Relationship of Zooplankton Community Structure with Dissolved Ions in Saskatchewan Lakes

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by

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Abstract

Salinity levels in lakes on the Great Plains naturally shift as the region goes through periods of drought and high precipitation. In the coming century, lake salinities are expected to rise as the region experiences prolonged drought. One group of organisms sensitive to changes in salinity are the zooplankton. Previous studies show negative correlations between measures of community structure, such as richness, diversity, and evenness, with salinity. In addition, community composition often shifts away from cladoceran zooplankton to copepods in higher salinity lakes. The objective of my study is to examine differences in zooplankton communities in relation to dissolved ion concentrations in Great Plains lakes. Zooplankton were sampled from eleven lakes surrounding Saskatoon, SK with salinities ranging from 0-20 ‰. Zooplankton were identified to the genus level and common measures of community structure were calculated (richness, diversity, evenness). None of the measures of community structure were correlated with concentrations of dissolved ions. However, lakes with higher salinities had fewer cladocerans and more copepods. My results are surprising given the strong relationships between community structure and salinity found in previous studies. My results may reflect the small number of lakes included in my study, or the limited range of salinities found in my study lakes. Future studies should incorporate a larger sample size and encompass a wider range of salinities.

Introduction

Climate change will affect future precipitation levels and temperature, which can change the physical, chemical, and biological characteristics of lakes (Vincent, 2009). On the Great Plains of North America, there are thousands of closed basin lakes which experience significant changes in salinity as the climate shifts between wet and dry periods (Grimm et al. 2011). During the next several decades, the climate in this region is expected to get drier, resulting in increased salinity levels in these lakes (Grimm et al. 2011). Salinity is one of the major drivers of biodiversity in these lakes, with high salinity lakes often having fewer species (Wissel et al. 2010). The salinity of lakes varies across the Great Plains, and freshwater is considered in the range of 0-3‰, brackish is considered 3-10‰, and high salinity conditions are considered in ranges from 10-30‰ (Elmarsafy et al. 2020). One of the groups most sensitive to changing salinity levels is the zooplankton. Zooplankton are well known biomonitors of ecosystems and changes in their community structure can provide clues as to how climate change is affecting those regions (Gannon & Stemberger., 1978). Zooplankton distribution varies due to salinity. Some species are typically present in higher salinity lakes such as *Artemia spp., A, salina* and *Harpacticoida* (Wissel et al. 2010). Many taxa are associated with low salinity levels, including *D. pulex, D. rosea, D. brachyrum, Bosmina longistris, Daphnia galeata mendota, C. retriculata,* cycloploids and gammarids (Wissel et al. 2010).

Zooplankton are heterotrophic microinvertebrates that are found in most aquatic environments. They feed on periphyton and phytoplankton and are important prey for large invertebrates and fish (Thompson, 2012). The zooplankton is often divided into three groups: Rotifers, copepods, and cladocerans. Rotifers are the smallest members, ranging between 200-

500 µm in length. Copepods are small aquatic crustaceans that are grouped into three main orders: The Calanoida, Cyclopoida, and Harpacticoida. Calanoid copepods are herbivorous filter feeders, while most cyclopoids are predatory (Barnett et al., 2007). Both calanoids and cyclopoids live in open waters, while the harpacticoids are often associated with the lake bottom. Cladocerans are also crustacean zooplankton and are mostly herbivorous filter feeders and commonly known as the 'water fleas' in the aquatic ecosystem. Zooplankton reproduction differs among groups since cladocerans can reproduce both asexually and sexually, while copepods require sexual reproduction to produce offspring.

The composition and abundance of zooplankton species in lakes is influenced by water quality. There are many important variables, including lake surface area, pH, phosphorus, nitrogen, dissolved oxygen, conductivity, chlorophyll-a, maximum depth, and temperature (Gray et al. 2021). Conductivity is a measure of the ability of water to move an electrical current, and it is influenced by the concentration of dissolved ions. Lakes with high levels of dissolved ions have high salinity and conductivity. While zooplankton communities can be diverse in freshwaters, there are very few species that inhabit lakes with high salinities in the Great Plains (Wissel et al. 2010). Declines in species richness occur above the critical threshold of 3-5 ‰, with very few freshwater species surviving above 10 ‰ (Wissel et al. 2010). However, recent studies show that some species can survive large swings in salinity that occur over decades (Elmarsafy et al. 2020). Elmarsafy et al. (2020) showed that the common cladoceran *Ceriodaphnia dubia* persisted throughout periods of high salinity in Moon Lake, North Dakota. In addition, a recent experiment demonstrated rapid evolution in salinity tolerance for the cladoceran *Daphnia pulex* in response to elevated sodium chloride associated with road salt

(Coldsnow et al. 2017). The study showed that if the zooplankton had been cultured in a high salinity environment, it would be able to tolerate low and moderate levels during acute toxicity testing (Coldsnow et al. 2017). These results suggest that species may be able to survive in lakes undergoing salinization through adaptation to rising salinity levels.

In addition to adapting to higher salinity levels, the dispersal of zooplankton among lakes may play a role in compensating for losses that may occur as lakes become saltier due to climate change. Huynh & Gray (2019) ran mesocosm experiments that simulated an increase in salinity levels for a freshwater lake. They hypothesized that zooplankton in lakes with elevated salinities may have evolved tolerance to those higher salt levels. Therefore, dispersal of salt-adapted zooplankton from these lakes may be beneficial for zooplankton communities in lakes that are undergoing salinization (Huynh and Gray 2019). Their results suggested that if lakes receive dispersal of zooplankton from lakes with moderate salinity levels (~2-8 ‰), the decline in cladoceran species richness with increasing salinities would be smaller in comparison to lakes that didn't receive such dispersal (Huynh & Gray 2019). Their study also showed that elevated salinities caused a reduction in the abundance of cladocerans in comparison to copepods, but these changes were muted by the immigration of individuals from surrounding salty lakes (Huynh & Gray 2019).

For my thesis, I am investigating the role that salinity and the concentration of dissolved ions play in structuring zooplankton communities in lakes on the Great Plains. I have two objectives: 1) To examine differences in zooplankton communities depending on different salinities in lakes on the Great Plains of North America; and 2) To determine how richness,

diversity, and evenness relate to concentrations of different dissolved ions. Based on previous research, I hypothesized that there would be fewer zooplankton species and lower diversity in lakes with higher salinities (above 5-10‰) (Wissel et al. 2010). I also hypothesized that there would be higher concentration of copepods in comparison to cladocerans in lakes with higher salinities (Huynh & Gray 2019).

Methodology

Site selection

To select lakes for the collection of zooplankton that exhibited a range of salinities, a published study on Saskatchewan lakes by Plancq et al. (2018) was consulted. Lakes varying in salinity from 0-20 ‰ were selected for data collection, and at least three lakes representing low (0-5 ‰), medium (5-10 ‰) and high (10+ ‰) salinities were included (Table 1).

Field data collection

Field sampling in Saskatchewan occurred during August 23- 26, 2022. At each lake, surface water was collected in a 1 L Nalgene bottle for water chemistry testing of the lake. The bottle was rinsed three times with lake water before collecting the sample. The samples were sent to Taiga Laboratories in Yellowknife for measurement of specific conductivity, chloride, sulphate, calcium, magnesium, sodium, and potassium. The salinity was also measured in the field for each lake using a Hanna digital refractometer (Model HI96822).

To sample the zooplankton community from each lake, a horizontal tow from the shoreline of each lake was conducted using an 80 µm mesh size zooplankton net with a 30 cm

diameter opening. The net was thrown horizontally from the shoreline to a distance of approximately 5 m and then allowed to sink before pulling back to the shoreline. The collected samples were rinsed into a 100 mL plastic container and preserved with 95% ethanol.

Table 1. The lakes from which zooplankton were collected along with salinity (‰) and location.

