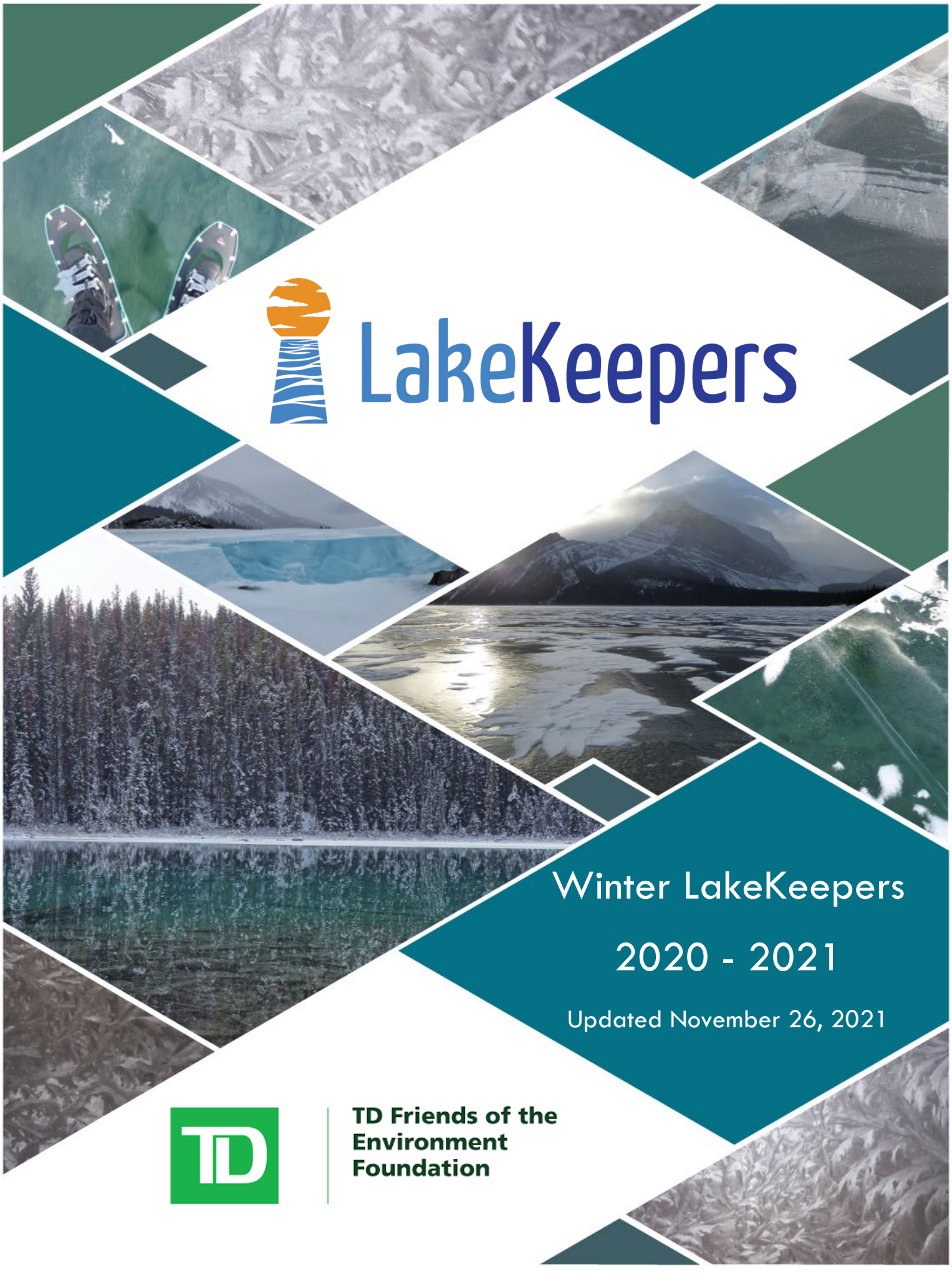


LakeKeepers

Winter LakeKeepers

2020 - 2021

Updated November 26, 2021

TD Friends of the Environment Foundation

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

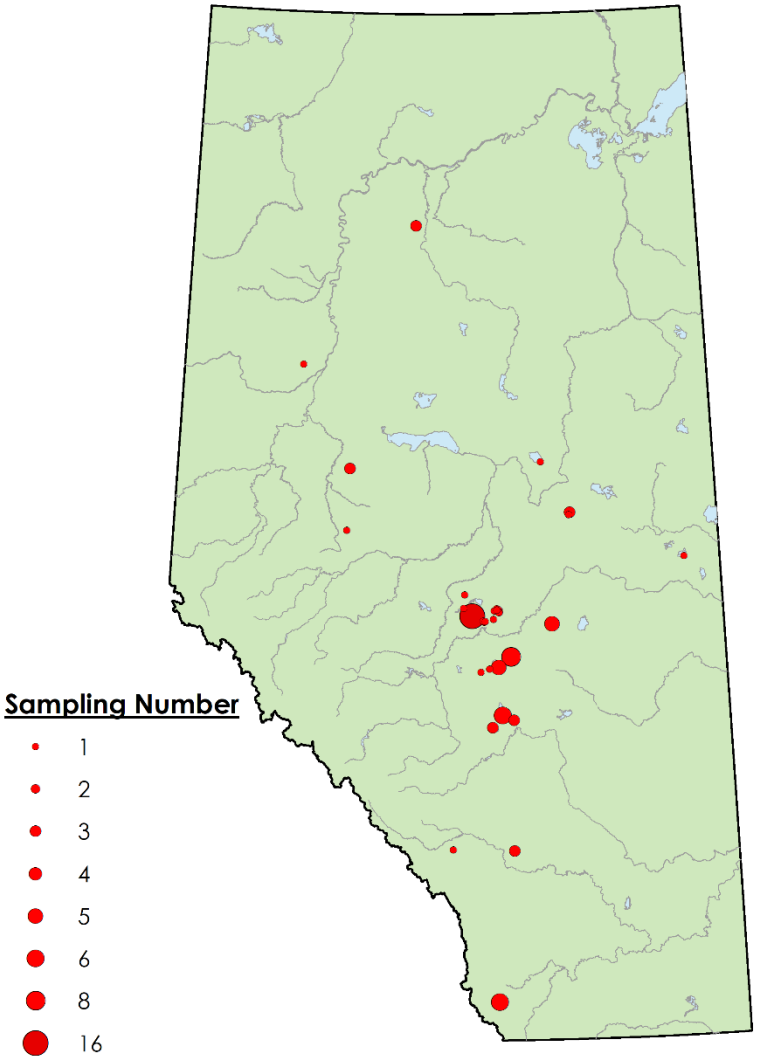
Winter LakeKeepers 2020-2021 was made possible with support from TD Friends of the Environment Foundation.

We would like to thank the all the volunteers and watershed stewardship groups who made this program happen. 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 26th, 2021

Executive Summary



Map 1. Geographic spread of lakes sampled as part of the Winter LakeKeepers 2020-2021 season. The size of the dot indicates the number of samples taken from the lake, both in terms of locations and number of times location was sampled through the winter of 2020-2021.

Following the successful seasons of Winter LakeKeepers in 2018-2019 and 2019-2020, the Alberta Lake Management Society (ALMS) delivered a third full Winter LakeKeepers season in 2020 – 2021, 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. 2020 – 2021 was the second season to include multiple sampling events at specific sites on lakes, as well as multiple sampling sites per lake. It was also the first season which included the collection of preserved phytoplankton samples, isotope samples, and additional water chemistry parameters. This season, three tiers of protocols were implemented depending on volunteer interest and sample logistics.

Sampling results per lake have been grouped by major watershed, and even further grouped by lake, or lakes within a geographical region within that major watershed (eg. North Saskatchewan Watershed section). A summary of hypoxia data is provided in the Appendix, as well as 'heat map' figures which further illustrate seasonal temperature and dissolved oxygen dynamics at sites sampled more than two times throughout the winter season.

Overall, 46 locations were sampled on 41 different lakes, ranging from the Oldman watershed in the south, up to the Peace watershed in northern Alberta (Map 1). 90 sampling events took place, from as early as December 14th, 2020, to as late as April 12th, 2021. This is nearly double the previous winter's sampling effort. 59 volunteers took part in Winter LakeKeepers 2020 – 2021, more than doubling the number from the previous year.

A variety of winter lake conditions were captured throughout the province. In the future, increased sampling frequency, additional biological parameters, and additional environmental parameters will support further investigation of seasonal trends and dynamics.

NOTE: Chlorophyll-a data not yet available. Will be incorporated into report once available.

Methods

Winter LakeKeepers sampling kit in action at Spring Lake, January 2021

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 also 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. One lake was sampled right after ice-off, in mid April (Beauvais Lake).

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), and total dissolved phosphorus (TDP) needed to arrive at the analysis laboratory within 3 days. ChlA samples not filtered in the field must 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 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), 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 then frozen prior to shipment.

Methods

Profile measurements for DO and temperature were taken first 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 location 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 from the Battle River Watershed Alliance collecting data from Battle Lake, February 2021

Data collected from the sites was 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 3 or more sampling events, to further investigate seasonal trends in lake temperature and dissolved oxygen. Hypoxia and heat map figures are 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 Pigeon Lake Watershed Association collecting data from Pigeon Lake, January 2021

A wide diversity of winter lake water chemistry parameters were captured through the Winter LakeKeepers 2020-2021 season. The overall findings build nuance into the major findings from the previous season.

The data from winter 2019-2020 pointed to the overall trends that dissolved oxygen (DO) decreases from the beginning of the winter season towards the end. While much of the DO data from winter 2020-2021 follows this trend, a few sites indicate that DO levels can be more dynamic, and begin to increase again later in the season, particularly in March. This trend was identified at Snipe, Pigeon, Wizard (West Basin), Half Moon, and Skeleton North (Appendix Figures 1-4). This may point to the impact of under-ice growth of algae & cyanobacteria, possibly stimulated by increased light and greater air temperatures later in the winter. While some lakes displayed low or no hypoxia, others had significant hypoxia which could lead to stressful conditions for fish (Appendix Tables 1a – 1d).

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, but deeper lakes in the north of province (Wadlin, Skeleton North) were the exception, and displayed much more stable seasonal temperature levels (Appendix Figures 1-5).

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, conductivity and pH appeared stable throughout the winter while nutrients appeared more dynamic. Nutrient and water chemistry data is explored further in the Results section below.

A wide range of ice thickness and snow depth were recorded. The average ice thickness was 58 cm, with a maximum of 100 cm and a minimum of 18 cm. For snow depth, the average through the season was 7 cm, with a maximum of 30 cm, and a minimum of 0 cm (22 of the 90 sampling events recoded a snow depth of 0 cm).

Results

Phosphorus is an essential nutrient for the growth of algae, cyanobacteria, and aquatic plants, and is often the most limiting nutrient for growth. High levels can indicate the lake is situated in naturally high nutrient soils, but also 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 dissolved phosphorus (TDP) indicates the portion of the total phosphorus that is more biologically available. Levels in lakes from Winter LakeKeepers 2020-2021 indicates a wide range of values, similar to the range of values from the summer (Figure 1). Lakes situated in the Carvel Pitted Delta in the North Saskatchewan River watershed have the highest TP and TDP levels (Figure 2).

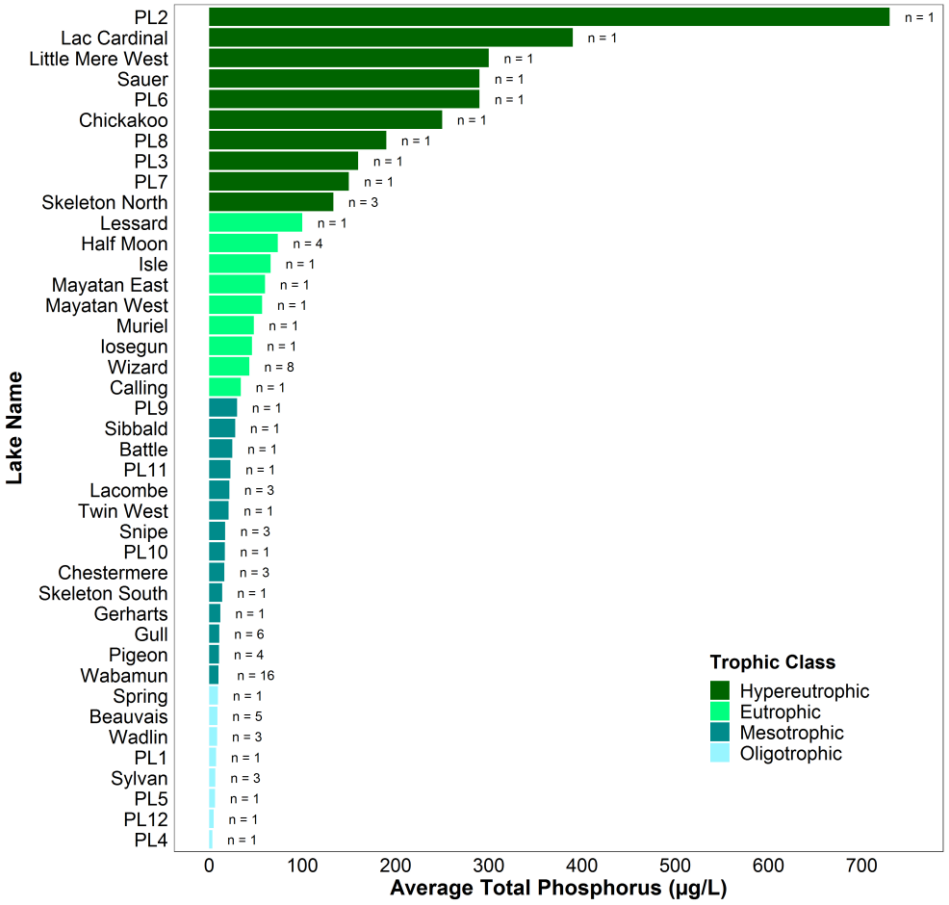


Figure 1. Average total phosphorus (µg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average total phosphorus represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

