The response of north temperate lakes phytoplankton to changes in their light environment

BIOS 33502: Practicum in Environmental Field Biology

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Abstract

Lake browning is a current process occurring in most of the north hemisphere lakes. That not only affects phytoplankton production, but the ability of the lake to sustain economic activities such as fishing, water sports and drinking water. Phytoplankton are the base of the aquatic food web, essential part of several biological cycles; and a very sensitive organism to light and nutrient related environment changes as well. Therefore, their response to these environment changes is key to understand the course that lakes are taking. Lakes are turning darker much faster over the last few decades, decreasing light availability in this freshwater ecosystem. Lake water incubations were made in similar and opposing light availability and dissolved organic carbon (DOC) concentration climates with the purpose to expose phytoplankton and observe their response to these factors, in chlorophyll concentration terms. Results showed that high DOC phytoplankton incubated on high light availability lakes were not as productive in comparison to low DOC phytoplankton in terms of chlorophyll concentration. While low DOC phytoplankton were more resilient to these changes. These findings provide new approaches about phytoplankton response to environment changes such as light availability, essential to understand the freshwater ecosystems fate with lake browning.

Key words: lake browning; phytoplankton; light availability; dissolved organic carbon; environmental changes; incubations.

Introduction

Climate change continues to threaten natural ecosystems. More specifically, lake ecosystem's physical, chemical, and biological structure are changing. Climate change can affect certain factors of a lake ecosystem such as fluctuations of the water level, the formation of ice, and can cause nutrient loading (Adrian et al. 2009, Mooij et al. 2005). For example, it is estimated that phosphorus concentrations will increase from 3.3% to 16.5% which could lead to eutrophication (enrichment of water with nutrients) in these water bodies (Jeppesen et al. 2008). Climate change can also increase temperatures in lakes which can stress phytoplankton, leading to lower rates of growth and less chlorophyll production. Therefore, the fate of lake ecosystems is uncertain and may change in a substantial way.

The phytoplankton present in these lakes are affected by these climate induced changes because they depend on physical factors such as water column mixing, water temperature, and the light available in the lake (Winder and Sommer 2012) which are often indirectly altered. In past studies, it has been suggested that phytoplankton composition and size structure is affected by climate change and taxa that are able to adapt quickly are the ones which can take advantage of a changing environment (Winder and Sommer 2012). Phytoplankton are very sensitive to light due to photoreceptors that allow them to recognize light sources (Colley and Nilsson 2016). As a result, one of the most important characteristics of phytoplankton, primary production; can be affected by changing conditions. Also, the rise of the temperature decreases the concentration of chlorophyll and the synthesis of proteins of the phytoplankton (G-Yull and Gotham 1981), which can also decrease the phytoplankton production. Further, phytoplankton are able to resist shifts in the lake ecosystem (Anneville et al. 2002). Previous studies have shown that many species

of phytoplankton maintain physiological plasticity that help them to respond to light variation during the day, which allows them to survive in a range of light penetration (Falkowski 1980). In the face of a changing environment, phytoplankton must be able to acclimate and in the absence of this, biological and chemical processes in lakes may be disrupted such as food web dynamics and nutrient cycling, respectively.

Lake browning is a process that plays an important role in lake ecosystem structure and function, especially primary production. This process can alter the temperature, light availability and nutrients of the lake. Lake browning consists of increased concentrations of light absorbing molecules known as dissolved organic carbon (DOC) that enters a lake by surface or ground water (Solomon et al. 2015). An increase in the absorbance of light results in a decrease of light availability and in turn, a rise in the temperature of the epilimnion in a lake. The lake has different sections, and the epilimnion is one of the most important because it is where sun light can penetrate the water providing ideal conditions for phytoplankton survival. A long period of lake browning could induce large changes to the habitat and the food web in the lake. For example, some species of zooplankton replaced others that were not able to adapt to the changes produced by the lake browning (Williamson et al. 2015). This can also happen to phytoplankton because lake browning limits the light that can penetrate the water and results in lowered production.

Lake browning alters temperature, light, and nutrients and therefore, it is expected that phytoplankton will respond to these changes in different ways. For example, phytoplankton growth rates were high when they were exposed to high concentrations of limiting nutrients, independent of the surface irradiances (Bjork et al. 2004). Moreover, lake browning reduces phytoplankton production as well their biomass and community

composition (Deininger et al. 2017). Besides affecting phytoplankton, lake browning also presents a new challenge on the treatment of drinking water (Köhler et al. 2013).

