The Dominance of Cyanobacteria in Ponds of the Hudson Bay Lowlands and the Limiting Factors to their Growth

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Abstract: Seventy and thirty four Churchill ponds were surveyed for physical, chemical and algal data during July 2012 and July 2013, respectively. The physical results confirm that these ponds vary widely in surface area due to different pond origins. Mean pond depth values confirmed that these ponds are shallow. These ponds are high in salinity, pH, specific conductance and range from mesotrophic to oligotrophic. The shallow depths of the ponds in the Hudson Bay Lowlands favoured the growth of benthic cyanobacteria over all other algal groups, likely due to their adaptation to extreme environments. The only instance when benthic cyanobacteria were not dominant was when benthic green algae dominated in organic ponds with very small surface areas. Ponds with small surface areas offered the least-extreme environment to algae in relation to nutrient availability and UV-radiation protection.

Dedication:

I would like to dedicate this thesis to my mother and my father for their continual support and love throughout my life. I would also like to thank God, my family and close friends for their continuous support and help throughout my academic career. I would not have been here if it were not for their continual advice and support.

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1.0 Introduction:

1.1 Climate change:

The Earth is currently warming at an alarming rate due to natural (sun) and anthropogenic (greenhouse gases) influences on air surface temperature (IPCC, 2014). The Earth experienced two warming periods in the twentieth century: 1900-1940 and the late 1960s to the end of the century. Historical data of the first period of warming (1900-1940) was most consistent with models that included both solar forcing and anthropogenic forcing. Historical data of the second period of warming (late 1960s-1999) was shown to be dominated by radiative forcing caused by greenhouse gases (IPCC, 2014). The warming trend has extended into the 2000's, where the annual anthropogenic greenhouse gas emissions have increased by 10 GtCO_2eq between 2000 and 2010 (IPCC, 2014). Based on climate change models, the Earth is expected to continue to warm continuously to the year 2100 due to increasing greenhouse gas emissions caused by anthropogenic processes (IPCC, 2014).

In general, solar forcing is variable across space; areas that are exposed to sunlight continuously, like the Equator, will experience continuous heating where heating of the polar areas is much more variable (IPCC, 2014). Solar forcing's heterogeneity results in coupled regional feedbacks around the world which accurately explain the patterns seen during periods of warming such as increased evaporation, reduced cloud cover in the tropics and strong monsoons that resulted from higher volumes of water that converged into the precipitation convergence zones (Meehl et al., 2002). Greenhouse gases, which are primarily produced by humans, are more uniform in space when compared to solar forcing; this causes an increase in temperature equally over all of the regions of the world (Meehl et al., 2002). When both the greenhouse gas forcing and solar forcing are modeled together, the strongest response from global warming occurs (IPCC, 2014). These results suggest that humans are partially responsible for the warming climate which is expected to cause dramatic biological, chemical, and physical changes across the Earth's surface. The current state of the Earth needs to be documented in order to track these changes; regional variabilities and the effect of thawing organic matter in permafrost which results in increased greenhouse gas emissions have not been included in climate models (Rautio et al., 2011). Also, possible changes to the Earth's environment should be created in laboratory settings or by *in situ* experimentation in order to determine how biotic communities will respond to changing environments (IPCC, 2014). The treeline is advancing, sea ice is diminishing and temperatures are warming, along with more extreme weather events caused by climate change (IPCC, 2014). There appears to have been a pole-ward shift in species over the past 200 years due to the industrial revolution and this pattern is expected to increase (IPCC, 2014). The climate is expected to continue warming unless humans drastically shift their reliance on fossil fuels towards renewable energy (IPCC, 2014). This study will document existing algal and water chemistry characteristics in the Hudson Bay Lowlands to serve as a baseline for future climate change studies.

1.2 Arctic and subarctic regions:

Arctic and Subarctic regions are the most sensitive regions to climate change and are expected to experience the highest increases in surface air temperatures over the next century due to changes in cloud cover, snow cover, increases in atmospheric heat transport from lower latitudes, increases in atmospheric water vapour, and declining sea ice (Pithan and Mauritsenm 2014). Primarily the Arctic temperature amplification is caused by the role of diminishing sea ice feedback (Screen and Simmonds, 2010). The decline in sea ice has caused and will continue to cause a sea ice-albedo feedback where the changes in the surface albedo associated with melting ice and snow will continue to enhance the warming in the Arctic (Screen and Simmonds, 2010).

As the climate warms, a positive global feedback begins where melting permafrost from the increased air surface temperatures results in increased decomposition of thawed peat stores in Arctic regions. The thawed peat, which has been accumulating carbon for thousands of years, decomposes and greenhouse gases such as carbon dioxide and methane are released into the atmosphere, further contributing to warming the entire Earth's climate (Hamilton et al.,1994). Northern peatlands are expected to shift from a carbon sink to a carbon source with the warming climate because it is known that peatlands will release more carbon with increasing air surface temperatures (Rouse et al., 2002). In particular, the thaw ponds in the peatlands and wetlands are important landscape features of the Arctic and Subarctic because they have a large influence on the contribution to greenhouse gas emissions to the atmosphere (Laurion, 2010). This phenomenon can partly be attributed to the fact that these regions contain wetlands and peatlands which hold a considerable storage of peat carbon frozen in permafrost (Laurion, 2010). However, it is also possible that the advancing treeline may offset the increased respiration of decomposing peat and cause an overall carbon sink over the next few decades; this topic is still under debate (Zhang et al., 2013).

1.3 Study site:

The Hudson Bay Lowlands are located along the south-western shores of Hudson Bay and James Bay. This region is an extensive subarctic peatland with up to 40% of its surface area covered by shallow ponds (Bello and Smith, 1990). Ponds are water bodies that freeze completely to the sediments over winter months; this results in the absence of fish in these ponds. The study site (Figure 1) is located around the Churchill Northern Studies Center in Churchill, MB. It is comprised of three ecoregions which makes it a popular study site for researchers: the boreal forest, Subarctic tundra, and Hudson Bay (Marine) (Figure 2) (Macrae, et al., 2004). Within this region, there are three main types of ponds which differ based on their origins: organic, thermokarst and topographic (Firanski, 2000). Organic ponds are created in fens when higher elevation areas accumulate carbon faster than lower, flooded elevations (Firanski, 2000). This is due to differences in their flora and this effect creates a pond over time. Thermokarst ponds develop in peatlands when ice wedges thaw and collapse in the soil, creating a depression that fills with water (Firanski, 2000). Topographic lakes and ponds are created by depressions in the mineral soil/ parent material once caused by retreating glaciers at the end of the most recent ice age (Firanski, 2000). The Hudson Bay Lowlands study site, Churchill, MB, is in a physiographic unit which overlies Ordovician and Silurian Dolomites, bordering the west coast of Hudson Bay (Matile and Keller, 2006). The continental treeline follows the original beach ridge of the Tyrell Sea prior to isostatic uplift (Matile and Keller, 2006). The Churchill climate consists of short warm summers and long cold winters with very little transitional periods (Gray, 1987).

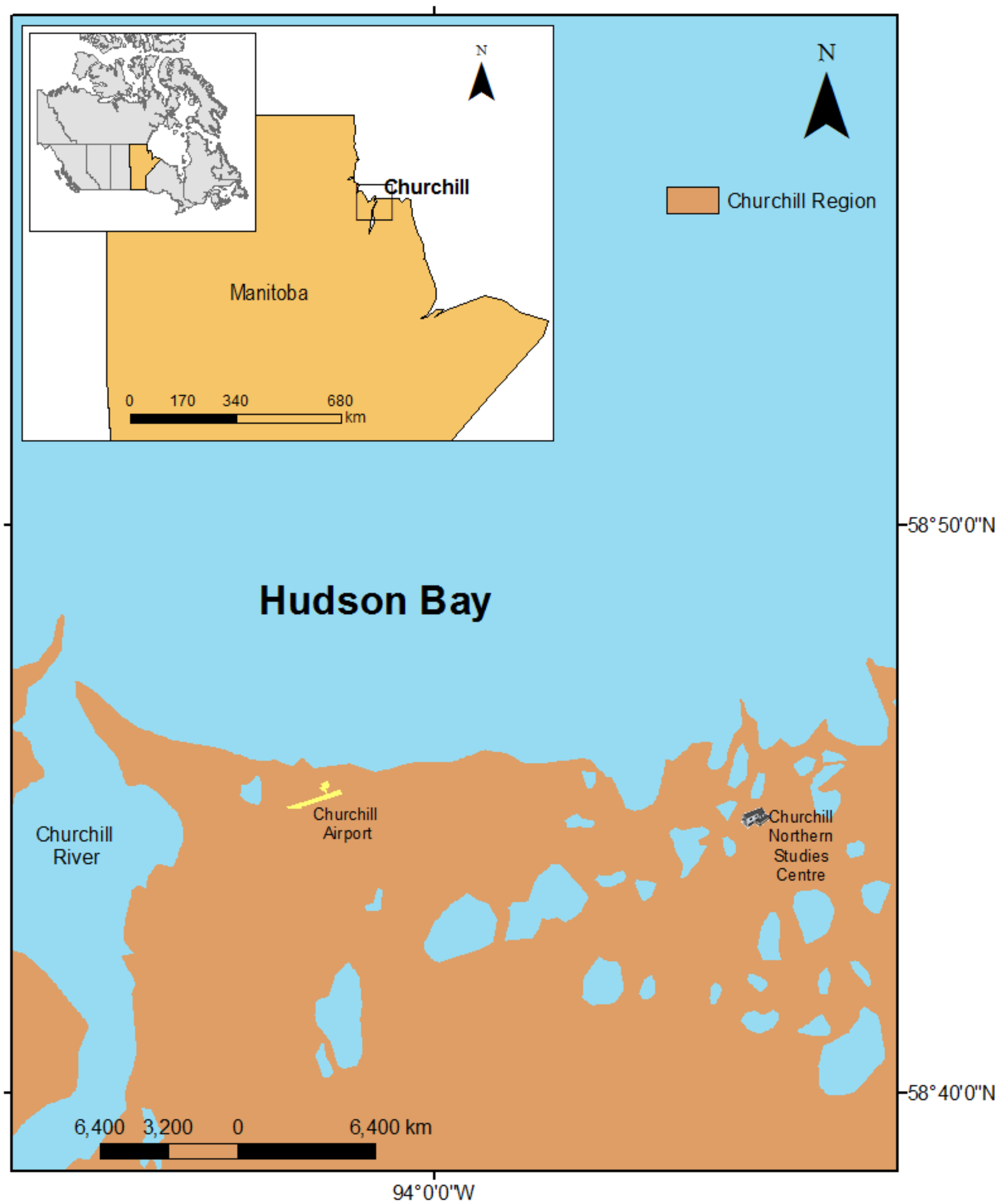


Figure 1: The study area in Churchill, MB, along the western coast of Hudson Bay. (Ghunowa, 2015).

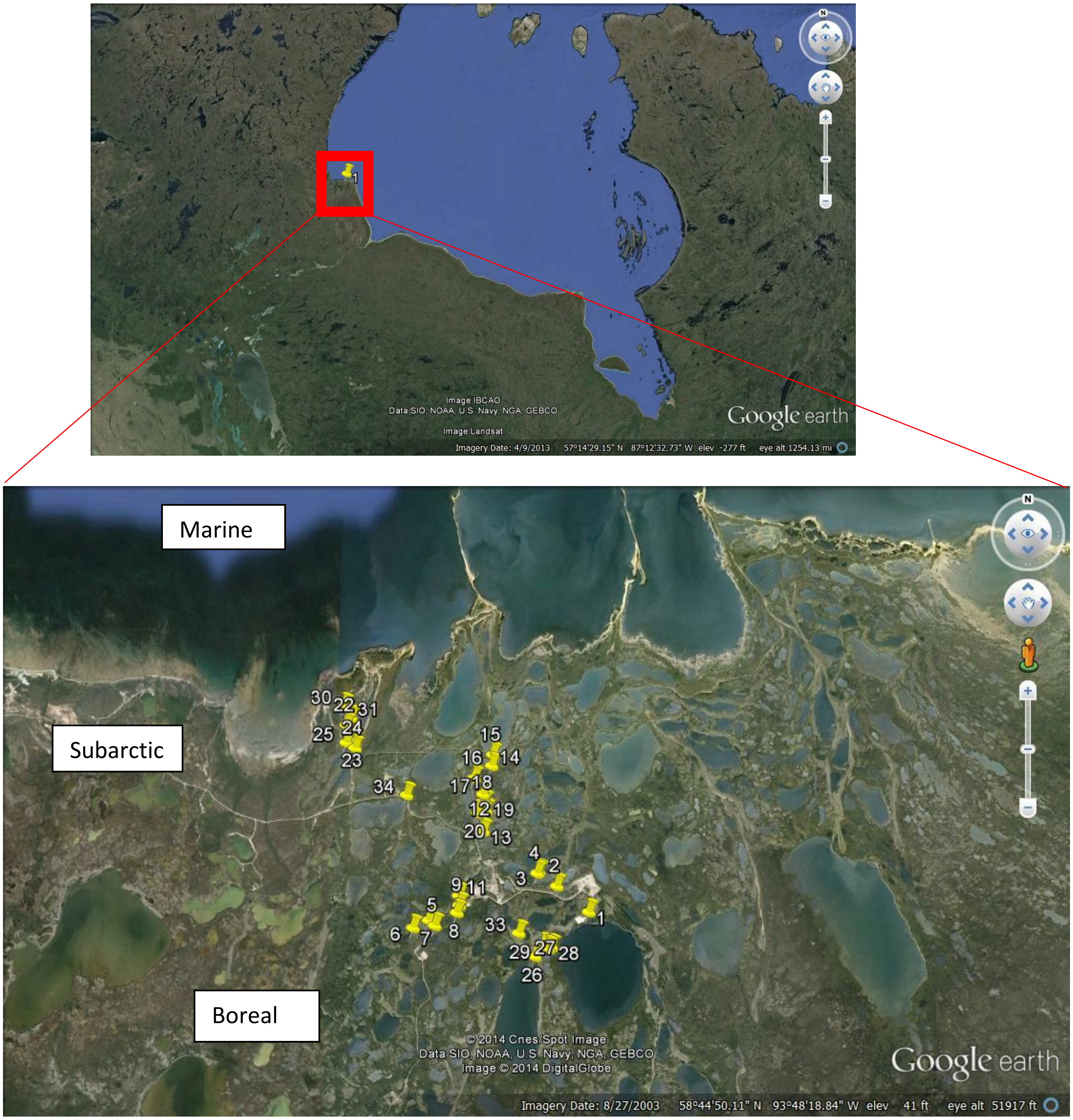


Figure 2: GPS points of ponds sampled in the 2013 physical, chemical and spectral survey (Google Earth)

1.4 Previous work on Churchill, MB algae:

A phytoplankton survey in the early 1980's on the ponds in the Cape Merry and Goose Creek areas in Churchill, MB (Figure 3) produced cell counts which showed that phytoplankton in these ponds were dominated by: Bacillariphyceae (diatoms) at ~38.5%, Chlorophyta (green algae) at ~32.2%, and Cyanophyta (blue-green algae) at ~6.5% (Gray, 1987). This 1980 and 1981 study on the phytoplankton in Rock Bluff and Goose Creek ponds determined that diatoms dominate in the water columns of ponds found in these areas (Gray, 1987). Furthermore, nutrient additions to these ponds showed that phosphorous was readily scavenged by the calcium from the calcium carbonate deposits in the pond sediments; phosphorous had to be repeatedly added to the water column for any shift in phytoplankton biomass to occur (Gray, 1987). In the same study, cyanobacteria biomass peaked in late June/ early July, diatoms dominated in most of the sampled ponds during the majority of the study period and green algae dominated in all of the ponds during August. The study that Gray (1987) conducted did not include benthic algal analyses.

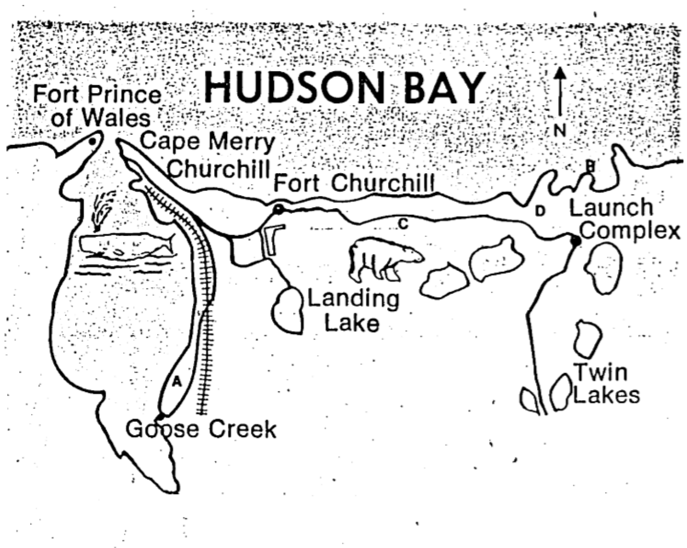


Figure 3: Study site for the phytoplankton survey in 1980 and 1981. (Gray, 1987).

The pond origin may influence the algal composition due to differences in surrounding land cover types, nutrient availability and physical characteristics. Organic and thermokarst ponds are likely to have higher productivity rates per unit area when compared to topographic ponds due to the lower nutrient supply within this latter pond class; this has been deduced from the fact that organic ponds begin to take in carbon dioxide during the summer months while topographic ponds continue to evade carbon dioxide from the ponds after the spring melt period (Macrae et al., 2004). The regional landscape is rich in calcium and some ponds have a white bottom, which may be marl or calcium precipitate, potentially caused by high photosynthesis levels during the summer (Wetzel and Likens, 1991); this can act as an important sink for phosphorous where calcium sediments readily precipitate with phosphorous available in the water column (Gray, 1987).

1.5 Types of primary producers:

Phytoplankton (pelagic algae) are free-floating algae that exist in the water column while benthic algae are those algae that attach themselves to the bottom sediments or substrate of the pond. Phytoplankton tend to be the preferred food for zooplankton when they are available; in environments like the Hudson Bay Lowlands, benthic algae are the main food source for zooplankton due to the lack of phytoplankton present (Mariash et al., 2011). In these shallow Subarctic ponds, benthic algae tend to out-compete phytoplankton due to a number of factors including: shallow mean pond depths (Appendix B), high UV radiation exposure, preferred zooplankton grazing of pelagic over benthic algae (Rautio and Vincent, 2006), high sediment nutrient concentrations, low water column nutrient concentrations, and the potential for ponds to experience drought (Rautio et al., 2011). Benthic microbial mats play an important role in the food chain and are partly responsible for the high zooplankton biomass usually found in these shallow Subarctic ponds; without the presence of benthic algae, zooplankton populations of this size would not be able to sustain themselves on the small number of phytoplankton alone (Rautio and Vincent, 2006). Depending on the grazing strategy of the zooplankton species, benthic mats can be directly grazed or grazed only during re-suspension processes. Benthic algae are usually found in shallow ponds and phytoplankton typically low in biomass because they require enough water depth to be protected from zooplankton grazing, harmful ultraviolet radiation (UVR), increased nutrient availability due to longer sedimentation rates and larger currents, potential thermoclines and sufficient storage of carbon dioxide in the water column to survive (Rautio et al., 2011). Zooplankton found in Churchill, MB included a copepod predator, *Heterocope septentrionalis*, four members of the genus

Daphnia (Cladocera) and 5 members of the genus *Diaptomus* (Copepod) (Good, 1982). It was found that the presence of the copepod predator eliminated 3 of the 4 members of *Daphnia* in the study ponds (Good, 1982).

1.5.1 Cyanobacteria:

Cyanobacteria (or blue-green algae) are a photosynthetic group of bacteria that have existed since the Precambrian period, roughly 3,000 million years ago (Likens and Vincent, 2009). They are a group of gram-negative bacteria that have the ability to photosynthesize (Likens and Vincent, 2009). They existed during atmospheric conditions that had little to no ozone layer (no UV protection) and produced a large amount of oxygen which gave the breath of life to many other organisms during what is known as "The Great Oxygenation Event" (Balskus et al., 2011). This explains why Cyanobacteria produce pigments which act as sunscreens by absorbing UV radiation. These pigments, which include Mycosporine-like amino acids (MAAs) and scytonemin, act as sunscreens and play a role in survival during drought and/or heat stress (Balskus et al., 2011). It is known that cyanobacteria tend to dominate in extreme environments due to their evolutionary advantages under drought, heat and saline stress (Balskus et al., 2011). Also, many cyanobacteria can fix atmospheric nitrogen which makes it a non-limiting nutrient for many cyanobacterial species (Singh, 2009). For these cyanobacteria, phosphorous and iron are the main limiting nutrients. Cyanobacteria also do well in ponds that have low carbon dioxide concentrations because of their ability to take carbon from calcium bicarbonate (Merz, 1992); although, they are not unique in this ability as diatoms are also able to take carbon from calcium bicarbonate (Milligan and Morel, 2002).

Many cyanobacteria produce cyanotoxins that are released during cell damage or death, Cyanotoxins can be potent neurotoxins, hepatotoxins, cytotoxins, and endotoxins (Berman-Frank et al., 2003). All cyanobacteria are believed to release lipopolysaccharides and BMAAs during stress or damage to the benthic mat; these lipopolysaccharides and BMAAs are not as potent as the other cyanotoxins but still have allelopathic effects (Chorus and Bartram, 1999). Two generea of cyanobacteria that are known to produce cyanotoxins have been found in the Churchill, MB study ponds: *Planktothrix* (Oscillatoria) and *Anabaena* (Gray, 1987).

Cyanobacteria tend to dominate in environments experiencing low silica supply and low nitrogen: phosphorous ratios (Sommer, 1996). Cyanobacteria are not as limited by silica as diatoms are or as limited by nitrogen as green algae are, which is why they do so well in low silica and nitrogen environments (Sommer, 1996). Overall, benthic cyanobacteria are well adapted to extreme environments. Benthic cyanobacteria tend to dominate in pond environments that have low carbon dioxide concentrations (Miyachi et al., 2003), high availability of phosphorus in the sediments or water (Sommer, 1996) and when stressors such as droughts, heat, high salinity or high amounts of incoming UV radiation occur (Balskus et al., 2011).

1.5.2 Green algae:

Green algae have been shown to have originated following a primary endosymbiotic event where a eukaryotic cell engulfed a photosynthetic cyanobacterium-like prokaryote; the prokaryote eventually became integrated into the cell, evolving into the membrane-bound organelle, the mitochondria (Keeling, 2010). Both green algae and diatoms can also synthesize the UV-absorbing pigments, MAAs (Karsten et al., 2007). Similar to cyanobacteria, green algae and diatoms also increase their production of carotenoid pigments as photo-protective mechanisms (Karsten et al., 2007). There are a group of calcareous green algae whose skeletons contain calcium, calcium carbonate or limestone; making them able to grow in environments with high calcium, medium light and low levels of other nutrients (Granier, 2012). Green algae are known to be dominant in environments with low silica supply and high nitrogen: phosphorous ratios (Sommer, 1996). In environments with non-limiting silica, diatoms out compete green algae with sufficient nutrient availability to build their cell walls (Sommer, 1996).

1.5.3 Diatoms:

Diatoms are a major group of algae, one of the most common types of phytoplankton and most often unicellular (Armbrust, 2009). Diatoms arose after green algae, when a second symbiosis occurred in which a different eukaryotic heterotroph engulfed a red algae (Armburst, 2009). Their attributes reflect this union between a host eukaryote and a photosynthetic red algae. They have an animal-like ability to obtain energy from the breakdown of fat (Lewin, 1953) and the plant-like ability to generate metabolic intermediates from the breakdown; this allows them to survive long periods of darkness as experienced in deep waters found in the Arctic (Armburst, 2009).

Diatoms' two-part cell walls are made of silica which explains why silica is a major limiting nutrient for them (Milligan and Morel, 2002). The silicate wall gives the diatoms an ecological advantage because they require less energy to construct compared to cell walls constructed of organic carbon. This silica-containing skeleton also acts as a UV filter, protects diatoms from zooplankton grazing, acts as a ballast to control water column position, and acts as a pH buffering site for the enzymatic catalyzation of bicarbonate into carbon dioxide (Milligan and Morel, 2002). Silicate is produced inside the cell, precipitated from supersaturated $Si(OH)_3$ and can be used to remove parasites from the diatom (Raven and Waite, 2004). During evolution, the silicification of diatoms' cell walls was most likely used first as a means to regulate their sinking rates (Raven and Waite, 2004). Diatoms have a high growth rate, making them an *r*-selected species, where they take advantage of favorable conditions by rapidly reproducing; after nutrients are depleted, the diatoms sink to sediments and enter a resting stage (Smetacek, 1985). Diatoms with small surface areas tend to remain suspended in the water column during light winds; their small surface areas helps keep them suspended (Smetacek, 1985). They tend to dominate in phosphorous-limited environments that have high silica: phosphorous ratios (Sommer, 1996). Under high UV stress, diatoms are known to experience a deformation and enlargement of their cells; this phenomenon was observed in a previous study on ponds found near

Churchill, MB (Macrae, 1999). A few diatom species can also produce MAAs which supports their survival in environments with high UVR exposure, drought conditions, salinity stress and/or thermal stress (Lotter et al., 2010). Diatoms dominate in medium light levels when silica is non-limiting; different types of diatoms dominate in phosphorous-limited versus nitrogen-limited environments (Sommer, 1996). Large pelagic diatoms do not do well in lakes with their heavy layers; they rely on wind to remain suspended; some benthic diatoms can glide and some exhibit some phototaxis (Smetacek, 1985).

1.5.4 Symbioses between algal groups:

Intracellular and extracellular symbioses have been observed in select cyanobacteria and diatom species. Select diatom species have cyanobacteria that fix nitrogen inside of their cells in order to obtain nitrogen during nitrogen limitation (Janson, 2003). It has also been observed that diatoms can be trapped inside spheres formed by cyanobacteria which act as refuge for the diatoms from harmful UV radiation, grazing, protection from physical disturbances and a substratum for mobility (Prema and Anand, 2012). Diatoms are single celled and non-motile (some benthic diatoms can glide) and rely on cyanobacterial mat structures for residency in benthic environments (Prema and Anand, 2012). Green algae are also known to create symbioses with cyanobacteria and their presence may depend on benthic cyanobacteria concentrations (Jungblut et al., 2014).

1.6 Nutrients, cations and dissolved organic carbon:

In order to determine which nutrients are limiting to the major groups of benthic and pelagic algae in the Churchill, MB ponds, nitrogen and phosphorus samples were taken during field collections. Major cations (Ca, Mg, Na, K), dissolved organic carbon (DOC) and $SUVA_{254}$ (the DOC concentration normalized to 254 nm) (Weishaar et al., 2003) were also measured in order to estimate their influence on the abundance of benthic and pelagic algae.

1.6.1 Phosphorus:

Phosphorus is a part of DNA, RNA and ATP which are all vital constituents in cells. Phosphorus is an important, abundant (though typically limiting) nutrient that enters freshwater systems through precipitation, inflows, sediments or dry fallout (Vollenweider, 1979). Phosphorus may be removed from the water via sedimentation or through the outflow. Phosphorus is an essential nutrient for plant and animal growth; fresh waters are often limited by phosphorus (Schindler, 1990). It has been observed in previous studies that the ponds found near the Churchill Northern Studies Center are phosphorus limited due to high removal rates by calcareous sediments (Gray, 1987).

