WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

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phrase: UNPUBLISHED MANUSCRIPT

Reference No. 58-43

ECOLOGY OF DUCK POND, WELLFLEET, MASSACHUSETTS, WITH SPECIAL REFERENCE TO THE VERTICAL DISTRIBUTION OF THE ZOOPLANKTON

By

Clinton V. MacCoy

Work supported by funds from the
National Science Foundation
under Grant No. 3838
Principal Investigator, George L. Clarke

August 1958

APPROVED FOR DISTRIBUTION

Paul M. Fye, Director

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Abstract

During the summers of 1956 and 1957 an investigation was made of certain ecological relations involving light in Duck Pond, Wellfleet, Massachusetts, because of the unusually high clarity of the water. The maximum transparency observed (extinction coefficient, k = 0.11) was far greater than most ponds and about equal to that in the slope water beyond the continental shelf off the Atlantic coast. The illumination reaching the bottom of the pond at 18 m was 11% of the surface light and made possible a thick growth of *Sphagnum* at that depth. Phytoplankton was scarce and consisted mostly of minute forms. The zooplankton, which ranged in abundance up to 78 organisms per liter, consisted almost entirely of one species of copepod, *Diaptomus minutus* Lillj. Quantitative sampling of this population by means of a pump at a series of depths and at various hours of the day revealed a partial migration of this species from near the bottom to the surface at sunset on one occasion, but no large fraction of the population carried out a vertical migration on 4 other sunset periods or 2 sunrise periods subsequently studied. On certain of these occasions, however, there was a slight but detectible movement of the animals toward the surface at sunset followed by a redistribution to deeper levels. At sunrise the animals showed a tendency to move at first toward the surface and then away from it, although on one occasion the population remained quite evenly distributed at all levels. It is pointed out that because of the high transparency those zooplankters living in the pond are able to withstand high illumination at all depths. Relations between the extreme water clarity and the activities of the zooplankton, as well as other unusual features of the pond are discussed.

INTRODUCTION

Duck Pond, a small pond in Wellfleet, Massachusetts is located in a basin covered mainly with a growth of pitch pine (*Pinus rigida*) and a scrub oak (*Quercus* sp.) about 1.5 km from the east shore of Cape Cod, and is one of six or eight nearly circular ponds arranged in a north-south line about 4.5 km long (Fig 1). The pond was visited early in 1956 and found to be unusually transparent. Further studies were carried out during the summers of 1956 and 1957.

Among the points considered in the work on the pond were its unusual transparency and the factors producing it, the effect of this on the biota especially plankton and its vertical movement, and other aspects of its physical environment particularly those pertaining to light. The clarity of the water made possible the use of underwater photography as an additional method of investigation.

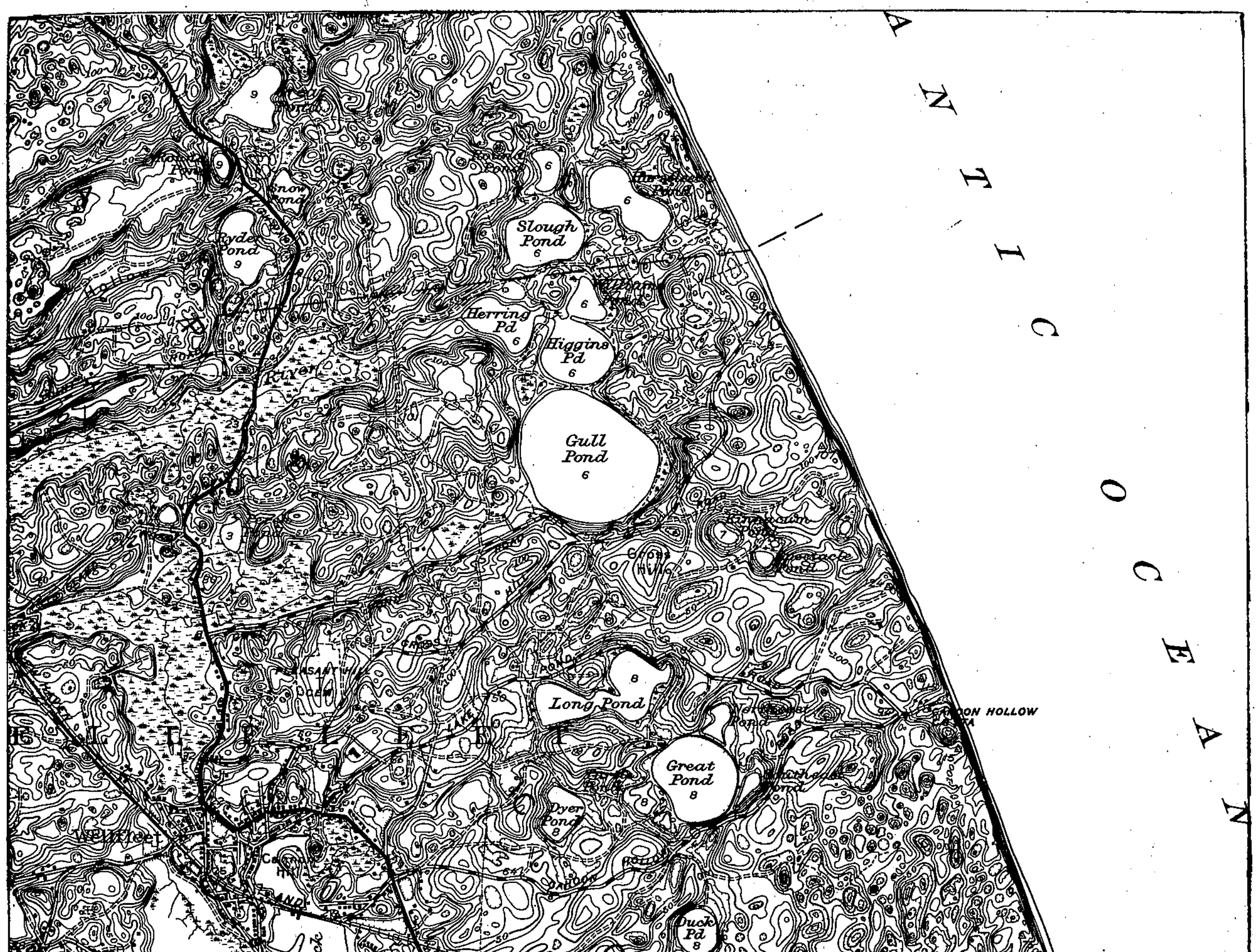

Fig 1 Map of Duck Pond, Wellfleet, and vicinity.
Reproduced from U. S. Geol. Survey Map.

ACKNOWLEDGEMENTS

The Woods Hole Oceanographic Institution is greatly indebted to Mr. Noble Foss and Mr. Benjamin S. Foss, owners of the area, for their kindness and generosity in allowing numerous investigators from the Institution to study the pond and to make use of their buildings, wharf, and boats. The Institution also wishes to express its appreciation to other members of the Foss family, especially Mr. and Mrs. John Garrison and Mr. and Mrs. Richard Heath, for their hospitality and kindness during the progress of the work.

Thanks go to G. L. Clarke for help in plankton, light and temperature work, to D. M. Owen who first brought the pond to the attention of investigators at the Institution and who made color motion pictures and still photography records, to C. J. George for diving and assisting in the general biology and to Gordon Allen for helping with the echo-sounding part of the project. Others who kindly assisted with field or laboratory work are C. J. Hubbard, C. S. Olson, J. O. Gates, A. R. Miller, C. S. Yentsch, Jean-Michel Cousteau, Bruce Bird, G. M. Gresswell, E. T. Moul, John Ryther, R. K. Brigham, R. G. Weeks, Richard Dimmock and Thomas Souza.

PHYSICAL AND CHEMICAL OBSERVATIONS

Surrounding Terrain

A circular basin with a thin, sandy soil of a podzolic type surrounds the pond. Shores east and west rise to about 15 m within 100 m of the shoreline. The northeast corner alone has flatter, grass-covered shores (Fig 2). Acting as ground cover underneath the pitch pine and scrub oak are blueberry (*Vaccinium*), bayberry (*Myrica*), and large mats of bearberry (*Arctostaphylos*). Along the shore are areas of *Polytrichum*, *Sphagnum*, cranberries and *Drosera filiformis*. Since there are no inlets or outlets large enough to be recognized, water exchange with the surrounding land must take place entirely, or almost entirely, by seepage. A cottage and dock stand on the north shore.

Surface Area

The pond surface, 2.7 m above sea level, is about 0.25 km in average diameter and its area is close to 4.5 hectares, or about 11 acres. The level varied irregularly between June 15 and August 15, 1956, within a range of about 30 cm. In August 1957 after a period of severe drought the level was about 60 cm below the high stage of June 1956.

