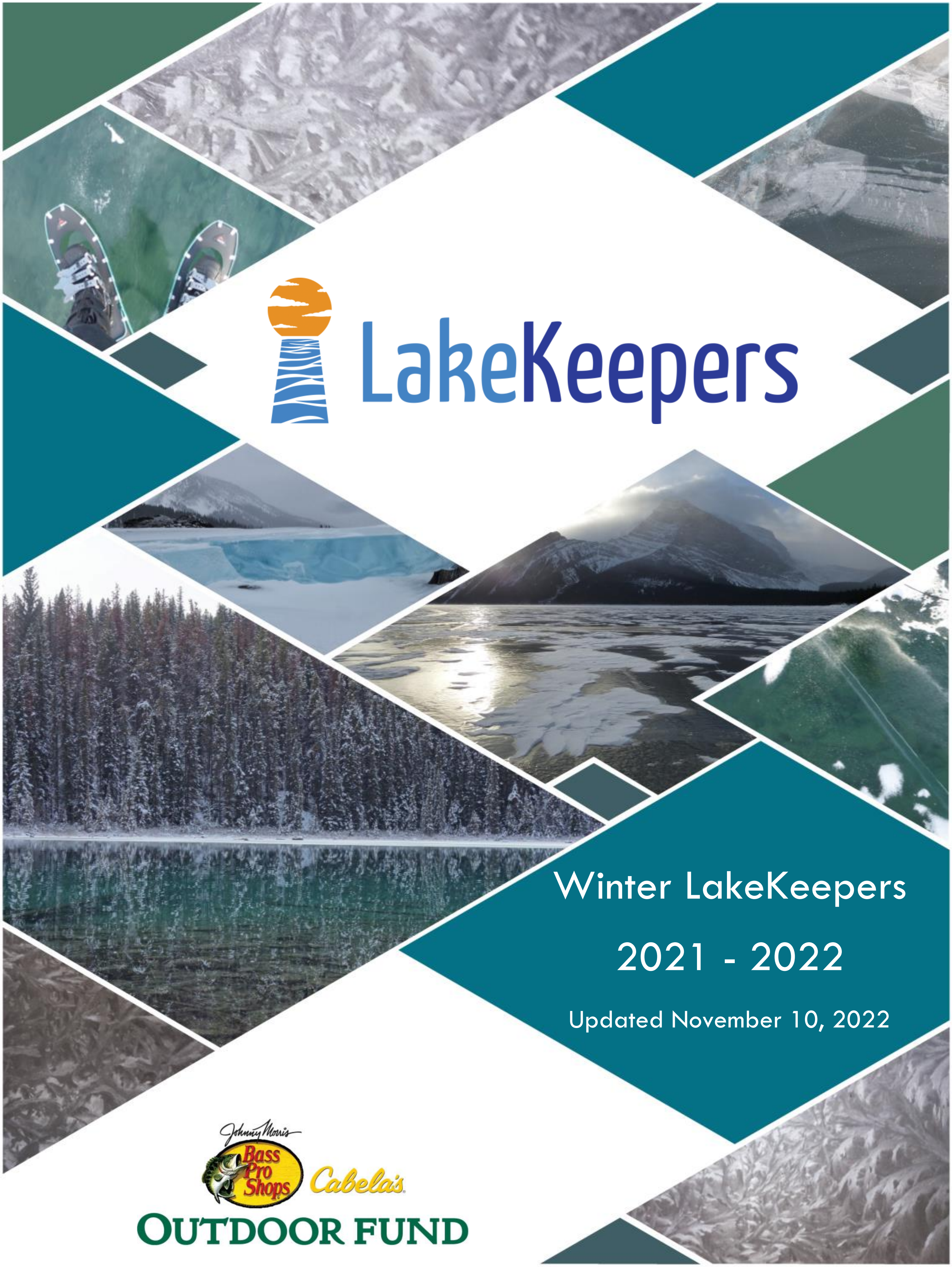


LakeKeepers

Winter LakeKeepers

2021 - 2022

Updated November 10, 2022

Johnny Morris Bass Pro Shops Cabela's OUTDOOR FUND

ALBERTA LAKE MANAGEMENT SOCIETY'S OBJECTIVES

The Alberta Lake Management Society (ALMS) has several objectives, one of which is to collect and interpret water quality data on Alberta Lakes. Equally important is educating lake users about their aquatic environment, encouraging public involvement in lake management, and facilitating cooperation and partnerships between government, industry, the scientific community and lake users.

ALMS would like to thank all who express interest in Alberta's aquatic environments and particularly those who have participated in the Winter LakeKeepers program. These leaders in stewardship give us hope that our water resources will not be the limiting factor in the health of our environment.

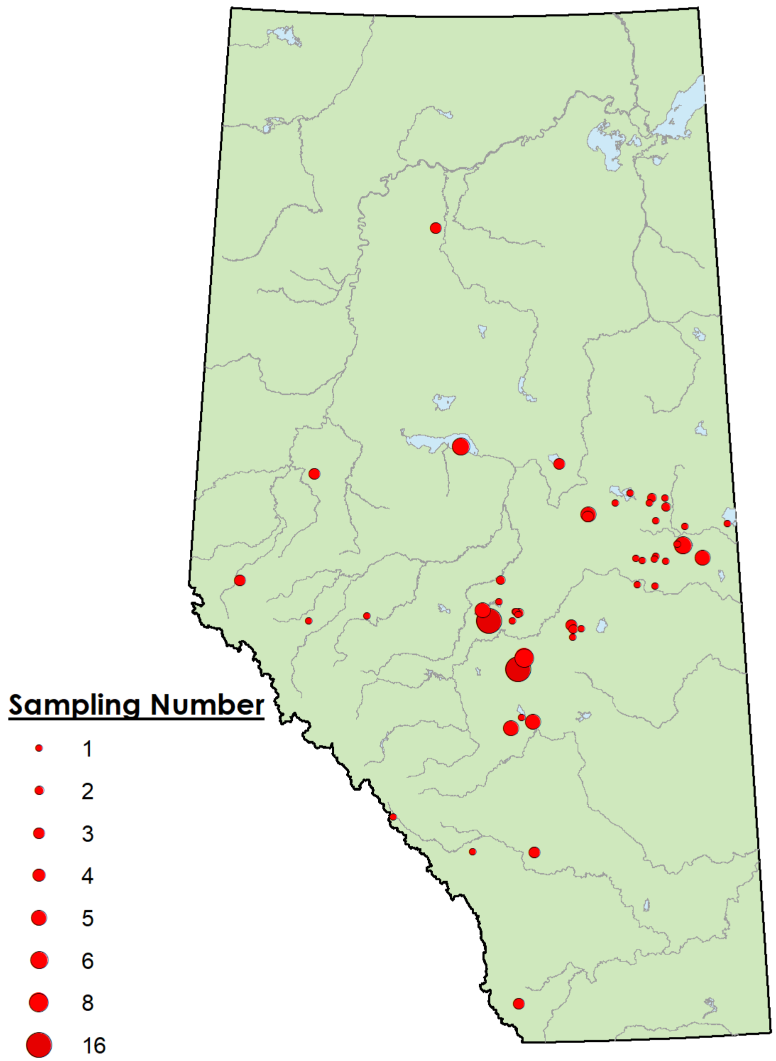
ACKNOWLEDGEMENTS

Winter LakeKeepers 2021-2022 was made possible with support from Bass Pro Shops and Cabela's Outdoor Fund.

We would like to thank all of the volunteers and partners who participated in sampling – without their commitment, this program would not exist. We would also like to thank the Mighty Peace Watershed Alliance for their assistance with coordinating volunteers and sample shipment, and to the Aquatic Ecology Laboratory at the University of Calgary for their advice on winter lake sampling methodology. This report has been prepared by Caleb Sinn and Bradley Peter.

Report last updated: November 10th, 2022

Executive Summary



Map 1. Geographic spread of lakes sampled as part of the Winter LakeKeepers 2021-2022 season. The size of the dot indicates the number of samples taken from the lake, both in terms of sites and number of times a site was sampled through the winter of 2021-2022.

Following three successful seasons of Winter LakeKeepers beginning in the winter of 2018-2019, the Alberta Lake Management Society (ALMS), delivered a fourth Winter LakeKeepers season during winter 2021-2022, the results of which are presented in this report.

As in previous seasons, the volunteer effort consisted primarily of volunteers associated with Watershed Planning and Advisory Councils (WPACs), or Watershed Stewardship Groups (WSGs), but also included some ice anglers and partner organizations. 2021-2022 is the third season to include multiple sampling events at specific sites on lakes, as well as multiple sampling sites per lake. It is also the second season which included the collection of preserved phytoplankton samples, isotope samples, and additional water chemistry parameters. Three tiers of protocols were implemented depending on volunteer interest and sample logistics.

Sampling results per lake have generally been grouped by major watershed.A summary of hypoxia data is provided in the Appendix, as well as a summary about a sensor array that was deployed at Pigeon Lake to collect high-frequency water temperature, dissolved oxygen, and light measurements through the winter.

Overall, 66 sites were sampled on 52 different lakes, ranging from the Oldman watershed in the south, up to the Peace watershed in northern Alberta (Map 1). 129 sampling events took place, from as early as December 9th, 2021, to as late as May 16th, 2022. This is approximately a 30% increase in effort relative to the previous winter's sampling effort. 70 volunteers and partners took part in Winter LakeKeepers 2021–2022 contributing over 600 hours of sampling.

A variety of winter lake conditions were captured throughout the province. In the future, increased sampling frequency, and repeat sampling at the same lakes will support further investigation of winter seasonal trends and dynamics.

Methods

Winter LakeKeepers sampling kit in action

Prior to sampling, volunteers were provided with an ice-safety manual, and then were required to take a quiz on ice safety. Volunteers needed to score 100% before their first sampling event, with unlimited attempts to do so. Volunteers were required to sign an informed consent form.

Volunteers were also provided with a training manual (available at https://alms.ca/winter-lakekeepers/). Lakes were to be sampled at least once during the ice-on period, coinciding with Alberta's ice fishing season (December 1st – March 31st), and ideally no more than once a month. Two lakes were sampled in late winter outside of the sampling season (Lake Louise, May 16th, 2022; Pigeon Lake, Grandview, April 20th 2022).

Volunteers chose their own locations for sampling, generally based on their desired location for ice fishing, or based on proximity to their residence. In some cases, ALMS provided site selection advice. Unlike other ALMS summer programs, this meant Winter LakeKeepers sampling did not necessarily occur at the deepest point in the lake.

Volunteers had the choice of following one of three different protocol tiers: P1, P2, or P2 + chlorophyll-*a* (ChlA) filtering. This was done in order to facilitate the analysis of additional parameters. Sample bottles for analysis of target parameters such as chloride (Cl), conductivity (Cond.), pH, dissolved organic carbon (DOC), nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and total dissolved phosphorus (TDP) needed to arrive at the analytical laboratory within 3 days. ChlA samples not filtered in the field needed to arrive at the ALMS office within 24hrs, while total phosphorus (TP) and total Kjeldahl nitrogen (TKN) could arrive at the lab as late as 2 weeks after the sampling date. Sample hold times dictated which sample bottles were filled during each sampling event.

For all protocol tiers, volunteers were provided with field sheets, a YSI ProODO or ProSolo dissolved oxygen (DO) and temperature meter, a 'G2-Preserved' sample bottle with preservative (analysis of TP and TKN), sampling gloves to protect volunteers from cold water and preservatives, an isotope bottle, a phytoplankton bottle with Lugol's preservative, and a hot water bottle that ensured the samples and the probe did not freeze. Volunteers following the P2 tier were also provided with a 'G2-F' bottle (analysis of TDP, DOC), a 'Routine' bottle (analysis of Cond., pH, Cl, NO_3, NO_2, NH_3), and two 1L bottles for ChlA analysis. Volunteer's following P2+ChlA filtering were also provided with a 5L jug to combine the two 1L ChlA bottles, as well as a ChlA filtering kit. ChlA filters were frozen prior to shipment.

Methods

Profile measurements for DO and temperature were first taken at 0.1m and then 0.5m, then every meter starting at 1m, until lake bottom. Grab samples filling the G2-Preserved, isotope, phytoplankton, G2-F, routine, and ChlA bottles were collected just below the surface of the ice, at around 0.1m depth. Environmental observations, such as site bottom depth, ice thickness, snow depth, air temperature, ice colour, water colour, and the presence of particles in the water were recorded on the field sheets. GPS coordinates of the sampling site were also recorded.

P1 samples were returned to ALMS within about one or two weeks, P2 samples were returned within 24hrs, and P2+ChlA filtering samples were returned within 3 days. ALMS coordinated delivery of samples to the analytical laboratories. In some cases, volunteers delivered samples directly to analytical laboratories. ALMS also coordinated the delivery of sampling kits to the volunteers throughout the season.

Volunteers collecting data from Chestermere Lake, December 2021

Data collected from the sites were compiled then formatted for upload to the Gordon Foundation's DataStream (https://gordonfoundation.ca/initiatives/datastream/), and for ALMS data visualization and reporting. Data analysis is done using the program R.[1] Data was reconfigured using packages tidyr [2] and dplyr [3], figures were produced using the package ggplot2 [4], and tables were produced using the package formattable [5]. Trophic status for each lake is classified based on lake water characteristics using values from Nurnberg (1996)[6]. The level of hypoxia used to calculate percent water column hypoxia is based on Alberta's chronic dissolved oxygen guideline for aquatic life [7], and The Canadian Council for Ministers of the Environment (CCME) guidelines for the protection of aquatic life in cold water for life stages other than early life stages.[8] Heat map style figures were produced for lakes with multiple sampling events, to further investigate seasonal trends in lake temperature and dissolved oxygen. Tables containing hypoxia data are found in the Appendix. A summary of the sensor array from Pigeon Lake is also found in the appendix.

[1] R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
[2] Wickman, H. and Henry, L. (2017). tidyr: Easily Tidy Data with 'spread ( )' and 'gather ( )' Functions. R package version 0.7.2. https://CRAN.R-project.org/package=tidyr.
[3] Wickman, H., Francois, R., Henry, L. and Muller, K. (2017). dplyr: A Grammar of Data Manipulation. R package version 0.7.4. http://CRAN.R-project.org/package=dplyr.
[4] Wickham, H. (2009). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.
[5] Ren, K. and Russell, K. (2016). formattable: Create 'Formattable' Data Structures. R package version 0.2.0.1. https://CRAN.R-project.org/package=formattable.
[6] Nurnberg, G.K. (1996). Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake and Reservoir Management 12: 432-447.
[7] Shaw, J. (1997). Alberta water quality guideline for the protection of freshwater aquatic life: Dissolved oxygen. Standards and Guidelines Branch, Alberta Environmental Protection, Edmonton, Alberta.
[8] Canadian Council of Ministers of the Environment (1999). Canadian water quality guidelines for the protection of aquatic life: Dissolved oxygen (freshwater). Canadian environmental quality guidelines, Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

Results

Volunteers from the Wabamun Watershed Management Council walking from a sampling site on Wabamun Lake, January 2022

A wide diversity of winter lake water chemistry and environmental observations were captured through the Winter LakeKeepers 2021-2022 season. The overall findings build nuance into the major findings from the previous seasons.

The data from winter 2019-2020 and 2020-2021 seasons pointed to the overall trend that dissolved oxygen (DO) decreases from the beginning of the winter season towards the end (late March), but that a few lakes display more dynamic DO levels, and begin to increase again later in the season. In 2021-2022, less lakes displayed late season increases in DO, which could be a result of high amounts of snow remaining on the lakes in March, limiting DO production by phytoplankton. While some lakes displayed little or no hypoxia, others had significant hypoxia which could lead to stressful conditions for fish (Appendix Tables 1a – 1g).

Trends with water temperature data were more variable, however the majority of lakes with sampling events spread throughout the winter were warmer toward the end of the season, compared to the beginning. This trend was most obvious for Beauvais and Chestermere which are situated towards the south of the province, as well at Pigeon Lake which was sampled as late as April 20th. Some deeper lakes in the north of the province (Calling, Lesser Slave, Skeleton North) were the exception, and displayed much more stable seasonal temperature levels (Figures 15 and 19).

A wide variety of nutrient and other water chemistry parameters existed across all lakes, and most interestingly, the variety is similar to what is observed in the summer. On a seasonal basis, parameters such as Cl, DOC, and conductivity appeared stable throughout the winter while nutrients appeared more dynamic. Interestingly, some lakes displayed dynamic seasonal pH levels. Nutrient and water chemistry data is explored further in the Results sections below.

2021-2022 was the first Winter LakeKeepers season to provide chlorophyll-*a* data (ChlA; which indicate the abundance of algae and cyanobacteria) for some lakes, along with additional nutrient parameters such as nitrate, nitrite, and ammonia. It is very informative to see ChlA levels at lakes during the winter, where algae are usually considered to be dormant and not able to grow like the summer. ChlA data from winter 2021-2022 indicates some lakes support levels of algae considered to be hypereutrophic or very high, comparable to levels in summer months (Hastings, Byers, PL17, Cooking, Skeleton North, Chickakoo, Half Moon, Ministik; Figure 4).

Results

Phosphorus and nitrogen are essential nutrients for the growth of algae, cyanobacteria, and aquatic plants, and are often the most limiting nutrients for growth. High levels can indicate the lake is situated in naturally high nutrient soils, but also indicate potential nutrient pollution from the lake's watershed. Total phosphorus (TP) is used most commonly to assess levels of phosphorus, and categorize the lake based on productivity (trophic class). Total Kjeldahl nitrogen (TKN) is also used commonly to assess levels of total lake nitrogen, and to categorize the lake based on productivity (trophic class). TKN and TP levels in lakes from Winter LakeKeepers 2021-2022 indicate a wide range of values, similar to the range of values from the summer (Figures 1, 2).

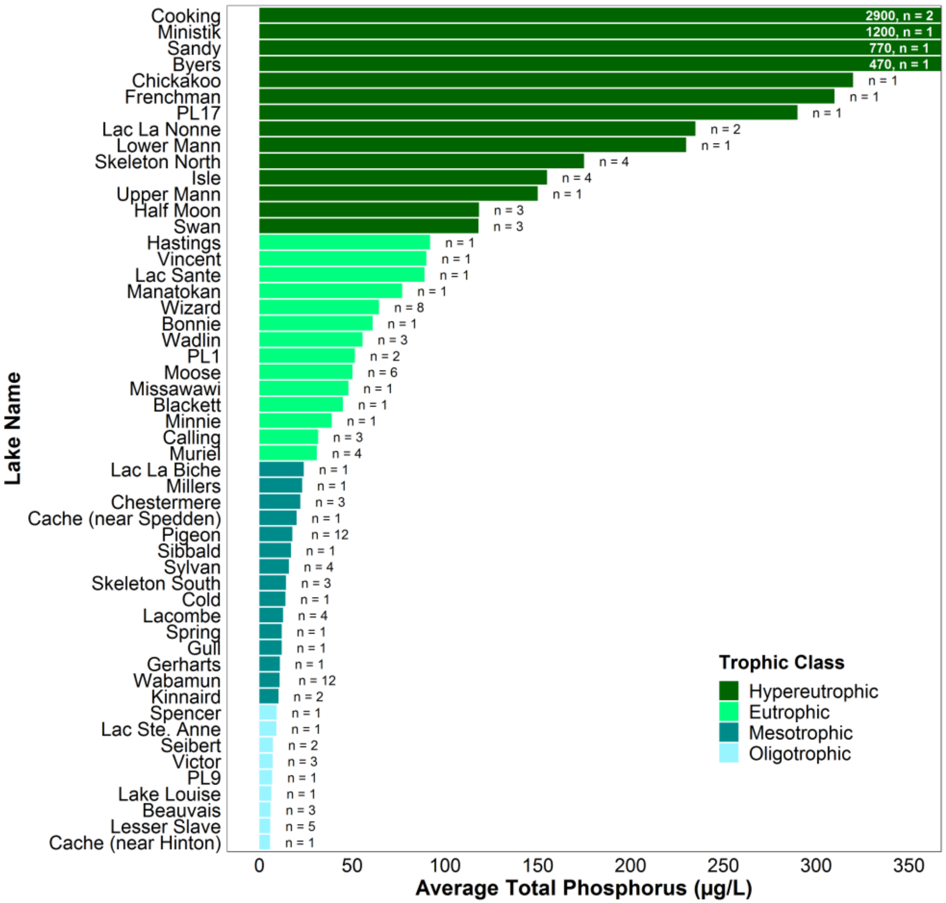


Figure 1. Average total phosphorus (µg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average total phosphorus represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

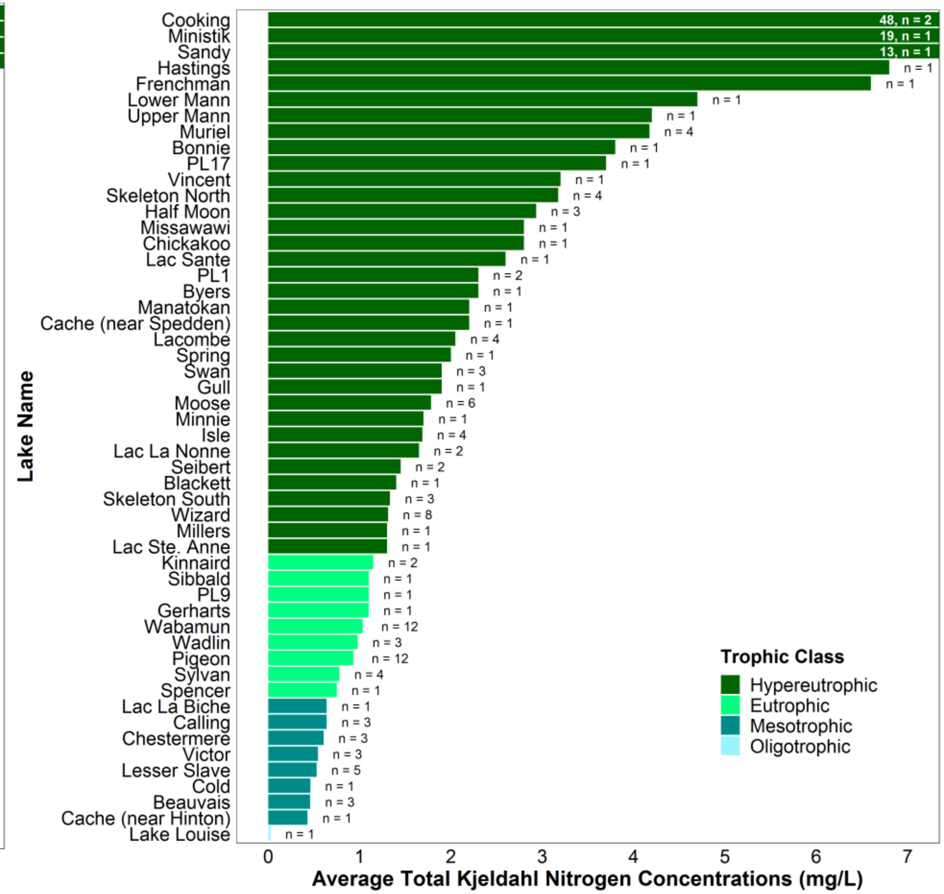


Figure 2. Average total Kjeldahl nitrogen from lakes sampled in Winter LakeKeepers 2021-2022. Average total Kjeldahl nitrogen represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

Results

Representing nutrient levels as ratios can describe the extent of nitrogen vs. phosphorus limitation. TKN:TP ratios indicate that most lakes are phosphorus limited (TKN:TP > 50, Figure 3), and only a few lakes (Lake Louise, Byers Lake, Lac La Nonne) may be nitrogen limited (TKN:TP < 20), although these ratios must be interpreted in the context of TKN and TP concentrations.[9] Chlorophyll-*a* is an indicator of the amount of algae and cyanobacteria within lakes. Average chlorophyll-*a* levels from winter 2021-2022 indicate many lakes have significant growth of algae and cyanobacteria in the winter months, however a higher proportion have very low (oligotrophic) levels (Figure4).

