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Abstract:
The purpose of this study was to determine what plankton species was more dominant in Townhouse Pond and what effects predation has on the food web. Plankton size is important when determining pelagic food web structure. Plankton size along with predation determines whether the lake is dominated by top-down or bottom-up control. Plankton size and biomass, grazing rates, light intensity, and chemistry parameters were all determined for Townhouse Pond in October 2008. We concluded that Townhouse Pond is a mesotrophic lake and is mainly dominated by phytoplankton, such as Microystis and Dinobryon. Alewife (Alosa pseudoharengus), planktivorous fish, are dominant in this pond resulting in top-down control. Although various studies were conducted here, further research could determine the abundance of alewife and their prey and specific parameter that effect their predation.

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Introduction:

The effects of alewife on size distribution in Townhouse Pond are relatively unknown. Townhouse Pond is currently a mesotrophic lake with moderate nutrient levels and productivity. However, the effects of plankton alone are widely studied. If concentrations are not properly monitored and managed, the nutrient levels and plankton abundance will continue to increase, resulting in health risks for both humans and animals which are great concerns to the neighboring population.

Plankton size is used to understand ecological and physiological behavior, including nutrient uptake, sinking rates and vertical light gradient (Naselli-Flores, Luigi, Meric, 2007). In addition, plankton size can be used for taxonomic and phylogenetic classifications along with natural selection and monitoring of water quality (Naselli-Flores, Luigi, Meric, 2007). Size determines environmental conditions, such as seasonal patterns, disturbances and perturbations caused by algal blooms (Naselli-Flores, Luigi, Meric, 2007). More importantly, plankton size can be used to determine grazing behaviors among zooplankton, phytoplankton and planktivores.

The size efficiency hypothesis by Dodson and Brooks (1965) is an important guide to understanding the effects of predation on different size fractions. The size efficiency hypothesis states that larger zooplankton(>2.0 μm), such as Daphnia, are more efficient grazers. When predation by planktivorous fish is low the system is dominated by large zooplankton, which graze on the smaller zooplankton (<2.0 μm). When predation is high from planktivorous fish the large zooplankton are eliminated, allowing the small zooplankton to dominate. When predation is moderate there are equal populations of small and large zooplankton along with planktivorous fish. (Brooks & Dodson, 1965) Another important factor in determining the effect of predation is whether the system is controlled by top-down or bottom-up effects. Top-down control occurs when there is an efficient predator and the mortality due to intraspecific competition is constant (Devaraj 2004). Bottom-up control occurs when there are inefficient predators

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and the mortality from intraspecific competition varies (Devaraj 2004).

Alewife (Alosa pseudoharengus) is an efficient planktivorous predator found in Townhouse Pond (Brown, 1996). The zooplankton community structure was found to be drastically different when alewives are present (Brooks & Dodson, 1965). Smaller zooplankton are more abundant because alewife are size selective predators. Alewife feed on larger zooplankton, thereby eliminating them from the community. Migration and movement of zooplankton are also effected by the presence of alewife. During the day, zooplankton migrate to lower depths to avoid predation from the planktivorous fish changing their vertical distribution. (Brown, 1996)

The objective of this study was to determine the effects of predation from alewife on the distribution and size fractions of zooplankton in Townhouse Pond.

Methods

Study site: Townhouse Pond is located in Milton, NH in Strafford County. It has an altitude of 125.882 m and a latitude of 43.4348° N and longitude of -70.9809° W. The sample site had a depth of 13 meters. Townhouse Pond can currently be classified as a mesotrophic lake. Additionally, there is a large population of alewife (Alosa pseudoharengus).

Water sampling: Whole lake water was collected to 3m using an integrated tube (IT). The whole lake water was used to determine concentrations of chlorophyll a (μg L^{-1}) and phycocyanin (cells L^{-1}), which is an accessory pigment to chlorophyll. Chlorophyll a (Channel B) and phycocyanin (Channel A) were measured using an AquaflourTM Handheld 2-Channel Fluorometer Turner Design. A subsample of whole lake water was used to determine total phosphorous at the Lakes Lay Monitoring Lab.

Vertical profile: An YSI Sonde 6600M multi-parameter probe (MP) was lowered 0.5 m min^{-1} to take a vertical profile to a depth of 13 m. The multi-parameter measured chlorophyll (μg L^{-1}), depth (m), dissolved oxygen (mg L^{-1}), oxidation-reduction potential (mV), pH, phycocyanin (cells L^{-1}), specific conductance (uS cm^{-1}), temperature (C) and turbidity (NTU). The multi-parameter collected data every 3 seconds until it reached the bottom of the lake, 13 m.

