Impacts of Road Dust Pollution on Zooplankton Communities in Arctic Lakes

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by

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Abstract

Gravel roads alter the surrounding environment in a myriad of ways that can influence surface-water flow, sedimentation runoff, and the delivery of dust and debris to nearby lakes. These changes have the potential to influence water quality and zooplankton communities in roadside lakes. Inspired by the results of recent studies, I hypothesized that: 1) higher calcium levels due to road dust deposition would lead to increased abundance of species of zooplankton that require high calcium levels*;* and 2) higher conductivity levels near the road would cause increases in species abundance but decreases in the species diversity and evenness of communities. I used zooplankton data from nine different lakes in the Boreal region in the Northwest Territories that fell into three distance categories from the Dempster Highway (0-300 m, 300-600 m, and >600 m). I analysed the resulting dataset using ANOVAs and a PERMANOVA to examine differences in richness, abundance, and species composition among lake distance categories. The ANOVA results for water quality variables and zooplankton community metrics showed no differences in means among the three distance categories. In addition, the principal component analysis did not show patterns suggesting that the relative abundance of zooplankton differed consistently based on distance from the road, and the PERMANOVA failed to find significant differences in zooplankton communities among road distance categories. Based on my results, it appears that road dust may not be having a measureable impact on roadside lakes. It is possible that natural variability among lakes masked any effects of road dust, and therefore future studies should consider incorporating information on important lake properties such as surface area and depth when examining the effects of roads on lakes.

Introduction

Rapid environmental changes caused by climate warming are occurring around the planet (Thienpont *et al* 2013). High-latitude regions are particularly susceptible to these changes, including the Canadian Arctic, which has warmed by 3-4°C over the last century (Thienpont *et al* 2013). At the same time, development in the Canadian Arctic has required the construction of new infrastructure, including roadways. In the Northwest Territories, the northernmost section of the Mackenzie Valley Highway, the Inuvik Tuktoyaktuk Highway (ITH) was opened in 2017 (Government of Northwest Territories 2017, Government of Northwest Territories 2019). This new highway is 138 km long and runs from Inuvik to Tuktoyaktuk on the Arctic coast. The ITH is a continuation of the Dempster Highway, which runs from Dawson City, Yukon to Inuvik, NT. Additional roadways are planned, including a highway to connect Norman wells to Wrigley, NT (Government of Northwest Territories 2019). Due to the harsh climate and the presence of permafrost, all these highways are gravel roads, which can emit dust to the surrounding environment. As a result, terrestrial and aquatic habitats along these highways will potentially be subjected to multiple stressors including changes in climate and pollution from the roadways.

Gravel roads are very common throughout the world and are frequently found in rural regions of North America. Despite their ubiquity, the effects of dust generated by travel on these gravel roads have not received much attention from an environmental perspective (Dixon *et al* 2022). The initial construction of roadways causes significant alterations to terrestrial and aquatic habitats along the highway corridor (Trombilak *et al* 2000). However, the environmental effects of gravel roads extend beyond the initial period of road construction (Trombilak *et al* 2000). Continued operation of gravel roads alters the physical environment, causing changes in temperature of runoff, soil water content, soil pH, light availability, rates of dust deposition, surface-water flow, and sedimentation in roadside lakes (Trombilak *et al* 2000). Recent studies that examined the impacts of gravel roads on water quality along the Dempster Highway in the Northwest Territories have shown that road dust emitted from the highway can lead to an increase in pH, conductivity, calcium, and magnesium in lakes located that are located within 1 km of the road (Gunter 2017; Zhu *et al* 2019).

The changes in the physical characteristics of the environmental caused by dust from gravel roads can also lead to changes in biological communities in terrestrial environments. Walker and Everett (1987) examined the effects of road dust on vegetation and plant communities alongside a high-speed gravel highway in Arctic Alaska, and observed that many species including cryptogams, and other mosses typically found on the roadside adversely affected (Walker & Everett 1987 and Myers-Smith *et al* 2006). The pH, total conductivity, and calcium of the water extracted from these species were the greatest in the heavily dusted areas immediately adjacent to the highway (Walker & Everett 1987; Myers-Smith *et al.* 2006). Chlorophyll and photosynthetic rates were also lowest in these heavily dusted areas and toxic effects of calcium were found (Walker & Everett 1987 and Myers-Smith *et al.* 2006). Changes in vegetation associated with roads can lead to changes in ground temperatures, snow accumulation, and permafrost (Gill et al. 2014). Ste-Marie *et al.* (2018) conducted a study with arthropod communities and how they respond to the effects of the gravel Dempster Highway. Their study showed that arthropod communities do respond to these abiotic effects of roads, as well as to the indirect effects of vegetation changes caused by changing soil properties (Ste-Marie *et al* 2018).

To date, very few studies have examined the effects of gravel roads on biological communities in aquatic environments. Diatoms have been examined in a previous study by Zhu *et al*. (2019), as they can be used as indicators of environmental change, including warming, decreasing ice cover, conductivity changes, and enhanced thermal stability of the water column. The study conducted by Zhu *et al.* (2019) focused on lakes located along the Dempster Highway and found that diatoms communities did not appear to change in response to road dust contamination, but did seem to be changing in response to regional warming (Zhu *et al* 2019). Similar results were found by Gunter (2017), who observed that changes in algal palynomorphs along the Dempster Highway were consistent with the increasing temperatures, but there was not a significant shift in the composition of genera in relation to road dust contamination during highway construction (Gunter 2017). Other than those two studies on diatoms and algal palynomorphs, I am unaware of any other studies that have examined the effects of road dust on other aquatic groups, such as macroinvertebrates and zooplankton.

