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SEASONAL ABUNDANCE AND VERTICAL MOVEMENTS OF PLANKTONIC CRUSTACEA IN LAKE MICHIGAN

By LaRUE WELLS

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ABSTRACT

Plankton collections were made in Lake Michigan on seven occasions between June 6 and November 18, 1954, and 3 times between June 30 and October 2, 1955. The 1954 sampling area was about 8 miles off Grand Haven, Mich., at a depth of 74 meters, and the 1955 sampling was done about 3 miles offshore near Frankfort, Mich., at a depth of 46 meters. Limited sampling was also completed off Sturgeon Bay, Wis., on May 4, 1958. Collections were made with a Clarke-Bumpus plankton sampler with a net of No. 2 bolting silk. Series of samples were taken at about 2-hour intervals from 10-meter depth intervals from the surface to 40 meters (collections also from 5 meters in 1955).

Eight species of cladocerans (*Daphnia galeata mendatae, Daphnia retrocurva, Bosmina longirostris, Diaphanosoma brachyurum, Holopedium gibberum, Sida crystallina, Leptodora kindti, Polyphemus pediculus*), and 9 species of copepods (*Cyclops bicuspidatus, Mesocyclops edax, Diaptomus minutus, Diaptomus ashlandi, Diaptomus sicilis, Diaptomus oregonensis, Epischura lacustris, Limnocalanus macrurus, Senecella calanoides*), as well as the malacostracans *Pontoporeia affinis* and *Mysis relicta* were collected in numbers sufficient to permit individual treatment. In addition the cladocerans *Chydorus sphaericus, Eurycercus lamellatus* and *Ceriodaphnia* sp., and the copepods *Eucyclops prasinus* and *Cyclops vernalis* were taken in extremely small numbers. *Eurycercus lamellatus, Polyphemus pediculus, Cyclops vernalis*, and *Senecella calanoides* are reported for the first time from Lake Michigan.

Most species reached only one population peak a year. Apparently all cladocerans and the copepods *Mesocyclops edax* and *Epischura lacustris* overwinter as eggs in Lake Michigan.

All species migrated vertically to some degree. The vertical movements were influenced most strongly by diurnal changes in light intensity. Water temperatures also affected the migrations, especially of the cold-water forms. Migration toward the surface usually began late in the day. Most species attained their greatest numbers at the surface near sunset or soon afterwards. Numbers at the surface usually decreased toward midnight and, according to limited evidence, some species increased at the surface again between midnight and dawn. A few cold-water forms did not ordinarily migrate through a sharp metalimnion.

SEASONAL ABUNDANCE AND VERTICAL MOVEMENTS OF PLANKTONIC CRUSTACEA IN LAKE MICHIGAN

By LARUE WELLS, *Fishery Research Biologist*, BUREAU OF COMMERCIAL FISHERIES

Lack of knowledge concerning the plankton offers a major impediment to the development of a better understanding of the trophic relationships that govern the biological productivity of the Great Lakes. Opportunities for systematic investigation of plankton have been few. Research vessels have operated in the Great Lakes on a most limited scale and when available have been largely obligated to other aspects of fishery research. Furthermore, plankton research is difficult, often almost to the point of frustration. The inevitably biased sampling of presently available equipment and the characteristics of the plankton itself, the erratic horizontal distribution, pronounced diurnal and seasonal changes in vertical distribution, and seasonal changes of species composition and abundance combine to deprive the investigator of the precision he wishes to attain. These difficulties are not overcome easily or quickly. We can, nevertheless, make substantial advances if we recognize clearly the importance of even limited contributions to knowledge. We must seize every opportunity to obtain new information even though the individual studies may of necessity have many faults and weaknesses. The present report on observations made from the research vessel *Cisco* in Lake Michigan in 1954 and 1955 is restricted as to time, locality, and problems considered. It does, however, add measurably to our understanding of conditions in the lake and can aid greatly in the planning and execution of the more extensive researches that we trust will be possible at a later date.

Previous zooplankton studies on Lake Michigan have been few, and usually have been based on samples from inshore areas. Actually, nothing more than scanty works have been published on the limnetic crustacean plankton of any of the upper Great Lakes. Ahlstrom (1936) excluded crustaceans from his study of plankton in deep-water samples from Lake Michigan. Among the earliest works on Lake Michigan zooplankton were a brief account of the daphnids in the Chicago water supply (Birge 1882) and a description of species in a few tow-net samples from Grand Traverse Bay, northeastern Lake Michigan, and southern Lake Michigan off Racine, Wisconsin, and Chicago (Forbes 1882). Birge (1894) found no cladocerans in samples taken in April from several locations in northern Lake Michigan. Marsh (1895) made rough estimates of the relative abundance of copepods in collections made during a limnological survey of Lake Michigan in the Grand Traverse Bay region in 1893. Details of the survey were discussed in Ward (1896). The most thorough study of Lake Michigan zooplankton to date has been an analysis of samples taken from inshore waters in southern Lake Michigan in 1887–88 and 1926–27 (Eddy 1927). Damann (1945) analyzed plankton collections taken from 32- to 38-foot depth off Chicago, but he did not identify zooplankters beyond genus.

The most important zooplankton studies in the other Great Lakes include those of Smith (1874), Forbes (1891), Birge (1893), and Eddy (1943), for Lake Superior; Sars (1915), and Bigelow (1922), for Georgian Bay (Bigelow included Lake Erie and the Lake Ontario data also); Wilson (1929), Chandler (1940), Andrews (1953), Davis (1954), and Tidd (1955), for Lake Erie. The previously listed reports by Birge (1894) and Marsh (1895) also contained information on zooplankton of Lake St. Clair. In other large bodies of water in North America, Langford (1938), and Rawson (1956) have made thorough plankton studies in Lake Nipissing and Great Slave Lake, respectively.

NOTE.—Approved for publication June 15, 1959. Fishery Bulletin 172.

Valuable suggestions concerning species identification and enumeration were made by David C. Chandler, Professor of Zoology, University of Michigan.

METHODS

COLLECTION OF SAMPLES

Ten series of day-and-night plankton collections were made in Lake Michigan in 1954 and 1955 from the U. S. Fish and Wildlife Service research vessel *Cisco*. In 1954, 7 series of samples were taken from June to November off Grand Haven, Michigan, and in 1955, 3 series were collected between June and October off Frankfort, Michigan. The collection area near Grand Haven was about 8 miles offshore at a depth of 74 meters, and the location near Frankfort was about 3 miles offshore at a depth of 46 meters. An additional single afternoon series was collected in May 1958 about 4 miles offshore at a depth of 33 meters off Sturgeon Bay, Wisconsin.

Collections were made with calibrated Clarke and Bumpus (1940) plankton samplers. Samples were taken in 1954 on June 6–7, 27–28, July 16–17, August 7, 27, October 7, and November 18; in 1955 on June 30, July 24, October 2; and in 1958 on May 4. Procedures varied from time to time, but on most dates samples from several levels were taken approximately every 2 hours from afternoon until near midnight; sampling continued until dawn on two occasions. Ordinarily each series of samples in 1954 consisted of 10-minute tows at the surface and at 10, 20, 30, and 40 meters. In 1955, a standard series included 5-minute tows at the surface and at 5, 10, 20, 30, and 40 meters. On June 6–7, 1954, nets were towed at only the surface and 10 meters. The single afternoon series on May 4, 1958, included samples from 5-minute tows at 2, 4, 8, 10, 15, and 20 meters.

The nets were made of No. 2 bolting silk (aperture 0.366 mm.) except for a few of the earlier tows on June 6, 1954, when No. 10 bolting silk (aperture 0.158 mm.) was used. The towing speed was approximately 4 miles per hour. At this speed an average of slightly more than 1,000 liters of water a minute passed through the samplers. The depths of the tows were controlled on the basis of calculations involving the length of cable below the surface and the angle between the surface and the cable.

All samples were preserved in 10-percent formalin and labeled with date, time, length of tow, depth of tow, mesh size, station number, and time at beginning of series. These records, as well as weather conditions and Clarke-Bumpus meter readings, were also kept on special forms. Bathythermograph tracings were made periodically and surface temperatures were recorded constantly during the collection periods. In the 1954 studies, water samples were taken from several depths with Nansen bottles preceding the collection of each 2-hour series of plankton samples. The water was analyzed for oxygen, pH, conductivity, and several other chemical characteristics.

COUNTING PROCEDURE

Vast differences in the size and numbers of the various species in the plankton required that counting procedures be varied. First, amphipods and mysids were removed from the samples and counted individually. Then all *Polyphemus* and *Leptodora* were enumerated, except that where the latter was very numerous only one-fourth of the sample was examined. For counting the remainder of the species, subsamples were removed from samples which had been diluted to either 50 cubic centimeters, 100 cc., or occasionally 200 cc., depending on the size of the sample. For most species, duplicate 5–cc. subsamples were taken; each sample consisted of 1.67–cc. portions taken with an automatic pipette from near the surface, center, and bottom of the container holding the thoroughly mixed sample. Only 0.5–cc. samples were employed to obtain counts of *Cyclops*, *Mesocyclops*, and *Diaptomus*, (duplicated for the former two), owing to the generally great abundance of these copepods. All organisms were identified to species except female and immature *Diaptomus*, which were combined to form a single category.

Counts were made under a binocular microscope at magnifications of 9× to 27×. Occasionally, higher magnification was necessary. Counts of the duplicate subsamples were averaged. Discrepancies between the two counts ordinarily were small although the percentage differences sometimes were high when a species was sparsely represented. When disagreement between the subsamples was so large that an error was considered likely, a third subsample was examined and the aberrant one disregarded. Most of the counts given here are adjusted so that they are on a basis of organisms per cubic meter (1,000 liters) of water. A unit volume of 10 cubic meters (10,000 l.) was required, however, for *Senecella*, *Leptodora*, *Polyphemus*, *Pontoporeia*, and *Mysis* to prevent the use of fractions. All final calculated values above 100 have been rounded off to two significant figures. Values less than 100 were rounded to the nearest 10 organisms for those species for which only 0.5-cc. samples were examined.

LIMITATIONS OF THE DATA

Probably the outstanding weakness in the collection method is the use of comparatively large mesh in the nets. The No. 2 bolting silk unquestionably allowed the loss of valuable data. Many of the copepods in early developmental stages escaped, and adults of *Eucyclops prasinus* were probably poorly sampled. The conclusions concerning copepods therefore apply mainly to adults and the larger immature forms. All important cladocerans and malacostrans, except possibly *Bosmina longirostris*, are believed to have been adequately sampled in all size groups. Actually, the original plans called for the use of No. 10 mesh, but after the first few tows in 1954 it became obvious that the large amounts of algae caught would make the counts of crustaceans extremely difficult. Even in the No. 2 mesh enough filamentous diatoms were caught at times to make accurate subsampling and counting troublesome. On some occasions fine mesh could have been used without difficulty, but the larger mesh was used throughout so that samples would be comparable. Moreover, the large mesh is no doubt superior to the smaller in the filtration of water. It is believed that the No. 2 bolting silk was good in this respect, whereas smaller meshes probably would have varied, depending on whether or not algae had clogged the net.

A second weakness of the methods is the lack of samples near the bottom in 1954. The 1955 samples, however, were much better in this respect. It is doubtful whether many serious misinterpretations of the data resulted from the lack of the tows near the bottom in 1954, since counts from the 40-meter tows show that most species were scarce below 30 meters. There were, however, two or three cold-water forms which, no doubt, were comparatively numerous near the bottom, at least in the daytime.

Objections are often raised to the use of horizontal tow nets for plankton collections because only certain levels are sampled and large concentrations of organisms may be missed. Vertical tows would have reduced the danger of missing crustaceans concentrated at certain levels, but would have been inferior in sampling organisms with uneven horizontal distribution. The nature of the horizontal distribution of zooplankton is still the subject of some argument, but the evidence for uneven distribution is strong (Marsh 1901, Southern and Gardiner, 1926, Wilson 1929, Cushing 1951).

The data on vertical migration would, of course, have been improved by 24-hour series of collections. The data do, however, show movements during the more important hours of the day, even though the material netted at daybreak is scanty. The discussion of migration will be concerned primarily with movements at twilight, but a fairly confident statement of movements at dawn can be made.

The lack of winter and early-spring samples permits only speculation on abundance during this period. The early-May collections are so few that they are useful only in determining the presence or absence of the various species at this time. Despite these shortcomings, an analysis of the population trends through the periods of collections permits estimates of abundance of many of the species during the winter.

HYDROGRAPHY OF SAMPLING AREAS

No attempt is made in this report to explore all possible factors affecting the vertical movements of crustacean plankton. It is clear from the data that change in light intensity was the dominant influence. It is equally evident that the water temperature had an effect on the movements of some species. Diurnal changes in dissolved oxygen, pH, and conductivity were so small that significant influence by these factors seems unlikely. Therefore, only diurnal changes in light intensity and the prevailing water temperatures are considered in the discussion of the vertical movements.

A certain amount of thermal stratification existed during each collection period except May

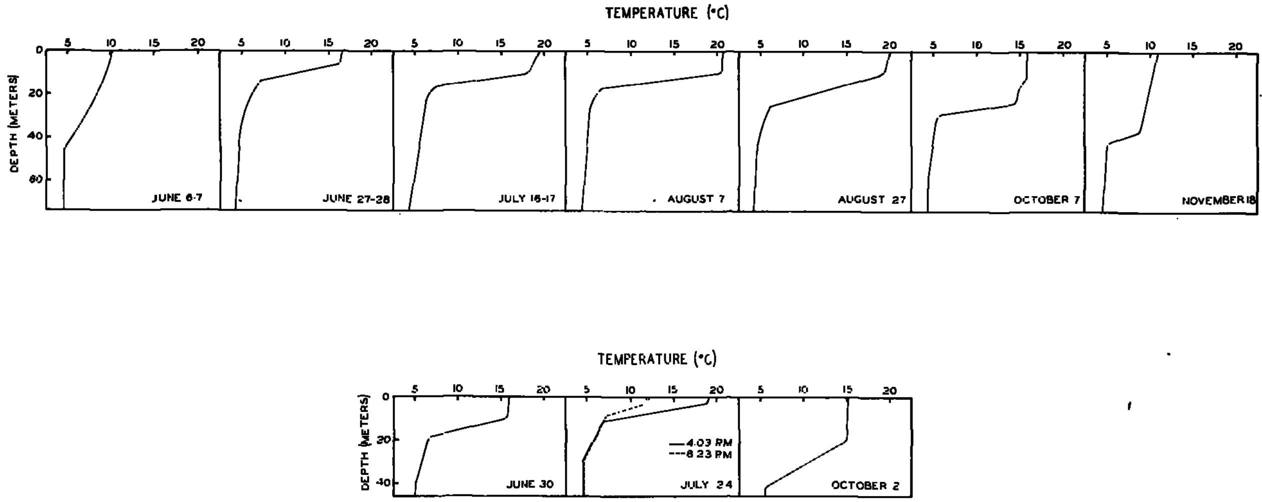

FIGURE 1.—Bathythermograph tracings for Lake Michigan in areas of plankton collections, 1954 (above); and 1955 (below).

