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PLANKTON STUDIES ON WOODS RESERVOIR, TENNESSEE[1]

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INTRODUCTION

Plankton is a term applied to small organisms which live, swim, and drift in water and are not independent of the currents therein. These organisms consist of plants or the producers in the food chain and small animals or primary converters which subsist on the plants and, in turn, are eaten by young fish, minnows, water insects and other preditors. Net plankton refers to the organisms of such size that they can be removed from the water with a fine plankton net. It usually constitutes a smaller amount of the total plankton bulk than does the nanno plankton which can pass through the meshes of a fine plankton net.

Generally speaking, ten pounds of food are required to build one pound of the animal that eats it. Thus in the food chain of the freshwater lake, 1,000 pounds of unicellular algae, bacteria, and protozoa would be required to make 100 pounds of animal plankton (chiefly crustacea), to make 10 pounds of minnows and small fish, to make one pound of bass, trout, perch, etc. to make 1/10 pound of man (for replacement of worn-out tissues or actual growth). If man eats the plankton directly, there is less waste since only one pound of it would be necessary to make the 1/10 pound of man. In future years, net plankton may become a direct source of food for man, and hence studies of plankton distribution and of the ecological requirements of plankton are highly desirable. Obviously, plankton is indispensable for the production of fish, etc., in both fresh and salt water.

In the spring of 1953, the Arnold Engineering Development Center completed a dam on the Elk River in Franklin County, Tennessee, to impound water for use in cooling wind tunnels. The lake so-formed has been named Woods Reservoir and covers an area of about 5,000 acres. Here was presented an opportunity to study the plankton of a lake from its beginning.

Plankton collections were made to determine (1) what kinds of plankton are present and in what abundance, (2) whether there is an ecological succession of forms while the reservoir matures, (3) whether there is a seasonal succession of various plankters, and (4) whether, certain chemicals, turbulence, and biological competition affect the distribution and presence or absence of certain plankters.

[1]These investigations were aided by grants from the Penrose Fund of the American Philosophical Society and the University of the South Research Fund. The writer wishes to express his gratitude for this assistance which made the project possible. Lastly, but not least, my thanks are due to my wife, Jean A. Yeatman, for her aid in collecting plankton, in analysis of water samples, and for constant aid during all the field work of the project.

Equipment and Methods

To determine what species were present, plankton collections were made using a no. 12 (125 mesh) silk bolting cloth net, 12 inches in diameter and 42 inches in length. This was slowly towed behind a boat for a distance of about 20 yards at the various collecting stations. Using this net, collections were made on 26 different days; usually two or three collections for each day. Those represent 14 different months (see Table No. 1). Greater depth was achieved by lengthening the tow rope and tying a small window sash weight to the net ring. This method of sampling gives more representative collections than a plankton pump, the intake of which some plankters can dodge, and a plankton trap which strains only a small sample of water. The horizonal distribution of all plankters is not uniform; they sometimes swarm in little groups and can be taken more successfully in horizonal net hauls.

With this plankton net and also the nets described later, the plankton organisms were collected in a glass vial tied in the sleeve at the apex of the plankton net. Most of the collections were preserved without further delay. Enough formalin was added to the vial to make the resulting mixture about a 20% commercial formalin solution. Back in the laboratory, this mixture was examined under the microscope, a pipetteful at a time and the approximate abundance of each species was marked on a chart, at the end of each vial examination. None of the material was thrown away; it was saved for future reference. In addition, a permanent slide mount was made of a concentrated drop from each collection. To make this permanent slide, a dropful of specimens was put on a microscope slide and a single drop of lactophenol added to clear and partly dehydrate the same. The slight amount of water was given time to evaporate, leaving the specimens in a light film of lacto-phenol. A drop of melted glycerine-jelly was added as were tiny square supports cut from a no. 2 plastic coverslip. Next, the round cover slip was placed on the glycerine jelly and specimens, and the glycerine jelly was allowed to set for a day. Care was required to keep the mixture of specimens and glycerine from covering an area greater than that of the cover slip. The mount was then ringed with two successive coats of murrayite, the first solution being more fluid than the second. Specimens requiring dissection were also mounted using this method, the specimens being dissected in the melted glycerine jelly before it set.

Approximately once a month live specimens were brought into the laboratory for identification purposes. These were promptly dumped from the collecting vial into a large thermos jug containing lake water. This kept them at the proper temperature and alleviated the crowded condition of the vial. Before examination, they were reconcentrated by pouring the jug con-

TABLE I
Species of Plankton Collected in Woods Reservoir with Relative Abundance of Each

Species	June 1953	July 1953	Aug. 1953	Sept. 1953	Oct. 1953	Dec. 1953	Apr. 1954	May 1954	June 1954	July 1954	Aug. 1954	Sept. 1954	Oct. 1954	Nov. 1954
CYANOPHYTA (BLUE-GREEN ALGAE)														
Microcystis aeruginosa Kuetz.	C		C		S	M	M	A	A	A	C	A	S	S
Merismopedia thermalis Kuetz.		C			R			C	M	S	S		C	S
Gomphosphaeria lacustris Chod.	S	C	S					C	M	M			S	S
Oscillatoria princeps Vauch.										M	A+	A	C	S
Spirulina major Kuetz					R									
CHLOROPHYTA (GREEN ALGAE)														
Pandorina morum Bory						S	S							
Eudorina elegans Ehr		M		S	S			M	C	S				
Pleodorina illinoisensis Kofoid		M		S	S			M	S					
Volvox perglobator Powers.			C	A				S	S					
Sphaerocystis schroeteri Chod.									M	A+	S			
Ulothrix zonata (Weber & Mohr)Kuetz.								M		S				
Pithophora kewensis Wittr.										C		A	A+	A+
Pediastrum simplex duodenarium Rab.		M	M		M	M	S	S	M	C	S	M	C	C
Spirogyra pratensis Trans.					M		M	C	C	M				S
Spirogyra ellipsospora Trans.					M			S	C	S				
Mougeotia sp							C							
Netrium digitus naegelii Krieg.													S	
Closterium acerosum (Schrank)Ehr.					R			C	C	S	S		C	
Pleurotaenium ehrenbergii DeBary										R			M	R
Cosmarium angulare Johns									S				S	
Micrasterias apiculata (Ehr.)Menegh.									R	R				S
Micrasterias radiata Hass.			S		S			S	M	S	S			S
Staurastrum setigerum Cleve								S						
Staurastrum paradoxum Meyen.									M					
Hyalotheca dissiliens (Smith)Breb.		M	A	M	M				M	S				
EUGLENOPHYTA (EUGLENA & ALLIES)														
Euglena oxyuris Schmarda													M	R
PYRRHOPHYTA (DINOFLAGELLATES)														
Ceratium hirundinella (O.F.M.)Schr	A	M	C	S	C	M	M	A+	M	S	M	S	M	S
CHRYSOPHYTA (DIATOMS & ALLIES)														
Dinobryon sertularia Ehr.	C		M			S	M	A			M		S	S
Tabellaria fenestrata (Lyngb.)Kuetz.					M	S	M	M						
Fragilaria crotonensis Kitton	S		S	A	S	S	C	A	C	S	M		A+	A+
Asterionella formosa Hass.							A	A+	C					S
Diatoma vulgare Bory						S								
Tetracyclus lacustris Ralfs.							M							
Navicula rhyncocephala Kuetz													M	

