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Studies on the Planktonic Protozoa and Other Microbiota of a Eutrophic Lake

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STUDIES ON THE PLANKTONIC PROTOZOA AND OTHER MICROBIOTA OF A EUTROPHIC LAKE

(TITLE)

BY

NEIL HOWARD CHANCE

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INTRODUCTION

The present study was conducted on a small lake in East-Central Illinois. Ashmore Lake is known to be subject to changes in mineral content due to the influence of water that is shed from surrounding agricultural fields. These fields consist mostly of corn, wheat, and soybean crops, with some pasture land. The lake is directly affected by run off water containing soluble elements from the commercial fertilizers used on the surrounding fields. These dissolved minerals are brought into the lake by the Polecat Creek which flows into the eastern border of Ashmore Lake on its westward flow toward the Embarras River.

Data obtained from reports of students that had made recent plankton collections in the lake as part of an Invertebrate Field Zoology course, and personal discussions, indicated a noticeable fluctuation in the composition of the zooplankton that seemed not to be related to the normal seasonal phenomena.

The preceding observation suggested the following course of investigation:

> To survey the zooplankton present in the upper one half meter of Ashmore Lake, and to determine if, and to what degree, the composition of the zooplankton is altered as changes in temperature, photoperiod, oxygen,

iron, nitrite-nitrogen, nitrate-nitrogen, sulfate, phosphate, turbidity, and pH occur during a three month period from late winter to mid-spring.

Ashmore Lake

Ashmore Lake is a eutrophic body of water 14,000 square yards in area, located NW¼, Sec.6 T12 N, R11 E, Coles County, Illinois, near the Village of Ashmore. The lake is a result of a limestone quarry which was operated intermittently from 1900 to the late 1940's. The average depth of the lake was 153 cm. on May 12, 1968; the bottom is covered with silt and small stones. In the shallower regions, the lake's surface is covered with water lilies (Nymphaea), which first broke the surface during the first week of April. A variety of trees including eastern cottonwood (Populus deltoides), white ash (Fraxinus americana), black willow (Salix nigra), silver maple (Acer saccharinum), and American sycamore (Platanus occidentalis), are found growing almost at the water's edge. This lake affords an opportunity to study the effects of a small stream and the minerals it contributes to the lake, and the responses to these minerals by the zooplankton.

Polecat Creek

This creek has its origin in Edgar County, Illinois, and flows in a south-westward direction through Edgar and Coles

Counties. As the creek meanders through the East-Central region of Illinois for approximately ten miles, it gathers the water shed from nearly 17,280 acres of agricultural fields, growing mostly corn, wheat, and soybean crops, with some pasture land. These fields are fertilized each year with commercial fertilizer.

The creek varies in depth from six centimeters to a depth of four meters, however, the average depth would be approximately one meter. The Polecat ends its flow as it enters the Embarras River.

REVIEW OF THE LITERATURE

General Considerations

Plankton investigations have been carried out on many lakes, rivers, and ponds in the world during the past century. Damann (1943) refers to the study by Mueller, of microscopic organisms occurring in the North Sea as early as 1845. The term plankton was not put into use until Hensen in 1887 used it to describe the organisms that drift suspended in natural occurring waters (Davis, 1955).

Needham and Lloyd (1930) in The Life of Inland Waters, state "The shallower a lake is, the better its waters are exposed to light and air; and other things being equal, the richer its production of organic life." Welch (1935) also states, "Within limits, and under strictly comparable conditions, the greater the areas of shallow water, the greater the biological

productivity." These statements apply to the rather shallow lake under investigation.

Yoshimura (1932) during a study of the seasonal variation in content of nitrogenous compounds and phosphate in water of a pond in Japan, found no relation between plankton fluctuations and soluble phosphate, although he did state that high total phosphorus corresponded with a high total plankton. His study does not take into account the extremes caused by leaching of commercial fertilizers into streams and lakes.

Ryther and Yentsch (1957) observed a relationship between photosynthetic rate and chlorophyll content in natural populations and cultures of marine phytoplankton.

Lackey (1961) sampled different environments at the bottom level in marine waters, and found many different biotas, both as to component species and total numbers. Lackey made use of aquaria into which bottom samples were placed, and found algae and Protozoa to be concentrated in the 2 to 5 mm. mud-water interface. Wieser (1959), in a study of Puget Sound beaches, found stratification of microbiota to be temperature dependent, all other factors being equal.

Swale (1964) studied the phytoplankton of a calcareous river in England for two years to obtain quantitative information of phytoplankton. He states that the greatest densities of plankton were found during periods of low rain fall.

Kofoid (1908) conducted a study of the plankton of the

Illinois River. In an earlier study (1894-99) he points out that the age of water within certain limits results in an increase in plankton numbers.

Galstoff (1924) concluded velocity of current to be the principal factor that affects the organic life of a river. Eddy (1929) made collections along the Sangamon River in Illinois during the summer of 1929 and concluded that the creation of Lake Decatur serves to remove pollution factors which resulted in clean water plankton in the river below the lake.

Reinhard (1931) reveals that environments which allow the greatest time for the development of plankton will produce the greatest crop. His studies were conducted on the upper Mississippi River. Roach (1932) studied the entire Hocking River, in Ohio, as a unit and concluded that average amounts of domestic pollution has no effect on plankton. He stated further that approximately fifteen days after a flood the plankton of a river return to normal, implying that dilution is of little lasting consequence. Chandler (1937) investigating the streams draining Lake Michigan, has shown that typical lake plankton decrease rapidly in streams draining lakes. This finding reinforces Reinhard's conclusion on lasting environment.

Lackey, _et al_. (1943) in considering the question "What is a normal stream plankton?" made studies of a small stream in Ohio. He found large plankton populations independent of any single factor such as age of water, presence of strong pollution,

distance from source, and the like. He also refers to the study of Gessner (1934), which states that phosphorous concentration is the limiting factor for microorganisms in the majority of natural waters, and gives figures showing many lakes had no phosphorous. Lackey goes on to say (in opposition to Reinhard) that rainfall is of enormous importance and results in a modification of the numbers and types of plankton found.

Damann (1950) made a plankton reconnaissance study of the Missouri River Basin during the summer of 1950 and gave high turbidity in the Missouri River as the apparent reason why the plankters do not multiply after leaving the tributaries flowing into the river. He found that tributaries from arid or nonagricultural land were noted to have the lowest plankton densities. The effect of added enrichment for the drainage basin in the agricultural areas seemed to be responsible for higher density in some tributaries.

Williams (1964) studying major rivers and lakes of the United States, shows some possible relationships between plankton-diatom species numbers and water quality estimates, stating especially that temperature, calcium hardness, and irrigation waters returned to streams account for significant increases in population densities.

Hartman (1965) in a study of the Ohio River relates that phytoplankton are definitely affected by phosphorus, nitrates, and nitrites.

Hanebrink (1966) during a study of the net plankton in Sardis Reservoir, Mississippi, found that plankton increased rapidly after the streams entered the reservoir. He found that high temperatures of the surface water resulted in a decrease in plankton counts. Again the validity of the lasting stable environment hypothesis is suggested.

Nilsen (1967) conducted a study of experimentally placed log substrates in the Kaskaskia River in Illinois, and states that many taxonomic groups seemed to prefer an intermediate depth and that this depth preference may change with the daily light cycle.

Pennak (1946) states that in most lakes and streams nearly all inorganic nutrients appear to be present in excess, even though these substances may occur in surprisingly small quantities. Phosphorus is considered to be the limiting factor much more frequently than nitrogen, even though the range of 0.002 to 0.005 milligrams per liter includes lake waters of very low to high productivity! Pennak relates that it is difficult to demonstrate the effect of nitrogen and phosphate as limiting factors directly, to the exclusion of all other factors.

Raymond (1937) made a study on the plankton of Bass Lake, in Michigan, a concretion-forming marl lake, and found large amounts of marl, largely calcium carbonate. This marl, in the littoral zone of the lake is indirectly responsible to a large degree, for low plankton production and results in a scarcity

of rooted vegetation.

Ahlstrom (1936) stated that the zooplankton of Lake Michigan was often equal to the diatom group in volume but not in numbers. Damann (1943) analyzed seventeen years of plankton data collected from Lake Michigan, and noted 316 "species" of diatoms and 182 "species" of Protozoa. He refers to Lake Michigan as primarily a "Diatom Lake," and secondarily a "Dinobyron Lake."

Orr (1954) compared the composition of Protozoa of two areas in a lake in Pennsylvania, one area--swamp, and the other a sewage area. He concludes that protozoan counts showed a quantitative and qualitative difference between the populations of the two areas.

Stern (1964) found that the more intensive the analysis the more difficult it becomes to isolate controlling physical and chemical variables. In an artificial pond, Stern found that the composition did not change rapidly in most instances, and that abundance fluctuated within a period of forty-eight hours.

Organic Factors

Food

Lackey (1938) investigated some ecologic factors affecting the distribution of Protozoa, in a variety of habitats. He indicates that if the principal food of a particular holozoic protozoan species consisted of certain green flagellates, these protozoans might disappear except during the summer months when these flagellates occur. Lackey believes that protozoans can live in

a wide range of pH, and in nature food requirements are only a quantitative limiting factor. Noland (1925) relates that in nature the amounts of available food has more to do with the distribution of fresh water ciliates than any one factor.

Lackey (1943) conducted a series of experiments using containers. To these containers, containing plankton, he added varying amounts of phosphorus and found that they either directly or indirectly excysted and the protozoan population increased very rapidly. In conclusion, he states as long as phosphorus is present in ample quantities, there is a rapid use of other food, but diminishing phosphorus below the critical point greatly retards the use of organic food. Lackey mentions the study of Sandon (1932) which states that food is largely the controlling factor for Protozoa.

Hall (1965) states that in some natural waters the protozoans barely escape starvation, managing to survive only as sparse populations, due to the lack of certain elements. He says that protozoan nutrition, so far as the Protozoa themselves are concerned, involves two general problems: (1) finding the necessary foods, which is usually a matter of chance, and (2) getting such foods inside the body for use in metabolism. He goes on to say that the addition of just one element might cause a greater density or result in the disappearance of some species. He indicates that it has been known for many years that increases in temperature modify the nutritional requirements of microorganisms.

Physical Effects

Temperature, Photoperiod, and Rainfall

Pennak (1953) relates that free-living protozoans show wide ranges of tolerance to single environmental factors, but at the same time it is thought that their activities may be affected by relatively slight environmental changes. He says that in general flagellates react more directly to single factors than do the ciliates, while amoebas are intermediate. Pennak goes on to say that the most pronounced seasonal population changes are quantitative, and temperatures below 10°C. and above 28°C. markedly affect the number of individuals present, but not the number of species and that summer and winter lists of species from the same habitats are often strikingly similar.

Hutner *et al.* (1957) noted that an increase in certain metals--iron, magnesium, zinc, and apparently specific amino acid requirements also increase with temperature.

Noland (1925) suggested several factors (such as food, temperature, oxygen, and carbon dioxide) that influence the distribution of fresh-water ciliate protozoans. He concluded that certain ciliates decidedly favor low temperatures.

Wang (1928) studied the seasonal distribution of Protozoa in a pond in Philadelphia, and listed a number of temperature effects, some of them directly affecting the Protozoa. He made use of the terms eurythermic, termophilic, and so on, to describe these organisms. Wang made his collections near the

surface of the pond.

Welch (1935) suggested when the interpretation of field results is being directly correlated to temperature, one should consider the modifications to which a body of water is subject. These modifications include changes in chemical composition and photoperiod.

Lackey (1938) states that marked seasonal changes due to temperature are quantitative. Reinhard (1931) found fluctuations in the Upper Mississippi due to temperature, but these changes were minor and affected principally the chlorophyll bearing forms. Lackey (1943) suggests that rainfall is of enormous importance in modifying the numbers and types of plankton found, and rains quickly reduce the total population from the source of a stream to the mouth.

Bamforth (1958) found the maximum values for temperature, pH, and dissolved oxygen occurred in mid-afternoon, and the minimum in early morning. Bamforth (1962) pointed out that plankton populations, predominantly Protozoa, often changed during the day, sometimes significantly within two hours after sunrise, pointing to either increased temperature and/or light intensity as factors.

Swale (1964) concludes that longer day length is most likely a "triggering" factor determining the onset of spring diatom growth. Beyers (1962) postulates, using aquaria, that the closer a living system approaches the integration of a balanced

ecosystem, the less it is affected by temperature. Beyers also believes that photosynthesis is not stimulated by this increase in the temperature. Hall (1965) mentions the fact that temperature modifies the nutritional requirements of microorganisms.

Manganese and Iron

Guseva (1939), in his studies, has shown that concentrations of more than 0.2 milligrams of manganese per liter are definitely toxic to some plankters. Hutner et al. (1957) states that need for increases in certain metals--iron, magnesium, manganese, zinc, and apparently specific amino acid requirements also increases with temperature. Bamforth (1962) noted a decline in iron during the day. Pennak (1946) finds concentrations of only a milligram or two per liter usually seems to be ample for such substances as silicon, magnesium, calcium, chlorine, potassium, and sodium.

Hydrogen Ion Concentration and Oxygen

Cowles and Schwitalla (1923) studied the hydrogen-ion concentration of a stream and series of pools in relation to the occurrence of Euglena, and found the pH to be modified by the aquatic fauna and flora. Lackey (1938) says that protozoans can live in a wide range of pH. Bamforth (1958) found the maximum value for pH and dissolved oxygen to occur in mid-afternoon, and the minimum in early morning. Hazelwood and Parker (1961) show that dissolved oxygen concentration is positively correlated to the density of Daphnia. They state that the density of

Diaptomus is also positively correlated with oxygen.

Phosphate, Nitrite-nitrogen, and Nitrate-nitrogen

Juday and Birge (1931) show from studies of Wisconsin lakes that the phosphate remained undiminished in the surface waters of lakes and many of them were high producers of plankton.

Yoshimura (1932) found no relation between plankton fluctuations and soluble phosphate. Gessner (1934), however, says phosphorus concentration is the limiting factor for microorganisms in the majority of natural waters.

Lackey *et al*. (1943) reasoned the increase in plankton below a sewage disposal plant to be due to materials such as phosphates, nitrates, and nitrites. Hutchinson (1944) concludes that all nutrients except nitrate and phosphate are normally present in such considerable excess, that qualitative effects due to their fluctuation are most unlikely.

Pennak (1946) says that phosphorus is considered to be the limiting factor much more frequently than nitrogen. Hays and Phillips (1958) noted that phytoplankton can take up a given amount of phosphate in five minutes in jar experiments, while aquatic plants require several hours. Bamforth (1958) found that nitrates increased slightly at night, while carbon dioxide, phosphate, and iron declined during the day. Bamforth (1962) saw no diurnal change could be noted for nitrate and nitrite.

