BIOLOGICAL SURVEY OF THE UPPER MISSISSIPPI RIVER, WITH SPECIAL REFERENCE TO POLLUTION

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INTRODUCTION

HISTORICAL

The people of Minnesota and Wisconsin who are interested in the conservation of the fish life of the Upper Mississippi River have claimed that the abundance of fish in the river below Minneapolis and St. Paul is declining. Inasmuch as these people know that all the sewage and industrial waste from the Twin Cities (a combined population of over 600,000) and from South St. Paul, where packing plants are situated, are thrown into the Mississippi River without previous treatment, they attribute the apparent decrease in the abundance of fish to the effects of this sewage and trade waste. The conservationists of Wisconsin and Minnesota have demanded that these cities be prohibited from dumping untreated sewage into the river.

That this general belief in the decline in abundance of the fish in this region is not unfounded may be seen from Table 1, in which the yields of the various species of food fish in 1903 are compared with those in 1922. It is at once apparent that although the total yield has more than doubled in the 19-year interval, this increase is due almost entirely to the enormous catch of carp in the latter year, while the total yield of all other food fish has declined materially. The most desirable or popular species (such as black bass, crappie, pickerel, pike perches, sunfish, yellow perch, and white bass) disappeared entirely from the commercial catch in 1922, the yield of suckers was reduced greatly, and only those fishes that formerly were considered of less value, such as the buffalo, bowfin, and drum (aside from carp), have increased in yield.

TABLE 1.—*Products of the fisheries of the Mississippi River from Minneapolis to Winona in 1903 and 1922*

[From unpublished files of the Bureau of Fisheries]

Species	1903		1922	
	Pounds	*Value*	*Pounds*	*Value*
Food fish, except carp:				
Black bass	325	$26		
Buffalo fish	405,245	10,460	409,310	$19,841
Bowfin			21,445	357
Catfish and bullheads	311,149	17,917	147,016	13,208
Crappie	19,317	827		
Drum	283,210	4,988	429,078	13,529
Eels	6,442	514	799	47
Paddlefish	202,260	6,142	16,271	633
Pickerel	57,525	2,702		
Pike perch (wall-eyed)	35,380	2,028		
Pike perch (sauger)	14,305	684		
Suckers	72,060	1,302	57,434	1,681
Sunfish	21,400	490		
Sturgeon	14,585	642	7,753	1,162
Yellow perch	300	14		
White bass	12,545	442		
Total	1,456,048	49,178	1,089,106	51,073
Carp	473,440	8,969	3,048,332	101,274
Grand total	1,929,488	58,147	4,137,438	152,347

There are few data to aid in estimating the rôle of the various factors (whether economic or biologic) in causing this decline in the fisheries. No doubt, changing market demand, legislation, overfishing, pollution, and changing physical environment all have affected the fisheries, and it is the object of this report to present new evidence bearing upon this important problem.

In 1925 a joint interim committee was appointed by the Legislatures of Wisconsin and Minnesota and instructed to obtain data on the general condition of the river and to present these data before the State legislatures in 1927. The interim committee decided that a biological survey should form a part of their general study of the Mississippi River and asked the United States Bureau of Fisheries to furnish an investigator to make this survey. The bureau agreed to do this on the condition that the field expenses of the bureau's investigator should be borne by the State governments.

Funds to the amount of $20,500 had been appropriated for the Mississippi River work by the conservation commissions of the two States, the Twin Cities, and the United States Public Health Service, of which $300 was made available for the work that the Bureau of Fisheries had been asked to do. This was supplemented by the bureau to the extent of about $1,000.

Because of the limited appropriation and time that could be devoted to field work, the results are not as complete as might be desired. Also, as most of the work was done after the heavy rains of last summer had begun, all of the results reported in this paper do not represent conditions as they exist when the river is at its lowest stage and when conditions are most critical.

AIM AND PLAN OF THE SURVEY

The aim of the biological survey was to determine whether the pollution from the Twin Cities is a factor in destroying aquatic life in the Upper Mississippi River; and if so, to ascertain, if possible, how far below these cities this pollution constitutes such a factor. To answer these questions, the following general plan of action was drawn up:

1. Collect and preserve the animals of the bottom sediments.
2. Collect and preserve samples of surface scums, if present.
3. Collect and preserve net plankton; enumerate after completion of the field work.
4. Collect and preserve samples of strained water, to be centrifuged for the nannoplankton; enumerate as in 3.
5. Make notes on submergent and littoral vegetation and on the presence of coves or quiet water (source of plankton) along the shore.
6. Seine for fish. Preserve the small ones and take notes on the larger ones.
7. Obtain hydrometric data from the United States Geological Survey.
8. Obtain dissolved oxygen determinations from H. R. Crohurst, who is in charge of the United States Public Health Service's sanitary survey of the Upper Mississippi River.

It was decided that in order to obtain data most representative of conditions in the river it would be more advisable to visit each field station two or more times (until the funds were exhausted) and reduce the number of samples collected at each station to a minimum than to take a large number of samples at one time and visit each station once. Also, due to the limited funds, the field work was reduced to a minimum. All work ordinarily performed immediately in the field, but which could be postponed, was done at the University of Wisconsin.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Dr. John Van Oosten, of the United States Bureau of Fisheries, for making the preliminary arrangements for the survey, for identifying the fishes, and for much valuable help rendered in the preparation of the report; to H. R. Crohurst, of the United States Public Health Service, for permission to use his data on dissolved oxygen; to Prof. Chancey Juday, of the Wisconsin Geological and Natural History Survey, for the loan of a centrifuge for the field work and for extending the privileges of his laboratory, where the plankton and the bottom samples were studied; and to the department of zoology, University of Michigan, for the loan of the plankton pump and the plankton net.

The writer is indebted also to Dr. Albert Mann, of the Smithsonian Institution, for the identification of the diatoms in some of the samples; and to Dr. V. Sterki, of New Philadelphia, Ohio, and C. F. Baker, of the Illinois Natural History Survey, for the identification of the mollusks.

The Minnesota Fish and Game Department furnished help and equipment for seining; the division of sanitation of the Minnesota State Board of Health furnished transportation to the station in the metropolitan area; and the biology department of the University of Minnesota furnished the writer an Ekman dredge and office space during the field work. The services of those responsible for these arrangements are greatly appreciated.

SAMPLING STATIONS

The stations selected for the taking of samples for the biological survey are the same as those that were selected for the sanitary survey by Mr. Crohurst. The locations of these stations are shown on the accompanying map. (Fig. 1.) Most of the stations are on the Mississippi River, of course, but in order to get some comparative data from unpolluted streams some sampling stations were chosen on the principal tributaries. The stations on the Mississippi River are so distributed that the data obtained represent conditions (1) before any sewage had been added, (2) after all the Minneapolis sewage had been added, (3) after all the St. Paul sewage

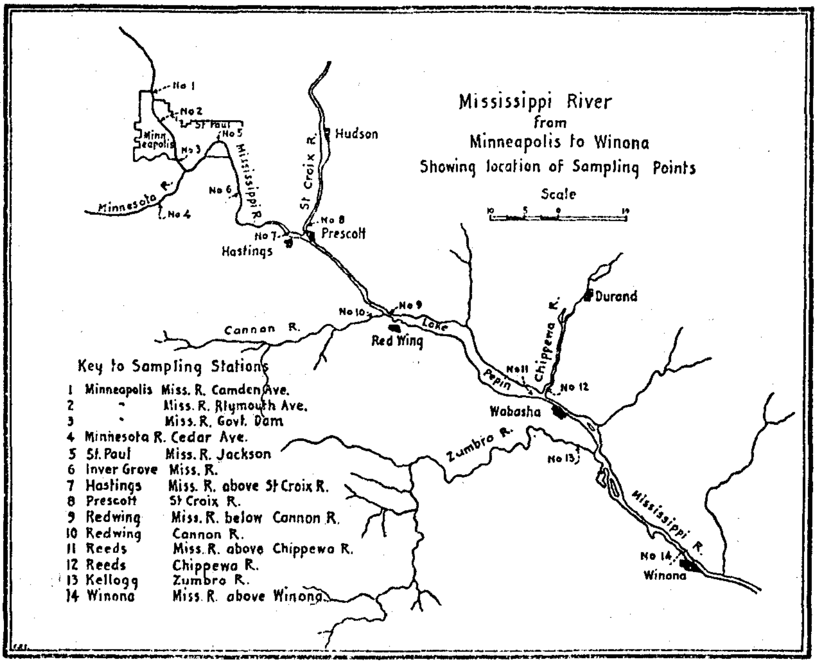

FIG. 1

had been added and one tributary had joined the river, (4) after the South St. Paul sewage had been added, and (5) at various distances below South St. Paul. In this way it should be possible to determine, approximately, the extent of the effect of the sewage from the Twin Cities and from South St. Paul. A brief summary of the distribution of the sampling stations follows:

Station No. 1 is on the Mississippi River above Minneapolis, at the Camden Power Plant, and represents the river before any sewage has entered it.

Station No. 2 is on the Mississippi River in the Minneapolis area, about 4 miles below No. 1. The river here is divided by an island into two branches. Considerable sewage has already entered the river above station No. 2. The right branch of the river receives additional sewage at this station and consequently is more polluted than the left branch.

Station No. 3 is above the Ford Dam, just below Minneapolis. By this time the river has received all the sewage that Minneapolis contributes. The dam here backs up the water, and as a result the current is very slack, so that most of the solid material settles out on the bottom. According to information received from Mr. Elsberg, city engineer at Minneapolis, already there is a layer of sludge, 12 feet in depth, behind the dam, and this is accumulating at a rate of 12 inches each year.

Station No. 4 is on the Minnesota River, about 8 miles above its mouth and about 15 miles below the towns of Chaska and Shakopee. The joint population of these two towns is approximately 4,000.

Station No. 5 is on the Mississippi River, just below St. Paul, a distance of approximately 10 miles below station No. 3. By this time the river has received all the St. Paul sewage and also the discharge from the Minnesota River. The waters of the Minnesota River flow for about a mile over shallow rapids before entering the Mississippi River, and presumably enter the latter in a well-aerated condition. For the discharge of the Minnesota River see Table 2.

TABLE 2.—*Monthly mean discharge in second-feet for the period October, 1925, to October, 1926*

Date	Mississippi River at Elk River, Minn.	Minnesota River at the mouth	Mississippi River at St. Paul	St. Croix River at the mouth	Cannon River at the mouth	Chippewa River at the mouth	Zumbro River at the mouth
1925							
October	2,990	379	4,370	1,848	----------	3,600	----------
November	2,140	335	2,990	1,812	----------	3,906	----------
December	1,550	546	2,470	1,602	----------	3,416	----------
1926							
January	1,060	271	1,880	1,404	----------	2,458	----------
February	947	(1)	1,680	1,572	----------	2,276	----------
March	3,900	2,893	5,620	2,784	----------	5,712	----------
April	3,820	1,265	7,150	4,392	----------	12,768	----------
May	2,230	606	3,650	3,060	184	6,841	260
June	2,160	325	2,860	2,820	139	5,137	307
July	2,150	145	2,590	2,040	98	3,354	170
August	2,050	259	2,810	2,460	95	8,898	170
September	5,110	1,661	8,630	4,680	281	21,736	448
October	5,190	(1)	9,970	(1)	253	11,472	448

[1] No record.

Station No. 6 is on the Mississippi River, about 3.5 miles below South St. Paul. The important change to occur between stations 5 and 6 is the addition of the sewage from South St. Paul, where packing plants are situated, and from a packing house situated across the river, opposite South St. Paul. Grease occurred commonly on the surface of the water when this station was visited.

Station No. 7 is on the Mississippi River at Hastings, about 37 miles below St. Paul. No sewage is added to the river between Hastings and station No. 6 at South St. Paul, yet a very marked change in the condition of the river takes place. At station No. 6 the water is relatively shallow and the current is fairly strong, so that there is little chance for much of the solid material to settle out. At Hastings (station No. 7) the current is rather slack, and consequently much of the solid material settles on the bottom. The water is much deeper, too, and therefore is less effectively aerated by winds.

Station No. 8 is at Prescott, Wis., on the St. Croix River, just above the junction of the St. Croix and the Mississippi Rivers.