A+ = "bloom"
A = abundant
C = common
M = moderate numbers
S = scarce
R = only 2 or 3 per collection

Species	June 1953	July 1953	Aug. 1953	Sept. 1953	Oct. 1953	Dec. 1953	Apr. 1954	May 1954	June 1954	July 1954	Aug. 1954	Sept. 1954	Oct. 1954	Nov. 1954
PROTOZOA (ONE-CELLED ANIMALS)														
Actinosphaerium eichhornii Ehrenberg					S	M								
Difflugia lobostoma Leidy			S	S	C	S		C	A	A+	A	A	M	R
Arcella vulgaris Ehrenberg									M	R				
Epistylis flavicans Ehrenberg				S	M	M			A	S			S	M
ROTATORIA (WHEEL ANIMALICULES)														
Pedalia mira Hudson									R	C	M		S	S
Polyarthra trigla Ehrenberg				S			S	C	R	S	M	S	M	
Filinia longispina Ehrenberg													R	
Kellicottia longispina (Kellicott)									R				R	C
Keratella cochlearis (Gosse)	C	S	M	M	C	M	C	C	A	C	M	C	C	M
Asplanchna priodonta Gosse	C		C	A+	C	M	C	M	S	S	M	C	M	M
Trichocerca multicrinis (Kellicott)			S	M		M	S	M	S	M	S	A	C	C
Brachionus quadridentata Hermann										R	R			
Brachionus angularis Gosse														R
Platyias platulus (Müller)										S	S			
Platyias quadricornis (Ehrenberg)														R
Lecane luna (Müller)			R							S	S		R	
Euchlanis propatula											R			
Conochilus unicornis Rousselet	A	A	A				C		M	C	A	C		
Conochilus hippocrepis (Schrank)											S			
Conochilus natans Seligo									M	C		M		
CLADOCERA (WATER "FLEAS")														
Diaphanosoma brachyurum (Liévin)		M	S	S	C	M	C	C	C	A+	C	M	C	C
Daphnia pulex (DeGeer)							C	M	M		S			S
Daphnia longispina galeata	C	M												
Ceriodaphnia quadrangula (O.F.M.)	C	C	C	A	A		M	A	C	C	M	M	C	C
Bosmina longirostris (O F.M.)		M	M	M	M	M	C	C	A+	C	A+	M	C	C
Chydorus sphaericus (O.F.M.)							S	S	S	S			R	S
COPEPODA (COPEPODS)														
Diaptomus pallidus Herrick	A+	M	S						S	C	S	C		
Diaptomus reighardi Marsh	S	C	A+	C	A	A	C	A+	A	A	A	C	A	A+
Diaptomus sanguineus Forbes							M							
Mesocyclops edax (S.A Forbes)	M	C	M	S	M	S	M	C	M	M	A	C		
Mesocyclops leuckarti (Claus)			M						S	S				
Cyclops vernalis Fischer			S				S			S	S			
Cyclops bicuspidatus thomasi S.A.F.							C							S
Tropocyclops prasinus (Fischer)			S		M					M	M	C		
DIPTERA (FLIES,MIDGES,ETC.)														
Chaoborus albipes (Joh.)										R	C			

A+ = "bloom" M = moderate numbers

A = abundant S = scarce

C = common R = only 2 or 3 per collection tents into a regular plankton net. Many of the soft-bodied rotifers could not be successfully identified except in the living condition.

To secure simultaneous collections of plankton at various depths for studies of vertical distribution, a series of 4 identical no. 12 plankton nets were fastened to a 15 foot metal rod at intervals of 4 feet. These nets were held by 5 inch diameter ring-stand rings, of which the screw clamps were sawed off and welded back at a right angle to the original position so that the ring would face in the proper direction when attached to the rod (see Fig. 1). Tin doors with attached elastic and draw strings enabled the nets to be opened and closed at will. An extra heavy VV table clamp held the rod to the boat side. The small diameter of the nets was necessary to lessen the water resistance of the equipment and enable the boat to move forward without so much difficulty.

During the day and night of November 13, 1954, and early morning of November 14, 1954 a series of plankton hauls were taken with the simultaneous, different depth apparatus (described above). Collections were taken at 10:30 AM (sun "ascending"), 1:10 PM (sun almost directly overhead), 5:00 PM (sun setting), 12:00 PM (midnight, moon nearly full), and at 6:00 AM (sunrise).

The exact amount of water filtered by my apparatus nets cannot be determined. When the nets were attached to the 5 inch diameter rings, the entrance of each was reduced to 4 inches due to the bulkiness of the cloth sewed around the ring. Hauls were taken slowly and coverd only about 5 meters distance to prevent clogging of the net meshes. Taking all factors into consideration, about 1/10 of a cubic meter of water was filtered by each net during a haul.

Of more importance than determination of amount of water filtered was to insure that the nets functioned similarly. The nets were made as similar as possible, and every effort was made to see that they filtered similar amounts of water. The 12:00 PM haul was repeated, and the second haul was found to be practically identical quantitatively to the first haul.