1.6.2 Nitrogen:

Nitrogen, just like phosphorus, is an essential nutrient for plant and animal growth (Hellstrom, 1996). Freshwater lakes with very high phosphorus concentrations tend to have cyanobacterial blooms due to cyanobacteria's nitrogen fixing capabilities; these lakes tend to be limited by nitrogen which explains why nitrogen fixing organisms dominate in these environments (Schindler, 1990). Nitrogen is abundantly available in natural environments via nitrogen fixing organisms, such as cyanobacteria, that assimilate nitrogen from the atmosphere (Singh, 2009). The majority of the atmosphere is made of nitrogen; nitrogenase enzymes in nitrogen-fixing organisms allows nitrogen to become available for plant growth (Singh, 2009). Nitrogen is found in all living organisms' proteins and nucleic acids (Jahn, et al., 2005). Since Churchill, MB ponds were previously found to be phosphorus limited (Gray, 1987), nitrogen was not expected to be a limiting nutrient in this study.

1.6.3 Major cations:

Cations are positively charged ions that are created when a metal ion loses electrons. Cations readily absorb to negatively charged anions such as phosphorus. It is known that the Hudson Bay Lowlands exist on a Paleozoic limestone bedrock (Gray, 1987) which produces calcium-rich pond sediments. This hard water ponds in Churchill, MB ponds are expected to be Ca-rich due to their parent material (Macrae, 1998). Calcium's binding capacity of phosphorus increases at higher pH values, similar to pH values in Churchill, MB (Gray, 1987), when calcite and apatite begin to form (Boström et al., 1982). The major cations will influence the bio-availability of phosphorus in Hudson Bay Lowlands ponds (Gray, 1987).

1.6.4 Dissolved organic carbon and $SUVA_{254}$:

DOC is a measurement of the amount of organic carbon which can be passed through a 0.45 µm filter (Krauskopf and Bird, 1995). $SUVA_{254}$ is the absorbance of UV light at 254 nm wavelength normalized by dissolved organic carbon (Weishaar et al., 2003). $SUVA_{254}$ can help determine DOC origin because it reflects the aromaticity of the DOC molecules; high aromaticity molecules are typically from the catchment (allochthonus) and low aromaticity molecules are typically from the pond (autochthonus). DOC that is high in aromaticity, can protect algae from UV radiation (Bertilsson and Tranvik, 2000). Dissolved organic matter (of which DOC is a component) is also an important source of organically-bound nutrients to algae; algae obtain nutrients from the nitrogen and phosphorus associated with the aromatic portion of DOC (Klug, 2005). Overall, high concentrations of DOC and $SUVA_{254}$ are beneficial to algal growth due to their UV protection and nutrient-binding characteristics in shallow waters; in deep waters shading can occur.

1.6.5 pH, dissolved oxygen, salinity and specific conductance:

In order to determine any other limiting factors on algal growth, the pH, dissolved oxygen concentration, salinity, and specific conductance of the pond water were measured. The pH is known to be basic in Churchill, MB as seen in previous studies: pH was 8.3 (Macrae, 1998), 8.1 +/- 0.1 (Rautio et al., 2011), 8.76 +/- 0.33 (White, 2011) and a range of 7.15-9.21 (Gray, 1987) in Churchill, MB. It is expected that the ponds will have a relatively high specific conductance caused by high concentrations of calcium, magnesium and sodium cations. Since these ponds are very shallow (Appendix B) and light penetrates to the benthic mat in almost all organic ponds, it is expected that the dissolved oxygen percentage will be high throughout the water column due to high rates of photosynthesis and mixing.

1.7 Study objectives:

The purpose of this study was to survey ponds found in the Hudson Bay Lowlands for their water chemistry, physical characteristics and benthic and pelagic algal community composition. This was the first study to survey Hudson Bay Lowland ponds for benthic algae and the results of this study will fill a gap in knowledge of algal distribution in the circumpolar Arctic. This study determined how pond characteristics and water chemistry influenced distributions of benthic and pelagic algae found in the Hudson Bay Lowlands.

The expected increases in air temperature, nutrient supply, and lower duration of ice-cover caused by the warming climate may favour planktonic production over the phytobenthos (Rautio et al., 2011). Increases in air temperatures are expected to degrade permafrost and lead to an increase in the transport of organic nutrients from land to water leading to eutrophication, increased turbidity of ponds and lower UVR exposure (Rautio et al., 2011). The oligotrophic water column would be enriched with nutrients and the phytoplankton would benefit in the increase in nutrient availability (Rautio et al., 2011). Increases in the quality and quantity of dissolved organic matter are likely to lower light penetration through the water column, resulting in an increase in microbial and phytoplankton activity (Rautio et al., 2011; Rautio and Vincent, 2006). During periods of reduced ice cover, phytoplankton tend to produce higher levels of photoprotective pigments in order to mitigate the effects of a decrease in water volume; though ponds are likely to have reduced volume and are more likely from increased evaporation rates which may negatively impact phytoplankton communities (Bonilla et al., 2009). In order to understand how climate change may affect algal communities in the Hudson Bay Lowlands, the current distribution of benthic algae and phytoplankton in the thaw ponds have been documented along with multiple pond water chemistry characteristics that have the potential to limit benthic or pelagic algal distribution. This study focused on which pond characteristics are the most influential in determining pelagic or benthic dominance in ponds found in the Hudson Bay Lowlands.

2.0 Methods

2.1 2012 field methodologies:

A preliminary assessment of the Churchill, MB research area was conducted in July 2012 in order to determine the physical and chemical characteristics of ponds in the Hudson Bay Lowlands. Seventy ponds were chosen within a 5 km radius of the Churchill Northern Studies Centre to maximize the range of pond surface areas and surrounding catchment characteristics. Where logistically possible, previously sampled ponds (Macrae et al., 2004) were sampled in order to build upon previous research. Each pond was sampled at one location near-shore depending on the accessibility and adequate water depth. If the pond had not been previously sampled, a name was created for it.

All glassware and water sample containers were acid soaked for 24hrs and washed with dilute (10%) HCl and rinsed 7 to 10 times with MilliQ ultrapure-grade water (Millipore). The glass fiber filters that were to be used in the field and in the laboratory were wrapped in tin foil, combusted in a muffle furnace at 450°C for 4 hours, dried in a desiccator and weighed before being placed into sealed polyethylene bags for transportation to the field.

Selected ponds were sampled for a variety of water characteristics. After a designated sampling site was selected, the date, time (Central Standard; Z-06), GPS coordinates, ruler water depth (+/- 0.5 cm), water surface temperature (+/- 0.1°C) (Fluke 62 mini infrared thermometer), air temperature (+/- 0.1°C), shoulder height wind speed (0.1 m/s) (Kestrel 3000) and a written description (riparian vegetation, color of sediments) of the sampling site was recorded. The ponds were sampled with a 5 cm submerged YSI multi-parameter 600QS probe in order to determine the pH (+/- 0.2 standard unit), dissolved oxygen concentration (DO) (+/- 0.2 ppm), salinity (+/- 0.1 ppt) and specific conductance (SC) (+/- 0.5% of reading + 0.001 mS/cm). The ponds were sampled between 9am and 4pm in order to ensure reliable pH and DO values were obtained due to the high variability in pH and DO caused by diurnal and windspeed changes, respectively. All water containers were rinsed at least three times with sample water before filling. Water samples were collected using a 1 L HDPE bottle that was submerged 10 cm underneath the water surface of the pond. A hand vacuum pumped flask was used with a graduated funnel with 47mm glass microfiber filters with a pore size of 0.7 µm (Whatman GF/F) to filter a total 500 mL of pond water in the field immediately following sampling; 2 filters each filtered 250 mL. The filtered water was poured into three 60 mL Nalgene plastic sample bottles and the two resulting filters were wrapped in tin foil and then placed into separate Ziplock© bags. The samples were stored and transported in the dark in a cooler containing ice during hot summer days to limit degradation. The water samples and filters were frozen within six hours of collection when the researchers returned to the Churchill Northern Studies Center from the field. Frozen samples were then transported with ice packs to York University where they were kept frozen until analysis. The filtered water samples were thawed in the dark at room temperature for 12 hours before analysis.

A Handheld JAZ (Ocean Optics) Spectroradiometer was used to take 2 sets of hyper-spectral reflectance readings in the 325 to 1075 nm waveband in 1 nm intervals at each sample location in order to determine if benthic algal data correlated with hyper-spectral reflectance readings. The first reading was comprised of the combined water column and sediments, while the second measured just the water column using a white 6 mm acrylic plate target (~100% reflectance of incoming light) submerged 10 cm below the water surface where water depths permitted. The actual water depth was recorded at all locations. Before each surface reflectance reading was taken, a dark reading (with the cap covering the fiber optic cable) and an incident radiation reading (using a standard white reflectance target with ~ 100% reflectance) were taken. This was done in order to remove noise from the baseline (dark reading) and provide a reference irradiance reading for the calculation of reflectance from the surface. The optical field of view was 10^0, providing a sampled target area of 10 cm^2 at a distance of 20 cm. A laser feature was used to confirm the focal point of the spectroradiometer. The detector was centered over the mid-point of the target using a custom designed extension arm so readings could be taken from shore without unduly disturbing the sediments. The data obtained from the Spectroradiometer© and more detailed methods appear in Ghunowa (2015).

2.2 2013 field methodologies:

A subset of 34 ponds were selected from the July 2012 dataset of 75 ponds to obtain as wide a range in chlorophyll a, pond surface area, dissolved organic carbon (DOC) and total suspended solids (TSS) values. For each of the 34 ponds, four samples were taken from shore at of each of the compass cardinal axis directions in order to incorporate spatial variability within ponds.

All glassware and water sample containers were acid soaked for 24hrs and washed with dilute (10%) HCl and rinsed 7 to 10 times with MilliQ ultrapure-grade water (Millipore). The glass fiber filters that were to be used in the field or in the laboratory were combusted in a muffle furnace at 450°C for 24 hours, decanted and weighed before being placed into bags for transportation in the field. All water containers were rinsed at least three times with the sample before filling. Water samples were collected 5-10 cm below the surface of the water. The Aquapen (Photon Systems Inc) and YSI-multiparameter probe were calibrated using deionized water before leaving for fieldwork each day from the Churchill Northern Studies Center.

When the team reached a sampling site, the GPS coordinates, weather, time, riparian vegetation, photos and other descriptive recordings were taken before all the measurements were collected. Spectral reflectance measurements were always taken first by the ASD's Fieldspec Handheld 2 VNIR Spectroradiometer© in order to ensure that the water column or sediments were not disturbed for the spectral data. YSI multi-parameter probe and water column chlorophyll fluorescence (AquaPen) readings were taken after the spectral reflectance at approximately the same time, for water chemistry at 10 cm depths and algal composition of the water column at 10 cm depths, respectively. Finally, benthic chlorophyll fluorescence (BenthoTorch) readings were taken to collect chlorophyll a concentrations (ug/cm^2) of benthic green algae, cyanobacteria and diatoms in the sampled ponds. The

Benthotorch and water depth readings were taken last at the sediment-water column interface (which caused sediments to become re-suspended). The laser pointer on the Handheld 2 Portable Spectroradiometer© was used to identify the exact sampling location before measurement and the Benthotorch was placed directly at that location afterwards.

2.2.1 Spectral reflectance:

A Handheld 2 Portable Spectroradiometer (ASD Inc.) was used to take 2 sets of hyper-spectral reflectance readings in the 325 to 1075 nm waveband in 1 nm intervals at each sample location: first of the combined water column and sediments; second of just the water column using a white 6 mm acrylic plate target (~100% reflectance of incoming light) submerged 10 cm below the water surface where water depths permitted. The 2013 spectral reflectance measurements were taken with the same procedure as 2012 (Section 2.1).

2.2.2 Pelagic algae:

In order to obtain pelagic quantum yield and instantaneous fluorescence data for cyanobacteria and green algae, the Z985 AquaPen© was utilized. The Z985 AquaPen© is a fluorometric device that measures the quantum yield (Qy) and instantaneous fluorescence(Ft).. The Aquapen© was toggled between 450 nm (green algae) and 620 nm (cyanobacteria) in order to collect: Ft, and Qy data. Aquapen sample water was obtained using a syringe device with screen mesh sheet over it (to prevent sediment from entering the sample) approximately 10 cm below the water's surface. The water was then transferred to 4mL polymethyl methacrylate (PMMA) plastic cuvettes and analyzed for quantum yield and instantaneous fluorescence at 680 nm and 720 nm. Instantaneous fluorescence (Ft) is an indicator of the amount of chlorophyll *a* fluorescence immediately after a sample is taken (PSI, 2015); which provides the rate of linear electron transport (indicating overall photosynthesis) (Genty and Baker, 1989). Quantum yield (Qy) is a measure of the photosystem 2 efficiency (PSI, 2015); it expresses photosynthesis performance (Genty and Baker, 1989).

The remaining portion of the water sample was first placed in a plastic water container in order to be used for a YSI multi-parameter probe readings in the field. The remaining water sample was kept cool in a 500mL sample container until processing later each evening. When the samples returned to the Churchill Northern Studies Center that evening, the 500mL samples were filtered through a 47mm circular glass microfiber filter with a 0.7 µm pore size. The filters were placed in bags and frozen immediately after filtering. The filtered water was placed into acid-washed 60mL plastic bottles and frozen until further analyses.

2.2.3 Benthic algae:

At every sample location, chlorophyll fluorescence readings of benthic algae were taken using a BenthoTorch© (Moldenke Inc) probe. The Benthotorch is a device that measures the benthic algae at the sediment-water interface and was placed directly on the sediment at each sample location to obtain triplicate readings of the total concentration of benthic algae, the concentration of green algae, cyanobacteria and diatoms groups individually, in µg [chl-*a*]/cm^2; it also collected the co-ordinates and reflectance of each sample. The Benthotorch was calibrated with factory settings before being shipped to the Research Center. The rubber shroud of the BenthoTorch was placed directly on the pond sediments during sample collection to exclude extraneous light.

2.3 Spatial analyses:

Mean water depths were determined for each of the 75 ponds based on diurnal temperature fluctuations of the sample pond compared with a reference pond of known mean water depth (Rouse et al, 1997). Submersible Hobo© temperature loggers were logged at 5 min intervals and placed in the reference pond (Some Pond at approximately 1m depth) and study ponds for minimum 24hr periods in order to determine their range (max-min) water temperature over daily heating and cooling cycles. Some Pond was chosen as the reference pond because its bathymetry was sampled in detail and daily water levels could be easily measured as a result of its close proximity to the Churchill Northern Studies

Center. The bathymetry of Some Pond was found by taking depth measurements every 10m along N-S transects that were spaced 10m E-W across the pond for a total sample size of 160 depth readings. The average depth of all the measurements was used for the mean water depth of Some Pond for that day which was adjusted daily depending on water level fluctuations recorded by a ruler anchored in the frozen sediments.   The mean depth of each pond was calculated from;

$$D_{avg}(x) = (\Delta T_{ref} / \Delta T_{x}) * D_{avg}(ref) \qquad (1)$$

Where $D_{avg}(x)$ is the average depth of Pond “x”, $D_{avg}(ref)$ is the average depth of Some Pond, Δt_{ref} is the range in temperature in the reference pond and ΔT_x is the range in temperature in the sample pond over the same 24-hour sampling period. Pond water volume can be computed from the product of pond area and mean depth.

2.3.1 Spatial imagery

Landsat 7 imagery was used to determine the pond surface areas and to determine if any spatial patterns existed. By conducting a Thresholding Image to Bitmap (THR) algorithm on the 4th band of Landsat 7 Imagery for Churchill, MB, the water bodies were successfully extracted. This THR shapefile was used to clip the other bands so that only the water bodies remained. The bands were then converted into a vector format and then the measurement tool was used to determine surface areas of the sampled ponds with the guidance of GPS points obtained during fieldwork. The GPS vector point file had data added to it through DNRGarmin 5.4.1. This layer was added to ArcGIS in order to map the spatial distribution of water characteristics. The spatial resolution of the Landsat 7 imagery was 30m x 30 m and many ponds with low surface areas were at a single pixel threshold; certain ponds were not visible in the imagery used in this study.

By using DEM data with a resolution of 5 feet generated from 1:25,000 Canadian military topographic maps, ArcGIS's ArcHydro toolbox was utilized to create approximate watersheds for the sampled ponds. Inadequate watersheds were produced by this method as some watershed boundaries ran through ponds with large surface areas; also, some watershed boundaries incorporated multiple ponds inside of them. Since there are so many ponds in this area and it is relatively flat, a more detailed DEM would be required to successfully employ this analysis for every pond sampled.

2.4 Lab analyses:

One of the 2012 60 mL water samples from each pond was analyzed in an Atomic Absorption Spectrometer to determine the major cation (Na, Ca, Mg, K) concentrations, using different lamps and standards for each cation. If the samples were too high in concentration of certain cations, they were diluted with deionized water by a factor of 10 in order to obtain readings within detectable ranges; the results were then multiplied by ten in order to account for the dilution effect. Cation-specific standard curves were created to determine each sample's major cation concentration.

The 2012 filtered solids were allowed to thaw for 12 hours at room temperature. One of the filters was put into the drying oven at 100°C for 12 hours in order to dry the filters. Filters were then cooled in a desiccator to prevent humidification and then weighed to determine the amount of suspended inorganic and organic sediments. Filters were then put into a muffle furnace at 450°C for 24 hours in order to burn off all of the organics left on the filter. The filters were then cooled in a desiccator and re-weighed to determine ash weight for calculation of the suspended sediment organic fraction after loss-on-ignition.

The second set of filters was used to analyze suspended chlorophyll *a* with a spectrofluorometer (Varian Cary Eclipse PCB150 Fluorescence Spectrophotometer, 190-1100 nm). A chlorophyll standard was created by extracting chlorophyll from a 5 cm^2 fresh green lettuce leaf with 25 ml of boiling ethanol to obtain a standard that was super saturated with lettuce chlorophyll, following Wetzel and Likens' (1991) procedure. All absorbance measurements for creating the standard were conducted using a Genesys 10S UV-VIS spectrophotometer. The standard was filtered and diluted so that E_{665} (1-cm path length) was approximately 0.6 (=ca. 6 mg chl *a*/L). After measuring the absorption of the diluted standard at 750, 665, and 645 nm against a blank (95% ethanol, 5% water), the chlorophyll *a* concentration was calculated as:

Chl *a*(mg/L) = $11.57E_{665} - 1.31E_{645}$, (2)

where $E_{665} = A_{665} - A_{750}$,

and $E_{645} = A_{645} - A_{750}$,

and A_{645}, A_{665} and A_{750} were the measured absorbance of light at 645 nm, 665 nm, and 750 nm, respectively (Wetzel and Likens, 1991). The resulting chlorophyll *a* stock solution was diluted to create a series of standards to bracket the range of concentrations from the field samples. Standards were measured in the spectrofluorometer, and fluorescence was plotted against chlorophyll concentration to produce a linear regression which allowed chlorophyll *a* concentrations to be calculated for collected samples.

To extract chlorophyll from filtered samples, the second set of 2012 filters were allowed to thaw, put into 20 mL glass test tubes and then 10mL of boiling ethanol was poured onto each filter in order to extract the chlorophyll on the filters following a procedure described by Nusch (1980). After cooling, the samples were processed in Cary Eclipse fluorescence spectrophotometer and analyzed for chlorophyll *a* concentrations. After the samples had been analyzed in the fluorometer with blanks and standards, the results were converted into chlorophyll *a* with the following equation:

Chl *a*(μg/L) = [(F)(fluorometer reading)(*v*)] / (V), (3)

where F = conversion factor created by the standard curve; *v* = volume of extract in ml; and V = volume of water filtered in ml (Wetzel and Likens, 1991). The excitation wavelength was 436 nm and the emission wavelength was 680 nm.

The water samples from both 2012 and 2013 field seasons were thawed in the dark for 12 hours and then measured in a Shimadzu Total Organic Carbon and Total Nitrogen Analyzer. This was done in order to determine the concentrations of dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) in mg/L for each pond sampled in 2012 and each pond quadrant sampled in 2013. The standard used for these analyses were mixed in order to analyze the water samples for both DOC and TDN at the same time (Shimadzu Manual). The TC standard contained reagent grade potassium hydrogen phthalate and the TN standard contained reagent grade potassium nitrate; when the TN and TC standard solutions were combined with hydrochloric acid, a mixed standard was created for use in the Shimadzu©.

For the measurement of $SUVA_{254}$ (Specific UltraViolet Absorptance at 254 nm: the amount of aromaticity per mg of DOC; measure of DOC quality), water samples from each pond in 2012 and from the 4 quadrants of each pond in 2013 were thawed for 12 hours in a shaded environment at room temperature. They were then placed in a 50mm Light Path Spectrophotometer Cell and analyzed in a GENESYS 10S UV-Vis v4.003 Spectrophotometer for absorbancy between 250-750 nm. The scans were set to a medium speed with an interval period of 1 nm. Deionized water was used for a blank during CDOM analyses. The average absorbance between 700-750 nm for each sample was used as a baseline and wavelengths from 250-699 nm were corrected by using this baseline (Helms et al., 2008). The corrected output for spectral slopes, absorbance ratios and absorbance at 254 nm was then converted into absorption coefficients by:

$$a = A/l, \qquad (4)$$

where a = absorption coefficient (m^{-1}), A = absorbance and l = path length (m) (Helms et al., 2008). The absorption coefficients were converted into humification values using the $SUVA_{254}$ technique: dividing a_{254} (m^{-1}) by the DOC concentrations (mg L^{-1}) in order to obtain units in liter per milligram of carbon per meter (Weishaar et al., 2003). The slope ratio S_R was calculated as the ratio of

$S_{275-295}$ to $S_{350-400}$; where $S_{275-295}$ and $S_{350-400}$ are the linear regressions of the log-transformed *a* spectra of their respective wavelengths (Helms et al., 2008). Also, the ratio of log-transformed absorption at 250 nm and 365 nm (E_2:E_3) was calculated to track changes in the relative size of DOM molecules and general humification (Helms et al., 2008). A high E_2:E_3 ratio indicates low molecular sizes and lower humification caused by lower absorption by low molecular weight compounds.

2.4.1 Total dissolved phosphorous (TDP):

Water samples from each pond in 2012 and from the 4 quadrants of each pond in 2013 were thawed for 12 hours in a shaded environment at room temperature. 20mL of each sample was analyzed for Total Dissolved Phosphorous (TDP) following the protocol outlined in Environmental Protection Agency (1978). The glassware used was primed before use in an autoclave with MilliQ ultrapure-grade water (millipore) and potassium persulfate. A stock solution with monopotassium phosphate (KH_2PO_4) and sulfuric acid (H_2SO_4) was created in order to produce standards during analyses. A pre-mixed reagent was produced with sulfuric acid (H_2SO_4), ammonium molybdate $(NH_4)_6Mo_7O_{24}$, and antimony potassium tartrate ($K_2Sb_2(C_4H_2O_6)_2$). Ascorbic acid ($C_6H_8O_6$) was added to the pre-mix reagent to create the reagent; this reagent was used immediately after its production due to its short shelf life. The blank (pure deionized water), phosphorous standards and samples were placed in 20 ml glass test tubes with 0.16g of potassium persulfate. The autoclave was set to liquids setting, 121°C and the glass test tubes in racks where placed in a water bath inside an autoclavable container and partially open bag. The autoclavable container filled with samples was placed into the autoclave and the samples were digested for 45 minutes in order to convert all of the phosphorous into orthophosphate. The samples were allowed to cool for at least twenty minutes and a mixed reagent was added to each sample immediately after cooling. After the mixed reagent was added, the samples were analyzed within the hour to prevent the acid in the reagent from digesting the sample. Samples were then analyzed using a cylindrical 50 mm spectrophotometer cell. The digestion method in the autoclave oxidized organic matter to release phosphates as orthophosphates. The blank and standards with known phosphorous concentrations were then used to create a curve; the samples were then converted from absorbance values into concentrations in µg/L.

3.0 Results:

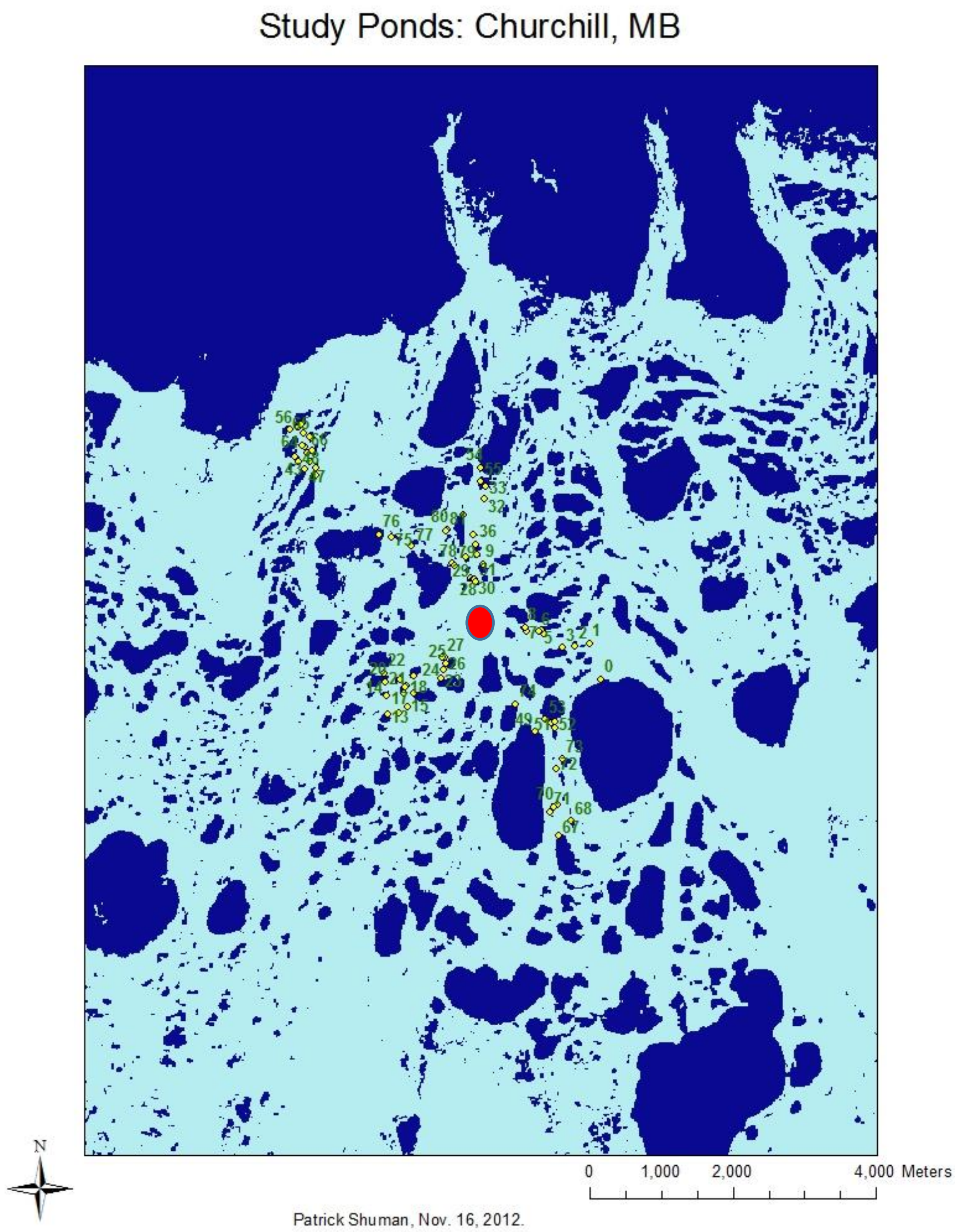


Figure 4: A map of GPS points for the ponds sampled in July of 2012. The GPS point represents the sample location for the pond or lake. The red circle represents the location of the Churchill Northern Studies Center.