Depths

Depths are generally less than a meter within 5 m from shore entirely around the pond. The bottom slopes gradually to the approximate center where maximum depth obtained by sounding line is 18.75 m. Eight bottom profiles (azimuths of 16, 61, 69, 94, 151, 196, 241 and 264° true) (Fig 3) were constructed from fathometer records made from a skiff powered by outboard motor and proceeding at a nearly constant speed. Because the fathometer did not record depths below 14 m the exact profile of the

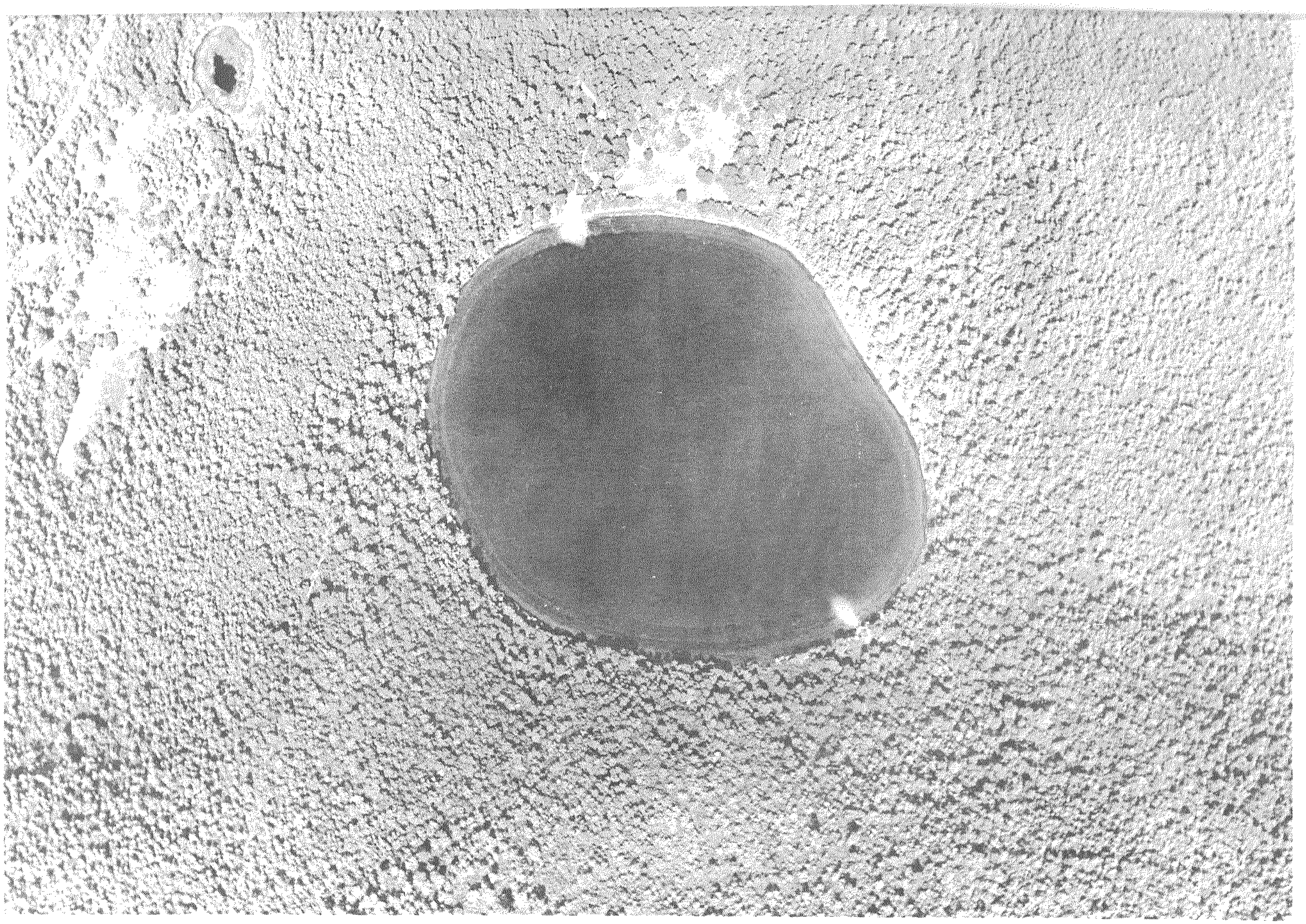

Fig 2 Duck Pond. Vertical view from about 6000 feet. Northeast is at top of page.

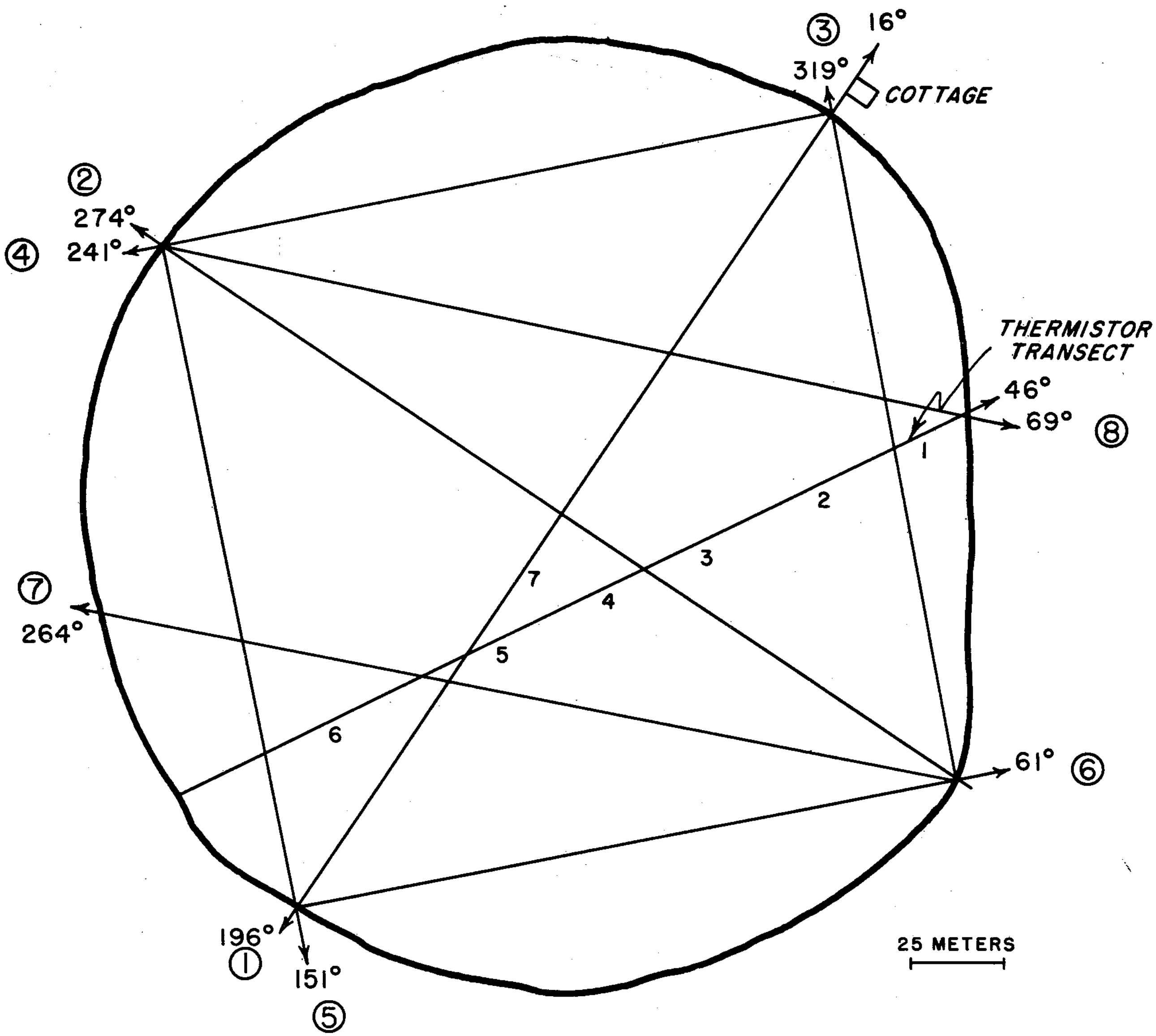

Fig 3 Transects made at Duck Pond, August 3, 1956, in establishing bottom profiles. Temperature stations are numbered. Angles as drawn are approximate only and degrees refer to true North. Circled figures refer to corresponding profiles in Fig 4.

deepest spot is not charted, but manual soundings indicate it to be about 10-12 m in diameter (Fig 4) and close to the center of the pond on profile No 1. Profile No 4 (Fig 4) (azimuth 241°) shows the berm observed by geologists and divers about 2-3 m deep and about 10-15 m from shore and nearly completely ringing the pond. A somewhat similar but deeper structure near the easterly shore is not apparent in the profiles or photographs. Otherwise the transects show a smoothly sloping profile.

Bottom Sediments

The substrate is mostly a quartz sand, with some gravel areas, to a reported depth of between 13 and 14 m. Below this point the small basin is covered with a poorly compacted black mud at least a half-meter thick and containing scattered sand grains (Fig 5).

Over an area of about a half hectare at depths of about 14 m on the pond's eastern side bog iron, goethite FeO(OH), was found, sometimes in irregular sheets about 0.5 cm thick and up to 17 cm in diameter (Fig 6). These plates are apparently formed by bacterial deposition, or precipitation of soluble iron, or both, and many quartz pebbles are embedded in the tortuous foldings of the matrix. A few isolated stones, none larger than 10 cm in diameter, were found resting half buried in the sand and ringed with a goethite halo deposited at the sand-water interface.

The surface of the bottom sediments is overlain by very scant accumulations of plant debris as logs and brush, only an occasional small branch being found. Leaves were surprisingly absent although oak trees were common around the pond.

Temperatures

Surface temperatures in 1956 maintained a surprising constancy, being 22.8 °C on June 15 and 24.7 ° on August 15. By July 26 a thermocline had developed with its upper level at 8 m and by August 23 this had dropped to 9 m (Fig 7A and Tables 3-5).

In 1957 surface temperatures again remained very constant. During the July visits they ranged from 23.5 to 25 °C and on August 29 the temperature was 22°. On July 11 a weak thermocline was present at about 9 m. On July 16 the temperature throughout the pond's depth was 23.5° except for 23.0° at 14 m. On July 17 the upper 2-3 m were 24° and the remaining levels 24°; on August 29 the pond was of uniform temperature throughout, all levels at the station giving a reading of 22° (Tables 6-10).

A transect at 46° true (Fig 3) running close to the pond center with seven temperature stations recorded by thermistor on August 3, 1956, across the pond revealed a horizontal uniformity of this thermal stratification (Fig 7A). The temperatures at Station No 7 and the nearby bathythermograph record are in close agreement; the greatest difference, 1.1°C discrepancy at 9 m, is possibly partially attributable to instrumental error.

Records show that during most of the summer the deep water remained between 16° and 18° C which is warmer and more constant than in ponds of this size in this part of New England.