At the time of the vertical distribution studies and collections, water conditions were excellent for the study of light effects on the plankton organisms. There was little or no difference in the oxygen content, temperature, and the pH of the surface water and at a depth of 20 feet, just off the bottom (see Table 2). On Nov. 6, 1954, Dr. H. Malcom Owen of this Biology Department recorded a surface temperature of 13.0° C. and a bottom temperature of 15.5° C. Shortly, the fall turnover commenced with this warmer, less dense bottom water replacing the colder more dense water at the surface. The vertical uniformity mentioned

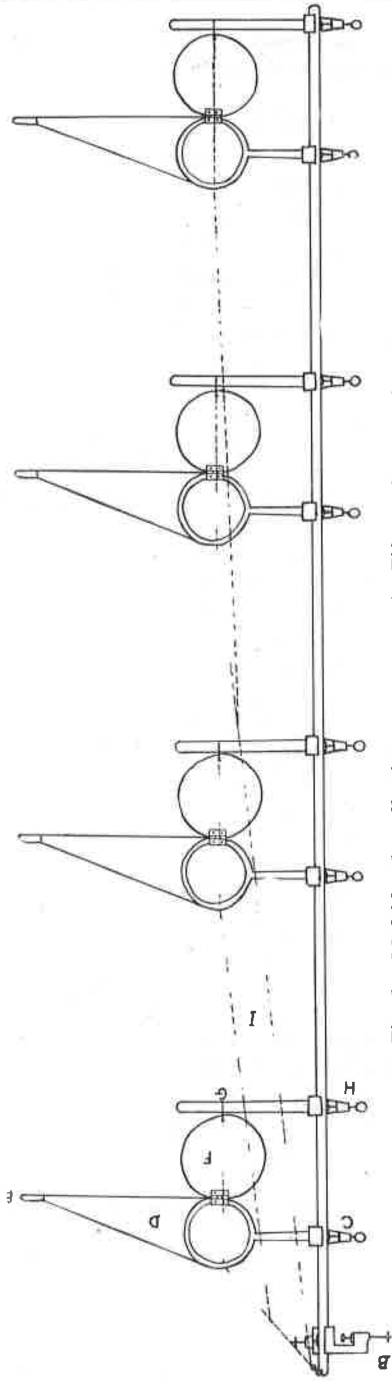

Fig. 1. Multidepth collecting apparatus. A. Fifteen foot meal rod. B. VV table clamp. C. Ring stand ring. D. Plankton net. E. Collecting vial. F. Tin door. G. Rubber band. H. Ring stand bar. I. Draw strings for tin doors.

above is a result of the turnover. At the time of the collections, turnover had temporarily ceased.

These 24-hour collections were preserved with formalin; quantity of plankton for each collection was measured in a small graduate cylinder; and finally counts were made, using a Sedgwick-Rafter chamber.

Transparencies of the water were determined by observing the depth at which an 8 inch white Secchi disc disappeared.

Water movements were secured by means of a 3½ foot tubular glass rod weighted at one end with lead shot so that only 3 inches projected above the surface of the water. Although not very accurate, it showed the locations of the strongest and of the weakest currents in the reservoir.

Water samples were obtained from various depths by means of Meyer's bottles. These samples were analyzed for hydrogen-ion concentration (with a La Motte colorimetric outfit), for temperature, for dissolved oxygen (using the Winkler method with results corrected for temperature and barometric pressure), and occasionally for presence and amounts of carbonate ion, bicarbonate ion, chloride ion, sulfate ion, calcium ion, and magnesium ion (using methods given by Hedgpeth, 1943).

The presence or absence and concentration of the various ions may influence the presence or absence of various kinds of plankters. The information here gathered may be useful in comparisons of this lake with other lakes.

Hedgpeth (1943) found indications that the presence of free carbonate may have had something to do with the absence of *Diaptomus franciscanus* in certain ponds in the San Francisco Bay region of California and also that a greater concentration of magnesium in proportion to calcium might be a factor in controlling the distribution of *Diaptomus washingtonensis* (=*D. novamexicanus* Herrick, according to Kincaid, 1953).

The List of Species

It was originally intended to restrict the study to the plankton crustacea inhabiting Woods Reservoir, but it was quickly realized that not dealing with the algae, rotifers, colonial and large protozoa, etc. would be a most serious omission. Even plankton organisms occur in associations. The complete removal of one species often results in the extermination of one or more associated species, particularly if the latter are dependent upon the former for food. Conversely, the elimination of one species may be of benefit to another species although every species is benefited by having some enemies to hold their numbers in check.

A genuine effort was made to identify the organisms down to the species category. The genus category is of little value in most present studies. Species within a genus may differ widely in their environmental requirements. The genus Diaptomus is represented in all my lake collections. Actually the lake contains three species in this genus, each differing from the other in its requirements. These three species are discussed later in the text. All down the list we find the same situation.

It is very exasperating to search haphazardly through the numerous references at the ends of articles, dealing with faunal and floral lists, for figures and short descriptions of the various species. Ideally such articles might include figures of the species collected, but time, publication space, expense, etc. make this impractical.

The algae (excluding diatoms) listed in this article are briefly described and figured in Herman Silva Forest's (1954) excellent "Handbook of Algae." Diatoms were identified with Smith's (1933) "Freshwater Algae of the United States," protozoa with Kudo's (1946) "Protozoology," and most of the remaining animals can be found in Pennak's (1953) "Freshwater Invertebrates of the United States." In this latter book, although incompletely named, *Asplanchna priodonta* is shown in Fig. 117A, *Trichocerca multicrinis* in Fig. 118F, *Euchlanis propatula* in Fig. 122E, *Lecane luna* in Fig. 122H, *Conochilus unicornis* in Fig. 128B, and *Conochilus natans* in Fig. 128C.

Table 1 lists the species, months collected, and the relative abundance of each species. In general, in regard to phytoplankton, the blue-green algae are conspicuous during the warm months and the diatoms are more abundant during colder weather. The presence of certain blue-green algae is said to indicate high nitrogen content of the water (Coker, 1954, p. 199). *Microcystis aeruginosa* (formerly called *Clathrocystis aeruginosa*), *Ceratium hirundinella, Difflugia lobostoma* and *Mesocyclops edax* were present in the plankton during most of the year, but were more abundant during warm months. Whipple (1947) states that the first mentioned species of this list seldom gives trouble to a city water supply unless the water temperature is above 70° F. and that *Ceratium* is to be considered a warm water species. Eddy (1930) found *Difflugia lobostoma* in all his collections from Reelfoot Lake, Tennessee and from sink hole ponds in southern Illinois (Eddy, 1931).

Gomphosphaeria lacustris (except for a few in October and November, 1954), *Oscillatoria princeps, Eudorina elegans, Pleodorina illinoisensis, Sphaerocystis schroeteri, Ulothrix zonata, Spirogyra, Hyalotheca dissiliens, Arcella vulgaris, Conochilus unicornis, Conochilus natans, Mesocyclops leuckarti, Diaptomus pallidus,* and *Chaoborus albipes* are present in the plankton only during warm months. Chaoborus is said to sometimes overwinter in the larval stage in some lakes (Pennak, 1953, p. 647), but as yet it has not showed up in our winter collections.