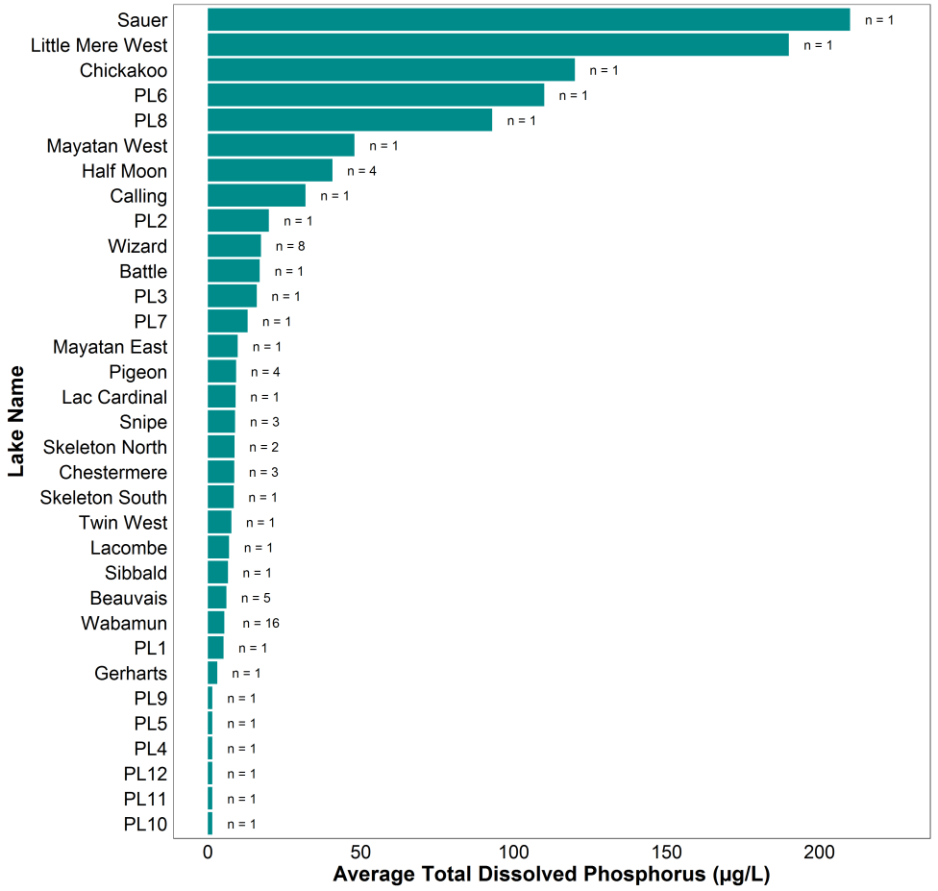


Figure 2. Average total dissolved phosphorus (µg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average total dissolved phosphorus represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

Results

Nitrogen is an essential nutrient for the growth of algae, cyanobacteria, and aquatic plants. High levels can indicate the lake is situated in naturally high nutrient soils, but also potential nutrient pollution from the lake's watershed. Total Kjeldahl nitrogen (TKN) is used commonly to assess levels of total lake nitrogen, and to categorize the lake based on productivity (trophic class). It represents the amount of organic-bound and ammonia derived nitrogen levels. Levels in lakes from Winter LakeKeepers 2020-2021 indicates a wide range of values, similar to the range of values from the summer (Figure 3).

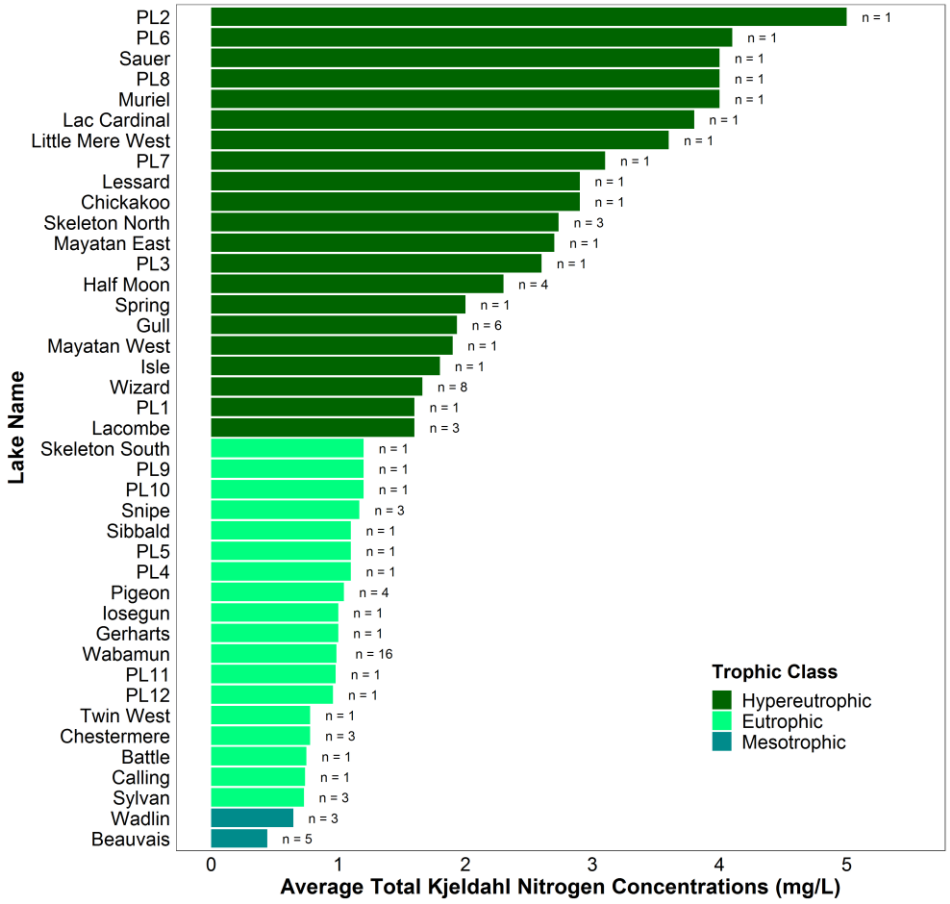


Figure 3. Average total Kjeldahl nitrogen (mg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average total Kjeldahl nitrogen represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

Results

Representing nutrient levels as ratios can help describe the extent of nitrogen vs. phosphorus limitation (TKN:TP), and also the proportion of phosphorus which is dissolved (TDP:TP), indicating extent of biological uptake. TKN:TP ratios indicate that the majority of lakes are phosphorus limited (TKN:TP > 50, Figure 4), and only one lake, PL2, may be nitrogen limited (TKN:TP < 20), although these ratios must be interpreted in the context of TKN and TP concentrations.[9] A wide range of TDP:TP ratios existed for the lakes, with some lakes nearing 1:1 TDP:TP, while the nine lowest lakes displayed TP values between 10 - 50 times larger than TDP (Figure 5).

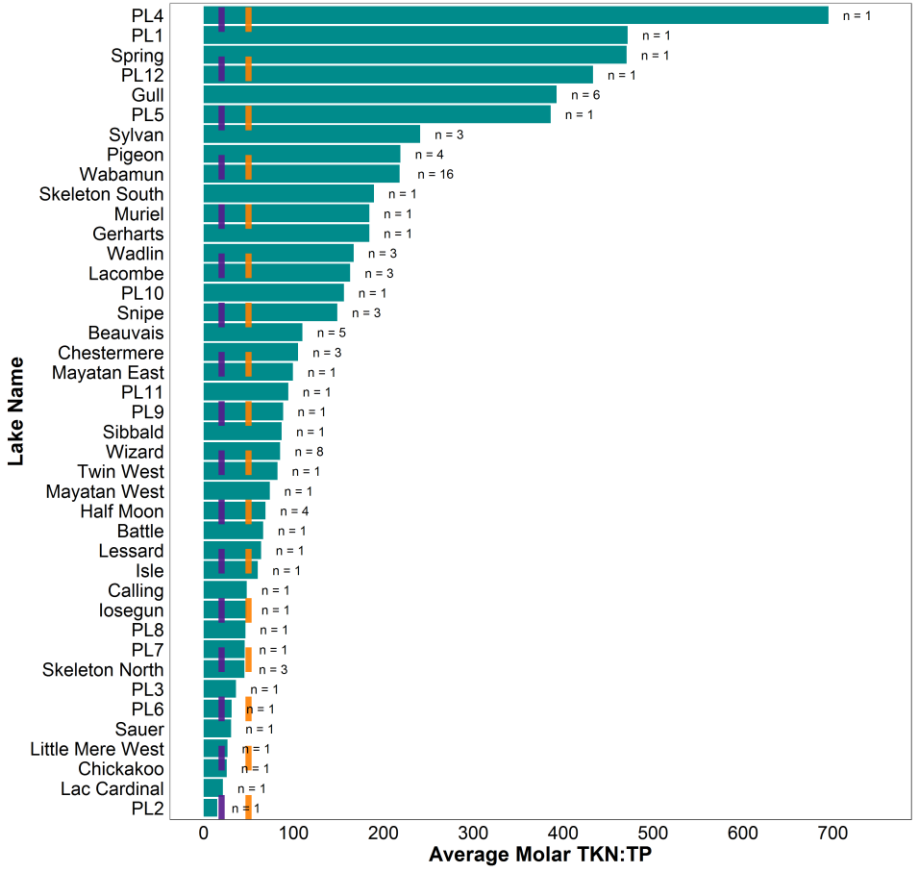


Figure 4. Average total Kjeldahl nitrogen (TKN) to average total phosphorus (TP) molar ratio from lakes sampled in Winter LakeKeepers 2020 -2021. Average TKN:TP represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021. 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.

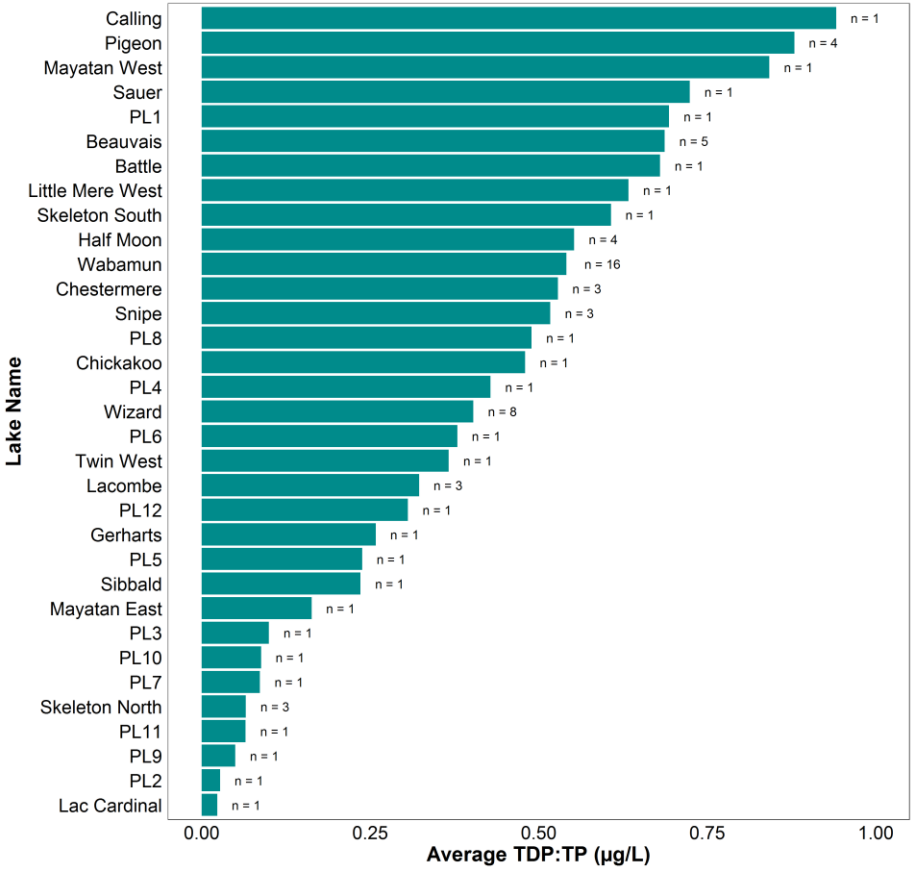


Figure 5. Average total dissolved phosphorus (TDP) to average total phosphorus (TP) ratio (µg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average TDP:TP represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple 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 2020 and April 2021.

[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

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 in lakes from Winter LakeKeepers 2020-2021 indicates a wide range of values, from as low as 3 mg/L at Chestermere Lake, to as high as 30 mg/L at Lac Cardinal (Figure 6). 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 from Winter LakeKeepers 2020-2021 had a range from 1 – 35 mg/L (Figure 7). Preliminary comparison with summer values from lakes samples in LakeWatch 2020 indicate winter Cl levels are usually higher.

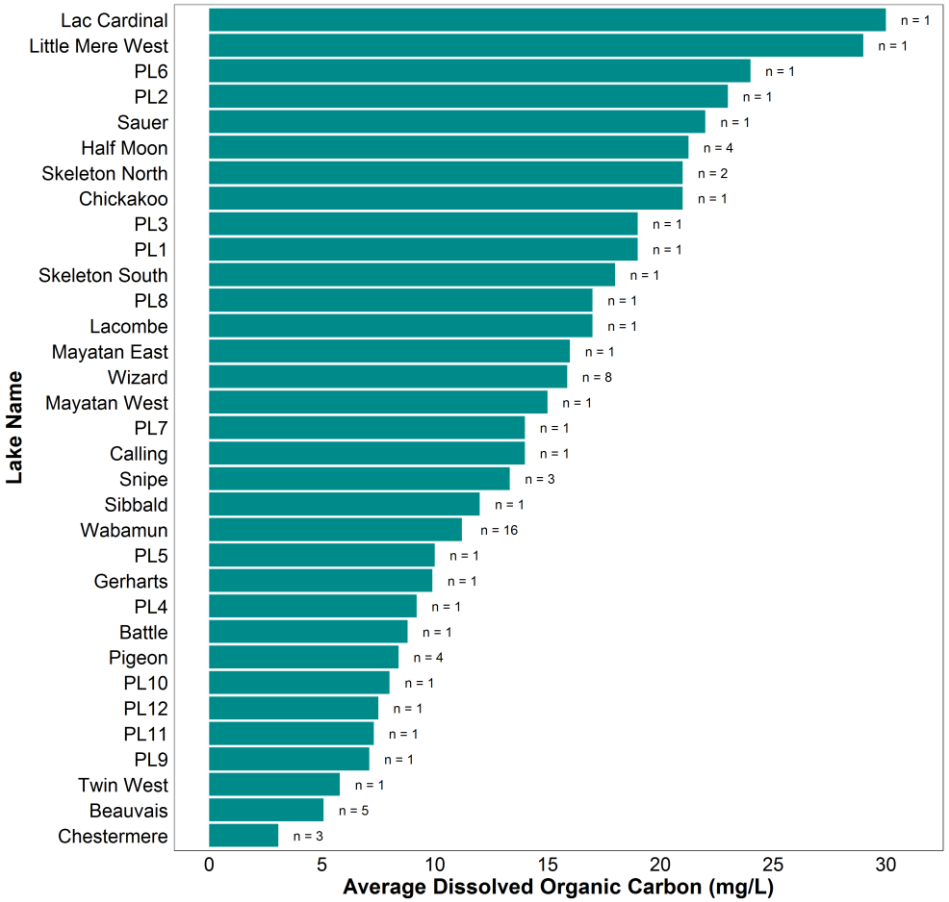


Figure 6. Average dissolved organic carbon (mg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average dissolved organic carbon represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

