The Distribution and Abundance of Tubificids in the Little Calumet River

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THE DISTRIBUTION AND ABUNDANCE OF TUBIFICIDS IN THE LITTLE CALUMET RIVER

by

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INTRODUCTION

Aquatic annelids of the Family Tubificidae are becoming increasingly important in the study of benthic communities of areas subjected to accelerated eutrophication and associated low dissolved oxygen. This recent emphasis on tubificid studies has been stimulated by the growing interest in biological methods of detecting and assessing water pollution. The development of very large tubificid populations below sources of organic pollution has been recognized for many years. The mere presence or absence of tubificid species reveals a great deal about the condition of the benthos. This is particularly true when suspect areas are compared to known natural localities, to previous records from the same locality, or to records from closely similar situations at a nearby locality (Brinkhurst, 1966).

Universally encountered are two species, *Tubifex tubifex* and *Limnodrilus hoffmeisteri*, both of which are found in tremendous numbers as the surviving species in the pollutional community. This survival would tend to indicate that these two species are the most resistant to pollution members of the Family Tubificidae.

The increased number of tubificids found in the vicinity of organic effluents can be attributed mainly to the adaptation of the respiratory physiology of the worms which allows

them to survive at a very low oxygen concentration (Palmer, 1968). Such adaptations to the conditions frequently found in organic effluents enable them both to survive and reproduce, while other forms are often excluded. At times individuals of Tubifex sp. and Limnodrilus sp. are so numerous that the whole floor of the stream resembles a red carpet (Goodnight and Whitley, 1960).

Aside from observations that tubificid worms are favored by organic pollution, very little information exists concerning the life histories and ecology of even the commonest species. The earliest records of tubificid ecology are limited to notes on the presence of mature specimens in field populations. Recent studies have recognized the presence of cocoons, newly hatched worms, immature worms, mature worms, and breeding individuals. Most of these studies suggest that breeding periods in tubificids vary within wide limits in most species, and that species characteristic for any particular habitat can be found at all seasons of the year. Often mature specimens make up a proportion of the population at all times.

The present study is an attempt to investigate the distribution and abundance of tubificids in the Little Calumet River, located in Indiana, as well as to relate their distribution to some physical and chemical properties of the river under investigation.

LITERATURE REVIEW

During the past decade, worms of the Family Tubificidae have drawn the interest of a number of aquatic biologists, especially those interested in polluted waters. The Family Tubificidae, according to present systematic studies, contains approximately eighteen genera. Representatives of two of the genera, Limnodrilus and Tubifex, are the most commonly found types. They differ in the arrangement of setae and the structure of their reproductive systems; and these characters are the major taxonomic characters used for their separation.

High densities of tubificids in rivers and lakes receiving sewage or other organic effluents are extensively reported in the literature (Brinkhurst, 1965a, 1966a, 1966b, 1970; Brinkhurst and Kennedy, 1962, 1965; Goodnight and Whitley, 1960; Surber, 1975). In heavily polluted waters, population densities of well over a million worms per square meter of the river bed are not uncommon (Gaufin and Tarzwell, 1956; Brinkhurst and Kennedy, 1965; Brinkhurst, 1970).

The tremendous numbers of worms which occur in polluted areas has led to their use as an index of pollution, particularly in localities where the structure of bottom sediment is fairly uniform. Surber (1957), for example, concluded that an abundance of tubificids in excess of $1100/m^2$ represented truly polluted habitats in a number of lakes in Michigan,

while Carr and Hiltunen (1965), working on Lake Erie, used the following numbers of oligochaetes per square meter of lake bed to indicate pollution: 100-999, light pollution; 1,000-5,000, moderate pollution; more than 5,000, heavy pollution. Goodnight and Whitley (1960) proposed a pollution index system based on the percentage of tubificid worms in the total population. A bottom invertebrate community containing 80% or more of tubificids indicated a high degree of organic enrichment from industrial pollution, while below 60% the stream was probably in good condition.

Whereas the presence of tubificids in polluted areas has been well established, the literature offers little insight into factors which may regulate the abundance and distribution of these worms.

Several studies on the life cycle of tubificids have been carried out. Those studies suggested that breeding in tubificids may be restricted to brief periods for certain species (Brinkhurst, 1965b, 1966a), and in some of these species (Peloscolex ferox, Aulodrilus pluriseta), fully mature individuals are only present just before breeding commences. Others, such as Limnodrilus hoffmeisteri (Claparéde) and Tubifex tubifex (Muller) may be found in mature condition and breeding at all times in some localities. These species often have periods of intensive breeding. The periods may be at different times in different places.

Kennedy (1966b) showed that the life history of

L. hoffmeisteri varied from site to site and even from year to year at one site. Kennedy pointed out that most of the worms became mature and reproduced within twelve months, but at other localities, worms might take as long as two years to mature. Laboratory experiments, carried out in conjunction with this study, showed that most worms died after breeding while others were capable of surviving as immature worms and breeding a second time, as they had developed a new set of reproductive organs. An annual peak in late winter and early spring from worms inhabiting selected streams in England was reported by Kennedy (1966b). Studies on T. tubifex in Ditton Brook have shown that this species, like L. hoffmeisteri, may take one or two years to attain maturity (Brinkhurst and Kennedy, 1965).

Brinkhurst (1964a, 1964b) has reviewed the distribution of tubificid worms in relation to their habitats. It is evident from these studies that no species of Limnodrilus is confined to a specific type of habitat. The distribution and abundance of the species of Limnodrilus appears to bear no relation to the common ecological factors of temperature, rate of flow, nature of the sediments and nontoxic inorganic ions present in the water. Studies by Kennedy (1965) provide adequate data on these characteristics, revealing a high degree of temporal and spatial variation in the abundance of tubificids. The work of Kennedy showed that there is no apparent relationship between the abundance of species and

any of the physical characteristics recorded at each station sampled. It was suggested by Kennedy that the factors influencing the distribution and abundance of the species of Limnodrilus are primarily biotic in nature and that attempts to relate distribution to abiotic factors are likely to be of limited value.

Despite the fact that there are few instances in which distribution and abundance of tubificids can be established with reference to the physico-chemical parameters of the environment, several studies contributing to the correlation of the distribution of Tubifex with some ecological factors have been undertaken (Aston, 1968, 1973; Brinkhurst, 1967; Brinkhurst and Chua, 1969; Brinkhurst and Simmons, 1968; Manwell, 1965). Most of these studies suggested that dissolved oxygen, temperature, type of bottom and food supply are important factors in the ecology of tubificids.

Dissolved oxygen. The dissolved oxygen may be a very important indirect factor when considering the distribution of an animal such as Tubifex, since the animal is able to survive complete oxygen deficiency. This marked physiological tolerance to oxygen deficiency may explain the spectacular growth of tubificids in organically polluted water. Competition for food and living space is reduced once the majority of the other benthos have been killed by exposure to water lacking oxygen. Fisher and Beeton (1975) stated that tubificids do not select the anaerobic habitats they

are often found in, but simply endure them because of other advantages those habitats possess. The ability of tubificids to withstand periods of oxygen deprivation including complete anaerobic conditions has been demonstrated by Aston (1968). Palmer (1968), in an attempt to define the limits of distribution of tubificids and to correlate their distribution with the oxygen concentration, pointed out that the oxygen consumption of *T. tubifex* is independent of the oxygen concentration of the external environment down to a level of about 1.5% oxygen. Below this critical level the oxygen consumption falls sharply as the oxygen concentration of the environment falls.

Respiratory exchange is said to be enhanced by the presence of hemoglobin and by undulating movements of the tail. However, the role of hemoglobin in this organism is a matter for conjecture. Manwell (1959) has suggested that it may function to prevent oxygen poisoning in organisms such as *T. tubifex* which normally function at very low internal oxygen concentrations. Palmer (1968), on the other hand, has evidence that hemoglobin does function in oxygen transport but only when the external oxygen concentration falls below the critical tension.

In spite of the various adaptations to life at low oxygen level, it has been assessed that growth and reproduction of tubificids may be curtailed by low concentration of dissolved oxygen. Adverse effects such as loss of weight

(Jonasson and Thorhauge, 1972), cessation of reproductive activity (Aston, 1973), reduction in metabolic rate (Berg, Jonasson, and Ockelmann, 1962) have been reported from experiments on which tubificids were exposed to anaerobic conditions or very low oxygen concentration.

Temperature. A search of the literature found very few papers dealing with temperature effects on abundance and distribution of tubificid worms. Kennedy (1966a) found that in very productive habitats *L. hoffmeisteri* bred throughout the year with increased activity during winter and spring, but a spell of very low water temperature caused a temporary cessation in activity. In less productive habitats, breeding took place in spring and summer, and in such habitats he suggested that the time of breeding was dependent on the higher water temperature in these seasons. According to Brinkhurst (1964a), all the tubificids in many lakes breed in the summer when the temperature exceeds 15°C. He also noted that where the summer season was longer there was more variation in the period of sexual activity among the tubificids. Aston (1973) found in *L. hoffmeisteri* that the number of cocoons produced per worm increased with temperature between 5°C and 25°C. The trend was the same for *T. tubifex*. Aston's study showed that at 25°C and at a low oxygen concentration, less than 2 ppm, *L. hoffmeisteri* deposited fewer cocoons, which also contained relatively lower numbers of eggs. No variations in the reproduction of *L. hoffmeisteri* were observed at

oxygen concentrations higher than 2 ppm. Increased numbers of sexually mature L. hoffmeisteri at places where there was an outflow of warm water have also been reported by Aston.

Although this is a subject which has received relatively little attention, studies of tubificids in relation to temperature are of fundamental importance in the interpretation of growth, life cycle and population dynamics of these worms.

Type of bottom. The possibility that the nature of the sediments plays an important role in the abundance and distribution of Tubifex has been mentioned in the literature, but there is no very consistent pattern in the ecological preferences claimed. Work on British lakes and other habitats has shown that worms are less common in stony, sandy substrata poor in organic matter, and most abundant in organic muds. This observation, however, was based on a superficial examination of those sediments. Careful analysis has shown few clear correlations between the variations in particle size or total matter present and the distribution and abundance of worms (Brinkhurst, 1965a, 1967). Kennedy (1965) claimed that correlations between type of sediment and distribution of Tubifex have little meaning when based on study of a single locality, and that any attempts to generalize must be based on detailed studies of several localities. Bagge and Ilus (1973) pointed out that even when the character of the substratum seems to be one of the main factors influencing the occurrence of the species in Finnish coastal

waters, the correlation between the quality of the substratum and the occurrence of the species is not easy to prove. The quality of the sediments depends on many factors including the configuration of the bottom, the exchange of water, the load of allochthonous material and the intensity of the biological cycles in the sediments.

From the evidence cited above, it is clear that this is a subject which is in need of more study.

Food supply. Studies on the biology of tubificid oligochaetes have indicated that the nature of food available to the worms may be a primary factor in determining the distribution and abundance of the species (Brinkhurst and Jamieson, 1971). The food of *Tubifex* is not really known. Invertebrate zoologists have assumed in the past that tubificid worms fed on detritus.

The role of microorganisms in the diet of tubificids was suggested by Brinkhurst (1967), and a correlation between the abundance of oligochaetes and bacteria (*E. coli* counts) has been established by Brinkhurst and Simmons (1968). In a further study by Brinkhurst and Chua (1969), the importance of microflora as food of worms was investigated. Their study demonstrated that most of the bacteria in the mud may be found in the gut of tubificid worms. In 1971, Wavre and Brinkhurst found that three tubificid species fed on the same sources digested different proportions of at least one representative fraction of the bacterial flora present, the

heterotrophic aerobes. It is said that the feces of one worm species contain a high proportion of bacteria that are the preferred food of another species. Results of laboratory studies (Brinkhurst, 1974) serve to support the assumption cited above. Brinkhurst's results showed that *T. tubifex* and *L. hoffmeisteri* are both attracted to the feces of *T. tubifex* rather than those of *L. hoffmeisteri*. Whitley and Seng (1976) isolated and identified eighteen species of bacteria from the gut of tubificid worms. All of the organisms identified were common in fresh water, organic decay processes or animal digestive systems.