Discrete plankton: Three replicate vertical tows were conducted with a 50 μm mesh. Each collection was placed into a 2 L covered container for 20 minutes until the zooplankton and phytoplankton separated. Zooplankton were found in the tube where light was present and the phytoplankton were found in the covered portion of the bottle. The samples were filtered through a 50 μm funnel mesh. The mesh from all three samples were placed in a container with 4% formalin sucrose solution for preservation until laboratory analysis. Zooplankton and phytoplankton were collected using a closing net every 2 m for 12 m and preserved for identification and counting.

Grazing experiment: Whole lake water was collected using an integrated tube (6 cm x 1.9 m) and filtered through a 375 μm mesh to remove zooplankton. A vertical tow (375 μm) collected concentrated zooplankton. The concentrated zooplankton were added to four 3 L bags. Water quality measurements were collected and recorded with the multi-parameter (MP) and hand-held flourometer in each bag prior to the experiment. The bags were lowered 3 m into the water column for 30 minutes to allow grazing to occur. The final measurements were then taken with the MP and hand-held flourometer. Each bag was filtered through 50 μm mesh and additional water measurements were taken using the MP and flourometer.

Calculations: Clearance Rates (mL mg^{-1} h^{-1})

$$\text{Control} = (\ln(C_o) - \ln(C_f)) / t\ (h)$$

Where $\ln(C_o)$= natural log of control initial zooplankton density, $\ln(C_f)$ = natural log of control final zooplankton density, t= time(hours).

$$E1, E2, E3 = (\ln(E_o) - \ln(E_f)) / t\ (h)$$

Where E1, E2, E3= the three trials, $\ln(E_o)$= natural log of trial initial zooplankton density, $\ln(E_f)$=

natural log of trial final zooplankton density, t= time (hours).

$$C(\text{mL mg}^{-1}\ \text{h}^{-1}) = V(\text{mL}) * (E - C) / b(\text{mg})$$

Where CR= clearance rate (% day^{-1}) C= clearance rate (mL mg^{-1} h^{-1}), B= lake biomass of zooplankton (mg L^{-1}).

Lamperts Equation (Lampert,1988):

$$L(\%\ \text{day}^{-1}) = 4.5 + (231 * zb\ (\text{mg L}^{-1}))$$

Where L= Lamperts predicted grazing rate (% day^{-1}), zb= zooplankton biomass (mg L^{-1}).

Light: Light was measured using a Secchi Disk (black and white) and view scope. The disk was lowered until it could no longer be seen in the view scope and raised until seen again. The mean of both values was recorded and used as the Secchi Disk Depth. Light was also measured using a LiCor Light Meter. The probe was lowered and the light intensity was measured both in the water and the sky for comparison.

Laboratory Methods: Data collected from the YSI was uploaded to Excel, then reviewed and graphed using Sigma Plot 11.0. The preserved samples of plankton from the integrated vertical tow and discrete depth tows were examined and identified under a microscope using the UNH Center for Freshwater Biology Zooplankton key. The dry weight of the zooplankton sample from the grazing experiment were taken. After drying in an oven for 3 minutes the weight of the filter was subtracted to reveal the mass of zooplankton present in mg L^{-1}. Finally, the water samples were taken to the Lakes Lay Monitoring Lab where total phosphorus concentrations were determined.

Results

Water sampling: Phycocyanin (cell L^{-1}) and chlorophyll a (µg L^{-1}) were calculated using the fluorescence of the Hand-Held Flourometer. Net plankton are all organisms larger than 50 µm, nanoplankton are organisms that are smaller than 50 µm, but larger than 2.0 µm, and picoplankton are all organisms smaller than 2.0 µm. The various size fractions equal 100% taken from the whole lake water sample for phycocyanin and chlorophyll a.

Phycocyanin and chlorophyll a have similar dominant size fractions that comprise whole lake water. Picoplankton comprises the largest amount of whole lake water for both phycocyanin and chlorophyll a, 53.38% (Figure 1) and 50.42% (Figure 2).