Zooplankton are a diverse group of animals that are commonly found in oceans, lakes, and ponds. The three main groups that make up the zooplankton in lakes are the Cladocera, Copepoda, and the Rotifera. They typically range in size between a few micrometers to a few millimeters (Suthers & Rissik 2009). Many zooplankton species are filter feeding herbivores, and they will commonly graze phytoplankton, including filamentous algae or diatoms (Huynh and Gray 2019). However, there are some other species of zooplankton that are omnivores or carnivores (Suthers & Rissik 2009). The number and diversity of zooplankton species that are in the water column can directly reflect the influence of several environmental factors and processes, as zooplankton species are extremely sensitive to environmental changes (Suthers & Rissik 2009). For example, Jeziorski *et al* (2009) showed that the decline of calcium concentrations in boreal lakes had a negative effect on the diversity and abundance of the cladoceran *Daphnia* (Jeziorski *et al* 2009). Past studies show that zooplankton are also sensitive to changes in pH levels (Gray and Arnott 2009), as well as temperature, conductivity, and dissolved oxygen concentrations (Gray et al. 2021). A recent study of zooplankton in Canadian Arctic lakes by Vucic et al. (2020) showed that calcium and conductivity were both positively related to zooplankton abundance in the region, but negatively related to their community's diversity and evenness.

To examine how zooplankton respond to environmental stressors, measures of community structure are often used. Community structure indicates what organisms are present in a given environment, in what numbers and how each species relates to one another in different ways (Adey & Loveland 2007). Measures of community structure include species richness, species diversity, species evenness, and the total abundance of organisms in a given area (Adey & Loveland 2007). Species richness is currently one of the most widely used diversity measurements, and represents the total number of unique species that are present within a defined region or location (Stirling & Wilsey 2001). Estimates of species richness depend strongly on the number of individual organisms identified, making it necessary to correct for sampling effort when comparing richness values among different samples (Moore 2013). Rarefaction is a process used to correct for sampling effort, such that comparisons among habitats occur on an even playing field. For example, if the smallest number of individuals identified for a lake is 100, then rarefaction will correct richness values for all other lakes in the dataset to values that would have been obtained if only 100 individuals were identified for each lake. Diversity is a community attribute that is related to stability, productivity, and trophic structure. One way to measure diversity is the Shannon Diversity Index (H), also commonly known as the Shannon-Wiener Index, which can be calculated as:

$$H = -\Sigma p_i * \ln(p_i)$$

Where p_i is the proportion of the entire community made up of species *i*. The higher the value of *H*, the higher the diversity of species in the particular community, therefore a lower value of *H* indicates a lower diversity in the community. Finally, species evenness takes into account the total number of species and the relative abundance of the species in a given community (Moore 2013). Pielou's evenness can be calculated using this formula

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

Where *H* is Shannon-Wiener diversity, and *S* is the species richness. A value close to 1 represents an even community with each species represented at approximately the same abundance, whereas a value closer to 0 represents an uneven community where one or a few species are much more abundant than others. Total abundance is simply the total number of individuals that are found at a given location (Stirling & Wilsey 2001). The relative abundance of species in a community is another important consideration, in that stressors may alter how common or rare certain species may be in a community relative to other members (Stirling & Wilsey 2001). The relative abundance of species is often examined using ordination analyses such as Principal Component Analysis or Nonmetric Multidimensional Scaling, which generate a diagram allowing for a visual assessment of the similarities or differences in the relative abundances of species at different sites (Stirling & Wilsey 2001).

The objective of my study is to determine if gravel roadways in the Arctic have an impact on zooplankton in roadside lakes. I have two hypotheses related to the objective of my research: 1) Higher calcium levels due to road dust deposition will lead to increased abundance of zooplankton that require high calcium levels such as *Daphnia*; 2) Higher conductivity levels near the road will cause increases in abundance but decreases in diversity and evenness of communities (Vucic et al. 2020).

Methods

Study area

My study focused on lakes located along the Dempster Highway in the Gwich'in Settlement Area of the Northwest Territories (Figure 1). The lakes are in located an area of the Boreal Forest, where the terrestreial environment is covered by coniferous trees such as black spruce (*Picea mariana*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*) and shoreline shrub vegetation such as dwarf birch (*Betula nana*) (Vucic *et al* 2020). The landscape includes a mix of morainal, glaciofluvial, lacustrine and alluvial deposits (Vucic *et al* 2020). This region is underlain by discontinuous permafrost which covered 50%-90% of the total area (Vucic *et al* 2020). The lakes that were chosen and studied were located along remote stretches of the highway and located in a boreal forested region (Kokelj 2009; Sweetman *et al* 2010; Vucic *et al* 2020).

Lake selection

Data for this study were obtained from lakes greater than $500m^2$ in surface area within 1 km of the roadway along the highway between Fort McPherson and Tsiigehtchic. All lakes with a surface area >500 m^2 within 1 km of the highway running between Tsiigehtchic and Fort McPherson were identified using Google Earth satellite imagery and were assigned a number. The distance of each lake from the road was then measured using the measurement tools in Google Earth and they were then classified into three distance categories: 0-300 m, 300-600 m, and 600-900 m. Three lakes were then randomly selected from each distance category using the sample function in R to draw random numbers from the list of numbers associated with each lake. Selected lakes were then included in the study (Figure 1).

Zooplankton collection and processing

Zooplankton samples were collected from each lake in July 2021 and August 2021, at the site of maximum depth and were then preserved on site in 95% ethanol. For lakes greater than 3m in depth, a single vertical haul using a 35-cm diameter, 50 μm mesh size zooplankton net was collected from each sample site (Vucic *et al* 2020). For lakes that were shallower than 3m ub depth, a vertical tow was not possible therefore a horizontal tow was used, and samples were collected by towing the net behind the boat for 60 seconds (Vucic *et al* 2020). A mechanical flowmeter was attached to the mouth of the net, in both situations, to determine the volume of water that passed through the net (Vucic *et al* 2020).