Station No. 9 is on the Mississippi River at Red Wing, about 50 miles below St. Paul. By this time the river has received the waters of the St. Croix and the Cannon Rivers. The discharge for these rivers is given in Table 2.

Station No. 10 is on the Cannon River, a tributary that enters the Mississippi about 3 miles above Red Wing. The sampling station is some distance above the mouth of the river. The water at the station is clear, shallow, and flows very rapidly.

Station No. 11 is on the Mississippi River at the lower end of Lake Pepin, a short distance above the mouth of the Chippewa River. By the time the water reaches station No. 11 it has passed through Lake Pepin and has lost much of the solid material held in suspension. That Lake Pepin acts essentially as a settling basin is shown by the bottom deposits at the head of the lake and by the greater transparency of the water when it leaves the lake than when it enters it just below Red Wing.

Station No. 12 is on the Chippewa River where the latter enters the Mississippi at the lower end of Lake Pepin. (Lake Pepin is the result of the delta formed by the Chippewa across the bed of the Mississippi.) The discharge of the Chippewa is given in Table 1.

Station No. 13 is on the Zumbro River. This station was not visited during the biological survey.

Station No. 14 is on the Mississippi River just above Winona, about 110 miles below St. Paul. The station here was chosen above the city to avoid the effect of local pollution. The Mississippi River receives the discharge of the Zumbro River above this station. The hydrometric data for the Zumbro are given in Table 2.

HYDROMETRIC DATA

The hydrometric data shown in Table 2 were prepared from the gauging station records furnished by Mr. Soule, of the United States Geological Survey. The gauging stations on all the tributaries are at some distance above the mouth of the rivers; therefore, the data, as given in the station records, do not show the actual discharge at the mouth of the tributary. The figures in Table 2, however, do give the approximate mean discharge at the mouth of each tributary. Values are shown for each month of the period October, 1925, to October, 1926. The writer obtained these values by multiplying the mean, as given in the station records, by the ratio of the total drainage area of the tributary to the drainage area above the gauging station.

The hydrometric data, where they extend over the entire year, bring out the important fact that on each river there are two periods during the year when the discharge reaches a minimum. The first minimum occurs either in January or February and the second comes in July or August. With one exception—the Minnesota River—the winter minimum for the last year was lower than the summer minimum. From a biological standpoint these low-water stages may become very significant.

It is possible that the large amount of water during the high-water stages may so dilute the sewage and other wastes dumped into a river that their deleterious effect is reduced to a point where no harm results to fish and other aquatic life, but that during the low-water stages this pollution becomes so concentrated that all life is destroyed in the contaminated areas of the river. The periods of minimum discharge, then, may be limiting factors that determine whether fish or other aquatic organisms can survive in the polluted river.

TABLE 3.—*Mississippi River study—dissolved oxygen (parts per million) in August*

Date	Sta. 1, Camden	Sta. 2, Plymouth	Sta. 3, Dam	Sta. 4, Minnesota River	Sta. 5, Jackson Street	Sta. 6, Invergrove	Sta. 7, Hastings	Sta. 8, St. Croix River	Sta. 9, Red Wing	Sta. 10, Cannon River	Sta. 11, Reeds	Sta. 12, Chippewa River	Sta. 13, Zumbro River	Sta. 14, Winona
2	6.22	5.63	0.77	7.61	0.67	0.08	0.33	9.75	2.48	7.11	5.29	6.40	8.29	------
3	6.27	5.62	.50	7.49	.41	.17	.10	9.09	2.30	7.50	4.95	7.23	8.10	7.80
4	6.00	5.23	.05	6.74	.90	1.20	.08	7.80	1.70	7.38	4.97	6.18	7.65	6.80
5	5.31	5.30	.00	5.73	1.00	.30	.20	7.53	1.90	7.61	5.31	5.68	8.20	7.51
6	6.24	5.69	.42	5.90	.02	.28	.05	7.00	1.82	7.13	5.85	6.30	8.64	------
9	6.57	6.25	.00	5.49	.00	.00	.65	6.65	1.40	7.30	5.82	5.60	8.60	4.81
10	6.98	5.29	.00	4.91	.40	.00	.18	6.61	1.60	8.10	5.43	6.90	8.30	4.51
11	6.37	6.22	.00	5.45	.90	.31	.30	6.95	1.70	7.82	4.98	7.29	8.71	5.33
12	6.85	6.29	.05	5.60	.14	.00	.20	6.77	1.97	7.65	4.80	6.74	8.72	6.21
13	6.50	6.27	.10	5.41	.27	.00	.19	6.50	2.55	7.89	5.26	6.35	9.00	5.90
16	6.73	6.85	.00	7.19	.54	.05	1.45	5.72	1.67	7.33	4.78	6.36	7.76	6.45
17	6.55	6.30	.00	6.59	.87	.40	.09	6.43	1.12	8.02	5.64	6.57	7.59	6.63
18	6.62	5.63	.00	6.71	1.38	.43	.18	7.00	1.80	7.24	5.30	6.31	7.88	6.42
19	6.74	6.17	.00	5.77	.99	.17	.00	6.55	2.14	7.20	4.90	6.20	8.02	7.47
20	6.70	6.40	.00	5.14	.00	.25	.00	6.57	2.55	6.08	4.80	------	7.30	6.10
23	6.82	6.41	3.67	4.18	2.52	1.60	1.20	6.93	1.55	7.12	5.50	5.20	7.77	6.34
24	6.63	6.32	2.04	3.93	2.40	1.97	.85	7.05	2.65	7.45	6.09	6.80	------	4.80
25	6.89	6.20	1.06	3.80	1.52	.97	.40	6.40	2.88	7.82	5.61	5.68	7.91	5.59
26	6.90	6.32	.85	4.21	.42	.23	.32	6.68	3.09	7.30	6.41	6.05	7.64	4.50
27	7.05	6.55	3.79	6.30	1.20	1.20	.15	6.95	2.83	7.56	6.01	6.02	8.11	4.76
30	7.09	6.53	.71	5.61	1.58	.96	1.43	8.01	3.79	7.64	6.09	5.86	7.97	5.90
31	6.92	6.34	.71	5.58	.90	.70	.15	7.23	4.01	7.24	4.39	5.77	7.62	------
Average	6.59	6.08	.67	5.70	.87	.51	.39	7.10	2.25	7.43	5.37	6.26	8.08	5.99
Average temperature	21.9	22.0	23.0	22.6	22.1	21.9	22.4	22.7	21.4	19.7	22.0	21.8	19.9	23.3
Per cent saturation	74.0	68.0	7.0	64.0	9.0	5.0	4.0	81.0	25.0	79.0	60.0	70.0	87.0	69.0

TABLE 4.—*Mississippi River study—dissolved oxygen (parts per million) in September*

Date	Sta. 1, Camden	Sta. 2, Plymouth	Sta. 3, Dam	Sta. 4, Minnesota River	Sta. 5, Jackson	Sta. 6, Invergrove	Sta. 7, Hastings	Sta. 8, St. Croix River	Sta. 9, Red Wing	Sta. 10, Cannon River	Sta. 11, Reeds	Sta. 12, Chippewa River	Sta. 13, Zumbro River	Sta. 14, Winona
1	6.99	6.09	0.42	6.10	0.44	0.40	0.10	7.19	4.30	7.56	4.54	5.81	8.71	7.17
2	6.75	5.98	.00	5.39	.51	.75	.10	8.72	2.89	7.42	4.70	5.67	8.10	6.93
3	6.50	6.04	.55	5.15	1.31	2.10	.29	8.70	3.41	8.69	5.30	5.81	8.31	6.69
7	7.79	7.12	5.59	4.81	4.43	3.81	2.70	7.11	2.89	8.31	6.11	6.01	8.78	7.03
8	7.62	7.49	4.61	6.68	4.06	3.01	2.50	6.98	4.43	7.80	6.58	6.79	8.04	------
9	7.69	7.40	4.20	5.97	3.70	2.92	1.60	------	3.43	8.27	7.15	6.85	7.81	5.39
10	7.81	7.49	4.06	6.99	4.39	3.43	1.01	7.14	3.00	8.71	6.68	7.61	9.18	7.03
13	8.43	8.74	6.66	7.01	6.18	5.79	3.69	7.50	3.72	9.66	6.80	7.20	9.50	7.31
14	8.30	7.95	5.94	6.86	6.02	6.08	3.95	7.62	4.37	9.01	6.80	7.42	9.10	7.07
15	8.01	7.88	5.25	7.36	6.15	6.20	3.09	7.23	4.16	8.81	6.51	6.90	8.69	7.30
16	7.70	7.61	5.48	8.40	5.73	5.54	3.50	------	3.43	8.62	7.25	6.63	8.94	7.11
17	7.74	7.31	5.80	8.62	5.68	5.68	3.13	6.97	4.39	------	6.24	6.47	9.03	8.05
20	7.79	7.36	6.44	6.38	6.46	6.19	4.20	7.27	3.93	7.43	7.79	7.41	8.13	------
21	8.00	7.49	5.94	6.98	6.14	5.92	4.45	6.53	4.78	7.72	7.08	7.09	7.34	7.62
22	7.68	7.62	6.09	5.30	5.91	6.02	4.12	7.01	4.27	7.69	6.92	6.55	7.53	------
23	7.76	7.40	6.01	6.30	5.88	5.31	4.20	7.08	4.49	8.15	7.38	6.38	7.90	7.69
24	8.05	7.82	6.33	5.55	------	5.81	4.30	7.40	5.20	8.80	7.80	6.60	8.95	------
27	9.10	8.94	8.52	7.59	8.14	7.53	5.92	7.30	5.08	9.58	8.32	8.70	9.60	8.11
28	8.87	8.81	7.33	8.25	7.32	7.31	6.14	------	6.44	9.41	8.30	8.61	10.18	7.40
29	8.95	8.74	7.42	8.28	7.62	7.41	5.68	7.90	5.10	9.36	8.39	7.99	9.63	------
30	9.62	9.31	8.10	8.59	7.70	7.52	5.87	7.27	6.07	9.33	8.71	8.58	9.58	8.85
Average	7.96	7.65	5.27	6.79	4.94	4.99	3.36	7.38	4.27	8.52	6.92	7.00	8.71	7.30
Average temperature	16.4	16.1	16.8	17.2	16.5	16.4	17.4	18.8	18.7	18.5	19.3	18.2	16.9	21.7
Per cent saturation	80.0	79.0	53.0	70.0	50.0	50.0	35.0	78.0	44.0	90.0	74.0	73.0	89.0	82.0

DISSOLVED OXYGEN

All organisms require oxygen for the maintenance of life. Aquatic animals, with the exception of air breathers, depend for their oxygen supply upon the oxygen dissolved in the water. The amount of dissolved oxygen, therefore, furnishes one good index as to the suitability of a body of water to support life. It is possible, of course, to find waters with a high dissolved oxygen content that are unsuitable for living organisms. This is often the case when waters are polluted by mineral acids, bases, and salts, or by other chemical ingredients that act as specific poisons. However, in a body of flowing water such as the Mississippi River, which does not stratify and stagnate, the presence of oxygen at normal temperatures in minimal quantities is an indication of pollution.

Tables 3 and 4 give the results of dissolved oxygen determinations made by Mr. Crohurst for the months of August and September, 1926. These tables also give the average monthly temperatures of the water at the various field stations. From these data the average percentage of saturation for each month was calculated. For some purposes it is more expedient to express oxygen content in terms of the degree of saturation than in terms of the absolute amount.

Table 3 shows that during August the amount of dissolved oxygen was far greater at some stations than at others. Dissolved oxygen was present in fairly large amounts at all the stations on the tributaries (the average ranged from 5.70 to 8.08 parts per million, or 64 to 87 per cent of saturation) as well as at stations 1, 2, 11, and 14 (average ranged from 5.37 to 6.59 parts per million, or 60 to 74 per cent of saturation) on the Mississippi River. The waters at stations 3, 5, 6, and 7 on the Mississippi River (average ranged from 0.39 to 0.87 parts per million, or 4 to 9 per cent of saturation) contain very small amounts of dissolved oxygen, sometimes a trace only, or none at all. At station No. 9 (average = 2.25 parts per million, or 25 per cent of saturation) conditions with respect to dissolved oxygen are much better than they are at stations 3, 5, 6, and 7, but are not nearly as good as they are at stations 1, 2, 11, and 14. The monthly average at No. 9 probably has been raised through the heavy rains that fell during the latter part of the month. Table 4 shows that a marked improvement with respect to dissolved oxygen occurred at stations 3, 5, 6, and 7 after the first week in September. This improvement undoubtedly is due to the cooler weather and to the large increase in the volume of water in the river, the results of heavy rains.

