FACTORS INFLUENCING PLANKTONIC ROTIFER COMMUNITY STRUCTURE IN SMALL ARCTIC LAKES

A Thesis Submitted to Wilfrid Laurier University

by

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In partial fulfilment of the requirements for the Bachelor of Science in Biology

April 2019

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ABSTRACT

The Northwest Territories (NWT) is experiencing rapid environmental changes due to a warming climate and human development. These stressors are causing significant changes in aquatic habitats, including increases in water temperature, conductivity, calcium concentrations, and water clarity. These changes may impact biota in lakes and ponds, but little is known about how some important aquatic organisms, such as rotifers, may respond. Rotifers are abundant microinvertebrates that are part of zooplankton assemblages in many freshwater ecosystems. This study aims to identify whether changing environmental conditions might impact the rotifer community structure in small Arctic lakes. Baseline data on water chemistry, lake bathymetry and rotifer communities were collected and analyzed from a total of 20 lakes located along the highway running between Fort McPherson, Inuvik and Tuktoyaktuk. A total of 21 rotifer genera were identified, with an average of 12 genera per lake. Analyses indicate that pH, conductivity, water clarity, total organic carbon (TOC) and calcium have a significant impact on rotifer richness, while diversity is significantly influenced by conductivity, water clarity and calcium concentrations. Several of the factors we identified as important for structuring rotifer communities are expected to be affected by climate change, permafrost thaw, and human development, including nutrient levels, conductivity, temperature, calcium and TOC concentrations. As a result, we expect the richness and diversity of rotifer communities in NWT lakes will be significantly affected by these stressors.

1. INTRODUCTION

The Gwich'in Settlement Area (GSA) and Inuvialuit Settlement Region (ISR), both located in the Northwest Territories (NWT), are experiencing rapid changes in climate. Temperatures in Canada's North have increased 3-4 ^{o}C over the last century and are predicted to increase further 5-7 ^{o}C by the end of this century (Frey and McClelland 2009; Houben et al. 2016). These increases in temperature have caused major physical and biological changes in the northern environment and are having an impact on the indigenous communities that live in the region (Throop et al 2012). This region is also experiencing increased development, as the main south-north transportation corridor between Fort McPherson and Tuktoyaktuk runs through the GSA and ISR (Figure 1). This includes the Dempster Highway which has been opened since the mid 1970s as well as the newly built Inuvik-Tuktoyaktuk highway which was completed in November 2017. This is the first road providing access to the Southern coast of the Arctic ocean, a region where significant development is anticipated (Vucic et al. 2019). This area is surrounded by thousands of small arctic lakes which vary in size, shape and hydrology, which might be impacted by road development and maintenance.

Changes in turbidity, conductivity, and pH, as a response to climate change, have been recorded in freshwater lakes throughout the Northwest Territories (Prowse 2009). Specifically, Kokelj et al. (2009) noted changes in water quality in response to permafrost thaw in Arctic regions; the study found that lakes impacted by permafrost thaw slumps had elevated ionic concentrations and water clarity in comparison to unimpacted lakes. In addition, Gunter (2017) assessed the impacts of road dust and found that alkalinity, conductivity, total dissolved solids (TDS), pH, calcium, hardness, magnesium, nitrate, sulfate and strontium decreased with distance from the highway. Both human development and climate change threaten freshwater rotifers as changes in abiotic factors influence the structure and function of communities.

1.1 ROTIFER COMMUNITIES

Rotifers are microscopic invertebrates which are a part of the zooplankton assemblage. These filter-feeding omnivores are typically found in the littoral zone of freshwater lakes and are often the dominant zooplankton taxa in freshwater environments (Radwan 1980). Rotifer communities play an integral role in connecting the microbial loop to the classic lake food web by consuming bacteria that process dissolved organic carbon (Radwan 1980). Therefore, they play in important role in recycling nutrients and energy back into the food web. In addition, rotifers are considered to be important basal consumers in many lakes as they are a major food source for a variety of larval organisms which in turn are a large food source for higher levels in the food web (Pejler 1982). Rotifers are vulnerable to physical and chemical changes occurring in their environments (Swadling et al. 2000; Wen et al. 2011); therefore, community structure and abundance may be impacted by climate change and pollution (Hobbie et al. 1999; Swadling et al. 2000). Changes in rotifer communities could have cascading effects on higher trophic levels, threatening freshwater biodiversity.

Studies show most rotifer communities contain anywhere between 50 – 500 individual rotifers per litre (Sládeček 1983). In addition, in many shallow aquatic ecosystems, rotifers are known to be the most abundant components of the zooplankton assemblages (Arndt 1993). Studies have observed rotifer abundances to be highest in temperate regions, but this is subject to change depending on the trophic state of the lake and the pollutants or physical factors affecting water quality (Arndt 1993). Rotifers are also known to be sensitive to changes in their environment; for example, rotifer abundance and community structure may vary due to changes in pH, temperature, calcium, nitrate and hardness (Sládeček1983). Pennak's classic (1953) study indicated that alkalinity and pH levels could influence rotifer abundance in freshwater habitats, with acidic waters having a higher species diversity, but lower abundance of rotifers (Pennak 1953). Studies have shown multiple environmental variables associated with climate change and road developed can cause changes in rotifer community structure such as drops in temperature, nutrient levels, and low food sources (Liping et al. 2018; Chengalath and Koste 1989). For example, an investigation done by Liping et al. (2018) analysed rotifer community structure and its response to environmental factors and determined that species distribution was correlated with temperature, pH, nitrite nitrogen and total phosphorus (TP) levels. Comparatively, previous studies have strongly associated rotifer species richness and distribution with trophic state and water temperature (Wen et al. 2011). Studies have shown that the harsh physical environment of Canadas Arctic are factors which influence rotifer community structure due to the low temperatures and low primary production (Chengalath and Koste 1989). Chengalath and Koste (1989) found that rotifer richness was correlated with lakes with low conductivity, indicating that species richness is related to the availability of nutrients and phytoplankton growth in a lake.

Additionally, abiotic environmental variables such as surficial geology and shoreline vegetation have been associated with zooplankton richness and diversity (Swadling et al. 2000). Lakes located in tundra and boreal vegetation zones exhibit a variety of physical and chemical characteristics due to the differences in plant community composition (Swadling et al. 2000). Canadas boreal region is characterized by plant communities which consist of coniferous tress, Aspen and black spruce; whereas the tundra is characterised by woody shrubs and its general lack of vegetation (Dodson et al. 2005; Bliss 2010). Swadling et al. found that lakes located in a boreal vegetation region were generally deeper with higher temperatures and higher ionic concentrations while lakes located in the tundra typically exhibited lower temperatures and nutrient levels. Swadling et al (2000) showed boreal lakes contained higher rotifer species richness in comparison to tundra lakes due to higher temperatures and nutrient availability in boreal lakes.

The effects of physical and chemical changes to lakes and rotifer communities have received limited study, particularly in the Northwest Territories. Generally, to assess the changes, univariate and multivariate metrics are used to measure variables such as species richness, diversity and evenness. Rotifer species richness refers to the number of different rotifer species found in each lake whereas rotifer species diversity is a measurement of species richness combined with evenness (Mittelbach 2012). The Shannon diversity index is commonly used to characterize species diversity in rotifer communities which is calculated using:

$$\mathrm{H}' = -\sum_{i=1}^{s} p_i ln p_i$$

where *i* is the proportion of species relative to the number of species (*pi*) in the entire population and S represents the number of species encountered (Peet 2003). In response to the environmental impacts on the lake, rotifer communities may see differences in species evenness and species diversity as well as reduced species richness. Multivariate measures such as Principal Component Analyses (PCA) will aid in analyzing rotifer community structure in terms of relative abundance of rotifer species. A PCA is a data visualization and exploration technique that allows the investigator to visually asses differences in the abundances and taxonomy of species among the communities. Past studies have shown that multivariate techniques are often more sensitive than univariate measures when examining change. A study done by Yan et al. (1996) suggests that multivariate methods are superior to univariate methods for detecting changes in communities, as univariate metrics ignore species interrelationships.