Williams (1964) has shown the return of irrigation water to streams may account for significant increases in population

density of phytoplankton. He believes this to be due to the nitrates, phosphates, and trace minerals taken from the agricultural soil.

Hutchinson (1944) in a review has indicated: "Clear cut correlations between chemical conditions and the qualitative composition of the phytoplankton and the zooplankton are not to be expected."

MATERIALS AND METHODS

Plankton collections were made near the noon hour twice weekly, beginning on March 7, 1968, and ending on May 23, 1968. A plankton net made of No. 12 standard silk cloth with "125 meshes to the inch" was towed in the upper one foot level of the water, at a two meter distance behind a rowed boat. The lake was arbitrarily divided into thirds, and the plankton net was raised and samples collected three times during the 200 meter tow. The tow was made from west to east in the longest portion of the lake.

During the early part of this study it was necessary to use the boat oars to break through ice which covered the surface of the lake, in order that samples might be obtained. Due to this ice formation, during the very cold days samples of the entire length of the lake were impossible.

One quart of water was taken from the upper .5 meter level near the center of the lake and taken to the laboratory for chemical analysis.

A measurement of air and water temperature, and parts per million (ppm) of oxygen was recorded, using a YSI Model 51 Oxygen Meter. A Hach, Model No. DR-EL portable water engineers laboratory was used to recheck oxygen and to determine turbidity. Turbidity readings were recorded in Jackson Turbidity Units (J.T.U.). Parts per million of sulphate, phosphate, iron, nitrate-nitrogen, nitrite-nitrogen, and pH values were also determined, using the same instrument. Hours of available sunlight and the amount of rainfall was recorded from standard meteorological data posted by the Eastern Illinois University's Department of Geography.

The sample containing zooplankton was not centrifuged, however, it was swirled by hand, and a syringe was used to remove a sample from the container into a Syracuse watch glass. The sample was viewed first under a Bausch and Lomb 0.7X - 3X binocular scope for survey of the larger zooplankton. Later, the watch glass and sample were transferred to an American Optical compound microscope with a 10X ocular, 10X low power objective and 45X high power objective, for observing the smaller plankters. Wet-mount slides were prepared in order to facilitate identification of Protozoa and other microfauna. All specimens were studied alive when possible, however, photographs and permanent slides were made of some organisms. A Sedgwick-Rafter counting chamber was used in the later observation. Data was tabulated, but inasmuch as qualitative information was sought, no attempt was made to make more than rough quantitations.

Systematic references for the various groups of organisms investigated included Ward and Whipple, 2nd Edition, W. T. Edmonson, editor (1959), Fresh Water Biology; Pennak, Robert W. (1953), Fresh-water Invertebrates of the United States; Kudo, Richard R. (1966) Protozoology, 5th Edition; Jahn, Theodore and Frances (1949), How to Know the Protozoa; Needham and Needham (1930), A Guide to the Study of Fresh Water Biology; and Eddy and Hodson (1961), Taxonomic Keys to the Common Animals of North America.

RESULTS

The contour of Ashmore Lake and its relationship to the Polecat Creek is shown in Fig. 1. The creek flows toward the west. Detail of the study area, showing depth, areas of emergent vegetation, and plankton collecting range is shown in Fig. 2. The average depth of the lake is 153 cm.

BIOLOGICAL DATA

Protozoa

As a group, the Protozoa were the most abundant animals. They were represented by sixty-six different species; of these there were twenty-five species in the Superclass Mastigophora, twenty-four members of the Ciliata, and sixteen Sarcodina.

Sarcodina

The Superclass Sarcodina, represented in plankton samples by sixteen species, was the group with the least numbers of species.

Several species of the testicate sarcodin Difflugia were collected (Table 1). At least one species, and at times more than one species, were present in each of the plankton tows. However, more individuals of this genus were found during times of high turbidity (Fig. 6). D. acuminata first appeared on March 3, 1968, and was observed on ten other occasions, but each time by only one or two organisms. D. corona was in eleven of the twenty-two plankton tows, however, a greater number of times in April and May (Table 1). Sometimes one or two organisms were present per microscopic field. Members of the species D. globosa occurred most frequently, being in seventeen of the twenty-two collections. This species was normally represented by one or two specimens per microscopic field. D. oblongata appeared only twice, once in March and again in April, then only two or three organisms were observed. D. urceolata occurred in two plankton tows in March, at which time two or three individuals were observed.

Arcella sp., a testacian related to Difflugia, appeared in four collections--all during the month of March.

The heliozoan Actinophrys sol was found each month of the study. It occurred on three occasions in March and once in April, and twice in May. During the May samples, three or four of these organisms were observed per microscopic field. Actinosphaerium sp., another helizoan, appeared first on April 14, and was observed on two other occasions that month.

It also appeared twice in May. Never more than two organisms per microscopic field were observed.

Naked amoebae, usually associated with the substrate, were occasionally collected. Gromia fluvialis was seen on April 11 and 14; on both occasions six or eight of these organisms were observed per microscopic field of vision. Mayorella sp. was observed once in March. Pelomyxa illinoisensis was present once in March and again on April 7 and 11, and on all occasions only one or two organisms were observed. Thecamoeba sp. was present twice in mid-March. A Valkampfia sp., attached to algae, was collected in a March sample.

Mastigophora

The kinetoplastid Bodo sp. was identified in nine plankton tows (Table 1). However, its small size (11-15 micra) permits it to escape notice unless great numbers of individuals are present. Only three Cephalothamnium cyclopum, a colonial stalked flagellate, were seen and on one occasion only, March 7.

Uroglena volvox: This colonial chrysomonad form was identified from single individuals seen on two occasions, once in April and once again in May. The colonial loricate chrysomonad Dinobryon was observed in very few numbers in March. However, it appeared in increasing numbers in six out of eight collections in May. In fact it became one of the more characteristic Protozoa in the plankton as the water became warmer.

Euglena spp. appeared in twenty of the twenty-two collections. This group continued to increase in numbers as the water temperature warmed and the photoperiod increased. Of all the euglenoids present, *E. acus* was found most frequently, appearing twelve times throughout the study (Table 1). *E. spirogyra* was observed on five occasions; *E. deses* was identified from a few organisms in three May collections. *E. rostrifera* and *E. tripteris* both were observed only once in May, and then they were not plentiful. *Eudorina elegans*, a plate-like colonial form, was present in late May on one occasion, and then only a few organisms were observed.

Trachelomonas spp. was present in seventeen collections during the study (Table 1). Of these, only two were identified to species *T. urceolata* and *T. volvocina*, both of which appeared in the study on only two occasions. It was later thought that many of the members observed were probably *T. volvocina*. Early in the study, *Trachelomonas* was not abundant; it was only in May that these flagellates began to appear in some numbers.

The chrysomonad *Synura uvella* was observed intermittently throughout the study. In fact, it appeared during times when the lake was covered with several inches of ice.

Members of the genus *Phacus* began to appear more frequently after the water had warmed somewhat. *P. longicauda* best represented this genus, being present on eleven occasions (Table 1). *P. pleuronectes* followed with four appearances, and *P. triqueter* appeared twice. This genus was very common. While dinoflagellates

such as Peridinium and Ceratium are normally abundant inhabitants of eutrophic lakes, this was not the case during this study. Ceratium hirundinella was observed in one March sample, represented by only very few organisms. Peridinium tabulatum was found first on March 10, and appeared on three other occasions in April and was observed twice in May. Gymnodinium sp. did not appear until May and was recorded three times that month and was then represented by three or four organisms per microscopic field. Glenodinium cinclum was seen four times in May and once in April.

The large colonial flagellate Volvox sp. did not appear until May, and was then only represented by one or two colonies twice that month.

The mastigophorians and the ciliates were almost equal in total number of species during this three month study. It is apparent, however, that the mastigophorians show a definite favor for increased photoperiod and warmer water. Their numbers increased greatly in May, a time when these two conditions were most favorable.

Ciliata

The ciliate which appeared most frequently throughout the study was the spirotrich Stentor sp., being present in eighteen of the twenty-two collections (Table 1). A peak in density and frequency of this protozoan was reached in March when the trumpet-shaped, pyriform and oval swimming stages were present in

all collections made during that month.

The peritrich Vorticella sp. was the second most frequently occurring ciliate, appearing in sixteen collections (Table 1).

Both Stentor and Vorticella are frequently thought of as being sessile, and more times than not attached by hold-fast structures to material present in the water. But here, these organisms were present, both free swimming and sessile.

A species of Vorticella was observed as an ectocommensal on several metazoans (Plate VII). It was observed on annelids, ostrocods, cladocerans, and copepods. There were other ecto-commensals observed: Epistylis sp. was found in March (Table 1) on Cyclops sp., and Cothurinia canthocampti was frequently observed on the hapacticoid Canthocamptus sp. (Table 1, Table 2, and Plates I-VI).

The hypotrich Stylonychia sp. was observed most frequently during the month of March, when it was absent in only one collection (Table 1). Euplotes patella, a hypotrich ciliate, occurred once each in April and May and was observed on four occasions in March.

The gymnostome Dileptus anser made five of its six appearances in March, and when observed only one or two were seen. Spirostomum teres is a very large ciliate that appeared on four occasions in April and once in March. S. teres reached a peak on March 31, when many organisms were observed per microscopic field.

The peritrich *Epistylis* sp. was observed on five occasions and when present was an ectocommensal on *Cyclops* sp. and on ostrocods.

Bursaria truncatella was not observed during April. However, this spirotrich did appear in three March collections and twice in May.

The oligotrich *Halteria grandenella* was present in one half of the collections and was absent in only one of the seven May collections. This ciliate was frequently the dominant protozoan in the plankton samples taken in May. There were times when *H. grandenella* was present in numbers upwards of thirty per microscopic field.

The holotrich *Coleps hirtus* was found once in April and twice in May, and then they were very sparse members of the plankton.

Vaginocola leptosoma was observed on three occasions, and each time this loricate ciliate was attached to filamentous algae.

Lacrymaria olor was observed on three occasions, all in the month of March. The gymnostome *Loxodes* sp. appeared only twice during March, and then only very few specimens were observed. On two occasions in May, the hymenostome *Paramecium* sp. was identified from only a few individuals. The holotrich *Didinum* sp. was recognized in two May collections (Table 1).

The hypotrich *Urosoma* sp. was seen twice in March. *Chidodonella caudata*, *Condylostoma* sp., *Cyclidium glaucoma*, *Lionotus fasciola*, and *Opercularia* sp. each appeared only once (Table 1).

Tokophyra cyclopum was the only individual of the Order Suctorida found during the course of the study. It was observed attached to the antenna of *Canthocamptus* sp., a harpacticoid copepod, which was also host to *Cothurina canthocampti*.

METAZOANS

Colentrata

One *Hydra* was observed during the study on April 14. It was attached to a maple bud which had passed into the collecting net. Maple buds had fallen into the lake as a result of high winds and rain.

Aschelminthes

Rotifers were present in all of the plankton samples taken. *Rotaria* sp., while never abundant in the cold water, appeared in increasing numbers as the water warmed, and when the nitrogen content was high it was observed in all samples (Table 2). Next in order of most frequent occurrence was *Asplanchna* sp. and *Synchaeta* sp., each appearing in twenty collections. These two organisms were abundant throughout most of the study, but reached a peak on May 5 and May 9, when five to ten would be observed per microscopic field.

Brachionus sp. was observed throughout the study, but was most frequent in May, where it appeared in increasing abundance during each collection that month. A few Keratella quadrata were present five times each for the three months the collections were made. Euchlanis sp. was not observed during the month of March, and made its first appearance on April 7 and in four other collections that month. This organism was present in all of the May collections. Filinia longiseta appeared a total of twelve times (Table 2). Rotaria neptunia was also present on twelve occasions, six of which were in April and three each for March and May.

Monostyla sp. did not occur until April, when it was observed in one half of the samples, but was absent in only one May collection. This species showed an increase in numbers through the month of May. Philodina sp. occurred once in April, on four occasions in March, and three times in May. Epiphanes senta was present in five of the seven March samples, and once in April and May, but was at no time very abundant.

Trichocera sp. was first observed on May 5 and in four other collections that month and in each sample more specimens were observed. Brachionus calyciflours was present in three samples, two of which were in May and one in April.

Mytillina sp. was also observed on three occasions, all occurring in May (Table 2). Brachionus urceolares, Notholca striata, and Testudenella sp. were observed only twice (Table 2).

The following rotifers were observed only once and most of the time identified from only one or two specimens: Cupelagagis sp., Hexarthra mira, Kellicottia longispina, Ketallea cochlearis, Notommata sp., and Polyarthra sp. (Table 2).

Chaetonotus sp. was the only gastrotrich observed; each time near the east end of the lake (Table 2).

Nematodes were frequently observed, but few in number. These minute worms were less than 2 mm. long and were not identified to genus (Table 2).

Platyhelminthes

Four species of Turbellaria (Table 2) were represented. These appeared sporadically throughout the study. Dalyella sp. was observed once in April. Macrostomum appendiculatum was present in one March sample. Stenostomum sp. was not observed until April, then only twice that month, and once in May during a period of high turbidity (Fig. 6). Typhloplana viredala was present on two occasions, once in March and again in April. These worms were never very abundant and were represented only by one or two organisms.

Ectoprocta

Ectoproct statoblasts were observed in collections in March and April, and the young polypid stages began to appear in May. These were identified as Plumatella.

Annelida

Three genera of oligochaetes were represented by one or two individuals. *Aleosoma* was found in four different samples (Table 2). *Dero* appeared only once in April, and *Nais* did not appear until May and was then observed three times.

Tardigrada

Early in the study the genus *Hypsibius* was observed in turbid water near the east and west ends of the lake (Fig. 2). This tardigrade (water bear) was not found in collections taken in the center of the lake. Plate VIII shows *Hypsibius* in the process of shedding its cuticle.

Arthropoda

Arthropods were represented by several groups. Ostracods were observed to have been evenly distributed throughout the samplings (Table 2) but were not keyed to genus. On one occasion a species of *Vorticella* was observed as an ectocommensal on an ostrocod.

Cladocerans (water fleas) were present in most all of the samples taken. *Chydorus sphaericus* was present in twenty-one of the twenty-two samples taken (Table 2). Of all the metazoans to be commensalized, *C. sphaericus* was most frequently observed to have commensals. A plankton sample was examined on May 1, 1968, three days after the collection was made. A random sampling was made of seventy-five organisms of this species of

Chydorus. Only twenty-seven of the organisms did not possess Vorticella sp. living on them as commensals. The number of vorticellids varied from one to fourteen on C. sphaericus. Alona guttata made three of its eight appearances in April and the remaining five in May. Daphnia sp. was recorded once in March and on two occasions in April and in five of the seven May samples. Daphnia continued to increase in numbers during the month of May (Table 2).