3.1 Physical and water chemistry characteristics of ponds sampled in the Hudson Bay Lowlands, July 2012:

The ponds were sampled in all cardinal directions (North, East, South and West) from the Churchill Northern Studies Center (Figure 4) to ensure that different pond types were sampled. The physical data from the 70 ponds sampled during July 2012 in the Hudson Bay Lowlands showed that these ponds ranged considerably in surface area (Table 1). The majority (54 of 70) ponds sampled had surface areas lower than 10,000 m^2. Only 4 ponds had a surface area greater than 60, 000 m^2. Roughly half (34 of 70) had low surface areas of 2,000 m^2 or less.

Table 1: Summary of the surface areas of sampled ponds (m^2):

Maximum	1,017,500.0
Minimum	Belowdetection
Average	47,191.1
Median	3,300.00
Standard Deviation	151,098.1
Covariance	3.6

The bodies of water were typically relatively small in surface area with a median of 3,300 m^2 and an average of 47,191 m^2. The average had been enlarged by a few extremes that had very large surface areas, specifically Lindy and Ramsey Lakes.

The imagery obtained from Landsat 7 had a spatial resolution of 30m by 30m. This low level of spatial resolution resulted in some ponds with very small surface areas being undetected by the satellite. Alternatively, Double, Sophia, Lindy Lake and Malcom Ramsey Lake were the largest water bodies in surface area (Table 2).

Table 1: Surface areas of sampled ponds (m²):

Name	Area of Polygons 2006 Landsat 7 (m^2)
Delijack	Below detection limit
Cherry	Below detection limit
Famas	Below detection limit
Grape	Below detection limit
Justin	Below detection limit
No Flower	Below detection limit
Nirvana	Below detection limit
Peanut	Below detection limit
Sleep	Below detection limit
Vanessa	Below detection limit
Yellow Flower	Below detection limit
York U	Below detection limit
Dugout	Below detection limit
Plugged	Below detection limit
Kerstina	Below detection limit
Frosty	100
Tundra Buggy	254.5
Ditch	383.5
Island Pond	500
Falco	500
Sandy	500
Cheese	500
Submarine	500
No Problems	700
Mosquito Rain	700
Red Berry pond	700
Dome	700
Zealot	707
Yoshi's Canyon	743
Some Pond	900
Delusional	957.5
Angry Bird	1,100
Micro	1,100
Stage	1,300
Swivel	1,500
Orange	1,500
Horner	1,900
Rotten Egg	1,900
Ali	2,300
Paddy	2,436
Frisbee	2,700
Banana	3,300
Rice	3,300
Left Pond	3,900
Pikachu	4,300
Puck	4,500
Rocky	4,700
Teapot	5,272.5
Galil	5,678
Some Pond	6,100
Disco	6,100
Larch	7,300
Rocky	7,900
Meander	8,700

Smokey	9,300
REM	12,100
Windy	16,700
Duel	19,200
Arctic Loon	22,100
Big Pond	23,900
Bell	28,600
Big Rock	29,100
Junior	33,500
Shimmering	42,700
Merrin	43,500
Ginger	59,700
Double	201,300
Sophia	249,300
Lindy Lake	502,300
Ramsey Lake	1,017,500

The majority 55 out of 70 ponds sampled were below 10,000 m² (Figure 5).

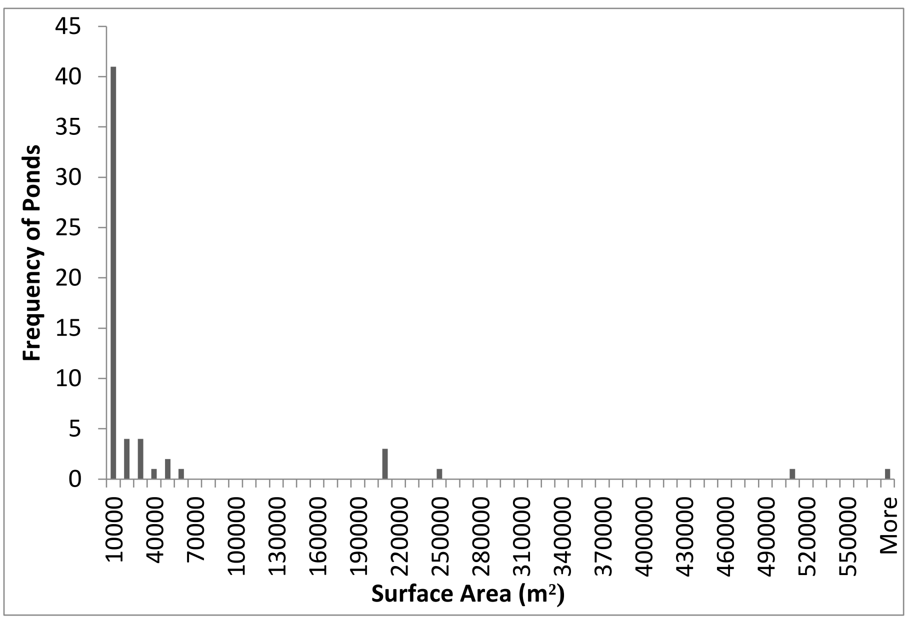


Figure 5: Frequency of the surface area of ponds sampled in 2012

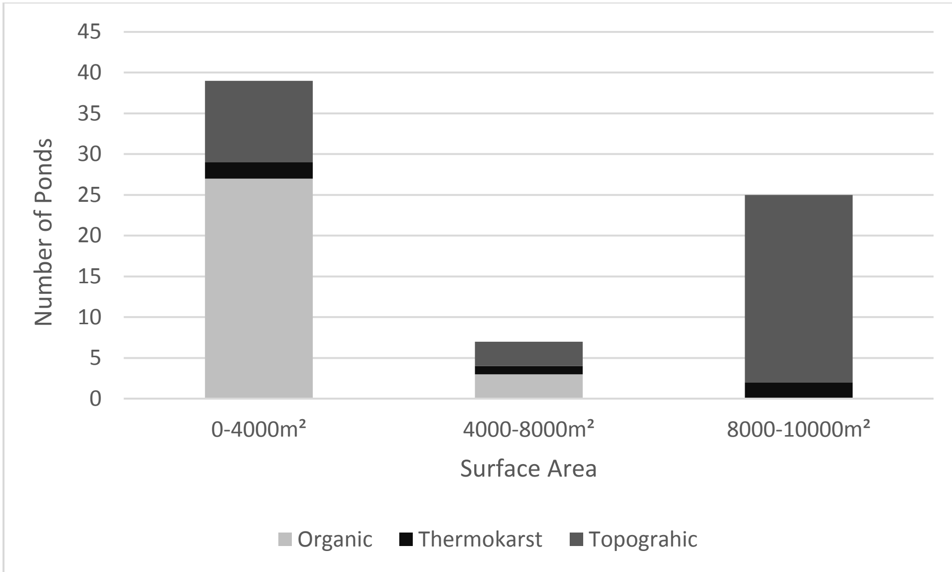


Figure 6a: Frequency of the type of pond by surface area groups; sampled by Firanski, 2000

Topographic ponds dominated in surface area classes > 8,000 m² and organic ponds dominated in surface area classes < 4,000 m²; ponds between 4,000 to 8,000 m² showed the greatest variability in pond type; this is a general comment about pond origin found by utilizing a pond sample set in Churchill, MB during the summer of 1999 (Firanski, 2000). The ponds were selected for sampling based on obtaining large variances of surface area; this was done to determine what different pond environments exist in the Hudson Bay Lowlands. Many of the sampled ponds were so small in surface area that they were not detected using Landsat imagery, these ponds were added to the <1,000 m^2 group. The frequency of ponds sampled in 2012 increased as ponds surface area decreased (Figure 6).

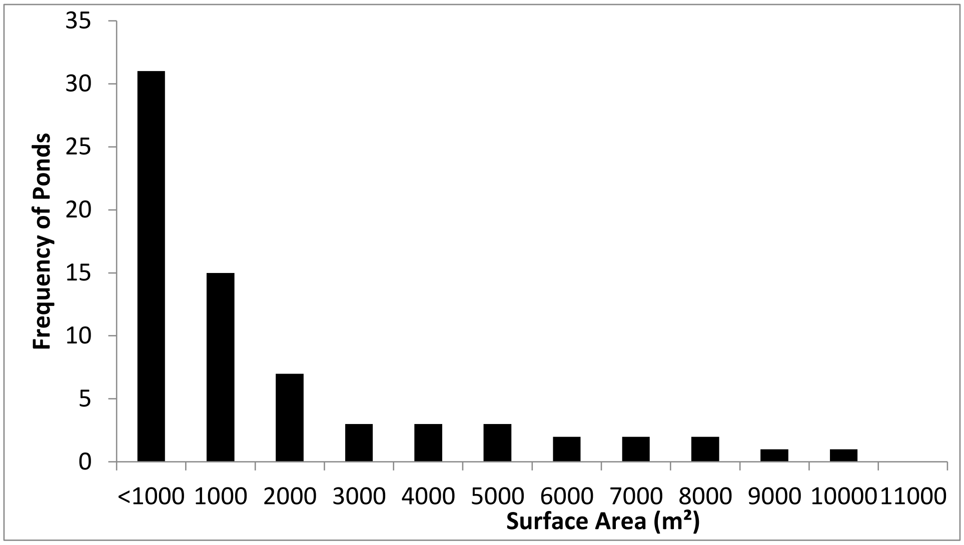


Figure 7: Frequency of the surface area of ponds sampled in 2012 (<11,000m²)

The ponds were sampled for major cation concentrations and exhibited the highest concentrations in sodium (Na), followed by calcium (Ca), potassium (K), and magnesium (Mg), respectively (Table 3). Freshwaters typically show dominant cations in the following order (highest to lowest): Ca, Mg, Na, and K (Likens, 2010). There is a large variability in cation concentrations in freshwater when compared to seawater due to the influences of precipitation, weathering and evaporation (Likens, 2010).

Table 2: Major cation concentration summary statistics of ponds sampled in 2012

	Na (mg/L)	**Ca (mg/L)**	**K (mg/L)**	**Mg (mg/L)**
Maximum	65.09	51.43	7.86	5.60
Minimum	10.81	5.014	0.81	0.40
Average	31.94	10.27	3.18	1.38
Median	30.81	8.53	2.83	1.17
Standard Deviation	12.09	6.52	1.64	0.88
Covariance	0.38	0.63	0.51	0.64

The YSI multi-parameter probe found that these ponds were basic, high in dissolved oxygen, salinity, and specific conductance when compared to typical freshwater environments (Table 4) (Likens, 2010,Sanders, 1998). The water samples from Hudson Bay Lowlands ponds were considered to be freshwater as determined by a threshold of 0.5 ppt in salinity; four ponds from this sample set exhibited brackish conditions (UNESCO, 1981).

Table 3: YSI multi-parameter summary statistics of readings of 2012 sampled ponds

	Specific Conductance (µS cm^{-1})	**Salinity (ppt)**	**Dissolved Oxygen [ppm]**	**pH**
Maximum	2841.50	1.88	15.85	9.06
Minimum	136.63	0.05	6.69	7.14
Average	494.08	0.24	13.05	8.41
Median	378.85	0.17	13.22	8.48
Standard Deviation	481.49	0.28	1.48	0.39
Covariance	0.97	1.15	0.11	0.04

The samples exhibited low chlorophyll a and total dissolved phosphorus concentrations when compared to other Arctic regions (Rautio et al., 2011). The samples also exhibited high DOC concentrations when compared to other Arctic regions; exhibiting relatively colourful water when compared to other Arctic regions (Rautio et al., 2011). The water sampled exhibited an average of oligotrophic conditions that did not support large pelagic algal colonies (Gray, 1987); though many ponds were mesotrophic due to the fact that many ponds crossed the TDP threshold of 10 ug/L (Schindler, 1990).

Table 4: Chlorophyll a, dissolved organic carbon, total dissolved nitrogen, total dissolved phosphorus and total suspended solids summary statistics from 2012 sampled Ponds

	Chlorophyll *a* (µg/L)	**DOC (mg/L)**	**TDN (mg/L)**	**TDP (µg/L)**	**TSS (mg/L)**
Maximum	5.26	24.03	0.95	38.26	8.00
Minimum	0.09	4.403	0.22	2.98	0.20
Average	1.29	9.29	0.52	8.17	2.82
Median	0.99	8.87	0.49	7.10	2.60
Standard Deviation	0.93	2.99	0.16	5.20	1.54
Covariance	0.72	0.32	0.30	0.64	0.55

The ponds in Hudson's Bay Lowlands had a few outliers that had high $SUVA_{254}$ concentrations greater than 2.7 L*mg C^{-1}*m^{-1}, but overall, exhibited low $SUVA_{254}$ concentrations (Table 6) when compared to other regions (Mostofa et al., 2012). Also, there were low values of humification and size of DOM molecules in the samples taken from ponds in the Hudson Bay Lowlands as shown by the high values of S_R and E2:E3, when compared to highly humic environments such as the Great Dismal Swamp and Suwannee River wetlands (Helms et al., 2008).

Table 5: $SUVA_{254}$, S_R and E2:E3 (a_{250nm}:a_{365nm})

	$SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$)	**S_R**	**E2:E3 (a_{250nm}:a_{365nm})**
Maximum	4.90	1.91	16.88
Minimum	0.61	0.30	3.99
Median	2.25	0.99	8.43
Average	2.43	1.04	8.98
Standard Deviation	0.92	0.29	2.85
Covariance	0.38	0.27	0.32

3.1.1 Significant relationships found during the 2012 study season:

According to the Shapiro-Wilk test (appropriate for <50 samples), the following parameters significantly deviate from the normal distribution: calcium, total suspended solids, perimeter and surface area (Table 7). The rest of the parameters held significance values that were greater than 0.05 and therefore, were considered normally distributed. Tests of normality were conducted to determine if linear regression and multivariate statistics were valid.

Table 7: Normality tests for all of the parameters sampled for in Hudson Bay Lowland ponds

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	p	Statistic	df	p
TDP (µg/L)	.156	12	.200*	.951	12	.652
S_R	.184	12	.200*	.930	12	.379
E2:E3	.181	12	.200*	.931	12	.389
$SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$)	.137	12	.200*	.948	12	.614
Na (mg/L)	.205	12	.175	.935	12	.433
Ca (mg/L)	.398	12	<0.001	.617	12	.000
Mg (mg/L)	.218	12	.121	.798	12	.009
K (mg/L)	.220	12	.112	.927	12	.348
TSS (mg/L)	.364	12	<0.001	.656	12	.000

Specific Conductance (µS/cm)	.262	12	.023	.810	12	.012
Dissolved oxygen concentration (%)	.111	12	.200*	.964	12	.840
pH	.179	12	.200*	.969	12	.904
H ion concentration	.272	12	.015	.869	12	.063
DOC (mg/L)	.205	12	.175	.917	12	.265
DON (mg/L)	.174	12	.200*	.913	12	.231
Shoreline development	.197	12	.200*	.911	12	.217
Perimeter (m)	.246	12	.044	.776	12	.005
Surface Area (m^2)	.292	12	.006	.725	12	.001
Chlorophyll a (µg/L)	.171	12	.200*	.862	12	.051
*. This is a lower bound of the true significance. a.Lilliefors Significance Correction						

The highest correlation between pond chemical characteristics and pelagic chlorophyll a from ponds sampled in 2012 was with total dissolved phosphorus, exhibiting a p-value of 0.023 (Figure 7). This is due to the extremely low concentrations of pelagic chlorophyll a and lack of suitable variability in the dataset.

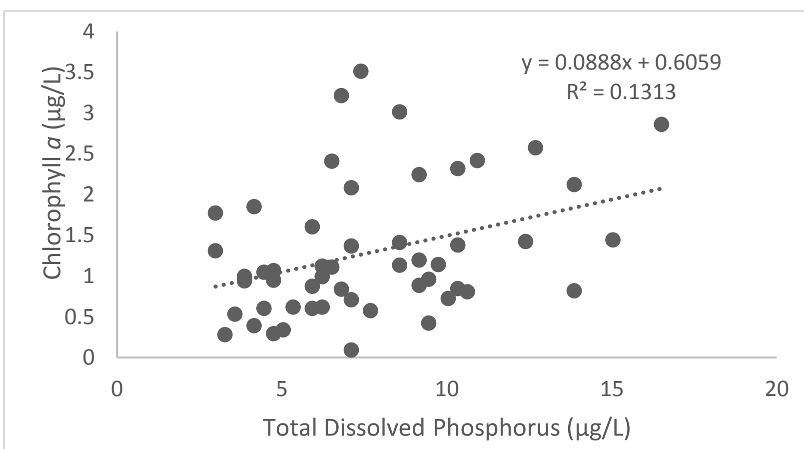


Figure 8: The relationship between total dissolved phosphorus and pelagic algae (chlorophyll a)

Concentrations of total dissolved phosphorus and $SUVA_{254}$ were positively correlated to each other; a p-value of 0.013 was obtained for this regression (Figure 8). These parameters may be animportant influence on algal growth in this region through limiting phosphorus conditions (Gray, 1987) and UV filtering abilities (Toming et al., 2009).

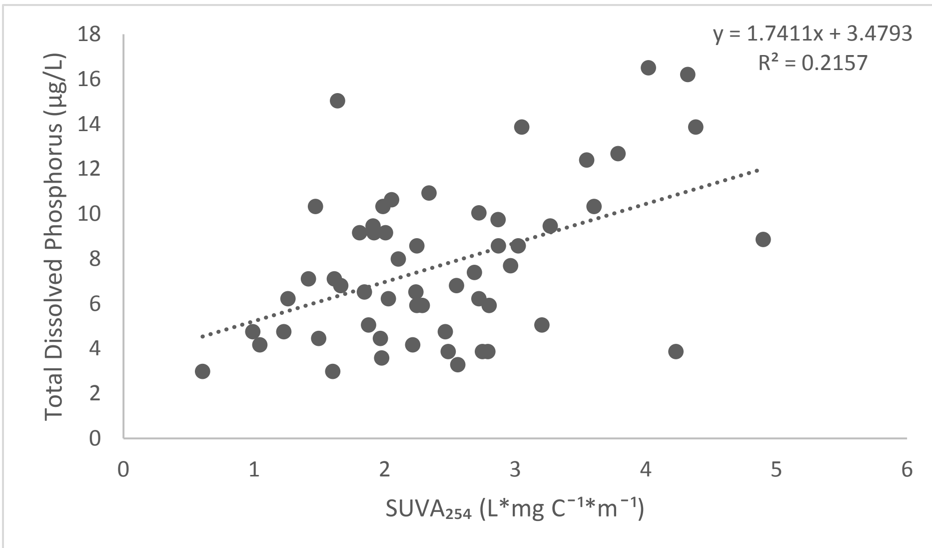


Figure 9: The relationship between total dissolved phosphorus and $SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$).

Values of $SUVA_{254}$ were negatively correlated with pH values, exhibiting a p-value of <0.001. The pHexplains 15.25% of the variability of $SUVA_{254}$ for the sample ponds dataset (Figure 9). Colored dissolved organic matter is partially comprised of fulvic and humic acids and the increase in colored dissolved organic matter explains the reduction in pH (Likens, 2010).

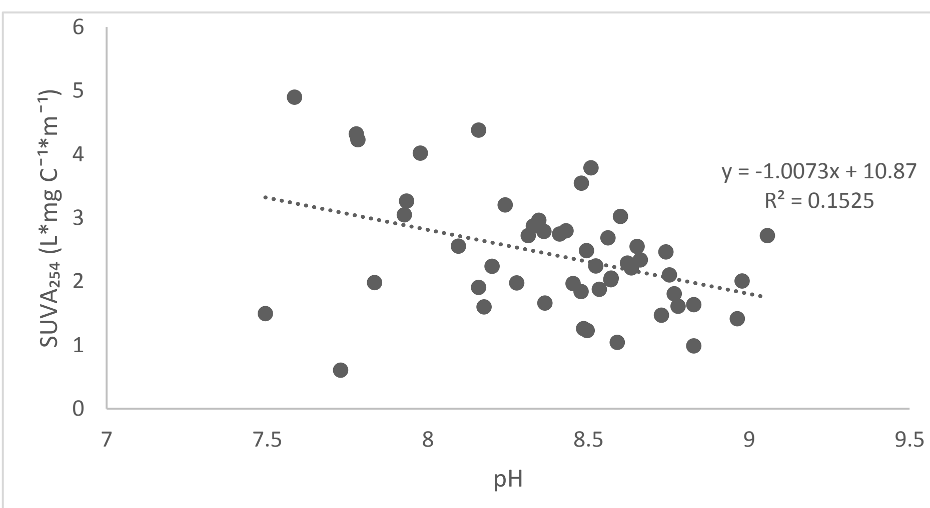


Figure 10: The relationship between pH and $SUVA_{254}$.

Ponds with lower surface areas (<2,000m²) tended to have higher values of total dissolved phosphorus (ug/L), dissolved calcium (mg/L) and $SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$) than ponds with larger surface areas (>8,000m²). The surface area groups of these box plots were based on the fact that organic ponds dominated in the surface area group <2,000m² and topographic ponds dominated in the surface area group >8,000m² (Firanski, 2000). A t-test between the two surface area groups revealed a p-value of 0.021 for TDP, a p-value of 0.013 for dissolved calcium and a p-value of <0.001 for $SUVA_{254}$, showing significant difference between the two groups of surface area size (Figures 10, 11 & 12).

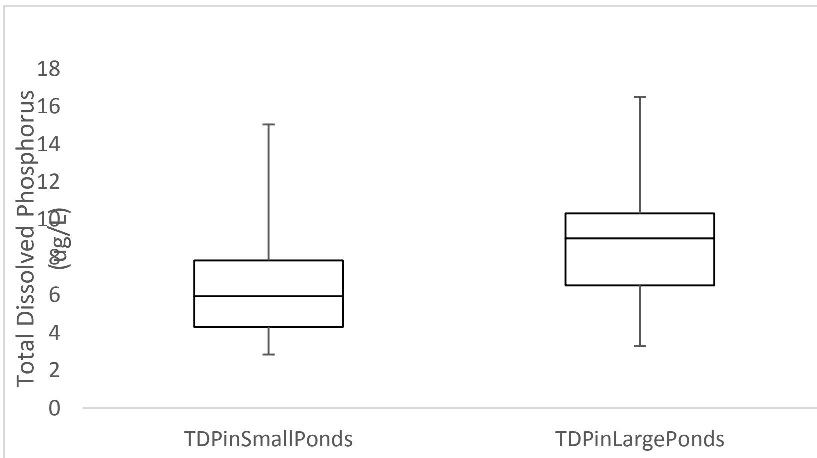


Figure 11: The relationship between pond surface area and total dissolved phosphorus concentrations

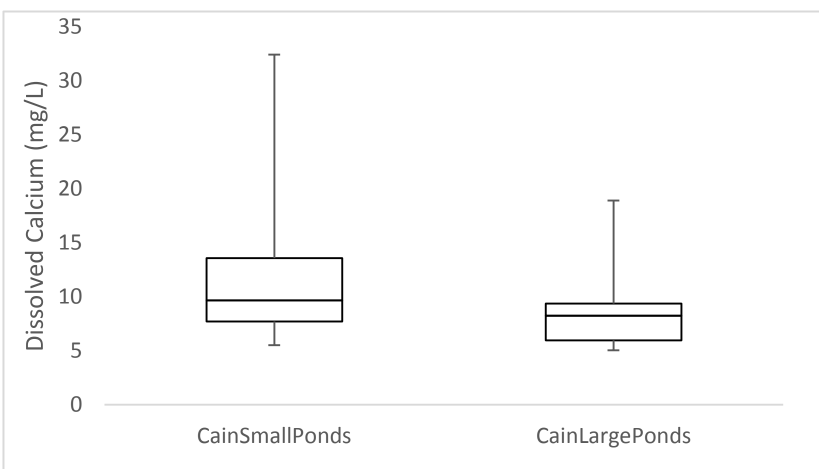


Figure 12: The relationship between pond surface area and dissolved calcium concentrations

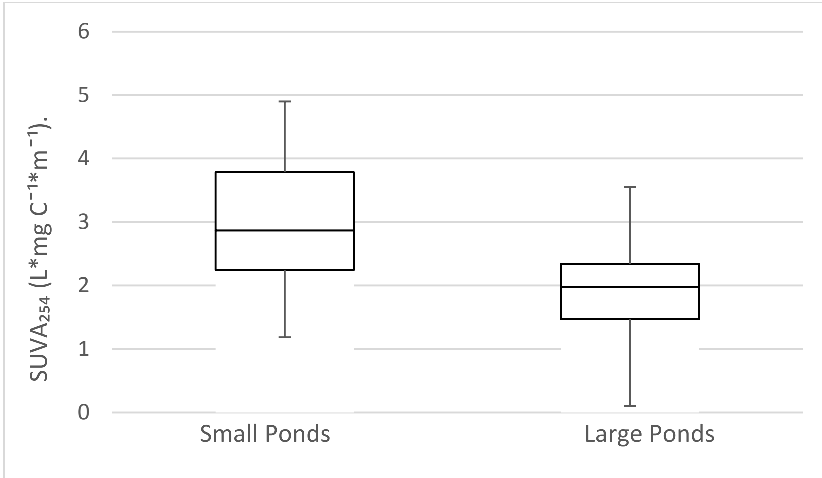


Figure 13: The relationship between pond surface area and $SUVA_{254}$ concentrations

3.2 Physical characteristics and water chemistry of ponds sampled in the Hudson Bay Lowlands, July 2013:

The subset of sampled 2013 ponds were selected based on obtaining large variances in algal and water chemistry parameters such as $SUVA_{254}$ and TDP. The ponds samples in 2013 had a large range in surface area (Table 8). The ponds were overall low in surface area with a few extremes that had a large surface area and were big enough to be called lakes.

Table 6: Summary of the surface areas of sampled ponds (m^2) in 2013:

Maximum	1004600
Minimum	Below detection limit
Average	82608
Median	17400
Standard Deviation	216920
Covariance	2.63
Sample Size	34

Out of the 34 ponds or lakes sampled, 4 were larger than 50,000m^2, 8 were undetectable or less than 100 m^2 and the rest of the ponds (22) ranged between these two values. Ramsey Lake was by far the biggest in surface area, followed by Lindy Lake; while Dugout Pond and Cherry Pond were among the smallest in surface area (Table 9).