Lake ecosystems are important for recreation, such as fishing, which represents a large part of the local economy; thus understanding how lakes are changing and how phytoplankton are affected by climate change is very significant. I will address this question by studying phytoplankton production in response to environmental changes such as light and temperature in lake ecosystems. This will allow for a better understanding of how phytoplankton will respond to these environmental changes. Because they are the foundation of the aquatic food web, there could be a cascading effect on the ecosystem.

Given that the process of lake browning has increased in the last decades (Kritzberg 2017) and decreased light availability, I want to know how phytoplankton will respond to these changes in their environment. To do this, I incubated phytoplankton from lakes with low and high light availability, which is controlled by dissolved organic carbon (DOC) concentrations; in lakes with similar and opposing light climate. I hypothesized that phytoplankton will be more productive when they are incubated in the lake from which they originate. On the other hand, the phytoplankton incubated from others lakes will be less productive, as they are unfamiliar with the environmental conditions.

Materials and methods

Study Site

Phytoplankton from ten lakes that represent both high light availability and low light availability were used to determine how phytoplankton respond to different light climates in terms of chlorophyll production (Table 1). Light availability in each lake was determined using color (g440) and DOC concentration (µg/L), in addition to Secchi depth measurements (Table 1). All lakes were located at the University of Notre Dame Environmental Research Center (UNDERC). The sampled water represented the natural assemblage of phytoplankton inhabiting the respective lake.

Field Work

I collected water at a depth of 0.5 m in three 1 L clear plastic sample bottle which were subsequently incubated at the average light climate in the lake from which they originate as well as a lake that had an opposing light climate using a contraption that we built ourselves (see Table 2 for incubation combinations). The contraption consisted of a round insulator panel for buoyancy with three holes for each bottle and a brick tied to a ten meter long rope which served as an anchor. Also, we used rope to tie the bottles to the contraption and added one tile per rope to counter the buoyancy of the bottles so they would be incubated at a depth of 0.5 m. On some occasions, we placed more than just one contraption in the lake for greater efficiency and a larger number of samples for the research. We decided to make different types of opposing and similar climates of incubation to give us a chance to compare phytoplankton production. In addition, the water collected was immediately transferred to a dark cooler to avoid uncontrolled sun light exposure while transferring the

samples. Then, the collected water was transported to a lake with the same or the opposite light climate (Table 1). Each water sample was incubated for a period of six hours, giving them enough time to photosynthesize. Besides the water samples that were going to be incubated, we collected an initial water sample at 0.5 m for each lake incubation, as a way to compare chlorophyll production at the end with the rest of the incubated water samples. Both of initial (T = 0) and final (T = 6) samples were brought back to the lab in a dark cooler and filtered to determine initial and final chlorophyll concentration, which is used as a proxy to estimate phytoplankton productivity. I took an epilimnetic temperature and light profile for each lake using a YSI temperature sensor and light meter, respectively. Further, light attenuation was determined using a Secchi disk. A water sample taken in isolation of the incubations determined the color of each lake as an estimate of DOC concentration. By performing incubations within the lake (in situ) it provided the opportunity to compare phytoplankton production in a natural environment.

Lab Work

To filter water samples, a filter manifold and pump were used. The water sample was first pre-filtered with 153 um tubing and then with a 47mm GF/F filter. For each sample I used 450 ml of water and filtered two samples per replicate for both initial and incubated water samples. The filtered samples were placed in black containers with 25 ml of methanol. Then, chlorophyll was extracted from the filters and analyzed for chlorophyll *a* using a fluorometer (Turner Designs) after 24 hours of rest. All samples were place in a freezer if chlorophyll could not be analyzed immediately. In addition, color was analyzed using a spectrophotometer at a wavelength of 440 nm. I compared the initial and final chlorophyll

concentrations between the two different sampling periods and measured the phytoplankton production response to environmental changes.

Statistical analysis

The data was not normally distributed after running a Shapiro Wilk test. So I proceeded to run a non-parametric test with R statistical analysis software. The Friedman test was used for the mean difference between final and initial chlorophyll concentration using source lake DOC concentration and light availability as factors both with two levels (high and low). In addition, an ANCOVA was used to analyze final chlorophyll concentration using initial chlorophyll concentration as a covariate. This was also performed using R statistical analysis software.