Simocephalis serrulatus was observed on March 31 and then returned on three different occasions in May. Macrotrix roseus occurred twice in March and once again in April. Bosmina longirostris appeared once in April and once again in May. Ceriodaphania lacustris and Ophroyoxus gracilus were both observed and identified from single individuals once in March.

Copepods were always present as napulis larvae (Table 2). The napuloid larvae were usually not abundant in the sample. The cyclopoid Cyclops sp. was absent from only one March collection. Cyclops was frequently found to be commensalized by the vaginicolid Cothurinia canthocampti (Table 1). The calanoid Diapotamus sp. was present in the last three samples. The harpacticoid Canthocamptus sp. usually appeared in the plankton only during times when the water was turbid (Fig. 6). The vaginicolid Cothurinia canthocampti was present on Canthocamptus sp. on several occasions (Plates I-VI). C. canthocampti was attached randomly over the exoskeleton of the copepods (Plate I).

Two orders of insects, Diptera and Pleooptera, were present. Chironomidae larvae (midge fly) were found in eighteen of the twenty-two samples, while plecopteran (stone fly) larvae appeared in only four samples (Table 2) and neither of these insects was identified to genus.

PHYSICAL DATA

Photoperiod

Sunlight (Fig. 3) increased from 11 hours and 37 minutes on March 7 to a maximum of 14 hours and 1 minute on May 23, 1968.

Temperature

Temperature of the air and water (Fig. 4) fluctuated throughout the study. Air temperature varied from a low of 3.5°C on March 21 to a high of 29°C on May 12, 1968. Water temperature was coldest on March 14 when a recording of 2.5°C was made under approximately one inch of ice. The warmest water temperature was 19.5°C on May 2, 1968.

Rainfall

The highest rainfall for the study was recorded on May 22, when a total of 1.85 inches was recorded (Fig. 5). Rainfall dates are placed (Fig. 5) in relation to the dates for plankton samples. Rainfall peaks tend to correspond to peaks in turbidity (Fig. 6), iron (Fig. 12), and sulfate (Fig. 13).

Turbidity

Turbidity (Fig. 6) was highest on April 4, 1968, the day following a 1.39 inch rainfall. Once again, on March 23, high turbidity followed a rainy period. On dates of high turbidity organisms commonly not found in the plankton were frequently dislodged from their normal niches and became suspended with other plankters. Oligochaetes, harpacticoids, and tardigrades were among those organisms found at times of high turbidity.

Oxygen

The highest parts per million oxygen (Fig. 7) occurred on May 9, when 11.5 parts per million (ppm) was recorded. The lowest recording was 7.6 ppm on May 23, 1968.

Hydrogen ion Concentration

The most acidic reading during the study was 6.3, on March 28. The highest alkaline recording was taken March 17, a reading of 8.7 (Fig. 8).

Nitrite-nitrogen

The peak of .429 ppm and .127 ppm, respectively, for nitrite-nitrogen occurred on May 12 (Fig. 9). This high reading followed two days of nearly one inch rains, which occurred on May 8 and May 10. These were periods following heavy fertilization of farm fields. The lowest parts per million nitrite-nitrogen of .059 and .025 was recorded on March 24, 1968.

Nitrate-nitrogen

Nitrate-nitrogen was found to be very high on May 5 when 396 ppm and 85 ppm (Fig. 10) were recorded. On this date many different species of euglenoids and many different species of rotifers were listed.

Phosphate

Phosphate reached its highest peak on May 5 (Fig. 11), as did nitrate-nitrogen. This peak did not come after a period of high rainfall. However, the next highest peak was observed on March 31, the date of a one half inch rain (Fig. 5). The lowest recorded ppm for phosphate was 25 ppm on May 16, 1968.

Iron

High iron readings, on most occasions, (Fig. 12) correspond to periods of rainfall (Fig. 5). The highest ppm iron of 70 was recorded on April 4, following a 1.39 inch rain on April 3 (Fig. 5). A low reading of 25 ppm was observed on March 17, 1968.

Sulfate

Sulfate peaks (Fig. 13) tend to correspond with rainfall (Fig. 5). Sulfate of 100 ppm was recorded on May 16 for the high reading, and the lowest was found on March 28 when 55 parts per million was registered. Turbidity peaks (Fig. 6) correspond to high sulfate peaks.

Table 1.--Planktonic Protozoa occurring in bi-weekly plankton tows and water temperature range, Ashmore Lake, Ashmore, Illinois, March to May 1968.

	March 7-31 2.5-14°C	April 4-28 9.5-12.5°C	May 2-23 11-19.5°C
Total Samples (22)	7	8	7
Protozoa			
Sarcodina			
Arcella sp.	4	0	0
Actinophrys sol	3	1	2
Actinosphaerium sp.	0	3	2
Centropyxis aculeata	2	2	0
Difflugia acuminata	2	4	5
Difflugia corona	2	4	5
Difflugia globosa	4	6	7
Difflugia oboglongata	1	1	0
Difflugia urceolata	2	0	0
Difflugia sp.	7	8	7
Gromia fluvialis	1	1	0
Mayorella sp.	1	0	0
Pelomyxa illinoisensis	1	2	0
Polychaos dubia	1	0	0
Thecamoeba sp.	2	0	0
Valkampfia sp.	1	0	0
Mastigophora			
Bodo sp.	5	3	1
Cephalothamnium cyclopum	1	0	0

Table 1. (continued)

	March 7-31 2.5-14°C	April 4-28 9.5-12.5°C	May 2-23 11-19.5°C
Total Samples (22)	7	8	7
Ceratium hirundinella	1	0	0
Cercomonas sp.	1	0	0
Dinobryon sertularia	1	6	6
Euglena acus	4	5	3
Euglena deses	0	0	3
Euglena rostrifera	0	0	1
Euglena spirogyra	1	2	2
Euglena tripteris	1	0	0
Euglena sp.	7	7	6
Eudorina elegans	0	0	1
Glenodinium cinctum	0	1	4
Gymnodinium sp.	0	0	3
Mastigamoeba sp.	0	1	0
Peridinium tabulatum	1	3	2
Phacus longicauda	2	5	4
Phacus pleuronectes	0	1	3
Phacus triqueter	0	0	2
Synura uvella	3	1	2
Trachelomonas urceolata	0	1	1
Trachelomonas volvocina	0	0	2
Trachelomonas sp.	5	5	7
Uroglena volvox	0	1	1
Volvox sp.	0	0	2

Table 1. (continued)

	March 7-31: 2.5-14°C	April 4-28: 9.5-12.5°C	May 2-23: 11-19.5°C
Total Samples (22)	7	8	7
Ciliata			
Bursaria truncatella	3	0	2
Chilodonella caudata	1	0	0
Coleps hirtus	0	1	2
Condylostoma sp.	0	1	0
Cothurina canthocampti	2	3	1
Cyclidium glaucoma	1	0	0
Didinium sp.	0	0	2
Dileptus anser	5	0	1
Epistylis sp.	4	1	0
Euplotes patella	4	1	1
Halteria grandinella	1	4	6
Lacrymaria olor	3	0	0
Lionotus fasciola	1	0	0
Loxodes sp.	2	0	0
Opercularia sp.	1	0	0
Paramecium sp.	0	0	2
Spirostomum teres	1	4	0
Stentor sp.	7	5	6
Stylonychia sp.	6	2	1
Tetrahymena sp.	2	2	1
Tokophrya cyclopum	0	1	0

Table 1. (continued)

	March 7-31 2.5-14°C	April 4-28 9.5-12.5°C	May 2-23 11-19.5°C
Total Samples (22)	7	8	7
Urosoma sp.	2	0	0
Vaginicola leptosoma	0	1	2
Vorticella sp.	5	5	6

Table 2.--Zooplankton other than Protozoa, occurring in bi-weekly plankton tows and water temperature range, Ashmore Lake, Ashmore, Illinois, March to May 1968.

	March 7-31	April 4-28	May 2-23
	2.5-14°C	9.5-12.5°C	11-19.5°C
Total Samples (22)	7	8	7
Coelentrata			
Hydra sp.	0	1	0
Aschelminthes			
Rotéfera			
Asplanchna sp.	7	7	6
Brachionus calyciflorus	0	1	2
Brachionus urceolares	0	0	2
Brachionus sp.	4	6	7
Cephalodella sp.	0	0	4
Cupelagagis sp.	1	0	0
Epiphanes senta	5	1	1
Euchlanis sp.	0	5	7
Filinia longiseta	4	3	5
Hexarthra mira	0	0	1
Kellicottia longispina	0	1	0
Keratella cochlearis	0	1	0
Monostyla sp.	0	4	6
Mytillina sp.	0	0	3
Notholca striata	1	0	0
Philodina sp.	4	1	3
Polyarthra sp.	1	0	0

Table 2. (continued)

	March 7-31: 2.5-14°C	April 4-28: 9.5-12.5°C	May 2-23: 11-19.5°C
Total Samples (22)	7	8	7
Rotaria neptunia	3	6	3
Rotaria sp.	7	8	7
Synchaeta sp.	7	6	7
Testudinella sp.	1	0	1
Trichocera sp.	0	0	5
Gastrotricha			
Chaetonotus sp.	3	0	0
Nematodea	6	5	0
Platyhelminthes			
Turbellaria			
Dalyella sp.	0	1	0
Macrostomum appendiculatum	1	0	0
Stenostomum sp.	0	2	1
Typhloplana viridata	1	1	0
Ectoprocta			
Plumatella (polypid)	0	0	2
Annelida			
Oligochaetea			
Aeolosoma sp.	2	2	0
Dero sp.	0	1	0
Nais sp.	0	0	3
Tardigrada			
Hypsibius sp.	2	1	0

Table 2. (continued)

	March 7-31	April 4-28	May 2-23
	2.5-14°C	9.5-12.5°C	11-19.5°C
Total Samples (22)	7	8	7
Arthropoda			
Ostracoda			
Ostracods	5	6	7
Cladocera			
Alona guttata	0	3	5
Bosmina longirostris	1	0	1
Ceriodaphnia lacustris	1	0	0
Chydorus sphaericus	6	8	7
Daphnia sp.	1	2	5
Macrothrix roseus	2	1	0
Ophryoxus gracilus	1	0	0
Simocephalus serrulatus	1	0	3
Copepoda			
Cyclopoida			
Cyclops sp.	6	8	7
Nauplius larvae	7	8	7
Calanoida			
Diaptomus sp.	0	0	3
Harpacticoida			
Canthocamptus sp.	3	1	1
Insecta			
Diptera			
Chironomid larvae	4	7	7

Table 2. (continued

	March 7-31 2.5-14°C	April 4-28 9.5-12.5°C	May 2-23 11-19.5°C
Total Samples (22)	7	8	7
Plecoptera			
Stone fly larvae	1	3	0

Fig. 1. Ashmore Lake located NW¼, Sec. 6, T12 N, R11 E, Coles County, Ashmore, Illinois.

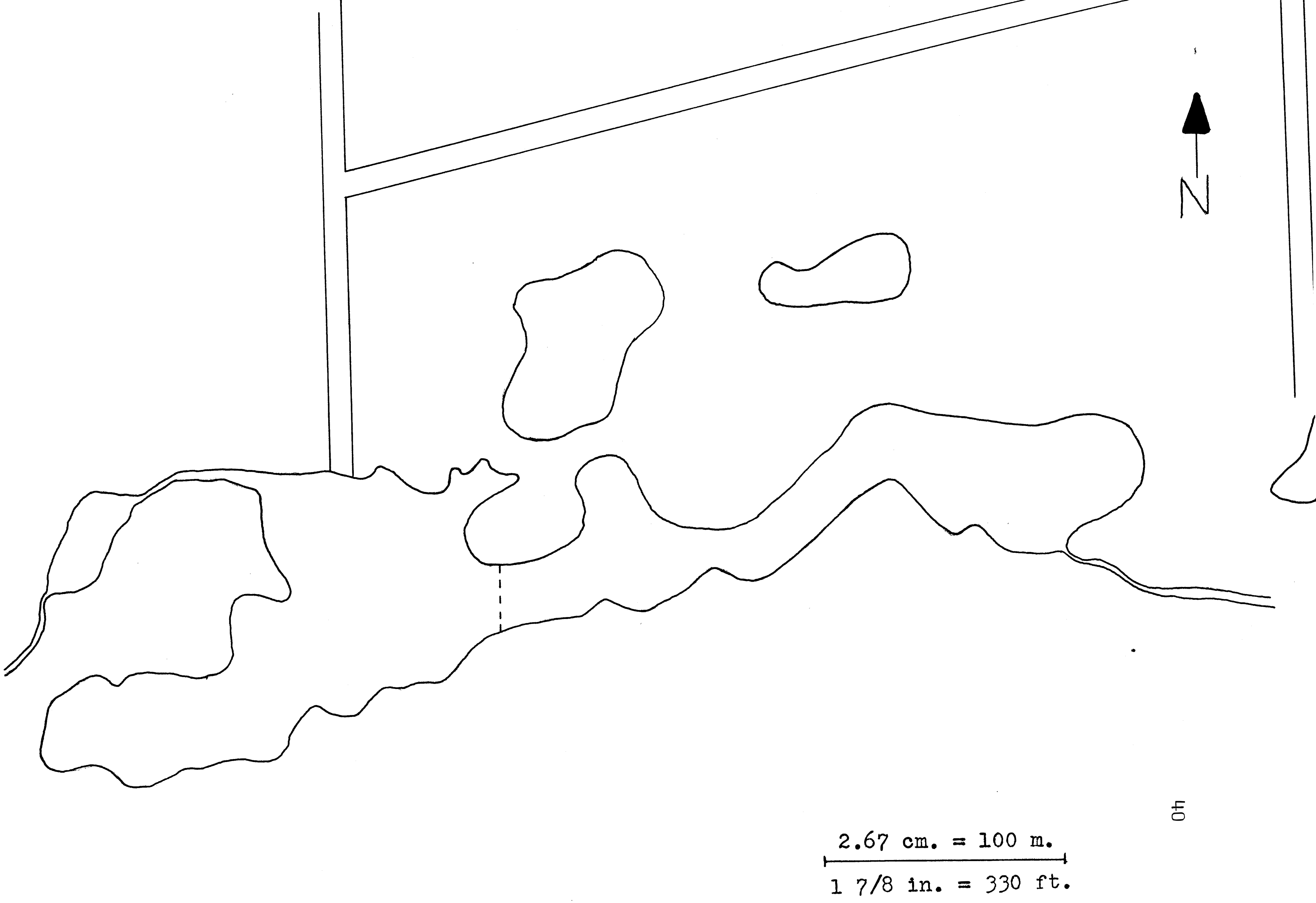

N
2.67 cm. = 100 m.
1 7/8 in. = 330 ft.