It would seem from the studies cited that the nutritional aspects of the biology of tubificid worms are not clear, and further research is suggested.

MATERIALS AND METHODS

Samples of the bottom fauna were taken at regular monthly intervals between September 1977 and August 1978. Three sampling stations were selected along one transect across the Little Calumet River: (1) at the left bank, (2) at the right bank, and (3) at midstream.

Samples of mud containing tubificids were taken by means of a shovel to a depth of approximately 6 cm. The area covered by each sample was approximately 18 cm x 19 cm x 6 cm. The bottom samples were brought back to the laboratory where they were stored at room temperature in glass jars open to the atmosphere. Worms and accompanying sediments were aerated continuously. Specimens were isolated by rinsing clumps of mud through a screen of .41 mm mesh size. The sieve residue was then placed in shallow white enamel pans with approximately .5 inches of water on their surface. In the absence of burrowing substrate, the worms coiled around each other, forming a ball. Under such conditions, the worms are presumably under considerable stress and therefore clump together into a tangled mass. Worms were then removed and counted.

Quantitative records of tubificid worms were based on a volume displacement method (Coler and Dutson, 1967). The method involved placing a given quantity of organisms in a 100 ml graduated cylinder. The volume of organisms needed

to displace 5 ml of water was collected and the number was counted. Using this as a basis for the determination of the entire sample, the remainder of the sample was placed in the graduated cylinder and the volume displaced was recorded. The ratio of this recorded volume with the 5 ml volume was the ratio of the number of organisms in the entire sample to the number in 5 ml from which the number in the entire sample was calculated.

Three samples consisting of thirty organisms each were randomly taken from the group of organisms that displaced the 5 ml of water. These ninety organisms were used to illustrate the diversity of the species and also to serve as a means of calculating the relative percentage of each species. Specimens were preserved in 70% alcohol and then were mounted in a mixture of Turtox CMS-9AB (carboxy methyl cellulose with aniline) on microscope slides, allowed to clear for two days, and then identified to species.

Morphological features listed by Brinkhurst and Johnson (1971) and Brinkhurst (1960) were used to separate *L. hoffmeisteri* from the *T. tubifex* obtained in field collections. The main distinguishing features of *L. hoffmeisteri* are the shape and dimensions of the penis tube and the shape of the setae. The penis sheath of *L. hoffmeisteri* is much longer than broad and has a variable head, frequently set at right angles to the shaft. There are no hair setae in members of this genus, and dorsal and ventral setae are alike, being

simple crotchets without intermediate teeth. In T. tubifex, the penis sheath is short, thin walled, and tube shaped. The hair setae are long and thin, having the longest hair setae in anterior segments.

Sampling identification was checked by Dr. Clarence J. Goodnight and Edward M. Block.

Estimations of the numbers of immature and mature worms were also recorded. It was felt that the occurrence of sexually mature specimens could give some indication about the reproductive periods of tubificids. Immature worms without hair setae were assumed to be members of L. hoffmeisteri, since they were the most common and widespread. Kennedy (1966b) stated that in any habitat where L. hoffmeisteri is clearly the numerically dominant oligochaete, as it is in the Little Calumet River, it is a fair assumption to include all immature worms as members of that species. Records were made of the number of worms with and without penis sheaths.

In an attempt to gain an understanding of the interplay of factors affecting the abundance and distribution of tubificids as well as to assess the extent of pollution of the river under consideration, chemical analyses were determined at each of the three stations across the river. The same collection periods were used, both water and bottom samples being taken at the same time. Chemical analyses involved quantitative determinations for dissolved oxygen, alkalinity, carbon dioxide, chloride, chromium, copper, hardness, hydrogen

sulfide, iron, manganese, nitrogen, pH, phosphate, silica, and sulfate. Water samples were taken one foot below the surface of the water. Gases were analyzed at location; other chemical parameters were determined in the laboratory. Analyses were performed according to procedures recommended in the Hach Chemical Laboratory Manual (1973).

In conjunction with the bottom sampling and chemical analyses of the water, limnological observations such as water and air temperatures, depth, transparency, and velocity were recorded at the time bottom samples were taken. Water and air temperatures were determined by means of a standard laboratory-type mercury thermometer, and recorded in degrees centigrade. Transparency was measured with a 20 cm black and white secchi disk. The velocity of the river at each station was estimated by the use of a small cork on the day of water collection. The rate of displacement of the cork was measured over a defined distance near the rod. The estimated velocity was recorded as meters per second.

Total count, total coliform, and total yeast and mold levels of each station were also determined. Those organisms have been suggested to be of value in assessing water quality. The presence of fecal coliform organisms in untreated water, according to Geldreich (1966), should be considered as an indication of recent fecal pollution.

Samples were treated in accordance with Millipore instructions (1966). White, 47 mm, type-HA filters were

used for the total count and total coliform levels of each station; black, 47 mm, type-HA filters were used for yeast and mold determinations. Sterile 2 ml nutrient media ampoules were used in all cases. The total count, total coliform, and total yeast and mold were run in triplicate. The mean and standard deviations were estimated. Counts were made under stereoscope at 18X, and all results were recorded as colonies per 100 ml.

DESCRIPTION OF THE STUDY AREA

The area investigated is the Little Calumet River in Indiana. This river runs through Lake County, Indiana, and Thornton and Hyde Park townships in Cook County, Illinois, in a northerly and westerly direction and empties into Lake Michigan.

According to U.S. Geological Survey (1975), the Little Calumet drains an area of about 382 square miles. It is a complex river consisting of two branches. Flow of the western branch of the Little Calumet River, recorded by the U.S. Geological Survey gauging station at Munster, Indiana, averages 62.7 cubic feet per second (cfs). The extremes range from a recorded high of 1,510 cfs to a low of 0.4 cfs. Flow through Burns Ditch to Lake Michigan from the eastern branch and the eastward-flowing part of the western branch averages 203 cfs, the maximum being 3,270 cfs and the minimum, 45 cfs.

The Little Calumet originally meanders westward on a lacustrine plain from its sources in Laporte County, through a swampy lowland between two former beach ridges into Illinois where it joins the Grand Calumet River, which flows eastward and runs for about twenty miles almost parallel with its upstream course, then enters Lake Michigan at the City of Gary; the flow at the junction with the Grand Calumet

may be toward the Mississippi, depending on river stage and rainfall. The Little Calumet River is intercepted in the northwest corner of Porter County by Burns Ditch. This part of the drainage also feeds into Lake Michigan. Figure 1 shows a map of the Little Calumet River and surrounding water system.

Only one portion of the cited river was of concern in this investigation. The study area of the Little Calumet River lies in the south part of Hammond. This locality is approximately one mile south of Indianapolis Boulevard interchange with Interstates 94 and 80. Figure 2 shows the location of the study area.

At first observation it is quite clear that this area is grossly polluted. Pollution can be said to occur if any discharge into the river occurs that alters its nature. If large quantities of organic material such as sewage are discharged into the river, the number of bacteria is greatly increased. During the breakdown of organic material, oxygen is removed from the water. The effect of the depletion of oxygen may be felt for some considerable distance, and is often characterized by disappearance of such animals as fish and insect larvae, and by an enormous increase in tubificids. These conditions were found in the Little Calumet River where *T. tubifex* and *L. hoffmeisteri* were more numerous than any other taxonomic group. As was previously mentioned, a great abundance of these worms has long been regarded as indicative

MAP OF THE LITTLE CALUMET RIVER AND SURROUNDING WATER SYSTEMS

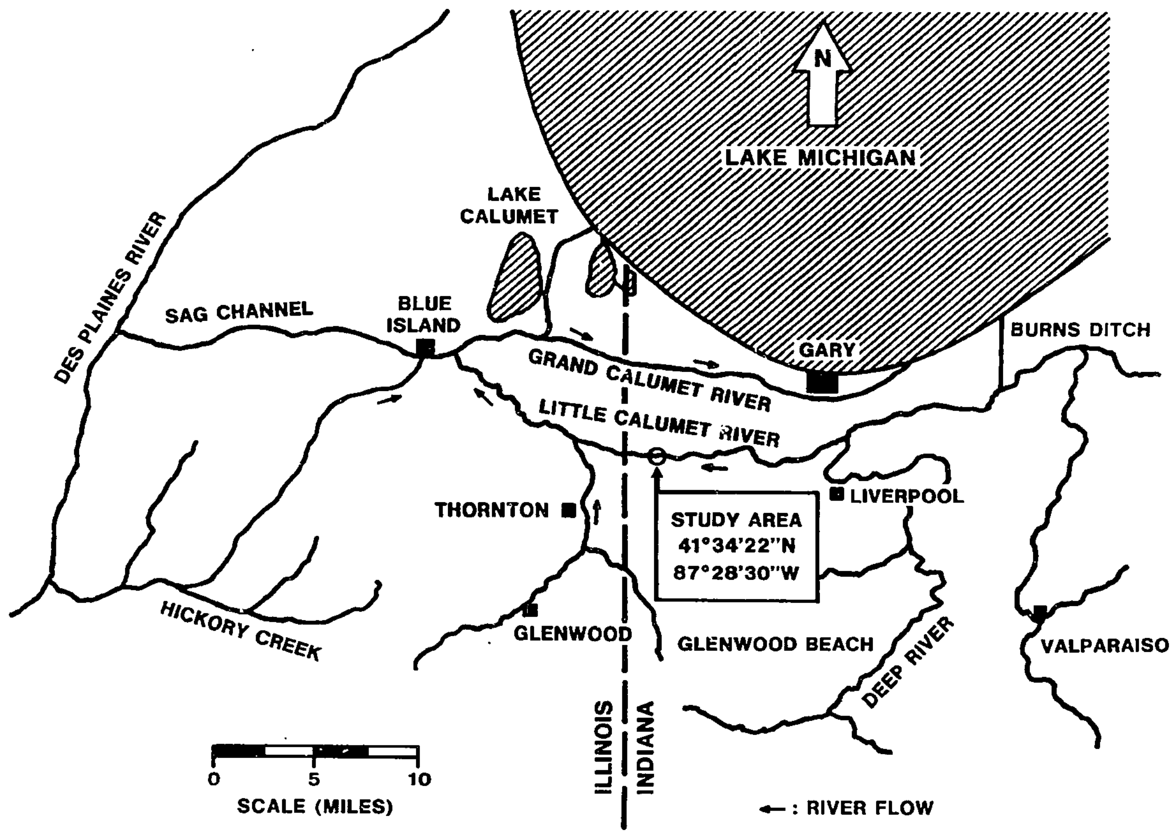


Figure 1.