Results

There were no statistically significant differences between final chlorophyll concentration in source lake DOC concentration ($F = 1.24$, $p = 0.299$), light availability ($F = 3.48$, $p = 0.0675$), and the interaction between the two ($F = 0.142$, $p = 0.708$). Although, initial chlorophyll concentration was used as a covariate in the ANCOVA analysis and was a statistically significant covariate ($F = 609.6$, $p < 0.05$). Lakes with high source DOC concentration, independent of light availability, had higher final chlorophyll concentrations than lakes with low source DOC concentration. Further, incubations in low light availability, independent of source DOC concentration, had higher final chlorophyll concentrations (Figure 1). The mean final chlorophyll concentrations ranged from 3 ug/L to 9 ug/L.

There were no statistically significant differences between mean difference in final chlorophyll concentration and initial chlorophyll concentration, ($p = 0.157$ $df = 1$, Figure 2). Lakes with high DOC source lake concentration and high light availability saw a decrease in chlorophyll with -0.818 ug/L mean difference while lakes with low source DOC concentration and low light availability saw the highest mean difference with a change of 0.482 ug/L. Both treatments with high source lake DOC concentration saw a decrease in chlorophyll over the course of the incubation while treatments with low source DOC concentration saw increases (Figure 2).

For the overall mean difference between initial (T=0) and final (T=6) of chlorophyll concentration (ug/L) lakes with low DOC like Bay, West Long, Crampton, Paul and Peter produced more chlorophyll at the end than lakes with higher concentrations of DOC like Hummingbird, East Long, North Gate, Bolger and Cranberry. The five combinations of lake incubations showed different results. Bay incubated in Bay decreased while the opposite incubation of Bay in Hummingbird increased in chlorophyll concentration (Figure 3). Also, West Long incubated in West Long exhibited a decrease in chlorophyll while the opposite incubation increased (Figure 4). Crampton showed a decrease in chlorophyll in its original incubation while its opposite incubation in North Gate increased in chlorophyll (Figure 5). Paul's incubation in its original habitat and opposite incubation, Bolger, both increased in chlorophyll concentration (Figure 6). Finally, dark lakes like Hummingbird increased in its opposite climate incubation only. While East Long increased in chlorophyll in its opposite climate incubation. North Gate, Bolger and Cranberry (Figures 5, 6, & 7) decreased in both incubations.

Discussion

The experimental results did not support the hypothesis where I suggested that phytoplankton incubated in their original light climate will be more productive than the ones that were incubated in the opposing light climate. In some cases, the majority of the original incubations were lower and not higher in chlorophyll concentration. Lakes with higher concentrations of DOC decreased in chlorophyll concentration at the end of the incubations. Research shows that chlorophyll *a* concentration, besides being affected by temperature is also affected by environmental factors related to light penetration (Lorena Longhi and Beisner, 2009). One reason why this happened could be the placement of phytoplankton in plastic bottles that could have blocked the complete entrance of sun light, changing the temperature and inducing stress on phytoplankton. Further, the bottles could have allowed a higher concentration of UV rays that could have destroyed algal cells and induced a decrease in chlorophyll because of being too close to the water surface. Phytoplankton originating from high DOC lakes could have been more sensitive to an artificial incubation than phytoplankton from light lakes. Phytoplankton from dark lakes may have certain adaptations to survive in low light availability lakes that are not translated to water bodies with high light availability (Rose 2016). Phytoplankton of light lakes are better acclimated to high light availability because it is their original environment and changing them to a low light availability lake may not be a huge factor influencing their chlorophyll production.

The final chlorophyll concentrations for low and high DOC lakes showed that even if dark lakes were incubated in light lake water they had more chlorophyll concentration in comparison to light lakes incubated in dark lakes. The high presence of phytoplankton in

high DOC lakes is because more nutrients are available for phytoplankton production. They might have decreased in chlorophyll production overall, but still had more final chlorophyll than light lakes because they are not nutrient limited like light lakes are. Nutrient limitation is usually associated with low phosphorus concentrations, which can restrict the productivity of freshwater organisms and freshwater ecosystems (Jansson 1998). There are more nutrients present in high DOC lakes than in low DOC lakes. This suggests that the limitation of phytoplankton in high DOC lakes is outweighed by the alleviation of nutrient limitation and therefore, can produce higher levels of chlorophyll.

Light water incubations in dark water mostly exhibited an increase in chlorophyll relative to dark water incubations in light water with the majority of their values negative (Figure 2). This could be due to a drastic change in environment, but previous research has shown that phytoplankton have good ability to resist shifts in the lake ecosystem (Anneville et al. 2002). As lakes get browner it is important to understand how the changing environment impacts organisms. Because lakes provide ecosystem services and therefore, are important to the economy. Understanding how they will respond to environmental change is fundamental to managing these ecosystems in a proper way.

