SOME FACTORS INFLUENCING ZOÖPLANKTON DISTRIBUTION IN THE HOCKING RIVER[1]

LYNN HUTCHISON
Northwestern University and Ohio University

The Hocking River is located in southeastern Ohio and is a tributary of the Ohio River into which it flows about 28 miles below Marietta, Ohio. The drainage area of the river is described by Roach (1931).

The following methods and apparatus were employed during the investigation. Sixteen sampling stations were established along the river, as indicated on a map of the Hocking River (fig. 1). Stations 1 and 2, near the source of the stream, were chosen as representative of a young and unpolluted stream. Stations 3, 4, and 5 were chosen as representative of a young stream greatly polluted by organic wastes from the city of Lancaster. Stations 8, 10, and 12 represent a stream into which organic wastes are emptied from towns smaller than Lancaster and where there is a pronounced increase in the volume of water; therefore, the degree of pollution is not as great as at Stations 3 and 4 due to a decreased amount of sewage and to the dilution of the wastes. Stations 6, 7, and 9 represent a maturing stream not appreciably affected by wastes. At Station 11 the stream is polluted with mine wastes flowing in from Sunday Creek, a sizeable tributary of the Hocking. At Station 13 a dam renders the water very sluggish, although the river has not yet taken on the characteristics of an old stream. Stations 14, 15, and 16 were chosen as representative of a comparatively old stream.

Samples of water were taken from the river at these sixteen stations at intervals of one month for a period of twelve months, starting November, 1935. Samples were taken from the river about eight feet from the edge. Twenty liters of water were dipped from the river and strained through silk bolting cloth, No. 12 mesh. The residue was preserved in 10% formaldehyde.

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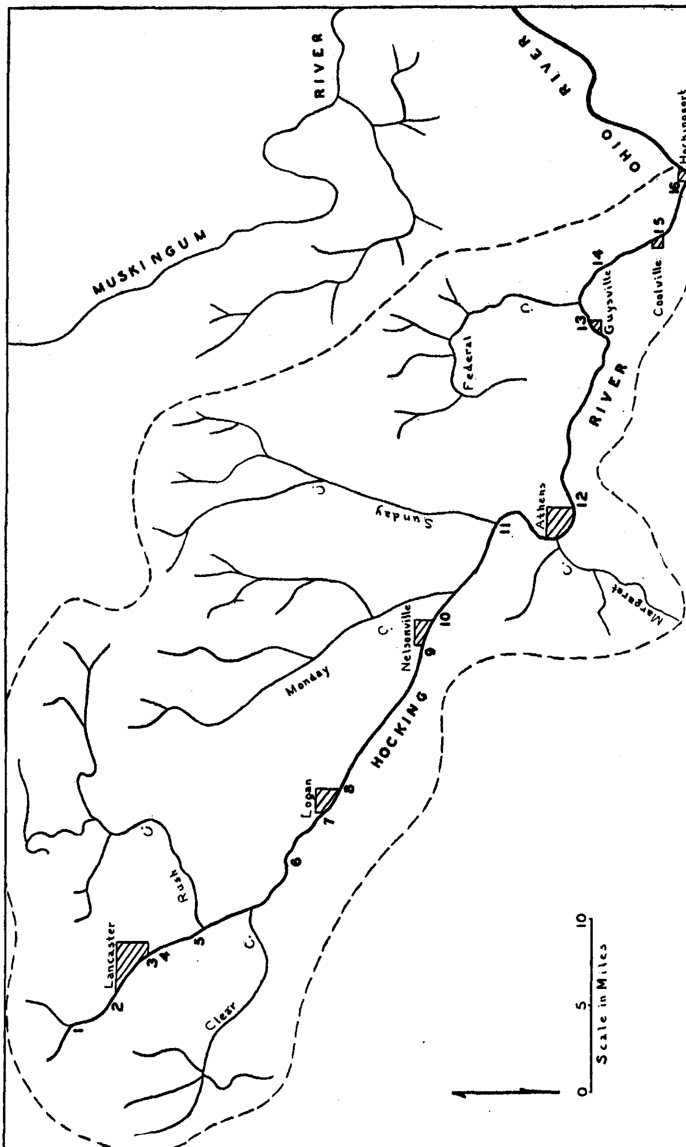

Fig. 1. Drainage area of the Hocking River. Broken line encloses the area. Numbers 1–16 indicate points where samples were taken from the river.