1.2 THREATS TO FRESHWATER BIODIVERSITY

Freshwater biodiversity is a priority when discussing aquatic conservation efforts around the world. Even though surface freshwater only makes up 1.2% of all water on the earth, it supports over 50,000 species of aquatic life (Williams 2014). In addition to holding economic and cultural value all around the world, freshwater holds great value to the organisms that thrive in it and is considered an important natural resource. Freshwater ecosystems have been experiencing larger than normal declines in biodiversity in the past decade, more than any other environment (Dudgeon 2006). Freshwater aquatic organisms are known to be more vulnerable to human activity and are therefore more likely to experience a large decline in biodiversity as human activity/interference increases. Freshwater biodiversity is also susceptible to decline because of factors such as overexploitation, water pollution and habitat degradation due to climate change (Dudgeon 2006).

Climate change may be especially significant in northern environments. Temperature changes, permafrost thaw, nitrogen deposition, and shifts in precipitation patterns are all factors influenced by climate change (Dudgeon 2006). Areas in the Northwest Territories, particularly the Mackenzie Delta region, are experiencing higher than average climate change effects and therefore organisms are more vulnerable to declines in biodiversity (Prowse 2009). Previous studies in the Mackenzie River Delta region have demonstrated modifications to permafrost, terrain and ecological conditions such as differences in water chemistry in response to the climate warming (Koklej 2009). Also, the thawing of ice-rich permafrost has led to the development of retrogressive thaw slumps particularly along the shorelines of lakes in the western Arctic (Koklej 2009). The degradation of the permafrost may cause changes in turbidity, conductivity and nutrients levels of the surrounding arctic lakes (Koklej 2009). As a result, the potential physical and chemical changes to these lakes may impact the biodiversity of arctic streams, lakes and wetlands (Chin et al. 2016).

Freshwater biodiversity may also be impacted by resource exploitation and development. Recent road development in Canada’s Arctic may severely impact the water chemistry of the surrounding arctic lakes. The newly opened Inuvik-Tuktoyaktuk transposition corridor as well as the Dempster highway may result in changes in alkalinity, conductivity, pH, calcium, nitrate and sulfate due to the increased road dust entering the lakes and be a potential source contributing to the change in water chemistry and community structure and freshwater biodiversity (Gunter 2017).

1.3 RESEARCH OBJECTIVES AND SIGNIFICANCE

This study has two main objectives: (i) To collect baseline data on water chemistry and rotifer communities for a minimum of 20 lakes along the Tuktoyaktuk-Inuvik-Fort McPherson (TIF) transportation corridor in the Northwest Territories and (ii): To use statistical models to identify the main factors that influence rotifer community structure in these lakes. This research will contribute to determining if changes in water chemistry due to climate change and increased development could lead to shifts in rotifer community structure.

Using this information, I will be able to determine how changes in the physical environment such as permafrost thaw and road development may impact rotifer community structure. Overall, my project will allow for a better understanding of the long-term impacts of climate change and development in the Northwest Territories and what these impacts might mean for freshwater biodiversity.

1.4 HYPOTHESES

I expect that the structure of rotifer communities will differ between lakes depending on environmental variables associated with road development and climate change such as temperature, nutrient levels, and ionic concentrations (i.e. Ca) (Chengalath and Koste 1989; De Smet and Beyens 1995; Wen et al. 2011; Kokelj et al. 2009). Several past studies have demonstrated similar relationships between the above environmental variables and rotifer richness and diversity (De Smet and Beyens 1995; Wen et al. 2011). I also expect to see differences in water quality between lakes located south of Inuvik in the boreal forest versus those north in the tundra due to factors such as latitude, temperature, turbidity and conductivity (Dodson et al. 2005; Bliss et al 2010; Swadling et al 2000).

2. METHODOLOGY

This study was conducted along the Dempster Highway and the Inuvik-Tuktoyaktuk Highway in the Northwest Territories (Figure 1). These highways run through the Gwich'in Settlement Area (GSA) and Inuvialuit Settlement Region (ISR). This area was chosen as natural lakes are easily accessible from the highway, and the latitudinal gradient of the ISR and the GSA make these sites more sensitive to climate change and permafrost degradation (Kokelj 2009). In addition, this study site is impacted by highway development pressure as they lay along the main south-north transportation corridor. For this study, 20 small-to-medium sizes lakes with surface areas less the 100 ha were sampled for a combination of morphometric, biological and water quality data (Figure 2). Lakes along the Dempster Highway, running between Fort McPherson and Inuvik, were sampled between August 2017 to September 2017. Lakes sampled in this area are located in a boreal Forest region dominated by a variety of coniferous trees which is underlain by discontinuous permafrost (Kokelj 2009; Sweetman et al. 2010). Lakes along the Inuvik-Tuktoyaktuk Highway were sampled between August 2018 to September 2018. Lakes sampled in this area are located in the tundra region underlain by a continuous permafrost zone therefore, more prone to permafrost degradation influencing water quality (Kokelj 2009).

2.1 OBJECTIVE 1

2.1.1 Water quality and Morphometry

To complete objective 1, a combination of morphometric, water quality and biological variables were collected for 20 study lakes. Morphometric data included mean depth, maximum depth and surface area of the lakes; these variables were collected using a Humminbird Helix 5 chart plotter (Johnson Outdoors Marine Electronics, Inc) in combination with Reef Master bathymetry software. Water quality data were collected at each of the lakes, including: Secchi depth (water clarity), turbidity, chlorophyll-*a*, conductivity, dissolved oxygen (DO), pH, total nitrogen (TN), total organic carbon (TOC), total phosphorus (TP), calcium, and water temperature. A multiparameter probe (Eureka Water Probes) was utilised in order to measure conductivity, DO, pH, turbidity, and water temperature. A Secchi disk was used to measure water clarity data for each of the lakes. In addition, a 1 L water sample was collected from each site at the deepest point of the lake using a 3 m polyethylene integrated tube sampler that collected a sample throughout the top 3 m of the water column. At the Center for Cold Regions and Water Science at Wilfrid Laurier University, the Perkin Elmer Optima 8000 Inductively

Coupled Plasma Optical Emission Spectroscopy (ICP-OES) was used to measure calcium concentrations. The Shimadzu TOC-LCPH Carbon and Nitrogen analyzer (Shimadzu Corp.) was used to measure TN and TOC. Samples for TP were digested in an autoclave with ammonium persulfate and sulfuric acid following EPA method 365.1. We then followed SEAL method G-103-93 to measure TP colorimetrically using a SEAL Continuous Segmented Flow Analyzer (SEAL Analytical, Inc.). Chlorophyll-*a* data were also obtained by collecting a 250 mL water sample from the shoreline in 2018. Samples were filtered using Fisherbrand G4 glass fiber filters, and chlorophyll-*a* was extracted from the filters using methanol and analyzed using a fluorometer (Turner TD700) at Queens University (Symons et al. 2012). A principal component analysis (PCA) was used to group lakes with similar water quality and morphometry characteristics. A PCA provides a visualization (ordination diagram) in which lakes that group closer together share more similarities in morphometry and water quality variables than sites that are located further apart on the plot (Dytham 2011).

2.2 OBJECTIVE 2

2.2.1 Rotifer Communities

Rotifer samples were collected from 20 lakes, 10 sampled along the Dempster Highway and 10 along the Inuvik-Tuktoyaktuk highway. For lakes greater than 3 m in depth, a vertical haul of 35-cm diameter and 50-µm net size was used. Horizontal hauls were used where vertical tows were not possible (depth < 3 m), by towing the net behind the boat for 60 seconds. Flowmeters were used in both cases to calculate the volume of water which passed through the net during each haul. Each lake sample was analyzed in the laboratory in order to identify individual rotifers present to the genus level according to the key by Haney et al (2013). A Sedgwick Rafter counting slide was used at a magnification of 40x to identify at minimum of

100 individual species in each sample. A minimum of three subsamples were analyzed from each sample in order to ensure an accurate estimate of species abundances.

2.2.2 Statistical Analysis of Rotifer Communities

Rotifer species richness was measured by compiling a dataset containing a count of different rotifer genera found at each study site. In order to compare species richness and diversity for the rotifers present in each lake, indices which correct for differences in the sample size among the lakes was utilized. For species richness, rarefaction was used to ensure richness values reflected equal sampling effort for each lake, ensuring that richness values were comparable. Rarefaction calculations account for the differences in sampling effort and correct richness values for sample size; this is done by resampling rotifer abundance data to determine the average number of species identified for the given number of rotifers collected (Gotelli and Colwell, 2001). Rotifer species richness was rarefied to communities of 404 individuals, which was the lowest number of individuals identified from a single lake. Species richness refers to the number of species present at each study lake, whereas species evenness refers to the relative abundance and density of each species (Morris et al. 2014). An evenly distributed community is characterised by a community which has a similar number of each species, while an uneven community may be dominated by one or a few species. To describe community evenness, Pielou's J index was calculated; *J* assumes a value between 0 and 1, with 1 being complete evenness.