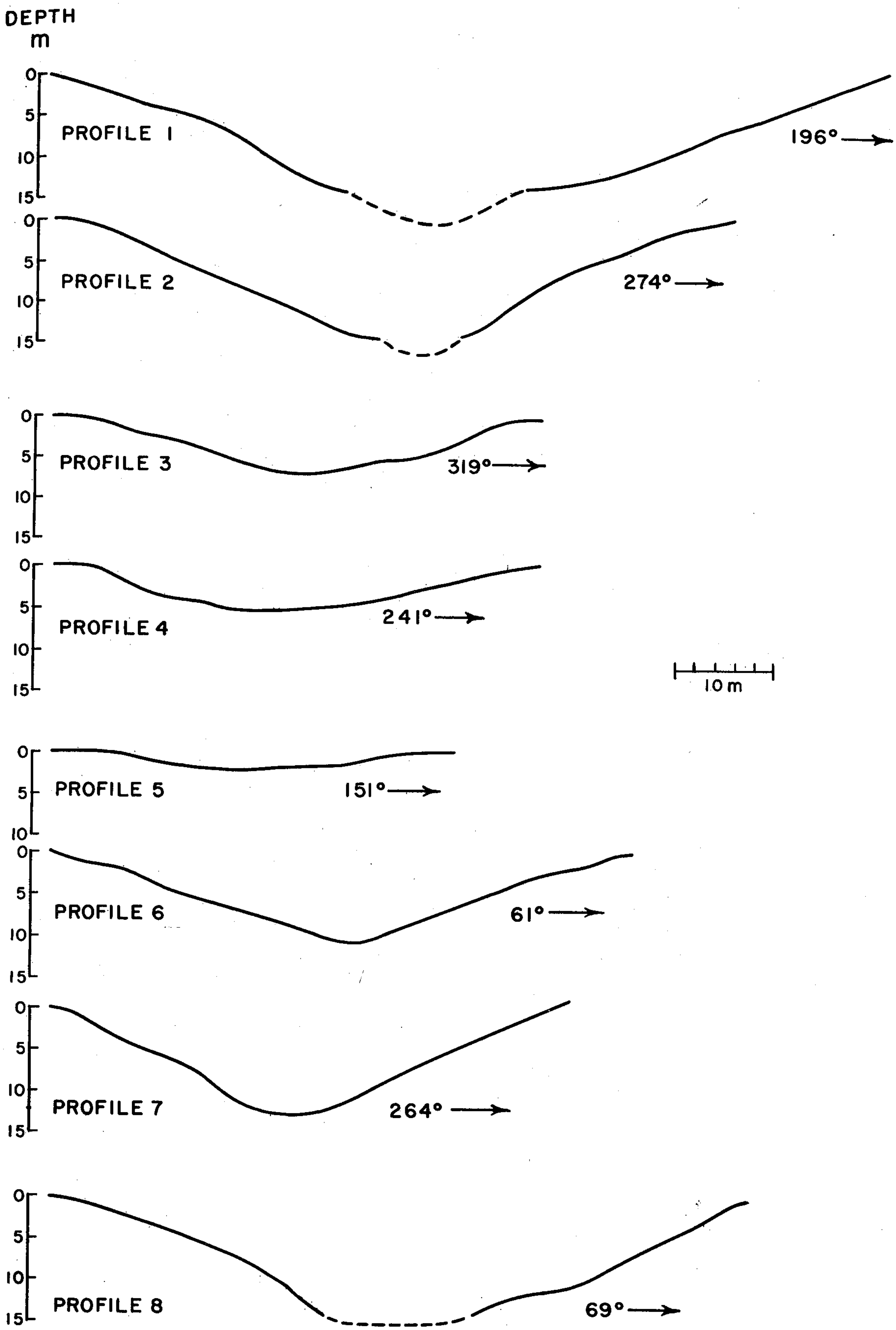

Fig 4 Bottom profiles of Duck Pond.

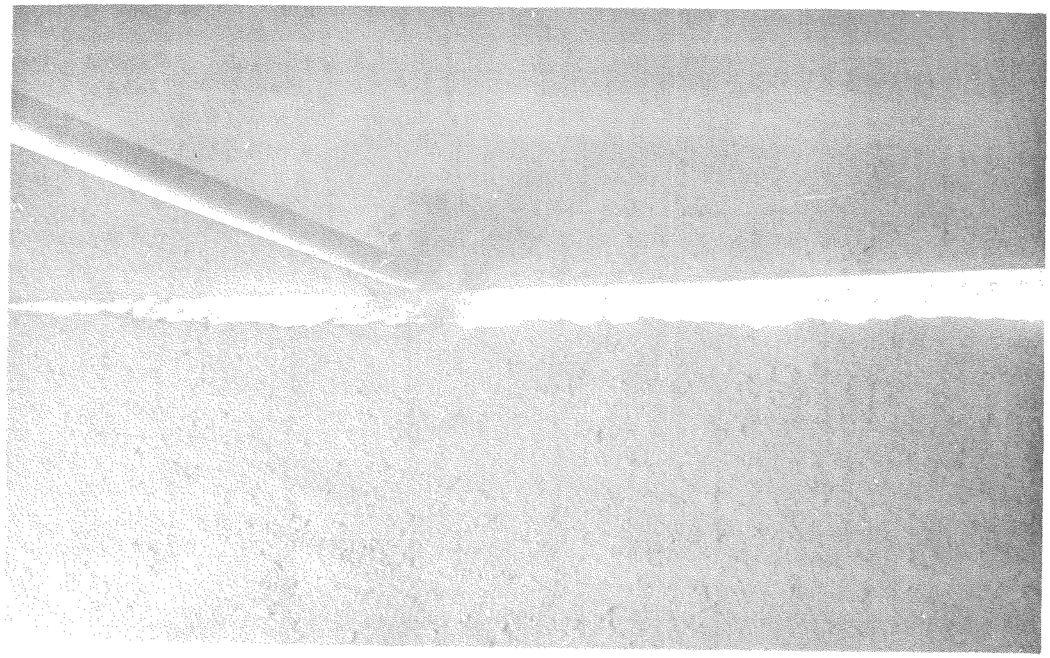

Fig 5 Black mud at pond bottom. Note how meter stick sinks into the poorly compacted material. Dark rod is for measuring object distance from camera.

Fig 6 Irregular sheets of goethite on pond bottom.

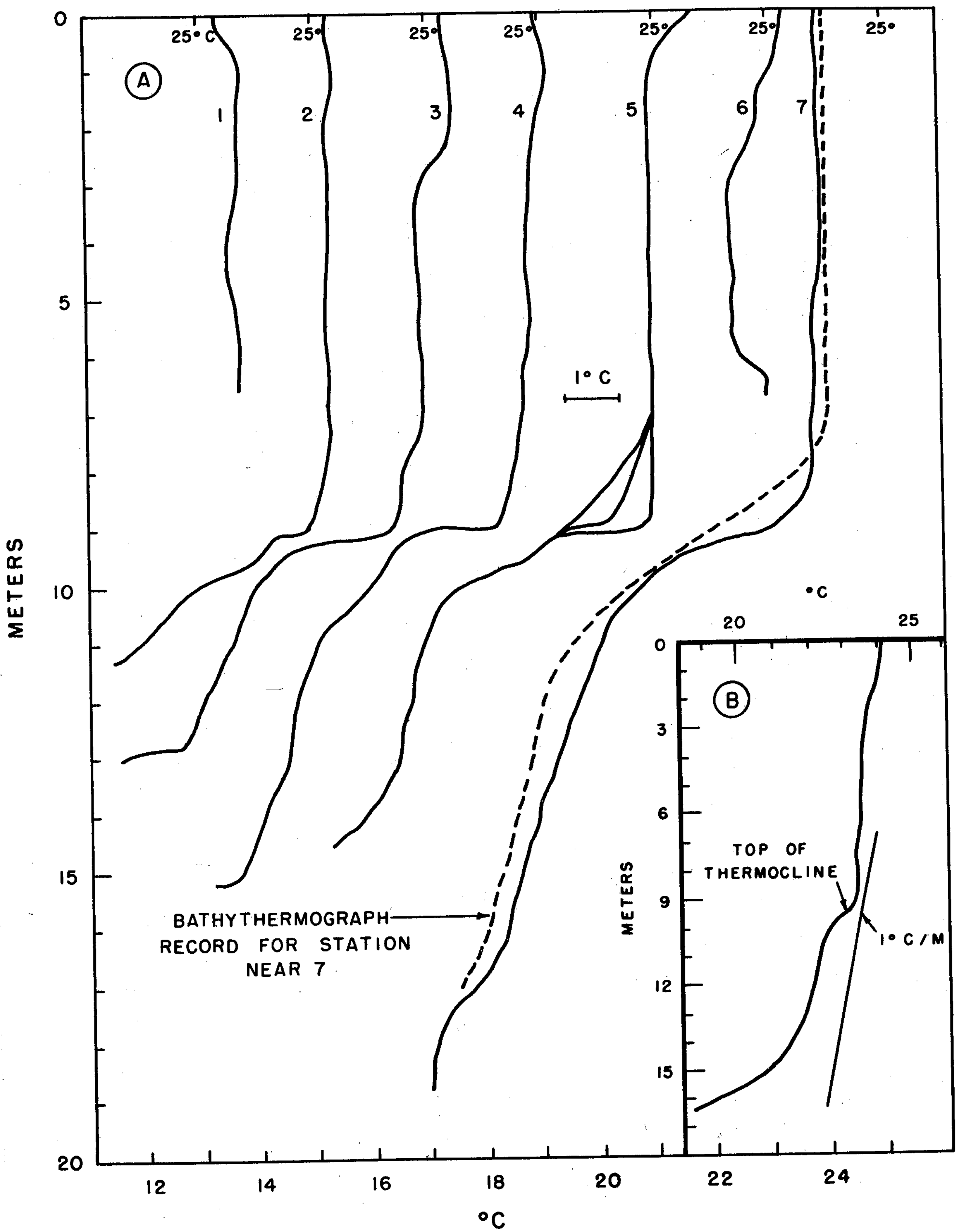

Fig 7A Thermistor records of temperature at seven stations on a transect, Duck Pond, August 3, 1956. See Fig 3.

Fig 7B Temperature profile. Duck Pond, July 8, 1957.