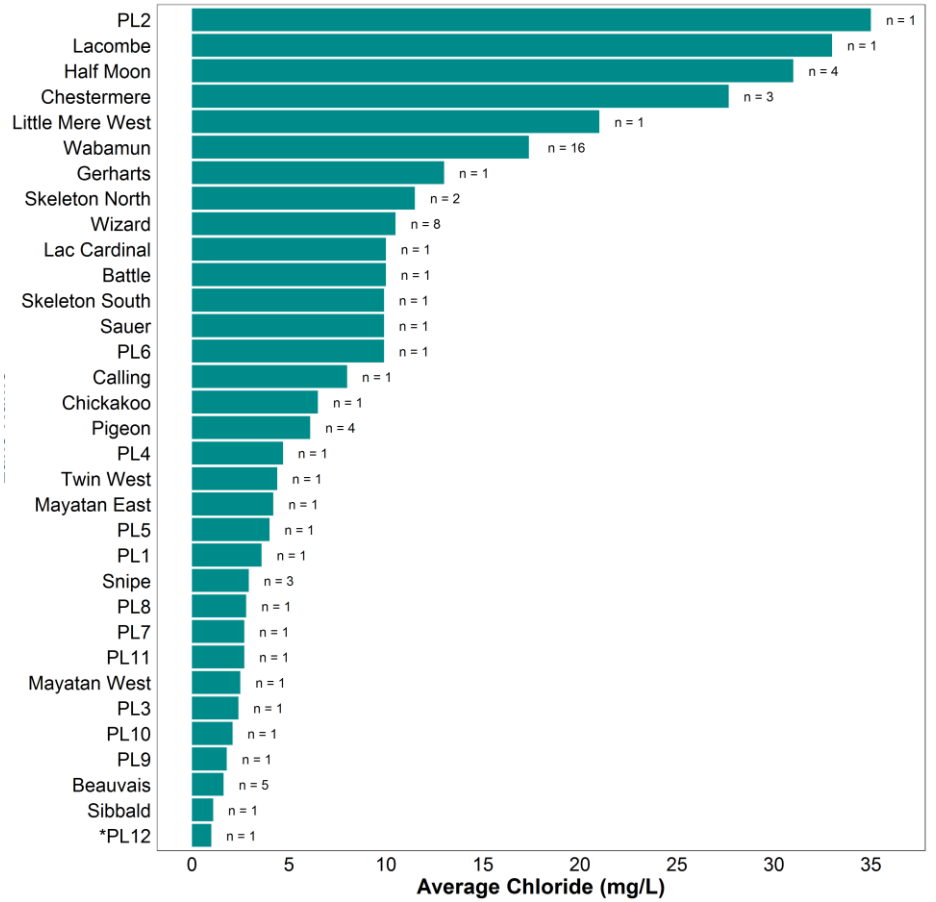


Figure 7. Average chloride (mg/L) from lakes sampled in Winter LakeKeepers 2020 -2021. Average chloride represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021. *Note: PL12 below detection limit of 1 mg/L.

Results

Conductivity indicates the total levels of dissolved ions or salt with 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 2020-2021 had a range from 120 – 1200 µS/cm (Figure 9). Preliminary comparison with summer values from lakes samples in LakeWatch 2020 indicate winter conductivity levels are usually higher. 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 2020-2021 had a range from 6.8 – 8.3 (Figure 10).

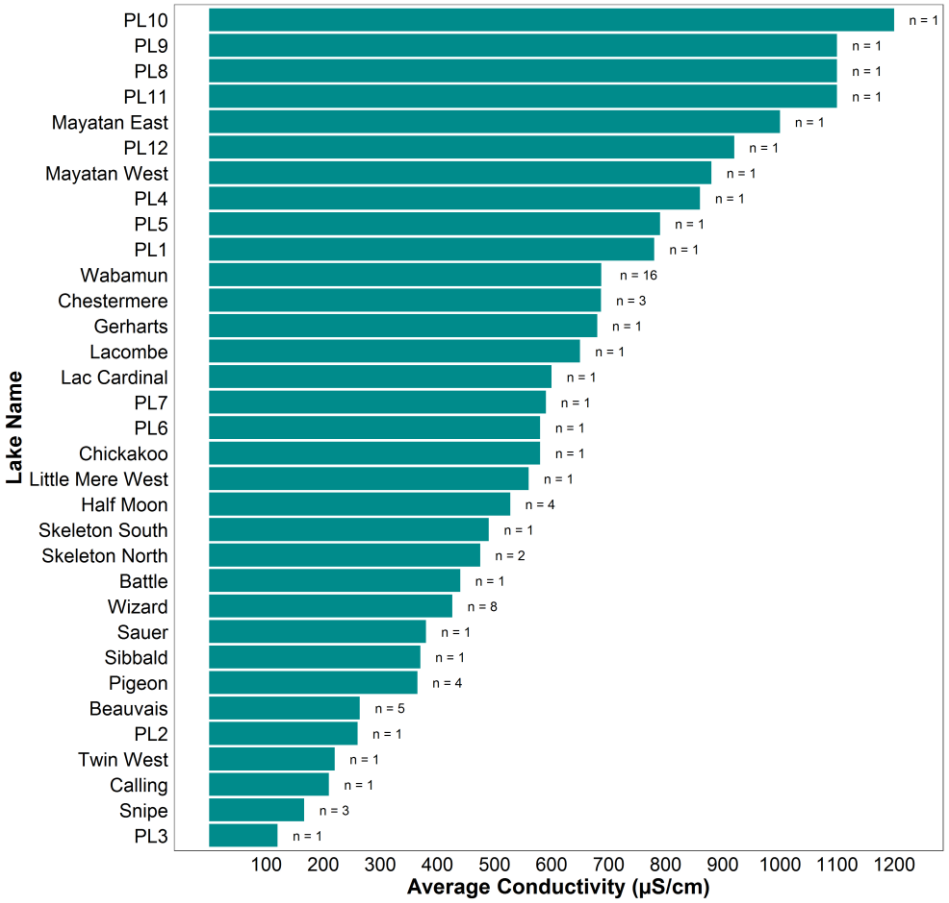


Figure 9. Average conductivity (µS/cm) from lakes sampled in Winter LakeKeepers 2020 -2021. Average conductivity represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

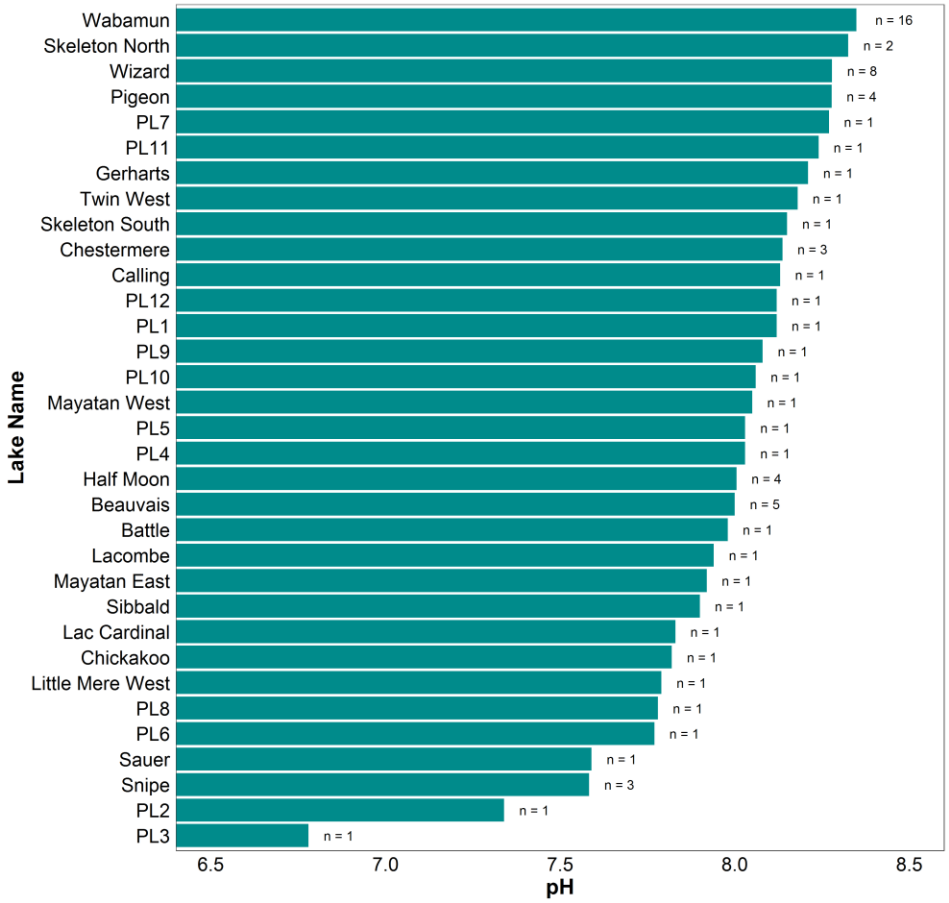
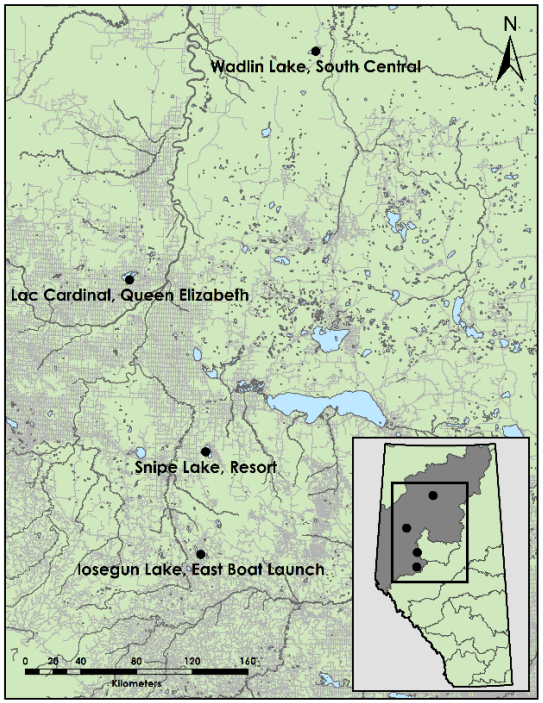


Figure 10. Average pH from lakes sampled in Winter LakeKeepers 2020 - 2021. Average pH represents the average from across sample dates, if lakes had multiple sample events, and across sample locations, if lakes had multiple sampled locations (number of samples indicated by the "n" value beside each bar). Samples were taken at 0.1m, right below the ice, between December 2020 and April 2021.

Peace River Watershed

Four lakes were sampled within the Peace River watershed in Winter LakeKeepers 2020-2021, which was the second highest number of lakes sampled in any watershed (Maps 1 & 2). Iosegun Lake and Lac Cardinal were sampled once each, and Snipe Lake and Wadlin Lake were sampled three times each between mid-January and mid-March. The lakes varied with their oxygen profiles, notably with Wadlin and Iosegun being fairly well oxygenated, Snipe displaying high surface levels but low bottom levels, and Lac Cardinal having low oxygen throughout its 4.8 m column (Figure 11). Nutrient levels were low for Wadlin and Snipe, with slight increases in total phosphorus (TP) through the season (Table 1a). Lac Cardinal had high nutrient levels, having the highest DOC levels of any lake sampled, and the second highest levels of TP (Figures 6 & 1). Wadlin had the deepest snow levels measured across all sampling events, having 30cm of snow cover for both the February and March sampling events (Table 1b).



Map 2. Sampling locations for Winter LakeKeepers 2020-2021, in the Peace River watershed. Peace River watershed highlighted in Alberta inset map.

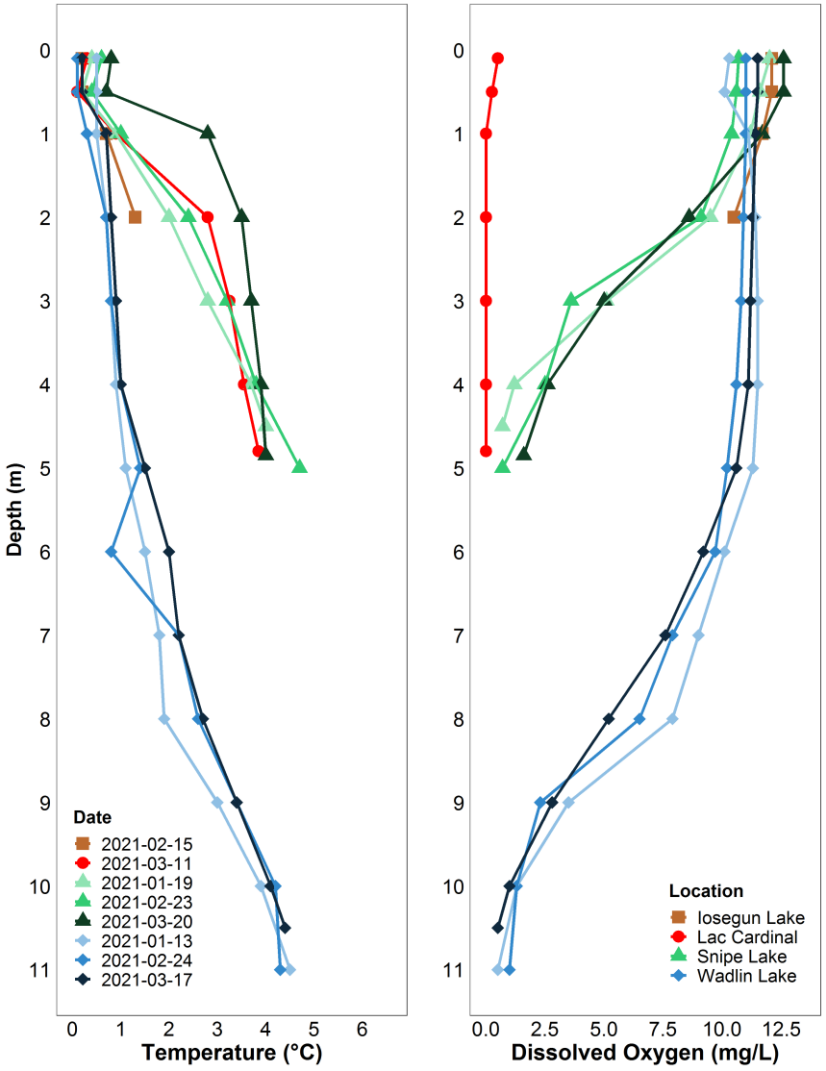


Figure 11. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Peace River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Peace River Watershed