To provide further insight, a PCA was used to view differences in community structure among lakes. Community structure displayed by a PCA takes into account both the species present in each lake as well as the relative abundance of those species. The output of a PCA allows for a visualization of the differences in rotifer abundances among lakes, as lakes with similar communities’ cluster together on the plot (Dytham, 2011). Furthermore, a cluster analysis was used to overlay clusters on the PCA, indicating groups that may share similar community structures. The k-means cluster analysis was applied using the stats package for R and is able to group data points into a specific number of clusters chosen by the user (R Core Team, 2016; Hartigan & Wong, 1979).

A redundancy analysis (RDA) was used to help identify spatial relationships and environmental variables which impact the structure of rotifer communities (Dytham, 2011). An RDA is a multivariate statistical method which is used to identify and summarize variation in a dataset that has multiple predictor variables and multiple response variables (SBH 2007). In this study, the response variables were rotifer species abundances separated by lakes while the predictor variables were latitude, mean depth, maximum depth, lake surface area, dissolved oxygen, turbidity, pH, phosphorus, chlorophyll-*a*, temperature, and conductivity. The RDA identified which predictor variables were most important for structuring rotifer communities. All statistical analyses were conducted in R (R Development Core Team 2019).

3. RESULTS

3.1 MORPHOMETRY AND WATER QUALITY

A total of 16 morphometric and water quality variables were measured at each of the 20 study lakes. For water quality, surface temperature for southern lakes ranged between 10.26 - 16.91 °C whereas northern lakes ranged between 8.81 – 16.35 °C (Table 1). The pH for all 20 lakes ranged between 6.1-10.65. Secchi depths values were larger in northern lakes whereas turbidity values were typically higher in southern lakes. In addition, chlorophyll-a, total phosphorus, and calcium values were all higher in northern lakes whereas TN and total organic carbon levels were generally higher in southern lakes (Table 1; Table 2). In terms of morphometry, northern lakes were typically deeper then southern lakes, with a mean depth of 1.49 m, and had a larger surface area than southern lakes (Table 3).

The first two PCA axes explained 42.8 % of variation among lakes (Figure 3). Lower latitude lakes in the boreal region clustered in the upper left and lower left quadrant of the PCA. These lakes are typically warm, rich in TOC and have high turbidity and TN concentrations. Lakes located at higher latitudes in the tundra region clustered in the upper right and lower right quadrant of the PCA. These lakes were cooler, deeper, clearer and had a larger surface area in comparison to the boreal lakes. Additionally, the tundra lakes were elevated in pH, DO, TP, chlorophyll-a, conductivity and calcium compared to boreal lakes.

3.2 ROTIFER COMMUNITIES STRUCTURE

A PCA was performed with rotifer species abundance data with the first two PCA axes explaining 39 % of the variation (Figure 4). The PCA suggests that rotifer genera *Polyarthra* and *Ascomorpha* are positively associated with southern lakes located in the boreal region while rotifer genera *Monostyla* and *Kellicottia* are positively associated with northern lakes located in the tundra region. The RDA analysis indicated that temperature, TN, and latitude were significant predictors of rotifer community composition with the first two RDA axes explaining 23.18 % of the variation (Figure 6). The RDA suggests that *Kellicotia* is associated with lakes that had higher TN and lower temperature whereas *Polyarthra* is associated in lakes with a lower TN value and higher temperatures. *Ploesoma*, *Synchaeta* and *Monostyla* were abundant in lakes located at higher latitudes in the tundra region. The results of the RDA hint that the rotifer genera

Conochilus, *Asplanchna* and *Keratella* were positively associated with lakes located at lower latitudes and higher temperatures. The cluster anlaysis identified three types of rotifer community found in my dataset (Figure 5), but these community types were not clearly related to the predictor variables.

4. DISCUSSION

4.1 ANALYSIS OF ROTIFER COMMUNITIES

There were clear differences in the structure of rotifer communities between lakes located south of Inuvik in the boreal forest versus those north in the tundra. In general, southern lakes were dominated by *Keratella*, *Conochilus*, *Asplanchna*, and *Polyarthra* while *Monostyla*, *Kellicottia*, *Synchaeta* and *Ploesoma* were abundant in northern lakes. My results contrast Paschale and Warwich (2017), as their study on arctic lakes was dominated by *Anuraeopsis*, *Polyarthra*, *Keratella*, and *Conochilus*. These results could be attributed to the geographical differences in study sites as Paschale and Warwichs (2017) study was located in northern Quebec. My results also differ from Nogrady and Smol (1989) as their most northern study pond, Beach Ridge pond, was dominated by *Colurella*, *Encentrum*, *Kellicotia*, *Keratella*, and *Lecane* however, this could be due to the temperature warming in the NWT as this study that took place 20 years ago.

Although there were many potential physical differences between northern and southern lakes that may have caused differences in community structure, the redundancy analysis showed that the main variables associated with these differences were temperature, latitude, and TN (Figure 6). These results support my hypothesis that the structure of rotifer communities would differ depending on environmental variables such as temperature and nutrients (TN). This hypothesis was supported by past studies analysing rotifer community structure in relation to physical and chemical conditions (Chengalath and Koste 1989; Wen et al 2011). Chengalath and Koste (1989) concluded that distributional patterns of arctic rotifers were correlated with temperature and latitude as rotifer community composition and rotifer species richness declined with increasing latitude and decreasing temperatures. Other studies have associated the low species richness and diversity of arctic rotifers relative to other regions was most likely due to the severe physical environment as well as the lack of research done in the arctic at the time (Rublee 1998). In addition, previous studies have shown that lake TN values play an important role in shaping rotifer community structure (Wen et al 2011). TN values are typically associated with the trophic state of a lake (Wen et al 2011); lakes with higher amounts of TN generally have higher nutrient levels and favor genera such as Kellicotrria, Monostyla and Synchaeta (Pejler et al. 1983; Wen et al 2011). This result was represented in my RDA as these genera were found in high abundances in norther lakes. *Kellicottia*, *Monostyla* and *Synchaeta* are all macro-filter feeders that feed mainly on edible algae and consume bacteria-detritus particles (Pejler et al 1983;Wen et al 2011); the filter-feeding habits of these specific rotifer genera may be the reason that they were found in high abundances in lakes with high TN values. Although TN will increase abundances of certain rotifer genera it will decrease the overall richness and diversity of rotifer communities. These results indicate that alterations in water quality due to climate change, including increases in temperature and TN, have the potential to cause significant changes in the composition of rotifer communities in the future.

Rotifer species diversity was positively correlated with variables that might be affected by climate change, including Secchi depth, conductivity, and calcium concentrations; and negatively correlated with surface temperature and TN (Table 4). For species richness, surface temperature, dissolved oxygen, and TN were negatively associated while Secchi depth, pH, conductivity, total organic carbon and calcium were all positively associated with richness. Additionally, variables that could be impacted by roadway development such as conductivity, calcium, and Secchi depth were positively associated with richness and diversity of rotifers. These results support my hypothesis that variables associated with development and climate change will be important for structuring rotifer communities. Several studies have demonstrated similar relationships between the above environmental variables and rotifer richness and diversity. For example, Chengalath and Koste's (1989), Rublee (1998), and De Smet and Beyens (1995) found that temperature was negatively correlated with species richness and diversity, while Liping et al (2018) and Wen et al (2011) found that rotifer richness and diversity was negatively associated with nutrient levels (i.e. TN).

Rotifer species richness was highly variable amongst all my study lakes. A total of 21 rotifer genera were identified, with an average of 12 genera per lake. Other studies have shown similar results for taxa richness in northern Canada. For example, Nogrady and Smol (1988) examined five arctic ponds in Cape Hershel, Ellesmere Island and the Northwest Territories, and found a total of 33 rotifer genera with an average of 13 genera per lake. Similarly, studies done by Rublee (1992) and (1998) which analyzed microplankton in arctic lakes found 20 rotifer taxa in their study lakes. My results showed that richness depended on latitude; the 10 study lakes located at northern latitudes from Inuvik to Tuktoyaktuk had a low taxon richness with an average of 10 rotifer genera per lake compared with 13 rotifer genera found in the 10 study lakes located in more southern latitudes from Inuvik to Fort Mchpherson. This latitudinal pattern corresponds with the results of the study by Paschale and Warwick (2017) who found that lakes located at higher latitudes in Quebec's subarctic region contained fewer species in comparison with southern lakes. Similarly, a study done by Moore (1978) which investigated the composition and structure of zooplankton communities in arctic and subarctic lakes found that latitude and low water temperatures heavily influences the diversity and abundance of arctic zooplankton.