Lake name	**Salinity (‰)**	**Location (degrees latitude, degrees longitude)**
Arthur Lake	13	(52.563, -105.445)
Blackstrap Lake	0	(51.784, -106.439)
Lake 783	10	(52.819, -106.223)
Middle Lake	8	(52.481, -105.303)
Nyuli Lake	2	(52.593, -105.502)
Pike Lake	0	(51.896, -106.797)
Porter Lake	8	(52.200, -106.287)
Shannon Lake	4	(52.649, -105.421)
Small Gull Lake	7	(50.106, -108.500)
Town of Herbert Lake	20	(50.427, -107.220)
Wakaw Lake	2	(52.640, -105.651)

Subsampling and counting zooplankton

In order to count and identify zooplankton, a subsampling method was used. A typical zooplankton sample contains thousands of individual zooplankters, making a compete count and identification of every individual very time consuming. Subsampling involves extracting a small volume of the original sample (e.g. 5 mL) and counting and identifying all organisms in the

subsample. The identity and abundance of species in the original sample can then be calculated based on the counts from a subsample. Subsampling often involves replication, since counting multiple subsamples allows for an estimate of how variable counts are due to the examination of small volumes of the original sample.

For this study, three replicate subsamples were created from the original zooplankton sample collected from each lake. To create a subsample, the ethanol from the preserved samples was removed by draining the samples through a 30-micron sieve. The animals in the sieve were then rinsed into a 250 mL beaker using tap water and topped off with tap water to a total volume of 100 mL. A stir bar was then put in the beaker, and it was placed on a magnetic stir apparatus set at low speed. With the stir apparatus mixing the sample, a Hensen-Stemple pipette was then used to take a 1 mL, 5 mL, or 10 mL subsample depending on the concentration of zooplankton in the particular sample. The goal was to count and identify at least 100 zooplankters from each subsample, so the subsample volume was adjusted based on the density of zooplankton in the original sample. If fewer than 100 individuals had been collected in 5 mL then another 5 mL of the subsample was taken using the Hensen-Stemple pipette and counted to reach the 100 individual threshold. If there were too many animals in a 5 mL subsample, then a 1mL subsample was used to create subsamples. Some lakes had fewer than 100 individuals in a 10 mL subsample and in those cases the whole sample was counted rather than conducting subsampling.

Each subsample was put on a zooplankton counting wheel which was placed on the stage of a dissecting microscope. The *Image-based key to zooplankton of North America* (Haney et al., 2013) was used to identify the animals in each subsample to the lowest taxonomic level possible.

In the laboratory, we used a dissecting scope on a zooplankton counting wheel with a magnification of 1x-3x magnification depending on the size of the species to identify certain animals and then if needed, the specimen was transferred to a slide using a pipette and then the slide was transferred to a compound microscope with a magnification of 40x-400x depending on the size of the species. Data from these counts were entered into an Excel file along with the site information recorded for each lake.

Analysis

Zooplankton and environmental data for each lake were imported into the R statistical program for calculation of rarefied species richness, Shannon diversity, and species evenness. Richness is the total number of unique species present in a certain location or region. Richness estimates for a habitat vary depending on the number of individuals examined for that habitat, meaning that as an investigator examines more specimens from a habitat, the number of species counted increases (Moore 2013). Therefore, it is important to correct for differences in the number of species examined when comparing two habitats. Rarified species richness or rarefaction is a technique that accounts for differences in the number of examined and is conducted by resampling abundance data for a certain site or habitat many times to determine the average number of species identified for a given number of individuals that were examined. In other words, the function in the R statistical program would take the value of the smallest number of individuals in a site and correct to that value for all the other sites so that there was an even playing field. To calculate rarified richness, the rarefy function in the Vegan package was used.

The Shannon Diversity Index (*H*), also known as the Shannon-Wiener Index is the measure of diversity which takes into account both the number of species in a community and the relative abundance of those species (Stirling &Wisley). Diversity is a community attribute related to stability, productivity, and trophic structure (Moore 2013). Shannon diversity was calculated using the diversity function in the Vegan library. Species evenness is the total number of species and the relative abundance of the species in a given community. Evenness (J) was calculated as

$$J = \frac{H}{\ln(S)}$$

Where *H* is the Shannon diversity and *S* is the species richness. Species evenness varies between 0 and 1 where the numbers closer to 1 mean that the community is even and if the numbers are closer to 0, it means that the community is uneven. An even community would have similar abundance values for each species (e.g., *5 Bosmina sp*., 5 *Daphnia sp*., 5 *Calanoid sp*., etc.) while an uneven community would be dominated by one or a few species (e.g., 20 *Bosmina sp*., 1 *Daphnia sp*., 2 *Calanoid sp*., etc.).

To examine the relationship between the water quality variables measured for each lake and zooplankton richness, diversity, and evenness, I used Pearson correlations. The Pearson correlation coefficient (*r*) is a common way of measuring linear correlation with positive correlation being when '*r*' is greater than 0, meaning both variables are increasing in the same direction. A negative correlation occurs when '*r*' is less than 0, meaning variables are changing in opposite direction where one variable is increasing, and another is decreasing. Lastly, there is no correlation when '*r*' is equal to 0. The Pearson correlation coefficient (*r*) also shows if there is a strong or weak correlation between two variables. An '*r*' value greater than 0.5 shows a strong

positive correlation, an '*r*' value less than -0.5 shows a strong negative correlation, an 'r' value of 0 again shows no correlation. In other terms, Pearson correlation 'r' can be classified into three groups: small which falls in the ranges from 0.10-<0.30, medium which falls in the ranges from 0.30-<0.50 and large which falls in the ranges from ≥ 0.50 (Cohen 1988).

To examine differences in the relative abundance of zooplankton species among my lakes, I will use Principal Component Analysis (PCA). Principal Component Analysis is an ordination technique which produces plots showing differences in the relative abundance of species among lakes along arbitrary axes that exhibit the most variation. It is commonly used in ecology to examine differences in the composition of communities among different sites (Cooper & Wissel., 2012). Points on the plot will be coloured by lake salinity, allowing me to examine if certain groups of species are more prevalent at certain salinities.

Results

Eleven lakes were sampled on the Great Plains, including Arthur Lake, Porter Lake, Middle Lake, Shannon Lake, Wakaw Lake, Blackstrap Lake, Lake 783, Town of Herbert Lake, Nyuli Lake, Small Gull Lake and Pike Lake (Figure 1). The lakes had a wide range of conductivity and salinity values. Town of Herbert Lake was highest at 20,000 µS/cm or 20 ‰ salinity (Table 1; Figure 5). Intermediate salinities were found in Small Gull, 783, Middle, Porter, and Arthur Lakes, with a conductivity range of 10,000-15,000 µS/cm or 7-13 ‰ (Table 1; Figure 5). Wakaw, Shannon, Blackstrap, and Nyuli Lakes were in the low range with a conductivity of 0- 5,000 µS/cm or 0-4 ‰ (Table 1; Figure 5).

Water quality

There were eight different water chemistry variables tested in the study lakes which included calcium, magnesium, potassium, sodium, conductivity, total dissolved solids (TDS), chloride and sulphate (Figure 6). Due to a shipping error, Pike Lake was not tested for water quality and therefore was removed from the analysis related to water chemistry. The most dominant salts among the lakes were sulphate, sodium, and magnesium (Figure 6). Sulphate was the most dominant in the lakes with the highest being in Town of Herbert (Figure 6). Sulphate was seen to be more dominant in the lakes in comparison to chloride (Figure 6). Town of Herbert Lake was seen to have an even distribution of all the salts among the different lakes (Figure 6).

There were strong positive correlations among all the water quality variables measured, with the exception of calcium (Figure 8). The PCA showed that the concentration of the various dissolved ions increased together in lakes in association with increasing conductivity (Figure 7). However, there were some differences in the relative concentrations of ions, with Arthur Lake exhibiting high calcium levels and Town of Herbert Lake exhibiting high chloride and sodium (Figure 7).

