Northwest Territories
Cumulative Impact Monitoring Program (NWT CIMP)

FINAL REPORT FORM 2021-2022

1. Project Information

NWT CIMP #	197		
Project Title	How does proximity to roadways impact water quality and invertebrates in Arctic lakes?		
Date Submitted	April 29, 2022	**Project Length:** *years of NWT CIMP funding*	2
Type of Research	☒ Science ☐ Indigenous Knowledge		
Valued Component *Check all that apply. If 'other' please specify.*	☐ Caribou ☐ Fish ☒ Water ☐ Other:		
Area/Region of Study and Closest NWT Community	☐ North/South Slave ☐ Dehcho ☐ Sahtú ☒ Gwich'in ☒ ISR ☐ Wek'èezhìı ☐ Community:		
Location *(provide specific coordinates; or if regional, provide 4 coordinates for the bounding box.)*	67.176, -135.265 67.176, -130.828 69.695, -132.079 69.489, -135.47		
Project Keywords *(at least four)*	Lakes, invertebrates, roads, road dust		
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2. Consent

I acknowledge that the completed report will be posted for public access on the NWT Discovery Portal.

☒ I agree

Northwest Territories
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3. Abstract

Gravel roads can be significant sources of dust to surrounding terrestrial and aquatic habitats. A recent study conducted along the Dempster Highway showed that road dust can affect water quality in roadside lakes, leading to higher calcium, magnesium, conductivity, and pH levels (Gunter 2017). These changes in water quality might affect the biota living in those lakes. For example, macroinvertebrates living on the bottom of lakes and zooplankton inhabiting the open water, are sensitive to changes in pH, conductivity, and calcium levels. Macroinvertebrates and zooplankton are important sources of food for fish, so changes in these small animals could impact fish communities. For this project we had two main objectives: 1) To determine if changes in water chemistry caused by deposition of road dust affects invertebrate communities in roadside lakes; and 2) To examine if the type of roadside vegetation influences the transport of road dust to aquatic habitats. To achieve these objectives, we collected biological and water quality data from 18 lakes at a range of distances from the road (30-1000 m) and measured the transport of dust from the highways to lakes surrounded by either boreal or tundra vegetation. Given the large changes in water quality noted in previous studies we hypothesized that invertebrate communities in lakes affected by road dust would show significant differences in community composition and species richness. We also hypothesized that boreal vegetation would provide a better roadside buffer than tundra shrubs, limiting the impacts of road dust to shorter distances in the boreal region.

Our measurements of dust drifting from the highway indicated that the majority fell on areas located within 300 m from the highway. However, there were not clear differences in water quality among our lakes based on distance from the highway or the region of study (boreal vs. tundra). The richness, diversity, and abundance of zooplankton also did not differ among our study lakes according to distance from the highway or region of study. There were differences in the relative abundance of zooplankton species between regions, but these differences did not appear to relate to the effects of the road. Processing of the macroinvertebrate samples in the laboratory is still ongoing, so results are not available for this group.

The lack of clear water quality differences based on distance from the highway are contrary to results from other studies in the region. We suspect that the small sample size for our study (18 lakes) combined with natural variability among the lakes may have masked any potential effects of road pollution on our study lakes. Alternatively, our focus on studying lakes located within 1 km of the highway may have limited our ability to detect road effects that may diminish at greater distances. Future studies should consider sampling more lakes, including those further from the highways. In addition, efforts to compare lakes that are more homogeneous in their physical characteristics, such as surface area and depth, may allow for a better understanding of the potential effects of road dust on water quality and invertebrate communities.

4. Key Messages

- Measurements show that most road dust drifting across the landscape seems to fall within 300 m from the highways
- There were not clear differences in water quality measurements among our study lakes related to pollution from the highways

- There were not clear differences in zooplankton communities among our study lakes related to pollution from the highways
- Although our study suggests that road dust may not be affecting lake water quality or zooplankton, our study was too small to be conclusive.
- Future studies should consider sampling more lakes and including those further than 1 km from the highway.

5. Project Objectives and Relevance to Cumulative Impact Monitoring and Research

The purpose of the proposed project was to improve our understanding of the effects of road development on lakes in Canada's north. To achieve this purpose, we pursued two objectives: 1) To determine if changes in water chemistry caused by deposition of road dust affects invertebrate communities in roadside lakes; and 2) To examine if the type of roadside vegetation influences the transport of road dust to aquatic habitats.

The project was designed to advance our understanding of the cumulative impacts from human activities by examining the impacts of one of the most common and persistent types of development in the Northwest Territories: roadways. Existing roadways such as the Dempster Highway and the Inuvik Tuktoyaktuk Highway affect thousands of lakes, and continued expansion of the highway system in the Northwest Territories (e.g. Mackenzie Valley Highway) has the potential to impact thousands more.

Work for objective 1 was meant to fill an important knowledge gap. While there have been studies of the impacts of road dust on terrestrial plants (Gill et al. 2014), insects (Ste-Marie et al. 2018), water quality (Gunter 2017), and algae (Zhu et al. 2019), we are unaware of any studies on aquatic invertebrates in Gwich'in and Inuvialuit lakes. Aquatic invertebrates are important members of lake food webs, as they recycle nutrients and transfer energy from primary producers (algae) to larger organisms such as fish. Therefore, it is important to understand how roadways may impact these important members of the lower food web. In the end, our results did not line up with our expectations. Water quality did not differ among our study lakes based on the distance they were located from the road, and therefore our zooplankton communities also did not differ. While this might be considered a good news story in that road dust does not appear to be affecting the adjacent lakes, the small sample size for our study (18 lakes) and natural variability in the properties of our lakes (e.g. depth, surface area) made it difficult to reach a definitive conclusion on whether road dust is a concern for roadside lakes in this region.

Work for objective 2 was meant to provide region-specific information on how roadways might impact aquatic habitats. For example, if boreal vegetation acts as a better barrier to the spread of road dust in comparison with tundra shrubs, then road developments may impact a larger number of lakes in Tundra habitats than in those further south. This information would be valuable for management boards as they assess the impacts of new developments in the region on aquatic ecosystems. However, the management implications of our results for objective 2 are unclear. Our measurements of road dust movement across the landscape hinted that the dust may spread further from the highway in the tundra region, but our results were not conclusive. There were not significant differences in water quality variables expected to be related to road dust pollution between lakes in the boreal and tundra region. Therefore, we cannot reach definitive conclusion about whether boreal vegetation may act as a barrier for the transport of road dust to the surrounding landscape.

6. Methods

Study location and site selection

Our study included 18 lakes located along the Dempster and Inuvik-Tuktoyaktuk Highways (ITH) in the Northwest Territories (Figure 1). We sampled lakes along both highways between July 30th and August 13th, 2021. Along the Dempster Highway, lakes were located in the Boreal Forest region dominated by coniferous trees, such as black spruce (*Picea mariana*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) (Sweetman et al. 2010), 2010). In comparison, lakes along the ITH were located in the Tundra region dominated by sedges (*Carex spp.*), lichen-heath and various dwarf shrugs (Sweetman et al. 2010).