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Tables

Table 1. UNDERC Lakes light and temperature profiles measurements performed during the summer of 2017.

Lake	Kd	Secchi depth (m)	Temperature at 0.5m (˚C)	Color (g440)	DOC (mg/L^{-1})
Bay	2.351	2.35	15.6	2.38	6.3
Bolger	1.464	1.0	22.2	2.33	5.6
Crampton	0.711	3.33	22.5	1.43	4.7
Cranberry	0.808	0.75	22.8	1.48	6.0
East Long	4.415	1.35	22.0	6.32	10.5
Hummingbird	7.795	0.8	15.1	19.74	20.5
North Gate	7.168	0.71	20.2	20.15	26.7
Paul	3.696	4.6	23.1	13.93	22.2
Peter	5.647	3.8	23.0	12.07	19.1
West Long	1.704	2.25	20.7	3.58	6.5

Table 2. Combinations of lake incubations on the UNDERC property conducted during the summer of 2017.

Source Lake	Incubation Lake
Bay	Bay
Bay	Hummingbird
Hummingbird	Hummingbird
Hummingbird	Bay
West Long	West Long
West Long	East Long
East Long	East Long
East Long	West Long
North Gate	North Gate
North Gate	Crampton
Crampton	Crampton
Crampton	North Gate
Bolger	Bolger

Bolger	Paul
Paul	Paul
Paul	Bolger
Peter	Peter
Peter	Cranberry
Cranberry	Cranberry
Cranberry	Peter

