12. PLANKTON

INTRODUCTION

The word "plankton" refers to the tiny plants and animals which live suspended or swimming freely in the water. Although unnoticed by most people, zooplankton (animal plankton) can be easily observed in Lake Winona by simply scooping up a jar of water and examining it closely. The jerky, swimming motions of the larger zooplankters makes them easy to see with the naked eye. Phytoplankton (plant plankton) are noticed by everyone who visits Lake Winona in summer. Their tremendous numbers and distinct green color give the lake water a "pea-soup" appearance.

Research on Lake Winona's plankton community has been limited to what biologists call "net plankton" or the plankton large enough to be retained in a net with openings 60 microns on a side. Plankters small enough to pass through the net are divided into two groups. The "nannoplankton" (5-60 microns) consists primarily of protozoans, immature net plankton, small rotifers, and single-celled algae. The "microplankton" or ultra nannoplankton (5 microns or less) consist primarily of bacteria.

The kinds of plankton and their abundance in a lake are indicators of its health. Lakes which are being polluted allochthonously (from outside sources) have distinctive plankton communities. The sources of these pollutants often determine which species of plankton will be present. Sewage effluent, for example, may cause the appearance of, or an increase in, the numbers of one species of plankton while an influx of agricultural runoff or urban storm water may favor another. Eutrophic lakes such as Lake Winona often have very complex cycles involving nutrient loading, primary production and plankton density and diversity. As these conditions change and the plankton community responds, obvious changes in the lake water occur. It was the purpose of this investigation to record these changes in Lake Winona's plankton community and in doing so to provide a data base from which others may proceed in future investigations. Methods of study are outlined at the end of this chapter. The taxonomy of all plankters studied is presented in Tables 12-1 and 12-2.

PHYTOPLANKTON

Most of Lake Winona's phytoplankters (Fig. 12-1) are members of the division Cyanophyta, also known as Cyanobacteria, and are commonly called blue-green algae. They are one-celled or filamentous prokaryotes which lack chloroplasts. They are ancient, primitive plants; based on the dating of stromatolites in Swaziland, the division Cyanophyta dates back to the early Precambrian period, 3.2 billion years ago. The presence of stromatolites indicates an early-evolved ability to carry on photosynthesis because they

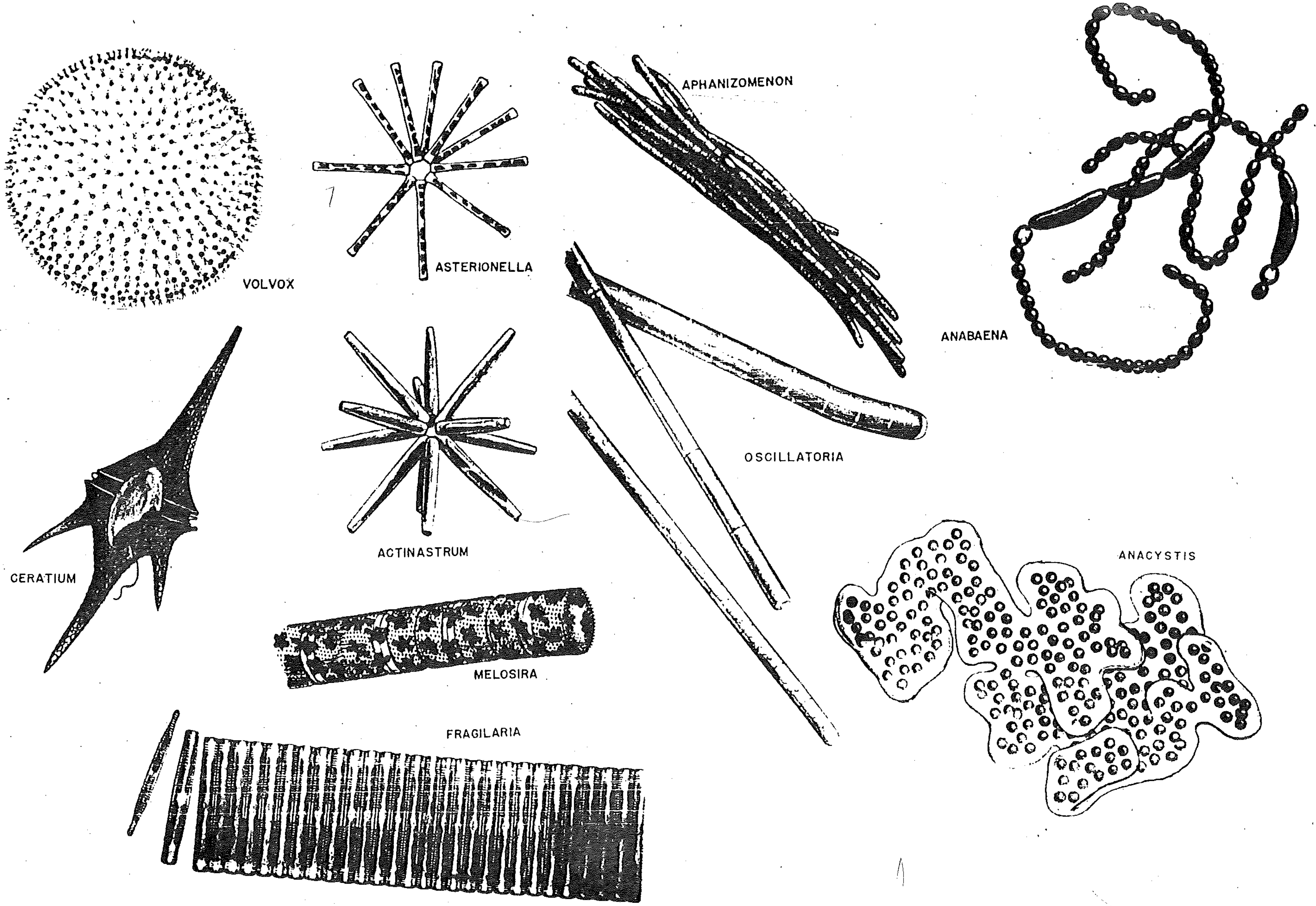


Figure 12-1. Phytoplankton common to Lake Winona. *Volvox* and *Actinastrum* are green algae; *Volvox* was abundant occasionally in past years. *Ceratium* is a dinoflagellate. *Asterionella*, *Melosira* and *Fragilaria* are diatoms. The rest are blue-greens. *Anacystis* is synonymous with *Microcystis*. Drawings from Standard Methods.

are formed of calcium carbonate, a mineral product of photosynthesis. The metabolic wastes of these Precambrian cyanophytes apparently inhibited, or were lethal to, other organisms which are absent in the fossil record where stromatolites occur. This trait may have been carried forward genetically to the present; toxic blooms of blue-green algae are occasionally reported. In modern times, blue-green algae are widely distributed; a single species may be found world-wide. Blue-greens are even found free-living in the atmosphere with over 55 species above the United States alone (Fogg et al., 1973).

Blue-green algae flourish in eutrophic, high pH lakes where they commonly replace green algae and diatoms. Blue-greens are more efficient utilizers of phosphate and carbon dioxide in high pH water than are other algae. Many species of blue-green algae are capable of fixing nitrogen from the atmosphere, further ensuring their ability to use all available phosphate. The rapid uptake of phosphate by blue-greens may shift the chemical balance between aquatic macrophytes and the lake water, causing the release of phosphate from the aquatic macrophytes into the water, thus accelerating the growth of the blue-greens (Shapiro, 1975). In Lake Winona, the rapid increase of the blue-green algae Aphanizomenon (Fig. 12-2) may be caused by the release of phosphate into the water by curlyleafed pondweed Potamogeton crispus as it ends its annual life cycle and dies in late June and early July. According to Cole (1983), the rapid growth of P. crispus and its attendant high photosynthetic rate causes precipitation of calcium carbonate (marl). Phosphate in the water adsorbs onto calcium carbonate particles at high pH, and is precipitated (settled to the bottom) along with the marl. This process may limit the population of blue-greens by denying them access to needed phosphate during the time P. crispus is undergoing its most rapid growth (May-June). The increase in Aphanizomenon (and other plankters) after the P. crispus die-off is reflected in decreasing transparency (Fig. 12-2).