Zooplankton

In total, 23 zooplankton taxa were identified, including cladocerans in the genera *Eubosmina, Bosmina, Moina, Diaphanosoma, Ceriodaphnia, and Chydorus. Daphnia* species identified included *Daphnia parvula, D. pulex, D. lumholtzi, D. ambigua, D. magna,* and *D. schodleri.* Copepods identified included *Microcyclops spp.*, harpaticoid copepods, *Diacyclops*

spp., *Orthocyclops spp., Acanthocyclops spp., Cyclops spp., Limnocalanus macrurus, Leptodiaptomus spp., Skistodiaptomus spp.,* and phantom midge larvae from the family *Chaoboridae*.

Richness varied between ~2.5 to ~10.0 between the different lakes. Most lakes were seen to have a richness closer to 7.5 (Figure 2). Shannon diversity varied between ~0.25 to ~1.75 between the different lakes (Figure 3). Evenness was not seen in any lakes since most of the lakes had a value closer to 0 than a 1 (Figure 4). Nyuli lake had been seen to have high species richness, diversity and evenness among other lakes in comparison to Porter which had the lowest species richness, diversity and evenness (Figure 2,3,4). Nyuli lake was seen to have a lower salinity in comparison to porter which may show a relationship between salinity and species richness, diversity and evenness (Figure 5).

The Principal Component Analysis (PCA) showed that the relative abundance of zooplankton differed among lakes (Figure 5). The first PCA axis showed a gradient of calanoid copepod numbers, as lakes with low PCA 1 scores had communities dominated by calanoids. The second PCA axis separated lakes with various cladoceran species from communities with more cyclopoid copepods (Figure 5). In general, the lakes with lower conductivities tended to have communities dominated by cladocerans, while those with higher salinities had more cyclopoids (Figure 5).

There were no significant relationships found between water quality variables measured for each lake and zooplankton richness, diversity, and evenness using Pearson correlations

(Figure 8). There were however some relationships between individual species and the water chemistry variables. In terms of cladocerans, *Daphnia lumholtzi* had a positive relationship with calcium and magnesium, and *Moina* had positive correlations with sodium, chloride, sulphate, conductivity, and total dissolved solids (Figure 9). However, it's worth noting that *D. lumholtzi* was found in only one of my study lakes. For copepods, *Skistodiaptomus* exhibited a significant positive relationship with calcium, and *Leptodiaptomus* was seen to have a positive relationship with sulphate, conductivity, and total dissolved solids (Figure 9). Magnesium was seen to have a positive relationship with *Orthocyclops* and *Limnocalanus macrurus* (Figure 9).

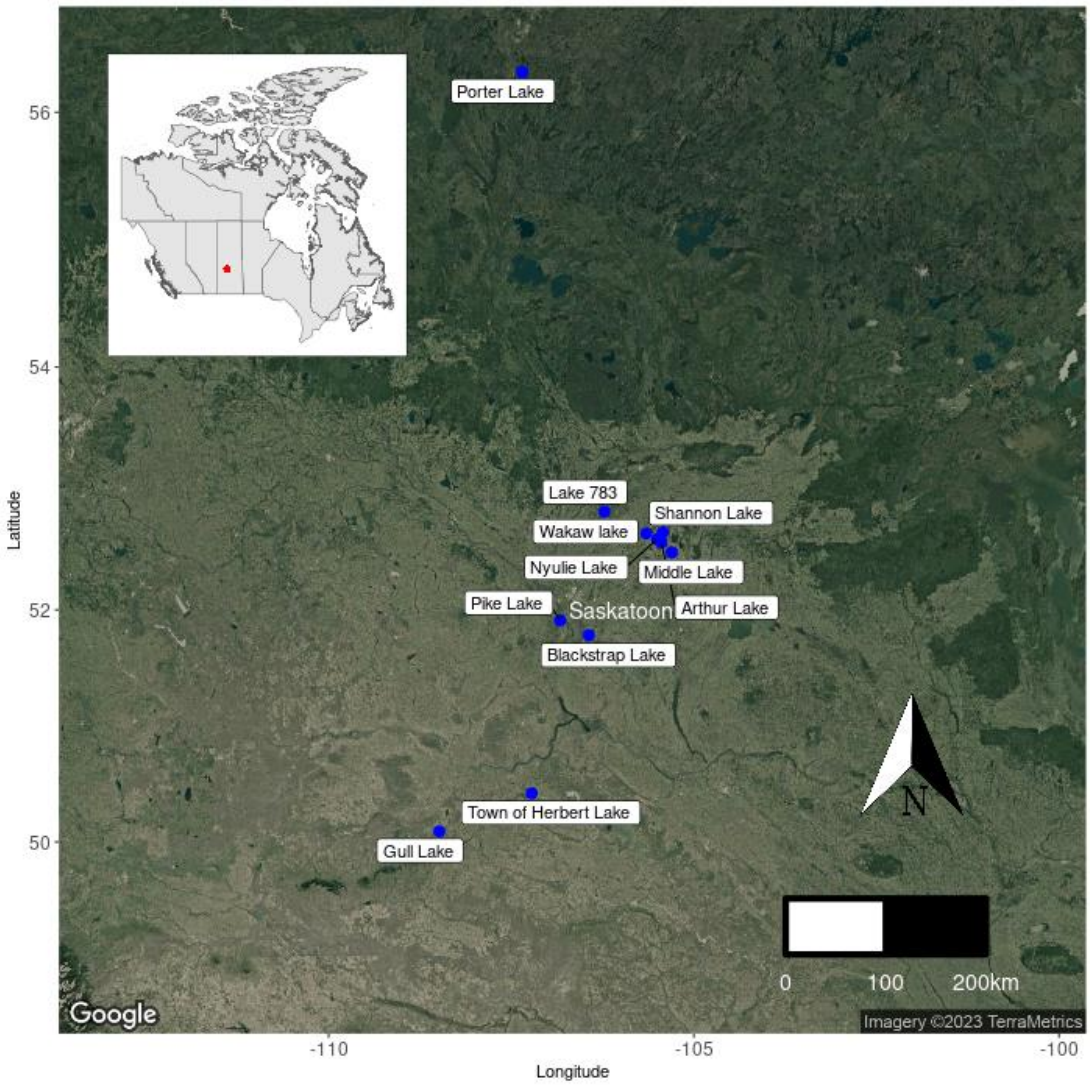

Figure 1. Map of all the sampled lakes on the Great Plains where the blue dots represent each lake.

