Phytoplankton Communities: Differences in community composition and impact on gross primary production

BIOS 35502: Practicum in Environmental Field Biology

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Abstract

Phytoplankton are vital components of ecosystems, connecting primary production and higher trophic level organisms. These fundamental autotrophic organisms can generate strong bottom-up interactions based on their community composition. Trait-based approximations of phytoplankton communities have rapidly become an area of discussion. Composition of these organisms can affect the productivity of a freshwater system, so a trait-based assessment of their primary production lends itself to prediction of a lake's productivity. Through sampling of five different lakes (Morris, West Long, East Long, Hummingbird, and Crampton) at UNDERC, the phytoplankton community composition varied significantly between the five lakes. Over a seven-week period, the community composition was significantly different from week to week for each of the lakes. Community composition estimation of light use efficiency was statistically the same as the model-calculated method provided by the Jones lab. Crampton Lake and West Long Lake showed weak relationships between the two light use efficiency calculations, but all other lakes lacked any definite relationship. Further research on community composition prediction models could improve the method and lead to a more accurate method for light use efficiency prediction.

Introduction

Phytoplankton are responsible for the vast majority of the primary production of lake ecosystems. These microscopic organisms bridge the trophic gap between sunlight and the upper levels of the food chain. Generally, the term phytoplankton covers a wide expanse of organisms in many different classes and refers to the autotrophic nature of the organism above all else (Reynolds 1984). The term phytoplankton encompasses many different classes of organisms, including both plant and animal-like organisms. Natural selection brought about the species of phytoplankton seen in today's freshwater ecosystems as a result of variable levels of limiting nutrients [phosphorous, nitrogen, etc.] (Litchman 2008). Size maintenance and functionality of phytoplankton directly correlate (Reynolds 1984), and thus give rise to a possible trait system for gross primary production.

Phytoplankton serve not only as the dominant primary producers of aquatic systems, but also affect trophic dynamics of the system based on their community composition (Edwards et al 2013). Litchman and Klausmeier describe the value in recognizing many different functional traits of phytoplankton, such as different nutrient uptake, cell size, nitrogen fixation, and photosynthesis rate (2008). Some functional groups, such as the diatoms or the cyanobacteria, can thrive under low light conditions and continue to photosynthesize, driving the productivity of a lake up even when an algal bloom restricts light penetration (Litchman 2008). Differences in light efficiency allow for community composition to have a possibly strong effect on the overall primary production of a freshwater system. Applying known photosynthetic traits to phytoplankton would allow estimation of a lake's primary production based on the community composition of phytoplankton, and can be a powerful tool to explore links between community and ecosystem ecology.

Furthermore, current models of primary lake primary production are typically based on a limited number of predictors, such as total phosphorous (Sterner 1997). These models can perform poorly when other predictors are important in governing primary production, such as light (Torremorell 2009). Accurate models of phytoplankton community composition may be a more complete and dynamic alternative to modeling ecosystem function if phytoplankton traits scale from community to ecosystems (Edwards et. al 2013). A community parameter of primary production for the phytoplankton community can be established through the summation of niche specific traits for each genus of phytoplankton (McGill et al 2006). This parameter can then be compared to the ecosystem functional parameter and determine the validity of a trait-based approach to estimating primary production of lakes.

For the community composition, the expectation is that different lakes will exhibit a difference in community composition based on type of lake and conditions. This comparison between community and ecosystem functional parameters will test how accurately trait-based community ecology of phytoplankton can predict the observed ecosystem function of lake primary production.

Methods and Materials

Study Site

University of Notre Dame Environmental Research Center is a pristine ecological study site untouched for the past 74 years. Research occurred during the summer months of May, June, and July. The region belongs to the Eastern Deciduous forest, a hardwood forest. Both mesotrophic and oligotrophic lakes were included in the study.

Lab Methods

Using a Van Dorn sampler, I collected samples from the permanently mixed layer of five different lakes (Morris, West Long, East Long, Hummingbird, and Crampton) over a seven-week time span. I stored samples in two different dark containers (125 mL and 250 mL) in a refrigerator. Using 25% glutaraldehyde, the samples were preserved until counted.

For counting and compilation of community structure, I concentrated the bottles of lake water down to 5 mL, by filtering lake water through a 35 μm filter, collecting the phytoplankton. The use of this filter designated a threshold limit at 35 micrometers for the size of phytoplankton studied in the experiment. Prior to counting the phytoplankton, I inspected the run-through water from the filter under the microscope to determine if any small phytoplankton were filtering through.

Using a Sedgewick rafter cell, I placed1 mL of lake water in the cell for counting. The Sedgewick rafter cell contained 1000 cells, each holding approximately 1 μL of water. A random number generator selected the cells for counting phytoplankton in the Sedgewick cell. I counted all phytoplankton in each cell and identified them to species or genus (if not possible for species identification).

Statistical Analysis

For community composition, I transformed count data into density of phytoplankton per liter and milliliter, which was then multiplied by the average cell size per genus of phytoplankton. I used a Chi-Squared test to determine any differences in community composition between the lakes sampled. Then I used a second Chi-Squared test determine any differences in community composition in each lake over the seven-week period.

I transformed the phytoplankton biovolume into pg C cell^{-1} by the formulas (Menden-Deuer 2000):

$$10^{-0.665 + 0.939*\log10(\text{biobolume})} \text{ (Protists)}$$

$$10^{-0.541 + 0.811*\log10(\text{biovolume})} \text{ (Diatoms)}$$

After conversion, the data was multiplied by the light use efficiency coefficient for its specific one of the seven types of phytoplankton: green algae, blue-green algae, yellow-green algae, diatoms, cryptomonads, dinoflagellates, and euglenoids (Schwaderer et al. 2011). From this number, a comparison to modeled ecosystem light use efficiency from measured variables could be performed. The Stuart Jones lab at the University of Notre Dame provided the light use efficiency data for comparison. The Jones lab collected the data during the same seven-week span as the phytoplankton collections. I used a Fisher’s exact test to determine any similarity between estimation of ecosystem parameter by community composition and recorded values for ecosystem light use efficiency. Following the t-test, I ran multiple regressions to determine if a pattern existed between the two methods of calculation light use efficiency. I used the statistical program R version 3.1.1 for all statistical analysis.