Fragilaria crotonensis is present during most of the year, but is more abundant during cold months.

Tabellaria fenestrata, Diatoma vulgare, Tetracyclus lacustris, Pandorina morum, Actinophrys sol, Kellicottia longispina, Cyclops bicuspidatus thomasi, and *Diaptomus sanguineus* were present only during cold months. *Kellicottia longispina* may not have been present in Woods Reservoir long enough to determine times of its occurrence and abundance.

Other species in the floral and faunal lists are rather irregular in occurrence.

Of special interest is the presence of the copepods *Mesocyclops edax, Mesocyclops leuckarti, and Diaptomus sanguineus.* Because we know some of the sources of their entry into the reservoir and because they have not been adequately dealt with in the text, they are briefly discussed here. The other copepod species are mentioned in various parts of the text.

Mesocyclops edax (S. A. Forbes) is perhaps the most common limnetic copepod in North America. It has often been confused with *M. leuckarti,* hence in many cases it has been incorrectly listed as that species (see Coker, 1943). I have found it in Arrow Lake near Mt. Pleasant, Tenn. and in Mt. Lake near Tracy City, Tenn., and doubtless it is common in most of the permanent lakes of the state. It showed up in the first collections from Woods Reservoir and has been found in collections every month since that time. One of the sources of its lake entry was the small Elder Pond which was engulfed by the reservoir.

Mesocyclops leuckarti (Claus) was at one time known as *Cyclops obsoletus* Koch until its present name was restored by Kiefer (Coker, 1943). It is readily distinguished from *M. edax* by the absence of hairs on the inner margins of its caudal rami and the presence of a deep notch in the hyaline plate of the last antennal segment, instead of a series of large hyaline teeth on this segment. Hoff's (1944) description of his specimens in collections from Reelfoot Lake indicates that he actually collected this species and not *M. edax.* Not nearly as widespread as *M. edax,* it was found in the August, 1953, and June and July, 1954, collections from Woods Reservoir. Hoff's Reelfoot Lake specimens were collected during June, July, and August. *M. leuckarti* was an inhabitant of Elk River prior to the completion of the Woods Reservoir dam as it was present in a collection taken September 13, 1952.

Diaptomus sanguineus Forbes was a surprise find in the lake during April, 1954. Ordinarly it inhabits temporary pools and makes an appearance in winter and early spring, only to disappear before warm weather becomes established. It is common in pools in Franklin County, Tennessee, usually accompanied by the red-colored but much larger *Diaptomus stagnalis* Forbes. Its read coloration makes it quite easy to distinguish and pick out from the other copepods of the lake. Some other species are also conspicuously red, but as yet they have not been found in this reservoir and are readily distinguished from *D. sanguineus* in size and structure. *D. sanguineus* was moderately common April 3 and scarce on April 24. It probably arose from resting eggs in the mud of shallow Elder Pond and other ponds which were flooded when the Elk River was impounded. Whether it will survive in such an environment will be answered by future spring collections.

Because this project was an investigation of the limnetic plankton, no regular collecting of littoral organisms (those inhabiting shallow water and also found in the weeds near the shore) was attempted. A few littoral collections in April, 1954, showed the following animals to be present at that time: the copepods *Macrocyclops albidus* (Forbes) and the cladoceran *Pleuroxus denticulatus* Birge, as well as innumerable unidentified ostracods. These may occasionlly swim into the open water and will probably show up in some future plankton collections.

Some kinds of plankters may have been present when they are not recorded in the list; if so, they must have been much restricted in numbers and in their distribution in the reservoir, or so small that they passed through the plankton nets. Collections taken from various stations during the same day and compared qualitatively showed remarkable similarity. Quantitatively they tended to be dissimilar if the stations differed in water depth, current, and proximity to shore.

Results of Vertical Distribution Studies

References to publications relating to diurnal movements of plankton organisms up to the year 1944 are included in the report of Pennak (1944). For this reason no attempt is made to list them in this paper. I will simply give the results of a series of hauls made at intervals over a 24 hour period (see section on Equipment and Methods). Also, the results of some few experiments using ultra violet and ordinary electric lights are included here.

Figures 2 through 7 show graphically the results of the 24 hour vertical distribution studies. These are essentially quantitative comparisons of certain common organisms for the four different depths to show the distribution patterns at the various hours when the hauls were made.

Figure 2 shows the quantities of net plankton taken at the 4 depths without regard to species or numbers of individuals. These measurements were taken with small graduate cylinders. At 10:30 AM the 8 foot depth net collected the most plankton;

at 1:10 PM the 12 foot depth net collected the most plankton; at 5:00 PM the 8 foot net; at 12:00 PM the 4 foot net had slightly more than the surface net; and at 6:00 AM the surface net slightly outranked the 8 foot net for the most plankton. Small volumes of plankton were taken at the surface at 10:30 AM, 1:10 PM, and 5:00 PM; and at the 12 foot depth at 12:00 PM and 6:00 AM. Comparing these graphs to the other graphs in which numbers of individuals of certain species are recorded, it is apparent that the plankton crustacea show the most influence in the results of volume comparisons of net plankton at the 4 depths. The graphs of the *Diaptomus reighardi* adults are strikingly similar to those in Fig. 2.

Pithophora kewensis and *Fragilaria crotonensis* were surprisingly similar in distribution patterns. They were mainly concentrated towards the surface during sunlight hours, as would be expected, but were also in large numbers at the twelve foot

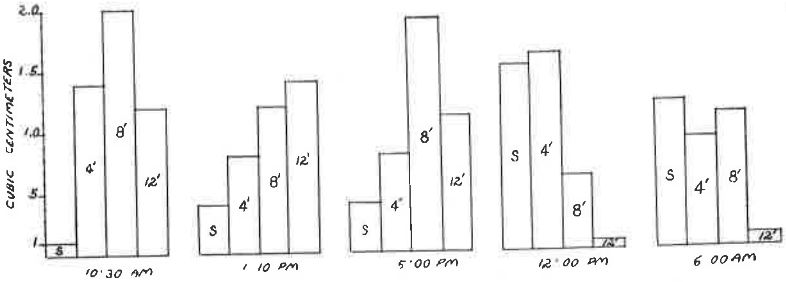

Fig. 2. Volumetric comparisons of net plankkton hauls taken at different depths and at intervals over a 24-hour period.

depth with fewer number at in-between depths. Those from the twelve foot zone showed a definite rise towards the surface during darkness (see Fig. 3). *Pediastrum simplex* with much fewer numbers of individuals showed somewhat similar tendencies in approaching the surface at night, but did not tend to concentrate at the surface during daylight (see Fig. 4).

