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FLUCTUATIONS OF ABUNDANCE
OF PLANKTONIC ROTIFERS IN A
POLLUTED PORTION OF THE KALAMAZOO RIVER

by

Rudolph Prins

A thesis presented to the
Faculty of the School of Graduate
Studies in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
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INTRODUCTION

The two objectives of this study were to determine the kinds and numbers of rotifers in the plankton in a portion of the Kalamazoo River and to ascertain the effects of various chemical constituents of the river water on the rotifers.

The Kalamazoo River is located in southwestern Michigan and flows westward into Lake Michigan. The study was conducted along a section of the river extending from Comstock, Kalamazoo County, to Plainwell, Allegan County (Fig. 1). About 90 per cent of this section is heavily polluted with wastes from several paper industries, a few other industries, and one municipal sewage treatment plant.

Exploratory samples of plankton were taken in October and November, 1960. Routine sampling of plankton and water for chemical analysis occurred between December 15, 1960, and August 3, 1961.

HYDROLOGY OF THE KALAMAZOO RIVER

The Kalamazoo River was formed by glacial recession during the Pleistocene Epoch. Its present length is about 140 miles. The main channel arises from the confluence of two main branches (Fig. 1). These branches arise in Jackson and Hillsdale Counties and converge near Albion, Michigan, in Calhoun County. The river flows generally westward and terminates at Lake Michigan at Saugatuck, Allegan County. The drainage basin is about 1,980 square miles; 1,010 square miles are drained above Comstock and 1,200 square miles are drained above Plainwell (Velz, 1947: Fig. 14).

The predominant bedrock underlying the watershed in Kalamazoo and Allegan Counties is Coldwater Shale. Lower Marshall and Napolian Sandstones underlie Calhoun and Jackson Counties (Martin, 1936). The Kalamazoo River has established its course through glacial drift that has been deposited above the bed-rock in the river valley (Deutsch _et al._, 1960:12).

Only one of the many dams on the Kalamazoo River was of concern in this study. This dam is about

3/4 mile above Comstock and impounds Marrow Lake (Sections 21, 22, and 23 of T2S/R10W) which has an area of 620 acres and a volume of 6,000 acre-feet. Water passing over the dam drops about 12 feet to the river below. Various quantities of water do not pass over the dam but are diverted as a cooling agent through a power plant adjacent to the dam. The river drops about 40 feet between Comstock and Plainwell.

SOURCES OF POLLUTION

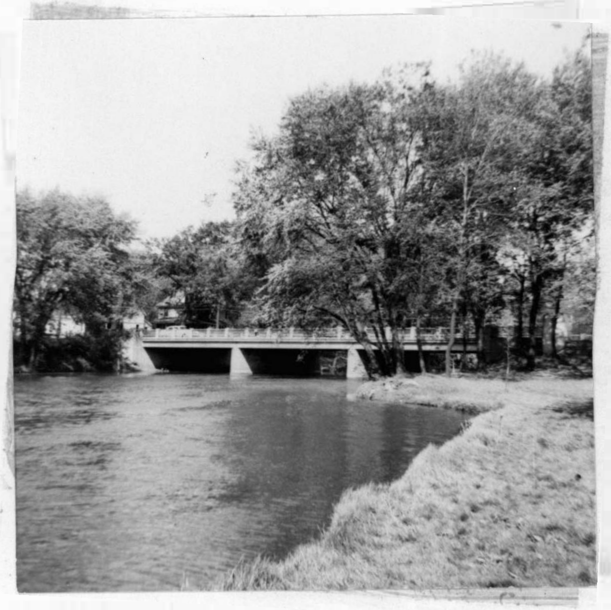
At Comstock the Kalamazoo River can be considered clean because most of the wastes of the city of Battle Creek have been removed by settlement, bacterial decomposition, and other natural processes. Surber (1953:83) found that the wastes which did persist served as fertilizer or indirectly as food for the bottom fauna at Comstock, and that 93.6 per cent of the bottom fauna was composed of clean-water forms.

The bacteria in the reach from Comstock, mile point 78.9 (MP 78.9) from the mouth of the river, to Plainwell (MP 60.0) require, or demand, about 90,000 pounds of oxygen each day; this is equivalent to

63,000 pounds of five-day BOD each day. (Biochemical Oxygen Demand, or BOD, is a measure of the amount of oxygen taken up by aerobic bacteria in a sample of water or effluent during a period of five days at 20°C. A high BOD indicates that large populations of bacteria are present and thus reflects the pollutional character of the sample. About 70 per cent oxidation occurs in samples over a five-day period of time. It is common practice to express BOD in terms of pounds. For example, if a sample of effluent requires ten pounds of oxygen for total oxidation, then 70 per cent of this, or seven pounds, is the five-day BOD.) About 52,270 of the 63,000 pounds are attributable to the wastes from the paper industries in the Kalamazoo area (Anon., 1961); most of the remainder is caused by the sewage from Kalamazoo. The first industrial outfall is less than two miles below Comstock, therefore, about 90 per cent of the study area is affected by industrial and municipal wastes.

LOCATION AND DESCRIPTION OF SAMPLING STATIONS

Four sampling stations were selected (Figs. 1 and 2). The descriptions and locations of these



a. Station I. Looking upstream at the River Street bridge in Comstock.

b. Station II. Looking downstream at the Mosel Street bridge. Note the laminar flow of the river.

c. Station III. Looking upstream at the Cooper Road bridge. Note the turbulent flow.

d. Station IV. Looking downstream. Note the overhanging vegetation.

Fig. 2. Sampling Stations.

stations are summarized in Table 1. Station I, in Comstock, was above the industrial and municipal outfalls. All of the wastes entering the study area were discharged into the river between Stations I and II. The water at Station II and the other downstream stations was always whitish and turbid owing to the titanium dioxide (white water) clay, sizing, and paper fibers discharged by the paper industries. An oily film often occurred on the surface of the water at Station II.

Colonies of bacteria (Sphaerotilus), commonly called sewage fungus, were in every sample of plankton taken at Stations II, III and IV. Mats of these bacteria also were on bridge piers and banks at water level and on the bottom of the channel. Other studies indicate that such colonies of bacteria have occurred for many years (Velz, 1947; Surber, 1953; Anon., 1958).

At Station III, clumps of eel grass (Vallisneria americana) and pondweed (Potamogeton sp.) grew in the shallow areas near the banks; however, it appeared that the pollutants were deleterious to them because they were dead by August.

Table 1. Description and Location of Sampling Stations.

Station	Elevation in feet above mean sea level	Miles from mouth of river	Approximate depth in feet at midstream	Approximate width of river in feet	Type of flow	Location
I	760	78.9	4	140-150	laminar	River St. Highway Bridge in Comstock
II	755	72.8	4	150-160	laminar	Mosel St. Highway Bridge in Kalamazoo
III	740	67.9	3	160-170	turbulent	Cooper Rd. Highway Bridge
IV	720	60.0	3	120-130	Semi-turbulent	Railroad tressel on main channel of river in Plainwell

PROCEDURES

Samples were collected between December 15, 1960, and August 3, 1961, at 15-day intervals. In all, 17 sampling trips were taken. At each station a sample of plankton was taken from mid-stream. From 7 to 100 liters of water, depending on the abundance of organisms, were poured through a plankton net of number 20 silk bolting cloth (173 meshes/inch) supported in a pail of water. The samples taken through February 16, 1961, were immediately preserved with formalin. After this date preservative was not added until counting was completed in the laboratory.

Temperatures of air and water were taken with a mercury thermometer, and general weather conditions were noted.

Dissolved oxygen was determined by the azide modification of the Winkler method (Anon., 1960). The samples were fixed immediately in the field and titrated two to three hours later.

One liter of water was saved for the determination of sulfates, total phosphates, iron (atomic), nitrates, nitrites, ammonia nitrogen, and turbidity with a

Bausch and Lomb Spectronic 20 Colorimeter. A Beckman pH meter was used to determine hydrogen ion activity.

Plankters were counted by using a Sedgwick-Rafter counting cell. The initial 70 cc concentrated sample was usually diluted to 100 cc. Often the samples from Stations II, III, and IV were further diluted because the heavy concentrations of paper fibers hindered accurate counting of the rotifers. All the rotifers occurring in two 1 cc subsamples were counted. The number of rotifers per liter of water was then computed from the average number of rotifers in the two subsamples.

Keys used for identification of the rotifers were Ahlstrom (1940;1943) for the genera *Keratella, Brachionus* and *Platyias;* Rousselet (1902) for *Synchaeta;* Bartos (1948) for *Pedalia (Hexarthra);* Harring and Meyers (1922, 1924, 1926, 1928); Meyers (1930) and Edmondson (1959) concerning various forms; and finally Harring (1913) and Gallagher (1957) were used for reference to proper generic and specific names. Identification and counting was done using a binocular dissecting microscope at various magnifications up to 120X. Confirmations were often made with higher powers under a compound microscope.

On three occasions, April 6-7, June 15-16, and August 1-2, 1961, tests were conducted to determine the daily variations in concentrations of chemicals at each station. On these dates, samples were taken at six-hour intervals so that four samples from each station were analyzed. Plankton was not sampled.

RESULTS

Factors Influencing Chemicals

The influence of the volume of flow on the concentrations of many chemicals in the Kalamazoo River was evident. Reinhard (1931:424) found that changes in the chemical quality of water due to dilution and concentration hinder one's finding concrete relationships between inorganic minerals and plankton cycles.

Volume of flow was measured by a United States Geological Survey water gage at Comstock (Station I). The greatest volume of flow that occurred on a routine sampling day was 1,880 cfs on April 27, and the smallest volume of 385 cfs occurred on July 6 (Fig. 3).

The water at Station I was normally clean and transparent, whereas at the other stations it was usually turbid (Fig. 4). Turbidity increased at Station I with an increase in water discharge. At the other stations the turbidity-discharge relationship was inverse. The gradual increase in turbidity at Station I from February to the end of May probably was the result of an increase in plankters, especially phytoplankton, and an increase in water discharge which scoured bottom materials into suspension. Reinhard (1931:417) found that increases in discharge of clean rivers increased their turbidity. The water at Stations II to IV was turbid because of the large quantities of paper fibers and "white water" entering the river. When the water volume increased, the paper fibers and "white water" were diluted, and the turbidity decreased.

The lowest concentration of dissolved oxygen measured at Station I was 5.1 ppm (63 per cent saturation) on July 20 when the water temperature was 27°C and water discharge 405 cfs (Fig. 5). Dissolved oxygen

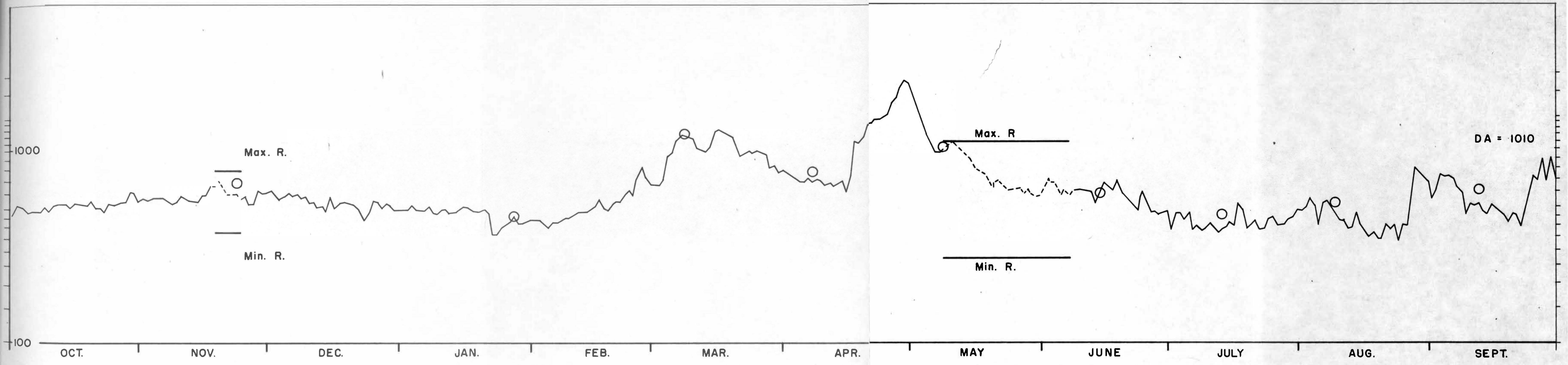


FIG. 3. Hydrograph of Kalamazoo River at Comstock, 1960 – 1961.

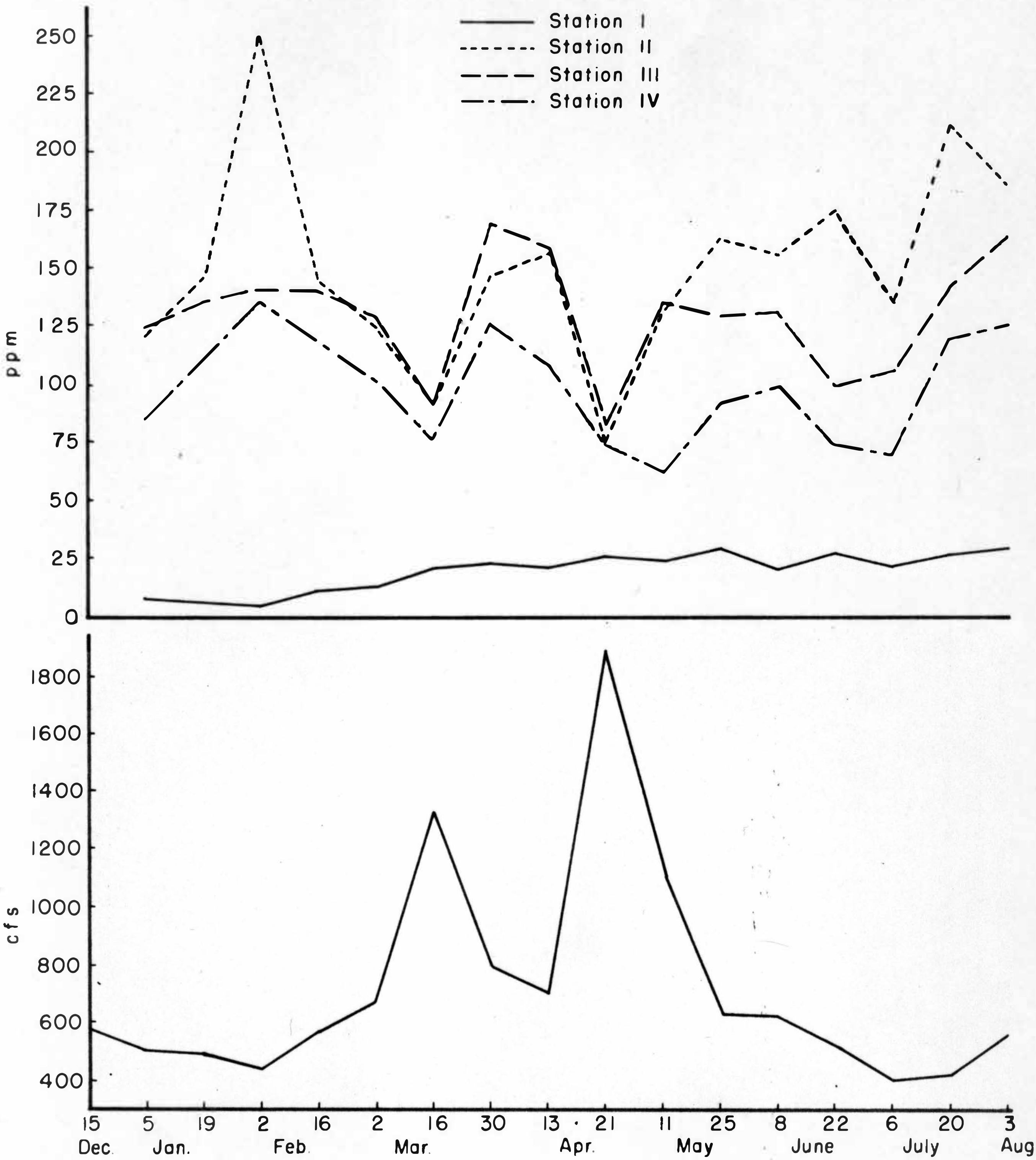


FIG. 4. Turbidity and Hydrograph.