4.2 ANALYSIS OF WATER QUALITY AND MORPHOMETRY

The water quality data obtained from the 20 study lakes generally conformed to the previous studies done in the NWT region. Previous studies found that the pH of the lakes in the region range between 6.9-7.6 (Houben et al. 2016; Kokelj et al. 2009); the pH values obtained for this study displayed a larger range of 6.1- 10.6 however, the mean pH concentration was 7.5 falling in the range of previous studies. The mean TOC concentration levels obtained for my lakes was 18.9 mg/L which is similar to findings by Kokelji et al (2009) of 16.1 mg/L for 39 study lakes in the same region. The mean chlorophyll- a concentration was 4.8 µg/L which falls within the 0.20µg/L to 19.60 µg/L measured by Houben et al. (2016). Calcium concentrations ranged between 8.2 mg/L to 51.2 mg/L, while previous studies in the area recorded a calcium concentration to range between 8.6-31.4 mg/L. The wider range of calcium concentrations in my study could be attributed to the impacts of roads and highways on the water chemistry of the lakes as previous studies have shown road dust as a significant source of calcareous dust (Gunter 2017).

Lake morphometry differed between northern and southern lakes in my dataset as northern lakes were typically deeper and larger in surface area than southern lakes (Table 3). Moreover, southern lakes were typically more turbid with lower Secchi depth values in comparison to northern lakes. The differences in turbidity were likely the result of lakes in the south being shallower, allowing for the resuspension of bottom sediments by wave action. The size differences between northern and southern lakes were likely chance differences due to non-random lake selection and so, they probably don't represent a real pattern across the landscape. Southern lakes were also found to have lower conductivity and calcium levels, and higher TOC levels. This supported my second hypothesis regarding differences in water quality between boreal and tundra lakes. I speculate that differences in calcium and conductivity may be related to the surrounding vegetation along the latitudinal gradient, as the southern study lakes were surrounded by coniferous forest species, while the northern lakes had shorelines dominated by small shrubs and sedges. The boreal vegetation located by the southern lakes might act as a more effective barrier against road dust contamination that could lead to lower conductivity and calcium levels (Parsons 1994). The elevated TOC levels in southern lakes are also likely a result of vegetation differences, as the boreal landscape would allow for a higher input of allochthonous material, raising organic carbon levels.

4.3 FUTURE DIRECTIONS

I believe that this study accomplished its objective as it was able to identify factors which affect rotifer community structure as well as assess the impacts of stressors such as climate change and increased development on rotifer communities in the NWT. However, there are some obvious limitation to my study. For example, the study only identified rotifer communities to the genus level, so the exact species composition was not used in this study. In addition, my study identified latitude as a factor which influences rotifer community structure and composition. Though, the latitudinal range for this study only differed 1 to 2 degrees as the northern-most lake sampled was 69.3^{o}N and the southern-most lake was 67.3 ^{o}N. In order to identify latitude as a factor which influences rotifer community structure it is possible for future studies to explore a larger latitudinal range in northern Canada. This study was also limited as it did not test the effects of predator population on rotifer community structure. Rotifer population tend to be predated upon by copepod communities as well as larger carnivorous rotifer species such as *Asplanchna* (Liping et al. 2018). Future work could improve this study by adding additional predicator variables such as rotifer predator abundance in order to identify factors which influence rotifer community structure.

4.4 CONCLUSION

In conclusion, several of the factors I identified as important for structuring rotifer communities are expected to be affected by climate change and human development, including nutrient levels, conductivity, temperature, calcium, and TOC concentrations. As a result, I expect the structure of rotifer communities in NWT lakes may significantly affected by these stressors in the future. Given the small number of lakes that will be impacted by road development, I hypothesize that the overall richness and diversity of rotifer communities in the Northwest Territories will decline due to climate-driven changes in surface temperatures and nutrient levels.

4.5 ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Dr. Derek Gray, for his invaluable patience, guidance and assistance while allowing me this research opportunity in his field of expertise. I am particularly grateful of the help of Jasmina Vucic for her valued constructive feedback during every aspect of my thesis. Her guidance, patience, encouragement and mentorship truly helped me accomplish this research project and I will always be grateful. I would also like to offer a special thanks to all of the lab members (Rachel Cohen, Mercedes Huynh, Matt Teillet, Tom Pretty, Mariam Elmarsafy, and Jackie Franceschini) for their friendly guidance and encouragement throughout the year. In addition, I would like to thank my family and friends, specifically my parents Seema Syed and Wajid Syed, for their unconditional support and praise throughout my entire undergraduate degree.

5. FIGURES AND TABLES

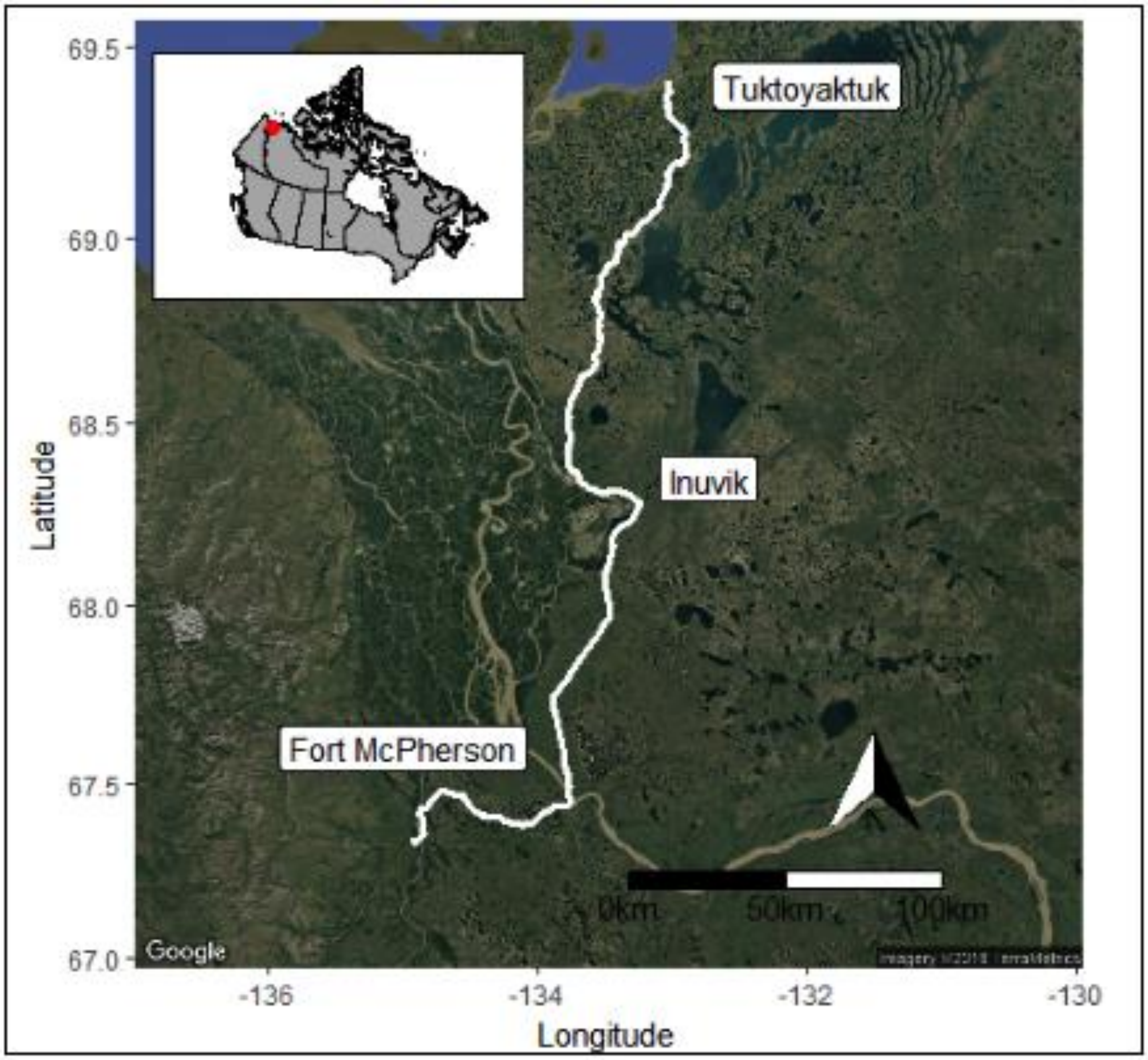

FIGURE 1. Map of the Northwest Territories showing study sites used which spans between Fort McPherson, Inuvik, and Tuktoyaktuk