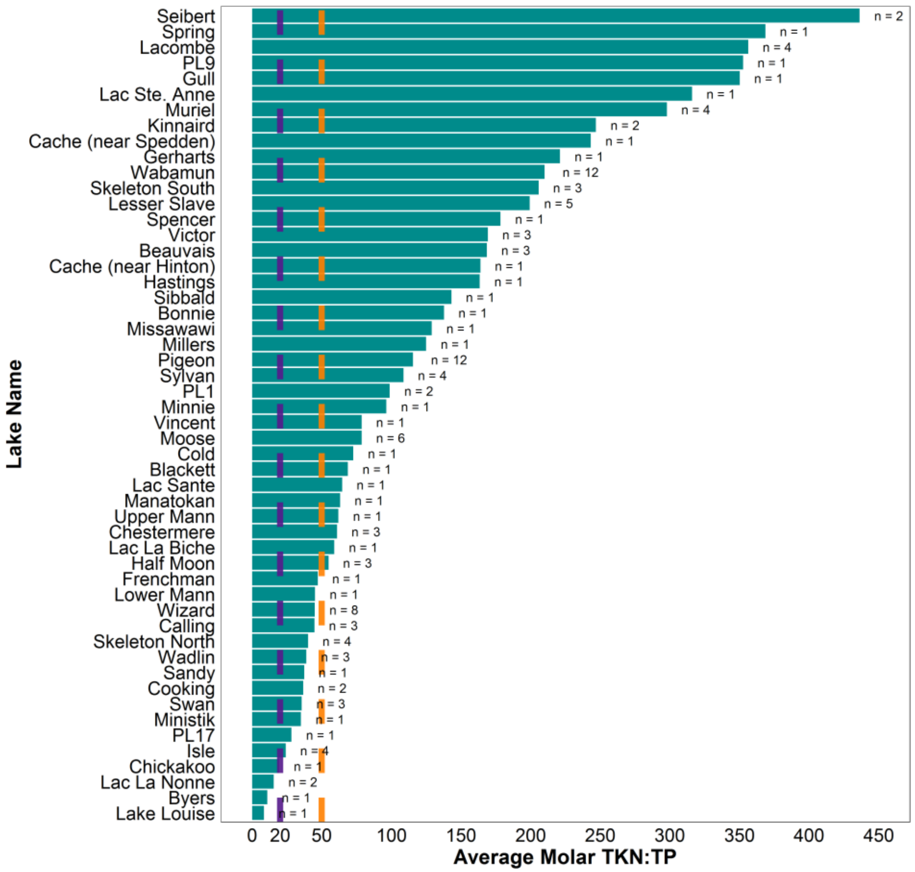


Figure 3. Average total Kjeldahl nitrogen (TKN) to average total phosphorus (TP) molar ratio from lakes sampled in Winter LakeKeepers 2021-2022. Average TKN:TP represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Ratio of 20 is indicated by a purple dashed line, and 50 by orange dashed line, as per P and N limitation cut-offs in Guildford and Hecky, 2000.

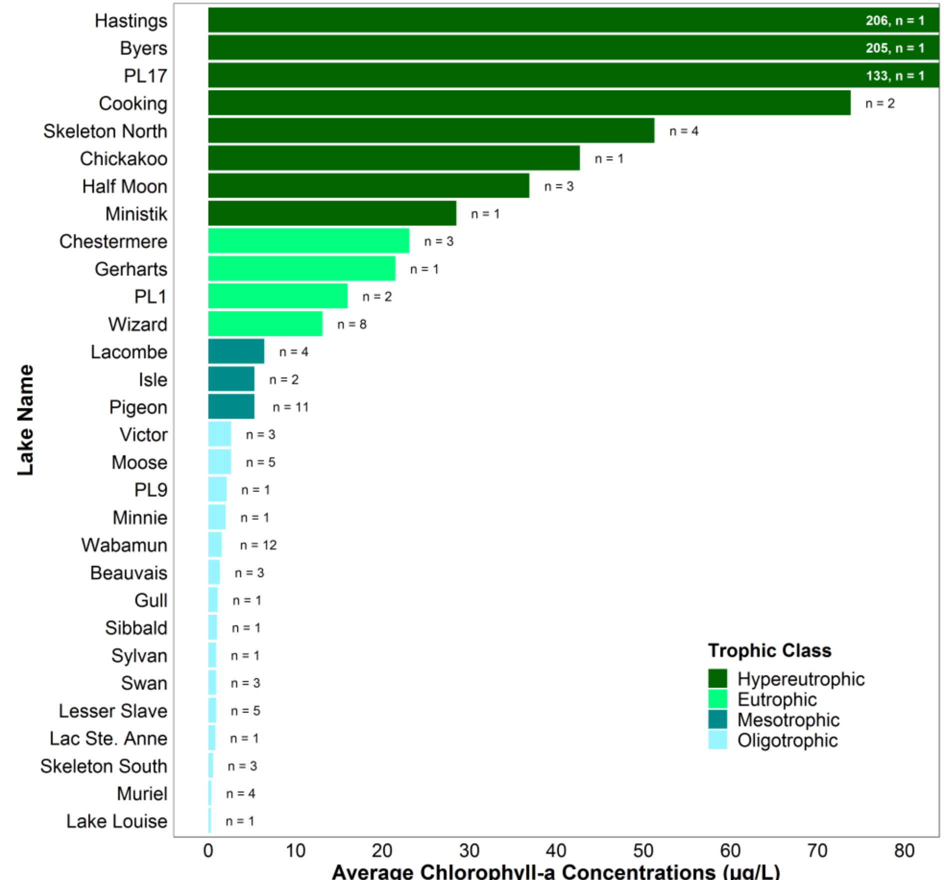


Figure 4. Average Chlorophyll-*a* (µg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average Chlorophyll-*a* represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and April 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

[9] Guildford, S. J., and R. E. Hecky (2000). Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? Limnology and Oceanography 45(6), 1213-1223.

Results

Total dissolved phosphorus (TDP) indicates the portion of the total phosphorus that is more biologically available. Generally, the distribution of TDP in lakes sampled in winter 2021-2022 is similar to their distribution of TP values (Figure 5). Representing nutrient levels as ratios can help describe the extent of the proportion of phosphorus which is dissolved (TDP:TP), indicating extent of biological uptake. A wide range of TDP:TP ratios existed for the lakes, with many lakes nearing 1:1 TDP:TP (Figure 6). Interestingly, low TDP:TP were observed in lakes with both high chlorophyll-*a* levels (PL17, Byers, Skeleton North Lake, Hastings, Half Moon) and low chlorophyll-*a levels* (Lake Louise, Victor, Sylvan). Low TDP:TP ratios in lakes with high chlorophyll-*a* may be a result of high biological uptake of nutrients.

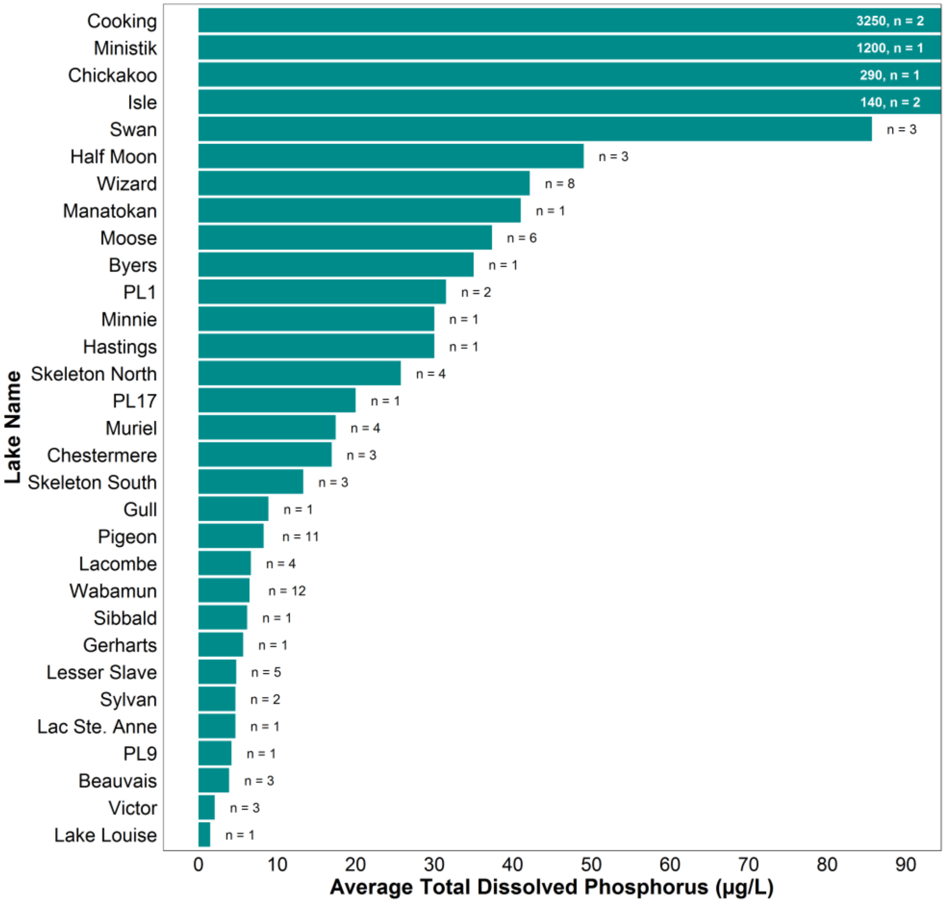


Figure 5. Average total dissolved phosphorus (µg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average total dissolved phosphorus represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022.

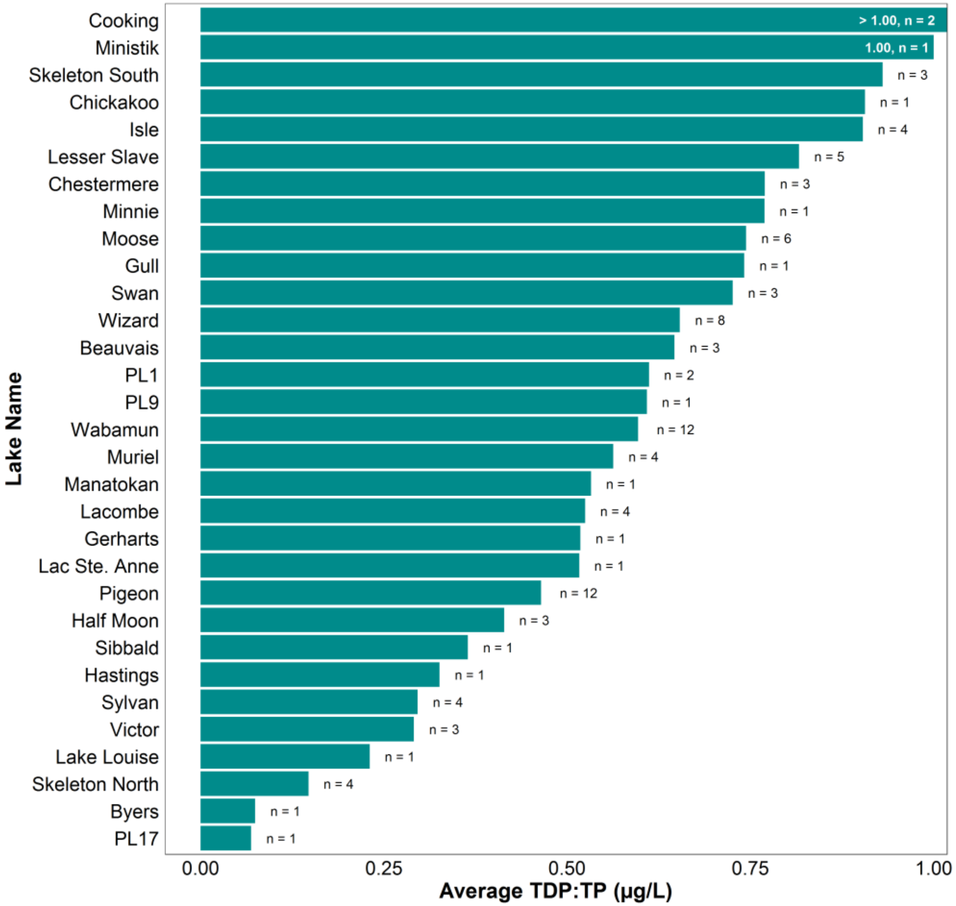


Figure 6. Average total dissolved phosphorus (TDP) to average total phosphorus (TP) ratio (µg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average TDP:TP represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Note: ratio >1 indicates laboratory anomaly of TDP > TP which may occur for extremely high phosphorus levels.

Results

LakeKeepers

Nitrate and Nitrite (NO3+NO2) and ammonia are more biologically available forms of nitrogen. High levels within the winter months can be a result of degradation of algae, cyanobacteria, and aquatic plants that grew in the summer months. High levels of ammonia can be toxic to fish and other organisms, but the level of toxicity is dependant on temperature and pH – the lower the temperature and the lower the pH, the less toxic.[10] Average NO3+NO2 levels from lakes sampled in winter 2021-2022 demonstrate a range of concentrations, and levels of ammonia are generally higher than levels of NO3+NO2 (Figures 7, 8). Interestingly, lakes with very high levels of ammonia (Cooking, Ministik) have vey low NO3+NO2.

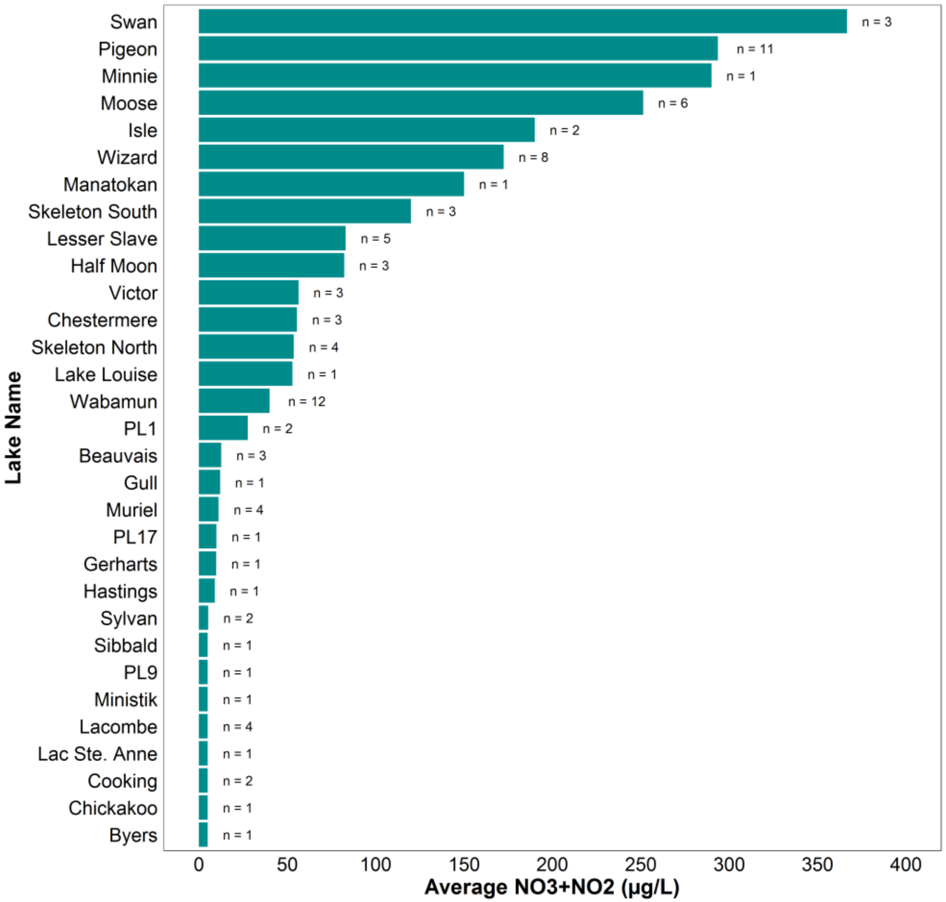


Figure 7. Average sum of nitrate and nitrite (NO3+NO2) (µg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average sum of NO3+NO2 represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022.

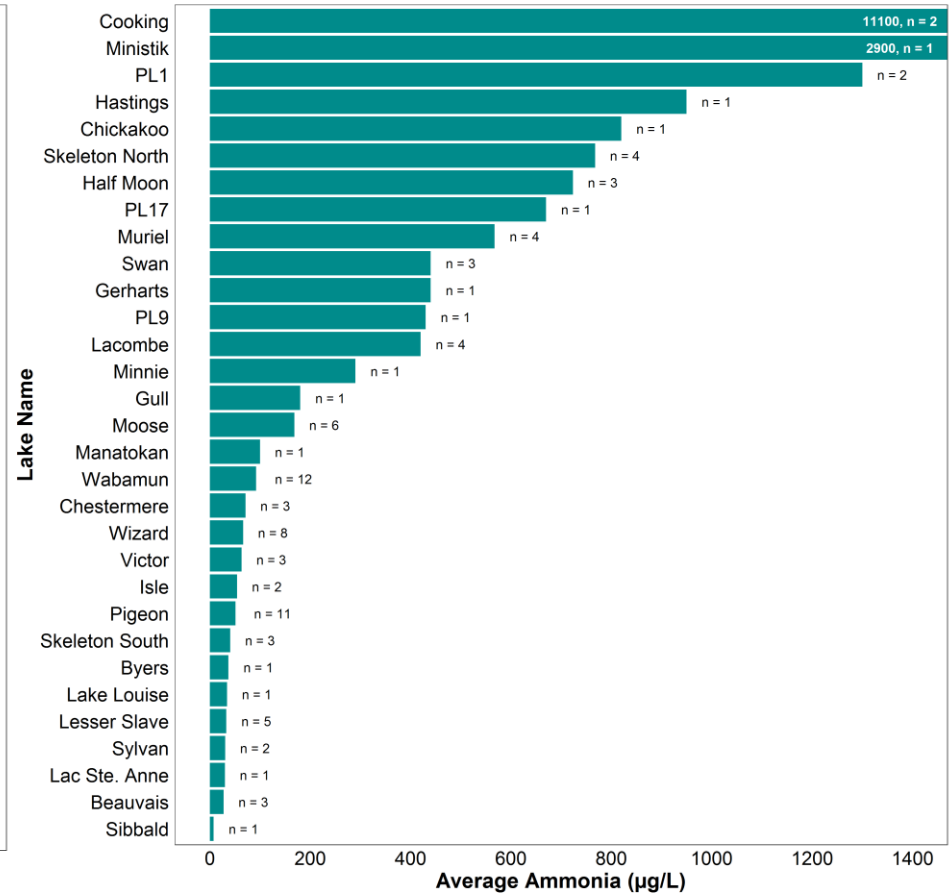


Figure 8. Average ammonia(µg/L) from lakes sampled in Winter LakeKeepers 2020 - 2021. Average ammonia represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

[10] Canadian Council of Ministers of the Environment (CCME). 2010. Canadian water quality guidelines for the protection of aquatic life: Ammonia. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Results

Dissolved organic carbon (DOC) is an important source of energy for microorganisms, is part of a lake's carbon cycle, and can impact light penetration. Levels measured from lakes in the winter of 2021-2022 indicate a wide range of values, from as low as below detection limit (<0.5 mg/L, given a value of 0.25 mg/L for Figure 9) at Lake Louise, to as high as 385 mg/L at Cooking (Figure 9). Chloride (Cl) is a salt which at high levels can negatively impact lake organisms. It can vary in lakes due to groundwater connectivity, watershed geology, lake surface area, as well as pollution from road salts. It can concentrate in lakes through the winter due to ice formation. Levels in lakes sampled in winter 2021-2022 had a range from 0.5 – 375 mg/L (Figure 10). Lake Louise had a level below detection limit of 1.0 mg/L, so a value of 0.5 mg/L was used for Figure 10.

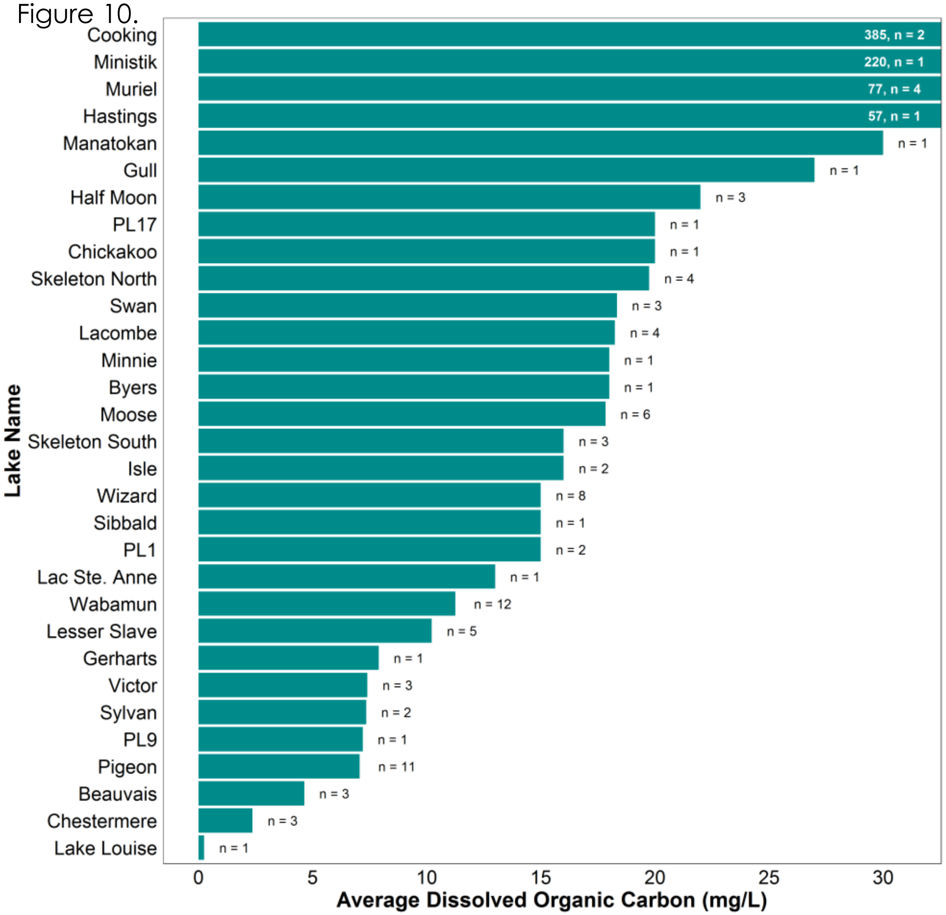


Figure 9. Average dissolved organic carbon (mg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average dissolved organic carbon represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

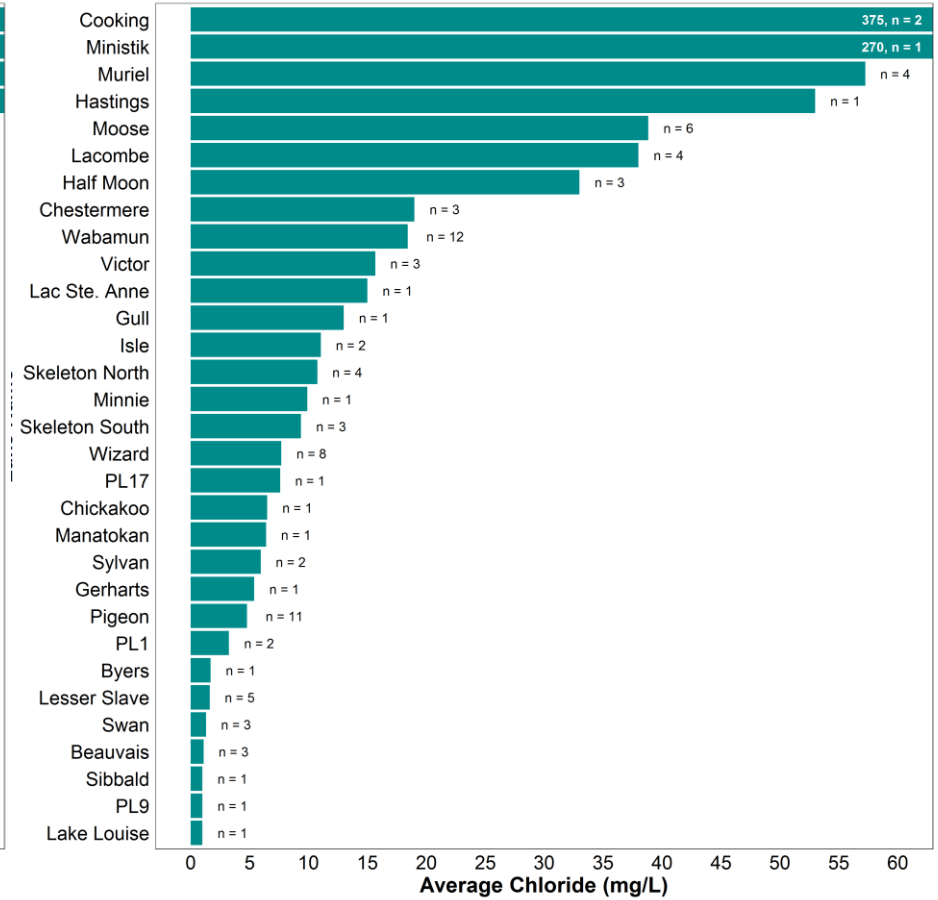


Figure 10. Average chloride (mg/L) from lakes sampled in Winter LakeKeepers 2021-2022. Average chloride represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

Results

Conductivity indicates the total levels of dissolved ions or salt within water, which can impact aquatic habitat for lake organisms, and can vary in lakes due to groundwater connectivity, watershed geology, lake surface area, as well as pollution from watershed runoff. It can concentrate in lakes through the winter due to ice formation. Levels in lakes from Winter LakeKeepers 2021-2022 had a range from 71 – 9650 µS/cm (Figure 11). pH is used to understand the acidity of water, and is important for evaluating fish habitat and general lake chemistry. Levels in lakes from Winter LakeKeepers 2021-2022 had a range from 7.3 – 9.0 (Figure 12).