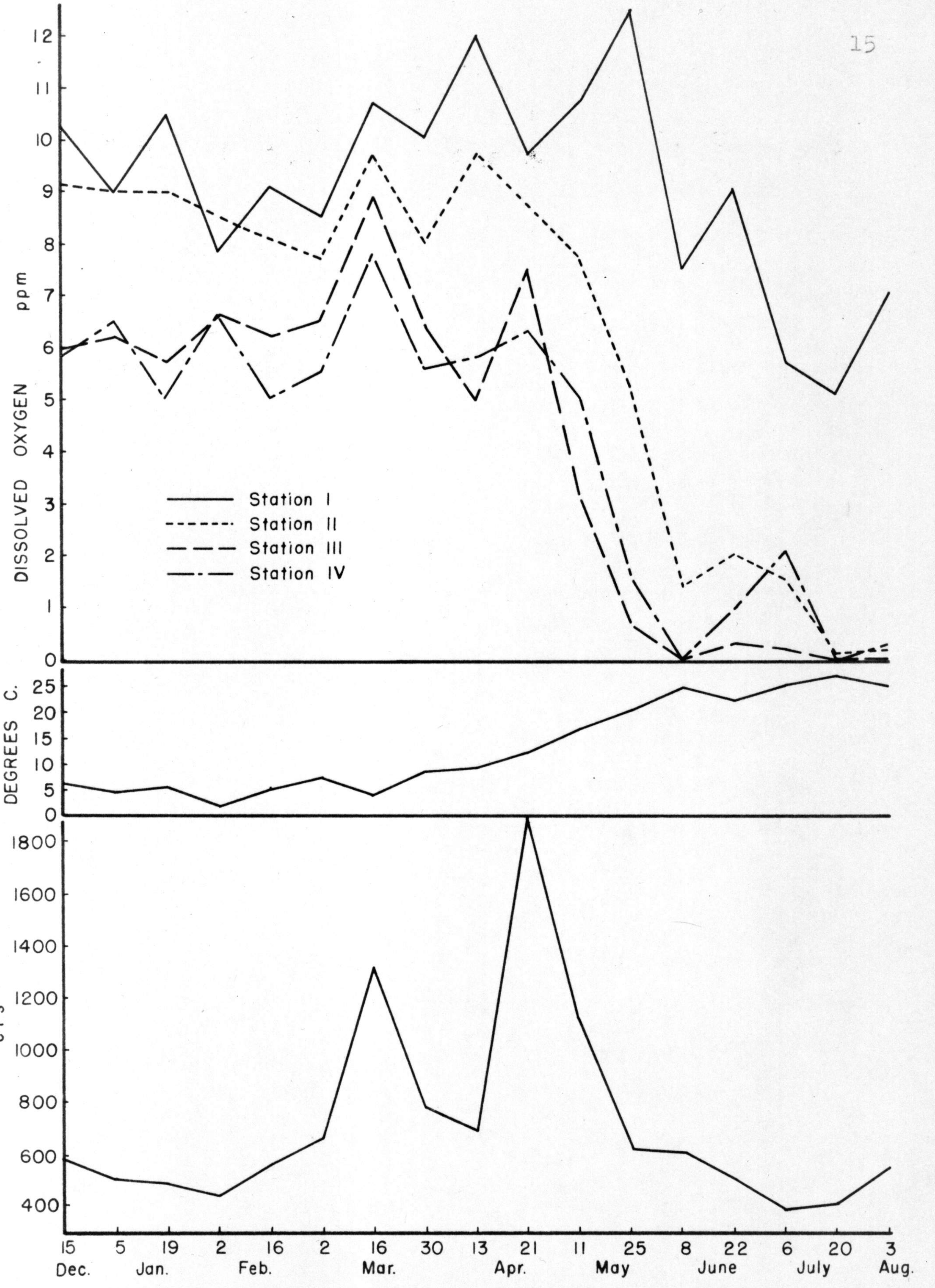


FIG. 5. Dissolved oxygen, Average water temperature °C, and Hydrograph.

at the other stations became rapidly depleted after April 27 as the water temperature increased and the water discharge decreased. The increase in dissolved oxygen at Stations III and IV on March 16 and April 27 probably was due to a combination of two factors: (1) the diluting and flushing action of large volumes of water reduced the numbers of bacteria per unit of volume and thus reduced the BOD; (2) and the scouring action of the water removed much of the settled organic sludge from the bottom of the channel and carried it downstream, reducing BOD still more.

More sludge was deposited in a dredged portion of the river extending about one mile above Station II than in the other areas investigated, especially when the flow at Station I was less than 700 cfs (Velz, 1947:18). A large amount of BOD was lost in the dredged area as a result of the deposition of sludge (Anon., 1958:Fig. 6). When biological digestion of this sludge occurred the deposits were agitated by escaping gas and portions were buoyed into the stream as mats of black sludge. These mats, up to 15 inches in diameter, were observed floating downstream at Station II from June 8, 1961, to the end of the study, August 3, 1961.

Comparison of water discharge with ammonia nitrogen (Fig. 6) shows that the two factors were somewhat inversely related except in May and June when the relationship was less consistent. The increase in ammonia nitrogen during low water discharge probably was due to the slight dilution rather than to an increase in the production of the substance.

Greater concentrations of ammonia nitrogen were found at Stations II, III and IV than at Station I, and the greatest concentration usually was at Station II. The large concentration at Station II probably was caused by the discharge of municipal wastes of Kalamazoo 0.7 mile upriver from the station. However, nitrogen in ammonium compounds can also be released into streams in the debris of vegetable and animal origin (Reid, 1961:200), in leachings from soil seepage, and in industrial wastes (Kofoid, 1903:192).

Nitrite concentrations dropped rapidly after December 15 at Stations II, III, and IV (Fig. 7). No clear relationship appeared to exist between nitrite concentration and water discharge.

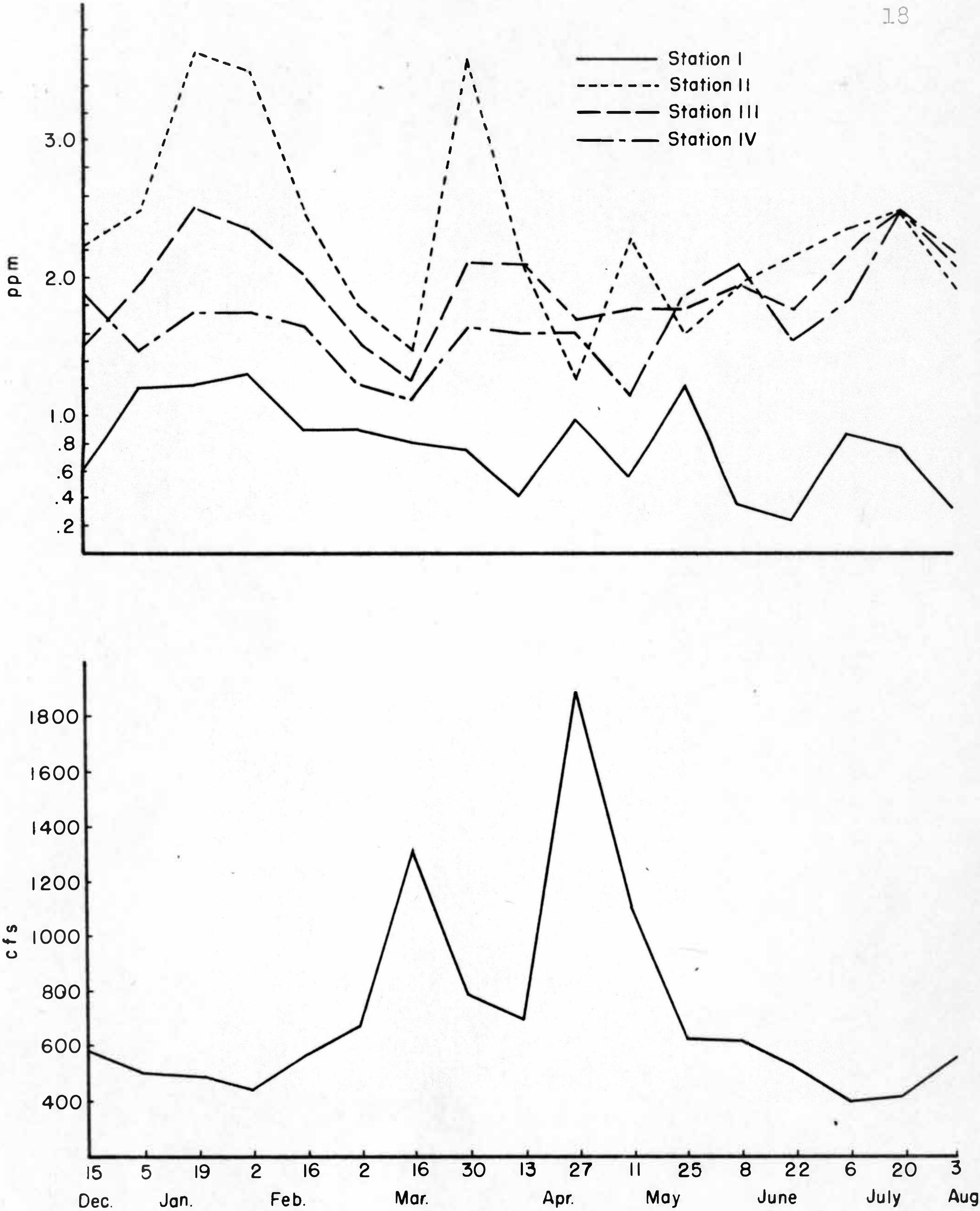


FIG. 6. Ammonia nitrogen and Hydrograph.

Nitrates are the final products of the oxidation of nitrogen compounds. Maximum concentrations of nitrates occurred during periods of high water discharge as on March 16 and April 27 (Fig. 7). However, on March 30, an increase in nitrates occurred at all but Station III, and the water discharge had decreased. Although Kofoid (1903:215) found that nitrates fluctuated with discharge, he found that they were present in greatest concentrations (0.3 to 0.4 ppm) during summer when the water level was low. In the Kalamazoo River, nitrates varied from 0.00 to 0.40 ppm after May 25, but were never less than 0.25 ppm prior to that time.

Sulfate concentration varied from about 60 to 85 ppm (Fig. 8). On three occasions (Feb. 2, Mar. 16, and May 25), sharp increases, for which I can give no explanation, were noted at Stations I and II. No such increases were detected at the other stations. Sulfates in the Kalamazoo River are derived primarily from the Coldwater Shale and basal till, which is derived mainly from the shale (Deutsch *et al*., 1960:73). Some sulfates probably came from the industrial wastes.

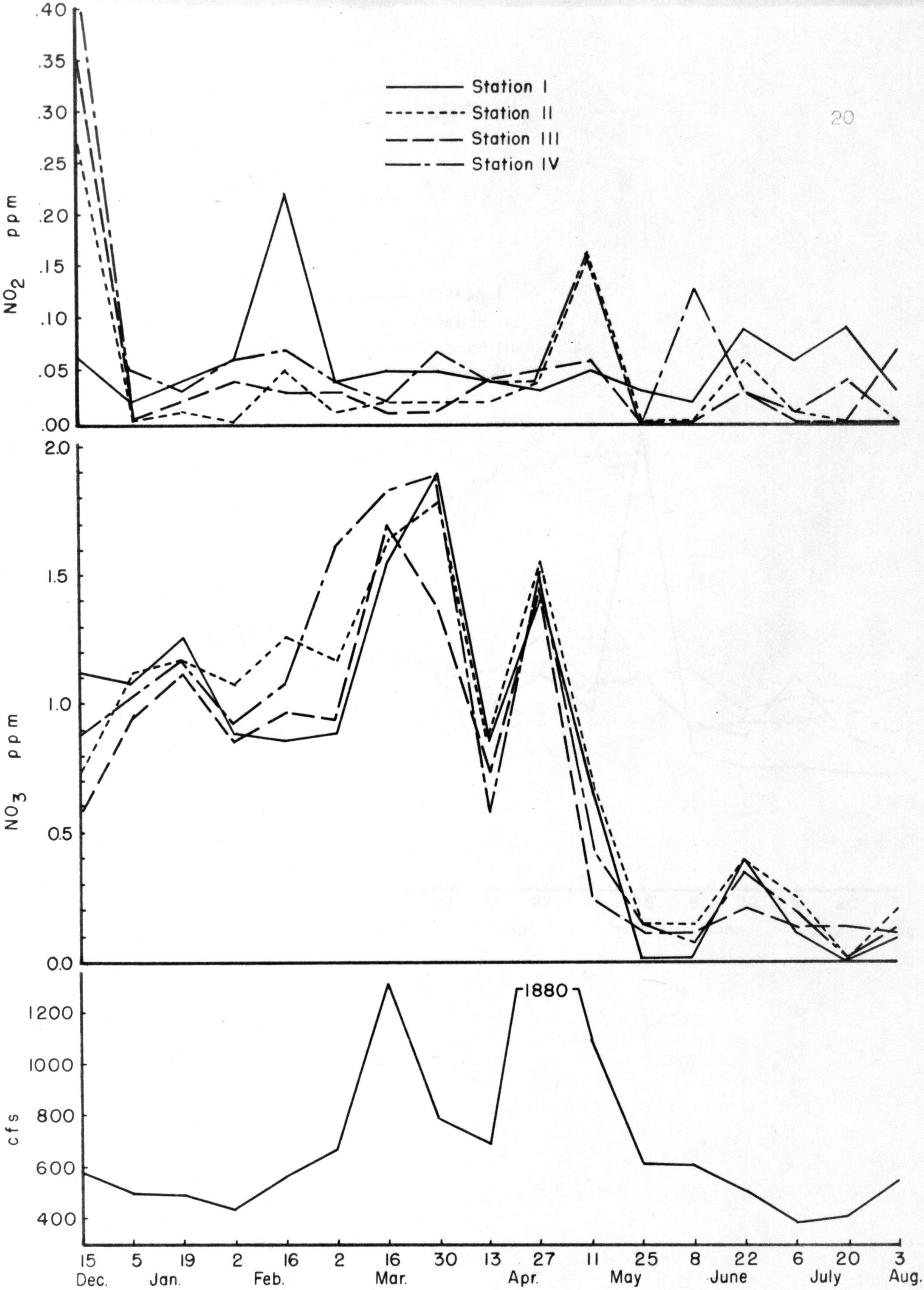


FIG. 7. Nitrites, Nitrates and Hydrograph.