Results

The Pearson Chi-Squared test shows a significant difference in average phytoplankton community composition between the lakes ($F_{360} = 79655811$, $p = 2.2x10^{-16}$). Average density of phytoplankton differed between each lake (Figure 1). As seen in Figures 2-6, the compositions of the lakes differ even when based on class identification. The test statistic originates from the differences in average genus density for each lake over the seven weeks compared to the other lakes.

After the initial comparison between the five lakes, a temporal comparison between the sampling weeks was done on each lake. Similarly, I used Chi-Squared test to determine if there was any significant difference in composition over time. The test showed a significant difference in community composition across seven weeks from late May to early July for all five lakes (Morris: $F_{408} = 252980475$, $p = 2.2 \text{ x } 10^{-16}$, West Long: $F_{306} = 165620195$, $p = 2.2 \text{ x } 10^{-16}$, East Long: $F_{330} = 245556204$, $p = 2.2 \text{ x } 10\text{-}^{16}$, Hummingbird: $F_{450} = 160465271$, $p = 2.2 \text{ x } 10^{-16}$, Crampton: $F_{348} = 183952344$, $2.2 \text{ x } 10^{-16}$).

From the fisher t-test comparing predicted lake primary production to recorded values, the results all proved statistically insignificant for differences (Morris: p = 0.8937, West Long: p = 0.1855, East Long: p = 0.9918, Hummingbird: p = 0.7215, and Crampton: p = 0.7657). Predicting light use efficiency figures from community structure could be interchangeable with models using recorded data. Results from the linear regressions on the light use efficiency data yielded insignificant p-values, yet some lakes showed weak relationships between the two methods of calculation (Morris: $F_5 = 1.092$, $p = 0.3439$, $R^2 = 0.1792$, West Long: $F_5 = 2.749$, $p = 0.1582$, $R^2 = 0.3548$, East Long: $F_5 = 0.3472$, $p = 0.5813$, $R^2 = 0.06494$, Hummingbird: $F_5 = 0.207$, $p = 0.6682$, $R^2 = 0.03976$, Crampton: $F_5 = 2.56$, $p = 0.1705$, $R^2 = 0.3386$). While this method of ecosystem parameter estimation may be a good approach to whole ecosystem estimation, the method may not be suited to an approximation of light use efficiency over time within singular lakes.

Discussion

From the initial densities of species in each lake, the Chi-Squared test showed a significant difference in the community compositions between the five lakes. A possible explanation for the differences in the community structure arises from the difference characteristics and locations of the lakes. Phytoplankton depend on different nutrients, generally either phosphorous or nitrogen, to limit their growth and reproduction. All lakes have differing levels of these nutrients, which dictate the community composition. Along with nutrient availability, the five lakes range in level of light availability and terrestrial carbon inputs.

East and West Long Lakes once constituted one lake, but were split for research. Each side of the lake experiences different conditions, resulting in different phytoplankton compositions. East Long receives higher levels of terrestrial carbon from the surrounding terrestrial landscape, resulting in darker color due to a higher dissolved organic carbon concentration. West Long contained a higher density of phytoplankton per liter than did East Long (Figure 4). All other factors aside, this could indicate the importance of light on the diversity of the communities. Four different classes of phytoplankton dominated West Long (Chlorellales, Chlorophyceae, Chrysophyceae, and Raphidophyceae), but only Raphidophyceae dominated East Long. The differences in community composition between these two lakes exclude spatial difference as a major factor contributing to these communities. Mikulyuk found that differences in community structure depend on a wide range of factors, spatial differences aside (2011). Further research on East Long and West Long Lakes could be done to determine what factors influence the community composition.

Morris Lake is a mesotrophic lake, with medium levels of dissolved oxygen and particulate organic matter. Three streams flow into Morris, allowing a higher level of nutrients to pass through the lake system. This could be a major contributor to the higher overall density of phytoplankton in the lake (42,186,219.3 phytoplankton/liter (P/L)) whereas the other lakes had lower densities. East Long, West Long, and Crampton had relatively similar densities (27,577,532.78 P/L, 30,691,642.57 P/L, 32,684,523.81 P/L, respectively). These lakes, while similar in density, still exhibited a difference in community composition. Due to the higher abundance of nutrients in Morris Lake, a more diverse composition of phytoplankton could exist as competition between species for nutrients does not exhibit as strong a driving force. Phytoplankton tend to exploit niches of nutrients, finding ways to avoid competition rather than forcing out other species (Hutchinson 1961).

Hummingbird Lake is a rather eutrophic lake and rich in nutrients. Although this usually indicates a good level of productivity, it could hamper the phytoplankton composition, allowing only those tolerant of low levels of light (diatoms and cyanobacteria). The class Chlorococcales dominates the community, which, according to Reynolds, aggregates in high nutrient water systems (2002). Another possible factor comes from the high levels of terrestrial carbon flowing into the lake. Hummingbird is a rather small lake surrounded by dense vegetation that contributed to the particulate organic matter in the water. The average total density for

Hummingbird was 17,728,523.96 P/L, a substantially lower density than all other lakes. Unlike Morris, the Hummingbird community showed an anomalous reaction to high nutrients and density decreased along with species diversity (Figure 2).