In the laboratory each sample was centrifuged for two minutes at a rate of 1500 revolutions per minute. A drop of the plankton which had been thrown to the bottom of the centrifuge vials was then placed in a Sedgwick-Rafter counting chamber and a quantitative and qualitative study made. As a rule, three

TABLE I

ZOÖPLANKTON ORGANISMS FOUND IN THE HOCKING RIVER

- PROTOZOA
  - Sarcodina
    - Arcella
    - Difflugia
  - Mastigophora
    - Ceratium
    - Eudorina
    - *Euglena
    - Gonium
    - *Pandorina
    - Phacus
    - Volvox
  - Infusoria
    - *Colpidium
    - Paramecium
    - Stentor
    - Stylonichia
    - Euplotes
    - Urocentrum
    - Vorticella
- TROCHFLMINTHES
  - Rotifera
    - *Anuraea
    - Asplanchnia
    - Brachionus
    - Cathypna
    - Diglena
    - Diplois
    - Monostyla
    - *Noteus
    - Notops
    - Pedetes
    - Pedalion
    - Philodina
    - *Polyarthra
    - Pterodina
    - Rattulus
    - *Rotifer
    - Triarthra
- NEMATHELMINTHES
  - Nematoda
- ANNELIDA
  - Chaetopoda
    - Chaetogaster
    - Dero
    - Naidium
    - Nais
    - Limnodrilus
    - Stylaria
    - Tubifex
- ARTHROPODA
  - Crustacea
    - Cladocera
      - Alona
      - Bosmina
      - Ceriodaphnia
      - Chydorus
      - Daphnia
      - Pleuroxus
    - Copepoda
      - Canthocampus
      - *Cyclops
      - Diaptomus
  - Insecta
    - Chironomid larvae
  - Arachnida
    - Macrobiotus

*Genera represented by an average of one organism per liter of water throughout the year.

samples were examined from each centrifuged sample. Identification was limited to genera (Ward and Whipple, 1918).

The H-ion concentration was measured by the LaMotte colorimeter. Samples of water for dissolved oxygen determination were taken during the months of February, March, April, May, June, and October. These samples were obtained with the Forest water bottle and also by immersing a sampling bottle in the water so that the water filled the bottle from the bottom upward. Determinations were carried out by the Winkler method.

Temperature of the air and water was taken at each station and recorded in degrees Centigrade. A record of the daily river height, precipitation, and temperature at Athens, 65 miles from the source of the river (Station 12) was obtained from the Athens Weather Bureau for the period of time under investigation.

THE PLANKTON

Fifty-two genera of zoöplankton organisms representing five phyla were identified during the investigation. The classification of these organisms appears in Table I. Of these, only eight genera were represented by an average of one organism per liter of water throughout the year. An asterisk has been placed before these eight genera in the classification table.

THE LONGITUDINAL DISTRIBUTION OF PLANKTON

The quantitative distribution of the plankton at the various stations is shown in Table II. At the bottom of this chart is a total of the number of genera represented by the occurrence of one or more individuals per liter of water at each station during the investigation. The greatest number of genera represented by more than one individual per liter was found at Stations 3, 4, 12, 13, and 14; Stations 5, 11, 15, and 16 rank next; Stations 6, 7, 8, 9, and 10 were represented by still fewer. At Stations 1 and 2 no genus was represented by more than one individual per liter.

Considering the average number of plankters per liter of water, as shown in Table III, it was found that Stations 3, 4, 12, and 13 were most abundantly populated, with an average of more than 80 plankters per liter of water. Stations 5, 8, 14, and 15 ranked next. Stations 6, 7, 9, 10, 11, and 16 were populated by an average of less than 21 individuals per liter. Stations 1 and 2 rank lowest.