In the laboratory, subsampling was used to estimate the abundance of zooplankton in each sample. Subsampling is necessary when the entire sample contains thousands of individuals, which prohibits enumerating every specimen. To collect a subsample, samples were drained through a 30-micron sieve into a beaker, capturing the ethanol preservative. Zooplankton captured in the sieve were then rinsed into a beaker with tap water. Tap water was then added into the beaker to adjust the final volume to 100 mL and placed the beaker onto magnetic stir apparatus on low speed. A Hensen-Stemple pipette was then used to take 5 mL subsamples and placed these subsamples were placed onto a counting dish or wheel. Samples were identified under a dissecting stereoscope at 5x to 50x magnification depending on the size of the species and were transferred to glass slides for examination of smaller features at a compound microscope when necessary. Zooplankton were identified to the species level using a taxonomic key by Haney et al. (2013). To ensure the counts were accurate, at least 100 individuals were identified from each subsample, for a total of 300 individuals per lake. Rotifers and copepod nauplii were excluded from counts.

Water quality measurement

At the maximum depth in each lake, a Manta+ multiparameter probe was deployed from the boat at 1 m depth to measure water quality variables including turbidity, conductivity, dissolved oxygen, pH, chlorophyll-a and temperature (Eureka Water Probes). In addition, a water clarity measurement was taken using a Secchi disk measurement at the same location by lowering a Secchi disk over the shady side of the boat. Approximately 1 L of water was collected from the surface of each lake at the deepest point for shipment to Taiga Laboratories in Yellowknife for measurements of total nitrogen, total phosphorus, alkalinity, metals, calcium, chloride, water hardness and dissolved organic carbon.

Statistical analysis

Water quality data and zooplankton species data was imported into RStudio 2021 to run analyses. To examine correlations between the water quality variables and zooplankton metrics (richness, diversity, evenness, total abundance), Spearman correlations were used (Algina & Keslamn 1999). The value of the correlation coefficient varies between +1 and -1, with values closer to zero indicating a weak or nonexistent correlation, and values closer to +1 or -1 indicating a perfect degree of association between two variables (Algina & Keslamn 1999). To conduct the Spearman correlations, the cor function was used in R with the method argument set to “spearman” (R Core Team 2021).

An Analysis of Variance (ANOVA) was used to determine if measures of community structure (richness, diversity, evenness) differed among lakes in my three different distance categories. To test that my data met the assumptions of an ANOVA, a Shapiro-Wilks test was conducted via the shapiro.test function in R to test response variables for normality (R Core Team 2021). To test for homogeneity of variances across distance category groups, a Levene’s tests was conducted using the leveneTest function in the car package (Fox and Weisberg 2019; R Core Team 2021).

A principal component analysis (PCA) was conducted to visualize differences in the relative abundance of zooplankton species among lakes. A PCA is used to group lakes that have similar water quality and morphometry characteristics. The PCA produces a visual representation of which lakes do have similar morphometry characteristics and which are very distinctly different on the plot (Dytham 2011; R Core Team 2016; Hartigan & Wong 1979). The PCA was created using the prcomp function in the stats package for R and the input was a matrix of zooplankton species abundances by lake (R Core Team 2021). A Permutational Analysis of

Variance (PERMANOVA) was run to assess if the relative abundance of zooplankton species differed among lakes distance categories in terms of their position or spread in multivariate space. PERMANOVA requires the calculation of similarity scores, so the Bray-Curtis index was used, as it works well with abundance data that can contain many zeros when species are absent. The Bray-Curtis index considers the difference in abundance between two lakes divided by the sum of the abundance for both lakes (Somerfield 2008). The PERMANOVA analysis was conducted using the adonis2 function in the vegan package for R (Oksanen et al. 2019).

Results

Water quality

Water quality samples were obtained from nine lake in the Boreal region of the Northwest Territories, along the Dempster Highway. The means and standard deviations of water quality characteristics, including conductivity, pH, calcium, nitrogen, phosphorus, and chlorophyll-a in each of the three categories, 0-300 m, 300-600 m, and >600 m, are summarized in Table 1. The correlation analysis showed that none of the measured water quality variables were significantly related to distance from the road (Figure 1). Results of the ANOVA tests for water quality variables showed no differences in means among the three lake distance categories (Table 2; Figure 2).

Zooplankton communities

Overall, there were 12 cladocerans species and 10 copepod species identified in the nine study lakes. The univariate measures of community structure, including richness, diversity, evenness, and total abundance were not correlated with distance from the road (Figure 2). The ANOVA results showed that richness, diversity, total abundance, and evenness did not significantly differ among distance categories, 0-300 m, 300-600 m, >600 m (Table 3; Figure 5).

The principal component analysis (Figure 3) shows differences in the relative abundance of zooplankton species in lakes found in the three different distance categories. Lakes can be divided into three groups based on the most abundant members of the zooplankton communities present: Cyclopoid copepodids, *Leptodiaptomus pribilofensis* or *Daphnia tenebrosa* + calanoid copepodids. There was not a strong indication that lake distance categories were related to the dominant types of zooplankton present in the lakes (Figure 3).

Discussion

The objective of my study was to determine if gravel roadways in the Arctic have an impact on zooplankton in roadside lakes. I hypothesized two things, first, there would be a increase in calcium levels due to road dust deposition leading to an increase in abundance of zooplankton that will require high calcium and second, higher conductivity levels near the road will cause an increase in zooplankton abundance but decreases in diversity and evenness of communities (Vucic et al. 2020).