1958 (water homothermous at about 4° C.), but the degree of stratification changed with the season (table 1, fig. 1). In 1954 the top of the metalimnion varied from near the surface to 10 meters below it, until the October and November collections when it was about 30 and 40 meters, respectively. Surface temperatures varied from 10.3° to 20.6° C. in 1954. In 1955 a most unusual thermal condition developed in the study area during the July sampling. An upwelling following strong north winds dropped the surface temperature from 18.9° C. at 4:03 p.m. to 11.7° C. at 8:23 p.m. (table 1, fig. 1), where it remained with little change during that study period. Limnological conditions in the area of upwelling probably resembled conditions usually confined to the hypolimnion so that comparisons of plankton catches made on this date with catches of other dates might be misleading. Surface temperatures during the June and October collections in 1955 were 15.9° and 15.1° C., respectively. The metalimnion was shallow and well defined on the former date; it was deeper and its temperature gradient was less pronounced on the latter.

No transparency measurements were made at the time of the collections, but close estimates can be made from the Secchi-disc readings obtained in the collection areas a few days before each study, excepting July 1955 (table 1).

Times of sunset and sunrise, if they occurred during the hours of sampling, are listed in table 1 for the various collection dates. Nighttime illumi-

TABLE 1.—*Hydrographic data and times of sunset and sunrise for dates on which plankton collections were made in Lake Michigan, 1954 and 1955.*

[Time of sunrise given only when sampling still was in progress]

Date	Surface Temperature (°C.)	Metalimnion			Secchi disc (meters)	Sunset (EST)	Sunrise (EST)
		Position below surface (meters)	Temperature change (°C.)	Change of temperature per meter			
1954							
June 6–7	10.3	0–47	10.3–4.5	0.1	4.2	8:20	
June 26–27	16.8	6–14	16.7–7.3	1.2	6.1	8:25	5:10
July 16–17	19.5	10–17	18.4–7.2	1.6	5.8	8:15	5:15
August 7	20.6	10–18	20.5–6.6	1.7	9.1	8:00	
August 27	20.0	10–26	19.4–6.1	0.9	6.4	7:30	
October 7	15.9	24–30	14.5–5.6	1.5	3.6	5:30	
November 18	10.9	37–43	8.9–5.1	0.6	5.5	4:35	
1955							
June 30	15.9	12–19	15.7–6.6	1.3	8.2	8:25	
July 24	[1] 18.9	3–12	18.9–6.7	1.4		8:15	
Do.	[2] 11.7	3–9	11.7–7.2	0.7			
October 2	15.1	20–42	15.0–5.5	0.4	4.9	6:25	

[1] 4:03 p.m. [2] 8:23 p.m.

nation was influenced by bright moonlight on July 16–17, 1954, and on June 30 and October 2, 1955.

SPECIES COLLECTED

Eight species of cladocerans and 9 of copepods, as well as the malacostracans *Pontoporeia affinis* (Lindström) and *Mysis relicta* Lovén were taken in sufficient numbers to permit individual treatment. The species of the first two groups are listed below:

CLADOCERA

Daphnia galeata mendotae Birge
Daphnia retrocurva Forbes
Bosmina longirostris (O. F. Müller)
Diaphanosoma brachyurum (Liéven)
Holopedium gibberum Zaddach
Sida crystallina (O. F. Müller)
Leptodora kindti (Focke)
Polyphemus pediculus (L.)

COPEPODA

Cyclops bicuspidatus Claus
Mesocyclops edax (Forbes)
Diaptomus minutus Lilljeborg
Diaptomus ashlandi Marsh
Diaptomus sicilis Forbes
Diaptomus oregonensis Lilljeborg
Epischura lacustris Forbes
Limnocalanus macrurus Sars
Senecella calanoides Juday

The cladocerans *Chydorus sphaericus* (O. F. Müller), *Eurycercus lamellatus* (O. F. Müller), and *Ceriodaphnia* sp., and the copepods *Eucyclops prasinus* (Fischer) and *Cyclops vernalis* Fischer were collected in extremely small numbers. *Eurycercus lamellatus* and *Cyclops vernalis*, both found only off Frankfort, are reported from Lake Michigan for the first time.

In the discussions to follow little attention is paid to differences in species composition in the two areas of study, as the year-to-year variations in either area are not known, and may be considerable.

SEASONAL DISTRIBUTION AND VERTICAL MIGRATION OF SPECIES

CLADOCERA

Daphnia

The taxonomy of the genus *Daphnia* has long been discouragingly confusing and controversial. Brooks (1957) has presented a strong argument for the "splitters" of this group, and his nomenclature is used here.

Daphnia was often the most conspicuous of the zooplankters; in some collections it constituted the bulk of the sample. Two species were represented, *D. galeata mendotae* and *D. retrocurva*. Both were considerably more abundant in 1954 than in 1955. In 1954 *retrocurva* was the more plentiful in late June and July and *galeata* during early June, October, and November; abundance was about equal in August. *D. galeata mendotae* was somewhat more numerous than *retrocurva* in practically all 1955 collections.

Daphnia galeata mendotae

In 1954 this species was rare in early June, somewhat more numerous by late June, considerably so by mid-July, and at a population peak in early August. Its abundance decreased through late August and early October and it was scarce in mid-November (table 2). In 1955, the species became more numerous on the successive collection dates, but never reached the abundance of 1954. It was absent in May 1958. Population trends indicate an absence of adults and juveniles in winter and early spring.

Comparisons of these findings with those of other workers are often difficult because the particular species to which they refer is not always evident. *Daphnia longispina*, a name which in recent years has been applied to most of the North American varieties of the genus except *D. magna*, *D retrocurva*, and *D. pulex*, has been found in all the Great Lakes. Most of these Great Lakes records are probably based on either *D. galeata mendotae* or *D. dubia* of Brooks (1957). Brooks has, in fact, observed the former in Lake Ontario samples. In Lake Erie *D. longispina* has been reported to have a spring and fall pulse (Chandler 1940) and a fall maximum (Davis 1954). In a definite reference to *D. galeata mendotae*, the species was found to attain maxima in June and again in late August and early September in Pymatuning Reservoir on the Pennsylvania-Ohio border (Borecky 1956). Birge (1898) reported that *D. hyalina* Leydig (a synonym of *D. galeata mendotae*, according to Brooks 1957) had spring and fall maxima and a winter minimum, in Lake Mendota, Wisconsin.

TABLE 2.—*Daphnia galeata mendotae per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	--------	0	--------	--------	--------
4:00 p.m.	0	--------	3	--------	--------	--------
6:00 p.m.	0	--------	0	--------	--------	--------
8:40 p.m.	2	--------	5	--------	--------	--------
10:00 p.m.	7	--------	2	--------	--------	--------
12:00 p.m.	2	--------	2	--------	--------	--------
1:00 a.m.	0	--------	--------	--------	--------	--------
June 27, 28:						
10:00 p.m.	--------	--------	26	--------	--------	--------
12:00 p.m.	280	--------	13	12	7	--------
2:00 a.m.	540	--------	--------	9	--------	--------
4:00 a.m.	210	--------	470	9	180	--------
July 16, 17:						
7:00 p.m.	12	--------	23	35	16	14
9:00 p.m.	3,000	--------	180	29	89	66
11:00 p.m.	3,000	--------	1,400	100	52	49
1:00 a.m.	1,200	--------	1,900	65	43	49
3:00 a.m.	2,500	--------	2,900	100	100	54
4:30 a.m.	920	--------	1,600	45	15	37
August 7:						
5:30 p.m.	100	--------	2,500	400	100	130
7:45 p.m.	2,200	--------	4,000	180	84	83
9:30 p.m.	5,100	--------	2,600	160	67	160
11:00 p.m.	4,400	--------	1,100	120	96	150
August 27:						
5:45 p.m.	0	--------	1,100	160	31	--------
7:30 p.m.	1	--------	640	87	--------	19
9:00 p.m.	2,300	--------	30	21	58	23
11:00 p.m.	1,400	--------	29	43	--------	9
October 7:						
5:15 p.m.	61	--------	650	130	31	24
7:00 p.m.	740	--------	780	34	23	--------
9:15 p.m.	600	--------	620	40	19	15
November 18:						
4:30 p.m.	18	--------	29	6	5	5
6:00 p.m.	32	--------	13	3	4	--------
8:00 p.m.	81	--------	--------	--------	2	5
10:00 p.m.	19	--------	29	14	3	--------
1955						
June 30:						
6:00 p.m.	1	4	9	8	3	2
8:30 p.m.	2	26	19	6	1	2
11:30 p.m.	24	11	8	3	1	0
July 24:						
4:15 p.m.	8	870	8	25	7	3
6:15 p.m.	50	540	220	3	1	2
8:15 p.m.	59	18	12	3	--------	1
10:45 p.m.	57	11	6	0	0	0
October 2:						
2:00 p.m.	9	680	1,300	--------	--------	--------
4:20 p.m.	27	1,100	1,500	530	49	27
6:30 p.m.	130	1,100	850	210	6	6
8:20 p.m.	290	1,100	910	110	6	9
10:30 p.m.	290	240	--------	--------	4	5

D. galeata mendotae was strongly partial to the upper strata. The young were generally nearer the surface than the adults. A similar distribution was observed for *D. hyalina* Leydig by Juday (1903) in Winona Lake, Indiana. In the present study *D. galeata mendotae* was never taken in large numbers below the metalimnion, although some, mostly large, were observed in the deepest samples. *D. galeata* was absent or scarce at the surface during the bright daylight hours, when the greatest numbers were usually taken at 10 meters. It moved to the surface in large numbers at dusk, however, and reached its maximum abundance there about 1½ hours after sunset. During the July 1954 study the maximum was observed in successive surface samples taken 45 minutes and 2 hours 45 minutes after sunset, but a sample between these times probably would have contained a still larger number. Abundance declined around midnight or somewhat before, and increased again toward dawn. The latter fluctuation occurred on both of the occasions when surface samples were taken until daybreak (June 27–28 and July 16–17, 1954). On both occasions, however, the numbers at the surface had dropped off sharply by the time (an hour before sunrise) the last samples were taken. The same type of drop in surface abundance in the middle of the night was noted for *Daphnia longispina* in two Colorado mountain lakes (Pennak 1944).

Vertical movement below the metalimnion was limited except in the early August study of 1954, when the small numbers at 20 meters (metalimnion 10–18 meters) decreased in evening samples. Considerable movement upward from the metalimnion was evident, however, on July 16–17 and August 7, 1954. Numbers at 10 meters (metalimnion 10 to somewhat less than 20 meters) on these dates increased out of proportion to decreases below the metalimnion. A graphical representation of the changes in vertical distribution of this species on August 7, 1954, is presented in figure 2. During the July 16–17 study there must have been a daytime concentration between th surface and 10 meters to account for the prodigious increase at the surface before numbers changed greatly at 10 meters.

The young of *D. galeata mendotae* appeared to reach the surface before the adults, perhaps because they had not so far to move. This difference of behavior was especially noticeable on August 7, 1954, when the young made-up the entire catch in the first surface collection (5:30 p.m.) and practically all in the second (7:45 p.m.), but the older ones had become numerous by the time of the third surface sample (9:30 p.m.).

Vertical movement of *D. hyalina* Leydig has been reported in several Wisconsin lakes (Juday 1904) but little was noted in Lake Mendota, Wisconsin (Birge 1895). Several accounts have been published of diurnal migrations of *D. longispina*, but since the exact variety is not usually known, they are not discussed here. Ordinarily the movements have been toward the surface at night, but in one lake a curious migration of large- and medium-sized individuals to the surface in daytime was observed (Southern and Gardiner, 1932).

Daphnia galeata mendotae reproduces sexually in Lake Michigan in the fall. In 1954 a few females with ephippia in early stages of development were seen in the early October collections, and many of the females (perhaps 20 percent) bore ephippia, some completely developed, in the mid-November collections. This sexual stage may be somewhat unexpected, since Pennak (1953), stated that ". . . in limnetic populations in large lakes it is thought that [*Daphnia*] reproduction may be entirely parthenogenetic the year round, especially in *Daphnia longispina*." Clemens and Bigelow (1922), however, found many *Daphnia* ephippia in stomachs of ciscoes (*Leucichthys* spp.) taken from Lake Ontario in October and Lake Erie in November. The species of *Daphnia* bearing the ephippia was not stated, but it must have been *D. longispina*, at least in the Lake Ontario fish, since this form (*D. l.* variety *hyalina galeata*) was the only one observed in that collection.

TABLE 3.—Daphnia retrocurva *per cubic meter of water off Grand Haven, Michigan, in 1954 and off Frankfort, Michigan, in 1955*

[None taken June 6-7, 1954]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 27, 28:						
10:00 p.m	-------	-------	30	-------	-------	-------
12:00 p.m	1,000	-------	19	6	7	-------
2:00 a.m	880	-------	-------	7	-------	-------
4:00 a.m	590	-------	380	11	18	-------
July 16, 17:						
7:00 p.m	20	-------	100	120	130	77
9:00 p.m	5,400	-------	370	70	220	150
11:00 p.m	9,500	-------	1,900	170	76	100
1:00 a.m	3,000	-------	1,500	150	53	85
3:00 a.m	4,800	-------	2,900	160	160	92
4:30 a.m	2,200	-------	3,300	130	64	94
August 7:						
5:30 p.m	14	-------	4,300	520	150	190
7:45 p.m	960	-------	3,900	280	100	86
9:30 p.m	4,500	-------	4,000	180	150	180
11:00 p.m	6,600	-------	860	150	77	170
August 27:						
5:45 p.m	0	-------	250	98	12	-------
7:30 p.m	1	-------	670	49	-------	13
9:00 p.m	2,200	-------	15	17	25	14
11:00 p.m	1,100	-------	18	23	-------	7
October 7:						
5:15 p.m	9	-------	210	7	4	3
7:00 p.m	24	-------	180	10	8	-------
9:15 p.m	120	-------	140	8	4	3
November 18:						
4:30 p.m	0	-------	2	0	(1)	1
6:00 p.m	0	-------	2	1	0	-------
8:00 p.m	2	-------	-------	-------	(1)	(1)
10:00 p.m	2	-------	0	0	1	-------
1955						
June 30:						
6:00 p.m	0	0	0	1	0	0
8:30 p.m	0	0	2	6	0	0
11:30 p.m	5	2	5	0	0	0
July 24:						
4:15 p.m	3	300	8	17	1	1
6:15 p.m	5	69	81	0	1	0
8:15 p.m	30	19	13	4	-------	2
10:45 p.m	11	11	6	0	0	0
October 2:						
2:00 p.m	2	110	670	-------	-------	-------
4:20 p.m	2	230	430	340	38	27
6:30 p.m	65	280	270	270	26	7
8:20 p.m	100	270	270	320	6	3
10:30 p.m	160	130	-------	-------	3	2

[1] Calculated value less than 0.5.