The data in Tables 3 and 4, then, show the following facts:

1. During August and the first week of September, 1926, the dissolved oxygen content is decidedly less in that section of the Mississippi River that extends from station No. 2, at the beginning of the metropolitan area, to station No. 9, at the head of Lake Pepin (a distance of approximately 64 miles), than it is above or below this section or in the tributary waters. The tributaries and the Mississippi River above the Twin Cities obviously are not polluted by the sewage of Minneapolis and St. Paul. As stated above (p. 142), many of the suspended materials in the Mississippi waters settle at the head of Lake Pepin, which virtually is a settling basin. The water at stations in and below this lake (Nos. 11 and 14), then, should be comparatively free from any sewage that may be carried down to station No. 9; and

if this sewage is the primary factor involved in the depletion of dissolved oxygen in the upper Mississippi River, the oxygen content at stations 11 and 14 should show a distinct increase above that of station No. 9. The data show that this increase does occur. The decrease in the dissolved-oxygen supply of the Mississippi waters in the section described above is unquestionably due to the pollution of the river.

2. The data in Table 4 show that the heavy rains in the fall quickly increase the oxygen content of the polluted waters and eventually restore the normal supply even in the most polluted areas. (See data for September 27 to 30, Table 4.)

BOTTOM FAUNA

RELATIONSHIP OF BOTTOM FAUNA AND POLLUTION

Next to a thorough chemical study, a study of the bottom-dwelling organisms is perhaps the best criterion to be used in determining whether or not a given body of water is polluted. We know with a fair degree of accuracy what kind of organisms are indicative of grossly polluted waters and what organisms can be expected only in fairly clean waters. Of course, numbers of individuals play quite as important a part here as does the species or kind of animals. The presence of a few specimens of the worms Limnodrilus and Tubifex, or of the mollusk *Musculium transversum*, or of the red midge *Chironomus plumosus* is not significant. Studies in the Illinois River, however, have shown that the presence of a large number of these organisms is indicative of pollution. Again, it has been shown that the presence of the larvæ of the caddis fly and the sand fly and the nymph of the May fly may be taken as evidence that the water inhabited by them is not polluted to any considerable extent. These facts are based on many years of study of a biological and a chemical nature by Forbes, Richardson, Shelford, Thompson, and others.

METHODS

Samples for the study of the bottom-dwelling forms were taken by means of a small Ekman dredge. An attempt was made to obtain on each trip at least two samples at each field station—one near the shore and the other in the channel. At times it was impossible to get a sample in the channel because of the nature of the bottom and the strength of the current. The small Ekman dredge works best in soft mud or in places where a great deal of organic débris has settled out. On hard, gravelly bottom it is not very effective; it is too light to go into the bottom to any appreciable extent and, also, the gravel gets behind the jaws and prevents them from closing. A record was kept of the number of hauls taken at each station. Then, either the entire sample or a known portion of it was preserved in 4 per cent formaldehyde.

In the laboratory, the samples were placed in a strainer having a bottom of bolting cloth of 50 meshes per square centimeter. In this strainer the samples were washed with tap water until they were free from mud. The coarse sand and organic débris, as well as the macroscopic animals, were retained in the strainer. After the removal of the mud the sample was placed in a dish and the animals were separated and counted. From the number of each kind of animal obtained from the sample, the area of the dredge, and the number of hauls made for the sample, the number of animals per square yard was calculated. In some cases the volume of the sample was ascertained before and after straining in order to obtain some information as to the relative amount of coarse organic débris, pieces of plants, chips of wood, and in some instances garbage, gravel, and fine mud. The partial results of these determinations are shown in Table 6.

RESULTS AND DISCUSSION

The abundance of the bottom-dwelling animals is expressed in numbers per square yard, and the data are shown in Table 5. The table shows that there is a marked difference in the kinds and numbers of animals that occur at the different stations.

TABLE 5.—*Bottom fauna, animals per square yard, 1926*

[S=shore; C=channel]

Bottom fauna	Sta. 1, Aug. 14	Sta. 1, Sept. 7	Sta. 2, Aug. 14	Sta. 2, Sept. 7	Biology Bldg., Sept. 10	Lake St. Bridge, Sept. 13	Sta. 3, Sept. 8	Sta. 3, Sept. 8	On stones Sta. 3, Sept. 8	Sta. 4, Aug. 17	Sta. 5-S, Aug. 17
Dragon fly nymphs	36										
May fly nymphs		144									
Caddis fly larvæ		72									
Simulium		396									
Tubificidae	252			15,120	364,000	118,000	10,800	632	[1] 6,159	108	11,970
Chironomus	36	108	36					36	5		144
Hyalella	36										
Planaria		72									
Campeloma rufum				1,600							
Sphærium sp	108										
S. notatum				54							
Musculium near transversum							85				1,620
M. near truncatum						500					
Musculium sp						72					
Beetle larvæ	72										
Leeches						72		14	1		

Bottom fauna	Sta. 5-S, Sept. 15	Jackson Street Bridge, Sept. 27	Sta. 6-S, Aug. 18	Lefts, Sta. 6-S, Sept. 16	Rights, Sta. 6-S, Sept. 16	Sta. 7-S, Aug. 18	Sta. 7-S, Sept. 16	Sta. 7-C, Aug. 18	Sta. 7-C, Sept. 16	On stones, Sta. 8, Aug. 19	Sta. 8, Sept. 16
May fly nymphs										([2])	72
Tubificidæ	5,832	2,880	2,520	75,400	10,260	103,860	126,000	31,680	65,400		360
Chironomus	3,240	144									
Hyalella											3,240
Planaria											432
Pleurocera acuta										9	
Physa sp										11	
Campeloma rufum										1	36
Heliosoma trivolvis										2	
Mussels											18
Leeches	1,157	36						720			167

Bottom fauna	Sta. 9-S, Aug. 27	Sta. 9-S, Sept. 17	Sta. 9-C, Aug. 27	Sta. 9-C, Sept. 17	Sta. 10, Aug. 27	Sta. 11-S, Aug. 28	Sta. 11-S, Sept. 18	Sta. 11-C, Aug. 28	Sta. 11-C, Sept. 18	Sta. 14-S, Aug. 31	Sta. 14-S, Sept. 19
Dragon fly nymphs		48		48		18	12				
Damsel fly nymphs						54	12			36	
May fly nymphs					([3])					144	342
Caddis fly larvæ				12							
Tubificidæ	1,980	2,900	36	240				18	900		180
Chironomus	18					54	36	36		684	
Hyalella	1,260	3,000		24		3,600	3,200	18		144	
Asellus	54							18			
Planaria						36		36			
Pleurocera acuta						90	18	90	18		
Campeloma integrum	252	288	108	72						36	18
Anodonta imbecillis		48									
Musculium near transversum				2,520							
M. transversum	1,600										
Heliosoma trivolvis	90										
Leeches	2,295	1,776	684	492			12	180		36	

[1] Per liter. [2] Many. [3] Some.

TABLE 6.—*Relative amounts of residue in bottom samples, expressed in cubic centimeters and per cent, the nature of the residue, and the character of the predominating animals of the bottom fauna*

[S=shore; C=channel]

Station	Sample, cubic centimeters, before straining	Sample, cubic centimeters, after straining	Per cent	Nature of residue after the animals were removed	Predominating animals in bottom samples
1				Clean, coarse sand	Clean-water forms.
2	450	290	64	Garbage	Tubificidæ and *Campeloma rufum*.
3	400	300	75	Cinders; coarse garbage; chips of wood	Tubificidæ.
5				Coarse organic débris; sand	Tubificidæ and bivalves.
6	310	120	38	Little organic débris; pieces of fat and gray sand	Tubificidæ.
7-C	200	150	75	Organic débris	Do.
8	250	50	20	Aquatic plants; cinders; but mostly sand	Clean-water forms.
9	400	350	87	Shells of bivalves	Leeches.
9-S	200	175	87	Aquatic plants; broken-up leaves	Leeches, Hyalella, and Tubificidæ.
11-S				Sand and aquatic plants	Hyalella.
14-S	300	230	77	Mostly coarse gravel; little organic débris	Aquatic insects (clean-water forms).

The sample taken near the right bank of the river, at station No. 1, showed that each square yard of the bottom contained 252 Tubificidæ, 36 midge larvæ (Chironomus—not the red midge), 36 dragon fly nymphs, 36 specimens of *Hyalella knickerbockeri*, and 108 individuals of Sphærium sp. ? (a small bivalve). The second sample was taken in the channel near the left bank of the river. Here the substratum consists of pure sand with a few scattered plants. In the channel the Tubificidæ are absent entirely. Midge larvæ are more numerous (108 specimens per square yard) here than near shore. A number (72 per square yard) of beetle larvæ (Elateridæ) occur in the channel, but these are not aquatic. Associated with the above forms were four species of animals known to prefer clean, running water. These are Planaria, caddis fly larvæ, larvæ and pupæ of the sand fly (Simulium sp. ?), and May fly nymphs. The residue of the strained sample, after the removal of the animals, consisted of pure sand.

At station No. 2 the first mud sample was taken in the left branch of the channel at the same place where the seine hauls for fish were made. The bottom here is fairly clean and solid. The only animal taken in this sample was a midge larvæ. The second sample was taken some 50 yards below a sewer outlet in the right branch of the river. The difference in these two samples demonstrates the effect of sewage on bottom fauna quite clearly. In the first sample there were only 36 midge larvæ per square yard, but in the second there were 15,120 Tubificidæ, 1,600 snails (*Campeloma rufum*), and 54 bivalves (*Sphærium notatum*) per square yard. The residue of the second sample, after straining and the removal of the organisms, consisted of garbage. The results from this second sample are not representative of a cross-section of the river at this place. In the channel of the right branch and along the left branch of the river the bottom is fairly clean. However, as mentioned before, it demonstrates the effect of sewage.

No reference has been found in the literature to the tolerance of *Campeloma rufum* in polluted waters, but the above data indicate that very likely it is one of the more tolerant forms. *Campeloma subsolidum* is classed by Richardson (1925) as one of the less tolerant snails.

Four bottom samples were taken at places other than those designated as stations 1 to 14. One of these samples was taken immediately below the Washington Avenue bridge, directly opposite the university campus. The sample contained no life of any sort; it had a tarry odor and contained tar. The tar was introduced into the river by a gas plant situated a short distance above the Washington Avenue bridge. The waste from this plant undoubtedly explains the absence of all bottom dwelling animals. The heavy tar settles to the bottom and the lighter tar and other oily substances form a film on the surface. This surface film was quite pronounced on some days, both as to extent and thickness. Shelford (1917) has demonstrated the detrimental effect of gas-plant waste on fish. He says, in part: "Illuminating gas, gas liquor, and 31 out of 34 representatives of the chief group of compounds found in gas and gas liquor are very toxic to fishes." In England it has been demonstrated that washings from tarred roads are killing fish in some streams. (Committee on pollution, 1924–25.)

Another sample was taken near shore behind the animal biology building at the University of Minnesota. Two dredge hauls here yielded a sample of 4 liters; 75 cubic centimeters of this sample yielded 385 tubificid worms. This gives the enormous number of 364,000 Tubificidæ per square yard. The sample contained a great deal of fine mud and a considerable amount of coarse organic débris.

A third sample[1] was taken at the Lake Street bridge, about 1 mile below the spot where the last-mentioned sample was taken. The sample was taken in mid-stream and consisted largely of dead aquatic plants. It is the writer's opinion that the dredge did not penetrate into the real sludge on account of these weeds. From this sample 3,300 worms were removed. This gives a tubificid population of 118,000 individuals per square yard. The data also showed that each square yard contained 500 *Musculium* near *truncatum,* 72 Musculium (species unknown), and 72 leeches.[2] The bivalves taken were gravid. *Musculium truncatum* is classified as unusually tolerant by Richardson (1925).

