Understanding Diurnal Vertical Migration of Zooplankton in Perialpine Freshwater Lakes

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ABSTRACT

Diurnal Vertical Migration(DVM) of zooplankton was studied for a one-year period in Lake Biel - a perialpine lake in Switzerland. The data was collected at a location near the center of the lake at a depth of 45 meters. Acoustic Doppler Current Profile (ADCP), Current Temperature Depth (CTD), biomass, and temperature data was collected during the months of February, August, September, October, and November 2014. The ADCP data was used to map vertical distributions of zooplankton, the CTD data was used for examining chlorophyll A density and temperature, and the net traps were employed to collect biomass data. The data was plotted together to confirm whether zooplankton perform DVM in perialpine lakes and to understand what factors influence their movements. Results suggested zooplankton migrate to the surface during nighttime hours and return during daylight hours. A search for food sources while minimizing predation was identified as the primary driving force behind their migrations, while temperature did not a have a significant impact.

KEYWORDS

Lake Biel, Cladocera, Net Trap, Acoustic Doppler Current Profile (ADCP), Current Temperature Depth (CTD)

INTRODUCTION

Lake Biel (39.3 km^2) is a perialpine freshwater lake located in northwestern part of Switzerland (Wright et al., 1980). The maximum depth is 74 meters and has a hydraulic residence time of 55 days, which corresponds to 10-20 days for the epilimnion (Berner-Fankhauser, 1983). The residence time is short, due to the large drainage area relative to lake volume of the major tributary, the Aare River. The Aare provides about 80-90% of the water, suspended particulate matter, and dissolved substances in the lake (Wright et al. 1980). Particles change light conditions, which can then alter species productivity, leading to changes in lake biological composition (Matzinger et al., 2007).

In addition to particulate matter in lakes, Zooplankton are microscopic creatures that occupy the water column as well. Their movements can either be active or passive, depending on water currents and other factors. In lakes, zooplankton either actively move by swimming less than a couple millimeters per second or remain passive and allow water currents to be the driving force (Huber et al. 2011). Zooplankton feed on phytoplankton and when phytoplankton biomass increases, zooplankton population increases as well suggesting that zooplankton migrate to follow food sources (Gasiunaite and Olenina 1998). In order for zooplankton to feed while avoiding predators, they perform cyclic vertical migrations. This is where they remain in deeper layers of the lake during the day and migrate to the surface at night to feed while staying hidden. A hypothesis proposed is optically orientating predator avoidance as the most important factor in vertical migration. Other theories include metabolic advantages of alterations in temperature or food (Stich and Lampert 1981). There are many factors that influence zooplankton migration patterns, but it is still not fully understood whether they are driven strictly by predator-prey cycles, temperature, or light.

A one-dimensional biological model can be used to determine the location and timing of essential natural sources in an ecosystem such as zooplankton. Using the computer program Matlab, the model can be used to map daily distributions of zooplankton and phytoplankton in the water column. The depth of the thermocline (the layer in a lake where temperature changes most rapidly) helps indicate where zooplankton will congregate, while chlorophyll A sampling indicates the mean primary productivity extinction depth (Perroud et al., 2009). Distribution of zooplankton is measured with acoustic observations from an Acoustic Doppler Current Profiler

(ADCP). The instrument is anchored at the bottom of a lake where it emits sound waves, which through the Doppler shift of the echo can be transformed into current velocity. The echo backscatter can furthermore be used to track particles in the water column. Measurements from different lakes reveal a strong temporal correlation between the onset of the up and downward migration of zooplankton and the local sunset and sunrise (Lorke et al 2004). Zooplankton have not been studied to a large extent in Lake Biel to date.

This study has been done to determine what causes zooplankton vertical migrations in perialpine lakes. Lake Biel zooplankton migrations have not been studied in great detail so the lake will serve as a site to test my hypothesis, which asks if zooplankton follow Diurnal Vertical Migration patterns in the lake. If this holds true, I will ask if they migrate to follow food sources while minimizing predation, to find optimum temperatures, or a combination of factors. Their movement is key for humans to understand overall lake composition and water chemistry changes. If phytoplankton populations are able to grow exponentially without limiting factors, they can alter the water quality of lakes (Huppert et al 2002). I plan to test out the three primary hypotheses to help determine which one best explains what factors control the daily vertical migration of zooplankton in perialpine lakes. This research project is information seeking and will help determine whether zooplankton follow phytoplankton populations for food or if other factors are responsible, using measurements of organisms' mobility and vertical location patterns. My null hypothesis states that food sources and predation, temperature, and a combination of other factors have no impact on daily vertical migration of zooplankton. I have three hypotheses explaining the drive behind their movements; zooplankton vertical migration is driven by food sources and predation, optimum temperature in the water column, or combination of factors.