An unusually large proportion of radiant energy reaches the lower water levels of the pond and the bottom itself as light radiation because of the very high transparency of the water. The absorption of this energy at or near the bottom is probably the chief reason for the unusually high temperatures observed. Seepage of ground water presumably could not account for the high values because water pumped from a driven well supplying the cottage on the north shore was 13 °C on August 15, 1956. The exact depth and location of the lowest point of the well could not be accurately determined but was probably about 4-5 m below the ground surface and perhaps 3-4 m below the pond surface.

Light

The pond's transparency is remarkable and has significant relation to its physical and biological make-up. Photometric measurements at 1-m intervals were made on July 18, 1956, with a clear sky and a Secchi-disk reading of 16 m; incident radiation reaching the surface averaged 0.84 g cal/cm^2/min. At 1 m the energy value was 0.76, at 10 m, 0.25, and at the deepest level measured, 18 m, was 0.09 g cal/cm^2/min (Table 1 and Fig 8). The measurements give an average extinction coefficient of $k = 0.11$ indicating, according to Clarke (1954, p 196, fig 6.8), far greater transparency than in most inland lakes and comparing favorably in transparency with continental slope water along the northwestern Atlantic coast.

Mr. James Crossen of the Electronics Laboratory at the U. S. Fish and Wildlife Service at Woods Hole reports that on September 6, 1956, a usable television picture was obtained at a horizontal distance of 7 m by a crew working 13 m below the surface. The equipment used included an RCA No 5820 image-orthicon pick-up tube sensitive to a half foot-candle together with three different lenses, a 28-mm f/3.3, a 39-mm f/2, and a 75-mm f/2. Mr. David M. Owen, who has dived in many waters in and around Cape Cod states that Duck Pond is "of unusual transparency and is eight times more transparent than is the Eel Pond at Woods Hole, Massachusetts."

A general seasonal decrease in transparency was indicated by a decrease of about 49 per cent in the Secchi disk depth between June 15 and August 23, 1956, and a decrease of 10 per cent between July 11 and August 29, 1957 (Table 2).

Oxygen

Only two oxygen measurements were made, and these at the center of the pond on July 11, 1956. At a depth of 10.7 m 6.3 ml/L and at 18.2 m 7.4 ml/L of oxygen were recorded during mid-afternoon. The inversion from the usual vertical distribution is thought to be a result of photosynthetic production by the dense bottom growth of *Sphagnum*.

BIOLOGICAL OBSERVATIONS

Emergent Vegetation

The vegetation of the pond generally is indicative of acid conditions. Emergent forms are nowhere dense and in most areas of the pond are very sparse. The most abundant of these is *Coreopsis rosea* growing

Table I

Light intensity distribution, Duck Pond, July 18, 1956.

Depth m	At Surface μw/cm²		At Surface gm cal/cm²/min	In Pond μw/cm²	In Pond gm cal/cm²/min	%
0	59,500		0.84	59,500	0.84	100
1	58,600		0.83	53,400	0.76	91
2	58,300		0.83	49,200	0.74	84
3	58,600		0.83	43,400	0.61	74
4	55,800	(cloud)	0.80	35,200	0.50	63
5	59,000		0.84	31,300	0.45	53
6	57,600		0.82	27,600	0.39	48
7	57,600		0.82	24,800	0.35	43
8	55,800		0.80	21,200	0.30	38
9	55,800		0.80	20,100	0.29	36
10	57,600		0.82	17,300	0.25	30
11	56,500		0.80	16,400	0.23	29
12	56,500		0.80	14,700	0.21	26
13	56,500		0.80	13,000	0.18	23
14	56,500		0.80	11,900	0.17	21
15	55,800		0.80	10,600	0.15	19
16	55,800		0.80	9,900	0.13	16
17	55,800		0.80	7,300	0.10	13
18	56,500		0.80	6,200	0.09	11

Secchi disk reading 16 m. Time 1030 EST. Weather: clear sky with few cirrus.

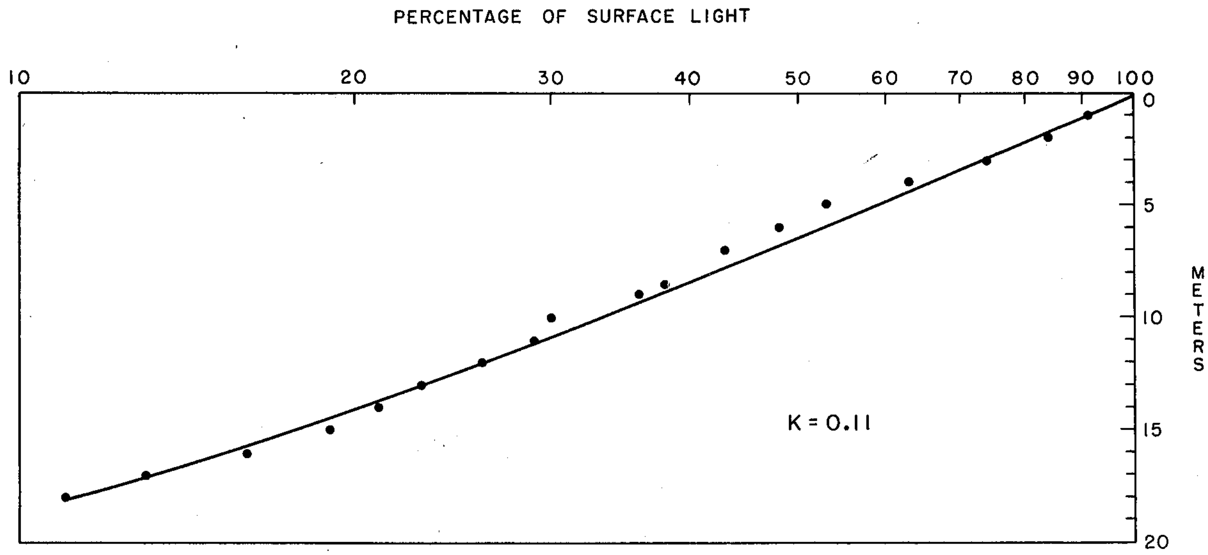

Fig 8 Light intensity distribution, Duck Pond, July 6, 1956. Clear sky with few cirrus, Secchi disk reading 16 m, time 1030 EST.

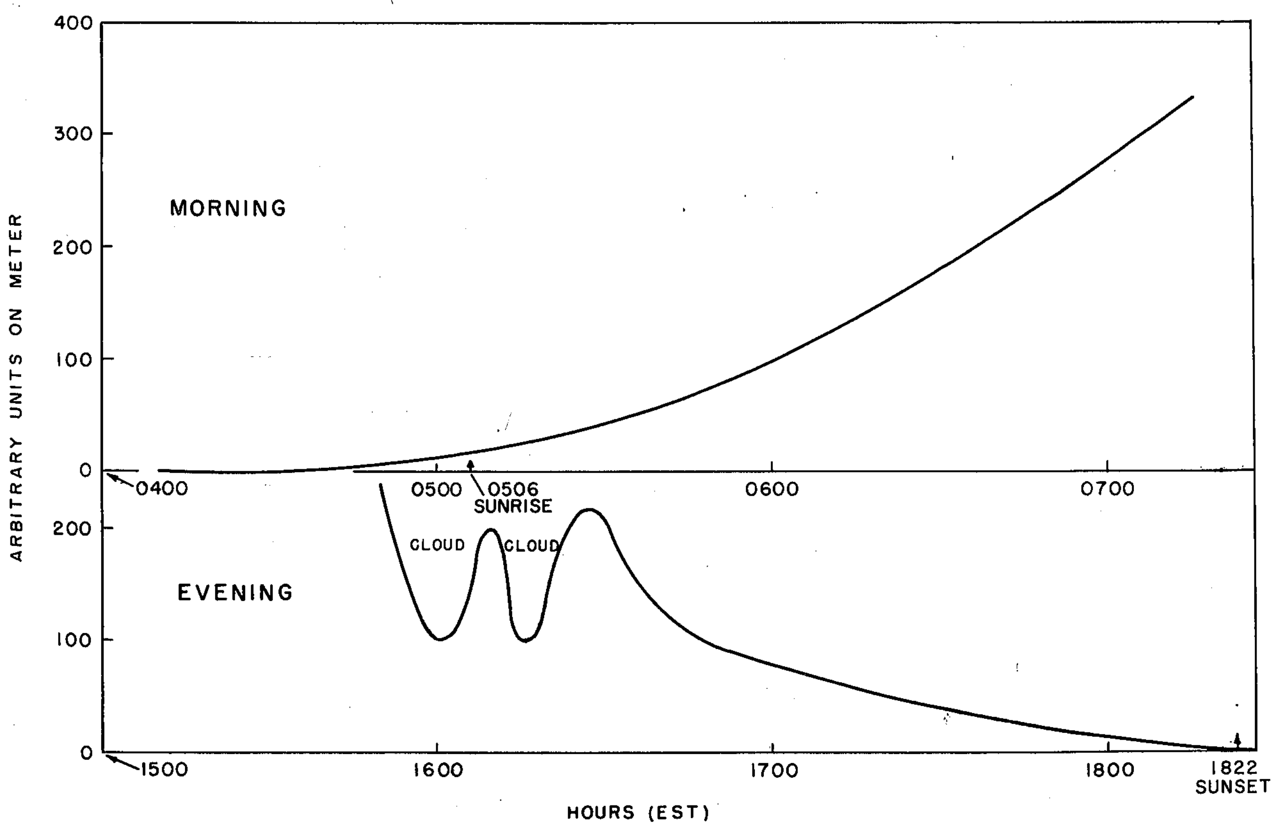

Fig 9 Surface light readings, Duck Pond. Sunrise and sunset, August 29, 1957.