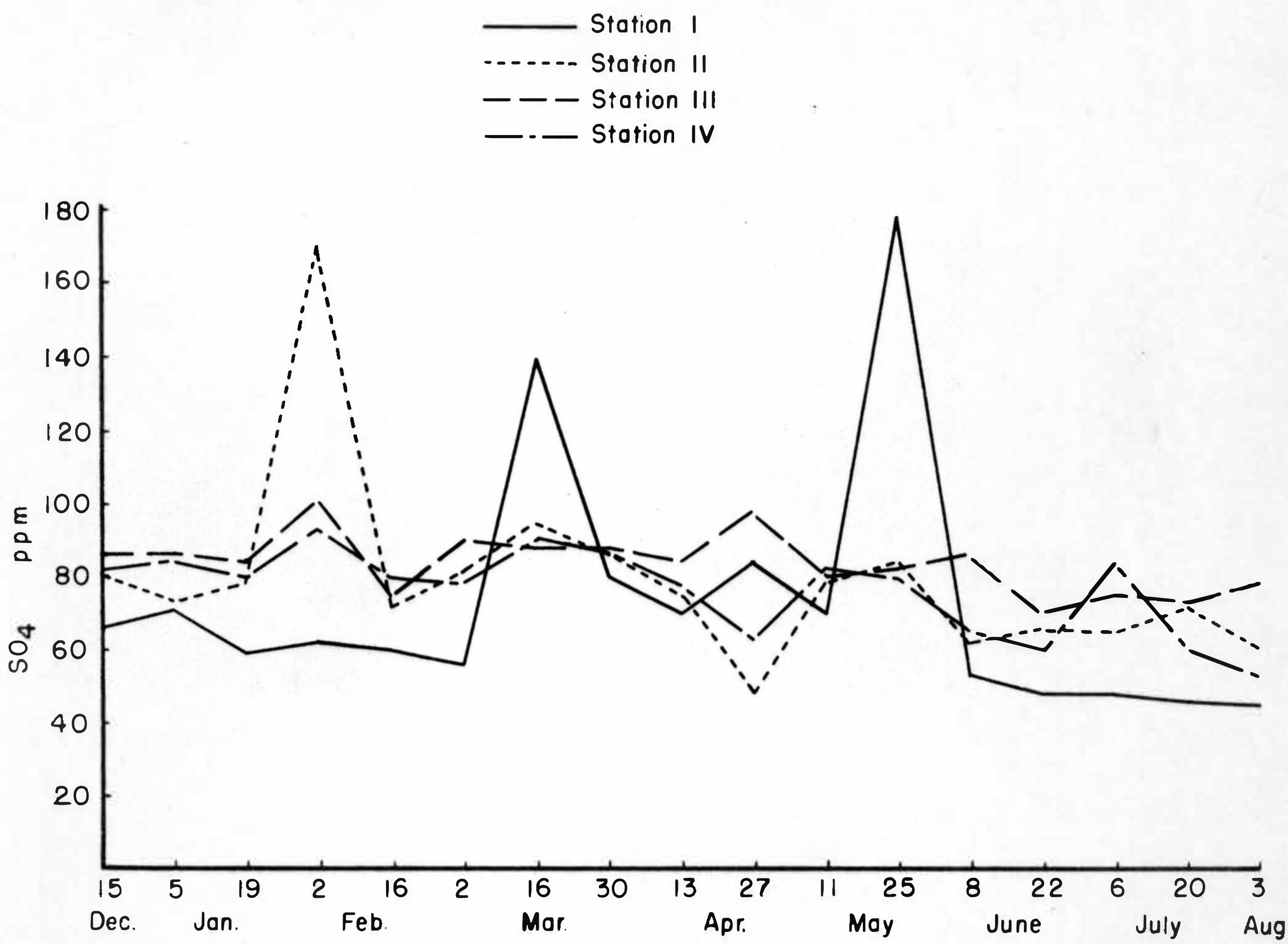


FIG. 8. Sulfates.

The maximum concentration of iron measured was 1.86 ppm on August 3 at Station II. Iron in the river is derived from glacial drift and bog ore; elsewhere in the Kalamazoo area it is found in concentrations up to 7.5 ppm (Deutsch et al., 1960:74).

Phosphates decreased very rapidly from January to June (Fig. 9). Probably the decrease in concentration was largely due to an increase in numbers of bacteria. Heron (1961:345) states that in lakes in the summer increases in phosphates may be caused by a combination of at least four factors; (1) heavy rainfall in the drainage basin; (2) release of phosphates from dead cells after an algal "bloom;" (3) contamination and non-uniform distribution of zooplankton excreta; (4) and changes in the populations of bacteria. Rigler (1961:167) has shown that about 95 per cent of the phosphorus in lake water is immediately taken up by bacteria. Bacterial populations increase rapidly with increasing temperatures from winter to summer especially when, as is the case in the Kalamazoo River, nutrients are plentiful. Therefore, the rapid depletion and short term fluctuations of phosphates as shown in Fig. 9 probably were the result of the fluctuations of the

FIG. 9. Total phosphates, Water temperature and Hydrograph.

*No sample

populations of bacteria.

Through March 16, the pH of the river at Station IV was generally higher than that at Station I. After March 16, Station IV had a pH lower than Station I (see Fig. 10). Water temperature increased steadily after March 16. Probably as the temperature of the water and activity of bacteria increased, the resulting carbon dioxide depressed the pH.

Diel Periodicities of Various Chemicals

On April 6-7, June 15-16, and August 1-2, samples were collected every six hours in a 24-hour period to obtain data on the daily fluctuations of various minerals. Summaries of the analyses are in Appendix II.

Expectably, the concentrations of dissolved oxygen increased in the day and usually decreased at night, except when no dissolved oxygen was present (Table 2). No dissolved oxygen was found at Station III on June 15-16, Station III and part of the time at Station IV on August 1-2. The shapes of the profiles of dissolved oxygen of these tests generally

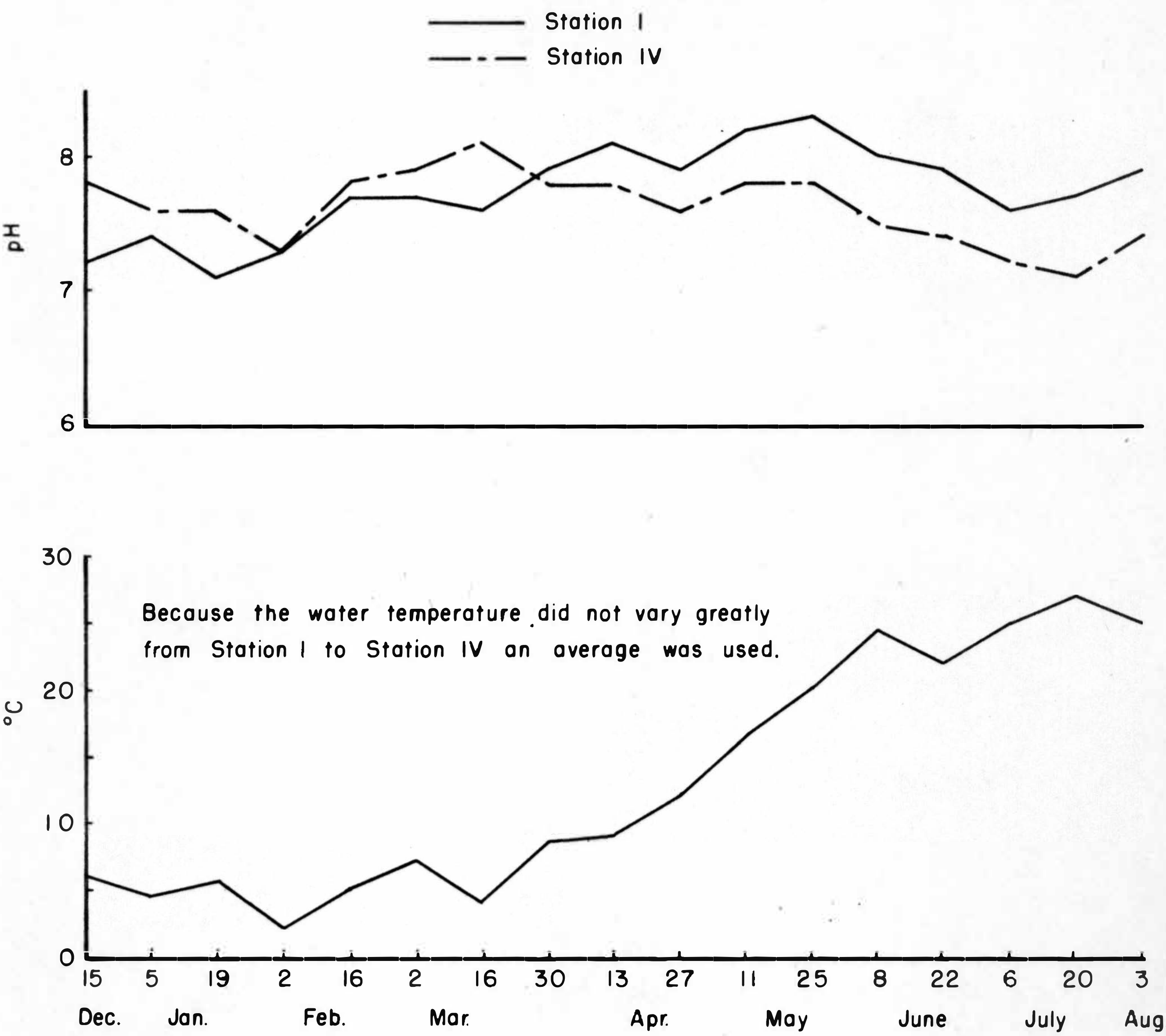


FIG. 10. pH and Average water temperature.

Table 2. Diel variations of five chemicals.

Chemicals and Dates	Station I				Station II				Station III				Station IV			
	6 AM*	12 N	6 PM	12 M	6 AM*	12 N	6 PM	12 M	6 AM*	12 N	6 PM	12 M	6 AM*	12 N	6 PM	12 M
Dissolved Oxygen ppm																
6-7 April	10.7	11.0	11.6	11.2	8.9	9.9	10.6	10.6	5.4	6.5	6.8	6.6	5.2	5.1	4.5	5.5
15-16 June	6.5	6.8	6.7	4.9	.8	3.3	3.2	2.2	0.0	0.0	0.0	0.0	0.6	0.6	0.6	1.5
1-2 August	7.8	7.2	7.7	6.4	1.3	3.2	3.7	2.4	0.0	0.0	0.0	0.0	0.9	0.2	0.0	0.0
Phosphates, total ppm																
6-7 April	.20	.21	.42	.21	.23	.28	.79	.25	.18	.05	.59	.15	.16	.05	.64	.13
15-16 June	.36	.37	.53	.23	.23	.13	.25	.05	.28	.05	.13	.05	.36	.11	.03	.16
1-2 August	.18	.18	.28	.28	.00	.00	.18	.07	.10	.00	.30	.13	.36	.20	.15	.02
Ammonia nitrogen ppm																
6-7 April	.80	.65	.69	.49	1.95	1.82	1.51	1.82	1.70	1.42	1.30	1.55	1.42	1.42	1.55	1.30
15-16 June	.69	.75	.67	.80	1.65	1.76	1.42	1.65	4.36	1.51	1.34	1.23	1.42	1.47	1.76	1.23
1-2 August	.00	.27	.33	.65	1.47	1.95	1.82	1.85	1.65	2.27	2.27	1.88	1.23	1.95	2.18	1.95
Nitrites ppm																
6-7 April	.80	.65	.69	.49	1.95	1.82	1.51	1.82	1.70	1.42	1.30	1.55	1.42	1.42	1.55	1.30
15-16 June	.06	.07	.06	.08	.05	.04	.06	.04	.00	.02	.12	.00	.00	.04	.00	.06
1-2 August	.01	.02	.02	.02	.00	.02	.00	.00	.01	.00	.00	.02	.00	.00	.00	.00
Nitrates ppm																
6-7 April	1.48	1.55	1.17	1.62	1.48	1.37	1.00	1.31	1.22	.94	1.26	1.22	1.03	1.03	.69	1.03
15-16 June	.20	.18	.17	.12	.26	.28	.22	.27	.16	.09	.12	.14	.15	.24	.15	.07
1-2 August	.04	.04	.05	.11	.20	.15	.16	.21	.15	.16	.15	.15	.15	.15	.19	.16

*NOTE: The 6 AM figures for 6-7 April actually are from 6 AM April 7. They were placed in their present place to enable clearer analysis.

follow those presented by Purdy (1959:Fig. 4) for Station II in August, 1956. Figure 11 shows the fluctuations of dissolved oxygen at Station II for all three sampling dates.

Total phosphate concentration often increased at 6-7 PM (e.g., April 6-7, Table 2) at all stations. The reasons for this are obscure.

Sharp increases in ammonia nitrogen occurring between Station I and Station II at all times of the day (Table 2) were caused by the municipal wastes from Kalamazoo; however, primary decay continued downstream, and on many occasions, concentrations of ammonia nitrogen increased between Stations II and IV (e.g., August 1-2). Low oxygen content at Stations III and IV as on August 1-2 would prevent oxidation of ammonia nitrogen to nitrite and nitrate. (Note Table 2. The concentrations of nitrite and nitrate were very low on August 1-2.)

Source of Rotifers

The bulk of the rotifer populations developed in Marrow Lake 3/4 mile above Station I. This fact