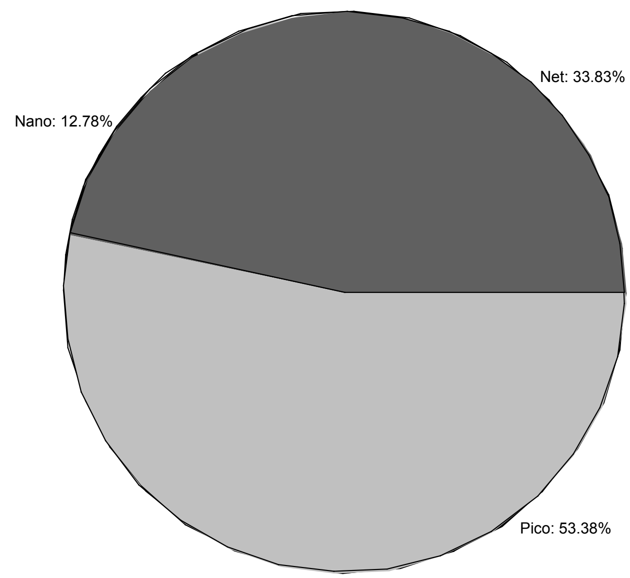

Figure 1: Different size fractions of phycocyanin determined by the Hand-Held flourometer. Net plankton is organisms larger than 50 ?m.Nanoplankton is organisms small than 50 ?m and larger than 2.0 ?m.Picoplankton are all organisms small than 2.0 ?m. Picoplankton are dominant in Townhouse Pond in October 2008.

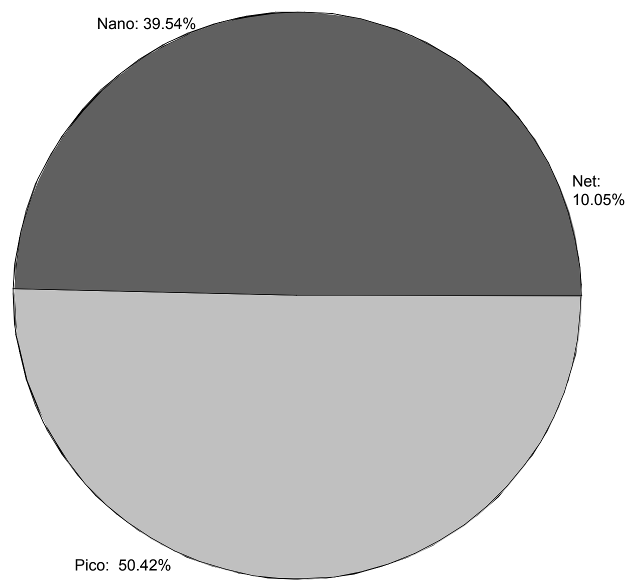

Figure 2: Different size fractions of chlorophyll a determined by the Hand-Held flourometer. Net plankton are organisms larger than 50 ?m. Nanoplankton are organisms smaller than 50 ?m and larger than 2.0 ?m. Picoplankton are all organisms smaller than 2.0 ?m. Picoplankton were the dominant size for chlorophyll a in Townhouse Pond in October 2008.

Net plankton is the next abundant for phycocyanin making up 33.83% of whole lake water (Figure 1). However, nanoplankton follows picoplankton for chlorophyll a making up 39.54% (Figure 2). Nanoplankton and net plankton have the smallest abundance for phycocyanin and chlorophyll a only comprising 12.78% (Figure 1) and 10.05% (Figure 2).

Vertical Profile: The epilimnion is from the surface to 5 m. This is where the temperature remains nearly constant at 18^{o} C. The metalimnion is from 5 m to 8.75 m and contains the thermocline, which is a change in temperature. The change in temperature is from 18^{o} C to 6^{o} C occurring over 3.75 m, which is around an estimated rate of 3.2^{o} C m^{-1}. The hypolimnion is from 8.75 m to the bottom of the lake. The hypolimnion remains at a constant temperature of 5.75^{o} C. (Figure 3)

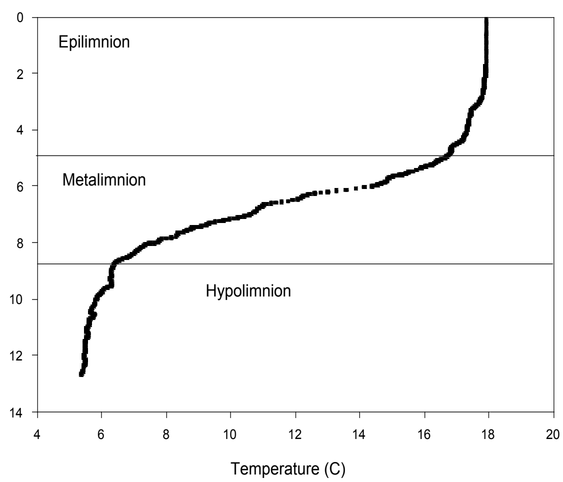

Figure 3: The depth range for the epilimnion, metalimnion, and hypolimnion for Townhouse Pond. Epilimnion is from 0 -5 m, the metalimnion is 5- 8.75 m and the hypolimnion is from 8.75- 13 m.The metalimnion contains the thermocline while the epilimnion and hypolimnion contain a constant temperature.

