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Migration of Net Phytoplankton and Zooplankton in Mendum's Pond, New Hampshire.

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Abstract

The study examines the vertical distribution and migratory behavior of net phytoplankton and zooplankton of Mendum's Pond in Barrington, N.H. The cyanobacteria, *Microcystis* and *Aphanocapsa* were the dominant net phytoplankton in this lake. Dominant zooplankton included *Daphnia ambigua*, *Daphnia catawba*, *Bosmina longirostris*, and both calanoid and cyclopoid copepods. Vertical distribution of net phytoplankton suggested migratory behavior, but no consistent pattern was observed. The zooplankton migrated nocturnally, however, calanoid copepods seemed to simultaneously migrate nocturnally and reversely at sunset, suggesting the presence of separate species or different age classes. Diel vertical migration (DVM) of zooplankton was not correlated with the distributions of net phytoplankton in the water column. However, grazing on smaller phytoplankton by zooplankton may have indirectly affected the abundance of the larger size class, net phytoplankton. SONAR analyses suggested that DVM of the phantom midge, *Chaoborus*, may have influenced the distribution of zooplankton. The findings suggest that a cascading effect of *Chaoborus*-zooplankton-phytoplankton may pressure vertical distributions of an entire ecosystem of planktonic organisms. Results from the study also raise concern in regard to abundant cyanobacteria and the future trophic status of Mendum's Pond.

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Introduction

Diel vertical migration occurs when plankton migrate vertically in the water column over a 24 h cycle. Zooplankton typically migrate nocturnally, occupying depths near the hypolimnion during the day and moving into the epilimnion during the evening (Haney 1993). Reverse migration is the opposite of nocturnal DVM, where plankton migrate from shallower water during the day to deeper water at night. Diel vertical migrations have been recorded to range from a few centimeters to over 100 meters and can occur among both marine and freshwater plankton (Lampert & Sommer 1997). Although there have been many studies on zooplankton DVM, little is known about the daily vertical movements of phytoplankton and possible interactions between zooplankton and phytoplankton migration.

The objectives of this study were to observe diel changes in the vertical distribution of net phytoplankton and zooplankton of Mendum's Pond. Transects using SONAR were run to assess migratory movements of phytoplankton and zooplankton. Chemical and physical parameters of the lake,

including chlorophyll a and phycocyanin fluorescence, were also recorded for comparisons with the distributions of dominant planktonic organisms in Mendum's Pond.

Methods

Study Site - Mendum's Pond is an oligomesotrophic lake in Barrington, N.H. with a surface area of 102.4 Ha, a mean depth of 6.4 m and a maximum depth of 15.9 m (Table 1) (Forsberg and Ryding 1980). Sampling took place on 29, September 2005 under variable weather conditions. A rapid moving front came through the area generating high winds and heavy rainfall for the diurnal portion of the study. By sunset (18:32 EST) the front had passed, skies appeared clear and the lake surface had calmed. Day samples were taken at approximately 1600 h and night samples at 1900 h.

Field Method - Biological samples were obtained using an 8-L Van Dorn water bottle. Samples were taken at depths of 0.5, 2.5, 4.5, 5.5, 6.5, 8.5, 10.5, and 12.5 m. Whole lake water sub-

Table 1. Chemical and physical characteristics of Mendum's Pond, Barrington, N.H. (Physical data from NH Department of Environmental Services; water quality from 1999 (Haney and Ikawa 2000)).

Parameter	Value
Town	Barrington
County	Strafford
Latitude	4311
Longitude	7104
River Basin	Coast
Volume (ha m ⁻¹)	656.7
Mean Depth (m)	6.4
Max Depth (m)	15.9
Relative Depth (%)	1.392
HRT (Years)	1.1
Watershed (ha)	1442.3
Lake Area (ha)	102.4
Watershed:Lake Ratio	14.08
Elevation (m,ASL)	67.5
Total P ($\mu\text{g L}^{-1}$)	3.3
Total N ($\mu\text{g L}^{-1}$)	250.7
Chl a ($\mu\text{g L}^{-1}$)	1.23
Secchi DD (m)	4.28

samples (~5 ml) were taken from each discrete sample for fluorescence measurements, in which chlorophyll *a* and phycocyanin concentrations were measured (Aquafluor™ Handheld 2-Channel Fluorometer, Turner Designs). Channel A measured chlorophyll *a* ($\mu\text{g L}^{-1}$) and Channel B measured relative fluorescence units of phycocyanin, an accessory photosynthetic pigment characteristic of cyanobacteria. Plankton from the discrete samples were concentrated onto a 50 μm Nitex mesh and preserved with a 4% formalin-sucrose solution (Haney 1973).

A Yellow Springs Instrument (YSI Sonde 6600 M) multi-parameter probe was used to measure lake profiles of dissolved oxygen concentration and percentage, light intensity, chlorophyll *a* fluorescence, pH, specific conductivity, turbidity, oxidation-reduction potential, temperature, and depth. The probe was lowered slowly at a rate of 0.5 m min⁻¹ to the bottom of the deep site of the lake (~13 m). Data were recorded on a YSI 650 datalogger and recorded at 3 s intervals (~2.5 cm depth change). A LI-92SA Underwater Quantum Sensor (LI-COR) was used to measure the light intensity profile (400-700 nm) of the lake. Measurements were recorded at 0.5 m depth inter-

vals on an LI-1400 (LI-COR). Secchi disk transparency depths were also determined (20 cm, black and white, with a view-scope).

A series of SONAR transects were run across the lake (LCX-25c Solar Max Sonar, Lowrance Electronics, Inc) beginning at sunset (18:32) to view the lake basin and distribution of fish, *Chaoborus* and other large zooplankton in the water column. SONAR was run at 15 min intervals before, during, and after twilight when zooplankton, *Chaoborus*, and ultimately phytoplankton are most active in migration (Teraguchi & Northcote 1966).

Laboratory Methods - Subsamples of concentrated plankton were counted on 1 ml Sedgwick Rafter counting cells to determine the concentration of zooplankton from the discrete depth samples. Each sample was weighed using a gram scale and recorded in volume. Net phytoplankton (~100 individuals) were also counted to determine relative abundance from each interval depth.

Data recorded from the YSI 6600 M multi-parameter probe were downloaded from the YSI 650 data logger and stored in Excel. The data were graphed and analyzed statistically with SigmaPlot 9.0 and SigmaStat 3.1 (Systat). SONAR images were downloaded and analyzed with SonarViewer (Version 1.2.2, Lowrance Electronics). The upper and lower *Chaoborus* migration boundaries were determined by selecting average boundary points observed on the SonarViewer's images (Figure 10 & 11) (Haney et al. 1990).

Results

The lake profiles recorded from the YSI multi-parameter probe were compared with the distribution of planktonic organisms in the water column. Temperature rapidly decreased between 6 and 9 m, indicating a thermocline (Figure 1). Dissolved oxygen concentrations ranged from 3.9 to 8.4 mg L⁻¹ near the surface and decreased at 5.5 m with a DO minimum of 1.8 mg L⁻¹ (Figure 1). At 8 m, DO increased from 1.8 to 2.5 mg L⁻¹ and then decreased again to 0.0 mg L⁻¹ at 11.5 m where conditions were anoxic (Figure 1).