LITTLE CALUMET RIVER SHOWING LOCATION OF THE STUDY AREA

SAMPLES COLLECTED MONTHLY SEPTEMBER,1977 - AUGUST,1978

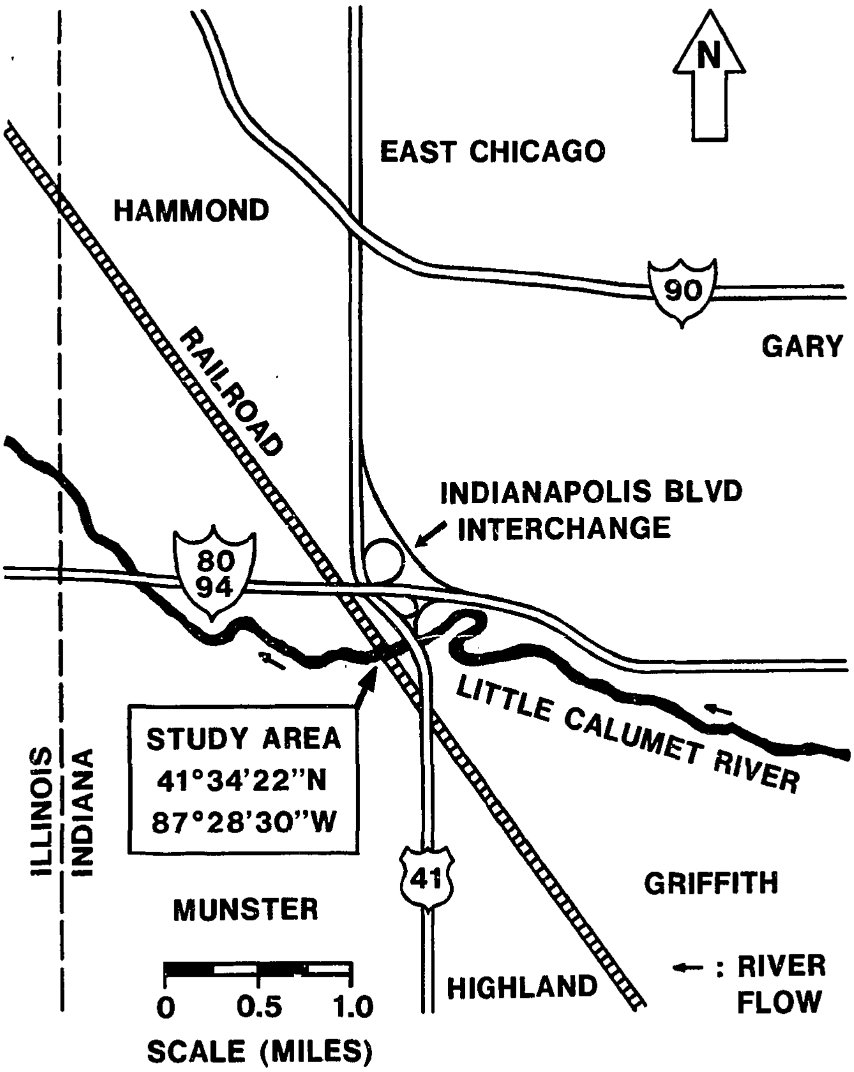


Figure 2.

of organic enrichment.

Although tubificid worms were the dominant group, it is interesting to note here that a considerable number of red chironomid larvae occurred frequently. The protozoans Stentor, Vorticella and Charchesium were also fairly abundant from April to June. Crustaceans belonging to the genera Bosmina and Daphnia were present in large numbers during summer months. Some groups or organisms, such as the Lumbriculidae and Physidae, could be observed throughout the period of investigation, although they were very scarce.

Vegetation present at the initiation of this study included sparse growth of duckweek (Spirodela polyrhiza) and abundant sewage fungus (Sphaerotilus sp.). Hynes (1966) reported that Sphaerotilus sp. was common in areas of pollution, due to the lack of competition from other organisms. Thers was also a slight growth of arrowhead (Sagittaria latifolia). With the advent of winter, most parts of the river became ice-covered, and aquatic vegetation and sewage fungus diminished. After the ice melted in the second week of March, floating mats of duckweed covered the surface of the stream. A moderate growth of sewage fungus was also present. At the conclusion of this study there was a dense growth of aquatic vegetation. Arrowhead was present in heavy growth. Duckweek was present to a large extent, as was sewage fungus. The vegetation surrounding the Little Calumet River was also

abundant during summer months, and was composed of reedgrass (Calamagrostis canadensis), ragweed (Ambrosia trifida) and waterpepper (Polygonum hydropiperoides). Common trees around the Little Calumet River include pin oak (Quercus palustris), willow oak (Quercus phellos) and some maple trees (Acer negundo). Figure 3 shows the growth of aquatic plants in and around the Little Calumet River.

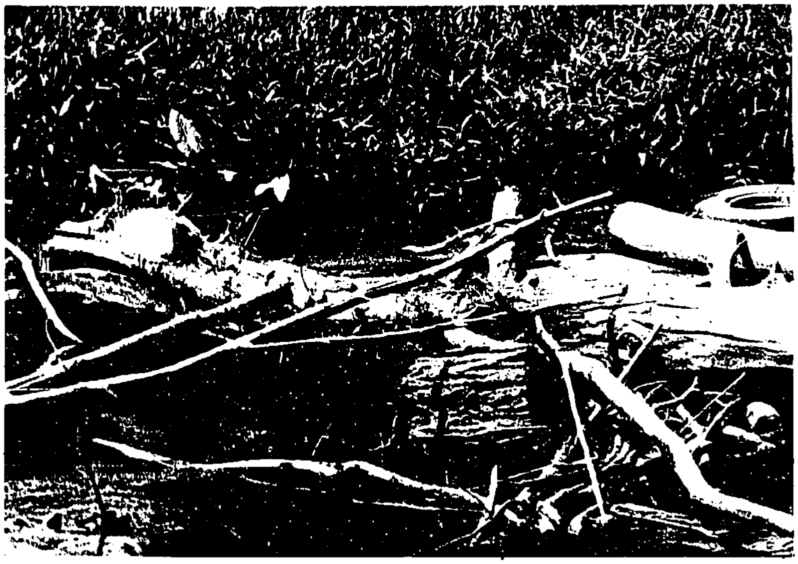
The stream bed of the river under consideration consists of a variety of materials including silt and clay, deposits of muck and peat, fine gravel with accompanying small stones, and a great thick layer of rich black mud. In addition, household garbage, fallen tree trunks and branches, demolition debris, paper, rags, rubber and many other items were usually present during the period of investigation. There were some fluctuations of the flow during the course of the study. The lowest flow occurred during summer months, and the highest flow occurred during spring. This corresponded directly with the levels of precipitation during those periods of time. Geological surveys of the Little Calumet River show that the rate of flow of this river is very sluggish because of its slight gradient of about .5 foot per mile and numerous physical obstructions in its channel.

Sources of pollution from sewage treatment plants, combined storm water/sanitary sewer overflows, surface drainage from residential, commercial and industrial areas as well as streets and highways should all be mentioned as probably

(a)

(b)

Figure 3. Location of stations as they appeared during (a) autumn, (b) winter, (c) spring, (d) summer.



(c)

(d)

Figure 3. (Continued)

being responsible for the heavy organic enrichment in the river under consideration.

RESULTS AND DISCUSSION

Bottom faunal communities of the Little Calumet River were characterized by a predominance of tubificid worms. The tubificid population was made up of two species: *Tubifex tubifex* and *Limnodrilus hoffmeisteri*. The percentage composition of the tubificid fauna at each of the sampling stations is shown in Tables 1, 2, and 3. *L. hoffmeisteri* appeared to be largely responsible for the heavy concentration of tubificids in the area under investigation, while *T. tubifex* was relatively less abundant compared to that found in other polluted streams. The fact that *L. hoffmeisteri* was found to be very abundant should not be considered unusual. *L. hoffmeisteri* is one of the most widespread and abundant species of tubificids. Its ability to adapt its life cycle to local conditions, and its increased breeding potential over other species due to its ability to breed at an early age, are largely and directly responsible for this situation (Kennedy, 1966b). Tables 1, 2, and 3 show that *T. tubifex* represented only about 15% of the tubificid fauna. This observation would indicate that while their ecological requirements may overlap, there are probably some separate factors which determine the abundance of each species.

A rough estimation of the numbers of worms collected during each sampling period is shown in Table 4. As seen in

Table 1

Percentage of Tubificid Species Based on Subsamples of 30 Specimens from Station #1 in the Little Calumet River, 1977-78

Month	Species	
	L. hoffmeisteri	*T. tubifex*
September	90%	10%
October	89	11
November	95	5
December	90	10
January	96	4
February	82	18
March	81	19
April	77	23
May	87	13
June	85	15
July	84	16
August	80%	20%

Table 2

Percentage of Tubificid Species Based on Subsamples of 30 Specimens from Station #2 in the Little Calumet River, 1977-78

Month	Species	
	L. hoffmeisteri	*T. tubifex*
September	87%	13%
October	90	10
November	87	13
December	90	10
January	93	7
February	80	20
March	89	11
April	87	13
May	87	17
June	83	17
July	83	17
August	80%	20%

Table 3

Percentage of Tubificid Species Based on Subsamples of 30 Specimens from Station #3 in the Little Calumet River, 1977-78

Month	Species	
	L. hoffmeisteri	*T. tubifex*
September	88%	12%
October	89	11
November	90	10
December	89	11
January	95	5
February	90	10
March	89	11
April	86	14
May	89	11
June	84	16
July	83	17
August	78%	22%

Table 4

Tubificidae Collected From One Transect Across the Little Calumet River, 1977-78 (Numbers Given Per 1,000 cm^3 of Mud)

Month	Station		
	Station #1	Station #2	Station #3
September	1,500	1,460	1,420
October	1,640	1,720	1,660
November	1,420	1,380	1,460
December	1,530	1,610	1,640
January	850	840	900
February	500	560	450
March	1,200	1,240	1,300
April	2,140	2,260	2,100
May	1,800	1,860	1,810
June	1,640	1,680	1,670
July	1,610	1,710	1,720
August	1,620	1,660	1,630

the table, the overall changes in the number of worms through the period of observation was, in general, similar at the three stations. This situation does not appear unusual when compared with chemical data recorded. Basic chemical determinations indicate that the geochemical conditions in the three stations were approximately the same. It is evident from Figures 4, 5, and 6 that the numbers of worms fluctuated considerably throughout the year. From April to August the size of the population remained fairly constant despite considerable breeding activity. The numbers declined in September and then increased again and remained at a fairly steady level until December. A sudden drop in the numbers of worms appeared during January and February. In March the size of the population increased considerably, being followed by the appearance of cocoons and large numbers of mature worms. Tables 5, 6, and 7 show the relative abundance of mature and immature worms expressed as a percentage of total number of specimens examined at each station. The data suggest that mature worms were present throughout the year, but were particularly abundant in late winter and spring. Thereafter, the number of mature specimens declined. In summer and autumn the bulk of the population was in the immature category. Figures 7, 8, and 9 show that the greatest percentage of immature worms was recorded in September, reaching more than 80% of the total number of specimens examined. Cocoons collected in April contained eggs, and very few contained worms,