Phycocyanin (cell mL^{-1}) and chlorophyll a (µg L^{-1}) have similar vertical profiles. Both start with high concentrations at the surface, then decrease steadily until 7 m where they start increasing again until 13 m. The depth where they begin to increase again is where the anoxic zone begins. The dissolved oxygen concentrations begin decreasing around 2.25 m. Before this depth it remains constant at 9 mg L^{-1}. The euphotic zone (100 % to 10% of surface light) goes to a depth of 2.25 m.

The dysphotic zone, where there is 1% of surface light intensity or less, begins at 8.5 m. The area between the euphotic and dysphotic zones is the compensation depth, where respiration roughly equals photosynthesis. The compensation depth is from 2.25 m to 8.5 m. (Figure 4)

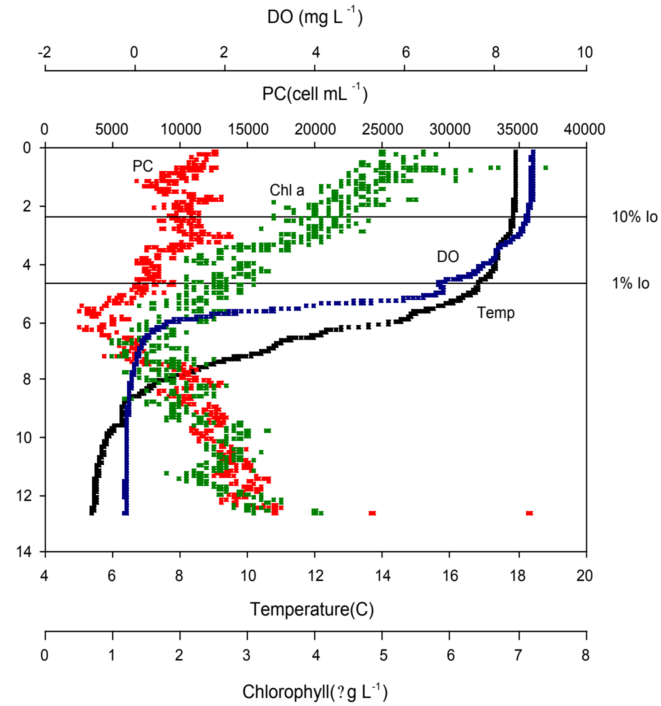

Figure 4: Phycocyanin (cells mL^{-1}), Chlorophyll a (?g L^{-1}), Temperature (C), and Dissolved oxygen (mg L^{-1}) are plotted against depth showing the verticle profile of Townhouse Pond. Phycocyanin and Chlorophyll a have similar profiles decreasing until 7 m then increasing until the bottom. The dissolved oxygen decreases until reaching the anoxic zone around 7 m.This figure shows where 10% and 1% of initial lights penetrates to what depth. Ten percent penetrates to 2.25 m and 1% reaches 4.5 m.

The turbidity of Townhouse Pond spikes at 8 m, which is consistent with the thermocline ending around 8 m (Figure 3). At this depth the phycocyanin and chlorophyll a begin to increase. From the surface to 7 m, the turbidity remains constant and from 10 m to 13 m it also remains constant at 3 NTU (Figure 5). The pH starts to decrease at 1 m and continues to decrease until 10 m. The pH at 1 m is 6.6 and decreases to 5.7. It then remains constant at 5.7 to 12 m following an increase to 5.8 at 13 m. However, around 12 -13m it increases from 5.7 to 5.9. (Figure 6)

Discrete plankton: Zooplankton in Townhouse Pond were not abundant or found in noticeably high concentrations at any depth. The dominant