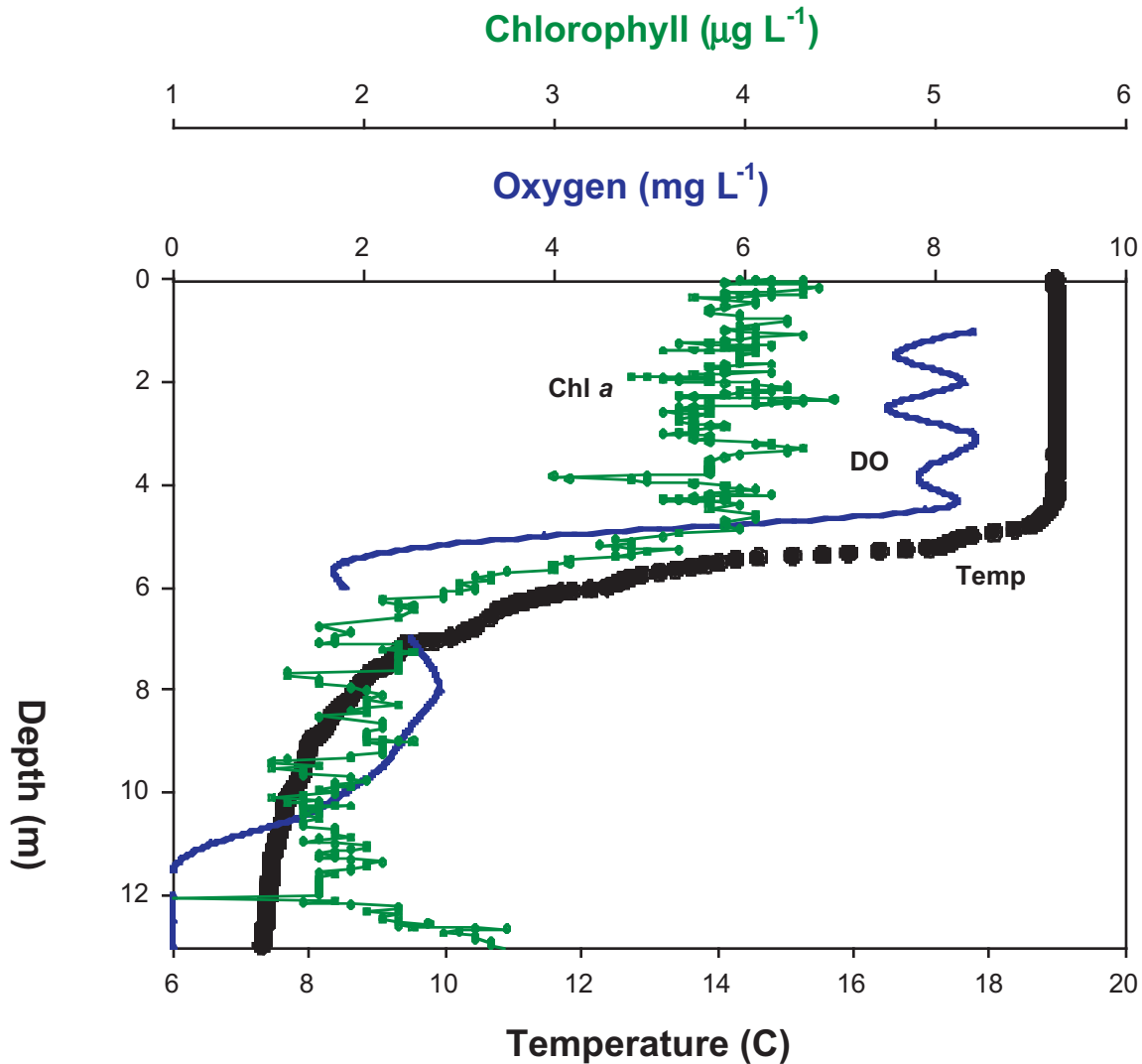


Fig. 1. Mendum's Pond vertical profile for chlorophyll *a* ($\mu\text{g L}^{-1}$), dissolved oxygen (mg L^{-1}), and temperature ($^{\circ}\text{C}$) over depth (m) on September 29, 2005.

Turbidity was uniform in the epilimnion and formed two maxima in the metalimnion (Figure 2). A significant increase in turbidity, reaching a peak value of 19.2 NTU, occurred between 11.5 to 12.5 m (Figure 2). The pH declined gradually in the epilimnion from a value of 7.4 to 6.4 (Figure 2), possibly varying due to rainfall and mixing at the surface. Chlorophyll *a* concentrations (measured by the YSI multi-parameter probe) ranged from 3.3 to 4.3 $\mu\text{g L}^{-1}$ in the epilimnion, decreasing in the thermocline (between 1.5 and 2.5 $\mu\text{g L}^{-1}$). At 12 m and deeper, chlorophyll *a* increased again reaching 3.5 $\mu\text{g L}^{-1}$ near the bottom of the lake (Figure 1), suggesting algal growth among the sediments. Discrete chlorophyll *a* fluorescence readings (Aquafluor™ Hand-held Fluorometer)

were consistent with the multi-parameter estimates (Figure 3). Fluorescence from the phycocyanin channel were also consistent with general vertical distribution measured by the probe (Figure 4). *For more lake profile data recorded from the multi-parameter probe, please email amurby@unh.edu.*

Net phytoplankton samples were collected and the most abundant taxa were counted. Major groups included, Cyanophyceae (blue-greens), Bacillariophyceae (diatoms), Chlorophyceae (greens), and Dinophyceae (dinoflagellates) (Figure 5 a). Cyanobacteria such as *Microcystis* and *Aphanocapsa* were the most dominant net phytoplankton in the water column (day and night) (Figure 5 b). Cyanobacteria collected during the