Water quality

My results showed that road dust did not seem to be influencing water quality in my nine study lakes. The correlation analysis showed that most of the water quality variables I measured, including calcium and conductivity, were not related to distance from the road (Figure 2). Similarly, my ANOVAs showed that there were no significant differences in conductivity, calcium pH, phosphorus nitrogen and chlorophyll among lakes assigned to different distance categories from the road (0-300 m, 300-600 m, and >600 m). I expected lake distance from the road to have a negative correlation with calcium and conductivity levels, resulting in higher levels found in lakes close to the road due to road dust deposition (Gunter 2017; Vucic *et al* 2020; Zhu *et al* 2019). There is possibility that there was not an enough difference in road dust deposition in the lakes within the 0-300 m distance category compared to those located >600 m from the road to make a significant difference in the water quality for my study (Zhu *et al* 2019). Zhu *et al* (2019), found that there was some evidence for elevation of conductivity and nutrients near the road, but the 28 lakes they studied showed a high degree of variability in these characteristics. Therefore, it is possible that, by chance, the nine study lakes I selected were not reflective of the true effects of road dust on lakes in this region, and others might have shown more obvious changes related to distance from the road. Gunter (2017) also found an elevation in calcium and conductivity of lakes within 1 km from the road compared to lakes further away. It is possible that all my study lakes were equally affected by road dust since they were all within 1 km from the road. A future study that includes lakes further than 1 km from the road may help to determine if my results underestimated the effects of road dust due to the small distance range covered.

While the main variables I expected to change with distance from the road did not differ based on distance category, there were some significant correlations in my dataset. Distance from the road was negatively correlated with phosphorus levels and positively correlated with dissolved organic carbon (DOC) in the water. A recent study by Murdoch *et al* (2021) hypothesized that road development was leading to increases in nutrients and DOC in roadside lakes. Although my patterns of DOC data do not match those found by Murdoch *et al* (2021), the nutrient data do support their hypothesis that landcover disturbance and permafrost thaw may be changing nutrient levels in roadside lakes. DOC plays a significant role to the carbon and nutrient cycling in water ecosystems (Knorr 2013). DOC will also influence mobility of organic contaminants and plays a significant contribution to carbon fluxes (Knorr 2013). This has caused an increased concern for the observation of DOC concentrations in discharge of many temperate lakes (Knorr 2013).

Zooplankton

I had predicted that there would be an increase in the relative abundance of *Daphnia* in lakes that were closest to the road, and that there would be a decrease in diversity and species evenness of communities due to the increased amount of road dust deposition (Vucic et al. 2020; Gunter 2017). I did not detect any significant differences in the zooplankton richness, diversity, evenness, or total abundance of communities in lakes that were in the three different distance categories. This result makes sense in light of the fact that there were not any consistent differences in the water quality based on distance from the road that I was expecting to drive the predicted differences among the distance categories. It also matches with the results of studies on other organisms, including diatoms and other algae, that failed to detect a difference caused by road pollution (Gunter 2017, Zhu et al. 2019).

My principal component analysis did not show any obvious differences in the relative abundance of zooplankton species among the lake distance categories. I had thought that increased pollution from road dust would lead to higher calcium levels in those lakes nearer the road, leading to a greater relative abundance of *Daphnia*. The failure to find this pattern is likely due to there not being any consistent differences in the water quality by distance, as there was no significant increase in calcium levels in lakes closer to the road. In my data, lakes in the 0 to 300 m range have a very slight increase in calcium when comparing with the other two distance category groups, in the box plot analysis (Figure 4). However, the box plots do show that these slight differences are not statistically significant. *Daphnia* does have an increase in abundance in some lakes, one lake in the 0 to 300 m and 300 to 600 m range and is directly pointing towards another lake in the 0 to 300 m range (Figure 3). This could indicate that there is still a relationship between *Daphnia* abundance and calcium, but no significant trends were detected in my data. Cairn & Yan (2009) performed a review literature regarding minimum calcium thresholds permitting survival, and calcium concentration. *Daphnia* was used an example to explore the ecological consequences of falling environmental calcium concentrations. Of only a handful of species, *Daphnia* was greatly affected by a calcium decline (Carin & Yan 2009). These results do indicate how vulnerable *Daphnia* species can react to change in calcium levels. However, in my data, there were no lakes that had a significantly higher calcium level.

Limitations

My results did not detect any difference in water quality among the lake distance categories, and therefore there were no differences in species diversity, richness, evenness, or total abundance that would have been caused by differences in water quality. This could possibly be due to the quantity of lakes that were sampled, as there were only nine lakes in total for the study. Having such a small sample limits the amount of data that is collected and does not show any significant trends that can detected in my data analysis. Increasing the quantity of lakes that are sampled will allow for a better estimate of these parameters. In my study, I wanted to get a strong estimate of the richness, abundance, and evenness of zooplankton in the lakes that were located at different distances from the road. If I were to have sampled a greater number of lakes in each distance category, I think I would have been able to get a better estimate of the zooplankton richness, abundance and evenness compared to only sampling two or three lakes (Gunter 2017; Viviuc *et al.* 2020; Thienpont *et al.* 2013).

Our chosen lakes were all randomly picked to sample and there was no prior information about lake depth , which could have resulted in two possible issues. First, there will be differences in important physical parameters among the lakes in the three distance categories, for example, one very large lake in the 0-300 m, 300-600 m and >600 m distance category, followed by two medium to small lakes in the 0-300 m, 300-600 m and >600 m category. The other possible issue could be that there was too much intra-lake variability that obscured any real patterns. It might be better to select lakes with the exact same surface area and depth in order to the remove the source of variability from the study, as species richness has been found to be positively related to the lake depth (O'Brien *et al.* 2004). Measuring out the distance of lakes from the road as well as the surface area and depth could all have an important factor on how the road dust will impact each lake differently (O'Brien *et al.* 2004).