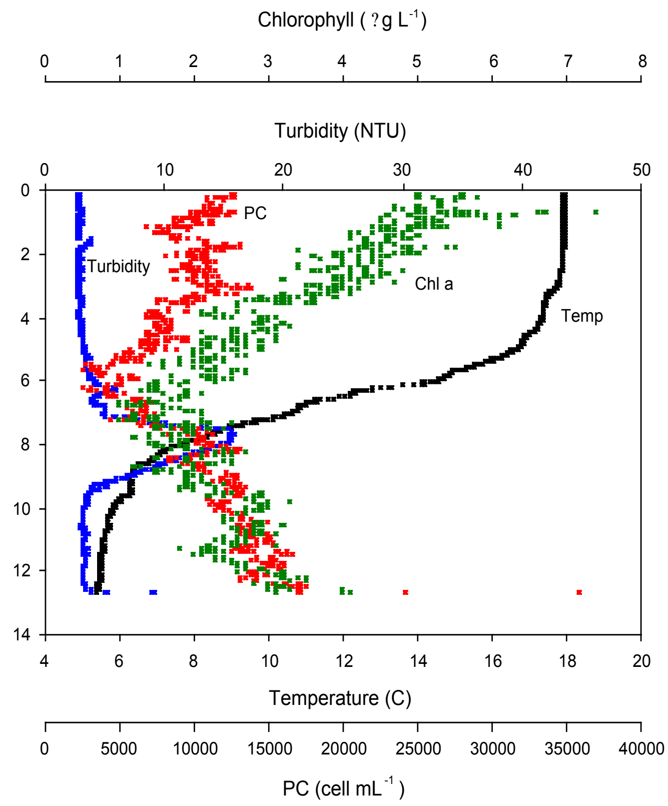

Figure 5: Phycocyanin (cell mL^{-1}), Temperature (C), Chlorophyll a (?g L^{-1}) and Turbidity (NTU) represent the vertical profile of Townhouse Pond. Turbidity remains constant from the surface to 7 m at 3 NTU. At 8 m there is a spike to 15 NTU. From 9 m to 13 m it remains constant again at 3 NTU.

cladoceran is Bosmina. The largest concentration was found between 6-8 m with 54 individuals L^{-1}. The dominant copepod present was Cyclopoid with 1 individual L^{-1}. The dominant zooplankton in Townhouse Pond are rotifers. Keratella is the dominant rotifer species with 19.4 individuals L^{-1}. Rotifers had high concentrations at all depths, especially 6-8 m. Rotifers appeared dominant over copepods and cladocerans when the samples were viewed under the microscope. (Figure 7) Temperature and dissolved oxygen were plotted against depth to show where the anoxic zone begins (5.95 m). Rotifers, cladocerans, and copepods are mainly found at 7 m which is in the anoxic zone. (Figure 7)

Phytoplankton diversity and abundance is important and dominant in Townhouse Pond. The dominant phytoplankton is Chrysophyceae, which is Dinobryon, found between 6-8 m with 97 individuals L^{-1}. Cyanobacteria and Dinophyceae have the highest concentrations between 6-8 m. The dominant cyanobacteria is Microsytis with 29 colonials L^{-1} and the dominant Dinophyceae is Ceratuim with 4.5 individuals L^{-1}. Similar to the zooplankton, phytoplankton are most abundant in the anoxic zone between 6-8 m.

Grazing Experiment: After the grazing experiment the clearance rates were calculated using the biomass from the filters collected at the end of the experiment and the MP readings. Positive clearance rates suggest net grazing occurred and negative rates suggest net growth. During the experiment, net grazing occurred in two bags for chlorophyll a, while net growth occurred in E2, with a -3.87 % day^{-1}(Table 1). Net grazing occurred in both E1, 10.47 % day^{-1} and E2, 51.50% day^{-1} for phycocyanin and net growth occurred in E3, -0.61% day^{-1} (Table 1).

Lampert's predicted: Lampert's predicted clearance rates were all positive suggesting that grazing should occur under these conditions. The mean for chlorophyll a and

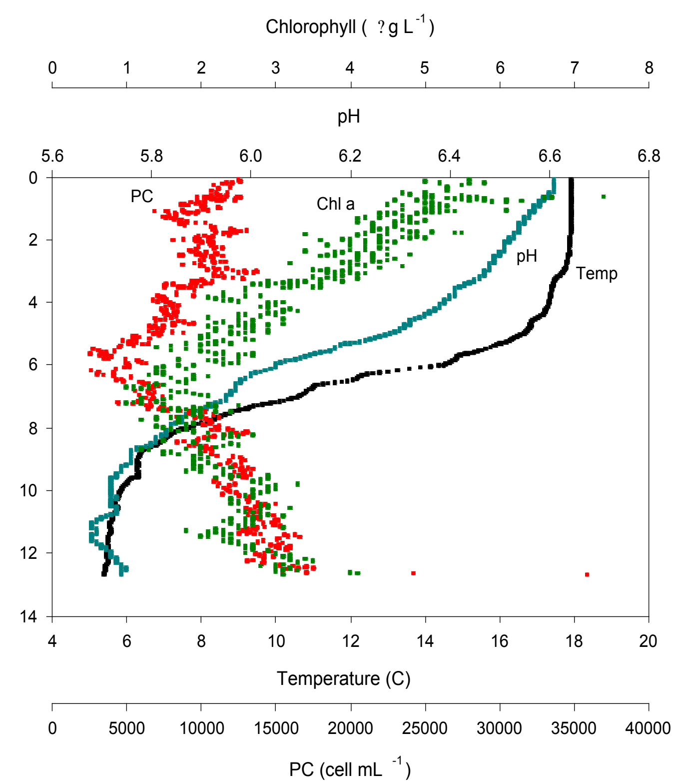

Figure 6: Phycocyanin (cell mL^{-1}), Temperature (C), pH and Chlorophyll a (?g L^{-1}) show the vertical profile of Townhouse Pond. pH has a constant decrease from the surface to 10 m. It remains nearly constant from 10 m to 12 m at 5.7. From 12 m to 13 m there is an icrease in pH from 5.7 to 5.8.