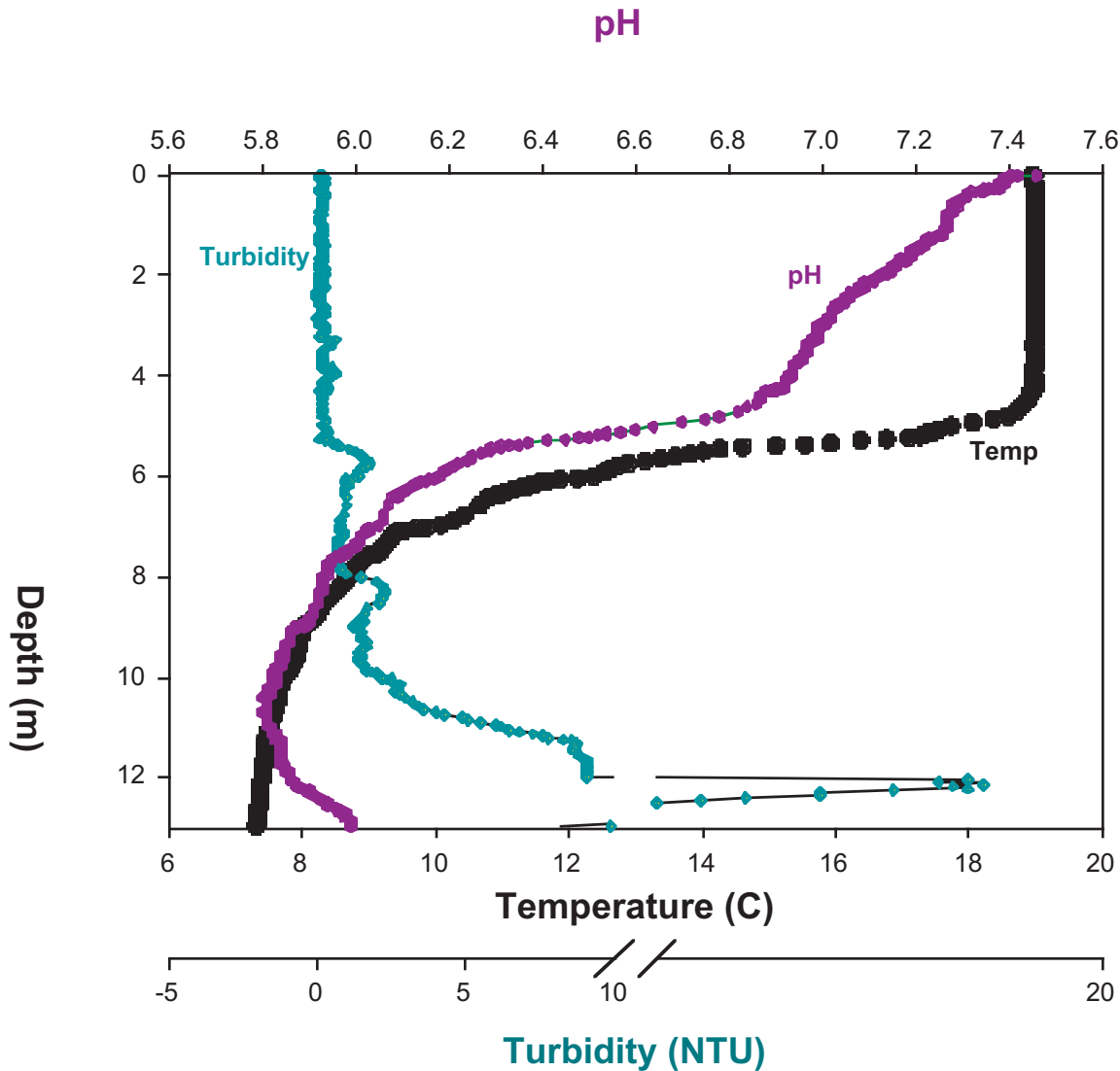


Fig 2: Mendums Pond vertical profile for temperature (C), pH, and turbidity (NTU) over depth (m) on September 29, 2005.

day were found deepest at 10.5 m, but were deeper at night at depths of 12.5 m suggesting a reverse migration (Figure 6). The diatom, *Asterionella*, was observed among the day samples, but was denser at night in the anoxic layers of the hypolimnion (Figure 7). Dominant genera of the dinoflagellates were *Peridinium* and of the green algae, *Staurastrum* (Figure 7).

Daphnia spp. (*Daphnia ambigua* and *Daphnia catawba*), *Bosmina longirostris* and both calanoid and cyclopoid copepods migrated upward in the water column from about 12.5 m in the hypolimnion to 5.5 m in the metalimnion (Figures 8 & 9). However, the calanoid copepods seemed to have migrated from both the epilimnion (downward) and the hypolimnion (upward) towards the

5.5 m depth (Figure 9). Calanoid copepods were later determined to be primarily *Skistodiaptomous pallidus*, but there were many unidentifiable organisms in the samples as well. Although undetermined, it would be interesting to identify whether the distributions of calanoids represent different species or different age classes to understand why there was a difference in migration. Interestingly, each of the four dominant zooplankton groups displayed a migration to the 5.5 m depth (Figures 8 & 9).

Quartiles (50 %) were calculated with the technique set by Pennak (1943). The mean depth for *Daphnia* spp. was 9.04 m during the day and 4.81 m at night (Figure 8). *Bosmina* sp. had a mean depth of 6.15 m during the day and 5.05 m

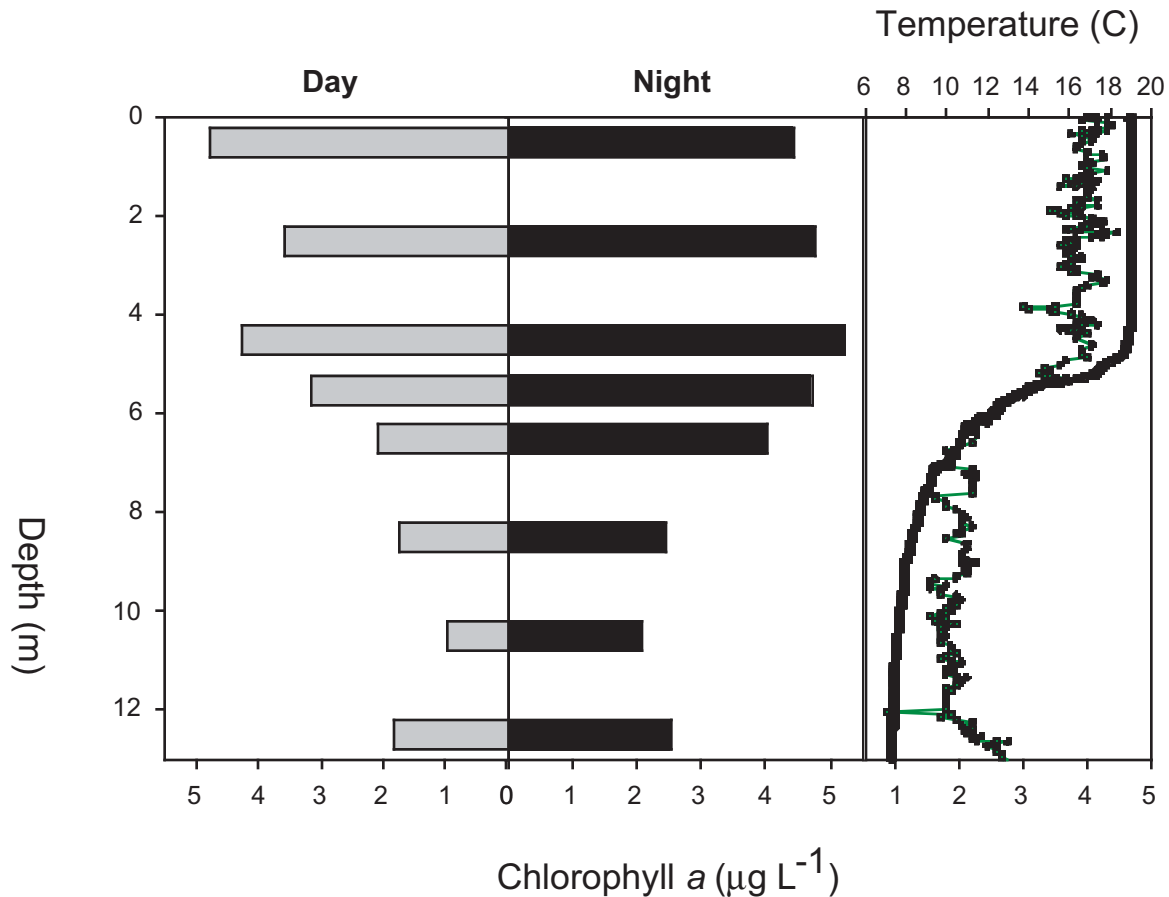


Fig. 3: Chlorophyll *a* ($\mu\text{g L}^{-1}$) measured by fluorometry (bars) for both day and night discrete samples, compared with chlorophyll *a* ($\mu\text{g L}^{-1}$) and temperature (C) measured by the multiparameter probe (scatter) for Mendum's Pond on September 29, 2005.

at night (Figure 8). Copepod quartiles showed similar characteristics with mean depths of 6.04 m during the day and 5.06 m at night for calanoids and 7.95 m during the day and 4.77 m at night for cyclopoids (Figure 9). With the mean depth of each zooplankton group rising to shallower depths at night, it can be assumed that a nocturnal DVM had occurred.

SONAR profiles indicated a significant upward migration of *Chaoborus* by sunset (Figure 10). Contents of discrete water samples also suggested a significant presence of *Chaoborus* ascending in the water column during sunset. In addition, images on SonarViewer were interpreted to be *Chaoborus* because the gas bladders of these zooplankton have been recorded to reflect from SONAR devices (Haney et al. 1990, Northcote 1964). *Chaoborus* are also known to tolerate anoxic conditions for long periods of time, occupying the sediments until proximate light cues ini-

tiate their migration (Haney et al. 1990). Shortly after sunset (~15 min duration) *Chaoborus* had risen to a depth of 4.07 ± 0.11 m from the sediments (~13 m). Another 45 min later, zooplankton (primarily *Chaoborus*) had ascended to an upper boundary depth of 3.34 ± 0.27 m. The lower boundary was recorded at 7.83 ± 0.10 m (Figure 10).