At station No. 3, one sample was taken just above the Ford Dam, where the water is taken into the power station. There is considerable current in this part of the river and, therefore, the bottom is kept fairly clean. (Behind the dam proper conditions are entirely different (p. 141), but no samples were obtained there.) The 5 dredge hauls made along shore here yielded a 200-cubic centimeter sample, which, after straining, left a residue of 60 cubic centimeters. Besides the fauna, the residue was composed of sand plus a small amount of organic débris. Each square yard of bottom here contained 632 tubificids, 36 midge larvæ, and 14 leeches. Mud scraped from stones at station No. 3 contained 6,159 Tubificidæ per liter.

A third sample at station No. 3 was taken a short distance above the Ford Dam. The water here is about 35 feet deep in mid-channel, and the current is very slack when the water is not going through the wheels or over the dam. One haul here yielded a 400-cubic centimeter sample. The entire sample was strained, leaving a residue of 300 cubic centimeters. In addition to the fauna, the residue consisted of coarse organic débris suggestive of garbage, cinders, and many chips of wood. The

[1] The last three samples were taken between stations 2 and 3.

[2] The vast majority of the leeches were *Helobdella stagnalis* Blanchard. In this connection, the author wishes to acknowledge the services of Dr. J. Percy Moore, whose report on leeches was of great help in identifying the species found.

odor of the sample was distinctly foul and oily. The sample yielded 10,800 Tubificidæ and 85 specimens of *Musculium* near *transversum* and near *truncatum* per square yard.

The sample from the Minnesota River (station No. 4) yielded 108 Tubificidæ per square yard. Besides the organisms, a few grains of coarse sand were left in the strainer after the sample had been washed with tap water.

The last of the extra samples (see p. 148) was taken just above the Jackson Street Bridge, about one-half mile above station No. 5. A sample taken here on September 27 yielded 2,880 Tubificidæ, 144 Chironomus larvæ, and 36 leeches per square yard. This sample was taken partly along shore and partly in the channel.

At station No. 5 no bottom samples were obtained in the channel. The current was rather swift in the channel, and with the prevailing high waters its bottom was kept fairly clean from deposits.

The first sample taken along shore at station No. 5 consisted (besides the animals it contained) of coarse sand and a considerable amount of organic débris. The sample yielded 144 midge larvæ, 11,970 Tubificidæ, and 1,620 bivalves per square yard. The bivalves were made up of *Musculium* near *transversum*, *M.* near *truncatum*, and a few specimens of Pisidium. This is the first instance where these bivalves occur in such large numbers. Both the worms and the bivalves are an indication of pollution.

The second sample at No. 5 was taken in a slough permanently connected with the river. The reason for taking the sample in the slough was the fact that what was shore when the first sample was taken (August 17) was now (September 15) channel, and the bottom deposits had been carried away. This slough now formed a part of the shore. One dredge haul here yielded a sample of 700 cubic centimeters, 200 cubic centimeters of which were strained. In addition to the fauna, the residue of 50 cubic centimeters consisted of sand and Elodea. Each square yard of the bottom here contained 3,240 midge larvæ, 5,832 Tubificidæ, and 1,157 leeches.

The first bottom sample at station No. 6 was taken near shore in shallow, swiftly flowing water. The sample showed that each square yard of the bottom contained 2,520 Tubificidæ. The residue left after the sample had been washed consisted of coarse sand. In September, two bottom samples were taken a little farther downstream, where the strength of the current was reduced greatly by wing dams. One sample was taken near the left bank of the river and the other near the right bank. The former yielded 75,400 Tubificidæ per square yard and the latter 10,260. The sample from the right bank contained several pieces of fat, a little organic débris, and gray sand.

The condition of the bottom at station No. 7 is the worst that was met below Minneapolis. When the first visit to this station was made (August 18), gas bubbles (nature of gas not known) were rising continually, not only along the shore but also in the channel. From time to time large pieces of solid material came to the surface. As mentioned above (p. 141), the current here is rather slack, and this facilitates the settling out of the solid materials. The organic materials presumably ferment at the bottom, partly, perhaps, under anærobic conditions. The gases resulting from these fermentations undoubtedly are responsible for raising large masses of solids to the surface. The bottom samples taken on August 18 consisted (besides the animals they contained) entirely of organic débris. The sample had an extremely foul odor.

That there was a considerable layer of this organic débris was shown by the fact that the dredge was filled to the top. Alongshore there was less of this organic débris but more fine mud. When this station was revisited on September 16, conditions were very much improved. Much of the bottom deposit in the channel had disappeared (result of heavy rains). No solid masses were seen rising to the top, but gas bubbles still were very much in evidence along the shore. The bottom animals here are mostly tubificids. In August there were 103,860 per square yard near shore and 31,680 per square yard in the channel. Associated with the tubificids in the channel were 720 leeches per square yard. On September 16 there were 126,000 tubificids per square yard along shore and 65,400 per square yard in the channel. The difference in the number of Tubificidæ in the August and the September samples is not significant, perhaps, and may be due to natural fluctuation or local variations in abundance.

Conditions at station No. 8 (in the St. Croix River) are in marked contrast to the conditions prevailing at No. 7. The first sample taken near shore on the Wisconsin side consisted of pure sand only; but along the shore, on stones, May fly nymphs and the snails, *Pleurocera acuta* and Physa sp.?, were abundant. One specimen of *Campeloma rufum* and two of *Heliosoma trivolvis* also were taken. It will be recalled that *Campeloma rufum* was very abundant near a sewer outlet at No. 2.

The second sample at No. 8 was taken just off the peninsula (on the St. Croix side), where the waters of the Mississippi and the St. Croix Rivers meet. In addition to the bottom fauna, the sample consisted of fine sand, cinders, pebbles, and live aquatic vegetation. Each square yard of the bottom here contained 360 Tubificidæ, 167 leeches, 3,240 Hyalella, 432 Planaria, and 72 May fly nymphs. One large mussel and a few specimens of *Campeloma rufum* also were taken.

The samples of stations No. 7 and No. 8 illustrate clearly the effect of environmental conditions on the character of the fauna. Whereas the badly polluted waters at station No. 7 contained large numbers of Tubificidæ and leeches only, the less polluted waters at station No. 8 contained not only these forms (which, however, were much reduced in numbers) but also *Hyalella knickerbockeri* (a crustacean), Planaria, May fly nymphs, a mussel, and the following snails: *Campeloma rufum, Pleurocera acuta*, Physa sp.?, and *Heliosoma trivolvis*. Planaria and the May fly nymphs are definitely known to be clean-water forms.

The bulk of the sample taken in the channel at station No. 9 in August consisted of empty shells of the small bivalve (*Musculium transversum*). The animals taken with these shells were as follows: 36 Tubificidæ, 684 leeches, and 108 specimens of *Campeloma integrum* per square yard. On September 17 three dredge hauls in the channel here yielded 65 cubic centimeters of empty shells. The sample also contained 240 Tubificidæ, 2,520 individuals of *Musculium* near *transversum*, 492 leeches, 72 *Campeloma integrum*, 24 Hyalella, 12 Caddis fly larvæ, and 48 dragon fly nymphs per square yard. In the shore sample there were in August, in each square yard of bottom, 1,980 Tubificidæ, 18 chironomid larvæ, 1,260 Hyalella, 54 specimens of Asellus, 252 *Campeloma integrum*, 1,600 *Musculium transversum*, 90 *Heliosoma trivolvis*, and 2,295 leeches. In September the shore samples gave 48 dragon fly nymphs, 2,900 Tubificidæ, 3,000 Hyalella, 288 *Campeloma integrum*, 48 specimens of *Anodonta imbecillis*, and 1,776 leeches per square yard. The much smaller number of Tubificidæ here, as compared with the number occurring at station No. 7, the presence of dragon fly nymphs, Caddis fly larvæ, Asellus, and the large number of Hyalella, may all be considered as marking a stage of transition in the conditions of the Mississippi River. Table 5 shows that dragon fly nymphs, Caddis fly larvæ, and Hyalella occurred at station No. 1 on the Mississippi River, and that these forms have not been taken at any of the stations on the Mississippi River between stations 1 and 9. In Europe, the presence of Asellus is taken as the first sign of improvement in a polluted stream (Wundsch, 1926).

The bottom sample taken at station No. 10 consisted of coarse sand. No animals were taken in this sample, but some May fly nymphs were seen clinging to the undersurface of stones. This suggests that the Cannon River is not polluted at this station.

Bottom samples from station No. 11, on the Mississippi River, indicate further improvement in the conditions of the river. Tubificidæ are absent entirely from the samples taken along the left shore. In August the shore sample gave 18 dragon fly nymphs, 54 damsel fly nymphs, 54 larvæ of Chironomus, 3,600 Hyalella, 36 Planaria, and 90 *Pleurocera acuta* per square yard. In September there were, near shore, 12 dragon fly nymphs, 12 damsel fly nymphs, 36 larvæ of Chironomus, 3,200 individuals of Hyalella, 18 *Pleurocera acuta*, and 12 leeches per square yard. In August the bottom fauna of the channel consisted of 18 Tubificidæ, 36 larvæ of Chironomus, 18 Hyalella, 18 individuals of Asellus, 36 Planaria, 90 *Pleurocera acuta*, and 180 leeches; and in September, of 900 Tubificidæ and 18 *P. acuta* per square yard.

Due to a lack of proper equipment, no bottom samples could be obtained at station No. 12.

Station No. 13, on the Zumbro River, was not visited.

The bottom samples of station No. 14 were all taken near shore. The samples for August showed that each yard of bottom contained 36 damsel fly nymphs, 144 individuals of Hyalella, 144 May fly nymphs, 684 larvæ of Chironomus, 36 individuals of *Campeloma integrum*, and 36 leeches. In the September samples there were 342 May fly nymphs, 180 Tubificidæ, and 18 specimens of *Campeloma integrum* per square yard. The May fly nymphs are the most significant element in the bottom fauna at station No. 14. They have not been found at any other station in the Mississippi River except at station No. 1, which is above Minneapolis. May fly nymphs also were taken in the St. Croix and Cannon Rivers. The presence of May fly nymphs at station No. 14 may be taken as an indication that conditions in the river above Winona are fairly good and probably are comparable with conditions as they exist at station No. 1 above Minneapolis.

A study of the bottom samples (Table 5) shows that the clean-water animals were taken at stations 1, 8, 9, 10, 11, and 14 only, and that at these stations and at No. 4 the tolerant forms, in general, were least abundant. The study shows, further, that all the bottom samples taken from the Mississippi River between stations 1 and 9, except one of those taken between stations 2 and 3 in the metropolitan area, which took no animals at all, contained relatively large numbers of typically tolerant forms but not a single individual of a clean-water form. Clean-water forms were expected at stations 1, 4, 8, and 10, inasmuch as they are situated outside the area polluted by the Twin Cities. That no clean-water forms were taken from the Mississippi River below the Twin Cities above station No. 9 indicates that somewhere between station No. 7 (at Hastings, about 39 miles below St. Paul) and station No. 9 (at Red Wing, about 50 miles below St. Paul) the Mississippi River is recovering from its grossly polluted condition. The bottom fauna at station No. 11 (at the lower end of Lake Pepin) suggests a still greater improvement in the Mississippi River, while that at station No. 14 (situated at Winona about 110 miles below St. Paul) indicates that the conditions in the river here are probably as good as they are at station No. 1 (situated above the Twin Cities). The few data shown on Table 6 support the above conclusions.

PLANKTON

RELATIONSHIP OF PLANKTON ORGANISMS AND POLLUTION

A quantitative study of the plankton—the ultimate source of the food of probably all fishes—gives some information as to the abundance of the food supply. Plankton studies, however, may do more than that. Some plankton organisms are suspected of being tolerant forms—that is, they seem to thrive best in a situation where large quantities of organic matter are in a state of decomposition. Therefore, the presence of such an organism in large numbers in a plankton sample may be taken as a sign of pollution. Plankton organisms known or suspected to be tolerant are *Nitzschia amphioxys*, *Synedra ulna*, *Pleurosigma acuminatum* and *attenuatum*, among the Diatomaceæ; *Spirulina oscillarioides* and *jenneri* and five species of Oscillatoria, among the Cyanophyceæ; and *Closterium acerosum*, *moniliferum*, and *parvulum* and three species of Cosmarium, among the Chlorophyceæ. Among the zooplankton organisms, one species of Paramecium, one species of Euglena, and at least one species of Rotifer are considered tolerant. (This list of organisms is taken from Fair's list in the revised edition of "The Microscopy of Drinking Water," by Whipple, in press, 1927.)