Table 7: Surface areas of sampled ponds (m²) in 2013:

Name	**Area of Polygons 2006 Landsat 7 (m2)**
Ninah	Below detection limit
Plugged	Below detection limit
Cherry	Below detection limit
YellowFlower	Below detection limit
No Flower	Below detection limit
Vanessa	Below detection limit
Peanut	Below detection limit
Dugout	Below detection limit
TundraBuggy	254.5
IslandPond	500
Falco	500
Sandy	500
Zealot	707
SomePond	900
Micro	1100
Orange	1500
PaddysPond	2436
Frisbee	2700
Banana	3300
LeftPond	3900
Shumas	8700
Smokey	9300
REM	12100
Windy	16700
Arctic Loon	22100
BigPond	23900
Bello	28600
Junior	33500
Shimmering	42700
Merrin	43500
DoublePond	201300
Sofia	249300
Lindy	502300
Ramsey	1017500

The majority of ponds sampled were below 10,000 m² (Figure 13) because it has been found that within that range of values, exists the highest differences in pond origin (Firanski, 2000).

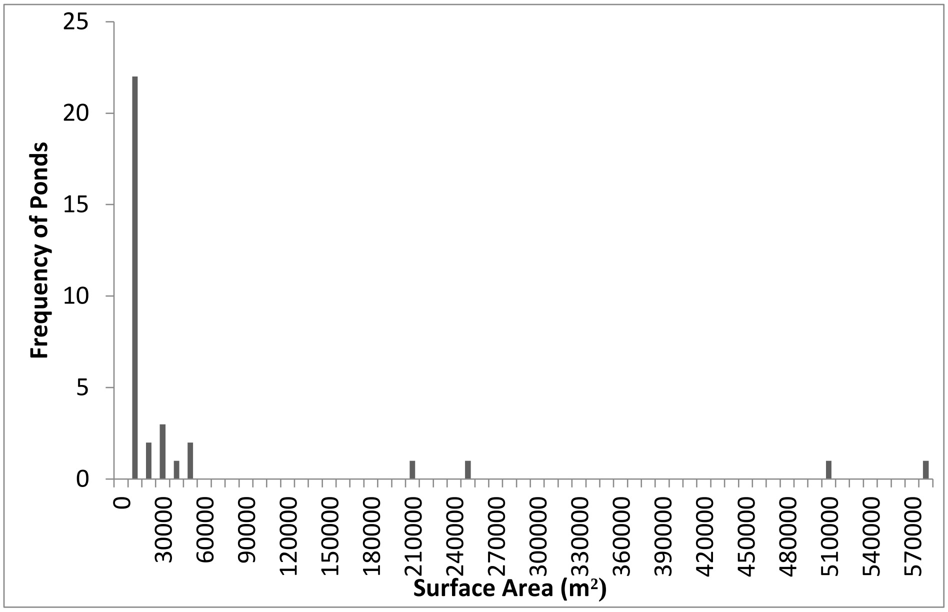


Figure 14: Frequency of the surface area of ponds sampled in 2013

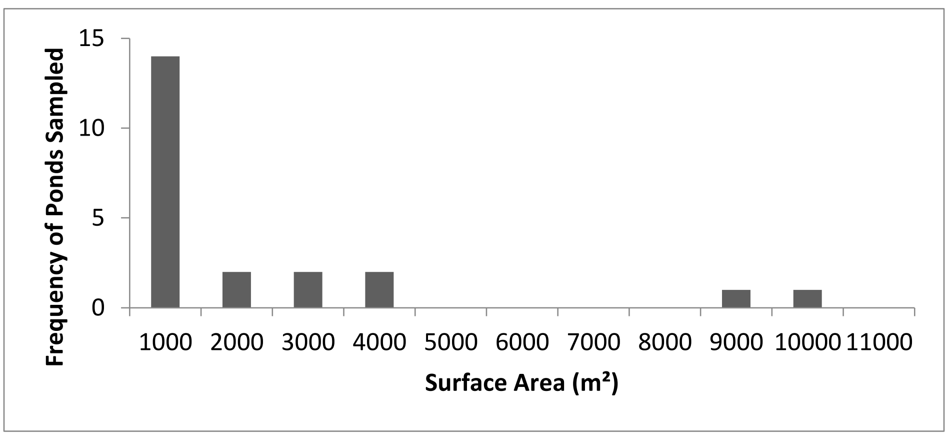


Figure 15: Frequency of the surface area of ponds sampled in 2013 (>11,000m²)

Similar to 2012, The YSI multi-parameter probe found that the 2013 subset of ponds were basic, high in dissolved oxygen, and specific conductance when compared to typical freshwater environments (Likens, 2010 andSanders, 1998). The sampled water from Hudson Bay Lowlands ponds were considered to be freshwater with a threshold of 0.5 ppt in salinity (Table 10); 3 ponds from this sample set exhibited brackish conditions (UNESCO, 1981).

Table 8: YSI multi-parameter probe readings of the 2013 surveyed ponds

	Specific Conductance ($\mu S\ cm^{-1}$)	**Salinity (ppt)**	**DO [ppm]**	**pH**
Maximum	1301.25	1.66	13.40	9.69
Minimum	136.63	0.00	8.87	8.36
Median	368.38	0.19	11.59	8.98
Average	420.73	0.25	11.56	8.97
Standard Deviation	236.64	0.30	0.92	0.27
Covariance	0.56	1.21	0.08	0.03

The ponds showed a high range in DOC, TDN, and TDP concentrations with a few large outliers in the ponds with low surface areas (Table 11). Overall, these ponds exhibited lowDON and TDP concentrations when compared to other Subarctic ponds (Rautio et al., 2011).

Table 9: Dissolved organic carbon, total dissolved nitrogen and total dissolved phosphorus concentrations of the ponds sampled

	DOC (mg/L)	**TDN (mg/L)**	**TDP (µg/L)**
Maximum	29.98	1.50	48.55
Minimum	4.78	0.24	5.48
Median	10.85	0.61	11.52
Average	13.32	0.70	15.67
Standard Deviation	6.55	0.31	10.80
Covariance	0.49	0.44	0.69

Similar to in 2012, the 2013 survey showed that ponds in Hudson's Bay Lowlands, overall, exhibited low $SUVA_{254}$ concentrations, $\mathbf{S_R}$ and **E2:E3 (a_{250nm}:a_{365nm})** (Table 12) (Helms et al., 2008).

Table 10: $SUVA_{254}$, S_R and E2:E3 (a_{250nm}:a_{365nm}).

	$SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$)	**S_R**	**E2:E3 (a_{250nm}:a_{365nm})**
Maximum	2.90	1.67	14.29
Minimum	1.10	0.78	4.02
Median	1.87	1.32	8.69
Average	1.95	1.25	8.75
Standard Deviation	0.52	0.19	1.93
Covariance	0.12	0.16	0.22

According to the Shapiro-Wilk test (appropriate for <50 samples), the following parameters significantly deviate from the normal distribution during the 2013 survey: E2:E3, DOC, Ft450 (instantaneous fluorescence of green pelagic algae), Ft620 (instantaneous fluorescence of pelagic cyanobacteria), and surface area. The rest of the parameters held significance values that were greater than 0.05 and therefore, were considered normally distributed (Table 13). Tests of normality were conducted to determine if linear regression and multivariate statistics were valid.

Table 11: Normality tests for all of the 2013 parameters sampled for in Hudson Bay Lowland ponds

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Shoreline	.156	16	.200*	.919	16	.164
Perimeter (m)	.305	16	<0.001	.640	16	.000
Surface area (m^2)	.439	16	<0.001	.366	16	.000
Average depth (m)	.238	16	.016	.903	16	.089
DOC (mg/L)	.189	16	.131	.814	16	.004
DON (mg/L)	.144	16	.200*	.922	16	.179
TDP (ug/L)	.195	16	.105	.879	16	.038
Specific Conductance (μS/cm)	.191	16	.122	.924	16	.195
S_R	.112	16	.200*	.981	16	.973
E2:E3	.404	16	<0.001	.548	16	.000
$SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$)	.185	16	.144	.967	16	.789
Cyanobacteria (μg/cm^2)	.115	16	.200*	.984	16	.988
Green algae (μg/cm^2)	.139	16	.200*	.941	16	.359
Diatoms (μg/cm^2)	.147	16	.200*	.901	16	.082
Total benthic concentration (μg/cm^2)	.161	16	.200*	.951	16	.506
Ft450	.189	16	.129	.795	16	.002
Qy450	.095	16	.200*	.959	16	.649
Ft620	.242	16	.013	.862	16	.021
Dissolved oxyen concentration (%)	.146	16	.200*	.937	16	.318
pH	.233	16	.020	.886	16	.048

*. This is a lower bound of the true significance. a. Lilliefors Significance Correction

3.2.1 The dominance of benthic cyanobacteria in Hudson Bay Lowlands and the significant relationships found with benthic algae:

Benthic cyanobacteria dominate in the Hudson Bay Lowland's Subarctic environment. A Tukey post hoc test found that the means of these three groups are different from each other; 95% confident that there are 0.45 +/- 0.05 μg/cm^2 more cyanobacteria than green algae on average, 0.66 +/- 0.05 μg/cm^2 more cyanobacteria than diatoms on average and 0.20 +/- 0.05 μg/cm^2 more green algae than diatoms on average (Figure 15). These findings of benthic cyanobacteria being the dominant algal group are consistent with other research in similar areas in the Subarctic and Arctic (Rautio et al., 2011).

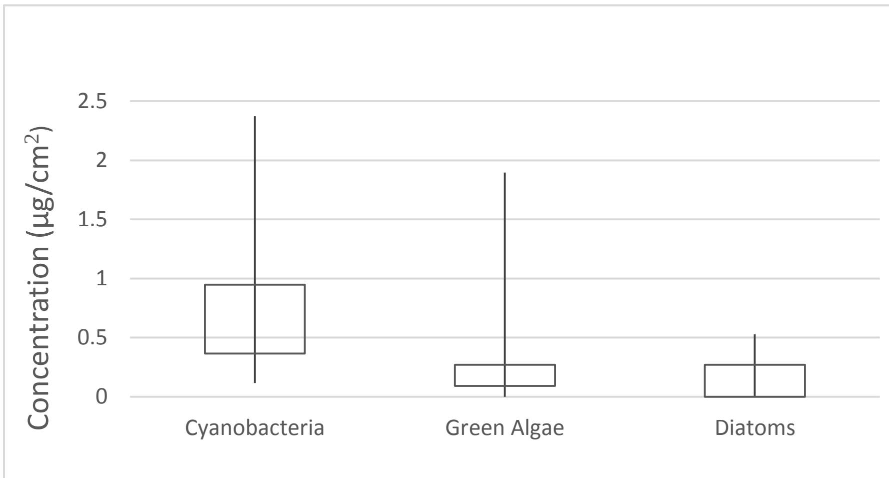


Figure 16: Box plots illustrating the dominance of benthic cyanobacteria in ponds sampled in the Hudson Bay Lowlands during the summer of 2013.

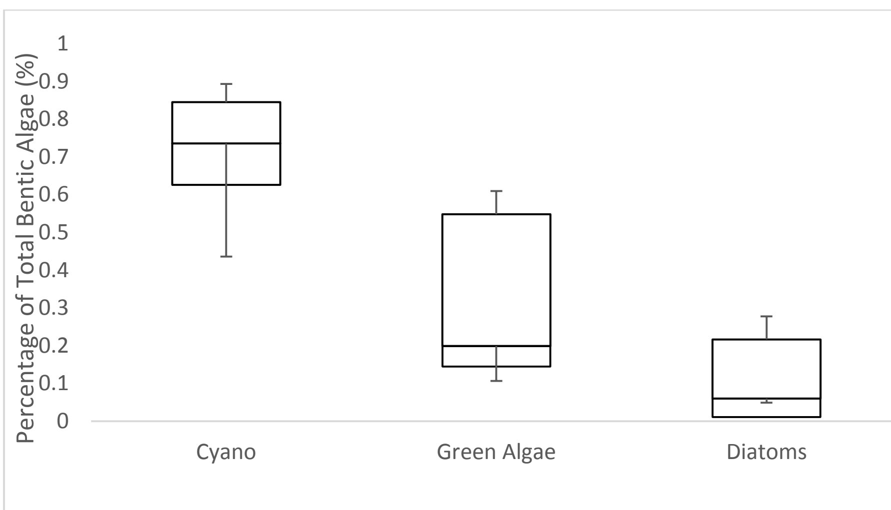


Figure 17b: Box plots illustrating the dominance of benthic cyanobacteria by percentage in ponds sampled in the Hudson Bay Lowlands during the summer of 2013.

Benthic cyanobacteria composed more than 50% of the sample in 32 of 34 ponds and 118 of 126 benthic algae measurements taken in Hudson Bay ponds during July 2013 (Figure 16). Benthic cyanobacteria are the dominant algal group in the study ponds sampled during July 2013. In Cherry

Pond, green algae (48.2% of total) and cyanobacteria (48.6% of total) were found in equal concentrations. Only one pond with a very low surface area, Dugout which wasthermokarst in origin, was dominated by benthic green algae (60.9% of total) . Diatoms were consistently the lowest proportion of benthic algae in almost all of the sampled ponds. Diatoms were higher in proportion than green algae, but still lower than cyanobacteria, in only three ponds, each of which had large surface areas: Sofia, Ramsey and Orange.

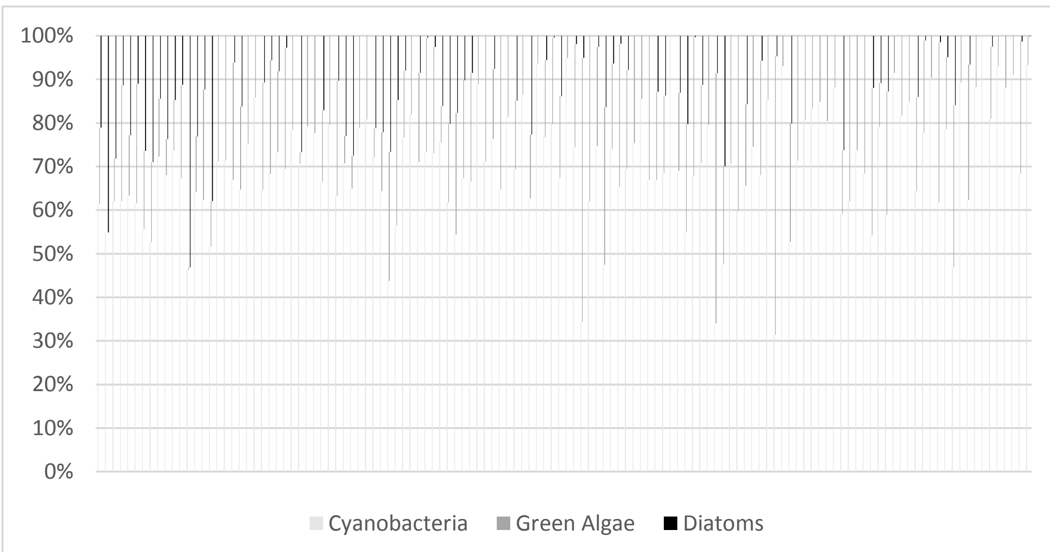


Figure 18: The relative percentage of each major class of benthic algae in the 2013 sampled ponds

A redundancy analysis on benthic algae for water chemistry parameters was performed using the XLstat add on for Excel. In Figure 16b, the results can be seen for benthic diatoms, cyanobacteria and green algae with the independent water chemistry parameters: $SUVA_{254}$, TDP and TDN. Diatoms were least correlated with all water chemistry parameters, most likely due to the low concentrations that diatoms exhibited. Cyanobacteria and green algae were most influenced by TDP as can be seen by their similar position on the F1 axis which explains most of the variability in the data. This is most likely due to the fact that they were most limited by this nutrient. The environmental variables $SUVA_{254}$, DOC, E2:E2, TDP and TDN were found to be significant with p-values less than 0.05.

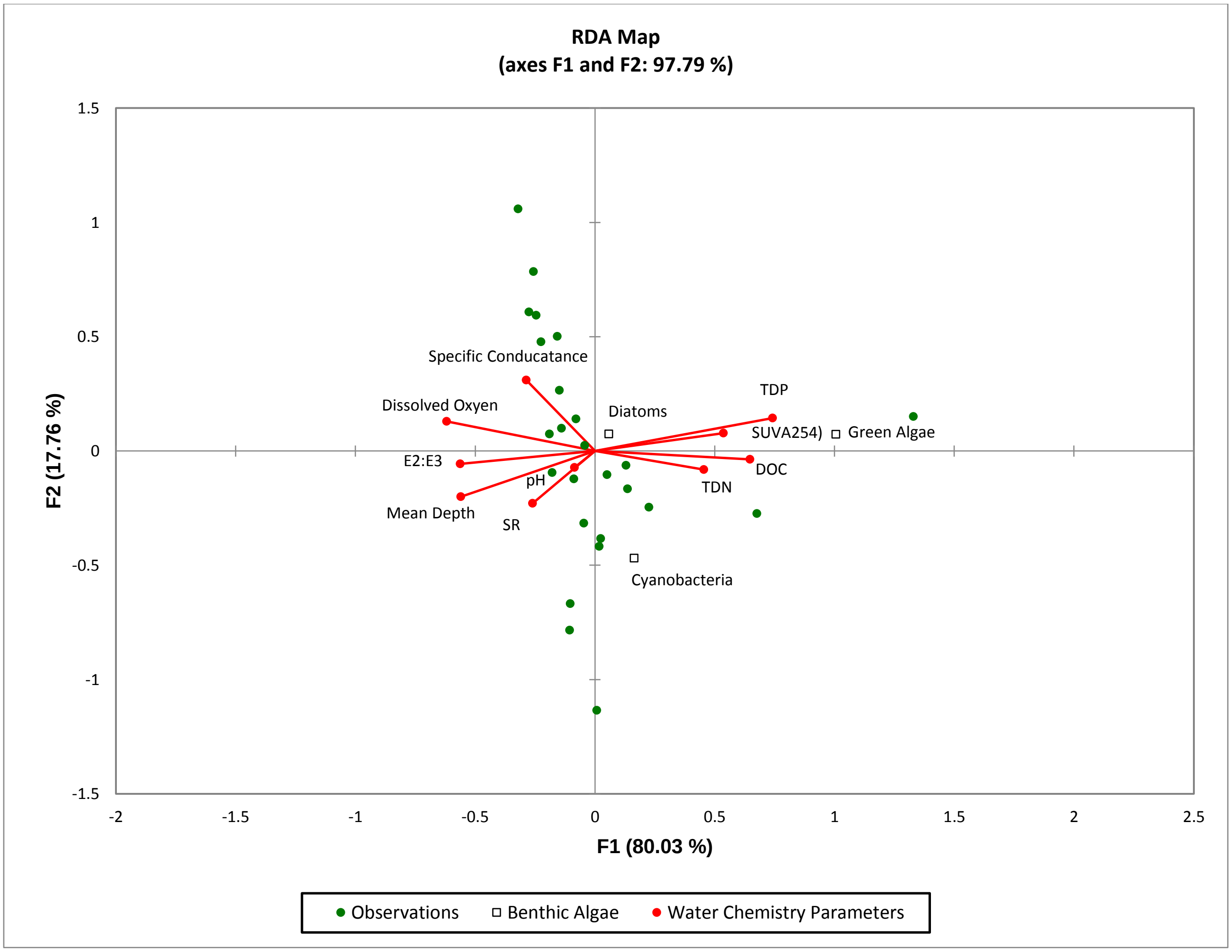


Figure 19b: Redundancy analysis on benthic algae for water chemistry characteristics

In the 2013 survey, total dissolved phosphorus and $SUVA_{254}$ tended to correlate with each other with a p-value of <0.001 (Figure 17); as discussed for the 2012 data, when both of these parameters are large, the environment favors algae growth due to higher nutrient availability (Boyd, 1971) and UV protection (Bertilsson and Tranvik, 2000); UV protection does not occur in dystrophic (brown) lakes (UK Biodiversity Action Plan, 2008). Phosphorus species may be adsorbed to the chromophoric component of dissolved organic matter, which would further explain their positive correlation; TDP is largely bound in organic molecules (Klug, 2005).

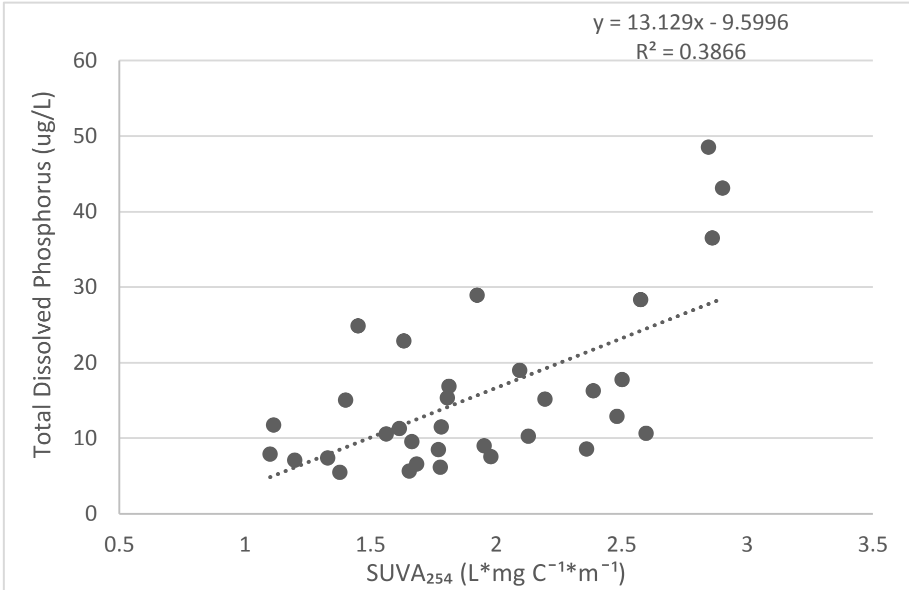
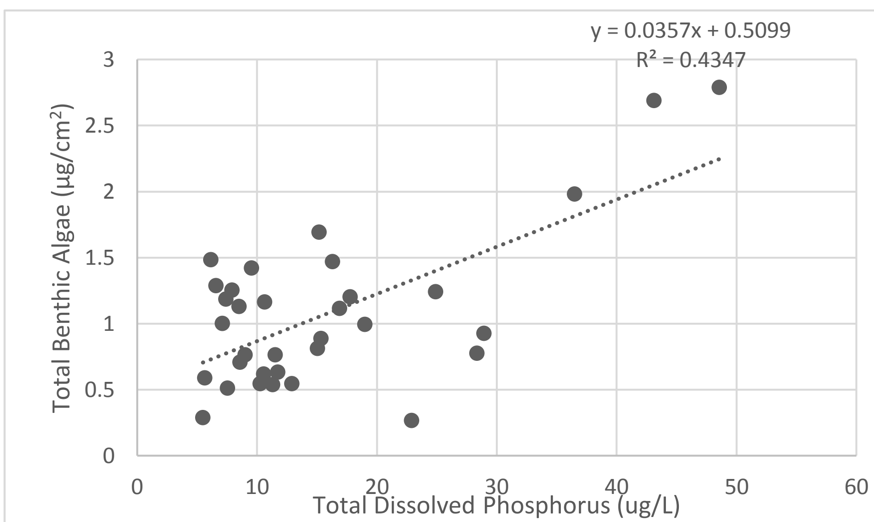


Figure 20: The relationship between total dissolved phosphorus and $SUVA_{254}$

Total dissolved phosphorus explained 43.5% of the variability in total benthic algae, exhibiting a p-value of <0.001. Phosphorus and total benthic algae exhibited three large values in the study ponds which were from Cherry, Dugout and Yellow Flower (Figure 18).

Figure 21: The relationship between total dissolved phosphorus and total benthic algae



The concentration of total dissolved phosphorus was positively correlated with benthic green algae readings; having a p-value of <0.001 and indicating that the concentration of phosphorus in the water reflects a favorable environment for benthic green algal growth (Figure 19).

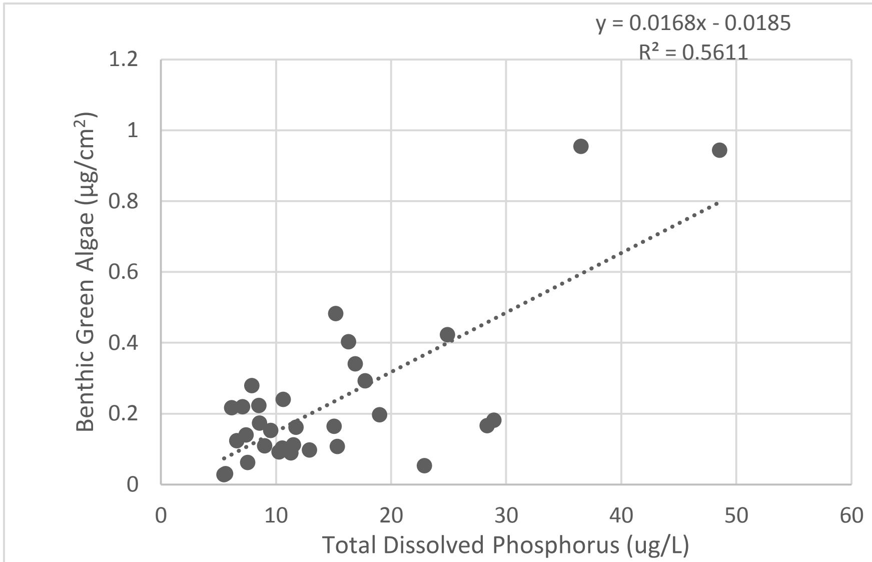


Figure 22: The relationship between total dissolved phosphorus and benthic green algae

Total dissolved phosphorus has a limited influence on benthic cyanobacteria; it only explains 11.7% of the variability in benthic cyanobacteria but has a significant effect with a p-value of <0.001 (Figure 20).

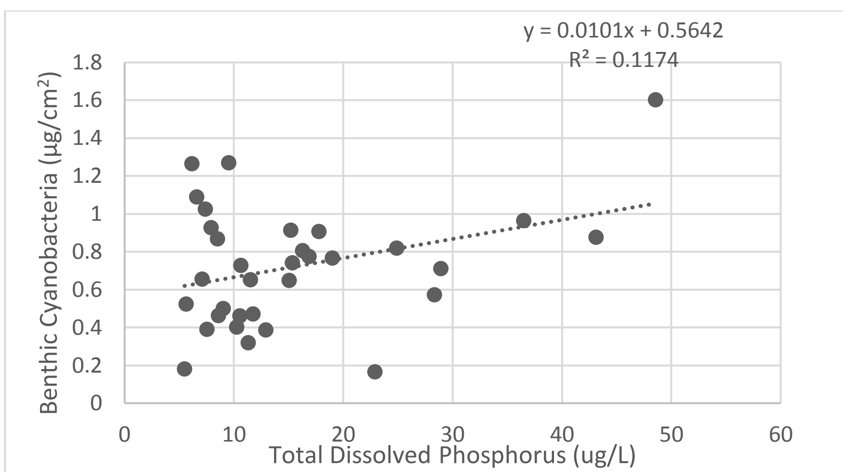


Figure 23: The relationship between total dissolved phosphorus and benthic cyanobacteria

$SUVA_{254}$ explains 29.2% of the total benthic algal variability with a p-value of <0.001 (Figure 21). There was a positive correlation between total benthic algal biomass and $SUVA_{254}$.