Discussion

Zooplankton often migrate upward at night due to initiated light cues (Haney et al. 1990), feeding on higher concentrations of phytoplankton in the epilimnion when visibility and reaction distance by planktivorous fish is reduced (Confer & Blades 1975). Predation on zooplankton by planktivorous fish are generally determined by visibility, reaction distance, and overall ease of capturing prey (Confer & Blades 1975). Other predators for

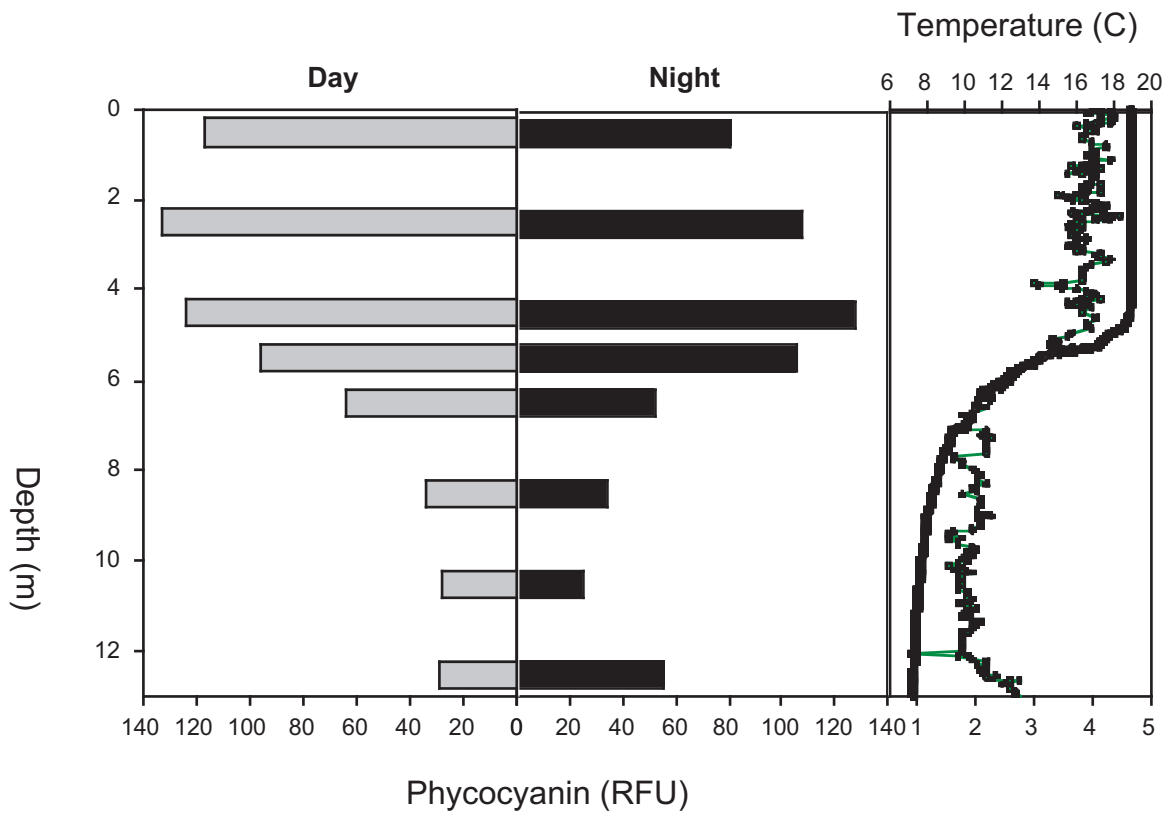


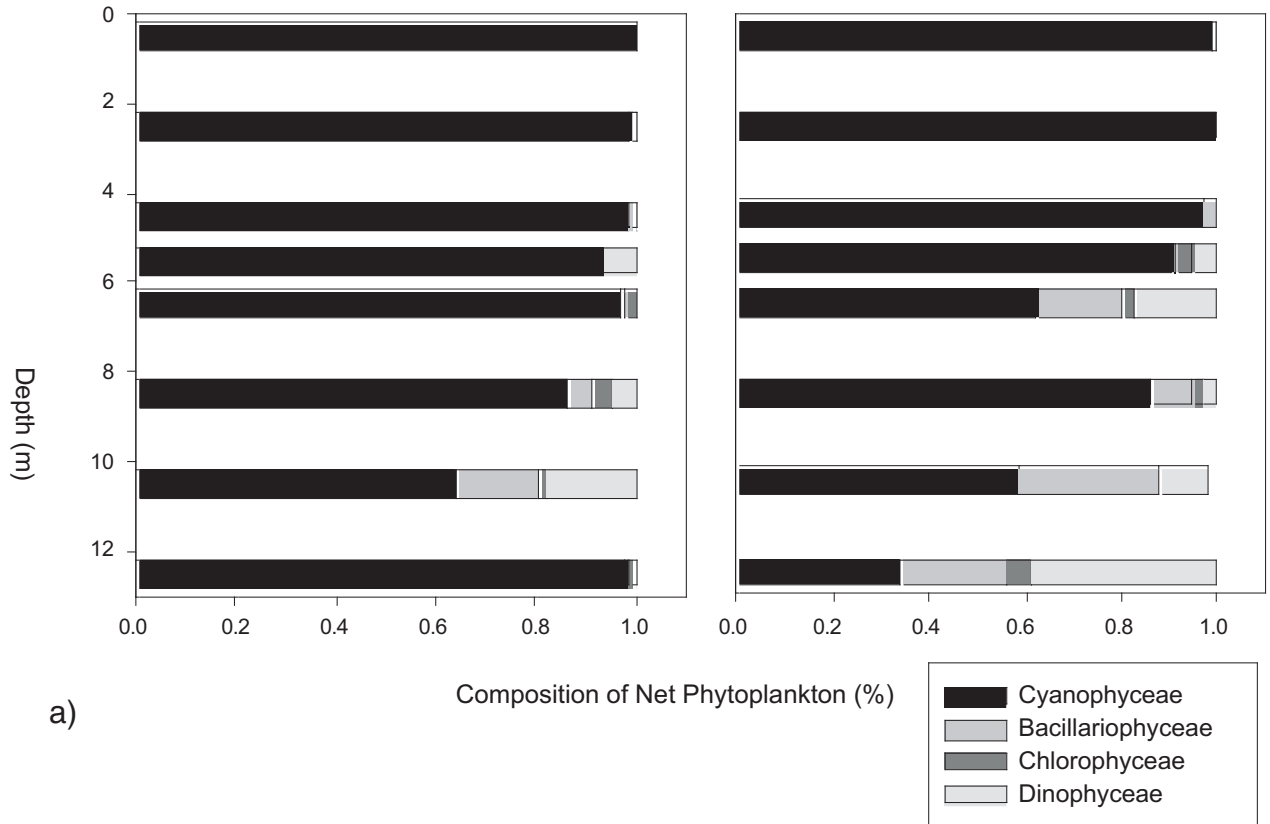
Fig. 4: Phycocyanin (RFU) measured by fluorometry (bars) for both day and night discrete samples, compared with chlorophyll *a* ($\mu\text{g L}^{-1}$) and temperature (C) measured by the multiparameter probe (scatter) for Mendum's Pond on September 29, 2005.

smaller zooplankton to avoid are the phantom midge, *Chaoborus*. SONAR images of Mendum's Pond indicated a vertical migratory mass movement up the water column at sunset, characteristic of *Chaoborus* (Haney et al. 1990, Teraguchi & Northcote 1966).