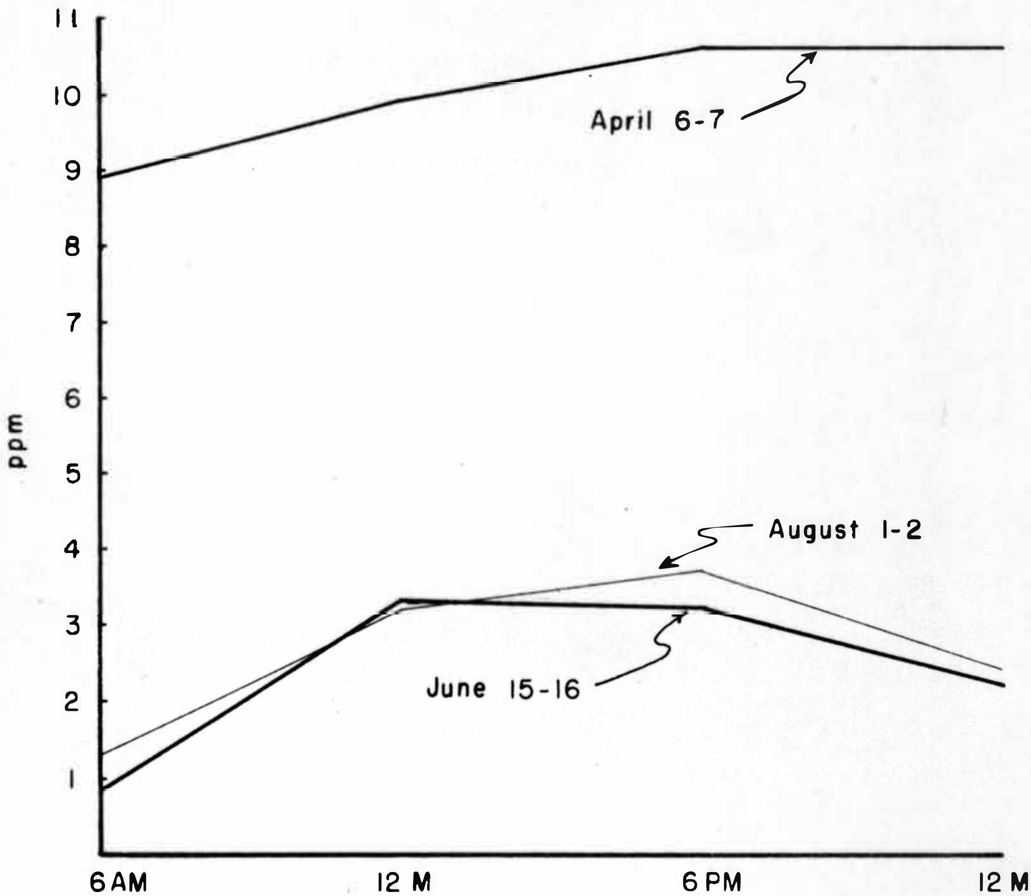


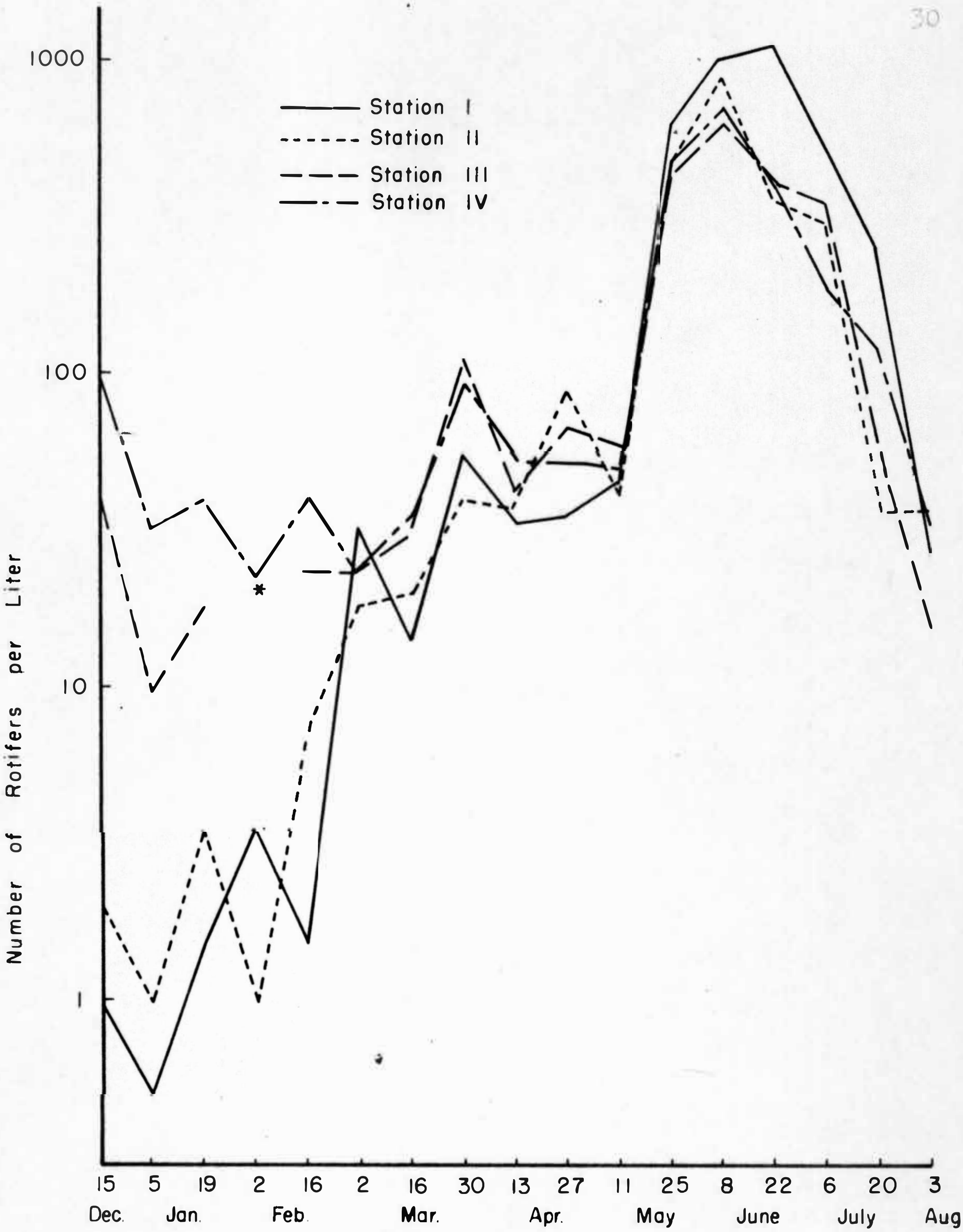
FIG. 11. Diel variations of dissolved oxygen (ppm) at Station 11.

was determined by taking samples on June 7, one day before a routine sampling day, from the river above Marrow Lake (at MP 88), and from Portage Creek at its juncture with the Kalamazoo River (MP 74.5).

Six kinds were found in the samples from MP 88; *Philodina* sp., *Keratella cochlearis*, *Polyarthra trigla*, *Euchlanis* sp., *?Itura* sp., and *Lepadella* sp. Only the first three appeared regularly in routine samples. *Philodina* sp. was most abundant (11 per liter); the others varied from 1 to 4 per liter. Marrow Lake was confirmed as the source of the bulk of the rotifers when, on June 8, routine sampling and subsequent counting of rotifers revealed the largest number of rotifers (sum of species) of the entire study period (Fig. 12). In the 21-liter sample taken from Portage Creek, two *Philodina* sp. per liter were found, and only one specimen of *Euchlanis* sp. was detected during an examination of the entire sample. The industrial wastes entering Portage Creek apparently eliminated most rotifers.

The Occurrence of Individual Species

A total of 25 kinds of rotifers representing 17 genera were identified during the course of this



*No sample.

FIG. 12. Distribution of Rotifers (all species).

study (Table 3). Figure 12 shows the distribution of the sum of all individuals of all species at each station throughout the study period. The sum of all species will hereafter be referred to as total rotifers.

Philodina sp. - Members of this genus were difficult to identify because of their similarity to members of the genus *Rotaria*. Perhaps members of the genus *Rotaria* and other similar rotifers were present but *Philodina* was undoubtedly the dominant form. *Philodina* sp. dominated the populations at all stations from December to May and was the most persistent rotifer throughout the study period. It reached its maximum numbers of 120 per liter at Station IV on May 25 (Fig. 13).

Brachionus - Ahlstrom (1940:143) noted that representatives of this genus are usually limited to water having a pH above 6.6. Purdy (1922:26) found that some members fed on suspended organic sewage. Rotifers were most abundant in May, June and July (Fig. 12). Members of the genus *Brachionus* dominated the rotifer populations during that time and accounted for the large populations at all stations.

Table 3. Rotifers found in Kalamazoo River

Asplanchna sp.

Brachionus
- *angularis* Gosse
- *bennini* (Leissling)
- *budapestinensis* Daday
- *calyciflorus* Pallas
- *caudatus vulgatus* Barrois and Daday
- *plicatilis* Muller
- *quadridentatus* Hermann

Euchlanis sp.

Filinia
- *longiseta* (Ehrenberg)
- *brachiata* (Rousselet)

Gastropus stylifer Imhof

Hexarthra (Pedalia) mira (Hudson)

?*Itura* sp.

Keratella
- *cochlearis* Gosse
- *quadrata* Müller

Lepadella sp.

Monostyla crenata Harring

Notholca striata (Müller)

Philodina sp.

Platyias patulus (Müller)

Polyarthra trigla Ehrenberg

Synchaeta spp. (at least 3 species)

Trichocera sp.

Trichotria sp.

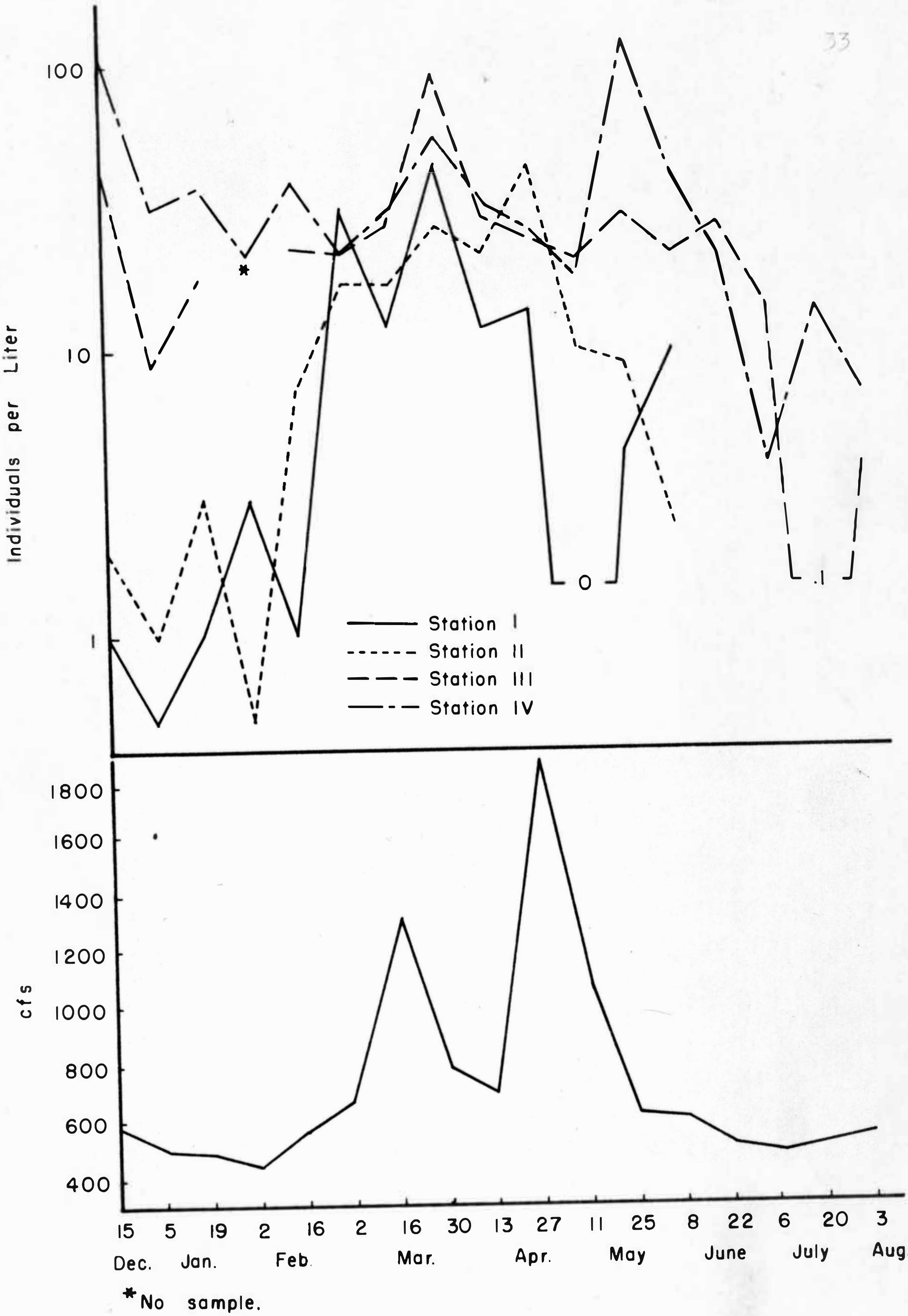


FIG. 13. Distribution of *Philodina* sp. and Hydrograph.

B. plicatilis was most abundant between May 25 and July 20 when water temperatures ranged from 19° C to 25°C. The maximum number was 100 per liter on May 25 at Station III (water temperature was 20°C). Allen (1920:97) found *B. plicatilis* abundant in polluted water from February to March and concluded that it was limited to water temperatures below 20°C.

B. calyciflorus, the most numerous rotifer, reached its maximum number in late May and early June (Fig. 14). Station I yielded 776 specimens per liter (76 per cent of the total population) on June 8.

B. angularis occurred only in July. It was most abundant at Stations I and II, therefore, it probably could not survive in the reaches between Stations II and IV. The largest number found was 35 per liter at Station I on July 20. In the San Joaquin River in California, it was found in May and June favoring moderate domestic pollution but not stagnation (Allen, 1920:94), and Kofoid (1908:165) found it most abundant in the Illinois River when the temperature of the water was at the summer maximum (about 25°C).

B. budapestinensis appeared in small numbers on July 6 at Stations I and II. Since it was dead when collected at Station II, it was no doubt intolerant

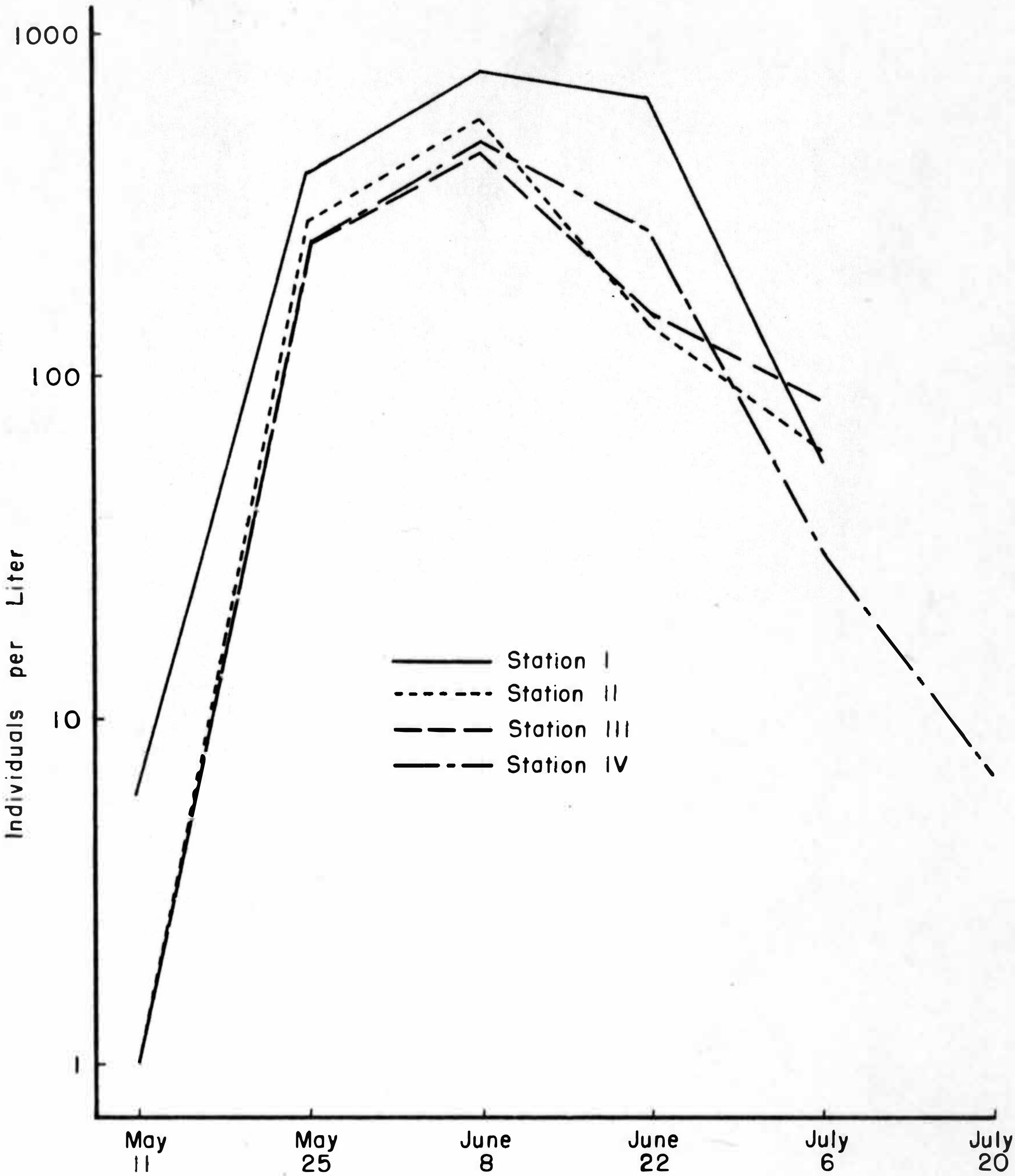


FIG. 14. Distribution of *Brachionus calyciflorus*.

of the pollutants. Allen (1920:95) found that domestic sewage hindered this species but, it apparently occurs only in summer (Kofoid, 1908:195).