Combining the results of these two aspects of quantitative distribution, namely, the number of genera represented by more than one individual per liter and the average number of plankters per liter, it will be seen that Stations 3, 4, 12, and 13 are indisputably the most abundantly populated, while at Stations 1 and 2 plankters were least abundant.

A compilation of the physical and chemical data, excluding the amount of dissolved oxygen and the H-ion concentration,

TABLE II

COMPOSITION OF THE PLANKTON LONGITUDINALLY

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arcella	–	–	–	–	–	–	–	–	–	x	x	xx	xx	xx	x	x
Colpidium	–	–	xx	xx	xx	x	xx	xx	xx	xx	xx	xxx	xx	–	x	x
Difflugia	–	x	–	–	–	–	–	–	–	–	–	–	x	x	–	–
Eudorina	.	.	.	.	–	–	–	–	.	–	.	.	xx	xx	xx	x
Euglena	–	–	xxx	xxx	x	x	xxx	xxx	xxx	xx	xx	x	–	–	.	–
Pandorina	–	–	–	.	–	–	–	–	x	x	xx	xxx	xxx	xxx	xxx	–
Paramecium	–	–	xxx	xx	xx	–	–	–	–	–	–	–	–	–	–	–
Stentor	.	–	–	xx	x	–	–	–	.	.	.	.	–	.	.	.
Euplotes	–	–	–	x	–	–	–	–	–	.	–	–	.	.	.	.
Vorticella	–	–	–	xx	x	x	–	–	–	–	–	–	–	–	–	–
Anuraea	–	–	–	–	.	–	.	–	–	–	–	x	xx	xxx	xx	xx
Brachionus	–	–	–	–	x	–	–	–	–	–	–	xx	xx	xx	x	x
Cathypna	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Monostyla	–	–	.	–	.	–	.	–	–	.	.	–	–	xx	–	–
Noteus	–	–	.	.	–	–	.	–	–	–	–	xx	xxx	xx	xx	xxx
Notops	–	.	–	–	–	–	–	–	–	–	–	x	xx	x	–	–
Philodina	–	–	xx	xx	xx	x	–	–	–	–	–	–	–	–	–	–
Polyarthra	–	–	.	.	.	.	.	–	–	–	xx	xxx	xxx	xx	–	.
Pterodina	–	–	–	–	–	–	–	.	–	–	–	–	.	–	.	–
Rattulus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rotifer	–	x	xxx	xxx	xxx	xx	xx	xx	x	x	xx	xx	xx	x	x	xx
Triarthra	–	–	–	.	–	.	–	–	.	–	–	x	–	–	.	–
Nematoda	–	x	xx	xx	x	x	x	x	–	–	x	xx	xx	x	x	–
Annelida	–	–	–	–	–	–	–	.	.	.	–	–	–	.	–	–
Cladocera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Copepoda	–	–	–	–	–	–	–	x	x	x	x	xx	xx	xx	xx	xx
Insecta	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–
Genera with more than one individual per liter	0	0	6	8	4	2	2	3	2	2	5	9	12	10	5	4

xxx More than five individuals per liter.
xx One to five individuals per liter.
x Five-tenths of one to one individual per liter.
– Less than five-tenths of one individual per liter.
. Absent.

as it appeared at each station, is included in Table III. An analysis of these factors follows.

The Hocking River, although not as rapid a stream as a number of others in the state, moves along without marked retardation over most of its course. Only at Station 13, where its flow is retarded by a dam, and at Station 16, where it empties into the Ohio River, does the river become sluggish. At station 13 there were, on an average, eighty plankters per liter of water. However, with this exception, there is no pronounced increase in the average number of plankters in the lower portion of the river where the flow is somewhat retarded as compared with its rapid flow in the upper portion (Table III).