There are three dangers that must be guarded against in drawing conclusions from plankton studies:

1. The mere presence of a tolerant organism does not necessarily indicate polluted conditions. Only when the organism occurs in comparatively large numbers may it be taken as a criterion.

2. The absence of tolerant organisms from certain waters may not be proof, necessarily, that these waters are unpolluted. This is especially true when the study, as in the present case, is continued for a limited period of time only. Every student of the plankton knows that there are two types of plankton cycles—(*a*) the total amount of the plankton in any body of water varies with the seasons of a year and may vary even with the years, (*b*) certain species may dominate the plankton population in one season and disappear entirely in another.

3. In a river, especially after a rise in the level of the water, organisms are carried downstream. This often makes it very difficult to tell whether an organism was produced where it was taken or whether it was carried there by the current.

METHODS

Plankton samples were taken by means of a plankton pump and plankton net made of No. 20 silk bolting cloth. While taking the samples, the net was suspended over a vessel of known capacity, to measure exactly the volume of water strained for each sample. As a rule, 25 liters were strained for each sample, but in a few cases larger volumes of water were strained. The samples were concentrated in the net to from 15 to 20 cubic centimeters and then transferred to a small vial. The materials were preserved in 4 per cent formaldehyde.

As some of the plankton organisms are too small to be retained by the net, a liter of the strained water was preserved in the field in 1 per cent formaldehyde and shipped to the laboratory for centrifuging. The centrifuging was done at the University of Minnesota with a Foerst continuous-acting centrifuge loaned by the Geology and Natural History Survey of Wisconsin. The organisms that are removed by the centrifuge constitute the nannoplankton. In the discussion of the plankton, the net plankton and nannoplankton are considered together for each station.

The method used in enumerating the phytoplankton, or plant organisms, was as follows: The sample was made up to definite volume and stirred, so that the organisms were well distributed; 1 cubic centimeter of this sample was then placed in a counting cell having an area of 1,000 square millimeters and a depth of 1 millimeter, and the number of each kind of organism in 20, 30, or 40 fields, as counted under a compound microscope, was determined. The area of the field of the microscope was known. From the concentration of the sample, the number of organisms in the various fields counted, and the area of the counting cell the number of individuals per liter was calculated. In practice, it is not necessary to make this calculation for each organism separately. All that is necessary is to make one calculation for a factor. The factor is that number which, when multiplied by the number of organisms found in the different squares counted, gives the number of organisms per liter or whatever other unit may be chosen. This factor will remain the same as long as the concentration and the number of fields counted remain constant. The factor may be calculated according to the formula $\frac{\frac{1,000}{a} c x V_1}{V} = X$. Where 1,000 is the area of the counting cell, a = the total area of the fields counted in mm.^{2}; V_1 = the volume of the sample in cubic centimeters; c = the total number of organisms in the fields counted; V = the volume of water strained through the net or centrifuge; and X = the factor. It is most convenient, in the calculations of the factor, to let c = unity.

In the case of the zoöplankton, or animal organisms, all the individuals occurring in 2 cubic centimeters of the sample, well stirred, were counted directly under a binocular. From these counts, and the concentration of the sample, the number per liter was then calculated.

Inasmuch as it is quite generally accepted that no vertical stratification of plankton organisms exists in a river with a fairly rapid flow, it was not always attempted to take samples from all levels by raising the hose of the pump at a uniform rate. As a rule, in the shallow places half the sample was taken near the surface and the other half close to the bottom. However, at stations where the water reaches considerable depth (20 to 25 feet) and where the current is slack, the pump hose was raised and lowered at a uniform rate so as to get approximately the same amount of water from all levels. Whenever expedient, two samples were taken at each station—one from the channel of the river, the other from the shallower water near shore. (See Table 7.)

TABLE 7.—*Total number of plankton organisms per liter of water*

[S=shore; C=channel]

Station	Date, 1926	Number of organisms	Station	Date, 1926	Number of organisms
1	Aug. 14	79,202	8	Aug. 19	33,494
1	Sept. 7	19,061	8	Sept. 16	186,920
2	Aug. 14	59,541	9-S	Aug. 27	49,844
2	Sept. 7	57,381	9-S	Sept. 17	92,420
3	Aug. 12	30,535	9-C	Aug. 27	65,691
3	Sept. 18	25,513	9-C	Sept. 17	98,462
4	Aug. 17	670,214	10	Aug. 27	24,596
5-S	Aug. 20	121,138	11-S	Aug. 28	23,783
5-S	Sept. 15	67,318	11-S	Sept. 18	47,551
5-C	Aug. 20	281,115	11-C	Aug. 28	11,529
5-C	Sept. 15	82,344	11-C	Sept. 18	8,518
6-S	Aug. 18	140,908	12	Aug. 28	48,081
6-C	do	45,617	12	Sept. 18	9,078
6-C	Sept. 16	43,602	14-S	Aug. 31	34,865
7-S	Aug. 18	356,678	14-S	Sept. 19	17,977
7-S	Sept. 16	60,486	14-C	Aug. 31	62,756
7-C	Aug. 18	31,585	14-C	Sept. 19	26,380
7-C	Sept. 16	73,603			

RESULTS AND DISCUSSION

Table 7 gives, for two dates (August and September), the number of plankton organisms—plants (Table 3) and animals (Table 10) combined—per liter of water at each station. The figures show that the quantity of plankton varies with the different stations (from 8,518 to 670,214 per liter). The data show also that the amount of plankton at one station varies with the date of collection. For example at station 5–C, on August 20, the number of plankton organisms per liter was 281,115; on September 15 it was 82,344; again, at station No. 8 the number per liter on August 19 was 33,494, but on September 16 it increased to 186,920.

Investigations have shown that plankton abundance can not be correlated with pollution, but to satisfy the skeptical an attempt has been made here to correlate the distribution of plankton with the varying degree of pollution. The average number of plankton organisms per liter for stations 1, 4, 8, 10, and 12 (waters at which, as shown by the dissolved-oxygen determination and a study of the bottom fauna, were not polluted) were compared with the average number for stations 3, 5, 6, 7, and 9, waters which the data on dissolved oxygen and bottom fauna had shown to be polluted. The average number for the unpolluted waters of the first group of stations was found to be 133,830; that for the polluted waters of the second group of stations was 98,050, a difference of 35,780. This difference at first may seem significant, but when one considers the great difference in the number of plankton organisms at the various stations of each of the above groups (Table 7), the differences between the shore and channel counts at the same station (Table 7), and the differences in numbers at the same station for August and September (Table 7), these differences between the above averages probably lose their significance. The differences in the number of plankton organisms in August and September can hardly be attributed to the fact that the rains had improved conditions in the river, for the plankton at station No. 1 decreased, while that at station No. 8 increased. Both of these stations are in unpolluted waters. Stations No. 5 and No. 9 are both in polluted waters, yet the plankton at No. 5 decreased, while it increased at No. 9. (Table 7.)

In the foregoing comparison station No. 4 on the Minnesota River has been grouped with the unpolluted stations; but the data on dissolved oxygen show that its waters may be slightly polluted by the two cities some 15 miles above. (See Tables 3 and 4 and location of sampling stations, p. 141.) If we omit station No. 4 from the group of unpolluted stations, the average number of organisms for that group is reduced to 50,054, or 47,996 below the average number of organisms in the grossly polluted stations. The average number per liter for the presumably slightly polluted waters (stations 2, 11, and 14) is 35,028, or 63,022 less than for the grossly polluted waters. The variations in the abundance of the plankton may very well be explained on a basis of seasonal variations, as the samples were taken on different days and in different months. (It is a common experience that two samples of plankton taken at one place on two consecutive days may show a great difference in the number of organisms.)

The seasonal variation is well illustrated in my samples by Melosira. This plankton form was present in very small numbers at station No. 8 in August (Table 8), while nearly a month later, in September, it was very abundant (176,960 filaments per liter). I therefore believe that the data of Table 7 warrant the conclusion that no correlation exists between the total number of plankton individuals and the degree of pollution in the upper Mississippi River system, and, therefore, the abundance of plankton can not be employed as a criterion of the degree of pollution in the river.

Table 8 shows, for each genus of phytoplankton, the number per liter of water taken on the various dates at each station. It may be seen that this table includes four of the genera of algæ (Nitzschia, Synedra, Pleurosigma, and Closterium) listed by Fair as including species that are known to be tolerant (p. 152). However, most of my species of these forms are not those listed by Fair as tolerant. The exceptions are *Closterium acerosum* and *Synedra ulna.* My data (Table 8) show that the former species occurred in very small numbers at stations 2, 7, 9, and 11 (waters at stations 2 and 11 are not grossly polluted), while the latter occurred in small numbers at station No. 14 only, the waters at which, as I have already shown, were at most only slightly polluted. Obviously, *C. acerosum* and *S. ulna,* the so-called "tolerant" algæ, are, in the present survey, valueless as criteria of conditions of pollution. The Synedra found at all the other stations were identified as *S. delicatissima,* a form whose degree of tolerance has not been established.

TABLE 8.—*Total number of phytoplankton organisms per liter of water*

[S=shore; C=channel]

Phytoplankton	Sta. 1, Aug. 14	Sta. 1, Sept. 7	Sta. 2, Aug. 14	Sta. 2, Sept. 7	Sta. 3, Aug. 12	Sta. 3, Sept. 8	Sta. 4, Aug. 17	Sta. 5-S, Aug. 20	Sta. 5-S, Sept. 15	Sta. 5-C, Aug. 20	Sta. 5-C, Sept. 15
Melosira	62	1,640	1,810	300	22	209	20,780	1,870	10,950	3,680	6,300
Synedra	2,712	1,620	330	6,400	9,710	1,611	617,600	93,900	10,185	248,060	11,680
Stephanodiscus				800		11		0	9,080	3,200	8,260
Pleurosigma							1,600		22,760		11,380
Scenedesmus	8,800	4,860	10,400	10,400			24,100	6,490	2,445	11,200	11,200
Chlorella (colony)	2,400		830		4,000			1,600	2,400		
Fragilaria	800	60	30	1,600		33			180		240
Pediastrum	80		90	2,520		44	2,000	90	800		1,720
Navicula	800	800		4,860	800	2,400			800		
Pandorina					2,400		300	4,800		4,800	
Selenestrum				800			700	800			
Cloeocopsa				1,600							
Small diatoms	19,450	5,720	15,320	17,600		22			1,600		8,060
Nitzschia	43,200	3,200	24,000	120		20,800		180			
Chlorella (single)				3,200	13,600			8,000	800	6,400	12,800
Oocystis									1,800		
Crucigenia			1,600						800		
Amphora	862		1,720	5,660		11			800		0
Synura								800	45		3,260
Ceratium		40	30			33	1,000	800	180		3,320
Anabæna			2,520				300	1,600	135		240
Lyngbya	31		800	60				90		3,620	120
Eudorina		40									
Asterionella						11					
Closterium				800							
Actinastrum							200		135		180
Diatoma		60	60								
Cocconema		800									
Tetraspora											1,600
Microcystis		100		360		187	1,200		360		480
Aphanocapsa		80		180		77			90		
Cœlosphærium				60		33			810		960
Aphanizomenon											420
Gomphosphæria											60
Staurostrum											60
Dictyosphærium		20					200				
Clathrocystis		20		60							
Sphærocystis									90		