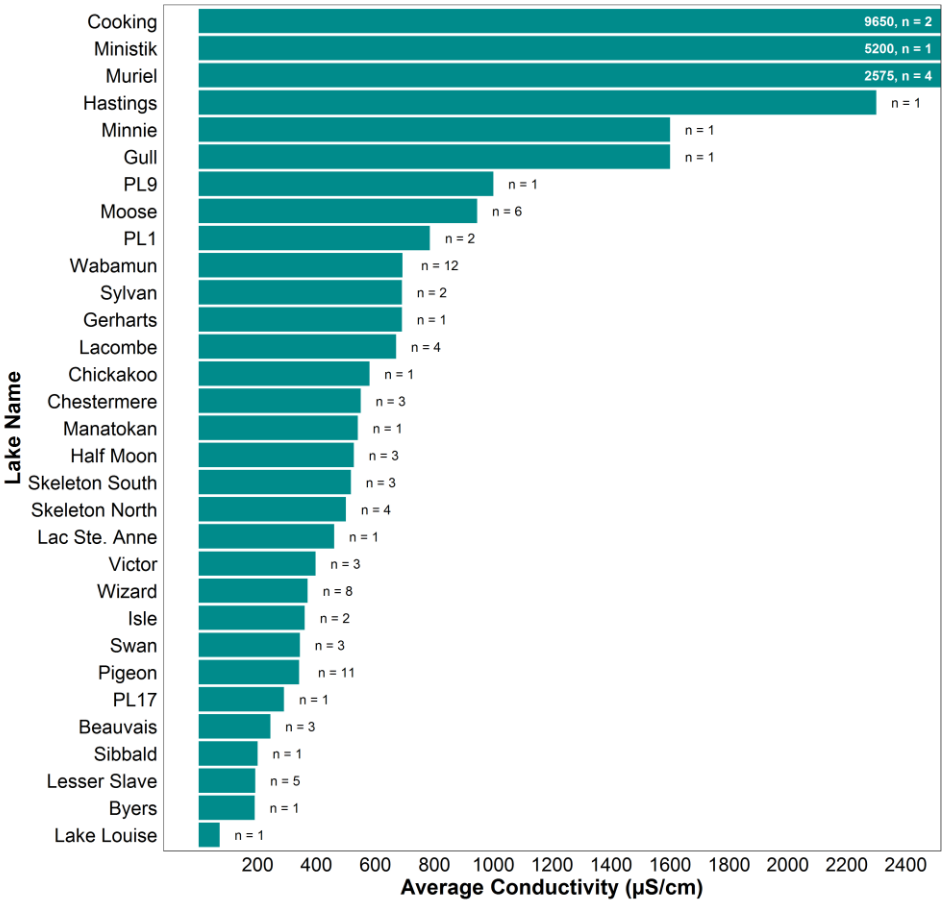


Figure 11. Average conductivity (µS/cm) from lakes sampled in Winter LakeKeepers 2021-2022. Average conductivity represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022. Extreme outliers on the upper range (>3*IQR) not fully plotted.

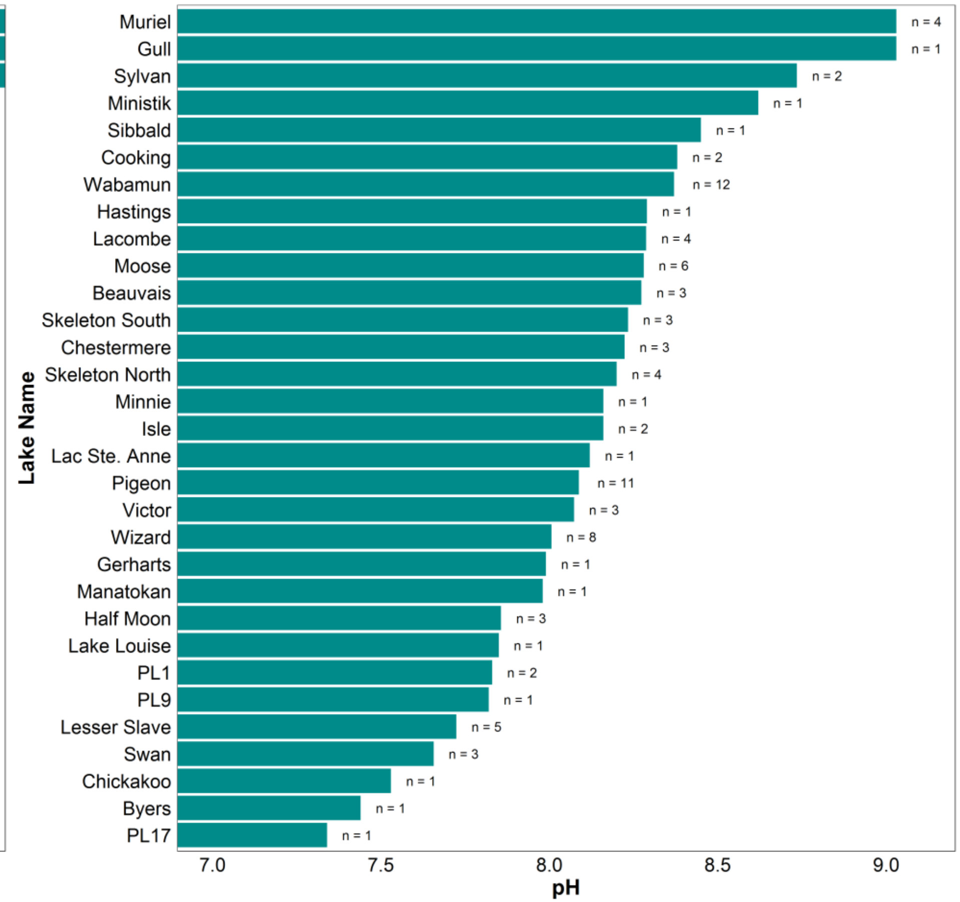
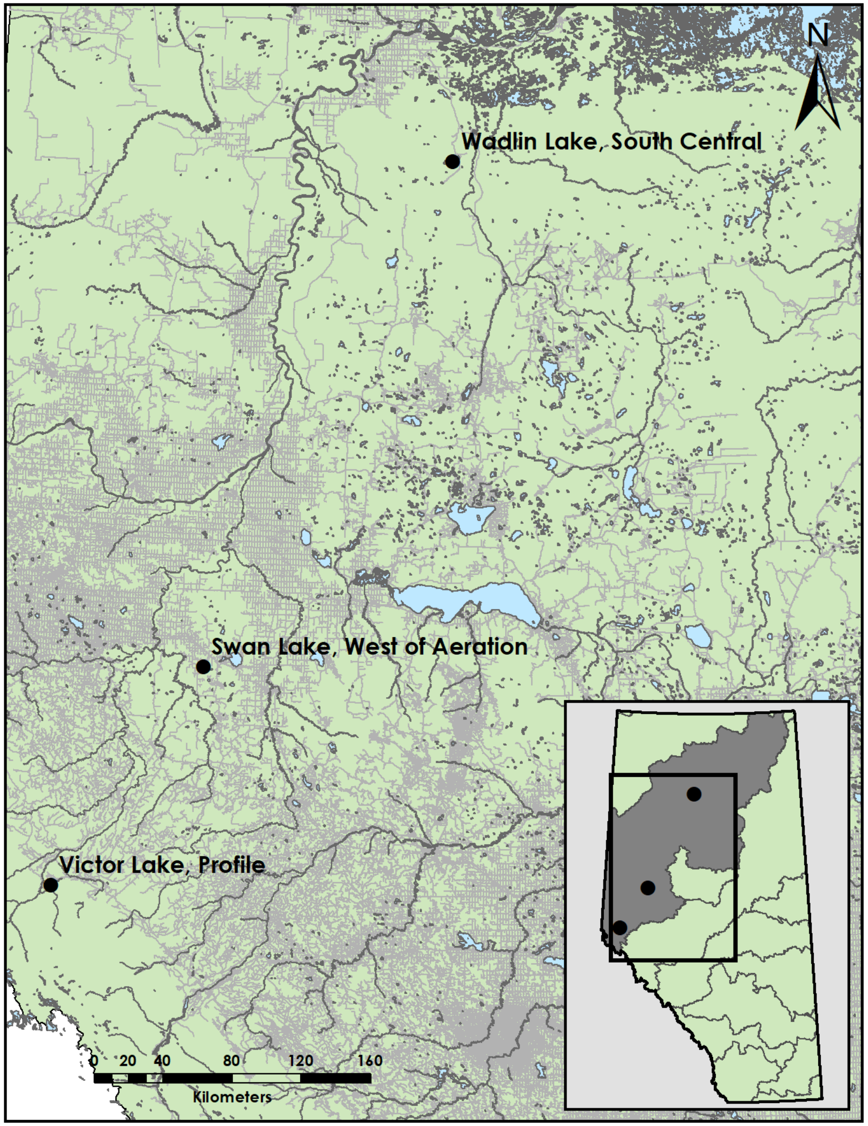


Figure 12. Average pH from lakes sampled in Winter LakeKeepers 2021-2022. Average pH represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2021 and May 2022.

Peace River Watershed

Three lakes were sampled within the Peace River watershed in Winter LakeKeepers 2021-2022. All three lakes, Wadlin, Swan, and Victor, were sampled three times through the winter , once each in January, February, and March. Temperature profiles are available only for Swan and Victor, and were not recorded at Wadlin due to instrument issues. The temperature profiles indicate that Swan remained at a consistent temperature across the season, while Victor warmed up from the January to March sampling events (Figure 13). All three of the lakes displayed decreasing levels of dissolved oxygen from their January to February sampling events. Every depth at Swan has relatively low levels, while the surface waters of Wadlin and Victor remained at a reasonably high level of dissolved oxygen. Nutrient levels were low for Victor, moderate for Wadlin, and high for Swan (Table 1a). Swan and Victor were sampled through the P2 protocol, and thus have more water quality information. Interestingly, Victor had consistently higher levels of chlorophyll-*a* (ChlA) than Swan, indicating more algae growth. Swan had higher levels of nitrate and nitrite (NO3+NO2) as well as ammonia, indicating elevated degradation of organic material through the winter months. Wadlin had the deepest snow levels measured across all sampling events in the Peace River watershed, having 30cm of snow cover for both the January and February sampling events (Table 1b). Wadlin also had the thickest ice recording, at 107cm during the March sampling event.



Map 2. Sampling locations for Winter LakeKeepers 2021-2022, in the Peace River watershed. Peace River watershed highlighted in Alberta inset map.

Peace River Watershed

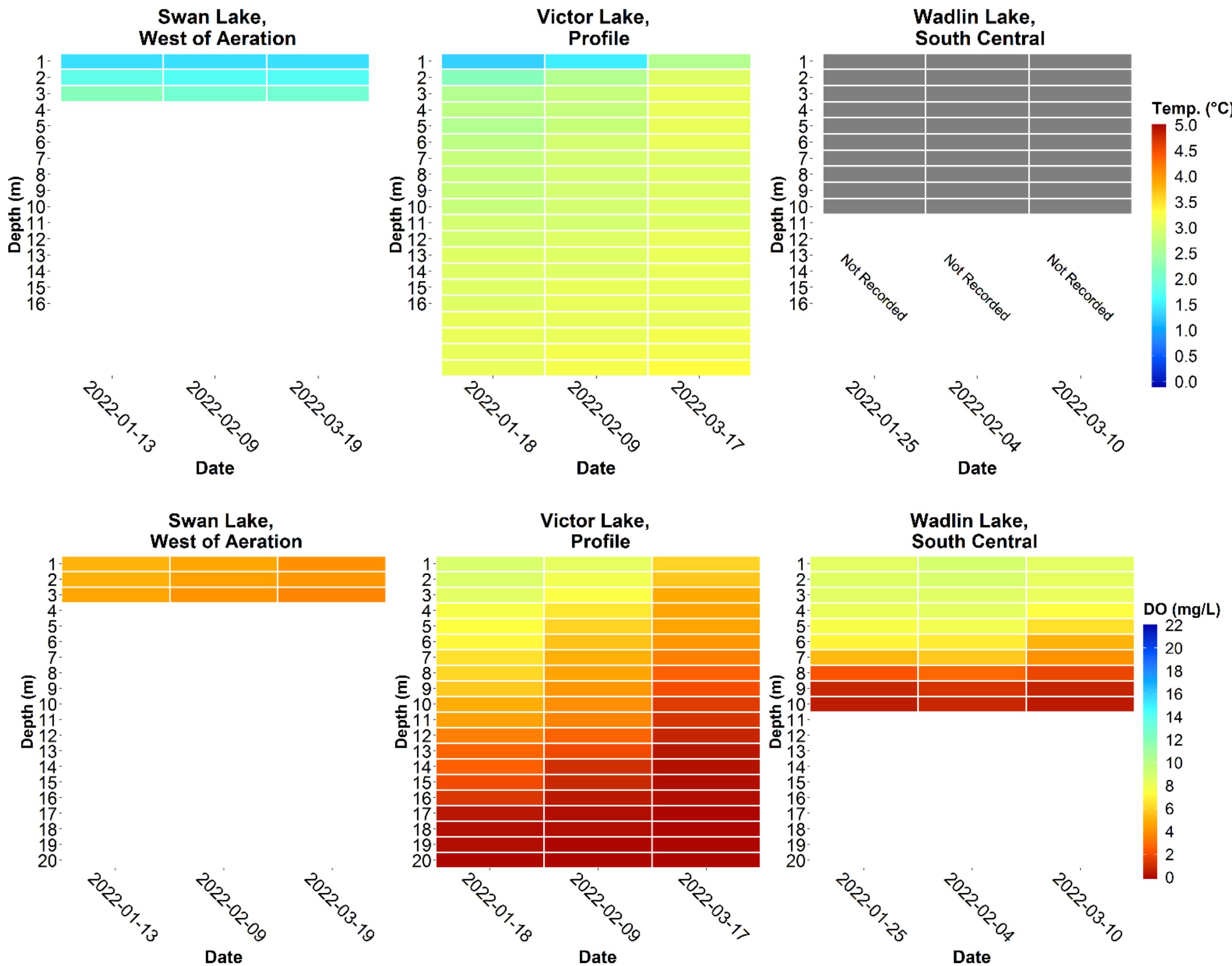


Figure 13. Heat maps of temperature (Temp.; °C) and dissolved oxygen (DO; mg/L) measurements recorded at lakes in the Peace River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps. Note: temperature not recorded at Wadlin Lake.

Peace River Watershed

LakeKeepers

Table 1a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Peace River watershed in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

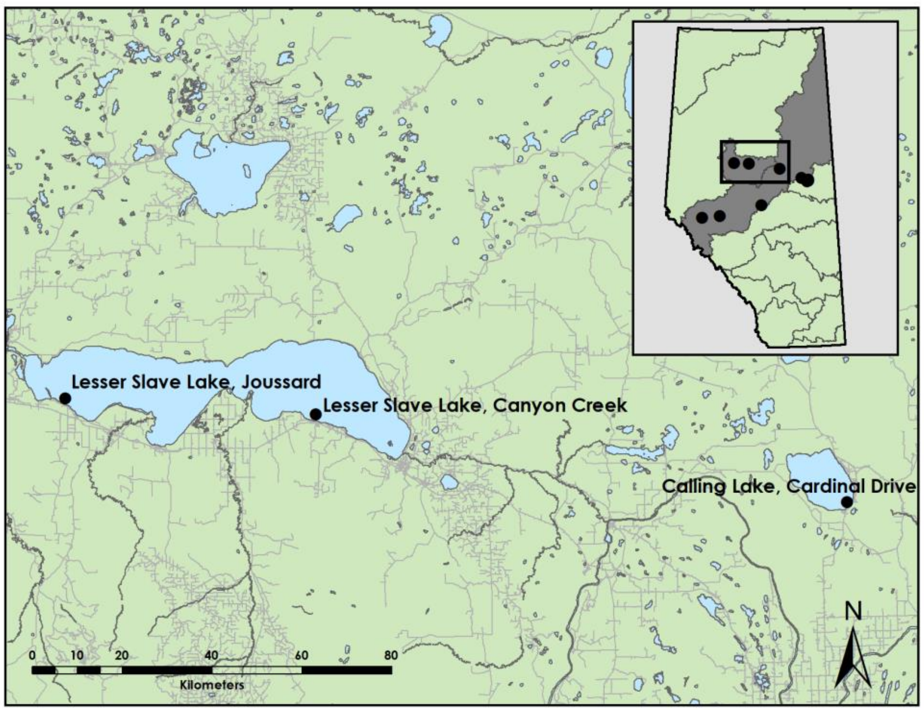
Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Swan Lake, West of Aeration	2022-01-13	2.1	0.7	94.0	85.0	190.0	590.0	20.0	0.5	360	7.66
Swan Lake, West of Aeration	2022-02-09	1.9	1.2	140.0	80.0	240.0	520.0	17.0	1.2	330	7.76
Swan Lake, West of Aeration	2022-03-19	1.7	0.8	120.0	92.0	670.0	210.0	18.0	1.7	340	7.55
Victor Lake, Profile	2022-01-18	0.6	2.7	10.0	3.2	24.0	100.0	7.2	16.0	410	8.05
Victor Lake, Profile	2022-02-09	0.5	1.4	4.4	1.5	49.0	82.0	6.7	15.0	380	8.10
Victor Lake, Profile	2022-03-17	0.6	3.8	6.9	1.5	96.0	7.5	8.3	16.0	400	8.07
Wadlin Lake, South Central	2022-01-25	0.9		35.0							
Wadlin Lake, South Central	2022-02-04	1.0		93.0							
Wadlin Lake, South Central	2022-03-10	1.0		39.0							

Table 1b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Peace River watershed in Winter 2021-2022.

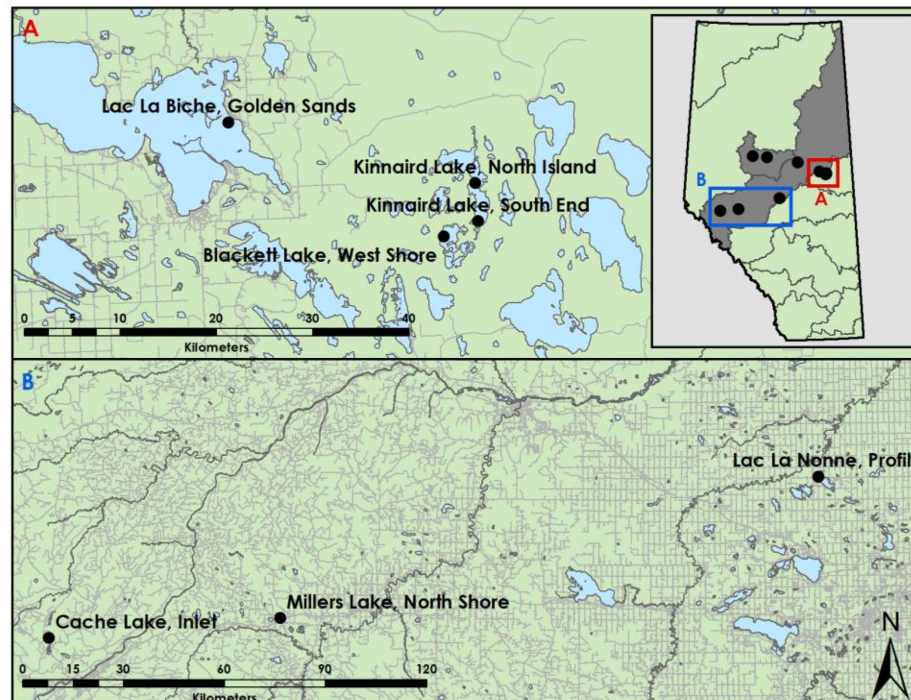
Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Swan Lake, West of Aeration	2022-01-13	-4	18	46	Opaque	Green	No
Swan Lake, West of Aeration	2022-02-09	3	3	48	Clear	Colourless	Yes
Swan Lake, West of Aeration	2022-03-19	-5	0	39	Opaque	Colourless	No
Victor Lake, Profile	2022-01-18	-17	4	56	Clear	Colourless	No
Victor Lake, Profile	2022-02-09	7	0	53	Clear	Colourless	No
Victor Lake, Profile	2022-03-17	0	0	43	Clear	Colourless	No
Wadlin Lake, South Central	2022-01-25	-5	30	61	Opaque	Colourless	No
Wadlin Lake, South Central	2022-02-04	-25	30	91	Clear	Colourless	
Wadlin Lake, South Central	2022-03-10	-20	15	107	Clear	Colourless	No

Athabasca River & Lesser Slave Lake Watersheds

Eight lakes were sampled within the Athabasca River and Lesser Slave Lake watersheds in Winter LakeKeepers 2021-2022 (Maps 3a and 3b), which was the third highest number of any major watershed in Alberta (Map 1). Two lakes, Lesser Slave and Kinnaird, had multiple sampling sites. Temperature and dissolved oxygen profiles of lakes with one sampling event each are displayed in Figure 14, and lakes with multiple sampling events are displayed in Figure 15. Temperature profiles indicate that lakes from the western range of the Athabasca River watershed (Cache, Miller's, Lac La Nonne) were generally warmer than lakes further north and east. For lakes with multiple sampling events, temperature appeared to rise slightly from beginning to end of the sampling season (Figure 15). Oxygen levels were high for all lakes sampled with the exception of Blackett and Lac La Nonne. Nutrient levels varied between lakes in the watershed, with the highest levels at Lac La Nonne, and lowest at both sites of Lesser Slave Lake (Table 2a). Lesser Slave Lake was the only lake to have been sampled through the P2 protocol, and thus has more water quality information. Chlorophyll-*a* levels from Lesser Slave indicates that the lake displayed low levels of algae growth compared to other lakes in the province (Figure 4) as well as low levels of chloride and conductivity compared to other lakes in the province (Figures 10 and 11). Kinnaird Lake had the deepest snow levels measured across all sampling events, having 30cm of snow cover at the 'North Island' site which was sampled in January (Table 2b).



Map 3a. Sampling locations for Winter LakeKeepers 2021-2022, in the Athabasca River watershed. Athabasca River watershed highlighted in Alberta inset map.



Map 3b. Sampling locations for Winter LakeKeepers 2021-2022, in the Athabasca River watershed. Athabasca River watershed highlighted in Alberta inset map.

Athabasca River & Lesser Slave Lake Watersheds

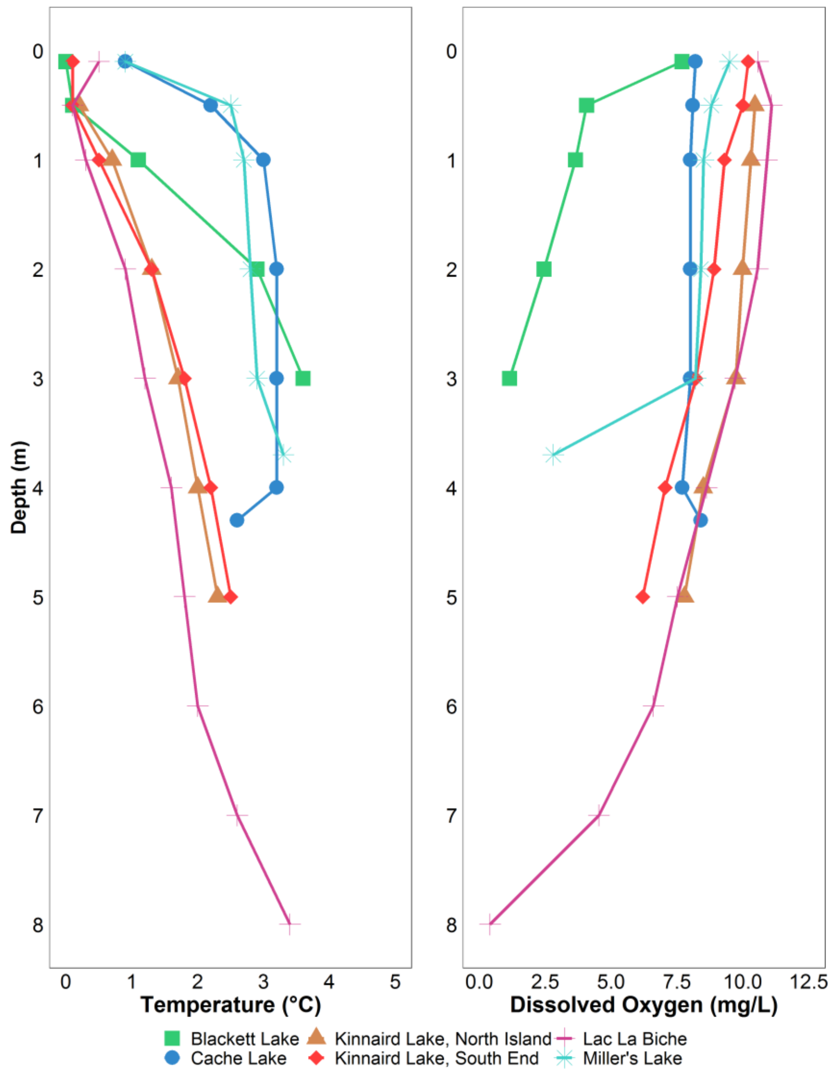


Figure 14. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Blackett, Cache, Kinnaird, Lac La Biche, and Miller's lakes in the Athabasca River and Lesser Slave Lake watersheds in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Sample dates can be found in Tables 2a and 2b.