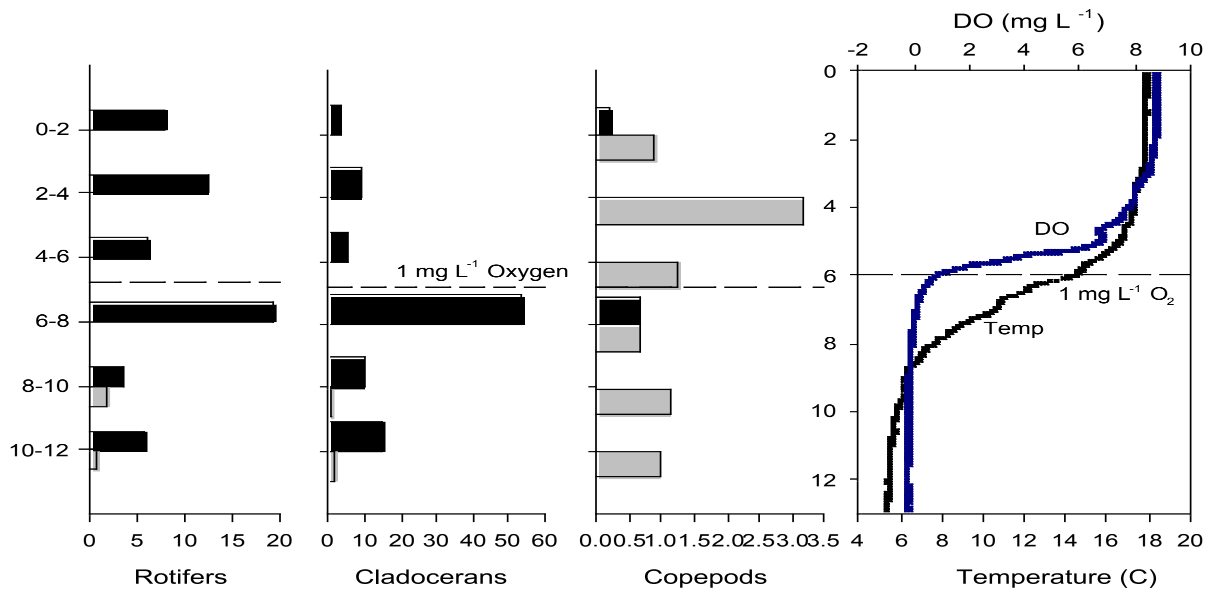

Figure 7: Zooplankton diversity and abundance in Townhouse Pond in October 2008. Rotifers contain *Keratella* (black) and *Kelacottia* (gray) species. Cladocerans contain *Bosimina* (black) and *Ceriodaphia* (gray) species. Copepods contain *Calanoid* (black) and *Cyclopoid* (gray) species.Temperature (C) and dissolved oxygen (mg L^{-1}) represent the vertical profile. The dashed line show where 1 mg L^{-1} of oxygen is present, 5.95 m.