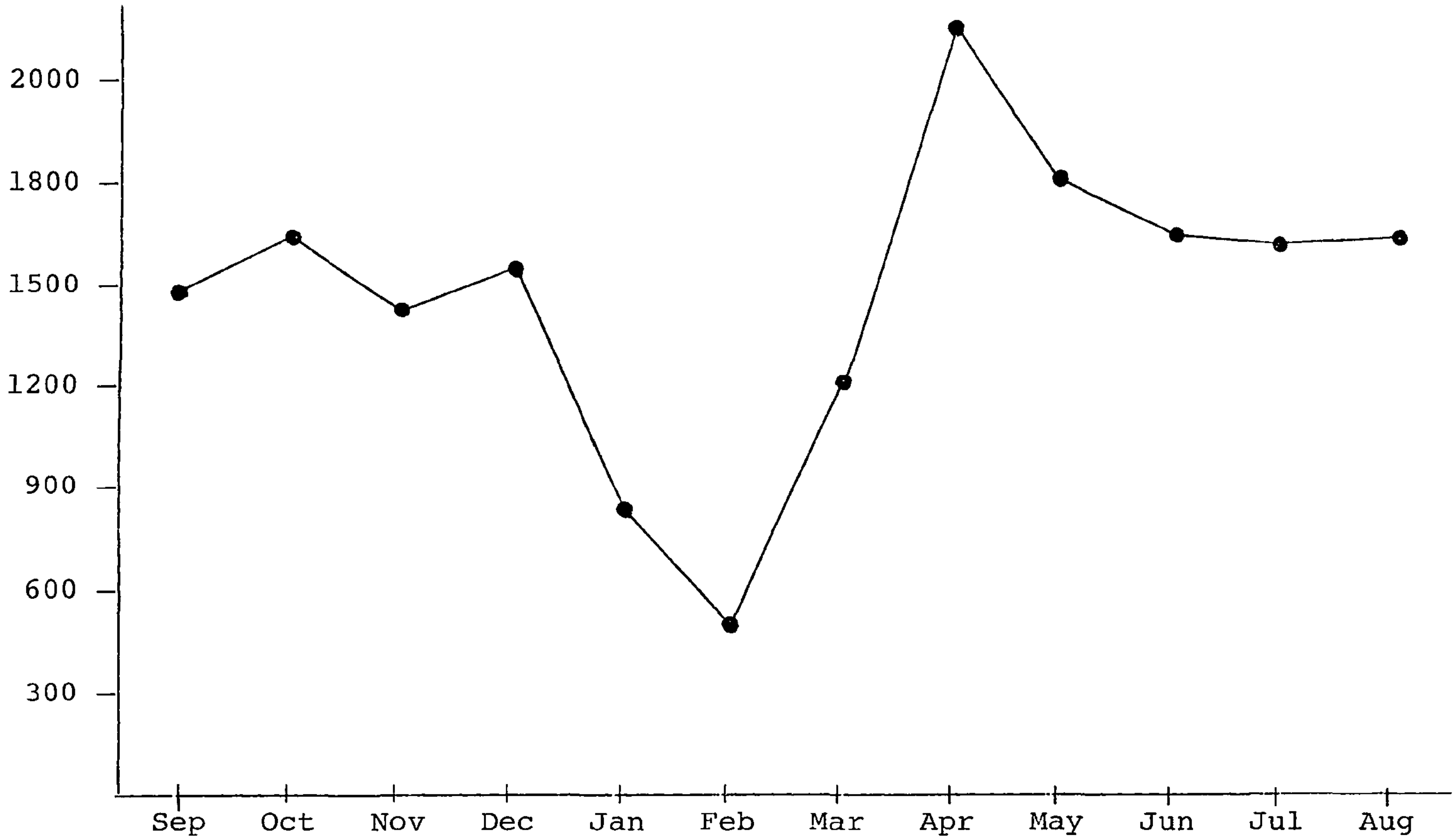


Figure 4. Numbers of tubificids recorded in the Little Calumet River, 1977-78, Station #1 (results are expressed as number of specimens per 1000 cm^3).

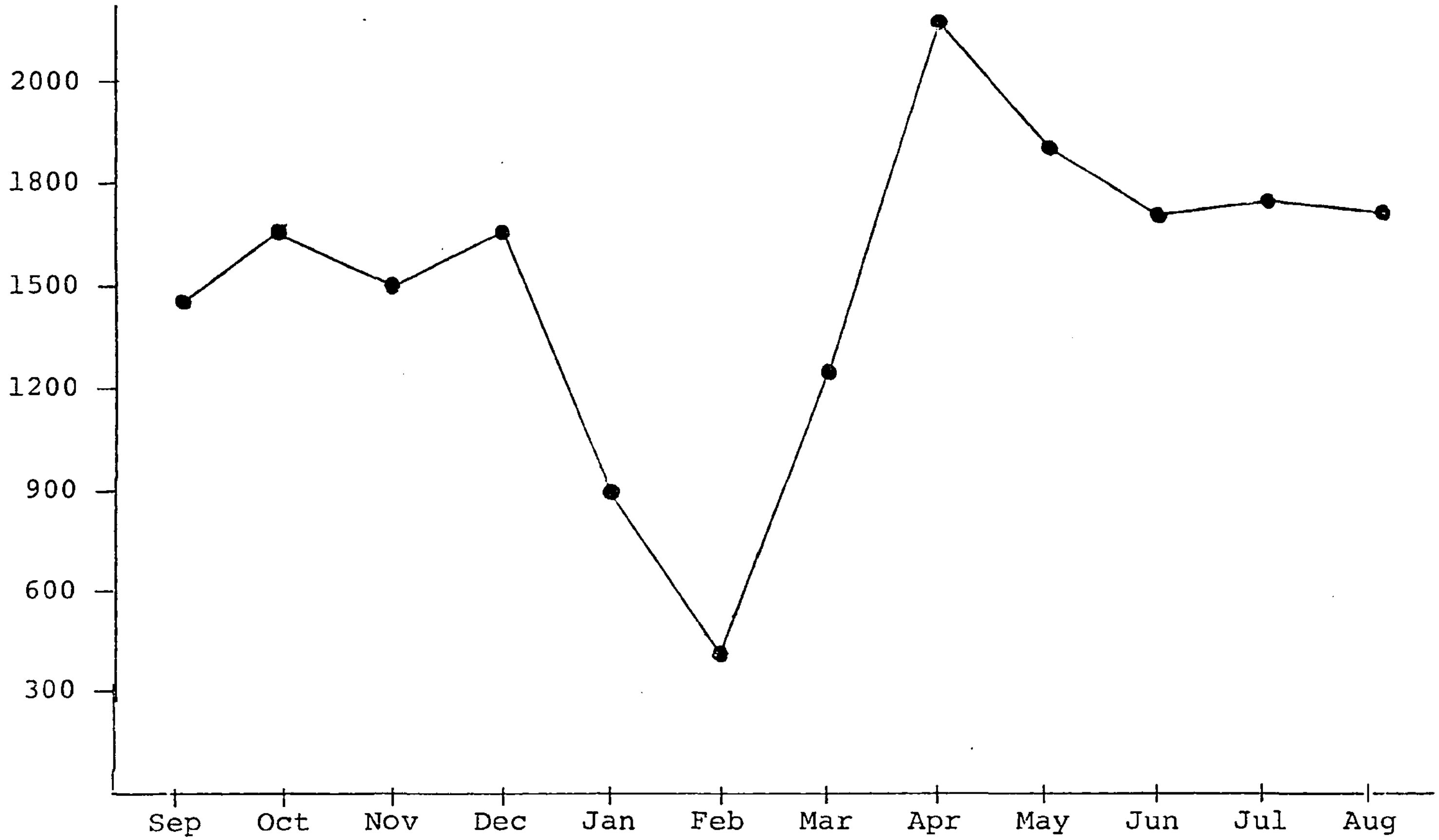


Figure 5. Numbers of tubificids recorded in the Little Calumet River, 1977-78, Station #2 (results are expressed as number of specimens per 1000 cm^3).

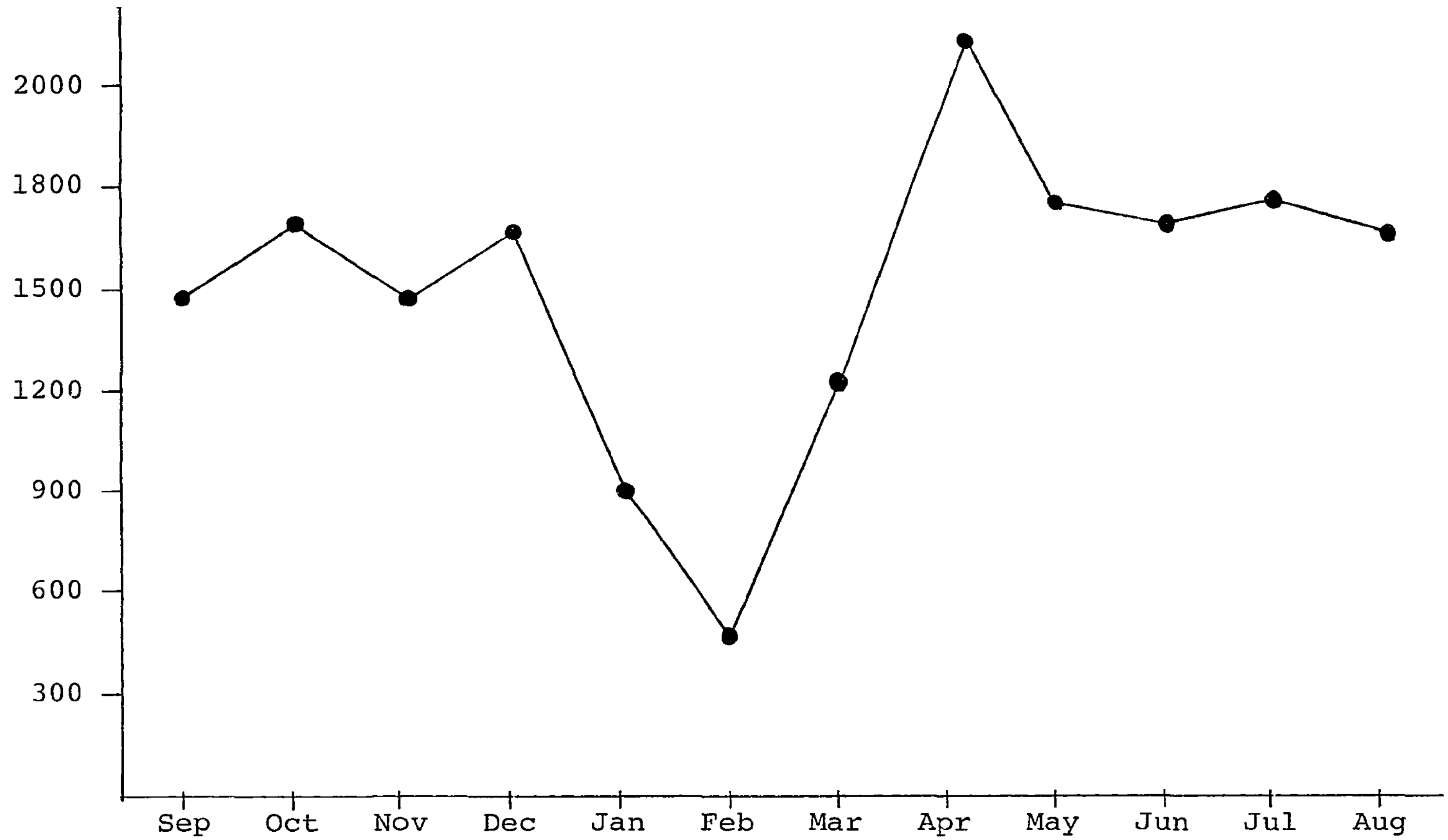


Figure 6. Numbers of tubificids recorded in the Little Calumet River, 1977-78, Station #3 (results are expressed as number of specimens per 1000 cm^3).