METHODS

Study Site

We collected zooplankton acoustic data at one location on Lake Biel in Western Switzerland. We did our sampling at M2 (figure 1); one of three possible study sites with a depth of 45 meters. I traveled to Lake Biel four times to retrieve data over a total of 14 days. For the past four years, seven deployments have been made at M2 where acoustic measurements have been recorded every twenty minute interval. In July 2015, I retrieved the data from Deployment 7 and redeployed the ADCP, which became the start of Deployment 8. For my analysis I plan to use data from Deployment 7.

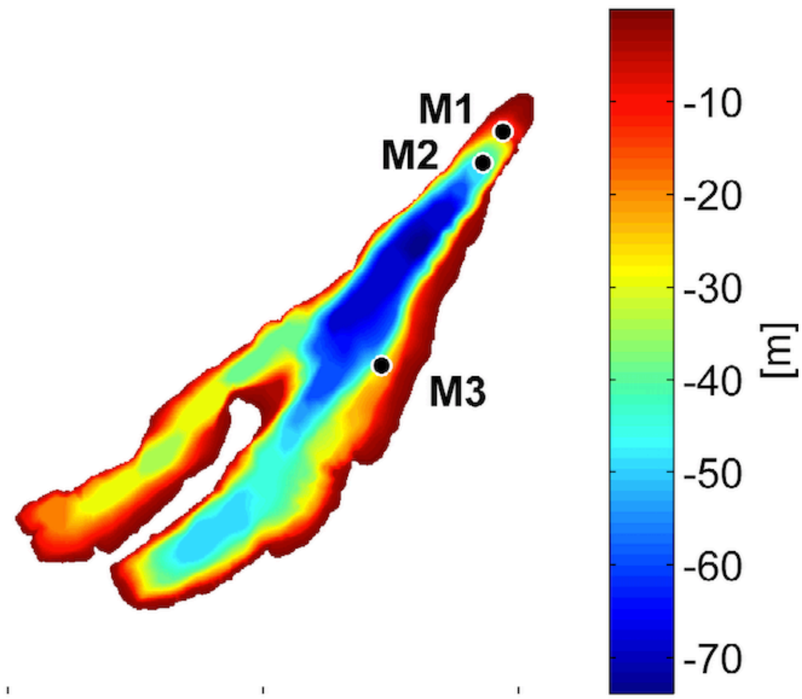

FIGURE 1. Lake Biel Map. Map of Lake Biel specifying three data collection locations with depth.

Data Collection

We gathered data over a one-week period by using an ADCP, a dual net trap, and a CTD instrument to measure zooplankton movements, chlorophyll a depth, and species in the water column. Deployments 1-7 were done in a similar fashion. We retrieved the ADCP recording the seventh deployment on 7/06/15 and redeployed it the following day. The ADCP works by sending out a sound signal, which reflects off zooplankton and returns to the instrument where it is recorded. It is an absent-present based system, which means the more zooplankton present, the stronger the signal reads. If zooplankton are absent, then the ADCP records a signal of 0 (Lorke et al., 2004). For the chlorophyll depth data collection, we sampled vertical profiles with the CTD. The device includes a turbidity and chlorophyll sensor that picks up chlorophyll A density in the water, and measures density in grams per liter (Rudnick & Klinke 2007). On 07/07/15, we went to M2 and sampled the entire day and collected the phytoplankton data. This was done by lowering the CTD at a constant rate of about one meter per second until reaching the bottom. We used a dual trap net to determine what species we were recording by taking two samples at dusk and dawn on 07/07/15; twenty meters and forty meters below the surface. The previous five dates selected in 2014 were done the same way by another team at EPFL. The samples were then sent to a lab where each species of plankton was classified, biomass in the water column calculated, and herbivore, carnivore, and phytoplankton numbers were calculated.. This was an important step because we wanted to know what zooplankton species the ADCP was recording. The ADCP does not differentiate between particle types and we wanted to see what types of primary producers the CTD was recording.