In this experiment I was unable to measure exact measures of dust that went into each lake. Knowing the amount of dust that did reach each lake could result in more accurate interpretations of the water quality data. Increased dust loads in lakes would be expected to cause high iron, calcium, and conductivity (Zhu *et al* 2019). Whereas if there was a larger difference between road dust deposition in the different lake categories other measures would have to have been considered when analyzing the results (Lemieux *et al.* 2016). The water quality results could also be due to unknown exposure or groundwater flush that was presented in each of the lakes (Lemieux *et al.* 2016). Ground water flow systems affect the surface water flow and water residence time (Lemieux *et al.* 2016)

Overall, there are no differences in water quality of my nine study lakes located at different distances from the Dempster Highway. The zooplankton communities in each of the lakes also did not have any differences associated with distance from the road. Based on my results, I would advise future investigators to conduct this study with more than nine lakes, and to consider controlling for lake properties such as surface area and depth for a comparison without natural variability caused by differences in the physical properties of the study lakes.

Acknowledgements

I cannot begin to express my thanks to Dr. Derek Gray for providing me this amazing research opportunity. This has allowed express my interest and love of research, and his guidance and assistance with this thesis is greatly appreciated. I would like to thank Natasha Hannan for her guidance and patience with lab work through the year. I would also like to thank Vivian Goa and Miles Dilon Jr for field data collection and Lynne Whitty for zooplankton taxonomy assistance. In addition, I would like to thank my parents, Sandy and Mike Rix, as well as my boyfriend, Robbie Kettles, for their love and support over my undergraduate career.

Figures and Tables

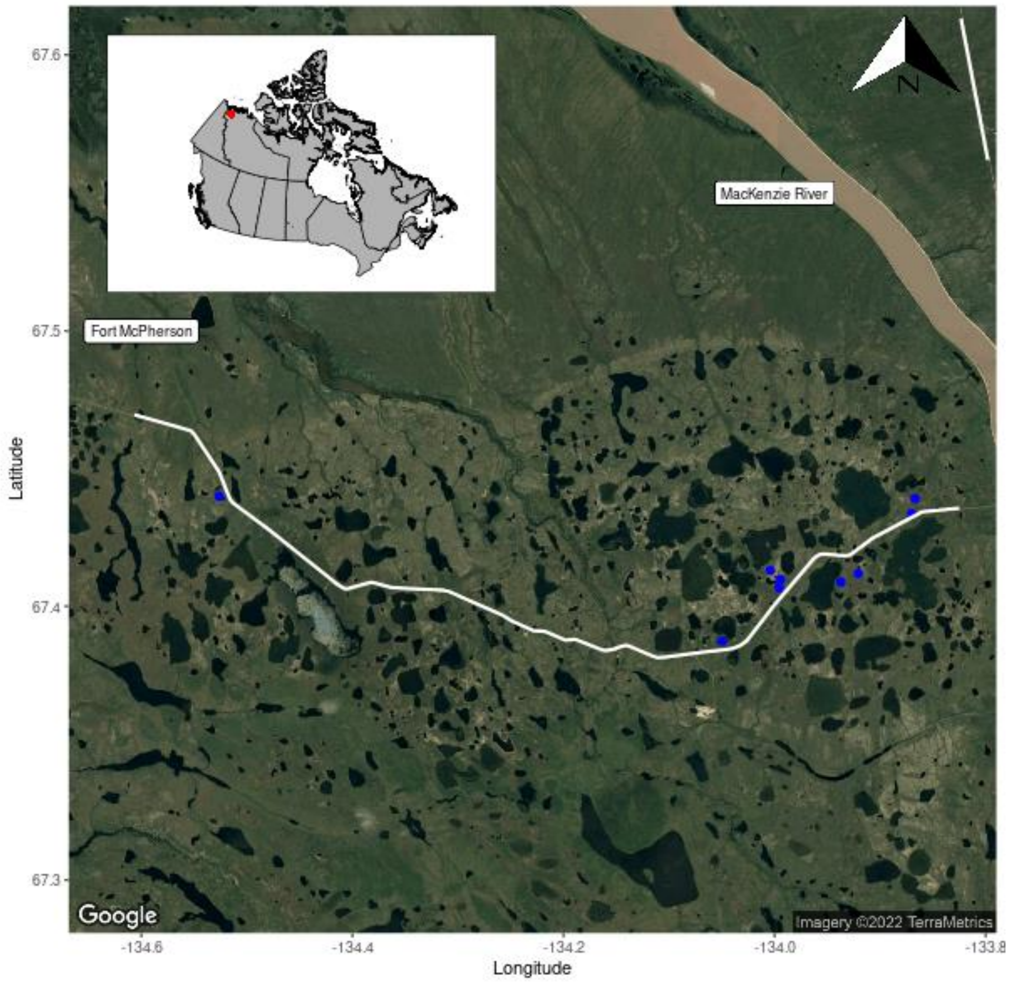

Figure 1. Map showing the portion of the Dempster Highway (white line) running between Fort McPherson and Tsiigehtchic, NT. Study lakes are represented by blue dots.