Table 5

Seasonal Maturity of Limnodrilus hoffmeisteri, 1977-78, Station #1 (Results Based on Subsamples of 30 Specimens)

Month	Reproductive Stage	
	Mature	Immature
September	10%	90%
October	28	72
November	17	83
December	23	77
January	25	75
February	35	65
March	66	34
April	88	12
May	70	30
June	24	76
July	15	85
August	18%	81%

Table 6

Seasonal Maturity of Limnodrilus hoffmeisteri, 1977-78, Station #2 (Results Based on Subsamples of 30 Specimens)

Month	Reproductive Stage	
	Mature	Immature
September	7%	93%
October	29	71
November	15	85
December	25	75
January	23	77
February	38	62
March	65	35
April	90	10
May	75	25
June	25	75
July	19	81
August	18%	82%

Table 7

Seasonal Maturity of Limnodrilus hoffmeisteri, 1977-78, Station #3 (Results Based on Subsamples of 30 Specimens)

Month	Reproductive Stage	
	Mature	Immature
September	9%	91%
October	28	72
November	16	84
December	24	76
January	20	80
February	35	65
March	63	37
April	91	9
May	75	25
June	20	80
July	19	81
August	17%	83%

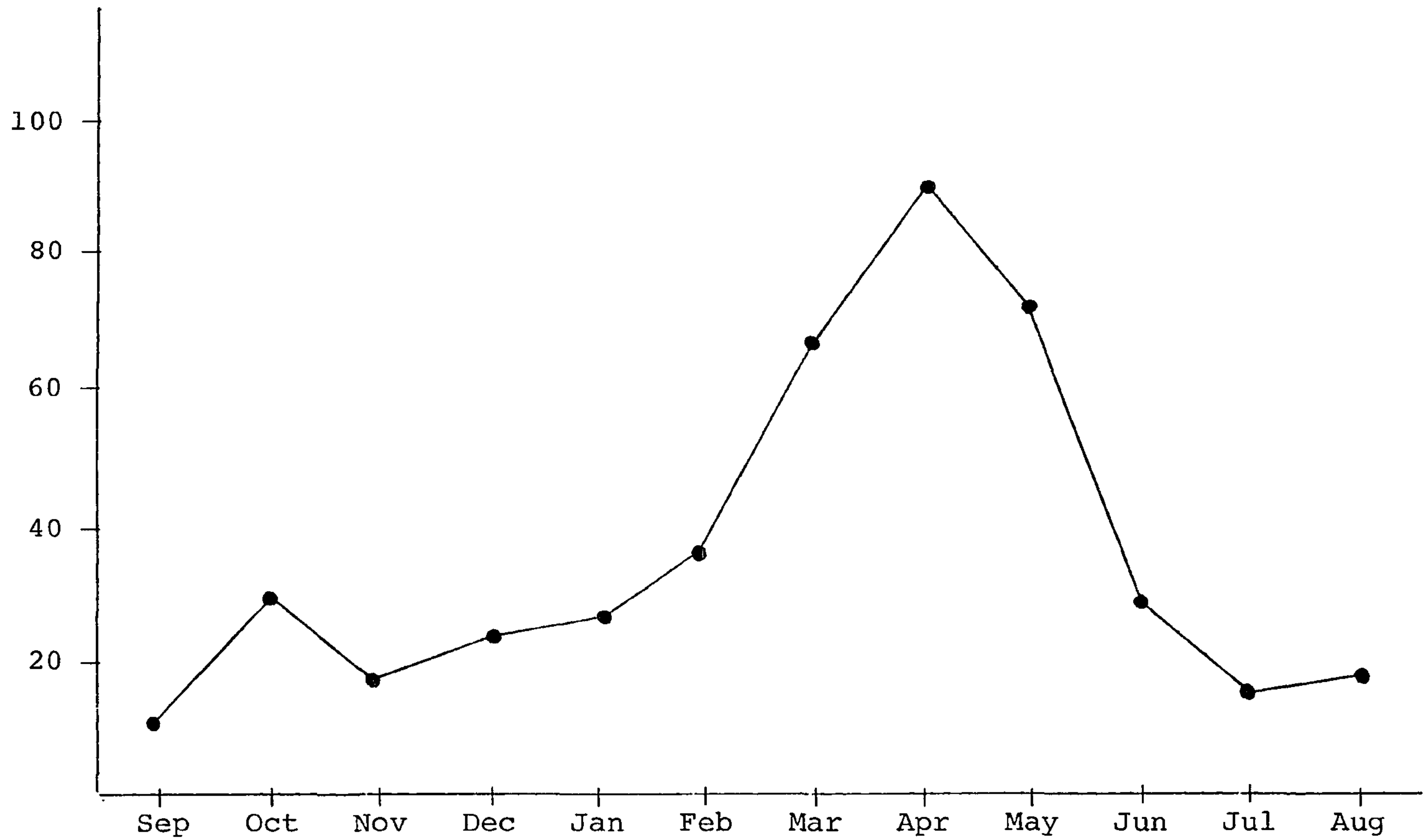


Figure 7. Seasonal percentage of mature worms of *Limnodrilus hoffmeisteri*, 1977-78, Station #1 (results based on subsamples of 30 specimens).

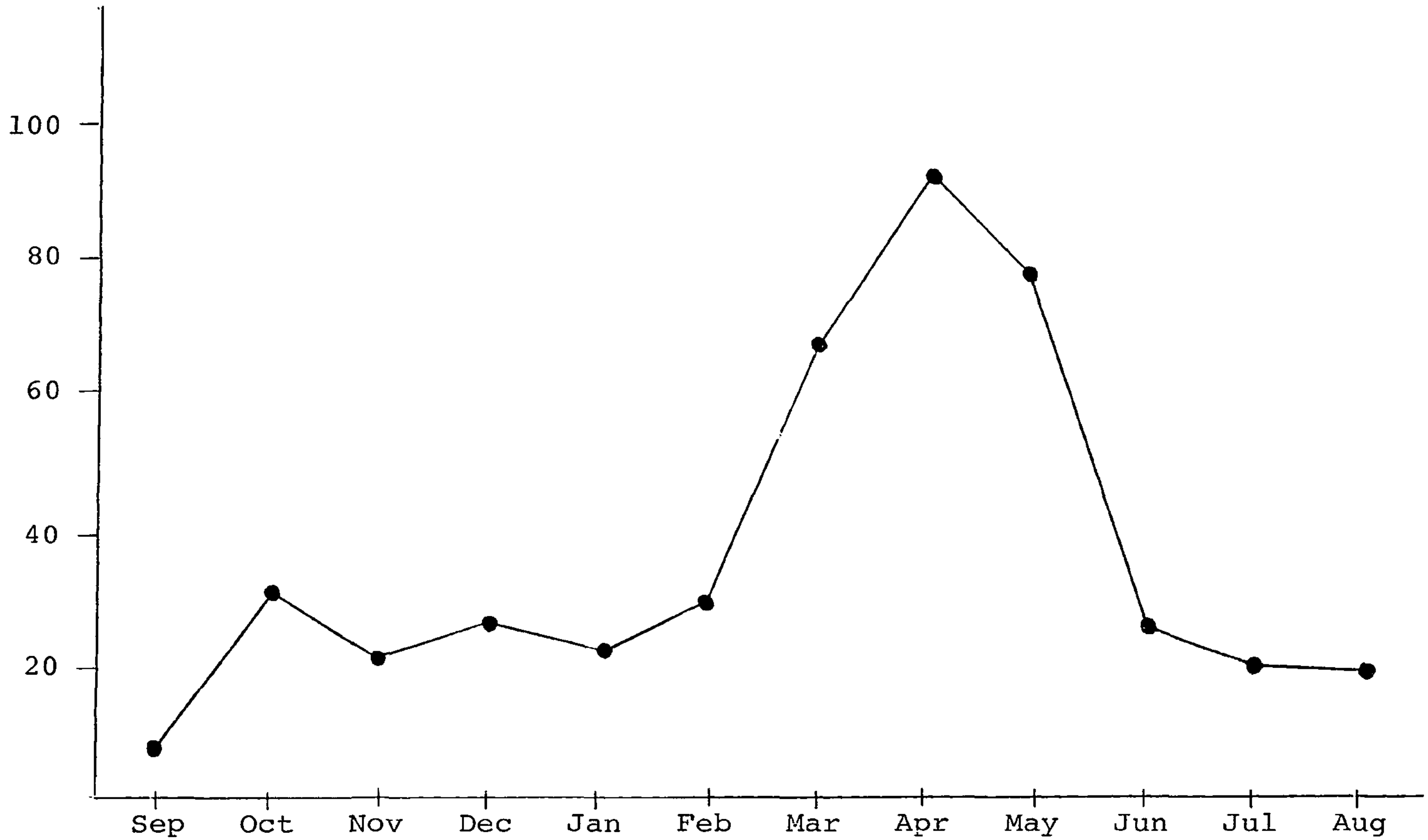


Figure 8. Seasonal percentage of mature worms of Limnodrilus hoffmeisteri, 1977-78, Station #2 (results based on subsamples of 30 specimens).

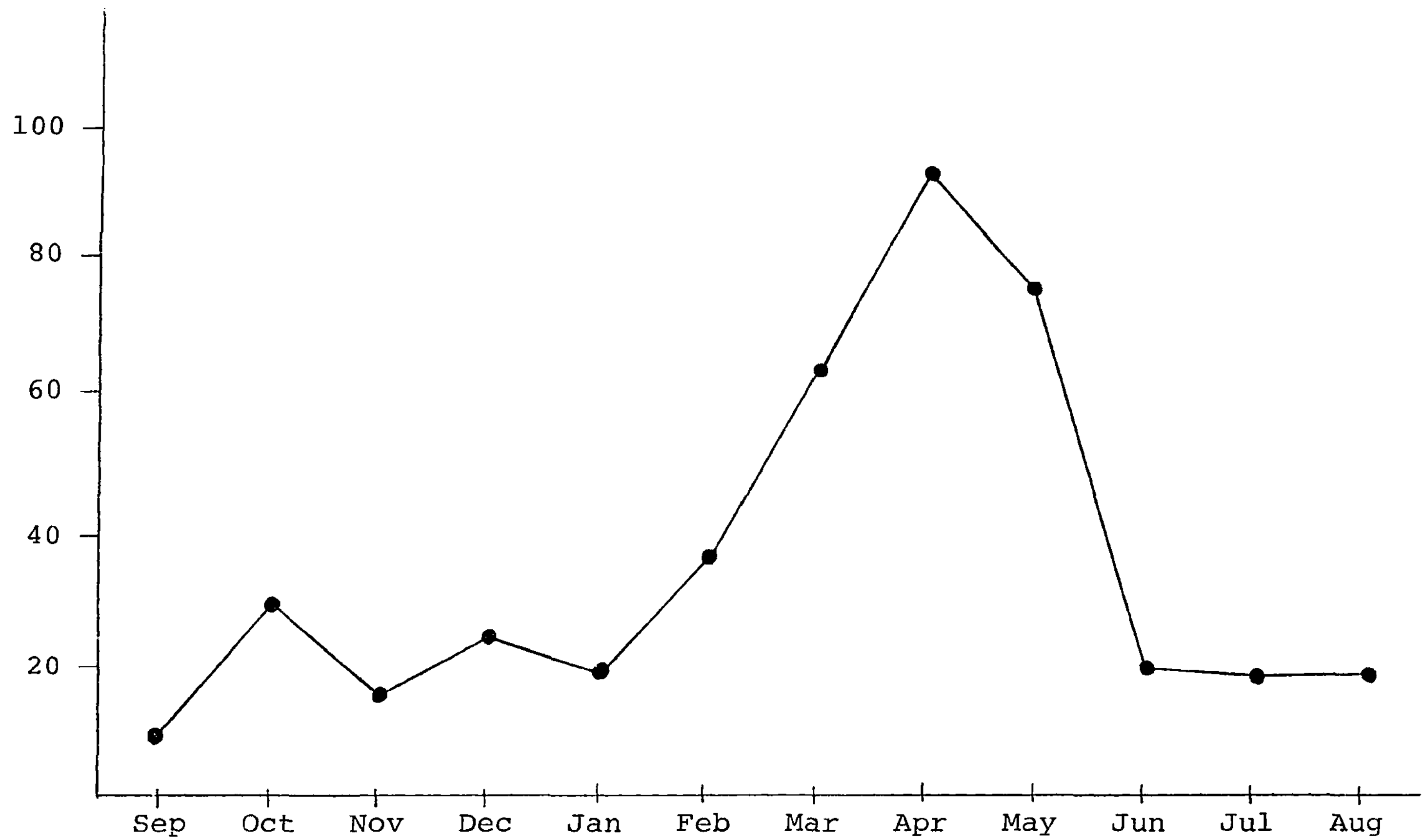


Figure 9. Seasonal percentage of mature worms of Limnodrilus hoffmeisteri, 1977-78, Station #3 (results based on subsamples of 30 specimens).

but those found in May and June contained small worms ready to emerge as they were seen through the microscope. Cocoons showed an oval shape, with plug-like forms at the ends (see Figure 10). Their surface was very transparent, so that eggs contained in the cocoons were observed without difficulty. The number of eggs per cocoon varied from 3 to 7. Those cocoons containing 5 eggs were fairly common.