A majority of the lakes, across all time, were dominated by the *Gloecystis nageli*. Although this one species of phytoplankton were extremely abundant, individuals within this species were also among the smallest of all the phytoplankton observed. Whereas species such as *Volvox teritus* achieved sizes of 200 micrometers, the *Gloecystis naegli* were hardly ever larger than 50 micrometers. Their biomass may not contribute as much to the community composition as their sheer abundance in the lakes does. Predicting the community structure accounts for the total species and abundance, but disregards the biomass and its influence. Though the biovolume of this smaller phytoplankton does not constitute much of the total biovolume, studies have found that oligotrophic lakes tend to be dominated by small phytoplankton whereas eutrophic lakes are composed mainly of large size phytoplankton. This pattern arises from the decrease of sediment loss in the system and reduces the potential for downward carbon transport. Smaller phytoplankton involve a more complex food web, whereas the larger phytoplankton are involved in a smaller food web that allows for carbon transport to deeper layers of the lake. Downward transport of this carbon results in a more eutrophic system (Huete-Ortega 2010). Given this pattern, the extreme dominance of *Gloeocystis nageli* in Crampton Lake could be a significant factor in the oligotrophic nature of the lake.

From May to July, each lake experienced a significant difference in the community composition. Across the seven weeks, the lakes significantly shifted in their composition of phytoplankton ($p = 2.2 \times 10^{-16}$). Pinckney et al. found that phytoplankton composition varies both spatially and temporally based on conditions (1998). All lakes experienced a temporal shift in community composition, which could be a result of the extended winter/spring season. Certain phytoplankton, such as dinoflagellates, peak in abundance during the winter months, while diatoms peak during the spring and summer months. It is possible that the remnants of winter prolonged the shift in the community further into the summer, thus making it apparent. This year the ice off for the lakes at UNDERC occurred on May 8th, which was just before the first phytoplankton collection. The first week sample (mid May) contained almost no diatoms, but by early June, the diatoms began to appear in samples. As shown in the results, phytoplankton community composition depends on the time of year and can shift even in a small time span between seasons.

Comparisons of the lake metabolism generated from community composition to recorded values appeared to differ very little from the modeling methods using ecosystem information. The two methods were not statistically different from each other, meaning that the methods varied little from each other, especially in the case of East Long ($p = 0.9918$). This information could open up the community-based approach to approximation of ecosystem parameters. Since the approximation of light use efficiency via community composition proved insignificantly different than that of model calculations, this approach may be a valid method in estimation of ecosystem parameters in the future.

Although the two methods show a similar outcome, the linear regressions run on the data show few relationships between the two over time. The p-value for both Crampton and West Long suggests non-significant relationships ($p = 0.1705$ and 0.1582, respectively), but the R-squared values show a slight relationship between the two methods throughout the seven weeks (0.3386 and 0.3548, respectively). Both lakes show a negative relationship, but the relationships are not strong. Morris, East Long, and Hummingbird exhibited almost no relationship between the two methods. While the community-based method of ecosystem parameter approximation may be a useful tool for predicting whole ecosystem values, it appears to be a weak tool for use within a lake over time.

Estimation of ecosystem parameters by community composition could prove useful for merging community and ecosystem ecology. Generally, ecosystem parameters emerge from compilation of data and then fitting of a model, but with community composition methods the same patterns could emerge and even predict the future of an ecosystem based on the current populations. Learning more about phytoplankton communities and their effects on total lake productivity could aid in predicting how both communities and ecosystem function will change in rapidly changing environments. After establishment of community parameters, an estimate of ecosystem function from initial conditions of an ecosystem alone could be possible. Models exist to transform raw ecosystem data from the nutrient level to the whole ecosystem, but community composition modeling could enhance and streamline these models (Sterner 1992). Different classes of phytoplankton exhibit a wide range of utilization of nutrients and expansion of this knowledge may lead to a more complete model of ecosystem predictions. Community composition has just begun to emerge as a study, but the use of current methods shows promising outcomes for future studies.

Acknowledgements

I would first like to thank my mentor Jake Zwart for all of his help on this project, which could not have been done without him. Members from the Stuart Jones lab at Notre Dame collected the lake water samples and contributed the light use efficiency data. I would like to thank Michael Cramer, Lauren Eckert, and Christy Lowney for their aid throughout the summer. I would also like to thank Elyssa Schwendy for her help with statistical analysis. Special thanks

goes to the Hank family for their generous endowment to the UNDERC program and their aid.