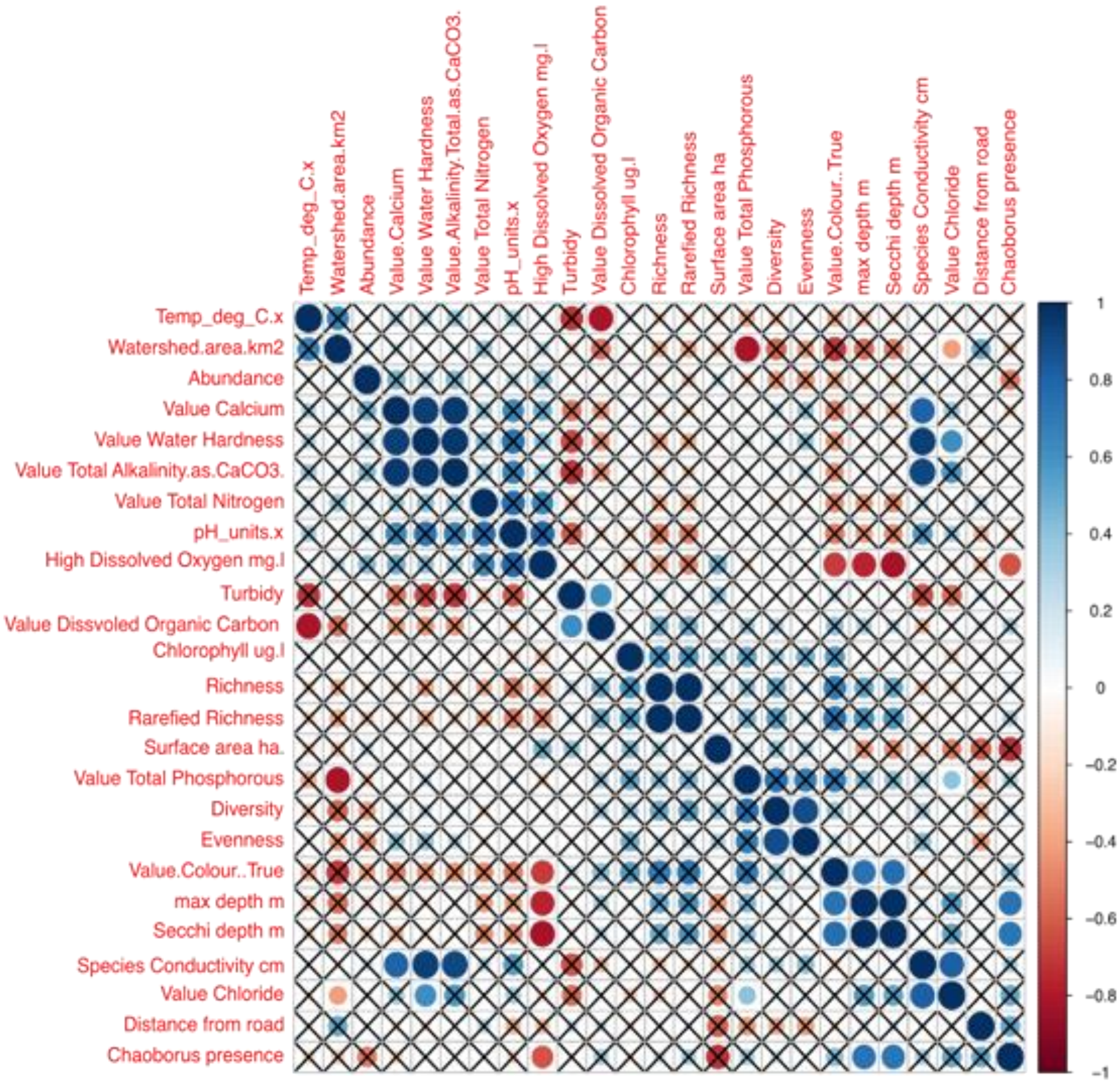

Figure 2. Correlation plot of lake characteristics and zooplankton richness, diversity, and evenness. The colour of the circle indicates what kind of correlation there is between the two variables, if the circle is blue, there is a positive correlation, and if the circle is pink/red, there is a negative correlation. The size of the circle shows how strongly the correlation is between the two variables, the larger the circle, the stronger the correlation is, the closer to a value of "1" it is, and the smaller the circle indicates a weaker correlation between the two variables. Circles that are crossed out with an "X", indicate correlations that were not statistically significant.