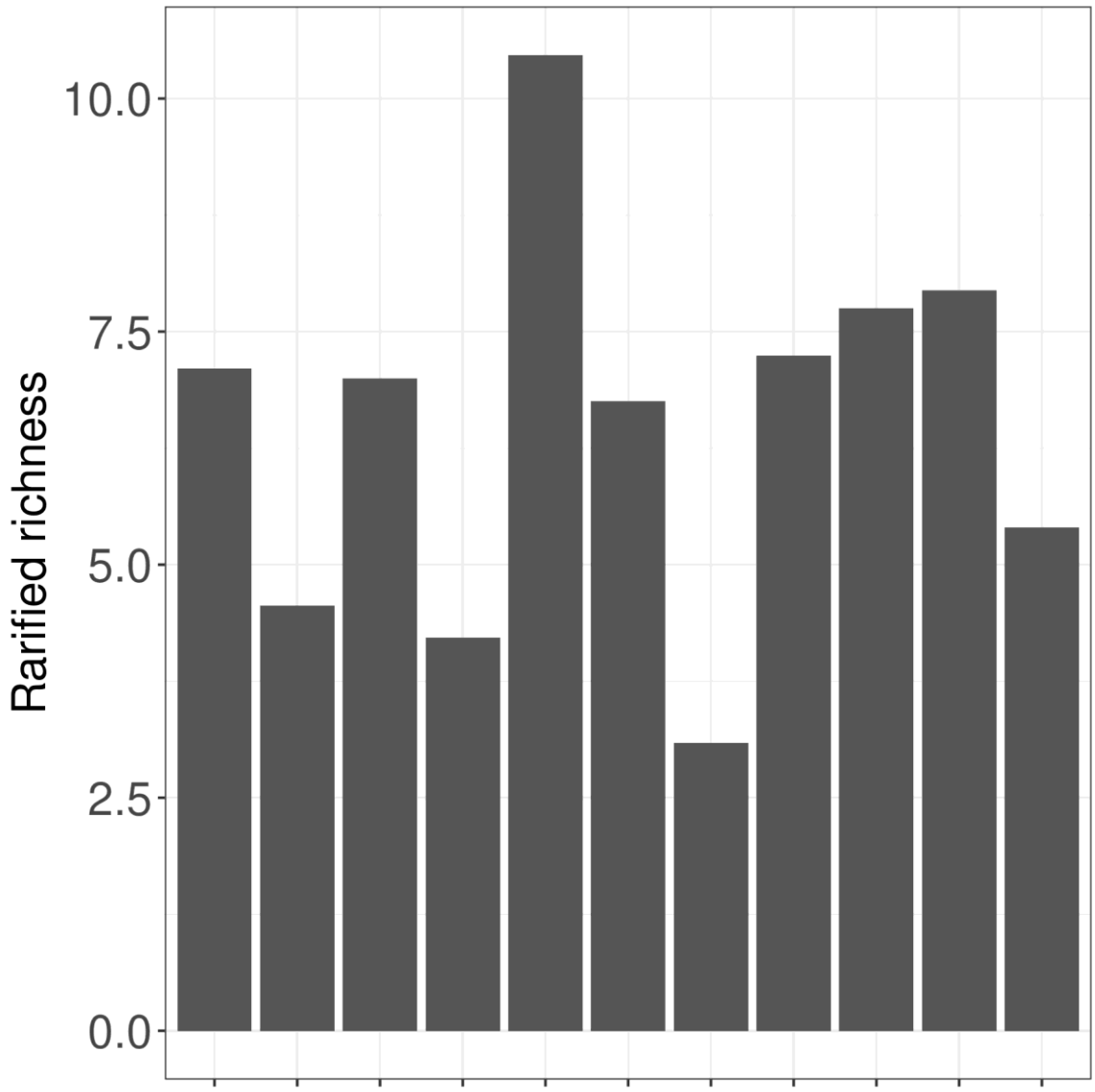

Figure 2. Rarefied richness in the eleven study lakes surrounding Saskatoon, SK.

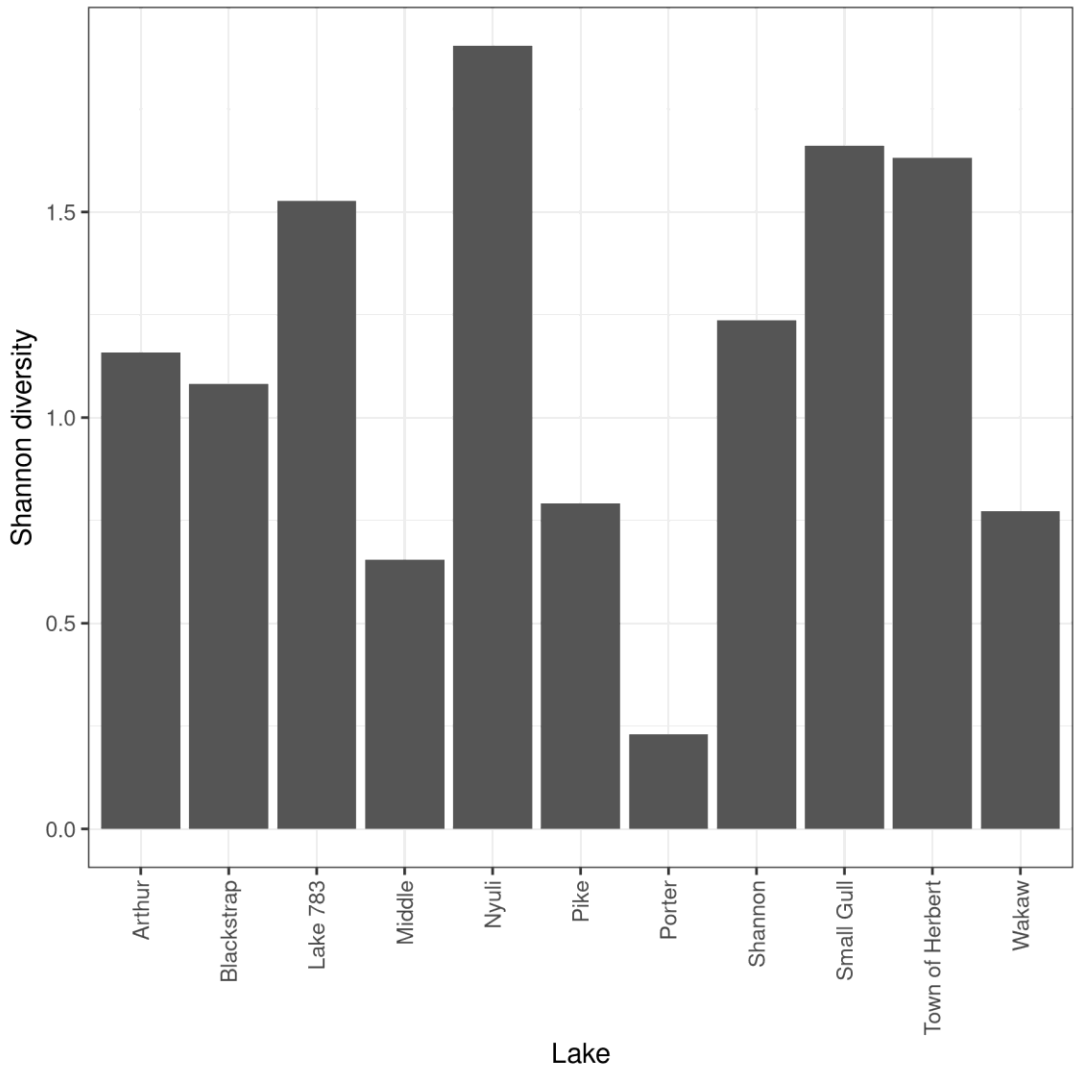

Figure 3. Shannon diversity values for zooplankton communities in the eleven study lakes surrounding Saskatoon, SK.