Table 2

Variation in Transparency of Duck Pond during summers of 1956 and 1957

Date	Secchi reading	EST	Sky	Wind
		1 9 5 6		
June 15	17 m	1015	Clear	Moderate
July 11	16	0950	Clear	Moderate
July 26	12.5	1300	Clear	Light
August 3	12	1010	Clear	Light
August 8	10	1300	Cloudy	Moderate
August 14	9.5	1245	Clear	Moderate
August 15	11	1455	Partly cloudy	Light
August 23	10	1605	Cloudy	Moderate
		1 9 5 7		
July 11	16	1315	Clear	Gentle
July 16	16.5	0645	Clear	Light
July 17	15.5	1615	Clear	Gentle
August 29	14.5	0730	Partly cloudy	Calm
August 29	14.5	1530	Partly cloudy	Calm

to a depth of about a half meter, the submerged stems frequently covered with epiphytes that give a furry appearance. Lobelia Dortmanna is a prominent shore form growing to a depth of two meters (Fig 10). Its green rosettes of basal leaves on the young plants are prominent on the sand substrate. These were both in bloom in August, 1957. Sphagnum imbricatum var. affine and Polytrichum grow near shore and are probably merely inundated.

Phytoplankton

Genera collected by plankton net with #10 silk bolting cloth and by water samples are:

Closterium sp. (Desmidiaceae), fairly common
Cosmarium sp. (Desmidiaceae), rare
Staurastrum sp. (Desmidiaceae), rare
Chroococcus sp. (Myxophyseae), rare
Eremosphaeria sp. (Chlorophyta), fairly common
Rhipidudivitia sp., a colonial form, moderately common

At the bottom at about 18 m the following forms were collected:

Microspora sp. (Microsporaceae)
Tabellaria sp. (Pennales), fairly common
Pennularia sp. (Pennales), few
Frustulia sp. (Chrysophyta), fairly common
Surirella sp. (Chrysophyta), common
Mougeotia sp. (Chlorophyta)
Chlamydomonas-like alga, quite abundant and of various species.

A spherical chlorella-like alga, 5-10 μ in diameter, collected on July 11 was found at a density of 94,800 cells/L at the surface and 360,000 cells/L at a depth of 8 m. On July 26 this alga, with presumably others, contained the following amounts of chlorophyll a at various levels:

Depth in m	Mg chlorophyll a/m^3
0.5	0.70
4	0.91
8	0.89
12	2.26

Submergent Vegetation

The central basin below the 14 m contour, an area about 13 m in diameter, supports a thick stand of Sphagnum subsecundum (Fig 11) growing to a height of a half meter. Occasional sub-circular patches, 1-3 m in diameter, within this stand give the appearance of having decayed. Associated with these patches are filamentous masses presumably algal.

Fig 10 Underwater view of Lobelia Dortmanna as it grows near shore.

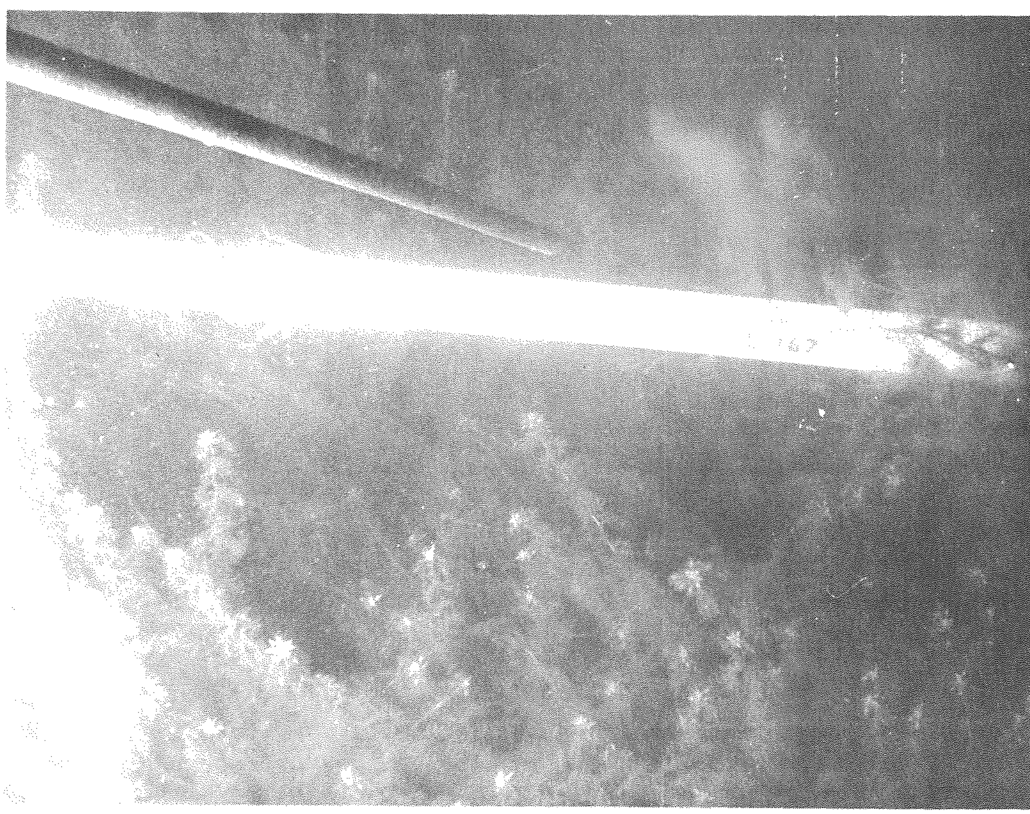

Fig 11 Sphagnum subsecundum in central part of pond basin.

Zooplankton

Hauls with #10 bolting-silk net caught almost exclusively a red calanoid copepod, Diaptomus minutus Lillj. This northern form is distributed in numerous ponds on Cape Cod and id described as having more or less of the anterior parts and sometimes the entire thorax bright orange-red (Wilson 1932, p 92). Another larger, gray copepod was frequently associated with it but never comprised more than 10 per cent of the catch and was not identified. Although most ponds have a fairly limited fauna as far as numbers of species of copepods go, Duck Pond is remarkable in the dense population of this one species and lacks the usual numbers of cladocerans and rotifers found in nearby ponds.

On August 8, 1957, a collection of Diaptomus resulting from a 6-minute collection of 2 hauls with a #20 30-cm plankton net, together with about four liters of pond water, was introduced as an inoculum for a culture of this copepod in the outside east tank at the Oceanographic Institution. The tank, filled with water from the town supply, held 30 m^3 and had added to it in addition to the copepods, a 5-gal carboy of pond water with its normal algal population, as well as 13.6 gm KH_2PO_4 and 282.0 gm $NaNO_3$. On August 16 several thousand copepods were observed in one corner; on August 20 a distinct green algal bloom was observed. By August 30 a dense population of Scapholeberis was present which continued until September 11 when observations ceased. The Diaptomus population disappeared soon after August 16.

Detritus

On July 26, 1956, divers in Duck Pond noted a dark layer about 5 cm thick at a depth of 9 m, extending well across the pond and containing adult copepods at a density of 12.5/L together with many dark globules (possibly fecal pellets or flocculent precipitates) at 193.5/L (Fig 12 and 13). In regard to these globules it is interesting to note that Ruttner (1953, p 74-78, 167-170), speaking of the iron chemistry of ponds, says that humic colloids on entering the water are "flocculated primarily through encountering dissolved salts (particularly calcium), and this material forms a characteristic gelatinous sediment of dirty-brown colour, . . . " but does not mention the size or shape of any of these floccules. At 8 m the adult copepods were present at 10.3/L and the globules at 25.6/L. Table 3 shows that whereas the globules may have some relation to water density at upper limit of thermocline, the copepods do not. An attempt to record this dark layer and hence plot any movement it might have on an echo-sounder record was unsuccessful; however, the layer was recorded on color motion-picture film.

On July 8, 1957, numerous, small, disassociated masses of organic detritus were distributed in varying abundance throughout the upper 10 m of the pond. Preliminary examination suggested it might be partially decomposed parts of Diaptomus as oil globules and bits of copepod exoskeleton were present in it. Later examination indicated it might be, or contain in addition to Diaptomus, bacterial or algal remains. On this date a generally distributed, dense population of Diaptomus was present consisting mainly of full-grown, mature specimens. The material was not found below the region of the thermocline which was at 10 m.

Fig 12 Dark layer with diver sighting along it.

Fig 13 Diver making collection of dark layer material.

Denser water below this depth may have prevented further sinking of this light, flocculent material (Fig 7B). On July 11, with a similar temperature distribution, the material was not found.

The vertical distribution as determined by random samples viewed in the microscope field is as follows:

Depth	Amount of material
0.5 m	No trace
4	About 5-10 per cent of microscope field occupied by the material
8	About 3-4 per cent of field occupied
10	About 8-10 per cent of field occupied
12	No material visible at this level.

The temperature distribution on this date is shown in Fig 7B.

Nekton

In a mass of the *Sphagnum* recovered from the bottom at center of pond a large population of the planarian, *Dugesia tigrina*, was found, together with a numerous amphipod, and a common mite. Here also the large cyclopoid copepod growing to a length of 1 mm was numerous.

Water mites (Acarinida) were seen commonly and odonate larvae observed. The chief odonate in July 1957, *Progomphus obscurus*, formed many slightly elevated sinuous burrows 2 cm wide by 50-80 cm long above water line. At their ends on the sand above water-line recently shed nymphal skins were found and also occasional nymphs themselves. No adults were seen.

Tadpoles about 2 cm long were found near shore and adults of either *Rana clamitans* or *R. Catesbeiana* were seen along the pond margin. About a dozen painted turtles, *Chrysemys picta*, were observed. *Fundulus diaphanus* was collected and one adult eel, *Anguilla bostoniensis*, was seen by divers near the bottom, but in general few fish species were observed. *Perca flavescens* was numerous and was collected: about 30 specimens moved into shallow water near the cottage at sunset on July 15, 1957.

Other Animals

Fresh deer tracks and those of the red fox were observed in July 1957 and an adult fox in mangy condition was observed drinking from the pond's edge in the early morning.

VERTICAL MIGRATION OF PLANKTON

Methods

In 1956 day and night plankton samples and other measurements were taken by the author and an assistant from a 2.4 m skiff anchored in the deepest water near the center of the pond. Water samples of 82 liters each were taken by means of a pump at depth intervals of 1 or 2 meters.