Data Analysis

To visually display my data, I used Matlab to graph zooplankton acoustic data alongside temperature and chlorophyll density data. The zooplankton data was displayed for all eight deployments. Five meters below the surface and above the bottom were removed completely because of sediment intrusion and surface reflection. The acoustic backscatter was normalized on a scale of zero to one; zero meaning no signal and one being the largest signal possible. Eight zones, each 5 meters starting at 2.5 meters and ending at 42.5 meters below the surface, were displayed with the mean backscattering signal at each depth. At each time step, the zone with the highest signal was recorded and plotted. For the chlorophyll A depth, there are only five full day recordings that can be compared with the ADCP data. There are five graphs total where I display the five-meter zone signals, the strongest signal zone, the chlorophyll data, and the temperature alongside one another. To determine if the zooplankton are following food sources or temperature, I see where zooplankton are during daylight hours. If they migrate above chlorophyll a extinction depth during the night, I assume zooplankton are performing DVM to follow food. For temperature, if I observe a set pattern zooplankton move between the thermocline, I can conclude temperature has an affect on zooplankton vertical migrations.

RESULTS

Net trap data was collected at M2 that included total biomass of zooplankton and phytoplankton as well as cladocera and copepod numbers for the entire water column. In general there was about 15-25 grams per meter squared of biomass at Lake Biel except for September. This could be due to a lack of available light or nutrients (Figure 2).

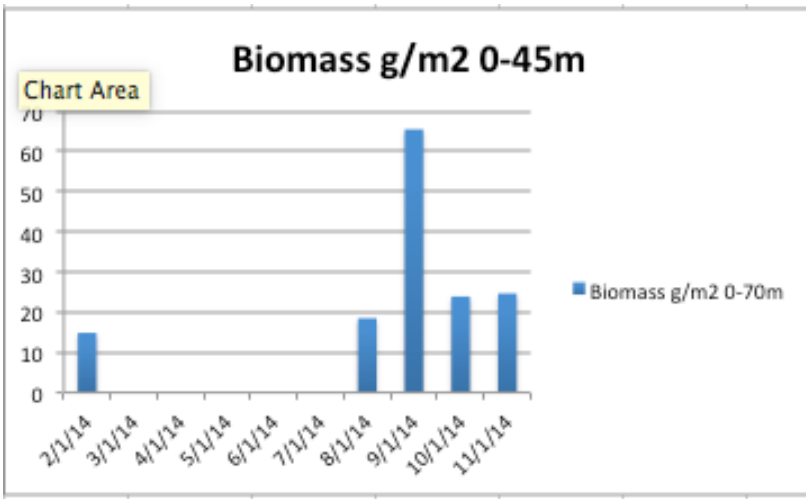

FIGURE 2. Total Biomass. Total biomass of all trophic levels within Lake Biel

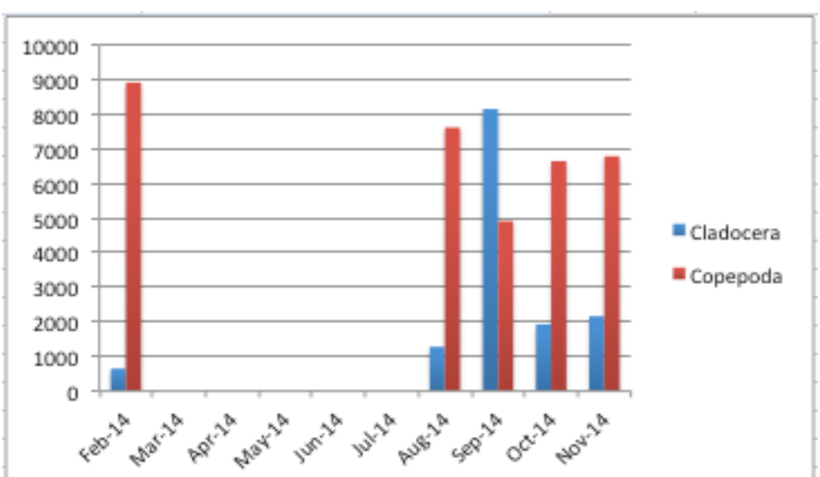

FIGURE 3. Zooplankton. Number of zooplankton found in the water column.

From the analysis in the lab at EPFL. There were only two types of zooplankton found; Cladocera and Copepoda. Both can be planktonic and benthic and found in both salt water and freshwater. Mostly Copepoda were found during the tested months other than September.