Daphnia retrocurva

Daphnia retrocurva was absent in the early June 1954 samples, fairly common in late June, at a population peak in July and early August, still common in late August, less so in early October, and scarce in mid-November (table 3). In 1955 it was scarce in late June, uncommon in late July, and fairly common in early October. It was not present in May 1958. Thus the species is probably absent except as eggs through the winter and most of the spring. Eddy (1927) considered the form generally common from April to November in his southern Lake Michigan samples. Population maxima of *D. retrocurva* have been observed in Lake Erie at various times between May and October (Chandler 1940, Davis 1954) and the species has been reported absent December to April (Tidd 1955). It has been found in Lake Superior (Forbes 1891, Birge 1893, Brooks 1957), Lake Ontario (Bigelow 1922, Brooks 1957), Georgian Bay (Sars 1915, Bigelow 1922), and Lake St. Clair (Birge 1894).

The vertical distribution and movements of *D. retrocurva* were almost identical to those of *D. galeata mendotae*, except for a somewhat later maximum at the surface. The comparison of data for *D. retrocurva* collected on August 7, 1954, with those for *D. galeata mendotae* (fig. 2) shows the similarities. *D. retrocurva*, especially the young, favored the upper layers. It avoided the surface in bright daylight, moved to the surface around and following sunset (the young more quickly than the older ones), and decreased at the surface during the middle of the night. On 1 of 2 occasions it increased in the early morning and declined again before sunrise. The evidence suggests some vertical movement as deep as 20 meters (just below the metalimnion) on August 7, 1954, and considerable migration up from a concentration in the metalimnion on July 16–17, 1954. Evidently many *D. retrocurva* concentrated between the surface and 10 meters on the latter date. They migrated up at night and caused a huge increase

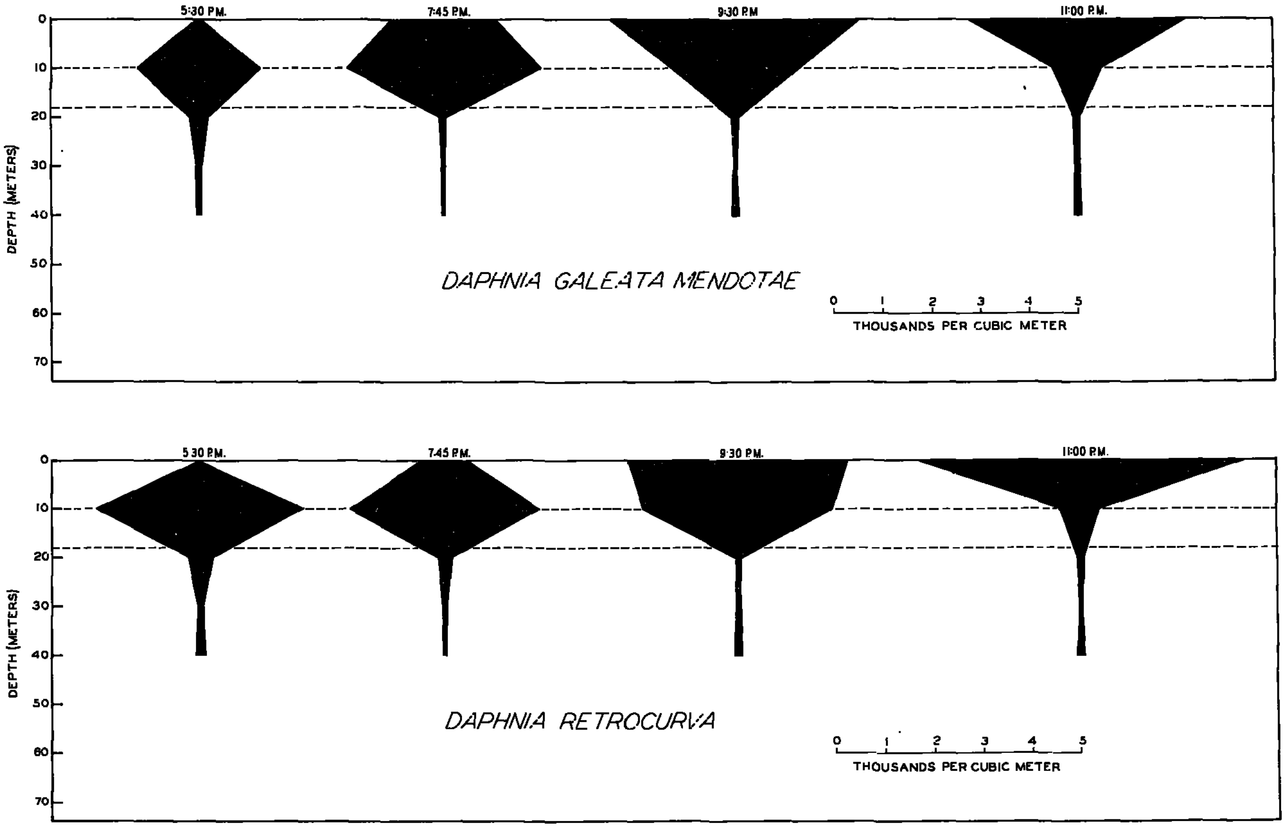

FIGURE 2.—Vertical distribution of *Daphnia galeata mendotae* and *D. retrocurva* on August 7, 1954 (time, Eastern standard; sunset 8:00 p.m.) The broken lines represent limits of the metalimnion. No samples were taken below 40 meters.

at the surface before any appreciable decrease appeared in the metalimnion. Several investigators have reported upward migration of *D. retrocurva* at night (Marsh 1898, Juday 1903 and 1904, and others).

No females bearing ephippia were observed.

Bosmina longirostris

Bosmina longirostris was present during all collection periods except May 1958, but usually was taken in small numbers (table 4). It is possible, however, that significant numbers of small individuals escaped through the No. 2 bolting silk. The species exhibited no striking changes in seasonal abundance, but their absence in May and small numbers in early June indicate that they carry over winter and early spring as eggs. Catches in late June and July of both years were sufficiently large to suggest an early-summer maximum, but differences are too small for definite conclusions. Eddy (1927) reported *B. longirostris* to be rare in southern Lake Michigan but stated that *B. longispina* was the most abundant cladoceran. *B. longirostris* has been reported most common in Lake Erie at various times from May to December and rare or absent at other times (Chandler 1940, Davis 1954, Tidd 1955). It is also present in Lake Superior (Forbes 1891) and Georgian Bay (Sars 1915, Bigelow 1922).

The generally small numbers of individuals taken and the rather erratic changes at the various levels prevent detailed analysis of the vertical distribution and migration of *B. longirostris*. This species ordinarily occurred in greater numbers in the upper layers, and on several occasions, including all three collection dates of 1955, increased at the surface at night. None were at the surface in mid-afternoon in early June 1954 but thereafter numbers at this level increased steadily until midnight. The largest numbers were found at the surface in the first series of samples in July and October 1954, but on both occasions the col-

TABLE 4.—Bosmina longirostris *per cubic meter of water off Grand Haven, Michigan, in 1954 and off Frankfort, Michigan, in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m	0	--------	0	--------	--------	--------
4:00 p.m	0	--------	0	--------	--------	--------
6:00 p.m	2	--------	0	--------	--------	--------
8:40 p.m	12	--------	3	--------	--------	--------
10:00 p.m	20	--------	5	--------	--------	--------
12:00 p.m	20	--------	9	--------	--------	--------
1:00 a.m	1	--------	--------	--------	--------	--------
June 27, 28:						
10:00 p.m	--------	--------	66	--------	--------	--------
12:00 p.m	460	--------	100	30	17	--------
2:00 a.m	420	--------	--------	10	--------	--------
4:00 a.m	1,200	--------	360	61	48	--------
July 16, 17:						
7:00 p.m	330	--------	13	29	17	6
9:00 p.m	37	--------	21	110	17	9
11:00 p.m	12	--------	5	23	21	5
1:00 a.m	5	--------	15	19	20	3
3:00 a.m	15	--------	45	23	13	5
4:30 a.m	79	--------	68	11	6	4
August 7:						
5:30 p.m	27	--------	19	35	9	5
7:45 p.m	26	--------	31	20	34	3
9:30 p.m	8	--------	87	6	25	11
11:00 p.m	31	--------	110	10	8	8
August 27:						
5:45 p.m	5	--------	47	7	4	--------
7:30 p.m	18	--------	37	13	--------	2
9:00 p.m	20	--------	8	5	8	3
11:00 p.m	11	--------	29	5	--------	4
October 7:						
5:15 p.m	160	--------	160	5	13	6
7:00 p.m	59	--------	130	21	6	--------
9:15 p.m	89	--------	89	84	15	7
November 18:						
4:30 p.m	33	--------	24	9	2	3
6:00 p.m	0	--------	10	2	4	--------
8:00 p.m	16	--------	--------	--------	8	5
10:00 p.m	20	--------	57	20	5	4
1955						
June 30:						
6:00 p.m	25	34	52	1	14	5
8:30 p.m	200	220	190	93	4	7
11:30 p.m	320	90	300	14	4	1
July 24:						
4:15 p.m	17	79	310	74	21	12
6:15 p.m	56	92	310	13	2	1
8:15 p.m	280	710	160	23	--------	4
10:45 p.m	160	1,100	300	55	6	3
October 2:						
2:00 p.m	12	99	46	--------	--------	--------
4:20 p.m	39	86	65	110	79	14
6:30 p.m	36	140	76	220	75	45
8:20 p.m	37	120	100	140	73	2
10:30 p.m	65	82	150	160	2	5

lection time was near sunset. Surface collections earlier in the day probably would have yielded smaller catches. The species showed an increase in the two dawn surface samples (June 27–28 and July 16–17, 1954). These limited data indicate that this form usually migrated toward the surface late in the day, and after sinking during the middle of the night, probably moved up again briefly near dawn. Previous investigators have arrived at various conclusions as to the vertical migration of *Bosmina* (several authors have failed to designate the species). Kikuchi (1930) stated that in Japanese lakes *B. longirostris* had a confusing mode of migration and that most did not rise. Pennak (1944) observed only slight movement of this species in a Colorado lake. Juday (1904) reported movement of *Bosmina* to the surface at night in 3 of 7 Wisconsin lakes, but Marsh (1898) found that in Green Lake, Wisconsin, *Bosmina* was more common at the surface in the daytime than at night.

Diaphanosoma brachyurum

Small catches of *Diaphanosoma brachyurum* were made during every collection period except June 1955 (table 5) and May 1958. The species was rare during the studies of early June 1954 and July 1955, but the very small catches on the latter date may have been the result of the upwelling at that time. Although numbers are too small for definite conclusions regarding seasonal abundance, maxima appear to have occurred in early summer and fall of 1954 and fall of 1955. The absence in May 1958 and June 1955 and the scarcity in June 1954 indicate that the form is probably absent during winter and early spring. Eddy (1927) found this species during only September and October in southern Lake Michigan; it was commoner in the latter month. Most of the literature on seasonal abundance of *D. brachyurum* in the Great Lakes as well as smaller bodies of water points to a scarcity or absence during late fall, winter, and early spring, and a population peak in late summer or early fall (Chandler 1940, Davis 1954, Tidd 1955, Marsh 1898 and 1903, Birge 1898, Kofoid 1908, Scheffer and Robinson, 1939; Pennak 1949, Borecky 1956). This species has been reported also for Lake Superior (Birge 1893) and Georgian Bay (Bigelow 1922).

D. brachyurum favored the upper layers but was found at all depths. It increased at the surface at night on every occasion when appreciable numbers were taken. In late August 1954 it was not found at the surface until after sunset; on most other dates a few were at the surface before sunset. The species' preference for the upper strata and its movement to the surface at night in Lake Michigan is similar to its behavior in other lakes (Marsh 1898, Juday 1903 and 1904, Kikuchi 1930, Worthington 1931, Grover and Coker, 1940).

Holopedium gibberum

Holopedium gibberum was taken in July and October 1955, but was not abundant at either

TABLE 5.—Diaphanosoma brachyurum *per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken June 30, 1955]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	--------	0	--------	--------	--------
4:00 p.m.	0	--------	0	--------	--------	--------
6:00 p.m.	0	--------	0	--------	--------	--------
8:40 p.m.	1	--------	0	--------	--------	--------
10:00 p.m.	0	--------	0	--------	--------	--------
12:00 p.m.	0	--------	0	--------	--------	--------
1:00 a.m.	0	--------	--------	--------	--------	--------
June 27, 28:						
10:00 p.m.	--------	--------	0	--------	--------	--------
12:00 p.m.	22	--------	0	2	0	--------
2:00 a.m.	11	--------	--------	0	--------	--------
4:00 a.m.	11	--------	3	0	0	--------
July 16, 17:						
7:00 p.m.	3	--------	3	6	0	0
9:00 p.m.	15	--------	2	2	2	0
11:00 p.m.	18	--------	11	4	2	1
1:00 a.m.	7	--------	9	2	0	0
3:00 a.m.	9	--------	3	5	5	2
4:30 a.m.	3	--------	3	0	1	0
August 7:						
5:30 p.m.	1	--------	0	1	([1])	0
7:45 p.m.	3	--------	3	0	1	0
9:30 p.m.	3	--------	9	0	([1])	0
11:00 p.m.	3	--------	3	2	0	2
August 27:						
5:45 p.m.	0	--------	9	3	1	--------
7:30 p.m.	0	--------	25	2	--------	1
9:00 p.m.	7	--------	3	1	1	1
11:00 p.m.	8	--------	1	1	--------	2
October 7:						
5:15 p.m.	18	--------	12	12	2	1
7:00 p.m.	38	--------	31	27	8	--------
9:15 p.m.	36	--------	39	8	8	2
November 18:						
4:30 p.m.	2	--------	10	4	0	1
6:00 p.m.	23	--------	4	1	([1])	--------
8:00 p.m.	12	--------	--------	--------	4	([1])
10:00 p.m.	5	--------	4	1	1	--------
1955						
July 24:						
4:15 p.m.	1	1	1	0	0	0
6:15 p.m.	1	0	0	0	0	0
8:15 p.m.	1	0	0	1	0	0
10:45 p.m.	0	0	0	0	0	0
October 2:						
2:00 p.m.	2	29	21	--------	--------	--------
4:20 p.m.	3	23	21	10	4	4
6:30 p.m.	11	34	19	21	10	3
8:20 p.m.	18	34	38	14	10	0
10:30 p.m.	19	32	34	51	0	2

[1] Calculated value less than 0.5.