Fig. 2. Map of Ashmore Lake showing depths, emergent vegetation, and location of plankton tows.

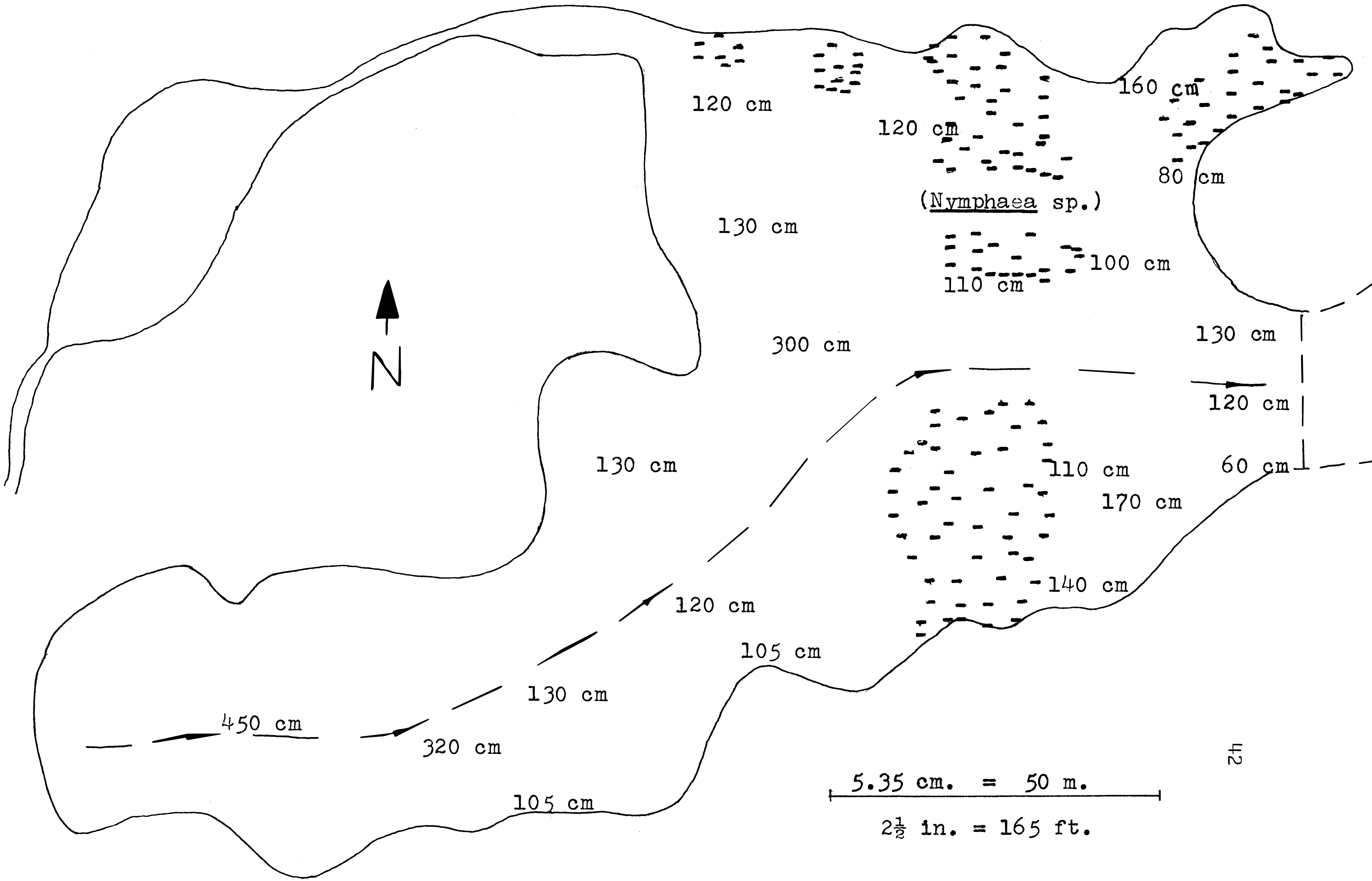

120 cm
120 cm
160 cm
80 cm
(Nymphaea sp.)
130 cm
100 cm
110 cm
300 cm
130 cm
N
120 cm
130 cm
110 cm
60 cm
170 cm
140 cm
120 cm
105 cm
130 cm
450 cm
320 cm
105 cm
5.35 cm. = 50 m.
2½ in. = 165 ft.

Fig. 3. Hours of sunlight for Coles County, Illinois, March 7 - May 23, 1968.

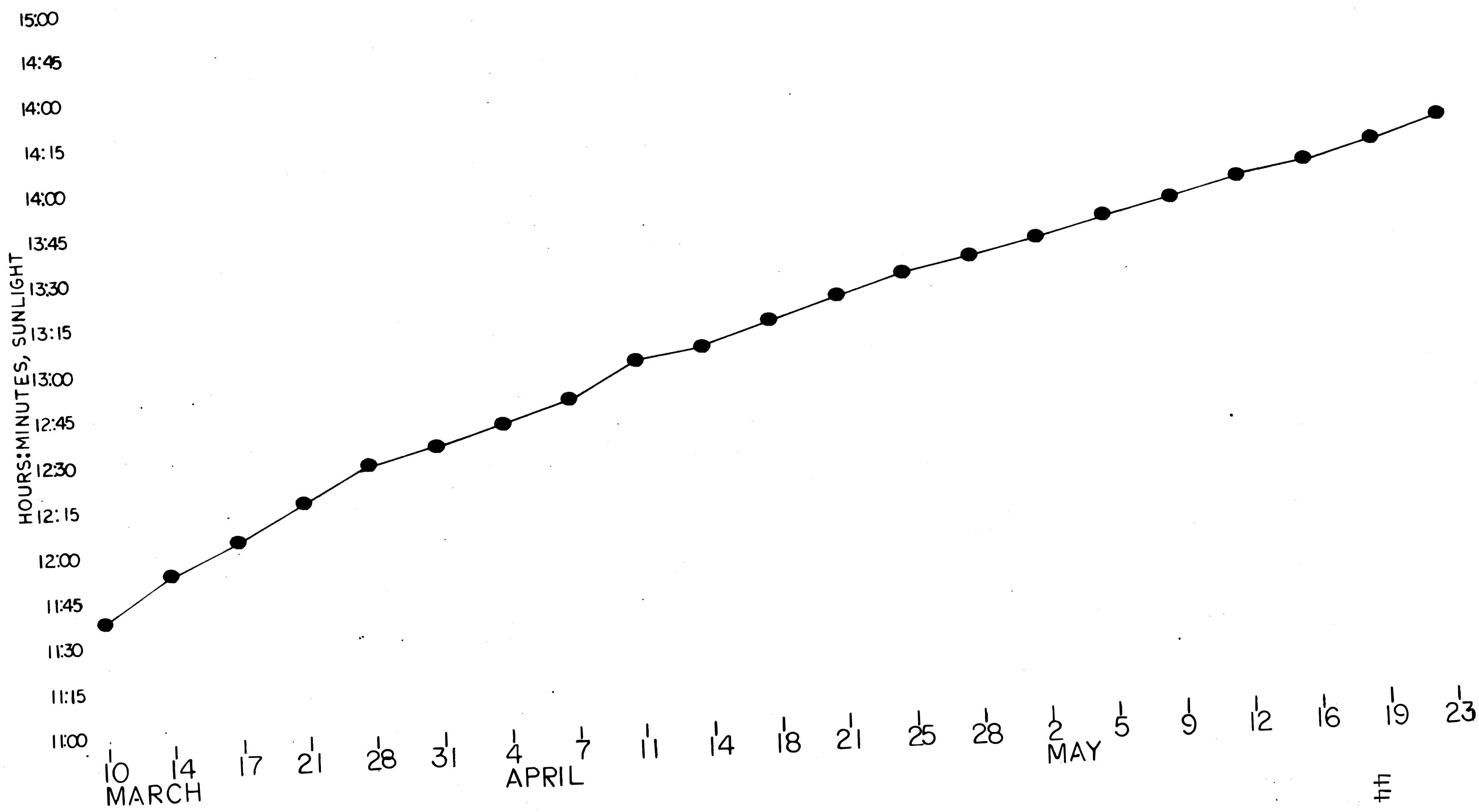

HOURS:MINUTES, SUNLIGHT
15:00
14:45
14:00
14:15
14:00
13:45
13:30
13:15
13:00
12:45
12:30
12:15
12:00
11:45
11:30
11:15
11:00
10 MARCH
14
17
21
28
31
4 APRIL
7
11
14
18
21
25
28
2 MAY
5
9
12
16
19
23

Fig. 4. Temperature of air and water in degrees C^{o} for Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.

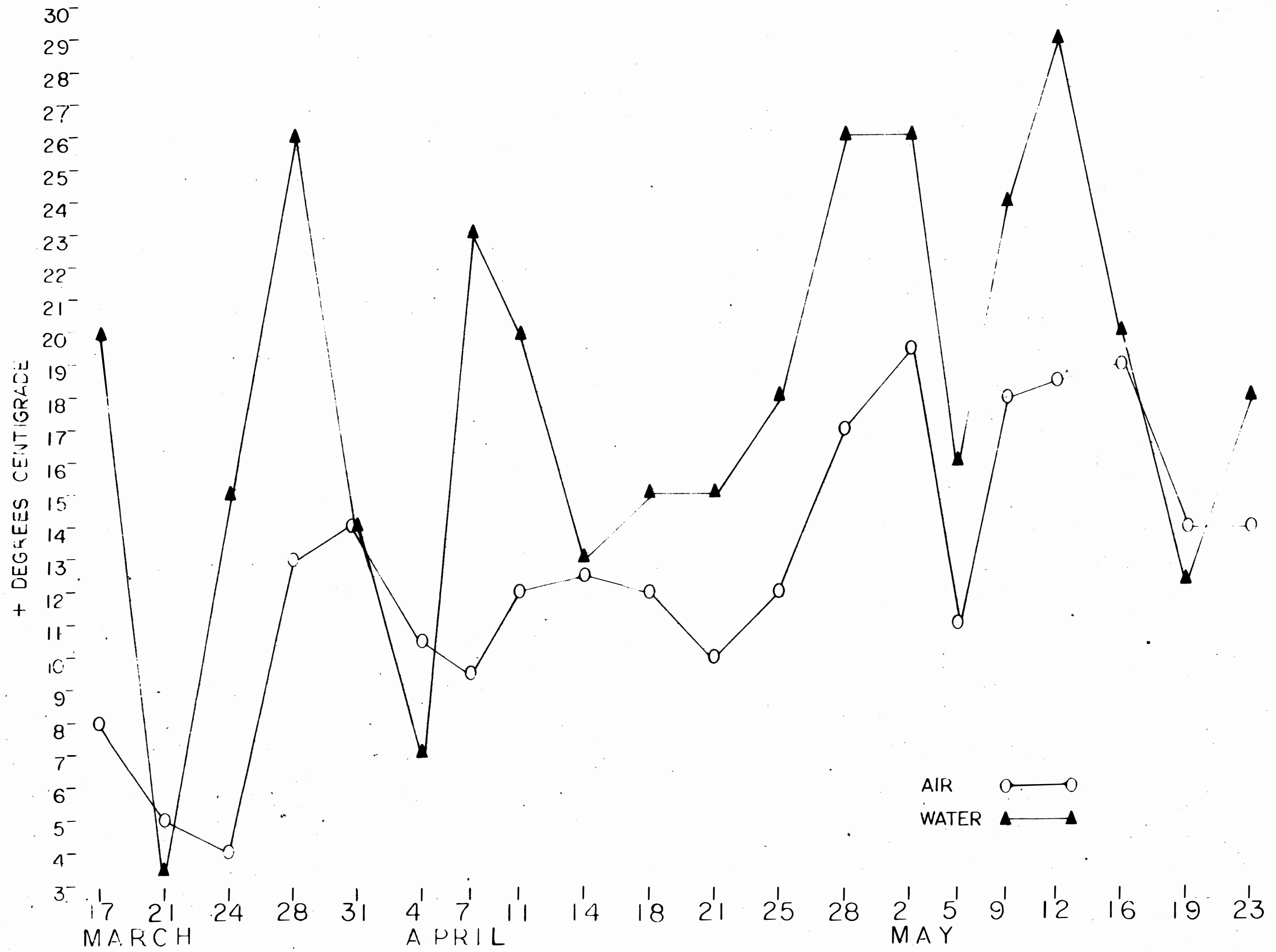

+ DEGREES CENTIGRADE
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY
AIR
WATER

Fig. 5. Precipitation for Coles County, Illinois, March 7 - May 23, 1968.

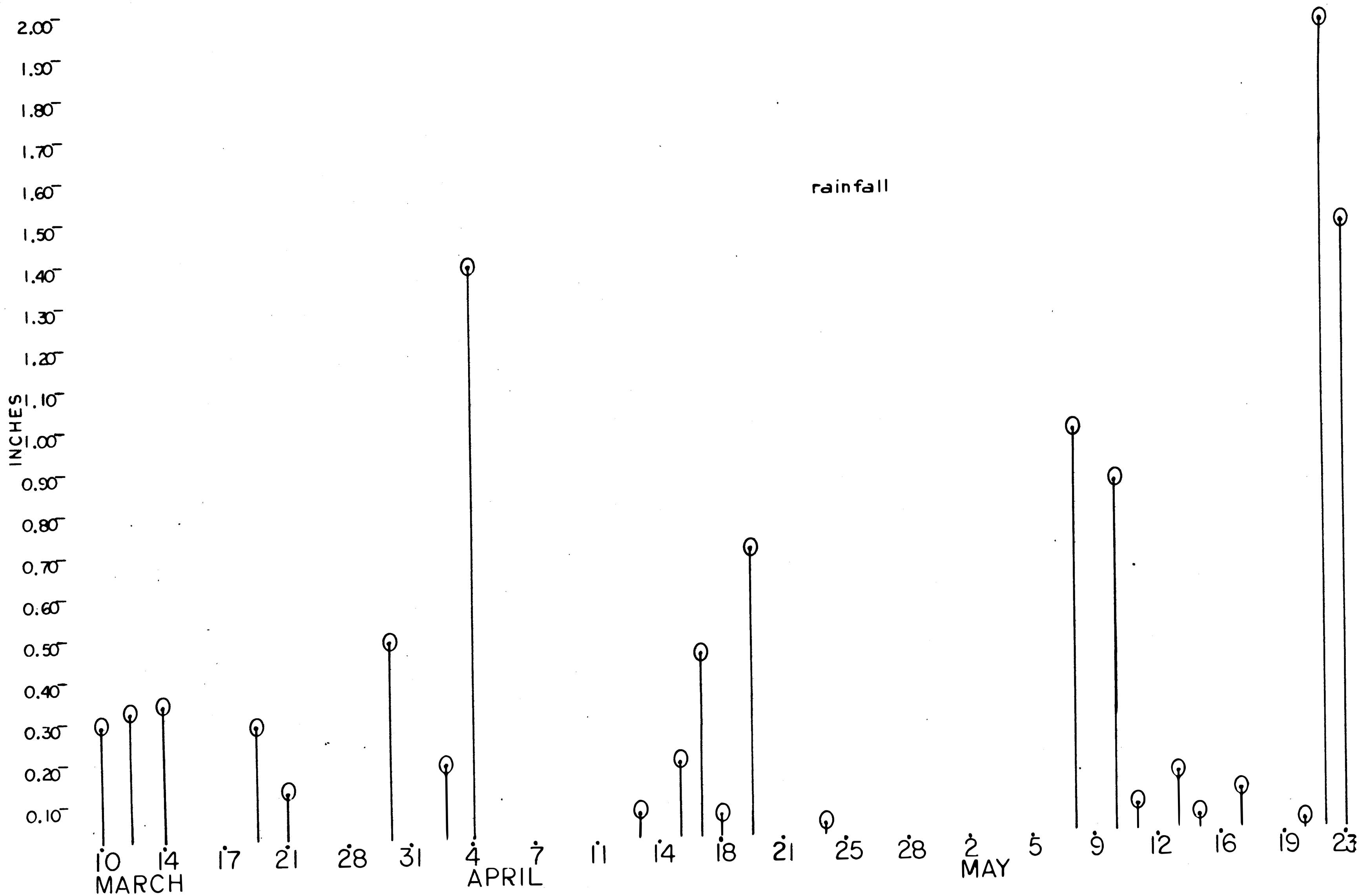

rainfall
INCHES
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
10 14
MARCH
17 21 28 31 4
APRIL
7 11 14 18 21 25 28 2
MAY
5 9 12 16 19 23

Fig. 6. Turbidity recorded in Jackson Turbidity Units for Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.