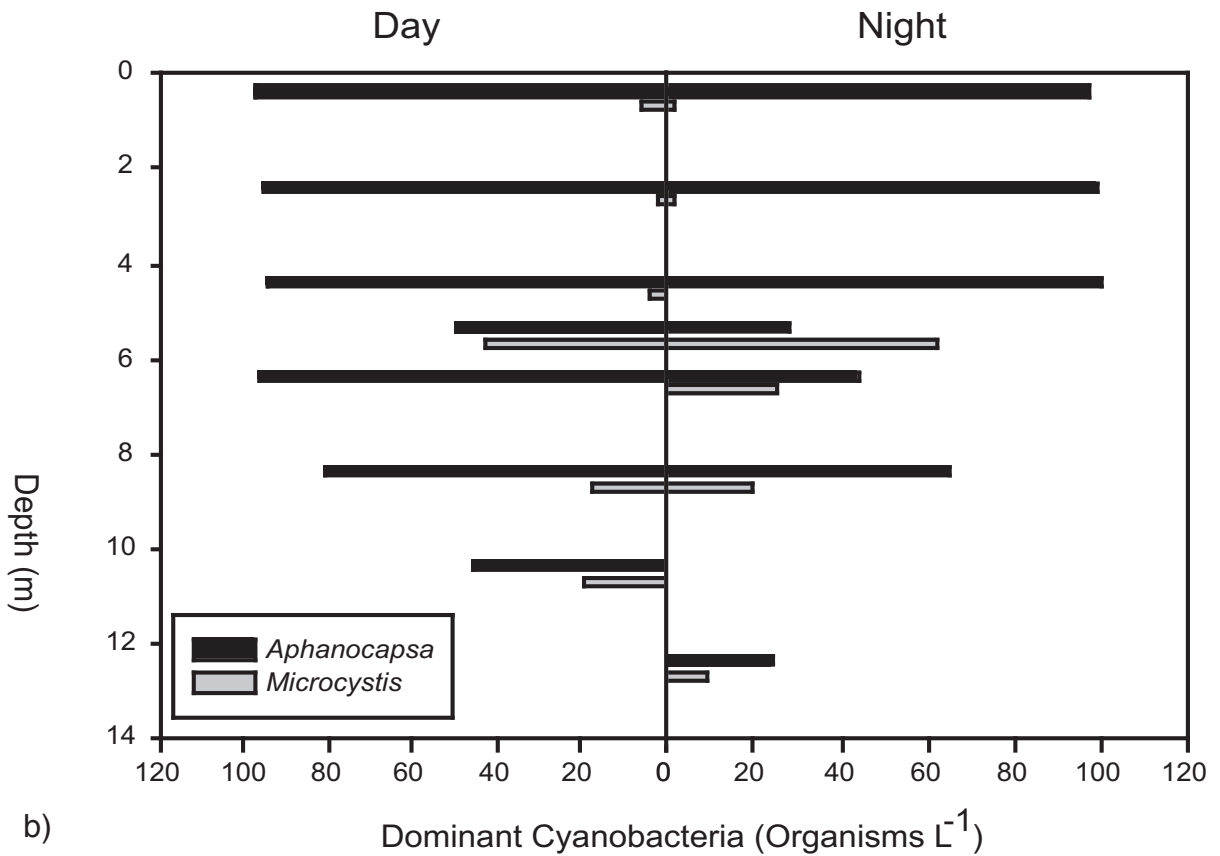
Interestingly dominant groups of zooplankton were abundant at 5.5 m during the evening where DO was slightly depleted and chlorophyll *a* levels had decreased (Figure 1). The DO minimum at 5.5 m could be explained by respiration of plankton. Due to little mixing of the metalimnion, the observed DO deficit may have accumulated over time (Figure 8 & 9). There may also be a fitness advantage for zooplankton to occupy this zone, even with the low dissolved oxygen content. Since fish show an avoidance of low oxygen, it can be assumed that fish were avoiding this depth allowing zooplankton to evade predation by planktivorous fish (Stefan et al. 1996). The 5.5 m depth was also slightly above the observed thermocline, where temperatures were considerably warmer

(~19 C) before gradually decreasing in temperature at this stratified depth range. SONAR images show that the lower limit of the *Chaoborus* boundary expanded after initial sunset, possibly due to foraging for smaller zooplankton (Figures 10 & 11). The (relatively) higher concentrations of zooplankton at 5.5 m may be explained by predatory avoidance, since *Daphnia* tend to swarm together which decreases their chances of being consumed individually (Lampert & Sommer 1997).

While zooplankton migrate to escape the ultimate cause of being preyed upon, grazing is also a factor determining their mass movement. Net phytoplankton (> 50 μm) are generally too large to be grazed upon by herbivorous zooplankton (Lampert & Sommers 1997, Walsby 1987). However, the grazing of smaller and edible phytoplankton by zooplankton may indirectly increase the abundance of the net phytoplankton because the competition for essential nutrients and light resources is reduced (Haney 1987). The most abundant net phytoplankton found in Mendum's



a)



b)

Fig. 5 a & b: Relative abundance of net phytoplankton genera at interval depth in Mendum's Pond for both day and night samples on September 29, 2005. *Microcystis* and *Aphanocapsa* were the most abundant genera of net phytoplankton sampled.

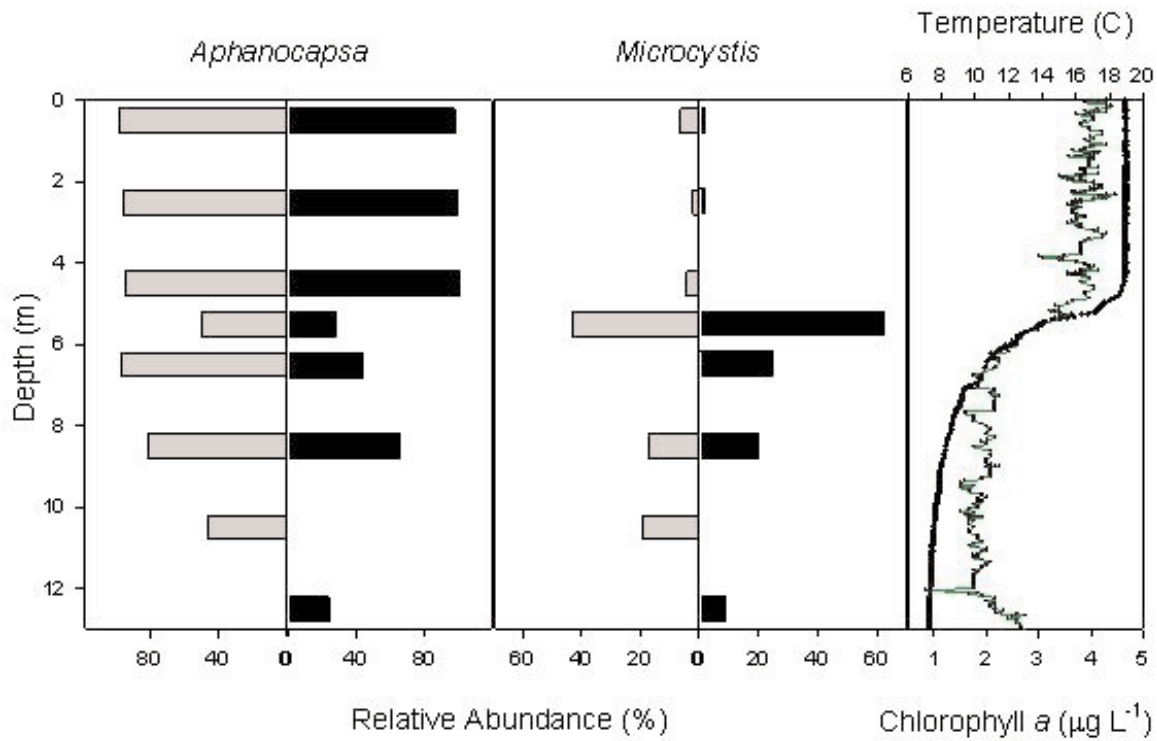


Fig. 6: Vertical profiles of the relative abundance for the cyanobacteria, *Aphanocapsa* and *Microcystis*, in Mendum's Pond on September 29, 2005. Dark bars denote night (1900 h), while light bars represent day (1600 h) samples.