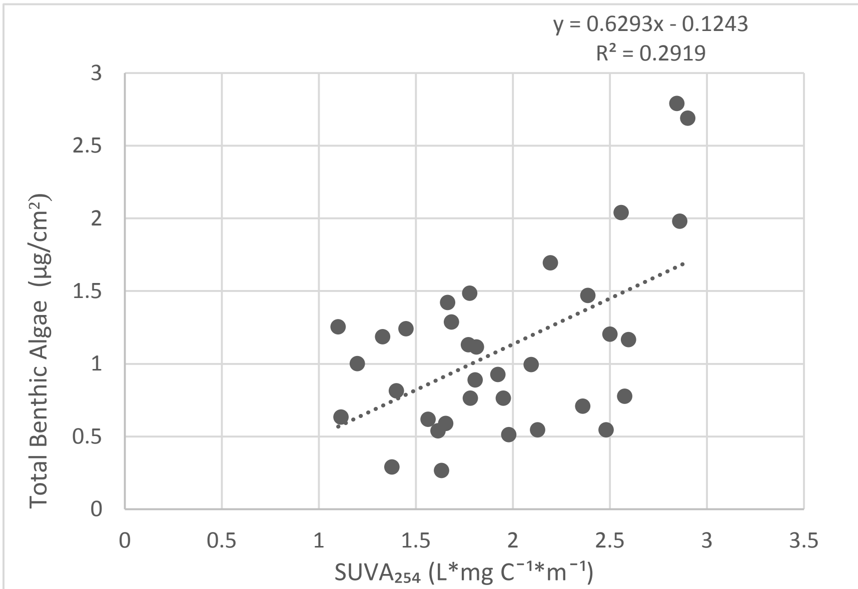


Figure 24: The relationship between $SUVA_{254}$ and total benthic algae

Benthic green algae tend to favor environments with high $SUVA_{254}$ values most likely due to its photoprotective effect on UV light, exhibiting a p-value of <0.001. Benthic green algae produce MAA's like cyanobacteria but are not as efficient in surviving in such harsh conditions (Carreto and Carignan, 2011). There are a couple outliers that are from ponds with very low surface areas; these exhibit the most favorable environments for benthic green algae (Figure 22).

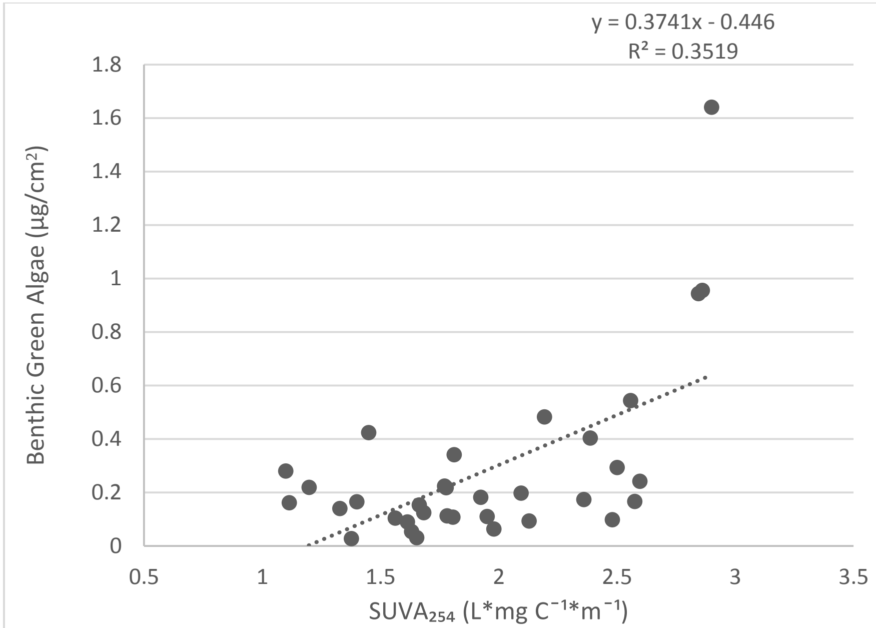


Figure 25: The relationship between $SUVA_{254}$ and benthic green algae

Figure 23 shows that benthic cyanobacteria abundances are not significantly correlated with $SUVA_{254}$, exhibiting a p-value of 0.11. This is likely due to the fact that they produce MAA (Mycrosporine-like Amino Acids) and other UV absorbing pigments (ex. Scytonemin) that effectively protect them from UV radiation (Bonilla et al., 2009). The algae tend to grow in benthic mats that have high concentrations of UV-absorbing pigments on the surface of the benthos with more photosynthetically-active pigments protected underneath (Hader et al., 2007). This natural adaption to UV radiation has shown that cyanobacteria are only slightly affected by the shading effect of $SUVA_{254}$ due to the competition of more favorable environments against green algae that live within these benthic mats (Figure 23).

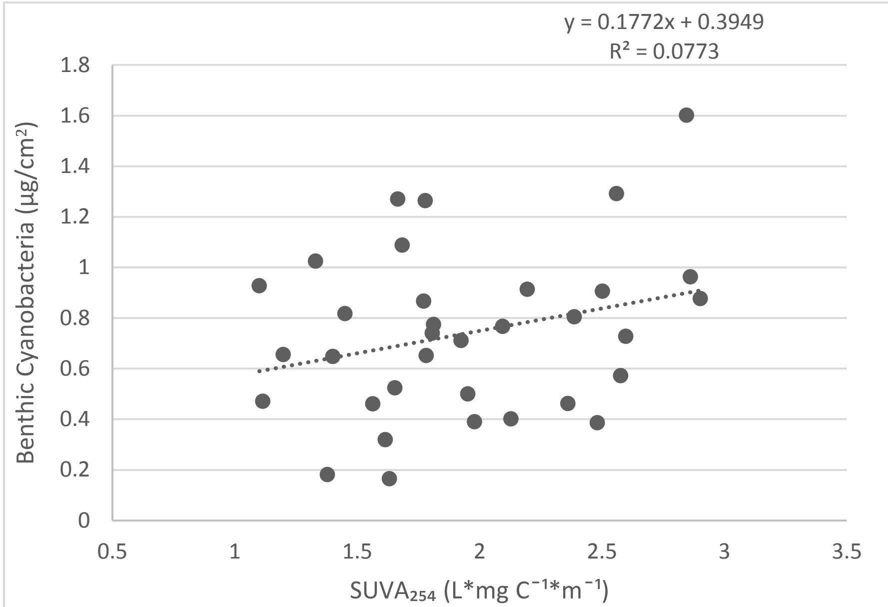


Figure 26: The relationship between $SUVA_{254}$ and benthic cyanobacteria

Benthic diatoms were very low in concentration overall, although some exhibit some phototaxis which is beneficial in this environment (Smetacek, 1985). Overall, benthic diatoms favored high concentrations of $SUVA_{254}$ with a p-value of <0.001 (Figure 24).

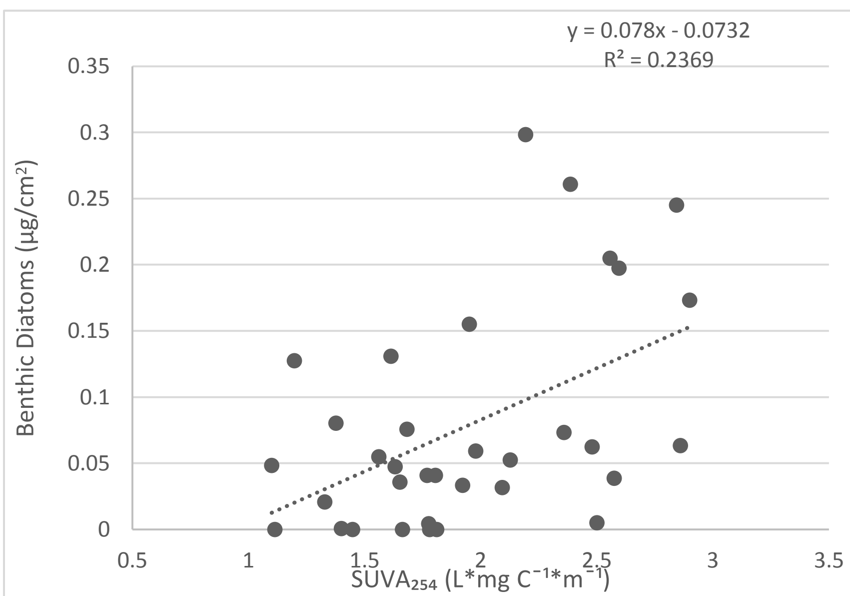


Figure 27: The relationship between $SUVA_{254}$ and benthic diatoms

The concentration of dissolved organic carbon was positively correlated with the abundance of benthic cyanobacteria, showing a significant p-value of 0.004 (Figure 25). The concentration of dissolved organic carbon indicates the amount of autochthonous and allochthonous carbon into the pond (Bade et al., 2007).

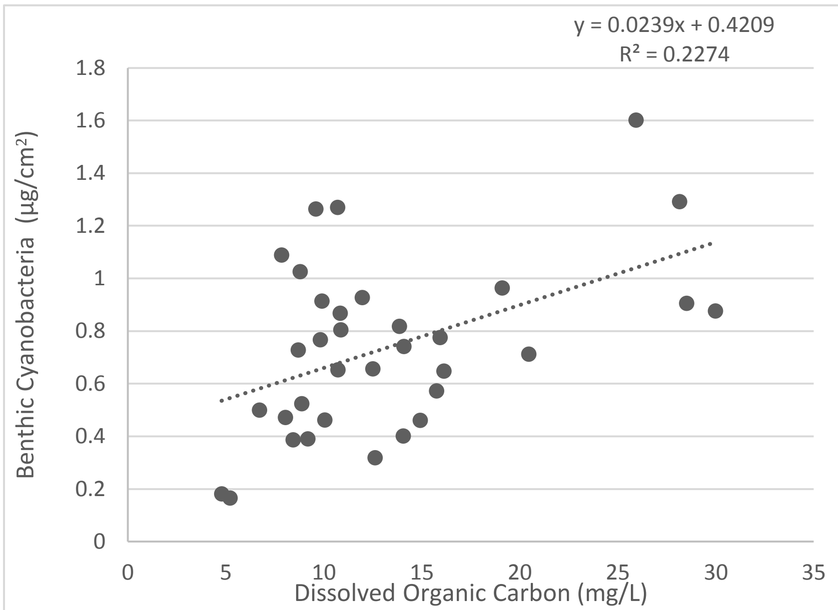


Figure 28: The relationship between dissolved organic carbon and benthic cyanobacteria

Cyanobacteria slightly favor environments with higher TDN concentrations, showing a p-value of 0.047 (Figure 26); this can be explained by the higher energy requirements on them to fix nitrogen. The more freely-available inorganic nitrogen is, the less energy cyanobacteria fix N_2 and the more energy is left from photosynthesis for other metabolic processes (Berman-Frank et al., 2003). Cyanobacteria require more energy to fix N_2 rather than obtaining it from NH_4 and NO_3, making it favorable for them to obtain nitrogen from the natural environment. Also, some energy and iron is required to reduce NO_3 to NH_4 inside the cell.

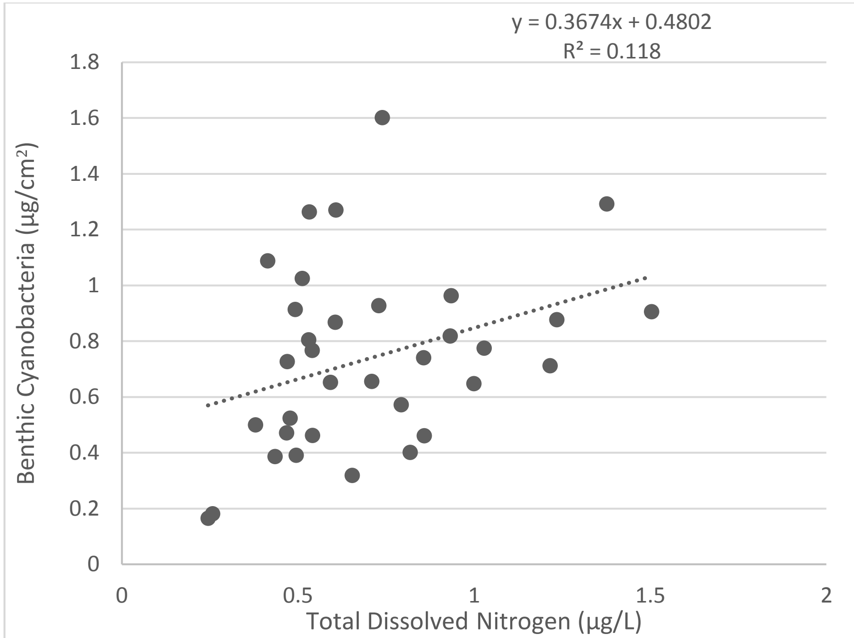


Figure 29: The relationship between total dissolved nitrogen and benthic cyanobacteria

The concentration of DOC was positively correlated with the abundance of benthic green algae with a significant p-value of <0.001 (Figure 27). The concentration of dissolved organic carbon explains 48.1% of the abundance of benthic green algae.

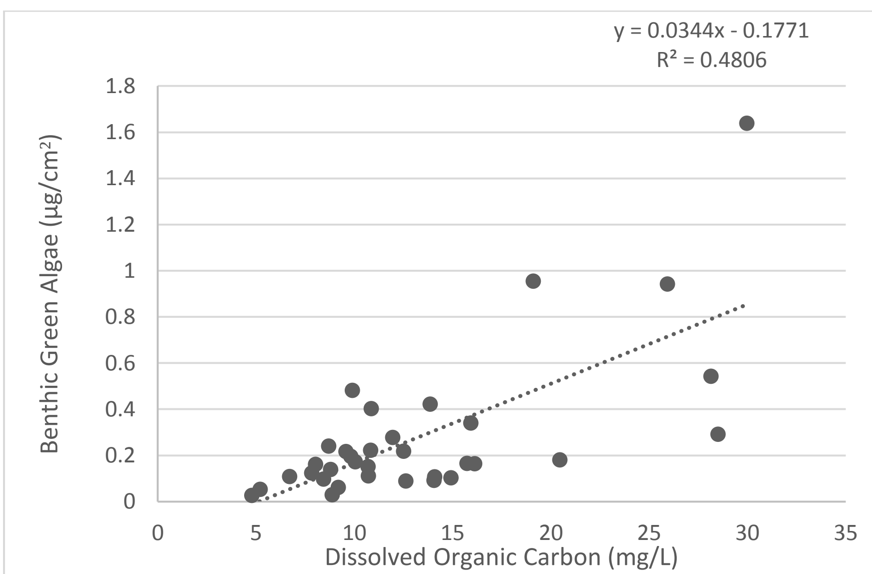


Figure 30: The relationship between dissolved organic carbon and benthic green algae

Green algae slightly favor environments with higher TDN concentrations, exhibiting a p-value of 0.006 (Figure 28). The concentration of total dissolved phosphorus seems to be the limiting nutrient for benthic green algae in this environment (Figure 16) and the shading effect by $SUVA_{254}$ is also more influential than total dissolved nitrogen on the concentration of benthic green algae (Figure 19).

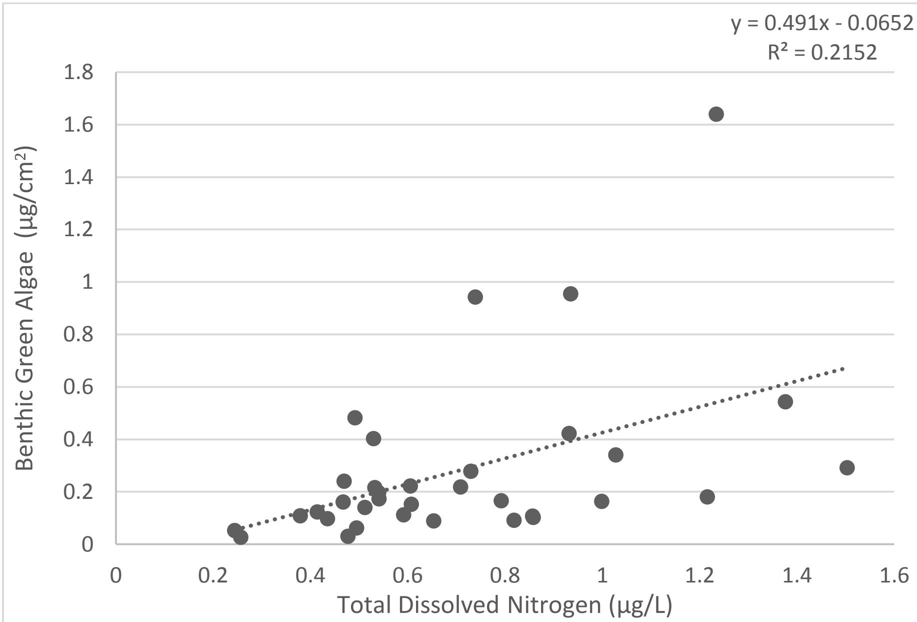


Figure 31: The relationship between total dissolved nitrogen and benthic green algae

It was observed that the concentration of benthic cyanobacteria was positively correlated to the concentration of benthic green algae at sampling locations during the July 2013 study season in Churchill, MB (Figure 35). There was a significant positive relationship between the concentrations of the two benthic algal groups with a p-value of 0.004 which suggests that similar factors control the distribution of both.

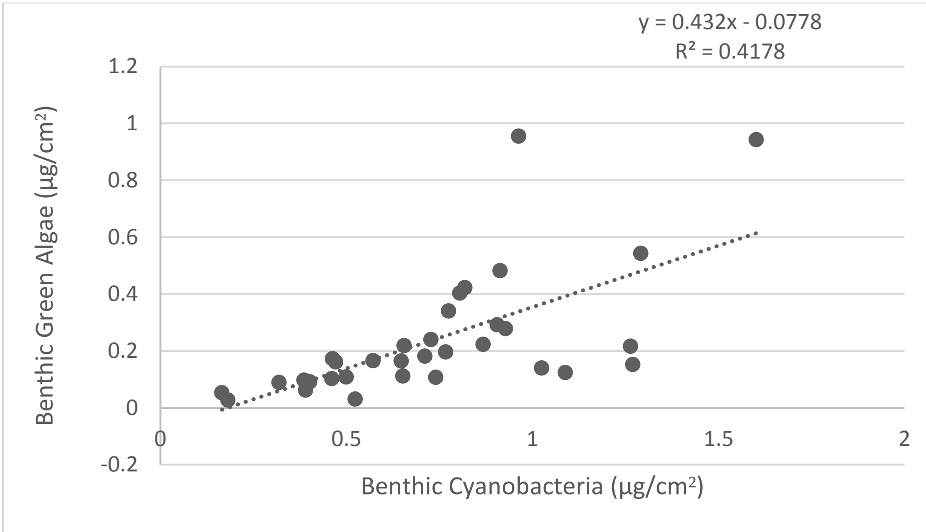


Figure 32: The mutualism between benthic cyanobacteria and benthic green algae

3.3 Comparison between 2012 and 2013 precipitation conditions:

Churchill, MB experienced higher levels of precipitation during July 2012 when compared to July 2013 (Table 14). July 2013 had lower total and more consistent precipitation than July 2012.

Table 12: Environment Canada rain data for July 2012 and 2013 in Churchill, MN.

Date	July 2012 Precipitation (mm)	July 2013 Precipitation (mm)
01-Jul	0	0.1
02-Jul	0	0.1
03-Jul	2.3	-
04-Jul	6.8	0.1
05-Jul	4.6	0
06-Jul	0.3	0
07-Jul	0	0.1
08-Jul	0	0.5
09-Jul	0.5	0
10-Jul	0	0.1
11-Jul	0	2.3
12-Jul	0	0.1
13-Jul	13.2	0.1
14-Jul	0	0.1
15-Jul	0	0.1
16-Jul	0	17.3
17-Jul	0	0.1
18-Jul	0	0.1
19-Jul	11	3.3
20-Jul	8.3	0.1
21-Jul	1.5	0
22-Jul	0	0.1

23-Jul	0.1	0
24-Jul	0	0.1
25-Jul	0	0.1
26-Jul	0	0.1
27-Jul	9.1	0.1
28-Jul	-	0.1
29-Jul	0	0
30-Jul	0	0.1
31-Jul	0	0.1
Total	**57.7**	**25.4**

July 2013 was a particularly dry month for Churchill, MB (Environment Canada Daily Data Report, 2013). Precipitation is the major inputs of water in the Hudson Bay Lowlands (Bello and Smith, 1990). The mean total precipitation for July in Churchill, MB through 1951-1980 was 45.6mm (Environment Canada, 1984); July 2012 was higher while July 2013 was lower than this mean.

Table 13: Environment Canada monthly rain data for 2012 and 2013 in Churchill, MB

	2012 Precipitation (mm)	**2013 Precipitation (mm)**
January	0.6	7.9
February	0	3
March	8.2	0.9
April	11.1	5.8
May	19.6	29.7
June	6.7	1.9
July	57.7	25.4
August	74.1	27.8
September	77.2	49.4
October	28.9	37
November	4.9	1.7
December	2.1	1
Total	**291.1**	**189.5**

The 2012 year experienced higher total precipitation levels when compared to the 2013 year in Churchill, MB (Environment Canada Daily Data Report, 2013). This could be partially due to the fact that 2012 was a La Nina year and did not experience the drought conditions of 2013 (Climate Prediction

Center, 2015). The mean precipitation for Churchill, MB through 1951-1980 was 402.3 mm (Environment Canada, 1984); both 2012 and 2013 datasets were well below this mean.

3.4 Comparison between 2012 and 2013 water chemistry:

A two-tailed paired t-test of DOC found in the same ponds in different years yielded a p-value of 0.002, proving a significant difference between the averages of DOC between years (Table 16). Two-tailed paired t-test of $SUVA_{254}$ found in the same ponds in different years yielded a p-value of 0.0143, proving a significant difference between the averages of $SUVA_{254}$ between years (Table 16). The ponds had slightly higher $SUVA_{254}$ and much lower DOC in the wet year of 2012 when compared to dry 2013. All ponds had higher allochthonous inputs in 2012 due to higher rainfall levels that increased water levels and basin connectivity to the ponds. $SUVA_{254}$ likely decreased in 2013 because of photo-bleaching caused by a longer residence time coupled with lower terrestrial inputs of 'new' carbon from the catchment (Helms et al., 2008). The increase in DOC from July 2012 to July 2013 was caused by a lack of dilution by precipitation and an increase in aeolian deposition from dry sources (Macrae, 1998).

Table 14: Comparison of the same ponds' $SUVA_{254}$ and Dissolved Organic Carbon concentrations between sampling years

	$SUVA_{254}$ 2012 ($L*mg\ C^{-1}*m^{-1}$)	**$SUVA_{254}$ 2013 ($L*mg\ C^{-1}*m^{-1}$)**	**DOC 2012 (mg/L)**	**DOC 2013 (mg/L)**
Maximum	4.90	2.90	24.03	29.98
Minimum	0.61	1.10	4.40	4.78
Median	2.38	1.99	9.46	13.23
Average	2.43	1.95	9.74	13.32
Standard Deviation	0.92	0.52	3.75	6.55
Covariance	0.38	0.18	0.39	0.49

A two-tailed paired t-test of S_R found in the same ponds in different years yielded a p-value of 0.021 (Table 17), while a two-tailed paired t-test of E2:E3 found in the same ponds in different years yielded a p-value of 0.01232 (Table 17). The same ponds sampled in 2012 had higher molecular weight compounds, aromaticity, and humification levels than in 2013 (Helms et al., 2008).

Table 15: Comparison of the same ponds' water sample spectral characteristics between sampling seasons

	S_R		E2:E3	
	2012	**2013**	**2012**	**2013**
Maximum	1.65	1.67	17.29	35.45
Minimum	0.30	0.78	2.29	4.49
Median	0.99	1.23	6.94	15.02
Average	1.03	1.24	6.90	14.87
Standard Deviation	0.30	0.20	3.61	7.34
Covariance	0.29	0.16	0.52	0.49

Two-tailed paired t-test of TDP found in the same ponds in different years yielded a p-value of 0.007 (Table 18). The ponds had a higher average concentration of TDP in July 2013 than July 2012 (Table 18).

Table 16: Comparison of the same ponds' total dissolved phosphorus concentrations between sampling seasons

	TDP 2012 (µg/L)	**TDP 2013 (µg/L)**
Maximum	38.26	72.66
Minimum	2.98	5.48
Median	8.32	16.50
Average	8.91	17.34
Standard Deviation	7.19	14.44
Covariance	0.81	0.83

3.4.1 Comparison of benthic green algae and cyanobacteria's instantaneous fluorescence and quantum yield for sampled ponds in 2013:

Pelagic green algae had higher instantaneous fluorescence (Ft) and quantum yield (Qy) results than the pelagic cyanobacteria in the 2013 study period. A two-tailed, t-test revealed a p-value of <0.001 for the average instantaneous fluorescence values and a p-value of <0.001 for the average quantum yields between the two algal groups. This indicates that pelagic green algae were more photosynthetically active than pelagic cyanobacteria during our measurements (Table 19).

Table 17: Comparison of the instantaneous flourescence and quantum yield of pelagic green algae and cyanobacteria in 2013 sample ponds

	Green Algae (Ft)	**Green Algae (Qy)**	**Cyanobacteria (Ft)**	**Cyanobacteria (Qy)**
Maximum	550.50	0.21	90.00	0.07
Minimum	122.50	0.04	43.00	0.00
Median	221.23	0.11	54.71	0.00
Average	227.63	0.12	56.91	0.00
Standard Deviation	106.78	0.04	11.32	0.01
Covariance	0.47	0.34	0.20	4.29

Instantaneous fluorescence of pelagic green algae was positively correlated with total dissolved nitrogen with a p-value of <0.001 (Figure 30). Pelagic green algae tended to be more photosynthetically active in environments that were high in total dissolved nitrogen (Figure 30).