Attempts to control algal blooms have become common in recent years. The wide-spread use of inorganic fertilizers in agriculture, and more recently on lawns in cities, has provided a broad, insidious source of nutrient overload in North American freshwaters which often triggers blooms of blue-green algae. Methods to reduce blooms include the use of copper sulfate, organic algicides, algal pathogens, and even explosives (Fogg, et al., 1973).

Naturally occuring pathogens are often species-specific. The fungus Chytridium cornutum, for instance, attacks only the heterocysts of Aphanizomenon flos aquae. Blue-greens are also parasitized by viruses and bacteria. Collectively, such pathogens may play an important role in the natural decline of algal blooms (Fogg, 1973). Ultimately, the best control is to reduce the amount of nutrients entering the lake. However, this is often difficult or impossible due to the non-point nature of the sources of these nutrients. In some cases the eutrophication of the lake may have progressed to the point that its own sediments can provide nutrients for algal blooms for many years. This is apparently true in Lake Winona.

Lake Winona's phytoplankton community changes its composition as the seasons progress. In the 1985 study, these changes were observed as weekly events, occurring independently in the upper and lower basins. Sampling on May 13, 1985 showed the most prevalent phytoplankton of the upper basin to be the diatom Asterionella (Fig. 12-3). Its delicate, siliceous skeleton resembles a spoked wheel with the outer rim removed. Actinastrum, a green algae (Chlorophyta), was the most abundant phytoplankter in the lower basin and second in abundance in the upper basin. Also occurring in both basins was the diatom Fragillaria, which usually occurs in filaments, and the dinoflagellate Ceratium hirundinella. Those four organisms collectively accounted for most of the phytoplankton in both basins during May. There were few if any blue-greens present then, and the water was quite clear; visibility often exceeded 2 meters (Fig. 12-2). As the photoperiod lengthened and the lake's temperature increased, changes occurred in the composition and numbers of phytoplankton.

In late May, P. crispus covered most of the lake, its protruding flower heads indicating the end of its seasonal growth. The stage was set; Lake Winona was about to wear its summer "colors". In early June, the blue-green Aphanizomenon made its seasonal debut (Fig. 12-2). Aphanizomenon takes its name from the Greek words "Aphanes" (unseen or invisible) and "Zom" (soup or broth). By the end of June, however, its "broth" was far from invisible.

Aphanizomenon is a heterocystous, filamentous blue-green whose trichomes are usually aggregated into flake-like bundles which are clearly visible to the naked eye. Under certain environmental conditions, however, the bundles may dissociate into free-living filaments. Such conditions are commonly encountered in eutrophic waters (Gleason, 1985). In Lake Winona, this phenomenon was observed towards the end of Aphanizomenon bloom and signaled its imminent decline.

In 1985, the upper basin supported the largest population of Aphanizomenon; its peak population occurred during the first week of July in both basins, with nearly 6 times more trichomes per volume of lake water in the upper basin than in the lower basin. Reasons for this large difference probably include the higher percentage of littoral area (water less than 10 feet deep) in the upper basin (93.5% vs. 74.0%), which translates into a higher percentage of its area supporting P. crispus which is implicated in releasing nutrients for Aphanizomenon. Another reason may be the introduction of nutrients from Gilmore Creek, which empties into the upper lake basin after picking up runoff water from Goodview and several west end storm sewers. In addition, the upper basin receives runoff from the cemetery and the discharge of 9.2 miles of city storm sewers. This compares with the lower basin's 7.3 miles of storm sewers and the effluent from the upper basin which has already been "processed" by aquatic plants.

Because light is essential for vegetative growth of blue-greens and because its intensity attenuates exponentially with depth, planktonic blue-greens have evolved mechanisms for buoyancy regulation.

Buoyancy is regulated via the containment of gas vesicles within the cells. Blue-greens, which accumulate at the surface, usually die because of exposure to supersaturated dissolved oxygen levels which prevent metabolic exchange of waste products. Furthermore, intense levels of solar radiation encountered at the surface catalyze reactions which inflict fatal damage to blue-green cells. When this happens, the resulting mass die-off of algae results in an increase in bacteria and then a rapid depletion of dissolved oxygen due to the high biochemical oxygen demand imposed by bacterial growth. In extreme cases, this sequence of events can cause oxygen depletion throughout the lake and may be accompanied by the accumulation of toxic organic compounds, strong odors, and fish deaths. Normally, this situation is prevented by the collapse of the gas vesicles as the algae near the surface. This convenient and essential condition is brought about through the following mechanism: 1) light intensity increases exponentially with decreasing depth, triggering an increase in photosynthetic activity, 2) the heightened photosynthetic rate increases the concentration of organic molecules in the cell creating higher intracellular pressures which compress the gas vesicles resulting in decreased buoyancy, 3) as the algae sink, photosynthetic rate decreases in response to lower light intensity encountered with increasing depth. Decreased photosynthesis results in decreased production of organic compounds, reduced cell pressures, expanded gas vesicles and increased buoyancy. This vertical migration seems to be the norm in planktonic blue-greens; neutral buoyancy does not appear to occur as might be expected. Some authors have suggested that this movement results in exposure to greater volumes of water, thus increasing the rate of removal of metabolic wastes and the rate of nutrient absorption (Prescott, 1968). In Lake Winona, the aeration system may be the only factor preventing summer fish kills caused by death and decay of aquatic algae and macrophytes.

In the upper basin, Aphanizomenon persisted through August (Fig. 12-2), while in the lower basin it had run its course by the end of July. The lake was not to be rid of its "pea soup" appearance, however. Early July brought with it a new blue-green alga, Oscillatoria agardhii (Fig. 12-4), which produced the year's densest population. Quantitative measurements were not accurately obtained until mid-August when it was realized that the tiny filaments (.0035 mm diameter) were being lost from the samples during filtering, necessitating development of an alternative sampling method. Sampling on August 13 showed more than 6000 filaments/ml. of lake water in the lower basin and 4000/ml. in the upper basin. Unlike Aphanizomenon, whose flakes are clearly visible to the naked eye, the tiny independent Oscillatoria trichomes are quite invisible, their presence indicated only by the green color of the lake water.

Toward the end of July, tiny fasicles .3 to .8 mm in length and containing many filaments of planktonic Oscillatoria appeared in both basins. The fasicles persisted until their peak at the end of August and then abruptly disappeared. Positive taxonomic identity to species is not claimed for this organism because there is great variation of description in the literature. Blue-green algae often exhibit pleomorphism (plasticity of morphology) which has resulted in many specific names for what may well be environmentally induced variations (ecophenes) of a single species.

According to Saunders (1972), O. agardhii possesses the unusual ability to utilize dissolved organic matter (DOM) as a source of carbon and energy. This ability decreases its dependence on dissolved carbon dioxide during photosynthesis and may account for Coles' (1983) report of its ability to thrive in dim light to the extent of supersaturating its surroundings with dissolved oxygen, a condition which would prove fatal to Aphanizomenon. O. agardhii remained the predominent phytoplankter in both basins through the end of the 1985 study. In early November, however, a qualitative check of the upper basin indicated that it had been replaced almost entirely by the filamenous diatom Melosira granulata.

Several other blue-greens were found in Lake Winona(Fig. 12-4). During the 1985 study, four species of Anabaena were identified and collectively enumerated in both basins. Anabaena numbers became great enough for counting in late May in the lower basin and in mid-June in the upper basin. By mid-July their populations had declined to levels unsuited for counting. In late September, Anabaena reappeared in the lower basin in moderate numbers. Two species of Microcystis appeared in both basins in June, and their populations peaked early in September. The lower basin consistently supported the greatest populations of this blue-green.

Microcystis is a colonial organism occurring in irregular but definitively formed globs or flattened masses made of many spherical cells enclosed in mucilage. Cells of Microcystis contain pseudovacuoles (gas pockets) used for buoyancy regulation, and thus have the potential to form surface scums and their attendant nuisance odors and oxygen depletion problems. Prescott (1968) states that Aphanizomenon and Microcystis seldom inhabit the same lake at the same time. Lake Winona is apparently an exception, although it should be noted that the Microcystis peak does not occur until Aphanizomenon numbers have become insignificant. At their peak in the lower basin, Microcystis colonies form a significant portion of the phytoplankton population and are visible to the naked eye.