TABLE 6.—Holopedium gibberum *per cubic meter of water off Frankfort, Mich., in 1955*

[None taken June 30, 1955; none taken off Grand Haven, Mich., in 1954 except for two individuals on August 27]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1955						
July 24:						
4:15 p.m.	2	4	0	0	0	0
6:15 p.m.	5	3	1	0	0	0
8:15 p.m.	4	0	0	0	--------	0
10:45 p.m.	0	1	0	0	0	0
October 2:						
2:00 p.m.	5	22	10	--------	--------	--------
4:20 p.m.	10	19	8	5	0	0
6:30 p.m.	24	12	14	1	0	0
8:20 p.m.	6	11	16	0	0	0
10:30 p.m.	6	4	12	2	0	0

time (table 6). Only two individuals were observed in the 1954 collections, both on August 27. Forbes (1882) found the species in Grand Traverse Bay; otherwise, it has not been previously reported for Lake Michigan. It has been found in Lake Superior (Forbes 1891, Birge 1893), Lake St. Clair (Birge 1894), Lake Erie (Bigelow 1922, Wilson 1929), and Georgian Bay (Sars 1915). It was described as very common only in the latter area.

The present data are not considered adequate to permit conclusions regarding the seasonal abundance of *Holopedium*, although there is evidence of absence in winter and spring and a fall maximum. In Lake Nipissing, however, this species was found only in spring in two successive years (Langford 1938).

In Lake Michigan *Holopedium* was taken only in the upper 20 meters, or above the metalimnion. It was found in the daytime surface samples, but increased at the surface toward sunset. The peak occurred 2 hours before sunset in July, but at about sunset in October. In both months the peak was immediately followed by a decrease early in the evening. The October observations are thought to be the more dependable, since very few were taken in July.

Kikuchi (1930) stated that in Japanese lakes *Holopedium gibberum* moved up at night from the region of the thermocline or just above, reaching the surface in one lake but not in 2 others. Langford (1938) reported that in Lake Nipissing *Holopedium* was confined to the upper strata, but he did not discuss its vertical migration.

Sida crystallina

Sida crystallina was taken only in the October 1955 collections (table 7). It was present in most of the upper-level samples, but was not abundant in any of them. It is perhaps somewhat surprising that the species was found at all in such a limnetic habitat. Birge (in Ward and Whipple—1918) considered *Sida crystallina* as intermediate between littoral and limnetic forms and said that such species ". . . are never present in large numbers in the open water, nor are they likely to be found far out from the weedy margin." Southern and Gardiner (1926) found *Sida* occasionally in the littoral zone and stated that Apstein (1896) considered it a littoral species. Wilson (1929), however, observed it in his "lacustric" zone (10–62 meters) in eastern Lake Erie. That the species was not taken in Lake Michigan in 1954 may be due to the greater distance of the collection area from shore. Most other workers have reported *Sida* from the shallow waters of the Great Lakes. The species usually has been reported as rare, although it was abundant in L'Anse Bay of Lake Superior (Forbes 1891) and in Lake St. Clair (Birge 1894).

Sida seems to be most abundant in the fall, as the present data would indicate. Southern and Gardiner (1926) stated that it reaches its maximum numbers in September and is absent during the winter. Eddy (1927) found it only in September and October, and then in very small numbers, in the inshore waters of southern Lake Michigan.

TABLE 7.—Sida crystallina *per cubic meter of water off Frankfort, Mich. in 1955*

[None taken June 30 and July 24, 1955, nor during any of the studies off Grand Haven, Mich., in 1954]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1955						
October 2:						
2:00 p.m	0	5	17	----	----	----
4:20 p.m	0	4	8	5	0	0
6:30 p.m	3	0	12	6	0	0
8:20 p.m	9	2	0	4	0	0
10:30 p.m	6	0	2	7	0	0

All *Sida* collected in the present study were in the upper 20 meters. This region was entirely in the epilimnion and had temperatures of 15.0°–15.1° C. The other levels sampled contained much colder water. No *Sida* were taken at the surface before sunset, but they were present in each of the three nighttime surface samples, and were most numerous about 2 hours after sunset. Numbers are too small for further conclusions regarding vertical migration.

Leptodora kindti

The large cladoceran *Leptodora kindti* was never taken in large numbers (table 8), but owing to its size it made up the bulk of a few of the samples. This species has been reported by nearly all investigators of Great Lakes zooplankton. It was absent in the early-June collection of 1954, but appeared in the late-June samples. It reached its peak of abundance in July and early August, decreased somewhat in late August and had nearly disappeared by mid-November. In 1955 it was lacking in the late-June collections, and was apparently somewhat less numerous in July than in early October. It was not taken in May 1958. The data indicate an absence of *Leptodora* in Lake Michigan during winter and spring.

TABLE 8.—Leptodora kindti *per 10 cubic meters of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken June 6-7, 1954 and June 30, 1955]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 27, 28:						
10:00 p.m	----	----	19	----	----	----
12:00 p.m	489	----	27	1	12	----
2:00 a.m	374	----	----	1	----	----
4:00 a.m	170	----	193	7	7	----
July 16, 17:						
7:00 p.m	950	----	55	46	28	21
9:00 p.m	182	----	286	157	37	19
11:00 p.m	301	----	625	20	22	14
1:00 a.m	45	----	241	30	6	11
3:00 a.m	413	----	587	34	10	15
4:30 a.m	41	----	562	34	16	12
August 7:						
5:30 p.m	9	----	316	33	10	23
7:45 p.m	890	----	499	27	23	28
9:30 p.m	398	----	1,811	27	24	37
11:00 p.m	658	----	926	18	23	31
August 27:						
5:45 p.m	10	----	146	14	5	----
7:30 p.m	46	----	123	71	----	6
9:00 p.m	273	----	4	2	8	6
11:00 p.m	219	----	8	4	----	4
October 7:						
5:15 p.m	0	----	22	4	1	0
7:00 p.m	10	----	20	0	2	----
9:15 p.m	19	----	35	2	1	1
November 18:						
4:30 p.m	0	----	0	1	0	0
6:00 p.m	8	----	2	0	0	----
8:00 p.m	1	----	0	0	0	0
10:00 p.m	0	----	0	0	0	0
1955						
July 24:						
4:15 p.m	0	120	21	2	0	0
6:15 p.m	16	82	32	0	2	2
8:15 p.m	345	9	0	0	----	1
10:45 p.m	160	10	4	2	0	0
October 2:						
2:00 p.m	0	139	153	----	----	----
4:20 p.m	1	197	181	128	34	11
6:30 p.m	23	163	178	87	14	0
8:20 p.m	173	200	189	120	10	2
10:30 p.m	86	52	163	94	4	0

The present findings on the seasonal distribution of *Leptodora* generally agree with those of other workers. In Lake Michigan, Birge (1894) found none in April and Eddy (1927) reported it in only July and October. It is most common in Lake Erie in late spring, summer, and early fall (Chandler 1940, Davis 1954). The species is absent in smaller lakes from late fall to late spring, and is usually most abundant in late summer to early fall (Birge 1898, Southern and Gardiner, 1926, Marsh 1898 and 1903).

Leptodora was found at all levels in Lake Michigan, but was rather uncommon below the metalimnion. Except for July 1954 the only relatively large catches as deep as 20 meters were made in October 1955, when the epilimnion extended to this depth. Numbers increased at the surface at night, but the time of maximum numbers at the surface varied from more than 1 hour before sunset to nearly 2 hours after sunset. A few were at the surface 2½ hours before sunset in early August 1954. The data for July 1954 suggest a movement to the surface at dawn, but records of surface catches for that date vary so erratically that no safe conclusions may be drawn. No dawn rise was apparent in the June 1954 collections. The vertical movements of *Leptodora* appear to have taken place both in the epilimnion and metalimnion. There is good evidence that in late August 1954 many individuals moved to the surface from a depth greater than 20 meters (metalimnion 10–26 meters). The maximum number was not reached at 20 meters until sunset, after which most individuals disappeared from this level and at 10 meters while the numbers at the surface increased greatly.

Marsh (1901) stated that *Leptodora* appeared at the surface at almost exactly 45 minutes after sunset and left 45 minutes before sunrise, but other workers have not been so definite. Juday (1904) said that in Wisconsin lakes it appeared from shortly after to 1½ hours after sunset, and showed a wide variation in time of leaving. According to Southern and Gardiner (1932) its vertical movements vary from day to day, and some may migrate downward at night. Forbes (1891) found large numbers at the surface on a bright, sunny afternoon in Lake Michigamme, Michigan. Thus it appears that vertical movements of *Leptodora* occur generally, but vary more than the movements of many other crustacean plankters.

Polyphemus pediculus

Polyphemus pediculus was taken only in the collections of late June, July, and early August 1954 and July 1955 (table 9). It was fairly numerous in July 1955, less so in early August 1954, and scarce otherwise. Southern and Gardiner (1926) who observed it in littoral swarms in Lough Derg and the River Shannon, stated that it was absent from November through April. The species has not been previously reported for Lake Michigan, probably owing to its relatively small numbers and short duration of occurrence. It has been found, however, in Lake Superior (Forbes 1891, Birge 1893), Lake Ontario (Pritchard 1931), and is common in Georgian Bay (Sars 1915, Bigelow 1922).

TABLE 9.—Polyphemus pediculus *per 10 cubic meters of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken June 6–7, Aug. 27, Oct. 10, and Nov. 18, 1954, and June 30 and Oct. 2, 1955]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 27, 28:						
10:00 p.m.	....	....	1	....	....	....
12:00 p.m.	9	....	0	0	0	....
2:00 a.m.	19	....	....	1	....	....
4:00 a.m.	28	....	1	0	1	....
July 16, 17:						
7:00 p.m.	77	....	1	0	0	0
9:00 p.m.	3	....	0	0	0	0
11:00 p.m.	1	....	1	0	0	1
1:00 a.m.	0	....	0	0	0	0
3:00 a.m.	0	....	0	0	1	0
4:30 a.m.	0	....	0	0	0	0
August 7:						
5:30 p.m.	16	....	3	2	0	0
7:45 p.m.	87	....	54	0	3	1
9:30 p.m.	17	....	179	1	0	1
11:00 p.m.	17	....	13	2	1	3
1955						
July 24:						
4:15 p.m.	416	126	8	0	40	1
6:15 p.m.	913	209	74	3	0	0
8:15 p.m.	1,159	127	21	8	....	0
10:45 p.m.	517	101	41	54	1	0

Polyphemus definitely favored the upper strata in Lake Michigan, although it was present in some of the samples from 40 meters. Some individuals were counted in all the afternoon samples, but the figures point to a movement to the surface at dusk and dawn such as was described for Japanese lakes by Kikuchi (1930). The meager data, of course, render the statement regarding the dawn movement somewhat tenuous. It seems nearly certain, however, that numbers decrease at the surface immediately following a peak at about sunset or slightly before. In late June 1954 *Polyphemus* increased at the surface from midnight to dawn, but in July of that year none were at the surface after midnight. The very bright moonlight on the latter collection date might have had a strong influence, however.

COPEPODA

Cyclops bicuspidatus

Cyclops bicuspidatus was present on all collection dates and occurred in practically every sample (table 10). It was abundant in June and July 1954, decreased in August, was least common in early October, and had increased moderately by mid-November. In 1955 the form was abundant in late June and July but had declined considerably by early October. It was abundant in the May 1958 samples. Thus the evidence is convincing that *C. bicuspidatus* is more numerous in Lake Michigan in spring and early summer than in late summer and fall. A lack of winter samples prohibits further conclusions regarding seasonal abundance.

TABLE 10.—Cyclops bicuspidatus *per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0		1,400	------	------	------
4:00 p.m.	20	------	1,200	------	------	------
6:00 p.m.	90	------	1,500	------	------	------
8:40 p.m.	1,900	------	750	------	------	------
10:00 p.m.	2,500	------	790	------	------	------
12:00 p.m.	1,700	------	600	------	------	------
1:00 a.m.	300	------	------	------	------	------
June 27, 28:						
10:00 p.m.	------	------	1,100	------	------	------
12:00 p.m.	1,200	------	480	420	80	------
2:00 a.m.	850	------	------	280	------	------
4:00 a.m.	630	------	1,400	310	190	------
July 16, 17:						
7:00 p.m.	1,200	------	730	750	480	170
9:00 p.m.	3,200	------	1,300	990	570	260
11:00 p.m.	1,600	------	780	510	240	110
1:00 a.m.	690	------	790	490	290	110
3:00 a.m.	720	------	740	370	160	110
4:30 a.m.	340	------	2,200	360	180	170
August 7:						
5:30 p.m.	0	------	870	380	250	150
7:45 p.m.	80	------	280	190	140	50
9:30 p.m.	100	------	580	100	100	60
11:00 p.m.	150	------	2,400	90	90	50
August 27:						
5:45 p.m.	(1)	------	150	300	100	------
7:30 p.m.	30	------	600	200	------	20
9:00 p.m.	130	------	530	200	100	60
11:00 p.m.	310	------	700	60	------	80
October 7:						
5:15 p.m.	0	------	60	30	0	20
7:00 p.m.	10	------	60	30	10	------
9:15 p.m.	30	------	50	20	10	0
November 18:						
4:30 p.m.	180	------	130	80	20	0
6:00 p.m.	550	------	150	40	10	------
8:00 p.m.	250	------	------	------	20	10
10:00 p.m.	270	------	80	20	20	------
1955						
June 30:						
6:00 p.m.	140	250	600	2,200	1,100	280
8:30 p.m.	570	380	440	1,600	250	190
11:30 p.m.	970	3,000	580	370	150	160
July 24:						
4:15 p.m.	0	820	1,600	680	310	140
6:15 p.m.	30	290	1,500	220	60	70
8:15 p.m.	170	470	280	80	------	90
10:45 p.m.	1,600	490	180	130	50	10
October 2:						
2:00 p.m.	10	90	350	------	------	------
4:20 p.m.	10	110	70	110	40	80
6:30 p.m.	30	240	90	180	70	30
8:20 p.m.	60	200	240	90	30	0
10:30 p.m.	220	60	------	------	20	10

[1] Calculated value less than 0.5.