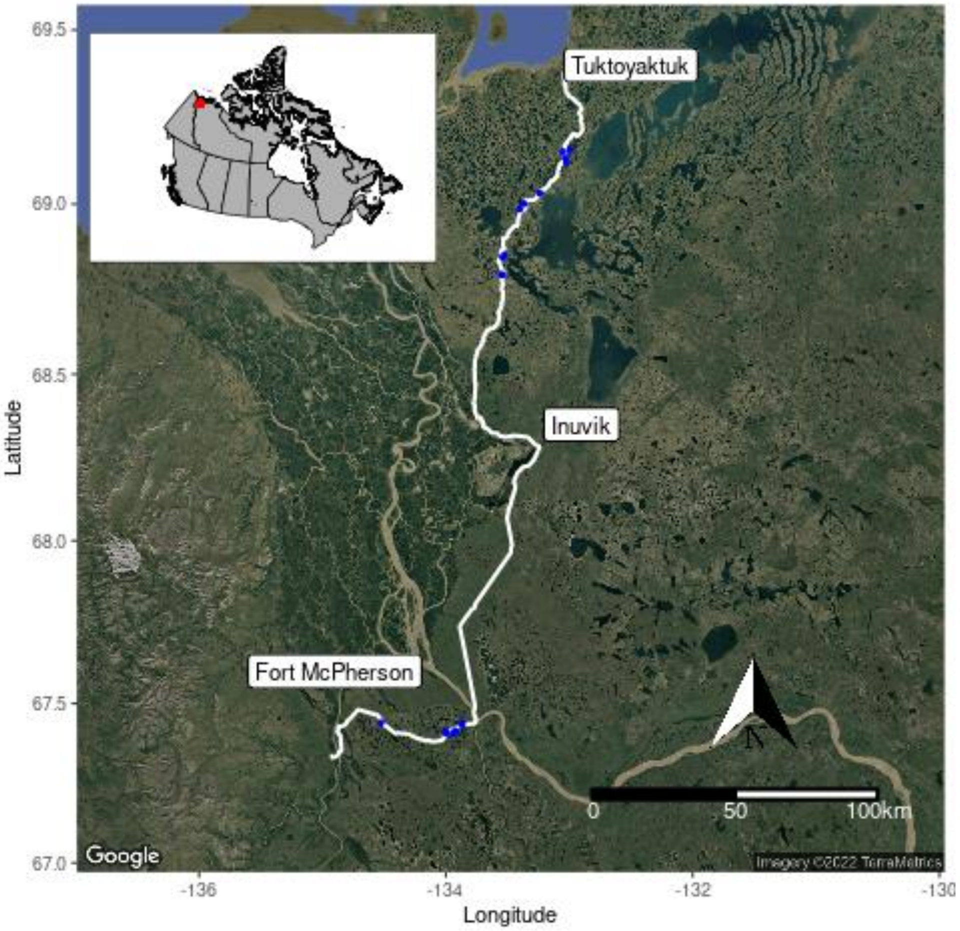

Figure 1. Lakes sampled along the Dempster and Inuvik-Tuktoyaktuk Highways (blue dots).

We selected the lakes for this study by randomly selecting lakes following a stratified random sampling design with two different categorical variables: distance from road and location. We divided the distance from road category into three levels based on the proximity of the lake to the road: 0-300 m, 300-600 m, or more than 600 m. We selected these categories based on past studies that showed road dust had the strongest effects within 1 km from the road (Walker and Everett 1987; Myers-Smith et al. 2006; Chen et al. 2017; Gunter 2017). The location category refers to whether the lakes were located in the boreal forest or the tundra. To ensure that the lakes were randomly selected for inclusion in the study, we used Google Earth to number all lakes within 1 km of the highway in the two sections: 1) Lakes in the boreal area along the Dempster Highway running between Tsiigehtchic and Fort McPherson; 2) lakes in the tundra area along the ITH running between Inuvik and Tuktoyaktuk (Figure 1). Next, we divided the lakes into three distance categories based on how far the closest shoreline was from the highway: 0-300 m, 300-600 m, and more than 600 m. We then used the sample function in R to randomly choose nine numbers associated with the lakes we numbered in each region. In this way, we were able to randomly select nine lakes in the boreal region and nine in the tundra region, with three in each region at each distance category (0-300 m, 300-600 m, >600 m). We selected lakes randomly to prevent any bias in the selection of lakes that might occur if they were chosen for convenience or other considerations.

Field data collection

We used funnel traps to measure the movement of dust from the road to the surrounding landscape (Figure 2). We placed a funnel with a 160 mm diameter opening was in the opening of a 10 L plastic jug. We then added approximately 2 L of milli-Q water to each jug before deploying the funnel traps to provide weight and stability. We deployed the funnel traps in transects running out from the road in both the tundra and boreal forest for five days each. We placed the jugs at distances of 0 m, 150 m, 450 m and 750 m from the road. These distances represent halfway between our lake distance categories (0-300m, 300-600m & > 600m). After we collected the dust traps, we filtered the water inside with a 500 μm sieve to eliminate any insects or plant matter without removing dust particles that may have been contributed by the roads. We then boiled each sample down to 1 L to ensure a consistent volume of liquid in all samples and to sterilize the sample so that biological sources of turbidity (e.g. bacterial blooms) were reduced. We then measured turbidity and conductivity of the 1 L of water from each dust trap using an Oakton T-100 turbidity meter and an Oakton CON150 conductivity meter, respectively. The turbidity and conductivity of the water allowed for an estimate of the dust dissolved in the water contained within the funnel traps.

Figure 2. Dust collection trap used to measure how far from the road dust was travelling across the landscape.

We collected data on lake surface area and distance of each lake from the road using the ruler function on Google Earth in preparation for fieldwork. We determined the maximum depth of each lake using a handheld depth finder (Speedtech Depthmate SM-5). We also collected water quality data including Secchi depth (water clarity), turbidity, conductivity, dissolved oxygen (DO), pH, dissolved nitrogen (DN), dissolved phosphorus (DP), dissolved organic carbon (DOC), calcium, chlorophyll-α, and water temperature. To obtain water clarity measurements, we lowered a Secchi dish over the shady side of the boat at the deepest point the lake. At the same location, we measured turbidity, conductivity, DO, pH, chlorophyll-a and temperature, using a Manta+ multiparameter probe (Eureka Water Probes) at a depth of 1 m. We also collected surface water samples to determine levels of DOC, DN, DP, calcium, and various other trace elements, at the same site. We filtered surface water samples through a 1.2 μm pore size glass fiber filter (Fisherbrand G4) and refrigerated them until they were shipped to TAIGA Laboratories for analysis. We measured the physical and water quality variables described above since they have shown to be significantly correlated with zooplankton community structure in past studies (Gray et al. 2021).

We collected zooplankton samples from each lake at the point of maximum depth and preserved them on site using 95% ethanol. For lakes greater than 3 m in depth, we collected zooplankton with a single vertical haul using a 35-cm diameter, 50 μm mesh size zooplankton net. For shallow lakes less than 3 m in depth, where a vertical tow was not possible, we collected zooplankton by performing oblique zooplankton tows with the same net by casting the zooplankton net out from the boat, allowing it to sink towards the bottom and then pulling the net toward the boat on an angle. When oblique tows were used, we repeated the tows three times and pooled the resulting sample for preservation. In both cases, we used a mechanical flowmeter attached to the mouth of the net to determine the volume of water that passed through the net. Determining the volume of water passing through the net allowed us to estimate the density of the zooplankton in the lake.

We identified benthic invertebrates to the family level using a combination of primary literature (Merritt et al. 2008; Thorp and Covich 2009; Thorp and Rogers 2011) and online image-based keys (Parker 2012). For efficiency purposes, we created sub-samples from each benthic macroinvertebrate sample using a Marchant Box, as it gives reliable estimates of abundance, is easily randomized, and is less costly and time-consuming than identifying every organism in the entire sample (OBBN and CABIN protocols; Jones et al., 2007; McDermott et al., 2014). We identified >100 individual benthic macroinvertebrates per subsample (≥5% needed to be analysed) to assess richness and abundance (≥300 total per lake; OBBN and CCME 9.3 protocols; Jones et al. 2007; CCME 2011). We estimated total abundance based on the percentage of the sample analyzed per station and then calculated a mean for each lake for use in analyses. Laboratory work identifying the macroinvertebrates is ongoing, and these results will not be presented in this report.

Laboratory work and analysis

In the laboratory, we identified crustacean zooplankton to the species level with the help of several keys, including Brooks (1959), Balcer et al. (1984), Witty (2004), and Haney et al. (2013). We examined samples under dissecting and compound microscopes at a magnification of 40x to 400x, depending on the size of the specimen. We took three subsamples from each sample, and counted and identified a minimum of 100 individuals for each subsample, resulting in the identification of at least 300 individuals per lake. We excluded copepod nauplii from all counts. During counts, we noted the presence/absence of the phantom midge *Chaoborus americanus* since their absence is often a good indicator that fish are present in the lake (Sweetman and Smol 2006).

We calculated univariate measures of community structure to describe zooplankton communities, including Shannon diversity, rarefied richness, species evenness, and total abundance. To calculate Shannon diversity for each lake, we used the “diversity” function, found in the Vegan package (Oksanen et al. 2015). We calculated species richness using rarefaction to produce richness values that reflect equal taxonomic/sampling effort for each lake (Hurlbert 1971). Rarefaction accounts for differences in sampling effort by resampling abundance data for a particular site thousands of times to determine the average number of species identified for a given number of individuals collected (Gotelli and Colwell 2001). We conducted rarefaction using the rarefy function in the Vegan package for R (Oksanen et al. 2015), which is based on the formulation by Hurlbert (1971). We calculated species evenness by dividing Shannon diversity by the log of the rarified species richness for each lake, and species abundance by determining the sum of the density for each species of zooplankton present in each lake.

We examined correlations among water quality variables, lake physical characteristics, univariate measures of zooplankton community structure, and individual species abundances using Spearman correlations. Spearman correlation is a non-parametric technique that uses ranks to determine if there is a monotonic relationship between two variables (Daniel 1990). We performed the correlation analysis using the rcorr function in the Hmisc package for R (Harrell and Dupont 2019), and we used the corrplot function in the corrplot package to make the associated plot (Wei and Simko 2017).