TD Friends of the Environment Foundation

LakeKeepers

Table 1a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

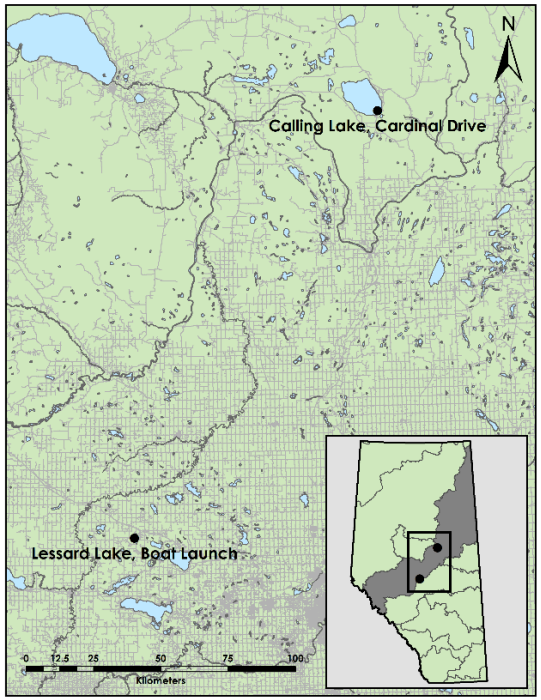
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Iosegun Lake, East Boat Launch	2021-02-15	1.0	46.0					
Lac Cardinal, Queen Elizabeth	2021-03-11	3.8	390.0	9.1	30.0	10.0	600	7.83
Snipe Lake, Resort	2021-01-19	1.1	13.0	6.0	13.0	1.9	170	7.63
Snipe Lake, Resort	2021-02-23	1.3	20.0	11.0	13.0	2.9	170	7.58
Snipe Lake, Resort	2021-03-20	1.1	19.0	9.9	14.0	4.0	160	7.54
Wadlin Lake, South Central	2021-01-13	0.7	7.1					
Wadlin Lake, South Central	2021-02-24	0.6	8.6					
Wadlin Lake, South Central	2021-03-17	0.7	10.0					

Table 1b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Peace River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Iosegun Lake, East Boat Launch	2021-02-15	-15	10	64	Opaque	Green	No
Lac Cardinal, Queen Elizabeth	2021-03-11	-19	17	75	Clear	Colourless	No
Snipe Lake, Resort	2021-01-19	1	8	38	Opaque	Colourless	No
Snipe Lake, Resort	2021-02-23	3	13	53	Opaque	Colourless	No
Snipe Lake, Resort	2021-03-20	3	0	53	Opaque	Colourless	No
Wadlin Lake, South Central	2021-01-13	-2	2	51	Clear	Colourless	No
Wadlin Lake, South Central	2021-02-24	-2	30	65	Opaque	Colourless	No
Wadlin Lake, South Central	2021-03-17	2	30	66	Clear	Colourless	No

Athabasca River Watershed

Two lakes were sampled within the Athabasca River watershed in Winter LakeKeepers 2020-2021 (Map 3). Lessard Lake was sampled on December 27th, 2020, and Calling Lake was sampled on March 6th, 2021. Oxygen levels were high for both lakes – Calling displayed 0% water column hypoxia, and Lessard only 6% (Appendix Table 1a & 1b). Nutrient levels were moderate for Calling, and it also displayed the highest TDP:TP ratio of any lake sampled, at 0.94 (Table 2a, Figure 5). Calling also had quite thick ice, at 81 cm (Table 2b). Lessard had high nutrient levels, ranking as eutrophic for TP and hypereutrophic for TKN. The lake was also reported as having a brown colour, with evidence of particles (Table 2b). The particles may have been under-ice algae or cyanobacteria, which may explain the very high levels of oxygen just below the ice-water interface. (Figure 12).



Map 3. Sampling locations for Winter LakeKeepers 2020-2021, in the Athabasca River watershed. Athabasca River watershed highlighted in Alberta inset map.

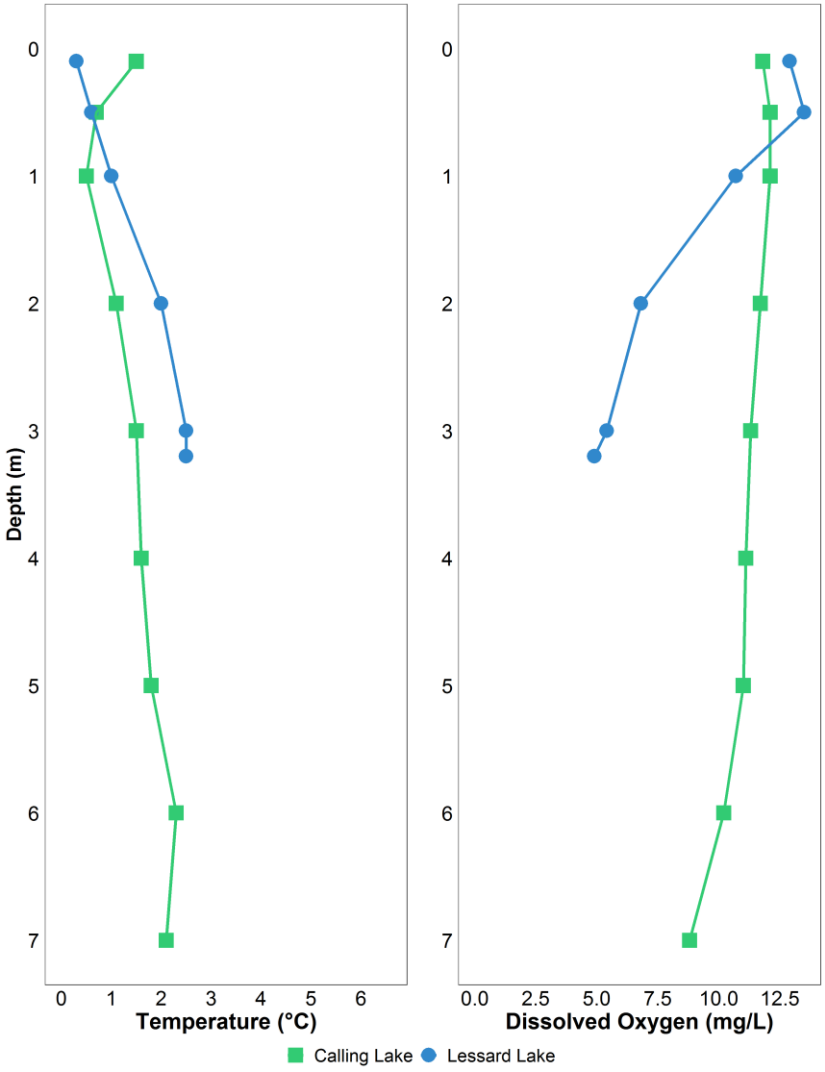


Figure 12. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Athabasca River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Athabasca River Watershed

Table 2a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 watershed in Winter 2020-2021. All samples taken at approximately 0.1 m depth.

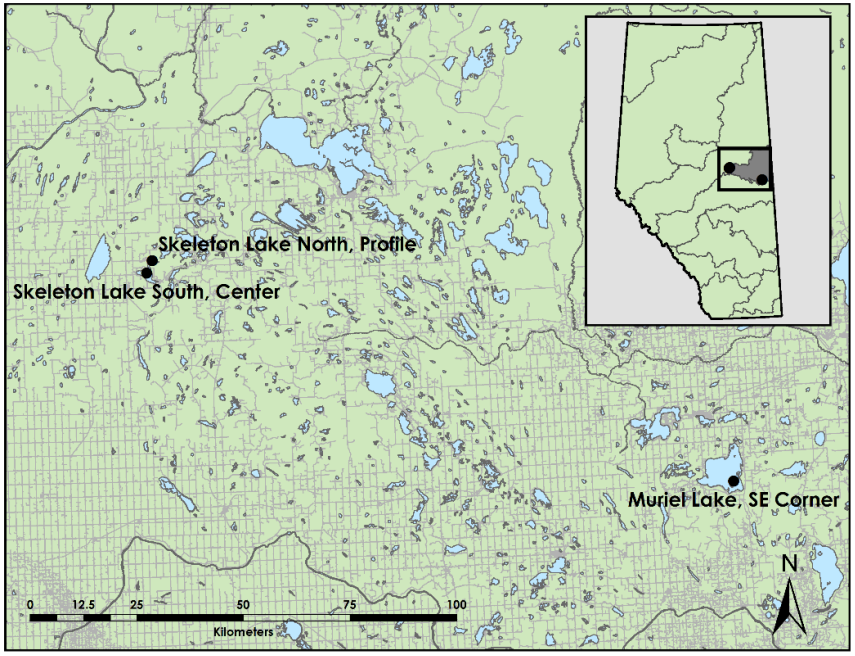
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Calling Lake, Cardinal Drive	2021-03-06	0.7	34.0	32.0	14.0	8.0	210	8.13
Lessard Lake, Boat Launch	2020-12-27	2.9	100.0					

Table 2b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Athabasca River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Calling Lake, Cardinal Drive	2021-03-06	2	9	81	Opaque	Colourless	No
Lessard Lake, Boat Launch	2020-12-27	-8	5	36	Opaque	Brown	Yes

Beaver River Watershed

Three lakes were sampled within the Beaver River watershed in Winter LakeKeepers 2020-2021 (Map 4). Muriel Lake and Skeleton Lake South were sampled once each, while Skeleton Lake North was sampled three times from January – March. The lakes varied with their oxygen profiles, notably with both basins of Skeleton Lake having high levels near the surface, and proceeding to anoxia (<1.0 mg/L) at the bottom (Figure 13). Muriel had low oxygen levels, displaying 100% hypoxia (Appendix Table 1b). Nutrient levels were high for Muriel and Skeleton North, with Muriel having among the highest TKN level of any lake (Table 3a, Figure 3). Skeleton South had proportionally lower levels of nutrients, having mesotrophic and eutrophic levels of TP and TKN, respectively (Figures 1 & 3, Table 3a). Additionally, Skeleton South had a much higher TDP:TP than Skeleton North, which was among the lowest ratios of any lake sampled (Figure 4). The brown colour and particles observed at Skeleton North are thought to be cyanobacteria within the *Planktothrix* genus (ALMS, microscope observation).



Map 4. Sampling locations for Winter LakeKeepers 2020-2021, in the Beaver River watershed. Beaver River watershed highlighted in Alberta inset map.

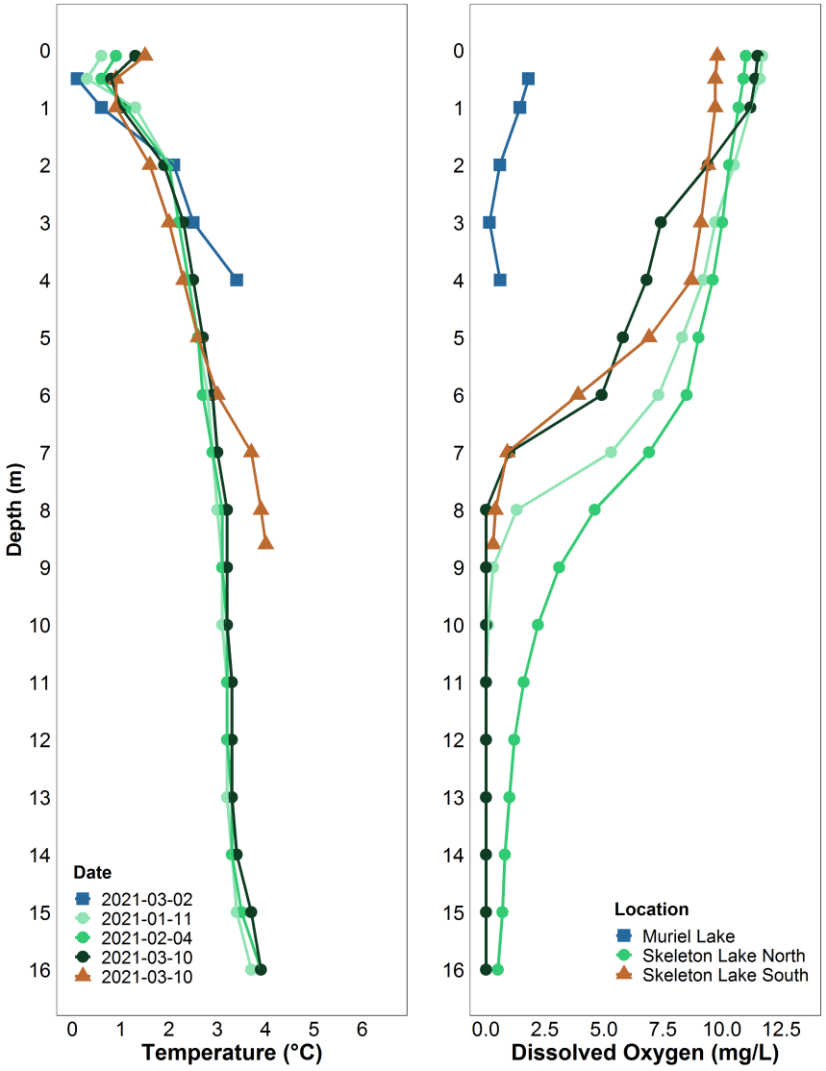


Figure 13. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Beaver River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Beaver River Watershed

TD Friends of the Environment Foundation

LakeKeepers

Table 3a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

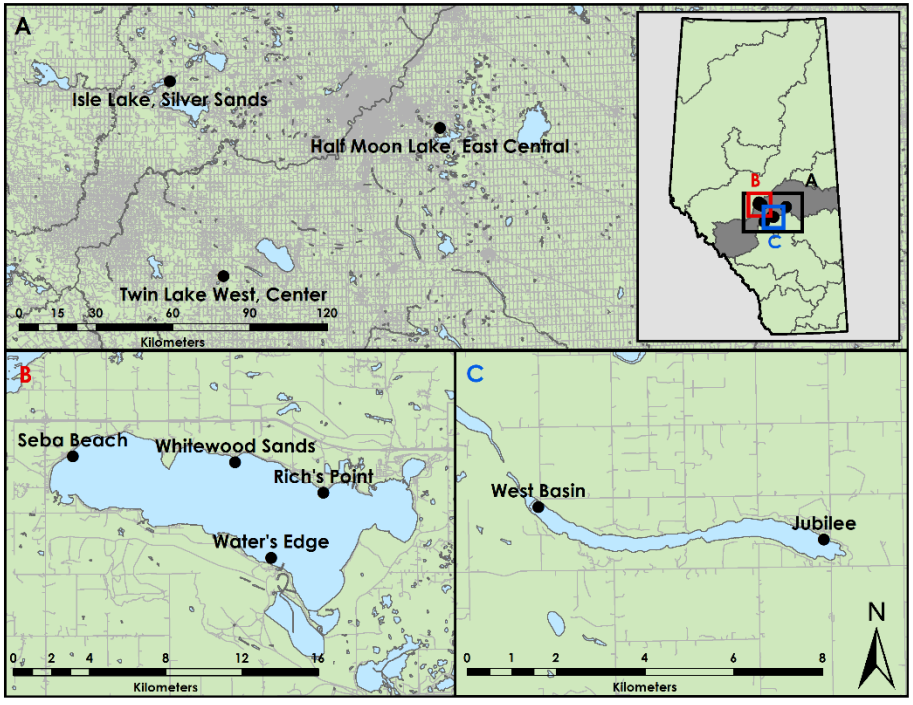
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Muriel Lake, SE Corner	2021-03-02	4.0	48.0					
Skeleton Lake North, Profile	2021-01-11	2.8	120.0					
Skeleton Lake North, Profile	2021-02-04	2.7	170.0	6.5	21.0	11.0	470	8.30
Skeleton Lake North, Profile	2021-03-10	2.7	110.0	11.0	21.0	12.0	480	8.35
Skeleton Lake South, Center	2021-03-10	1.2	14.0	8.5	18.0	9.9	490	8.15

Table 3b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Beaver River watershed in Winter 2020-2021.