Eddy (1927) reported *C. bicuspidatus* common in southern Lake Michigan in April (his earliest sampling date) and May, but lacking in June. It was common to abundant from July to September, rare in October, common again in November, and absent in December. These findings are similar to those of the present study, except for the June data. Lake Erie workers have observed a spring maximum and generally low abundance the remainder of the year (Chandler 1940, Andrews 1953, Davis 1954, Tidd 1955). In smaller bodies of water *C. bicuspidatus* usually has been found to be uncommon in summer (Marsh 1903, Kofoid 1908, Plew and Pennak, 1949). Pennak (1949) described an exception, however, in one Colorado mountain lake which had an indefinite summer maximum. A summer scarcity existed in the shallow ends of Lake Washington (Scheffer and Robinson, 1939).

C. bicuspidatus generally preferred the upper 20 meters, but fairly large numbers occasionally were found at 30 and 40 meters. The species migrated to the surface at night; good evidence exists of some movement even at the 40-meter level. There appeared to be some movement through the metalimnion. Surface samples contained maximum numbers only 45 minutes after sunset on two occasions, but the numbers in surface samples were usually largest in the last sample taken, as late as 4 hours after sunset. *C. bicuspidatus* exhibited little vertical movement in Winona Lake, Indiana (Juday 1903) and in Colorado mountain lakes (Pennak 1944), but it ascended at night in Lake Mendota, Wisconsin (Birge 1895), in Caroga Lake, New York (Maloney and Tressler, 1942), and in Merom Gravel Pit Lake, Indiana (Plew and Pennak, 1949). In the latter lake it migrated during all seasons, but the vertical range was small during the warm months.

Mesocyclops edax

In this report *Mesocyclops edax* and *M. leuckarti* are treated as distinct species, as suggested by Coker (1943). Because *edax*, according to Coker, is much more common and widespread than *leuckarti*, it is probable that the *M. leuckarti* of North American literature is usually the same form as *M. edax* of this report. Comparisons with the findings of other workers are made on this assumption.

No striking changes took place in the abundance of *M. edax* in 1954 from late June to early October (table 11). During most of this period the species was perhaps slightly less plentiful than *Cyclops bicuspidatus*, but in early October it was the more numerous of the two. In mid-November, however, *M. edax* was rare and in early June it was absent. It was not taken in May 1958. Thus *M. edax* is probably absent except in the egg stage in winter and early spring. It was common in the June and October 1955 collections, but rare in those of July. In view of the 1954 data, however, the reality of July scarcity seems questionable. The small catches well may have been a result of the upwelling in which the study was conducted. The scarcity of this species in the upwelled water might have been a result of its avoidance of cold water.

Table 11.—*Mesocyclops edax per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken June 6–7, 1954]

Date and time	Surface	Depths in meters				
		5	10	20	30	40
1954						
June 27, 28:						
10:00 p.m.	-----	-----	0	-----	-----	-----
12:00 p.m.	920	-----	10	20	(1)	-----
2:00 a.m.	690	-----	-----	0	-----	-----
4:00 a.m.	630	-----	500	50	40	-----
July 16, 17:						
7:00 p.m.	1,200	-----	0	0	10	0
9:00 p.m.	500	-----	100	20	20	0
11:00 p.m.	2,100	-----	100	50	50	20
1:00 a.m.	2,000	-----	410	50	0	10
3:00 a.m.	720	-----	320	0	40	10
4:30 a.m.	270	-----	60	20	10	0
August 7:						
5:30 p.m.	120	-----	30	50	20	70
7:45 p.m.	730	-----	1,000	20	10	10
9:30 p.m.	310	-----	580	50	20	10
11:00 p.m.	550	-----	270	50	10	10
August 27:						
5:45 p.m.	20	-----	150	10	10	-----
7:30 p.m.	180	-----	110	0	-----	10
9:00 p.m.	1,300	-----	0	20	0	20
11:00 p.m.	510	-----	70	10	-----	20
October 7:						
5:15 p.m.	30	-----	140	30	50	30
7:00 p.m.	90	-----	280	20	30	-----
9:15 p.m.	330	-----	440	30	40	40
November 18:						
4:30 p.m.	0	-----	0	0	0	0
6:00 p.m.	0	-----	0	10	0	-----
8:00 p.m.	20	-----	-----	-----	0	(1)
10:00 p.m.	90	-----	0	0	0	-----
1955						
June 30:						
6:00 p.m.	110	410	300	40	0	0
8:30 p.m.	180	410	200	10	30	0
11:30 p.m.	190	520	340	80	0	0
July 24:						
4:15 p.m.	20	70	0	0	0	0
6:15 p.m.	0	50	0	0	0	0
8:15 p.m.	40	0	0	0	-----	0
10:45 p.m.	30	0	0	0	0	0
October 2:						
2:00 p.m.	0	110	340	-----	-----	-----
4:20 p.m.	0	180	40	290	40	40
6:30 p.m.	80	380	280	220	20	20
8:20 p.m.	230	340	460	80	30	10
10:30 p.m.	330	270	-----	-----	20	30

[1] Calculated value less than 0.5.

Other workers also have found *M. edax* to be a warm-season species. In the various Lake Erie studies it has been reported most common from June to September (Chandler 1940), late August to early September (Andrews 1953), May to October (Davis 1954), and June to August (Tidd 1955). Both Andrews and Tidd reported it lacking from December until mid-spring. The same summer maxima and winter scarcities have been described for several smaller bodies of water (Birge 1898, Marsh 1903, Kofoid 1908). In the Great Lakes other than Lake Erie, *M. edax* has been reported as common in Lakes St. Clair and Michigan (Marsh 1895) and Georgian Bay (Sars 1915). Eddy (1927) did not take it in southern Lake Michigan. The species apparently has not been reported for Lake Superior.[1]

M. edax was more nearly restricted to the upper strata than was *Cyclops bicuspidatus*. Not many *edax* were taken below the metalimnion, even though most series contained a few even at 40 meters. Numbers at the surface increased markedly at night, except during the late June 1955 study. Migration up from the metalimnion took place in July and early August 1954, but there was no evidence of movement in the hypolimnion. The data on time of maximum abundance at the surface are inconclusive, due to the variability. *M. leuckarti* [*edax*] was an active vertical migrant in Lake Mendota (Birge 1895) and was assumed to behave similarly in Lake Erie (Wilson 1929). Juday (1903) reported little increase at the surface at night in Winona Lake, Indiana.

Eucyclops prasinus

Only a single *Eucyclops prasinus* was observed in all collections. Since, however, Eddy (1927) found the species common to abundant in southern Lake Michigan and Marsh (1909) stated that it was common in all of the Great Lakes, it seems likely that many individuals of this minute cope-

[1] Forbes (1891) in his report on Lake Superior Entomostraca, listed *Cyclops edax*, but stated in his text. "This *Cyclops* was taken in moderate numbers from Lake Michigamme only." Davis (1954) apparently misinterpreted the listing (an understandable mistake in view of the title of the paper) and erroneously credited Forbes with having found the species in Lake Superior.

pod escaped through the meshes of the No. 2 bolting silk. Fortunately several samples taken with No. 10 bolting silk at 5 meters near the 1955 sampling area were available for examination. One each of these collections had been made in May, June, August, September, and November, 1955. *E. prasinus* was present in all but the May sample, and was most numerous, although not abundant, in the September collection. It appeared to be much less plentiful than either *Cyclops biscuspidatus* or *Mesocyclops edax*, but the evidence for this conclusion is of course limited.

Diaptomus

The abundant genus *Diaptomus* was represented by the species *minutus*, *sicilis*, *ashlandi*, and *oregonensis*. Only the mature males were enumerated separately. Females and copepodites of all species were combined in the counts. The same species were reported for Lake Michigan by Marsh (1895) and all but *D. oregonensis* were found by Eddy (1927). All four are also present in Lake Erie (Wilson 1929, Chandler 1940, Davis 1954, and Tidd 1955), and in Lake St. Clair (Birge 1894). Forbes (1891) stated that *D. sicilis* was the most abundant entomostracan in Lake Superior, and Eddy (1943) reported this species as among the most numerous copepods in the same lake. Sars (1915) found *D. oregonensis* abundant and *D. minutus* less so in Georgian Bay.

In the following treatment of the individual species, the discussion, of course, refers to mature males only, although most findings probably apply to mature females as well. Because only a small portion of each sample was examined for diaptomids, final figures for mature males are for the most part based on the observation of relatively few individuals. For this reason the figures vary somewhat erratically. Despite this weakness, however, the data reveal certain obvious features of seasonal abundance and vertical distribution. The comparisons with results of other investigators may not always be completely valid, since some workers may have included copepodites as well as adults in their observations.

Diaptomus minutus

The adult males of this species were most numerous in late June, and did not decline sharply until late August (table 12). They were entirely absent in October 1955, and nearly so in October 1954, but in 1954 they reappeared in considerable numbers in November. They were present in the May 1958 samples. Findings of other workers differ appreciably, but generally *D. minutus* has been reported to have maximum abundance in summer. Eddy (1927) found *D. minutus* common in southern Lake Michigan from July to November in one year and in all months of collection (May, July, October) of another year. Chandler (1940) found the species in Lake Erie from June to September only. Tidd (1955) reported it present in Erie throughout the year but most plentiful in summer, and Davis (1954) found the maximum abundance in April, May, and July. It was scarce in Lake Nipissing in May, but the abundance rose

TABLE 12.—Diaptomus minutus *(adult males) per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken October 2, 1955]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m	0	-------	100	-------	-------	-------
4:00 p.m	0	-------	30	-------	-------	-------
6:00 p.m	30	-------	30	-------	-------	-------
8:40 p.m	60	-------	60	-------	-------	-------
10:00 p.m	200	-------	130	-------	-------	-------
12:00 p.m	220	-------	60	-------	-------	-------
1:00 a.m	250	-------	-------	-------	-------	-------
June 27, 28:						
10:00 p.m	-------	-------	0	-------	-------	-------
12:00 p.m	910	-------	10	0	10	-------
2:00 a.m	600	-------	-------	40	-------	-------
4:00 a.m	670	-------	90	20	40	-------
July 16, 17:						
7:00 p.m	750	-------	10	30	10	0
9:00 p.m	70	-------	0	0	20	0
11:00 p.m	200	-------	30	20	20	0
1:00 a.m	270	-------	50	0	0	0
3:00 a.m	210	-------	100	20	0	0
4:30 a.m	90	-------	0	40	10	0
August 7:						
5:30 p.m	30	-------	30	50	0	20
7:45 p.m	140	-------	30	0	0	0
9:30 p.m	40	-------	90	0	0	0
11:00 p.m	310	-------	40	0	0	0
August 27:						
5:45 p.m	10	-------	0	20	0	-------
7:30 p.m	40	-------	0	0	-------	0
9:00 p.m	40	-------	0	0	0	0
11:00 p.m	70	-------	20	0	-------	0
October 7:						
5:15 p.m	0	-------	20	0	0	0
7:00 p.m	0	-------	0	0	0	0
9:15 p.m	0	-------	0	0	0	0
November 18:						
4:30 p.m	80	-------	90	60	60	60
6:00 p.m	480	-------	90	70	120	-------
8:00 p.m	90	-------	-------	-------	160	20
10:00 p.m	50	-------	170	140	60	-------
1955						
June 30:						
6:00 p.m	180	410	80	0	70	20
8:30 p.m	710	240	120	30	0	40
11:30 p.m	180	200	0	30	0	0
July 24:						
4:15 p.m	0	150	0	0	0	0
6:15 p.m	110	180	60	0	0	0
8:15 p.m	180	40	50	-------	0	0
10:45 p.m	150	0	0	110	0	0

rapidly in June to a maximum in July and August (Langford 1938).

Adult males of *D. minutus* strongly favored the upper layers. They were taken in appreciable numbers in deeper water only in November 1954, when the metalimnion was deep and poorly developed. The number at the surface increased definitely at night. On two occasions *D. minutus* was absent at the surface in the afternoon but it later appeared there in number. The time of maximum abundance at the surface, however, does not bear a consistent relation with time of sunset. Langford (1938) also found this form concentrated in the upper layers of Lake Nipissing, where its diurnal movements were complex. Movement to the surface at night did not always occur and when it did the sexes behaved differently. Marsh (1898) observed no evidence of vertical migration in Green Lake, Wisconsin. In Caroga Lake, New York, adults were concentrated below the thermocline, and showed a slight vertical movement (Maloney and Tressler, 1942).

Diaptomus sicilis

The relatively large numbers of adult males of this form in early June and mid-November 1954 suggests that it is the predominant species during the cold months. The mature males were fairly common in early June 1954, less so in late June and July, rare in early August, absent in late August, moderately represented in early October, and most abundant in November (table 13). The catches in 1955 were similar to those of the corresponding dates of 1954. The species was present in the May 1958 collections. Eddy (1927) found the species only occasionally in southern Lake Michigan in June, August, and September of one year, and not at all in another. Davis (1954) reported *D. sicilis* from Lake Erie throughout the year, but Tidd (1955) found it lacking in September–December.

Mature males of *D. sicilis* preferred the upper layers, but avoided the surface in bright daylight. After sunset, however, they were often most numerous at the surface. References to the vertical migration of this species are few. Wilson (1929) stated only that it does not migrate as actively in Lake Erie as *D. ashlandi*, and Marsh (1898) observed no evidence of vertical migration in Green Lake, Wisconsin.