Distilled Water = 0 JTU.

Scale Measures 0 - 500 JTU.

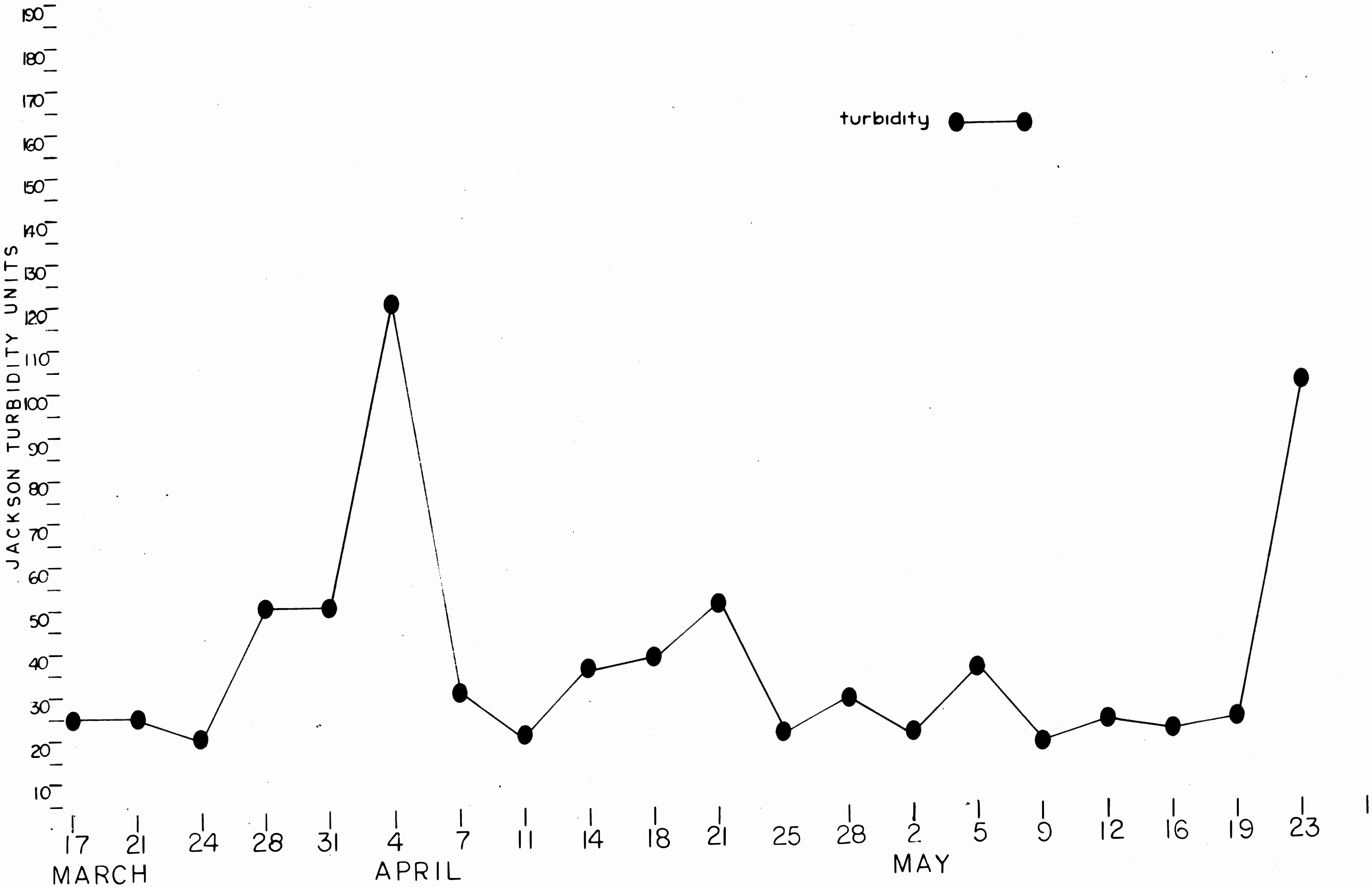
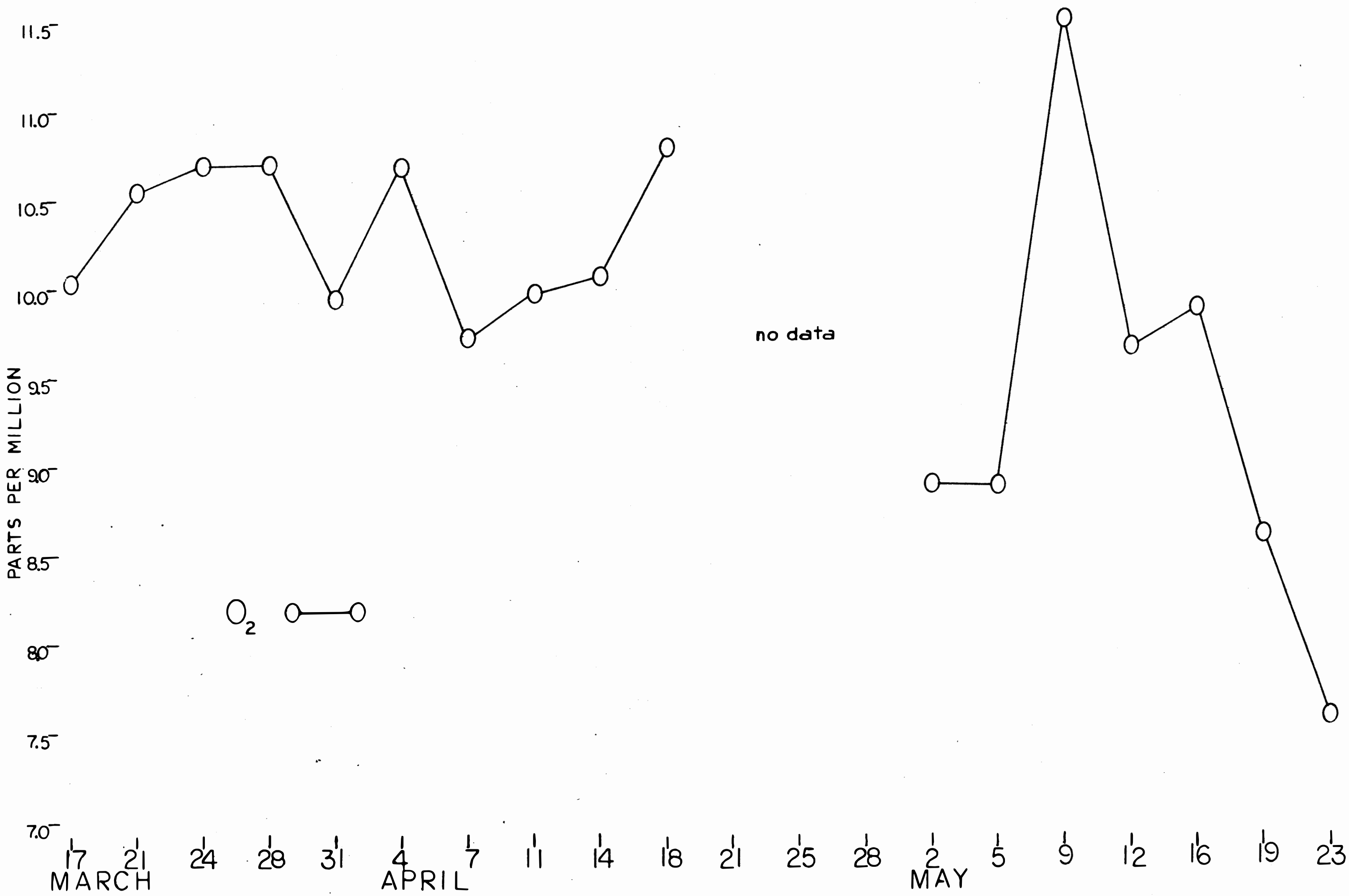
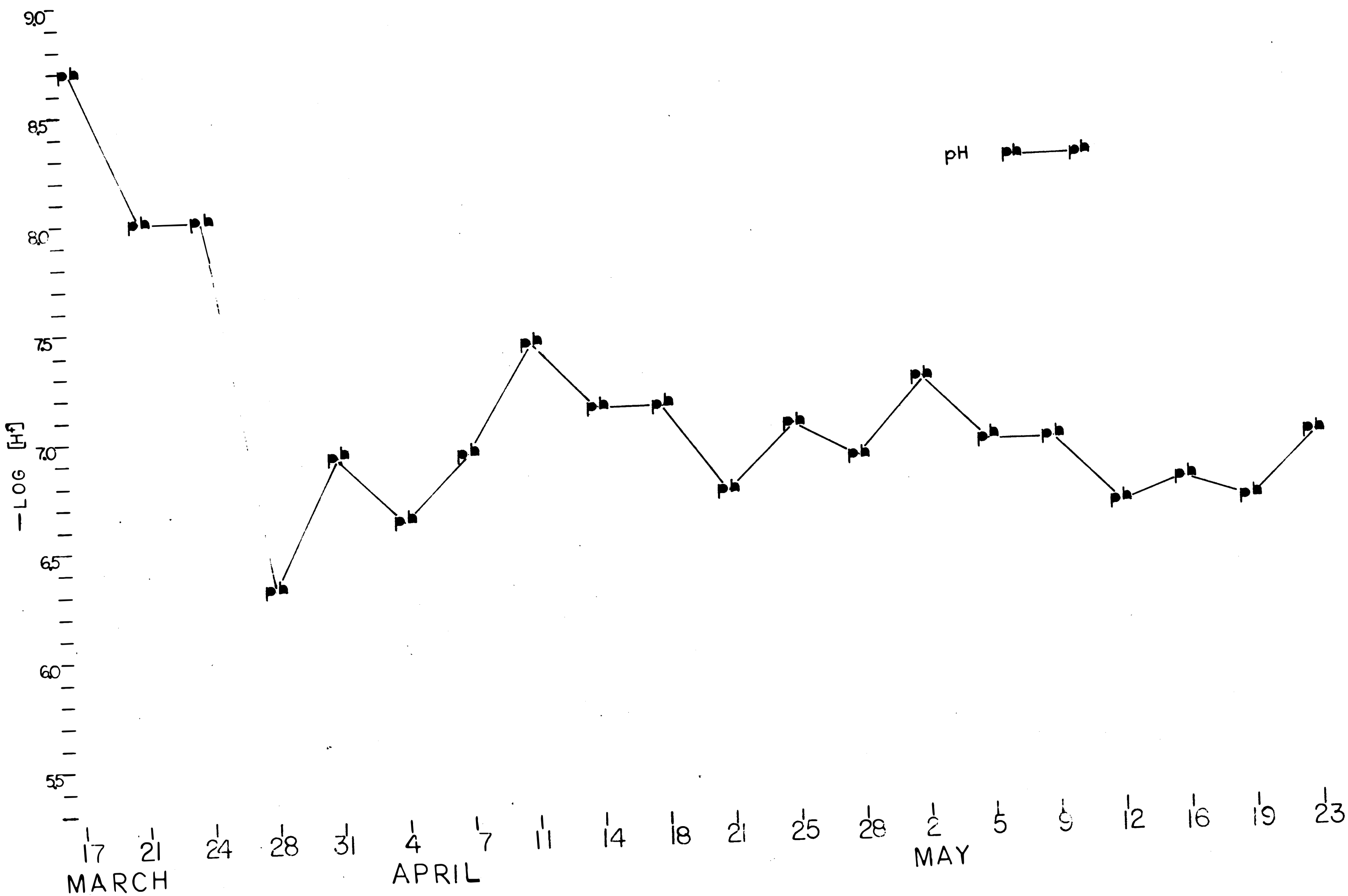

turbidity
JACKSON TURBIDITY UNITS
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY

Fig. 7. Parts per million of Oxygen for Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.



PARTS PER MILLION
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
no data
O_2
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY

Fig. 8. Hydrogen ion concentration for Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.



9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
—LOG [H⁺]
pH
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY

Fig. 9. Parts per million of Nitrite-Nitrogen, Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.