To visualize the movement of dust from roads to the surrounding landscape, we fit negative exponential functions to the turbidity and conductivity data obtained from the funnel traps used to measure dust loads:

$$Turbidity = Turbidity_0 \, e^{-r*distance}$$

$$Conductivity = Conductivity_0 \, e^{-r*distance}$$

In these equations, $Turbidity_0$ and $Conductivity_0$ are the turbidity and conductivity levels we measured in the dust traps closest to the road, *r* is the decay rate and *distance* refers to the distance the funnel traps were placed from the road. We fit the functions to the dust trap data using the nls function in R.

We used a two-factor Analysis of Variance (ANOVAs) to determine if key water quality variables and univariate measures of community structure differed among distance from the road categories (0-300 m, 300-600 m, >600 m) or between locations (boreal, tundra). Prior to conducting ANOVAs, we tested the response variables for normality using a Shapiro-Wilks test using the shapiro.test function in R. We tested for homogeneity of variances using Levene's test as performed by the leveneTest function in the car package for R (Fox and Weisberg 2019). All univariate response variables were normally distributed and demonstrated homogeneity of variances among categories, with the exception of total abundance. We used the bestNormalize package in R (Peterson 2021) to identify a suitable transformation for total abundance and based on these results we used the Box-Cox transform. The transformed total abundance data met the assumptions of normality and homogeneity of variances.

We used non-metric multidimensional scaling (NMDS) ordination to compare the relative abundance of zooplankton species in different lakes. We also ran a permutational analysis of variance (PERMANOVA) to test if there were differences in the centroid (middle position) or dispersion of zooplankton communities based on their assignment in distance categories or locations (tundra vs. boreal). The NMDS was created using the metaMDS function, while the PERMANOVA used the adonis function and was based on the Bray-Curtis dissimilarity measure (Oksanen et al. 2015).

7. Results

Dust movement

The dust traps we set up to measure the distance of travel for road dust showed that dust influenced the conductivity and turbidity of the water in the traps out to approximately 300 m (Figure 3).

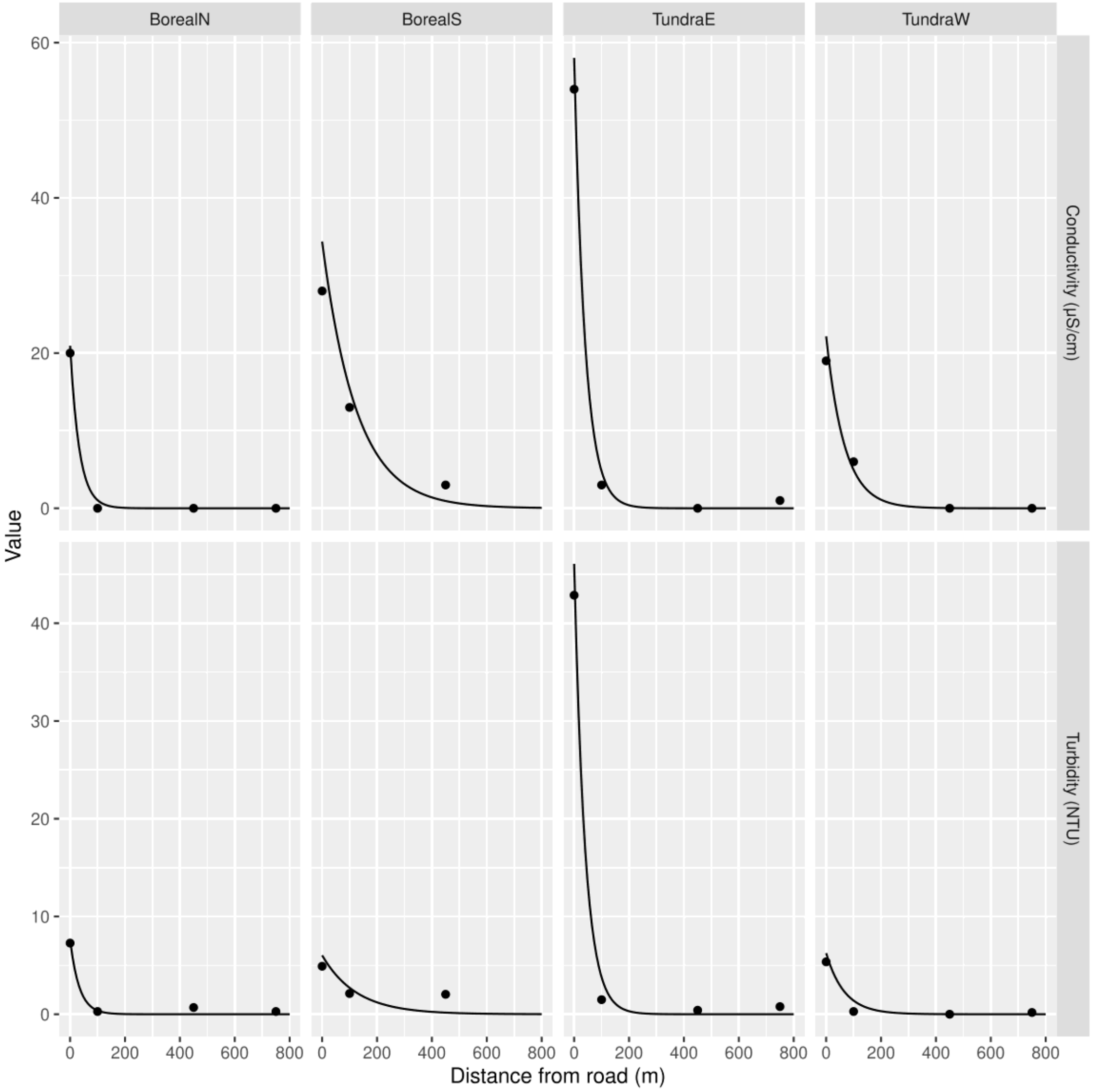

Figure 3. Conductivity (top panels) and turbidity (bottom panels) measured in the water found in our dust traps in either the boreal or tundra region. Traps were set on the East or West side of the road in the tundra (TundraE, TundraW) or North or South of the highway in the boreal region (BorealN, BorealS). Points represent measurements and the line is a negative exponential function fit to the data.

Lake physical characteristics and water quality

Important physical characteristics of lakes in the three distance categories, including surface area, maximum depth, and temperature, did not differ significantly based on distance category (ANOVAs, $p>0.05$ in all cases, Figure 4). There were significant differences in these variables between regions, with tundra lakes having larger surface areas, higher maximum depths, and warmer surface temperatures (ANOVAs, $p<0.05$ in all cases; Figure 5).

Distance from the road was negatively correlated with dissolved phosphorus and positively correlated with watershed area (Figure 5). Distance from the road did not correlate with lake water quality variables we expected to be influenced by road dust, such as conductivity and calcium (Figure 6).

The water quality variables we expected to change with distance from the road, including conductivity, calcium, pH, dissolved oxygen, chlorophyll-a, dissolved organic carbon (DOC), and nutrients did not differ based on distance from the highway (Table 1; Figures 7, 8). Dissolved nitrogen and DOC were the only variables to differ between regions (Table 1; Figure 8).

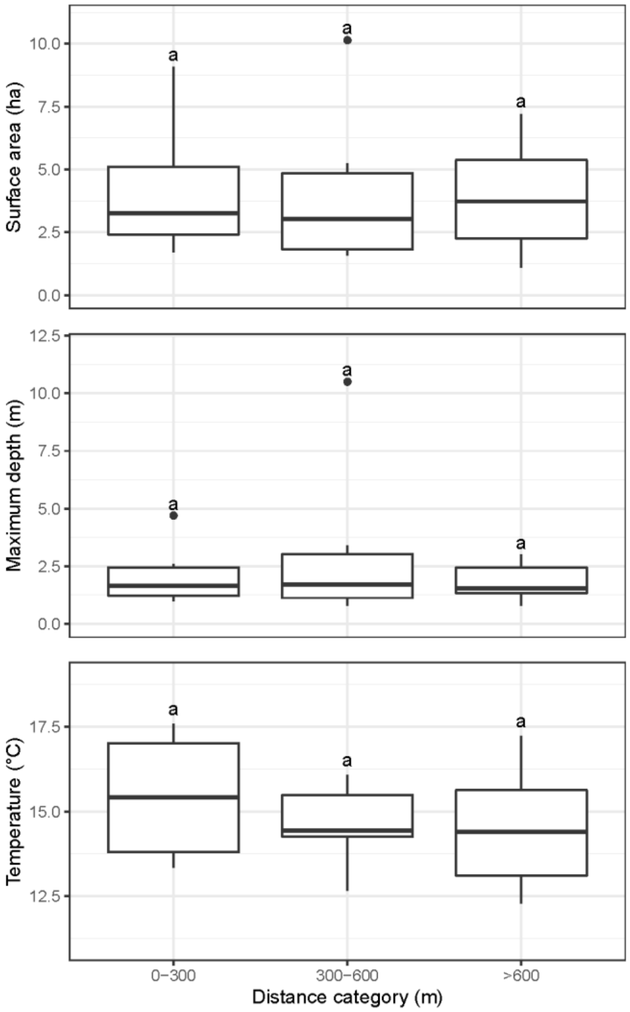

Figure 4. Physical characteristics of our study lakes based on their assignment to distance categories based on their distance from the road.