ADCP zooplankton migration for the five months collected all display similar trends where zooplankton congregate around 25 meters below the surface during the night and migrate to a zone between 5 meters and 15 meters below the surface (Figure 4). Zooplankton in February remained near the surface the longest while August's patterns were cylic, but not influenced by the timing of daylight. September, October, and November's all share the same characterics where migration towards the surface begins around 18:00 and end by about 08:00.

Zooplankton Diurnal Pattern

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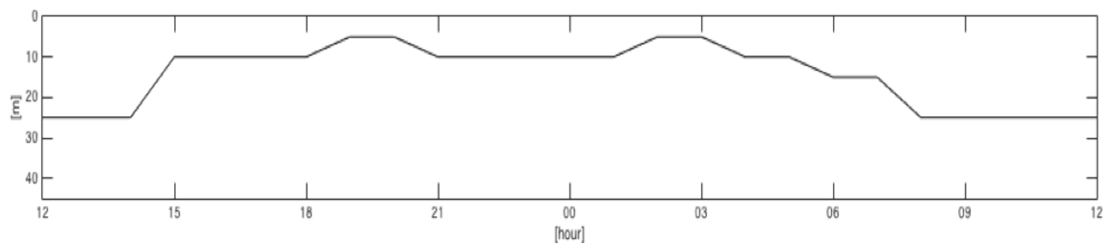

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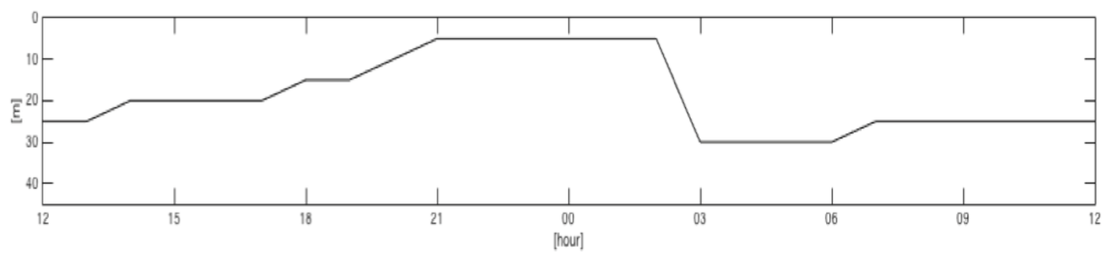

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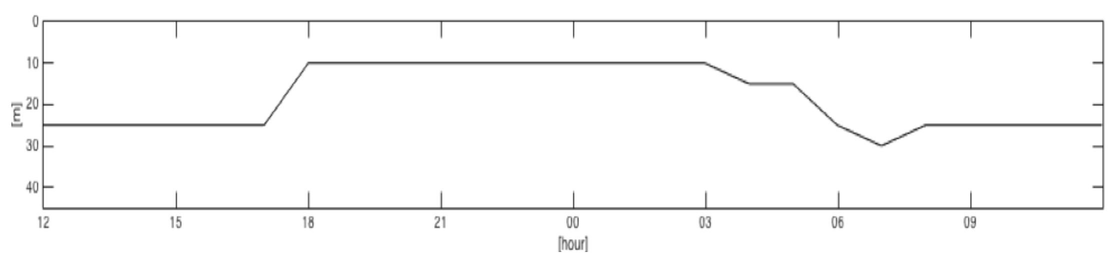

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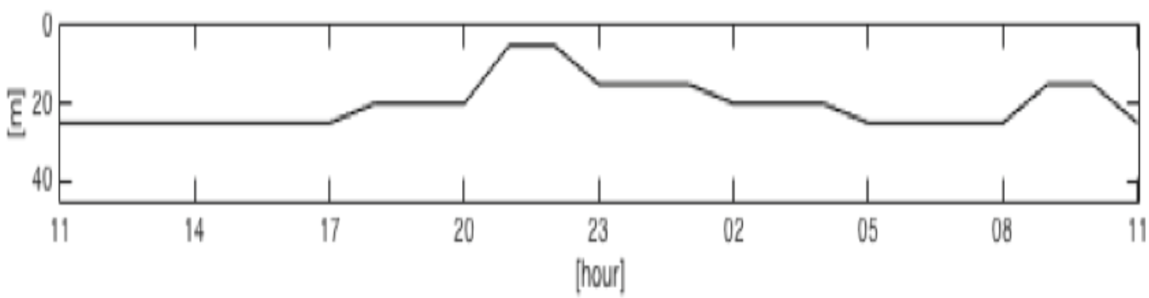