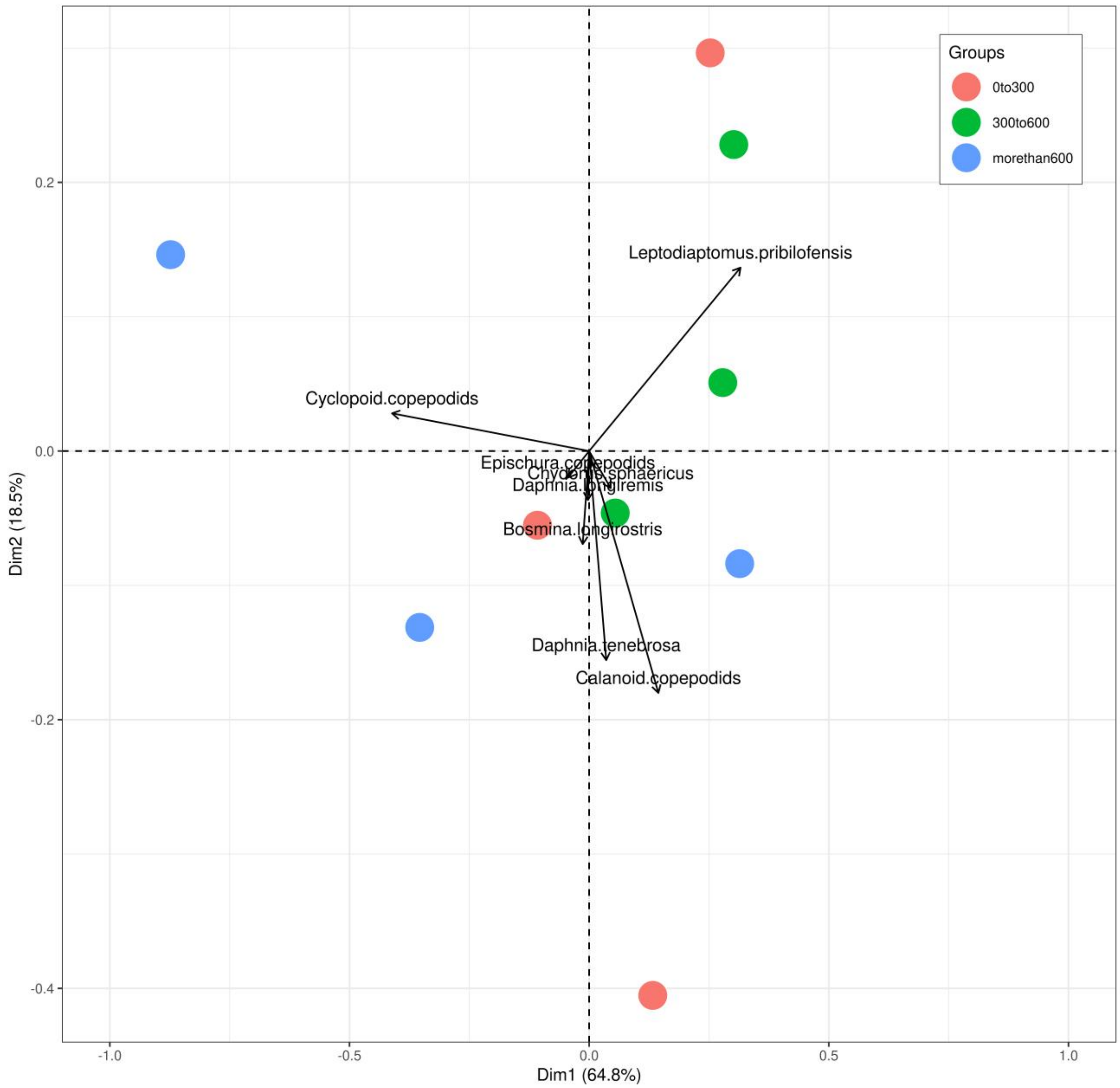

Figure 3. Principal component analyses showing differences in zooplankton species abundance among lakes. Each circle represents one of the lakes included in the study. The closer a circle is located to a species name, the more abundant that species is in that lake.

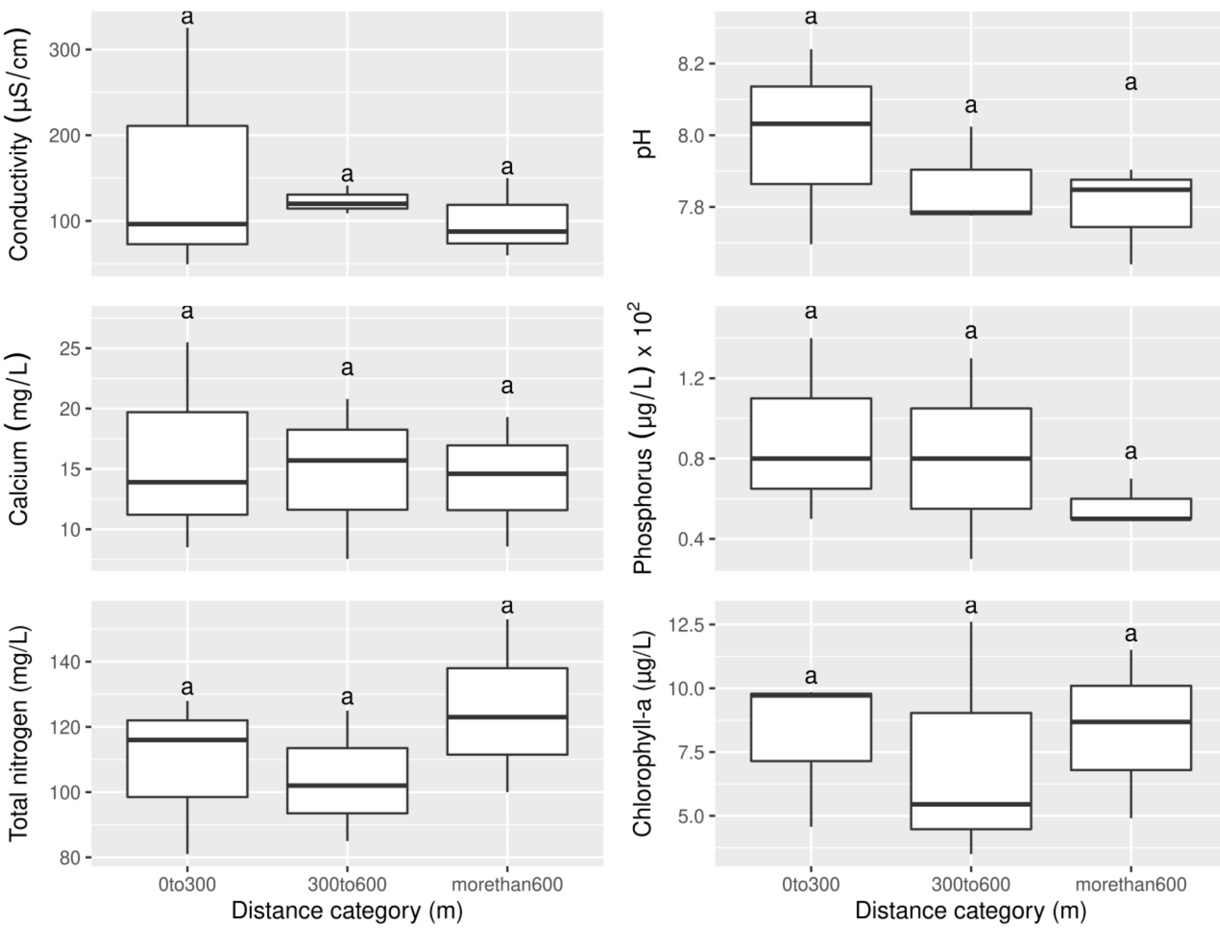

Figure 4. Box plots showing water quality characteristics measured for our study lakes located at 0-300 m, 300-600 m, or >600 m from the Dempster Highway. Letters above the boxes indicate results from ANOVAs showing that there were no significant differences.