The temperature in the lower portion of the stream averaged slightly higher than the temperature at the stations near the

TABLE III

Physical and Chemical Factors as they Occur at Each Station

Stations	Rate of Flow Determined by Topography	Yearly Averages of Temperature of Water	Age of Stream	Average Plankters Per Liter
1	Rapid	12.0° C.	Young	2.0
2	Rapid	14.3° C.	Young	2.5
3	Rapid	14.8° C.	Old	345.0
4	Rapid	14.5° C.	Old	194.0
5	Rapid	13.5° C.	Mature	27.0
6	Rapid	13.8° C.	Adolescent	10.0
7	Rapid	13.7° C.	Mature	21.0
8	Rapid	14.2° C.	Old	40.0
9	Rapid	14.8° C.	Mature	20.0
10	Rapid	14.7° C.	Adolescent	8.5
11	Rapid	14.0° C.	Adolescent	15.0
12	Retarded	14.9° C.	Old	94.0
13	Sluggish*	15.4° C.	Old	80.0
14	Retarded	15.0° C.	Old	40.0
15	Retarded	15.2° C.	Mature	28.0
16	Sluggish†	16.1° C.	Mature	17.0

*Dam.
†Backwater.

source of the stream. It is apparent that the higher temperature and the abundance of plankters per liter in the lower portion of the river correlate closely (Table III).

"Old" age of the stream, in the sense used in Table III, refers to any region of the river where it becomes productive, as indicated by the great increase in the number of plankters. Regions where the stream was not productive were designated as "young," "adolescent," or "mature" regions, depending on the number of plankters present. It has been pointed out that the plankton was abundant at various stations in the lower half of the river; therefore, those regions were designated as being old. A somewhat retarded rate of flow and higher temperature can be correlated with the productivity at these stations. Furthermore, Stations 3 and 4 were highly productive; therefore, they too might be considered as old regions of the stream. Retarded rate of flow and higher temperature of water cannot be correlated with the productivity at these stations. It will be recalled, however, that at Station 3, just below the city of Lancaster, the river receives a great amount of domestic sewage. Again, at Station 8, below the town of Logan, and at Station 12, just below the city of Athens, a large amount of domestic sewage is emptied into the river. Here, too, are productive regions of the river. Therefore, it seems apparent that a region may be rendered productive by addition of domestic sewage. In fact, such addition seems to counteract detrimental effects of rapid rate of flow and lower temperature as found at Stations 3 and 4. Sewage probably stimulates productivity directly by acting as food, and indirectly by rendering conditions favorable for increases in bacteria which in turn act directly as food.

The productivity of the river at Station 10, below the town of Nelsonville, is an exception to the statement that organic wastes act as stimulators of productivity. However, the influence of mine and brick plant wastes can, in all probability, account for this deviation.

The dissolved oxygen content of the water was lowest at those stations where the greatest number of organisms occurred and where sewage disposal was greatest. This might be expected, for the greater the number of organisms present, and the greater the amount of sewage, the more oxygen consumed.

The H-ion concentration varied so slightly throughout the course of the stream that effects were not apparent.

The qualitative distribution of the plankton genera appearing most abundantly is indicated by fig. 2. The figure shows that certain forms were more characteristic of some portions of the river than of others. Forms such as *Paramecium*, *Stentor*, *Euplotes*, *Vorticella*, and *Philodina* seem to be characteristic of the upper portions of the stream, especially at Stations 3, 4 and 5. Forms such as *Arcella*, *Eudorina*, *Pandorina*, *Anuraea*, *Brachionus*, *Noteus*, *Polyarthra*, *Copepoda*, and insect larvae appeared more often in the lower portions of the stream, Stations 11 to 16.