TABLE 13.—Diaptomus sicilis *(adult males) per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken August 27, 1954]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	-------	0	-------	-------	-------
4:00 p.m.	0	-------	0	-------	-------	-------
6:00 p.m.	10	-------	0	-------	-------	-------
8:40 p.m.	500	-------	60	-------	-------	-------
10:00 p.m.	920	-------	30	-------	-------	-------
12:00 p.m.	400	-------	0	-------	-------	-------
1:00 a.m.	410	-------	-------	-------	-------	-------
June 27, 28:						
10:00 p.m.	-------	-------	130	-------	-------	-------
12:00 p.m.	180	-------	10	0	20	-------
2:00 a.m.	210	-------	-------	40	-------	-------
4:00 a.m.	110	-------	30	60	0	-------
July 16, 17:						
7:00 p.m.	20	-------	90	0	0	0
9:00 p.m.	130	-------	10	0	10	0
11:00 p.m.	0	-------	20	80	0	0
1:00 a.m.	0	-------	20	0	0	0
3:00 a.m.	70	-------	30	20	0	0
4:30 a.m.	0	-------	30	40	0	0
August 7:						
5:30 p.m.	0	-------	0	0	0	0
7:45 p.m.	0	-------	0	0	0	0
9:30 p.m.	0	-------	0	0	0	0
11:00 p.m.	50	-------	0	0	0	0
October 7:						
5:15 p.m.	0	-------	40	60	10	10
7:00 p.m.	0	-------	40	60	10	-------
9:15 p.m.	50	-------	100	20	0	0
November 18:						
4:30 p.m.	90	-------	1,100	540	120	80
6:00 p.m.	2,800	-------	1,500	200	110	-------
8:00 p.m.	1,500	-------	-------	-------	30	90
10:00 p.m.	2,500	-------	540	450	80	-------
1955						
June 30:						
6:00 p.m.	30	90	50	80	60	30
8:30 p.m.	120	0	0	60	60	0
11:30 p.m.	0	30	0	30	0	30
July 24:						
4:15 p.m.	0	40	100	290	0	10
6:15 p.m.	0	50	30	130	0	0
8:15 p.m.	50	80	100	80	-------	0
10:45 p.m.	110	80	90	160	30	0
October 2:						
2:00 p.m.	0	0	0	-------	-------	-------
4:20 p.m.	0	0	0	30	0	0
6:30 p.m.	50	50	50	0	0	0
8:20 p.m.	0	0	0	0	0	0
10:30 p.m.	60	0	-------	-------	0	0

Diaptomus ashlandi

Adult males of this species were taken on all collection dates, and they were the most numerous of the diaptomids in the July collections of both years. The population was relatively low in early June, but increased rapidly in late June and continued abundant in July and early August (table 14). Numbers had declined by late August, and *ashlandi* was scarce in early October of both years. By mid-November, however, the abundance had reattained the summer levels. Definite maxima of adult males occurred, therefore, in early summer and late fall. Other Great Lakes investigators have generally agreed on a peak of abundance in the summer, but not in the fall. Eddy (1927) reported this species most plentiful in Lake

Michigan in July in his 1926–27 samples (collection made also in May and October), but did not find it in his 1887–88 samples. Chandler (1940) observed *D. ashlandi* in nearly all of his Lake Erie samples and reported a May–September maximum; Davis (1954) observed maxima in January and June–July; and Tidd (1955) failed to take them in September–December. The peak abundance of this species in Lake Washington, reached in April and May, was followed by a near-disappearance in July and a small pulse in October (Scheffer and Robinson, 1939).

Adult males of *D. ashlandi* favored the upper layers, but during the summer of 1954 did not avoid the lower levels as much as did the other diaptomid males. They were usually absent from the surface in bright daylight, but were often most abundant there at night. For some unknown reason, however, few migrated to the surface in early June 1954. Wilson's (1929) daytime samples from eastern Lake Erie indicated that *D. ashlandi* was mostly near the bottom in deeper water and near the surface in shallower water. He concluded that the species was an active diurnal migrant in the "lacustric" zone, but not in the littoral area.

TABLE 14.—Diaptomus ashlandi *(adult males) per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m	0	—	20	—	—	—
4:00 p.m	0	—	0	—	—	—
6:00 p.m	0	—	30	—	—	—
8:40 p.m	0	—	60	—	—	—
10:00 p.m	0	—	60	—	—	—
12:00 a.m	20	—	80	—	—	—
1:00 a.m	0	—	—	—	—	—
June 27, 28:						
10:00 p.m	—	—	90	—	—	—
12:00 p.m	700	—	60	40	20	—
2:00 a.m	460	—	—	20	—	—
4:00 a.m	40	—	240	60	40	—
July 16, 17:						
7:00 p.m	20	—	0	60	10	0
9:00 p.m	230	—	190	50	80	50
11:00 p.m	1,600	—	340	70	70	50
1:00 a.m	340	—	170	80	50	60
3:00 a.m	380	—	390	60	70	30
4:30 a.m	20	—	320	90	10	0
August 7:						
5:30 p.m	0	—	170	0	20	40
7:45 p.m	310	—	520	30	40	0
9:30 p.m	460	—	360	0	30	20
11:00 p.m	670	—	80	30	10	30
August 27:						
5:45 p.m	0	—	40	0	0	—
7:30 p.m	20	—	110	0	—	0
9:00 p.m	290	—	0	0	0	0
11:00 p.m	150	—	60	50	—	10
October 7:						
5:15 p.m	0	—	0	0	0	0
7:00 p.m	20	—	0	0	0	—
9:15 p.m	0	—	50	0	0	0
November 18:						
4:30 p.m	90	—	980	100	50	10
6:00 p.m	380	—	970	70	40	—
8:00 p.m	270	—	—	—	20	20
10:00 p.m	930	—	250	210	20	—
1955						
June 30:						
6:00 p.m	0	0	160	80	60	0
8:30 p.m	90	110	70	60	30	0
11:30 p.m	220	80	110	60	0	0
July 24:						
4:15 p.m	0	150	210	0	0	0
6:15 p.m	0	230	250	0	20	0
8:15 p.m	0	120	50	0	—	0
10:45 p.m	370	80	40	40	0	0
October 2:						
2:00 p.m	0	30	0	—	—	—
4:20 p.m	0	0	0	0	0	0
6:30 p.m	0	50	0	0	0	0
8:20 p.m	0	0	0	0	0	0
10:30 p.m	60	50	—	—	0	0

TABLE 15.—Diaptomus oregonensis *(adult males) per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m	0	—	0	—	—	—
4:00 p.m	0	—	0	—	—	—
6:00 p.m	0	—	0	—	—	—
8:40 p.m	100	—	0	—	—	—
10:00 p.m	0	—	0	—	—	—
12:00 p.m	0	—	20	—	—	—
1:00 a.m	40	—	—	—	—	—
June 27, 28:						
10:00 p.m	—	—	0	—	—	—
12:00 p.m	40	—	0	0	0	—
2:00 a.m	40	—	—	0	—	—
4:00 a.m	80	—	30	0	0	—
July 16, 17:						
7:00 p.m	20	—	230	90	10	0
9:00 p.m	760	—	30	0	10	0
11:00 p.m	30	—	30	0	0	0
1:00 a.m	30	—	50	0	0	0
3:00 a.m	70	—	60	0	0	0
4:30 a.m	0	—	0	20	0	0
August 7:						
5:30 p.m	0	—	0	0	0	0
7:45 p.m	30	—	180	0	0	0
9:30 p.m	40	—	670	0	10	20
11:00 p.m	70	—	190	20	0	30
August 27:						
5:45 p.m	0	—	150	40	20	—
7:30 p.m	0	—	0	50	—	0
9:00 p.m	20	—	0	0	0	10
11:00 p.m	290	—	0	50	—	10
October 7:						
5:15 p.m	0	—	40	0	10	0
7:00 p.m	40	—	40	0	0	—
9:15 p.m	30	—	50	0	0	0
November 18:						
4:30 p.m	80	—	850	140	140	0
6:00 p.m	1,100	—	1,100	70	120	—
8:00 p.m	1,600	—	—	—	30	140
10:00 p.m	1,400	—	660	190	40	—
1955						
June 30:						
6:00 p.m	0	130	110	0	0	0
8:30 p.m	0	0	30	0	0	0
11:30 p.m	0	50	110	0	0	0
July 24:						
4:15 p.m	0	150	0	100	0	0
6:15 p.m	0	280	0	0	0	0
8:15 p.m	20	0	0	0	—	0
10:45 p.m	70	80	40	0	0	0
October 2:						
2:00 p.m	10	20	110	—	—	—
4:20 p.m	10	50	60	0	0	0
6:30 p.m	0	50	90	0	0	0
8:20 p.m	0	270	50	0	0	0
10:30 p.m	60	50	—	—	0	0

Diaptomus oregonensis

The adult males of this species were by far the most numerous diaptomid in the October 1955 collections, and were second only to *D. sicilis* in the November 1954 samples. This high abundance was perhaps surprising in view of the opinions of Marsh (1893, 1895, and 1907), that *D. oregonensis* is not nearly so common as the other species in the upper Great Lakes. Eddy (1927) did not, as a matter of fact, find it at all in his southern Lake Michigan collections. It has been reported to be abundant in Georgian Bay, however, by Sars (1915). In the present study *D. oregonensis* was taken on all collection dates, but was most abundant in November; another less definite pulse occurred in July and August (table 15). A single maximum has been generally observed by other investigators (Chandler 1940 in Lake Erie, April–September; Davis 1954 in Lake Erie, July–October; Langford 1938 in Lake Nipissing, late July and August; Birge 1898 in Lake Mendota, late May and June; Marsh 1903 in Lake Winnebago, June–November).

D. oregonensis was concentrated above the metalimnion, although a few were taken below this level. Diurnal movement resembled that of the other diaptomids in that definite movement to the surface took place at night. This tendency for some reason was not so marked in 1955. Mature males of the species moved up at night on 3 of 5 dates in Lake Nipissing (Langford 1938). Juday (1903) reported a marked increase of *D. oregonensis* at the surface at night in Winona Lake, Indiana, but Birge (1895) observed no vertical movement in Lake Mendota, Wisconsin.

Copepodites of Diaptomus

A description of the seasonal changes of abundance of the copepodites of *Diaptomus* is difficult because mature females were combined with the copepodites in the enumerations (table 16). A fairly reliable estimate of copepodite numbers on each collection date was arrived at, however, by assuming that the mature males and females were of approximately equal numbers on any given date, and subtracting the number of mature males from the combined figures for mature females and copepodites. The above assumption may be risky, but Davis (1954) indicated that adult males and females were equally represented in his Lake Erie collections, at least in midsummer. The calculated numbers of copepodites included, of course, only those immature individuals large enough to be taken in No. 2 bolting silk; thus all nauplii and metanauplii and probably some small copepodites were excluded.

The abundance of copepodites in 1954 was low in early June, much higher in late June, at a peak in July and early August, moderately high in late August, at another maximum in early October, and low in November. The estimation of low abundance in early June was based on the assumption that no concentrations existed below 10 meters, since no deeper samples were taken in that period. The 1955 calculations show a progressively higher number of copepodites during the three collection periods of late June, late July, and early October, but a decrease could have oc-

TABLE 16.—*Total adult female and immature* Diaptomus *per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	--------	2,300	--------	--------	--------
4:00 p.m.	0	--------	1,100	--------	--------	--------
6:00 p.m.	10	--------	1,000	--------	--------	--------
8:40 p.m.	150	--------	940	--------	--------	--------
10:00 p.m.	590	--------	980	--------	--------	--------
12:00 p.m.	820	--------	790	--------	--------	--------
1:00 a.m.	460	--------	--------	--------	--------	--------
June 27, 28:						
10:00 p.m.	--------	--------	3,900	--------	--------	--------
12:00 p.m.	3,400	--------	1,900	1,300	360	--------
2:00 a.m.	4,000	--------	--------	1,700	--------	--------
4:00 a.m.	2,500	--------	3,000	1,700	1,100	--------
July 16, 17:						
7:00 p.m.	310	--------	4,000	4,800	1,600	640
9:00 p.m.	2,600	--------	2,500	2,400	1,100	640
11:00 p.m.	4,500	--------	2,100	3,200	1,200	540
1:00 a.m.	3,900	--------	2,600	3,700	980	700
3:00 a.m.	3,800	--------	1,700	3,500	1,300	520
4:30 a.m.	1,500	--------	3,500	2,500	1,000	540
August 7:						
5:30 p.m.	70	--------	4,900	3,800	970	990
7:45 p.m.	3,100	--------	4,300	2,900	1,200	590
9:30 p.m.	2,500	--------	3,200	3,300	1,300	1,000
11:00 p.m.	3,400	--------	2,600	2,300	990	1,100
August 27:						
5:45 p.m.	40	--------	580	4,100	2,000	--------
7:30 p.m.	180	--------	870	3,500	--------	720
9:00 p.m.	1,900	--------	1,500	3,500	1,500	1,300
11:00 p.m.	1,400	--------	1,900	5,600	--------	660
October 7:						
5:15 p.m.	1,500	--------	5,300	2,900	480	570
7:00 p.m.	6,400	--------	7,400	1,800	550	--------
9:15 p.m.	4,700	--------	5,100	1,900	810	380
November 18:						
4:30 p.m.	1,300	--------	3,800	830	500	310
6:00 p.m.	5,900	--------	5,500	620	840	--------
8:00 p.m.	4,900	--------	--------	--------	540	400
10:00 p.m.	5,900	--------	1,700	1,100	560	--------
1955						
June 30:						
6:00 p.m.	430	1,300	1,000	1,500	2,900	510
8:30 p.m.	920	1,700	1,100	940	1,100	1,300
11:30 p.m.	1,400	1,600	1,300	2,000	960	300
July 24:						
4:15 p.m.	110	2,200	7,700	7,900	1,200	120
6:15 p.m.	410	1,300	3,400	2,900	430	130
8:15 p.m.	1,200	2,900	5,400	3,700	--------	220
10:45 p.m.	4,100	5,100	4,100	2,300	300	70
October 2:						
2:00 p.m.	160	3,200	6,300	--------	--------	--------
4:20 p.m.	480	6,400	4,800	5,000	870	5,800
6:30 p.m.	3,300	7,100	4,100	1,800	1,300	1,900
8:20 p.m.	4,100	8,400	4,200	1,200	920	460
10:30 p.m.	4,400	2,200	--------	--------	1,000	120

curred between the latter two dates. Davis (1954) reported juvenile diaptomids most common in Lake Erie from May to October.