The presence of cocoons in this particular area appeared to be very significant. On the basis of these observations, important points of interest were raised during this study. In the first instance, there was no doubt that the production of cocoons from April to June suggested a peak of breeding activity during this period. At the time of the greatest breeding activity, mature and breeding worms formed the bulk of the population. A reasonable assumption is that most, if not all, worms breed each year, indicating the existence of a single-year class in the population. Laboratory studies on L. hoffmeisteri have shown that this can occur. Kennedy (1966b) stated that worms may take from six months to even a year to reach maturity, and breed in either their first or second year of life.

The number of cocoons formed decreased after June, and it was followed by the appearance of young worms. It seems quite possible that in this particular habitat young worms hatch in spring and probably form the bulk of the population in early summer; they may reach sexual maturity by late

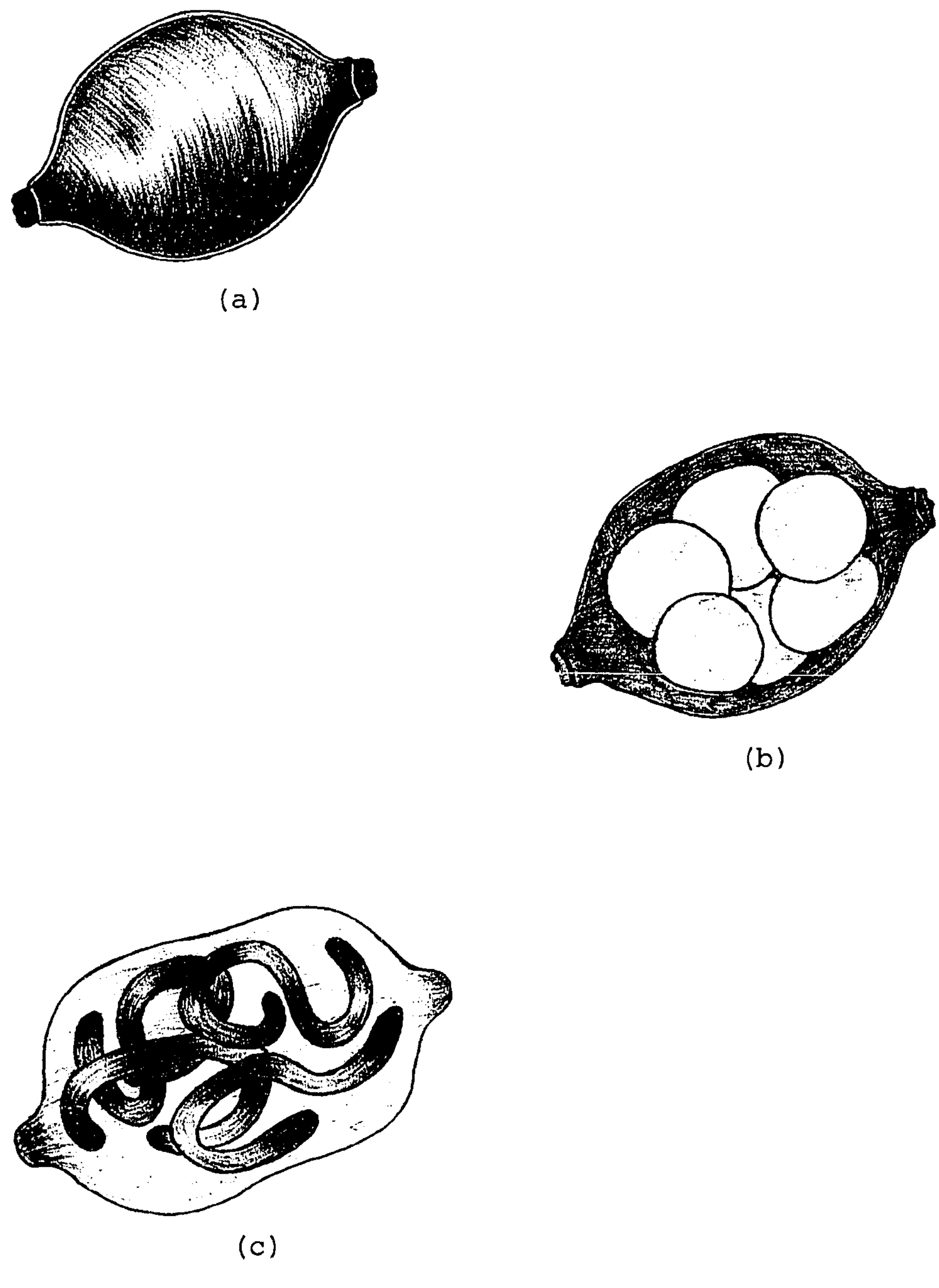


Figure 10. Cocoons of Limnodrilus hoffmeisteri: (a) external aspect, (b) eggs in cocoon, (c) cocoon with young worms.

autumn and winter and breed in the early spring. This pattern of breeding is in rather good accordance with previous observations (Brinkhurst and Kennedy, 1965; Kennedy, 1966a).

Another important consideration that can be raised is the apparent correlation between temperature and the incidence of breeding in tubificids. Data from field collections appear to justify the assumption that the life cycle is closely related to the temperature regimen of the stream. The stream was partially frozen over during the winter months and warmed up during the spring and summer months. Some investigations have supported the idea that temperature should be considered as one of the main factors influencing the beginning of breeding in some common species of tubificid worms. It has been shown that in many northern European lakes tubificids are only able to breed during a restricted period in summer when the water temperature rises above 15°C following the spring thaw. Kennedy (1966b) found that in some habitats breeding can take place in spring and summer, and he suggested that in such habitats the time of breeding was dependent on the higher water temperature during these seasons.

A similar relationship between breeding activity and temperature has been suggested for *Potamothrix hammoniensis*. Thorhaugh (1975) pointed out that breeding of tubificid worms in Lake Ersom, Denmark, did not take place in winter due to the low temperature. Aston (1973), working with

L. hoffmeisteri, showed that the number of cocoons produced per worm increased with temperatures between 5°C and 25°C. The trend appears to be the same for T. tubifex.

It is probable that a similar situation prevailed in the Little Calumet River where the incidence of breeding seems to have some correlation with the rise of the water temperature in spring (see Tables 8 and 9).

In considering the results of this study, it was noticed that despite considerable breeding activity, the number of worms collected after June remained fairly constant. This observation contrasts with the general assumption that breeding activity would lead to an increase in the number of specimens. Two possible explanations can account for the constancy of numbers recorded. First, it is likely that because of the small size of the newly hatched tubificids, worms may have passed through the wire mesh during the sieving process and thus were not counted. It is also possible that mature worms may have reverted back to an immature stage. The field data tend to support this contention, as many large immature worms were present after breeding. Tubificids are known to be capable of reabsorbing their reproductive organs after breeding. Laboratory observations on the life cycle of L. hoffmeisteri provide adequate evidence of these characteristics.

Comparison of previous results with those of the present study suggests the possibility that the reduction in the

Table 8

The Number of Worms Displacing 5 ml of Water

Month	Station		
	Station #1	Station #2	Station #3
September	700	742	735
October	643	692	672
November	710	738	695
December	633	588	570
January	604	620	646
February	520	535	501
March	503	527	506
April	427	450	431
May	463	452	471
June	597	587	571
July	674	670	653
August	655	640	670

Table 9

Temperature of Water at the Time of Collection

Month	Temperature
September	22°C
October	12
November	6
December	2
January	1
February	0
March	2
April	10
May	17
June	23
July	28°C
August	. .

expected abundance of tubificids might be attributable to death of the mature worms that were present at the time of peak activity. This possibility is less likely, however, since it does not seem to be supported by the data.

Other changes are more difficult to interpret. The decline in numbers after August and the increase in October appear to bear no relation to the breeding activity of the population. Of interest is the marked drop in the number of worms during January and February. This situation is probably not due to chance alone. It would thus appear that some factor had acted on the population during winter months that had kept the size low, but subsequent to that time of the year its influence was reduced and the population was able to maintain itself at a high level, despite fluctuations. Some interpretations of the nature of such factors appear to be likely. At first observation it would be assumed that the tubificids were absent during January and February, probably due to the effects of the severe winter 1977-78. This possibility cannot be ignored, but a close examination of Table 4 discourages that assumption, since it presents the question: If this were the case, from where has the high number of worms in June been derived? Obviously, they cannot be related to any peak of breeding activity. This already complex picture is further confused by the fact that a great number of the tubificids collected at that time were in the mature condition. Evidence from the literature suggests

that worms take at least six months to attain sexual maturity (Kennedy, 1966b). It can be said, therefore, that this situation cannot be explained on the basis of the death of tubificids during winter months.

Another interpretation of this situation would be migration. This assumption seems justified, as it would be possible that under such severe winter conditions, tubificid worms would go deeper into the stream bed or banks and would not be taken by the sampling methods used. Vertical migration is known to occur in zooplanton populations. A search of the literature found very few papers dealing with the distribution of tubificids in relation to depth. However, most of these studies support the idea that while the majority of the worms may be found in the uppermost 0-6 cm layer of sediment, significant numbers may be found down to at least 20 cm, as evidenced from samples taken in Ditton Brook, England, where worms could be found throughout cores 11 cm in depth (Brinkhurst and Kennedy, 1965).

Migration of tubificids is said to occur during stress. Analysis of the chemical data (Table 10) suggests the possibility that the apparent absence of tubificid worms would be associated with the shortage of oxygen. In contrast with the generally accepted view that tubificids are able to tolerate anoxia for long periods, evidence from the literature suggests that prolonged exposure to anaerobic conditions or very low dissolved oxygen concentration may exert control

Table 10

Chemical Analysis of the Little Calumet River (mg/l), 1977-78

Month	Alkalinity	Carbon Dioxide	Chloride	Chlorine	Chromium	Copper
September	320.5	62.3	90.3	.01	.02	.01
October	270.3	78.3	87.3	.02	.02	.01
November	262.0	65.7	85.0	.01	.03	.02
December	196.0	80.4	88.3	.02	.02	.01
January	200.0	90.5	89.0	.02	.02	.02
February	193.3	90.0	95.0	.01	.01	.02
March	194.0	88.3	87.0	.02	.02	.01
April	174.0	65.5	94.0	.02	.02	.02
May	230.5	45.5	95.0	.02	.01	.01
June	270.0	46.6	89.3	.02	.01	.01
July	272.0	45.5	95.0	.02	.01	.01
August	279.3	40.0	90.5	.02	.01	.01

Table 10--Continued

Month	Hardness Total	pH	Hydrogen Sulfide	Iron	Manganese	Nitrogen Nitrate
September	323.3	7.9	.1	.5	.02	2.0
October	321.6	7.5	.1	.3	.02	2.1
November	325.0	7.5	.1	.5	.02	1.8
December	280.0	7.4	.1	.4	.02	2.3
January	320.0	7.3	.1	.5	.01	2.0
February	321.6	7.4	.1	.3	.01	2.2
March	281.6	7.7	.1	.5	.01	1.7
April	273.0	8.1	.1	.4	.02	1.9
May	271.6	7.7	.1	.4	.02	1.5
June	280.0	7.7	.1	.3	.01	1.0
July	299.5	8.0	.1	.3	.02	1.1
August	288.3	8.2	.1	.3	.01	0.8

Table 10--Continued

Month	Nitrogen Nitrite	Dissolved Oxygen	Phosphate Ortho	Meta	Silica	Sulfate
September	.01	5.2	3.0	1.5	35	140.0
October	.02	3.4	3.4	1.3	33	140.5
November	.01	3.0	3.2	2.8	30	125.0
December	.02	1.8	3.4	2.9	25	140.0
January	.04	0.0	2.9	2.9	28	120.4
February	.03	0.0	3.4	2.0	29	130.3
March	.04	1.0	2.9	1.6	35	140.5
April	.02	3.4	2.9	2.0	34	130.5
May	.03	6.2	2.4	1.8	38	130.0
June	.04	6.0	2.3	1.3	29	140.8
July	.04	5.0	2.6	1.8	31	150.3
August	.03	6.0	2.3	1.3	79	150.0

over tubificid abundance. As pointed out by Palmer (1968), the oxygen consumption of tubificids is independent of the oxygen concentration of the external environment down to a level of about 1.5% oxygen. Below this critical level, the oxygen consumption falls sharply as the oxygen concentration of the environment falls.