Green algae in Lake Winona are conspicuous by their absence. With the exception of Actinastrum early in the season, green algae were never encountered in sufficient numbers for counting. Contrasting this is a report by a Winona State University ecology class on September 15, 1982 showing the green algae Volvox to be extremely abundant and three other genera to be common in the lower basin. Green algae are important to the lake food chain because large, herbivorous zooplankters depend upon them as a primary food source. Bluegills, in turn, depend upon large zooplankters for their food. This is espeiclaly true in Lake Winona, which produces relatively few benthic food organisms.

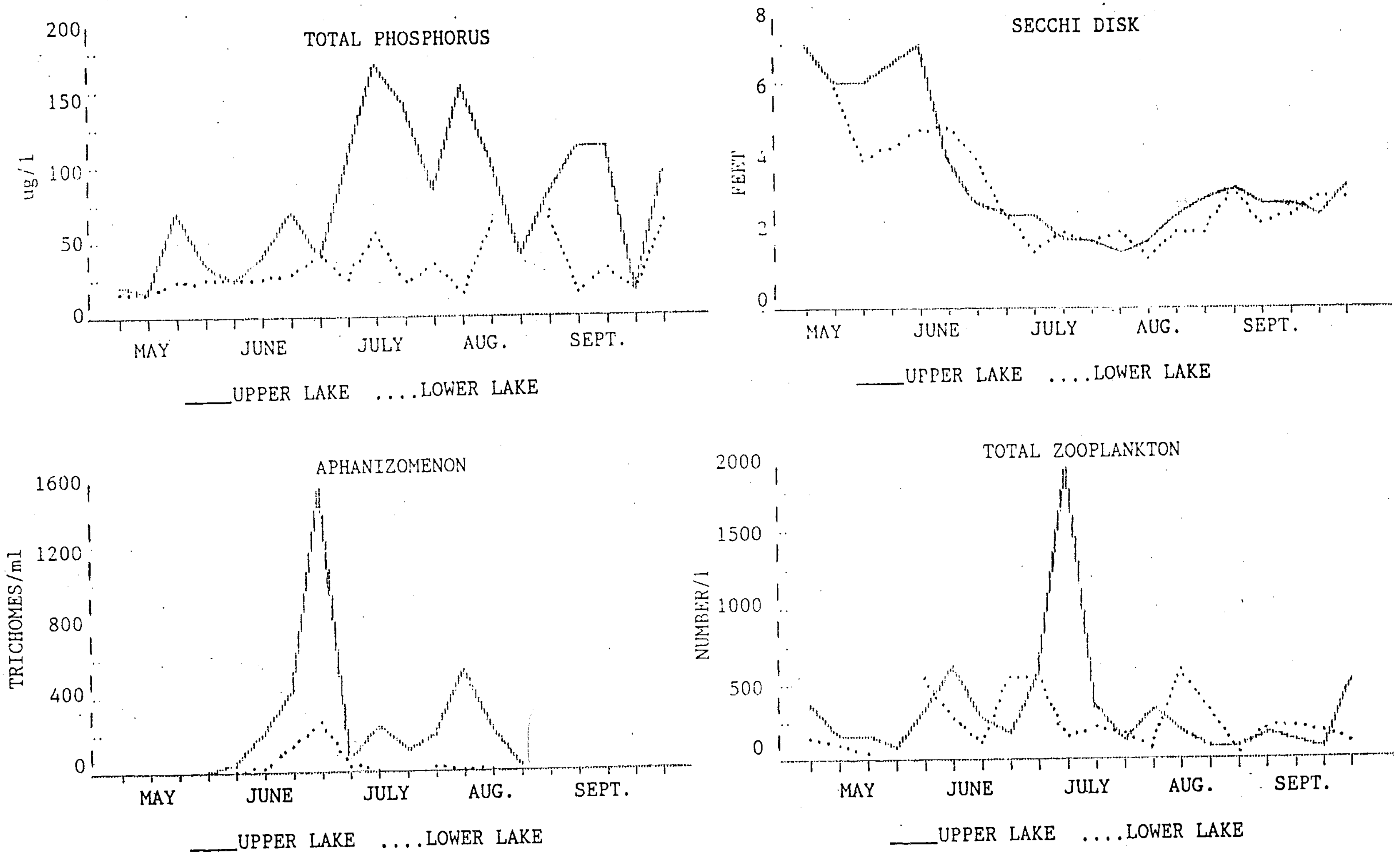


Figure 12-2. Relationships among phosphorus, *Aphanizomenon* algae, zooplankton and Secchi disk transparency in Lake Winona.

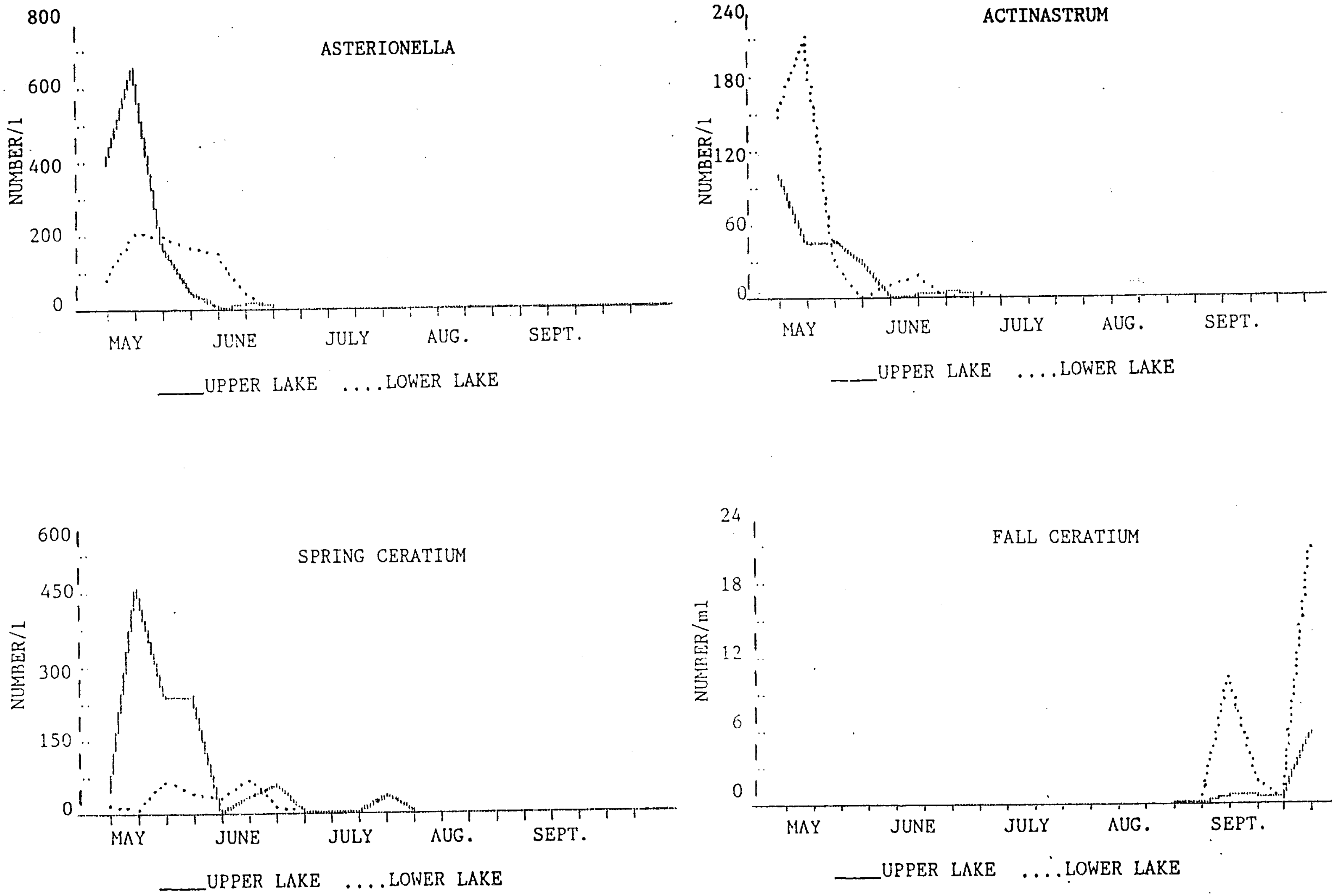


Figure 12-3. Lake Winona phytoplankton densities. Asterionella is a diatom, Actinastrum a green alga and Ceratium a dinoflagellate. Note that the above species are most abundant inspring and fall.