Figures

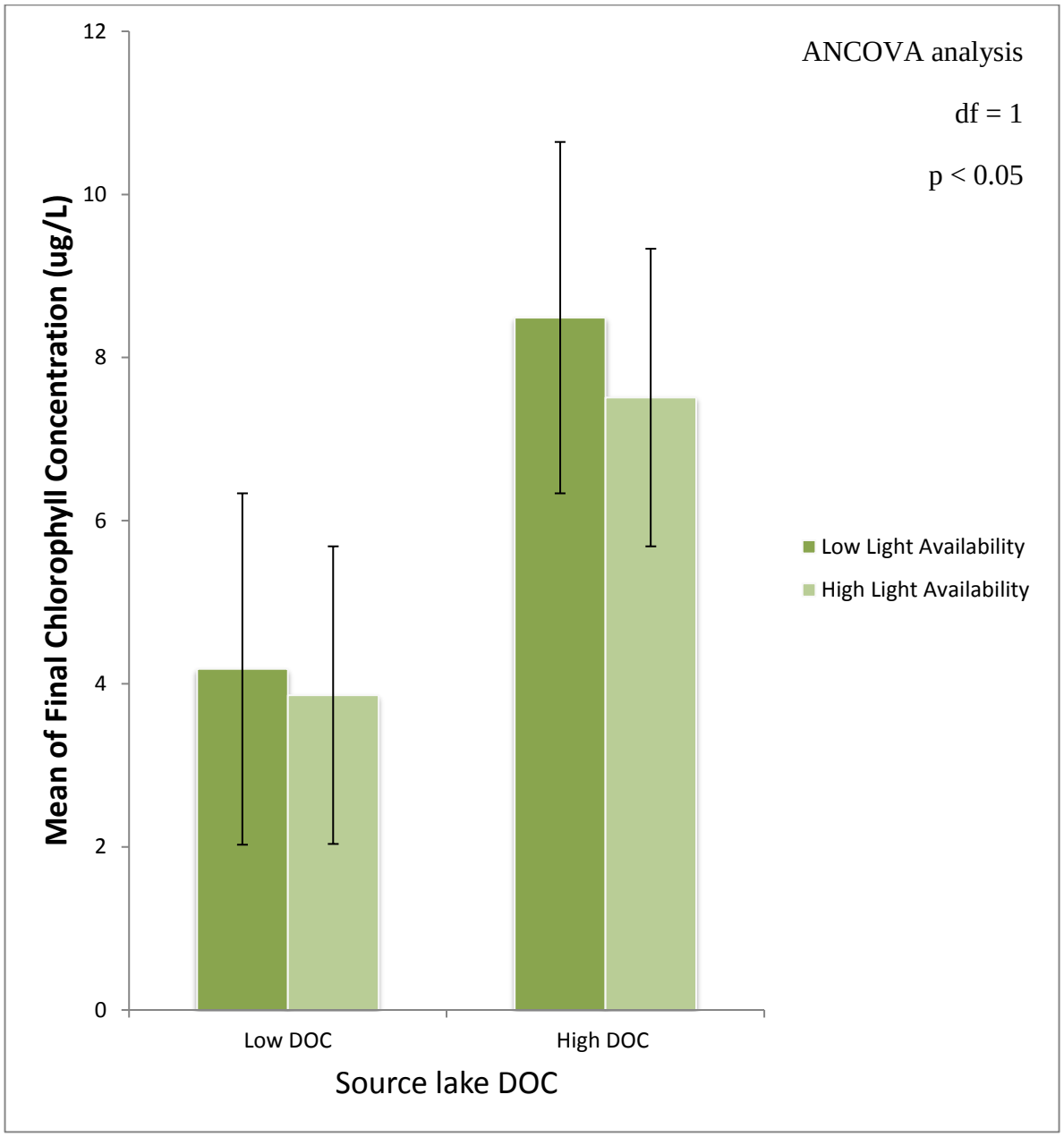

Figure 1. Mean values of Final (T = 6) Chlorophyll *a* overall concentration (ug/L) for low and high DOC lakes and with low and high light availability.