Reference to Table 10 will show that not only did critically low average dissolved oxygen conditions prevail throughout the winter months, but some samples showed zero dissolved oxygen. It seems reasonable to think that tubificids may have migrated to greater depths in the sediment in response to environmental hypoxia stress. This assumption does not stand without precedent in the literature. Fisher and Beeton (1975) pointed out that tubificids, not being animals that can live indefinitely in the absence of oxygen, might actually wander through the sediments in prolonged anoxia. Their laboratory investigations of the effects of dissolved oxygen on burrowing movements of L. hoffmeisteri showed that a lesser percentage of worms occurred in the upper 6 cm in hypoxic experiments than in the higher dissolved oxygen experiments and that the greatest percentage in the depth range of 6-18 cm occurred in the hypoxic experiments.

In addition to the direct or indirect relationship between the distribution of worms and dissolved oxygen concentration, there is a possibility that other factors are

involved. To gain an understanding of this situation, further consideration will be given to the analysis of the chemical data collected.

The Little Calumet studies showed that the chemical character of the water was similar at all three stations; there were no significant variations of the values recorded between the three stations. Therefore, values present in Table 10 were established by averaging the data from the three sampling stations. On the basis of the results obtained, dissolved oxygen appears to be a very sensitive indicator of the trophic conditions of the river under consideration. The dissolved oxygen concentration in the study area ranged from a high of 6 mg/l on August 4, 1978, to a low of .0 mg/l recorded during January and February, 1978. The maximum dissolved oxygen value may be explained by increased photosynthesis through rapid proliferation of submerged vegetation during the summer months. The dissolved oxygen values at or near zero during the winter period were probably due to high biochemical oxygen demand and the removal of vegetation by scouring at that time. The rate at which oxygen saturation deficit in a stream is satisfied depends on temperature, turbulence, magnitude of deficit, amount of oxygen needed for biological oxygen demand, and amount of oxygen contributed by photosynthesis of submerged vegetation (Reid, 1961). Although oxygen depletion is usually the chief concern with sewage pollution, other

chemical parameters need to be considered as a necessary step in obtaining a general picture of the water quality of the Little Calumet River.

Determination of pH and alkalinity of water samples revealed that alkalinity was high in late summer, fall and early winter, and the related carbon dioxide and pH values were highest and lowest, respectively, at these times. Apparently, rainwater flowing over soils of the area rapidly dissolved carbonates, resulting in a rapid loss in carbon dioxide content, and change toward an alkaline pH. Values of pH varied from 7.4 to 8.2, with alkalinity and carbon dioxide content of the water varying accordingly. Carbon dioxide content of the water varied inversely with oxygen content levels. Waters with high alkalinity and hardness values are normally quite productive. The highest value for alkalinity found in the Little Calumet River was 325 mg/l. The total hardness in the water tested was high, as might be expected, with values ranging from 325 mg/l to 282 mg/l.

Chloride concentrations in the Little Calumet River varied from 95 mg/l to 85 mg/l. The highest concentration was found in July, but chloride values remained essentially identical throughout the period of the observations. Chloride content can be partly attributed to the widespread use of de-icing salt during the winter season. Domestic sewage and human wastes can also be mentioned as responsible for the high values recorded. Chloride is often associated with

urbanization and domestic pollution. This ion is stable in water, is not biologically concentrated, and is easily measured. As such, it has been proposed as an indicator of domestic sewage pollution.

Another environmental factor that showed a high value was the concentration of silica and sulfate. Concentration of silica remained fairly uniform throughout the period of the study. Silica content can be attributed to leaching from soils and rocks, due chiefly to the nature of the ground water. Sulfate concentrations varied from 120 mg/l to 150 mg/l. Sulfate may be present in natural waters in concentrations ranging from a few to several hundred mg.

From the chemical data collected it was evident that all metal concentrations were very low. Concentrations of chromium, copper, iron, and manganese were not found to be large enough to have an appreciable effect. Consequently, they do not appear to be a reliable pollution indicator in this situation. Generally these metals are present in small quantities, but in places where they are present in sufficient quantity they are an important part of the chemical character of the water.

In regard to nutrient concentrations, it can be said that they varied considerably throughout the year. Reid (1961) stated that the nutrient content of the water varied considerably depending upon the day, the season, the amount of dilution, temperature and other factors. Nitrite

concentrations were generally low, ranging from .001 mg/l to .004 mg/l, while nitrate concentrations were moderately high, ranging from 2.3 mg/l to .8 mg/l. The maximum values recorded for orthophosphate and metaphosphate were 3.4 mg/l and 2.9 mg/l, respectively. The lowest concentrations of phosphate in its various forms were recorded during the summer months. This is probably a reflection of the fact that phosphorus is very quickly tied up by the plants. Hynes (1966) pointed out that, although considerable amounts of nutrients do enter the streams, relatively small quantities may actually occur in solution in the water, especially during the season plants, and perhaps bacteria, grow.

In connection with these chemical analyses, three bacteriological parameters were measured: fecal coliform, total coliform, and yeasts and molds. Analysis of Tables 11, 12, and 13 shows high densities of bacteria. Both fecal and total coliform bacteria show seasonal fluctuations (see Figures 11 and 12). Fecal coliform densities vary from 61,000 per 100 ml to 96,000 per 100 ml. The presence of fecal organisms has long been recognized as an accurate indicator of water pollution by untreated sewage. The high densities recorded in the Little Calumet River were probably due to overflow of spetic tanks or contact with feces of mammals.

Total coliform densities varied from 127,000 per 100 ml in February 1978 to 197,000 per 100 ml in May 1979. As shown in Figure 13, the level of yeasts and molds was quite low

Table 11

Fecal Coliform Expressed as Average Colonies per 100 ml with Mean and Standard Deviation

Month	
September	100,000 ± 7,071
October	126,000 ± 2,550
November	133,000 ± 7,071
December	72,000 ± 816
January	64,000 ± 1,225
February	56,000 ± 707
March	92,000 ± 707
April	110,000 ± 7,071
May	115,000 ± 3,536
June	139,000 ± 816
July	124,000 ± 1,225
August	121,000 ± 1,871

Table 12

Total Coliform Expressed as Average Colonies per 100 ml with Mean and Standard Deviation

Month	
September	174,000 ± 2,450
October	162,000 ± 1,871
November	194,000 ± 1,225
December	146,000 ± 707
January	141,000 ± 1,225
February	127,000 ± 1,225
March	175,000 ± 1,225
April	183,000 ± 707
May	197,000 ± 707
June	194,000 ± 1,225
July	192,000 ± 1,414
August	185,000 ± 708

Table 13

Yeast/Mold Expressed as Average Colonies per 100 ml with Standard Deviation

Month	
September	88,000 ± 3,742
October	91,000 ± 707
November	81,000 ± 1,633
December	73,000 ± 707
January	73,000 ± 707
February	61,000 ± 707
March	87,000 ± 707
April	93,000 ± 1,215
May	92,000 ± 707
June	96,000 ± 1,225
July	96,000 ± 1,871
August	96,000 ± 707

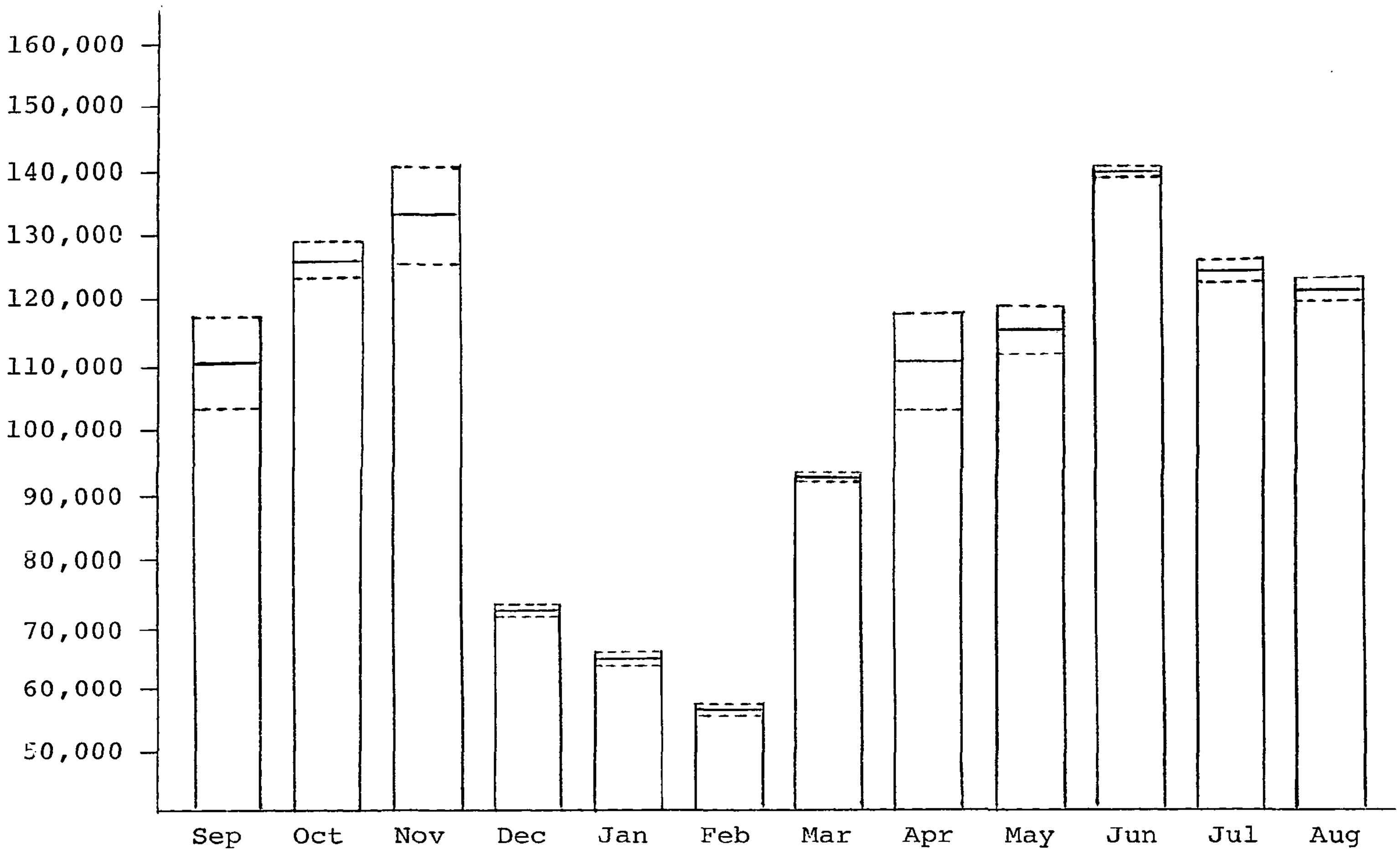


Figure 11. Fecal coliform expressed as number per 100 ml from September to August during 1977-78.