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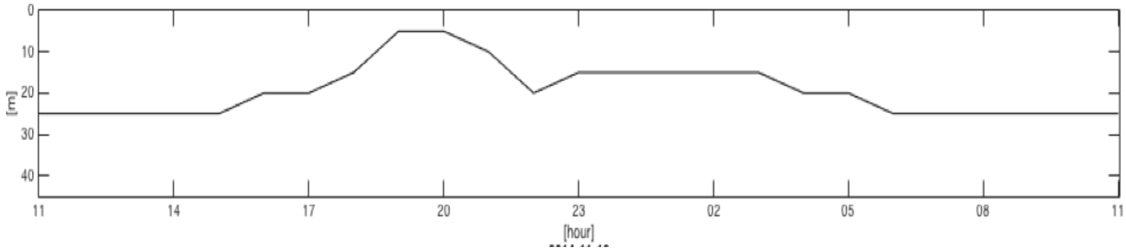

FIGURE 4. Zooplankton Patterns. 24-hour zooplankton migration pattern for five dates in 2014.

The mean chlorophyll A extinction depth was around 15 meters for all the months except for February (Figure 2). On February 19th, the extinction depth reached nearly 30 meters below the surface. Comparing months between figure 1 and 2, we see that for every day tested, zooplankton stay below the mean chlorophyll A extinction depth during daylight hours and migrate past it at night.

Mean Chlorophyll A Extinction

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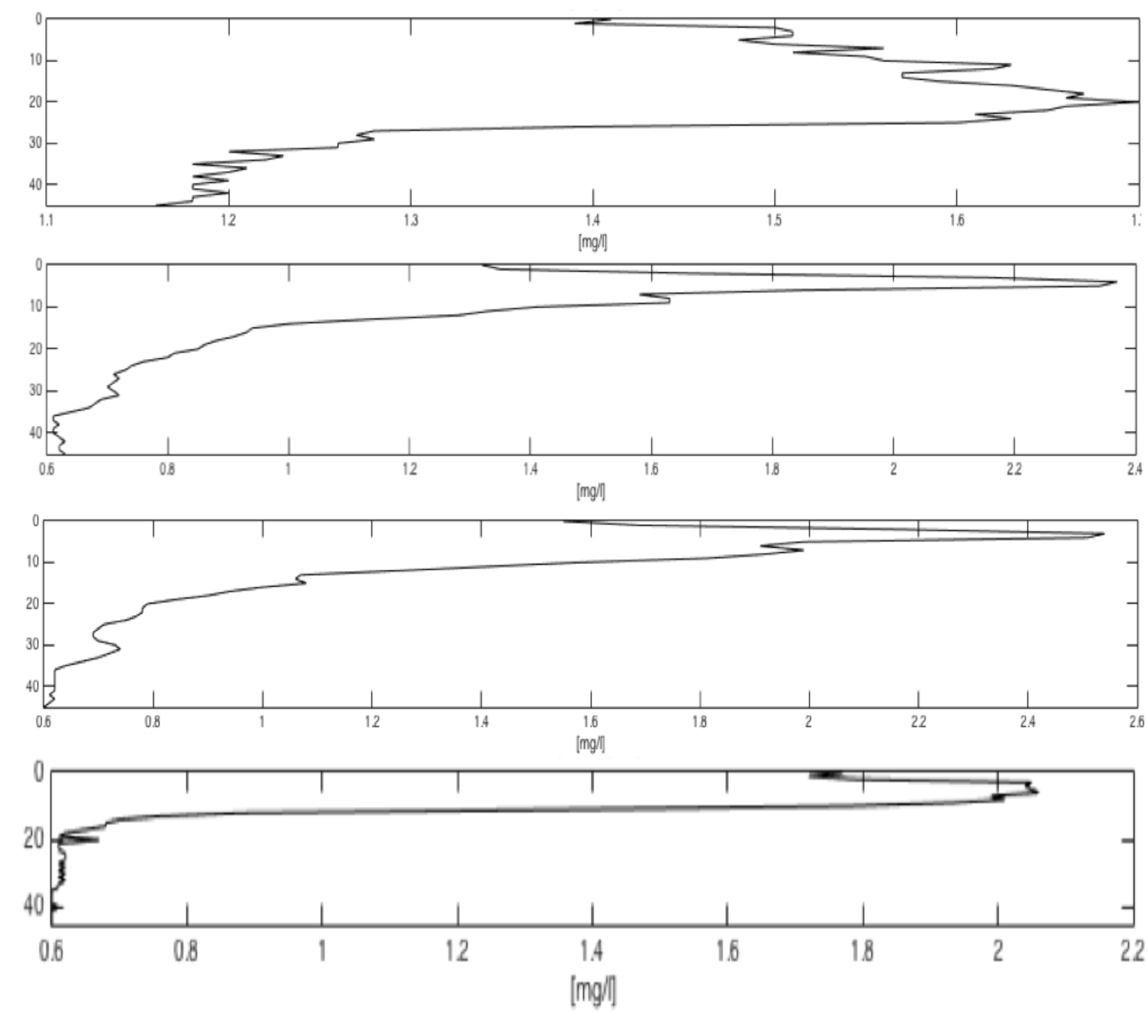