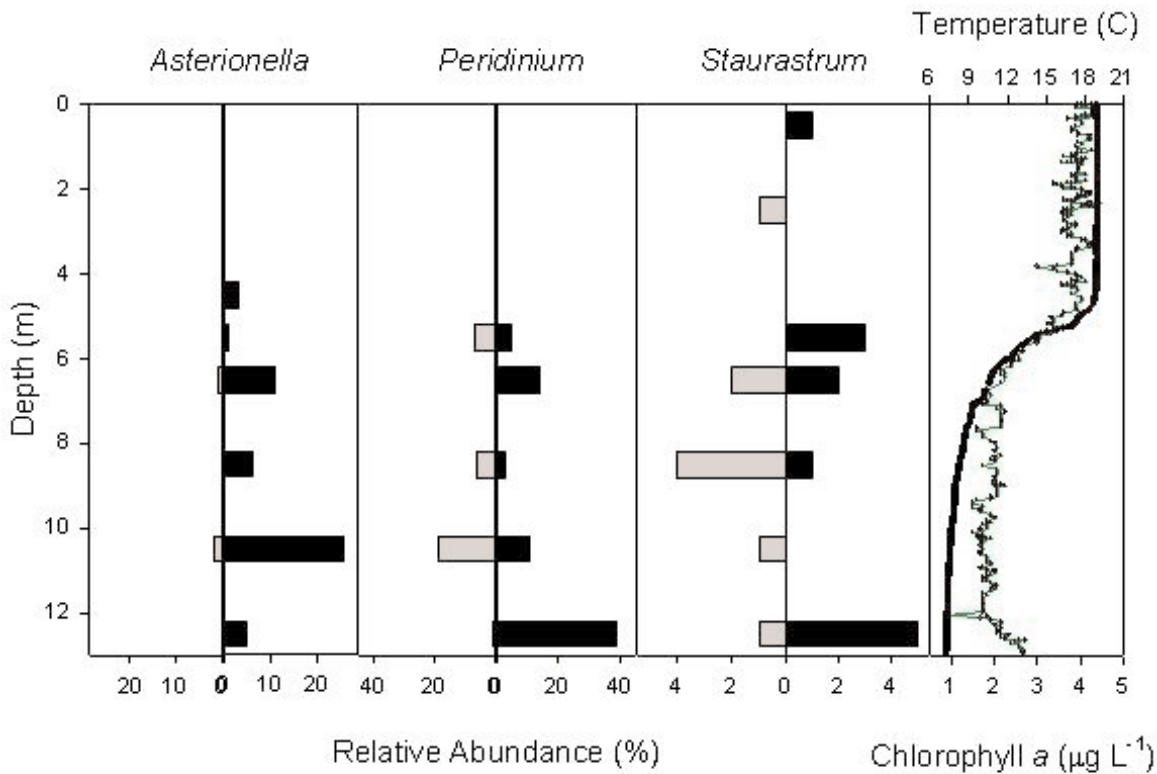


Fig. 7: Vertical profiles of the relative abundance for *Asterionella*, *Peridinium*, and *Staurastrum* as well as temperature and chlorophyll *a* in Mendum's Pond on September 29, 2005. Dark bars denote night (1900 h), while the light bars represent day (1600 h) samples.

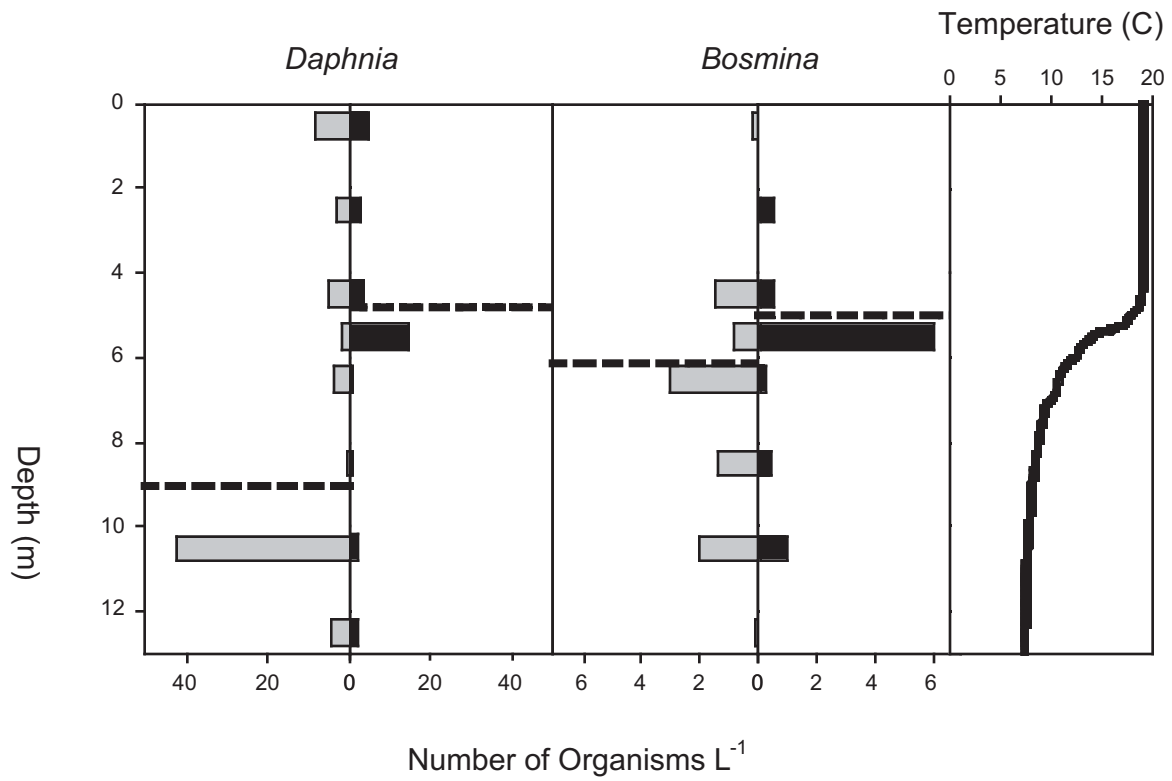


Fig. 8: Cladocera (*Daphnia* and *Bosmina*) distributions from day to night for Mendums Pond on September 29, 2005. Dashed lines indicate the 50 % quartile depth (Pennak 1943). The mean depth for *Daphnia* sp. was 9.04 m during the day, migrating to a mean depth of 4.81 m at night. *Bosmina* sp. had a mean depth of 6.15 m and 5.05 m at night.