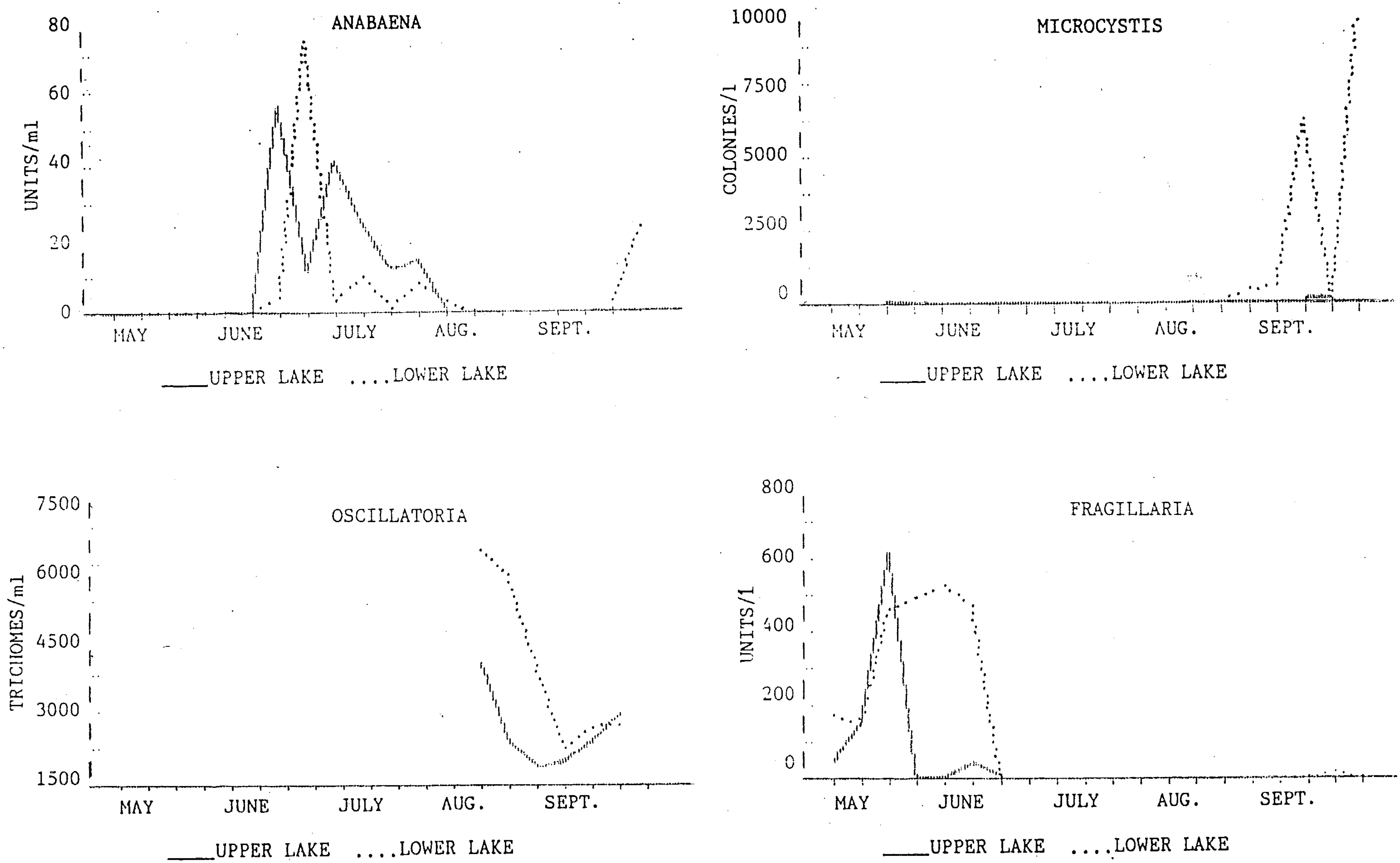


Figure 12-4. Lake Winona phytoplankton densities. Anabaena, Oscillatoria and Microcystis are blue-green algae, Fragillaria is a diatom.

ZOOPLANKTON

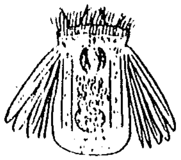
Lake Winona's zooplankters are primarily members of two phyla, Rotifera and Arthropoda. Each is represented by a single class, Monogonata in Rotifera and Crustacea in Arthropoda. Lake Winona's zooplankters are illustrated in Figure 12-5; their taxonomy is outlined in Table 12-2.

The phylum Rotifera is comprised mainly of freshwater species. Less than 5% of the 1700 known species are marine. Rotifers are widely distributed, ranging from the deepest regions of large lakes to small puddles. They are characterized by rythmic waving of many cilia surrounding their retractile mouths, giving the appearance of rotation as the Latin root word "rota" in their name implies. It is the motion of these rows of cilia which moves water toward the rotifer's mouth enabling it to feed and simultaneously propel itself through the water, assisted by undulations and spiraling movements of its whole body. Rotifers are omnivorous consumers of almost any organic particles including, in the larger genera such as _Asplanchna_, other rotifers.

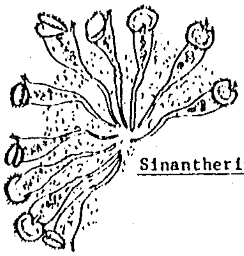
Rotifers were commonly found in Lake Winona during May and June, but seemed to be absent when blue-green algae were the prevalent phytoplankters (Fig. 12-6). Largest of the rotifers was _Asplanchna_ Fig. 12-7), an urn-shaped rotifer from .45 to .82 mm. long, large enough to be selected as food by bluegills. _Asplanchna_ occurs as free-living individuals primarily in June. Another June-appearing rotifer _Keratella_ made a brief one to two week appearance in both the upper and lower lakes and another, stronger, appearance in the lower basin in mid-September. September also brought the only appearnace of _Polyarthra_, which resembles a beer can with four groups of feathers hanging from its side.

Most interesting of all the Lake Winona rotifers was _Sinantherina socialis_, a colonial species found in the first samples taken in the 1985 study. First appearing in May as free swimming larval colonies in both basins, they abruptly disbanded, spent the month of June as free-swimming individual larvae, and then disappeared. After leaving the plankton, _Sinantherina_ larvae form sessile adult colonies on aquatic substrates, not returning to the open water until the following year (Edmonds, 1966). _Sinantherina_ densities are shown in Figure 12-6.

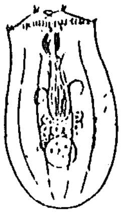
Lake Winona's planktonic crustaceans (Fig. 12-5) can be placed into two categories; the Cladocera (water fleas) and the Copepods, probably best known by members of the genus _Cyclops_. Both groups are found worldwide in both marine and freshwater habitats. Most species of Cladocera are inhabitants of slow-moving freshwaters. Some species are benthic (bottom dwelling), some are limnetic (open water), and some are found crawling among vegetation in the littoral zone of lakes. Some species are found only in temporary seasonal ponds while others spend their lives clinging to the film of water at the surface of lakes and ponds (the neuston community).



Polyarthra sp.

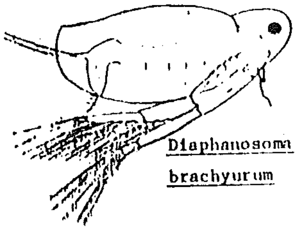


Sinantherina socialis



Asplanchna sp.

ROTIFERA



Diaphanosoma brachyurum

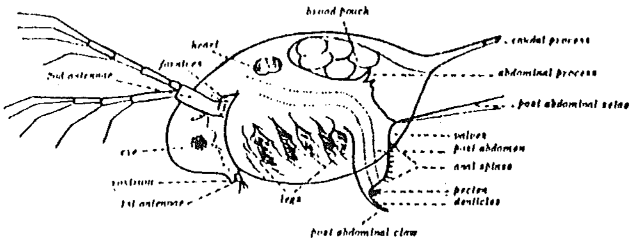
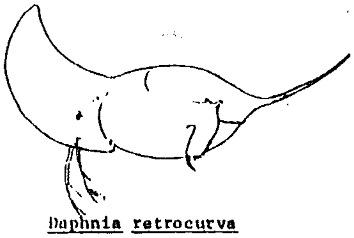
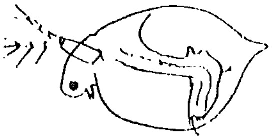


DIAGRAM OF A CLADOCERAN



Daphnia retrocurva

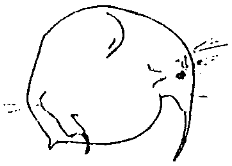


Ceriodaphnia sp.