Athabasca River & Lesser Slave Lake Watersheds

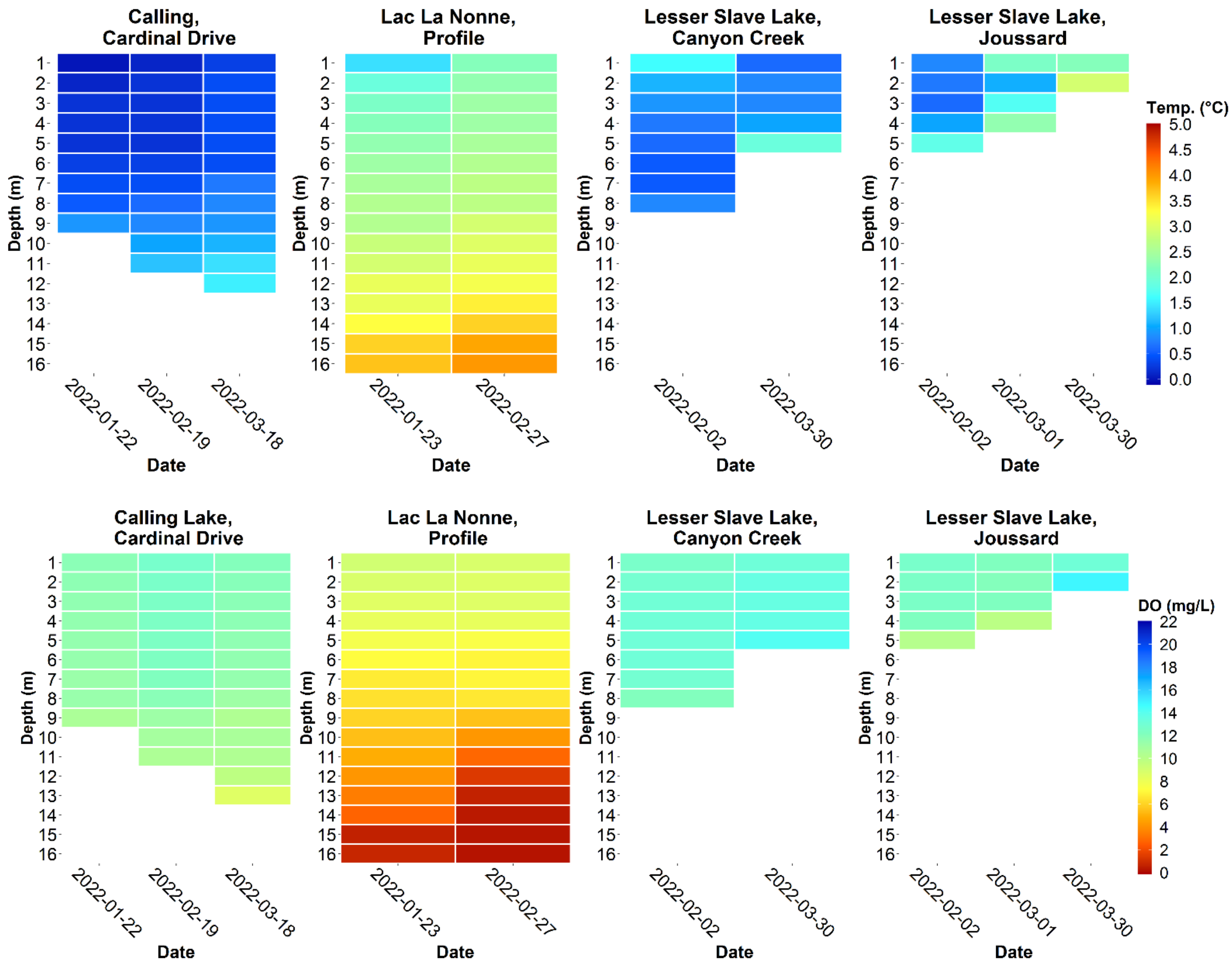


Figure 15. Heat maps of temperature (Temp.; °C) and dissolved oxygen (DO; mg/L) measurements recorded at Calling, Lac La Nonne, and Lesser Slave lakes in the Athabasca River and Lesser Slave Lake watersheds in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

Athabasca River & Lesser Slave Lake Watersheds

LakeKeepers

Table 2a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Athabasca River and Lesser Slave Lake watersheds in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Blackett Lake, West Shore	2022-02-14	1.4		45.0							
Cache Lake, Inlet	2021-12-11	0.4		5.8							
Calling Lake, Cardinal Drive	2022-01-22	0.6		24.0							
Calling Lake, Cardinal Drive	2022-02-19	0.7		36.0							
Calling Lake, Cardinal Drive	2022-03-18	0.6		35.0							
Kinnaird Lake, North Island	2022-01-17	1.1		11.0							
Kinnaird Lake, South End	2022-02-14	1.2		9.6							
Lac La Biche, Golden Sands	2022-03-17	0.6		24.0							
Lac La Nonne, Profile	2022-01-23	1.6		230.0							
Lac La Nonne, Profile	2022-02-27	1.7		240.0							
Lesser Slave Lake, Canyon Creek	2022-02-02	0.4	1.2	5.2	3.9	16.0	30.0	10.0	1.7	200	7.81
Lesser Slave Lake, Canyon Creek	2022-03-30	0.5	0.8	3.2	3.6	33.0	7.5	10.0	1.7	200	7.74
Lesser Slave Lake, Joussard	2022-02-02	0.7	0.6	10.0	6.4	86.0	93.0	12.0	1.7	220	7.45
Lesser Slave Lake, Joussard	2022-03-01	0.6	1.4	7.5	6.5	160.0	7.5	13.0	1.5	220	7.93
Lesser Slave Lake, Joussard	2022-03-30	0.4	0.5	3.5	3.6	120.0	26.0	6.1	1.5	120	7.69
Millers Lake, North Shore	2021-12-12	1.3		23.0							

Athabasca River & Lesser Slave Lake Watersheds

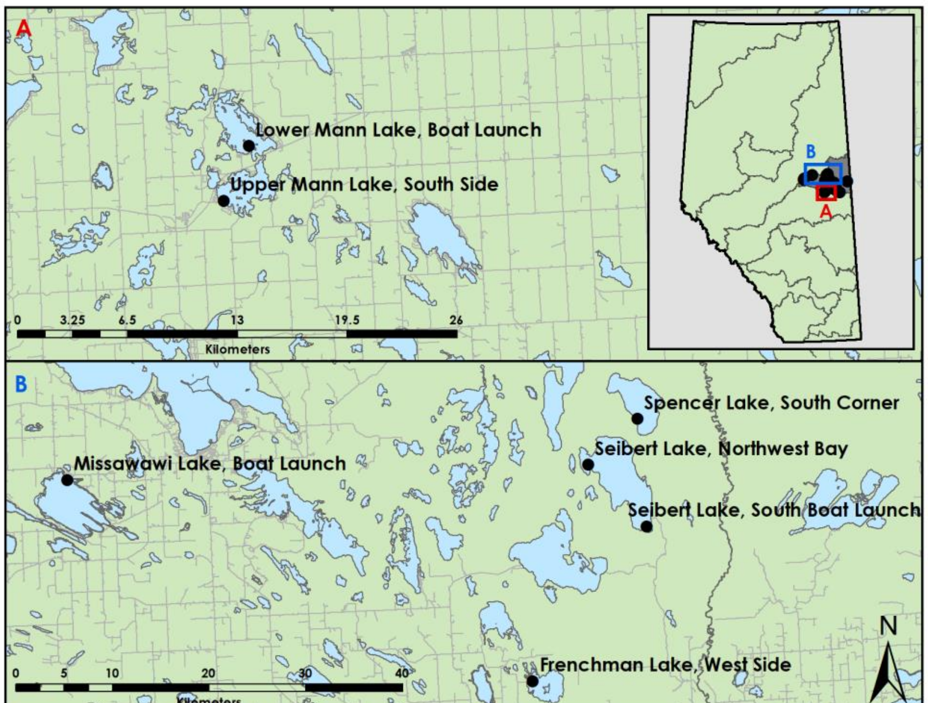
LakeKeepers

Table 2b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Athabasca River and Lesser Slave Lake watersheds in Winter 2021-2022.

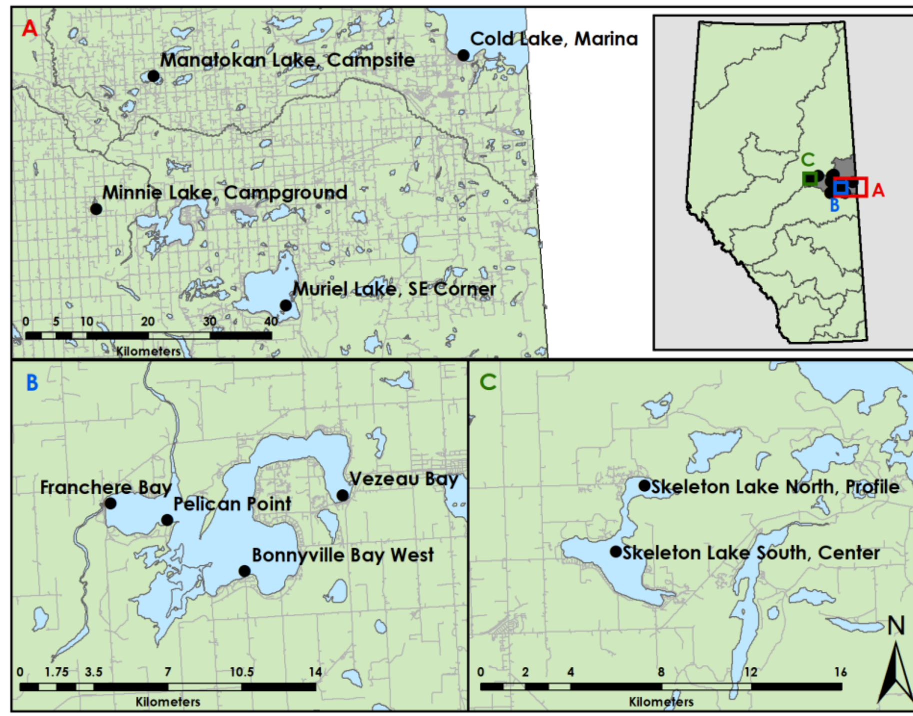
Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Blackett Lake, West Shore	2022-02-14	-8	10	51	Opaque	Colourless	No
Cache Lake, Inlet	2021-12-11	-8	6	30	Clear	Colourless	No
Calling Lake, Cardinal Drive	2022-01-22	-9	23	42	Opaque	Colourless	No
Calling Lake, Cardinal Drive	2022-02-19	-10	8	61	Clear	Colourless	No
Calling Lake, Cardinal Drive	2022-03-18		18	74	Clear	Colourless	No
Kinnaird Lake, North Island	2022-01-17	-3	30	36	Clear	Colourless	No
Kinnaird Lake, South End	2022-02-14	-13	5	51	Opaque	Colourless	No
Lac La Biche, Golden Sands	2022-03-17	10	23	61	Opaque	Colourless	No
Lac La Nonne, Profile	2022-01-23	5	20	36	Clear	Colourless	Yes
Lac La Nonne, Profile	2022-02-27	-7	5	50	Clear	Colourless	No
Lesser Slave Lake, Canyon Creek	2022-02-02	7	5	61	Opaque	Colourless	No
Lesser Slave Lake, Canyon Creek	2022-03-30	3	0		Opaque	Colourless	No
Lesser Slave Lake, Joussard	2022-02-02	9	4	60	Opaque	Colourless	Yes
Lesser Slave Lake, Joussard	2022-03-01	-6	10	68		Colourless	No
Lesser Slave Lake, Joussard	2022-03-30	4		66	Opaque	Colourless	No
Millers Lake, North Shore	2021-12-12	8	3	36	Clear	Colourless	No

Beaver River Watershed

Thirteen lakes were sampled within the Beaver River watershed in Winter LakeKeepers 2021-2022 (Maps 4a and 4b), which is the second highest number of any major watershed in Alberta (Map 1). All lakes except for Skeleton North, Skeleton South, Moose, and Muriel were only sampled once. Moose and Seibert had multiple sample sites. Temperature and dissolved oxygen profiles for Moose Lake are in Figure 16, all lakes sampled once are in Figures 17 and 18, and Muriel, Skeleton North, and Skeleton South are in Figure 19. Generally, for lakes with one sampling event, cooler temperatures through the water column corresponded with higher levels of dissolved oxygen. The multiple site sampling at Moose Lake indicates that the 'Bonnyville Bay West' sample site had slightly higher dissolved oxygen levels than the other three sample sites across the lake. Muriel Lake displayed oxygen depletion from the December to March sampling events, with oxygen essentially absent by the March sampling event. Both Skeleton North and South displayed partial oxygen depletion between December and March sample events, but a portion of the water column still remained above hypoxic (>6.5 mg/L) levels, which was more pronounced in Skeleton South than Skeleton North (Appendix Table 1e). Skeleton North had chlorophyll-*a* (ChlA) levels that were an order of magnitude higher than any other lake sampled in the Beaver River watershed (Tables 3a and 4a), and among the highest of any lake across the province (Figure 4). High levels of nutrients were also present at Skeleton North, along with Frenchman, Moose Vezeau Bay, Upper Mann, and Lower Mann. Cold Lake, Skeleton South, Seibert, and Spencer had among the lowest nutrient levels of lakes sampled in the watershed. At Muriel, nutrient levels, along with conductivity, chloride, and ammonia, increased from December to March.



Map 4a. Sampling locations for Winter LakeKeepers 2021-2022, in the Beaver River watershed. Beaver River watershed highlighted in Alberta inset map.



Map 4b. Sampling locations for Winter LakeKeepers 2021-2022, in the Beaver River watershed. Beaver River watershed highlighted in Alberta inset map, and sampling locations for Moose Lake in panel 'B.'

Beaver River Watershed

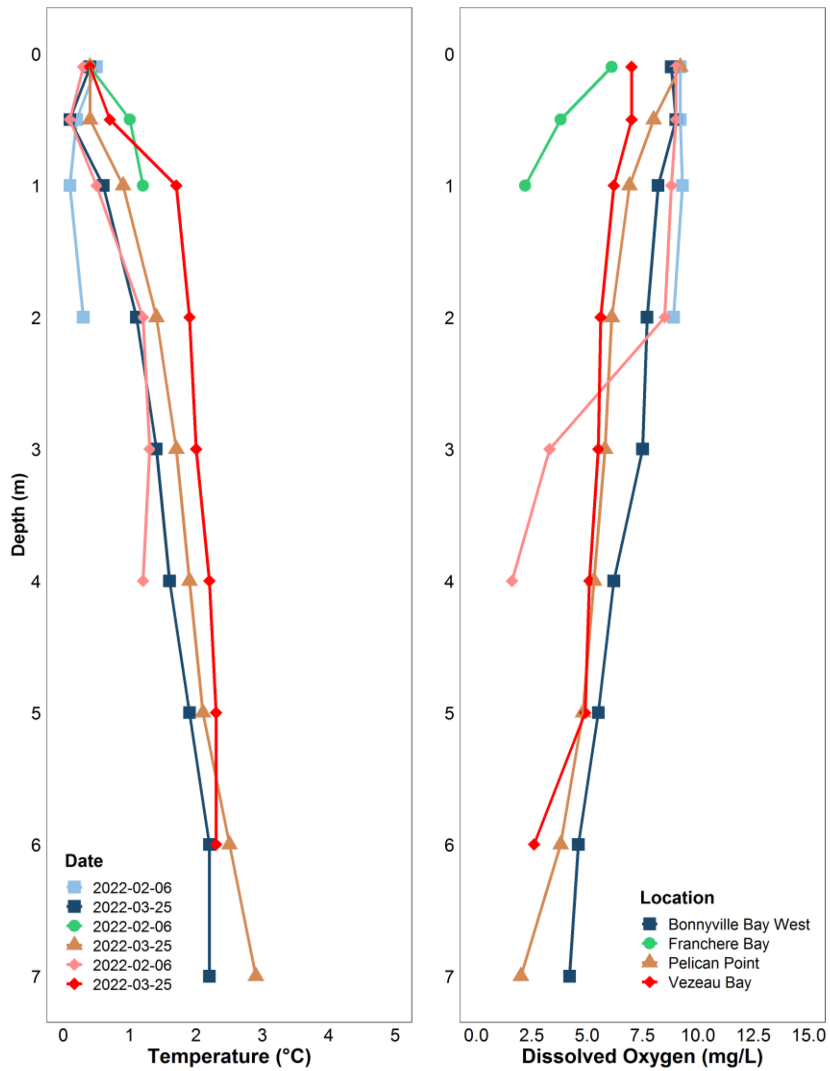


Figure 16. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Moose Lake in the Beaver River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Beaver River Watershed

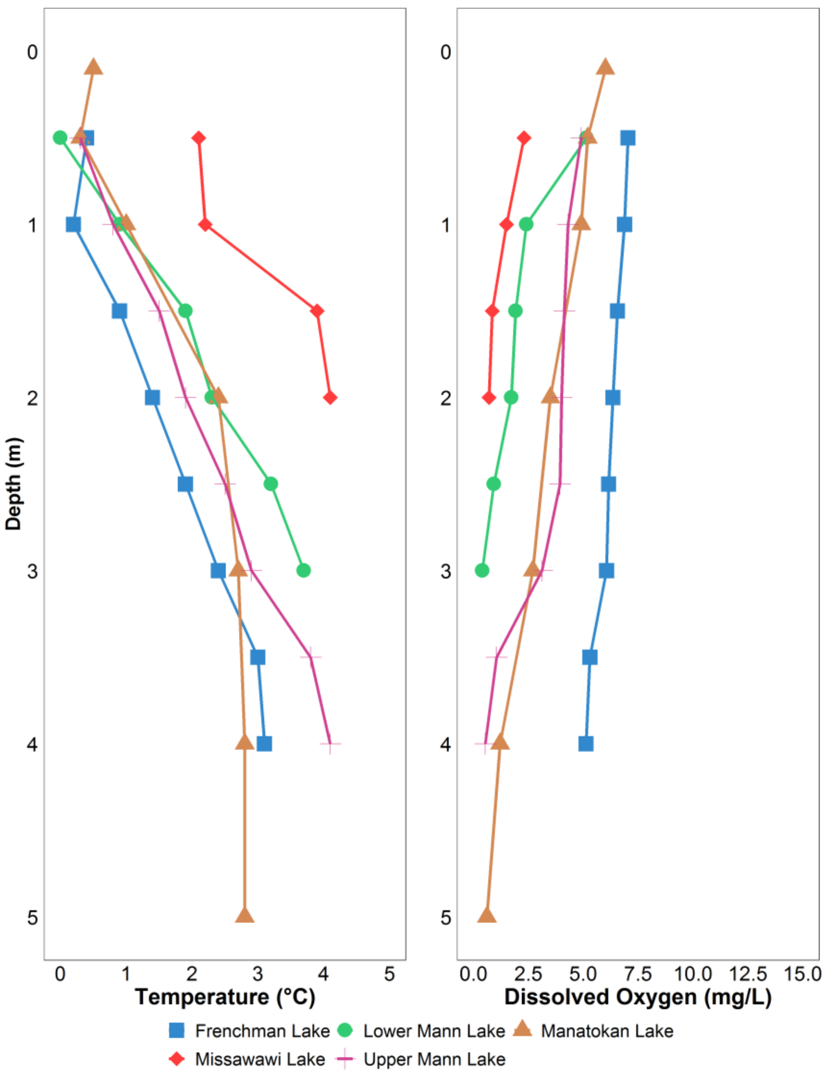


Figure 17. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Frenchman, Lower Mann, Manatokan, Missawawi, and Upper Mann lakes in the Beaver River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Sample dates can be found in Tables 3a, 3b, 4a, and 4b.

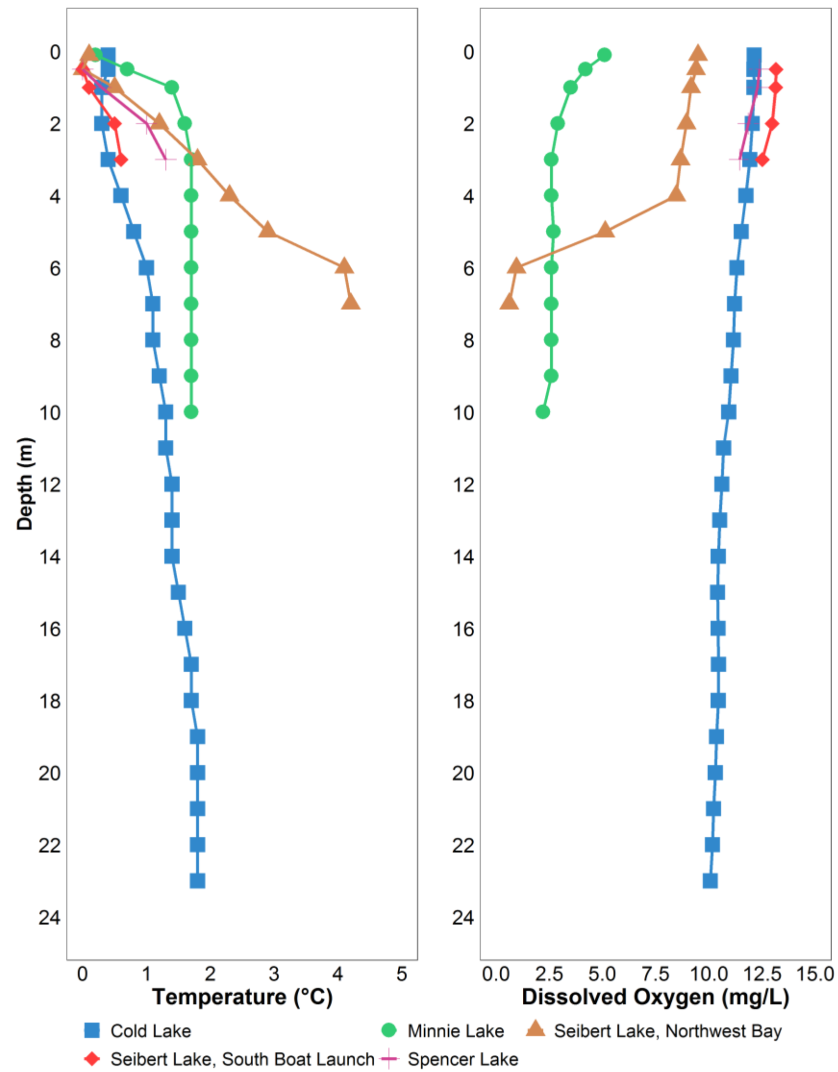


Figure 18. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Cold, Minnie, Seibert, and Spencer lakes in the Beaver River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Sample dates can be found in Tables 3a, 3b, 4a, and 4b.

Beaver River Watershed

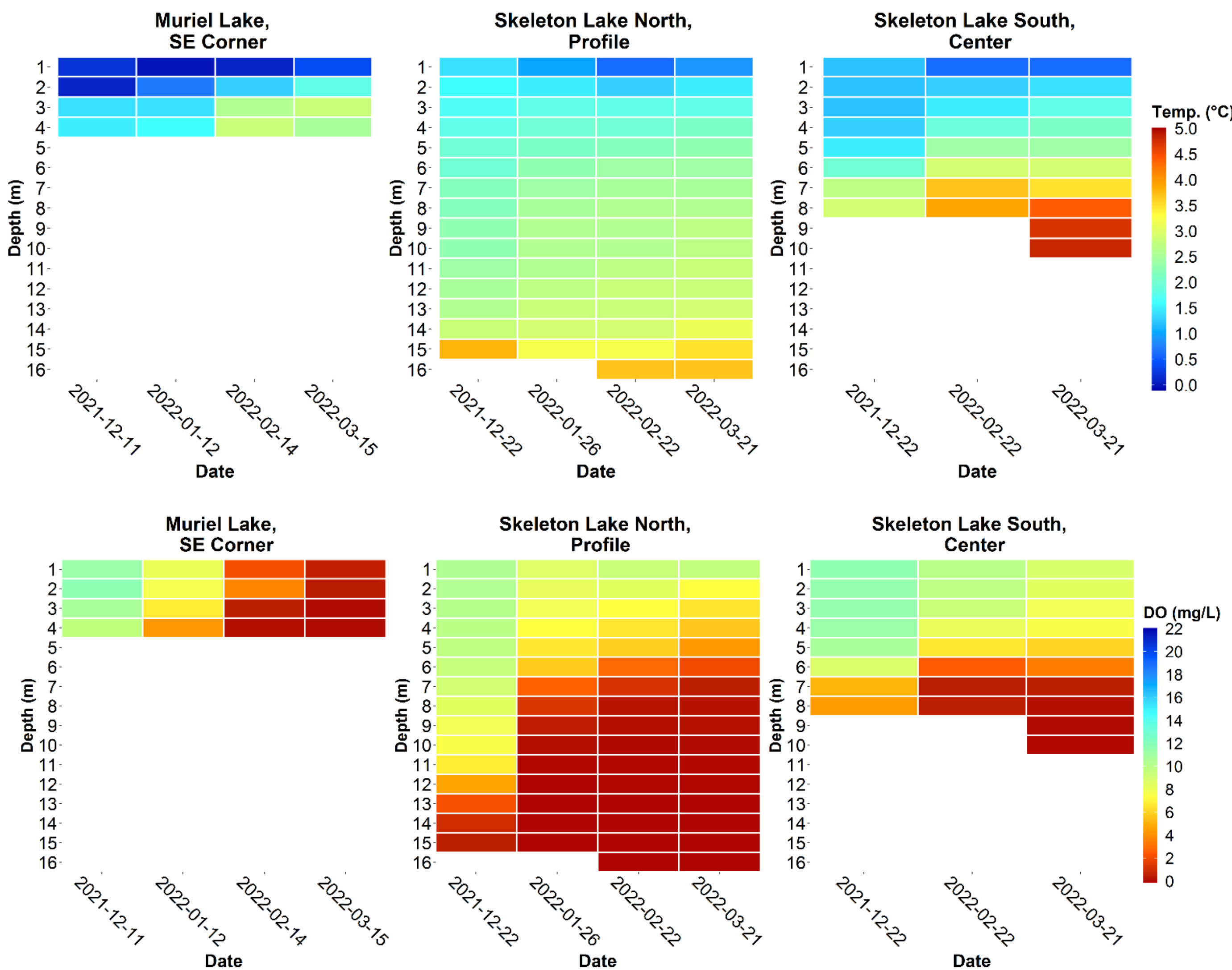


Figure 19. Heat maps of temperature (Temp.; °C) and dissolved oxygen (DO; mg/L) measurements recorded at Muriel Lake, Skeleton Lake North, and Skeleton Lake South in the Beaver River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

Beaver River Watershed

Table 3a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Beaver River watershed in Winter 2021-2022. All samples taken at approximately 0.1 m depth (1 of 2 water chemistry tables for lakes in the Beaver River watershed).