Because the diaptomids in the samples were largely copepodites during the summer and early fall, especially the latter, an estimate of vertical distribution and movement of the copepodites may be made by reference to the figures for combined female and immature *Diaptomus* for these months. Nothing more than general observations would be justified, however, since several species were combined and each may act differently from the others. The juveniles favored the upper layers, but not so sharply as the adults. The large numbers of copepodites at the 20-meter level in late August 1954 suggests a concentration in the metalimnion at that time. Practically all the diaptomids at the 30- and 40-meter levels during summer and early fall were copepodites, except for a fair number of *D. ashlandi*. The juveniles, like the mature males of all species, moved upward at night. Ordinarily this migration was not pronounced below 20 meters, but during the October 1955 sampling, when the *Diaptomus* population consisted almost exclusively of immature individuals, the numbers decreased successively at the 40-meter level during the afternoon and evening. Langford (1938) found copepodites of *D. oregonensis* in Lake Nipissing almost entirely below the metalimnion, where they moved very little diurnally. Juveniles of *D. minutus* at the same time were mostly above the metalimnion.

Limnocalanus macrurus

Limnocalanus macrurus was common in all series of collections in 1954 and 1955 (table 17). The numbers varied little throughout the season except for an indication of a maximum in early June. The species was present in only small numbers in the May 1958 samples, but the collections are too few for a reliable estimate of the population size at that time. Eddy (1927) found *Limnocalanus* in only the September 1888 samples of his collections from shallow water in the vicinity of Chicago, but Forbes (1882) considered the species abundant in southern Lake Michigan. Its presence has been reported by most of the other zooplankton investigators in the Great Lakes. Marsh (1898) found *Limnocalanus* throughout the year in Green Lake, Wisconsin, with peaks of abundance in November and especially in May. In Lake Nipissing, however, Langford (1938) reported considerably fewer in May than during the summer.

In the present study *Limnocalanus* was taken primarily in the deeper layers, but it frequently migrated to the surface at night. A sharp metalimnion definitely hindered the vertical movement but did not always stop it. Figure 3 presents graphically the migration when the metalimnion was pronounced and when it was weak. A few individuals were taken at the surface when the water temperature was 20.6° C., but many more appeared there when the temperature was

TABLE 17.—Limnocalanus macrurus *per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0		0			
4:00 p.m.	0		5			
6:00 p.m.	(1)		1			
8:40 p.m.	8		89			
10:00 p.m.	2,900		340			
12:00 p.m.	1,100		190			
1:00 a.m.	850					
June 27, 28:						
10:00 p.m.			190			
12:00 p.m.	19		600	140	59	
2:00 a.m.	11			240		
4:00 a.m.	0		9	260	180	
July 16, 17:						
7:00 p.m.	0		7	4	180	83
9:00 p.m.	0		350	430	40	40
11:00 p.m.	0		0	380	42	14
1:00 a.m.	0		0	410	76	28
3:00 a.m.	0		0	360	68	37
4:30 a.m.	0		3	230	110	70
August 7:						
5:30 p.m.	0		0	180	78	95
7:45 p.m.	0		0	280	97	120
9:30 p.m.	0		0	320	90	52
11:00 p.m.	2		5	400	73	32
August 27:						
5:45 p.m.	0		0	2	150	
7:30 p.m.	0		0	140		44
9:00 p.m.	0		20	170	100	42
11:00 p.m.	0		1	330		49
October 7:						
5:15 p.m.	0		1	11	39	100
7:00 p.m.	3		6	79	85	
9:15 p.m.	8		20	10	200	82
November 18:						
4:30 p.m.	2		2	1	47	170
6:00 p.m.	15		7	41	340	
8:00 p.m.	72				130	56
10:00 p.m.	28		110	62	110	59
1955						
June 30:						
6:00 p.m.	0	0	0	8	31	45
8:30 p.m.	0	2	2	4	120	9
11:30 p.m.	8	16	9	12	32	18
July 24:						
4:15 p.m.	0	5	110	90	110	78
6:15 p.m.	22	19	100	160	69	37
8:15 p.m.	58	65	57	210		82
10:45 p.m.	690	69	150	70	32	63
October 2:						
2:00 p.m.	0	0	1			
4:20 p.m.	0	0	1	0	0	34
6:30 p.m.	0	0	2	0	5	5
8:20 p.m.	1	0	3	5	24	10
10:30 p.m.	6	0	2	2	28	18

[1] Calculated value less than 0.5.

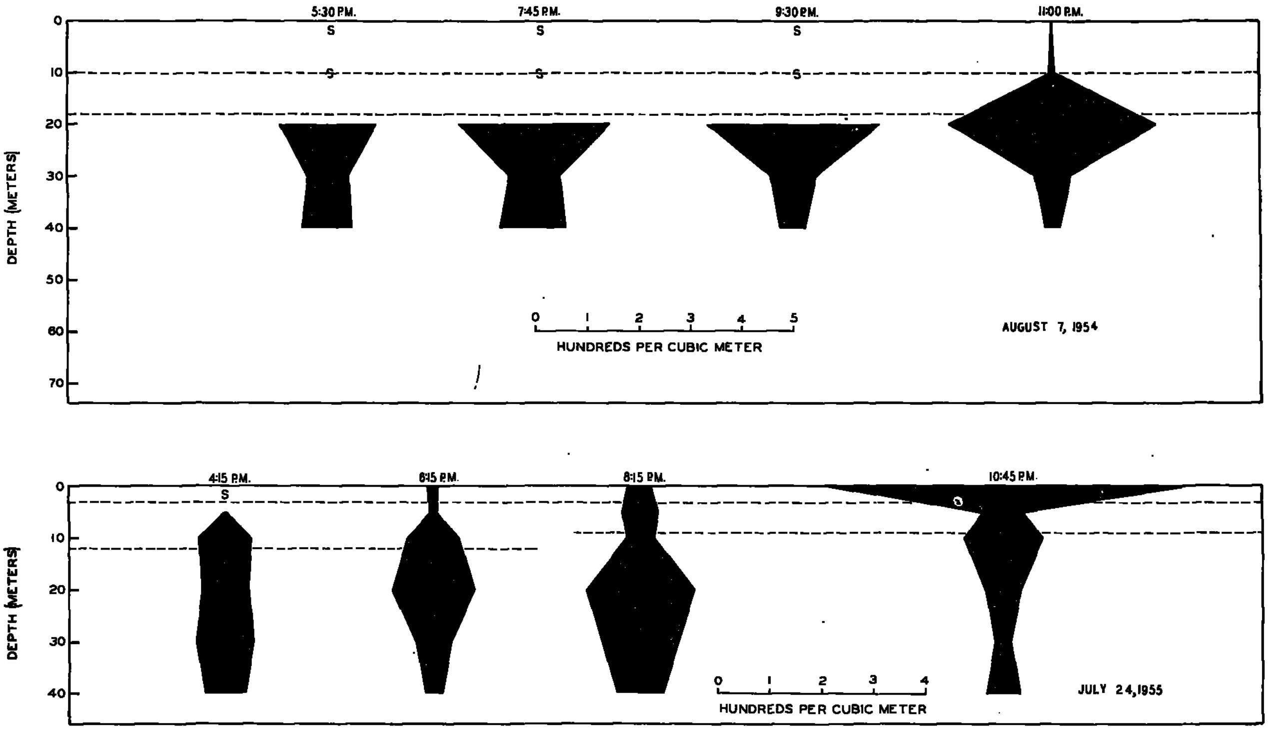

FIGURE 3.—Vertical distribution of *Limnocalanus macrurus* on August 7, 1954 (sunset 8:00 p.m.), and July 24, 1955 (sunset 8:15 p.m.; Eastern standard time). The broken lines represent the limits of the metalimnion. The metalimnion was pronounced on August 7. On July 24 it was distinct at 4:15, less so at 6:15, and weak at 8:15 and 10:45 (see fig. 1). The bottom line of each panel shows the depth of the lake at the sampling locality. No samples were taken below 40 meters; an S indicates samples in which *L. macrurus* did not occur.

8–10° lower. Maximum numbers reached the surface one and one-half to four hours after sunset, but a few were present there two hours before sunset in July 1955, probably as a result of the upwelling on that date. The June 1954 data suggest that the species begins to leave the surface soon after its peak is reached and probably deserts this level by sunrise or sooner. Observations of other investigators suggest, however, that *Limnocalanus* may not always avoid the surface in bright daylight. It has been found in surface samples which presumably were collected in full daylight from comparatively shallow water in Lakes Michigan, Superior, and Erie (Eddy 1927 and 1943, Wilson 1929). In Lakes Superior and Erie the species was actually most abundant at the surface. In the deeper areas of Lake Erie, however, it was almost wholly confined to the lower strata. The same situation prevailed in the deep water of Lake Nipissing (Langford 1938). Juday (1904) reported that in Green Lake, Wisconsin, *Limnocalanus* was not found in the epilimnion, but migrated up to the metalimnion at night.

Epischura lacustris

Although it was never extremely numerous, *Epischura lacustris* was taken on every collection date except May 1958 (table 18). It was less common in early June and November than in the summer of 1954. All individuals in the early June collections were very small juveniles. Thus the evidence is strong that this species is absent in Lake Michigan during the winter and early spring. The density of the summer population varied little. The small number in July 1955 was probably a result of the upwelling. Forbes (1882) was the first to report *Epischura* from Lake Michigan (Grand Traverse Bay). Marsh (1895) found it common in the Traverse Bay region. Eddy (1927) did not find it in southern Lake Michigan in one year, but it was abundant from April to November (lacking at other times) in another. The species has been reported as common in Lake Superior (Forbes 1891) and very abundant in Georgian Bay (Sars 1915). In Lake Erie, Davis (1954) found the form most common in May–October, and Chandler (1940) reported it present in April–October. Apparently disappearance in winter is normal in small lakes also (Marsh 1898 and 1903).

Relatively few *Epischura* were found below the metalimnion in the present study. The species was most plentiful at 10 meters and above in late June, July, and August, when the top of the metalimnion was at 10 meters, but its relative numbers were high at 20 meters in October and November when the metalimnion was below this level. Without exception *Epischura* moved toward the surface at night. The main movement was in the epilimnion, but some individuals appeared to move up from the metalimnion, since the numbers just above this level occasionally increased at the same time the numbers were increasing at the surface. Large concentrations must have existed at depths not sampled, probably between the surface and 10 meters, because the numbers in the surface samples often increased far out of proportion to the decreases in the samples from lower levels. Although some *Epischura* usually were at the surface by sunset, or even somewhat before, the maximum numbers ordinarily did not appear until one to one and one-half hours after sunset. Numbers at the surface then decreased except possibly for a small increase near dawn.

TABLE 18.—Epischura lacustris *per cubic meter of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	------	0	------	------	------
4:00 p.m.	[1]	------	0	------	------	------
6:00 p.m.	21	------	0	------	------	------
8:40 p.m.	10	------	0	------	------	------
10:00 p.m.	5	------	0	------	------	------
12:00 p.m.	1	------	0	------	------	------
1:00 a.m.	0	------	------	------	------	------
June 27, 28:						
10:00 p.m.	------	------	2	------	------	------
12:00 p.m.	93	------	1	1	1	------
2:00 a.m.	48	------	------	0	------	------
4:00 a.m.	54	------	15	0	0	------
July 16, 17:						
7:00 p.m.	11	------	4	.3	2	0
9:00 p.m.	78	------	82	3	3	3
11:00 p.m.	260	------	93	2	6	3
1:00 a.m.	1,400	------	30	2	3	6
3:00 a.m.	85	------	42	1	4	[1]
4:30 a.m.	98	------	11	0	1	1
August 7:						
5:30 p.m.	0	------	6	4	1	1
7:45 p.m.	25	------	57	1	3	3
9:30 p.m.	490	------	56	1	2	1
11:00 p.m.	130	------	33	0	1	6
August 27:						
5:45 p.m.	0	------	58	3	0	------
7:30 p.m.	0	------	47	2	------	0
9:00 p.m.	420	------	18	0	2	1
11:00 p.m.	260	------	19	4	------	1
October 7:						
5:15 p.m.	0	------	47	13	5	2
7:00 p.m.	77	------	25	23	3	------
9:15 p.m.	6	------	17	46	6	2
November 18:						
4:30 p.m.	21	------	2	1	0	[1]
6:00 p.m.	140	------	2	3	1	------
8:00 p.m.	1	------	------	------	1	0
10:00 p.m.	0	------	0	8	0	0
1955						
June 30:						
6:00 p.m.	1	6	22	0	3	1
8:30 p.m.	17	9	8	0	0	2
11:30 p.m.	12	74	6	1	0	0
July 24:						
4:15 p.m.	0	10	0	0	0	0
6:15 p.m.	1	1	1	1	0	0
8:15 p.m.	.9	1	0	0	------	0
10:45 p.m.	1	0	0	0	0	0
October 2:						
2:00 p.m.	0	92	150	------	------	------
4:20 p.m.	2	15	150	46	8	17
6:30 p.m.	6	10	120	71	28	0
8:20 p.m.	130	59	24	68	24	0
10:30 p.m.	47	12	31	44	22	1

[1] Calculated value less than one.

The July 16–17 observations offer a notable exception to the usual migration. At this time the maximum abundance at the surface was not reached until 1:00 a.m., when unusually large numbers were taken. This apparently aberrant behavior has no obvious explanation, but it might have been caused by the brightness of the moonlight throughout the night. The moon was full also on June 30 and October 2, but few *Epischura* were present June 30 and the moon did not become bright until nearly midnight on October 2.

Vertical distribution and movements of *Epischura lacustris* in Lake Michigan are similar to those in several other lakes. Marsh (1898) and Maloney and Tressler (1942) found this species to be most abundant in the upper, warm regions of Green Lake, Wisconsin, and Caroga Lake, New York, respectively. They came to the surface within ½ to 1½ hours after sunset in Winona Lake, Indiana (Juday 1903), and within 1 hour after sunset in several Wisconsin lakes (Juday 1904).