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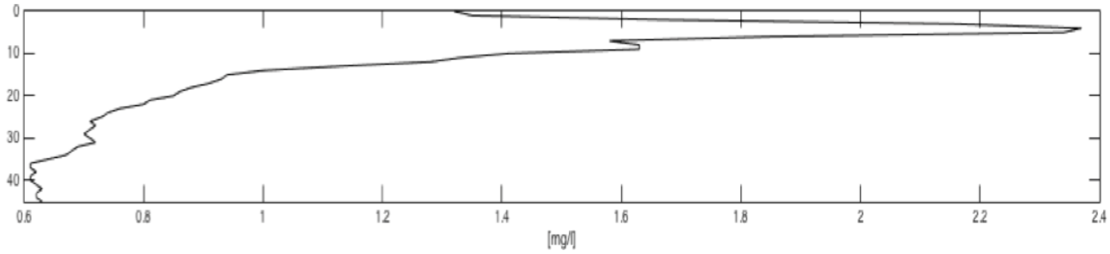

FIGURE 5. Chlorophyll. Mean chlorophyll A extinction depth for five days tested using the CTD and recorded in milligrams per liter

The thermocline is located at about 20 meters below the surface for samples taken in August through November, but there is no clear distinction in February (Figure 3). I compare Figure 1 and Figure 3 to see if there is pattern between zooplankton movements and temperature. For each sample, zooplankton start sometimes below the thermocline before migrating and other times above it. Thus, there is no observable pattern that correlates temperature and zooplankton movements.

Temperature Profile

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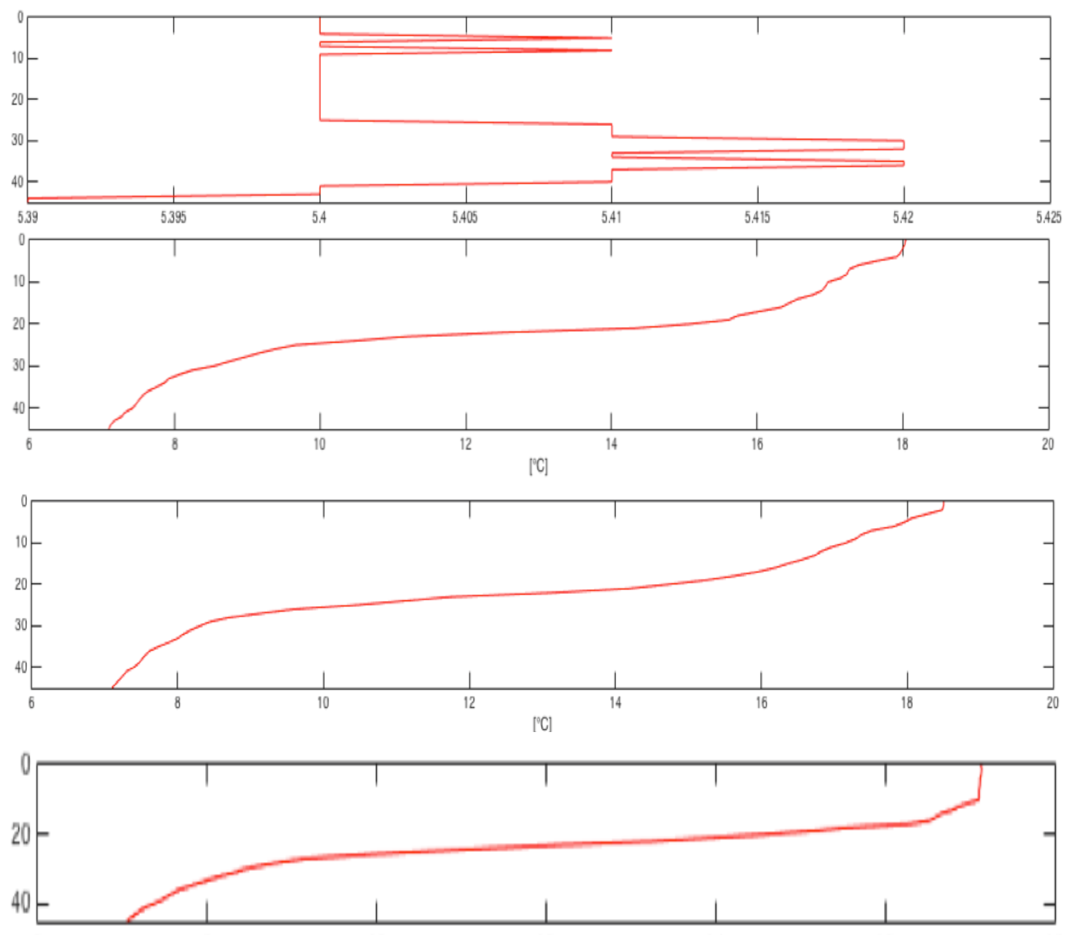