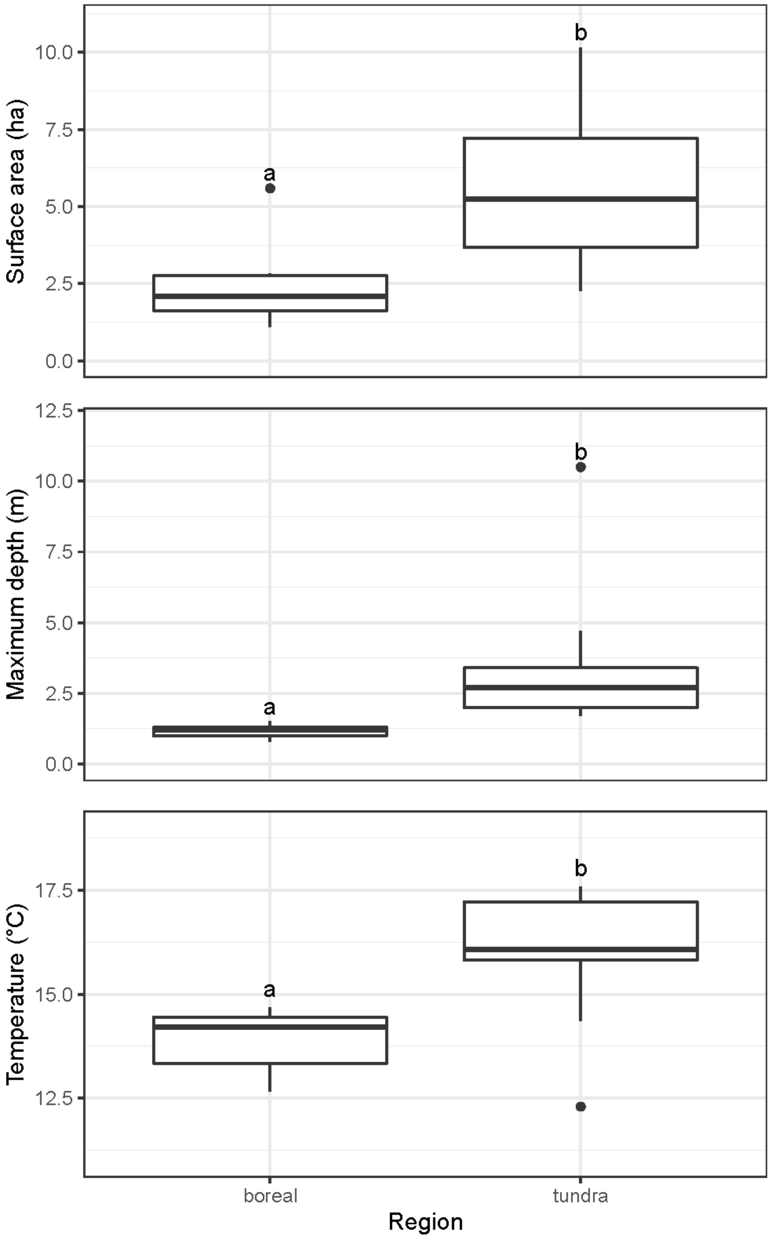

Figure 5. Comparison of surface area, maximum depth, and temperature in our study lakes in the boreal versus tundra region.

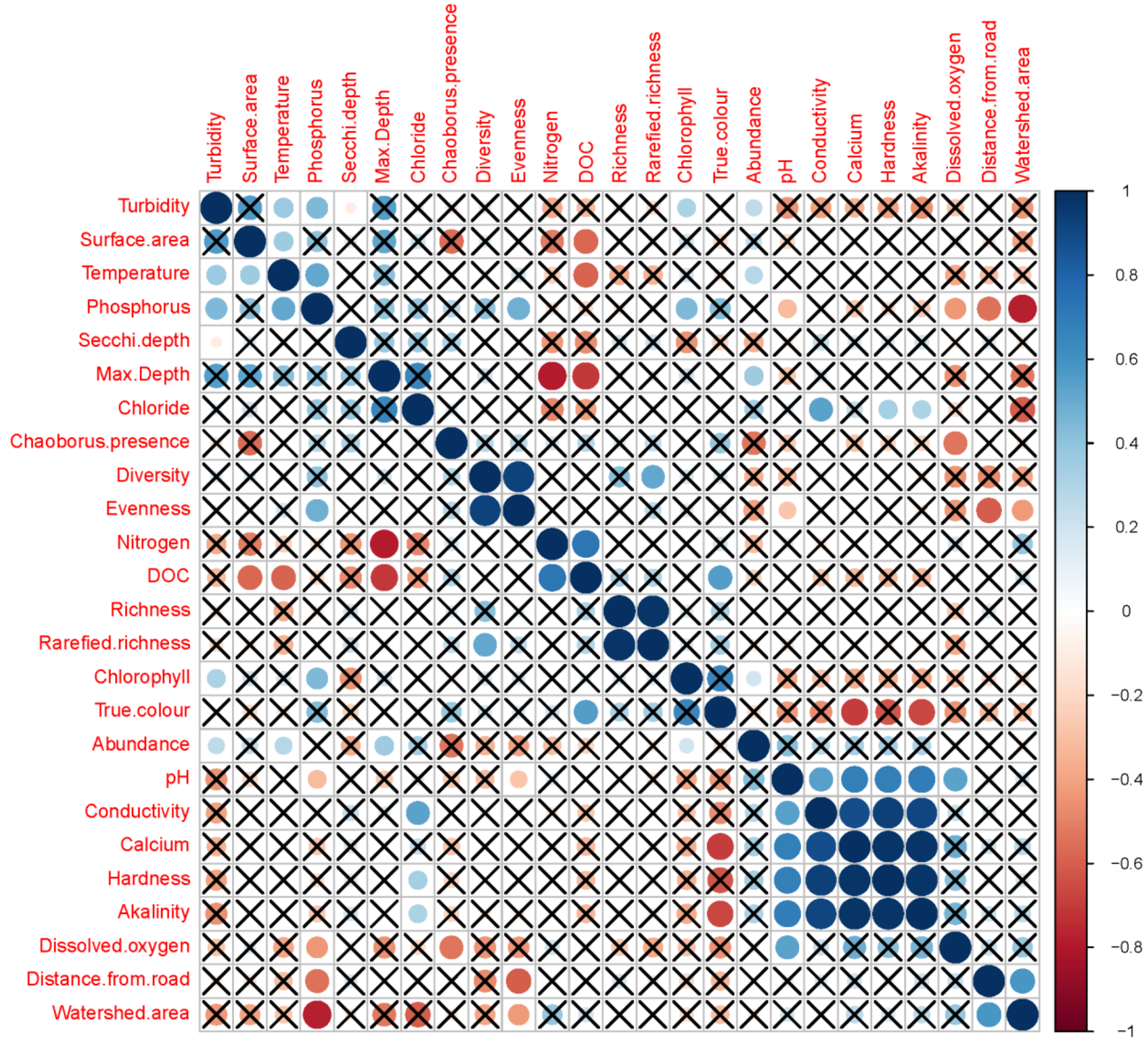

Figure 6. Correlation plots showing Spearman correlations among physical, water quality, and zooplankton community characteristics (richness, rarefied richness, diversity, evenness, abundance). Cells that have an X through them indicate those correlations were not significant. The strength of the correlation is indicated by both the size of each circle, as well as the intensity of the colour, with dark red colour indicating a strong negative correlation, and a dark blue colour indicating a strong positive correlation.

Table 1. Results of analysis of variance tests conducted to examine if water quality variables differed among distance categories or the region of study (boreal versus tundra). DFn= degrees of freedom, numerator, DFd=degrees of freedom denominator.