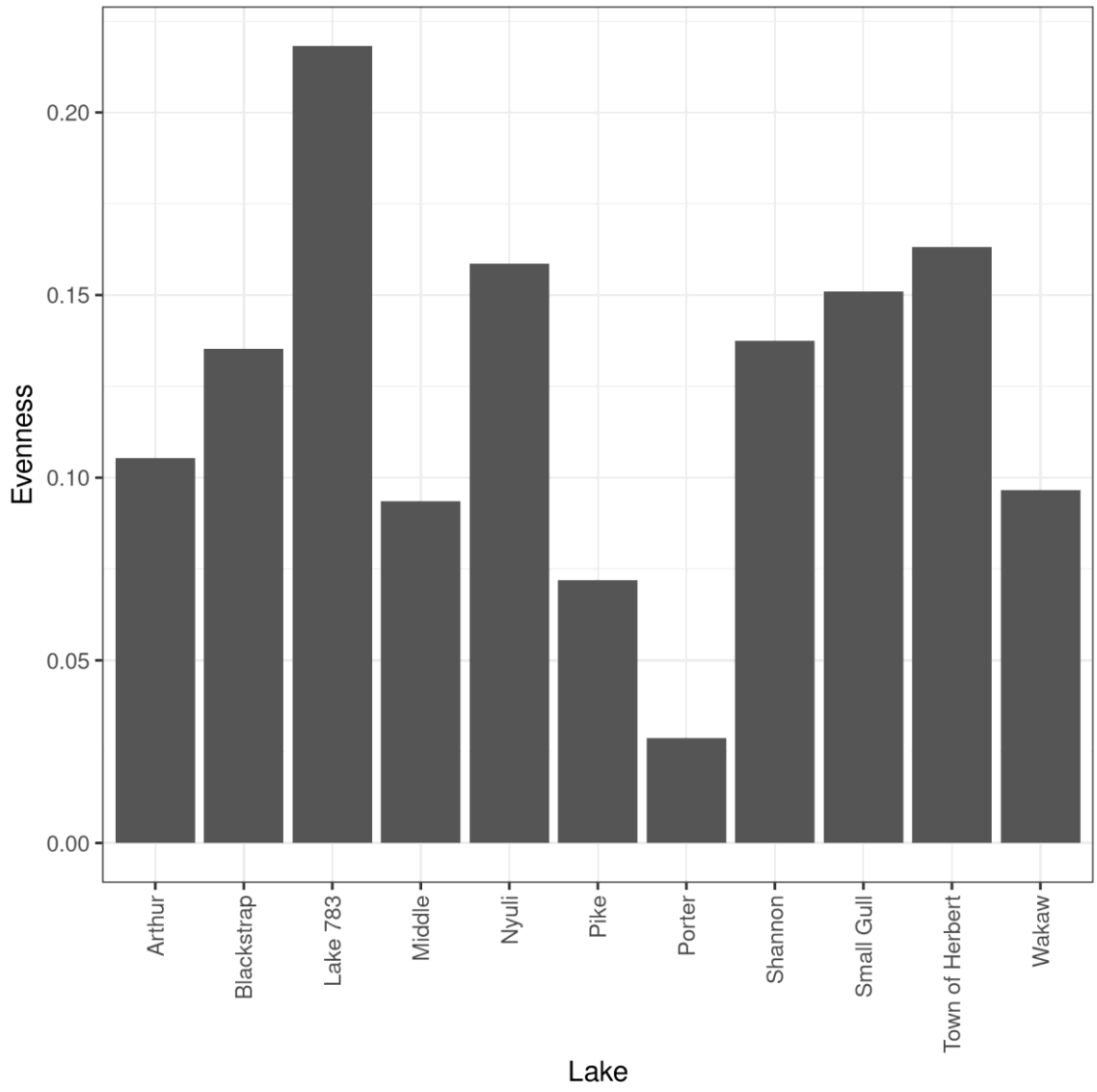

Figure 4. Community evenness found in the eleven study lakes surrounding Saskatoon, SK.

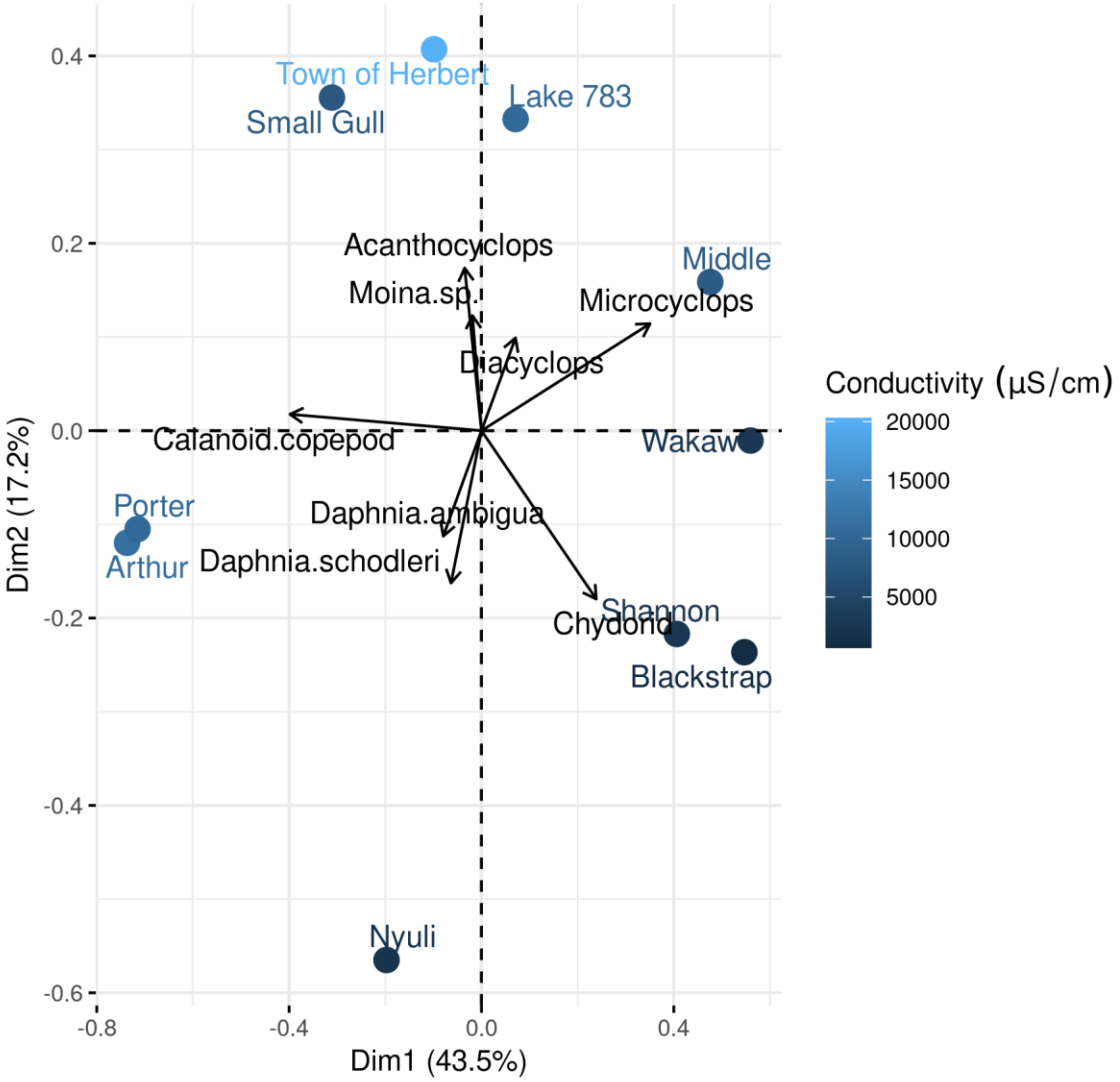

Figure 5. Principal Component Analysis (PCA) of relative abundances of different species among lakes. Blue dots represent each lake with different shades of blue representing different levels of conductivity shown in the legend on the right