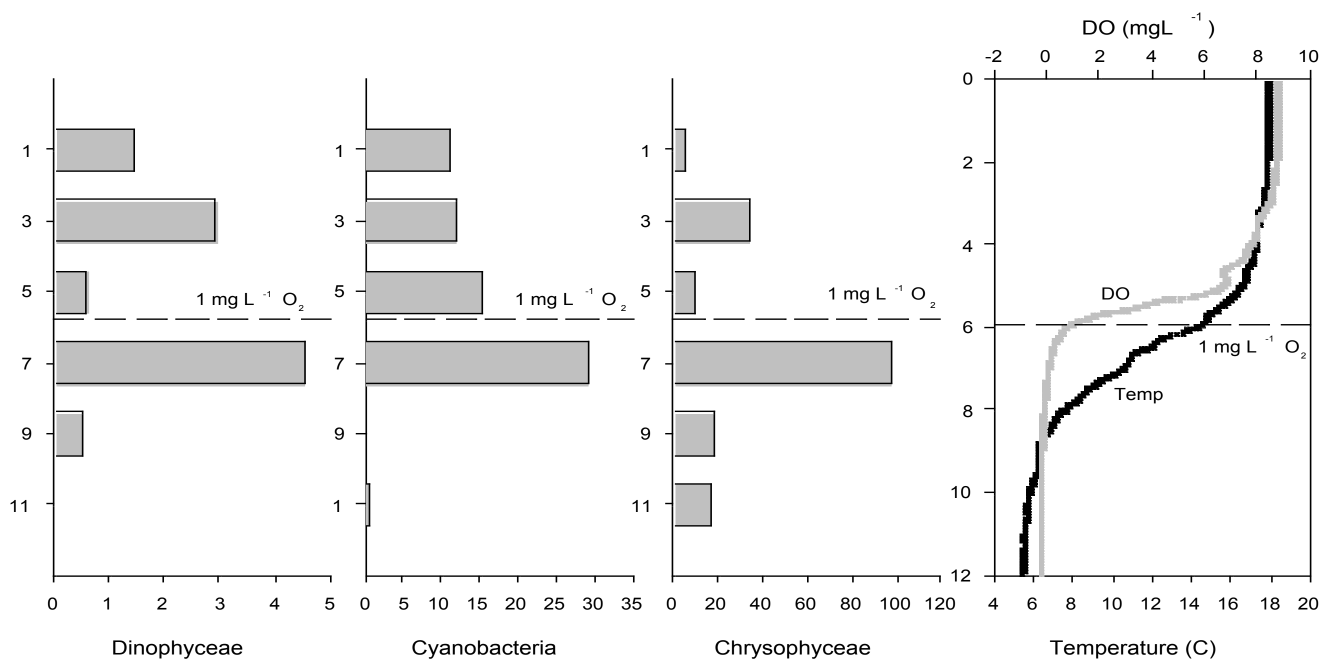

Figure 8: Phytoplankton diveristy and abundance in Townhouse Pond. Dinophyceae, Cyanobacteria and Chrysophyseae are related by dominance from least(left) to greatest (right). Dinophyceae contains *Ceratium*. Cyanobacteria present is *Microsystis*. The Chrysophyseae present is *Dinobryon*. Dissolved Oxygen (mg L^{-1}) and temperature (C) taken from the MP vertical profile. The dashed line represent the depth where there is 1 mg L^{-1} of oxygen. Below 5 m is the anoxic zone. vertical profile.

phycocyanin are both positive meaning that grazing was more dominant than growth within each bag. A t-test was preformed and demsostrated no significant difference between the calculated and predicted clearance rates for chlorophyll a (p=0.906).

Light: The data from the LiCor light meter show that the light intensity dramatically decreases

	Clearance Rates (% day^{-1})				
	E1	E2	E3	Mean	Standard Error
Chlorophyll *a* (ug L^{-1})	74.34	-3.87	2.47	24.31	25.08
Phycocyanin (cell mL^{-1})	10.47	51.50	-0.61	20.45	15.85
Lamperts Predicted	43.08	20.67	19.05	27.60	7.75

Table 1: Clearance rates (% day^{-1}) for the grazing experiment. The negative values represent growth growth within the bag and the positive clearance rates show that grazing occurred. Lamperts clearance rates are predicted rates using the lake biomass of plankton and a standard equation.

around 2 m. At 3 m the light intensity remains constant until the bottom. At the surface the light intensity is from 60-160 and at 2m it is around 0. This corresponds with the Secchi Disk reading of 3.01 m. After this point there is a small amount of light penetrating the water; however, not measureable.

Discussion

The presence of alewife in the lake is an important factor in the pelagic food web of Townhouse Pond. The size efficiency hypothesis states that when predation from fish is high then small zooplankton are dominant (Brooks & Dodson, 1965). Townhouse Pond has a large population of alewife, which are size selective planktivores that mainly feed on lager zooplankton such as, Daphnia (Brown, 1996). Without the predation of alewives on Daphnia, smaller zooplankton such as Bosmina can thrive. This may be the reason for the absence of Daphnia and the high concentrations of Bosmina in this lake (Figure 7).

The vertical migration of zooplankton is also altered by the presence of planktivorous fish. Zooplankton migrate to deeper depths during the day to avoid predation (Brown, 1996). When analyzing the abundance of zooplankton, most were found between 6-8 m (Figure 7) causing the spike in turbidity at 8 m (Figure 5). Zooplankton avoid predation from fish by moving below the epilimnion, 0-5 m (Figure 3). Fish are unable to stand the change in temperature and decrease in oxygen thus not allowing them to penetrate past 5 m (Figure 4) (Brown, 1996). The dissolved oxygen curve (Figure 4) represents the large anoxic zone present at Townhouse Pond. The anoxic zone is found approximately between 6-13 m (Figure 4). This large anoxic zone makes it hard for alewife to survive at these depths allowing refuge for the zooplankton (Brown, 1996).