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Figures

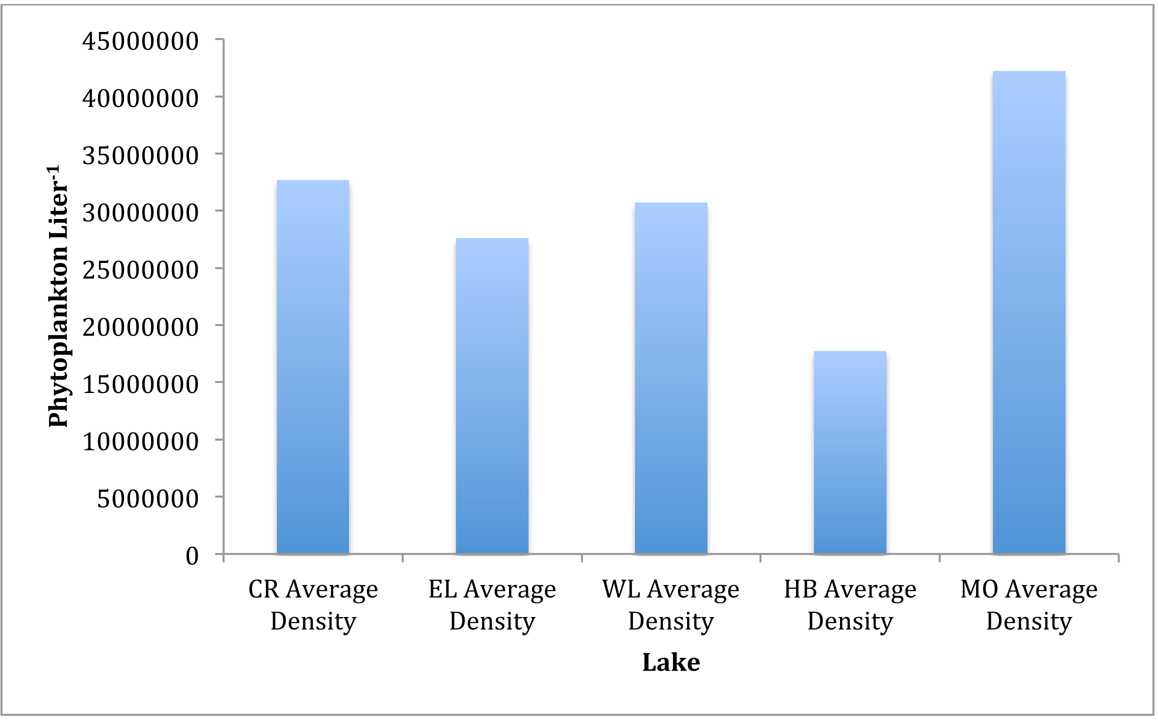

Figure 1. Average density of phytoplankton per lake across seven weeks. Values were computed by averaging the total phytoplankton density per lake over the entire time period. The number per cell was scaled up to phytoplankton per liter. The community compositions of the five lakes were significantly different ($p = 2.2x10^{-16}$). As seen visually, the densities of phytoplankton varied, with Morris having the highest density of phytoplankton per liter.

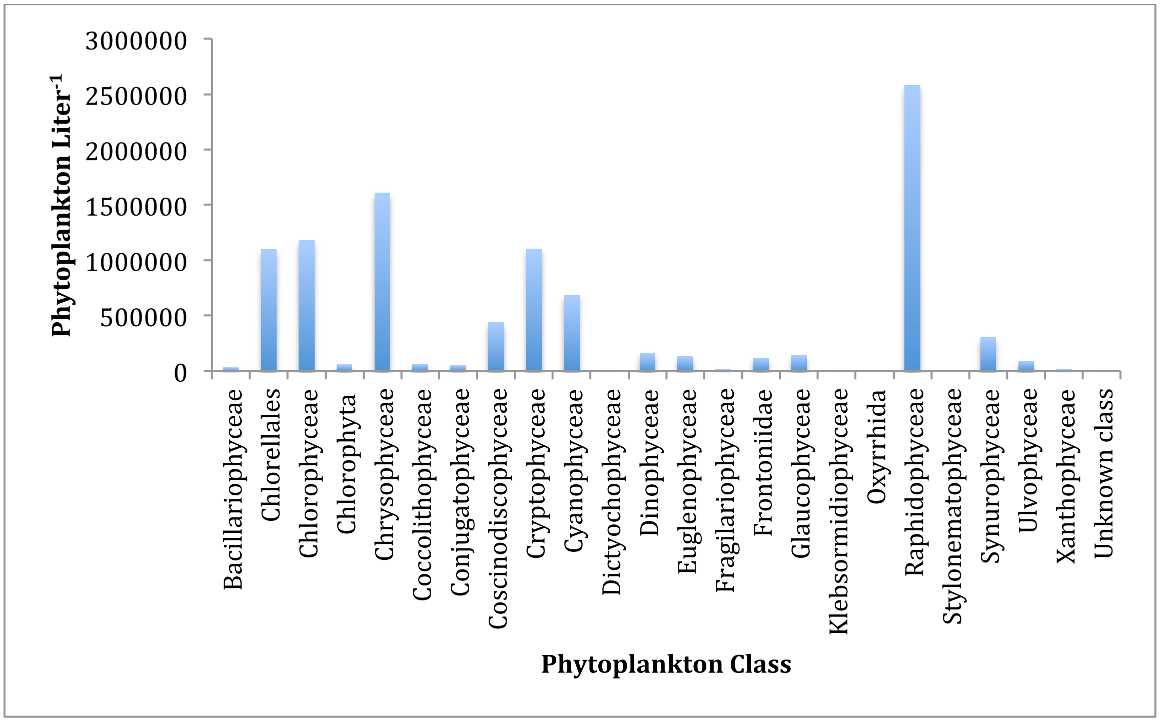

Figure 2. Community composition of Morris Lake, sorted by class. For each class, the sum of the densities of all genus of phytoplankton in the class was compiled. Raphidophyceae dominates Morris Lake. This trend is similar to both East and West Long Lakes.