Since Stations 3 and 4 are rendered productive, quantitatively speaking, by domestic sewage, it seems probable that the qualitative nature of the distribution at those points is also, at least in part, determined by pollution. Forms such as *Stentor* and *Euplotes* were found to be present in this region of the

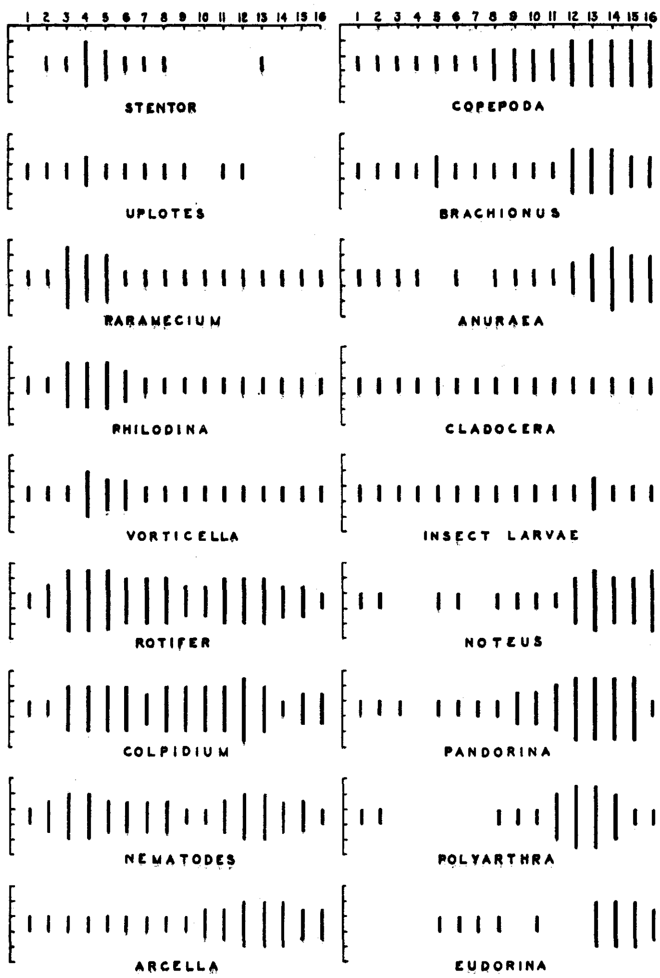

Fig. 2. Qualitative distribution of zoöplankton organisms.
- less than five tenths of one individual per liter.
- five tenths to one individual per liter.
- one to five individuals per liter.
- more than five individuals per liter.

stream and to disappear entirely in the lower regions. In addition, *Paramecium*, *Philodina*, and *Rotifer* might be considered as abundant forms in regions of high sewage concentration. On the other hand, forms such as *Polyarthra* and *Eudorina* were never found in this region where sewage was concentrated. However, they appeared in great numbers at Station 12 where the amount of sewage disposed is great; but it must be kept in mind that the concentration of pollution at that station is greatly altered by an increase in the amount of water. The river is approximately three times as wide and four times as deep at Station 12 as at Station 3.

Following a model by Wiebe (1927), Table IV has been made, the purpose being to indicate, by numbers representing abundance, the qualitative distribution of zoöplankters with reference to degree of pollution. It can be stated that these results correspond favorably with those of Wiebe.

TABLE IV

MOST ABUNDANT ZOÖPLANKTERS AT EACH GROUP OF STATIONS

Genus	Group I Rank	Group II Rank	Group III Rank	Genus	Group I Rank	Group II Rank	Group III Rank
Arcella	3	2	2	Anuraea	......	2	1
Eudorina	......	2	1	Brachionus	3	2	2
Euglena	1	1	2	Noteus	......	2	2
Pandorina	......	1	1	Notops	3	2	2
Colpidium	2	2	2	Philodina	1	2	2
Paramecium	1	2	1	Polyarthra	......	2	1
Stentor	4	......	......	Rotifer	1	2	2
Nematode	2	2	2	Cyclops	3	2	2

Group I—Extremely polluted stations 3, 4, and 5.
Group II—Moderately polluted stations 8, 10, 12, and 13.
Group III—Comparatively unpolluted stations 6, 7, 9, 11, 14, 15, and 16.
Rank 1—very abundant; Rank 2—present; Rank 3—scarce; and Rank 4—present only in one portion.