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Cold Lake, Marina	2022-02-03	0.5		14.0							
Frenchman Lake, West Side	2022-01-24	6.6		310.0							
Lower Mann Lake, Boat Launch	2022-01-27	4.7		230.0							
Manatokan Lake, Campsite	2022-02-06	2.2		77.0	41.0	150.0	100.0	30.0	6.4	540	7.98
Minnie Lake, Campground	2022-03-25	1.7	2.0	39.0	30.0	290.0	290.0	18.0	9.9	1600	8.16
Missawawi Lake, Boat Launch	2022-01-24	2.8		48.0							
Moose Lake, Bonnyville Bay West	2022-02-06	1.9		30.0	22.0	98.0	230.0	18.0	41.0	1000	8.32
Moose Lake, Bonnyville Bay West	2022-03-25	1.5	2.2	20.0	15.0	300.0	110.0	16.0	29.0	780	8.30
Moose Lake, Franchere Bay	2022-02-06	1.7	2.3	46.0	37.0	180.0	220.0	19.0	42.0	1100	8.23
Moose Lake, Pelican Point	2022-03-25	1.9	1.8	45.0	30.0	510.0	110.0	18.0	34.0	920	8.19
Moose Lake, Vezeau Bay	2022-02-06	1.9	4.3	40.0	35.0	110.0	210.0	19.0	40.0	1000	8.38
Moose Lake, Vezeau Bay	2022-03-25	1.8	2.5	120.0	85.0	310.0	130.0	17.0	47.0	870	8.26
Muriel Lake, SE Corner	2021-12-11	3.6	0.9	25.0	14.0	5.0	350.0	53.0	54.0	2400	9.06
Muriel Lake, SE Corner	2022-01-12	4.0	0.1	29.0	9.8	19.0	450.0	64.0	57.0	2600	9.00
Muriel Lake, SE Corner	2022-02-14	4.3	0.1	30.0	23.0	14.0	620.0	60.0	58.0	2600	9.05
Muriel Lake, SE Corner	2022-03-15	4.8	0.1	40.0	23.0	6.7	850.0	130.0	60.0	2700	9.01

Beaver River Watershed

Table 3b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Beaver River watershed in Winter 2021-2022 (1 of 2 environmental measurement tables for lakes in the Beaver River watershed).

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Cold Lake, Marina	2022-02-03	-28	25	47	Clear		No
Frenchman Lake, West Side	2022-01-24	-8	38	51	Clear	Colourless	No
Lower Mann Lake, Boat Launch	2022-01-27	-2	41	53	Opaque	Colourless	No
Manatokan Lake, Campsite	2022-02-06	3	36	61	Opaque	Colourless	No
Minnie Lake, Campground	2022-03-25	-6	5	79	Clear	Colourless	No
Missawawi Lake, Boat Launch	2022-01-24	-5	18	30	Opaque	Brown	No
Moose Lake, Bonnyville Bay West	2022-02-06	3	25	61	Clear	Colourless	No
Moose Lake, Bonnyville Bay West	2022-03-25	-6	9	81	Clear	Colourless	No
Moose Lake, Franchere Bay	2022-02-06	3	20	61	Clear		No
Moose Lake, Pelican Point	2022-03-25	-6	5	81	Clear	Colourless	No
Moose Lake, Vezeau Bay	2022-02-06	3	25	61	Clear	Colourless	No
Moose Lake, Vezeau Bay	2022-03-25	-6	5	76	Clear	Brown	No
Muriel Lake, SE Corner	2021-12-11	-2	2	45	Clear	Colourless	No
Muriel Lake, SE Corner	2022-01-12	3	15	60	Opaque	Colourless	No
Muriel Lake, SE Corner	2022-02-14	-7	15	84	Opaque	Colourless	No
Muriel Lake, SE Corner	2022-03-15	-5	20	94	Opaque	Colourless	No

Beaver River Watershed

LakeKeepers

Table 4a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Beaver River watershed in Winter 2021-2022. All samples taken at approximately 0.1 m depth (2 of 2 water chemistry tables for lakes in the Beaver River watershed).

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Seibert Lake, Northwest Bay	2022-03-22	1.5		8.6							
Seibert Lake, South Boat Launch	2022-01-16	1.4		6.1							
Skeleton Lake North, Profile	2021-12-22	2.7	43.9	140.0	24.0	46.0	690.0	20.0	10.0	480	8.13
Skeleton Lake North, Profile	2022-01-26	3.7	80.0	240.0	33.0	48.0	750.0	18.0	11.0	500	8.25
Skeleton Lake North, Profile	2022-02-22	3.3	35.3	160.0	20.0	60.0	810.0	20.0	11.0	510	8.12
Skeleton Lake North, Profile	2022-03-21	3.0	45.9	160.0	26.0	61.0	820.0	21.0	11.0	510	8.30
Skeleton Lake South, Center	2021-12-22	1.2	0.8	14.0	10.0	70.0	76.0	16.0	9.1	490	8.22
Skeleton Lake South, Center	2022-02-22	1.4	0.4	13.0	15.0	140.0	38.0	16.0	9.6	530	8.16
Skeleton Lake South, Center	2022-03-21	1.4	0.4	16.0	15.0	150.0	7.5	16.0	9.4	530	8.32
Spencer Lake, South Corner	2022-01-16	0.8		9.3							
Upper Mann Lake, South Side	2022-01-27	4.2		150.0							

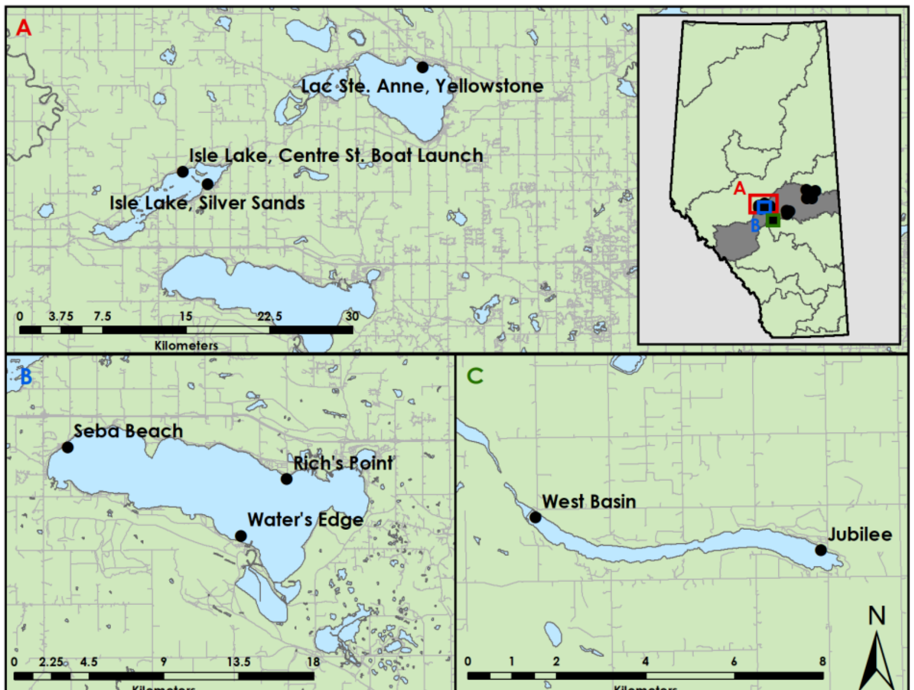
Beaver River Watershed

Table 4b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Beaver River watershed in Winter 2021-2022 (2 of 2 environmental measurement tables for lakes in the Beaver River watershed).

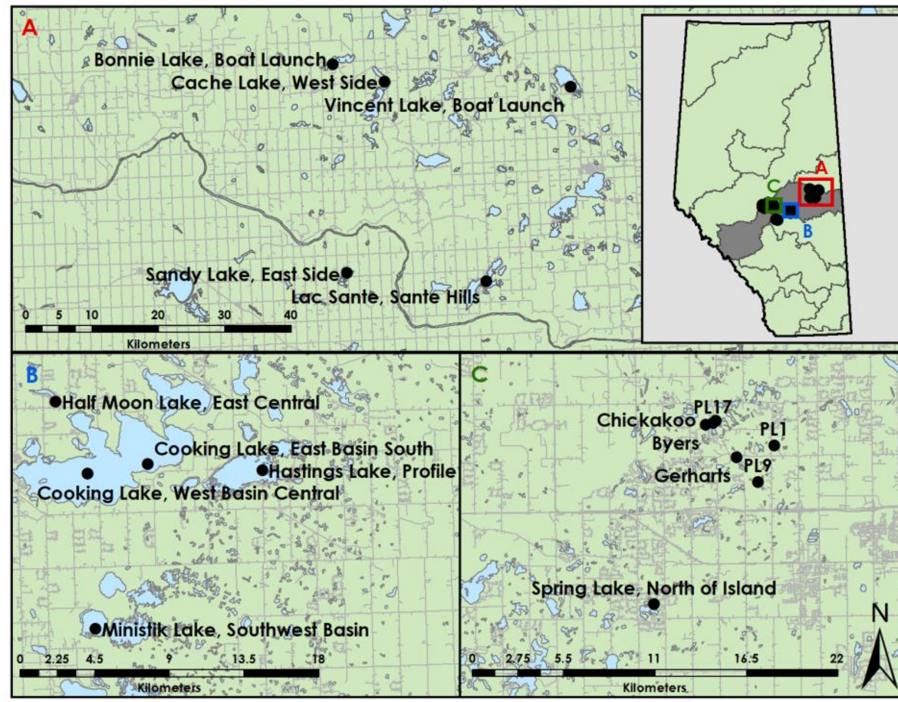
Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Seibert Lake, Northwest Bay	2022-03-22		15	64	Opaque	Colourless	No
Seibert Lake, South Boat Launch	2022-01-16	-1	28	44	Opaque	Colourless	No
Skeleton Lake North, Profile	2021-12-22	-11	15	33	Opaque	Brown	Yes
Skeleton Lake North, Profile	2022-01-26	0	13	56	Opaque	Brown	Yes
Skeleton Lake North, Profile	2022-02-22	-21	6	69	Opaque	Olive green	Yes
Skeleton Lake North, Profile	2022-03-21	0	2	71	Opaque	Colourless	No
Skeleton Lake South, Center	2021-12-22	-11	13	33	Clear	Colourless	No
Skeleton Lake South, Center	2022-02-22	-24	7	66	Opaque	Colourless	No
Skeleton Lake South, Center	2022-03-21	-1	2	72	Opaque	Colourless	No
Spencer Lake, South Corner	2022-01-16	-3	28	36	Clear	Colourless	No
Upper Mann Lake, South Side	2022-01-27	-8	10	41	Clear	Colourless	No

North Saskatchewan River Watershed

Twenty lakes were sampled in the North Saskatchewan River watershed in Winter LakeKeepers 2021-2022 (Maps 5a and 5b), which was the most of any watershed (Map 1). This watershed also had the greatest sampling effort in terms of number of sampling events, and number of lakes with multiple sampling sites. Temperature and dissolved oxygen profiles along with water quality and environmental measurements are split into several figures and tables and are grouped into Wabamun, Wizard, Isle and Lac Ste. Anne, lakes sampled in the Carvel Pitted Delta, lakes sampled in the Beaverhills region, and lakes sampled in the Frog subwatershed. Temperature and dissolved oxygen profiles varied between each lake. At Wabamun and Wizard, only the Seba Beach and Jubilee locations displayed appreciable oxygen depletion through the season (Figures 20 and 21). Lac Ste. Anne had high oxygen levels during its single December sampling event, while Isle saw a decrease from early season to late season sampling events (Figure 22). Lakes sampled in the Carvel Pitted Delta generally had low levels of oxygen, with the exception of Spring, PL9, and Gerharts (Figure 23). All lakes in the Beaverhills region had low levels of dissolved oxygen (Figure 24), and only Lac Sante and Vincent had high levels of dissolved oxygen in the Frog subwatershed (Figure 25). Notably, shallow lakes in the North Saskatchewan River watershed tended to have the highest levels of nutrients, chlorophyll-*a* (ChlA), conductivity, dissolved organic carbon, and chloride (Figures 1, 2, 4, 5, 6, 8, 9, 10, 11).



Map 5a. Sampling locations for Winter LakeKeepers 2021-2022, in the North Saskatchewan River watershed. North Saskatchewan River watershed highlighted in Alberta inset map, and sampling locations for Wabamun Lake in panel 'B,' and in 'C' for Wizard Lake.



Map 5b. Sampling locations for Winter LakeKeepers 2021-2022, in the North Saskatchewan River watershed. North Saskatchewan River watershed highlighted in Alberta inset map. Lakes sampled in the Frog subwatershed in panel 'A,' Beaverhills region lakes in panel 'B',' and cluster of lakes sampled in the Carvel Pitted Delta in panel 'C.'

North Saskatchewan River Watershed

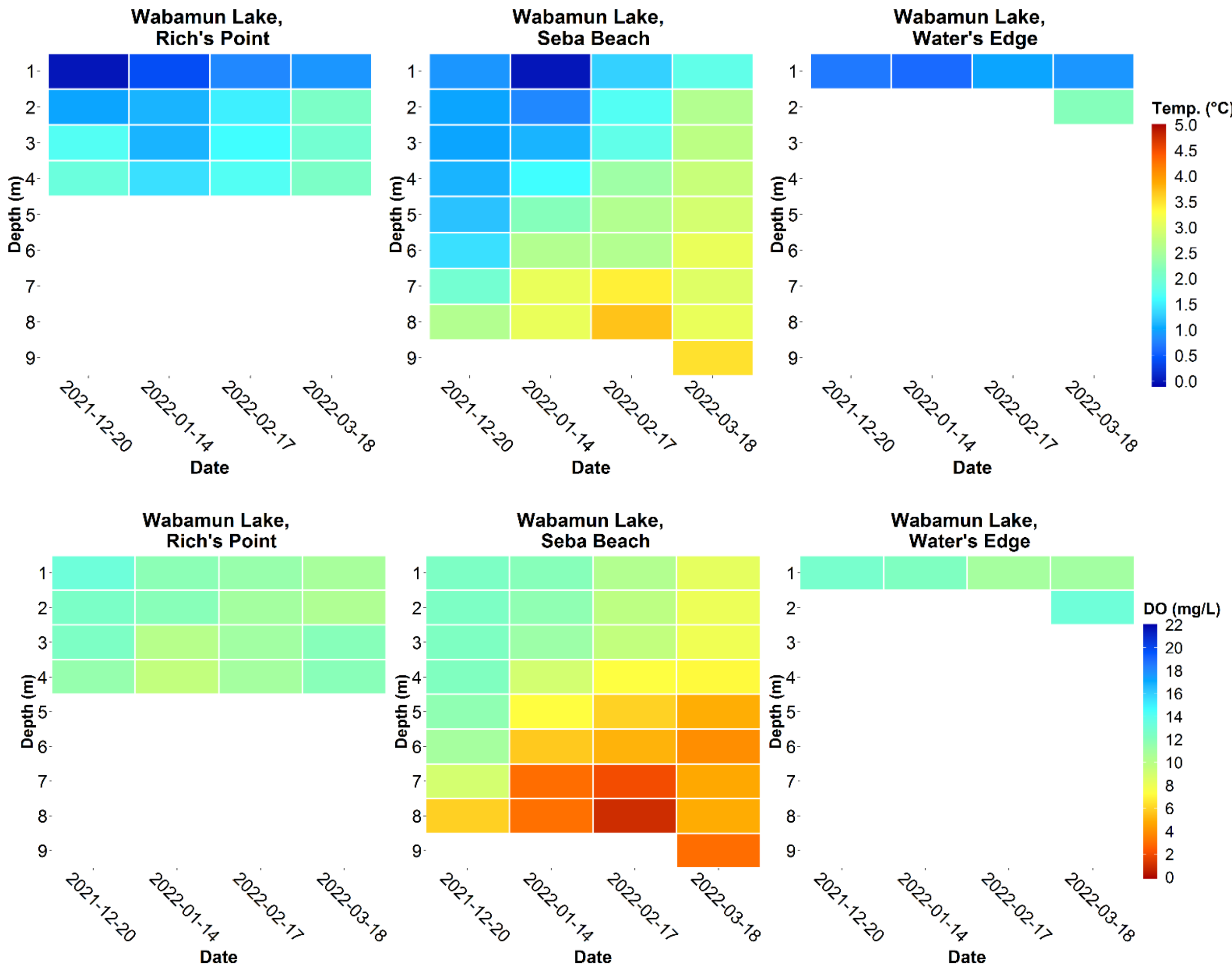


Figure 20. Heat maps of temperature (Temp.; °C) and dissolved oxygen (DO; mg/L) measurements recorded at Wabamun Lake in the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

North Saskatchewan River Watershed

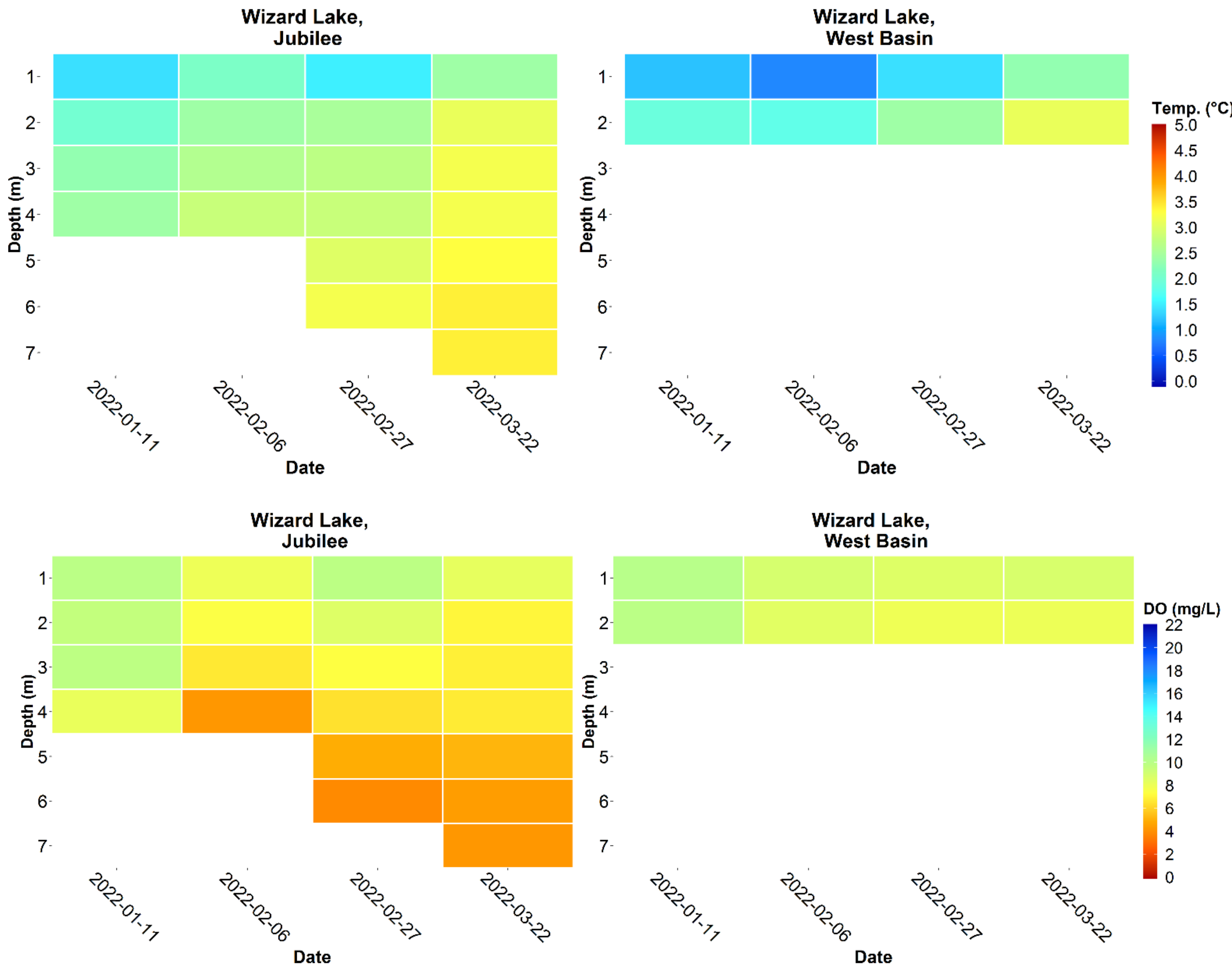


Figure 21. Heat maps of temperature (Temp.; °C) and dissolved oxygen (DO; mg/L) measurements recorded at Wizard Lake in the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

North Saskatchewan River Watershed

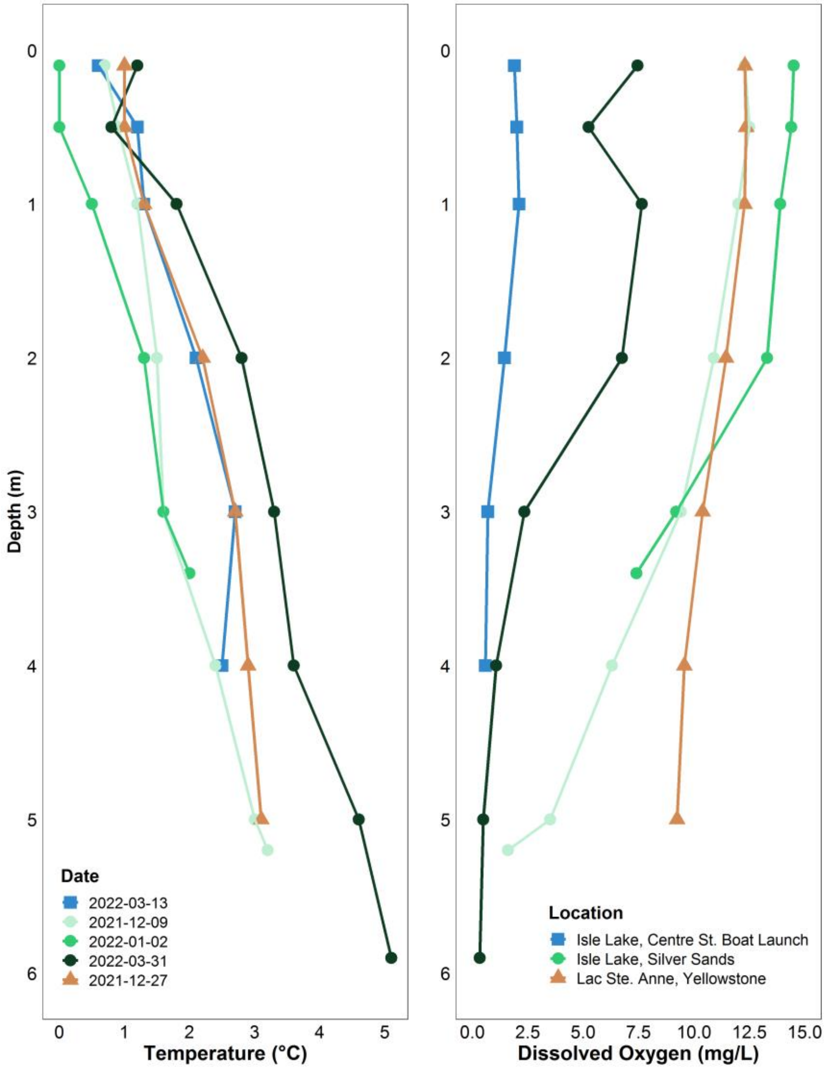


Figure 22. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Isle Lake and Lac Ste. Anne in the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