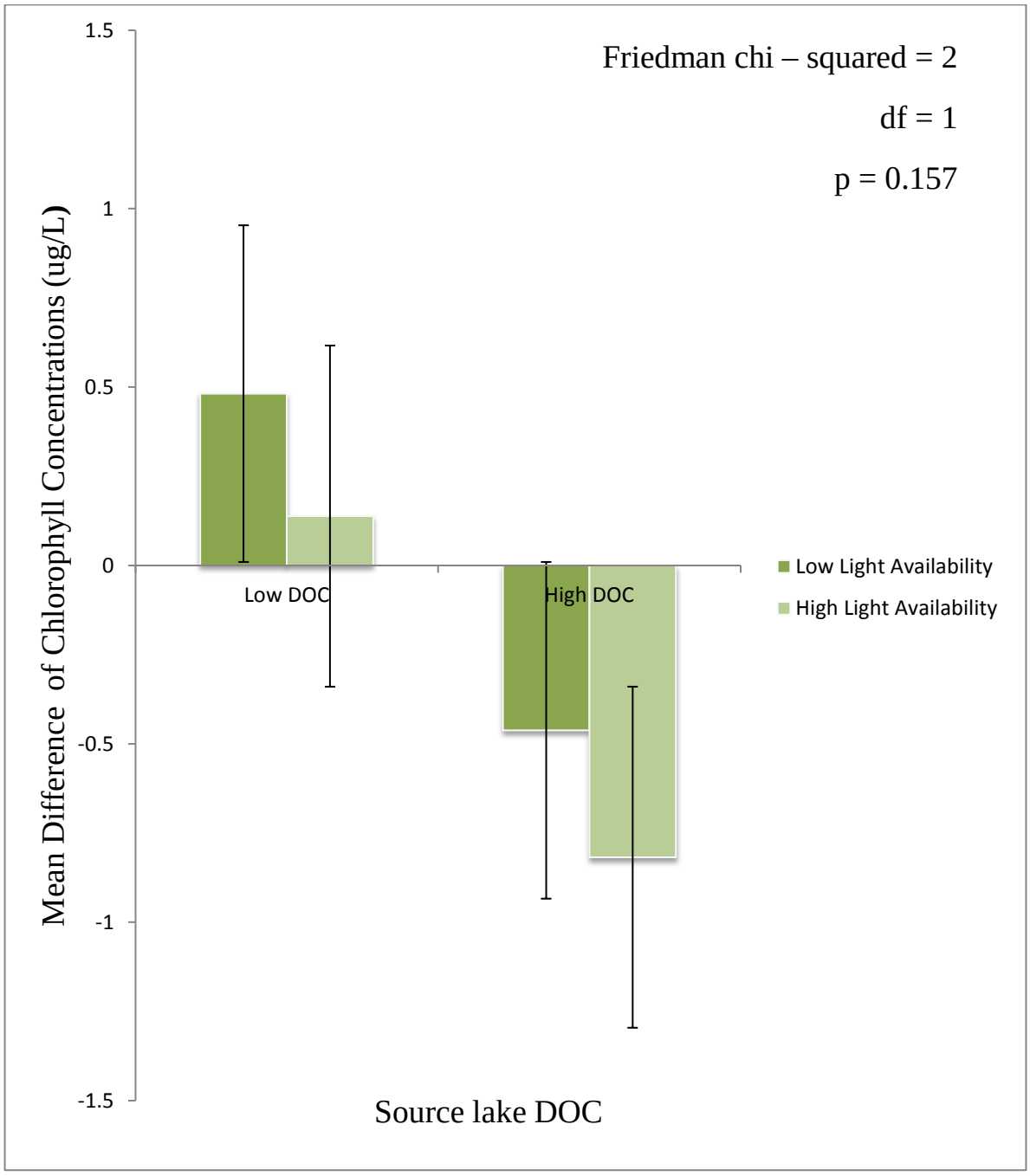

Figure 2. Mean difference between final (T=6) and initial (T=0) chlorophyll concentrations (ug/L).

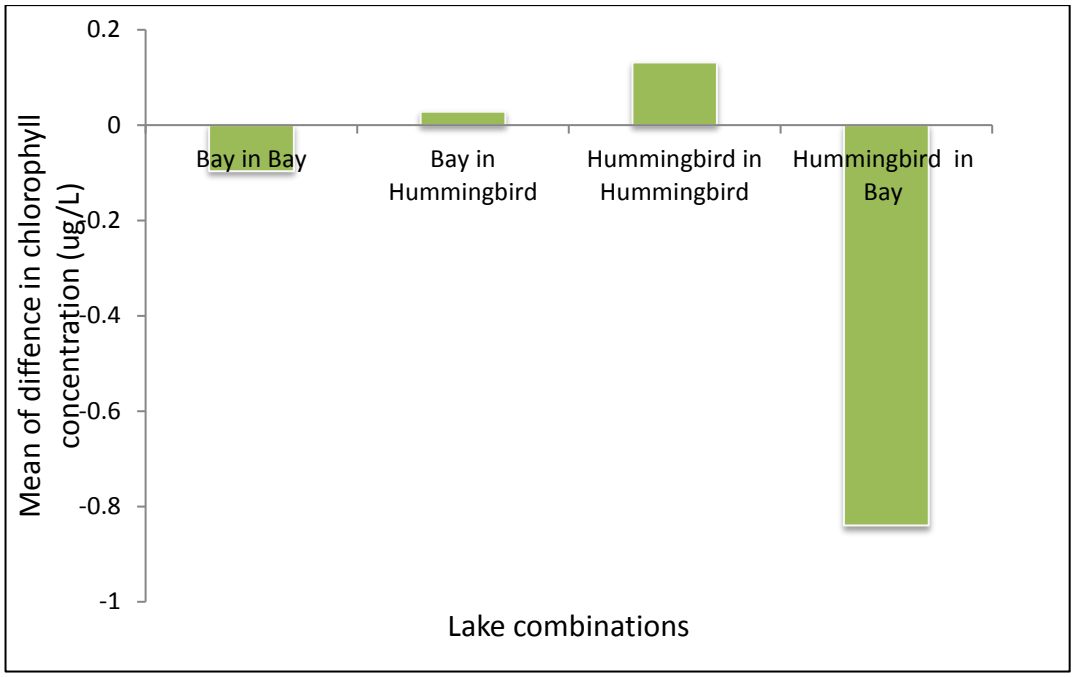

Figure 3. Mean difference of final and initial chlorophyll concentration for Bay and Hummingbird lake incubations.