B. caudatus vulgatus occurred sporadically from late June to July. Individuals found at Station I were active, however, after July 6 those found at Stations II to IV were dead or moribund. The largest number found was 40 per liter at Station III on July 6. Allen (1920:95) judged it to be a summer plankter possibly thriving in sewage and stagnation; the wastes of the Kalamazoo River seemed to be fatal.

B. quadridentatus appeared from late June through July at nearly all the stations, being most persistent at Stations III and IV, appearing in three consecutive samples. The maximum number of 42 per liter occurred at Station I on June 22.

Synchaeta spp. Three species of this genus were detected; S. pectinata, S. stylata, and S. tremula. Positive identification could not be consistently made so they were counted together as one group. This group of species occurred from March to July (Fig. 15), but attained its maximum abundance of 160 per liter in late

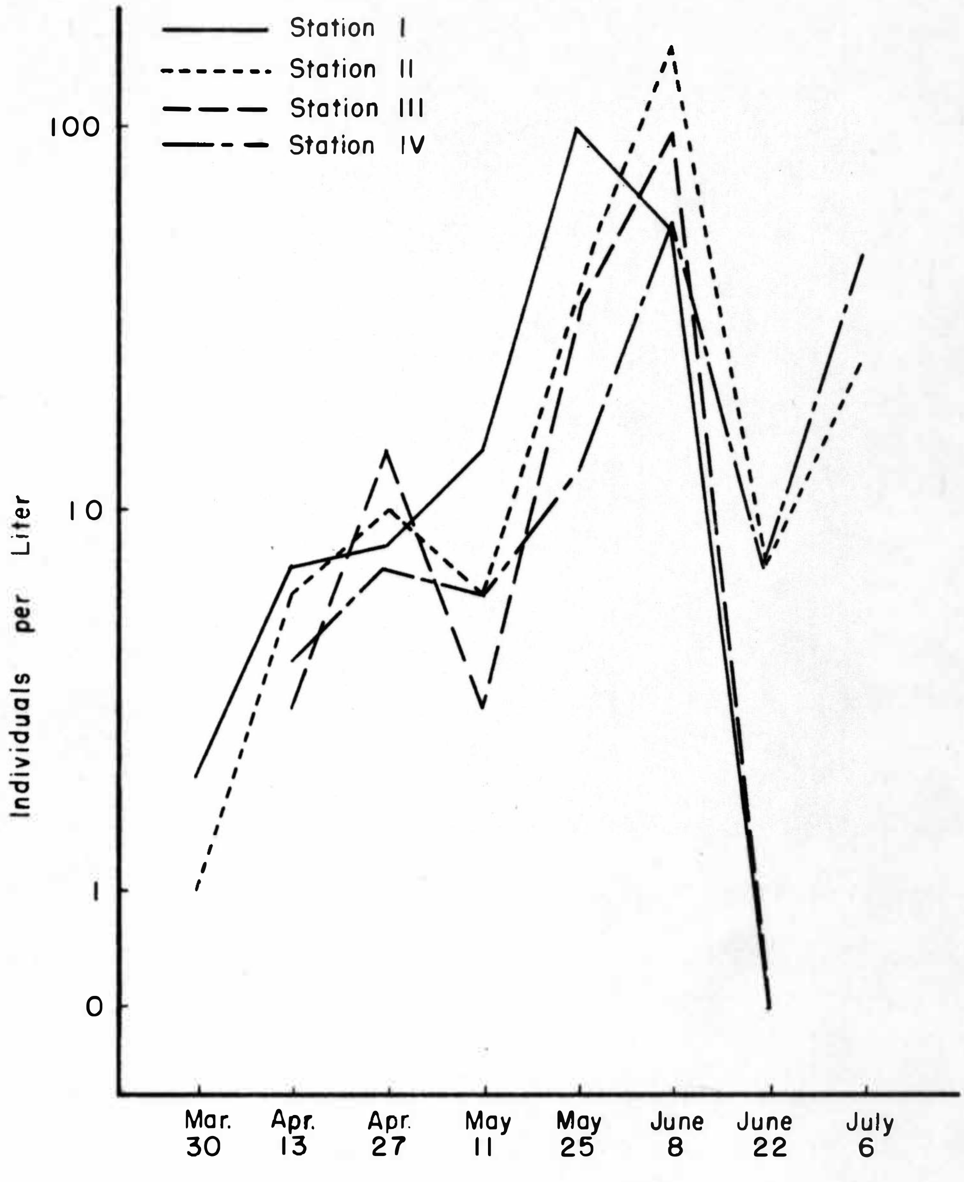


FIG. 15. Distribution of *Synchaeta* spp.

May and early June. Water temperatures ranged from 19°C to 25°C. Although the large pulse of total rotifers (Fig. 12) which occurred on June 8 was largely comprized of members of the genus *Brachionus*, on the same date *Synchaeta* spp. comprised 5, 18.5, 15, and 8 per cent of the populations at Stations I to IV respectively.

S. stylata was suspected of being the dominant form during the warmer months. Rousselet (1902:274) found *S. stylata* only from July to September, and *S. pectinata* and *S. tremula* in the winter and early spring.

Notholca striata. Few of this species were found after April 27; however, prior to that time, when the water temperature never exceeded 12°C, it appeared at all stations. Temperature appeared to limit this species, as other workers have shown (Allen, 1920:103; Kofoid, 1908:202).

N. striata first appeared on January 19 at Station II (0.5 per liter). It appeared most abundantly at all stations on March 30, with a maximum population of 12 per liter at Station III. Since this rotifer is supposedly intolerant of pollution, it was surprising that it had not succumbed and settled out of the plankton before reaching Station III. Perhaps the adequate oxygen supply (6.4 ppm on March 30 at Station III) and the low water temperature (9°C) allowed it to exist.

Polyarthra trigla. When the total rotifer population reached the maximum on June 8, this species occurred in fewer numbers than on the previous sampling day--except at Station IV where an increase occurred (Fig. 16). It was absent at Station I on June 8, and from Stations II and III on July 20. It reappeared at all stations on August 3. Seventy specimens per liter were found at Station I on June 22 and July 6; however, on the former date this was only 6.5 per cent of the total population whereas on the latter it was 13.5 per cent. The largest number of P. trigla found was on July 6 at Station II when it comprised 24 per cent (72 per liter) of the total population.

Filinia longiseta. This species appeared sporadically at all stations from March to July. It reached its maximum number at Stations I, II, and III on June 22; 84 per liter at Station I, 56 per liter at Station II, 28 per liter at Station III, but none at Station IV. The decrease in numbers from Station I to Station IV was

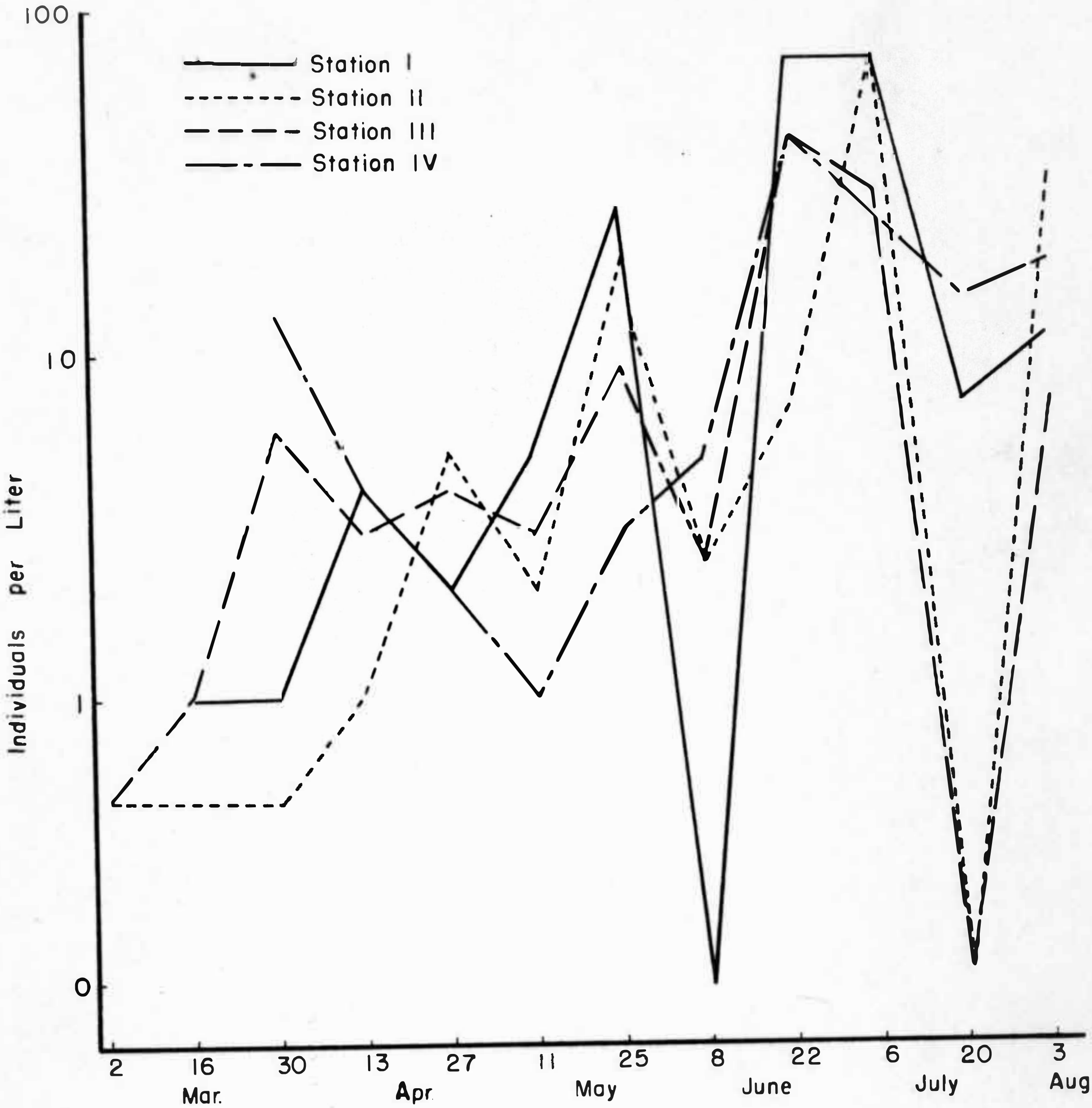


FIG. 16. Distribution of *Polyarthra trigla*.

by a factor of about 25 per cent, thus, settling out must have occurred when the rotifers succumbed to the adverse effects of the pollution.

Hexarthra mira. This species first appeared on June 22 in the sample at Station I where its density of 154 per liter comprised 14 per cent of the total population. By July 6, it had increased to 290 per liter, 57 per cent of the total population at Station I. Again on July 20 it was the dominant species at Station I comprising 36 per cent (88 per liter) of the total population. It decreased in numbers from Station I to II but from Station II to Station IV its numbers varied. *H. mira* probably was intolerant of polluted water. Most of the specimens observed in the samples from Stations II to IV on July 6 and 20 were dead or moribund.

Keratella cochlearis. This species appeared regularly from about March 30 to July 20 (Fig. 17). The maximum number found was 56 per liter at Station I on June 22. Sometimes it increased in numbers from one station to the next and at other times decreased.

K. quadrata. This species was found prior to May 25, but never in abundance, the maximum number being 3 per liter. It was found most often at Station IV occurring

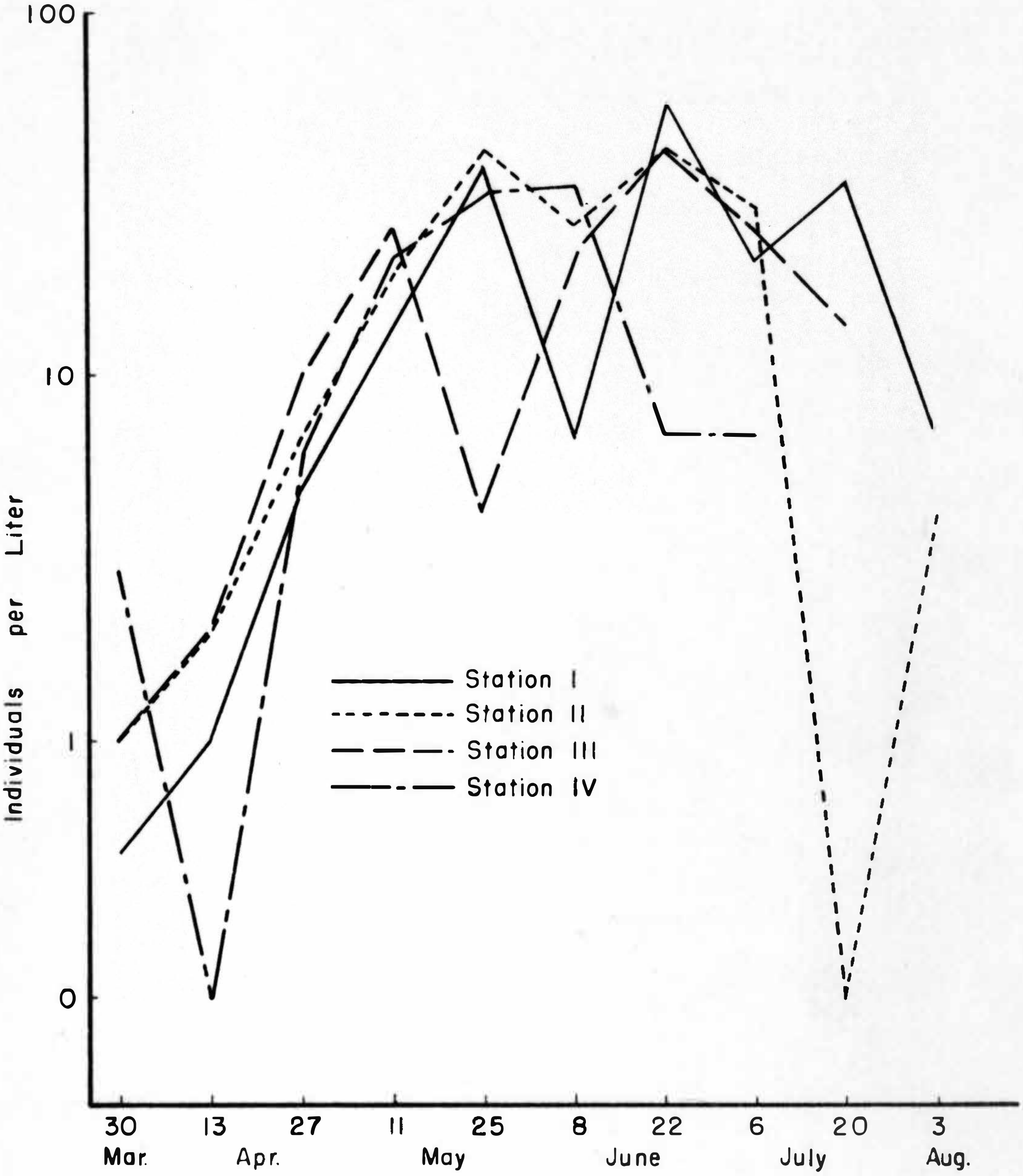


FIG. 17. Distribution of *Keratella cochlearis.*

in six consecutive samples. This was the most numerous plankter in Allen's study (1920:101) and domestic sewage was considered to be an important item of food. Reinhard (1931:454) found it to be a spring form reaching a maximum number of 110 per liter in May in the Mississippi River.