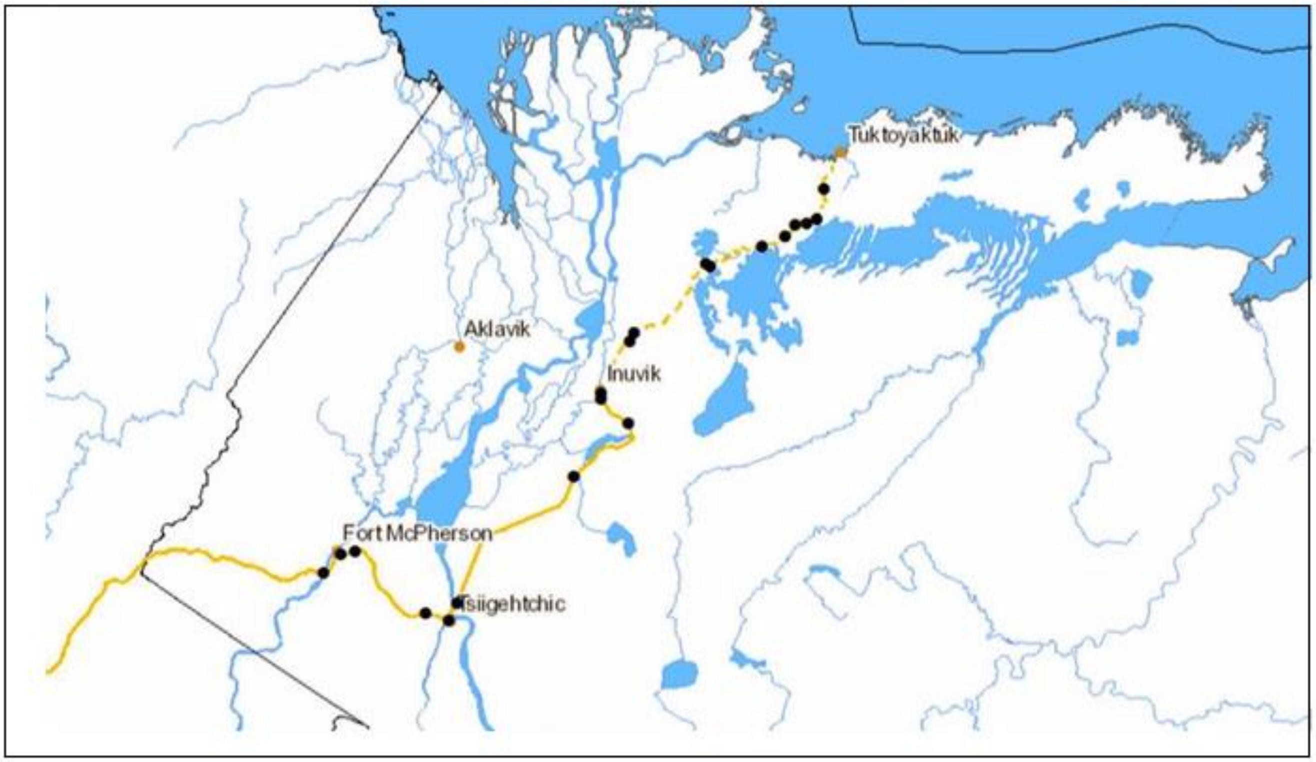

FIGURE 2. Map displaying 20 study sites in the Northwest Territories which span between Fort McPherson, Inuvik, and Tuktoyaktuk

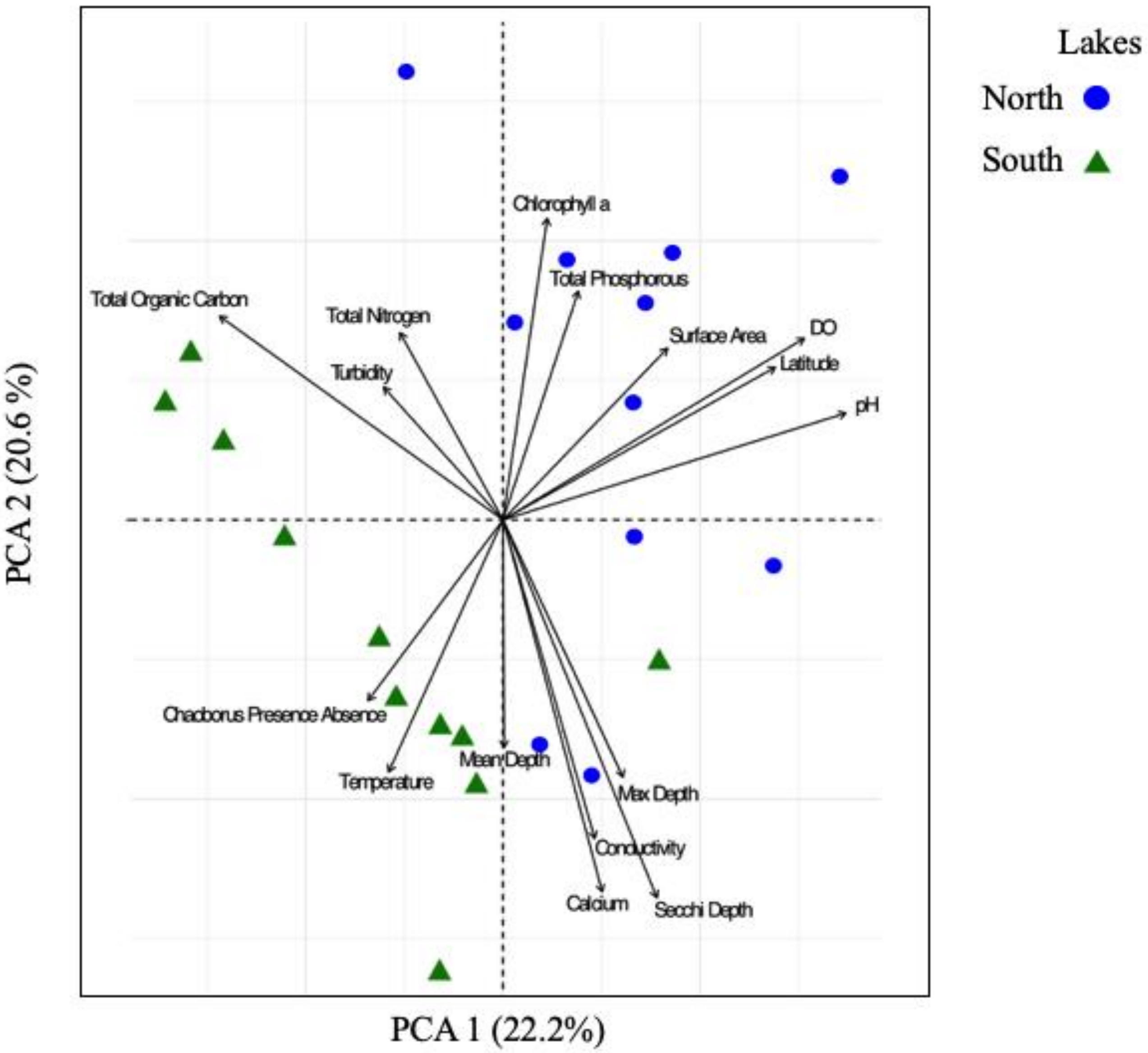

FIGURE 3. Principal component analysis of water quality variables found in 20 lakes located in both tundra and boreal regions. Circles represent lakes located at higher latitudes in the tundra while triangles represent lakes located at lower latitudes in the boreal