Daphnia galeata

Chydorus sphaericus

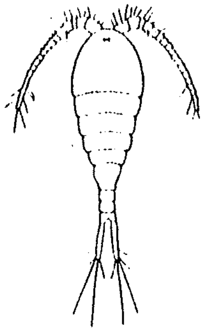
Leptodora kindtii



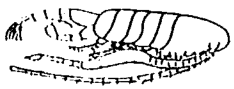
Bosmina longirostris

Daphnia dubia

CLADOCERA



Cyclops bicuspidatus



Diaptomus sp.

COPEPODA

Figure 12-5. Zooplankton found in Lake Winona during the summer of 1985. Drawings reproduced from Taxonomic Keys to the Common Animals of the North Central States by S. Eddy and A.C. Hodson, with permission of Burgess Publishing Company

Life spans of individual cladocerans varies from a few days to over 100 days depending on species and environmental conditions. Winter life spans are generally longer than summer. After hatching, juveniles progress through 3 to 6 instar stages. Adults continue to increase their size by molting 18 to 25 times during their lifespan. With each molt, a clutch of eggs is released, usually 10 to 20 eggs per clutch. Because of this large reproductive capacity, dense populations of cladocerans can develop quickly in lakes. Hall (1964) calculated the reproductive potential for the cladoceran Daphnia galeata in Base Line Lake, Michigan as 87,450/liter of lake water, but found instead that the observed population was only 4.13/liter. This vast difference in population ws attributed to a loss through predation of 25 to 28% of the Daphnia population/ day. Cladocerans are obviously important in the food chains of lakes. Young of the year fishes often feed exclusively on cladocerans or other zooplankters.

Cladocerans are filter feeders, consuming a wide range of foods, mainly organic detritus and bacteria, but also protozoans and some algae. Arnold (1971), in a study of Daphnia pulex, found green algae to be preferred over seven species of blue-green algae. He noted lower survivorship, reproduction and assimilation of nutrients in Daphnia fed blue-greens. In some cases, blue-greens seemed to pass through Daphnia's digestive tract intact and in an enriched condition, apparently having absorbed nutrients from the cladoceran's gut. It is probable that Lake Winona's abundant blue-green algae do not constitute a good food source for Daphnia pulex or other cladocerans. Possibly, only after bacteria have consumed dying blue-greens can the carbon compounds fixed by the blue-greens during photosynthesis be assimilated by zooplankters. Evidence for increased zooplankton populations following an increase in bacteria can be extrapolated from the graph of Lake Winona's total zooplankton (Fig. 12-2) which shows a rapid increase in zooplankters in early July following the decline of Aphanizomenon and its presumed bacterial decay. Another period of zooplankter abundance follows the mid-summer death and decay of curlyleaf pondweed which increases the bacterial populations as well as the amount of organic detritus in the lake.

Copepods can be placed into three major non-parasitic categories; calanoid copepods, cyclopoid copepods and harpatacoid copepods. Harpatocoids do not appear in the plankton and are denizens of the littoral areas of lakes where they crawl about on aquatic vegetation and other submerged substrates. Calanoid and cyclopoid copepods are swimmers and are found in the plankton of fresh and marine waters world-wide.

Calanoid copepods in Lake winona are represented by a single genus Diaptomus (Fig. 12-5), a filter feeder which utilizes its second antennae to produce a flow of water through its mouthparts. According to Pennak (1978) calanoids are able to select food particles as to size and type. Diaptomus moves steadily through the water during feeding by the motion of its mouthparts and second antennae. At intervals it moves rapidly in a jerky fashion by folding its first antennae (which are normally held at 90° to

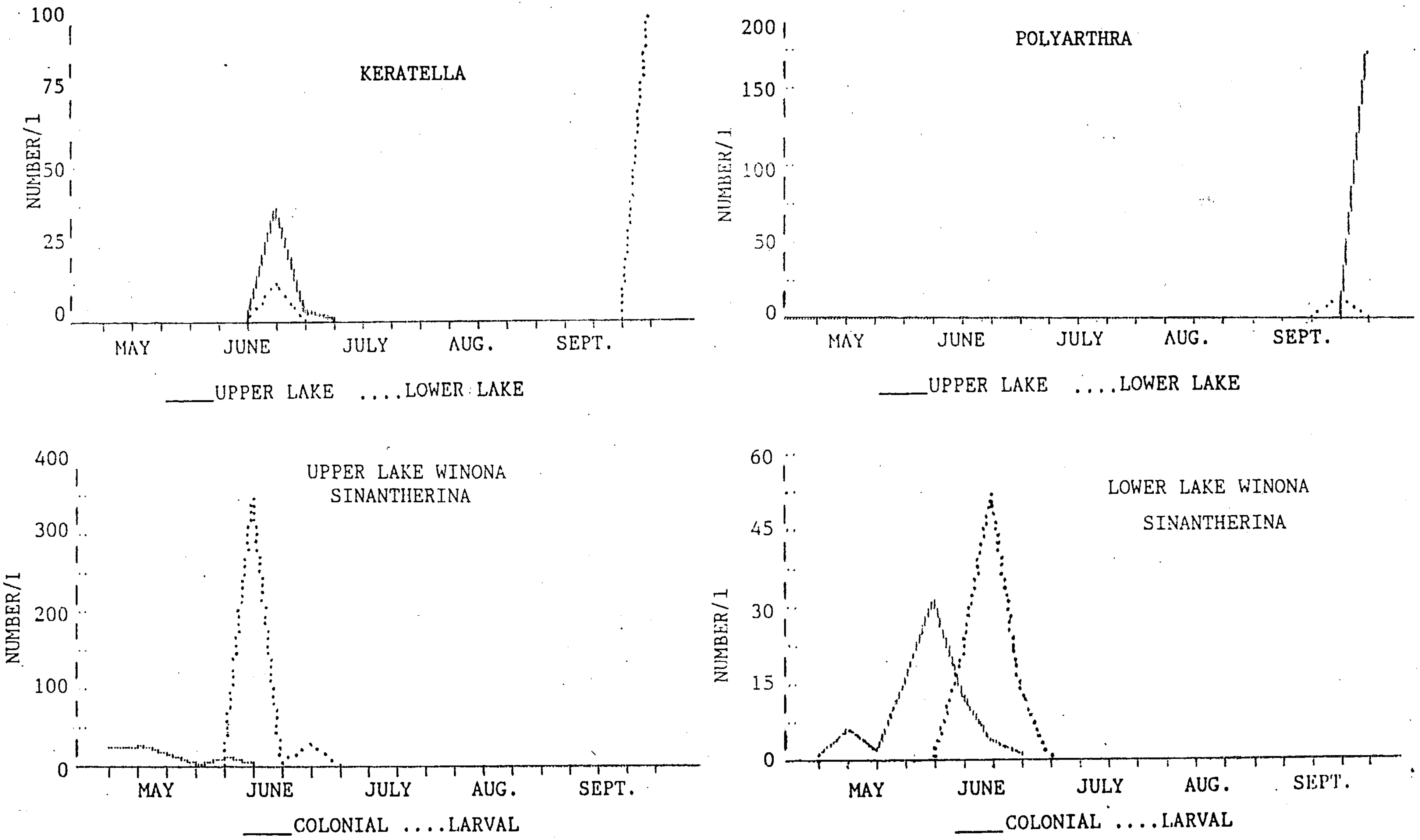


Figure 12-6. Rotifer densities in Lake Winona during the summer of 1985.