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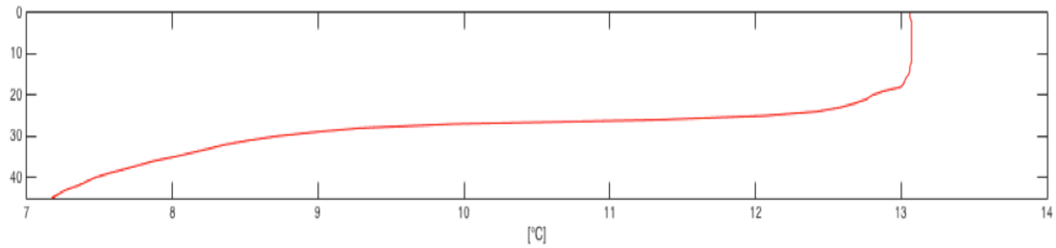

FIGURE 6. **Temperature**. The temperature profile of site M2 displaying the thermocline

DISCUSSION

This study has been done to determine what causes zooplankton vertical migrations in alpine lakes. Lake Biel zooplankton migrations have not been studied in great detail so the lake will serve as a site to test my hypothesis, which asks if zooplankton follow Diurnal Vertical Migration patterns in the lake. If this holds true, I will ask if they migrate to follow food sources, to find optimum temperatures, or a combination of factors. Their movement is key for humans to understand overall lake composition and water chemistry changes. If phytoplankton populations are able to grow exponentially without limiting factors, they can alter the water quality of lakes]

The data collected in 2014 suggests that the availability of food predominately drives Diurnal Vertical Migration of zooplankton in Lake Biel. Although we collected data specifically for temperature and food sources availability, a few other factors may also be responsible for the observed cyclic patterns, such as predator evasion and light availability (Hays 2003). Understanding zooplankton migration patterns help scientists better understand how changes in climate, surrounding urban communities, and linked species in the food web may impact aquatic ecosystems. Conclusions from my study at Lake Biel can be applied to other similar perialpine lakes globally.

Diurnal Vertical Migration

The five months displayed cyclical patterns of zooplankton migration signifying that Diurnal Vertical Migration exists. There is a general consensus in the scientific community that the patterns are due to a combination of factors due to complexity that affects zooplankton in the water column such as predation, food sources, temperature, and light (Folt & Burns 1999). I sampled two variables directly, temperature and food sources, but can also draw some conclusions based upon innate biological factors and predator evasion hypotheses. There is a direct correlation between food availability depth and timing of zooplankton migration but no pattern observed between temperature and movements. My observations are from a five-month period, so drawing a conclusion between temperature and vertical movements may be premature. A long-term study would be more adequate to link temperature changes and migrations.

Food Availability and Predation

I confirm my sub question that zooplankton migrate daily to search for food sources while minimizing predation. During the five months tested, zooplankton showed a steady pattern of remaining under the chlorophyll A extinction depth during daylight hours and migrating to phytoplankton populations during the night. If zooplankton were exclusively searching for food sources, they would remain in the top fifteen meters of the water column to maximize feeding. There is a factor limiting them to only nighttime hours. This is explained by their need to minimize predation while still getting their daily nutrients. Optically oriented predator such as fish and other organisms cannot prey as easily on zooplankton when there is no available light. Therefore, they only feed when they minimize risk.