Miscellaneous species. Other kinds of rotifers that appeared only a few times and usually in small numbers were *Asplanchna* sp., *Brachionus bennini, Filinia brachiata, Gastropus stylifer, Platyias patulus,* the planktonic forms, and *Euchlanis* sp., *?Itura* sp., *Lepadella* sp., *Monostyla crenata, Trichocera* sp., *Trichotria* sp., the littoral forms.

DISCUSSION

The complexity of the chemical make-up of a lotic environment prevents one from forming hasty conclusions concerning the effects of specific chemicals on rotifers. Most of the chemicals analyzed could not be confidently related to fluctuations of populations of rotifers. Nevertheless, pollution seemed to be a factor strongly influencing the fluctuations of rotifers. The polluted condition of the study area was indicated by the following: (1) Each day, 63,000 pounds of BOD entered the study area below Comstock resulting in a significant depletion of dissolved oxygen at the downstream stations. Figure 18 shows a drastic differential in dissolved oxygen between Stations I and II. The amount of dissolved oxygen often was less than 2 ppm after May 25 at all stations but Station I where the dissolved oxygen never was less than 5.1 ppm (July 20). (2) The amount of ammonia nitrogen was nearly always appreciably higher at Stations II to IV than at Station I, reaching concentrations of 3.64 and 3.60 ppm on January 19 and March 30 respectively at Station II compared with a maximum of 1.30 ppm on February 2 at Station I (Fig. 18). Station II is compared with Station I because the greatest concentrations of ammonia nitrogen occurred at Station II. Ammonia nitrogen was high at Stations II and IV because of the municipal sewage plant 0.7 mile above Station II and the primary decay of the wastes from the paper industries. (3) There was a scarcity of rooted vegetation on the bottom of the channel, presumably because plants were smothered by sludge. (4) An abundance of sewage fungus (*Sphaerotilus*) occurred on the bottom and along the banks of the channel, and on piers of bridges. The presence of bacterial slimes, such as *Sphaerotilus*,

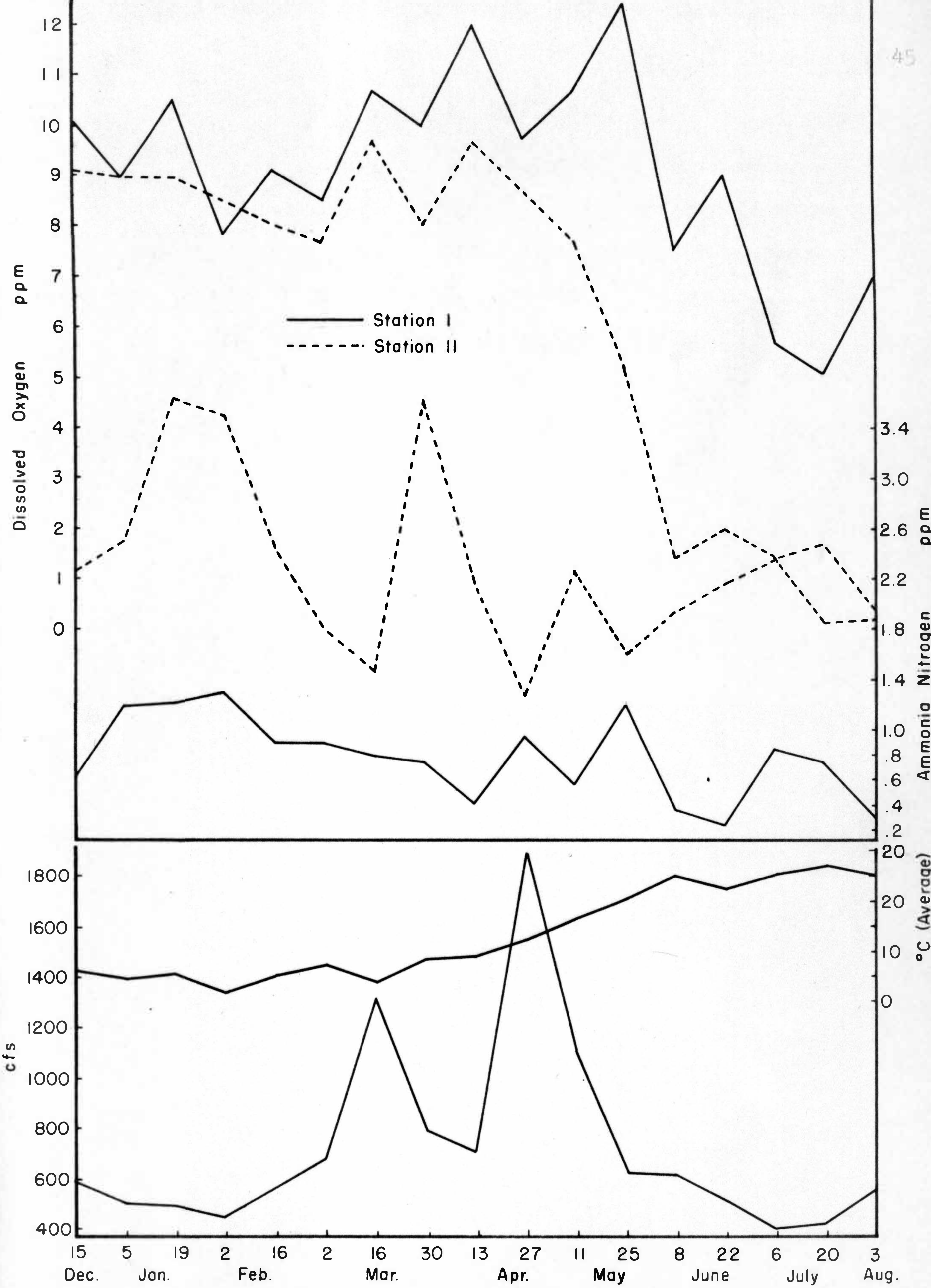


FIG. 18. Dissolved Oxygen, Ammonia Nitrogen at Stations I and II, and Average Temperature and Discharge.

is an indication of a polluted environment (Bartsch and Ingram, 1959:107). (5) Large colonies of sludge worms (*Tubifex*) occurred along the banks and in the deeper portions of the river at the downstream stations. Sludge worms are known to reach great numbers in polluted environments (Bartsch and Ingram, 1959:110; Surber, 1953:84).

Philodina sp. dominated the rotifer populations at all stations from December to May and was the most persistent rotifer throughout the study. The abundance of this rotifer at the downstream stations seemed to be influenced more by pollutants and heavy concentrations of paper fibers than by high water volume (see Fig. 19) or a decrease in competition with other rotifers for food and survival. Since *Philodina* is a littoral form, its increase in the plankton during periods of increased water discharge (*e.g.*, March and April) probably resulted from its being scoured from the bottom of the channel, for Kofoid (1908:141) attributed the summer fluctuations of Bdelloids in the Illinois River to floods. Since *Philodina* tolerates pollution (Patrick, 1950:933; Wiebe, 1927:159) and since the heavy concentrations of paper fibers may have simulated a littoral habitat--*Philodina*

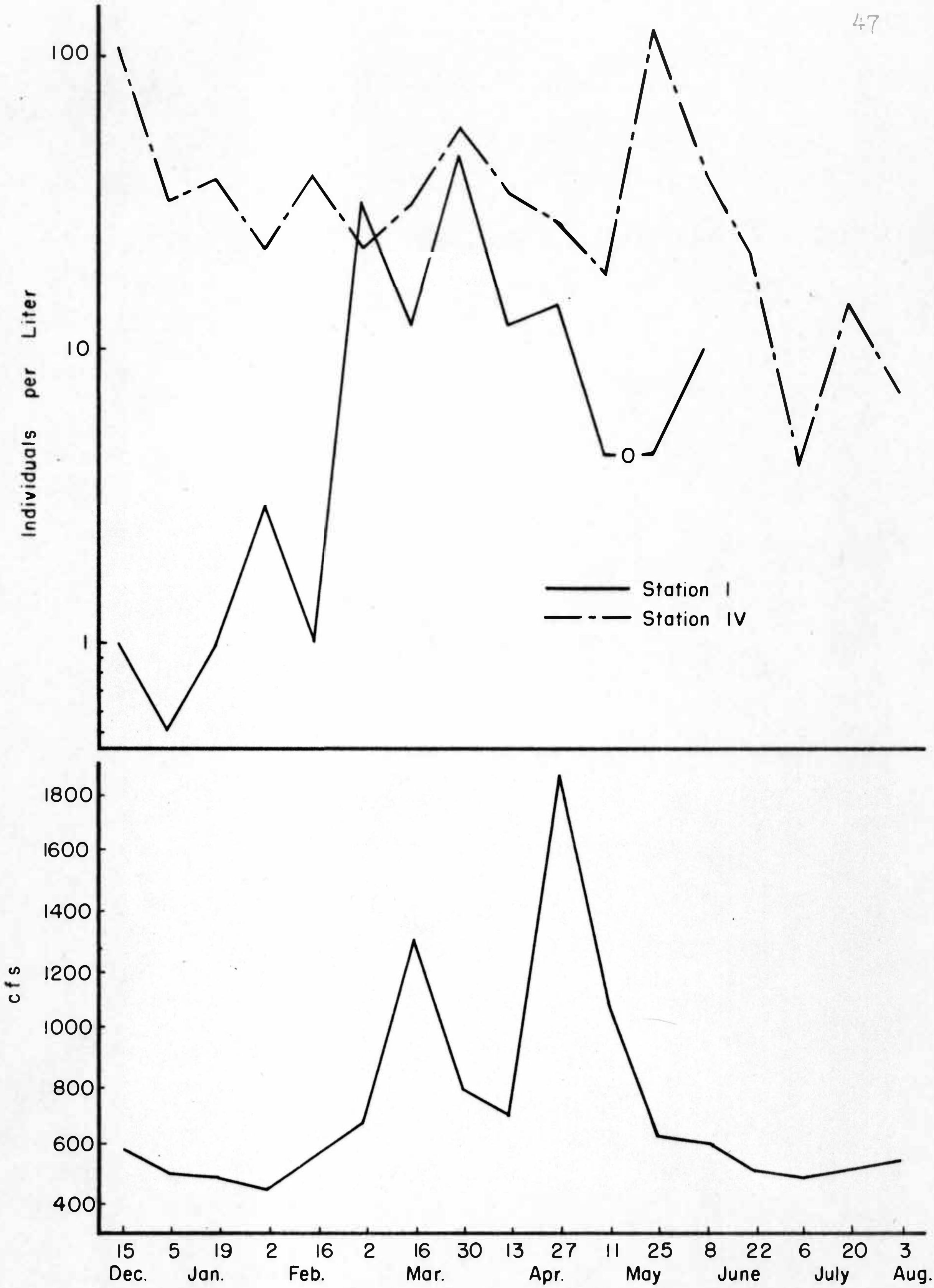


FIG. 19. Distribution of *Philodina* sp. at Stations I and IV, and Hydrograph.

could cling to the fibers--an environment in which this rotifer could thrive was provided. Comparison of the portion of the rotifer population comprized by *Philodina* at Station I with that at Station IV (Figs. 20 and 21) shows that *Philodina* was the dominant species much of the time; however, the average number of *Philodina* from December through March at Station I was only 12 per liter whereas it was 44 per liter at Station IV.

Brachionus calyciflorus was the most numerous rotifer, reaching a maximum number of 776 per liter at Station I on June 8. Also, this species comprized the greatest per cent of the total populations from May 25 to June 22 (Figs. 20 and 21). Although *B. calyciflorus* appeared to be somewhat tolerant of the pollutants, many specimens were dead at the downstream stations. From May 11 to July 6 the average number of *B. calyciflorus* per liter at Stations I and IV was 374 and 205 respectively. This decrease was presumably the result of pollution.

The sporadic appearance of *Keratella cochlearis* in the Kalamazoo River was an indication of the adverse conditions, for this rotifer is usually well represented in rivers (Allen, 1920:100; Beach, 1960:356; Kofoid,

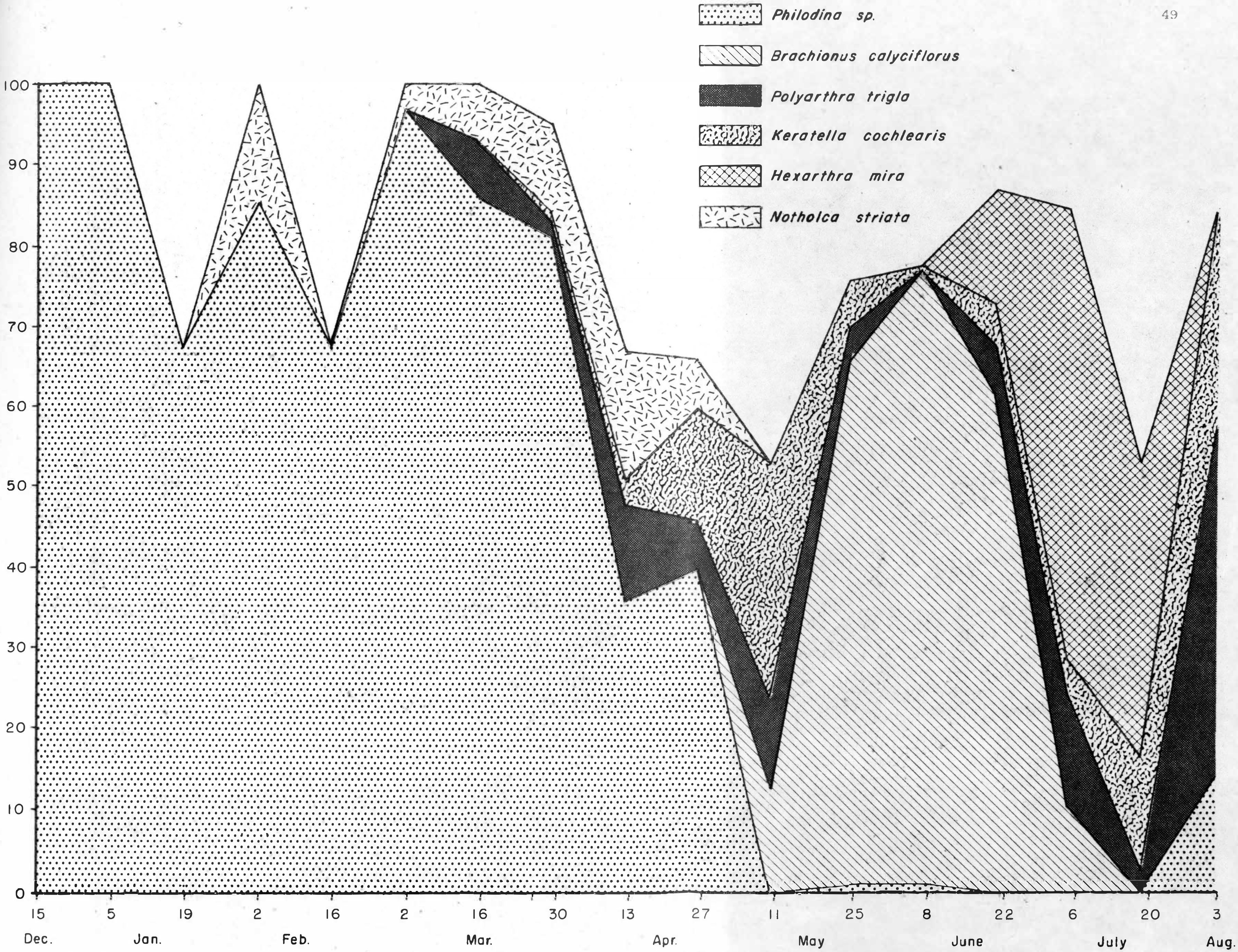


FIG. 20. Percentage of population of six rotifers at Station I.