Variable	**Effect**	**DFn**	**DFd**	**F**	**p**
Conductivity	distance category	2	14	0.02	0.98
	region	1	14	0.002	0.966
	distance category:region	2	14	0.991	0.396
Calcium	distance category	2	14	2.618	0.108
	region	1	14	2.429	0.141
	distance category:region	2	14	0.579	0.573
pH	distance category	2	14	0.328	0.726
	region	1	14	0.245	0.628
	distance category:region	2	14	1.19	0.333
Dissolved oxygen	distance category	2	14	0.473	0.632
	region	1	14	0.312	0.585
	distance category:region	2	14	1.725	0.214
Chlorophyll-a	distance category	2	14	0.982	0.399
	region	1	14	0.44	0.518
	distance category:region	2	14	0.508	0.612
Dissolved nitrogen	distance category	2	14	0.264	0.772
	region	1	14	19.044	**0.000648**
	distance category:region	2	14	0.983	0.399
Dissolved organic carbon	distance category	2	14	1.216	0.326
	region	1	14	50.797	**5.11x 10^{-6}**
	distance category:region	2	14	1.238	0.32
Dissolved phosphorus	distance category	2	14	2.618	0.108
	region	1	14	2.429	0.141
	distance category:region	2	14	0.579	0.573

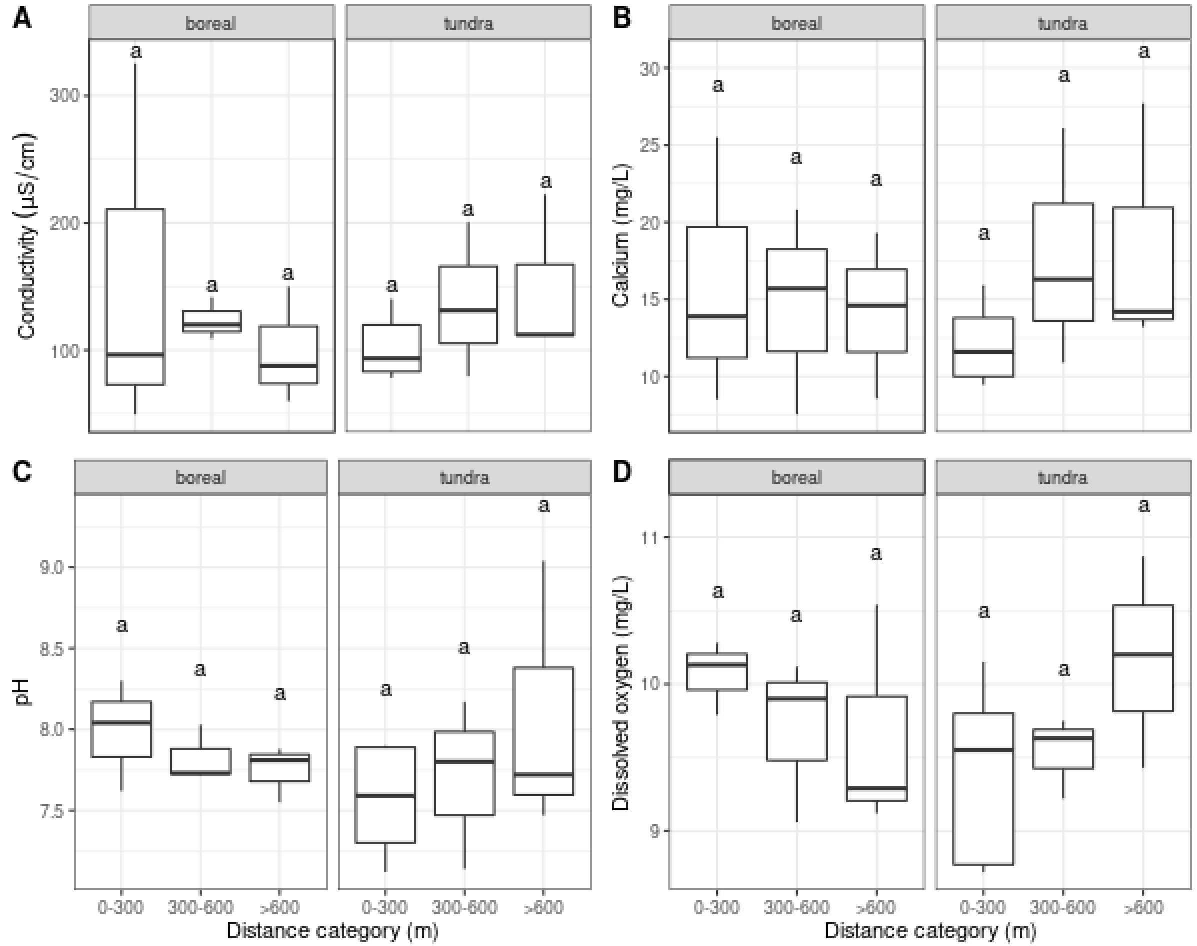

Figure 7. Values of conductivity (A), calcium (B), pH (C), and dissolved oxygen (D) based on lakes categorized by distance from the road and region (boreal versus tundra). Letters above bars indicate the results of our ANOVAs. Matching letters indicate no difference, while differing letters indicate a statistically significant difference.

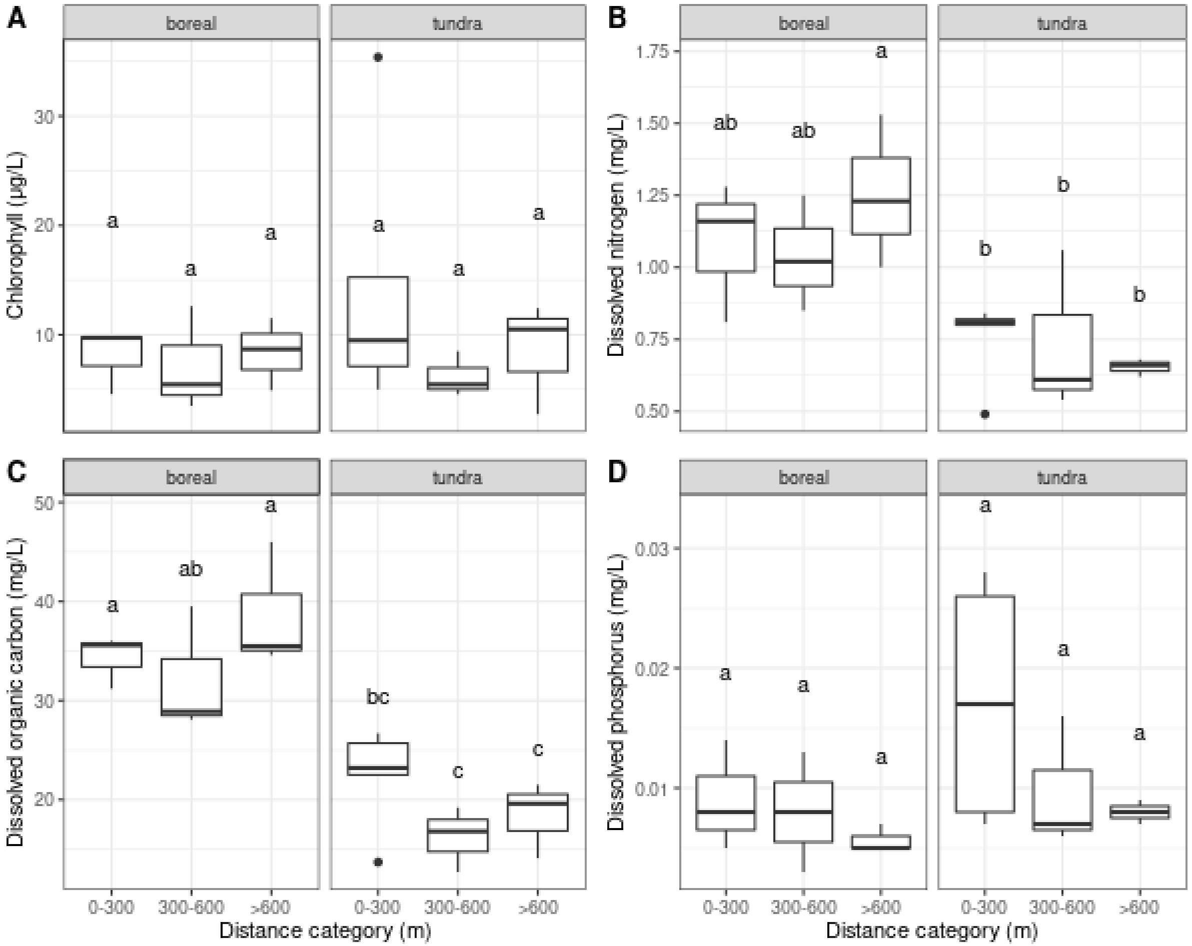

Figure 8. Values of chlorophyll-a (A), dissolved nitrogen (B), dissolved organic carbon (C), and dissolved phosphorus (D) based on lakes categorized by distance from the road and region (boreal versus tundra). Letters above bars indicate the results of our ANOVAs. Matching letters indicate no difference, while differing letters indicate a statistically significant difference.

Zooplankton communities

Diversity and rarefied richness of the zooplankton communities were not correlated with any physical or water quality variables (Figure 6). Total abundance was positively correlated with turbidity, temperature, maximum depth, and chlorophyll-a levels (Figure 6). Evenness was positively correlated with dissolved phosphorus and negatively correlated with pH, distance from the road, and watershed area (Figure 6).