Degree of pollution can be considered, then, as a factor partially responsible for both the quantitative and qualitative distribution of plankton along the course of the Hocking. Retarded rate of flow, size of stream as influencing degree of pollution, and higher temperature must also be considered as partially responsible for distribution, especially of such forms as *Pandorina*, *Polyarthra*, the cladoceran *Chydorus*, and insect larvae.

DISTRIBUTION BY MONTHS

Figure 3 shows that the plankton was more abundant during the summer and autumn months (June to December), than during the winter and spring months (December to June). The months during which conditions were apparently most favorable for various plankters were:

Phylum	Months
Protozoa	June, August, September
Rotifera	June, August, September
Annelida	June, November
Arthropoda	June, September, November

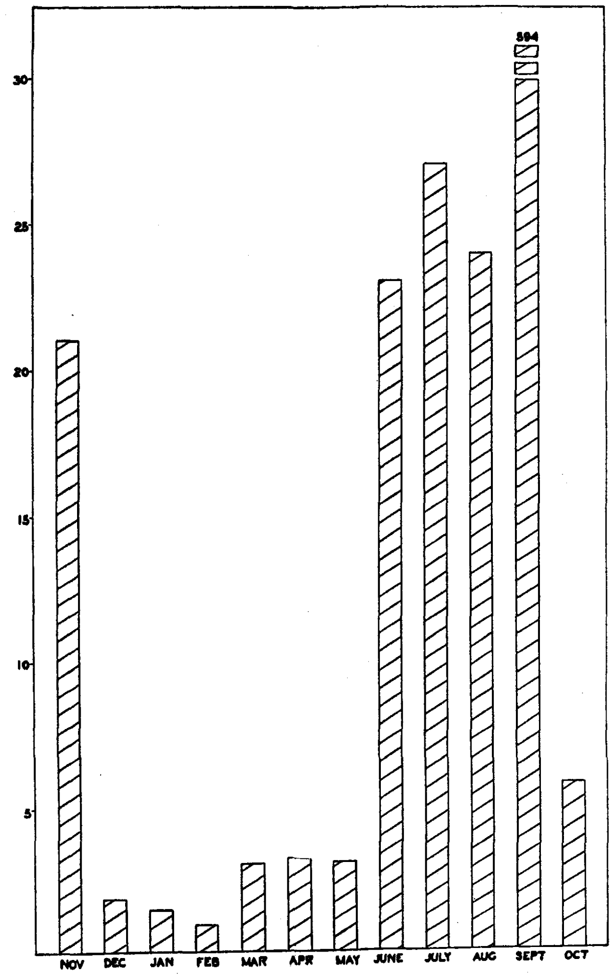

Fig. 3. Monthly distribution of zoöplankton. The number of individuals per liter is indicated on the ordinate.

The monthly distribution of the plankters is shown in Table V. This table and figure 3 illustrate that minimum production occurred at times of low temperatures. Water temperatures were lowest in the months of January and February, averaging 4.0° C. and 4.5° C. respectively, and highest in the month of July, averaging 27° C. Figure 3 shows that the smallest numbers of organisms were present during the months of

TABLE V

DISTRIBUTION OF PLANKTON BY MONTHS
(Individuals per Liter)