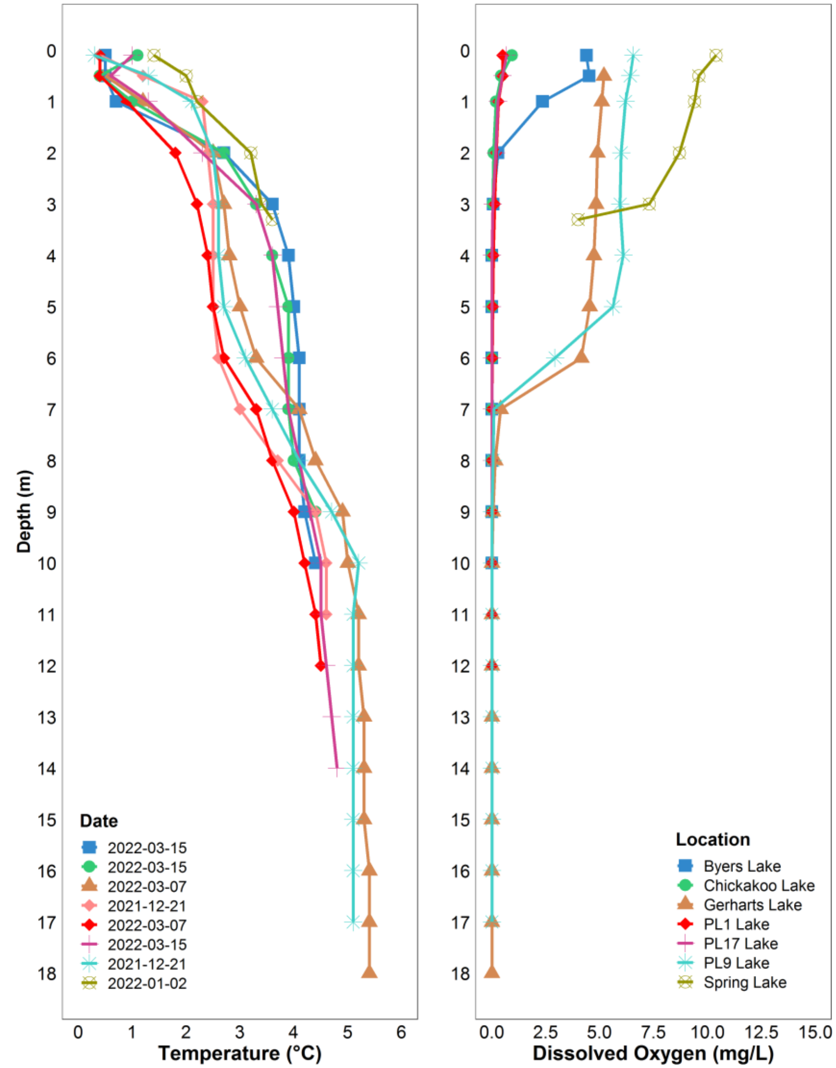


Figure 23. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes sampled in the Carvel Pitted Delta in the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

North Saskatchewan River Watershed

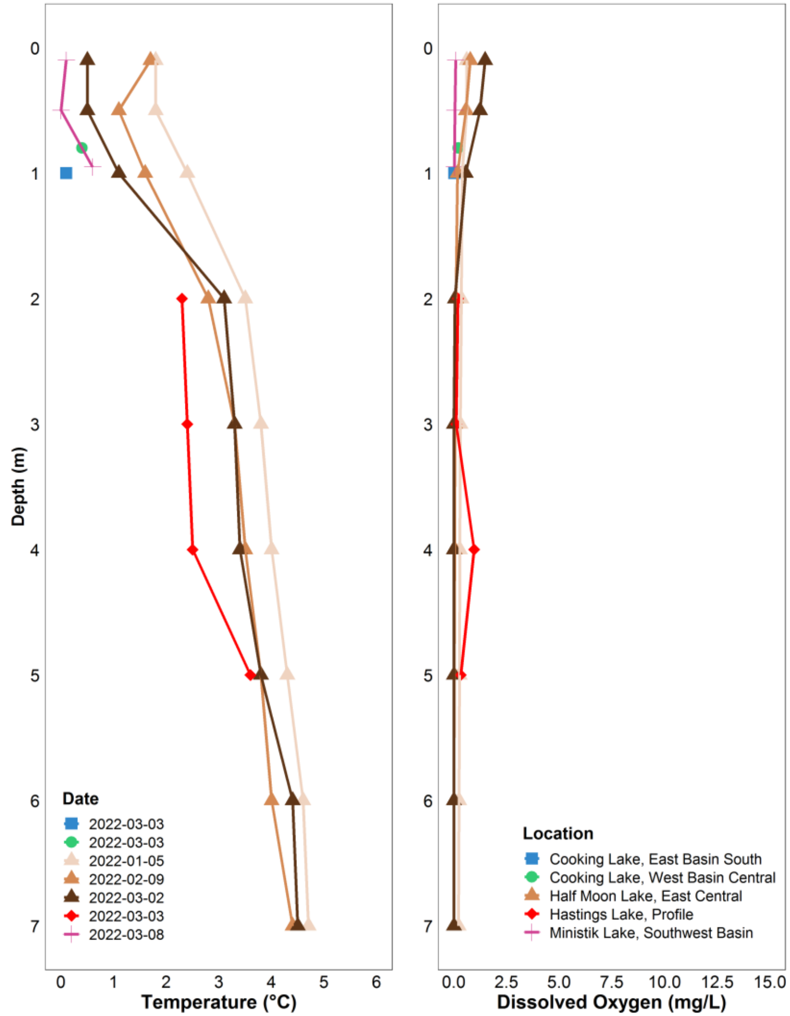


Figure 24. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes sampled in the Beaverhills region in the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

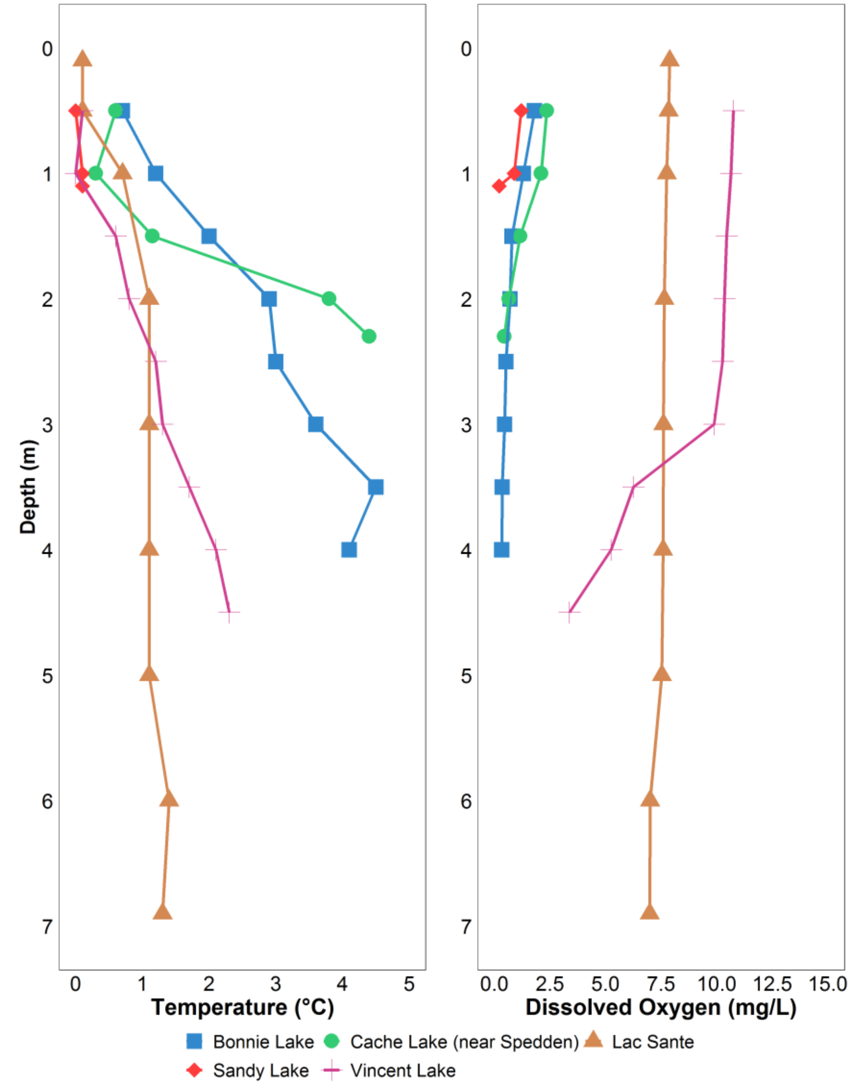


Figure 25. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes sampled in the Frog subwatershed of the North Saskatchewan River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Sample dates can be found in Tables 10a and 10b.

North Saskatchewan River Watershed

Table 5a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in μg/L, TP = total phosphorus in μg/L, TDP = total dissolved phosphorus in μg/L, NO3+NO2 = nitrate plus nitrite in μg/L, NH3 = ammonia in μg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in μS/cm) from Wabamun Lake, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Wabamun Lake, Rich's Point	2021-12-20	1.0	2.0	10.0	5.4	38.0	61.0	11.0	19.0	700	8.32
Wabamun Lake, Rich's Point	2022-01-14	1.0	1.0	11.0	8.9	34.0	85.0	12.0	18.0	710	8.02
Wabamun Lake, Rich's Point	2022-02-17	1.0	1.8	12.0	7.2	32.0	110.0	11.0	19.0	710	8.38
Wabamun Lake, Rich's Point	2022-03-18	1.2	1.6	9.3	4.7	48.0	69.0	12.0	18.0	690	8.34
Wabamun Lake, Seba Beach	2021-12-20	0.9	2.7	11.0	6.1	16.0	93.0	11.0	18.0	670	8.45
Wabamun Lake, Seba Beach	2022-01-14	0.9	0.5	10.0	7.0	21.0	130.0	11.0	18.0	690	8.13
Wabamun Lake, Seba Beach	2022-02-17	1.1	2.3	11.0	7.3	37.0	160.0	11.0	19.0	690	8.37
Wabamun Lake, Seba Beach	2022-03-18	1.1	1.0	11.0	6.0	99.0	73.0	11.0	17.0	640	8.23
Wabamun Lake, Water's Edge	2021-12-20	1.0	1.7	13.0	5.4	35.0	64.0	11.0	19.0	710	8.41
Wabamun Lake, Water's Edge	2022-01-14	0.8	0.7	9.6	8.5	37.0	78.0	11.0	18.0	700	8.08
Wabamun Lake, Water's Edge	2022-02-17	1.1	0.6	12.0	7.4	32.0	110.0	11.0	19.0	700	8.39
Wabamun Lake, Water's Edge	2022-03-18	1.3	2.4	11.0	4.2	51.0	74.0	12.0	19.0	690	9.32

Table 5b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at Wabamun Lake in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Wabamun Lake, Rich's Point	2021-12-20	-19	13	38	Clear	Colourless	No
Wabamun Lake, Rich's Point	2022-01-14	-5	24	40	Clear	Colourless	No
Wabamun Lake, Rich's Point	2022-02-17	3	3	60	Clear	Colourless	No
Wabamun Lake, Rich's Point	2022-03-18	3	0	70	Clear	Colourless	No
Wabamun Lake, Seba Beach	2021-12-20	-21	10	33	Clear	Colourless	No
Wabamun Lake, Seba Beach	2022-01-14	-6	24	40	Clear	Colourless	No
Wabamun Lake, Seba Beach	2022-02-17	3	2	55	Clear	Colourless	No
Wabamun Lake, Seba Beach	2022-03-18	3	0	65	Clear	Colourless	No
Wabamun Lake, Water's Edge	2021-12-20	-25	10	38	Clear	Colourless	No
Wabamun Lake, Water's Edge	2022-01-14	-10	22	35	Clear	Colourless	No
Wabamun Lake, Water's Edge	2022-02-17	2	2	60	Clear	Colourless	No
Wabamun Lake, Water's Edge	2022-03-18	-2	0	68	Clear	Colourless	No

North Saskatchewan River Watershed

LakeKeepers

Table 6a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-a in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from Wizard Lake, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Wizard Lake, Jubilee	2022-01-11	1.2	4.1	10.0	9.3	150.0	160.0	20.0	7.7	410	7.88
Wizard Lake, Jubilee	2022-02-06	1.2	2.7	20.0	13.0	260.0	30.0	14.0	8.7	410	7.97
Wizard Lake, Jubilee	2022-02-27	1.5	16.4	110.0	60.0	230.0	7.5	14.0	8.7	370	8.03
Wizard Lake, Jubilee	2022-03-22	1.8	52.7	280.0	200.0	88.0	23.0	15.0	4.9	210	7.68
Wizard Lake, West Basin	2022-01-11	1.2	3.2	23.0	12.0	51.0	170.0	18.0	7.9	410	8.19
Wizard Lake, West Basin	2022-02-06	1.3	1.7	26.0	20.0	190.0	86.0	15.0	8.7	420	8.07
Wizard Lake, West Basin	2022-02-27	1.3	9.2	27.0	13.0	230.0	18.0	13.0	8.4	390	8.06
Wizard Lake, West Basin	2022-03-22	1.0	15.0	20.0	10.0	180.0	35.0	11.0	6.6	340	8.17

Table 6b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at Wizard Lake in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Wizard Lake, Jubilee	2022-01-11	4	18	43	Clear	Colourless	No
Wizard Lake, Jubilee	2022-02-06	6	9	51	Opaque	Colourless	No
Wizard Lake, Jubilee	2022-02-27	0	6	55	Opaque	Colourless	No
Wizard Lake, Jubilee	2022-03-22	3	3	56	Opaque	Green	No
Wizard Lake, West Basin	2022-01-11	2	29	43	Clear		
Wizard Lake, West Basin	2022-02-06	6	11	53	Opaque	Colourless	No
Wizard Lake, West Basin	2022-02-27	-1	9	61	Opaque	Colourless	No
Wizard Lake, West Basin	2022-03-22	6	1	61	Opaque		Yes

North Saskatchewan River Watershed

LakeKeepers

Table 7a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-a in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from Isle Lake and Lac Ste. Anne, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Isle Lake, Centre St. Boat Launch	2022-03-13	1.9	7.1	200.0	170.0	260.0	38.0	20.0	14.0	440	8.15
Isle Lake, Silver Sands	2021-12-09	2.0		160.0							
Isle Lake, Silver Sands	2022-01-02	1.9		150.0							
Isle Lake, Silver Sands	2022-03-31	0.9	3.5	110.0	110.0	120.0	70.0	12.0	8.1	280	8.17
Lac Ste. Anne, Yellowstone	2021-12-27	1.3	0.8	9.1	4.7	5.0	30.0	13.0	15.0	460	8.12

Table 7b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at Isle Lake and Lac Ste. Anne, sampled in Winter 2021-2022 .

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Isle Lake, Centre St. Boat Launch	2022-03-13	-3	5	66	Clear	Green	No
Isle Lake, Silver Sands	2021-12-09	-10	3	33	Clear	Brown	Yes
Isle Lake, Silver Sands	2022-01-02	-17	13	38	Clear	Colourless	Yes
Isle Lake, Silver Sands	2022-03-31	-2	7	61	Clear	Colourless	No
Lac Ste. Anne, Yellowstone	2021-12-27	-24	13	33	Clear	Colourless	No

North Saskatchewan River Watershed

Table 8a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-a in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes in the Carvel Pitted Delta west of Stony Plain, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Byers Lake, Profile	2022-03-15	2.3	205.0	470.0	35.0	5.0	37.0	18.0	1.7	190	7.44
Chickakoo Lake, Profile	2022-03-15	2.8	42.7	320.0	290.0	5.0	820.0	20.0	6.5	580	7.53
Gerharts Lake, Profile	2022-03-07	1.1	21.5	11.0	5.7	9.8	440.0	7.9	5.4	690	7.99
PL1 Lake, Profile	2021-12-21	2.4	16.4	44.0	28.0	50.0	1300.0	15.0	3.3	780	7.80
PL1 Lake, Profile	2022-03-07	2.2	15.6	59.0	35.0	5.3	1300.0	15.0	3.2	790	7.86
PL17 Lake, Profile	2022-03-15	3.7	133.0	290.0	20.0	10.0	670.0	20.0	7.6	290	7.34
PL9 Lake, Profile	2021-12-21	1.1	2.1	6.9	4.2	5.0	430.0	7.2	0.5	1000	7.82
Spring Lake, North of Island	2022-01-02	2.0		12.0							

Table 8b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Carvel Pitted Delta west of Stony Plain, sampled in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Byers Lake, Profile	2022-03-15	-3	20	55	Opaque	Green	Yes
Chickakoo Lake, Profile	2022-03-15	5	10	58	Opaque	Colourless	No
Gerharts Lake, Profile	2022-03-07	-1	10	50	Clear	Colourless	No
PL1 Lake, Profile	2021-12-21	-10	10	30	Opaque	Green	No
PL1 Lake, Profile	2022-03-07	0	20	55	Opaque	Colourless	No
PL17 Lake, Profile	2022-03-15	3	10	52	Opaque	Green	Yes
PL9 Lake, Profile	2021-12-21	-10	10	30	Clear	Colourless	No
Spring Lake, North of Island	2022-01-02	-15	12	36	Clear	Colourless	Yes

North Saskatchewan River Watershed

LakeKeepers

Table 9a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes in the Beaverhills region, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Cooking Lake, East Basin South	2022-03-03	47.0	6.6	3500.0	4300.0	5.0	14000.0	350.0	370.0	9300	8.32
Cooking Lake, West Basin Central	2022-03-03	49.0	141.0	2300.0	2200.0	5.0	8200.0	420.0	380.0	10000	8.44
Half Moon Lake, East Central	2022-01-05	3.0	15.2	130.0	60.0	230.0	600.0	23.0	32.0	530	7.81
Half Moon Lake, East Central	2022-02-09	2.8	13.2	85.0	24.0	12.0	880.0	21.0	33.0	520	7.80
Half Moon Lake, East Central	2022-03-02	3.0	82.3	140.0	63.0	4.7	690.0	22.0	34.0	530	7.96
Hastings Lake, Profile	2022-03-03	6.8	206.0	92.0	30.0	9.0	950.0	57.0	53.0	2300	8.29
Ministik Lake, Southwest Basin	2022-03-08	19.0	28.5	1200.0	1200.0	5.0	2900.0	220.0	270.0	5200	8.62

Table 9b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Beaverhills region, sampled in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Cooking Lake, East Basin South	2022-03-03	-11	5	66	Clear	Brown	No
Cooking Lake, West Basin Central	2022-03-03	-11	5	58	Clear	Brown	Yes
Half Moon Lake, East Central	2022-01-05	-25	30	81	Opaque	Colourless	No
Half Moon Lake, East Central	2022-02-09	4	15	91	Opaque	Colourless	No
Half Moon Lake, East Central	2022-03-02	-7	5	86	Opaque	Colourless	No
Hastings Lake, Profile	2022-03-03	-10	10	69	Clear	Colourless	No
Ministik Lake, Southwest Basin	2022-03-08	-9	8	71	Opaque	Brown	Yes

North Saskatchewan River Watershed

Table 10a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes in the Frog subwatershed of the North Saskatchewan River watershed, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

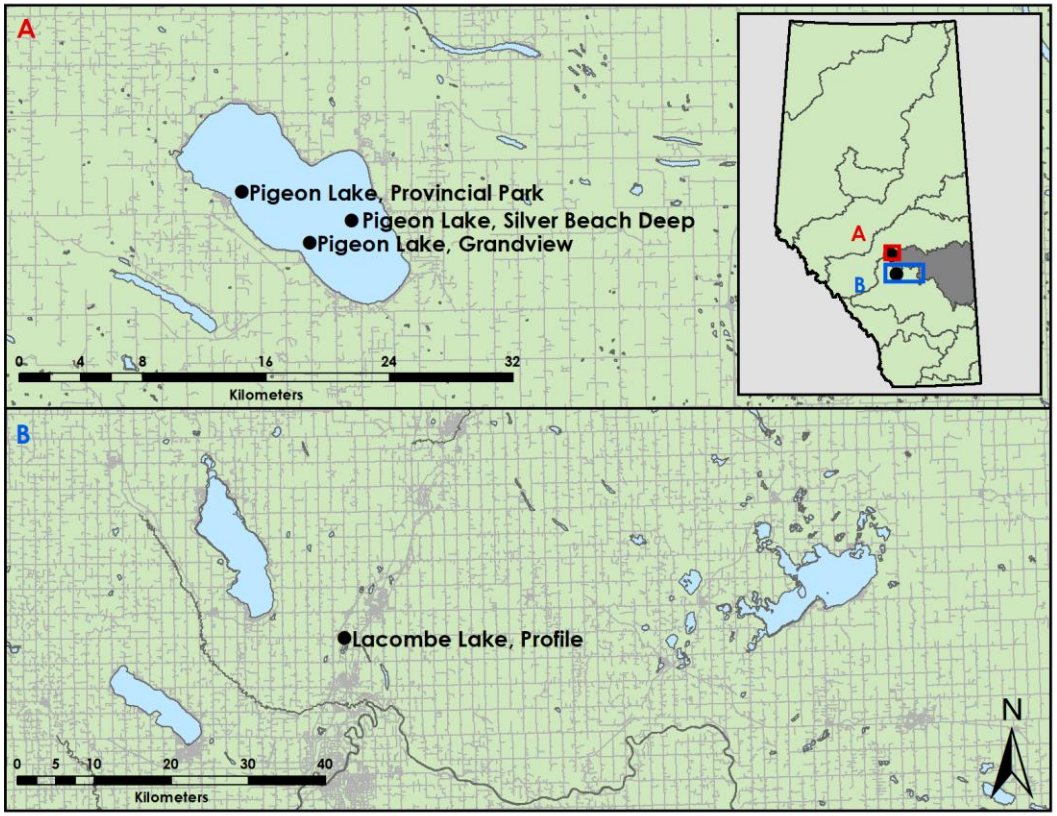
Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Bonnie Lake, Boat Launch	2022-01-26	3.8		61.0							
Cache Lake, West Side	2022-01-26	2.2		20.0							
Lac Sante, Sante Hills	2022-02-25	2.6		89.0							
Sandy Lake, East Side	2022-02-03	13.0		770.0							
Vincent Lake, Boat Launch	2022-01-27	3.2		90.0							

Table 10b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Frog subwatershed of the North Saskatchewan River watershed, sampled in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Bonnie Lake, Boat Launch	2022-01-26	-20	24	46	Clear	Colourless	No
Cache Lake, West Side	2022-01-26	-20	38	56	Clear	Colourless	No
Lac Sante, Sante Hills	2022-02-25	-10	64	64	Clear	Colourless	No
Sandy Lake, East Side	2022-02-03	-23	25	57	Opaque	Yellow	Yes
Vincent Lake, Boat Launch	2022-01-27	-4	30	67	Clear	Colourless	No

Battle River Watershed

Pigeon and Lacombe were the only lakes sampled within the Battle River watershed in Winter LakeKeepers 2021-2022 (Map 6). Pigeon was one of two lakes in the province which had 12 sampling events (the other being Wabamun), which is the highest sample number of any lake in the 2021-2022 season (Map 1). For the Grandview and Provincial Park sites at Pigeon, which were sampled 5 and 6 times between December-April and December-March, respectively, both sites displayed the coldest water temperatures mid-winter (Figure 26). Notably, the entire water column had warmed considerably at the Grandview site during the April sampling event, corresponding with a notable increase in dissolved oxygen (DO), chlorophyll-a (ChlA) and total phosphorus (TP), and a decrease in other water chemistry parameters, as well as ice thickness (Tables 11a and 11b). This indicates the influence of spring conditions on increasing algae or cyanobacteria growth (DO and ChlA), as well as, dilution of the water closest to the ice as the ice melts. Notably, nitrate-nitrite (NO3+NO2) levels in Pigeon were consistently high in both sites through the season, and among the highest levels in lakes sampled across the province (Figure 7). Lacombe displayed consistent water temperatures through the season, but decreasing DO levels (Figure 26). Notably, Lacombe had chloride levels on the higher end compared to other lakes in the province (Figure 10). Levels of ammonia were much higher than NO3+NO2 (Table 11a), which may indicate degradation of aquatic plants through the winter months that grow in high abundance in the lake within the summer months.



Map 6. Sampling locations for Winter LakeKeepers 2021-2022, in the Battle River watershed. Battle River watershed highlighted in Alberta inset map.

