokuk drawbridge, left shore.	480⅜	...do...	9.40 - 10 a. m.	5.2	...do...	0	21.7									.13	.44	10	Do.
161. Lake Keokuk, 3 miles above the Keokuk drawbridge, mid lake.	480⅜	...do...	10 - 10.30 a. m.	7.9	...do...	0	21.1	4	3	3	2.7	40	63	40	7	.21	.6	8	Calm; rain.
						1.5	19.8	4	3			40		0					
						3.0	19.7	4	3			120		0					
						4.1	19.6	4	3			0		0					
						6.1	19.0	4	3			40		0					
						7.6	18.6	4	3			140		0					
162. Lake Keokuk, 3 miles above the Keokuk drawbridge, right shore.	480⅜	...do...	11 - 11-30 a. m.	8.5	...do...	0	21.1				2.2					.12	.38	8	Do.
163. Lake Keokuk, 3½ miles below Galland, Iowa, right shore.	479½	...do...	12 - 12.15 p. m.	6.7	...do...	0	21.1				1.8					.22	.73	9	
164. Lake Keokuk, 3½ miles below Galland, Iowa, mid lake.	479½	...do...	12.30 - 1 p. m.	7.0	...do...	0	21.1				1.7					.34	1.13	8	
165. Lake Keokuk, 3½ miles below Galland, Iowa, left shore.	479½	...do...	1.15 - 1.40 p. m.	7.3	...do...	0	21.1				1.7					.17	.55	9	
166. Lake Keokuk, opposite Nauvoo, Ill., left shore.	469⅞	...do...	2–2.30 p.m.	7.0	...do...	0	21.1				2.7	0	0	0	0	.48	1.57	8	
167. Lake Keokuk, opposite Nauvoo, Ill., mid lake.		...do...	2.30 - 2.45 p. m.	5.8	...do...	0	20.5				2.5	0	0	0	0	.26	.86	8	
168. Lake Keokuk, opposite Nauvoo, Ill., right shore.	469⅞	...do...	2.45–3 p.m.	6.7	...do...	0	20.5				2.1	0	0	0	0	.08	.27	10	
169. Lake Keokuk, opposite Fort Madison, Iowa, left shore.	462⅝	...do...	4–4.30 p.m.	3.0	...do...	0	20.5	4	2	2	2.9	40				.19	.62	10	
170. Lake Keokuk, opposite Fort Madison, Iowa, mid lake.	462⅝	...do...	4.30 - 4.45 p. m.	5.2	...do...	0	20.0	7	3	3	3.6	0	0	0	0	.43	1.40	8	
171. Lake Keokuk, opposite Fort Madison, Iowa, right shore.	462⅝	...do...	4.45–5 p.m.	5.8	...do...	0	20.0	6	4	4	3.6	0	0		0	.61	1.99	8	

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