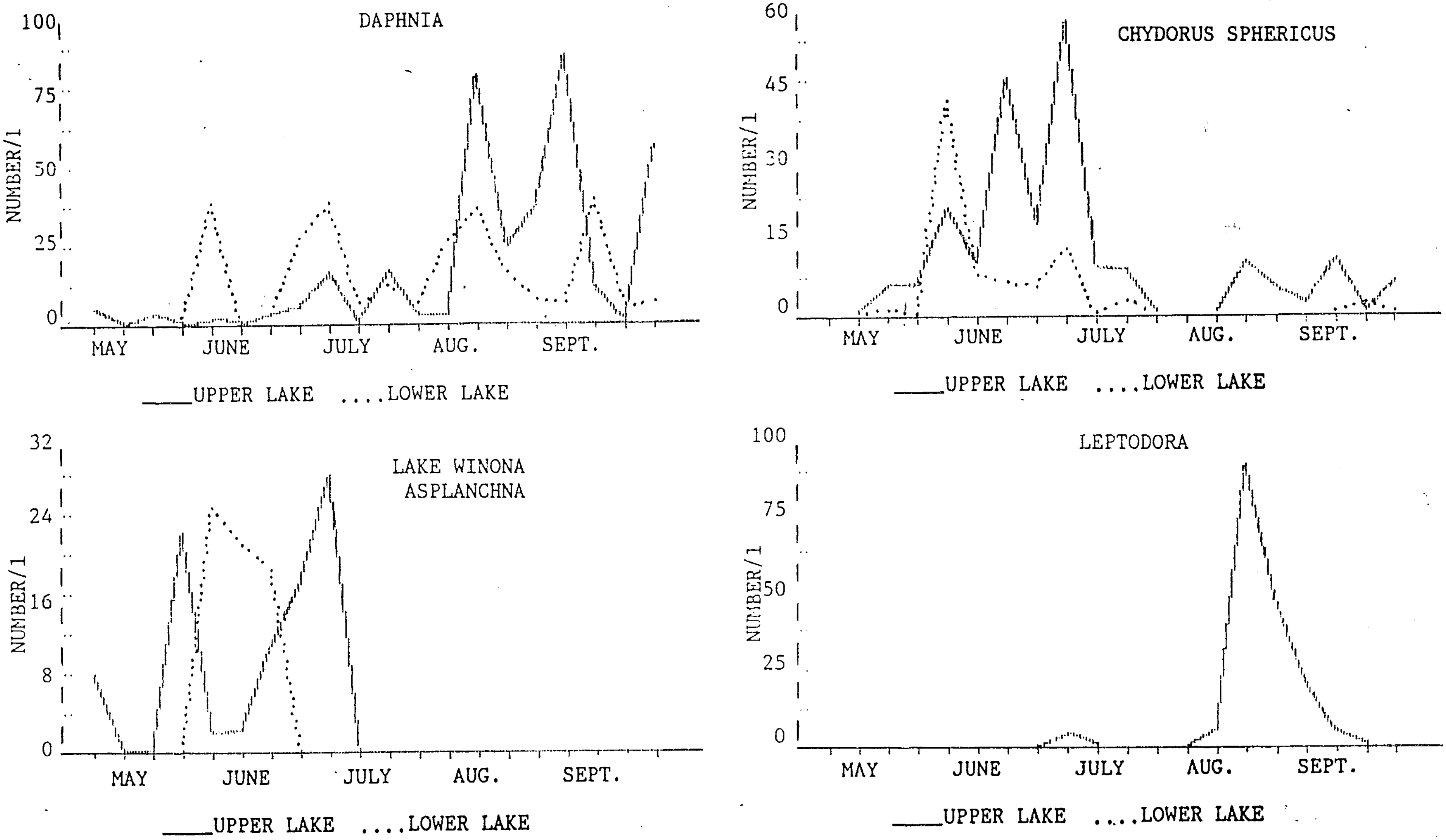


Figure 12-7. Densities of cladocerans and the rotifer Asplanchna in Lake Winona during the summer of 1985.

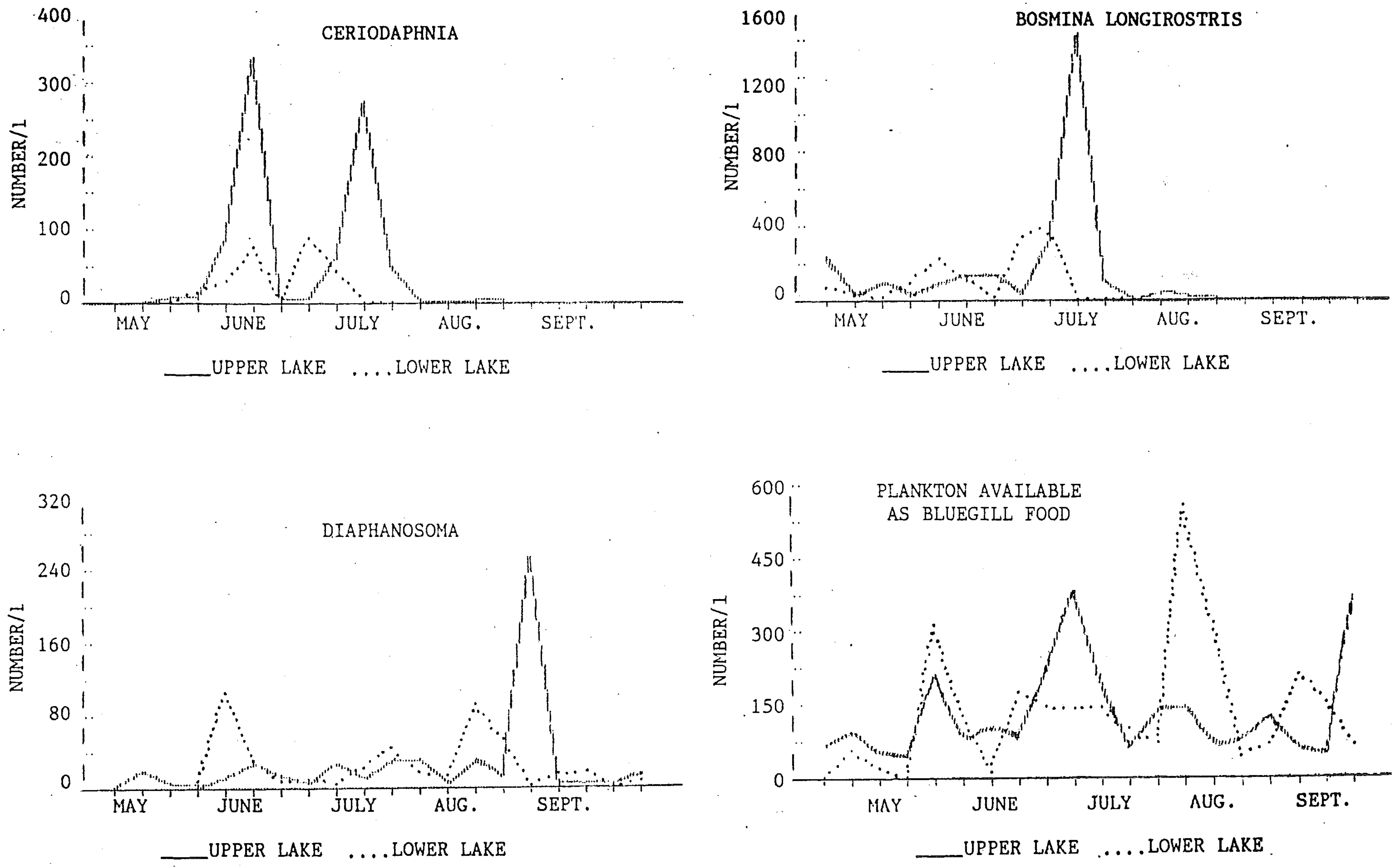


Figure 12-8. Zooplankton densities in Lake Winona during the summer of 1985. The lower right graph shows the densities of zooplankters large enough to be captured by the gill rakers of 0.11-lb bluegills.