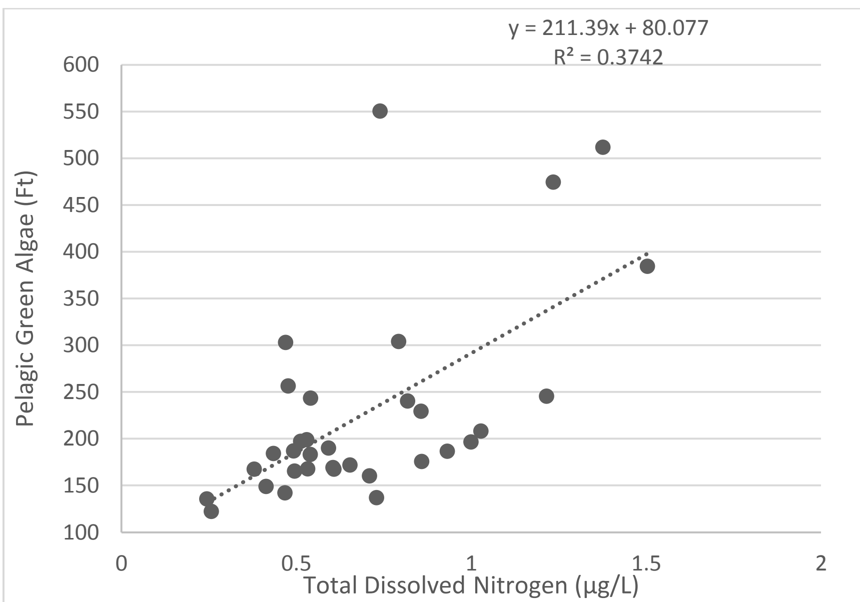


Figure 33: The relationship between total dissolved nitrogen and pelagic green algae's instantaneous fluorescence

Instantaneous fluorescence of pelagic cyanobacteria was positively correlated with total dissolved nitrogen with a significant p-value of 0.016 (Figure 31). Pelagic cyanobacteria tended to be slightly more photosynthetically active in environments that were high in total dissolved nitrogen but were not as influenced by total dissolved nitrogen as pelagic green algae was (Figure 31).

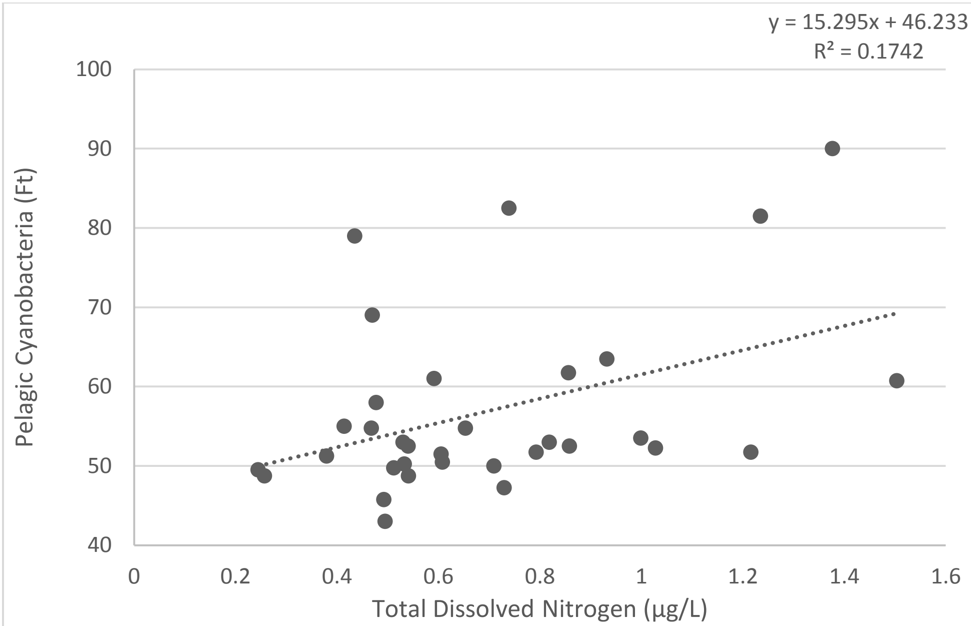


Figure 34: The relationship between total dissolved nitrogen and pelagic cyanobacteria's instantaneous fluorescence

Instantaneous fluorescence of pelagic green algae was positively correlated with total dissolved phosphorus with a p-value of <0.001 (Figure 32). Pelagic green algae tended to be more photosynthetically active in environments that were high in total dissolved phosphorus (Figure 32).

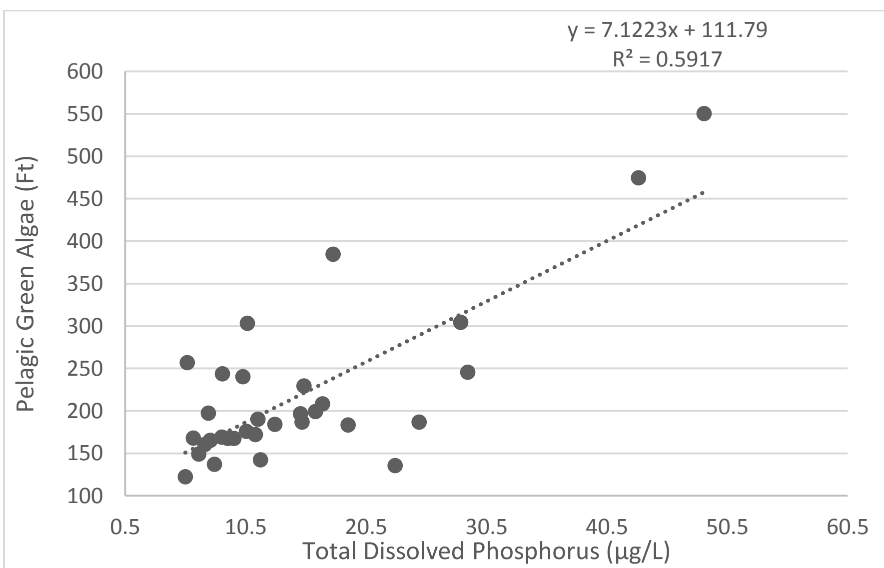


Figure 35: The relationship between total dissolved phosphorus and pelagic green algae's instantaneous fluorescence

Instantaneous fluorescence of pelagic cyanobacteria was positively correlated with total dissolved phosphorus with a p-value of <0.001 (Figure 33). Pelagic cyanobacteria tended to be more photosynthetically active in environments that were high in total dissolved phosphorus, showing two high values in both parameters in Dugout and Cherry pond (Figure 33).

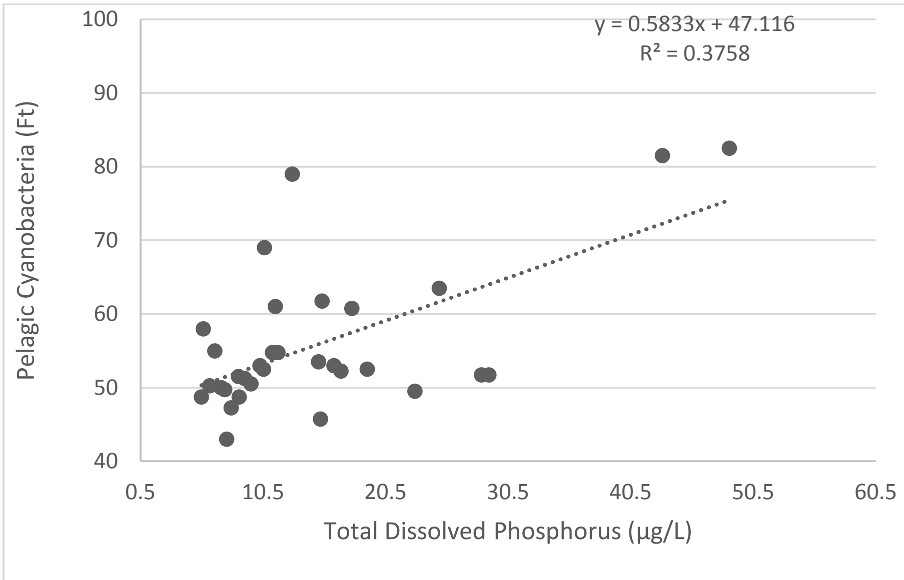


Figure 36: The relationship between total dissolved phosphorus and pelagic cyanobacteria's instantaneous fluorescence

Instantaneous fluorescence of pelagic green algae was positively correlated with $SUVA_{254}$ with a p-value of <0.001 (Figure 34). Pelagic green algae tended to be more photosynthetically active in environments that were high in $SUVA_{254}$ (Figure 34).

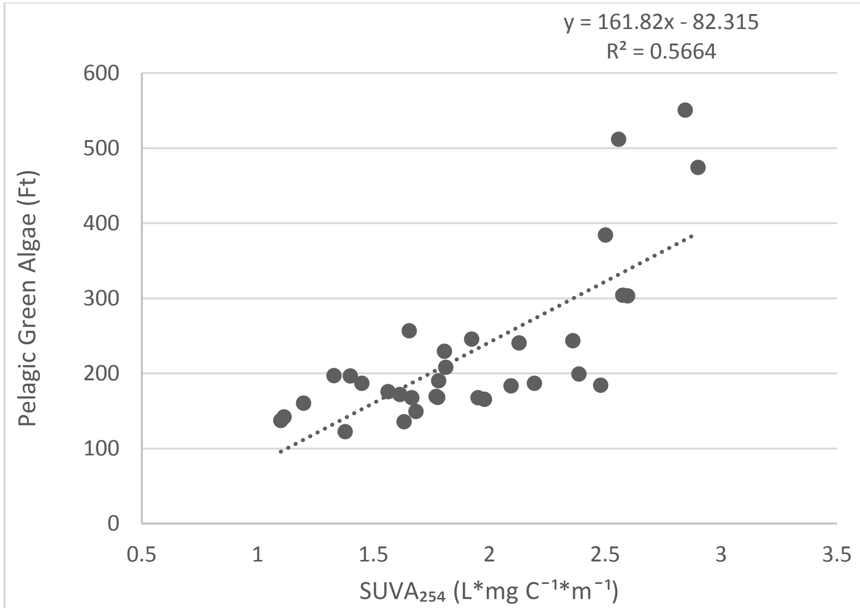


Figure 37: The relationship between $SUVA_{254}$ and pelagic green algae's instantaneous fluorescence

Instantaneous fluorescence of pelagic cyanobacteria was positively correlated with $SUVA_{254}$ with a p-value of <0.001 (Figure 35). Pelagic cyanobacteria tended to be more photosynthetically active in environments that were high in $SUVA_{254}$.

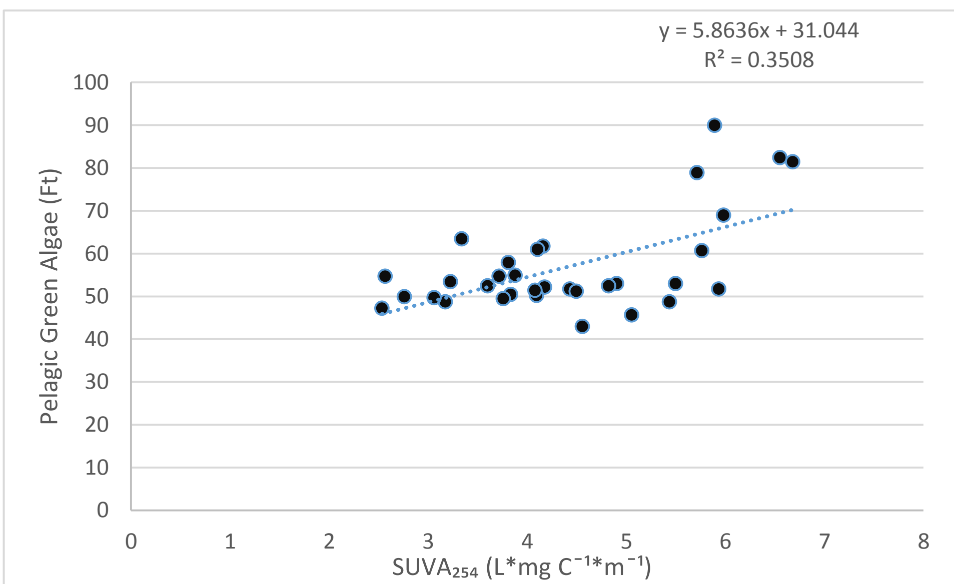


Figure 38: The relationship between $SUVA_{254}$ and cyanobacteria's instantaneous fluorescence

3.5 Extremes in the 2013 dataset:

As seen above in Figures 10 and 12, small ponds show higher nutrient levels (Figure 10) and $SUVA_{254}$ concentrations (Figure 12) when compared to ponds with higher surface areas; these facts are supported by Table 20 where four ponds wit very large and very small extremes in surface areas exhibit large differences in nutrient statuses. Small ponds cover a large proportion of the number of ponds that exist in the Hudson Bay Lowlands (Firankski, 2000) and are an important source of greenhouse gases (Negandhi et al., 2013).

Table 18: Extremes in the 2013 dataset

Name	Dugout Pond	Cherry Pond	Lindy Lake	Ramsey Lake
Surface Area (m2)	5	5	502300	1017500
DOC (mg/L)	30.0.	19.1	5.2	4.8
TDN (mg/L)	1.23	0.93	0.244	0.26
TDP (ug/L)	43.12	36.50	22.90	5.48
$SUVA_{254}$ (L*mg C^{-1}*m^{-1})	2.9	2.8	1.6	1.4
Benthic Cyanobacteria (µg/cm^3)	0.88	0.96	0.17	0.18
Benthic Green Algae (µg/cm^3)	1.64	0.96	0.05	0.03
Benthic Diatoms (µg/cm^3)	0.17	0.06	0.05	0.08
Total Concentration of Benthic Algae (µg/cm^3)	2.69	1.98	0.27	0.29
Reflection	0.67	0.17	10.17	13.21
Longitude	-93.84	-93.86	-93.81	-93.79
Latitude	58.73	58.76	58.72	58.73
Ft (450)	474.50	493.00	135.75	122.50
QY450	0.20	0.10	0.10	0.04
Ft (620)	81.5	122.5	49.5	48.75
QY620	0.07	0.035	0.000	0.000
Specific Conductance (µS cm^{-1})	222.67	490.17	167.75	182.46
TDS (µg L^{-1})	0.14	0.32	0.11	0.12
Salinity (ppt)	0.11	0.24	0.08	0.09
pH	8.66	8.60	8.95	8.81

4.0 Discussion:

4.1 Surface area:

The surface area of the 75 ponds sampled in July 2012 (Figure 5, Figure 6), and the subset sampled in 2013 (Figure 13 and 14), varied considerably (Table 1 and Table 8, respectively); ponds were chosen to be proportionate to their distribution in the surrounding region (Firanski, 2000). This was done in order to capture a wide variety of pond types with different origins; different pond types dominated in different surface area groups as proved by Firanski, 2000. Organic ponds dominated the 0-4,000m² class and topographic lakes dominate in the 8,000-10,000m² class (Firanski, 2000). The proportion of ponds within a size class increased as the surface area of the pond group decreased for the study site (Firanski, 2000); hencethe pond group with the lowest surface area would have the highest number of ponds (Figure 5, 6, 13 and 14).

The concentrations of total dissolved phosphorus, $SUVA_{254}$ and calcium were found to be significantly higher in ponds with <2,000m² surface areas when compared to ponds with >8,000m² surface areas (Figure 10, 11, and 12). This suggests that ponds with <2,000m² surface areas are harder and more eutrophic than ponds with >8,000m²(Figure 10) (Likens, 2010). Organic ponds also dominate in the <2,000m² pond group (Firanski, 2000). All ponds have organic matter in them to varying degrees but the term organic pond is used to describe a pond type in fens with small surface areas; these ponds were created by a higher buildup of organics on the sedges around the perimeter of the pond (found in higher elevations) than the buildup of organics on the lower grassy areas (Firanski, 2000).

4.2 Cations and pond water quality:

The average sodium concentrations was 31.9 mg/L (Table 3) which is high for freshwater (Likens, 2010). The average sodium concentration of previous samples was 10.219 +/- 6.143 mg/L (White, 2011). Also, in another study near the Churchill Northern Studies Center, the sodium concentrations in 2014 were 15.05 +/- 6.78 mg/L (Morison, 2014). The Churchill ponds had an average of 8.5 mg/L of calcium in 2012 which was lower than Gray's lowest results, possibly due to the increased rainfall (Table 14 and 15) during that period (Gray, 1987). The average is also on the low end of Macrae's results which ranged from 0 to 63 mg/L (Macrae, 1998). The average calcium concentration of a previous study was 15.247 +/- 3.235 mg/L (White, 2011). The average calcium concentration of a previous study near the Churchill Northern Studies center showed similar values of 10.78 +/- 7.15 mg/L (Morison, 2014). The average 2012 dissolved magnesium concentrations for Churchill, MB were 1.2 mg/L; which was low compared to Macrae's results which ranged from 0 to 25 mg/L due to increased rainfall (Table 14 and 15) during that period (Macrae, 1998). The average magnesium concentration in White's study was 8.024 +/- 2.532 mg/L (White, 2011). The average concentration of magnesium in a previous study near the Churchill Northern Studies Center was much higher at 9.89 +/- 5.39 mg/L (Morison, 2014). The average 2012 potassium concentrations for this study were 3.18 +/- 1.64 mg/L. The average potassium concentration for White's study was 2.371 +/- 1.413 mg/L (White, 2011). The average potassium concentrations of a pervious study near the Churchill Northern Studies Center was 1.38 +/- 0.88 mg/L (Morison, 2014).

The high levels of calcium observed in 2012 is consistent with high alkalinity and pH (Macrae, 1998). This explains the relatively high specific conductance in the sampled water (Table 4). The calcium carbonate deposits in the ponds surrounded by limestones and dolomites are sources of the high levels of calcium (Macrae, 1998). Overall, the sampled ponds exhibited high calcium levels supplied by bedrock weathering in the ponds sampled (Macrae, 1998). The high sodium concentrations can be explained by the close proximity of the sampled ponds to the Hudson Bay Coast (Macrae, 1998). Also, differences in cation concentrations between this study and others can be explained by differences in ponds sampled, pond type, the season of sampling, weather dynamics, sampling/analysis methods and temporal differences. Furthermore, there are high variances in the cation concentrations between ponds sampled. Calcium is known to bind to phosphorus and explains relatively low concentrations found in these ponds (Gray, 1987).

The average specific conductance for Churchill, MB in the 2012 sampled ponds was 449.01 (µS cm^{-1}) (Table 4). The average specific conductance for Churchill, MB in the 2013 sampled ponds was 420.7 (µS $cm^{-1}s$) (Table 10). Both of the study seasons exhibited slightly lower pond specific conductivities than previous studies on Churchill ponds. The average specific conductance for Churchill, MB was 582 +/- 93 (µS $cm^{-1}s$) (Rautio et al., 2011), and 198-590 (µS $cm^{-1}s$) (Gray, 1987). The average specific conductance of White's 2011 samples was 353.9 +/- 214.83 (White, 2011). The average pH for the study ponds in 2013 was 8.97 (Table 10) and for the study ponds in 2012 was 8.4 (Table 4). The average pH for Churchill ponds were 8.3 (Macrae, 1998), 8.1 +/- 0.1 (Rautio et al., 2011), 8.76 +/- 0.33 (White, 2011) and a range of 7.15-9.21 (Gray, 1987). The sampled ponds exhibited similar values of high conductivity and basic pH when compared to previous studies done in similar regions (Rauito et al., 2011). The specific conductance and pH averages were considered high when compared to other regions (Rauito et al., 2011). The high dissolved oxygen concentrations obtained can be explained by photosynthesis and the high mixing rates of the ponds in Churchill, MB where the ponds don't stratify so that oxygen reflects the atmospheric conditions (Macrae, 1998).

4.3 Pelagic chlorophyll:

The sampled 2012 ponds had an average pelagic chlorophyll a concentration of 1.29 +/- 0.93 (µg/L) (Table 5); compared to the 1.82 +/- 1.75 (µg/L) average chlorophyll a concentration collected in a previous study (White, 2011). The thaw ponds found throughout the Arctic tundra are considered to be mesotrophic to oligotrophic in the water column and eutrophic in the sediments which explains the low concentrations of pelagic chlorophyll in the ponds that have been studied previously (Rautio et al., 2011). The shallow water column existing in these thaw ponds produces an unfavorable environment for pelagic algal growth; only algae adapted to harsh UV radiation can survive in these types of clear, shallow (Appendix B) and mesotrophic oligotrophic environments (Seckbach, 2007).

4.4 DOC and nutrient levels:

The average concentration of dissolved organic carbon for 2012 study ponds was 9.28 +/- 3.00 (Table 5) and for 2013 study ponds was 13.32 +/- 6.55 mg/L (Table 11); the DOC concentrations were 12.0 +/- 1.0 mg/L in previous studies (Rautio et al., 2011). The 2013 and 2012 concentrations of DOC were close to previous DOC concentrations collected in Churchill, MB (Rautio et al., 2011). However, a large range in DOC concentrations existed in the 2012 and 2013 datasets indicating different types of pond origins (Firanski, 2000). The surrounding soil properties, position in relation to the tree line, and the catchment characteristics of the pond sampled results in a high variance in DOC concentrations (Rautio et al., 2011). Churchill ponds that were sampled had a large range in surrounding soil properties and catchment characteristics; they were either surrounded by fens, Arctic tundra or bare rock (Gray, 1987).

Nitrogen is also a major nutrient that is vital to plant and algal growth (Gray, 1987). The total amount of nitrogen in a water sample consists of nitrate, nitrite, ammonia and organic nitrogen; nitrate, nitrite and ammonia are available for phytoplankton growth (Chin, 2006). Organic nitrogen is split into particulate (detritus or phytoplankton) and dissolved nitrogen groups (Chin, 2006); this study sampled total dissolved nitrogen. The average concentration of TDN for the 2012 study ponds was 0.52 +/- 0.16 (Table 5) and for the 2013 study ponds was 0.7 +/- 0.31 mg/L (Table 11). This suggests that Churchill ponds are oligotrophic, low in nitrogen concentrations and similar to other Arctic thaw ponds' water columns (Rautio et al., 2011).

The average concentration of TDP for 2012 study ponds was 8.17 +/- 5.20 (Table 5) and for the 2013 study ponds was 15.67 +/- 10.80 µg/L (Table 11). Total phosphorus concentrations of 3 study ponds found in Churchill, MB ranged of 13-22 µg/L; it was found that phosphorus was the limiting nutrient in these ponds considered mesotrophic (small surface area) to oligotrophic (large surface area) (Macrae, 1998). The total phosphorus found in Churchill, MB in a previous study was 12.0 +/- 1.0 µg/L and soluble reactive phosphorus was 4.0 +/- 0.5 µg/L (Rautio et al., 2011). These values are relatively low when compared to other regions, suggesting the water column in these Hudson Bay Lowland ponds (Macrae, 1998). Organic nitrogen, organic carbon and organic phosphorus flushes into the water column during spring melt and fall storms that cause hydrological conductivity between ponds and their surrounding catchments; during the summer, these sources become minimal, the atmospheric deposition and precipitation inputs become important nutrient sources (Macrae, 1998). The lower but more constant rates of precipitation in the study year of 2013 caused an increase in total dissolved nutrient concentrations in the study ponds when compared to 2012 (Table 18); the higher DOC concentrations in the same ponds are higher in 2013 due to increased catchment connectivity caused by consistent precipitation (Table 16). The total suspended solids results for ponds sampled in 2012 had an average of 2.6 +/- 1.55 (mg/L) (Table 5); this value is quite low compared to permafrost thaw ponds in the Arctic (Laurion et al., 2010).

Phosphorus can be divided into two groups: dissolved and particulate (Chin, 2006). Total dissolved phosphorus is often referred to as the bioavailable fraction of phosphorus to plant and algae growth (Fresh Water Quality Monitoring & Surveillance, 2013). The total dissolved phosphorus includes dissolved reactive phosphorus (orthophosphates) that are available for phytoplankton growth and complex dissolved organic phosphorus which is not available for phytoplankton growth (Chin, 2006). When phosphorus is added to the water, most of it is absorbed by the sediments and not the algae or plants (Boyd, 1971). The calcium-rich sediments of ponds found in the Hudson Bay Lowlands tend to readily absorb to the available phosphates that have been added to the water; a noticeable change in concentration occurs only after continuous additions (Gray, 1987). The phosphorus in the sediments may be released by calcium, aluminum or iron depending on the dynamic equilibrium maintained between the sediment and water interface (Boyd, 1971) or by bioturbation by benthic invertebrates and chemical transformations by water chemistry changes (Danos, et al., 1983). Overall, phosphorus is a limiting nutrient in this environment that is readily scavenged and limits algae growth (Figure 18). Phosphorus is a major limiting nutrient for cyanobacteria (Lurling and Faassen, 2012) and green algae (Parr and Smith, 1976). Phosphorus in sediment pools can be accessed by cyanobacteria which explains the low correlation between benthic cyanobacteria and total dissolved phosphorus; some taxa of cyanobacteria have the ability to access phosphorus in sediments even under oxygenated environments (Cottingham et al., 2015). Certain cyanobacteria taxa have a high-affinity phosphate uptake system activated at low phosphorus conditions, the capacity for luxury uptake so they can store phosphorus for later and the production of an extracellular polyphosphatase enzyme to access organic or sediment-bound phosphorus (Cottingham et al., 2015).

The total dissolved phosphorus explained 13% of the variability in the pelagic chlorophyll a concentrations found in the 2012 summer field season (Figure 7). Phosphorus concentration correlated positively with pelagic algae, suggesting that the pelagic algae in the water column were limited by phosphorus (Gray, 1987). (Table 11). The average instantaneous fluorescence (Ft) and quantum yield (Qy) found for the 2013 pelagic green algae (450nm) were significantly higher than the 2013 pelagic cyanobacteria (620nm) (Table 19). This suggests that the green algae were more photosynthetically active in the water column of sampled ponds when compared to cyanobacteria (Table 19).

The instantaneous fluorescence of pelagic green algae and cyanobacteria are positively correlated with phosphorus, nitrogen and $SUVA_{254}$ pond concentrations throughout this study. When the instantaneous fluorescence of green algae and cyanobacteria are plotted against total dissolved nitrogen (Figure 29 and 30), there is a slightly stronger correlation for green algae. This could be explained by the nitrogen-fixing characteristics of many cyanobacteria (Berman-Frank et al., 2003). The instantaneous fluorescence of pelagic green algae and cyanobacteria are both higher in ponds that exhibit high levels of phosphorus (Figure 31 and 32); mainly because it is a major limiting nutrient that is essential for algal growth (Gray, 1987).

Nitrogen was not limiting to algae growth in this environment; cyanobacteria species are capable of fixing nitrogen in their heterocysts during low nitrogen conditions (Figure 26) (Berman-Frank et al., 2003). The benthic green algae concentrations are better related to $SUVA_{254}$ (Figure 22) and phosphorus (Figure 19) than nitrogen (Figure 28). Benthic cyanobacteria and benthic green algae do not appear to be primarily limited by nitrogen in the Hudson Bay Lowlands (Gray, 1987; Macrae, 1998).