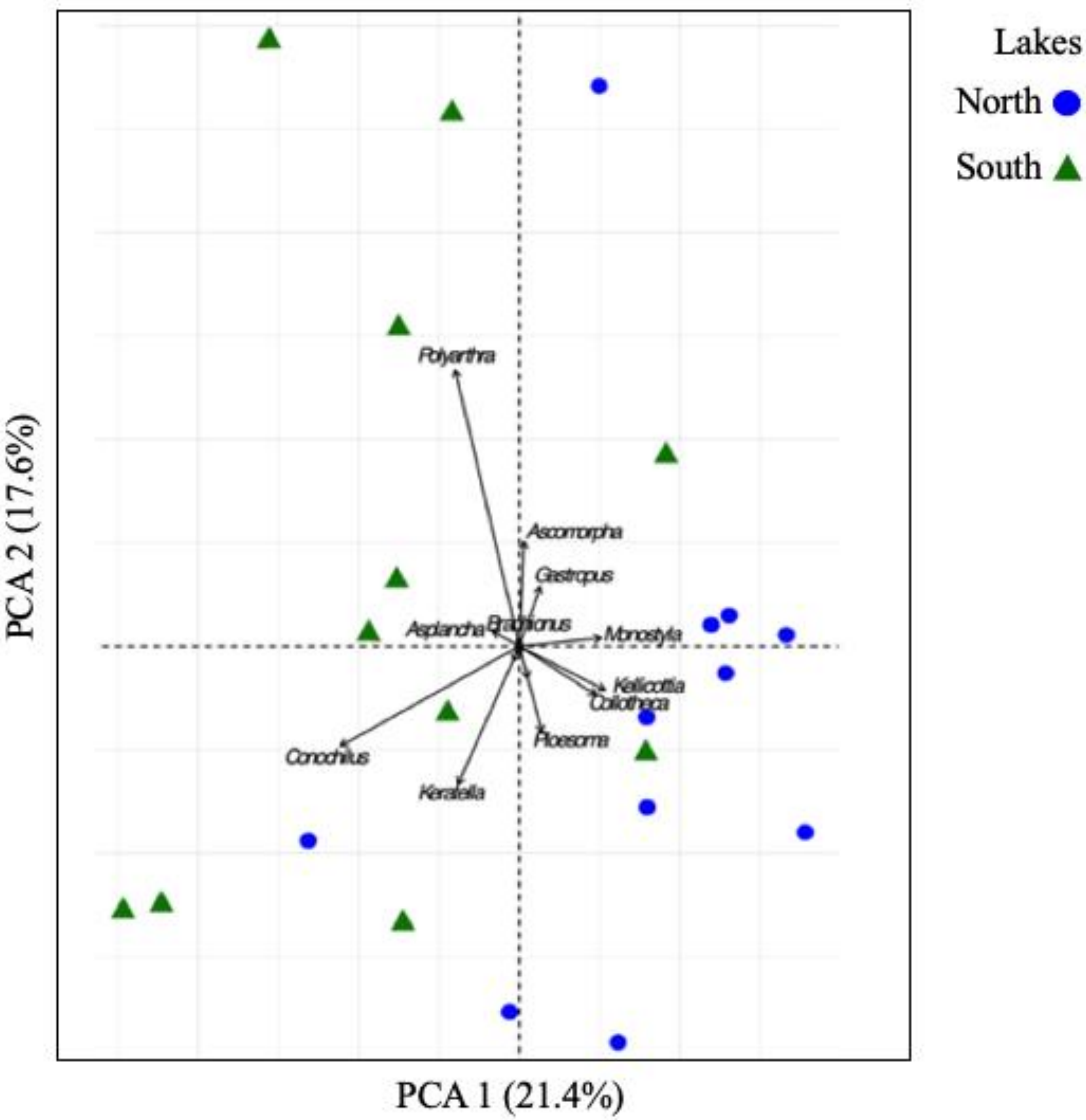

FIGURE 4. Principal component analysis of rotifer genera present found in 20 lakes both tundra and boreal regions. Circles represent lakes located at higher latitudes in the tundra while triangles represent lakes located at lower latitudes in the boreal

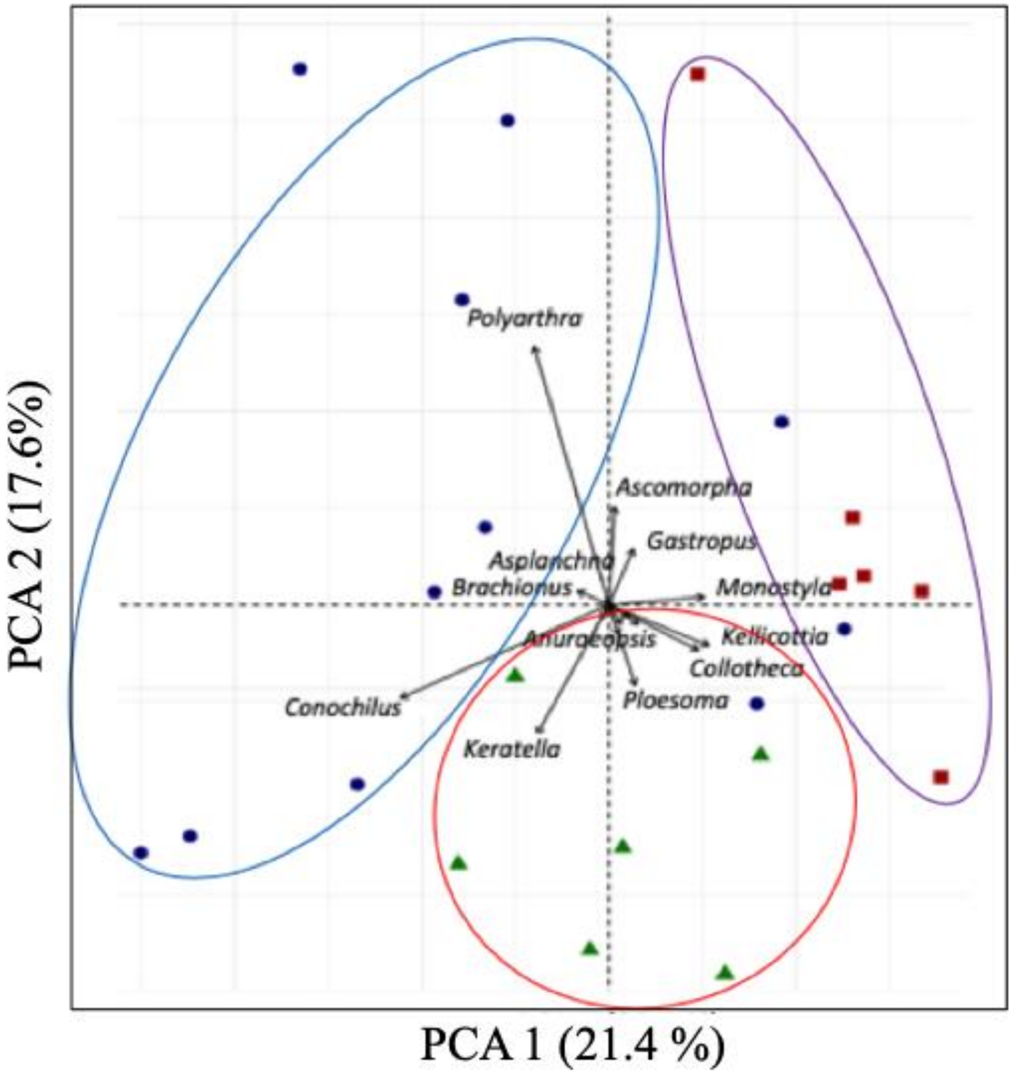

FIGURE 5. Principle components analysis plotted with markers showing the results of a cluster analysis. The cluster analysis shows the three main types of rotifer community found in my lakes