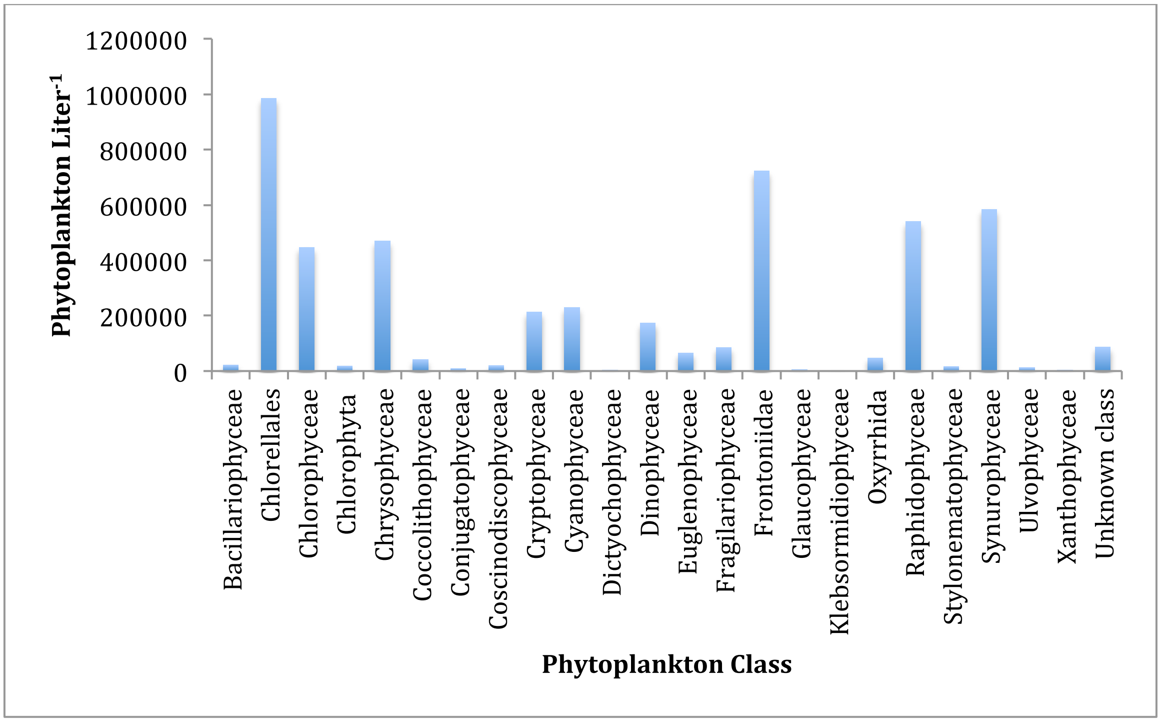

Figure 3. Community composition of Hummingbird lake, sorted by class. For each class, the sum of the densities of all genus of phytoplankton in the class was compiled. Bacillariophyceae dominates Hummingbird Lake and Frontoniidae is the second most abundant. This trend only occurred in Hummingbird Lake.

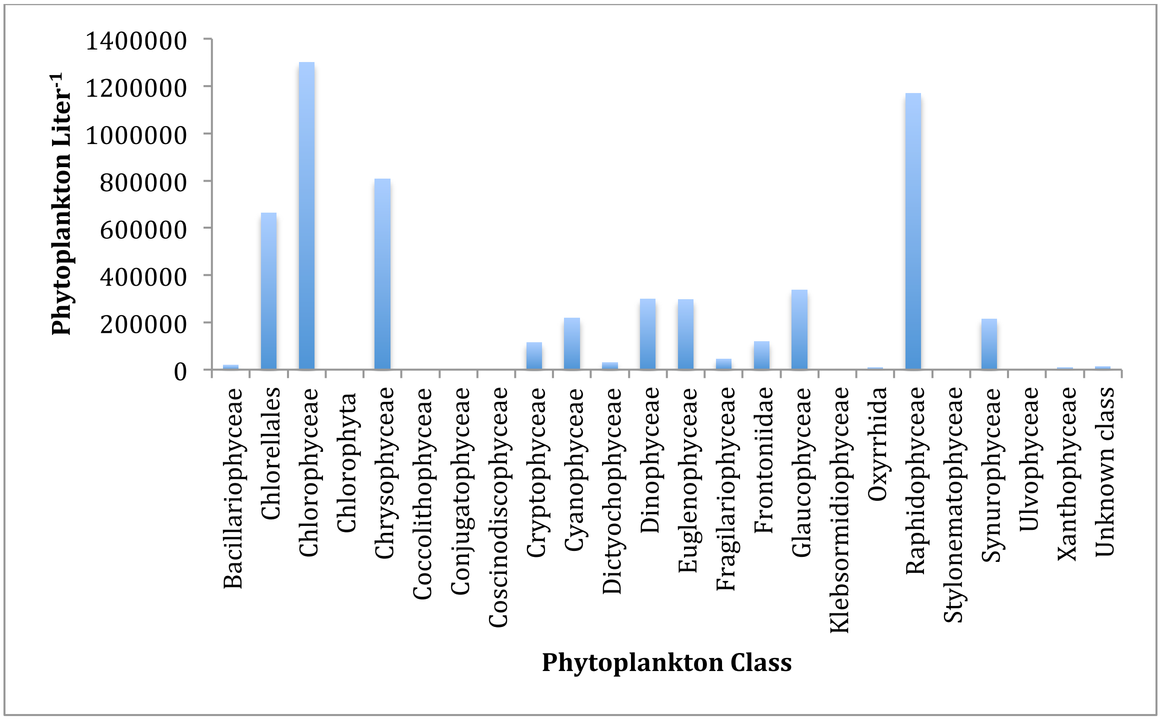

Figure 4. Community composition of West Long lake, sorted by class. For each class, the sum of the densities of all genus of phytoplankton in the class was compiled. Classes Raphidophyceae and Chlorellales dominate West Long Lake. West Long is the only lake to have Chlorellales as a dominant class of phytoplankton.