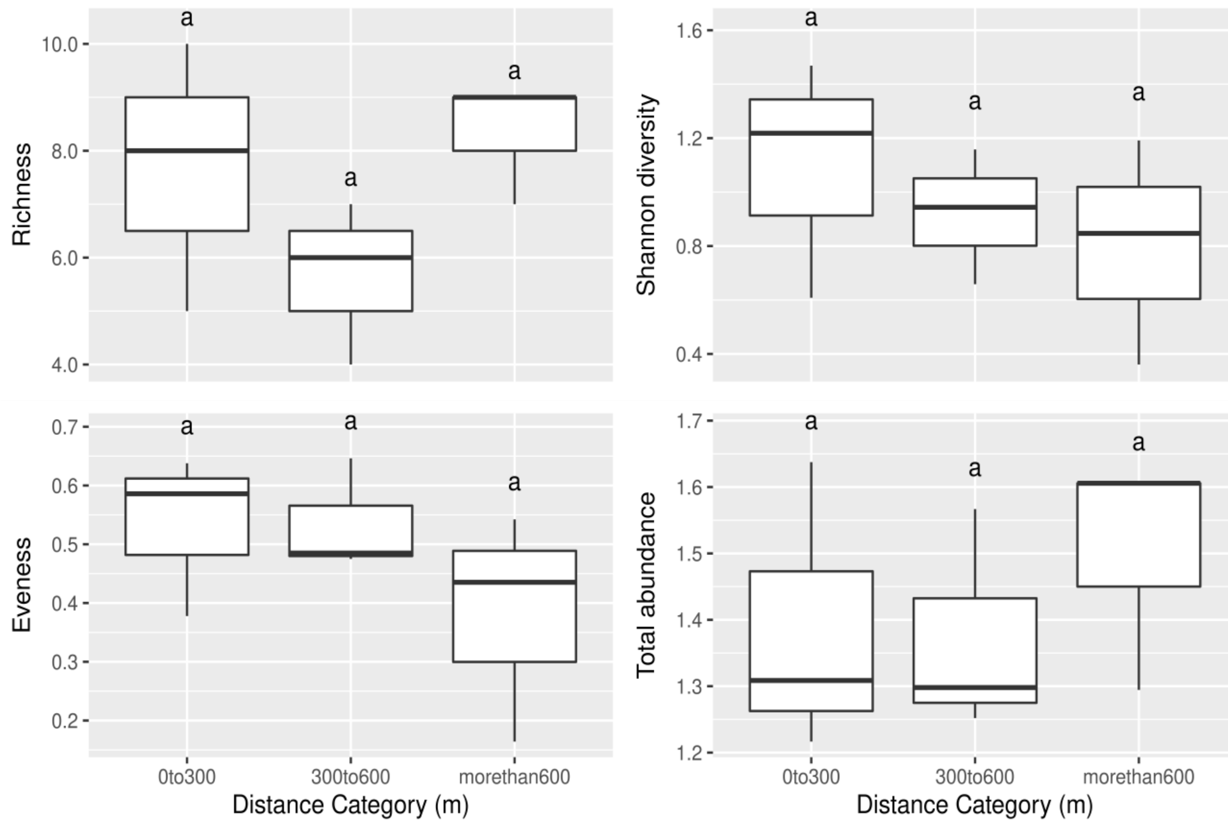

Figure 5. Box plots showing zooplankton community characteristics measured for our study lakes located at 0-300 m, 300-600 m, or >600 m from the Dempster Highway. Letters above the boxes indicate results from ANOVAs showing that there are no significant differences.

Table 1. Category means and standard deviations of conductivity, pH, calcium, nitrogen, phosph orus, and chlorophyll-a

	Conductivity		**pH**		**Calcium**		**Nitrogen**		**Phosphorus**		**Chlorophyll**	
Category	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
0-300	157.03	147.68	7.99	0.34	15.97	8.68	1.08	0.24	0.009	0.005	8.05	3.01
300-600	123.43	16.52	7.83	0.18	14.68	6.69	1.04	0.20	0.008	0.005	7.19	4.80
> 600	99.10	46.14	7.75	0.17	14.16	5.38	1.25	0.26	0.006	0.001	8.37	3.31

Table 2. ANOVA results comparing water quality metrics among distance categories (0-300 m, 300-600 m, 600-900 m).

Variable	Term	df	Sum squares	Mean squares	F	p
Conductivity	Category	2	5077	2539	0.315	0.741
	Residuals	6	48424	8071	-	-
Calcium	Category	2	5.23	2.61	0.053	0.949
	Residuals	6	298.09	49.68	-	-
pH	Category	2	0.0896	0.04480	0.751	0.512
	Residuals	6	0.3580	0.05967	-	-
Phosphorus	Category	2	1.756e-05	8.778e-06	0.556	0.6
	Residuals	6	9.467e-05	1.578e-05	-	-
Nitrogen	Category	2	0.0763	0.03814	0.671	0.546
	Residuals	6	0.3411	0.05686	-	-
Chlorophyll	Category	2	2.23	1.117	0.078	0.926
	Residuals	6	86.09	14.348	-	-

Table 3. ANOVA results comparing zooplankton community metrics among distance categories (0-300 m, 300-600 m, 600-900 m).

Variable	Term	df	Sum squares	Mean squares	F	p
Richness Corrected	Category	2	7.865	3.932	1.151	0.377
	Residuals	6	20.498	3.416	-	-
Diversity	Category	2	0.1354	0.0771	0.469	0.647
	Residuals	6	0.8659	0.14432	-	-
Total Abundance	Category	2	0.03013	0.01506	0.41	0.681
	Residuals	6	0.22032	0.03672	-	-
Evenness	Category	2	0.04747	0.02374	1.076	0.399
	Residuals	6	0.13230	0.02205	-	-

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