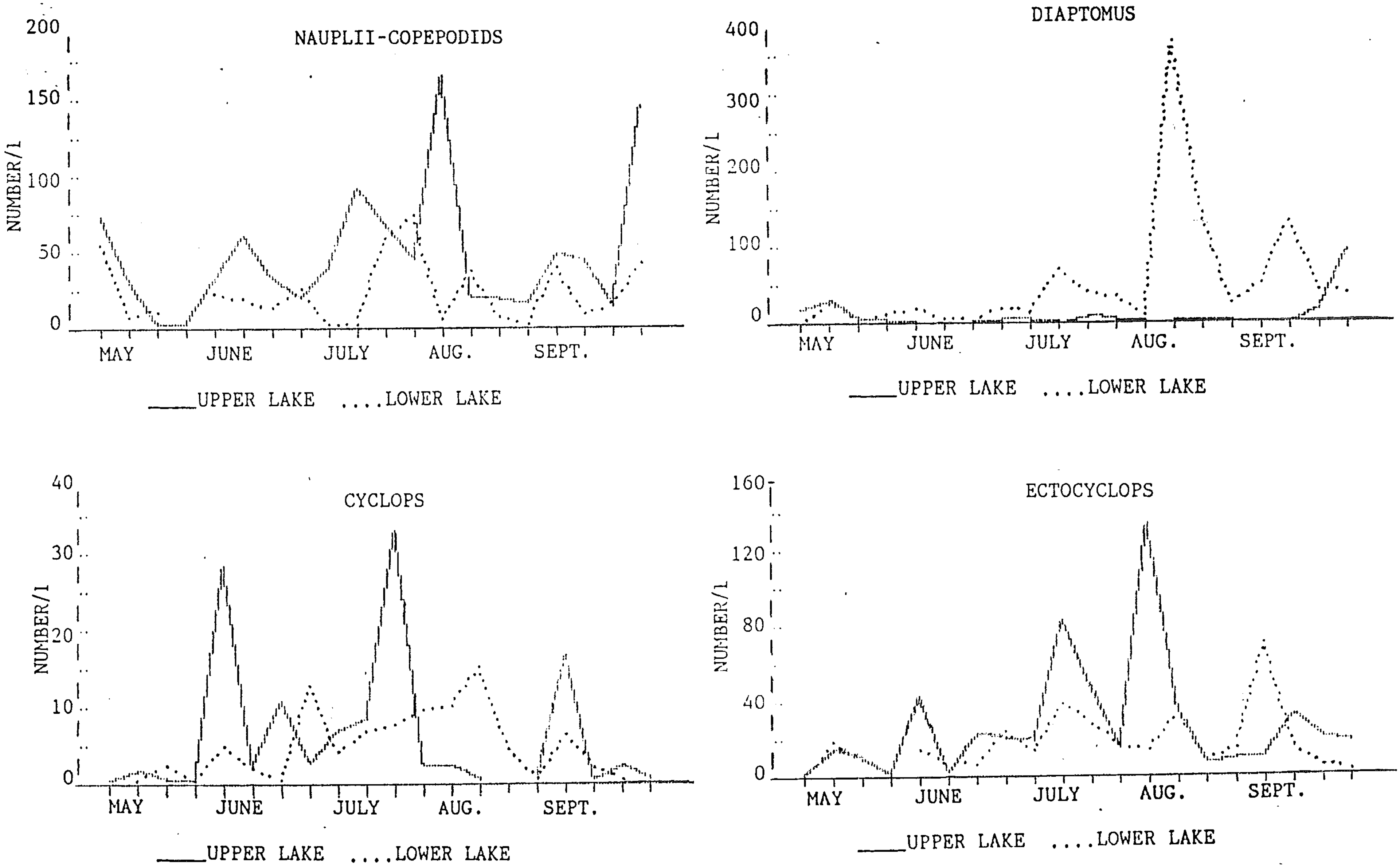


Figure 12-9. Copepod densities in Lake Winona during the summer of 1985.

its body) to its sides and rapidly moving its five pairs of legs. When extended laterally, the first antennae seem to minimize sinking, much like a parachute does in air.

Reproduction in copepods is sexual. Fertilized eggs are retained in a pair of ovisacs which are attached near the top of the abdomen. Eggs hatch into nauplius larvae, which grow through six stages followed by five copepodid stages. Reproductive maturity occurs in from seven days to one year depending on species and environmental conditions.

Copepods are much more tolerant of low dissolved oxygen than are cladocerans. They are not uncommonly found living in the hypolimnion of stratified lakes. A water sample collected from the hypolimnetic zone of Lake Winona's lower basin in July, 1985 contained several active copepods even though the dissolved oxygen content was only 0.2 ppm.

In the upper basin, Ectocyclops was usually the most abundant copepod (Fig. 12-9); in the lower basin, Diaptomus was normally the most abundant. Nauplii and copepodid numbers fluctuated in fairly regular cycles in both basins, each peak coinciding with the peak of one of the adult copepod genera.

STOMACH CONTENTS OF BLUEGILLS

The stomachs from five bluegills caught at the east end fishing pier on June 14, 1985 were opened and their contents examined with the aid of a stereo dissecting microscope. Identification of Cladocera and Copepoda was accomplished with the aid of a compound microscope at 100X magnification. In descending order of occurence, the stomachs contained: calanoid copepods of the genus Diaptomus; larval chirononids (midge larvae); cladocerans Bosmina longirostris smallest organism, .25 mm length) and Daphnia retrocurva; adult terrestrial insects (one deer fly and one ant); one leech; one partially digested fish (probably a largemouth bass, length 3 cm). The average total length of the bluegills was 12 cm and the average gill raker opening was .23 mm. One black crappie was examined on the same date; it contained almost 100% Diaptomus. The crappie's gill raker openings averaged .18 mm, considerably smaller than the bluegills', while its overall length was greater (15 cm). None of the fish examined had empty stomachs.

Although Bosmina was the most abundant zooplankter in the lake (Fig. 12-8), the bluegills selected heavily for Diaptomus (Fig. 12-9) which, with its greater length (1.18 mm) and protruding antennae, may have been more easily retained by the gill rakers. Bosmina's average length, as measured with an ocular micrometer, was .25 mm, nearly the size of the gill raker opening. It is probable that many Bosmina would pass through bluegill gill rakers during feeding. By removing Bosmina, Sinantherina larvae, and nauplii, an approximation of the numbers of zooplankters available as food for bluegills can be made (Fig. 12-8). Brooks and Dodson (1963), in studying predator effects on lake plankton, state that intense predation tends to favor small species of zooplankton such as Bosmina longirostris. During periods of low predation, larger zooplankters, such as Daphnia, increase in numbers while small species decrease. In Lake Winona, the peak abundance of the larger zooplankters (excluding Asplanchna) does not occur at the same time as the peak abundance of small cladocerans, such as Bosmina and Chydorus, supporting the findings of Brooks and Dodson.

Twelve more stomachs of bluegills (0.1 lb.) were collected at 10:00 a.m. on July 30, 1985. In descending order of occurance they contained cladocerans (Leptodora kindtii, Daphnia galaeta, Daphnia retrocurva), ostracods, cladocerans (Diaphanosoma brachyurum), copepods (Diaptomus, Cyclops) and chironomid larvae. Leptodora kindtii, an unusually large cladoceran, outnumbered all other organisms combined. Several bluegills fed exclusively on L. kindtii which is commonly thought to be active only at night when it rises to the surface to prey on other zooplankton. If it is assumed that light inhibits Leptodora's ascent, bluegills may be feeding below the depth to which light penetrates.

METHODS

Weekly sampling was begun on May 13, 1985 in the upper lake from the Dakota Street dock and in the lower lake from the east end fishing pier. Qualitive samples were obtained with a conical plankton tow net (mesh size #10), which was hand cast about 3 meters out into the lake, allowed to sink approximately one meter and pulled back to the dock. Contents of the tow net were emptied into a Mason jar containing 10 ml of 1.5% 2-phenoxypropanol. Tap water was added to give a total volume of 100 ml. The resulting 0.15% solution served as a relaxant and preservative as recommended by McKay and Hartzband (1970). At the laboratory, one ml of 100% formalin was added to ensure preservation. Quantitive samples, which were taken just below the surface with a Kemmerer water sampling bottle, were passed through a #20 mesh sieve, stored in pint Mason jars containing 0.15% 2-phenoxypropanol and 1% formalin, and adjusted to a 100 ml total volume.

Each preserved sample was divided equally between two test tubes, sample jars were rinsed twice with 4% formalin solution into the test tubes, and 0.5 ml of detergent was added to each tube to facilitate sedimentation (Rand, et al., 1976). Samples were allowed to settle for at least 72 hours. After settling, the supernatant was withdrawn from the test tubes, examined for accidental resuspension of plankton, and discarded. The remaining liquid containing the plankton was then resuspended, withdrawn into a pipette with a propipetter and placed into a single 20 ml test tube. The original test tubes were rinsed twice with 4% formalin solution into the 20 ml tube. The resuspended plankton sample was again allowed 72 hours for settling, supernatant was withdrawn, examined and discarded until a final volume of from 1.4 to 4.8 ml was obtained. This final sample was again resuspended and 1 ml was placed into a Sedgewick-Rafter counting cell for microscopic examination.