Univariate measures of zooplankton community structure, including rarefied richness, diversity, evenness, and abundance did not differ according to distance from the road (Figure 9; Table 2).

Our nonmetric multidimensional scaling analysis combined with the PERMANOVA showed that the relative abundance of zooplankton did not differ based on distance from the road, but did differ between the two regions (Table 3; Figure 10). The differences between regions appeared to be caused by high abundances of *Bosmina longirostris* and *Daphnia longiremis*, and *D. pulicaria* in some tundra lakes that were not found in the boreal region. *Daphnia pulicaria* was positively correlated with lake surface area (Figure 11), while *B. longirostris* and *D. longiremis* were negatively correlated with Secchi depth and positively correlated with temperature and chlorophyll-a levels (Figure 11).

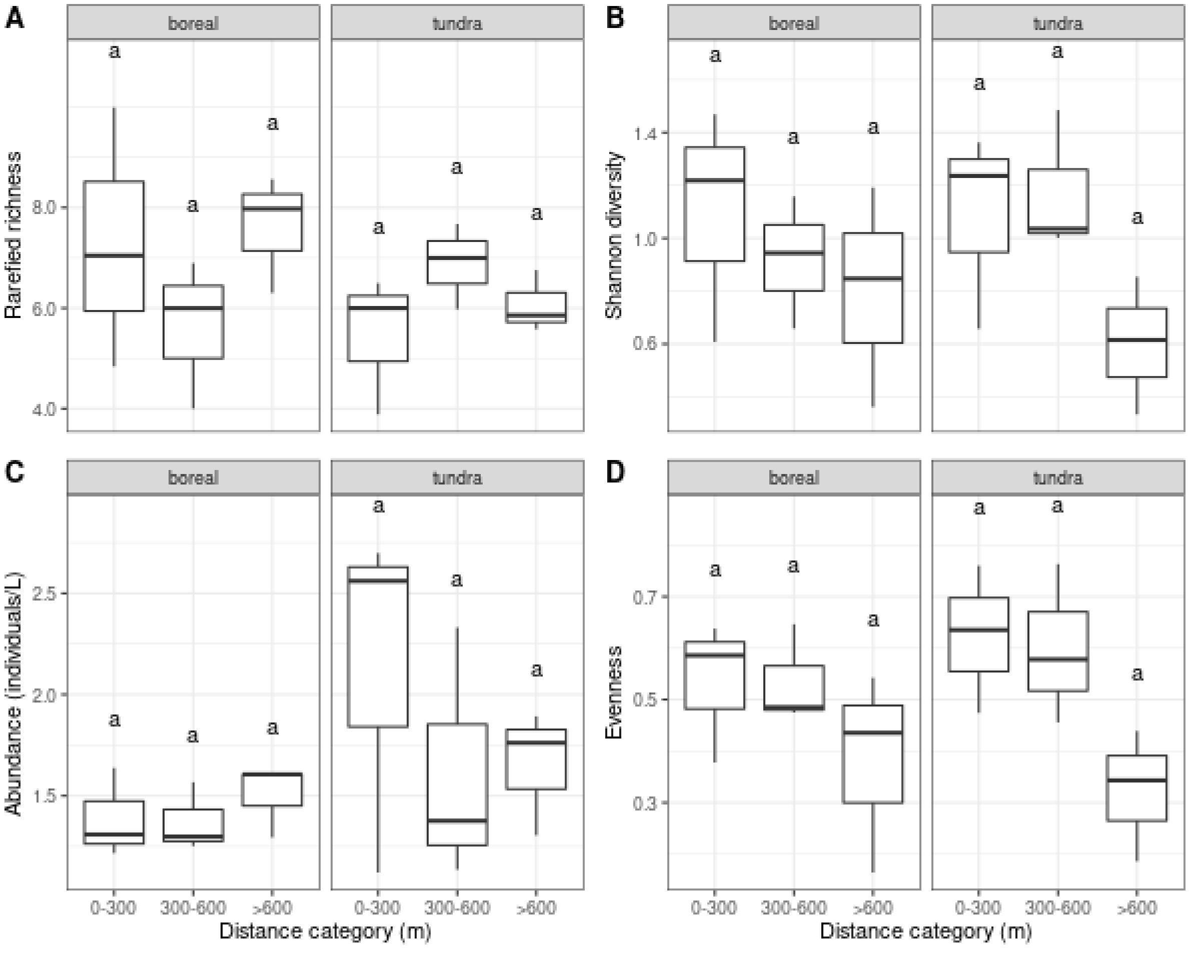

Figure 9. Values of rarefied richness (A), Shannon diversity (B), total abundance (C) and evenness (D) for zooplankton communities in lakes categorized by distance from the road and region (boreal versus tundra). Letters above bars indicate the results of our ANOVAs. Matching letters indicate no difference, while differing letters indicate a statistically significant difference.

Table 2. Results of a two factor analysis of variance tests for univariate measures of zooplankton community structure. DFn= degrees of freedom, numerator, DFd=degrees of freedom denominator.

Metric	Effect	DFn	DFd	F	p
Rarefied richness	region	1	12	1.023	0.332
	category	2	12	0.257	0.778
	region:category	2	12	1.967	0.182
Shannon diversity	region	1	12	0.007	0.933
	category	2	12	2.311	0.142
	region:category	2	12	0.652	0.538
Evenness	region	1	12	0.214	0.652
	category	2	12	4.632	**0.032**
	region:category	2	12	0.438	0.655
Total abundance	region	1	12	2.809	0.12
	category	2	12	0.479	0.631
	region:category	2	12	0.66	0.535

Table 3. Results of permutational analysis of variance to test for differences in the dispersion of species abundances among distance categories and regions. Df= degrees of freedom; SS= sum of squares; MS= mean square.

Source	Df	SS	MS	F	R^2	p
region	1	0.775	0.775	3.967	0.191	0.006
distance category	2	0.546	0.273	1.397	0.135	0.186
residuals	14	2.734	0.195	NA	0.674	NA
total	17	4.054	NA	NA	1.000	NA

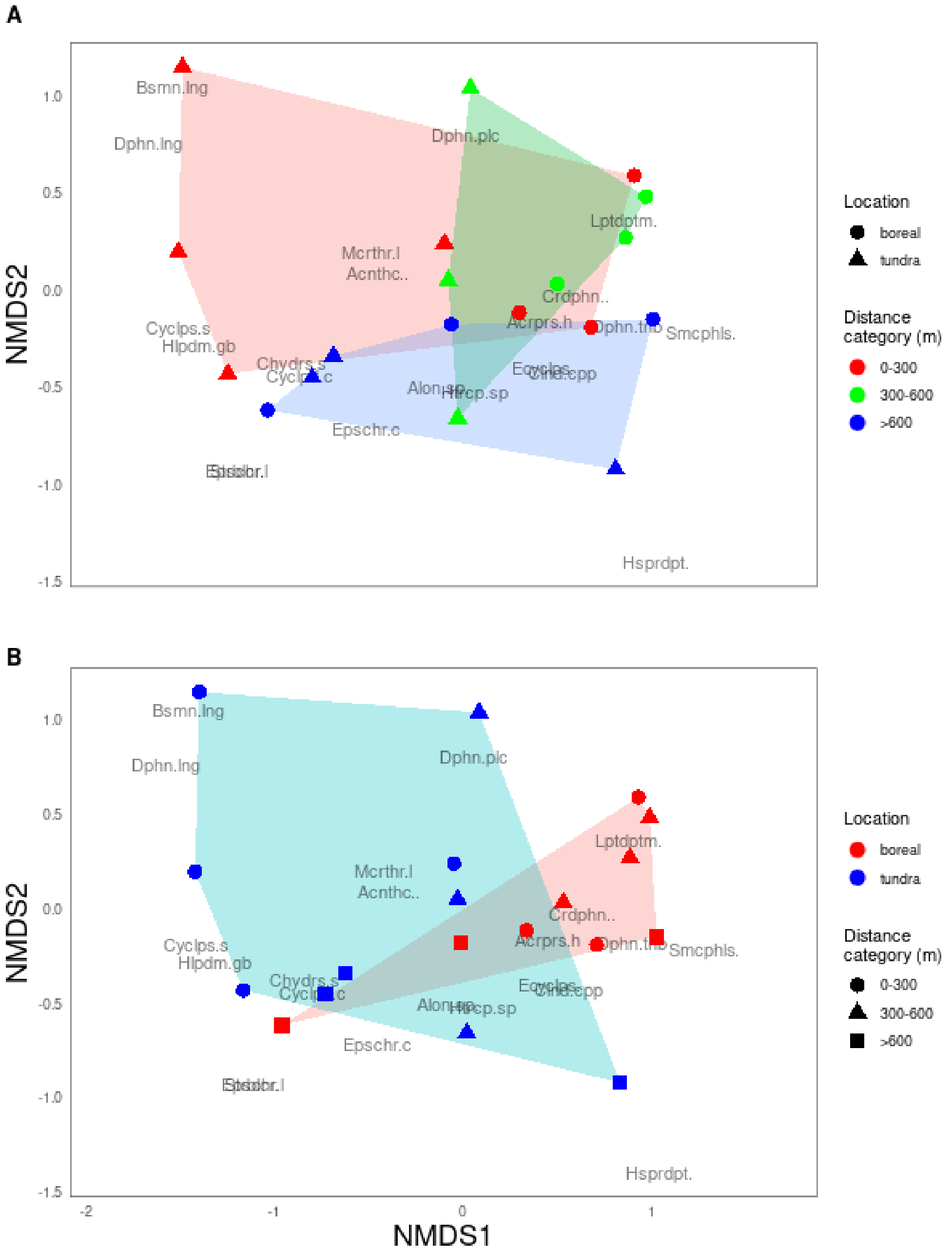

Figure 10. Nonmetric multidimensional scaling plots with shading by distance category (A) and location (B). Each dot represents one of the study lakes and text represents zooplankton species names. Dots closer to a species name indicates that lake contains a higher relative abundance of that species.