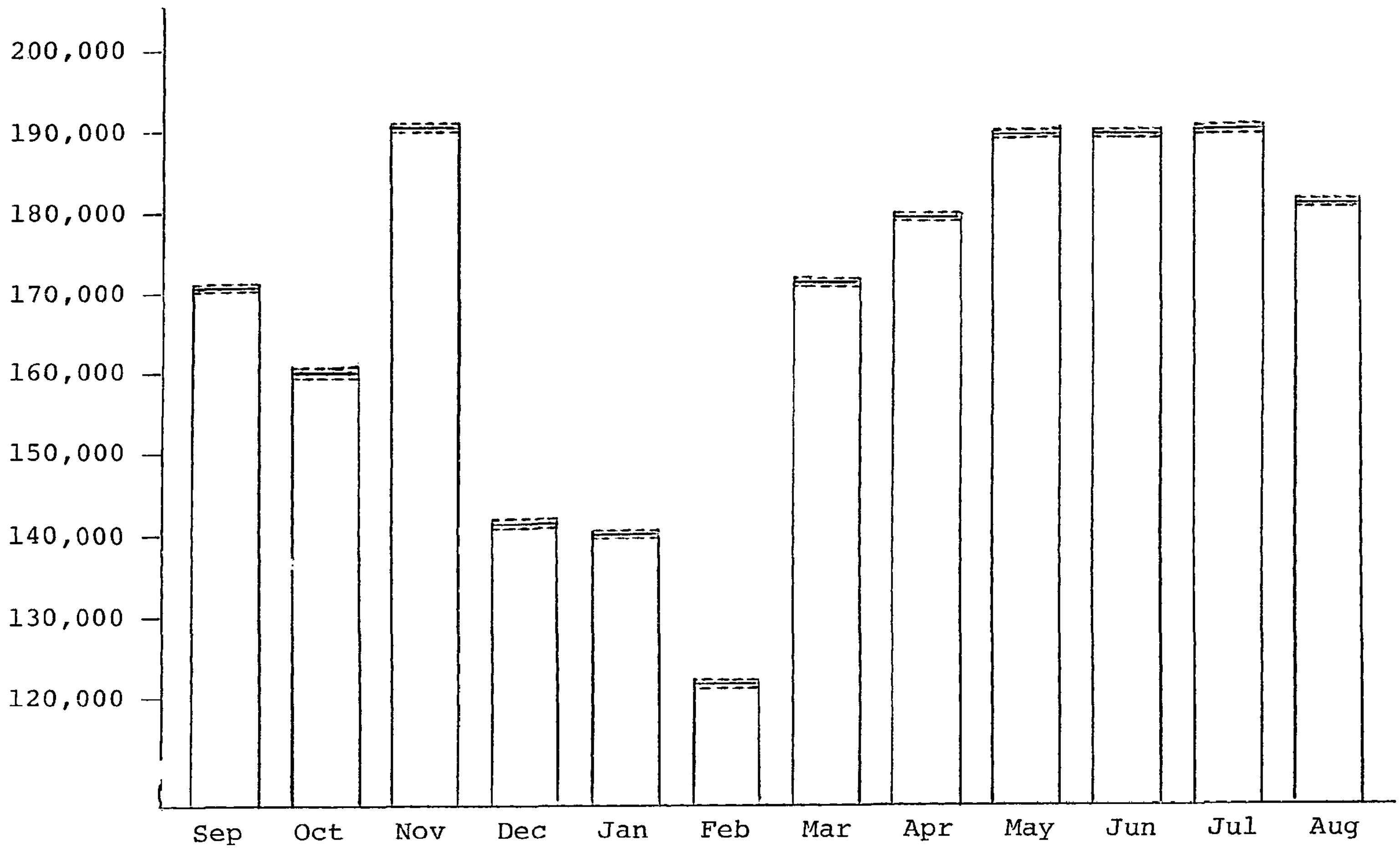


Figure 12. Total coliform expressed as number per 100 ml from September to August during 1977-78.

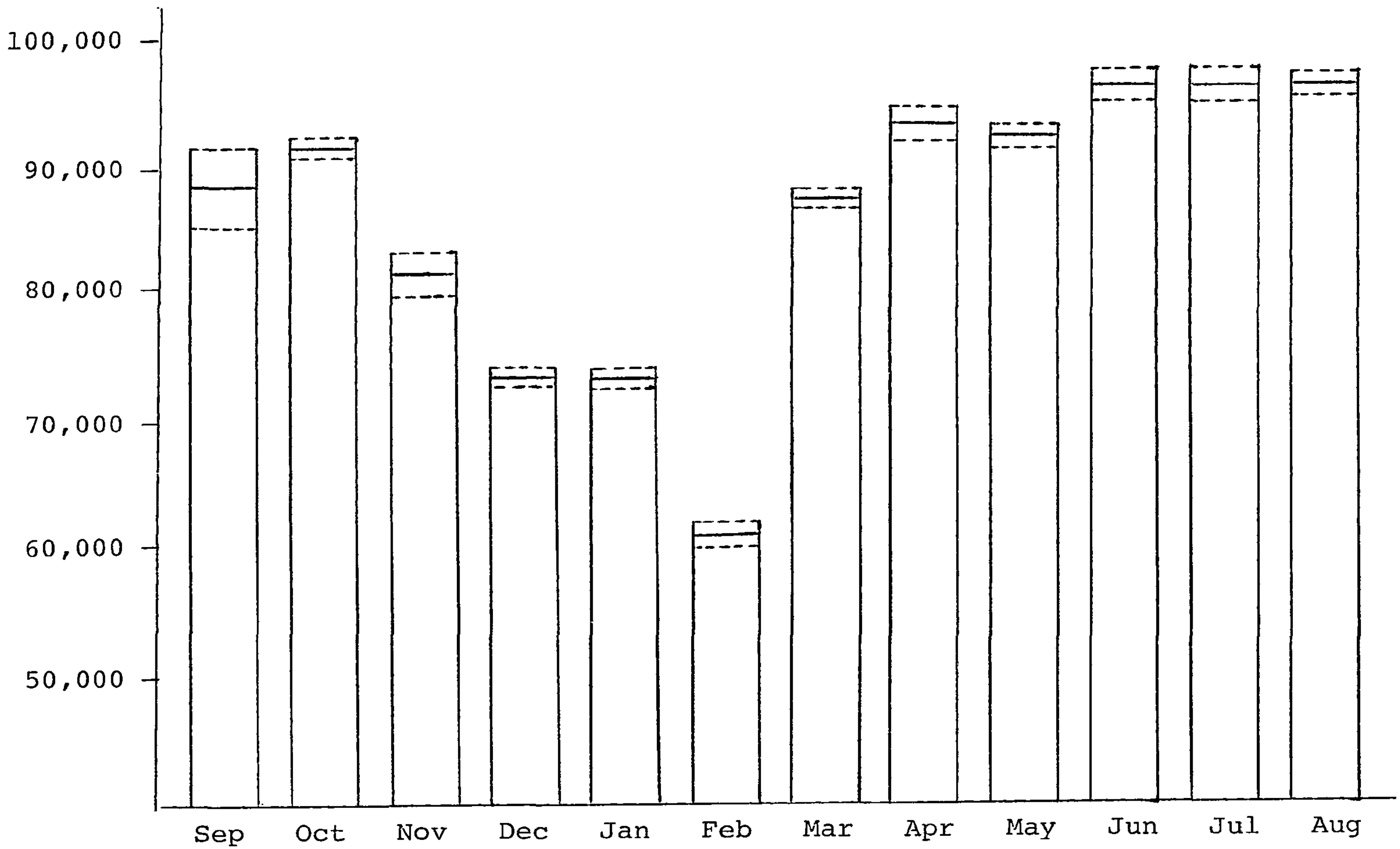


Figure 13. Yeast and mold expressed as number per 100 ml from September to August during 1977-78.

throughout the duration of this study. This low level of yeasts and molds was most probably due to the slightly alkaline pH, as yeasts and molds usually flourish in an acid environment.

Many factors probably operate to determine the variation in the occurrence and abundance of the species observed. However, one difficulty in making any generalization of this matter of correlation between abundance and distribution of tubificids and physico-chemical parameters is the fact that the numbers of both species and individuals seem to vary in a manner apparently unrelated to any obvious chemical or physical factor of the environment. Many species occur in rivers, streams, pools, and lakes, of all sorts and conditions, mostly inhabiting mud but demonstrating no clear habitat preferences (Brinkhurst, 1965b).

Attempts to identify factors limiting the distribution of individual species have been noted in a number of papers, but conclusions drawn from these studies are fragmentary and conflicting. Even from localities studied in great detail, as the River Thames, England, no conclusions can be generalized since the distribution of the worms showed an overall lack of correlation with the observed physico-chemical characteristics of the habitat. Only factors limiting the distribution of the genus as a whole, such as salinity, and organic or inorganic pollution have been recognized (Brinkhurst and Jamieson, 1971).

In considering the results of the present study, it should be noted that analysis of the data collected differed little from station to station. Since this lack of variation is correlated with the location of the stations, it would be useful to study several stations at different points along the Little Calumet River. It can be stated in general, however, that the present results paralleled the general finding that tubificids often occur very abundantly in polluted localities. The ecological basis of this phenomenon is obvious. The suppression of predators and absence of competition for space, plus the availability of nutritional material, provide a perfect situation for the high density of tubificid worms often exhibited in polluted waters.

The degree of pollution in the Little Calumet River indicated by the high number of tubificids was also supported by the chemical data. Tubificids have a reputation for resistance to pollutants; however, very few studies on the extent of this resistance have been carried out. Bagge and Ilus (1973), in an attempt to study the distribution of benthic tubificids in Finnish coastal waters in relation to hydrography and pollution, found no clear correlation between the abundance and distribution of tubificids and the concentration of total phosphorus in the water. Whitley (1968) found that T. tubifex and L. hoffmeisteri were quite tolerant to toxic materials such as lead, phenol and zinc. The median tolerance limit for pH levels in modified Knop's solution has

been shown to be 5.8 to 9.8. Their median tolerance limit for lead was 49.0 ppm at pH 6.5, and 27.5 at pH 8.5. For zinc, the median tolerance limit was 46.0 ppm at pH 7.5. Whitley suggested that the toxic action of the ions is probably produced by a mucous metal complex which precipitates on the body wall of the worm, blocking the exchange of oxygen and carbon dioxide. There is also evidence from laboratory experiments carried out by Whitten and Goodnight (1966) that tubificids are able to tolerate high concentrations of the insecticide DDT. The worms were able to survive, for example, at concentrations exceeding 100 ppm.

In the present study, tubificids appear to be very resistant to high content of silica, chloride, sulfate, phosphate and nitrate, as is evidenced in Table 10. The important question, however, which is as yet unanswered, is which factor(s) of the water chemistry governs the distribution and abundance of these worms.

CONCLUSIONS

(1) In the Little Calumet River, two species of tubificid worms were found to coexist: *Limnodrilus hoffmeisteri* and *Tubifex tubifex*. *L. hoffmeisteri* made up more than 70% of the tubificid fauna. The number of *T. tubifex* remained relatively low through the period of investigation, suggesting that while their ecological requirements may overlap, there are probably some separate factors which determine the abundance of each species.

(2) Considerable variations in the numbers of worms were observed throughout the year. The lowest numbers of worms occurred in January and February, whereas the greatest numbers were recorded during late spring and summer. There was no major observable difference in the relative abundance of the species at each sampling point. This situation is correlated with the fact that the three stations were in close proximity to each other.

(3) A high proportion of sexually mature worms of *L. hoffmeisteri* was present from April to June. However, few sexually mature *T. tubifex* worms were found at that time, suggesting that its reproductive cycle may differ from that of *L. hoffmeisteri* or that the then existing conditions were not conducive to reproductive behavior.

(4) A short but well-defined period of breeding activity

of L. hoffmeisteri was found to occur in the Little Calumet River. Part of this activity was marked by the production of cocoons containing eggs. Cocoons were produced between the months of April through June. At the time of the breeding period, mature worms formed a large proportion of the population, indicating that most of the worms were breeding at that time and were at least twelve months old.

(5) Since the size of the population remained fairly constant despite breeding activity, it is assumed that the majority of the newly hatched worms were not counted, as they may have passed through the wire mesh during the sieving process. Return of mature worms into immature conditions was partly responsible for the numbers of immature worms collected at that time.

(6) With the exception of temperature and dissolved oxygen, which could be closely related to the life cycle of L. hoffmeisteri, no clear relationship between physical and chemical parameters and the abundance and distribution of tubificids was observed.

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