In general, the three species of rotifers in Fig. 5, the three cladocera in Fig. 6, and *Diaptomus reighardi* adults and nauplii (Fig. 7) showed retreat from the surface during the morning and rise to or near the surface during darkness. As expected, there are minor differences in distribution patterns between the different rotifers, between the cladocera, and even between the immatures and adults of *Diaptomus reighardi*. Nauplii of the latter species tended to approach closer to the surface during daylight than did the adults.

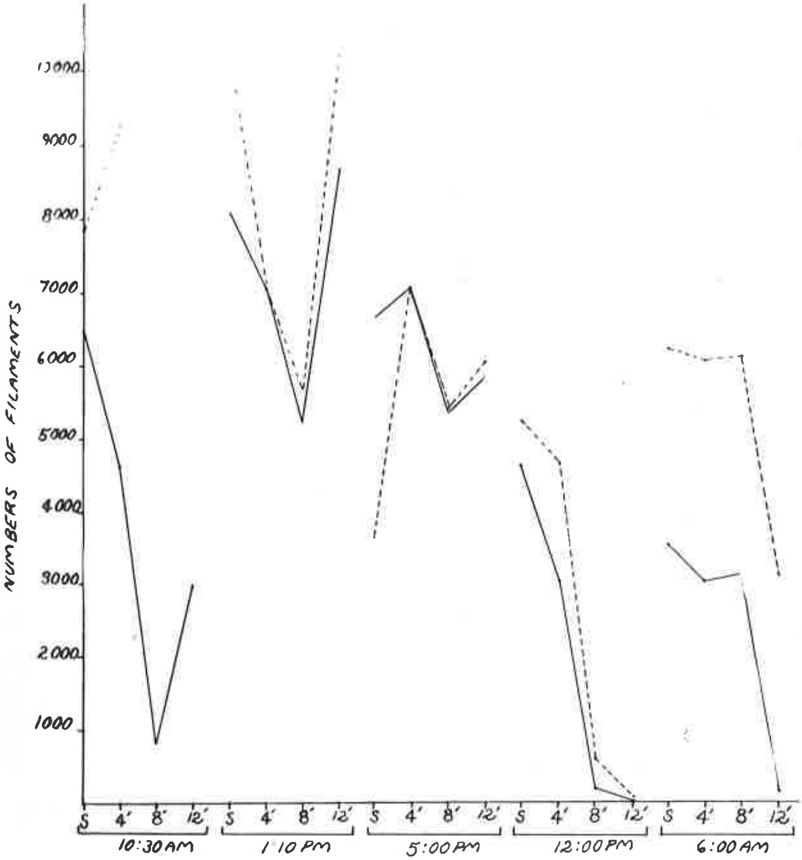

FIG 3 ——— = FRAGILARIA CROTONENSIS
- - - - - = PITHOPHORA KEWENSIS

Upon finding a great abundance of phytoplankton during daylight at a certain depth which is characterized by abundance of oxygen, little carbon dioxide, alkaline in reaction, and with a larger amount of calcium carbonate than at other depths, one might wrongly conclude that such phytoplankton was present at that depth because such conditions were ideal for their existence and reproduction. Actually the phytoplankton was not seeking out these conditions, but was rather the cause of them. Plants in light utilize carbon dioxide for photosynthesis and hence there is little amount in their presence, and also little or no carbon dioxide to combine with calcium carbonate to form calcium bicarbonate or to combine with water to make carbonic acid. Oxygen will naturally be abundant in the vicinity of plants undergoing photosynthesis under good light conditions when the oxygen production will exceed plant respiratory requirements.

During daylight most zooplankton is seeking and utilizing oxygen for respiration and avoiding ultraviolet light rays penetrating into the water. Hence zooplankton is likely to be found at a depth below that of the phytoplankton. At such depth, there will be much carbon dioxide being given off by the respirating organisms, and calcium bicarbonate being formed when the carbon dioxide combines with the calcium carbonate. Also the water at that depth will be less alkaline, neutral, or acid because carbon dioxide plus water will form carbonic acid.

These were the conditions which prevailed when all the regular qualitative sampling was done in the daytime. To secure phytoplankton, hauls were made near the surface; to secure zooplankton, hauls were made several to many feet below the surface.

FIG. 5 ——— = TRICHOCERCA MULTICRINIS — — — = ASPLANCHNA PRIODONTA ------ = KELLICOTTIA LONGISPINA

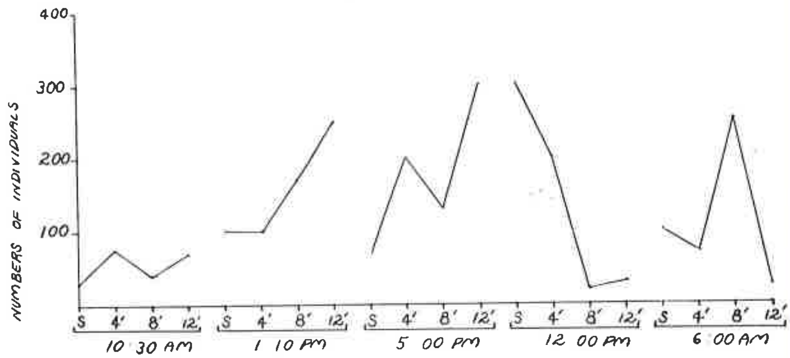

FIG 4 ——— = PEDIASTRUM SIMPLEX

Some of the collections were brought back to the laboratory alive, placed in large, deep, rectangular aquaria in a darkroom, and subjected to light shining on the water surface from above. First, an ordinary electric light was utilized; and to this light source, the larger zooplankton reacted with a positive phototropism. The smaller zooplankton and the phytoplankton could not be distinguished with a hand lens or the unaided eye, and so their reactions were not known. *Diaptomus reighardi, Ceriodaphnia quadriangula, Bosmina longirostris, Diaphanosoma brachyurum*, and *Mesocyclops edax* were readily distinguishable, and all moved towards the surface to form a layer of swimming organisms just below the surface. It is a well-known fact that ordinary electric lights attract plankton. I have some vials of marine plankton collected by oceanographic expeditions. These organisms had been attracted to the surface by playing searchlights thereon and then easily collected with nets. My ordinary light bulbs gave off no ultraviolet light, for when tested, they caused no fluorescence of uranium glass.