Battle River Watershed

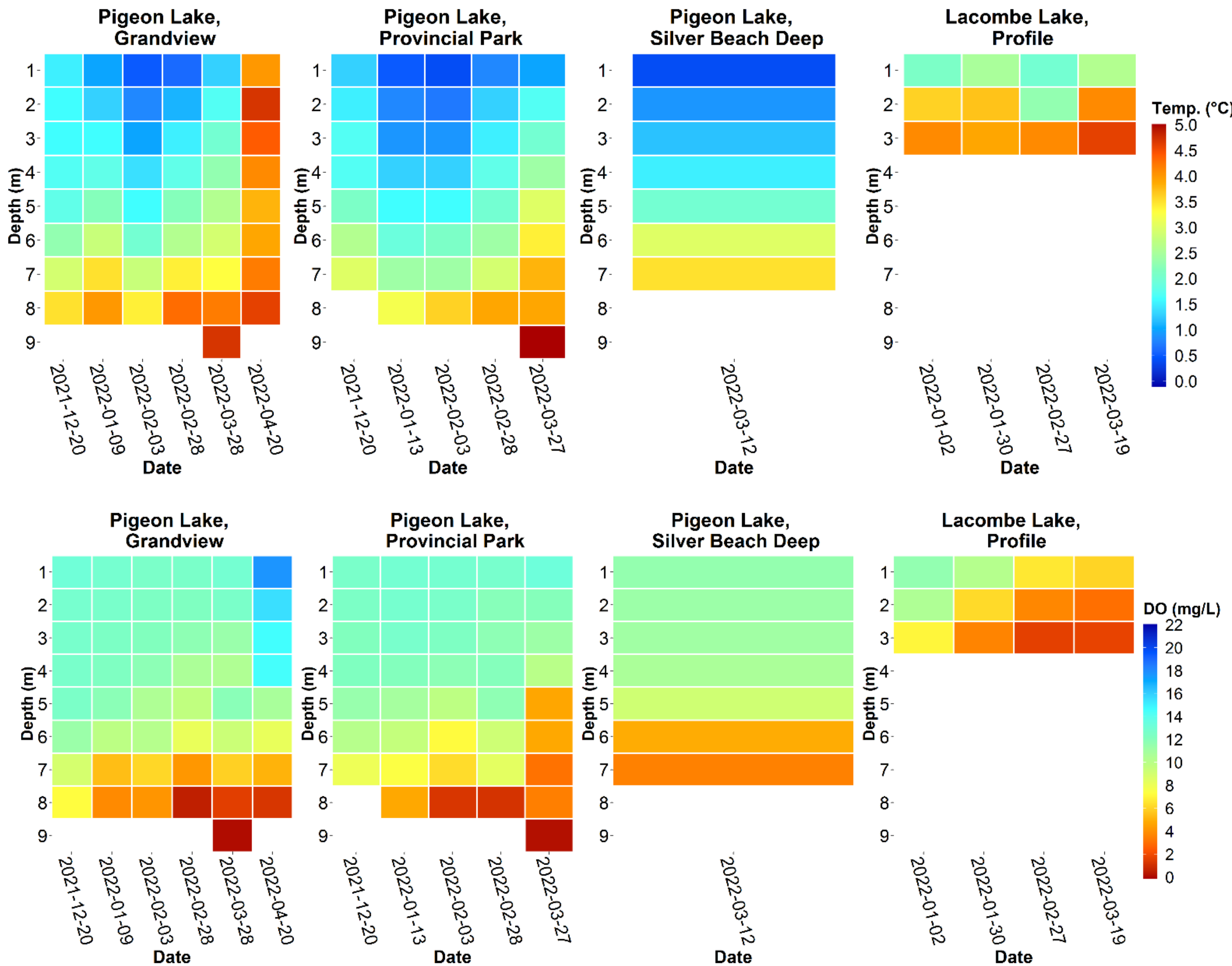


Figure 26. Heat maps of temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Battle River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

Battle River Watershed

Table 11a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Battle River watershed, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Lacombe Lake, Profile	2022-01-02	2.1	7.6	15.0	15.0	5.0	330.0	16.0	36.0	630	8.25
Lacombe Lake, Profile	2022-01-30	1.8	4.8	9.9	3.5	2.1	420.0	19.0	37.0	650	8.32
Lacombe Lake, Profile	2022-02-27	2.2	10.8	14.0	5.0	6.4	540.0	18.0	39.0	720	8.31
Lacombe Lake, Profile	2022-03-19	2.1	2.6	12.0	3.2	6.5	390.0	20.0	40.0	680	8.27
Pigeon Lake, Grandview	2021-12-14	1.0	6.5	13.0	8.9	330.0	38.0	7.5	5.2	370	7.92
Pigeon Lake, Grandview	2022-01-09	0.9	1.0	16.0	9.3	290.0	72.0	9.2	5.2	380	8.16
Pigeon Lake, Grandview	2022-02-03	0.9	0.4	15.0	12.0	320.0	62.0	7.6	5.1	380	7.84
Pigeon Lake, Grandview	2022-02-28	1.1	2.5	17.0	12.0	320.0	77.0	7.4	6.1	380	8.18
Pigeon Lake, Grandview	2022-03-28	0.8	9.5	13.0	6.4	290.0	21.0	6.9	4.7	350	8.28
Pigeon Lake, Grandview	2022-04-20	0.4	19.3	21.0	4.0	30.0	19.0	0.8	0.5	34	7.72
Pigeon Lake, Provincial Park	2021-12-20	0.8	4.9	12.0	4.0	390.0	57.0	7.9	5.0	360	8.15
Pigeon Lake, Provincial Park	2022-01-13	0.8	1.0	15.0	5.0	340.0	64.0	8.2	5.3	380	8.20
Pigeon Lake, Provincial Park	2022-02-03	0.9	0.9	15.0	10.0	330.0	57.0	8.0	4.1	390	8.01
Pigeon Lake, Provincial Park	2022-02-28	1.0	3.8	15.0	12.0	340.0	60.0	7.2	6.0	380	8.19
Pigeon Lake, Provincial Park	2022-03-27	1.2	8.4	17.0	7.5	250.0	33.0	7.0	4.9	350	8.31
Pigeon Lake, Silver Beach Deep	2022-03-12	1.3		45.0							

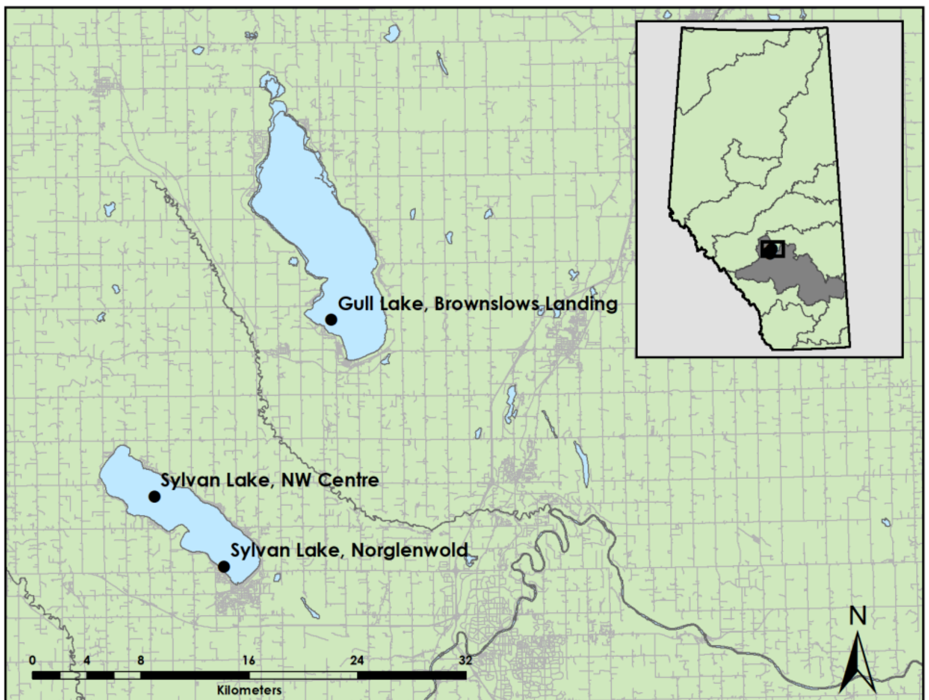
Battle River Watershed

Table 11b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Battle River watershed in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Lacombe Lake, Profile	2022-01-02	-7	8	38	Clear	Colourless	No
Lacombe Lake, Profile	2022-01-30	-1	8	51	Clear	Colourless	No
Lacombe Lake, Profile	2022-02-27	-4	8	58	Clear	Colourless	No
Lacombe Lake, Profile	2022-03-19	3	1	58	Clear	Colourless	No
Pigeon Lake, Grandview	2021-12-14	-18	5	30	Clear	Slight Green	No
Pigeon Lake, Grandview	2021-12-20	-4	8	42	Clear	Colourless	No
Pigeon Lake, Grandview	2022-01-09	-20	25	51	Clear	Colourless	No
Pigeon Lake, Grandview	2022-02-03	6	15	58	Clear	Colourless	No
Pigeon Lake, Grandview	2022-02-28	-3		64	Clear	Colourless	No
Pigeon Lake, Grandview	2022-03-28	-2	3	69	Opaque	Colourless	No
Pigeon Lake, Grandview	2022-04-20	5	8	50	Clear	Colourless	No
Pigeon Lake, Provincial Park	2021-12-20	-4	15	43	Clear	Colourless	No
Pigeon Lake, Provincial Park	2022-01-13	3	25	47	Clear	Colourless	No
Pigeon Lake, Provincial Park	2022-02-03	-18	13	46	Clear	Colourless	No
Pigeon Lake, Provincial Park	2022-02-28	-2			Clear	Colourless	No
Pigeon Lake, Provincial Park	2022-03-27	3	3	61	Clear	Colourless	No
Pigeon Lake, Silver Beach Deep	2022-03-12	-3	15	56	Clear	Colourless	No

Red Deer River Watershed

Two lakes were sampled within the Red Deer River watershed in Winter LakeKeepers 2021-2022 (Map 7). One site at Gull Lake was sampled once, and two sites at Sylvan were sampled twice. All sites at both lakes had high dissolved oxygen (DO) levels in the first 4m of the water column on all dates (Figure 27). Notably, the 'NW Centre' site at Sylvan displayed oxygen depletion in the bottom depths, while the 'Norglenwold' site did not show oxygen depletion at depth. The sampling sites at Sylvan also displayed increases in water temperature between their first and second sampling events. Gull had among the highest conductivity levels of any lake in the province (Figure 11). Interestingly, the March 26th 2022 sampling event at Sylvan, Norglenwold had a relatively high level of total phosphorus compared to the other three sampling events at Sylvan (Table 12a). The increase corresponded with a relatively high total Kjeldahl nitrogen (TKN) as well.



Map 7. Sampling locations for Winter LakeKeepers 2021-2022, in the Red Deer River watershed. Red Deer River watershed highlighted in Alberta inset map.

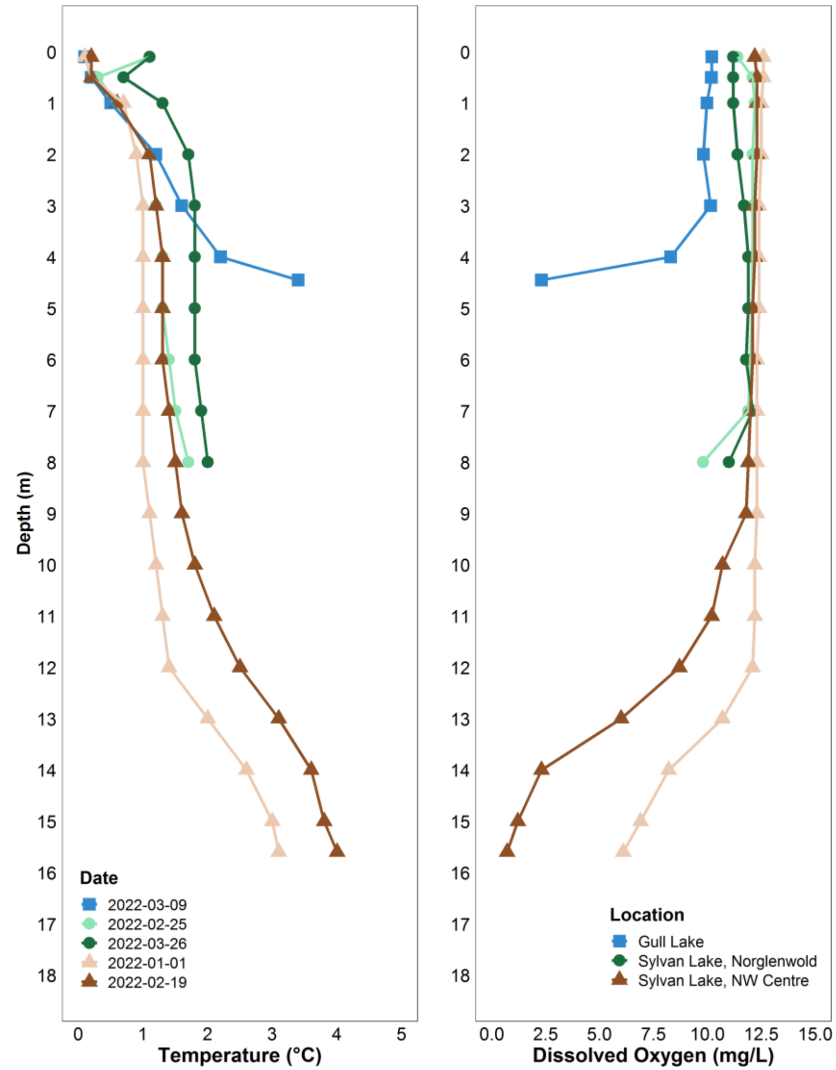


Figure 27. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Red Deer River watershed in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Red Deer River Watershed

Table 12a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Red Deer River watershed, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

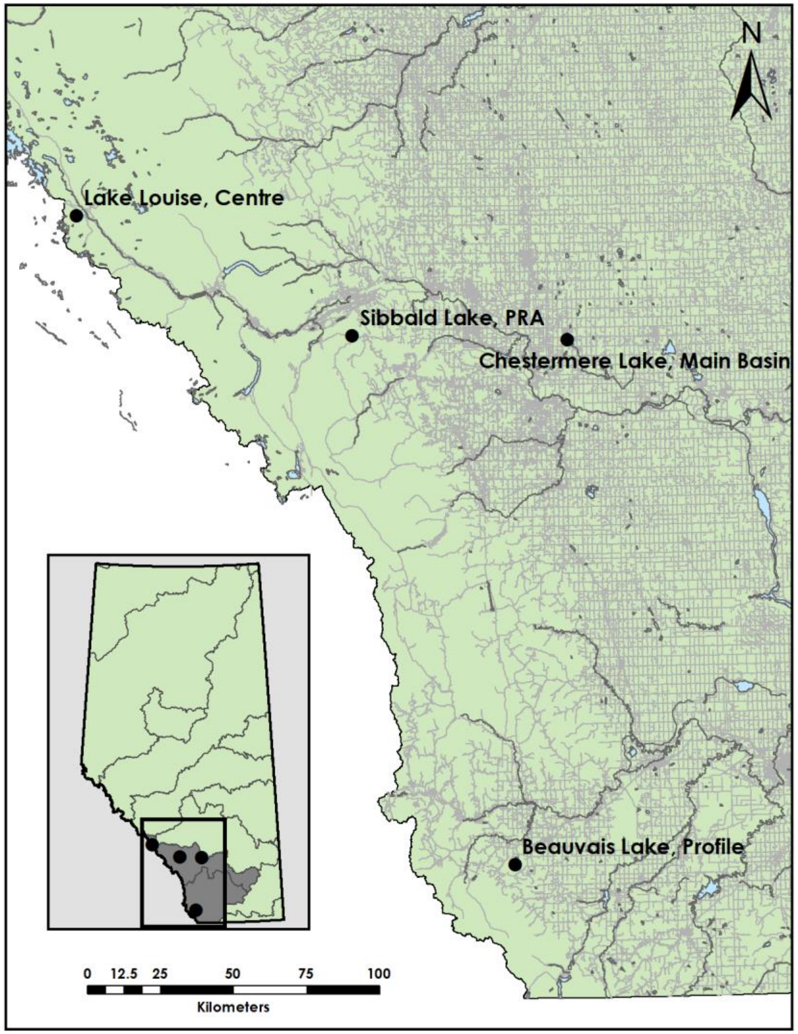
Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Gull Lake, Brownslows Landing	2022-03-09	1.9	1.1	12.0	8.9	12.0	180.0	27.0	13.0	1600	9.03
Sylvan Lake, Norglenwold	2022-02-25	0.7		7.0							
Sylvan Lake, Norglenwold	2022-03-26	1.1		44.0							
Sylvan Lake, NW Centre	2022-01-01	0.8	0.9	6.6	5.5	5.0	21.0	7.6	6.2	690	8.70
Sylvan Lake, NW Centre	2022-02-19	0.6		5.9	3.9	5.6	40.0	7.1	5.7	690	8.77

Table 12b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Red Deer River watershed in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Gull Lake, Brownslows Landing	2022-03-09	-11	7	76	Opaque	Brown	No
Sylvan Lake, Norglenwold	2022-02-25	-19	10	90	Clear	Colourless	No
Sylvan Lake, Norglenwold	2022-03-26	0	0	90	Opaque	Colourless	No
Sylvan Lake, NW Centre	2022-01-01	-17	10	42	Opaque	Colourless	Yes
Sylvan Lake, NW Centre	2022-02-19	0	10	67	Clear	Colourless	No

Bow & Oldman River Watersheds

Four lakes were sampled across the Bow and Oldman River watersheds in Winter LakeKeepers 2021-2022 (Map 8). Chestermere, in the Bow River watershed, was the only reservoir sampled in the 2021-2022 season, and was sampled three times through the winter. Beauvais, the only lake sampled in the Oldman watershed, was also sampled three times, while Sibbald and Lake Louise were each sampled once. Chestermere and Beauvais both displayed trends of decreasing dissolved oxygen (DO) throughout the season, although Chestermere displayed an interesting surface spike of DO during the March sampling event (Figure 28). Beauvais displayed among the warmest whole-column lake temperatures in the province during both of the March sampling events. The sampling site of 'Lake Louise, Centre,' at a profile depth of 70m (profile measurements to 63m), is the deepest site sampled in the Winter LakeKeepers 2021-2022 season. Notably, oxygen levels were consistently high down to 63m, and temperature remained consistent at about 4°C below 3m. Sibbald displayed high oxygen levels and low temperatures in the top of the water column, and then changed drastically to low oxygen levels and warmer temperatures in the lower depths, even though the lake was only 1.6m deep at that sample site. Chestermere had a relatively high level of chlorophyll-*a* during the December sampling event, which is notable because most other lakes sampled across the province displayed their highest levels during the March sampling events. (Table 13a). The air temperature during the December sampling event at Chestermere was also the lowest recorded for any sampling event in the province, at -32°C (Table 13b). Lake Louise had among the lowest levels of most water quality parameters of any lake sampled in winter 2021-2022. All nutrients were the lowest in the province with the exception of nitrate and nitrite (NO_3+NO_2; Figure 7). Chloride levels at Chestermere were relatively high compared to other lakes sampled in the Bow and Oldman River watersheds, as well as across the province (Figure 10). Nutrient levels of Beauvais and Sibbald were also relatively low compared to other lakes in the province. Nutrient levels at Beauvais decreased through the season, while pH increased through the season.



Map 8. Sampling locations for Winter LakeKeepers 2021-2022, in the Bow and Oldman River watersheds. Bow and Oldman River watersheds highlighted in Alberta inset map.

Bow & Oldman River Watersheds

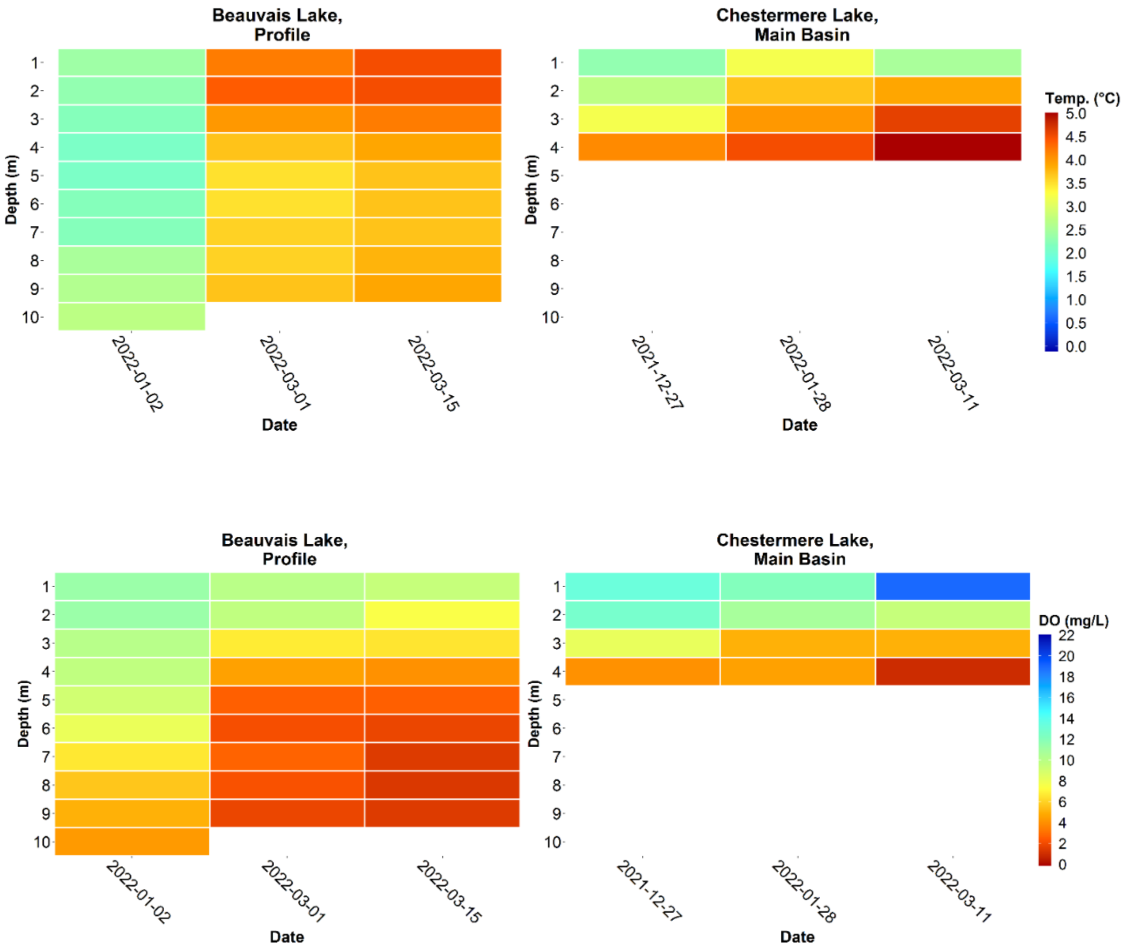


Figure 28. Heat maps of temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Bow River and Oldman River watersheds in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Only measurements at 1m and below are plotted as heat maps.

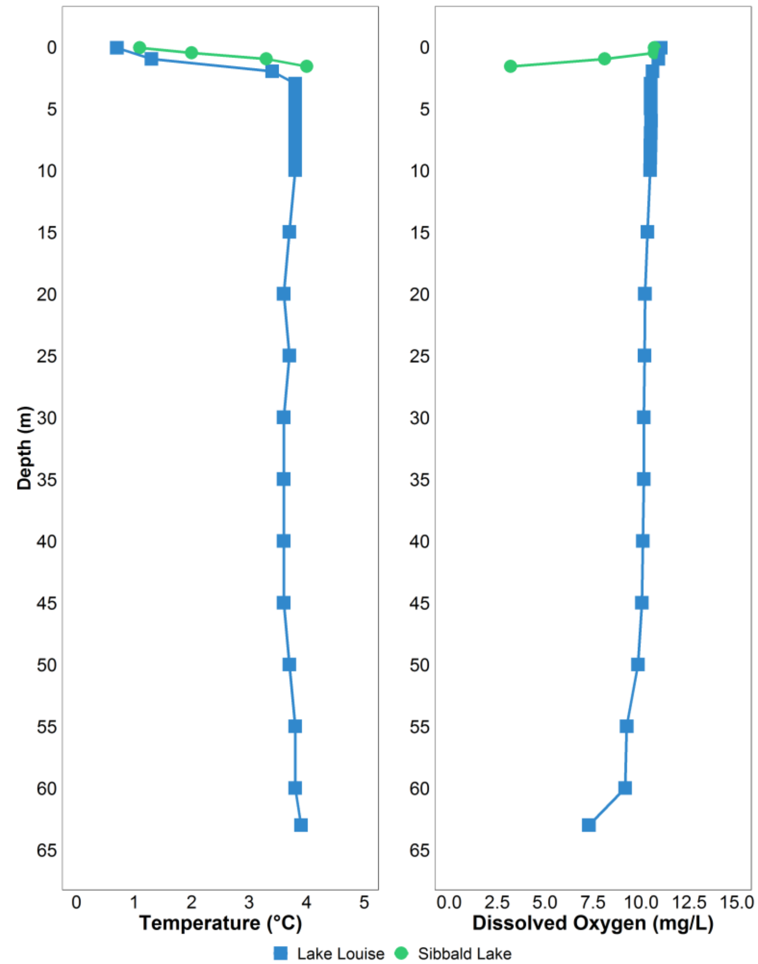


Figure 29. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in Bow River and Oldman River watersheds in Winter 2021-2022. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Sample dates can be found in Tables 13a and 13b.

Bow & Oldman River Watersheds

Table 13a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, ChlA = chlorophyll-*a* in µg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, NO3+NO2 = nitrate plus nitrite in µg/L, NH3 = ammonia in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes sampled in the Bow River and Oldman River watersheds, sampled in Winter 2021-2022. All samples taken at approximately 0.1 m depth.

Site	Date	TKN	ChlA	TP	TDP	NO3+NO2	NH3	DOC	Cl-	Cond.	pH
Beauvais Lake, Profile	2022-01-02	0.5	2.3	6.4	7.1	17.0	23.0	5.6	1.3	290	7.83
Beauvais Lake, Profile	2022-03-01	0.5	0.8	5.8	3.1	19.0	29.0	5.3	1.0	250	8.22
Beauvais Lake, Profile	2022-03-15	0.3	0.9	5.9	1.5	2.1	30.0	3.0	1.0	190	8.77
Chestermere Lake, Main Basin	2021-12-27	0.9	55.9	39.0	36.0	49.0	93.0	2.5	18.0	530	7.79
Chestermere Lake, Main Basin	2022-01-28	0.5	4.7	13.0	11.0	110.0	83.0	2.4	20.0	590	8.23
Chestermere Lake, Main Basin	2022-03-11	0.4	8.7	14.0	3.8	7.5	37.0	2.2	19.0	530	8.65
Lake Louise, Centre	2022-05-16	0.03	0.3	6.5	1.5	53.0	34.0	0.2	0.5	71	7.85
Sibbald Lake, PRA	2021-12-20	1.1	1.0	17.0	6.2	5.0	7.5	15.0	0.5	200	8.45

Table 13b. Environmental measurements (Air Temp. = air temperature in °C, Snow Depth and Ice Thickness in cm) and observations recorded at lakes in the Bow River and Oldman River watersheds in Winter 2021-2022.