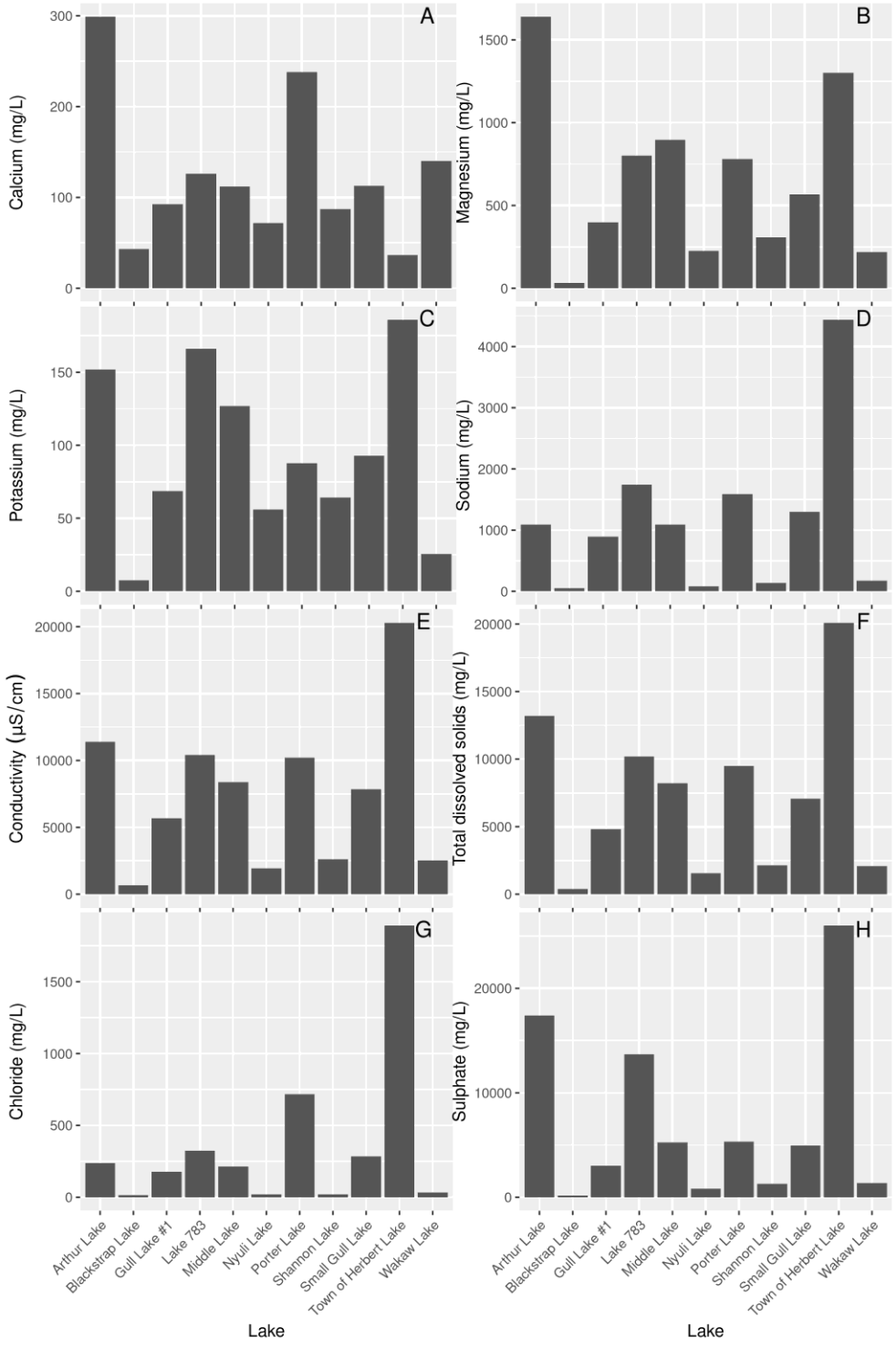

Figure 6. Dissolved ions in the eleven study lakes surrounding Saskatoon, SK.

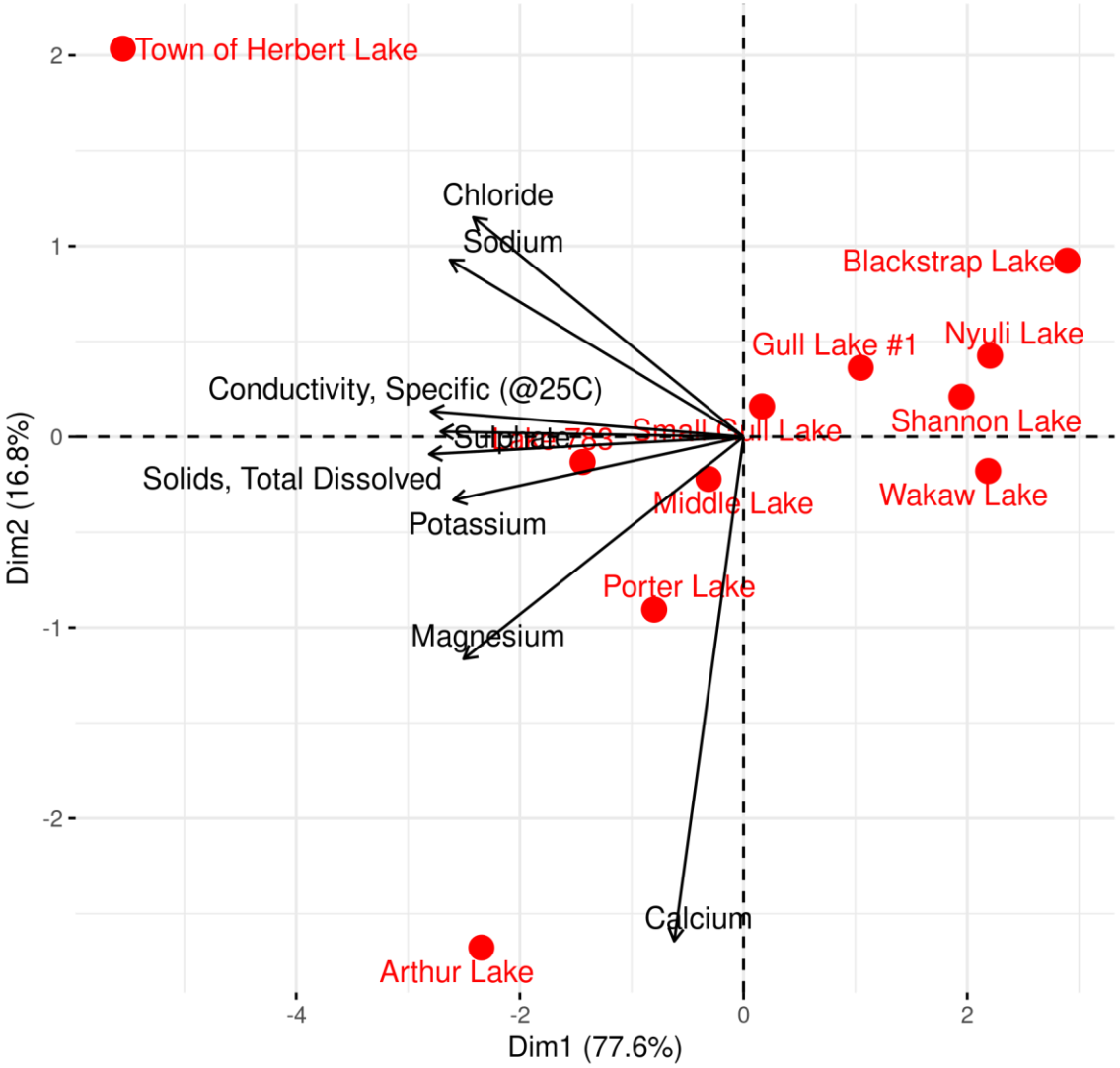

Figure 7. Principal Component Analysis (PCA) of water chemistry variables. Red dots represent each study lake.