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.
Arcella	2.3	0.1		_	0.3	0.1	_	0.4	0.4	0.3	3.9	0.1
Colpidium	...	...	...	...	...	.4	.1	...	21.8	.2	.1	...
Difflugia	_	...	...	...	_	.9	_	...	.9	.2	.2	.6
Eudorina	...	...	...	...	...	...	_	...	...	6.6	_	...
Euglena	.1	...	...	...	_	...	_	.3	...	.2	340.0	.1
Gonium	...	...	...	...	...	...	...	...	...	.8	1.0	...
Pandorina	...	...	...	...	...	_	_	...	.4	_	65.6	...
Paramecium	.7	.2	_	...	_	_	.1	4.0	.5	.2	1.1	...
Stentor	_	...	...	...	...	...	...	1.0	.1	.1	.6	...
Euplotes	.2	_	_	...	...	_	_	.6	_	_	...	...
Vorticella	.4	.1	_	...	.5	.9	.3	.7	...	...	.6	.1
Anuraea	.1	...	...	...	...	...	_	_	...	...	14.5	_
Brachionus	1.7	_	...	_	_	_	.2	.5	.7	1.0	2.4	.2
Monostyla	...	...	...	...	...	...	...	...	...	...	.9	.2
Noteus	.5	...	...	...	...	...	...	...	.4	10.0	5.7	_
Notops	.9	_	...	...	...	...	...	...	...	...	2.2	...
Philodina	.5	.1	.1	_	.1	.1	.2	4.7	_	.7	.5	.2
Polyarthra	...	...	...	...	...	...	...	...	...	_	50.2	...
Pterodina	.6	_	_	...	...	...	...	...	...	...	...	...
Rotifer	2.9	.5	.3	.1	.3	.1	.7	9.5	.1	2.8	104.0	2.5
Triarthra	...	...	...	...	...	...	...	...	_	...	.9	...
Nematoda	2.1	.3	.7	.7	1.2	.5	.7	.3	...	.3	.4	.7
Annelida	.1	_	...	...	...	...	_	_	_	_	...	...
Cladocera	.8	.1	...	...	_	_	...	...	.2	_	_	.1
Copepoda	5.6	.3	.1	_	.3	.1	.2	1.3	.5	.5	1.0	.6
Chironomidae	1.3	.1	_	_	_	_	_	.1	_	.1	_	.1

_ present in numbers less than one-tenth per liter.

January and February, and that the numbers present in July were exceeded only by the numbers present in September when the temperature had not decreased sufficiently to affect plankton productivity. Actually the plankton of February is approximately four per cent of that present in July.

On the basis of data obtained from the Athens Weather Bureau, an attempt was made to correlate stability of hydrographic conditions with abundance of organisms at Station 12, situated at Athens. The results showed that the periods of greatest productivity, both quantitatively and qualitatively, occurred during those months, June, July, August, and September, when hydrographic conditions were most stable. The abundance of organisms in November is an exception to this statement but may be explained by the fact that, during that month, sampling was done the day following the first heavy precipitation for approximately a month. Such a precipitation, according to Kofoid (1903), flushes the back waters and tributaries of their plankton, thereby increasing the numbers in the main stream.

DISTRIBUTION BY SEASONS

All plankton occurred more abundantly during the autumn than during any other season. It was interesting to note that the nematodes were least abundant during the summer season. The approximate ratio between the total number of organisms per liter of water during the fall season and the other seasons is as follows:

Seasons	Ratio	Percent
Fall to Winter	208 to 1.5	¾%
Fall to Spring	208 to 3.0	1%
Fall to Summer	208 to 25.0	12%

Evidence has already been given concerning the effect of low temperatures on monthly plankton distribution. Therefore, the small number of forms present in the stream during the winter season can be ascribed to the effect of temperature. The comparatively small increase in the number of forms during the spring is probably due to the detrimental effect of floods which occurred Feb. 16 and 27, March 22, and April 8.

ECOLOGICAL SUCCESSION

An interesting succession of genera occurred at Stations 3, 4, 5, and 6. These stations demonstrate the progressive change of the nature of the stream from an extremely polluted condition to an unpolluted condition. At Station 3, the genera *Euglena*, *Paramecium*, and *Rotifer* occurred abundantly during the entire year. *Stentor*, *Vorticella*, and *Philodina* reached their greatest abundance at Station 4. The nature of the water at Station 5 seemed favorable for *Colpidium*, the numbers of which had increased gradually since Station 3. *Pterodina* and *Chaetogaster* also occurred abundantly at this station. At Station 6 *Volvox* appeared. This is one of the three stations at which it did occur in the entire stream. *Monostyla*, *Noteus*, *Bosmina*, *Chydorus*, and *Diaptomus* increased markedly at Station 6 in contrast with the reduction they suffered below Station 2. *Eudorina* appeared frequently for the first time at Station 6. *Euglena*, *Paramecium*, *Stentor*, *Euplotes*, *Vorticezla*, *Philodina*, and *Rotifer* had decreased considerably in numbers here. It is evident that a change in the polluted nature of the river is accompanied by a change in the occurrence of plankters. Forms which occurred abundantly in the comparatively polluted region of the river gradually declined in numbers, while forms which were present before the river became polluted reappeared after the river had become relatively unpolluted.