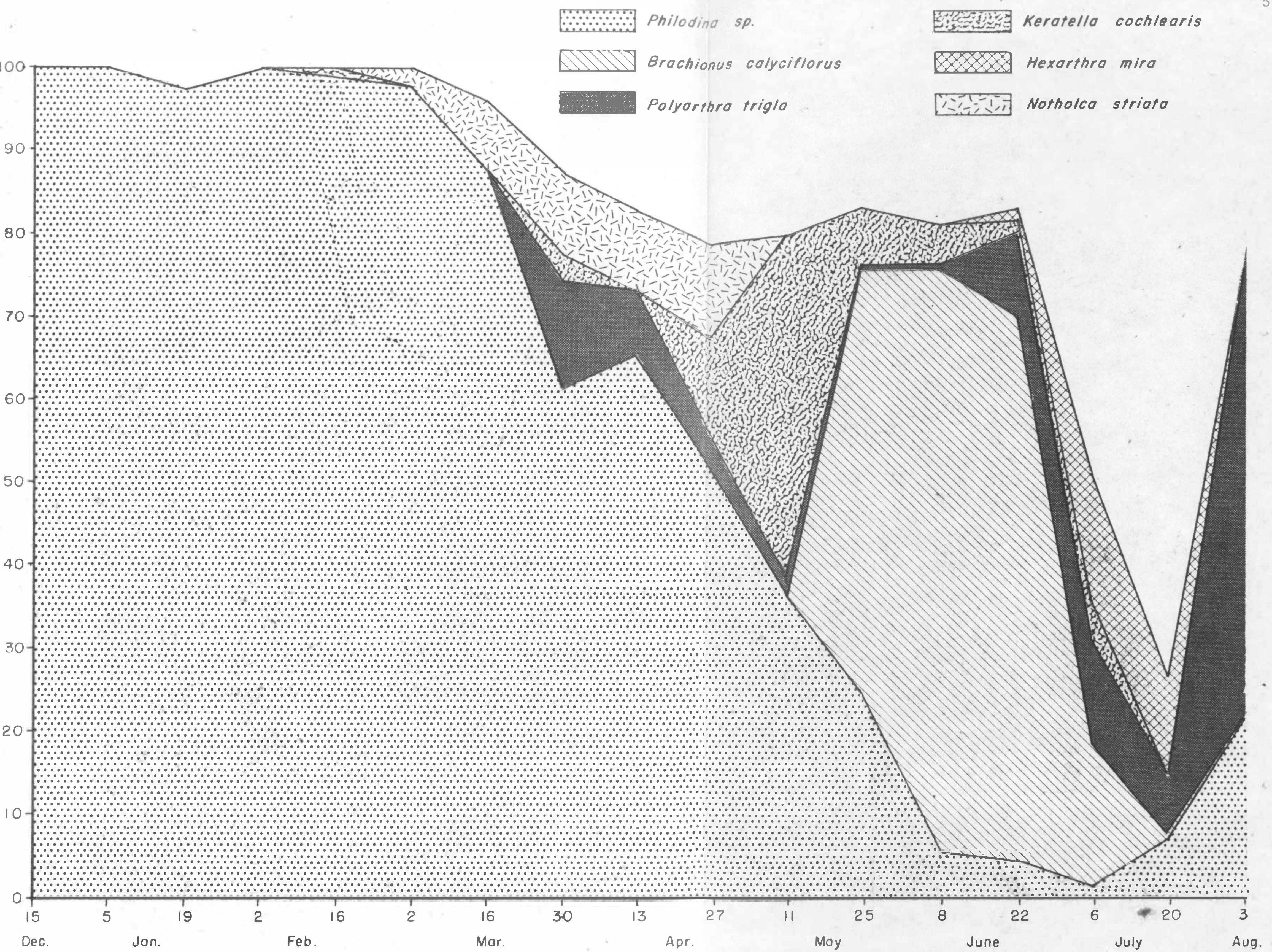


FIG. 21. Percentage of population of six rotifers at Station IV.

1908:153). The maximum number of 56 per liter occurred at Station I on June 22; however, the occurrance of a larger population at Station I than at any other station did not indicate that K. cochlearis was intolerant of pollutants, for it often increased in numbers from Station I to Station IV (e.g., June 8). Although the percentage of the population comprised by this rotifer at Stations I and IV on May 11 (Figs. 20 and 21) appeared large, only 13 and 20 specimens per liter were found at these respective stations.

Hexarthra mira and Filinia longiseta were clearly intolerant of the pollutants. The former rotifer, a summer form, occurred in only three consecutive samples (June 22, July 6 and 10) and specimens were usually dead at the downstream stations. From June 22 to July 20 the average number of H. mira was 177 per liter and 19 per liter at Stations I and IV respectively, and on July 6 it decreased in numbers from 290 per liter at Station I to 29 per liter at Station IV. Figures 20 and 21 clearly show, also, that the percentage of the populations comprised by H. mira declined from Station I to Station IV. Filinia longiseta supposedly eats sewage (Allen, 1920:99), and Kofoid (1908:217) found it in every month of the year. The decrease in numbers of this rotifer from Stations I to IV, as on June 22 (84 per liter to 0 per liter), indicated that the adverse effects of the industrial wastes, and perhaps the drastic drop in dissolved oxygen from Station I to Station II (from 9 to 2 ppm), overshadowed the supposedly salutary effects of municipal sewage.

Although I could not confidently ascertain the effects of specific chemicals on rotifers, I could classify some of them as tolerant of pollution or intolerant of pollution. I would classify as tolerant forms *Philodina* sp., *Brachionus plicatilis*, *B. quadridentatus*, and *Keratella quadrata*. The intolerant forms are *Brachionus angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. caudatus vulgatus*, *Notholca striata*, *Filinia longiseta* and *Hexarthra mira*.

The 24-hour tests which were conducted on three occasions suggested a method by which a clearer picture of the effects of the chemicals on the plankton could be obtained, namely taking chemical samples concurrently with plankton samples on a 24-hour basis. Plankton populations are somehow influenced by the fluctuations of the chemicals in the river. Plankters may be able to tolerate certain chemicals and will pass down stream unhindered by them. However, if the chemistry of the water is changed (as for example, by the discharge of certain wastes into the river by various industries at different times of the day), all organisms passing by at that time, except perhaps the tolerant forms, might succumb to the adverse effects of the wastes.

Since the water at Station I was relatively free from industrial pollutants, it might be expected that the populations of rotifers should have been greater there considering the size of the Kalamazoo River. In the Ocqueoc River, a clean river in northern Michigan, populations of rotifers reached numbers near 500 per liter in June and July (Beach, 1960:347) in spite of the decimating, straining effect of rooted vegetation. In the Kalamazoo River the maximum rotifer population (e.g., June 8), was only about twice that of the Ocqueoc system and the Kalamazoo River above Comstock drains an area of 1,010 square miles compared to 100 square miles drained by the entire Ocqueoc system. Beach (1960:356) found 34 species of 24 genera of rotifers, whereas I found only 25 species of 17 genera.

The scarcity of rotifers in the Kalamazoo River could be attributed to three things: (1) Waste materials entering the Kalamazoo River at Battle Creek (MP 110) undoubtedly depressed the growth of rotifer populations there. Surber (1953:83) classified all of the bottom dwelling organisms directly below Battle Creek as pollutional. Station I at Comstock was only about 30 miles downstream from Battle Creek and rotifer populations probably had insufficient time to develop after reaching the recovery zone some distance below the city. The small number of rotifers found at MP 88 above Marrow Lake on June 7 seems to confirm this conclusion. (2) Retention of the water in Marrow Lake probably was too brief to allow for maximum potential growth of the populations. (3) The adverse effects of pollution in the study area itself probably prohibited or reduced reproduction of many of the rotifers.

SUMMARY

This study was conducted to determine the qualitative and quantitative occurrence of rotifers in the plankton of a polluted portion of the Kalamazoo River in southwestern Michigan, and to ascertain the effects of pollution on the rotifers. The study area was 18.9 miles long. Samples were taken at 4 stations, at 15

day intervals, from December 15, 1960, to August 3, 1961.

Station I was clean, whereas about 90 per cent of the area below Station I was heavily polluted by wastes from several paper industries, some other industries and one municipal sewage treatment plant.

Samples of water were taken concurrently with plankton samples and analyzed for dissolved oxygen, sulfates, total phosphates, iron (atomic), nitrates, nitrites, ammonia nitrogen, and turbidity. Hydrogen ion activity was determined, and water and air temperatures noted.

Station I never had less than 5.1 ppm of dissolved oxygen, whereas at the other stations, dissolved oxygen ranged from 2.1 to 0.0 ppm during the summer months. Oxygen depletion was largely due to oxidation of organic pollutants.

Ammonia nitrogen fluctuated with water discharge so that its effect on the rotifers was masked. However, wastes from the municipal sewage plant contributed the greatest share of this chemical as indicated by the consistently high concentrations at Stations II to IV. Concentrations varied from 0.31 to 1.30 ppm at Station I and from 1.11 to 3.64 ppm at the other stations (inclusive). Nitrite concentrations varied from 0.02 to 0.22 ppm at Station I and from 0.00 to 0.39 ppm at the other stations (inclusive), reaching the highest concentration at Station IV.

Sulfates in the Kalamazoo River are derived mainly from Coldwater Shale and appeared in large concentrations (45 - ?170 ppm). On three occasions sharp increases in concentration were noted for which no explanation could be given.

The maximum concentration of iron was 1.86 ppm at Station II. Glacial drift and bog ore are responsible for the large concentrations of iron in the Kalamazoo area.

Phosphate concentrations decreased rapidly from winter to summer, mainly because bacteria and other phytoplankters utilized phosphorus more rapidly when their numbers increased in the summer.

The pH of the water in the study area fluctuated around 7, usually remaining above. In the winter pH was lower at Station I than at the other stations; however, just the reverse occurred in summer.

On three occasions samples were taken at 6-hour intervals in a 24 hour period and analyzed for the minerals discussed previously. Total phosphate concentration often increased at 6-7 PM at all stations. The cause of this increase is not known. Sharp increases in ammonia nitrogen occurred from Station I to Station II.

The bulk of the rotifers found in the study area developed in Marrow Lake, an impoundment 3/4 mile above Station I.

A total of 25 species of rotifers representing 17 genera were identified from the plankton. *Philodina* sp., a littoral form, was the most persistent rotifer throughout the study. Heavy concentrations of paper fibers seemingly were responsible for the persistence of *Philodina* in suspension.

Members of the genus *Brachionus* were most abundant of all rotifers during May, June, and July. *B. calyciflorus* was the most abundant species of the genus and attained a population of 776 per liter at Station I on June 8.

The sporadic appearance of *Keratella cochlearis* in the Kalamazoo River indicated that conditions were not always salutary. The maximum number found was 56 per liter at Station I on June 22.

Rotifers which showed tolerance of pollutants in the Kalamazoo River were: *Philodina* sp., *Brachionus plicatilis*, *B. quadridentatus* and *Keratella quadrata*. The intolerant forms were: *Brachionus angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. caudatus vulgatus*, *Notholca striata*, *Filinia longiseta*, and *Hexarthra mira*. No judgement could be made for many other rotifers, either because they occurred in such small numbers or because they appeared to be borderline cases.

The Kalamazoo River has a smaller number of rotifers than some other streams. The paucity is explained by the following: (1) Waste materials from Battle Creek, 30 miles upstream from Station I, depressed the growth of rotifer populations there and the population remaining had insufficient time to "re-build" before reaching Station I. (2) Although Marrow Lake was the source of the bulk of the rotifers, they may not have been detained there long enough to develop maximum potential populations. (3) Pollutants in the study area had deleterious effects on the rotifers.

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APPENDIX I.

TABULAR SUMMARIES OF BI-WEEKLY PHYSICAL DATA

Dates	D.O. ppm	% Sat. D.O.	Temperatures °C Water	Air	pH	Turbidity ppm	Discharge (cfs) at Comstock	Sulfates ppm	Total Phosphates ppm	Iron, Atomic ppm	Nitrates ppm	Nitrites ppm	Ammonia Nitrogen ppm
15 Dec. 1960	10.2	79	5	1	7.2	---	578	66	.45	.35	1.12	.06	.61
5 Jan. 1961	9.0	70	5	-5	7.4	7	500	71	.82	.25	1.08	.02	1.20
19 Jan.	10.5	84	6	-6	7.1	6	488	59	1.20	.41	1.26	.04	1.23
2 Feb.	7.8	56	2	-17	7.3	4	440	62	.64	.29	.89	.06	1.30
16 Feb.	9.1	71	5	-2	7.7	10	563	60	.84	.29	.86	.22	.89
2 Mar.	8.5	69	7	4	7.7	12	669	56	.36	.35	.89	.04	.89
16 Mar.	10.7	81	4	-5	7.6	20	1320	140	.26	.55	1.55	.05	.80
30 Mar.	10.0	84	8	1	7.9	23	784	80	.25	1.32	1.90	.05	.75
13 Apr.	12.0	103	9	7	8.1	21	693	70	.18	.35	.86	.04	.41
27 Apr.	9.7	89	12	13	7.9	25	1880	84	.15	.26	1.42	.03	.97
11 May	10.7	107	16	14	8.2	24	1100	70	---	.26	.67	.05	.57
25 May	12.5	139	21	20	8.3	29	620	178	.09	.48	---	.03	1.20
8 Jun.	7.5	90	25	21	8.0	19	615	53	.23	.38	.02	.02	.37
22 Jun.	9.0	104	23	23	7.9	26	507	48	.21	.38	.40	.09	.23
6 July	5.7	67	25	23	7.6	21	385	48	.28	.22	.12	.06	.84
20 July	5.1	63	27	28	7.7	26	405	46	.23	.31	.00	.09	.75
3 Aug.	7.0	83	24	20	7.9	28	551	45	.42	.45	.10	.03	.31

Summary of physical data from Station I

Dates	D.O. ppm	% Sat. D.O.	Temperatures °C Water	Air	pH	Turbidity ppm	Discharge (cfs) at Comstock	Sulfates ppm	Total Phosphates ppm	Iron, Atomic ppm	Nitrates ppm	Nitrites ppm	Ammonia Nitrogen ppm
15 Dec. 1960	9.1	73	6	2	7.8	---	578	80	.25	1.36	.73	.26	2.27
5 Jan. 1961	9.0	67	4	-4	7.5	120	500	73	.49	1.40	1.12	.00	2.50
19 Jan.	9.0	70	5	-5	7.4	145	488	78	.82	1.36	1.17	.01	3.64
2 Feb.	8.5	61	2	-15	7.3	250	440	170	.28	1.70	1.08	.00	3.50
16 Feb.	8.1	63	5	-2	7.8	145	563	71	.61	1.40	1.26	.05	2.50
2 Mar.	7.7	62	6	5	7.8	125	669	82	.37	1.16	1.17	.01	1.82
16 Mar.	9.7	73	4	-4	8.1	92	1320	95	.34	.91	1.64	.02	1.47
30 Mar.	8.0	67	8	2	7.9	145	784	86	.20	1.50	1.79	.02	3.60
13 Apr.	9.7	83	9	8	7.9	156	693	75	.25	1.28	.89	.02	2.18
27 Apr.	8.7	80	12	15	7.8	74	1880	48	.11	.54	1.55	.04	1.27
11 May	7.7	77	16	15	8.0	131	1100	78	---	.85	.71	.16	2.27
25 May	5.2	55	19	20	7.9	163	620	84	.15	1.10	.15	.00	1.60
8 Jun.	1.4	16	24	21	7.5	156	615	62	.05	1.60	.15	.00	1.95
22 Jun.	2.0	22	22	20	7.4	174	507	65	.03	1.56	.39	.06	2.18
6 July	1.5	17	25	23	7.3	135	385	65	.11	1.23	.26	.01	2.37
20 July	0.1	1	28	26	7.1	212	405	71	.02	1.42	.00	.00	2.50
3 Aug.	0.2	2	25	22	7.4	185	551	60	.16	1.86	.20	.00	1.95