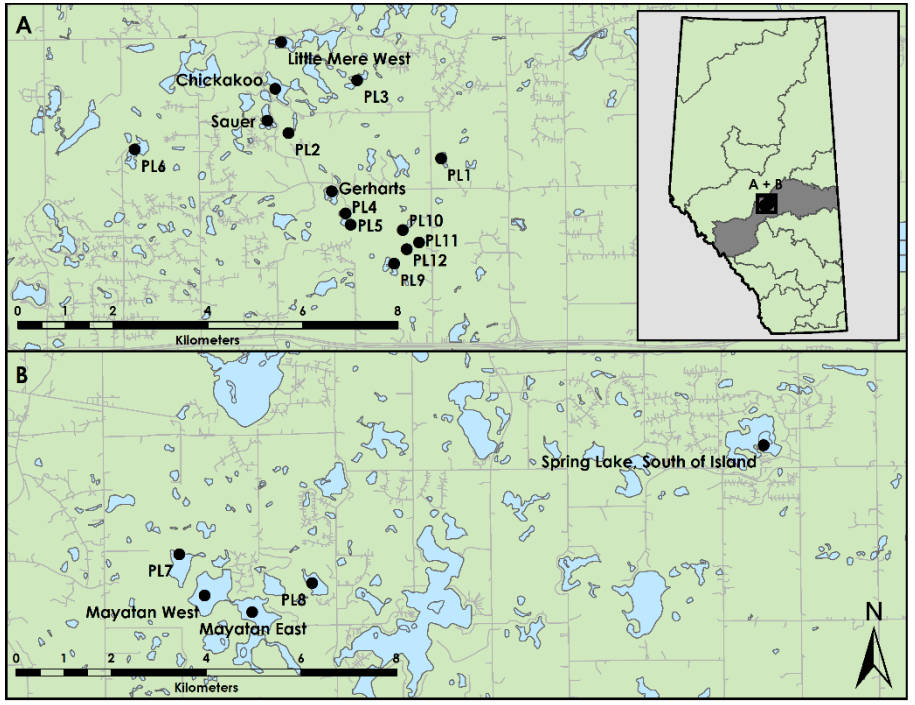
Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Muriel Lake, SE Corner	2021-03-02	-5	15	70	Opaque	Colourless	No
Skeleton Lake North, Profile	2021-01-11	-4	0	51	Opaque	Colourless	No
Skeleton Lake North, Profile	2021-02-04	-21	23	61	Opaque	Brown	Yes
Skeleton Lake North, Profile	2021-03-10	-12	13	67	Opaque	Brown	Yes
Skeleton Lake South, Center	2021-03-10	-13	15	72	Opaque	Colourless	No

North Saskatchewan River Watershed

Twenty-four lakes were sampled within the North Saskatchewan River watershed in Winter LakeKeepers 2020-2021, which was the most of any watershed (Maps 1 & 5). This watershed also had the greatest sampling effort, with 49 of the 90 sampling events that occurred across the province. Wabamun Lake and Wizard Lake had multiple sites sampled four times each, and a site at Half Moon Lake was also sampled four times. The lakes were sampled from December 14th – March 18th. The lakes varied in their dissolved oxygen (DO) levels, with Wabamun having good oxygenation throughout the season at all sites, except for moderate hypoxia in the lower third of the water columns of Seba Beach and Whitewood Sands during February and March (Appendix Table 1d). Sites at Wizard were similar, with water column hypoxia detected in the lower part of the water column at the Jubilee site only in January. Half Moon displayed high percentages of water column hypoxia through the season (Appendix Table 1a). Other lakes sampled in the watershed primarily displayed elevated surface DO levels, with decreases towards the bottom, regardless of lake depth (Figures 16-18). The majority of lakes within the Carvel Pitted Delta had high levels of water column hypoxia (Appendix Tables 1a – 1c). Heat map figures for Wabamun, Wizard and Half Moon revealed interesting seasonal dynamics – Seba Beach and Whitewood Sands displayed relatively unidirectional decreases in DO, while the other sites from the three lakes display late-season increases DO (Appendix Figures 2 & 3), highlighting the complexity winter lake DO levels.



Map 5.1 Sampling locations for Winter LakeKeepers 2020-2021, 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 5.2 Sampling locations for Winter LakeKeepers 2020-2021, in the North Saskatchewan River watershed. North Saskatchewan River watershed highlighted in Alberta inset map. Northern cluster of lakes sampled in the Carvel Pitted Delta in panel 'A,' and in 'B' for the southern cluster, plus Spring Lake.

North Saskatchewan River Watershed

Green lake water drawn up by the auger at PL2 Lake, March 2021

Water chemistry levels from lakes across the watershed also displayed high variability. Lakes sampled in the Carvel Pitted Delta occupy both the upper and lower ranges for TP, TDP, DOC, Cl, conductivity and pH (Figures 1-10). PL2 also displayed the highest TP and TKN levels of any lake (Figure 1, Figure 3), corresponding to the only lake with TKN:TP below 20 (Figure 4). PL1, PL4, PL5, PL12 also displayed oligotrophic levels of TP (Figure 1), which is relatively uncommon for lakes situated outside the alpine and foothill ecoregions in Alberta. Many lakes in the Carvel Pitted Delta were described as being green in colour, with corresponding observations of particles being present, suggesting elevated productivity of algae or cyanobacteria near the ice-water interface of those lakes (Table 5b-7b).

Wabamun: Water chemistry was mostly stable throughout the season and between sites, with the exception of TDP, which displayed dynamic levels through the season and between sites (Table 3a). The water chemistry from Water's Edge was the most different when all sample sites were compared. Ice thickness and snow cover were consistent across sites (Table 3b).

Wizard: Water chemistry varied much more between the two sites. In particular, under-ice levels of TP, TDP, and TKN were higher in the West Basin than at Jubilee (Table 4a). From a seasonal perspective, TKN appeared to increase in the lake through the season, and an appreciable decrease in conductivity and corresponding increase in pH was observed for the February and March sampling events. These results indicate a relatively high degree of heterogeneity between the two ends of the lake within the winter.

Half Moon: Levels of TKN, DOC, Cl and pH remained relatively stable throughout the season. TP appeared to increase throughout the season, with a relatively high and somewhat linear increase from 59 µg/L to 91 µg/L between the December and March sampling events. TDP levels jumped by 44 µg/L from the December to January sampling events, but do not track from that point with further increases of TP. TDP levels remained near 60 µg/L in February, then decreased greatly in March to 20 µg/L. Synthesizing these dynamics with DO levels may indicate that near sediment anoxia (DO < 1.0 mg/L) may explain phosphorus loading and TP increases through the winter, but late season increases of DO near the ice-water interface likely caused by an increase of algae and cyanobacteria growth would results in an uptake of the bioavailable TDP, and a lowering of the TDP:TP ratio (Table 4a, Figure 16, Appendix Figure 2).

North Saskatchewan River Watershed

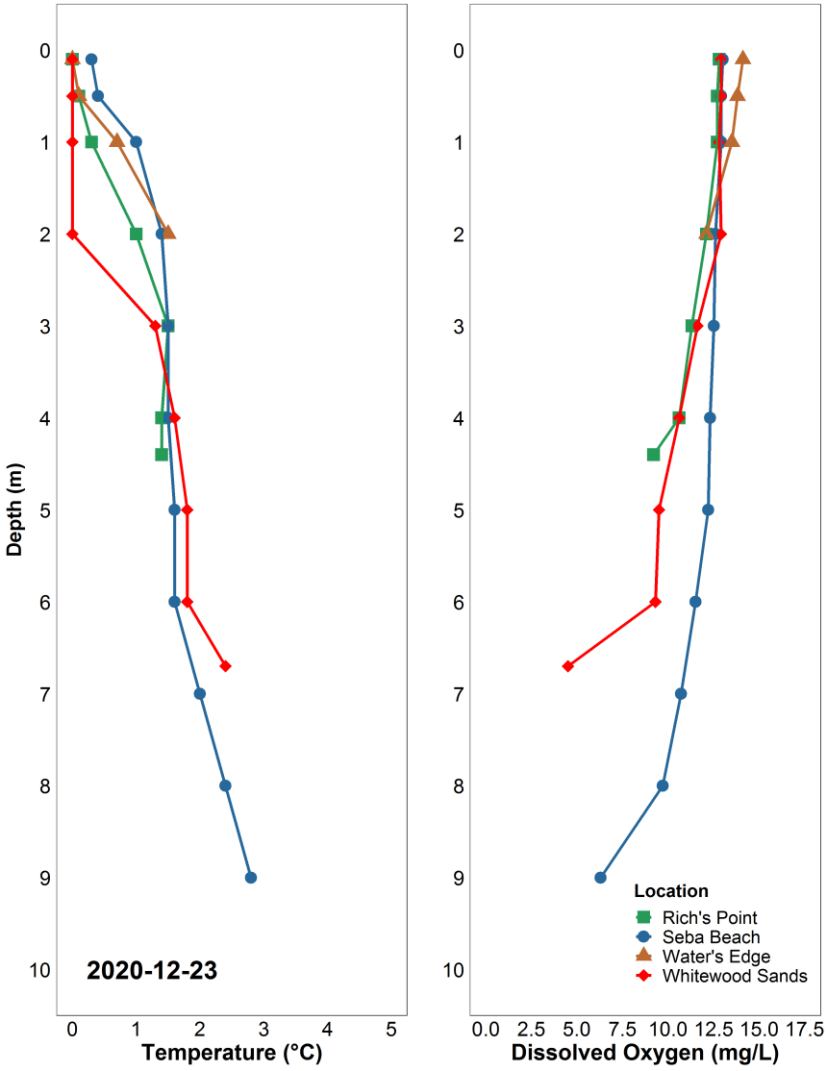


Figure 14a. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Wabamun Lake on December 23, 2020 . Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

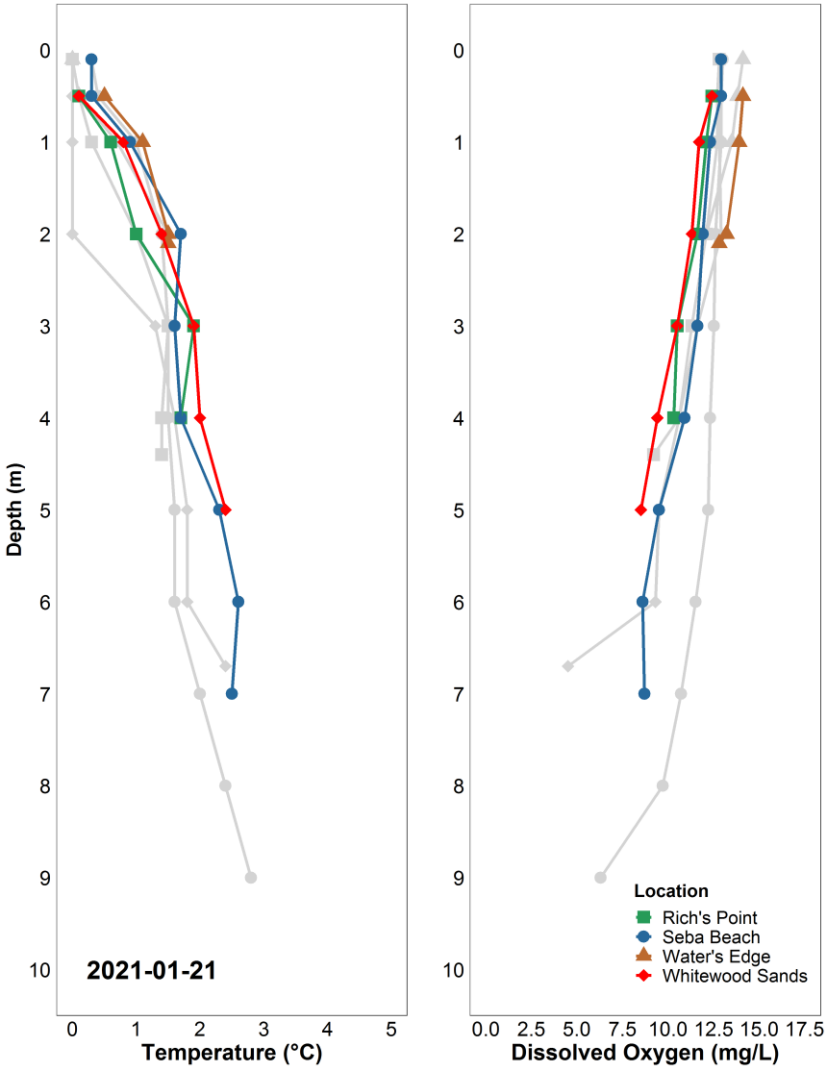


Figure 14b. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Wabamun Lake on January 21, 2021, with December 23, 2020 measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