Mulitvariate statistics on algal data and nutrient/DOC/SUVA (Appendix C) has found that TDP and DOC are highly variable and correlated with each other (Table C1). This is due to the fact that TDP and DOC originate from organic molecules and are typically associated with each other (Klug, 2005). The presence of organic molecules increases the concentration of both TDP and DOC, which makes it difficult for the data to be separated to determine which parameter is more limiting to algal growth (Klug, 2005). Appendix C expresses how the DOC and TDP express similar variabilities and are difficult to determine which is more influential on algal variability (Appendix C). What the data explains is that these organic molecules as a whole brings TDP and DOC into the environment which facilitates algal growth (Klug, 2005). The organic molecules both shades the algae from UV radiation and provides limiting nutrients to the algae (Klug, 2005). It serves a dual purpose and it is difficult to separate these highly correlated variables due to the fact that they originate from the same source (Klug, 2005). TDP tended to have the highest and most significant correlations to benthic cyanobacteria and green algae while SUVA tended to have the highest and most significant correlations to benthic diatoms. The diatom concentrations were very low and the only time they were found was when SUVA was high. The benthic cyanobacteria and benthic green algae were most limited by TDP, suggesting that these communities are limited by phosphorus as seen in previous studies (Gray, 1987). Pelagic green algae were limited by both SUVA and TDP, suggesting that these communities required both shading and nutrient enrichment. TDP and TDN were the most limiting nutrients to pelagic cyanobacteria, suggesting that these communities were mesotrophic to oligotrophic (Appendix C).

4.5 Absorbance characteristics:

$SUVA_{254}$ is a measurement of the absorbance of UV light by a water sample which provides an understanding of the protecting effect of the water sample for algae found in it (Weishaar et al., 2003). $SUVA_{254}$ affects algae growth in many ways due to the resource availability (Klug, 2005) and UV radiation absorbance (Bertilsson and Tranvik, 2000 and Oestreich et al., 2015). The S_R parameter indicates a change from high-molecular-weight to low-molecular-weight as it increases, making it a good indicator of CDOM characteristics (Helms et al., 2008). The molecular size of the DOM molecules also increased as the E2:E3 ratios decreased because of stronger absorption by high molecular weight molecules (Helms et al., 2008). The concentrations of $SUVA_{254}$ in the sampled ponds produced an average of 2.43 +/- 0.97 in 2012 (Table 6) and 1.95 +/- 0.52 in 2013 (L*mg C^{-1}*m^{-1}) (Table 12); these values are much lower than the average of 5.4 (L*mg C^{-1}*m^{-1}) obtained in lakes found near the Arctic LTER site in Brooks Range Alaska (Cory et al., 2007). The S_R slope average for 2012 sampled ponds was 1.03 +/- 0.3 (SU) (Table 6) and 1.28 +/- 0.19 (SU) for 2013 sampled ponds (Table 12). The average E2:E3 ratios for samples taken in July 2012 were 8.98 +/- 2.85 (SU) (Table 6). The average E2:E3 for samples taken in July 2013 were 8.75 +/- 1.93 (SU) (Table 12). These values suggest that the Churchill ponds are low in molecular weight, humification and aromaticity relative to the Elizabeth River, Virginia, USA (Helms et al., 2008). $SUVA_{254}$ is relative to the allochthonous carbon inputs in the water column (Helms et al., 2008) and these low values suggests that there is a lack of allochthonus input through low rainfall, leading to increased hydrological connectivity between ponds and input of organic matter from the surrounding watershed (Environment Canada, 2012 and 2013), a lack of organics in surrounding soil types (Gray, 1987) and primarily the high photo-degradation of DOC (Rautio et al., 2011). Only a few outliers exhibit high $SUVA_{254}$ concentrations due to small surface areas of the ponds (Table 20), and high organic matter inputs (Firanski, 2000).

The instantaneous fluorescence of pelagic green algae and cyanobacteria are higher in ponds with greater concentrations of the UV-absorbing estimator $SUVA_{254}$ (Oestreich et al., 2015). The concentrations of total benthic algae (Figure 21), green algae (Figure 22), cyanobacteria (Figure 23) and diatoms (Figure 24) are positively correlated with $SUVA_{254}$ due to its UV-absorbing (Oestreich et al., 2015) and resource-containing properties (Klug, 2005). The cyanobacteria were the least (7.7%) ex well correlated to $SUVA_{254}$ (Figure 23); this is due to the fact that cyanobacteria have the ability to create scytonemin and mycrosporine-like amino acids that protect them from UV radiation (Hader et al.,2007). These benthic mats have already adapted to high UV radiation conditions and do not respond to further shading by $SUVA_{254}$. This is also seen in the pelagic environment where pelagic cyanobacteria have a lower positive correlation with $SUVA_{254}$ than pelagic green algae (Figure 33 and 34).

The concentration of $SUVA_{254}$ was positively correlated with total dissolved phosphorus concentrations (Figure 8 and 12); indicating a higher import of both nutrients and carbon into certain ponds. Dissolved organic carbon is an estimate of organic matter that contains nitrogen and phosphorus which would become available to phytoplankton or cyanobacteria following photochemical or microbial degradation (Klug, 2005). The elevated values of phosphorus and $SUVA_{254}$ indicate a favourable growth environment for algae (Boyd, 1971; Klug, 2005). Phosphorus is retained by organic matter that is allochthonus and autochthonous; some of the phosphorus is bound to calcareous sediments and is immobilized (Gray, 1987) until it is eventually precipitated (Wandruszka, 2006).

The concentration of $SUVA_{254}$ was negatively correlated with pH values (Figure 9). This could be partially due to the effect of organic acids in CDOM to naturally lower pH in freshwaters. Also, the dissolved oxygen values are high in Churchill ponds and do not limit CDOM consumption due to the high rates of circulation in these ponds (Table 4).

4.6 The effect of the surface area of the pond on available nutrients

The ponds of low surface areas exhibited higher concentrations of total dissolved phosphorus than ponds of higher surface areas (Figure 10); this was also observed for $SUVA_{254}$ (Figure 12). The larger the surface area of the pond, the higher the chance that the pond type is of topographical origin and will have lower amounts of stored peat (Firanski, 2000). Topographic ponds or lakes are relatively young in age and usually found in steeper, well drained areas that would result in lower peat accumulation. The smaller the surface area of the pond, the higher the chance the pond type is organic or thermokarst and will have higher amounts of stored peat and nutrient availability than topographic lakes or ponds (Firanski, 2000). Also, the smaller surface areas allow for greater inputs from the catchment per volume of pond water (Firanski, 2000). The ponds of low surface areas also exhibited higher concentrations of dissolved calcium than ponds of higher surface areas due to their binding effect with phosphorus in the water column (Figure 11). The calcium carbonate in the water column binds to phosphorus and is indicative of the nutrient status of the ponds or lakes (Boyd, 1971).

4.7 Benthic algae:

The total concentrations of benthic algae were positively correlated with TDP (Figure 18) and $SUVA_{254}$ (Figure 21). Total dissolved phosphorus was generally low in concentration throughout the study period with a select few large outliers that were low in surface area values and high in total benthic algae concentrations (Table 20). Similar to pelagic algae, total dissolved phosphorus is the limiting nutrient for benthic algal growth in this environment; these findings are consistent with findings from Macrae (1998) and Gray (1987). $SUVA_{254}$ is known to cause a shading effect and is seen here to have a positive correlation with total benthic algae in the sampled ponds; most likely due to a UV protection effect by the CDOM during photodegradation (Oestreich et al., 2015) and the release of nutrients (Klug, 2005).

The benthic cyanobacterial mats dominated in the Hudson Bay Lowland ponds; these ponds were found in the coast, rock bluffs, fen, and Subarctic tundra environments near the Churchill Northern Studies Center (Figure 15 and 16). This is consistent with other studies done in Subarctic regions (Jungblut et al., 2012). The water columns of these ponds are considered to be mesotrophic to oligotrophic while the sediments are nutrient-rich and considered to be eutrophic (Rautio et al., 2011). The pelagic algae suffer from high UV radiation levels due to the shallow depths of these ponds (Appendix B) (Rautio et al., 2011) and their relatively low concentrations of colored dissolved organic matter (Laurion and Mladenov, 2013). Colored dissolved organic matter absorbs UV radiation and protects algae from its harmful effects (Ayoub et al., 2008).

Benthic cyanobacteria form mats overlying the sediments that have a vertical transition from UV-absorbing pigments, MAAs and scytonemin, to more photosynthetically-active pigments such as chlorophyll a (Hader et al., 2007). These structured mats are adapted to survive in these highly radiative environments (Hader et al., 2007). The scytonemin, MAA and other pigments are also able to resist stress from desiccation, salinity or low temperatures (Bonilla et al., 2009); this makes them valuable to have in drought-prone, Subarctic areas such as Churchill, MB (Bonilla et al., 2009). The benthic cyanobacteria mats co-exist with green algae (Figure 35) where UV-A radiation stimulates scytonemin production and a crust or layer is produced that protects the organisms underneath (Hader et al., 2007). The benthic cyanobacteria and green algae can mechanically create deposits of calcium carbonate from biological and physical processes (Aizawa and Miyachi, 1986); they are also capable of having their thalli contain biochemically precipitated calcium carbonate as skeletal material (Reitner and Thiel, 2011). Cyanobacteria species are capable of fixing nitrogen in their heterocysts during low nitrogen conditions (Berman-Frank et al., 2003). All cyanobacteria produce the cyanotoxins: BMAA (Cox et al., 2004) and

Lipopolysaccharides (Chorus and Bartram, 1999). Gray found *Anabaena* and *Oscillatoria* pelagic cyanobacteria in Churchill, MB ponds during 1980 and 1981 field seasons (Gray, 1987); these are both producers of unique cyanotoxins (Chorus and Bartram, 1999). *Anabaena* can produce microsystis, anatoxin-a, anatoxin-a(s), and saxitoxinin while oscillatoria can produce microsystis, anatoxin-a, and aplysiatoxins (Chorus and Bartram, 1999). These toxins prevent excessive grazing and predation on them by zooplankton (Work and Havens, 2003). Also, they are capable of controlling their buoyancy, using H_2S as an electron donor and fixing harmed cells by creating multiple versions of chromosomes as backup copies (Likens and Vincent, 2009). The reason benthic mats are important is because they are a major food source for zooplankton and are the basis of the aquatic foodwebs (Rautio and Vincent, 2006; Mariash, 2014). Also, benthic mats are a source of nutrients for pelagic algae during re-suspension events which occur as a result of bioturbation, heavy rains or winds (Saint-Beat et al., 2014).

The extreme environment that algae experience in the Hudson Bay Lowlands (long winters, extreme temperature changes, extreme variations in solar radiation inputs, shallow and clear water) result in low pelagic algal concentrations that vary slightly from pond to pond and in dominance of benthic mats as shown in other studies in Arctic and Subarctic environments across Canada (Rautio et al., 2011). Benthic algal mats are a primary source of food for zooplankton and also a source of pelagic algal through re-suspension (Rautio and Vincent, 2006). Without these benthic algae, the food web would be impovrished in this extreme environment.

4.8 Extremes:

I would like to draw attention to four ponds that had values which were consistently extremes during data analysis in both years (Table 20). Two ponds with very low surface areas: Dugout and Cherry, were highest in benthic green algae concentrations. While two ponds with the largest surface areas, Ramsey Lake and Lindy Lake had low concentrations of benthic green algae and total benthic algae (Table 20);. The percentage of total benthic area of the low surface area ponds (less than 5m in surface area) is not exposed to as much direct sunlight as the high surface area ponds due to this physical barrier; these ponds are the least pan-shaped in the area. Also, ponds with low surface areas exhibit higher TDP, TDN, and $SUVA_{254}$ concentrations which favor benthic algal growth and explains the higher total concentration of benthic algae in low surface area ponds (Table 20). The reflection is much lower in ponds with a low surface area, most likely due to higher photosynthetic and pigment absorbance rates by benthic algae (Table 20). There seems to be a slightly higher presence of pelagic algae in small surface area ponds; this is caused by re-suspension of higher benthic algae concentrations that promote phytoplankton growth (Saint-Beat et al., 2014). The higher concentrations of nutrients and cations in small surface area ponds causes the specific conductance to rise (Table 20). The ponds with very low surface areas tend to have lower pH values, indicating the influence of organic acids in $SUVA_{254}$ that lower the pH of freshwater ponds (Toming et al., 2009). Overall, these low surface area ponds exhibit eutrophic conditions and are favourable to all algae growth, especially benthic green algae.

5.0 Conclusion:

The data obtained has shown that these Subarctic, basic, mesotrophic to oligotrophic, and saline ponds are dominated by benthic cyanobacteria. Cyanobacteria have evolved to survive in the most extreme environments including the Subarctic tundra located in the Hudson Bay Lowlands. Also, green algae dominate in ponds with extremely low surface areas which may be the largest proportion of pond size in the Hudson Bay lowlands, indicating a higher nutrient status; although only a select number of sampled ponds represent these ponds with very low surface areas. The reason that ponds with extremely low surface areas were not sampled often was due to the fact that they were too small to be detected on satellite imagery and were hard to find; also, they were not represented well in previous studies (Firanski, 2000). They may not take up a large portion of the overall region alone, but, together they may make up a significant portion of the land surface; as you decrease in surface area, the number of ponds increases exponentially (Firanski, 2000). This study serves as a baseline for future studies on water chemistry and algae in the Churchill, MB environment. This study was the first to obtain benthic algal data for Churchill,, MB will fill the benthic and pelagic algal data gap for Churchill, MB. This study contributes to previous studies by supporting previous data on phosphorus limitation of algal communities (Gray, 1987). It also incorporates new ideas of how pond size indicates the origin of ponds (Firanski, 2000) and plays a significant role in indicating the nutrient status or greenhouse gas emissions by those ponds (Negandhi et al., 2013) and (Laurion et al., 2014). With further studies, it may be possible to map the number of extremely small ponds in the Hudson Bay Lowlands and confirm with high spatial resolution satellite imagery. It may be found that benthic green algae tend to dominate in extremely small ponds throughout the Hudson Bay Lowlands. This data is the first of its kind in North America; the BenthoTorch has never been used in North America before this study and serves as a baseline dataset for future studies with the BenthoTorch.

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Appendix A: Pond extremes in surface area

Cherry Pond (July 2013):

Dugout Pond (July 2013):

Ramsey Lake (July 2013):

Lindy Lake (July 2013):

Appendix B: Parameters for every pond sampled

Table B1: 2012 physical data

Name	Surface Area (m2)	Shoreline Development	Perimeter (m)	Pond Depth (cm)	Water Temperature (C)	Avg. Wind Speed (m/s)
Ramsey Lake	2,035,000	1.138			14.6	4.1
Swivel	3000	1.200	233.1	31	12.4	4.7
Horner	3800	1.067	233.1	40	12.2	4.1
Plugged	34,600	1.286	847.7		13.2	3.2
Kerstina	200	1.129	56.6	15	14.2	3.3
Smokey	18,600	1.388	671.1	14	14	3.0
No Problems	1400	1.030	136.6	19	15.8	3.3
Ditch				22	15.2	3.4
Stage	2600	1.068	193.1	29	14.6	2.8
Side Road	12,200	1.161	454.6	14	14.2	3.4
Arctic Loon	44,200	1.175	876	24	14.2	1.1
Delijack				13	16.8	2.1
Larch	14,600	1.100	471.1	20.5	18.8	0.3
Frisbee	5400	1.374	358	22	18.6	2.3
Justin				14	22.6	2.5
Meander	17,400	1.264	591.1	13	22.4	2.2
Dugout				18	14.4	1.3
Ali	4600	1.136	273.1	22.5	15.8	1.5
Big Rock	58,200	1.842	1575.4	30.5	16.4	1.4
Angry Bird	2200	1.161	193.1	18	15.8	2.3
Bell	59,200	1.450	1250.5	24	19.6	3.9
Vanessa				34	20.2	2.4
Rocky	15,800	1.147	511.1	19.5	21.5	3.4
Peanut				22	22.6	0.5
Orange	3000	1.166	226.3	18	22.6	1.1
Paddy	600	1.111	96.5	36	14.8	3.7
Zealot				28	15.8	3.9
Famas				25	15.8	4.1
Galil	1800	1.096	164.9	12	16.4	5.9
Tundra Buggy	200	1.129	56.6	30	13.2	4.2
Double				14	12.6	4.3
Big Pond	47,800	1.461	1132.5	25.5	15.6	2.9
Island Pond	1000	1.114	124.9	15.3	15.2	4.2

Left Pond	7800	1.090	341.4	16	12.8	6.3
Some Pond	1800	1.284	193.1	25	13.2	4.1
Falco	1000	1.366	153.1	24	9.8	3.3
Pikachu	8600	1.368	449.7	36	10.2	3.5
Sandy	1000	1.219	136.6	16	10.5	3.8
Duel	38,800	1.457	1017.4	19	12.2	3.6
Micro	2200	1.161	193.1	22	12.2	3.3
Shimmering	85,400	1.921	1990	24	15.8	3.5
Windy	33,400	1.771	1147.1	19	16.4	2.9
Mosquito Rain	1400	1.243	164.9	15	17.6	2.9
Lindy Lake	1,004,600			27	14.2	2.4
Yellow Flower				29	16.8	3.6
No Flower				28	16.2	3.5
Puck	9000	1.183	398	13	18.2	3.6
Merrin	87,000	1.119	1170.5	10	17.6	3.2
Ryan and Patrick	402,600			23	18.2	0.8
Delirious				22	18.2	0.4
Sleep				26	12	2.7
REM	24,200	0.782	431.1	25	12.6	4.1
Nirvana				17.5	15.4	2.5
Red Berry pond	1400	1.154	153.1	29	17.6	1.9
Banana	6600	1.300	374.6	28	18	2
Cherry				20	19.2	1.7
Cheese			136.6	17	17.2	2
Grape				17	20.4	1.7
Delusional				18	19.8	2
Ginger	119,400	1.407	1723.7	27	15	3.8
Rotten Egg	3800	1.196	261.4	14	14.4	4.1
Yoshi's Canyon				19	15.6	4.6
Dome	1400	1.243	164.9	15	15.2	4.8
Frosty	200	1.129	56.6	17	14.2	3
Teapot	9800	1.409	494.6	14	15.4	3.1
Disco	12,200	1.191	466.3	15	18.4	1.4
Junior	67,000	1.167	1071.1	18	18.8	1.3
Rocky	9400	1.501	516	37	14	2.9
Sophia	509,800			16		0.3

Rice	6600	1.145	329.7	26	18.4	1
Submarine						
York	200	1.127	56.5			

Table B2: 2012 pond water quality parameters and cation concentrations

Name	**Specific Conductance (us/cm)**	**DO [ppm]**	**pH**	**Na (mg/L)**	**Ca (mg/L)**	**Mg (mg/L)**	**K (mg/L)**
Ramsey Lake	188	10.87	7.72	31.89	6.07	0.72	1.23
Swivel	160	12.45	9.05	17.61	5.78	0.40	1.50
Horner	213	14.53	8.8	25.69	8.03	0.83	1.79
Plugged	217	11.94	8.45	13.39	5.94	0.72	1.26
Kerstina	236	13.15	8.09	18.99	8.21	0.97	1.14
Smokey	246	13.26	8.27	26.68	5.37	0.77	1.57
No Problems	350	12.41	8.25	16.68	10.33	1.04	0.81
Ditch	590	12.2	8.2	37.36	12.88	1.04	2.25
Stage	396	12.78	8.31	40.84	10.15	1.83	5.63
Side Road	568	13.3	8.57	38.19	8.53	1.44	4.91
Arctic Loon	403	12.09	7.49	25.21	6.93	0.88	2.27
Delijack	114	13.8	8.89	10.81	5.51	0.48	1.49
Larch	228	14.86	8.87	20.39	6.17	0.80	1.65
Frisbee	332	12.13	8.36	20.48	10.06	0.58	1.89
Justin	299	14.39	8.64	29.06	11.52	0.87	1.55
Meander	627	13.88	8.77	48.25	12.20	1.84	5.23
Dugout	154	7.79	7.72	27.86	7.82	0.78	3.27
Ali	180	13.37	8.82	41.12	11.04	1.26	2.46
Big Rock	327	12.93	8.64	24.30	8.53	0.78	2.37
Angry Bird	340	12.7	8.45	34.05	9.47	1.00	2.52
Bell	437	14.43	8.62	31.82	8.43	0.83	2.13
Vanessa	524	12.07	7.92	19.83	12.71	0.92	1.61
Rocky	442	13.93	8.49	40.55	9.78	1.38	2.66
Peanut	240	12.14	7.83	24.94	18.06	1.39	2.61
Orange	202	11.74	8.41	33.09	6.56	0.98	2.47
Paddy	373	11.7	8.15	33.31	8.82	1.29	3.40
Zealot	634	11.27	7.93	27.87	9.56	1.16	3.24
Famas	616	13.74	8.5	45.82	13.76	1.86	5.20
Galil	554	11.22	8.75	46.68	7.88	1.48	6.07
Tundra Buggy	351	12.97	8.74	50.24	16.37	2.77	5.84
Double	267	13.23	8.96	37.00	10.68	1.73	3.59

Big Pond	593	12.26	8.82	39.22	8.42	1.60	3.45
Island Pond	465	12.73	8.65	27.85	9.22	1.84	2.83
Left Pond	857	12.3	8.36	30.59	9.36	1.67	3.31
Some Pond	812	12.36	8.57	47.57	10.68	2.49	5.95
Falco	399	14.41	8.56	38.19	8.49	1.69	2.91
Pikachu	339	13.07	8.47	29.05	6.32	0.95	2.82
Sandy	355	13.74	8.31	27.59	9.64	1.29	3.16
Duel	369	14.19	8.24	36.57	7.92	1.39	4.09
Micro	466			24.90	13.74	1.17	2.08
Shimmering	249	14.28	8.58	36.61	10.99	1.78	3.71
Windy	338	13.95	8.49	23.72	5.01	0.74	2.64
Mosquito Rain	388	14.12	8.34	31.03	6.02	1.12	2.53
Lindy Lake	137	12.57	8.17	16.90			0.97
Yellow Flower		14.93	7.97	65.09			
No Flower		14.73	8.15	59.32	32.40	4.31	4.94
Puck	333	13.03	8.32	56.93	18.90	3.70	5.99
Merrin	556	12.89	8.48	39.59	5.78	1.69	5.47
Ryan and Patrick	467	12.68	8.45	16.05	7.48	1.02	5.58
Delirious	521	13.21	8.49	44.45	10.75	1.54	5.95
Sleep	577	12.89	7.78	37.23	14.16	1.67	4.47
REM	356	12.42	8.63	34.05	5.30	0.82	2.91
Nirvana	542	11.37	7.58	33.48	17.03	1.31	2.54
Red Berry pond	443	14.8	8.59	32.46	7.38	1.40	4.59
Banana	357	13.76	8.66	28.18	8.33	1.43	2.87
Cherry	418	14.4	7.77	19.93	7.59	0.74	1.72
Cheese	351	13.71	8.47	15.10	6.67	0.78	1.59
Grape				30.01	7.28	1.24	2.99
Delusional				35.46	13.35	2.16	3.11
Ginger	299	13.66	8.43	17.27	5.44	0.46	1.19
Rotten Egg	278	13.82	8.53	25.22	7.98	0.80	2.67
Yoshi's Canyon	283	15.85	8.59	20.73	11.75	1.47	2.26
Dome	178	13.35	8.97	14.11	7.56	0.64	1.35
Frosty	191	13.67	8.76	11.26	7.91	0.74	1.12
Teapot	1138	15.26	8.36	50.91	15.41	1.98	4.25
Disco	782	13.43	8.52	42.31	9.34	1.09	2.69
Junior	211	13.93	8.91	30.59	5.79	0.58	1.85
Rocky	1051	13.63	8.72	52.12	8.11	2.04	7.29
Sophia				56.00	9.15	3.32	7.86

Rice				28.49	5.86	0.59	3.33
Submarine				19.85	6.82	0.65	2.98
York				33.82	15.52	1.84	4.14

Table B3: 2012 dissolved organic carbon concentrations and associated humification values

Name	**DOC (mg/L)**	**SUVA254 (L*mg C^{-1}*m^{-1})**	**Slope 275-295**	**Slope 350-400**	**S_R**	**E2:E3**
Ramsey	11.74	1.40	-0.02	-0.02	1.21	8.48
Swivel	6.47	6.27	-0.02	-0.02	0.88	8.43
Horner	6.62					
Plugged	6.50					
Kerstina	7.48	5.89	-0.03	-0.02	1.11	16.88
Smokey	7.50	4.56	-0.03	-0.04	0.71	12.97
No	6.98					
Ditch	8.94	5.16	-0.02	-0.03	0.70	12.18
Stage	7.84	6.27	-0.02	-0.02	1.01	6.27
Side Road	10.48	4.67	-0.02	-0.02	1.42	8.65
Arctic Loon	10.66	3.44	-0.02	-0.02	0.98	9.11
Delijack	9.12					
Larch	10.48					
Frisbee	16.88					
Justin	11.69					
Meander	11.86	3.72	-0.03	-0.02	1.11	16.88
Dugout			-0.01	-0.02	0.82	3.99
Ali	12.14	3.77	-0.02	-0.02	1.47	6.88
Big Rock			-0.02	-0.01	1.39	6.39
Angry Bird			-0.02	-0.02	1.26	6.80
Bell	7.15	5.27	-0.03	-0.03	0.91	14.10
Vanessa	11.49	7.03	-0.02	-0.02	0.88	7.54
Rocky	12.75	2.83	-0.02	-0.04	0.67	11.14
Peanut	12.36	4.57	-0.02	-0.03	0.74	7.64
Orange	6.30	6.33	-0.02	-0.02	1.01	7.94
Paddy	11.31	4.40	-0.02	-0.02	0.94	7.63
Zealot	8.45	7.53	-0.02	-0.01	1.29	5.47
Famas	8.94	8.72	-0.02	-0.02	1.01	5.91
Galil	9.00	4.85				
Tundra	9.91	5.68	-0.02	-0.03	0.71	7.91
Double	12.36	3.26	-0.03	-0.04	0.76	13.46
Big Pond	11.21	2.28	-0.02	-0.02	1.45	8.30

Island Pond	11.69	5.88	-0.02	-0.02	1.23	7.95
Left Pond	10.03	3.83	-0.02	-0.02	1.41	8.53
Some Pond	9.93	4.73	-0.02	-0.02	1.29	8.09
Falco	8.78	6.19	-0.02	-0.02	0.99	8.46
Pikachu	6.89	8.17	-0.02	-0.02	0.87	8.04
Sandy	8.22					
Duel	7.60	7.38	-0.02	-0.02	0.97	5.48
Micro	4.44					
Shimmering	8.76	2.40	-0.02	-0.01	1.65	7.13
Windy	7.72					
Mosquito	6.47	6.83	-0.02	-0.02	1.06	7.14
Lindy Lake	4.40	3.69				
Yellow	12.40	9.26	-0.02	-0.02	0.95	6.76
No Flower	13.07	10.09	-0.02	-0.02	0.96	6.59
Puck	8.87	6.61	-0.02	-0.03	0.90	11.05
Merrin	8.85	2.90	-0.03	-0.10	0.30	
Ryan and	6.91	4.53	-0.02	-0.03	0.84	11.68
Delirious	7.03	5.73	-0.02	-0.02	0.91	8.63
Sleep	5.67	9.74	-0.02	-0.02	0.79	6.94
REM	7.13	5.10	-0.03	-0.03	0.78	12.44
Nirvana	10.30	11.28	-0.02	-0.02	0.90	5.57
Red Berry	5.97	6.96	-0.02	-0.04	0.66	11.36
Banana	7.68	5.39	-0.02	-0.02	1.29	9.31
Cherry	8.41	9.95	-0.02	-0.02	1.05	5.34
Cheese	9.18	4.25	-0.03	-0.03	0.81	12.71
Grape	8.03	8.30	-0.02	-0.02	0.98	7.12
Delusional	7.21	6.60	-0.02	-0.02	1.11	8.67
Ginger	7.24	6.45	-0.02	-0.02	1.20	9.80
Rotten Egg	11.16	4.32	-0.03	-0.02	1.05	11.36
Yoshi's	10.88					
Dome	10.55	4.62	-0.02	-0.02	1.13	9.75
Frosty	10.58	4.17	-0.02	-0.01	1.62	7.86
Teapot	8.46	6.42				
Disco	7.82	5.18	-0.02	-0.02	1.04	10.36
Junior	4.71					
Rocky	12.48	3.39	-0.03	-0.03	0.81	14.15
Sophia	9.55	5.17	-0.02	-0.02	1.31	9.46
Rice	6.31					
Submarine	10.80	4.42	-0.02	-0.01	1.91	5.66
York			-0.02	-0.02	1.01	9.58