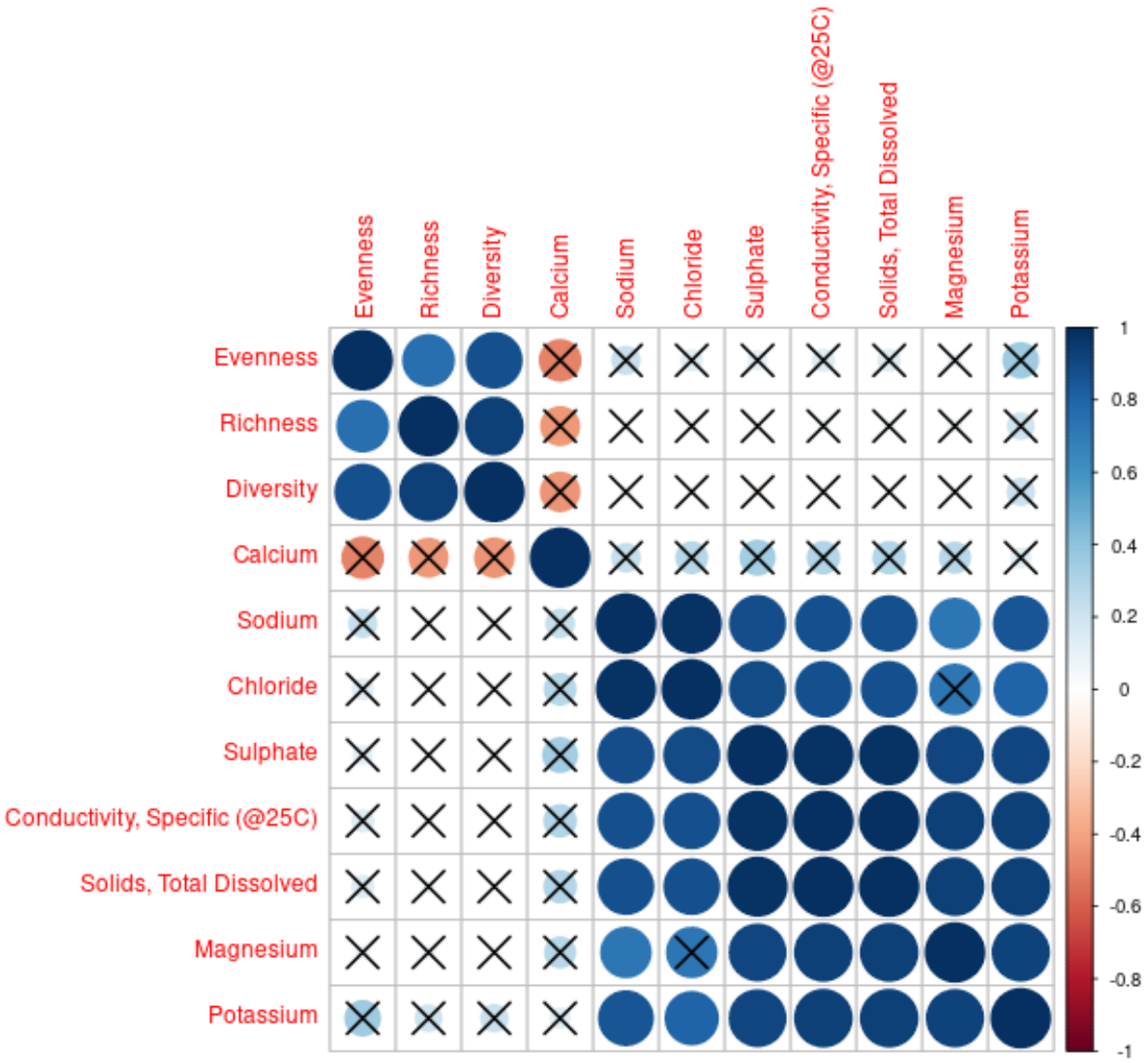

Figure 8. Relationship between the water quality variables measured for each lake and zooplankton richness, diversity, and evenness using Pearson correlations. Cells with and X indicate no significant correlation. Positive correlations are shown in blue and negative correlations are shown in red.

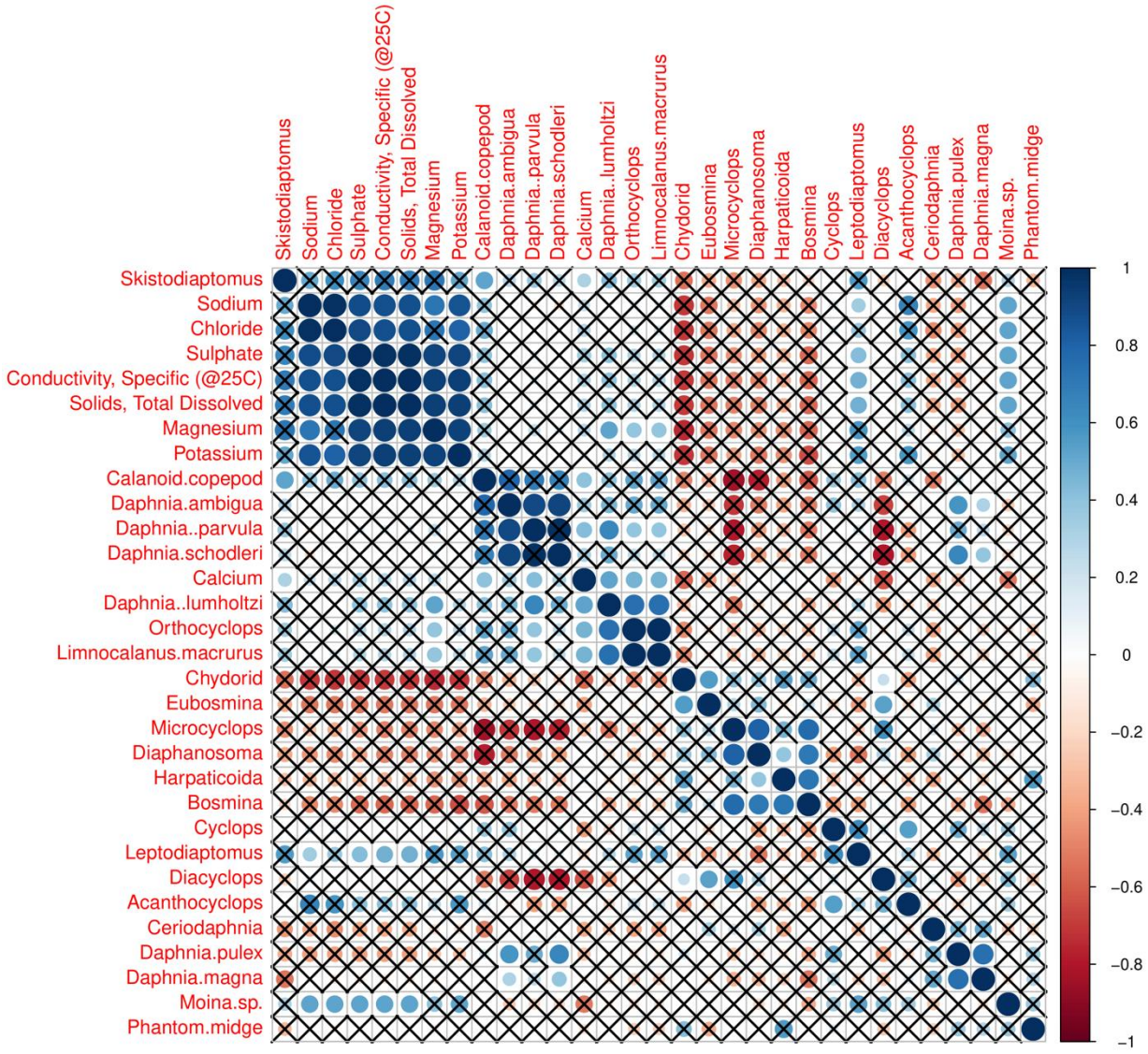

Figure 9. Correlation of dissolved ions to different zooplankton taxa found in the eleven study lakes. Cells with and X indicate no significant correlation. Positive correlations are shown in blue and negative correlation are shown in red.

Discussion

The objective of my study was to investigate how the structure of zooplankton communities related to salinity in lakes on the Great Plains. I had two hypotheses. First, there would be differences in the zooplankton community structure depending on lake salinity and the types of dissolved ions present. Lakes with higher concentration of dissolved ions were expected to have lower species richness and diversity and those with higher salinity levels would have one or two dominant species that would make up the community (Lin et al., 2017). My study did not provide support for my first hypothesis, as I found no correlation between water quality variables such as conductivity and total dissolved solids to measures of zooplankton community structure such as richness, diversity, and evenness. Secondly, I hypothesized that there would be higher concentration of copepods in comparison to cladocerans in lakes with a higher salinity (Huynh & Gray 2019). My analysis supported this hypothesis, as the PCA of relative abundances of zooplankton among the lakes showed that lakes with lower conductivities tended to have communities dominated by cladocerans, while those with higher salinities had more cyclopoids. Below I discuss these results in more detail and put them in context of past research on salinity and zooplankton on the Great Plains.