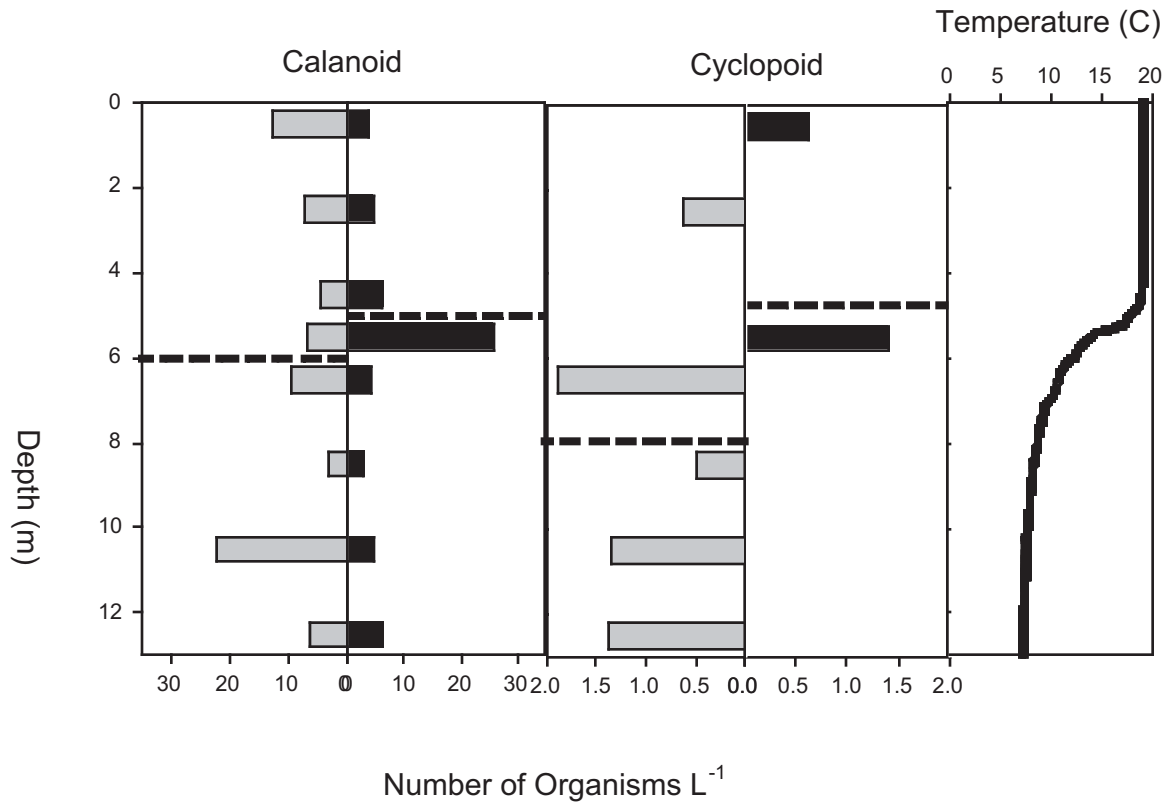


Fig. 9: Copepod (calanoid and cyclopoid) distributions from day to night for Mendums Pond on September 29, 2005. Dashed lines indicate the 50 % quartile depth (Pennak 1943). Mean depth for calanoid was 6.04 m during the day and 5.06 m at night. Cyclopoid mean depth was at 7.95 m during the day and 4.77 m at night.

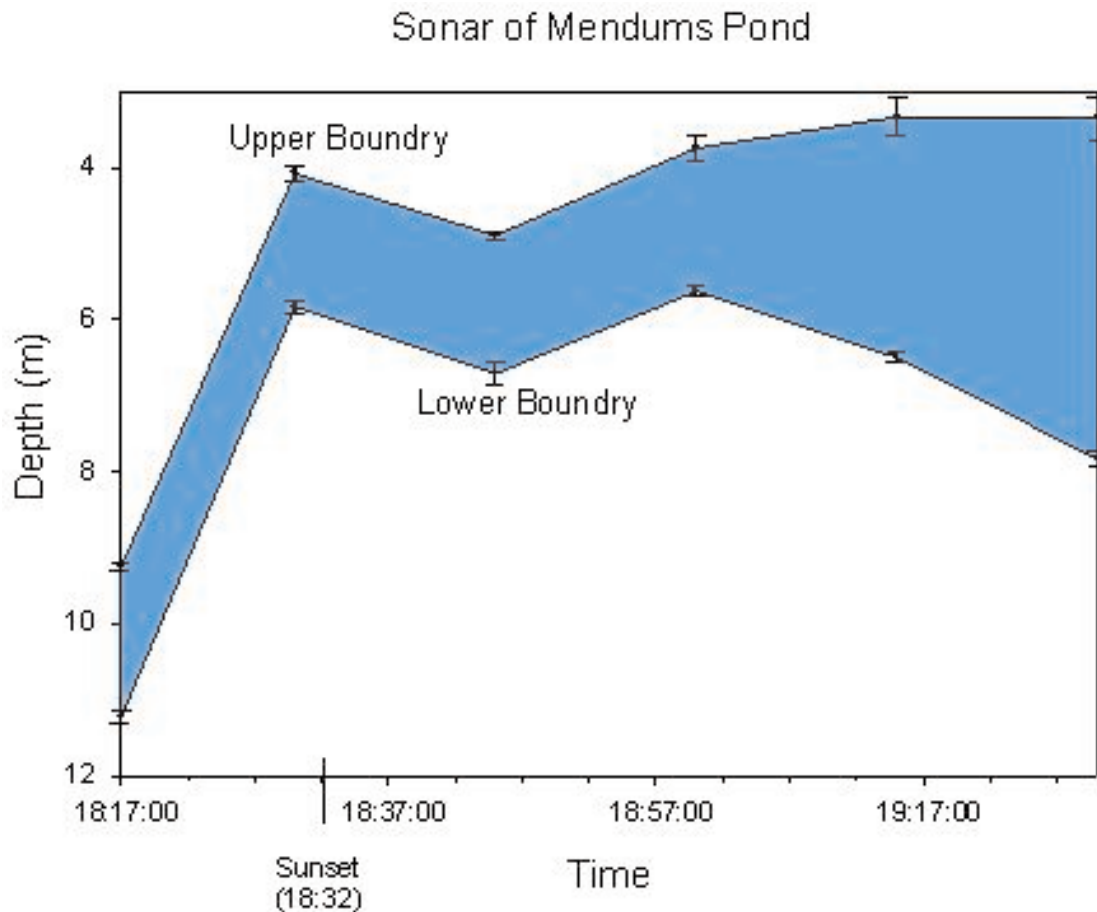


Fig 10: Upper and lower boundaries for *Chaoborus* distributions in 15 minute intervals (Haney et al. 1990). Migration occurs rapidly at sunset and disperses among the epilimnion during the evening.

Pond were cyanobacteria. Some species of cyanobacteria are inedible for zooplankton due to large, colonial sizes and/or potential toxicity of cyanobacteria (Haney 1993).

Colonial *Microcystis* and *Aphanocapsa* were the dominant cyanobacteria in Mendum's Pond. These genera of cyanobacteria are typically considered to be surface dwellers that float in spherical colonies, too large for small zooplankton to graze (Walsby 1987). The buoyancy of cyanobacteria colonies change in response to light intensity and varying pressures on gas vacuoles (Walsby 1987, Tilzer 1973). Walsby's in-lab experiment (1987) demonstrated that colonies sunk after exposure to light (at the end of the day) and remained floating after periods of dark (after an evening period). Sinking is caused by the carbohydrate accumulation during photosynthesis, creating a higher density for the colonies, which in effect causes sinking (Walsby 1987). *Microcystis* and *Aphanocapsa* were abundant relative to other

net phytoplankton and were the dominant genera at every sampled depth in the water column (day and night). Due to the colonial structure and characteristics of these genera, light exposure and wind mixing may be the major source for the migration of cyanobacteria in this study. Furthermore the abundance of *Aphanocapsa* in the water column of Mendum's Pond may be related to the time of year when they were collected (early fall). *Aphanocapsa* are most abundant in summer and increase in abundance throughout the season into early fall when organic content is high (Flint 1938). Although these genera were consistently dominant at depth, the findings of abundant cyanobacteria were surprising due to the pristine appearance and overall low nutrient content of the lake (Table 1).