The time required to complete each vertical series varied from 28 to 56 minutes. Therefore, successive series could follow one another at hourly intervals. When morning samples were taken, the work period started about two hours before sunrise and ended about two hours after sunset. Occasional samples were taken for comparison as much as six hours before and three hours after sunrise or sunset. The evening series similarly extended from two hours before to two hours after sunset. As far as practicable the mid-point in time of collecting each vertical series of samples was either at sunrise, sunset, or one or two hours before or after. As far as possible the work was done during clear weather with a minimum of cloud cover. Cloud and moonlight conditions are noted on the pertinent tables. Two series of sunset hauls were made eight days apart to determine whether or not the migration pattern changed significantly during periods of this duration.

Sampling apparatus in 1956 and in the early part of the work in 1957 consisted of a hand-operated pump with 20 m of plastic hose (internal diameter 20.5 mm). A weight attached to the open end of the hose carried it to any desired depth. Effluent from the pump passed into a #10 silk plankton net (30 cm diameter) with bottle attached which was suspended in a galvanized bucket of 41 liters capacity placed in the skiff. The bucket was filled twice to obtain the required 82-liter sample at each depth. During each sampling the skiff was slowly rowed in irregular pattern within a circle about 8 m in diameter. Tests in Flax Pond in 1955 had demonstrated that this procedure provided more reliable samples than those obtained from a hose held stationary.

On August 29 a change was made to a Jabsco pump (model 1673) driven by a 1/2 HP motor, a combination which produced a 205-liter sample in 6 min. These larger samples were desirable as being more representative but comparison indicated that the smaller samples were sufficiently reliable for the purposes of this study. The efferent hose from the pump discharged into a #10 silk net (12.3 cm diameter), the rim of which was fitted into a hole in a board floating alongside the skiff so that the net was suspended in the water. The hose discharged into the net through a 2.5 cm brass pipe, 45 cm long and perforated with about a dozen 5-mm holes so as to reduce the force of water. With the electrically-driven pump only about 6 min of pumping was required at each level and six levels could be sampled in less than 60 min. The samples were preserved in 4% formalin.

In the laboratory each sample was reduced to a volume with sufficient concentration of copepods to give a valid count in a one-ml subsample. Water was removed by means of a pipette, the mouth of which was covered with a piece of netting.

After measuring the resulting volume, the sample was stirred and a one-ml subsample was withdrawn by means of a Henson-Stempfel pipette. The subsample was placed in a modified Sedgwick-Rafter counting cell (lucite base with brass retaining strips and scribed on its upper surface in 4-mm squares) and closed with a cover glass. The number of copepods in 1 ml (w) was determined by counting under a dissecting microscope. By using the volume of pond water originally filtered (L), the volume of the concentrated sample (c), and the equation $n = \frac{wc}{L}$ (Welch 1948, p 287-289) the number of copepods per liter of pond water was obtained. When the number of animals in the subsample was less than 150, several additional subsamples were counted in order to increase the reliability of the calculation of total numbers. A check on the subsampling procedure made by counting the whole of each sample taken on July 11 and 16 showed a good agreement with the values reached by calculation from the subsamples. In the tables presenting the results, given in the next section, the values in the percentage column show what percentage the numerical value at each level is of the total of the values at all the levels sampled. These values are not, of course, the percentages of the whole population in the entire vertical water column at those precise levels but indicate percentages in the various strata sampled.

Observations

In 1956 three series of hauls were made: on the afternoon of July 26 (Table 3), at sunset on August 15, and at sunset on August 23 (Tables 4 and 5). In 1957 five series of hauls were made: at sunset on July 11 (Table 6), at sunrise on July 16 (Table 7), at sunset on July 17 (Table 8), and at both sunrise and sunset on August 29 (Tables 9 and 10). The numerical values given in the tables refer to the abundance of *Diaptomus minutus* only since other species were too scarce to be of significance.

Table 3 presents figures showing *Diaptomus* population distribution during mid-afternoon, together with a count of the "dark layer" globules, and Tables 4 and 5 represent two sunset distributions within eight days of each other. Two sunset patterns within seven days of each other, studied the following year, are shown in Tables 6 and 8.

Some comparison of distribution pattern in time within the same season is presented, such as sunset patterns on July 11, 1957 (Table 6) and on August 29, 1957 (Table 10). Similarly sunrise patterns can be compared between that on July 16, 1957 (Table 7) and that on August 29, 1957 (Table 9).

Finally, difference in distributions resulting from a sunrise and a sunset migration on the same day, August 29, 1957, is shown in Tables 9 and 10. Measurements of surface illumination made during these last series of hauls is presented in Fig 9.

DISCUSSION

1956

During mid-afternoon on July 26, 1956, adult *Diaptomus* were found mostly at the deeper levels and below the thermocline, with a density of 12.5/L at 9 m and 14.0 at 12 m (Table 3). Few adults were at the surface, the 0.5-m sample showing only 1.0/L. The copepodid distribution correlated closely with that of the adults, as it did generally throughout the entire study, while the nauplius population was scarce at all levels except at 9 m where their density was 11.4/L in a sample made directly within the "dark layer."

A series of sunset samplings on August 15 (Table 4 and Fig 14A), showed a distinct correlation of migratory pattern with illumination decrease. At 1400 the upper level contained very few adult copepods while at 12 m the count was 27/L. At 1944 the figures were more nearly reversed, and at 2100, over 2 hours after sunset, a general downward movement of animals principally from 0.5 to 4 m followed this upward sunset migration. Eight days later, on August 23, with similar weather and temperature conditions, the series of population samples presented a somewhat similar distribution, the noticeable difference being a less pronounced vertical change (Table 5 and Fig 14B).

On August 15 the figures show (1) the occurrence of a major percentage of the population at 12 to 12 m during the afternoon, (2) the appearance of greater population density at the upper levels after sunset, and (3) the redistribution of the many animals throughout the deeper water two and three hours after sunset. The less extended and less distinct movement on August 23 does not appear to be correlated with any of the factors examined at the time. Field notes record larval stages fairly abundant on August 23. No relation to the weak thermocline (about 9 m on August 15 and about 13 m on August 23) was evident. On August 23 no upward migration of consequence occurred but a uniform distribution appeared at 2032.

1957

In 1957 two similar series of sunset samplings to show any variation in sunset pattern of Diaptomus population were taken six days apart, about four weeks earlier than those in 1956 (Tables 6 and 8 and Fig 14E and D). On July 11 a rise of the large percentage of the population, 56 per cent at 12 m at 1620, near the surface 38 per cent at 0.5 m, occurred at about sunset, 1920. Following this a redistribution of population occurred at all levels with, finally, at 2140, 42 per cent of the animals at 14 m.

Of interest at this time was the low density of population per volume of water, 0.4 to an exceptional high of 13.6 adults/L, coupled with the presence of numerous other dead Diaptomus not readily apparent in samplings on other dates. This indicates a higher peak of population somewhat earlier in the month.

On July 17 a similar change in vertical distribution seems apparent, any movement being somewhat less compared to that six days earlier. This population was largely copepodids and that on July 11 mostly adults with a few gravid females in each haul. Further, the copepod population in the pond on July 11 and 17 was low as far as it has been observed in this study, the August 15, 1956 population being roughly five to six times more dense, and that on August 29, 1957 being even greater. Of interest is the fact that a full moon shone July 11 and no moon was visible July 17.

Comparison of sunrise and sunset patterns on successive days, July 16 and 17, may be made (Tables 7 and 8 and Fig 14C and D). An examination of the July 16 sunrise table and histogram shows that animals moved up toward the 0.5 m and 4 m levels at 0422 and at 0522.

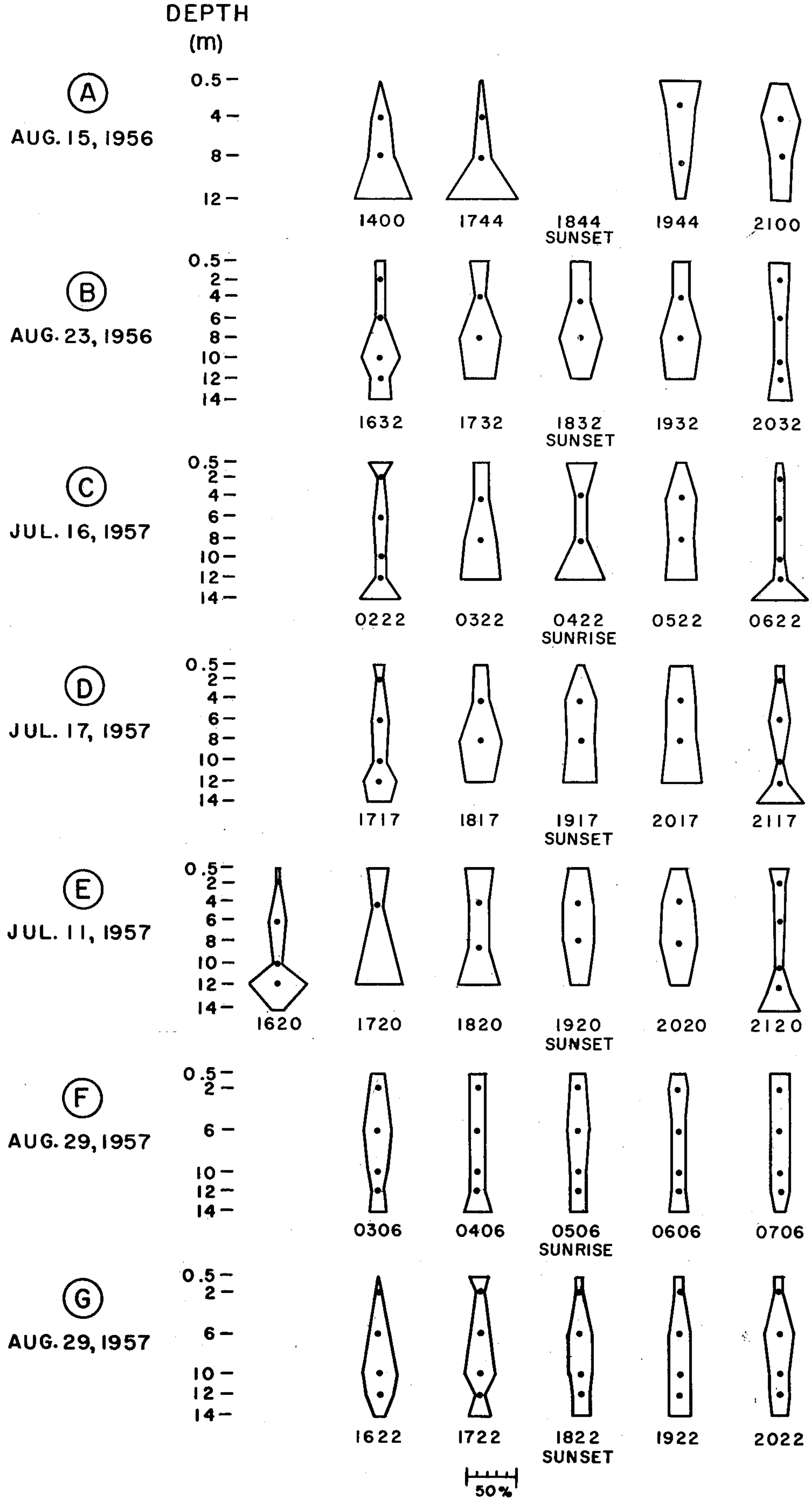

Fig 14 Vertical distribution of Diaptomus.