Water Quality

My results showed that the most dominant ion in the lakes was sulphate, followed by sodium and magnesium. The dominance on these dissolved ions in the Saskatchewan region are supported by previous studies by Hammer et al. (1993). In Wissel et al. (2010), there were high levels of sulphate seen in all lakes in comparison to chloride which showed that sodium sulphate brines are more common on the Great Plains than sodium chloride (Wissel et al. 2010). The

Spearman correlations and the PCA for water quality variables showed that there was a strong positive correlation among all the dissolved ions measured, with the exception of calcium. This is likely because as the salinity increases in a lake, if one of the dissolved ions increases in concentration, the other dissolved ions would also increase. The lack of relationship for calcium might be due to the small lake sample size which will be further discussed in the limitations section below.

Zooplankton

My results showed that there were no significant relationships between dissolved ions measured for each lake and zooplankton richness, diversity, and evenness using Pearson correlations. This had not been predicted since zooplankton richness, diversity, and evenness are often correlated to water quality variables (Gray et al., 2021). In addition, previous studies have shown that there is a decrease in species richness (Hammer et al., 1993) and diversity (Cooper and Wissel 2012) at higher salinities. In these previous studies, the number of lakes sampled was much larger than for my study as they collected data from 20 prairie lakes (Cooper and Wissel 2012) and 94 lakes (Hammer et al., 1993). Therefore, the lack of a significant correlation between salinity and zooplankton richness, diversity, and evenness may be a consequence of my small sample size (11 lakes) which would have reduced the statistical power of my correlation analyses. In addition, my study included lakes only up to 20 ‰ salinity, while Wissel and Cooper (2012) had a salinity range of 0.4-64 ‰. It is often easier to identify relationships when looking across a larger environmental gradient, so my study may have missed relationships based on the low range of salinities in my study lakes.

Although overall community structure did not appear related to salinity or any of the dissolved ion concentrations in my study lakes, there were some significant relationships between individual species and dissolved ion concentrations. Interestingly, only some cladocerans showed significant correlations with dissolved ions which was unexpected since cladocerans are known for being one of the more sensitive groups of zooplankton (Coldsnow et al. 2017). The waterflea *Daphnia lumholtzi* showed a significant correlation with magnesium levels but was only found in one of my study lakes. *D. lumholtzi* is an invasive species and can pose a substantial threat to biodiversity (Simberloff et al., 2013). Another cladoceran that showed significant correlations was *Moina* sp. to multiple dissolved ions. In Hammer et al. (1993), *Moina sp.* were found in intermediate salinity lakes with a high pH and were especially abundant in lower salinity lakes. This is inconsistent with my results since *Moina* sp. was found in some of the higher salinity lakes. However, Bos et al. (1996) found that *Moina* sp. were abundant in British Columbia lakes with higher salinities, and other studies show that this genus can thrive in high salinity lakes (Shadrin et al. 2020). The genus also does well in highly eutrophic lakes (Petrusek 2002). As many of our lakes were located next to agricultural operations, they often had large amounts of algae and appeared eutrophic. For copepods, *Skistodiaptomus* showed a significant positive relationship with calcium which had not been previously reported. *Leptodiaptomus* was seen to have a positive relationship with sulphate, and this had been shown in previous studies where they are found in sulphate or carbonate dominated lake water (Derry et al., 2003). Magnesium having positive correlation with *Orthocyclops* and *Limnocalanus macrurus* had however not been previously reported.

The types of species found in my study lakes may have changed through time. My results for individual species present in lakes in the Saskatchewan region were different than those reported by Hammer et al. (1993), which showed that Wakaw lake had *Diaptomus oregonenesis* which was not found in my study, but *Diaphanosoma* were present in both this study and in Hammer et al. (1993). There were also species indicative of low salinity which were present in that study which included *Diaptomus nevadensis, D. silcis and Diacyclops* sp., but in this study, *Diaptomus nevadensis* and *D. silcis* were not found and *Diacyclops* sp. had no correlation with lower salinity levels. In a more recent study by Cooper & Wissel (2012) for the region, *D. galeata mendotae, D. rosea, Ceriodaphnia* and *B. longirostris* were present in low salinity lakes. These taxa were however not found in my study. In the same study, *D. pulex* and *Leptodiaptomus sicilis* were found in salinities above 2 ‰ (Cooper and Wissel 2012). Although *L. sicilis* was not found in my study; *D. pulex* was found in a lake which had a salinity of 2 ‰. A reason for this difference could be that the 20 lakes sampled by Cooper and Wissel (2012) were selected based upon previous data obtained from the Wissel et al., (2010) paper which had sampled the lakes throughout the different seasons which included fall, spring, and summer. Therefore, the vast range of sampling seasons from May to September may have accounted to the differences in abundance of zooplankton due to seasonal variation which will be discussed further in the next paragraph. Overall, based on previous studies, there were some discrepancies in zooplankton abundance and the zooplankton identified in the region than the ones found in this study. This can however be a factor of not sampling enough lakes to find a wider range of zooplankton abundances.

One explanation for the differences in the species composition of zooplankton communities in comparison with past studies could be due to salinity changes over time, or due to the timing of sampling due to seasonal patterns in these communities. In Hammer et al., (1993), the samples were collected during the open water period and were collected in at least four different months. This sampling design provided a wide range of seasonal variation in temperature and productivity throughout those months. In my study, the samples were collected two decades later during a period of drought and were only sampled once in mid-summer. These differences in sample timing and precipitation could have led to changes in dynamics of the zooplankton community. Another reason that zooplankton composition may have changed in some of my study lakes through time could relate to the increased impacts of agricultural, municipalities and industries on aquatic environments (Cooper and Wissel 2012). Agriculture usage has increased over time in the region I visited for my study, which could impact the dissolved ion concentration through agricultural runoff and change the ionic composition among lakes (Lychuk et al., 2021). These changes in water quality would likely result in changes in zooplankton community composition.

Limitations

One of the limitations which may have led to the lack of significant relationships between dissolved ions and species diversity, richness and evenness could have been the sample size for my study. The hypotheses I developed when I planned my work were based on studies with 94 lakes (Hammer et al., 1993) and 20 lakes (Cooper & Wissel., 2012). The larger number of lakes in those studies were able to provide a broader range of salinities and a more statistical power to detect relationships. Starks et al. (2014) encountered a similar problem with statistical power in

their study of 18 lakes, which suggested a curvilinear relationship between species richness and environmental productivity. They concluded that the lack of a statistically significant relationship could have been a result of low statistical power (Starks et al. 2014). Including evidence from previous studies that show how a small lake sample size can affect the data analysis, only eleven lakes were sampled, and water quality data for one of them was not measured due to a shipping error. Therefore, there were only ten lakes included in my study. Another limitation was the lack of variation in salinities among my study lakes. The study by Hammer et al. (1993) showed a larger variation in salinities with it being 0-7 ‰. as low salinity, 7-100 ‰. being intermediate and most saline conditions being greater than 100 ‰. This broader range in salinity would be better to examine relationships than the one in my study. Lastly an important limitation for my study would be the lack of time series to show the seasonal variation among the lakes, as well as the impacts of increased agricultural and industrial use for road salts among the lakes that could account for long-term changes in zooplankton communities.

Conclusion

In my study, there were no correlations between zooplankton and dissolved ion concentrations, but there were a few significant correlations between individual species and dissolved ions. This contrasts with the results of previous studies where significant correlations were found between water quality variables and zooplankton community structures (e.g. Wissel et al., 2012). However, I did find that lower salinity lakes tended to have communities dominated by cladocerans instead of copepods. This pattern was also found in experiments conducted by Huynh & Gray (2019). It is also important to mention that one of the lakes, Arthur Lake, appears to have been invaded by *Daphnia lumholtzi,* and management efforts should be implemented to

reduce the risk of spread to other lakes in that region. In the future, there needs to be further research done on the zooplankton communities in the same lakes to see if the species diversity, richness, and evenness changes as the salinity levels change in response to global warming. The future research however needs to be done with a larger sample size and a higher range of salinities to better evaluate how zooplankton communities are shaped by salinity. It is also recommended that the future research is conducted through different seasons to account for seasonal changes in the zooplankton community and its effects on salinity on the lakes.

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