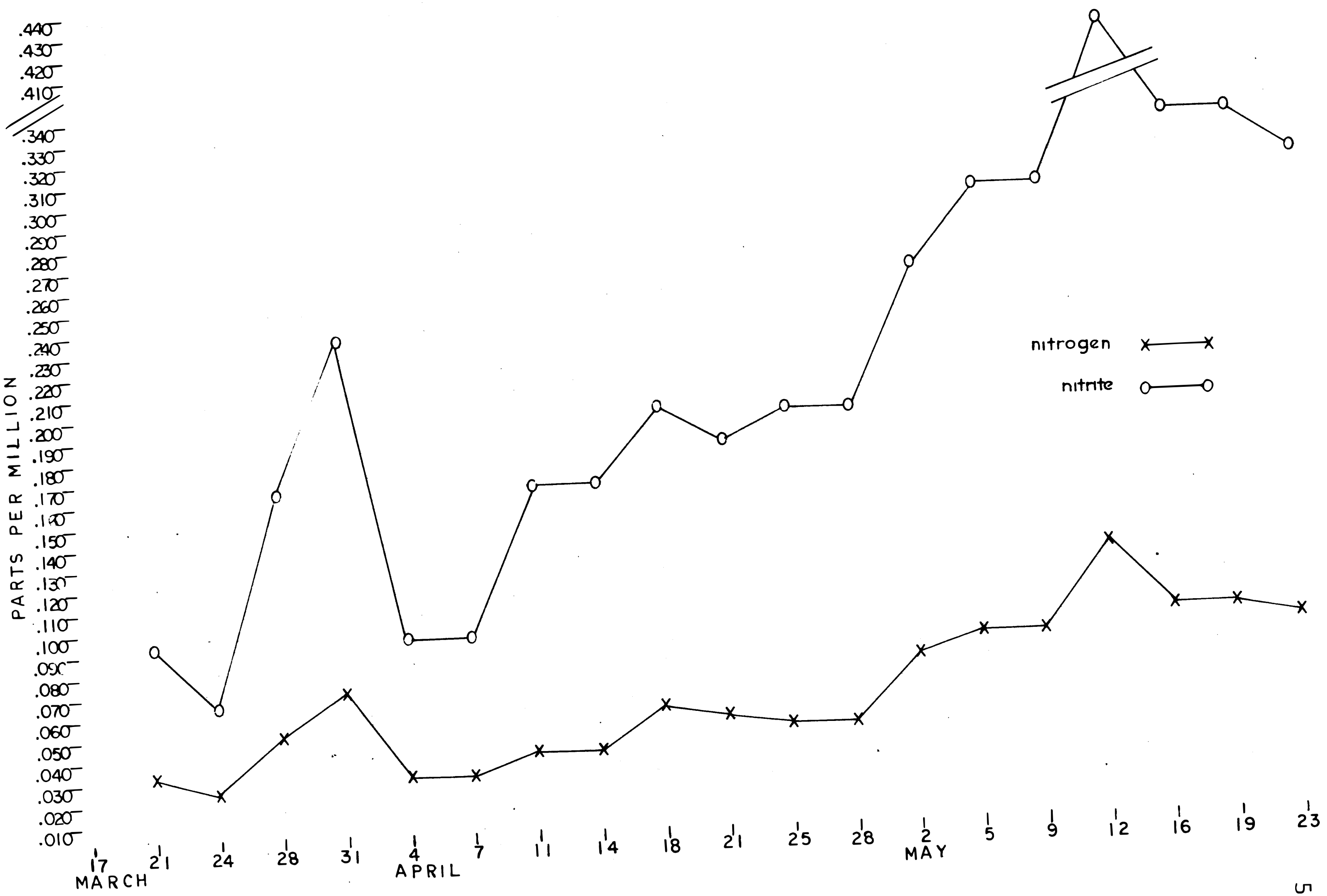
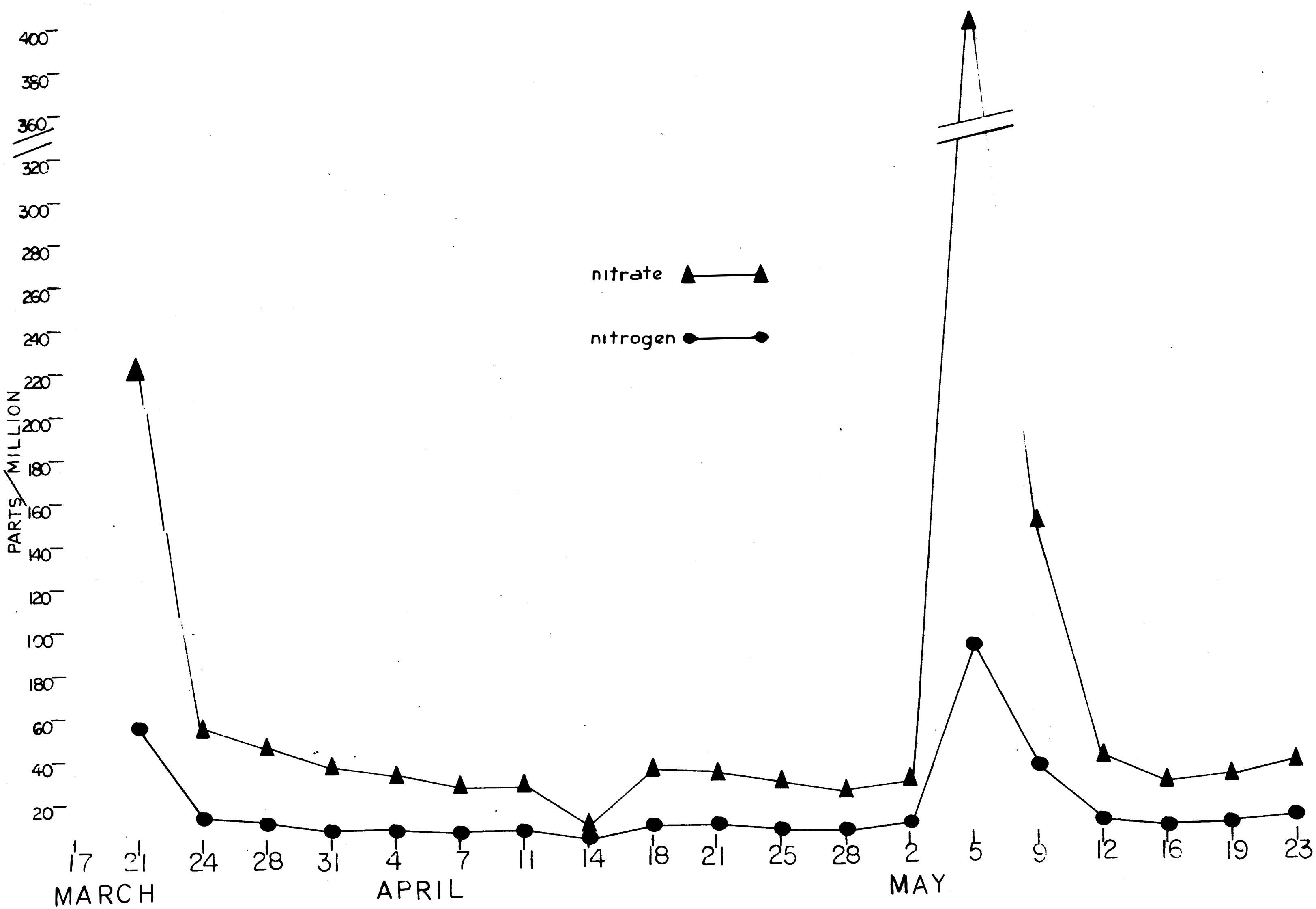
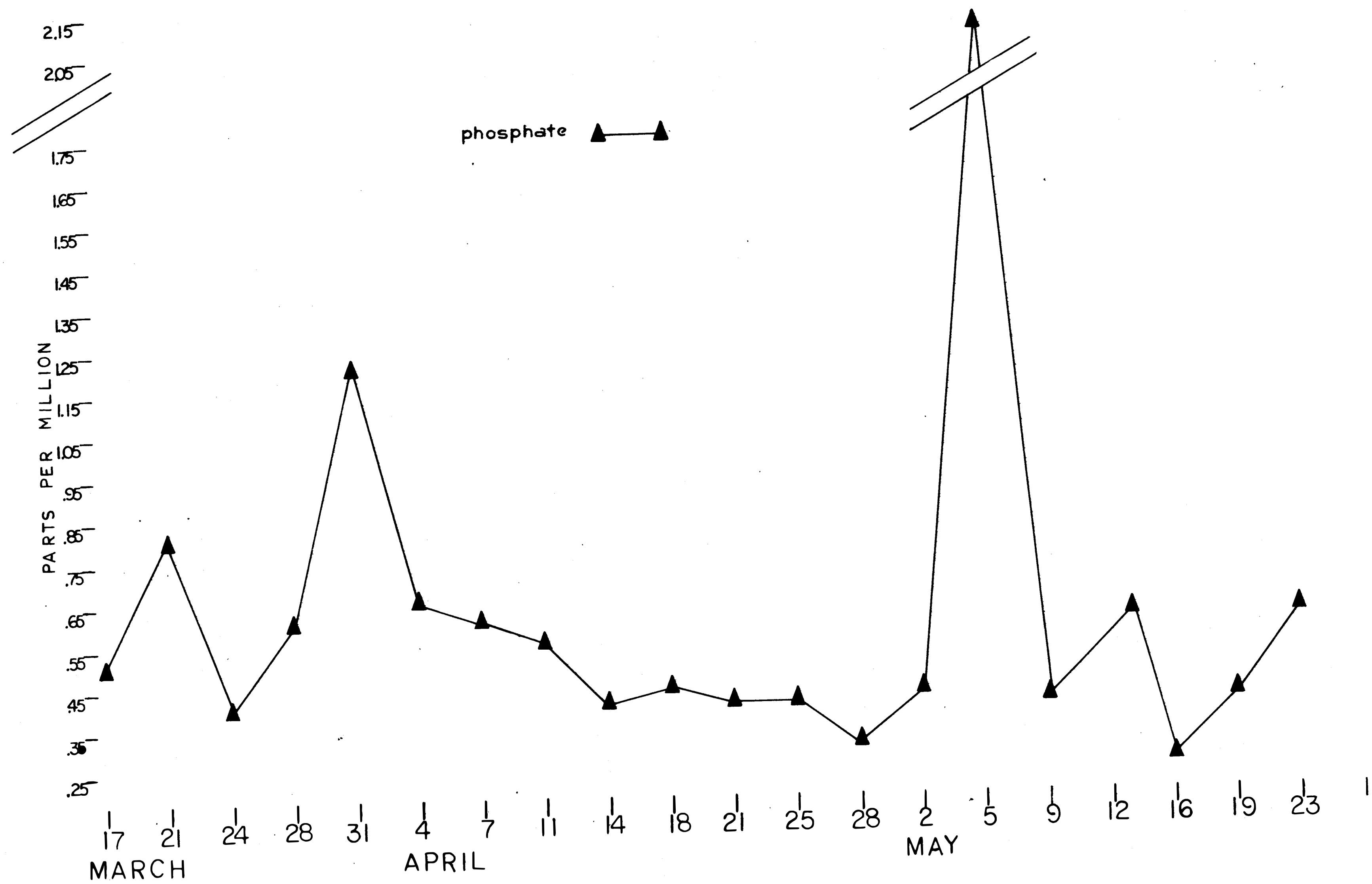

PARTS PER MILLION
.440
.430
.420
.410
.340
.330
.320
.310
.300
.290
.280
.270
.260
.250
.240
.230
.220
.210
.200
.190
.180
.170
.160
.150
.140
.130
.120
.110
.100
.090
.080
.070
.060
.050
.040
.030
.020
.010
17
MARCH
21
24
28
31
4
APRIL
7
11
14
18
21
25
28
2
MAY
5
9
12
16
19
23
nitrogen
nitrite

Fig. 10. Parts per millinn of Nitrate-Nitrogen,
Ashmore Lake, Ashmore, Illinois,
March 17 - May 23, 1968.



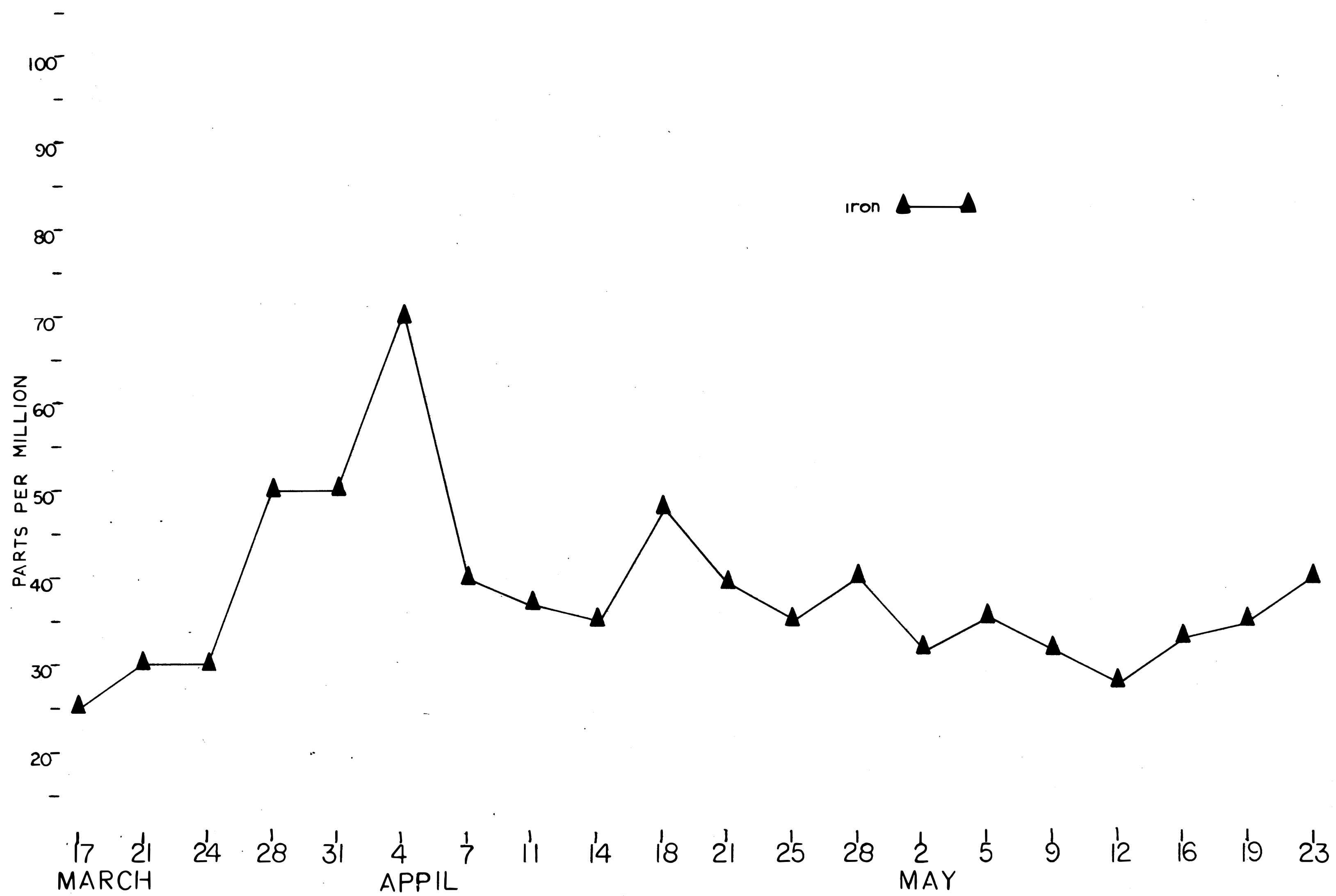
PARTS/MILLION
400
380
360
320
300
280
260
240
220
200
180
160
140
120
100
180
60
40
20
nitrate
nitrogen
17 21 24 28 31 4 7 11 14 18 21 25 28 2 5 9 12 16 19 23
MARCH
APRIL
MAY

Fig. 11. Parts per million Phosphate,
Ashmore Lake, Ashmore, Illinois,
March 17 - May 23, 1968.