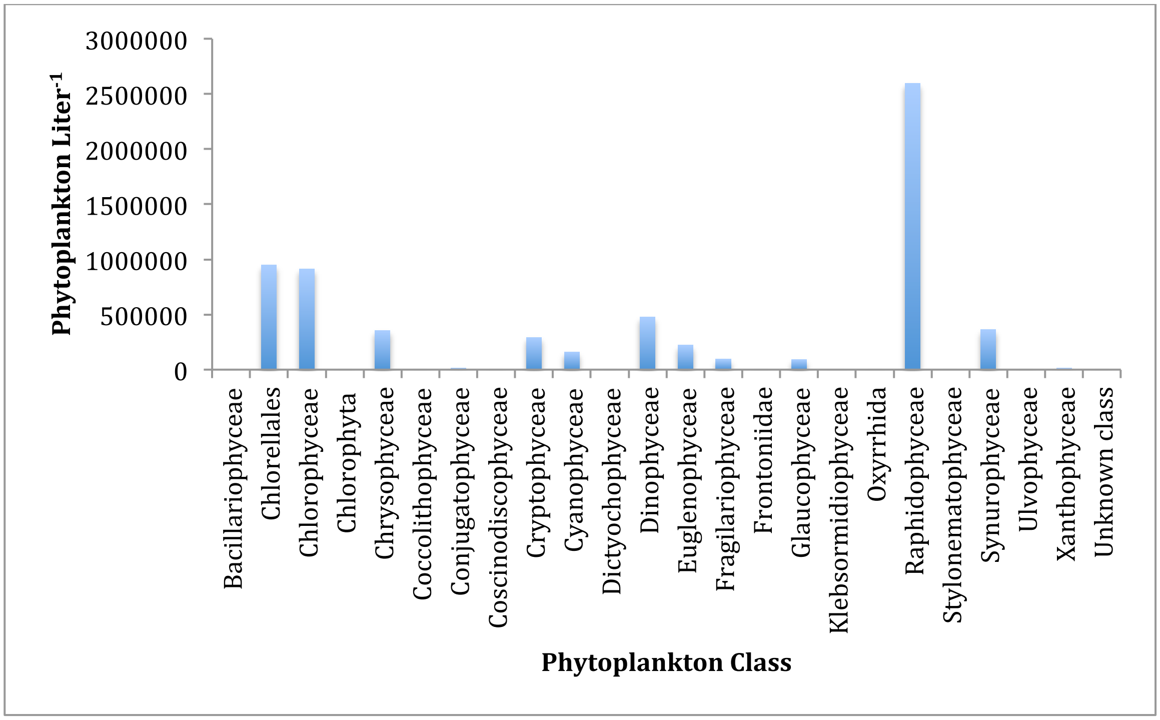

Figure 5. Community composition of East Long Lake, sorted by class. For each class, the sum of the densities of all genus of phytoplankton in the class was compiled. Raphidophyceae is the only class with a high abundance in the lake. Unlike West Long, East Long contains only one major class and no other class comes close to the density of Raphidophyceae.

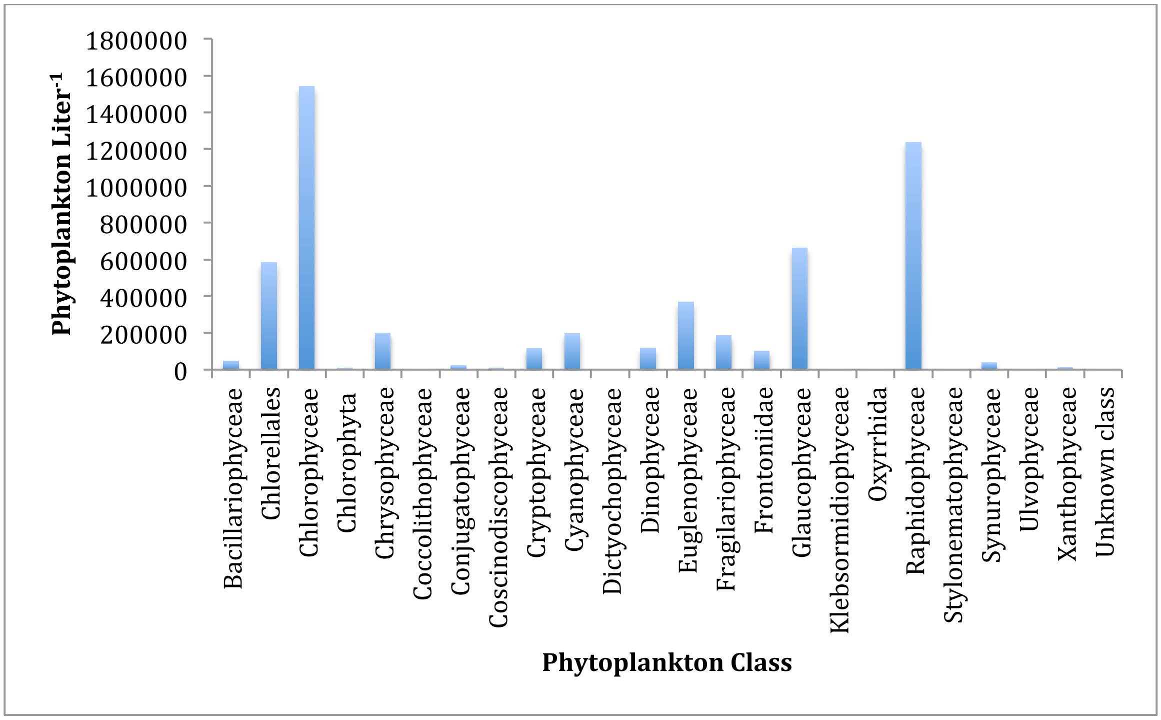

Figure 6. Community composition of Crampton Lake, sorted by class. For each class, the sum of the densities of all genus of phytoplankton in the class was compiled. Chlorophyceae dominates Crampton Lake. Gloeocystis nageli was the predominant form of phytoplankton in the lake. This species is one of the smallest found in any of the lakes, which could be a contributing factor to the oligotrophic nature of the lake.