TableB4:2012 nutrient and pelagic algae concentrations

Name	Chla (ug/L)	P (ug/L)	DON (mg/L)	TSS w/out tray (mg/L)	TSS w/ tray (mg/L)	Average TSS (mg/L)
Ramsey Lake	0.06	2.98	0.75	2.80	2.80	2.80
Swivel	0.20	10.04	0.36	1.60	1.20	1.40
Horner			0.39		0.40	0.40
Plugged	0.00		0.37	2.20	1.60	1.90
Kerstina	0.07	3.28	0.38	1.80	2.00	1.90
Smokey	0.07	3.57	0.38	2.00	2.40	2.20
No Problems	0.00		0.34			
Ditch	0.13	6.51	0.49	5.40	5.40	5.40
Stage	0.12	6.22	0.50	1.60	1.80	1.70
Side Road	0.12	6.22	0.78	1.60	1.60	1.60
Arctic Loon	0.09	4.45	0.58	3.20	2.80	3.00
Delijack	0.00		0.57	2.60	2.80	2.70
Larch	0.00		0.53	3.20	3.20	3.20
Frisbee	0.00		0.76	3.40	3.00	3.20
Justin	0.00		0.63	3.60	3.80	3.70
Meander	0.14	7.10	0.64	3.20	3.60	3.40
Dugout			0.95	7.80	7.00	7.40
Ali	0.30	15.04	0.65	1.20	1.00	1.10
Big Rock	0.14	7.10		1.40	2.20	1.80
Angry Bird	0.00		0.80	1.60	1.20	1.40
Bell	0.12	5.92	0.35	1.60	2.40	2.00
Vanessa	0.28	13.86	0.51	3.40	3.20	3.30
Rocky	0.09	4.75	0.47	2.20	2.00	2.10
Peanut	0.21	10.33	0.84	1.40	1.40	1.40
Orange	0.08	3.87	0.39	3.00	3.20	3.10
Paddy	0.19	9.45	0.71	2.20	2.20	2.20
Zealot	0.19	9.45	0.44	2.20	2.00	2.10
Famas	0.25	12.69	0.46	4.80	4.80	4.80
Galil		7.98	0.41	3.20	3.20	3.20
Tundra Buggy	0.09	4.75	0.55	2.20		2.20
Double	0.14	7.10	0.84	4.00		4.00
Big Pond	0.09	4.75	0.52	2.60		2.60

Island Pond	0.14	6.81	0.66	4.20		4.20
Left Pond	0.27	6.81	0.64	4.40		4.40
Some Pond	0.21	10.63	0.57	2.20		2.20
Falco	0.15	7.39	0.46	2.00	2.00	2.00
Pikachu	0.25	12.39	0.42	2.80	3.00	2.90
Sandy	0.00		0.51	3.40	3.40	3.40
Duel		5.04	0.31	6.60	2.20	4.40
Micro	0.00		0.29	3.80	3.80	3.80
Shimmering	0.08	4.16	0.49	1.80		1.80
Windy	0.00		0.34	4.20	3.80	4.00
Mosquito Rain	0.15	7.69	0.35	0.20		0.20
Lindy Lake	0.06	2.98	0.28	1.40	1.80	1.60
Yellow Flower	0.33	16.51	0.60	6.00	6.00	6.00
No Flower	0.28	13.86	0.60	4.40	4.20	4.30
Puck	0.17	8.57	0.53	8.00	8.00	8.00
Merrin	0.12	6.22	0.50	5.60	6.00	5.80
Ryan and Patrick	0.09	4.45	0.40	2.80	2.60	2.70
Delirious	0.08	3.87	0.40	1.80	2.00	1.90
Sleep	0.08	3.87	0.22			
REM	0.08	4.16	0.37	2.40	2.40	2.40
Nirvana		8.86	0.45	1.60	1.80	1.70
Red Berry pond	0.17	8.57	0.34	1.20	0.80	1.00
Banana	0.22	10.92	0.45	3.40	3.40	3.40
Cherry		16.21	0.40	2.80	3.40	3.10
Cheese	0.13	6.51	0.67	3.00	2.60	2.80
Grape	0.21	10.33	0.42	3.40	3.40	3.40
Delusional	0.19	9.75	0.43	1.80	3.00	2.40
Ginger	0.12	5.92	0.43	2.00	2.00	2.00
Rotten Egg	0.10	5.04	0.63	1.20	2.40	1.80
Yoshi's Canyon	0.00		0.62	2.60	3.00	2.80
Dome	0.18	9.16	0.64	2.00	2.00	2.00
Frosty	0.18	9.16	0.73	2.60	3.20	2.90
Teapot	0.08	3.87	0.48	3.00	4.00	3.50
Disco	0.12	5.92		2.20	2.20	2.20
Junior	0.00		0.29	0.60	1.40	1.00
Rocky	0.21	10.33	0.66		2.40	2.40
Sophia	0.17	8.57	0.55			

Rice	0.14	7.10	0.40	2.80	2.80	2.80
Submarine	0.18	9.16	0.71		2.80	2.80
York	0.11	5.34		0.80	1.40	1.10

Table B5: 2013 physical pond characteristics

Name	Shoreline Development	Perimeter (m)	Surface Area (m2)	Mean Depth (cm)	Longitude	Latitude	Depth (cm)
LeftPond	1.09	341.40	7800.00	21.81	-93.82	58.74	8.00
SomePond	1.28	193.10	1800.00	28.60	-93.82	58.74	11.13
IslandPond	1.11	124.90	1000.00		-93.82	58.75	6.13
BigPond	1.46	1132.50	47800.00	46.19	-93.83	58.75	17.25
DoublePond				35.24	-93.82	58.75	10.25
TundraBuggy	1.13	56.60	200.00	15.06	-93.82	58.75	18.25
PaddysPond	1.11	96.50	600.00	42.54	-93.82	58.74	30.00
Zealot				38.72	-93.82	58.74	20.00
Falco	1.37	153.10	1000.00	21.52	-93.86	58.76	6.75
Sofia			509800.00	14.62	-93.85	58.75	12.00
Ramsey					-93.79	58.73	37.25
Ninah	1.03	136.60	1400.00	15.69	-93.81	58.73	7.75
Plugged	1.29	847.70	34600.00		-93.80	58.73	31.88
Smokey	1.39	671.10	18600.00		-93.80	58.73	22.00
Sandy	1.22	136.60	1000.00	32.26	-93.86	58.76	8.25
Micro	1.16	193.10	2200.00	17.71	-93.86	58.76	11.50
Shimmering	1.92	1990.00	85400.00		-93.86	58.75	22.50
Banana	1.30	374.60	6600.00		-93.86	58.76	17.50
Cherry				20.06	-93.86	58.76	12.50
Dugout				19.10	-93.84	58.73	21.50
Windy	1.77	1147.10	33400.00	20.07	-93.86	58.75	23.50
REM	1.63	899.40	24200.00	33.20	-93.87	58.76	26.00
Junior	1.17	1071.10	67000.00	22.58	-93.81	58.72	22.00
Lindy	1.30	4605.30	1004600.00	31.17	-93.81	58.72	24.75
Merrin	1.12	1170.50	87000.00	22.40	-93.80	58.72	20.00
Yellow Flower				14.82	-93.80	58.72	25.00
No Flower				14.17	-93.80	58.72	17.50
Vanessa				22.42	-93.83	58.73	22.00
Frisbee	1.37	358.00	5400.00	16.26	-93.84	58.73	11.00
Shumas	1.26	591.10	17400.00	27.87	-93.82	58.74	15.50
Peanut				19.49	-93.83	58.73	10.75
Orange	1.17	226.30	3000.00		-93.83	58.73	20.50

Bello	1.45	1250.50	59200.00	20.71	-93.83	58.73	11.25
Arctic Loon	1.18	876.00	44200.00	36.87	-93.83	58.73	16.50

Table B6: 2013 water chemistry parameters

Name	Specific Conductance (us/cm)	Salinity (ppt)	DO Concentration (ppm)	pH
LeftPond	250.08	0.00	11.26	9.69
SomePond	357.90	0.03	12.54	9.22
IslandPond	432.35	0.00	13.19	8.98
BigPond	401.58	0.00	11.59	8.97
DoublePond	778.00	0.16	13.06	8.80
TundraBuggy	897.50	0.41	12.21	8.65
PaddysPond	333.50	0.06	11.59	8.95
Zealot	378.85	0.18	11.75	8.91
Falco	379.35	0.18	11.53	9.56
Sofia	1301.25	0.61	11.82	9.30
Ramsey	148.05	0.09	11.61	8.81
Ninah	349.28	0.22	11.97	8.75
Plugged	191.88	0.11	12.23	9.12
Smokey	237.30	0.14	11.22	8.84
Sandy	312.65	0.17	13.40	9.09
Micro	345.20	0.19	12.14	9.07
Shimmering	243.55	0.11	13.05	9.09
Banana	345.93	0.19	11.03	9.05
Cherry	401.10	0.24	11.04	8.60
Dugout	218.55	0.11	10.04	8.66
Windy	324.90	0.12	11.62	9.06
REM	356.75	0.22	11.45	9.05
Junior	192.45	0.09	11.44	9.14
Lindy	136.63	0.08	10.57	8.95
Merrin	729.75	0.34	11.67	9.11
Yellow		1.66	11.79	8.70
No Flower		0.89	12.00	8.85
Vanessa	479.03	0.26	11.30	8.45
Frisbee	501.90	0.25	10.78	9.07
Shumas	516.50	0.31	11.11	8.98
Peanut	430.43	0.29	11.28	8.36
Orange	457.23	0.28	8.87	8.89
Bello	615.00	0.40	10.42	9.14
Arctic Loon	418.83	0.24	10.36	9.21

Table B7: 2013 dissolved organic carbon concentrations and associated humification values

Name	DOC (mg/L)	SUVA254 (L*mg $C^{-1}*m^{-1}$)	Slope (275-295)	Slope (350-400)	S_R	E2:E3
LeftPond	15.9325	4.173559	-0.03	-0.02	1.360181	10.41076
LeftPond	15.93	4.17	-0.03	-0.02	1.36	10.41
SomePond	16.13	3.23	-0.02	-0.02	1.51	10.92
IslandPond	20.46	4.43	-0.03	-0.02	1.28	9.91
BigPond	11.96	2.53	-0.02	-0.02	1.58	11.07
DoublePond	9.18	4.56	-0.02	-0.02	1.15	8.16
TundraBuggy	10.04	5.43	-0.02	-0.02	1.11	7.56
PaddysPond	9.90	5.05	-0.02	-0.02	1.13	7.26
Zealot	10.87	5.50	-0.02	-0.02	1.09	7.11
Falco	14.09	4.16	-0.03	-0.02	1.35	9.20
Sofia	12.62	3.72	-0.02	-0.02	1.41	10.30
Ramsey	4.78	3.17	-0.02	-0.02	1.26	7.82
Ninah	14.05	4.90	-0.02	-0.02	1.35	8.05
Plugged	8.44	5.71	-0.03	-0.02	1.27	8.41
Smokey	8.88	3.81	-0.03	-0.02	1.40	10.40
Sandy	10.72	4.10	-0.03	-0.02	1.42	9.46
Micro	13.86	3.34	-0.03	-0.02	1.58	10.47
Shimmering	8.04	2.57	-0.03	-0.02	1.67	9.93
Banana	10.70	3.83	-0.02	-0.02	1.45	9.40
Cherry	19.11	6.59	-0.01	-0.02	1.07	5.12
Dugout	29.98	6.68	-0.03	-0.02	0.78	4.02
Windy	8.79	3.06	-0.02	-0.02	1.53	9.43
REM	9.82	4.82	-0.02	-0.02	1.31	8.44
Junior	7.83	3.88	-0.02	-0.02	1.34	8.45
Lindy	5.22	3.76	-0.03	-0.02	1.26	8.28
Merrin	12.50	2.76	-0.02	-0.02	1.30	14.29
Yellow	25.94	6.55	-0.02	-0.02	1.00	6.25
No Flower	28.15	5.89	-0.02	-0.02	1.01	7.05
Vanessa	15.74	5.93	-0.02	-0.02	1.06	7.55
Frisbee	28.51	5.76	-0.03	-0.02	1.15	8.15
Shumas	14.91	3.60	-0.02	-0.02	1.33	10.40
Peanut	8.69	5.98	-0.02	-0.02	1.07	6.30
Orange	6.71	4.50	-0.02	-0.02	1.14	8.05
Bello	9.58	4.09	-0.02	-0.02	1.33	9.72

Table B8: 2013 pelagic algae data

Name	Ft (620)	QY620	Ft (450)	QY450
LeftPond	52.25	0.00	208.25	0.16
SomePond	53.50	0.00	196.75	0.11
IslandPond	51.75	0.00	245.50	0.21
BigPond	47.25	0.00	137.25	0.11
DoublePond	43.00	0.00	165.50	0.11
TundraBuggy	48.75	0.00	243.75	0.09
PaddysPond	45.75	0.00	187.00	0.15
Zealot	53.00	0.00	199.25	0.12
Falco	61.75	0.00	229.50	0.09
Sofia	54.75	0.00	172.00	0.18
Ramsey	48.75	0.00	122.50	0.04
Ninah	53.00	0.00	240.50	0.09
Plugged	79.00	0.00	184.25	0.15
Smokey	58.00	0.00	256.75	0.10
Sandy	61.00	0.00	190.25	0.14
Micro	63.50	0.00	186.75	0.13
Shimmering	54.75	0.00	142.25	0.16
Banana	50.50	0.00	167.75	0.10
Cherry		0.04		0.10
Dugout	81.50	0.07	474.50	0.20
Windy	49.75	0.00	197.25	0.12
REM	52.50	0.00	183.50	0.11
Junior	55.00	0.00	149.25	0.16
Lindy	49.50	0.00	135.75	0.10
Merrin	50.00	0.00	160.50	0.13
Yellow Flower	82.50	0.00	550.50	0.15
No Flower	90.00	0.00	512.00	0.12
Vanessa	51.75	0.00	304.25	0.08
Frisbee	60.75	0.00	384.50	0.08
Shumas	52.50	0.00	175.75	0.06
Peanut	69.00	0.00	303.25	0.09
Orange	51.25	0.00	167.75	0.11
Bello	50.25	0.00	168.00	0.06
Arctic Loon	51.50	0.00	169.25	0.14

Table B9: 2013 nutrient concentrations and benthic algae data

Name	TDP (ug/L)	TDN (mg/L)	Benthic Cyanobacteria (ug chl-a/cm2)	Benthic Green Algae (ug chl-a/cm2)	Benthic Diatoms (ug chl-a/cm2)	Total Concentration of Benthic Algae (ug chl-a/cm2)
LeftPond	16.88	1.03	0.78	0.34	0.00	1.12
SomePond	15.04	1.00	0.65	0.16	0.00	0.81
IslandPond	28.93	1.22	0.71	0.18	0.03	0.93
BigPond	7.91	0.73	0.93	0.28	0.05	1.26
DoublePond	7.54	0.49	0.39	0.06	0.06	0.51
TundraBuggy	8.57	0.54	0.46	0.17	0.07	0.71
PaddysPond	15.19	0.49	0.91	0.48	0.30	1.69
Zealot	16.29	0.53	0.81	0.40	0.26	1.47
Falco	15.33	0.86	0.74	0.11	0.04	0.89
Sofia	11.29	0.65	0.32	0.09	0.13	0.54
Ramsey	5.48	0.26	0.18	0.03	0.08	0.29
Ninah	10.26	0.82	0.40	0.09	0.05	0.55
Plugged	12.91	0.43	0.39	0.10	0.06	0.55
Smokey	5.63	0.48	0.52	0.03	0.04	0.59
Sandy	11.51	0.59	0.65	0.11	0.00	0.76
Micro	24.89	0.93	0.82	0.42	0.00	1.24
Shimmering	11.73	0.47	0.47	0.16	0.00	0.63
Banana	9.53	0.61	1.27	0.15	0.00	1.42
Cherry	36.50	0.93	0.96	0.96	0.06	1.98
Dugout	43.12	1.23	0.88	1.64	0.17	2.69
Windy	7.39	0.51	1.03	0.14	0.02	1.19
REM	19.01	0.54	0.77	0.20	0.03	1.00
Junior	6.59	0.41	1.09	0.12	0.08	1.29
Lindy	22.90	0.24	0.17	0.05	0.05	0.27
Merrin	7.10	0.71	0.66	0.22	0.13	1.00
Yellow Flower	48.55	0.74	1.60	0.94	0.25	2.79
No Flower		1.38	1.29	0.54	0.21	2.04
Vanessa	28.34	0.79	0.57	0.17	0.04	0.78
Frisbee	17.76	1.50	0.91	0.29	0.01	1.20
Shumas	10.56	0.86	0.46	0.10	0.06	0.62
Peanut	10.63	0.47	0.73	0.24	0.20	1.17
Orange	9.01	0.38	0.50	0.11	0.16	0.76

Appendix C: Multivariate statistics on water chemistry parameters that influence algal concentrations

Multivariate statistics were used to find the limiting factors on algal growth and determine if certain independent factors are highly correlated, resulting in false positives created in linear regression models. Principal components analysis and multiple linear regression analyses were conducted to determine the true limiting factors in algal growth. Principal components analysis was utilized to determine that DOC and TDP were highly correlated to each other. This suggests that even though algal concentrations were highly correlated with TDP, they may be aided by the presence of DOC which provides UV protection and nutrient supply to the algal communities. DOC is an influential factor due to the fact that these ponds are so shallow and the algal communities have little to no protection from UV radiation; also, the high correlation may be a result of phosphorus covaletntly bound to DOC.

Multiple linear regression analysis was performed to determine how algal concentrations were correlated with multiple variables in an attempt to distinguish which factor exerted the greatest control on algal growth. TDP tended to have the highest and most significant correlations to benthic cyanobacteria and green algae while SUVA tended to have the highest and most significant correlations to benthic diatoms. The diatom concentrations were very low and the only time they were found was when SUVA was high. The benthic cyanobacteria and benthic green algae were most limited by TDP, suggesting that these communities are limited by phosphorus as seen in previous studies (Gray, 1987). Pelagic green algae were limited by both SUVA and TDP, suggesting that these communities required both shading and nutrient enrichment.TDP and TDN were the most limiting nutrients to pelagic cyanobacteria, suggesting that these communities were mesotrophic to oligotrophic (Appendix C).

A Principal Components Analysis (PCA) was performed for the independent variables that had the highest correlations with algae in 2013. This was done to find which variables were the true drivers of algal concentrations. The variables that were entered into the principal components analysis were: Hydrogen ion concentration, average pond depth, $SUVA_{254}$, dissolved organic carbon, total dissolved nitrogen and total dissolved phosphorus. The produced component 1 which was correlated with $SUVA_{254}$, dissolved organic carbon, total dissolved nitrogen and total dissolved phosphorus. Dissolved organic carbon had the highest correlation for component 1, suggesting that it explained the most variability in the dataset. [H] was the least correlated with both the component 1, suggesting that it produced the least variability in the dataset. Dissolved organic carbon and TDP were highly correlated with the components, suggesting they produced similar variabilities in the dataset. This PCA explains how closely related these variables were in the dataset and how the correlation of TDP with algal data could be due to the fact that TDP is highly correlated with DOC.

Table C1: PCA Total Variance Explained by [H], $SUVA_{254}$, DOC, Average Pond Depth, TDN and TDP

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.111	51.852	51.852	3.111	51.852	51.852	2.532	42.205	42.205
2	1.420	23.662	75.514	1.420	23.662	75.514	1.999	33.309	75.514
3	.787	13.118	88.632						
4	.412	6.862	95.494						
5	.218	3.640	99.134						
6	.052	.866	100.000						

Table C2: PCA Correlation Matrix of [H], $SUVA_{254}$, DOC, Average Pond Depth, TDN and TDP

Correlation Matrix

		DOC (ug/L)	TDN (ug/L)	TDP (ug/L)	SUVA	AvgDepth (m)	Hionconc
Correlation	DOC (ug/L)	1.000	.865	.699	.530	-.412	.129
	TDN (ug/L)	.865	1.000	.396	.242	-.364	-.066
	TDP (ug/L)	.699	.396	1.000	.652	-.277	.350
	SUVA (L*mg C^{-1}*m^{-1})	.530	.242	.652	1.000	-.296	.670
	AvgDepth (m)	-.412	-.364	-.277	-.296	1.000	-.223
	Hionconc	.129	-.066	.350	.670	-.223	1.000

Table C3: PCA Component Matrix of [H], $SUVA_{254}$, DOC, Average Pond Depth, TDN and TDP

Component Matrix[a]

	Component	
	1	2
DOC (ug/L)	.892	-.385
TDP (ug/L)	.821	
SUVA (L*mg C^{-1}*m^{-1})	.787	.485
TDN (ug/L)	.691	-.633
AvgDepth (m)	-.562	
Hionconc	.478	.784

Extraction Method: Principal Component Analysis.[a]

a. 2 components extracted.

A multilinear regression was performed for benthic green algae using the following independent variables: average depth of the ponds, $SUVA_{254}$ (L*mg C^{-1}*m^{-1}), TDN (ug/L) and TDP (ug/L). These variables were chosen based on their predicted correlations from singular regression analyses. TDP showed the only significant correlation to benthic green algae, suggesting that this variable was the most limiting to benthic green algae concentration; standardized coefficient (slope) = 0.646. TDP shows the only significant variable when all other independent variables are considered, p = <0.001.

Table C4: Mulitlinear Regression of Average Depth of the Ponds, $SUVA_{254}$, TDN and TDP for Benthic Green Algae

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.550	.294		-1.872	.075
	TDN (ug/L)	.237	.180	.184	1.315	.203
	TDP (ug/L)	.020	.005	.646	3.784	<0.001
	SUVA ($L*mg\ C^{-1}*m^{-1}$)	.052	.048	.178	1.085	.290
	AvgDepth (m)	.005	.005	.123	.908	.374

a. Dependent Variable: BenthicGreenAlgae

A multilinear regression was performed for benthic cyanobacteria using the following independent variables: average depth of the ponds, $SUVA_{254}$ ($L*mg\ C^{-1}*m^{-1}$), TDN (ug/L) and TDP (ug/L). TDP showed the highest correlation to benthic cyanobacteria, suggesting that this variable was the most limiting to benthic cyanobacteria concentration; standardized coefficient (slope) = 0.321. None of the variables are significantly correlated to benthic cyanobacteria.

Table C5: Mulitlinear Regression of Average Depth of the Ponds, $SUVA_{254}$, TDN and TDP for Benthic Cyanobacteria

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.561	.425		1.321	.201
	TDN (ug/L)	.014	.261	.013	.054	.957
	TDP (ug/L)	.009	.008	.321	1.119	.276
	SUVA ($L*mg\ C^{-1}*m^{-1}$)	.006	.070	.025	.092	.927
	AvgDepth (m)	.001	.008	.019	.084	.934

a. Dependent Variable: BenthicCyano

A multilinear regression was performed for benthic diatoms using the following independent variables: average depth of the ponds, $SUVA_{254}$ (L*mg C^{-1}*m^{-1}), TDN (ug/L) and TDP (ug/L). $SUVA_{254}$ showed the highest correlation to benthic diatoms, suggesting that this variable exerted the greatest control on benthic diatoms concentration; standardized coefficient (slope) = 0.486. TDN is the only significant variable when all other independent variables are considered, p = 0.049.

Table C6: Mulitlinear Regression of Average Depth of the Ponds, $SUVA_{254}$, TDN and TDP for Benthic Diatoms

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-.071	.101		-.703	.490
TDN (ug/L)	-.105	.062	-.335	-1.698	.104
TDP (ug/L)	.001	.002	.164	.681	.503
SUVA (L*mg C^{-1}*m^{-1})	.035	.017	.486	2.094	.049
AvgDepth (m)	.002	.002	.203	1.061	.301

a. Dependent Variable: BenthicDiatoms

A multilinear regression was performed for pelagic green algae instantaneous fluorescence using the following independent variables: average depth of the ponds, $SUVA_{254}$ (L*mg C^{-1}*m^{-1}), TDN (ug/L) and TDP (ug/L). $SUVA_{254}$ and TDP showed the highest correlation to pelagic green algae Ft, suggesting that this variable was the most limiting to pelagic green algae Ft; standardized coefficient (slope) = 0.461 and 0.395, respectively. $SUVA_{254}$ and TDP were the two significant variables when all other independent variables are considered, p = <0.001 and <0.001, respectively.

Table C7: Mulitlinear Regression of Average Depth of the Ponds, $SUVA_{254}$, TDN and TDP for Pelagic Green Algae Ft

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-13.983	54.682		-.256	.801
	TDN (ug/L)	74.812	33.147	.201	2.257	.035
	TDP (ug/L)	3.769	.997	.395	3.779	<0.001

	SUVA (L*mg C^{-1}*m^{-1})	41.054	8.972	.461	4.576	<0.001
	AvgDepth (m)	-2.122	.970	-.190	-2.187	.041

a. Dependent Variable: GreenFt

A multilinear regression was performed for pelagic cyanobacteria instantaneous fluorescence using the following independent variables: average depth of the ponds, $SUVA_{254}$ (L*mg C^{-1}*m^{-1}), TDN (ug/L) and TDP (ug/L). TDP showed the highest correlation to pelagic cyanobacteria Ft, suggesting that this variable was the most limiting to pelagic cyanobacteria Ft ; standardized coefficient (slope) = 0.583. None of the independent variables were significantly correlated to pelagic cyanobacteria fluorescence.

Table C8: Mulitlinear Regression of Average Depth of the Ponds, $SUVA_{254}$, TDN and TDP for Pelagic Cyanobacteria Ft

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	48.298	8.513		5.673	.000
	TDN (ug/L)	2.799	5.161	.079	.542	.594
	TDP (ug/L)	.529	.155	.583	3.405	.003
	SUVA (L*mg C^{-1}*m^{-1})	.989	1.397	.117	.708	.487
	AvgDepth (m)	-.289	.151	-.271	-1.910	.071

a. Dependent Variable: CyanoFt