METHOD FOR COUNTING ZOOPLANKTON

Examination of one Sedgewick-Rafter cell at 40X was conducted for each sample and all zooplankters were counted by genus. Zooplankton per liter was calculated for each genus according to the following formula:

$$\frac{\text{(zooplankters)}}{\text{(S-R cell)}} \times \frac{\text{(S-R cells)}}{\text{(final sample)}} \times \frac{\text{(final samples)}}{\text{(1160 ml)}} \times \frac{\text{(1000 ml)}}{\text{(liter)}} = \frac{\text{(zooplankters)}}{\text{(liter of lake water)}}$$

Where:
1 sample = 1 Kemmerer bottle = 1160 ml
1 Sedgewick-Rafter cell = 1 ml
1 final sample = 1.4 to 4.8 ml

METHOD FOR COUNTING PHYTOPLANKTON

Phytoplankton counts were made from the Sedgewick-Rafter cell via one of the following methods as deemed appropriate for the situation:

1) Same procedure as for zooplankton.

2) For very dense populations, a Whipple grid under 100X magnification was used. The average number of units/Whipple grid was determined from 10 uniformly-spaced counting locations on the Sedgewick-Rafter cell. From this, the units/liter of lake water was calculated according to the following formula:

$$\frac{\text{(phytoplankters)}}{\text{(grid square)}} \times \frac{\text{(2040 grid squares)}}{\text{(S-R cell)}} \times \frac{\text{(S-R cell)}}{\text{(final sample)}} \times \frac{\text{(final samples)}}{\text{(1160 ml)}} \times \frac{\text{(1000 ml)}}{\text{(liter)}} = \frac{\text{(phytoplankters)}}{\text{(liter of lake water)}}$$

3) Some squares were of an intermediate density, such that the number per square was usually 0, but counting the total contained in a Sedgewick-Rafter cell still involved large numbers. For these situations the following method was used:

The area of one microscope field at 40X was determined and the average number of units/field from counting 10 fields was obtained. The number of units per liter was calculated as follows:

$$\frac{\text{(1 field)}}{(16.62\ \text{mm}^2)} \times \frac{(1000\ \text{mm}^2)}{\text{(S-R cell)}} \times \frac{\text{(phytoplankters)}}{\text{(1 field)}} \times \frac{\text{(S-R cells)}}{\text{(final sample)}} \times \frac{\text{(final samples}}{\text{(1160 ml}} \times \frac{\text{(1000 ml)}}{\text{(liter)}} = \frac{\text{(phytoplankters)}}{\text{(liter of lake water)}}$$

Table 12-1

Taxonomic List of Phytoplankton
Found in Lake Winona
5/13/85 - 9/24/85

	ORDER	FAMILY	GENUS	SPECIES
DIVISION: Cyanophyta				
	Chroococcales	Chroococcaceae	Microcystis	flos-aquae
			Microcystis	aeruginosa
			Coelosphaerium	sp.
	Hormonogonales	Oscillatoriaceae	Oscillatoria	agardii
			Oscillatoria	sp.
		Nostocacea	Anabaena	subcylindrica
			Anabaena	circinalis
			Anabaena	spiroides
			Anabaena	wisconsinenses
			Aphanizomenon	flos-aquae
DIVISION: Chrysophyta				
	Centrales	Coscinodiscaceae	Melosira	sp.
	Pennales	Tabellariaceae	Tabellaria	sp.
		Fragillariaceae	Asterionella	sp.
			Fragillaria	sp.
DIVISION: Pyrrophyta				
	Dinokontae	Peridiniaceae	Peridinium	sp.
		Ceratiaceae	Ceratium	hirundinella
DIVISION: Chlorophyta				
	Volvocales	Volvocaceae	Volvox	sp.
	Ulotrichales	Ulotrichaceae	Ulothrix	sp.
	Chlorococcales	Botryococcaceae	Botryococcus	sp.
		Characiaceae	Characium	sp. (epizooic)
		Hydrodictyaceae	Pediastrum	sp.
		Oocystaceae	Ankistrodesmus	sp.
			Chlorella	sp.
		Scenedesmaceae	Actinastrum	sp.
			Scenedesmus	sp.
		Desmidiaceae	Closterium	sp.
			Staurastrum	sp.

Table 12-2.

Taxonomic List of Zooplankton
Found in Lake Winona
5/13/85-9/24/85

Phylum: Coelenterata

CLASS	ORDER	FAMILY	GENUS	SPECIES
Hydrozoa	Hydroida	Hydridae	Hydra	sp.
Phylum: Rotifera				
Monogononta	Flosculariaceae	Flosculariidae	Sinantherina	socialis
		Conochilidae	Conochiloides	sp.
			Conochilus	unicornis
	Ploima	Synchaetidae	Polyarthra	sp.
		Asplanchnidae	Asplanchna	sp.
		Brachionidae	Keratella	sp.
Phylum: Arthropoda				
Crustaceae	Cladocera	Sididae	Diaphanosoma	brachyurum
		Chydoridae	Alona	sp.
			Chydorus	sphaericus
		Daphnidae	Daphnia	pulex
			Daphnia	retrocurva
			Daphnia	dubia
			Daphnia	galeata
			Ceriodaphnia	sp.
		Bosminidae	Bosmina	longirostris
		Leptodoridae	Leptodora	kindti
	Copepoda	Diaptomidae	Diaptomus	sp.
		Cyclopidae	Ectocyclops	phaleratus
			Paracyclops	fimbriatus
			Euclyclops	prasinus
			Cyclops	bicuspidatus
	Ostracoda	Unknown	Unknown	Unknown

REFERENCES

American Public Health Association.
1976. Standard methods for the examination of water and wastewater. Washington, DC.

Arnold, D.E.
1971. Ingestion, assimilation, survival and reproduction by Daphnia pulex fed seven species of blue-green algae. Limnol. and Oceanogr. 16(6): 906-920.

Brooks, J.L., and S.I. Dodson.
1965. Predation, body size and composition of plankton. Science 150: 28-35.

Carr, N.G., and B.A. Whitton. [ed.].
1973. The biology of blue-green algae. University of California Press, Berkely, CA.

Cole, G.A.
1983. Textbook of limnology. Mosby Co., St. Louis, MO.

Drovet, F.
1968. Revision of the classification of the Oscillatoriaceae. Monograph 15, The Academy of Natural Sciences of Philadelphia, Fulton Press Inc., Lancaster, PA.

Edmonds, W.T. [ed.].
1966. Ward and Whipple's freshwater biology. John Wiley and Sons Inc., New York, NY.

Fogg, G.E., W.D.P. Stewart, P. Fay, and A.E. Walsby.
1973. The blue-green algae. Academic Press, London.

Gleason, F.
1985. Personal communication. Gray Freshwater Biological Institute, Minneapolis, MN.

Hall, D.J.
1964. An experimental approach to the dynamics of a natural population of Daphnia galeata mendotae. Ecology 45: 94-112.

Korde, K.B.
1972. Ancient blue-green algae. Paleontological Institute, Academy of Sciences, Moscow, U.S.S.R.

McKay, C.R. and D.J. Hartzband
1970. Propylene phenoxetol: narcotic agent for unsorted benthic invertebrates. Trans. Amer. Microsc. Soc. 89(1): 53-54.

Pennak, R.W.
1978. Freshwater invertebrates of the United States, 2nd Edition. The Ronald Press Co., New York, NY

Prescott, G.W.
1962. Algae of the western Great Lakes area. Wm. C. Brown Co. Inc., Dubuque, IA.

1964. The freshwater algae. Wm. C. Brown Co., Dubuque, IA.

1968. The algae: A review. Houghton Mifflin Co., Boston, MA.

Saunders, G.W.
1972. Potential heterotrophy in a natural population of *Oscillatoria agardhii var. isothrix Skuja*. Limnol. and Oceanogr. 17(5): 704-711.

Shapiro, J., V. Lamarra, and M. Lynch.
1975. Biomanipulation: An ecosystem approach to lake restoration. Limnological Research Center, University of Minnesota.

Stewart, W.D.P.
1970. Heterocysts of blue-green algae. *In* Desikachary, T.V. [ed.]. Papers submitted to the first international symposium on taxonomy and biology of blue-green algae held at Madras.