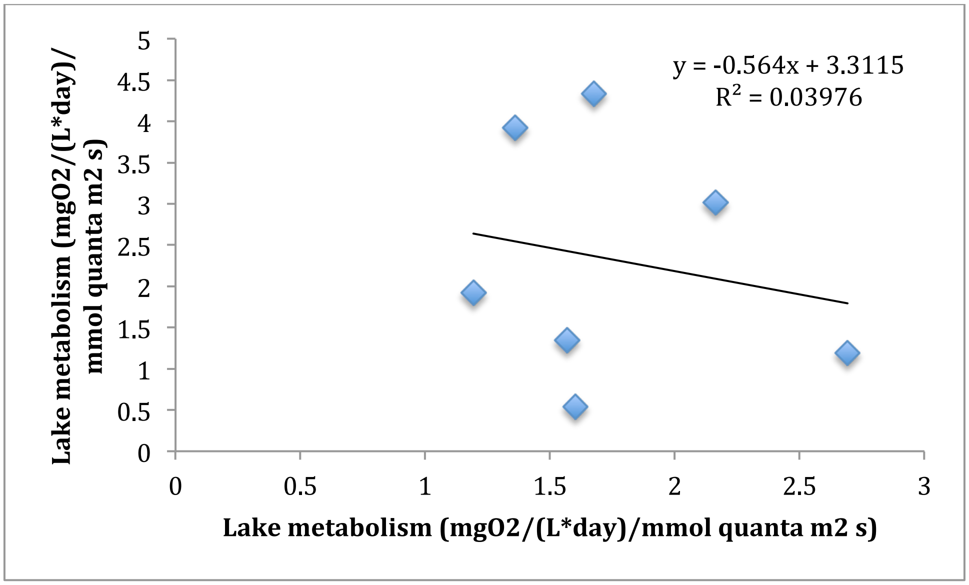

Figure 7: Linear Regression of Community Composition Light Use Efficiency and Recorded Light Use Efficiency for Hummingbird Lake. Light use efficiency values for community composition were scaled up from density of phytoplankton per liter and summed to get the whole lake light use efficiency. These values were compared to the recorded data for light use efficiency. The linear regression showed no significant relationship between the two methods although the t-test showed them to be statistically equivalent (Hummingbird: $F_5 = 0.207$, $p = 0.6682$, $R^2 = 0.03976$). Through time there seems to be no relationship between the two methods of calculating light use efficiency.

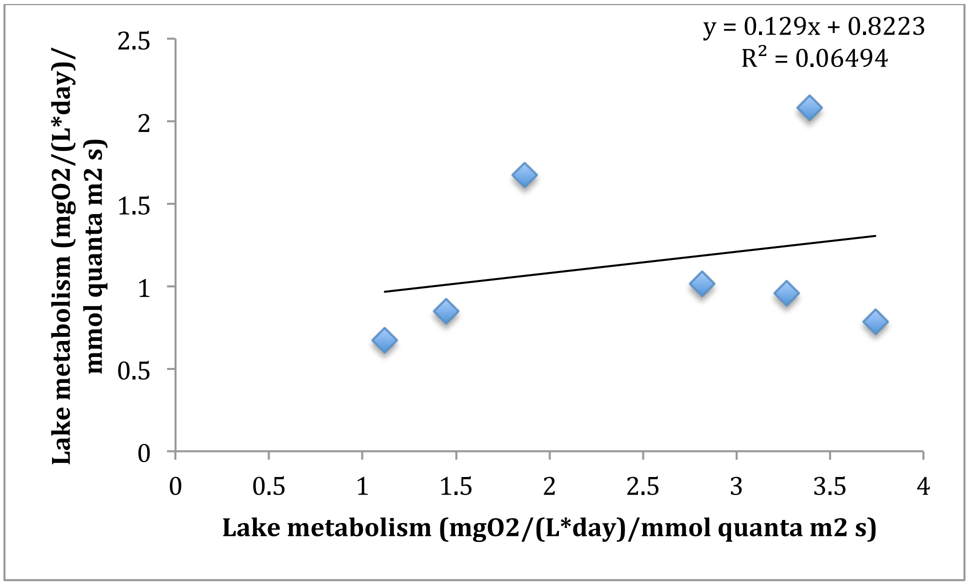

Figure 8: Linear Regression of Community Composition Light Use Efficiency and Recorded Light Use Efficiency for East Long Lake. Light use efficiency values for community composition were scaled up from density of phytoplankton per liter and summed to get the whole lake light use efficiency. These values were compared to the recorded data for light use efficiency. The linear regression showed no significant relationship between the two methods although the t-test showed them to be statistically equivalent (East Long: $F_5 = 0.3472$, $p = 0.5813$, $R^2 = 0.06494$). East Long exhibited no pattern over the seven weeks for the two methods.