Phytoplankton	Sta. 6-S, Aug. 18	Sta. 6-C, Aug. 18	Sta. 6-C, Sept. 16	Sta. 7-S, Aug. 18	Sta. 7-S, Sept. 16	Sta. 7-C, Aug. 18	Sta. 7-C, Sept. 16	Sta. 8, Aug. 19	Sta. 8, Sept. 16	Sta. 9-S, Aug. 27	Sta. 9-S, Sept. 17	Sta. 9-C, Aug. 27
Melosira	11,100	0	7,230	12,720	11,800	1,920	9,080		176,960	4,000	70,220	5,430
Synedra	46,200	20,990	4,090	281,680	11,440	26,520	10,400		800	22,360	1,100	27,300
Stephanodiscus			6,500	1,660	11,960		9,000		1,720		4,040	
Pleurosigma			16,045		13,720		18,580				3,260	
Scenedesmus		8,000	3,200	35,520	1,600	120	11,320		800	12,240	3,230	15,380
Chlorella (colony)			800	3,200		60	60	3,200		4,800		10,460
Fragilaria		8,000			300		120				150	
Pediastrum				320	60	120	860			360		150
Navicula	12,300				1,720				2,400			
Pandorina					2,400		60			60		
Selenestrum				3,240	800							
Cloeocopsa				1,600	60		800			60		800
Small diatoms	12,000			160		360	240	1,600				
Nitzschia	600	8,180	800	6,400			6,400			1,720		1,600
Chlorella (single)	27,000		1,600	4,800	2,400		3,200	9,600	2,400	2,400	8,000	
Synura			800		120			1,600			1,600	30
Ceratium			1,630		360		180			860	150	30
Anabæna	3,000			160	66		60	45	800	180		90
Kirchneriella							800		800			
Lyngbya	25,200	360	45	3,400		840					30	1,660
Eudorina							60	1,600			120	60
Epithemia	3,000											
Asterionella				1,040	60	1,440	60			300	360	360
Closterium				40								
Actinastrum				200	240		980					630
Diatoma			800									
Microcystis				120	120		660		240	240	90	420
Aphanocapsa				80	60			1,350		180		90
Cœlosphærium			45	80	60		420	450				150
Aphanizomenon								13,950		60		
Dictyosphærium							120				30	30
Clathrocystis												
Campylodiscus								90				

TABLE 8.—*Total number of phytoplankton organisms per liter of water*—Continued

[S=shore; C=channel]

Phytoplankton	Sta. 9-C, Sept. 17	Sta. 10, Aug. 27	Sta. 11-S, Aug. 28	Sta. 11-S, Sept. 18	Sta. 11-C, Aug. 18	Sta. 11-C, Sept. 18	Sta. 12, Aug. 28	Sta. 12, Sept. 18	Sta. 14-S, Aug. 31	Sta. 14-S, Sept. 19	Sta. 14-C, Aug. 31	Sta. 14-C, Sept. 19
Melosira	83,500	90	4,790	4,100	60	460	28,840	4,010	14,760	1,200	17,470	3,380
Synedra	4,270	90	3,000	1,600	800	400	920		1,800	1,600	3,300	4,800
Stephanodiscus	3,090			270	550	1,320	3,710	1,000	3,600	890	2,380	1,660
Pleurosigma	800							890	900	1,600		
Scenedesmus	1,630	1,645	780	1,600			3,260	530	990	45	4,400	
Chlorella (colony)	800		4,200						900			
Fragilaria	30		360		60		1,500	30	270	90	720	
Pediastrum	30	90	600				60	30	180		180	
Navicula		9,600	690	1,600			4,000	1,000	900		6,600	
Pandorina	800						90					
Selenestrum	800											
Small diatoms	800	8,935		3,200	1,600	1,200	90	150				9,720
Nitzschia	1,600	1,645	1,800						2,700		1,100	
Chlorella (single)		1,600		28,800		3,600	3,200			12,000	16,000	
Amphora				2,400		400	1,630	500				
Synura				800		400	30					1,600
Ceratium	90		1,710	1,070	6,340	360	60		4,500	270	5,510	240
Anabæna	90		1,800					30			180	
Lyngbya	90										1,100	
Eudorina			1,080				120					
Asterionella	510			1,520	1,100	240	30	60	270	180	270	120
Stauroneis		900										4,800
Closterium	30		360	90								
Actinastrum	30						90		270			
Microcystis	210		2,340		570	120	210	360	2,520		1,800	60
Aphanocapsa	150				210		60	30			90	
Cœlosphærium	480		90	180	60		60	300	90	45	180	
Aphanizomenon											900	
Staurastrum			90	270	30		90			45	180	
Dictyosphærium					90		30					
Clathrocystis	30							150	270		360	

In this survey, *Pleurosigma spencerii,* although not known to be tolerant, is consistently much more abundant in the polluted section of the river than in the unpolluted sections and in the tributaries. It is possible, therefore, that the distribution of *P. spencerii* is correlated with the degree of pollution and that this species is a tolerant form.

To determine more definitely whether the character of the phytoplankton changes with the degree of pollution in the river, I compared the nine most abundant phytoplanktonic forms (see Table 8) found at each of three groups of stations, each group representing a different degree of pollution. Group I comprises stations 1, 8, 10, and 12 and represents unpolluted waters; Group II includes stations 2, 11, and 14 and represents presumably slightly polluted waters; and Group III consists of stations 3, 5, 6, 7, and 9 and represents grossly polluted waters. The comparative data are shown in Table 9. In this table the genera are listed according to their abundance in Group I, in a descending order. In each of the last three columns the numeral indicates the order of abundance.

Table 9 shows that seven of the genera that are among the nine most abundant in Group I are also included in the nine that are most abundant in Group III. Six of these seven genera are also among the nine listed for Group II, while Groups I and II have eight of the nine most abundant genera in common. It may be seen that *Pleurosigma spencerii* and Lyngbya sp.? are listed under Group III but nowhere else. If, in the present survey, these species are considered tolerant forms, they corroborate the conclusion based on a study of the bottom fauna, "that somewhere between station No. 7, at Hastings, * * * and station No. 9, at Red Wing, * * * the Mississippi River is recovering from its grossly polluted condition"

(p. 152); for it may be noted in Table 8 that the number of *Pleurosigma spencerii* and of Lyngbya sp.? is greatly reduced between stations 7 and 9. Table 9 shows that, to a large extent, at least, the genera that are most abundant in the unpolluted waters are also most abundant in the polluted waters.

TABLE 9.—*Nine most abundant genera for each group of stations*

Genus	Rank of genera in Group I (stations 1, 8, 10, and 12)	Rank of genera in Group II (stations 2, 11, and 14)	Rank of genera in Group III (stations 3, 5, 6, 7, and 9)	Genus	Rank of genera in Group I (stations 1, 8, 10, and 12)	Rank of genera in Group II (stations 2, 11, and 14)	Rank of genera in Group III (stations 3, 5, 6, 7, and 9)
Melosira	1	2	2	Synedra	7	5	1
Nitzschia	2	4	7	Chlorella (colony)	8		9
Scenedesmus	3	3	3	Amphora	9	9	
Navicula	4	7		Ceratium		6	
Chlorella (single)	5	1	4	Pleurosigma			5
Stephanodiscus	6	8	6	Lyngbya			8

To recapitulate, a study of the phytoplankton of Table 8 indicates (1) that those species of plants listed by Fair as tolerant forms, and taken by me, are valueless in the present survey as criteria of conditions of pollution, and (2) that none of the other well-represented species of plants taken by me (except, possibly, *Pleurosigma spencerii* and Lyngbya) show a distinct preference for polluted waters and may be employed as criteria of the presence of pollution. Table 9 showed that, in so far as my material is concerned, the character of the phytoplankton changes little with the degree of pollution in the river, and that the plankton organisms that are most abundant in the unpolluted waters are, in general, also most abundant in the grossly polluted waters.

Table 10 shows for each date of collection the abundance per liter of water for each genus of zoöplankton taken at each field station. It may be seen that the genus Rotifer, listed by Fair as including tolerant species, occurred in my samples. Rotifer sp? occurred regularly in samples from the polluted waters and was decidedly more abundant there than in the unpolluted waters. The average number per liter for the polluted stations (Group III, Table 9) is 70.4; that for the unpolluted stations (Group I, Table 9) is 2.5. The rotifer, therefore, seems to be a tolerant form. Table 10 shows also that Nauplii are about four times as abundant in the grossly polluted waters (average per liter, 9.5) as in the unpolluted waters (average, 2.3 per liter), but that they are twice as abundant in the slightly polluted waters (17 per liter) as in the grossly polluted waters. A nauplius, therefore, can not be employed as a criterion of polluted waters. For Cyclops the average numbers of individuals per liter are 0.3 for unpolluted, 6.8 for slightly polluted, and 11.5 for grossly polluted waters. The average numbers per liter for Anuraea are 0.2 for unpolluted, 1.36 for slightly polluted, and 6.8 for grossly polluted waters. It is believed that the numbers given here for the most abundant forms (the genus Rotifer excepted), are too small to enable one to ascertain the degree of tolerance of the various species of zoöplankton. It is to be noted from Table 10 that the tolerant Rotifer is very abundant at stations 5, 6, and 7, on the Mississippi River, and declines suddenly at station No. 9. This, as in the case of bottom fauna (p. 151) and the phytoplankton (p. 157), suggests a change in the condition of the river between Hastings and Red Wing.

TABLE 10.—*Number of zoöplanktonic organisms per liter of water*

[S=shore; C=channel]

Zoöplankton	Sta. 1, Aug. 14	Sta. 1 Sept. 7	Sta. 2, Aug. 14	Sta. 2, Sept. 7	Sta. 3, Aug. 12	Sta. 3, Sept. 8	Sta. 4, Aug. 17	Sta. 5-S, Aug. 20	Sta. 5-S, Sept. 15	Sta. 5-C, Aug. 20	Sta. 5-C, Sept. 15
Nauplii	0.8	0.4		0.8		0.4	91	16	5.4		0.8
Cyclops	.8	.2	.6			.3	18	4	1.2		
Moina						30					
Bosmina								4			
Chydorus						.1					
Ceriodaphnia	2										
Noteus		.2				.6	23	8	14		
Anuraea						.4	81	8	15	55	.8
Rotifer	.8	.2			3		1.2	78	36	100	2.4
Polyarthra							90	4	1.2		
Triarthra							1.2	.4			
Distyla				.4					1.2		
Asplanchina							1.2				

Zoöplankton	Sta. 6-S, Aug. 18	Sta. 6-C, Aug. 18	Sta. 6-C, Sept. 16	Sta. 7-S, Aug. 18	Sta. 7-S, Sept. 16	Sta. 7-C, Aug. 18	Sta. 7-C, Sept. 16	Sta. 8, Aug. 19	Sta. 8, Sept. 16	Sta. 9-S, Aug. 27	Sta. 9, S, Sept. 17	Sta. 9-C, Aug. 27
Nauplii	36	3	0.2	22	13	10	12	8	2.4	9	17	8
Cyclops	60	1.2		40	.8	11				5.2	.8	2.8
Dioptomus								.6				
Bosmina				1.6							.4	
Ceriodaphnia				2						.4		1.4
Noteus				2	6		12	.6		1.8	6.4	3.2
Anuraea			.4	.8	5		11			4.4	5.2	3.2
Rotifer	408	83	16	183	33	184	46			.8	9	
Polyarthra	4			3		.8				.8		
Triarthra			.2	2.4	2.4		2.4				.8	
Distyla				1.6								2.4
Asplanchina											.4	

Zoöplankton	Sta. 9-C, Sept. 17	Sta. 10, Aug. 27	Sta. 11-S, Aug. 28	Sta. 11-S, Sept. 18	Sta. 11-C, Aug. 28	Sta. 11, C, Sept. 18	Sta. 12, Aug. 28	Sta. 12, Sept. 18	Sta. 14-S, Aug. 31	Sta. 14-S, Sept. 19	Sta. 14-C, Aug. 31	Sta. 14-C, Sept 19
Ostracoda			4.8	1.8								
Nauplii	11.2	0.4	32.4	30	39	16	0.4	4	25	7.2	19	1.2
Cyclops	.4		24	13	9	4.8	.4	.4	4	2.4	7.7	2.4
Diaptomus				.6	1.6	.8			3	1.2	1.2	
Simocephalus				2.4								
Bosmina			4.8		.4				1		.6	
Daphnia					.8				.6		4.8	
Chydorus			20	.6				1.6		.6		.6
Ceriodaphnia	.8				.4				1.2			
Noteus	5.6		1.2		.4		.4					
Anuraea	7.2	.4	2.4		7.2	1.2		1.2	1		1.8	
Rotifer	14.8				.4			.8				
Monostyla				1.4								
Polyarthra	1.6		1.2	.6							1.2	
Triarthra	.4		2.2				.4					
Distyla				.6								
Asplanchina				.6								

In an attempt to determine whether the character of the zoöplankton changes with the varying degrees of pollution, the same procedure employed for the phytoplankton (p. 157) was followed here. Table 11 lists the five most abundant zoöplanktonts for each of the three groups of stations selected (the groups of stations are described on p. 157). From this table it may be seen that four of the five planktonts that are most abundant in the grossly polluted waters occur also among the five that are most abundant in the unpolluted waters. My inadequate material shows that the zoöplankton in the unpolluted sections of the river and tributaries is not markedly different in quality from the zoöplankton of the polluted sections of the river, and that, with the exception of Rotifer, the species taken by me can not be employed as indices of the degree of pollution in the Mississippi River.