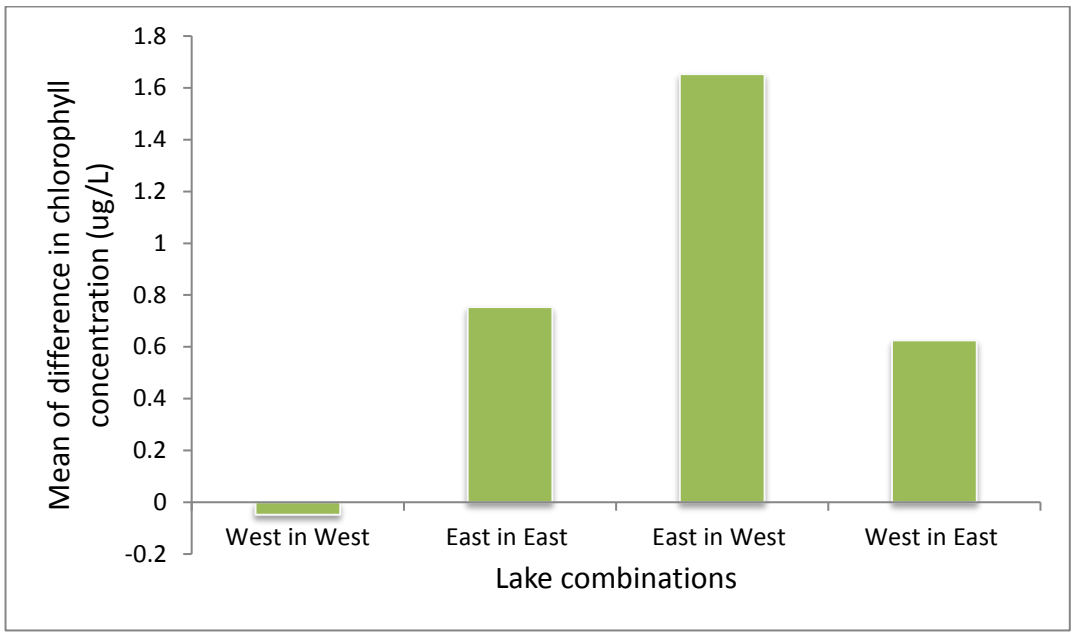

Figure 4. Mean difference of final and initial chlorophyll concentration for West Long and East Long lake incubations.

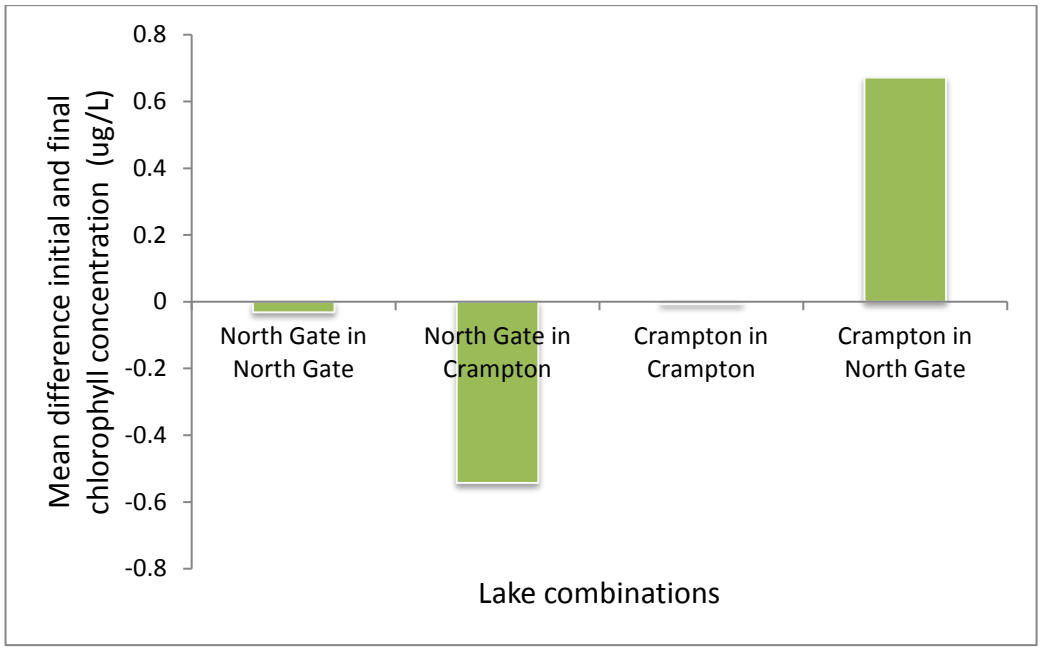

Figure 5. Mean difference of final and initial chlorophyll concentration for North Gate and Crampton lake incubations.