2.15
2.05
1.75
1.65
1.55
1.45
1.35
1.25
1.15
1.05
.95
.85
.75
.65
.55
.45
.35
.25
PARTS PER MILLION
phosphate
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY

Fig. 12. Parts per million of Iron for Ashmore Lake, Ashmore, Illinois, March 17 - May 23, 1968.



PARTS PER MILLION
100
90
80
70
60
50
40
30
20
iron
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APPIL
MAY

Fig. 13. Parts per million Sulfate,
Ashmore Lake, Ashmore, Illinois,
March 17 - May 23, 1968.

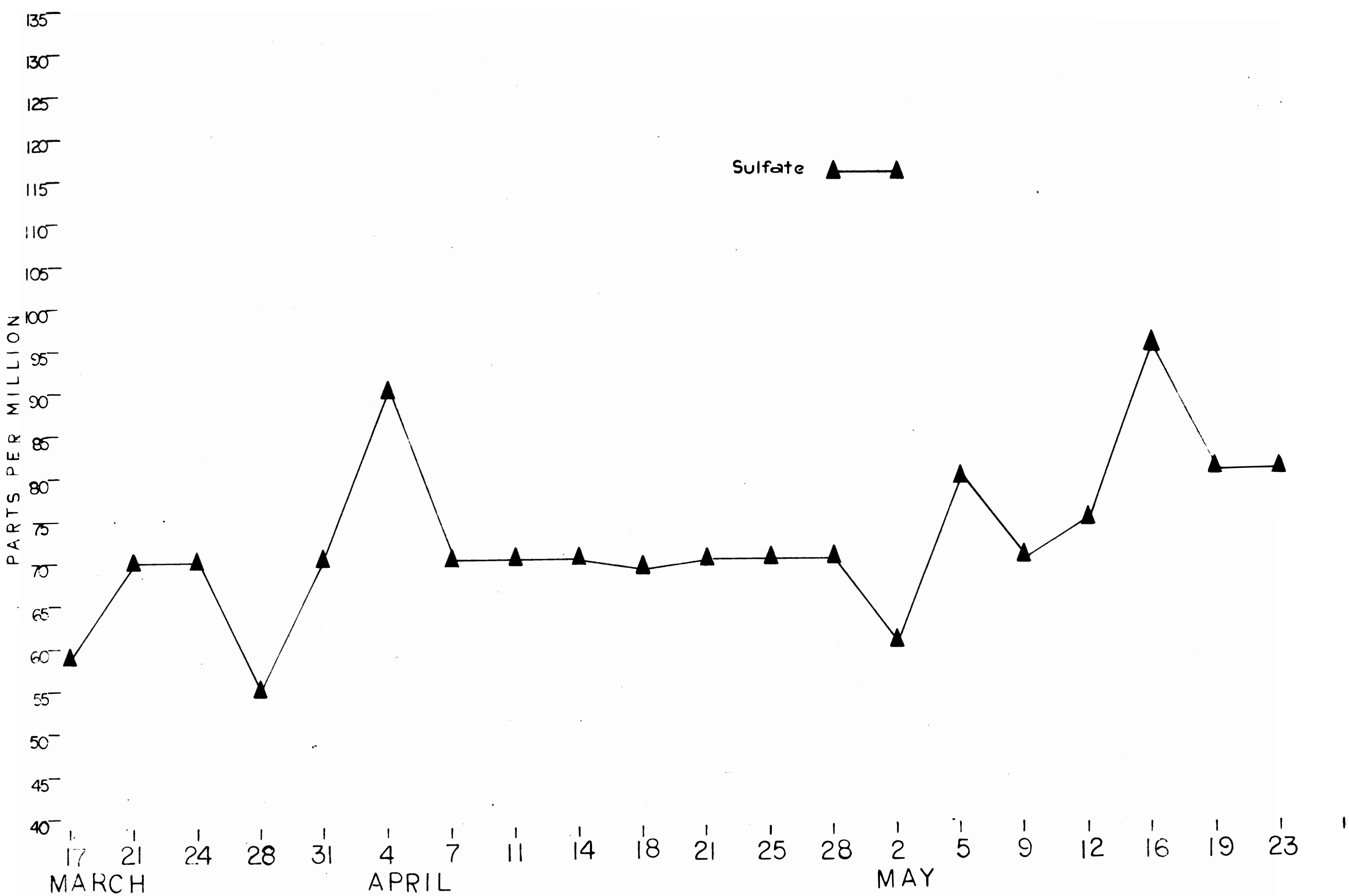

PARTS PER MILLION
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
Sulfate
17
21
24
28
31
4
7
11
14
18
21
25
28
2
5
9
12
16
19
23
MARCH
APRIL
MAY

Plate I. <u>Cothurina canthocampti</u> attached to <u>Canthocamptus</u> sp.

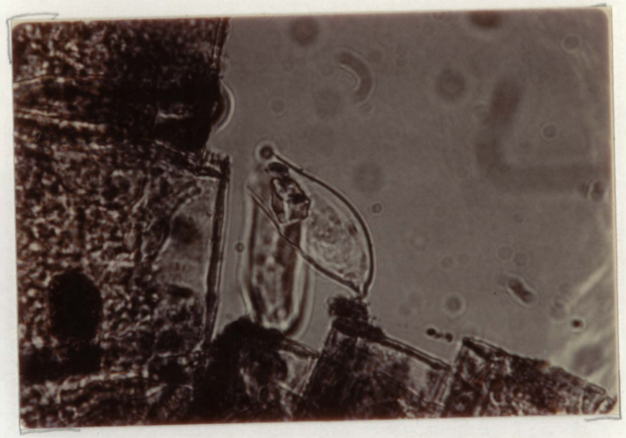
Plate II. <u>Cothurina canthocampti</u> attached to <u>Canthocamptus</u> sp.

Plate III. <u>Cothurina canthocampti</u> attached to <u>Canthocamptus</u> sp.

Plate IV. <u>Cothurina canthocampti</u> attached to <u>Canthocamptus</u> sp.

206 μ

Plate I

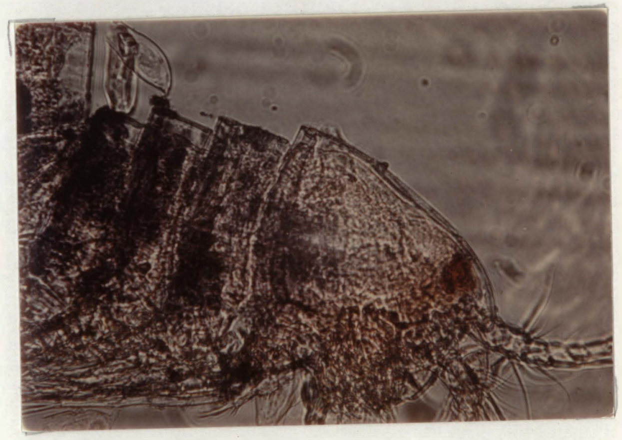


32 μ

Plate II

107 μ

Plate III



107 μ

Plate IV

Plate V. *Cothurina canthocampti* attached to *Canthocamptus* sp.

Plate VI. *Cothurina canthocampti* attached to *Canthocamptus* sp.

Plate VII. *Vorticella* sp. attached to *Chydorus sphaericus*.

Plate VIII. *Hypsibius* sp. in ecdysis.

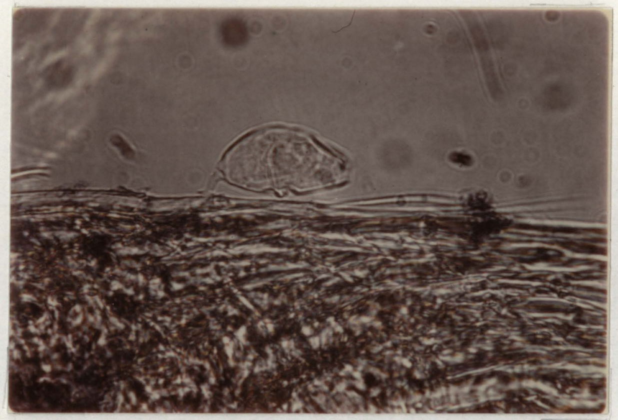


Plate V 32 μ

Plate VI 206 μ

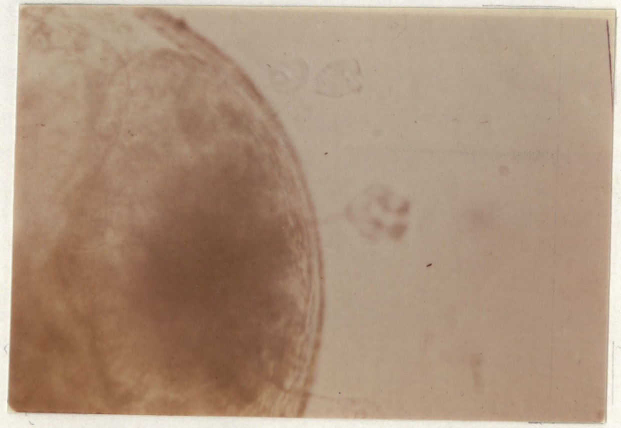


Plate VII 85 μ

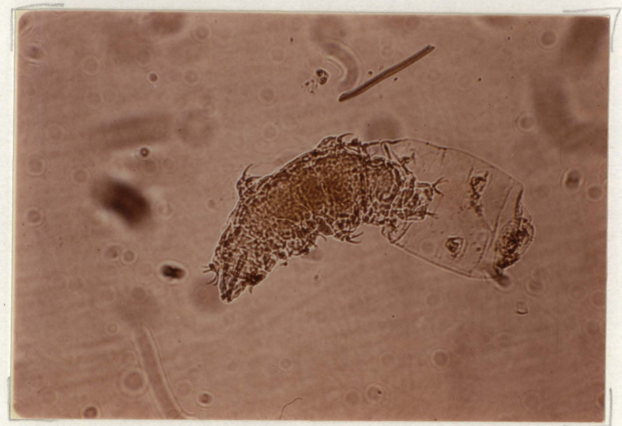


Plate VIII 187 μ

DISCUSSION

The chemical composition of the water in Ashmore Lake showed changes during the period, March 7 through May 23, 1968. Polecat Creek drains approximately 10,000 acres of largely cultivated land located above the lake. During the spring, this land is extensively fertilized, using balanced commercial fertilizers. Increased concentrations of certain chemicals were observed following periods of rainfall, and are demonstrated by comparing the data of Figs. 5, 9, 10, and 11. It is probable that rise and fall in lake water concentrations of the chemicals in question is due, in great part, to the shedding of water from these fertilized fields into the Polecat, and thence into Ashmore Lake.

A very direct correlation was observed between the number of species of rotifers and euglenoids, and nitrogen and phosphorus peaks. The nitrogen and phosphorus content of commercial fertilizers was noted, and roughly correlated to the lake nitrogen and phosphorus.

According to Pennak (1946) phosphorus is considered to be a limiting factor for naturally occurring planktonic organisms much more frequently than nitrogen. Damann (1950) decided that it was added enrichment from the drainage basin in the agricultural areas which seemed to be responsible for high plankton densities in certain lakes and streams. In the present study, increases in

phosphorus and nitrogen were accompanied by an increase in the kinds and numbers of planktonic organisms, suggesting that Damann's idea is essentially correct.

The highest peaks of lake nitrogen and phosphorus concentrations (Figs. 9, 10, and 11) were observed five to ten days after many farmers in the drainage basin of Polecat Creek were known to have applied fertilizers to their fields. In the ensuing interval considerable rainfall was recorded (Fig. 5). Three days following the cessation of heavy rains (Fig. 5), nitrogen peaks at 90 ppm and phosphate at 2.22 ppm. The date of highest nitrogen and phosphorus was May 5, and plankton samples from the lake on this date contained 33 genera of zooplankters. This was an increase of 13 genera (39% increase) over the two previous plankton collections (April 28 and May 2), obtained before the sharp rise in nitrogen and phosphorus concentration of the lake.

Protozoans and rotifers showed the greatest density response to the discussed changes in chemical composition. The density of euglenoids increased from one or two individuals per microscopic field (100X), observed on April 28 and May 2, to six or eight per microscopic field, on the dates corresponding to nitrogen and phosphorus peaks. Ploimid rotifers, of the genus Brachionus, Platyias, and Synchaeta increased from one or two individuals per microscopic field, on the dates indicated above, to four or five per field on May 5. As the concentration of nitrogen and

phosphorus receded the variety of genera in the plankton collection declined, as did the density of euglenoids and ploimate rotifers.

While the assumption of the preceding paragraphs is that changing concentrations of nitrogen and phosphorus are the chemical factors most responsible for the observed variations in plankton, and indeed these were elements showing the greatest fluctuation, it must be borne in mind that other explanations are tenable. Iron and sulfate (Figs. 12 and 13) concentrations increased less acutely, but according to the same pattern, and probably for the same reason, as nitrogen and phosphorus. Trace elements, not detected or taken into consideration could have elicited the response observed in the plankton.

Certain ciliates seemed to show preference for colder water. These ciliates were Dileptus anser, Epistylis sp., Euplotes patella, Lacrymaria olor, Lionotus fasciola, and Urosoma sp. These protozoans were seen only when the water temperature was below 10^{o} centigrade. This finding is in accordance with Noland's (1925) conclusion that some holotrichous ciliates decidedly favor low temperature.

Although some euglenoids were present in very cold water (2.5^{o}C.) the numbers of chlorophyll bearing flagellates were very few until the temperature warmed to 10^{o}C. It is possible that these organisms were responding not only to increased water temperature (Fig. 4), but to the increasing intensity and length of daylight (Fig. 5).

Warmer water was favorable for several species of mastigophorans, mainly Dinobryon sertularis, Glenodinium, Phacus pleuronectes, Phacus triqueter, Trachelomonas, Uroglena volvox, and Volvox sp. The densities of Phacus, Trachelomonas, and Dinobryon continued to increase in numbers from their first appearance, and Peridinium and Synura uvella appeared sporadically. In part, this seems to support the contention of Reinhard (1931) that fluctuations due to temperature are minor and affect principally the chlorophyll bearing forms (Table 1). That is to say, warmer water favors a greater increase in the variety of phytoflagellates than it does other protozoans or metazoan plankters. This line of thought must consider also that warming water may be accompanied by changes in photoperiod. One cannot say that it is temperature alone that is the important factor. Kudo (1966) lists falling temperature as one of the major factors for encystment and does not mention photoperiod as having an influence on excystment. Lackey et al. (1943) noted that addition of phosphorus quickly stimulated either directly or indirectly the excystment of numerous protozoa, but did not list specific genera.