Next, ultraviolet light was played upon the aquaria containing the plankton. The visible zooplankters, mentioned above, showed a definite negative reaction and quickly swam to the bottom where they dashed themselves against the glass there. Several hours of ultraviolet light produced heavy mortality in these organisms. A uranium glass plate at the bottom showed striking fluorescence.

To get some idea of the penetration of ultraviolet light in the lake water, I used a diving mask and descended into the lake with the uranium glass plate on a sunny mid-day. The uranium glass showed fluorescence from the surface down to a depth of 5½ feet. Many factors can affect the depth of pen-

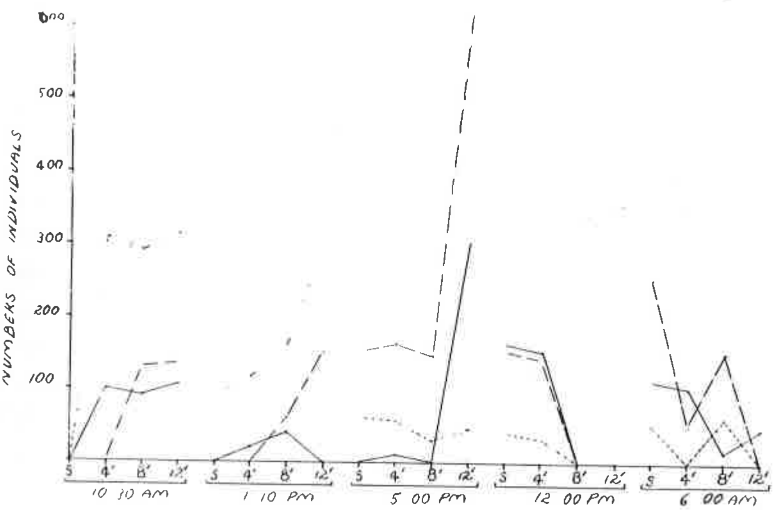

FIG. 5 ——— = Trichocerca Multicrinis - - - - = Asplanchna Priodonta .... = Kellicottia Longispina

etration of ultraviolet light—color of water, wave action, turbidity, etc. No attempt was made to determine the intensity of light at different depths.

When a lake has a winter ice cover, the temperature of the water underneath is rather uniform. If the ice is clear (without a snow cover), the zooplankters distribute themselves as they did without an ice cover; in other words, show their regular diurnal movements. If there is a heavy snow cover over the ice, the zooplankters are distributed rather uniformly from the surface down to great depths (see Ruttner, 1953). All these observations indicate that sun light (especially the ultraviolet light waves) rather than temperature is the main factor in keeping these organisms away from the surface during daylight hours.

Most zooplankters show a negative geotropic reaction and swim towards the surface when not repelled by ultraviolet light and thus move upward at night.

Ecological Succession

Ecological succession refers to the succession of species which occur in an ecological habitat as it progresses from origin, through early stages, through succeeding stages and old age, and perhaps to obliteration.

Internal conditions are gradually changing within a body of water; silt is being built up, changing the depth; organic and

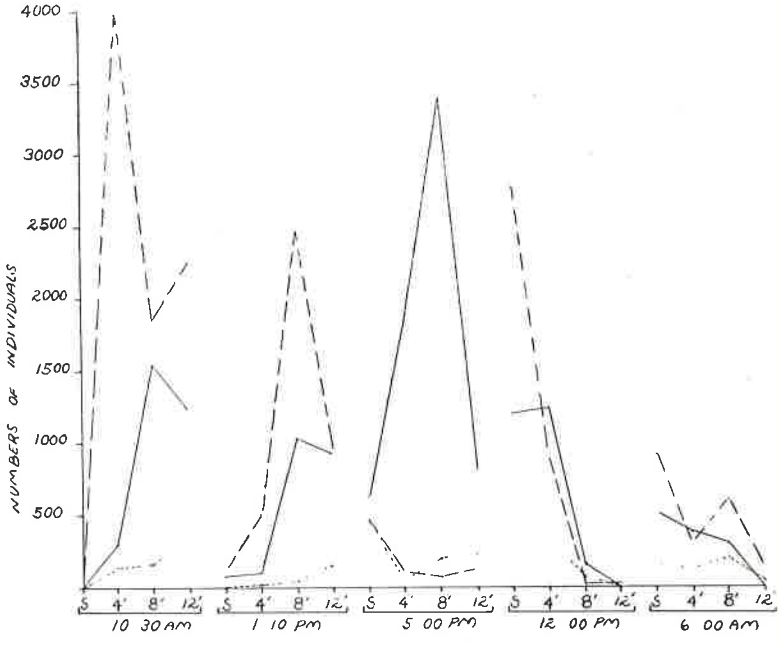

FIG. 6. ——— = DIAPHANOSOMA BRACHYURUM ····· = CERIODAPHNIA QUADRIANGULA — — — = BOSMINA LONGIROSTRIS

inorganic materials are flowing into the lake, changing its chemical composition. When the environment changes, the animal and plant life change. Species are introduced (naturally and sometimes inadvertedly by man) which are at the time better adapted to live in the lake than those already existing therein. Biological competition and temperature, chemical and other tolerance limits either eliminate the old species or vastly reduce them in numbers.

Woods Reservoir is a new lake, but already ecological succession is shown in the plankton collections.

A series of plankton collections were taken in the Elk River on September 13, 1952, prior to completion of the dam to form Woods Reservoir. The water was fairly swift, but a fair number of plankton specimens were secured. These included *Diaptomus*