Summary of physical data from Station II

Dates	D.O. ppm	% Sat. D.O.	Temperatures °C Water	Temperatures °C Air	pH	Turbidity ppm	Discharge (cfs) at Comstock	Sulfates ppm	Total Phosphates ppm	Iron, Atomic ppm	Nitrates ppm	Nitrites ppm	Ammonia Nitrogen ppm
15 Dec. 1960	6.0	49	7	2	7.8	---	578	86	.23	1.16	.57	.35	1.50
5 Jan. 1961	6.2	48	5	-2	7.6	124	500	86	.34	1.28	.94	.00	1.95
19 Jan	5.7	45	6	-4	7.5	135	488	84	.32	1.28	1.12	.02	2.50
2 Feb.	6.6	47	2	-15	7.3	140	440	101	.23	1.23	.86	.04	2.37
16 Feb.	6.2	49	6	-2	7.8	140	563	75	.59	1.10	.97	.03	2.02
2 Mar.	6.5	53	7	6	7.9	128	669	90	.30	1.02	.94	.03	1.55
16 Mar.	8.9	67	4	-3	8.1	92	1320	88	.21	.79	1.70	.01	1.23
30 Mar.	6.4	55	9	3	7.7	168	784	88	.15	1.50	1.37	.01	2.10
13 Apr.	5.0	43	9	8	7.8	158	693	84	.11	1.40	.73	.04	2.10
27 Apr.	7.5	69	12	15	7.6	82	1880	98	.05	.48	1.42	.05	1.70
11 May	3.2	32	17	17	8.0	135	1100	80	---	.82	.25	.06	1.76
25 May	0.7	7	20	20	7.8	128	620	82	.00	.91	.12	.00	1.76
8 Jun.	0.0	0	25	22	7.6	131	615	86	.10	1.06	.12	.00	1.95
22 Jun.	0.3	3	22	20	7.4	98	507	70	.13	.86	.21	.03	1.76
6 July	0.2	2	25	24	7.2	105	385	75	.03	1.06	.14	.00	2.18
20 July	0.0	0	28	27	7.0	140	405	73	.01	1.10	.14	.00	2.50
3 Aug.	0.0	0	25	22	7.4	163	551	78	.21	1.56	.12	.07	2.10

Summary of physical data from Station III

Dates	D.O. ppm	% Sat. D.O.	Temperatures °C Water	Air	pH	Turbidity ppm	Discharge (cfs) at Comstock	Sulfates ppm	Total Phosphates ppm	Iron, Atomic ppm	Nitrates ppm	Nitrites ppm	Ammonia Nitrogen ppm
15 Dec. 1960	5.8	46	6	2	7.8	---	578	82	.21	.79	.88	.39	1.88
5 Jan. 1961	6.5	49	4	0	7.6	85	500	84	.40	1.06	1.03	.05	1.47
19 Jan.	5.0	39	5	-3	7.6	110	488	80	.26	1.10	1.17	.03	1.76
2 Feb.	6.6	47	2	-15	7.3	135	440	93	.32	1.10	.94	.06	1.76
16 Feb.	5.0	39	5	-2	7.8	118	563	80	.66	.99	1.08	.07	1.65
2 Mar.	5.5	45	7	7	7.9	102	669	78	.26	1.02	1.62	.04	1.23
16 Mar.	7.8	59	5	-1	8.1	76	1320	90	.37	.65	1.84	.02	1.11
30 Mar.	5.6	48	9	4	7.8	125	784	86	.26	.58	1.90	.07	1.65
13 Apr.	5.8	50	9	10	7.8	108	693	78	.49	1.02	.58	.04	1.60
27 Apr.	6.3	57	12	17	7.6	74	1880	63	.11	.48	1.48	.04	1.60
11 May	5.0	50	16	15	7.8	62	1100	82	---	.50	.44	.16	1.14
25 May	1.6	16	20	22	7.8	92	620	80	.09	1.17	.15	---	1.88
8 Jun.	0.0	0	24	23	7.5	98	615	65	.01	.95	.08	.13	2.10
22 Jun.	1.0	10	21	20	7.4	74	507	60	.04	1.16	.35	.03	1.55
6 July	2.1	24	24	25	7.2	68	385	84	.03	.65	.20	.01	1.82
20 July	0.0	0	26	27	7.1	118	405	60	.05	.78	.02	.04	2.50
3 Aug.	0.3	3	25	22	7.4	125	551	53	.42	1.28	.14	.00	2.18

Summary of physical data from Station IV

APPENDIX II.

TABULAR SUMMARIES OF 24-HOUR TESTS

	Station I				Station II				Station III				Station IV			
	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM
Dissolved oxygen ppm	11.0	11.6	11.2	10.7	9.9	10.6	10.6	8.9	6.5	6.8	6.6	5.4	5.1	4.5	5.5	5.2
Per cent Saturation-D.O.	88	101	95	85	83	95	94	77	56	59	57	46	44	38	47	44
Water temperature °C	6.0	9.5	8.0	6.0	8.0	11.0	10.0	9.0	9.0	10.0	10.0	9.0	9.5	9.5	9.0	9.0
Air temperature °C	10.0	4.5	1.0	1.0	6.5	6.0	3.0	0.0	7.5	5.0	3.0	1.0	9.5	4.5	3.0	2.0
pH	7.5	8.0	8.0	7.9	7.7	7.9	7.9	7.7	7.7	7.8	7.7	7.6	7.5	7.6	7.7	7.7
Turbidity ppm	17	23	21	24	128	102	131	156	158	94	114	135	125	145	135	110
Sulfates	71	73	71	65	82	82	75	80	86	88	88	86	90	84	86	84
Total phosphates ppm	.21	.42	.21	.20	.28	.79	.25	.23	.05	.59	.15	.18	.05	.64	.13	.16
Iron (Atomic) ppm	.41	.45	.23	.61	1.16	.99	.85	1.40	1.40	.91	.69	1.10	1.16	1.25	.56	.95
Nitrates ppm	1.55	1.17	1.62	1.48	1.37	1.00	1.31	1.48	.94	1.26	1.22	1.22	1.03	.69	1.03	1.03
Nitrites ppm	.03	.04	.04	.02	.02	.04	.02	.00	.02	.03	.02	.01	.06	.07	.04	.04
Ammonia nitrogen	.65	.69	.49	.80	1.82	1.51	1.82	1.95	1.42	1.30	1.55	1.70	1.42	1.55	1.30	1.42

Diel variations - April 6-7, 1961

	Station I				Station II				Station III				Station IV			
	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M
Dissolved oxygen	6.5	6.8	6.7	5.9	0.8	3.3	3.2	2.2	0.0	0.0	0.0	0.0	0.6	0.6	0.6	1.5
Per cent saturation-D.O.	73	80	80	69	8	37	37	25	0	0	0	0	5	6	6	16
Water temperature	22	24	25	24	23	22	25	24	22	23	23	23	21	23	24	21
Air temperature	10	14	14	13	11	17	16	11	12	16	16	8	12	15	18	10
pH	7.9	7.9	7.9	7.9	7.8	7.8	7.7	7.6	7.7	7.5	7.7	7.5	7.7	7.5	7.5	7.5
Turbidity	26	23	20	20	168	128	102	145	156	135	92	94	108	102	120	86
Sulfates	51	48	41	48	55	56	50	55	59	62	70	70	60	62	57	57
Total phosphates	.36	.37	.53	.23	.23	.13	.25	.05	.28	.05	.13	.05	.36	.11	.03	.16
Iron (Atomic)	.20	.23	.48	.55	1.14	.85	.99	1.23	.72	.78	.71	.71	.51	.60	.91	.65
Nitrates	.20	.18	.17	.12	.26	.28	.22	.27	.16	.09	.12	.14	.15	.24	.15	.07
Nitrites	.06	.07	.06	.08	.05	.04	.06	.04	.00	.02	.12	.00	.00	.04	.00	.06
Ammonia nitrogen	.69	.75	.67	.80	1.65	1.76	1.42	1.65	4.36	1.51	1.34	1.23	1.42	1.47	1.76	1.23

Diel variations - June 15-16, 1961

	Station I				Station II				Station III				Station IV			
	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M	6 AM	12 N	6 PM	12 M
Dissolved oxygen	7.8	7.2	7.7	6.4	1.3	3.2	3.7	2.4	0.0	0.0	0.0	0.0	0.9	0.3	0.0	0.0
Per cent saturation-D.O.	94	90	95	80	21	39	45	29	0	0	0	0	10	3	0	0
Water temperature	25	27	27	28	26	27	27	27	25	26	25	26	24	24	25	24
Air temperature	19	20	22	20	18	20	22	20	18	21	22	20	19	22	21	19
pH	7.9	7.9	7.9	7.7	7.4	7.4	7.4	7.3	7.4	7.3	7.3	7.3	7.3	7.2	7.2	7.2
Turbidity	30	34	33	30	149	125	140	163	135	192	174	140	135	120	205	174
Sulfates	50	46	41	42	59	56	44	57	73	78	70	62	80	66	57	59
Total phosphates	.18	.18	.28	.28	.00	.00	.18	.07	.10	.00	.30	.13	.36	.20	.15	.02
Iron (Atomic)	.83	.55	.16	.41	1.90	1.32	1.02	1.56	2.50	1.56	.99	1.28	1.06	.91	1.20	1.36
Nitrates	.04	.04	.05	.11	.20	.15	.16	.21	.15	.16	.15	.15	.15	.15	.19	.16
Nitrites	.01	.02	.02	.02	.00	.02	.00	.00	.01	.00	.00	.02	.00	.00	.00	.00
Ammonia nitrogen	0.00	0.27	0.33	0.65	1.47	1.95	1.82	1.95	1.65	2.27	2.27	1.88	1.23	1.95	2.18	1.95

Diel variations - August 1-2, 1961

APPENDIX III.

TABULAR SUMMARIES OF ROTIFERS

Dates	Asplanchna sp.	Brachionus angularis	B. budapestinensis	B. calyciflorus	B. caudatus vulgatus	B. plicatilis	B. quadridentatus	Filinia longiseta	Gastropus stylifer	Hexarthra mira	Keratella cochlearis	K. quadrata	Notholca striata	Philodina sp.	Platyias patulus	Polyarthra trigla	Synchaeta spp. (stylata, pectinata, tremula)	Unknown	Totals
12-15-60									+					1					1
1-5-61														0.5					0.5
1-19-61						0.5								1					1.5
2-2-61													0.5	3					3.5
2-16-61												0.5	+	1		+			1.5
3-2-61													1	31			+		32
3-16-61													1	12		1			14
3-30-61								1			0.5		6	44		1	2		54.5
4-13-61									3		1	3	6	12		4	7		33
4-27-61								1	2		5		2	14		2	8		35
5-11-61				6				2			13	3				5	14		45
5-25-61				390		38		2			38	3	2	4.4		26	98.5		602
6-8-61	70			776		26		5			7			10			53		1017
6-22-61				644	21	21	42	84		154	56					70			1092
7-6-61	14		7	56	26	7		42		290	21				7	70			513
7-20-61	14	35			28		7			88	35				21	7		7	242
8-3-61		4									7			4		11			26

Summary of Rotifers per liter - Station I.

+ Trace.

Dates	Asplanchna sp.	Brachionus angularis	B. budapestinensis	B. calyciflorus	B. caudatus vulgatus	B. plicatilis	B. quadridentatus	Filinia longiseta	Gastropus stylifer	Hexarthra mira	Keratella cochlearis	K. quadrata	Notholca striata	Philodina sp.	Polyarthra trigla	Synchaeta spp.	Unknowns	Totals
12-15-60														2				2
1-5-51														1				1
1-19-61													0.5	3				3.5
2-2-61													0.5	0.5				1
2-16-61														7				7
3-2-61													0.5	17	0.5			18
3-16-61								0.5			1		0.5	17	0.5			19.5
3-30-61									0.5		1		9	27	0.5	1		39
4-13-61								1	1		2	2	2	22	1	6		37
4-27-61								6	4		7	2	7	44	5	10	1	86
5-11-61				1							19	2		10	2	6		40
5-25-61				280		48			2		42			9	17	35		433
6-8-61	79			560		31		2.4			26			2.4	2.4	160		863
6-22-61	7			140		42	21	56		28	42				7	7		350
7-6-61			4	61	22		4	25		54	29				72	25		296
7-20-61		28								7								35
8-3-61											4				32			36

Summary of Rotifers per liter - Station II.

Dates	*Asplanchna* sp.	*Brachionus angularis*	*B. calyciflorus*	*B. caudatus vulgatus*	*B. plicatilis*	*B. quadridentatus*	*Euchlanis* sp.	*Filinia longiseta*	*Gastropus stylifer*	*Hexarthra mira*	?*Itura* sp.	*Keratella cochlearis*	*K. quadrata*	*Lepadella* sp.	*Notholca striata*	*Philodina* sp.	*Polyarthra trigla*	*Synchaeta* spp.	Unknowns	Totals
12-15-60																43				43
1-5-61					0.5											9				9.5
1-19-61																18				18
2-2-61																				*
2-16-61																23				23
3-2-61															0.5	22	0.5			23
3-16-61								0.5							1	28	1			30.5
3-30-61								1				1	3		12	92	6			115
4-13-61								1				2			3	29	3	3		41
4-27-61								3	4		3	10	1		2	25	4	14		66
5-11-61			1					1				26	2			21	3	3	1	58
5-25-61			235		100				2			4.4	2		2	30	9	30		414
6-8-61	26		450		14.4							22				22	2.4	94		630
6-22-61			154	7	42	28		28		21		42				28	42			406
7-6-61			86	40	32	4	4	7		32		25				14	29			341
7-20-61		14				7				14		14		7		+				56
8-3-61		4														4	7			15

Summary of Rotifers per liter - Station III.

*Sample lost.

Dates	Asplanchna sp.	Brachionus angularis	B. bennini	B. calyciflorus	B. caudatus vulgatus	B. plicatilis	B. quadridentatus	Filinia longiseta	F. brachiata	Gastropus stylifer	Hexarthra mira	Keratella cochlearis	K. quadrata	Lapadella sp.	Monostyla crenata	Notholca striata	Philodina sp.	Platyias patulus	Polyarthra trigla	Synchaeta spp.	Trichocera sp.	Trichotria sp.	Unknowns	Totals
12-15-60																	106							106
1-5-61																	32							32
1-19-61																	38						1	39
2-2-61																	22							22
2-16-61												0.5					39							39.5
3-2-61																0.5	22							22.5
3-16-61												+	0.5			3	31			1				35.5
3-30-61								3		3		3	3			9	56		13				1	91
4-13-61						1				1			3			5	34		4	4				52
4-27-61								1		2		6	1			6	27		2	7				52
5-11-61										1		20	1		1		18		1	6			1	49
5-25-61				240		63						32	3				120		3	12				473
6-8-61	43		12	481		7						34					41		5	55		5		683
6-22-61	14			266		7	28		7		7	7					21		42	7				406
7-6-61				32	14	4	4	18			29	7					4		25	47	4			188
7-20-61	7	7		7	14	14	7	7			21			7			14		14					119
8-3-61																	7	7	18					32

Summary of Rotifers per liter - Station IV.

+ Trace.