Vertical stratification of non-motile species depends on currents and turbulence of the water as a migration mechanism (Frempong 1981). During this study harsh rains and winds occurred between

14:00 h and 17:00 h which could have caused mixing and turbulence, keeping particles such as phytoplankton closer to the surface. Once the turbulence resides, heavier particles may sink into the hypolimnion (Tilzer 1973). The non-motile diatom, *Asterionella*, tends to sink rapidly due to their size and structure (Frempong 1981). For large and relatively heavy bacillariophytes, such as *Asterionella*, mixing of the epilimnion during the day could cause distributions to shift toward the surface. During the evening, when weather conditions had calmed, *Asterionella* may have sunk downward to 10.5 m and deeper (Figure 7). However, due to the insufficient number of *Asterionella* collected in the day samples, it was difficult to identify the direction of migration for these phytoplankton. Though, it is likely these heavy particles ultimately sunk down to the sediments.

Chlorophyll *a* fluorescence is generally a good indicator for the presence of phytoplankton. Phycocyanin fluorescence is also useful in determining phytoplankton since it is typically emitted

by cyanobacteria. In Mendum's Pond, fluorescence readings supported that cyanobacteria were abundant in the water column (Figure 3). Fluorescence (of chlorophyll and phycocyanin) provided a relative index for percentage of cyanobacteria. Detecting cyanobacteria is important because many forms may produce toxins, potentially harmful to public health. Toxic phytoplankton give off odors and can be harmful for zooplankton to consume as well (Lampert & Sommers 1997). Studies suggest that zooplankton may even avoid toxic cyanobacteria by detecting toxicity through kairomones (Jim Haney, pers. comm.). Toxic cyanobacteria have been a worldwide problem, affecting drinking water and causing animal and human deaths. The high abundance of cyanobacteria in Mendum's Pond may be a sign of possible eutrophication and should be monitored further to assess whether cyanobacteria are becoming a growing problem in this lake.

The abundance of large net phytoplankton is often associated with problems of algal blooms. Because Mendum's Pond is classified as oligo-

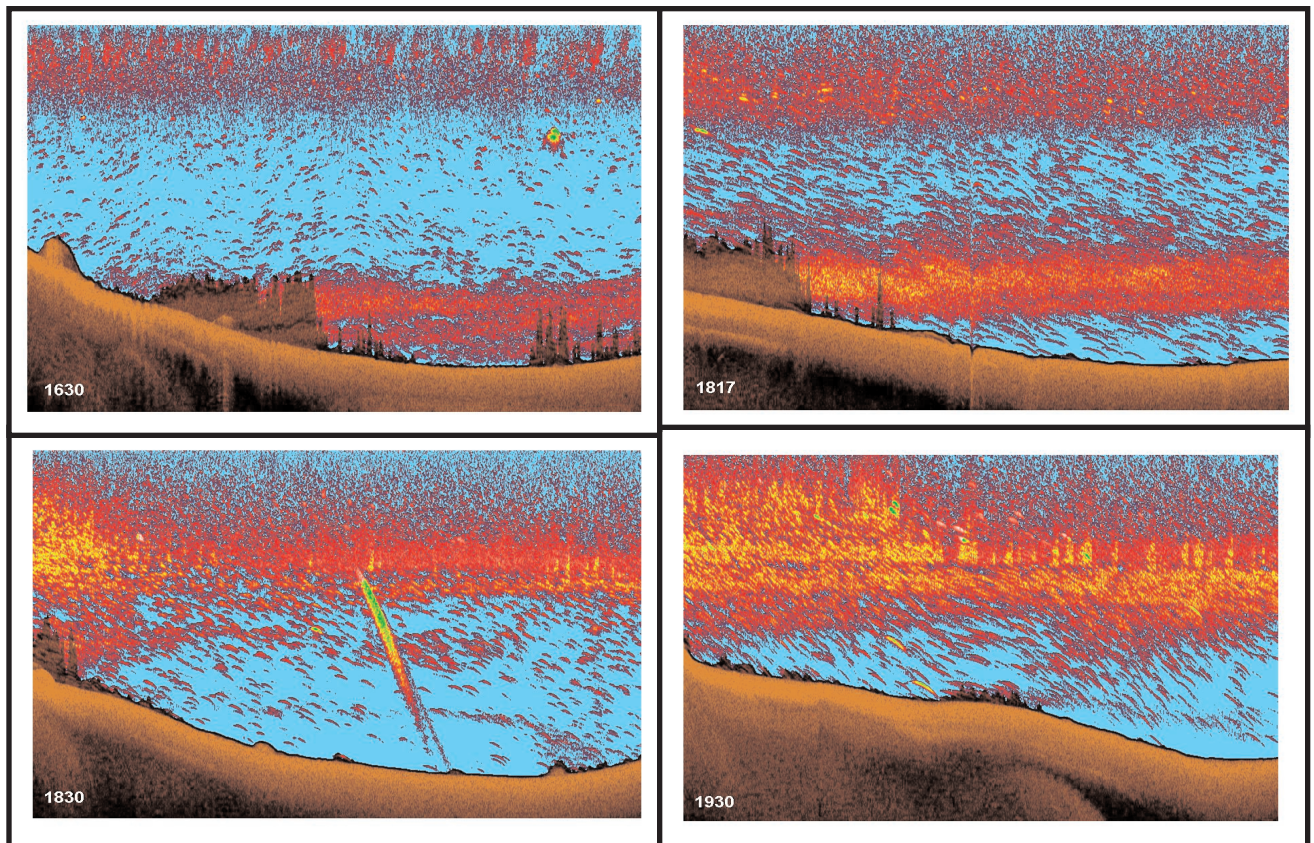


Fig. 11 Sonar images indicate the migration of *Chaoborus* in the water column over time. By sunset the organisms had risen from the bottom of the basin finally reaching the surface waters during the evening.

mesotrophic, it is questionable whether the observed dominance of colonial cyanobacteria is an indicator of changing trophic status. However, it would be interesting to examine the migration of smaller size-fractions of phytoplankton (<50 μm), as these phytoplankton have a more direct relation to herbivorous zooplankton and trophic levels of the lake (Haney et al. 1990).

Physical and chemical parameters of a lake can largely define the physical niche of an organism (Lampert & Sommer 1997). However, plankton interactions (whether it be direct or indirect) are important to consider when studying the migration of plankton. Many factors (whether ultimate or proximate) may affect the distributions and migratory behaviors of plankton. As was suggested with the zooplankton densities in this study (particularly calanoid copepods), these influences can occur simultaneously, pressuring the organisms to a specified niche or depth (Figure 9). Abundance of zooplankton in Mendum's Pond may raise questions to the presence of visual and non-visual predators of the lake, such as fish and *Chaoborus*, respectively. In Mendum's Pond, SONAR images display an abundance of fish and *Chaoborus*, which suggests that zooplankton must have effective adaptive behaviors (DVM) and spatial refuges to survive in this habitat (Figure 11). Net phytoplankton also display effective behaviors for survival, such as the cyanobacteria that are toxic or too large for consumption. Additionally, the distribution of non-motile plankton, such as *Asterionella*, can also suggest how physical parameters may influence migration and spatial distributions of plankton.

Due to the abundance of cyanobacteria in this lake and the dynamic migratory patterns of plankton observed in this research, it would be of considerable interest to carry out a more comprehensive study of Mendum's Pond in the future.

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