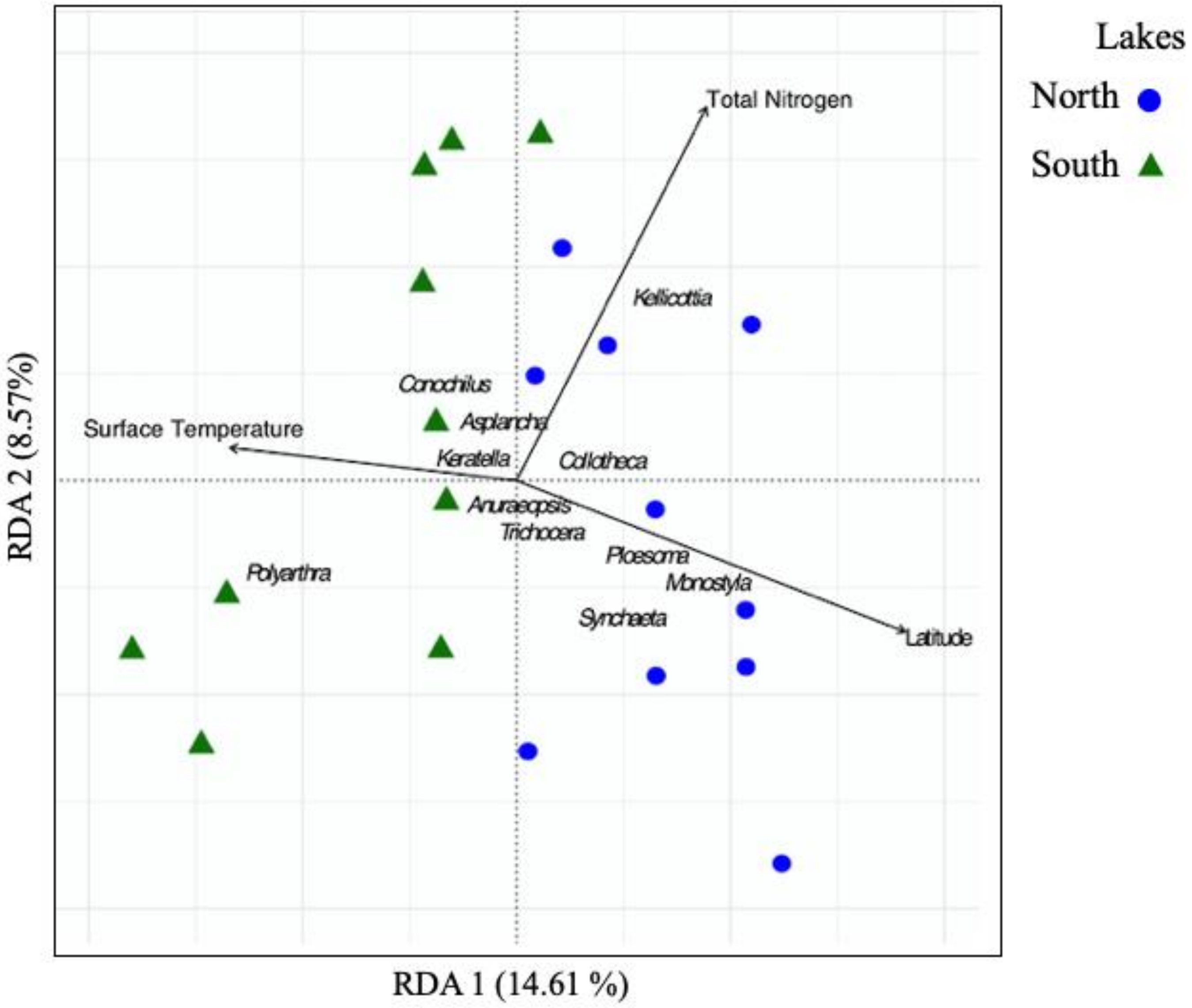

FIGURE 6. Redundancy analysis comparing water quality variables with rotifer genera found in 20 lakes. Circles represent lakes located at higher latitudes in the tundra region while triangles represent lakes located at lower latitudes in the boreal

TABLE 1. Water quality data for the ten southern study sites in the Northwest Territories which span between Fort McPherson to Inuvik.

Lake	CIMP 1	CIMP 2	CIMP 7	CIMP 19	CIMP 23	CIMP 27	CIMP 33	CIMP 35	CIMP 38	CIMP 43
Surface Temp	16.12	16.39	12.49	14.77	16.13	12.88	16.19	11.82	13.05	10.26
Secchi (m)	3.32	3.65	0.79	1.49	3.43	0.52	0.46	1.98	2.32	0.47
pH	7.94	7.69	7.09	7.84	9.78	6.81	6.46	6.69	6.65	6.12
Conductivity	427.1	180.1	91.9	211.2	228.6	19.9	80.7	187.9	187.4	71.7
Chlorophyll-a	1.87	1.34	0.33	0.96	4.53	3.82	0.73	0.38	0.26	0.63
DO	9.55	9.27	8.54	9.71	12.52	10.37	8.04	9.78	8.61	9.23
Turbidity	11.17	6.73	14.82	1.14	0.91	8.63	0.73	3.15	2.23	6.43
TP (mg/L)	0.08	0.08	0.03	0.06	0.08	0.06	0.08	0.04	0.05	0.06
TOC (mg/L)	11.61	16.93	26.36	19.73	21.31	40.39	32.29	14.19	12.14	34.01
TN (mg/L)	0.43	0.43	0.54	0.61	0.13	0.98	0.12	0.36	0.41	0.74
Ca (mg/L)	51.3	21.7	14.9	32.7	25.6	19.9	8.2	23.7	22.6	8.7

TABLE 2. Water Quality Data for the ten northern study sites in the Northwest Territories which span between Inuvik to Tuktoyaktuk.

Lake	FISH 1	FISH 3	FISH 11	FISH 14	FISH 24	FISH 20	CIMP 10	CIMP 18	CIMP 28	FISH 21
Surface Temp	15.9	16.3	13.2	11.4	8.7	12.8	11.4	9.6	8.3	8.8
Secchi (m)	2.43	1.94	0.58	1.49	1.68	2.29	1.22	1.37	1.98	0.46
pH	7.77	9.18	7.34	9.13	8.85	7.91	7.72	8.97	9.31	10.65
Conductivity	140	243	64	156	116	122	115	157	174	132
Chlorophyll-a	4.84	20.31	24.13	5.25	5.28	4.29	7.33	6.83	2.61	2.21
DO	9.73	11.32	9.89	10.86	11.94	9.85	10.04	11.5	12.44	12.56
Turbidity	0.14	11.83	12.79	3.45	2.89	0.43	6.48	4.43	2.95	2.77
TP (mg/L)	0.04	0.13	0.08	0.04	0.13	0.05	0.07	0.08	0.054	0.067
TOC (mg/L)	10.03	21.41	22.17	14.33	17.33	10.17	15.27	13.34	12.48	14.34
TN (mg/L)	0.85	0.71	0.74	0.72	0.52	0.34	0.57	0.65	0.33	0.43
Ca (mg/L)	12.4	15.8	13.3	21.7	11.2	22.7	15.7	14.9	23.4	19.4

TABLE 3. Morphometric Data for lakes 20 study sites in the Northwest Territories which span between Fort McPherson, Inuvik, and Tuktoyaktuk

Lake	Latitude	Surface Area (km2)	Mean Depth (m)	Max Depth (m)	Standard Deviation
CIMP 1	68.35	0.212	1.7	5.9	2.96
CIMP 2	68.33	0.323	2.1	5.2	2.19
CIMP 7	68.06	0.032	2.3	7.3	3.53
CIMP 19	68.31	0.013	1.5	5.2	2.61
CIMP 23	67.44	0.019	0.9	3.4	1.76
CIMP 27	67.42	0.036	1	1.5	0.35
CIMP 33	67.46	0.099	1.2	2.6	0.98
CIMP 35	67.42	0.068	1.9	4.8	2.05
CIMP38	67.34	0.008	1.3	4.5	2.26
CIMP 43	67.50	0.009	2	4.1	1.48
FISH 1	68.54	1.531	2.3	13.1	7.63
FISH 3	68.57	1.133	1.3	2.4	0.77
FISH 11	68.89	0.576	1	3.3	1.62
FISH 14	69.04	0.374	1.7	9.5	5.51
FISH 24	69.22	0.634	2	3.4	0.98
FISH 20	69.16	0.665	1.9	10.7	6.22
FISH 21	69.19	1.901	1.31	3.4	1.47
CIMP 10	68.89	0.424	0.9	4.2	2.33
CIMP 18	69.11	0.229	1.3	3.8	1.76
CIMP 28	69.31	1.330	1.8	8.9	5.02

TABLE 4. Multiple linear regression table displaying relationships between environmental variables and rotifer species richness and diversity

Univariate Metric	Significant Variable	Positive/Negative	p-Value	r^2
Richness	Surface Temperature	-	0.0442	0.4652
	Secchi Depth	+		
	pH	+		
	Conductivity	+		
	DO	-		
	TOC	+		
	Total Nitrogen	-		
	Calcium	+		
Diversity	Surface Temperature	-	0.01714	0.4054
	Secchi Depth	+		
	Conductivity	+		
	Calcium	+		

6. REFERENCES

Bliss, L, C., Strong, W,I., Roy, L, T., Meidinger, D., Robert, T., Maycock, P, F., Scott, J, P., Bird, C, J. 2010. Vegetation Regions. The Canadian Encyclopedia.