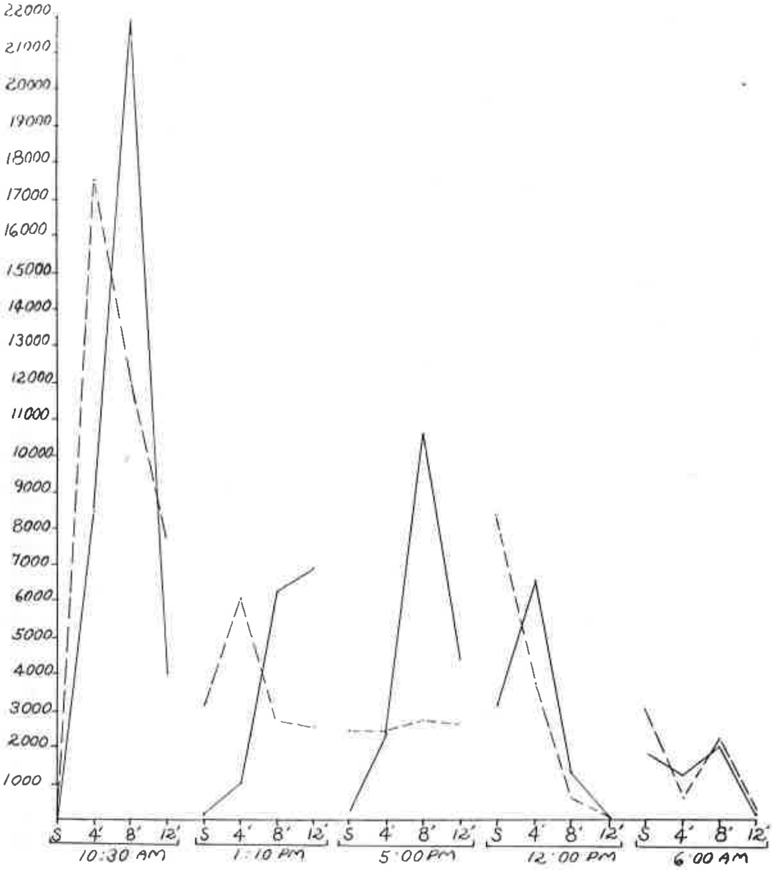

FIG. 7 DIAPTOMUS REIGHARDI

——— = ADULTS ---- = IMMATURES

pallidus, *Tropocyclops prasinus*, and *Mesocyclops leuckarti*. Noteworthy was the abundance of the calaniod copepod, *D. pallidus*. This species often occurs in ponds and lakes, but Comita (1951) has taken it from Devil River near Del Rio, Texas, in shallow, fast moving water and I have found it in collections from the Neches River near Beaumont, Texas. Thus it demonstrates that it can survive in streams and therefore differs from many of the other species of the genus. As noted above, it was the dominant plankton form in June, 1953, when the reservoir began to fill. At about that time *Diaptomus reighardi* appeared in small numbers. By the end of August, 1953, *D. pallidus* had disappeared and *D. reighardi* had become the dominant plankter. *D. pallidus* made a reappearance in June, July and early August, 1954, but not in their 1953 abundance. They occurred chiefly in the old channel region of the lake. They may have survived the intervening months in small numbers which were not collected in nets, or as resting eggs, or may have become reintroduced from the Elk River. It is noteworthy that Hoff (1944) collected it from Reelfoot Lake, Tennessee from June 19 to July 18, 1942, but not in late July and August. Whatever the requirements may be for *D. pallidus,* it can survive in a water current better than can *D. reighardi,* but the latter is either a more efficient feeder or more efficient breeder in lake water and either replaces the former or holds its numbers in check, except in regions of more water current. In addition to biological competition, temperature has a limiting effect on the presence and abundance of *D. pallidus.* As noted above, it has been collected only during the warm summer and sometimes fall months.

Daphnia longispina galeata was common in Woods Reservoir at its beginning in June, 1953, but diminished in numbers in July, 1953, and has not taken in any collections since that time. During that time, *Diaptomus reighardi* was on the rise in abundance. I have witnessed the competition of these two species in another lake with the same result. University Lake at Chapel Hill, N. C., was made by the impoundment of Morgan's Creek in 1932. Until 1950, *Daphnia longispina galeata* was the chief plankter; to my knowledge, no diaptomid copepod was reported from this lake. In that year, *Diaptomus reighardi* made an appearance and become the chief plankter. *D. reighardi* more quickly replaced *Daphnia l. galeata* in Woods Reservoir than in University Lake because it was more available to do so. Most of the lakes in counties near Woods Reservoir have thriving populations of *D. reighardi,* whereas I can find no published records of this species even occurring in North Carolina. *Daphnia pulex,* a more robust species than *Daphnia l. galeata,* seems to more successfully survive in the presence of *Diaptomus reighardi.*

Dr. Samuel Eddy (1930) listed the copepods *Diaptomus siciloides, Diaptomus sicilis, Cyclops viridis,* and *Cyclops bicuspidatus* from Reelfoot Lake in 1929. Hoff (1944) listed *Osphranticum labonectum, Diaptomus mississippiensis, Diaptomus pallidus, Mesocyclops obsoletus, Cyclops viridis, Macrocyclops albidus, Eucyclops agilis, Eucyclops prasinus* (=*Tropocyclops prasinus*), and *Microcyclops bicolor* from the same lake in summer 1942. Only *"C. viridis"* (actually specimens of *C. vernalis,* see Yeatman, 1944) was found in collections of both men. During the time between their respective collections the

Table 2. Physical and chemical data (all taken about middle of day)

Date	Locality	Clarity (Secchi disc)	Depth of samples	Oxygen cc per liter	Oxygen % saturation	pH	Temperature (centigrade)	Carbonate ion (CO_3^{--})	Bicarbonate ion (HCO_3^-)	Chloride ion (Cl^-)	Sulfate ion (SO_4^{--})	Calcium ion (Ca^{++})	Magnesium ion (Mg^{++})
July 24, 1954	near dock		10 ft.	3.49	68%								
July 31, 1954	near pump station	8.8 ft.	32.6 ft.	1.745	28%	7.2	19°						
			surface	3.839	77.6%	8.4	31.8°						
Aug. 4, 1954	near pump station	8.0 ft.	42 ft.	2.443	38.7%	7.0	18.6°		122.0 ppm	10 ppm			
			surface	3.6994	73.4%	8.2	30.5°		117.12 ppm	20 ppm			
Aug. 7, 1954	near dock over algae		4 in.	4.3276	85.7%		30.5°		104.92 ppm	10 ppm			
Aug. 14, 1954	near dock		surface					12 ppm	85.4 ppm	5 ppm	8 ppm	120 ppm	0.3 ppm
Aug. 21, 1954	near dam	8.0 ft.	49 ft.	2.094	31.2%	7.0	16.2°	none	97.6 ppm	3 ppm	2 ppm	133 ppm	1.2 ppm
			surface	2.443	47.0%	8.0	30.5°	9.6 ppm	85.2 ppm	5 ppm	2 ppm	106 ppm	1.2 ppm
Nov. 13, 1954	near pump station	9.6 ft.	20 ft.	4.188	57.3%	6.8	12.4°	none	102.48 ppm				
			surface	3.769	52.7%	6.8	13.7°	none	97.6 ppm				

lake had aged, ecological succession was progressing, and as Hoff (1944) points out, a levee and spillway had been constructed to keep out the Mississippi overflow and maintain a constant level in the lake. Hoff took more samples than did Eddy and therefore possibly got some species overlooked by the latter. Hoff's samples were taken only during the summer, so would not be expected to include specimens of *C. bicuspidatus* (see following section on seasonal succession).