At 0622 most of the animals had descended to 14 m. An unobscured 18-day-old moon crossed the meridian at 0256. On July 17 sunset table and histogram reveal a similar upward movement followed by a sudden descent two hours after sunset. The moon remained below the horizon throughout the period of observation and cloud cover was insignificant until 2050 when a 0.7 cumulus cover appeared. July records show that nocturnal vertical distribution apparently remained constant from 2100 to 0300 as well as during the middle of the day.

To determine the nature of any population change during sunrise and sunset hours of the same day and also to compare with distribution later in season, hauls were made morning and evening on August 29 (Tables 9 and 10; Fig 14F and G). Surface illumination readings for these periods are presented (Fig 9). The vertical distribution of zooplankters was remarkable for its uniformity at all levels during the sunrise series. The hourly differences at any level were never more than 12%. At sunset a gradual but slight rise in population level occurred from a maximum at 10 m at 1622 and to a maximum at 6 m at 2022. However, the distribution tended to be relatively uniform vertically during most of this period.

The results in 1957, and 1956 as well, show a general decline in migratory activity as the summer season progressed, with an indication that the age of the populations might possibly exert some effect on this movement. A thermocline, when present, seemed to create no environmental barrier to movement. The presence or absence of moonlight made no detectable difference. The unusually high transparency of the water may possibly have an effect on the relatively slight vertical migration of the population. In certain previous instances of vertical migration the movement of the animals has been shown to keep them in roughly the same light intensity. If the animals had not migrated vertically, they would have been subjected to a change of intensity of several orders of magnitude as the sun rose or set. In Duck Pond a migration from the surface to the bottom would produce a light reduction of about one order of magnitude. This difference may be of no significance to the animals in comparison with the tremendous change in illumination during the course of a day. Since the zooplankters in Duck Pond are unable to escape high illumination by migrating, only those species can live in this pond which can withstand relatively intense light. The fact that high illumination extends to the bottom of Duck Pond also means that zooplankters could be seen by enemies at all levels and that phytoplankton could grow at all levels. Therefore, three of the causes frequently suggested for vertical migration -- avoidance of intense light, escape from the sight of predators, and movement into zones of phytoplankton growth -- do not apply in Duck Pond. Their absence may account, in part at least, for the lack of a regular and pronounced migration in this pond. That this is not the only possible explanation is evidenced by the failure of zooplankton to migrate in certain instances in ponds of average or low transparency.

The foregoing observations in Duck Pond may be compared with similar sunrise and sunset series of samples taken in Flax Pond, Falmouth, Massachusetts, a pond 8 m deep. This study was confined to the vertical migration of the cladoceran, <u>Bosmina longirostris</u> (O. F. Müller), from a mixed zooplankton community. On August 14, 1957, a slight rise of these animals to the surface took place an hour before sunrise and a portion of the population remained in the upper layers thereafter. For the remainder of the period the population remained rather uniformly distributed throughout the water column (Table 11). The evening series on this day showed a remarkable static population with the greatest percentage remaining at 7 m (Table 12). The thermocline on this day was at about 6 m. The Secchi disk reading for this date was 3.5 m, similar to that for most of the summer, and a dense population of diatoms including Asterionella and much algal debris occurred at the 7-m level. The intestinal tracts of the cladocerans were always full. In this case an abundance of algal food, together with a temperature change at the thermocline of 5°C in 2 m, may have been responsible for the lack of vertical movement.

A second series at Flax Pond on September 7, 1955 (Table 13) showed the majority of Bosmina at the surface one hour before sunrise but at sunrise and for six hours thereafter 67 to 98% of the population remained at the 5-m level with only a few animals at the surface and at 8 m. The animals remained in the epilimnion, which contained Asterionella commonly, and were practically absent from the deeper, colder water in and below the thermocline.

On two occasions, then, a definite movement at sunrise or sunset occurred. At sunrise on August 14 the animals which were on the bottom moved up, at sunrise on September 7 those which were near the top moved down, while at sunset on August 14 no significant migration occurred. At sunrise on August 14 and sunrise on September 7 after the first hour of observation no further significant migration occurred.

After the first hour of observation in each case the major part of the population on August 14 remained uniformly distributed (sunrise), or stayed near the pond bottom (sunset), and on September 7 most of the animals remained at 5 m.

As previously indicated, Diaptomus in Duck Pond showed a decrease in migratory activity as the summer progressed. Langford (1938, p 47), reporting on this species in much deeper water of Lake Nipissing, Ontario, says "Great variation in the extent and type of migration occurred during the season May - September. At times no change was found between daylight and midnight distributions, whereas at other times there is a definite movement to the surface at night." In some of his diagrams the thermocline is indicated as forming a limiting factor of distribution in late summer.

The investigation has shown Duck Pond to fall definitely into the oligotrophic class of lakes as far as its life history goes. The transparency of the water coupled with low plankton density, especially of the larger planktonic forms, the paucity of growth of higher plants, and lack of organic detritus on the bottom are all factors which indicate youth. Hence, it cannot be considered a productive pond in the sense of forming a large biomass of vertebrate forms as fishes. Chlorophyll production is certainly not higher than in other ponds on Cape Cod and is probably much less than most. An interesting feature of the unicellular phytoplankters is their small individual cell size as compared with that in many other ponds. The almost pure population of Diaptomus is quite unique and hence a useful biological device for measuring a relatively uncomplicated plankton population.

Future significant studies might well deal with energy transfer related to this part of the food web and any seasonal aspects thereof. In conjunction with this it would be worth while to discover the exact identity and density of the physical and biotic factors producing the seasonal increase in turbidity. More study should be made of the seasonal aspects in the vertical diurnal migration pattern of the red copepod so typical of this pond, especially with reference to micro-chemical stratification that might be associated with it, such as oxygen, carbon dioxide, hydrogen-ion concentration, temperature, and distribution of microautotrophs.

Another interesting aspect of the pond's chemistry, and probably biology as well, is the cycle which iron plays in the water and the history of the formation of the iron deposits in some parts of the pond's bottom. In conjunction with this an analytical chemical study of the dark-layer globules might be revealing. Correlated with seasonal change in the nature of population movement may be a factor of age class of the populations which might have a bearing on the type and degree of movement. A study of this with series of samplings at weekly intervals starting in May or June might lead to fruitful results.

Table 3

Vertical distribution of *Diaptomus* and globules of "dark layer." July 26, 1956.

Depth m	Objects	Animals or globules/L	Percentage
0.5	adults	1.0	2.4
	adults & copepodids	1.5	2.6
	nauplii	1.0	6.9
	globules	10.6	4.2
4	adults	4.7	11.1
	adults & copepodids	7.3	12.9
	nauplii	2.6	17.9
	globules	12.5	5.0
8	adults	10.3	24.3
	adults & copepodids	13.1	23.3
	nauplii	0	0
	globules	25.6	10.2
9 "Dark layer"	adults	12.5	29.4
	adults & copepodids	16.3	28.8
	nauplii	11.4	78.5
	globules	193.5	77.3
12	adults	14.0	32.9
	adults & copepodids	18.5	32.6
	nauplii	0.5	3.5
	globules	8.5	3.4

Wind SE-SW, light, clear.
Past weather: fair and warm.
Secchi reading: 12.5 m at 1300.
Moon 16 days old.
82-L samples; hand pump.

Temp. °C.	
air	26
0 m	22.5
3	23.5
6	23.0
9	21.5
12	18.5
15	18.0

Table 4

Vertical distribution of *Diaptomus*. Sunset, August 15, 1956.

EST	Depth m	Animals/L	Percentage	
1400	0.5	0.5	1	18
	4	7.9	17	
	8	12.0	25	83
	12	27.3	58	
1744	0.5	2.1	4	12
	4	4.4	8	
	8	9.9	18	87
	12	37.1	69	
SUNSET 1844				
1944	0.5	24.9	42	69
	4	15.7	27	
	8	13.1	22	31
	12	5.4	9	
2100	0.5	11.5	19	60
	4	24.9	41	
	8	13.9	23	40
	12	10.5	17	

Wind NW, light, clear.
Past weather: fair and warm, with some heavy showers 48 hrs. previously.
Secchi reading: 11 m at 1455.
Moon 9 days old.
82-L samples; hand pump.

Temp. °C.	
air	27
0 m	25.0
0.5	25.0
4	24.0
8	24.0
12	20.5

Table 5

Vertical distribution of Diaptomus. Sunset, August 23, 1956.