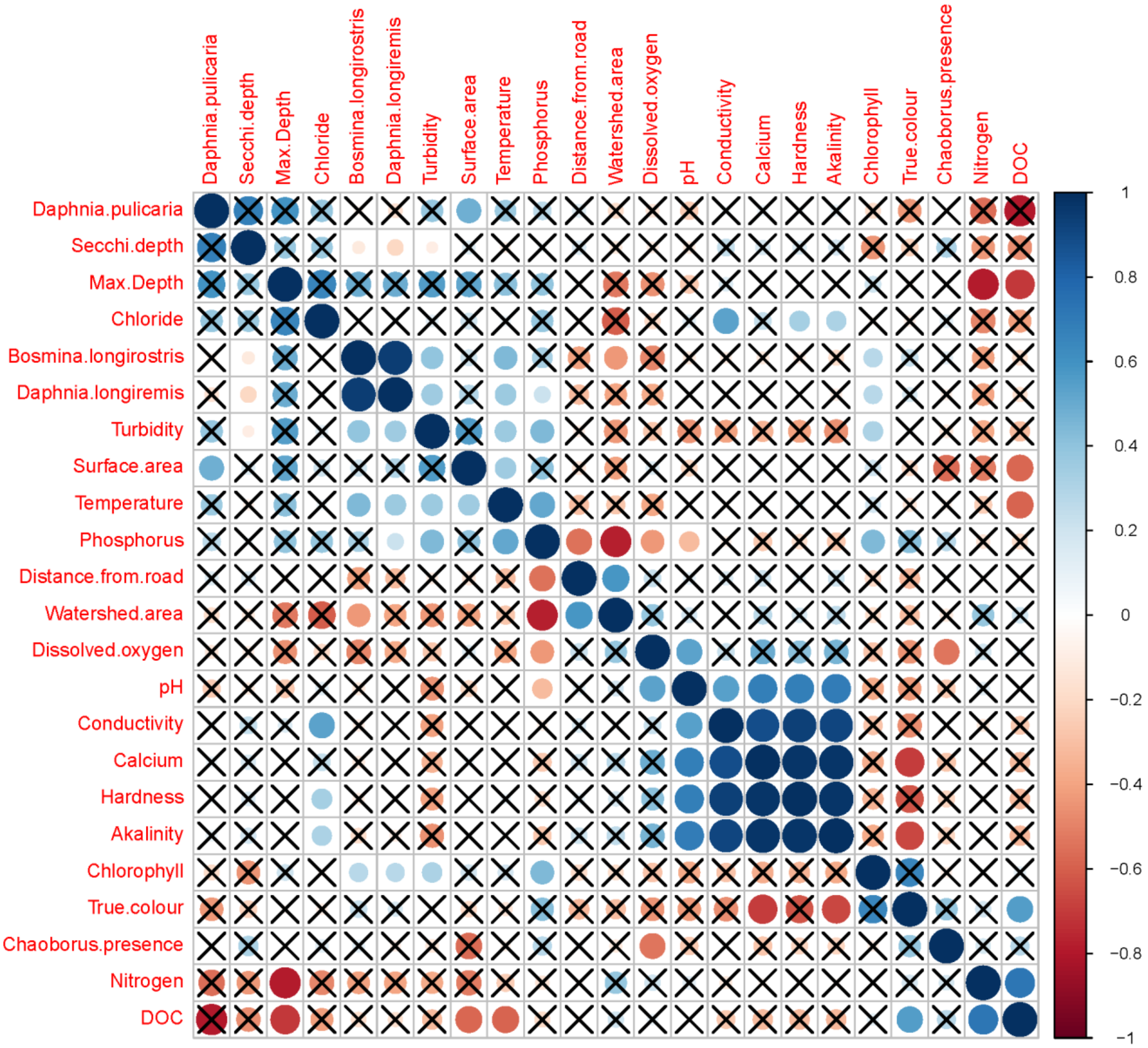

Figure 11. Correlation between *Bosmina longirostris*, *Daphnia longiremis*, *D. puliciaria*, and physicochemical variables.

8. Discussion and Contribution to Understanding

Government of
Northwest Territories

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Cumulative Impact Monitoring Program (NWT CIMP)
FINAL REPORT FORM 2021-2022

Part 1: *Check all boxes that apply for the* **duration of the project** *and provide a numbered reference to a text explanation in Part 2.*
Part 2: *Provide a brief description and explanation of each of the areas checked in Part 1. Use plain language. Provide enough detail to give an understanding of the progress that was made and its significance. It should be clearly articulated how the project advances the understanding of cumulative impact monitoring in the NWT.*

Part 1		
Monitoring and research conducted *during this year* led to:		**Numbered reference to Part 2**
New or enhanced knowledge in the field of study	☒	1
New or enhanced knowledge of cumulative effects	☒	2
Directly impacted a current decision-making process* * Must provide evidence that project results have been directly used in a NWT environmental decision-making process between April 1, 2021 and March 31, 2022.	☐	
Could contribute to a future decision-making process	☒	3
Development of a standardized monitoring protocol(s)	☐	
Adoption of standardized monitoring protocol(s) by decision-maker	☐	
Responded to a community concern	☒	4
New or enhanced community capacity	☐	
New or enhanced analytical tool	☐	
New or enhanced modeling capacity	☐	
Other:	☐	
Part 2		

Key Points

1. Our study did not find any significant effects of road dust on water quality or zooplankton communities in lakes along the Dempster or Inuvik-Tuktoyaktuk Highways.
2. Previous studies on lakes in this region suggested that road dust pollution could exacerbate water quality issues caused by permafrost thaw (Vucic et al. 2020; Cohen et al. 2021). However, according to our study, this does not appear to be cause for concern.
3. If our results hold up in follow-up studies, roadways may not have a significant influence on water quality and zooplankton communities in the region. This could mean that this concern could be removed when assessing the design and routing of new highways. We believe that further study is needed to confirm our results before making this conclusion.
4. We visited Inuvik, Tsiigehtchic, and Fort McPherson for community meetings in September 2021 to discuss their concerns about water quality as part of a separate project (CIMP225). In Inuvik and Fort McPherson, community members raised concerns about road dust and its effects on the surrounding environment.

General Discussion

Our dust traps confirmed that dust was moving from the highways out to a distance of at least 300 m across the landscape. The effects of dust were measured through changes in conductivity and turbidity of the water in our dust traps. Therefore, it is possible that if we left the traps out for a longer than five days at each location, we might have detected elevated conductivity or turbidity at distances greater than 300 m from the highway. Our dust traps also showed that the movement of dust was not uniform across the landscape. Traps located downwind of the highway in both the boreal and tundra areas had higher conductivity and turbidity levels than those upwind of the highway. The conductivity and turbidity of dust traps in the tundra were highest, and we speculate that this might relate to a lack of tree cover. However, more data will be needed to test this hypothesis. Overall, these results are largely consistent with past studies that have suggested dust has an effect on terrestrial and aquatic habitats within 1000 m from the road (Chen et al. 2017; Gunter 2017; Zhu et al. 2019).