Senecella calanoides

Although it was uncommon at all times, *Senecella calanoides* was taken in every collection period except early June 1954 and May 1958 (table 19). This species has not been previously found in Lake Michigan. Marsh (1933), however, reported immature forms from Pine Lake (Lake Charlevoix), Michigan, which is connected to Lake Michigan by a short channel. Immature individuals were also found in Lake Superior by Marsh (1933). The species was found in a single cisco stomach from Lake Ontario (Pritchard 1931). There are no other reports of occurrences in the Great Lakes, but *Senecella* is known to occur in several other deep lakes in North America (Juday 1923; Rawson 1956). Nothing has been published previously of its seasonal abundance, nor can estimates of seasonal population changes be made here, since the numbers of individuals taken are much too small.

Senecella is regarded as a deep- and cold-water form, a view borne out by the present study. The evidence suggests that most individuals spend the bright daylight hours very near the bottom, but begin ascending before dark. On two occasions in 1955, when the deepest (40-meter) samples were collected only 6 meters above the bottom, no *Senecella* were found in any of the samples of the first afternoon series, but they were present in all the subsequent series. The species often appeared in samples taken from levels well above the bottom somewhat before dusk. It usually avoided the warm upper layers, and was found at the surface only once (Nov. 1954), when the surface-water temperature was 10.9° C.

The literature contains no mention of the vertical migration of *Senecella*.

TABLE 19.—Senecella calanoides *per 10 cubic meters of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken June 6-7, 1954]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 27, 28:						
10:00 p.m.	--------	--------	11	--------	--------	--------
12:00 p.m.	0	--------	0	0	40	--------
2:00 a.m.	0	--------	--------	10	--------	--------
4:00 a.m.	0	--------	0	0	0	--------
July 16, 17:						
7:00 p.m.	0	--------	0	15	0	0
9:00 p.m.	0	--------	0	0	0	0
11:00 p.m.	0	--------	0	0	9	4
1:00 a.m.	0	--------	0	0	17	11
3:00 a.m.	0	--------	0	0	7	10
4:30 a.m.	0	--------	0	0	3	14
August 7:						
5:30 p.m.	0	--------	0	0	4	0
7:45 p.m.	0	--------	0	0	0	5
9:30 p.m.	0	--------	0	0	13	5
11:00 p.m.	0	--------	0	8	7	0
August 27:						
5:45 p.m.	0	--------	0	0	0	--------
7:30 p.m.	0	--------	0	0	--------	6
9:00 p.m.	0	--------	5	0	13	12
11:00 p.m.	0	--------	0	0	--------	12
October 7:						
5:15 p.m.	0	--------	0	0	0	0
7:00 p.m.	0	--------	0	5	9	--------
9:15 p.m.	0	--------	0	16	44	14
November 18:						
4:30 p.m.	0	--------	0	0	4	3
6:00 p.m.	0	--------	0	6	57	--------
8:00 p.m.	0	--------	--------	--------	60	35
10:00 p.m.	22	--------	0	12	112	18
1955						
June 30:						
6:00 p.m.	0	0	0	0	0	0
8:30 p.m.	0	0	0	0	0	18
11:30 p.m.	0	0	0	0	0	8
July 24:						
4:15 p.m.	0	0	0	0	0	0
6:15 p.m.	0	0	14	0	0	44
8:15 p.m.	0	0	0	14	--------	52
10:45 p.m.	0	39	11	30	10	43
October 2:						
2:00 p.m.	0	0	0	--------	--------	--------
4:20 p.m.	0	0	0	0	0	14
6:30 p.m.	0	24	0	0	0	0
8:20 p.m.	0	0	0	0	13	0
10:30 p.m.	0	0	0	0	11	0

AMPHIPODA

Pontoporeia affinis

Pontoporeia affinis was taken in small numbers during every collecting period except October 1955 and May 1958 (table 20). It is generally regarded as a bottom form, although Pennak (1953) stated that it also may be in the plankton. It showed a definite affinity for the deeper, cold water but came to the surface during early June and November when the surface-water temperatures were 10.3° and 10.9° C., respectively. It usually avoided temperatures warmer than these, and was rarely above the metalimnion. In October 1954, however, it was taken from 10 meters where the temperature was 16.7° C.

The vertical migration of *Pontoporeia* was rapid. Because the species never appeared in samples taken before sunset, it is assumed to have been on the bottom during the daytime. In November 1954, none were present in a series of samples collected between 4:30 and 5:30 p.m. (sunset 5:15 p.m.), but the presence of several in the surface sample at 6:00 p.m. suggests that some individuals moved at least 40 and possibly 74 meters (from the bottom) vertically in one-half hour or less.

No large-scale vertical migration of *Pontoporeia* has been reported before, at least in North America. In Great Slave Lake, however, it was observed to come to the surface in shallow water (1 or 2 meters deep) just before dark (Larkin 1948). It reached a peak about 1 hour later and then decreased until dawn. The data from the November samples provide evidence that in Lake Michigan *Pontoporeia* shows a similar migration pattern, but the numbers are too small for definite conclusions. Neither can anything be concluded regarding the percentage of the total population which migrates. It is known that some remain

Table 20.—Pontoporeia affinis *per 10 cubic meters of water off Grand Haven, Mich., in 1954 and off Frankfort, Mich., in 1955*

[None taken October 2, 1955]

Date and time	Surface	Depth in meters				
		5	10	20	30	40
1954						
June 6, 7:						
2:00 p.m.	0	--	0	--	--	--
4:00 p.m.	0	--	0	--	--	--
6:00 p.m.	0	--	0	--	--	--
8:40 p.m.	2	--	0	--	--	--
10:00 p.m.	11	--	0	--	--	--
12:00 p.m.	5	--	2	--	--	--
1:00 a.m.	8	--	--	--	--	--
June 27, 28:						
10:00 p.m.	--	--	3	--	--	--
12:00 p.m.	0	--	0	2	4	--
2:00 a.m.	0	--	--	0	--	--
4:00 a.m.	0	--	0	0	0	--
July 16, 17:						
7:00 p.m.	0	--	0	0	0	0
9:00 p.m.	0	--	0	0	0	1
11:00 p.m.	0	--	0	0	2	2
1:00 a.m.	0	--	0	0	0	1
3:00 a.m.	0	--	0	1	0	1
4:30 a.m.	0	--	0	0	1	0
August 7:						
5:30 p.m.	0	--	0	0	0	0
7:45 p.m.	0	--	0	0	1	0
9:30 p.m.	0	--	0	2	1	0
11:00 p.m.	0	--	0	0	1	2
August 27:						
5:45 p.m.	0	--	0	0	0	0
7:30 p.m.	0	--	0	0	0	0
9:00 p.m.	0	--	0	0	0	0
11:00 p.m.	0	--	0	0	0	1
October 7:						
5:15 p.m.	0	--	0	0	0	0
7:00 p.m.	0	--	1	0	0	--
9:15 p.m.	0	--	0	0	0	1
November 18:						
4:30 p.m.	0	--	0	0	0	0
6:00 p.m.	23	--	0	0	3	--
8:00 p.m.	11	--	1	0	1	0
10:00 p.m.	5	--	0	0	1	0
1955						
June 30:						
6:00 p.m.	0	0	0	0	0	0
8:30 p.m.	0	0	0	0	0	7
11:30 p.m.	0	5	0	4	0	16
July 24:						
4:15 p.m.	0	0	0	0	0	0
6:15 p.m.	0	0	0	3	0	0
8:15 p.m.	0	0	0	0	--	0
10:45 p.m.	0	1	1	2	0	3

on the bottom, because they have been abundant in dredge samples taken from the bottom at night.

Juday (1904) found the amphipod *Gammarus* in surface samples at night in limnetic regions of Wisconsin lakes where the water was 18 meters or more deep. Since he never found it in the surface samples taken during the day, he concluded that it migrated horizontally from the littoral region at night.

MYSIDACEA

Mysis relicta

Data from the present samples on the vertical migration of *Mysis relicta* were part of a detailed study by Beeton.[2] Only a brief summary of Beeton's findings is presented here since details are to be included in a publication by that investigator.

Mysids were concentrated within 1 or 2 meters of the bottom during the day but migrated into the upper strata at night. Light is the most important factor in the initiation and control of their vertical movement. They usually ascended when the surface light intensity was decreasing from 15 to 1 foot candle, and descended when the surface light intensity was increasing from 10^{-3} to 10^{-2} foot candle. Thermal conditions also affected vertical distribution. The degree of temperature change was more effective in limiting vertical distribution than actual temperature. In early evening the mysids frequently migrated through the metalimnion, but later at night the distribution changed and a maximum concentration of mysids occurred in or immediately beneath the metalimnion. This downward movement was more pronounced among the sexually differentiated mysids than with the younger ones; the latter were more inclined to remain above the metalimnion. The vertical migration of male and female mysids was closely similar.

No striking differences in seasonal abundance of *Mysis relicta* were apparent, but numbers are too small for definite conclusions.

SUMMARY

(1) Day-and-night zooplankton collections were made in Lake Michigan on seven occasions between June 6 and November 18, 1954, and on 3 occasions between June 30 and October 2, 1955. The 1954 sampling area was about 8 miles off Grand Haven, Michigan, at a depth of 74 meters and the 1955 sampling area was about 3 miles offshore near Frankfort, Michigan, at a depth of 46 meters. Limited sampling was also done off Sturgeon Bay, Wisconsin, on May 4, 1958.

(2) Collections were made with a Clarke-Bumpus plankton sampler with a net of No. 2 bolting silk. Series of samples were taken at about 2-hour intervals; each series usually included 10-minute tows from the surface and at depths of 10, 20, 30, and 40 meters in 1954 and 5-minute tows from the surface and at 5, 10, 20, 30 and 40 meters in 1955.

(3) Subsamples were employed for the enumeration of most species, but total counts were made

[2] Beeton, Alfred M. The vertical migration of *Mysis relicta* in Lakes Huron and Michigan. Doctoral dissertation, University of Michigan, ix + 131 pp. 1957.

of *Polyphemus*, *Leptodora* (usually), *Pontoporeia*, and *Mysis*.

(4) Twenty-four species of crustaceans were observed in the samples; 4 of them (*Polyphemus pediculus*, *Eurycercus lamellatus*, *Cyclops vernalis*, and *Senecella calanoides*) are reported from Lake Michigan for the first time. Data permitted an analysis of seasonal distribution for 15 species and of vertical migration for 19 species.

(5) Most species of crustaceans in Lake Michigan reach only one population peak a year, and many apparently are present only as eggs in winter and early spring.

(6) All species taken in sufficient numbers for study showed some degree of vertical migration. Diurnal changes in light intensity had a major influence on the migration. Most species migrated to the surface late in the day, and had peaks at that level near sunset or soon afterwards. Numbers at the surface commonly decreased toward midnight, and for some species, according to the limited evidence, increased between midnight and dawn. Water temperatures also affected vertical movements, especially of cold-water forms. A few species were reluctant to migrate up through a pronounced metalimnion.

(7) *Daphnia galeata mendotae*.—Population peak early August in 1954, but greatest numbers in 1955 in October samples; probably absent in winter and early spring; strongly partial to the upper layers; vertical movement below metalimnion limited, but evidence of considerable movement up from the metalimnion; young usually taken at surface earlier than adults.

(8) *Daphnia retrocurva*.—Population changes much like *D. galeata*, except probably absent for greater length of time in winter and spring; vertical distribution and migration similar to *D. galeata*.

(9) *Bosmina longirostris*.—(Limited data). Indefinite suggestion of early summer population peak; probably absent in winter; preference for upper layers; migration toward surface late in day, downward during the middle of the night and again toward surface at dawn.

(10) *Diaphanosoma brachyurum*. — (Limited data). Abundance at maxima in early summer and fall of 1954 and fall of 1955; probably absent in winter and early spring; preference for upper levels; definite increase at surface early in night.

(11) *Holopedium gibberum*.—Taken only in July and October, 1955; probably absent in winter and spring; not found below metalimnion; increased at surface near sunset.

(12) *Sida crystallina*.—Taken only in October 1955; none below metalimnion; some at surface at night.

(13) *Leptodora kindti*.—Most abundant in July and early August 1954 and in October 1955; most common in upper strata; maximum numbers at surface early in night.

(14) *Polyphemus pediculus*.—Taken only in summer; preference for upper levels; some at surface in afternoon, but more early in night.

(15) *Cyclops bicuspidatus*.—Probably present year-round; population pulse late spring and early summer, possibly again in late fall; most plentiful in upper layers but on occasion in moderately large numbers below metalimnion; strong migration to surface at night; indication of some movement through metalimnion.

(16) *Mesocyclops edax*.—No striking population changes from late June to early October, but species scarce or absent at other times; more nearly restricted to epilimnion than *Cyclops bicuspidatus;* pronounced increase in numbers at surface at night; probably no movement through metalimnion.

(17) *Diaptomus minutus* (adult males).—Most abundant in late June and scarcest in October; strong preference for upper levels; migration to surface at night pronounced.

(18) *Diaptomus sicilis* (adult males).—Most abundant in November and lacking in late August; preference for upper layers but plentiful at surface only after sunset.

(19) *Diaptomus ashlandi* (adult males).—Population maxima in early summer and middle or late fall; scarce in early October; preference for upper strata less strong than in other adult male diaptomids; migration to surface at night definite.

(20) *Diaptomus oregonensis* (adult males).—Most abundant in mid-November; less definite pulse in July and August; primarily in epilimnion; strong migration to surface at night.

(21) Copepodites of *Diaptomus*.—Population peaks from mid-July to early August and in early October; preference for upper levels less strong than in adult males; migration similar to adults.

(22) *Limnocalanus macrurus.*—Fairly uniform in number throughout season, possible population peak in early June; distributed primarily in deeper layers, but occasionally at surface at night; vertical movement hindered but not always blocked by a sharp metalimnion.

(23) *Epischura lacustris.*—Most common in summer; probably absent during winter and early spring; scarce below metalimnion; main vertical migration apparently in epilimnion, but some movement up from the metalimnion probable.

(24) *Senecella calanoides.*—Present during all collection periods except early June 1954 and May 1958; collections too small to estimate seasonal abundance; most individuals apparently near bottom by day; ordinarily no migration through metalimnion; found at the surface in November 1954 when thermal stratification was weak (surface-water temperatures 10.9° C.).

(25) *Pontoporeia affinis.*—No basis for estimate of seasonal abundance; on or near bottom during daytime; rapid vertical migration at night; at surface during only early June and mid-November (water temperatures 10.3° and 10.9° C., respectively).

(26) *Mysis relicta.*—No basis for estimate of seasonal abundance; concentrated within 1 or 2 meters of bottom during the day; occasional migration through metalimnion at night; stay of adults in epilimnion usually short.

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