EST	Depth m	Animals/L	Percentage
1632	0.5	5.5	4.6
	2	6.8	5.7
	6	11.8	9.9
	10	44.8	37.5
	12	21.9	18.3
	14	28.7	24.0
1732	0.5	20.1	15.2
	4	13.6	10.3
	8	54.1	40.9
	12	44.5	33.6
1832 SUNSET	0.5	18.5	20.1
	4	17.1	18.6
	8	38.2	41.5
	12	18.3	19.9
1932	0.5	12.4	14.4
	4	14.7	17.0
	8	33.8	39.2
	12	25.5	29.5
2032	0.5	20.4	16.5
	2	21.3	17.2
	6	15.9	12.8
	8	15.4	12.4
	12	21.7	17.5
	14	29.2	23.6

Wind SE moderate, fair.
Past weather: cloudy, NE storm 48 hrs. previously.
Secchi reading: 10 m at 1605.
Moon 16 days old, broke horizon at 1940.
82-L samples; hand pump.

Temp. °C.	
air	20
0.5m	24
2	24
4	24
6	23.5
8	23.5
10	23
12	22
14	20.5

Table 6

Vertical distribution of Diaptomus. Sunset, July 11, 1957.

EST	Depth m	Animals/L	Percentage
1620	0.5	0.4	2.3
	2	0.5	2.3
	6	3.5	18.2
	10	1.5	7.8
	12	10.9	55.6
	14	2.5	12.9
1720	0.5	2.0	19.5
	4	0.8	7.7
	8	2.8	26.0
	12	5.0	46.5
1820	0.5	2.9	26.6
	4	1.8	16.7
	8	1.8	16.9
	12	4.3	39.8
1920 SUNSET	0.5	4.2	37.7
	4	3.1	27.2
	8	1.4	12.6
	12	2.6	22.8
2020	0.5	1.9	15.1
	4	4.3	33.1
	8	4.3	33.4
	12	2.4	18.5
2120	0.5	5.2	17.0
	2	3.1	10.1
	6	2.0	6.5
	10	1.8	5.8
	12	5.4	17.6
	14	13.6	42.4

Wind SW gentle, fair.
Past weather: hot, clear.
Secchi reading: 16 m at 1315.
Moon 14 days old, broke horizon at 1920.
82-L samples; hand pump.

Temp. °C.	
air	22
0.5 m	24
2	24
6	24
10	23
12	23
14	22

Table 7

Vertical distribution of Diaptomus.
Sunrise, July 16, 1957.

EST	Depth m	Animals/L	Percentage
	0.5	5.8	20.6
	2	1.5	5.1
	6	3.5	12.0
0222	10	2.8	8.6
	12	4.1	12.0
	14	10.8	41.4
	0.5	0.9	15.4
0322	4	1.1	15.4
	8	1.9	30.8
	12	3.0	38.4
	0.5	7.3	28.0
0422	4	2.6	12.0
SUNRISE	8	3.2	12.0
	12	11.5	48.0
	0.5	2.2	11.1
	4	5.1	33.3
0522	8	4.6	25.0
	12	5.3	30.5
	0.5	0.9	3.3
	2	2.9	10.0
	6	1.9	6.6
0622	10	1.8	8.3
	12	4.9	15.0
	14	15.6	56.7

Wind W light, clear.
Past weather: clear, dry, hot.
Secchi reading: 16.5 m at 0645.
Moon 18 days old, crossed meridian at 0256.
82-L samples; hand pump.

Temp. °C.	
air	19
0.5 m	23.5
2	23.5
6	23.5
10	23.5
12	23.5
14	23

Table 8

Vertical distribution of Diaptomus.
Sunset, July 17, 1957.

EST	Depth m	Animals/L	Percentage
	0.5	2.8	10.5
	2	1.1	5.3
	6	4.2	15.8
1717	10	2.7	12.4
	12	9.1	33.3
	14	6.3	23.0
	0.5	4.4	14.3
1817	4	3.6	15.8
	8	9.7	42.8
	12	5.8	27.0
	0.5	1.7	7.5
1917	4	7.3	31.1
SUNSET	8	8.0	26.4
	12	8.9	33.9
	0.5	3.8	22.2
	4	3.8	27.7
2017	8	5.6	30.5
	12	3.6	19.4
	0.5	2.5	6.6
	2	2.4	5.3
	6	7.1	20.0
2117	10	1.8	5.3
	12	7.0	16.0
	14	16.3	46.7

Wind W gentle, fair.
Past weather: fair, warm.
Secchi reading: 15.5 m at 1615.
Moon 19 days old, rose at 2208.
82-L samples; hand pump.

Temp. °C.	
air	25.5
0.5m	25
6	24
10	24
12	24
14	24

Table 9

Vertical distribution of _Diaptomus_.
Sunrise, August 29, 1957.

EST	Depth m	Animals/L	Percentage
0306	0.5	20.3	13
	2	22.2	14
	6	42.2	27
	10	31.0	20
	12	18.6	12
	14	21.8	14
0406	0.5	36.4	17
	2	39.0	18
	6	36.0	17
	10	29.3	14
	12	25.5	12
	14	47.3	22
0506 SUNRISE	0.5	39.2	15
	2	41.2	16
	6	56.7	22
	10	40.5	16
	12	38.3	15
	14	38.7	15
0606	0.5	50.9	17
	2	52.2	18
	6	43.3	15
	10	46.6	16
	12	44.2	15
	14	56.6	19
0706	0.5	45.8	16
	2	59.0	20
	6	62.0	21
	10	50.2	17
	12	48.0	16
	14	27.9	10

Wind SW calm-light, partly cloudy.
Past weather: fair, moderate temp., heavy rain 4 days previously.
Secchi reading: 14.5 m at 1730.
Moon 4 days old, set at 2045.
205-L samples; electric pump.

Temp. °C.	
air	11
0.5 m	22
2	22
6	22
10	22
12	22
14	22

Table 10

Vertical distribution of _Diaptomus_.
Sunset, August 29, 1957.

EST	Depth m	Animals/L	Percentage
1622	0.5	8.7	4
	2	14.6	6
	6	46.9	20
	10	78.0	34
	12	61.9	27
	14	20.8	9
1722	0.5	26.9	14
	2	13.0	7
	6	47.6	24
	10	56.5	28
	12	17.3	9
	14	37.3	19
1822 SUNSET	0.5	22.7	9
	2	15.8	6
	6	63.6	25
	10	62.0	24
	12	43.5	17
	14	47.5	19
1922	0.5	15.8	8
	2	18.9	9
	6	46.6	22
	10	41.6	20
	12	45.6	22
	14	39.1	19
2022	0.5	17.4	9
	2	17.7	9
	6	52.3	28
	10	37.7	20
	12	38.5	20
	14	26.5	14

Wind NE calm-light, fair.
Past weather: partly cloudy.
Secchi reading: 14.5 m at 1530.
Moon 4 days old, set at 2045.
205-L samples; electric pump.

Temp. °C.	
air	19
0 m	22
0.5	22
2	22
6	22
10	22
12	22
14	22

Table 11

Vertical distribution of *Bosmina longirostris*. Flax Pond, Sunrise, August 14, 1957.

EST	Depth m	*Bosmina longirostris*/L	Percentage
0250	0.5	15.7	9
	3	33.5	18
	5	21.2	12
	7	112.0	61
0350	0.5	37.2	26
	3	36.8	25
	5	17.5	12
	7	54.1	37
0450 SUNRISE	0.5	46.3	24
	3	29.8	15
	5	43.9	22
	7	76.5	39
0550	0.5	29.6	19
	3	22.9	16
	5	31.1	21
	7	64.9	44
0650	0.5	31.9	25
	3	26.2	20
	5	24.3	19
	7	45.9	36

Wind SW light, fair.
Past weather: fair.
Secchi reading: 3.5 m at 1630.
Moon 18 days old, rose at 2023.
574-L samples; electric pump.

Temp.	°C.
air	16
0 m	23
0.5	22
3	23
5	22
7	17

Table 12

Vertical distribution of *Bosmina longirostris*. Flax Pond, Sunset, August 14, 1957.

EST	Depth m	*Bosmina longirostris*/L	Percentage
1646	0.5	75.5	14
	3	56.8	10
	5	63.7	12
	7	354.1	64
1746	0.5	28.5	5
	3	32.4	6
	5	73.4	13
	7	436.6	76
1846 SUNSET	0.5	15.9	6
	3	34.0	14
	5	34.5	14
	7	164.4	66
1946	0.5	51.3	14
	3	47.4	13
	5	34.4	9
	7	243.2	64
2046	0.5	45.4	18
	3	25.7	11
	5	17.4	7
	7	158.9	64

Wind SW gentle, partly cloudy.
Past weather: partly cloudy, SW, windy.
Secchi reading: 3.5 m at 1630.
Moon 18 days old, rose at 2023.
574-L samples; electric pump.

Temp.	°C.
air	21
0 m	23
0.5	23
3	23
5	22
7	17

Table 13

Vertical distribution of *Bosmina longirostris*. Flax Pond, Sunrise, September 7, 1955.

	EST	Depth m	*Bosmina longirostris*/L	Percentage
	0400	0.5	69	68
		5	33	32.5
		8	0.4	0.3
SUNRISE 0515	0500	0.5	35	33
		5	70	67
		8	0.5	0.4
	0600	0.5	7	10
		5	64	89.5
		8	0.5	0.7
	0700	0.5	5	10
		5	43	88
		8	0.7	2
	0800	0.5	6	6
		5	91	93
		8	0.5	0.5
	0900	0.5	3	3.5
		5	81	95.5
		8	0.9	0.2
	1000	0.5	3	4
		5	63	94
		8	0.8	2
	1100	0.5	0.7	1
		5	55	97.5
		8	0.6	1

Temp. °C.	
0.5 m	21.5
5	21
8	12

Literature Cited

Clarke, G. L.

1954. Elements of ecology. John Wiley & Sons, Inc.: New York.

Ruttner, Franz

1955. Fundamentals of limnology. Univ. Toronto Press: Toronto.

Langford, R. R.

1938. Diurnal and seasonal changes in the distribution of the limnetic crustacea of Lake Nipissing, Ontario. Univ. Toronto Stud. Biol. Ser. No. 45: 1-42.

Welch, P. S.

1948. Limnological methods. The Blakiston Co.: Philadelphia, Pa.

Wilson, C. B.

1932. The copepods of the Woods Hole region, Massachusetts. Bull. U. S. Nat. Mus. 158.