TABLE 11.—*The five most abundant zoöplanktons for each group of stations*

Genus	Rank in Group I (stations 1, 8, 10, and 12)	Rank in Group II (stations 2, 11, and 14)	Rank in Group III (stations 3, 5, 6, 7, and 9)	Genus	Rank in Group I (stations 1, 8, 10, and 12)	Rank in Group II (stations 2, 11, and 14)	Rank in Group III (stations 3, 5, 6, 7, and 9)
Cyclops	3	2	2	Ceriodaphnia	2		
Rotifer	3		1	Noteus	5		
Nauplii	1	1	3	Bosmina		5	
Anuræa	4	4	4	Chydorus	4		
Polyarthra			5				

FISHES

SUMMARY OF SEINING OPERATIONS AND RESULTS

As stated in the introductory part of this report, the people of Minnesota and Wisconsin claim that the number of fish has decreased in their section of the Mississippi River, but no specific data are available to support this contention. Unfortunately, the writer was not able to seine at all the stations, but the stations where seining was done are so distributed that it is possible to determine whether there is any correlation between the number of fish and the degree of pollution in the river. Seine hauls were made at or near stations 1, 2, 4, 5, 6, 7, 9, and 10. The equipment used consisted of a flat-bottomed gasoline launch, a rowboat, and a seine 150 by 6 feet of ¼-inch mesh. The fish were preserved in 4 per cent formaldehyde and sent to Dr. John Van Oosten, of the United States Bureau of Fisheries, for study. Doctor Van Oosten's determinations were checked by Carl L. Hubbs, of the University of Michigan zoological museum.

Stations 1 and 2.—The seining at stations 1 and 2 was done on August 21. The first haul at station No. 1 yielded the 362 fish shown in Table 12, in addition to one 18-inch common sucker and 75 crayfish. The second haul contained at least 1,500 small wall-eyed pike, numerous minnows, a few bullheads, a few suckers, and a number of crayfish. The fish retained are listed in Table 12.

The first haul at station No. 2 consisted of the 547 fish, shown in Table 12, one 10-inch pickerel, and one 6-inch smallmouth black bass. The second haul consisted of a school of black bullheads, many wall-eyed pike, and several hundred shiners. Part of this haul is listed in Table 12. The hauls at station No. 2 were made in the left branch of the channel, which is less polluted locally than is the right branch. Many fish were seen along the left bank (east side) of the river at station No. 2. A few were seen also along the side of the island in the right branch of the channel.

Station 4.—On August 17 three seine hauls were made in the Minnesota River at station No. 4. The partial results of these hauls are shown in Table 12. In one of the hauls 350 gizzard shad were taken but were thrown back. They do not appear in the table. A number of shiners and sunfish likewise were thrown back into the river. Crayfish seemed to be plentiful at this station.

Station 5.—On August 20 three seine hauls were made at station No. 5. Only one 1.5-inch stickleback was taken.

TABLE 12.—*Upper Mississippi River biological survey, 1926. Number of each species of fish retained from each haul at the various field stations. Names of species are taken from Hubbs' Check List of Great Lakes Fishes*

Species	Station 1, Camden Bridge, Aug. 21		Station 2, Plymouth Bridge, Aug. 21		Station 4, Minnesota River, Aug. 17			Station 8, St. Croix River, Aug. 19			Total
	Haul 1	Haul 2	Haul 1	Haul 2	Haul 1, above Cedar Avenue bridge	Haul 2, below Cedar Avenue bridge	Haul 3, Fort Snelling	Haul 1, junction of the two rivers	Haul 2, above bridge	Haul 3, a mile below junction	
Dorosoma cepedianum (gizzard shad)					12	2					14
Catostomus commersonnii (common sucker)	49	2	125			2					178
Moxostoma anisurum (white-nosed sucker)			1								1
Moxostoma lesueurii (short-nosed red horse)	19		5								24
Pimephales promelas p. (black-head minnow)					5	3	8				16
Hyborhynchus notatus (blunt-nosed minnow)	12		28	1			2				43
Semotilus atromaculatus a. (horned dace)	14		14								28
Notemigonus crysoleucas (golden shiner)								2		1	3
Ceratichthys vigilax (bullhead minnow)					5	1	32				38
Notropis anogenus					1						1
N. atrocaudalis					2		3		1		6
N. heterodon richardsoni								2		2	4
N. deliciosus (straw-colored minnow)					80	1	8			10	99
N. gilberti					1		9				10
N. hudsonius selene (spot-tailed minnow)			1	1			7	79	10	33	131
N. whipplii whipplii (steel-colored minnow)					29		12	5			46
N. cornutas frontalis (common shiner)	113	1	311	27							452
N. blennius					3		8		1	6	18
N. antherinoides (shiner)				1	140	2	5				148
N. rubrifrons (rosy-faced minnow)										2	2
N. buchanani							31				31
N. boops							1				1
Rhinichtys atronasus (black-nosed dace)			1								1
Nocomis biguttatus (river chub)	11		37								48
Ameiurus melas (black bullhead)	5		10								15
Schilbeodes gyrinus (tadpole cat)			1								1
Fundulus diaphanus menona (menon top minnow)			4		1	2	9				16
Percopsis osmisco maycus (trout perch)	71	2	2								75
Pomoxis annularis (white crappie)					4	1	8				13
Pomoxis sparoides (black crappie)	24		1			1	1	3	35		65
Ambloplites rupestris (rock bass)	12							3			15
Apomotis cyanellus (green sunfish)	2		1			1					4
Lepomis humilis (orange-spotted sunfish)					2	3					5
Helioperca incisor (bluegill)						9	3				12
Eupomotis gibbosus (pumpkinseed)	2					2					4
Micropterus dolomieu (small-mouth black bass)			2								2
Aplites salmoides (large-mouth black bass)								3	2		5
Stizostedion vitreum (wall-eyed pike)	2		2								4
Perca flavescens (yellow perch)						1		105	46	60	212
Percina caprodes zebra (log perch)									10	94	104
Imostoma shumardi										2	2
Boleosoma nigrum nigrum (Johnny darter)	26		1		16	3	83		1		130
Lepibema chrysops (white bass)								1	2		3
Percina X Cottogaster (hybrid)										1	1
Total	362	5	547	30	301	34	230	203	108	211	2,031

Stations 6 and 7.—On August 18 two seine hauls were made at station No. 6, on the Mississippi River. No fish were caught in these hauls. On the same day another haul was made about 7 miles below station No. 6, but here, again, no fish were taken. At this latter place one haul was made in a slough still connected with the Mississippi River. Here one short-nosed gar was taken. This fish was very sluggish. A haul made at station No. 7 on the evening of August 18 likewise took no fish.

On August 19 four hauls were made on the Mississippi River between Hastings and St. Paul. Three of these were made between stations 6 and 7. One was made just above South St. Paul (that is, between stations 5 and 6). Not a single fish was taken in these hauls.

Station 8.—On August 19 four seine hauls were made at station No. 8. One haul was made on the St. Croix side at the junction of the St. Croix and the Mississippi Rivers. This haul was not very successful because the net rolled; yet it netted the 203 fish shown in Table 12, 1 adult red horse, and 1 adult yellow perch. The last two were thrown back and were not recorded in the table. The second haul, made on the Mississippi River side, netted one turtle. The waters of the two rivers have not yet mixed here. A third haul was made in the St. Croix River, about ⅓ mile above its mouth. Here aquatic plants were very abundant along the shore and interfered seriously with making the haul. The bulk of the fish taken here consisted of yellow perch and black crappies. At least 150 of each were thrown back and were not recorded in the table. The fourth haul was made on the Wisconsin side of the Mississippi River, about 1 mile below the mouth of the St. Croix River. This haul yielded the 211 fish shown in Table 12, besides 1 large red horse, 1 large pumpkin seed, and 5 four-inch yellow perch. It is doubtful if the waters of the two rivers are mixed to any great extent even here. Time did not permit the making of another haul on the Minnesota side of the river.

Stations 9 and 10.—On August 28 two seine hauls were made in the Cannon River, a short distance below station 10, and one in the Mississippi River, about 1½ miles above Red Wing (station No. 9). Because of the high water, weeds, and fallen logs, these hauls were not successful. No fish were taken in the Cannon River, and only one common shiner was taken in the Mississippi River. The waters of the Mississippi River were pushing up into the Cannon River. This made the latter so turbid that if any fish were present they could not be seen. When the writer revisited this river about 2 miles farther up its course, the water was clear and a number of small fish were seen.

The above data show (1) that fish are abundant at stations 1 and 2 on the Mississippi River, at stations 4 and 8 on the Minnesota and St. Croix Rivers, respectively, and in the Mississippi River (Wisconsin side) about 1 mile below the mouth of the St. Croix River; (2) that fish are very scarce, if present at all, in the Mississippi River at and between stations 5, 6, and 7, and in the waters of the Mississippi proper (that is, in the Mississippi waters that were not yet mixed with those of the tributaries), at or near stations 8 and 9. Commercial fishing above Red Wing did not commence until the latter part of August, and then only around the mouths of tributaries. Below St. Paul carp fishing did not begin until about the middle of September, one month after the beginning of the heavy rains.

DISCUSSION—FISH AND POLLUTION

It was shown on page 144 that during August (all my seining was done from August 17 to 28) "the dissolved-oxygen content is decidedly less in that section of the Mississippi River which extends from station No. 2, at the beginning of the metropolitan area, to station No. 9, at the head of Lake Pepin (a distance of approximately 64 miles) than it is above or below this section or in the tributary waters," and "at station No. 9 conditions with respect to dissolved oxygen are much better than they are at stations 3, 5, 6, and 7, but are not nearly as good as they are at stations 1, 2, 11, and 14." Again, it was concluded from a study of the bottom fauna (p. 151) and of the phytoplankton and zoöplankton (pp. 157 and 159, respectively) that somewhere between station No. 7 (at Hastings, about 39 miles below St. Paul) and station No. 9 (at Red Wing, about 50 miles below St. Paul) the Mississippi River is recovering from its grossly polluted condition.

It is precisely in that section of the Mississippi River (from stations 1 to 9) where the oxygen content was decidedly low that fish were extremely scarce or absent altogether (see p. 162). At the stations on the Mississippi River (Nos. 1 and 2), where oxygen was plentiful, fish also were abundant. Fish were numerous also in the relatively unpolluted tributaries—the Minnesota and the St. Croix Rivers. The close correlation between the abundance of fish and the presence of oxygen is well demonstrated by the results of the seining at a near station (No. 8, p. 162, fig. 1). A seine haul made in the polluted waters of the Mississippi River proper took one turtle only, whereas hauls made in the relatively unpolluted waters of the St. Croix or in the partially polluted waters of the Mississippi, below the mouth of the St. Croix, netted many fish. It is unfortunate that attempts to seine succeessfully at station No. 9 met with failure, for it would be of great interest to know whether the improvement in the condition of the river here was sufficient to permit fish to live. The fact that one shiner was taken suggests that fish were present at this station in August.