Arndt, Hartmut. 1993. Rotifers as predators on components of the microbial web (Bacteria, Heterotrophic Flagellates, Ciliates)—a review. Hydrobiologia. 255-256. 231-246. 10.1007/BF00025844.

C. Duggan, J. D. Green & K. Thomasson. 2001. Do rotifers have potential as bioindicators of change for northern Canada: Freshwater, marine, and terrestrial ecosystems. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/19714961.

Chengalath, R. & Koste, W. 1989. Composition and dirstubtional pattern in arctiv rotifers. Hydrobiologia 186: 191. Doi: https://doi.org/10.1007/BF00048912.

Chin, K. S., Lento, J., Culp, J. M., Lacelle, D., & Kokelj, S. V. 2016. Permafrost thaw and intense thermokarst activity decrease the abundance of stream benthic macroinvertebrates. *Global Change Biology*. 22(8), 2715-2728. doi:10.1111/gcb.13225.

De Smet, W. H. & L. Beyens. 1995. Rotifers from the Canadian High Arctic (Devon Island, Northwest Territories). Hydrobiologia 313/314: 29–34.

Dodson SI, Richard AL, Will-Wolf S. 2005. Land use, water chemistry, aquatic vegetation, and zooplankton community structure of shallow lakes. Ecological Applications 15:1191–1198.

Dytham, C. 2011. Choosing and using statistics a biologist's guide. Chichester: Wiley-Blackwell.

Frey, K. E., and J. W. McClelland. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. Hydrological Processes, 23(1), 192-182. doi:10.1002/hyp.7196.

Gotelli, N,J, and Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters*, 4: 379-391.

Gunter, A. R., 2017. The impact of road dust on arctic aquatic ecosystems, Northwest Territories, Canada. *Masters Thesis,* Brock University.

Haney, J.F. et al., An Image-based Key to the Zooplankton of North America version 5.0 Released. 2013. University of New Hampshire Center for Freshwater Biology.

Hartigan, J. A. and M. A. Wong. 1979. Algorithm AS 136: A K-means clustering algorithm. ***Applied Statistics****,* 28, 100-108. doi: 10.2307/2346830.

Hobbie E. J., Peterson, J., Bettez, N., Deegan, L., O'Brien, J., Kling, W., George W. Kipphut, William B. Bowden & Anne E. Hershey. 1999. Impact of global change on the biogeochemistry and ecology of an Arctic freshwater system, Polar Research, 18:2, 207-214, doi: 10.3402/polar.v18i2.6576.

Houben, A. J., French, T. D., Kokelj, S. V., Wang, X., Smol, J. P., & Blais, J. M. 2016. The impacts of permafrost thaw slump events on limnological variables in upland tundra lakes, Mackenzie Delta region. Fundamental and Applied Limnology / Archiv Für Hydrobiologie, 189(1), 11-35. doi:10.1127/fal/2016/0921

Kokelj, S. V., B. Zajdlik, and M. S. Thompson. 2009. The impacts of Thawing permafrost on the chemistry of lakes across the subarctic boreal-tundra transition, Mackenzie Delta region, Canada. Permafrost and Periglacial Processes, 20(2), 185-199. doi:10.1002/ppp.641

Liping, Yin., Yu, Ji., Yinjiang, Zhang., Linxuan, Chong., Lijing, Chen. 2018.Rotifer community structure and its response to environmental factors in the Backshore Wetland of Expo Garden, Shanghai. Aquaculture and Fisheries, 3(2), 90-97, doi: https://doi.org/10.1016/j.aaf.2017.11.001.

Mittelbach, G. G. 2012. *Community ecology*. Sunderland, MA: Sinauer Associates.

Moore.,W, J. 1978. Compositions and structure of zooplankton communities in eighteen arctic and subarctic lakes. Hydrobiology. 63(4): 545-565.

Morris, E. K., T. Caruso, F. Buscot, and others. 2014. Choosing and using diversity indices: Insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution, 4(18), 3514-3524. doi:10.1002/ece3.1155

Nogrady, T. & J. P. Smol. 1989. Rotifera from five high arctic ponds (Cape Herschel, Ellesmere Island, N.W.T.). Hydrobiologia 173: 231–242.

Paschale, N, B., Warwick, F, V. 2017.Permafrost thaw lakes and ponds as habitats are abundant rotifer populations. Arctic Science. 3:354-377. Doi: https://doi.org/10.1139/as-2016-0017.

Peet, Robert. 2003. The Measurement of Species Diversity. Annual Review of Ecology and Systematics. 5. 285-307. 10.1146/annurev.es.05.110174.001441.

Pejler, B., Starkweather, R., Nogrady, T. 1982. Biology of Rotifers. Hydrobiologia : 104: 156-389. doi: 10.1007/978-94-009-7287-2.

Pennak, R. W. 1953. Freshwater invertebrates of the United States. Ronald Press, New York, 769 pp.

Prowse, T. D., Furgal, C., Wrona, F. J., & Reist, J. D. 2009. Implications of climate change for northern Canada: Freshwater, marine, and terrestrial ecosystems. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/19714961

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Radwan, S. 1980. The Effect of Some Biotic and Abiotic Factors on the Fertility of Planktonic

Rotifer Species. Rotatoria, 59-62. doi:10.1007/978-94-009-9209-2_12.

Rublee, P. A. 1992. Community structure and bottom-up regulation of heterotrophic microplankton in arctic LTER Lakes. Hydrobiologia 240 (Dev. Hydrobiol. 78): 133–142.

Rublee, Parke. 1998. Rotifers in arctic North America with particular reference to their role in microplankton community structure and response to ecosystem perturbations in Alaskan Arctic LTER lakes. Hydrobiologia. 387-388. 153-160. 10.1023/A:1017010313812.

SBH. 2007. Principal component analysis and redundancy analysis. In: Analysing Ecological Data. Statistics for Biology and Health. Springer, New York, NY.

Sládeček, V. 1983. Rotifers as indicators of water quality. Hydrobiologia, 100(1), 169-201.

Swadling, K. M., Pienitz, R., and Nogrady, T. 2000. Zooplankton community composition of lakes in the Yukon and Northwest Territories (Canada): relationship to physical and chemical limnology. *Hydrobiologia*, 431: 211–224, doi: https://doi.org/10.1023/A:1004056715976.

Sweetman, J. N., Rühland, K. M., and Smol, J. P. 2010. Environmental and spatial factors influencing the distribution of cladocerans in lakes across the central Canadian arctic treeline region. *Journal of Limnology*, 69: 7, doi: https://doi.org/10.3274/JL10-69-1-07.

Throop, J., A. G. Lewkowicz, and S. L. Smith. 2012. Climate and ground temperature relations at sites across the continuous and discontinuous permafrost zones, northern Canada. Canadian Journal of Earth Sciences, 49(8), 865-878. doi:10.1139/e2012-002.

Vucic, J.M., Cohen, R.S., Gray, D.K., Murdoch, A.D., Shuvo, A., and Sharma, S. 2019. Young gravel pit lakes along Canada’s Dempster Highway: How do they compare with natural lakes. Arctic, Antarctic, and Alpine Research.

Wen, Xin-Li & Xi, Yi-Long & Qian, Fang-Ping & Zhang, Gen & Xiang 项贤领, Xian-Ling.

2011. Comparative analysis of rotifer community structure in five subtropical shallow lakes in East China: Role of physical and chemical conditions. Hydrobiologia. 661. 303-316. 10.1007/s10750-010-0539-6.

Williams, D. D. 2014. *The biology of temporary waters*. Oxford: Oxford University Press.

University Press.

Yan, N.D., Keller, W., Somers, K.M., Pawson, T.W., and Girard, R.E. 1996b. Recovery of

crustacean zooplankton communities from acid and metal contamination: Comparing manipulated and reference lakes. Canadian Journal of Fisheries and Aquatic Sciences 53: 1301-1327.