North Saskatchewan River Watershed

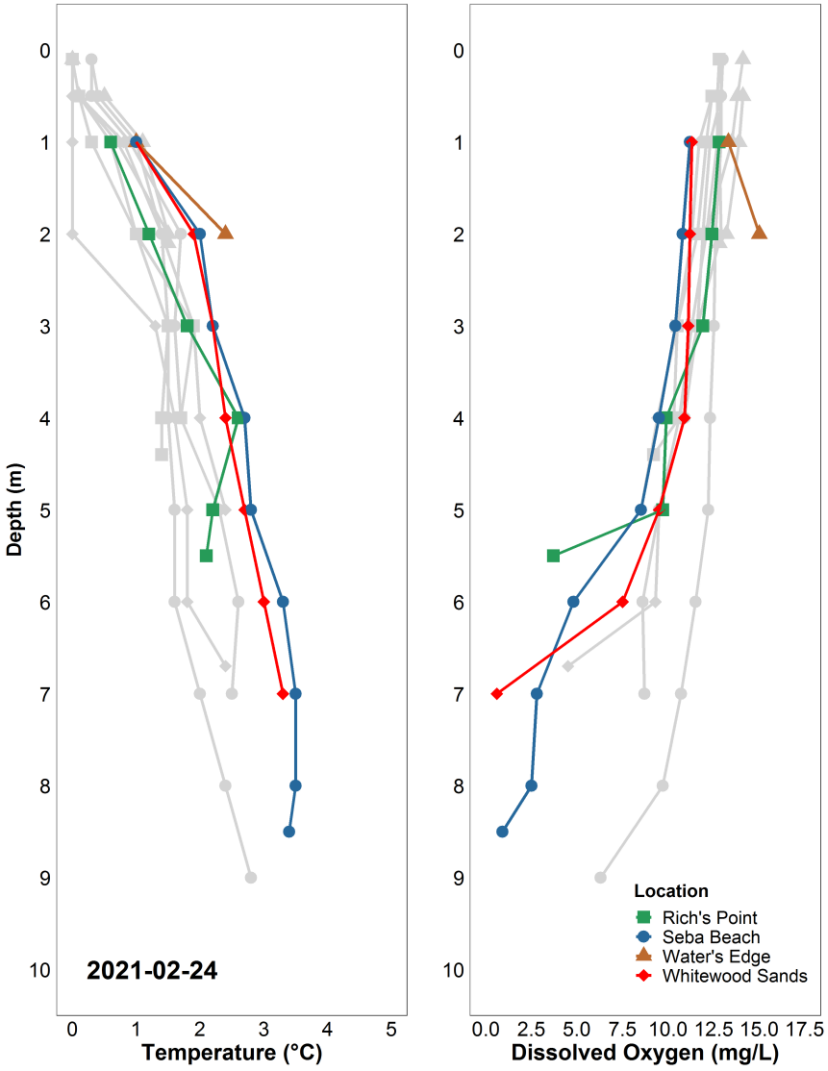


Figure 14c. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Wabamun Lake on February 24, 2021, with December 23, 2020 and January 21, 2021 measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

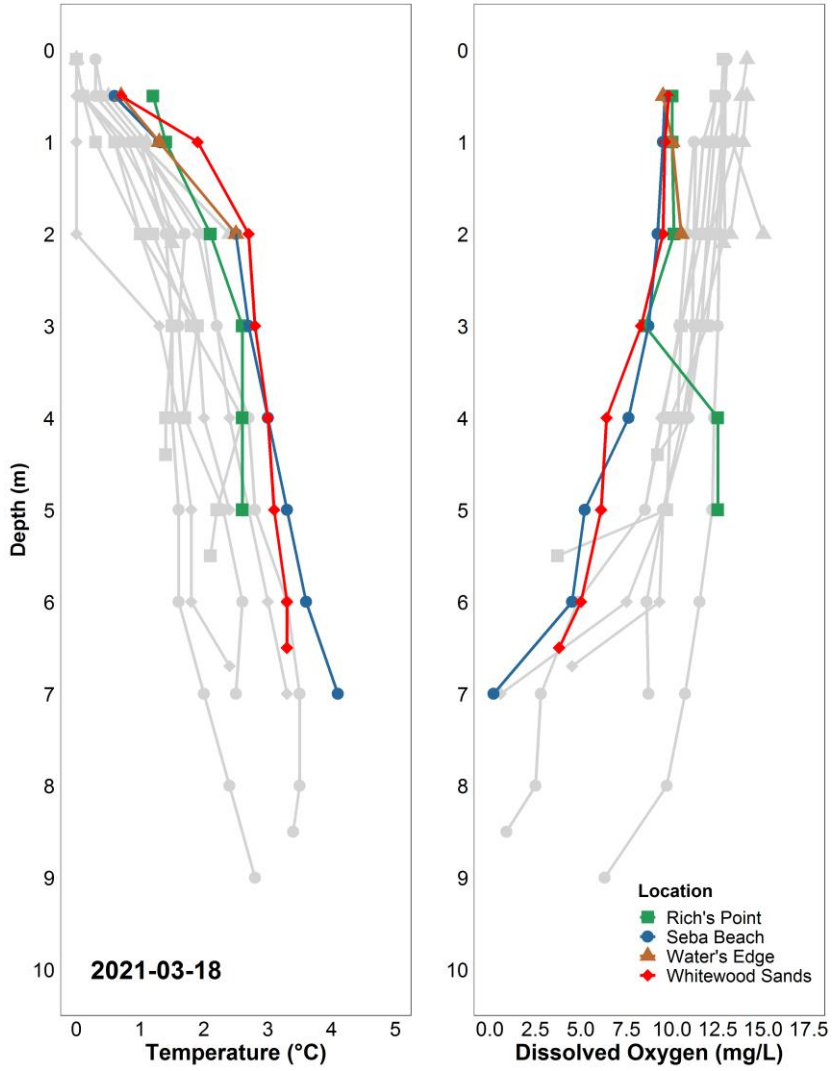


Figure 14d. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Wabamun Lake on March 18, 2021, with all previous winter profile measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

North Saskatchewan River Watershed

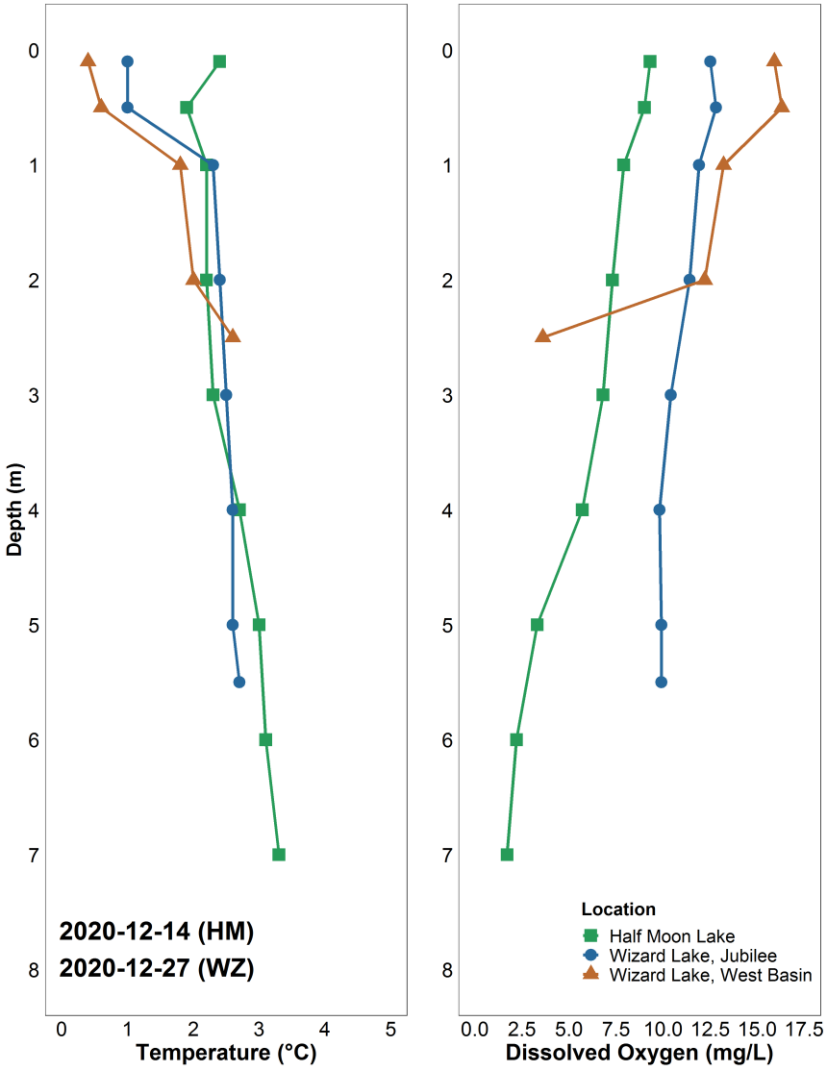


Figure 15a. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Half Moon Lake (HM) and Wizard Lake (WZ) during December 2020 (date of sample indicated on figure). Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

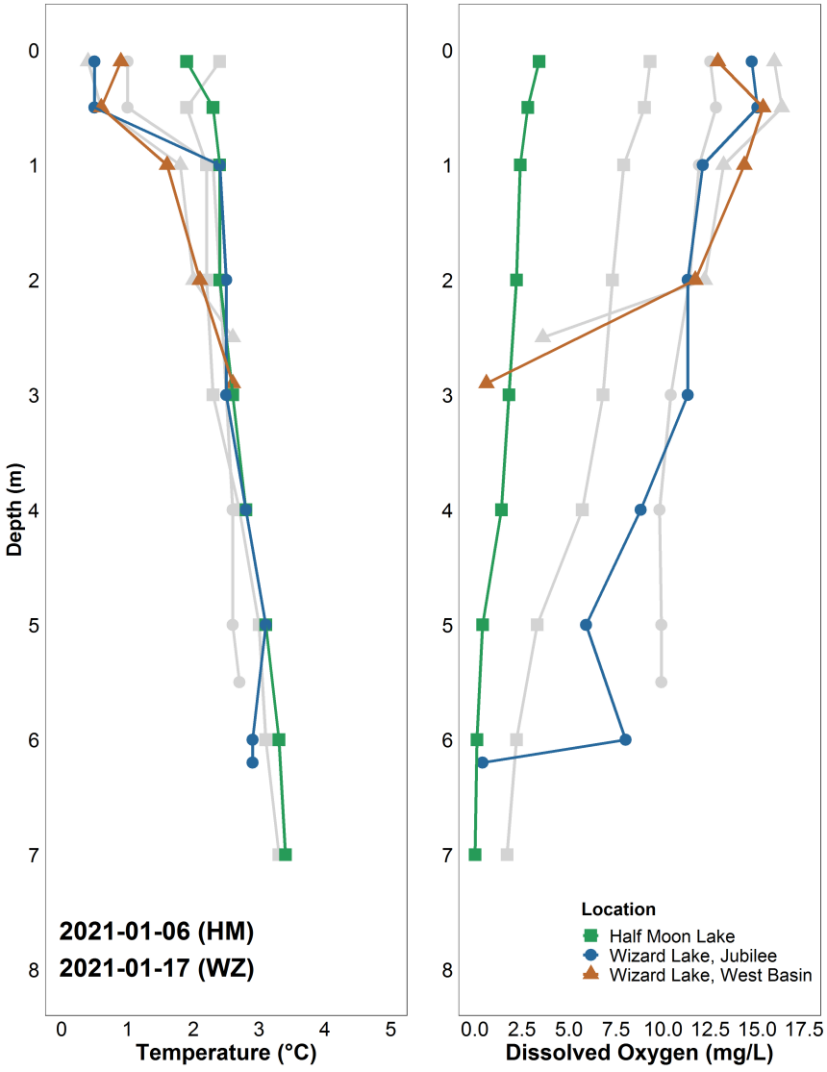


Figure 15b . Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Half Moon Lake (HM) and Wizard Lake (WZ) during January 2021 (date of sample indicated on figure), with December 2020 measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

North Saskatchewan River Watershed

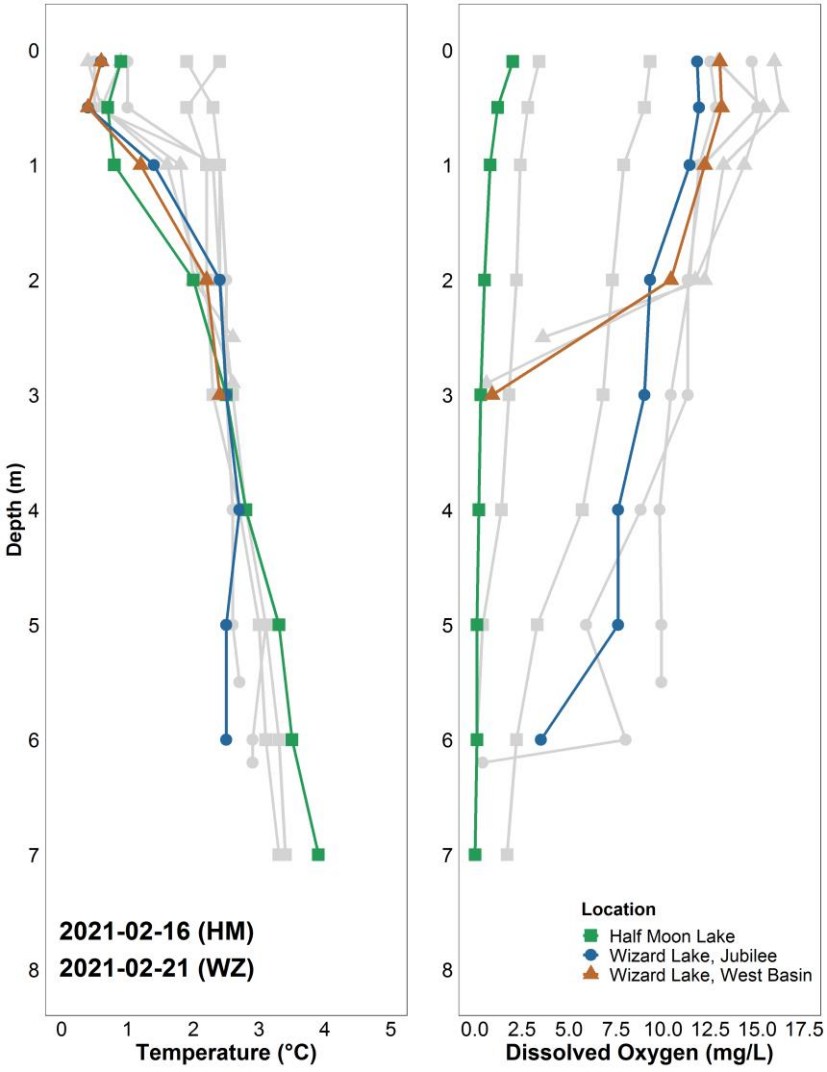


Figure 15c. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Half Moon Lake (HM) and Wizard Lake (WZ) during February 2021 (date of sample indicated on figure), with December 23 2020 and January 2021 measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