DISCUSSION

Domestic pollution as a factor determining the qualitative distribution of plankton was included in this paper with a great degree of caution. The results of investigations are not in agreement as to the role, whether active or passive, played by pollution in lotic environments. Roach (1931) in his investigation of the plankton of the Hocking River, discards domestic pollution as an active determining factor in the distribution of plankton. However, Forbes and Richardson (1919), Wiebe (1927), and the report on pollution in the survey of the Genesee River System of New York (1927), support the active role of pollution. In the present investigation the succession of plankton organisms from Stations 3 to 6 accompanying the very profound change from septic tank conditions to clear water, and the occurrence of certain genera in the profoundly polluted regions of the stream, but not elsewhere, indicates that pollution is an active factor in determining the quality of plankton. In terms of quantity, the fact that at Stations 3 and 4 the sewage renders the Hocking productively old before it can become old according to Shelford and Eddy's (1929) statement that water in the Sangamon River was not productive till twenty days old, seems to necessitate consideration of pollution as an active factor in production in the Hocking. This view is supported by Lackey (1938) who, upon investigating factors affecting the distribution of Protozoa, found pollution to be an active factor in quantitative and qualitative distribution.

In general, the results of this investigation are in close agreement with those of other investigators of lotic environments. Kofoid (1903), Allen (1920), and Galtsoff (1924) have pointed out that a retarded rate of flow is effective in rendering a portion of a stream productive. In the Hocking River the productivity of Station 13, a more slowly moving portion of the river, has been considered due, at least in part, to the retarded rate of flow. However, the investigator, like many others, fails to correlate the decrease of organisms at the last two stations.

The negative correlation between dissolved oxygen and plankton abundance might be expected since at no time did the dissolved oxygen content become less than 3.0 cc. per liter. Welch (1935) states that many animals do not show evidence of response to declining oxygen until it has been reduced to 0.2 or 0.3 cc. per liter, and Kofoid (1908) noted that there was no correlation between seasonal chemical and plankton flux. Both of these statements substantiate, more or less, the above dissolved oxygen and plankton relationship.

Kofoid (1903), Roach (1931), and Reinhard (1931) have described the detrimental effects of floods, the beneficial effects of hydrographic stability, and the effect of tributary plankters on plankton production. Hydrographic stability and flood effects have been noted in the present investigation as vital factors in seasonal and monthly distribution of plankton. The abundance of plankton in the main stream during November has been attributed to the washing in of tributary plankters following heavy precipitation.

The correlation between high temperature and increased plankton production need not be discussed. The fact that nematodes were more abundant during the fall, winter and spring months than during the summer months challenges investigation; resistance by nematodes to extremes in environment has been pointed out in numerous cases (Hoeppli, 1926).

SUMMARY

1. In a limnological survey of the Hocking River fifty-two genera of zoöplankton were found. The plankton consisted of sixteen genera of Protozoa, seventeen genera of Annelida, and eleven genera of Arthropoda.

2. A combination of retarded rate of flow, higher temperature, and senescence of the water at a given point along the river tend to increase plankton productivity. Domestic pollution probably hastens senescence and increases abundance. Inorganic wastes tend to decrease abundance of organisms.

3. Stability of hydrographic conditions and high temperature, except in the case of nematodes, are important factors in determining the monthly and seasonal distribution.

4. There is some evidence that degree of pollution determines the quality as well as the quantity of plankton along the Hocking River.

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