Surprisingly, we did not find any differences in water quality related to distance of a lake from the road. We hypothesized that conductivity and calcium would be elevated in lakes closer to the road due to the transport of calcareous dust across the landscape. Given that our dust traps confirmed the movement of dust from the highway, these results were unexpected. These results are not consistent with previous studies in the region (Chen et al. 2017; Gunter 2017; Zhu et al. 2019). There are several potential reasons for the apparent lack of an effect of road dust on our study lakes. First, our random selection of study lakes may have underrepresented the effects of road dust on lakes in the region. 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 eighteen study lakes we 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. Second, we may not have sampled lakes far enough from the road to see a clear pattern. Gunter (2017) 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 of our study lakes were equally affected by road dust since they were within 1 km from the road. However, this seems unlikely given the measurements we obtained from our dust traps. A future study that includes lakes further than 1 km from the road would help to determine if our results underestimated the effects of road dust due to the small distance range covered. Third, it is possible that the flushing rate of the lakes is high enough to dilute road dust pollution, leading to little change in calcium and conductivity levels in our study lakes. Even lakes without obvious stream connections can experience inputs from groundwater, which may be enough to dilute this type of pollution. Unfortunately, we do not have hydrological data for our study lakes to evaluate this hypothesis.

There were no differences in univariate metrics of zooplankton communities. Richness, diversity, evenness, and total abundance of communities did not correlate with distance from the road, and our ANOVAs showed now differences in these univariate measures of community structure among lakes in the different distance categories. Based on the relationships between conductivity, calcium and the structure of zooplankton communities in a recent study by Vucic et al. (2020), we hypothesized that communities in roadside lakes would diverge from those not subjected to road dust contamination. However, as described above, water quality did not differ based on distance of a lake from the road, and therefore, the lack of differences in zooplankton communities at different distances from the road should not be unexpected. These results are also consistent with studies on other organisms which also showed no affect of road pollution on algal communities or diatoms in particular (Gunter 2017; Zhu et al. 2019).

Our analyses of the relative abundance of zooplankton using an NMDS and a PERMANOVA showed that there were differences based on region (boreal vs. tundra) but not based on distance from the road. The differences were largely caused by higher abundances of *Bosmina longirostris, Daphnia longiremis*, and *D. pulicaria* in tundra lakes. Our correlation analysis showed that these species were likely more abundant in tundra lakes due to differences in lake surface area, Secchi depth, temperature, and chlorophyll-a levels. Our study lakes in the tundra were larger, deeper, clearer, and warmer. The size and water clarity difference between tundra and boreal lakes was also found in recent studies by Cohen et al. (2021) who found road-accessible lakes in the boreal tended to be smaller, shallower, and had higher dissolved organic carbon levels. Many of the boreal lakes along the Dempster highway could be described as bog lakes due to the shallow, high DOC environments with an abundance of sphagnum moss on the bottom (Vucic et al. 2020; Cohen et al. 2021). The warmer surface temperatures for tundra lakes corresponds to the time of sampling, as they were sampled July 30-August 7th, 2021 while the boreal lakes were visited August 8th – 13, 2021.

Although we believe our study design was sound for testing our hypotheses about the effects of road dust on lakes, there were several limitations to our study. First, our sample size of 18 lakes was relatively small, leading to only three replicates per factorial combination (e.g. three lakes at 0-300m in the tundra). Larger sample sizes produce better parameter estimates. In our case, a larger number of lakes would likely have produced better estimates for water quality parameters, as well as for zooplankton richness, diversity, evenness, and abundance for lakes in each distance category and in each region. Smaller sample sizes combined with sampling error can lead to poor parameter estimates, and low statistical power, which may lead to erroneous conclusions. We had planned to sample more lakes for this project, but the cancellation of the 2020 field season due to covid made this impossible. Another limitation to our study was our decision to sample lakes only within 1 km of the road. We accessed our study lakes on foot and the terrain made it very difficult to hike more than 1 km to access lakes. If we had access to a helicopter or float plane, sampling more distant lakes would have been more feasible. We suggest that future studies consider sampling lakes further from the highway to determine if the lack of significant differences found in our study are an artefact of the sampling design. Finally, natural variability in the properties of our study lakes may have been an issue. Ideally, we would have chosen lakes with identical physical properties, such as surface area and maximum depth. While there were not statistically significant differences in these properties among our distance categories, there was variability in these parameters both within and among regions and distance categories. Variability in physical characteristics can lead to natural differences in water quality and zooplankton communities, complicating efforts to determine if a stressor is affecting the lake, or if differences are simply a product of differing environments. Unfortunately, we did not have prior data on key properties, such as lake depth. Our solution was to select lakes randomly for inclusion in the study, but we suggest that a future study more carefully consider how to compare the effects of road dust on lakes with similar physical properties.

In summary, our study did not detect any significant effects of road dust on water quality or zooplankton communities for lakes within 1 km of the Dempster and Inuvik-Tuktoyaktuk Highways. While this is welcome news, we are concerned that our water quality results differ from other recent studies that have suggested a significant affect of road dust. Before reaching a definitive conclusion on this question, we believe that a follow up study that increases the number of lakes sampled and considers reducing inter-lake variability in physical characteristics would be helpful.

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9. Resource Management Implications

In the key points of our discussion above, we listed two important conclusions related to resource management:

1. Previous studies on lakes in this region suggested that road dust pollution could exacerbate water quality issues caused by permafrost thaw (Vucic et al. 2020; Cohen et al. 2021). However, according to our study, this does not appear to be cause for concern.
2. If our results hold up in follow-up studies, roadways may not have a significant influence on water quality and zooplankton communities in the region. This could mean that this concern could be removed when assessing the design and routing of new highways. We believe that further study is needed to confirm our results before making decisions based on this conclusion.

We also discuss the limitations of our study in the discussion section, and we believe these limitations should be scrutinized before resource managers make decisions based on the two points above.

10. Project Linkages

This project adds additional baseline data to the dataset collected for CIMP197. However, CIMP197 only sampled lakes within 300 m from the road, leaving questions about whether the lakes in that dataset were truly representative of lakes in the region, or if their water quality had been affected by the road. The current study suggests that there are not significant differences based on road proximity, and that the dataset provided by CIMP197 (nearly 60 lakes) offer a good representation of the state of lakes in the Mackenzie Delta Region.

11. Deliverables

Deliverable (*report, presentation, model, etc.*)	**Intended user(s)** (*be specific*)	**Significance of the deliverable** (*'So what?'*)	**Sent to NWT CIMP?** ☐ Yes ☐ No (*if no, state reason*)
Hannan, N. and Gray, D.K. How does road proximity affect zooplankton communities in lakes in the Northwest Territories? Canadian Society of Limnologists Meeting. Vancouver, BC, February 2022 (Oral presentation)	Academics and resource managers	MSc student provided a summary of our research results to a mixed audience of government and academic scientists and resource managers	Yes
Gao, V., Gray, D.K, and Kheyrollah-Pour, H. 2022. Gravel road runoff in an Arctic environment: An assessment of the impact on macroinvertebrates in roadside	Academics and resource managers	MSc student provided a summary of our research results to a mixed audience of government and academic scientists and resource managers	Yes

lakes. Canadian Society of Limnologists Meeting. Vancouver, BC, February 2022 (Poster presentation)			
Rix, C. 2022. Impacts of road dust pollution on zooplankton communities in Arctic lakes. Honours thesis, Department of Biology, Wilfrid Laurier University (thesis)	Environmental researchers	Undergraduate student worked with data from the Gwich'in Settlement Area to examine how road dust affects lakes	Yes
Rix, C. 2022. Impacts of road dust pollution on zooplankton communities in Arctic lakes (presentation)	Academics and resource managers	Undergraduate student provided a summary of our research results to a mixed audience of government and academic scientists and resource managers	Yes
Dixon, H.J., Elmarsafy, M., Hannan, N., Gao, V., Wright, C., Khan, L., Gray, D.K. (2022). The effects of roadways on lakes and ponds: a systematic review and assessment of knowledge gaps. Accepted for publication in Environmental Reviews (Publication)	Academics and resource managers	As part of gathering background research for our CIMP research, we conducted a literature review of the effects of roads on lakes and ponds. Using that information, we wrote a comprehensive review of the subject that will be published in a refereed journal	Yes (manuscript has not been formatted for the journal yet)
Wilfrid Laurier University. 2022. "2022 water quality data collected for CIMP197" (dataset). 1.0.0. DataStream. 10.25976/b2cz-mn27. (Dataset)	General public, academics, resource managers	We have uploaded our water quality data to Mackenzie Datastream so that it is publicly available	Yes (sent upload template for your reference)

12. Budget *(see separate template)*

Thank you for your submission!

Northwest Territories
Cumulative Impact Monitoring Program (NWT CIMP)
FINAL REPORT FORM 2021-2022

Final Report Submission Checklist

Please ensure your Final Report is complete with the following:

- ✓ All sections are complete in the correct font style and size.
- ✓ Complete budget template (provided).
- ✓ All deliverables stated in the original proposal and subsequent annual reports if not yet submitted to NWT CIMP. If not available, rationale is to be provided.
- ✓ I sent my Final Report in PDF format to nwtcimp@gov.nt.ca

Reminder: Deadline for Final Report is April 29th, 2022.

Contact Us!
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