Light intensity affects the predation on zooplankton by alewives. Planktivorous fish are less selective where there is low light intensity (Brown, 1996). Light intensity starts to decrease from the surface and reaches low levels around 2 m (Figure 9). Larger amounts of chlorophyll a, 4 μg L^{-1},

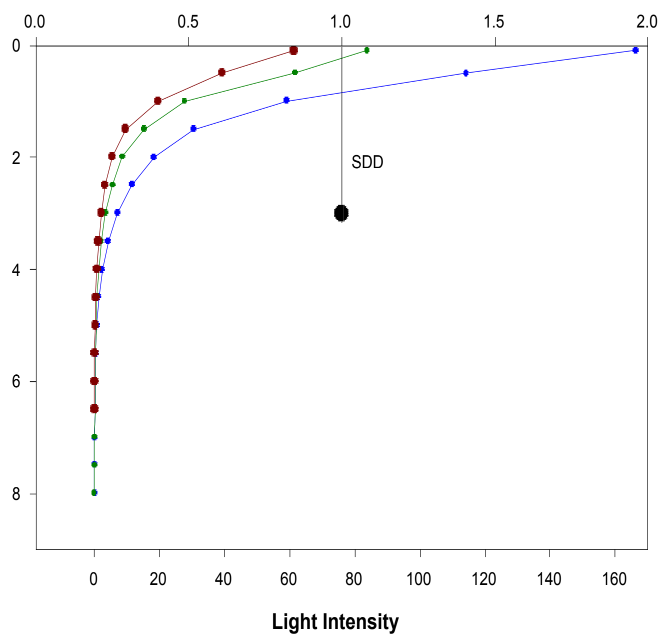

Figure 9: Three trials were taken from the LiCor meter and plotted against depth. The light intensity for each trial reaches 0 around 2 m. The mean Secchi Disk Depth is shown with the black circle at 3 m. All of the light data was collected from Townhouse Pond in October 2008.

(Figure 4) do not allow light to penetrate deep in the water column which can be seen by decreasing Secchi disk depth. (Carpenter, Kitchell & Hodgson, 1985) The low light intensity after 2 m may be another reason why zooplankton migrate to deeper depths to avoid predation.

The different size fractions of phycocyanin and chlorophyll a measured by fluorescence with the Hand-Held flourometer concluded that picoplankton account for half the productivity in the whole lake water. Net plankton makes up 33.83% of phycocyanin and 10.05% of chlorophyll a (Figure 1, 2). Nanoplankton contains 12.78% of phycocyanin and 39.54% of chlorophyll a (Figure 1, 2). The size fraction data and the clearance rates for the grazing experiment represent the lack of efficient grazers in the system. The grazing occurring in the lake is very inefficient only clearing 24.3 % of water day^{-1} for chlorophyll a and 20.5 % of water day^{-1} of phycocyanin (Table 1). There is not significant grazing occurring in the lake because of the absence of large zooplankton caused by the predation of the alewives.

Past studies have been conducted to determine if large populations of fish have top-down effects on the lake food web. Top-down effects occur when an organism in a higher trophic level affects the growth and production of organisms in lower trophic levels. A study conducted in nineteen Michigan lakes determined that the increase in strength of planktivorous fish has indirect effects on phytoplankton (Tessier & Woodruff, 2002). Furthermore, a study done in Northern Israel on Lake Kinnert focused on predation pressure on herbivorous zooplankton by top-down forces of planktivorous fish. Predation pressure is largely indicated by water temperature and predator biomass (Blumenshine, Hambright, 2003) Therefore, the alewife in Townhouse Pond may have a direct effect on the size fraction and abundance of zooplankton.

In conclusion, Townhouse Pond is a mesotrophic lake that is greatly impacted by the presence of alewife. Alewives eliminate Daphnia from the system allowing Bosimina to become dominant. Bosmina feed on Chlorophyceae allowing other phytoplankton species like Chrysophyceae to become abundant (Figure 8) (Acharya, Bukaveckas, Jack, Kyle and Elser, 2006). The impact of alewives on the zooplankton community results in top-down control. Temperature, dissolved oxygen, and light intensity all effect the movement of alewife, directly effecting the vertical migration and diversity of zooplankton. Zooplankton migrate to deeper depths to avoid predation changing the zooplankton abundance at various depths. Alewife are an important consideration when trying to understand the zooplankton community and the entire lake system of Townhouse Pond because of their large impact on the pelagic food web.

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