As Woods Reservoir changes so will its species complex change, and when species presently isolated from this water finally reach it, some of these will become part of its flora and fauna. As ecologists say, a given species is not present in a particular place either because it could not get there, or once it got there it could not survive or breed in that environment, or perhaps over a long period of time, it mutated sufficiently to be considered a new species.

Seasonal Succession

Seasonal succession is the gradual replacement of species active in a particular habitat by other species as the seasons succeed each other during the year. If ecological succession is not progressing very rapidly, so that environmental conditions are not changing greatly from year to year; often we may find a seasonal succession of the same species year after year over a long period of time.

Some species completely disappear from the plankton during certain seasons, but can be often found in the bottom ooze in some inactive form—spores, cysts, resting eggs, "cocoons," etc. Other species can be found in the plankton throughout the year, but exhibit periods of terrific increase in numbers of individuals, so that they make up the bulk of the plankton during those times. Such increases are commonly known as "blooms." Table no. 1, showing lists of species collected at Woods Reservoir and their abundance, indicates blooms by means of a "+" sign after the letter "A".

In a large body of water where amount of water is not a problem, temperature is one of the chief external factors influencing seasonal succession. This is the case in Woods Reservoir where seasonal succession is already established, in spite of the fact that the lake is less than 5 years in existence. *Cyclops bicuspidatus thomasi* and *Diaptomus sanguineus* are cold water copepods which show up in winter and early spring collections, but disappear before May 16. The former usually survive the warm seasons in the 4th copepodid stage enclosed in a sort of mud "cocoon" or cyst, whereas the latter exist in the egg stage during these times. Cole (1953) gives a good summary of what is now known concerning copepod encystment. As he points out, it is not at all clear what environmental conditions influence encystment. I am not sure what part temperature plays in encystment, but to believe that *C. b. thomasi* and *D. sanguineus* may be termed cold water species because my specimens could not survive more than one day in water warmed to and kept at 25° C. Much of the reservoir water exceeded this in temperature during the summer. Perhaps encystment may be an inherited behavior pattern brought about by mutation and established in certain water by environmental selection. Experiments might clear up this matter in the future.

Amount and intensity of sunlight, chemical composition of the water, biological competition (both competition for food and predation), and amount of food also have their influence on seasonal succession. So little is known of the requirements of the various plankters, that it is difficult or almost impossible to determine which factor or factors bring about the activation, reproduction, and huge increase in numbers of individuals within a species during a certain season or seasons. Optimum light conditions naturally will increase the abundance of plants in the plankton and, in turn, some of the animals which feed on these will increase in numbers if other environmental conditions are satisfactory. It is obvious that a cold-water species such as *Cyclops bicuspidatus thomasi* will not become abundant in water that is becoming warmer, even if its plant food is increasing.

Conclusion

Woods Reservoir shows most of the characteristics of a eutrophic type lake. It has an excellent supply of nutrients and hence is high in productivity of plankton. Except during the fall and spring turnovers, the circulating top-water or epilimnion exceeds the hypolimnion in volume, also there is low transparency and high calcium content. The deep water is usually about neutral in reaction and the upper water is usually slightly alkaline. As in other eutrophic lakes, there are many individual plankters, but few species. As yet, I have recorded only 69 different plankton species. Harrington and Myers (1928) have indicated that alkaline waters contain large numbers of individual rotifers, but few species; and that acid waters contain few individual rotifers, but many different species.

Temperature affects organisms directly and indirectly and thus appears to be a major factor in influencing seasonal succession. Some organisms live and reproduce best at high temperatures and others at low temperatures. They pass through the unfavorable seasons in cysts, spores, or dormant in the bottom mud, etc. Other species are widely tolerant of temperature conditions, but most of these reproduce best within certain narrow temperature limits.

Indirectly, temperature is responsible for summer stratification of lakes, for fall and spring turnovers and winter stratification, if it occurs in a body of water. Maximum growths of diatoms occur after periods of stagnation and stratification and during turnover periods when important chemicals are carried from the bottom region to the surface.

Ultra-violet light appears to be the main factor in keeping certain organisms away from the surface during daytime. Visible light waves, especially yellows, tend to attract organisms as demonstrated by a simple experiment discussed above. Temperature may also influence vertical distribution by limiting certain cold-water species to the bottom areas of a lake during the summer when the surface water is too warm for their survival. Negative geotropic tendencies cause zooplankters to swim towards the surface when not inhibited by ultra-violet light waves.

Many of the organisms were present in the Elk River before the dam was constructed, others were carried in by tributaries, still others came from ponds inundated by the reservoir. Perhaps a few were introduced with water dumped into the reservoir when stocking with fish or dumping unused minnows or were carried to the reservoir on the feet of the numerous waterfowl. Spores, cysts, and resting eggs could be carried by the wind, on the bottom of boats and other objects moved from other bodies of water. I have known instances of organisms being sucked up by whirlwinds, either with water from ponds or as spores with dust from dried ponds, and shortly thereafter fall with rain in another locality. Some spores, cysts, etc. can pass unharmed through the digestive tracts of birds, fish, etc.

The species which get to the reservoir first and are adapted to the ecological conditions therein are the first to multiply in numbers and fill the ecological niches; other species are being constantly introduced and some may be better adapted for the changing conditions of the reservoir than some of the first species and soon replace them. This ecological succession of different species has been going on in Woods Reservoir and some of the changes are considered in that section of this report.

No special work was attempted on horizonal distribution in this investigation. During the collecting of organisms, certain facts were brought out rather clearly. Species are not uniformly distributed throughout the lake at the depth at which they are found. They sometimes occur in swarms with areas of scarcity in between. For this reason plankton traps and plankton pumps are not as effective as plankton nets in getting a true picture of the plankton quantity and quality. *Diaptomus pallidus*, when present, was usually confined to the old river channel region of the reservoir where it survives better in the current than does its competitor *Diaptomus reighardi*. The shallow areas near the shore are rather deficient in true planktonic organisms, especially is this true in the summer when such waters are quite warm.

Finally, the results of these investigations indicate the inadequacy of a few collections in establishing what plant and animal species inhabit a particular lake. This is particularly true if the latter is newly constructed.

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