Rotifers were present at water temperatures below 10° centigrade, but the greatest number of genera appeared after the water temperature had reached 18° centigrade, and they continued to generally increase not only in number of individuals per microscopic field but also in number of genera present (Table 2).

The rotifers Brachionus calyciflorus, B. urceolares,

Cephalodella sp., Mytillina sp., and Trichocera sp. did not appear until the water temperature was well above 10°C. and the longest lists of rotifer genera were compiled on dates when nitrogen and phosphorus peaked (Figs. 9, 10, and 11). Most rotifers, according to Pennak (1953) are not specialized feeders, therefore, it is difficult to draw any conclusions relating their increase to the increase in phytoflagellates or any other possible plankton food. An exception must be noted. The density of the forcipate rotifer Asplanchna is probably related to the density of its favorite food source, rotifers of the genus Brachinous. Asplanchna also utilizes a number of other food sources. In fact it is said to ingest any planktonic organisms it can catch and hold larger than 15 microns in diameter (Pennak 1953). This may explain, in part, the existence of Asplanchna, in relatively small numbers, in the plankton samples collected while water temperature was below 10°C. and its rather explosive increase in later samples collected from warmer (Brachionus containing) water.

The majority of copepods taken in plankton during this study are of the Suborder Cyclopoida and these were first observed in plankton samples collected after the water temperature was above 10° centigrade. However, information furnished by student reports on plankton collections obtained in Ashmore Lake during September, 1967, show the most abundant copepod to have been calanoids of the genus Diaptomus, though cyclopoids were also present. These data,

coupled with the fact that calanoids were not seen in any samples, collected in the present investigation, until late May (Table 2), suggest that copepods of the Suborder Calanodia, in general, and the genus Diaptomus, in particular, are creatures of the warmer summer lake plankton. While cyclopoids have raptorial mouth parts, calnoids are filter feeders utilizing mainly nannoplankton (unicellular algae, bacteria, some diatoms, very small phytoflagellates) and micro-particles of detritus from decaying aquatic plants. The increased abundance of both these food sources in late spring and throughout the summer are perhaps directly responsible for the rise in calanoid numbers rather than increased temperature as such. Harpacticoids are substrate dwellers and their occasional appearance in plankton samples can be explained as a result of bottom material temporarily suspended in shallow water. This explanation can be extended to account for finding an occasional gastrotrich such as Chaetonotus and tardigrades such as Hypsibus. This latter animal is shown in Plate VIII undergoing ecdysis.

No temperature correlation could be drawn for some of the Protozoa present; for example Stentor sp., Vorticella sp., Difflugia sp., and certain euglenoids fall into this category. These protozoans were found not only on the coldest days, but also on the very warm days and with (for some genera) little change in population density. The same is true for some rotifers, namely Synchaeta sp., Asplanchna sp., Filinia longiseta, and Rotaria (Table 2).

Tartar (1961) says that rising temperatures, up to a limit, can be related to larger size in Stentor but gives no reason why they might occur in such a wide temperature range. Pennak (1953) relates that many rotifers are omnivorous and ingest all organic particles of the appropriate size and may therefore be independent of a temperature dependent food source.

Increases in water temperature undoubtedly increase the metabolic rate of rotifers, and consequently induces greater egg production. The same is true for many protozoans; metabolic rate increases in warmer water and binary fission also increases, resulting in greater densities.

It appears that once the water temperature has reached 10° centigrade, further warming is only a quantitative factor affecting most of the plankton. Tables 1 and 2 show that after March 28 the water temperature remained above 10°C., with only one exception occurring on April 7, when the water temperature dropped to 9.5° centigrade. During this period, the numbers of genera present did not fluctuate markedly. These findings support Pennak (1953) who says that temperatures below 10°C. and above 28°C. markedly affect the numbers of individuals present, but not the numbers of species, and that the summer and winter species lists from the same habitat are very similar.

Lackey (1938) stated that seasonal changes due to temperature are quantitative. But as Welch (1935) has stated one should

take into consideration the modifications to which a body of water is subject when interpreting field results as being directly correlated to temperature.

The presence of Difflugia, a substrate dweller, in the plankton presents a puzzle. One is at first inclined to explain its presence as a result of "churning up" of the bottom material. This explanation seems reasonable in light of the rather rapid flow of water through the lake and the fact that at places the plankton net was pulled through water only 18 to 36 inches deep, but this organism was one of those more constant in plankton samples and it was obtained even on short tows through parts of the lake 12 feet deep. The suggestion here presented is that Difflugia is an intermittent plankton dweller, able to alter its buoyancy in order to facilitate ascent and descent. This may be accomplished by the secretion of gas bubbles into the test, as does Arcella (also found on occasion in the plankton, or by some as yet unknown mechanism.

What advantage is to be gained by the planktonic existence of Difflugia? According to Hall (1965), the diet of these animals consists of bacteria, diatoms, and other Protozoa, and other very small organisms it can capture and hold. Of the prey mentioned, it is only other Protozoa and diatoms that might be more abundant in the plankton than benthos. Assuming that food is the advantage, how is it caught? None of the Difflugia observed showed other

than the lobopodial type of pseudopods, a type not particularly adapted for other than substrate browsing. There is a precedent among sarcodins, and flagellates as well, for production of occasional reticulopodial feeding nets. If this holds for Difflugia (at this time there is no direct evidence that it does), it would strongly suggest plankton as a Difflugia feeding ground. Other reasons for the presence of this organism in plankton may revolve around increased oxygen or higher temperature in water near the surface. Davis (1955) does not list Difflugia as being a plankton dweller. However, Raymond (1937) found Difflugia in plankton of a marl lake, and Damann (1945) recorded Difflugia in the plankton of Lake Michigan. Orr (1954) listed Difflugia oblongata tests in the plankton of a lake in Pennsylvania. Lackey et al. (1943) did not find Difflugia in the plankton of a small stream in Ohio.

Information collected on Dinobryon supports the findings of Hutchinson (1944) in which she found marked multiplication of Dinobryon occurring often after a decline of heavy spring populations of diatoms. A tremendous number of diatoms were present in early March samples; however, Dinobryon did not appear until the diatom density decreased, appearing first on March 31, 1968 (Table 1).

High water and heavy rainfall may serve as limiting factors for some plankters. These are times of high turbidity (Fig. 6), and light penetration into the water is reduced. Also the

increased volume and movement of waters serve as dilution factors.

According to Pennak (1946), the surface waters of the great majority of lakes and streams lies in the pH range of 6.0 to 8.5. He goes on to say that hydrogen ion concentration is believed to be of little real significance in reducing plankton abundance. Pennak believes that pH is a convenient measure of the sum of a good many chemical complexities, and it is the individual members of the complex which presumably affect and limit the plankton rather than the total.

The hydrogen ion concentration range for Ashmore Lake was from an acid reading of 6.3 to an alkaline reading of 8.7 (Fig. 8). The average pH was near neutral 7.1 which is within the limits stated by Pennak (1946) for high plankton productivity.

Williams (1964) has shown the return of irrigation water to streams may account for significant increases in population density of phytoplankton. He believes this is due to the nitrates, phosphates, and "trace" elements taken from agricultural soil. This finding is in keeping with the results of Damann's (1950) study of the Missouri River Basin. This was also a result of this study and it gives support to Mead et al. (1945) which states that "Inorganic nitrogen may be a limiting factor in regard to the amount of growth which could be produced and the inorganic phosphorus acting largely as a governor upon the rate

at which growth occurred." "Trace" elements may be of great importance in plankton environments for certain species. Hutchinson (1944) concludes that all nutrients except nitrate and phosphate are normally present in such considerable excess, and that qualitative effects due to their fluctuations are most unlikely.

Oxygen did not appear to be a limiting factor in this study. There always seemed to be an ample oxygen supply to support the planktonic life. Iron peaks are directly related to peaks in turbidity (Fig. 6) and sulfate (Fig. 13) which are in turn related to rainfall (Fig. 5).

The dominant species in the study for each class of Protozoa was as follows: Class Sarcodina, Difflugia globosa with seventeen appearances, Class Mastigophora, Euglena sp. was observed in twenty collections, Class Ciliata, Stentor sp. was seen on eighteen occasions, Vorticella sp. in sixteen samples, and Halteria grandinella in eleven collections (Table 1).

Edmondson (1920) gives the typical precentage for protozoan species composition in lakes as follows: Mastigophora 14%, Sarcodina 19%, Ciliata 67%. From a qualitative standpoint, Ashmore Lake differs from this in percentage composition by taxonomic classes. The class percentage for Ashmore Lake was: Mastigophora 38%, Cilata 37%, and Sarcodina 25%. Orr (1954) found Sanctuary Lake, Pennsylvania, to contain over 50% mastigophorans during the summer of 1951. The possible differences

are due to the fact that Orr's study was conducted during the months of July and August, a very favorable time for the phyto-mastigophora. The present study was conducted from March through May, periods in which a much greater fluctuation in water temperature can be observed; also the photoperiod is not as long and the light is not as intense. The effect of a creek running through the study area resulting in a rapid water turn-over might account for an atypical lake plankton percentage. On the other hand, a yearly study on the same area might show changes in the species percentages.

Sporadically throughout the study Vorticella sp. (Plate VII), Epistylis sp., Tokophrya cyclopum, and Cothurina canthocampti (Plate I - VI) were observed in symbiotic associations. These protozoans were found living attached to several different metazoans, namely Dero sp., Chydorus sphaericus (Plate VII), Simocephalus sp., Canthocamptus sp. (Plate VI), Cyclops sp., and ostracods. Vorticella was found attached to Dero sp., Cyclops sp., Diaptomus sp., C. sphaericus, and Simocephalus sp., the numbers of these vorticellids present varied from only one to twenty-five per host. Kudo (1956) indicates that Cothurinia canthocampti Stokes, does occur on Canthocamptus minutus, and that Lagenophrys vaginicola Stokes, is found attached to the caudal bristles and appendages of Cyclops minutus and Canthocamptus sp. Pennak (1953) says that many fresh-water metazoa have Protozoa living on their

general external surfaces. Some of these species are thought to be obligatory commensals, but it is sometimes difficult to decide just what special benefits the protozoan derives from such an association. Early in the study colonies of Epistylis (Table 1) were observed on Cyclops. But although the numbers of Cyclops in samples increased during the course of the study no epistylid ectocommensals were present. The question comes to mind as to why these ectocommensals are found only at certain times, on certain metazoans and why they are absent in some samples and present in others.

During a recent forty-eight hour study (July 12-14, 1968), of Ashmore Lake (an appendix to the present study), it was found that the mid-night and four A.M. collections were the ones that contained the greatest number of commensalized metazoans. Pennak (1953) conveys that Cladocera, and some common species of plankton copepods show a daily rhythmic cycle of vertical migrations in lakes, with a greater concentration of individuals in the upper waters during the hours of darkness. Quantitative data collected during the forty-eight hour study supports Pennak's statement. Since C. canthocampti is sessile many of the copepods may bring the commensals up from the substrate. This would be especially true for Canthocamptus sp., since it normally remains on the substrate, and is not especially adapted for swimming or a planktonic life. A review of the literature has not given any information as to how these commensals attach on metazoans and what advantages

are to be gained by such an existence or what disadvantages result for the metazoan involved. It was undetermined at what stage in the life cycle the commensals attach themselves to the host.

It is difficult to determine which factors have the greatest influence independent of the other factors and conditions acting upon the plankton in Ashmore Lake. In attempting to interpret the effect of changes in chemical composition, one should draw conclusions with care, taking into account other concurrent conditions.

Viewing the study in retrospect, a quantitative study would have been desirable in order to determine with greater accuracy the degree to which each species was responding to shifts in environmental conditions. More information might be gained from a stratification study, in which samples are taken from various depths.

It can be stated, that in the present study two sources of variation in lake plankton were observed: 1. The changes associated with warming of water and increased photoperiod, i.e., the change from winter to spring and spring to summer, which are natural rather stable cycles, and 2. The changes associated with fluctuations in nitrogen and phosphorus, and other chemicals, resulting from the influx of fertilizer materials from cultivated fields. These induce short term changes, of perhaps no great significance at present magnitude.

SUMMARY AND CONCLUSIONS

1. Ashmore Lake was found to be subject to changes in chemical composition during a three-month study conducted from March 7 to May 23, 1968. The plankton present was identified and a rough quantitation was made.

2. A study of certain physico-chemical features was carried out. The following chemicals were observed and parts per million for each was recorded: oxygen, nitrite-nitrogen, nitrate-nitrogen, phosphate, iron, and sulfate. Peaks for these chemicals were recorded with reference to the plankton.

3. The hours of sunlight, temperature of the air and water, precipitation, hydrogen ion concentration and turbidity were recorded.

4. The greatest modifying factor on the plankton is believed to be the influence of commercial fertilizers introduced by the Polecat Creek.

5. A relatively large plankton density and the greatest number of species occurred during peak periods for nitrogen and phosphorus.

6. The hydrogen ion concentration was found to be within the limits of most lakes that have high plankton productivity.

7. Warming of the water and increase in the photoperiod resulted

in excystment of several euglenoid species and a greater density of all phytoflagellates.

8. Temperatures above 10^{o}C. have a more quantitative than qualitative effect on many members of the plankton.

9. Certain ciliates were found to favor temperatures below 10^{o}C.

10. Peaks in nitrogen and phosphorus correspond to periods of rainfall and follow periods of heavy fertilization of farm fields with commercial fertilizer.

11. Swift water accompanied by periods of high turbidity serves as a limiting factor for phytomastigophorans.

12. High turbidity results in organisms being in the plankton that are normally thought of as being benthic.

13. Difflugia was found to be planktonic. This organism is normally thought of as being a substrate dweller due to its mode of feeding.

14. Vorticella sp., Epistylis sp., Tokophyra sp., and Cothurina canthocampti were observed as ectocommensals attached to several metazoans, namely: Dero sp., Chydorus sphaericus, Canthocamptus sp., Cyclops sp., and ostracods.

15. Dinobryon "blooms" appeared after the decrease in spring diatom "blooms."

16. The protozoans were found to be best represented in the plankton of Ashmore Lake, followed by the rotifers.

17. A total of 114 different planktonic organisms were recorded for Ashmore Lake during the three month study.

18. Two kinds of variation in lake plankton were observed: A. The changes associated with the warming of water and increased photoperiod, i.e., the changes from winter to spring, and spring to summer, which are rather stable cycles. B. The changes associated with nitrogen and phosphorus and other chemicals resulting from the influx of fertilizer chemicals from cultivated fields. These chemicals induce short term changes associated with them.

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