Thompson (1925), who has made an extensive study of the oxygen requirements of fishes in the Illinois River, writes: "It seems quite certain that dissolved-oxygen concentration between zero and two parts per million will kill all kinds of fish. Carp and buffalo have been found living in water showing as low as 2.5 parts per million. As a rule, a variety of fishes was found only when there were four or more parts per million, and the greatest variety of fishes was taken when there were nine parts per million."

If the findings of this author are applicable to the fish of the Upper Mississippi River, an examination of the data on oxygen (Tables 3 and 4) shows (1) that no fish whatsoever can live continuously in the waters at stations 3, 5, 6, and 7 during August and the first week of September, or at station 9 during the first three weeks of August; (2) that a limited variety of fishes (the more tolerant species) can live at station No. 9 (Red Wing) after the third week in August; (3) that virtually any fish can live, in so far as oxygen is concerned, at the stations not mentioned above during August and September; and (4) at all stations, polluted and unpolluted, with the possible exception of Nos. 7 and 9, during the high-water stage after the heavy rains in September.

These conclusions agree very well with the statements made on page 162, which suggest that the commercial fish make their first appearance in the fall, during the latter part of August, in the vicinity of Red Wing (station No. 9), and about the middle of September farther up the river near St. Paul.

The correlation between the abundance of the species and of the individuals of species, and the characteristics of each station at which seine hauls were made, is most striking. Table 13 shows the relationship between the amount of dissolved oxygen, the character of the bottom fauna, the abundance of tolerant planktonts, the estimated average number of fish per seine haul, and the approximate number of species of fish. From this table it may be seen that the stations at which the dissolved-oxygen content is high, the dominant bottom animals are clean-water forms, or the tolerant bottom forms are relatively scarce, and the presumably tolerant planktonts (*Pleurosigma spencerii*, Lyngbya sp.? and Rotifer sp.?) are absent or sparse, have many fish and many species of fish; and, vice versa, those stations at which the oxygen concentration is low, the dominant bottom forms are tolerant, clean-water forms are absent, and the tolerant planktons are relatively very abundant, have practically no fish. Table 13 shows, beyond any doubt whatsoever, that the absence or scarcity of fish in August in that section of the Mississippi River that extends from the beginning of the metropolitan area of the Twin Cities to Prescott, Wis. (a distance of approximately 39 miles), is due to the pollution from the former cities.

TABLE 13.—*Relationship between the amount of dissolved oxygen, the character of the bottom fauna, and the abundance of the tolerant planktonts Pleurosigma spencerii, Lyngbya sp. ?, and Rotifer, and the estimated number of fish per seine haul and the approximate number of species at stations 1 to 8, No. 3 excepted*

Station	1	2	4	5	6	7	8
Parts per million dissolved oxygen, average for August	6.59	6.08	5.70	0.87	0.51	0.39	7.10
Character of bottom fauna	Clean-water forms dominate; tubificids few.	Few midge larvæ only.	Few tubificids only.	Tolerant forms abundant; no clean-water forms.	As in 5.	As in 5.	As in 1.
Abundance of *Pleurosigma spencerii*, average number per liter	0	------------	1,600	17,070	16,045	16,150	0
Abundance of Lyngbya sp. ?, average number per liter	31	430	0	1,276	8,535	2,120	0
Abundance of Rotifer sp. ?, average number per liter	.5	0	1.2	54.1	169	111.5	0
Average number of fish per seine haul	[1] 1,000?	750?	330?	1/3	0	0	330?
Number of fish species per seine haul	[2] 14?	19?	24?	1	0	0	17?

[1] Questionable values were estimated.
[2] Questionable values indicated that the species thrown back and not identified are not included.

It may be emphasized here that, so far as our data show, the distribution of fish in the polluted upper Mississippi River is primarily—probably entirely—limited by the amount of oxygen present in the waters. If toxic chemical ingredients are present in sufficient quantities to act as poisons, they may be the primary controlling factors; but we have no direct information concerning this subject. The abundance of plankton and tolerant bottom forms in the grossly polluted waters suggests that chemical poisons, if present, are not sufficiently concentrated to destroy life outright. The paucity in the variety of bottom foods in the polluted areas may be a minor factor in the distribution of fish that subsist mainly on bottom fauna; but plankton as food is not a factor in the scarcity of fish, for we have shown (p. 154) that the planktonts are abundant, in individuals and in variety of species, in both polluted and unpolluted waters.

In conclusion, it should be stated that the data presented in this paper suggest that the pollution of the upper Mississippi River is severe only (in so far as fish are concerned) during the periods of low water—that is, sometime during midwinter (January and February) and during midsummer (July and August). (See p. 142.) From the point of view of conservation this is highly significant; it should be investigated by continuous observations throughout a period of at least one year.

SUMMARY OF RESULTS

1. This biological survey of the upper Mississippi River system was undertaken by the Bureau of Fisheries at the request of the States of Minnesota and Wisconsin. The field work was done during the period August 12 to September 27, inclusive, and covered approximately the same territory now under investigation by the United States Public Health Service—viz, the Mississippi River from above Minneapolis (Camden Bridge) to Winona, Minn., a distance, by water, of approximately 120 miles, and the following tributaries: The Minnesota, St. Croix, Cannon, and Chippewa Rivers.

2. During August and the first week of September, 1926, the dissolved-oxygen content was decidedly less in that section of the Mississippi River that extends from station No. 2, at the beginning of the metropolitan area of the Twin Cities, to station No. 9, at Red Wing, at the head of Lake Pepin (a distance of approximately 64 miles), than it was above or below this section or in the tributary waters. It was concluded that this decrease or depletion of dissolved oxygen was due primarily to the pollution of the river by the cities of Minneapolis and St. Paul.

3. All the bottom samples taken from the Mississippi River between station No. 1, above the metropolitan area, and station No. 9, at Red Wing, at the head of Lake Pepin (except in one of the samples taken between stations 2 and 3 in the metropolitan area, which took no aninals at all), took relatively large numbers of typically tolerant (pollution) forms, but not a single individual of a clean-water form. Clean-water forms first appeared in the bottom samples of the Mississippi below Minneapolis, at station No. 9, at Red Wing.

4. The major portion of the organic residue of the strained bottom samples taken from the Mississippi River between stations 1 and 9 consisted of coarse organic débris and garbage, whereas the greater part of the residue of the samples taken outside of this area and examined consisted of cleaner materials such as aquatic plants, empty mollusk shells, sand, chips of wood, etc.

5. A study of the plankton showed that only three of the species taken by me may be considered tolerant forms—that is, forms that may be employed as rough criteria of the degree of pollution. Two of the three species (*Pleurosigma spencerii* and Lyngbya sp.?) are plants (phytoplankton), while the third (Rotifer sp.?) is an animal (zoöplankton). These forms usually were found to be comparatively very abundant when taken at stations situated in the more polluted waters but relatively sparse when taken from less polluted waters. All three forms showed a marked decline in abundance at station No. 9, at Red Wing. The species of phytoplankton listed by Fair as tolerant forms and taken by me could not be employed in this survey as criteria of conditions of pollution.

6. The data on dissolved oxygen, the organic composition of the residue of strained bottom samples, the bottom fauna, and the tolerant plankton forms all show (1) that the waters of the Mississippi River were badly polluted from Minneapolis to Hastings, a distance of about 49 miles; (2) that somewhere between Hastings and Red Wing (situated about 15 miles farther downstream) the river recovered somewhat from its grossly polluted condition; (3) that at station No. 11, at the lower end of Lake Pepin, conditions with respect to pollution were much improved;

and (4) that at station No. 14, above Winona (situated about 110 miles below St. Paul) very little, if any, pollution was present, for conditions here compared favorably with those at station No. 1, situated above the polluted areas at Minneapolis.

7. Fewer species of bottom forms were taken in the more polluted waters (about 6 species) than in the less polluted or unpolluted waters (about 20 species).

8. I found that no correlation existed between the total number of plankton individuals and the degree of pollution in the upper Mississippi River system, and therefore the abundance of plankton can not be employed as a criterion of the degree of pollution.

9. My samples show that, on the whole, the character of the phytoplankton and zoöplankton changes very little with the degree of pollution in the river; the plankton organisms that are most abundant in the unpolluted waters are, in general, also most abundant in the grossly polluted waters.

10. The hydrometric data show that the discharge of the Mississippi River and of its tributaries varies considerably during the year, the rate alternating in cycles of minimum and maximum flow. The periods of low water occur sometime during midsummer (July and August) and midwinter (January and February), the periods of high water sometime during March, April, and May and during September and October.

11. The data on seine hauls show (*a*) that fish were abundant at stations 1 and 2, on the Mississippi River at the beginning of the polluted metropolitan area; at stations 4 and 8, on the Minnesota and St. Croix Rivers, respectively; and in the Mississippi River about a mile below the mouth of the St. Croix, but (*b*) very scarce, if present at all, in the section of the Mississippi River that extends from station No. 5 (just below St. Paul) to the St. Croix River, a section about 39 miles long. In 1926, commercial fishing in the Mississippi River commenced about the latter part of August in the vicinity of Red Wing and about the middle of September in the vicinity of St. Paul.

12. From a study of dissolved-oxygen concentration, it was concluded (*a*) that no species of fish could live continuously in the Mississippi River between stations 3 (in the metropolitan area) and 7 (Hastings) during August and the first week of September, or at station 9 (Red Wing) during the first three weeks in August; (*b*) that the more tolerant fish could live at station No. 9 after the third week in August; and (*c*) that virtually any fish could live, in so far as oxygen is concerned, at the stations not included in the above during August and September, and (*d*) at all stations, polluted and unpolluted (with the possible exception of 7 and 9), during the high-water stage after the heavy rains in September.

13. At stations where the dissolved-oxygen content is high, it was shown that the dominant bottom animals are clean-water forms, the tolerant bottom forms are relatively scarce, the tolerant planktons are absent or sparse, and fish are numerous and of many species; and, vice versa, at stations where the oxygen concentration is low the dominant bottom forms are tolerant, clean-water forms are absent, the tolerant planktons are relatively very abundant, and there are virtually no fish. From these facts it was concluded that the absence or scarcity of fish in the upper Mississippi River during August, 1926, was due primarily to the pollution from Minneapolis and St. Paul.

14. It was suggested that dissolved oxygen is the controlling factor in the distribution of fish in the polluted upper Mississippi River. The paucity in the variety of bottom foods in the polluted areas may be a minor factor in the distribution of fish that subsist mainly on bottom fauna. Plankton, as food, is not a factor in the distribution of the fish, for plankton was abundant, both in individuals and in species, in polluted as well as in unpolluted waters.

15. It was suggested further that the data indicate that the pollution of the upper Mississippi River is severe only (in so far as fish are concerned) during the periods of minimum discharge—that is, the periods of low water. It is highly desirable that the distribution of the fish be studied through the various periods of minimum and maximum discharge.

BIBLIOGRAPHY

FORBES, STEPHEN A., and R. E. RICHARDSON.
1913. Studies on the biology of the upper Illinois River. Bulletin, Illinois State Laboratory of Natural History, Vol. IX, 1910–1913 (1914), Art. X, pp. 481–574, Pls. LXV–LXXXV, tables. Urbana.

RICHARDSON, ROBERT E.
1925. Illinois River bottom fauna in 1923. Ibid., Vol. XV, 1924–1925 (1926), Art. VI, pp. 391–422. Urbana.

SHELFORD, VICTOR E.
1917. An experimental study of the effects of gas wastes upon fishes, with especial reference to stream pollution. Ibid., Vol. XI, 1917, Art. VI, pp. 381–412, 4 tables, I Pl. Urbana.

STANDING COMMITTEE ON RIVER POLLUTION, MINISTRY OF AGRICULTURE AND FISHERIES, GREAT BRITAIN.
1924. River pollution and fisheries. An introductory, nontechnical report on the work of the standing committee on river pollution, appointed in 1921. 42 pp. His Majesty's Stationery Office, London.

THOMPSON, DAVID H.
1925. Some observations on the oxygen requirements of fishes in the Illinois River. Bulletin, Illinois State Natural History Survey, Vol. XV, 1924–1925 (1926), Art. VII, pp. 423–437. Urbana.

WUNDSCH, H. H.
1926. Die Reinhaltung unserer Fischgewässer. Handbuch der Biennenfischerei Mitteleuropas, Vol. IV, Part 2.