Temperature

The thermocline and water temperature were roughly constant during the months tested, suggesting that 2014 was not a typical year at the study site. River inflow and seasonal variability causes mixing in the water column during certain periods of the year in Lake Biel (Wright et al., 1980). During the summer months, Lake Biel is stratified with two predominant layers of water, cold and warm, that are separated by the thermocline. During the winter, the colder lower layer rises towards the surface as there is less penetrating radiation to warm the top layer. There was very little change between the months, which could mean why there was no observed pattern between temperature and zooplankton movements. Thinking about climate change, it happens slowly compared to seasonal temperature variation. Comparing zooplankton migration to climate change is difficult to analyze because temperature difference is small on a one-year time basis. If zooplankton patterns are not affected by more rapid change during the year, I do not see how a smaller change over a long period of time will affect their patterns as well.

Light Availability

Data suggests light availability may also play a key role in zooplankton migration within the water column. During daylight hours, abundance is highest below the mean chlorophyll A extinction depth. At night, abundance levels are highest above the extinction depth. Because this pattern is not random and shows a very clear daily cycle, the importance of light availability cannot be ignored. It suggests that zooplankton have some sensitivity towards light, which could be a biological mechanism or predator avoidance, both which I did not test directly. I assume light penetration depth is about the same as the mean chlorophyll extinction depth because chlorophyll a cannot survive in any depths absent of light. In addition, I am not certain of the depth light penetrates Lake Biel as it changes throughout the year.

Ecosystem Health

Diurnal Vertical Migration is important for ecosystem health. Zooplankton predation on phytoplankton structures the water column and may contribute to carbon cycling as phytoplankton consume a significant portion of $CO2$ in the environment (Kenner & Ahmed 1975). If zooplankton stop migrating, they may not be able to reach food sources at night and may be more vulnerable to predators, which can lead to food web collapse (Carpenter et al 1985). In addition, global average climate, industrialization, and urbanization are all increasing so lakes will soon see a rapid change in nutrient inflow and water temperature.

Limitations

There were several limitations that impacted my study, such as issues with data analysis in Matlab and available times to collect and assess data. I originally planned to use data from 2014 and my collection during the summer of 2015 for this study. Matlab and programming in general were very new to me so I had a very short time frame to learn how to use it. I had problems graphing and displaying the 2015 data so I stuck with just 2014 for simplicity. Because my data was limited to only five months, I was unable to analyze movements over an entire year. If I were able to get data for all the months, I could map seasonal variability that would help me understand temperature change better. My data was collected during five months of 2014, mostly winter and summer, but a longitudinal study would be ideal. It would then be possible to compare patterns between seasons or time periods when other variables are kept constant. Lastly, the months tested may have been abnormally warm or wet and this may have skewed my results.

Future Directions

Future direction for this study should involved sampling the zooplankton predators in addition to prey, and should have a larger timeline for the testing period. While zooplankton migrate for food availability, they also do it, in theory, to avoid predators. In addition, light played a role in their movements, but I am unsure if it pertains to avoiding predators or searching for prey. My data was taken from five months of 2014 but in reality a full year of data or a few years would be ideal. A longer timeline would enable me to look at different years where weather patterns and average temperature could change. Then, analyzing seasons between years would allow for clearer interpretation of the data.

CONCLUSION

My findings will help researchers understand factors behind Diurnal Vertical Migration. When ecosystems collapse, we can look at key organisms, such as zooplankton, and observe whether their feeding patterns play a role in an effort to intervene in the ecosystem. Pollution and nutrient runoff can have huge effects on delicate ecosystems so it is important to know how they respond to change. For example, zooplankton patterns can shift when depth of primary producers increase due to excess nutrients. This can potentially lead to an entire ecosystem collapse. If depth of primary producers increases due to excess nutrients, for example, zooplankton patterns can shift leading to changes in the entire ecosystem that can cause it to collapse. Zooplankton in perialpine lakes are influenced by a combination of factors, but most notably food sources, for which I observed obvious patterns. I did not observe any patterns between temperature and movement. In addition to food sources, light and predator avoidance likely played a role in zooplankton's movement in Lake Biel.

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