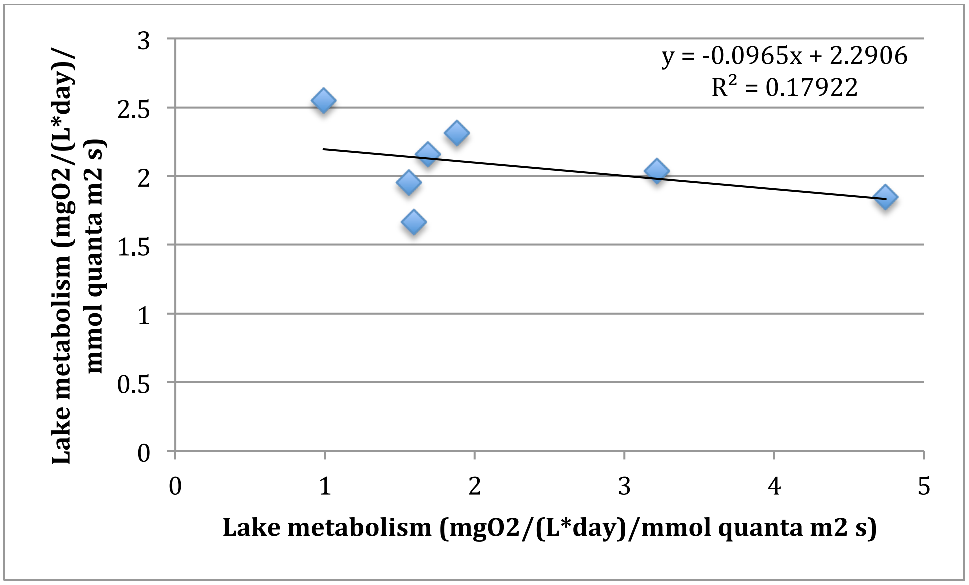

Figure 9: Linear Regression of Community Composition Light Use Efficiency and Recorded Light Use Efficiency for East Long Lake. Light use efficiency values for community composition were scaled up from density of phytoplankton per liter and summed to get the whole lake light use efficiency. These values were compared to the recorded data for light use efficiency. The linear regression showed no significant relationship between the two methods although the t-test showed them to be statistically equivalent (Morris: $F_5 = 1.092$, $p = 0.3439$, $R^2 = 0.1792$). The regression showed a weak relationship between the two methods of calculations, even though the p-value indicates insignificant results.

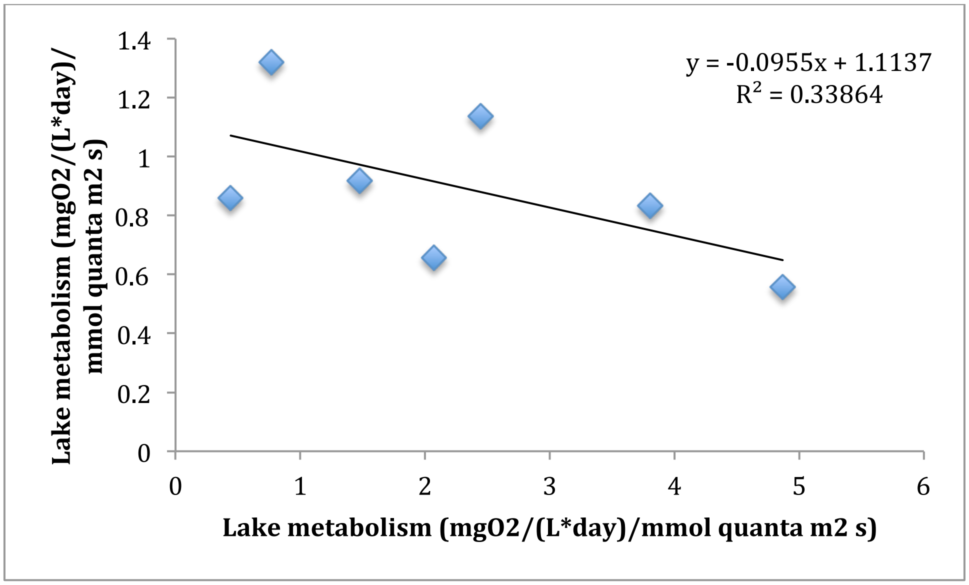

Figure 10: Linear Regression of Community Composition Light Use Efficiency and Recorded Light Use Efficiency for Crampton Lake. Light use efficiency values for community composition were scaled up from density of phytoplankton per liter and summed to get the whole lake light use efficiency. These values were compared to the recorded data for light use efficiency. The linear regression showed no significant relationship between the two methods although the t-test showed them to be statistically equivalent (Morris: $F_5 = 1.092$, $p = 0.3439$, $R^2 = 0.1792$). The regression showed a weak relationship between the two methods of calculations, even though the p-value indicates insignificant results.

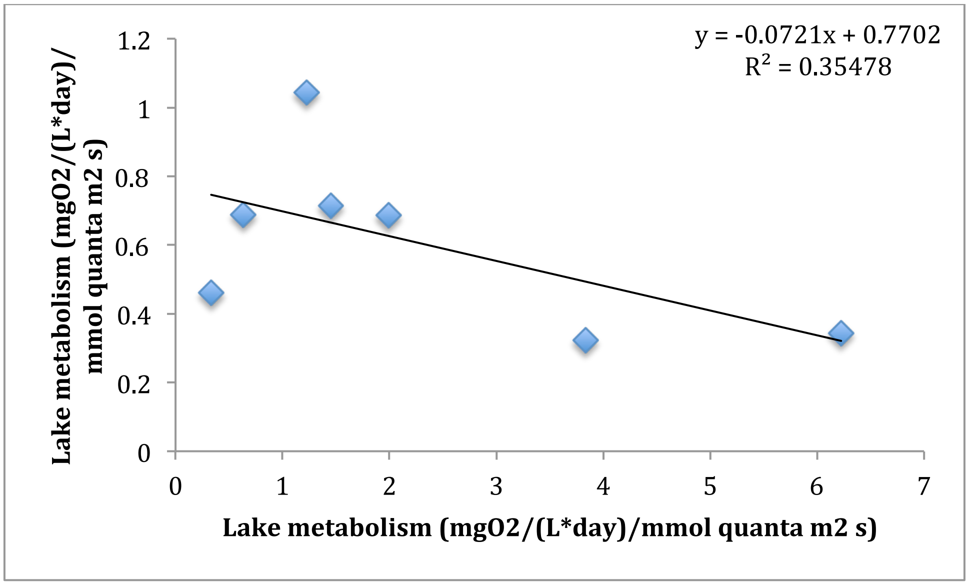

Figure 11: Linear Regression of Community Composition Light Use Efficiency and Recorded Light Use Efficiency for West Long Lake. Light use efficiency values for community composition were scaled up from density of phytoplankton per liter and summed to get the whole lake light use efficiency. These values were compared to the recorded data for light use efficiency. The linear regression showed no significant relationship between the two methods although the t-test showed them to be statistically equivalent (West Long: $F_5 = 2.749$, $p = 0.1582$, $R^2 = 0.3548$). The regression showed a weak relationship between the two methods of calculations, even though the p-value indicates insignificant results. West Long demonstrated the strongest relationship out of all the lakes, but the t-test showed them to be less similar.