Site	Date	Air Temp.	Snow Depth	Ice Thickness	Ice Colour	Water Colour	Particles?
Beauvais Lake, Profile	2022-01-02	-5	8	30	Opaque	Colourless	No
Beauvais Lake, Profile	2022-03-01	12	8	36	Opaque	Colourless	No
Beauvais Lake, Profile	2022-03-15	6	8	27	Opaque	Colourless	No
Chestermere Lake, Main Basin	2021-12-27	-32	7	35	Clear	Colourless	No
Chestermere Lake, Main Basin	2022-01-28	6	0	71	Clear	Colourless	No
Chestermere Lake, Main Basin	2022-03-11	-8	12	59	Clear	Colourless	No
Lake Louise, Centre	2022-05-16	12	18	61	Clear	Colourless	No
Sibbald Lake, PRA	2021-12-20	-18	15	25	Opaque	Colourless	No

Appendix – Lake Hypoxia

Appendix Table 1a. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Beauvais Lake, Profile	2022-01-02	20	10.0
Beauvais Lake, Profile	2022-03-01	60	9.9
Beauvais Lake, Profile	2022-03-15	60	10.0
Blackett Lake, West Shore	2022-02-14	86	3.7
Bonnie Lake, Boat Launch	2022-01-26	100	4.2
Byers Lake, Profile	2022-03-15	100	10.3
Cache Lake, Inlet	2021-12-11	0	4.3
Cache Lake, West Side	2022-01-26	100	2.3
Calling Lake, Cardinal Drive	2022-01-22	0	9.5
Calling Lake, Cardinal Drive	2022-02-19	0	11.7
Calling Lake, Cardinal Drive	2022-03-18	0	12.0
Chestermere Lake, Main Basin	2021-12-27	9	4.4
Chestermere Lake, Main Basin	2022-01-28	36	4.7
Chestermere Lake, Main Basin	2022-03-11	33	4.5
Chickakoo Lake, Profile	2022-03-15	100	9.3
Cold Lake, Marina	2022-02-03	0	23.2
Cooking Lake, East Basin South	2022-03-03	100	1.5
Cooking Lake, West Basin Central	2022-03-03	100	1.0

Appendix – Lake Hypoxia

LakeKeepers

Appendix Table 1b. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Frenchman Lake, West Side	2022-01-24	51	4.1
Gerharts Lake, Profile	2022-03-07	100	18.2
Gull Lake, Brownslows Landing	2022-03-09	0	4.4
Half Moon Lake, East Central	2022-01-05	100	7.3
Half Moon Lake, East Central	2022-01-05	100	7.3
Half Moon Lake, East Central	2022-02-09	100	7.4
Half Moon Lake, East Central	2022-03-02	100	7.4
Hastings Lake, Profile	2022-03-03	100	5.5
Isle Lake, Centre St. Boat Launch	2022-03-13	100	4.0
Isle Lake, Silver Sands	2021-12-09	23	5.2
Isle Lake, Silver Sands	2022-01-02	0	3.4
Isle Lake, Silver Sands	2022-03-31	92	5.9
Kinnaird Lake, North Island	2022-01-17	0	5.6
Kinnaird Lake, South End	2022-02-14	9	5.5
Lac La Biche, Golden Sands	2022-03-17	19	8.6
Lac La Nonne, Profile	2022-01-23	51	16.3
Lac La Nonne, Profile	2022-02-27	45	16.3
Lac Sante, Sante Hills	2022-02-25	0	7.0

Appendix – Lake Hypoxia

Appendix Table 1c. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Lac Ste. Anne, Yellowstone	2021-12-27	0	5.0
Lacombe Lake, Profile	2022-01-02	0	3.1
Lacombe Lake, Profile	2022-01-30	43	3.5
Lacombe Lake, Profile	2022-02-27	39	3.3
Lacombe Lake, Profile	2022-03-19	71	3.5
Lake Louise, Centre	2022-05-16	0	70.0
Lesser Slave Lake, Canyon Creek	2022-02-02	0	8.1
Lesser Slave Lake, Canyon Creek	2022-03-30	0	5.0
Lesser Slave Lake, Joussard	2022-02-02	0	7.4
Lesser Slave Lake, Joussard	2022-03-01	0	4.8
Lesser Slave Lake, Joussard	2022-03-30	0	3.0
Lower Mann Lake, Boat Launch	2022-01-27	100	3.1
Manatokan Lake, Campsite	2022-02-06	100	5.3
Millers Lake, North Shore	2021-12-12	0	3.7
Ministik Lake, Southwest Basin	2022-03-08	100	0.9
Minnie Lake, Campground	2022-03-25	100	11.3
Missawawi Lake, Boat Launch	2022-01-24	100	2.1
Moose Lake, Bonnyville Bay West	2022-02-06	0	2.5

Appendix – Lake Hypoxia

Appendix Table 1d. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Moose Lake, Bonnyville Bay West	2022-03-25	45	7.3
Moose Lake, Franchere Bay	2022-02-06	100	1.5
Moose Lake, Pelican Point	2022-03-25	73	7.4
Moose Lake, Vezeau Bay	2022-02-06	33	4.5
Moose Lake, Vezeau Bay	2022-03-25	83	5.9
Muriel Lake, SE Corner	2021-12-11	0	4.3
Muriel Lake, SE Corner	2022-01-12	5	4.2
Muriel Lake, SE Corner	2022-02-14	100	4.4
Muriel Lake, SE Corner	2022-03-15	88	4.3
Pigeon Lake, Grandview	2021-12-20	0	8.9
Pigeon Lake, Grandview	2022-01-09	21	8.9
Pigeon Lake, Grandview	2022-02-03	21	8.8
Pigeon Lake, Grandview	2022-02-28	21	8.9
Pigeon Lake, Grandview	2022-03-28	21	8.9
Pigeon Lake, Grandview	2022-04-20	21	8.9
Pigeon Lake, Provincial Park	2021-12-20	0	7.3
Pigeon Lake, Provincial Park	2022-01-13	9	8.8
Pigeon Lake, Provincial Park	2022-02-03	18	8.5

Appendix – Lake Hypoxia

LakeKeepers

Appendix Table 1e. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Pigeon Lake, Provincial Park	2022-02-28	3	8.2
Pigeon Lake, Provincial Park	2022-03-27	33	8.9
Pigeon Lake, Silver Beach Deep	2022-03-12	18	7.3
PL1 Lake, Profile	2022-03-07	100	12.1
PL1 Lake, Profile	2022-03-07	100	12.1
PL17 Lake, Profile	2022-03-15	100	14.2
PL9 Lake, Profile	2021-12-21	97	17.5
Sandy Lake, East Side	2022-02-03	100	1.1
Seibert Lake, Northwest Bay	2022-03-22	36	7.8
Seibert Lake, South Boat Launch	2022-01-16	0	3.7
Sibbald Lake, PRA	2021-12-20	0	1.6
Skeleton Lake North, Profile	2021-12-22	23	15.5
Skeleton Lake North, Profile	2022-01-26	62	15.8
Skeleton Lake North, Profile	2022-02-22	69	15.9
Skeleton Lake North, Profile	2022-03-21	74	15.5
Skeleton Lake South, Center	2021-12-22	15	8.2
Skeleton Lake South, Center	2022-02-22	29	8.4
Skeleton Lake South, Center	2022-03-21	42	8.6

Appendix – Lake Hypoxia

LakeKeepers

Appendix Table 1f. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Spencer Lake, South Corner	2022-01-16	0	3.4
Spring Lake, North of Island	2022-01-02	0	3.3
Swan Lake, West of Aeration	2022-01-13	100	3.6
Swan Lake, West of Aeration	2022-02-09	87	3.8
Swan Lake, West of Aeration	2022-03-19	100	3.9
Swan Lake, West of Aeration	2022-03-19	100	3.9
Sylvan Lake, Norglenwold	2022-02-25	0	8.1
Sylvan Lake, Norglenwold	2022-03-26	0	8.6
Sylvan Lake, NW Centre	2022-01-01	0	15.6
Sylvan Lake, NW Centre	2022-02-19	17	15.6
Upper Mann Lake, South Side	2022-01-27	100	4.0
Victor Lake, Profile	2022-01-18	67	21.0
Victor Lake, Profile	2022-02-09	76	20.7
Victor Lake, Profile	2022-03-17	98	21.0
Vincent Lake, Boat Launch	2022-01-27	24	4.6
Wabamun Lake, Rich's Point	2021-12-20	0	4.5
Wabamun Lake, Rich's Point	2022-01-14	0	4.0
Wabamun Lake, Rich's Point	2022-02-17	0	4.0
Wabamun Lake, Rich's Point	2022-03-18	0	4.4

Appendix – Lake Hypoxia

Appendix Table 1g. Percent water column hypoxia, where hypoxia is defined as dissolved oxygen less than 6.5mg/L, according to the Alberta Government and the Canadian Council for Ministers of the Environment chronic guidelines for the protection of aquatic life, for Winter LakeKeepers lakes in the 2021-2022 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Wabamun Lake, Seba Beach	2021-12-20	0	8.0
Wabamun Lake, Seba Beach	2022-01-14	32	8.8
Wabamun Lake, Seba Beach	2022-02-17	43	8.8
Wabamun Lake, Seba Beach	2022-03-18	44	9.0
Wabamun Lake, Water's Edge	2021-12-20	0	1.5
Wabamun Lake, Water's Edge	2022-01-14	0	1.8
Wabamun Lake, Water's Edge	2022-02-17	0	1.8
Wabamun Lake, Water's Edge	2022-03-18	0	2.0
Wadlin Lake, South Central	2022-01-25	35	10.8
Wadlin Lake, South Central	2022-02-04	35	10.8
Wadlin Lake, South Central	2022-03-10	54	10.8
Wizard Lake, Jubilee	2022-01-11	0	4.9
Wizard Lake, Jubilee	2022-02-06	19	4.9
Wizard Lake, Jubilee	2022-02-27	37	6.3
Wizard Lake, Jubilee	2022-03-22	26	6.8
Wizard Lake, West Basin	2022-01-11	0	2.7
Wizard Lake, West Basin	2022-02-06	0	3.0
Wizard Lake, West Basin	2022-02-27	0	2.5
Wizard Lake, West Basin	2022-03-22	0	2.8

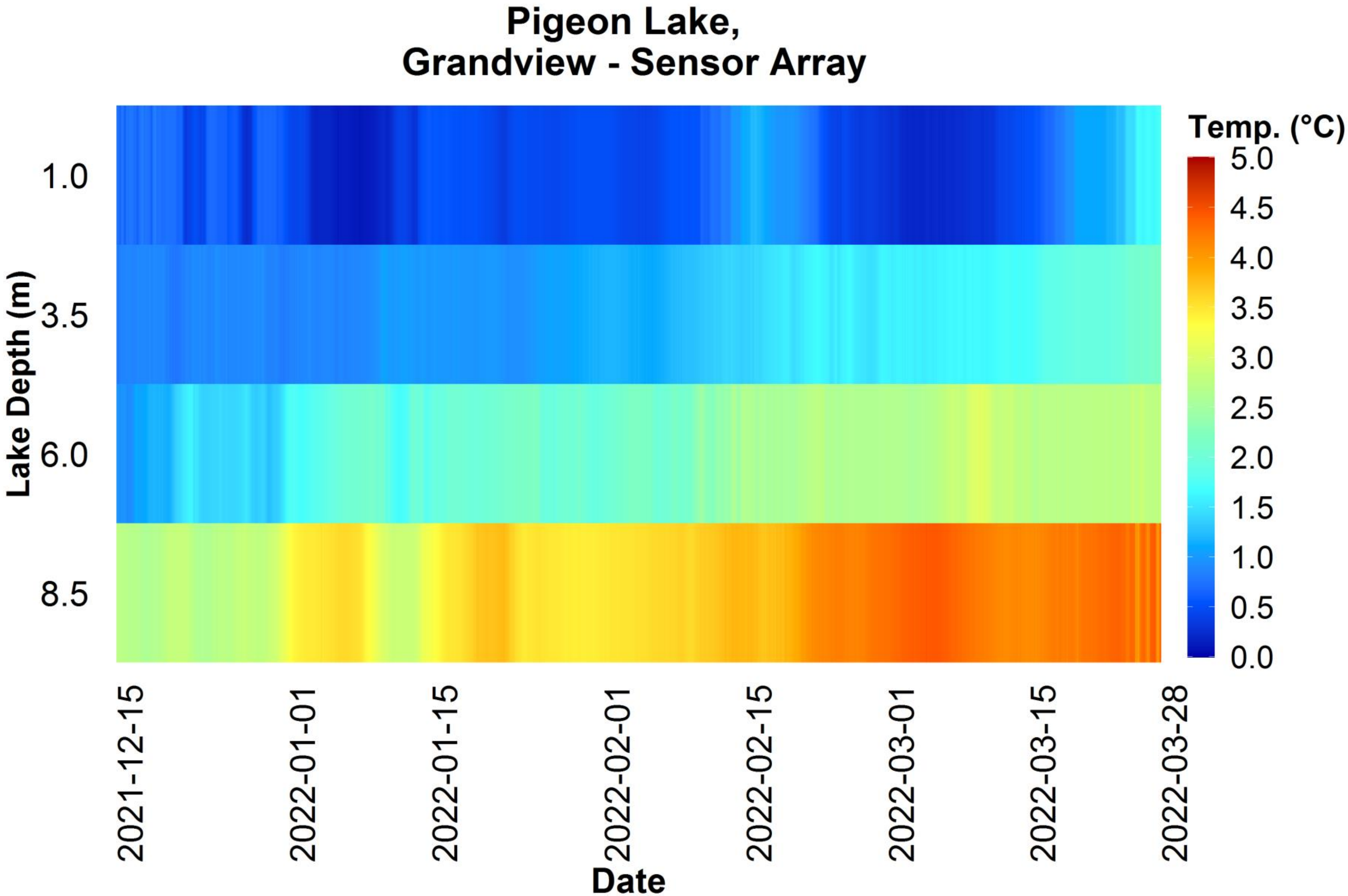
Appendix – Pigeon Lake Sensor Array

A sensor array was deployed in Pigeon Lake at the Grandview site during the winter 2021-2022 season in order to learn more about water temperature, dissolved oxygen, and light dynamics under the ice. The sensor array consisted of dissolved oxygen (DO) and temperature (temp) loggers attached to a chain at 1m, 3.5m, 6m and 8.5m depth relative to the level of water within the ice auger hole. These loggers were programmed to record DO and temp readings every 30min. The array also consisted of light loggers measuring light intensity (lux) deployed at 1m, 3.5m, and 8.5m. These loggers were programmed to record lux measurements every hour. The sensor array was deployed on December 14th, 2021 and removed March 28th, 2022 by ALMS staff and Pigeon Lake Watershed Association (PLWA) volunteer Don Davidson. Video footage from mid-winter confirmed that the light logger deployed at 3.5m became dislodged, and was not oriented upwards, and therefore the light data from that depth is not presented. The bottom depth of the Grandview site is 8.9m. Appendix Figure 1 displays the temperature data through the season, and indicates a gradual warming of water at all depths below 1m from the beginning of the season to the end, and an increase of stratification between each depth through the season. It also demonstrates the high variability of under-ice lake temperatures through the season, especially at 1m. Appendix Figure 2 displays the DO data through the season, and indicates a gradual but variable decrease in oxygen through the season at 6m and 8.5m. It also demonstrates daily variability of DO later in the winter at 1m and 3.5m, and to some extent down to 6m as well. Appendix Figure 3 displays the light measurements at 1m and 8.5m through the season, and demonstrates that for the majority of the season, very little light penetrates to the bottom of the lake, but still does on days when light penetration is highest near the surface. ALMS would like to thank Don Davidson for his assistance in deploying and removing the sensor, as well as monitoring the sensor array through the season. ALMS would also like to thank Alberta Environment and Parks for providing the loggers for the sensor array.

PLWA volunteer Don Davidson about to cut ice in order to install the sensor array at Pigeon Lake on December 14th 2021.

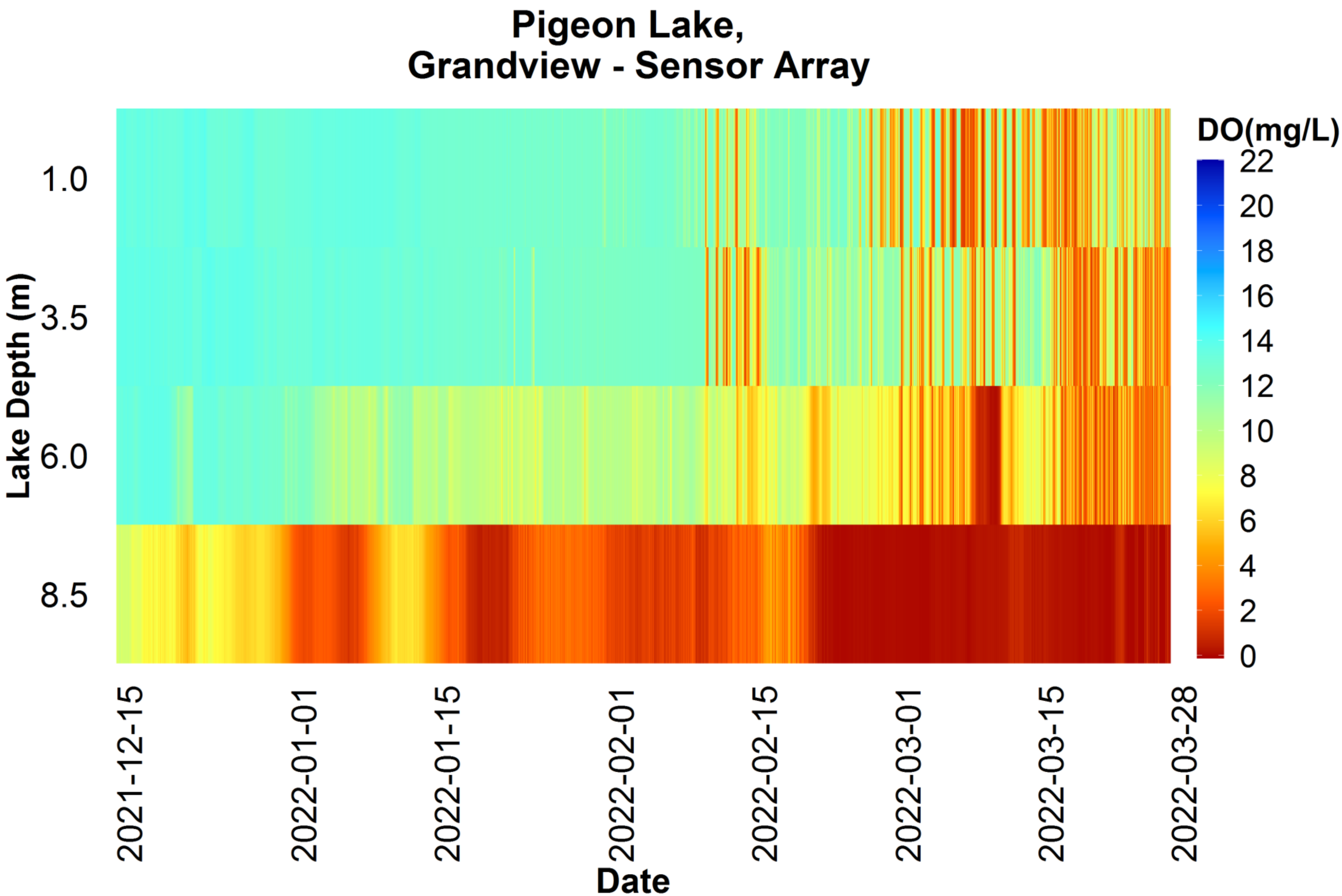
ALMS staff Kurstyn Cappis removing the sensor array from Pigeon Lake on March 28th 2022.

Appendix – Pigeon Lake Sensor Array



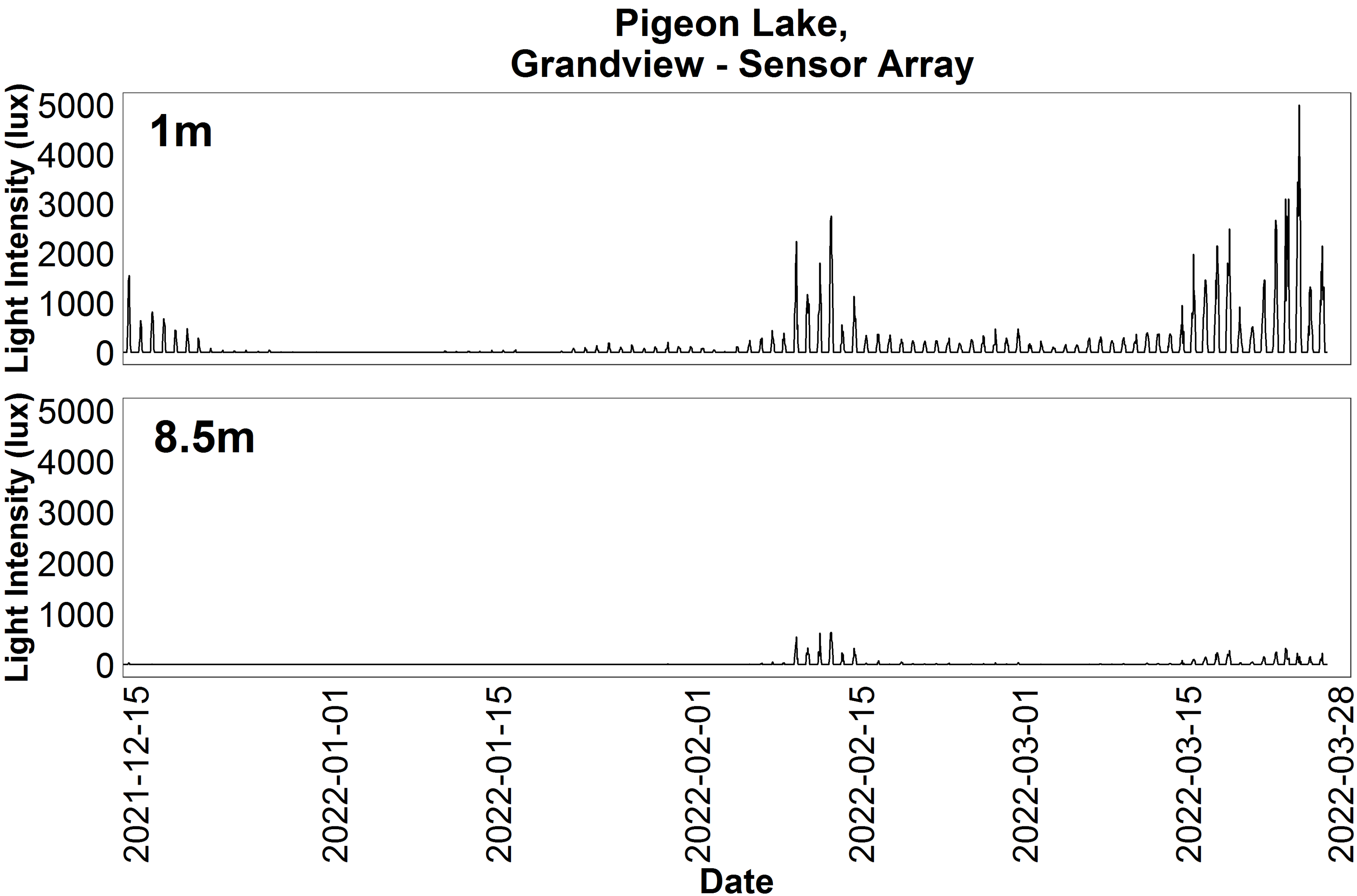
Appendix Figure 1. Heat map for temperature (Temp. °C) measurements recorded at temperature loggers (HOBO Dissolved Oxygen Logger – U26-001) deployed at 1m, 3.5m, 6m and 8.5m on a sensor array at the Pigeon Lake, Grandview sample site. Measurements logged every 30 minutes. The sensor array was deployed on December 14th 2021, and removed on March 28th 2022.

Appendix – Pigeon Lake Sensor Array



Appendix Figure 2. Heat map for dissolved oxygen (DO; mg/L) measurements recorded at dissolved oxygen loggers (HOBO Dissolved Oxygen Logger – U26-001) deployed at 1m, 3.5m, 6m and 8.5m on a sensor array at the Pigeon Lake, Grandview sample site. Measurements logged every 30 minutes. The sensor array was deployed on December 14th 2021, and removed on March 28th 2022.

Appendix – Pigeon Lake Sensor Array



Appendix Figure 3. Light Intensity (lux) measurements recorded at the light loggers (HOBO Pendant Temperature/Light Data Logger – UA-002-08) deployed at 1m, and 8.5m on a sensor array at the Pigeon Lake, Grandview sampled site. Measurements logged every 1 hour. The sensor array was deployed on December 14th 2021, and removed on March 28th 2022.