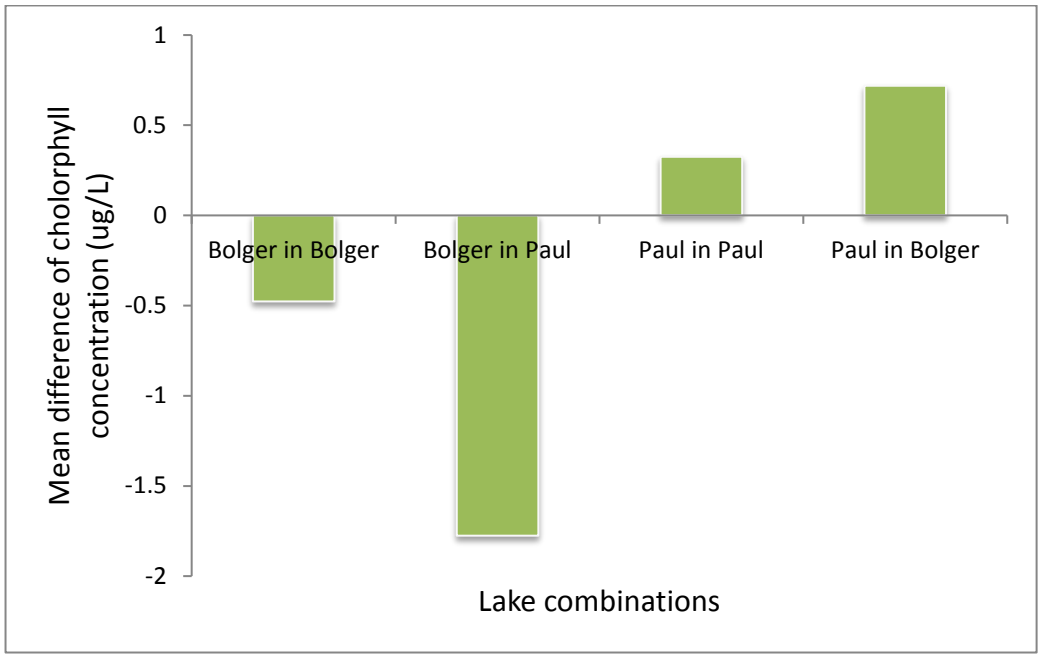

Figure 6. Mean difference of final and initial chlorophyll concentration for Bolger and Paul lake incubations.

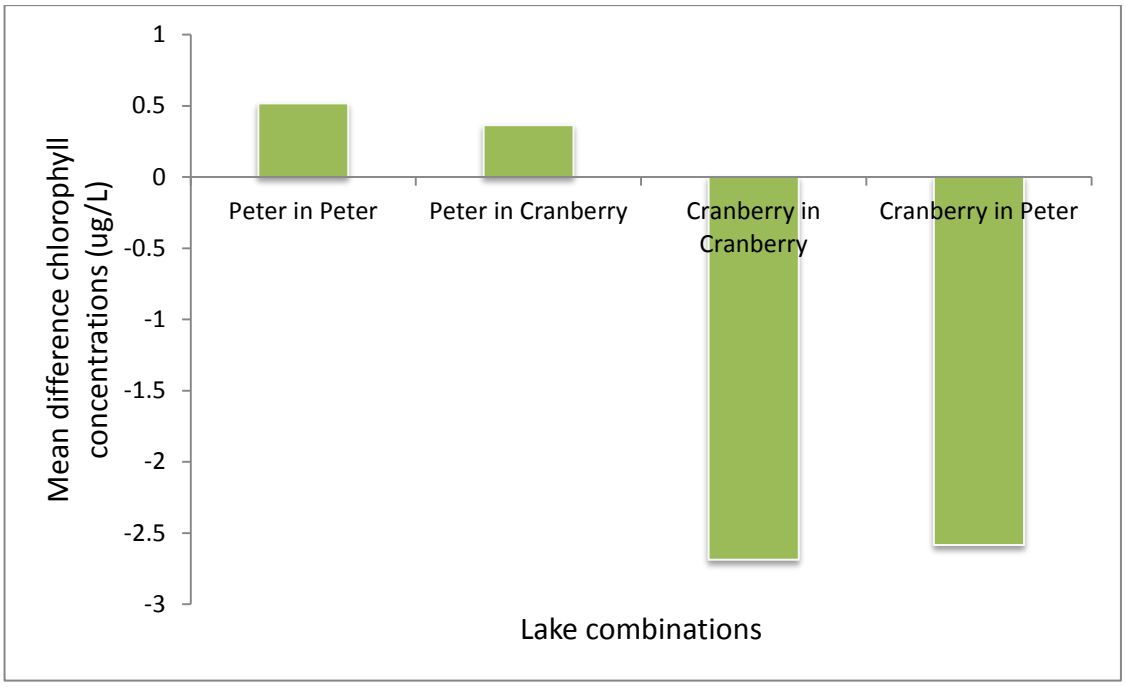

Figure 7. Mean difference of final and initial chlorophyll concentration for Peter and Cranberry lake incubations.