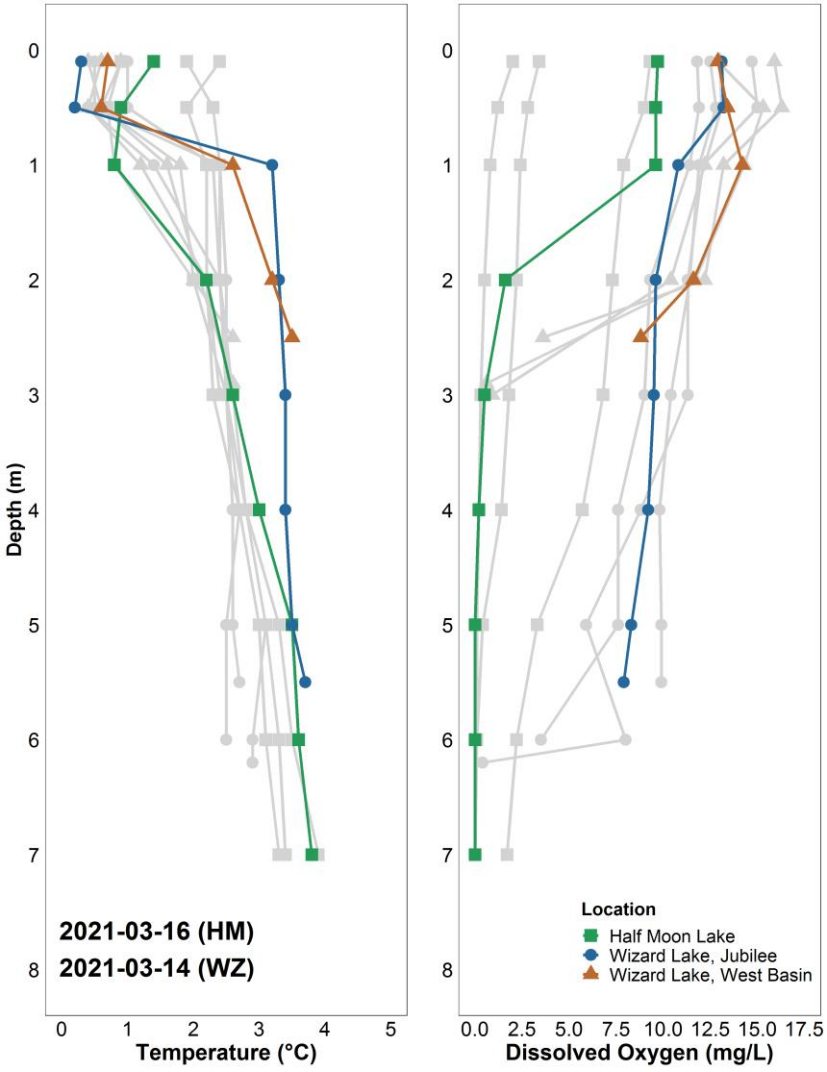


Figure 15d. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at Half Moon Lake (HM) and Wizard Lake (WZ) during March 2021 (date of sample indicated on figure), with all previous winter profile measurements in gray for context. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

North Saskatchewan River Watershed

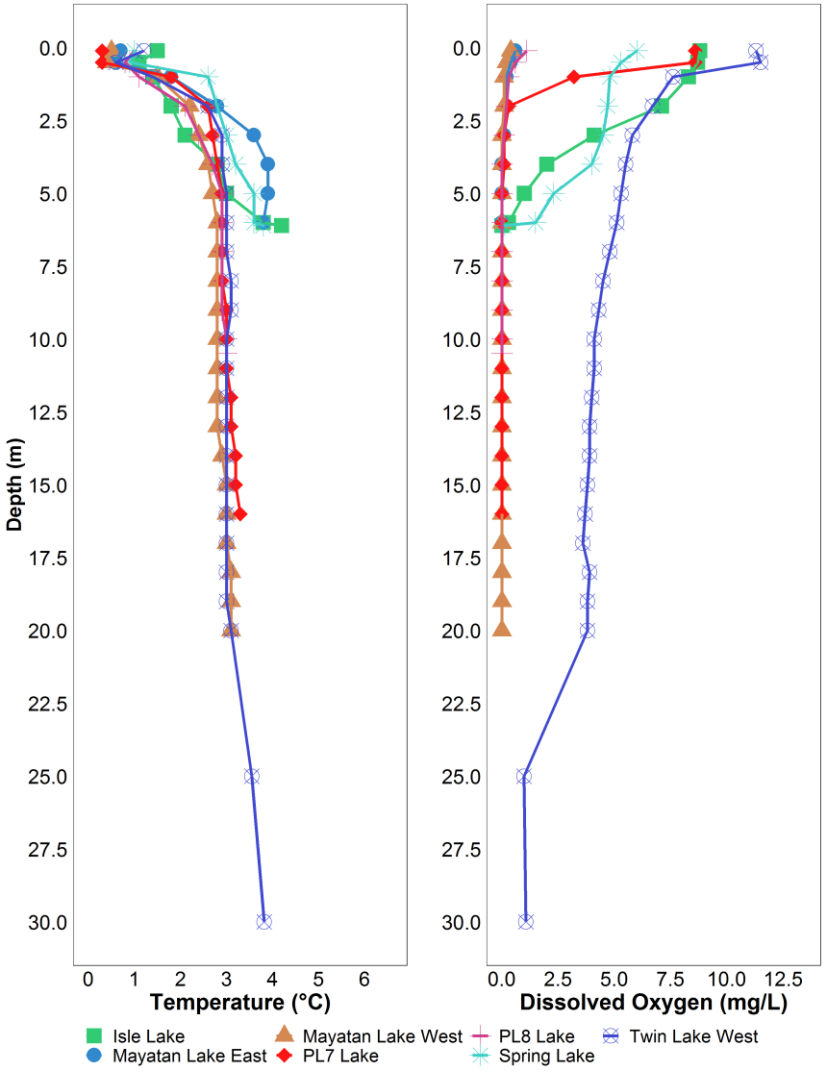


Figure 16. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the North Saskatchewan River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Lakes of similar location grouped together.

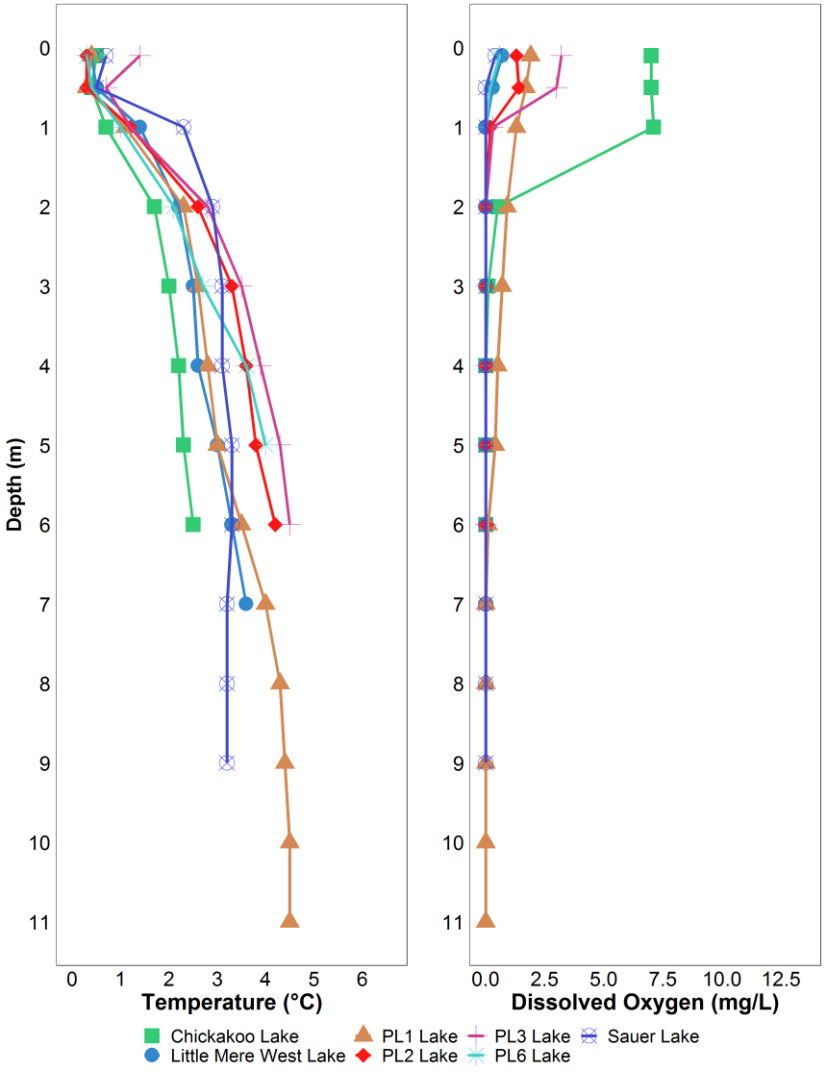


Figure 17. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the North Saskatchewan River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Lakes of similar location & depth grouped together.

North Saskatchewan River Watershed

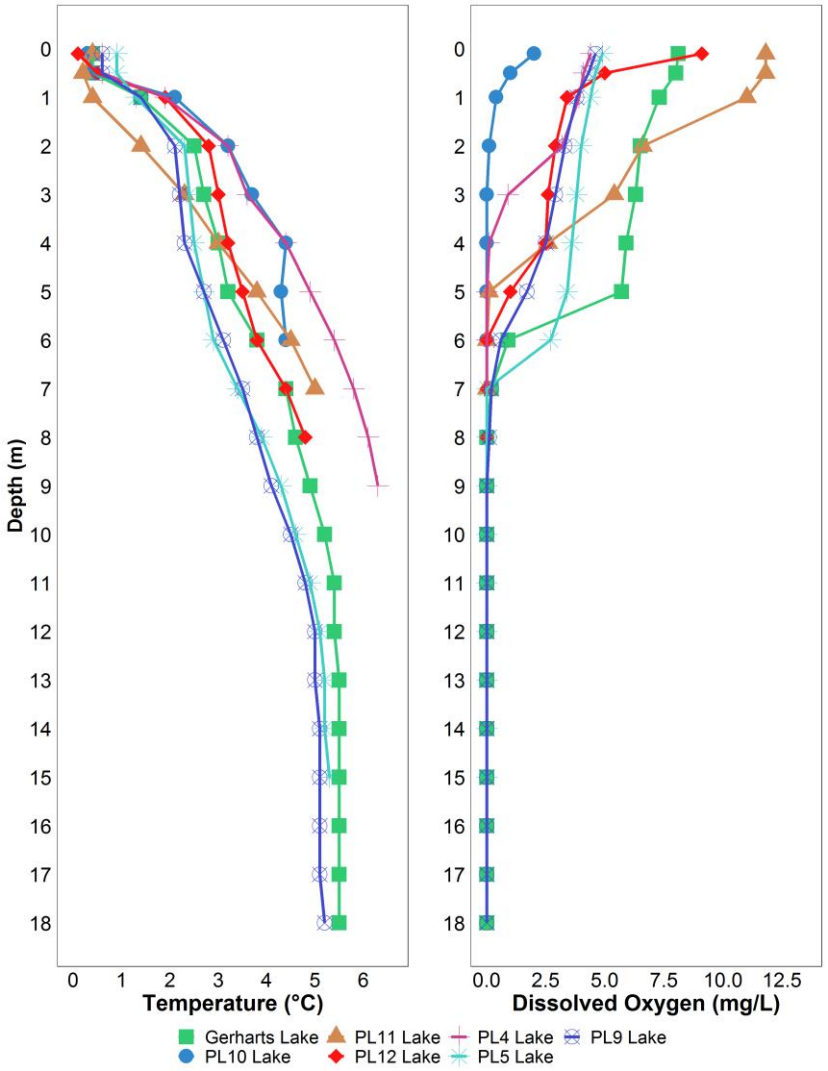


Figure 18. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the North Saskatchewan River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Lakes of similar location & depth grouped together.

North Saskatchewan River Watershed

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Table 3a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Wabamun Lake, Rich's Point	2020-12-23	0.91	9.7	7.6	11.0	17	690	8.34
Wabamun Lake, Rich's Point	2021-01-21	0.97	11.0	5.4	12.0	17	710	8.36
Wabamun Lake, Rich's Point	2021-02-24	1.10	8.6	8.1	12.0	19	740	8.37
Wabamun Lake, Rich's Point	2021-03-18	1.20	11.0	7.0	12.0	18	690	8.29
Wabamun Lake, Seba Beach	2020-12-23	1.10	9.9	6.3	12.0	17	670	8.35
Wabamun Lake, Seba Beach	2021-01-21	1.00	9.4	3.5	11.0	17	690	8.42
Wabamun Lake, Seba Beach	2021-02-24	1.00	12.0	7.1	11.0	18	680	8.38
Wabamun Lake, Seba Beach	2021-03-18	1.00	7.3	6.5	11.0	18	680	8.30
Wabamun Lake, Water's Edge	2020-12-23	0.62	7.2	5.5	8.3	18	660	8.27
Wabamun Lake, Water's Edge	2021-01-21	0.78	15.0	3.5	12.0	17	690	8.39
Wabamun Lake, Water's Edge	2021-02-24	0.97	10.0	5.5	11.0	18	700	8.39
Wabamun Lake, Water's Edge	2021-03-18	0.88	9.1	3.1	10.0	15	610	8.27
Wabamun Lake, Whitewood Sands	2020-12-23	0.95	9.5	4.9	12.0	17	680	8.33
Wabamun Lake, Whitewood Sands	2021-01-21	1.10	10.0	5.3	12.0	16	700	8.38
Wabamun Lake, Whitewood Sands	2021-02-24	1.10	11.0	5.8	10.0	18	720	8.39
Wabamun Lake, Whitewood Sands	2021-03-18	1.10	9.4	1.5	12.0	18	680	8.35

North Saskatchewan River Watershed

Table 3b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at Wabamun Lake in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Wabamun Lake, Rich's Point	2020-12-23	-5	5	36	Clear	Colourless	No
Wabamun Lake, Rich's Point	2021-01-21	-3	0	53	Opaque	Colourless	No
Wabamun Lake, Rich's Point	2021-02-24	0	0	76	Opaque	Colourless	No
Wabamun Lake, Rich's Point	2021-03-18	7	0	86	Opaque	Colourless	No
Wabamun Lake, Seba Beach	2020-12-23	-5	5	38	Clear	Colourless	No
Wabamun Lake, Seba Beach	2021-01-21	-4	0	53	Opaque	Colourless	No
Wabamun Lake, Seba Beach	2021-02-24	-3	0	66	Opaque	Colourless	No
Wabamun Lake, Seba Beach	2021-03-18	4	0	81	Opaque	Colourless	No
Wabamun Lake, Water's Edge	2020-12-23	-5	5	41	Clear	Colourless	No
Wabamun Lake, Water's Edge	2021-01-21	-4	0	53	Opaque	Colourless	No
Wabamun Lake, Water's Edge	2021-02-24	-4	0	81	Opaque	Colourless	No
Wabamun Lake, Water's Edge	2021-03-18	-4	0	81	Opaque	Colourless	No
Wabamun Lake, Whitewood Sands	2020-12-23	-6	5	41	Clear	Colourless	No
Wabamun Lake, Whitewood Sands	2021-01-21	-3	0	53	Opaque	Colourless	No
Wabamun Lake, Whitewood Sands	2021-02-24	-2	0	76	Opaque	Colourless	No
Wabamun Lake, Whitewood Sands	2021-03-18	5	0	81	Opaque	Colourless	No

North Saskatchewan River Watershed

Table 4a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from Half Moon Lake and Wizard Lake, sampled in Winter 2020-2021. All samples taken at approximately 0.1 m depth.

Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Half Moon Lake, East Central	2020-12-14	2.4	59	19.0	22	30.0	500	8.16
Half Moon Lake, East Central	2021-01-06	2.2	61	63.0	19	29.0	520	7.71
Half Moon Lake, East Central	2021-02-16	2.2	84	61.0	21	33.0	550	8.03
Half Moon Lake, East Central	2021-03-16	2.4	91	20.0	23	32.0	540	8.12
Wizard Lake, Jubilee	2020-12-27	1.1	28	9.5	14	8.2	400	8.15
Wizard Lake, Jubilee	2021-01-17	1.5	47	9.8	18	8.6	450	8.33
Wizard Lake, Jubilee	2021-02-21	1.5	27	10.0	15	8.9	450	8.28
Wizard Lake, Jubilee	2021-03-14	1.6	26	5.8	14	13.0	370	8.48
Wizard Lake, West Basin	2020-12-27	1.5	49	23.0	15	8.7	420	8.40
Wizard Lake, West Basin	2021-01-17	1.9	75	15.0	16	8.4	440	7.95
Wizard Lake, West Basin	2021-02-21	2.1	40	33.0	19	19.0	480	8.21
Wizard Lake, West Basin	2021-03-14	2.1	53	33.0	16	9.2	400	8.43

North Saskatchewan River Watershed

Table 4b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at Half Moon Lake and Wizard Lake in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Half Moon Lake, East Central	2020-12-14	-10	0	32	Opaque	Colourless	No
Half Moon Lake, East Central	2021-01-06	0	1	40	Opaque	Colourless	No
Half Moon Lake, East Central	2021-02-16	-22	8	86	Colourless	Colourless	No
Half Moon Lake, East Central	2021-03-16	0	0	91	Clear	Colourless	No
Wizard Lake, Jubilee	2020-12-27	-6	2	43	Clear	Colourless	No
Wizard Lake, Jubilee	2021-01-17	3	0	48	Clear	Colourless	Yes
Wizard Lake, Jubilee	2021-02-21	6	8	67	Opaque	Colourless	No
Wizard Lake, Jubilee	2021-03-14	9	0	69	Opaque	Colourless	No
Wizard Lake, West Basin	2020-12-27	-7	2	36	Opaque	Colourless	No
Wizard Lake, West Basin	2021-01-17	4	1	53	Clear	Colourless	No
Wizard Lake, West Basin	2021-02-21	7	8	69	Opaque	Colourless	No
Wizard Lake, West Basin	2021-03-14	11	0	74	Opaque	Colourless	No

North Saskatchewan River Watershed

Table 5a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes of similar location in the North Saskatchewan River watershed, sampled in Winter 2020-2021. All samples taken at approximately 0.1 m depth.

Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Isle Lake, Silver Sands	2020-12-30	1.8	66.0					
Mayatan Lake East, Profile	2021-02-17	2.7	60.0	9.8	16.0	4.2	1000	7.92
Mayatan Lake West, Profile	2021-02-17	1.9	57.0	48.0	15.0	2.5	880	8.05
PL7 Lake, Profile	2021-03-11	3.1	150.0	13.0	14.0	2.7	590	8.27
PL8 Lake, Profile	2021-02-17	4.0	190.0	93.0	17.0	2.8	1100	7.78
Spring Lake, South of Island	2021-01-02	2.0	9.4					
Twin Lake West, Center	2021-03-14	0.8	21.0	7.7	5.8	4.4	220	8.18

Table 5b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes of similar location in the North Saskatchewan River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Isle Lake, Silver Sands	2020-12-30	-6	5	43	Opaque	Slight Yellowish	Yes
Mayatan Lake East, Profile	2021-02-17	-8	20	60	Clear	Brown	No
Mayatan Lake West, Profile	2021-02-17	-11	20	50	Clear	Colourless	No
PL7 Lake, Profile	2021-03-11	4	9	54	Clear	Colourless	No
PL8 Lake, Profile	2021-02-17	-7	20	50	Clear	Green	No
Spring Lake, South of Island	2021-01-02	-2	3	41	Opaque	Colourless	No
Twin Lake West, Center	2021-03-14	5	10	56	Opaque	Green	No

North Saskatchewan River Watershed

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Table 6a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes of similar location & depth in the North Saskatchewan River watershed, sampled in Winter 2020-2021. All samples taken at approximately 0.1 m depth.

Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Chickakoo Lake, Profile	2021-03-07	2.9	250.0	120.0	21.0	6.5	580	7.82
Little Mere West Lake, Profile	2021-03-07	3.6	300.0	190.0	29.0	21.0	560	7.79
PL1 Lake, Profile	2021-03-06	1.6	7.5	5.2	19.0	3.6	780	8.12
PL2 Lake, Profile	2021-03-06	5.0	730.0	20.0	23.0	35.0	260	7.34
PL3 Lake, Profile	2021-03-07	2.6	160.0	16.0	19.0	2.4	120	6.78
PL6 Lake, Profile	2021-03-07	4.1	290.0	110.0	24.0	9.9	580	7.77
Sauer Lake, Profile	2021-03-07	4.0	290.0	210.0	22.0	9.9	380	7.59

Table 6b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes of similar location & depth in the North Saskatchewan River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Chickakoo Lake, Profile	2021-03-07	2	5	60	Clear	Green	Yes
Little Mere West Lake, Profile	2021-03-07	7	3	54	Opaque	Green	Yes
PL1 Lake, Profile	2021-03-06	7	15	46	Clear	Brown	No
PL2 Lake, Profile	2021-03-06	8	15	56	Opaque	Green	Yes
PL3 Lake, Profile	2021-03-07	7	5	57	Opaque	Brown	Yes
PL6 Lake, Profile	2021-03-07	8	5	53	Opaque	Green	No
Sauer Lake, Profile	2021-03-07	3	5	52	Opaque	Brown	No

North Saskatchewan River Watershed

Table 7a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus in µg/L, DOC = dissolved organic carbon in mg/L, Cl- = dissolved chloride in mg/L, Cond. = conductivity in µS/cm) from lakes of similar location & depth in the North Saskatchewan River watershed, sampled in Winter 2020-2021. All samples taken at approximately 0.1 m depth.

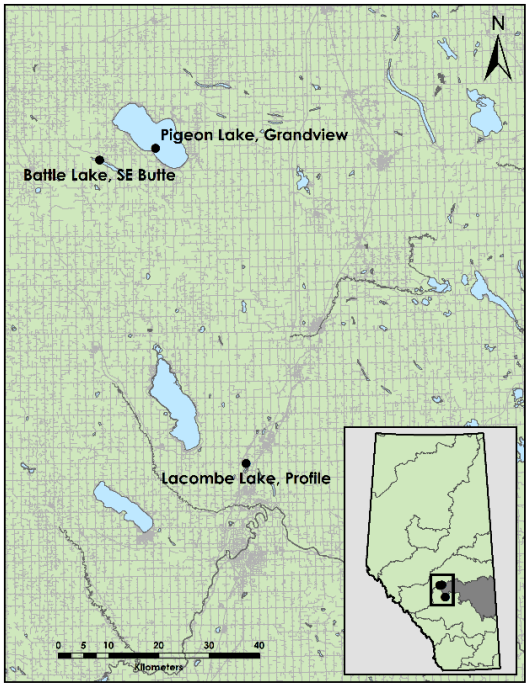
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Gerharts Lake, Profile	2021-03-06	1.0	12.0	3.1	9.9	13.0	680	8.21
PL10 Lake, Profile	2021-03-14	1.2	17.0	1.5	8.0	2.1	1200	8.06
PL11 Lake, Profile	2021-03-14	1.0	23.0	1.5	7.3	2.7	1100	8.24
PL12 Lake, Profile	2021-03-14	1.0	4.9	1.5	7.5	1.0	920	8.12
PL4 Lake, Profile	2021-03-06	1.1	3.5	1.5	9.2	4.7	860	8.03
PL5 Lake, Profile	2021-03-06	1.1	6.3	1.5	10.0	4.0	790	8.03
PL9 Lake, Profile	2021-03-10	1.2	30.0	1.5	7.1	1.8	1100	8.08

Table 7b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes of similar location & depth in the North Saskatchewan River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Gerharts Lake, Profile	2021-03-06	7	4	53	Clear	Colourless	No
PL10 Lake, Profile	2021-03-14	5	15	45	Clear	Green	No
PL11 Lake, Profile	2021-03-14	5	2	55	Clear	Colourless	No
PL12 Lake, Profile	2021-03-14	5	9	42	Clear	Colourless	No
PL4 Lake, Profile	2021-03-06	8	13	58	Clear	Colourless	No
PL5 Lake, Profile	2021-03-06	8	6	64	Clear	Colourless	No
PL9 Lake, Profile	2021-03-10	-8	3	55	Clear	Colourless	No

Battle River Watershed

Pigeon Lake, Lacombe Lake and Battle Lake were lakes sampled within the Battle River watershed in Winter LakeKeepers 2020-2021 (Map 6). Temperature and DO dynamics at Pigeon Lake were among the most interesting of any lake sampled. The temperature of the water column gradually warmed through the winter months, while DO levels above 5 m remained remarkably consistent and high (Figure 19, Appendix Figure 2). Below 5 m, levels decreased until the lowest levels measured in February, but then increased considerably during the March sampling event. Lacombe Lake was very warm near the bottom, but with decreases from January to February (Figure 19). Battle Lake displayed 92% water column hypoxia (Appendix Table 1a). TP levels between the three lakes were relatively low, with the exception of the large increase in TP from the second sampling event in February at Lacombe (Table 8a). Lacombe also displayed one of the highest levels of Cl from any lake across the program, at 33 mg/L (Figure 7). Also of note was the high average TDP:TP at Pigeon, being the second highest of any lake (Figure 5).



Map 6. Sampling locations for Winter LakeKeepers 2020-2021, in the Battle River watershed. Battle River watershed highlighted in Alberta inset map.

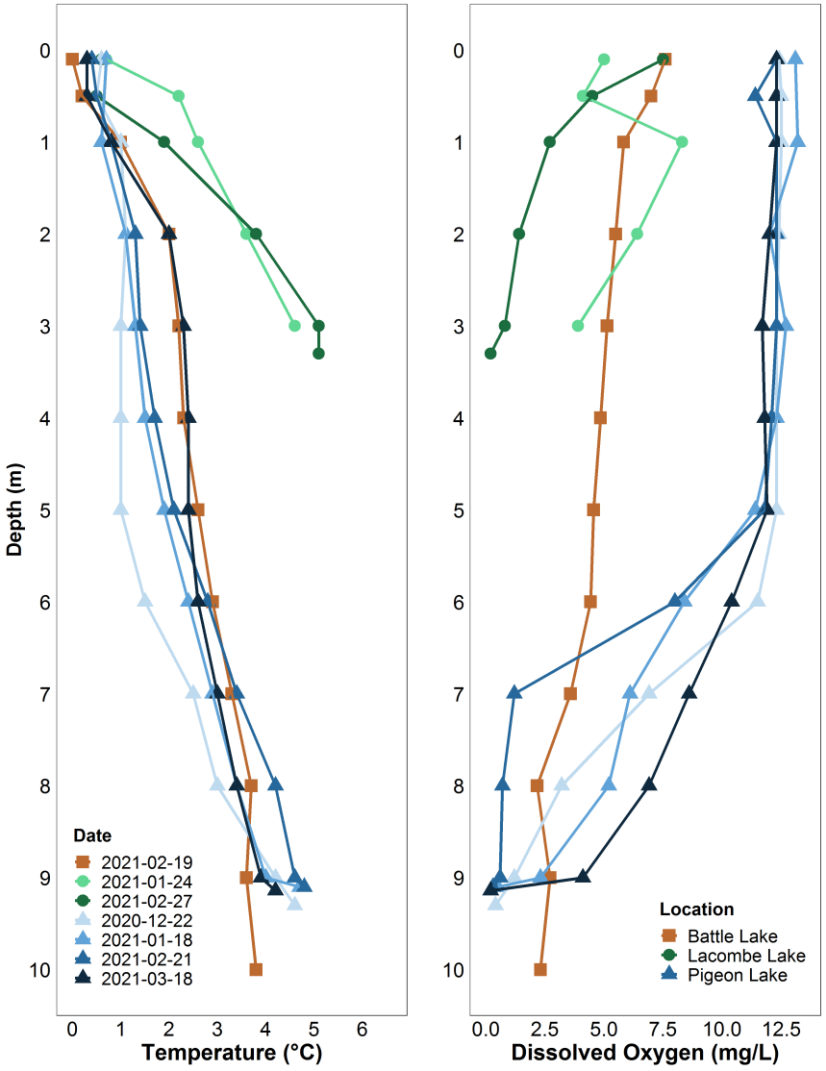


Figure 19. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Battle River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom. Note: no temperature and dissolved oxygen available for Lacombe Lake 2021-03-22 sampling event.

Battle River Watershed

TD Friends of the Environment Foundation

LakeKeepers

Table 8a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

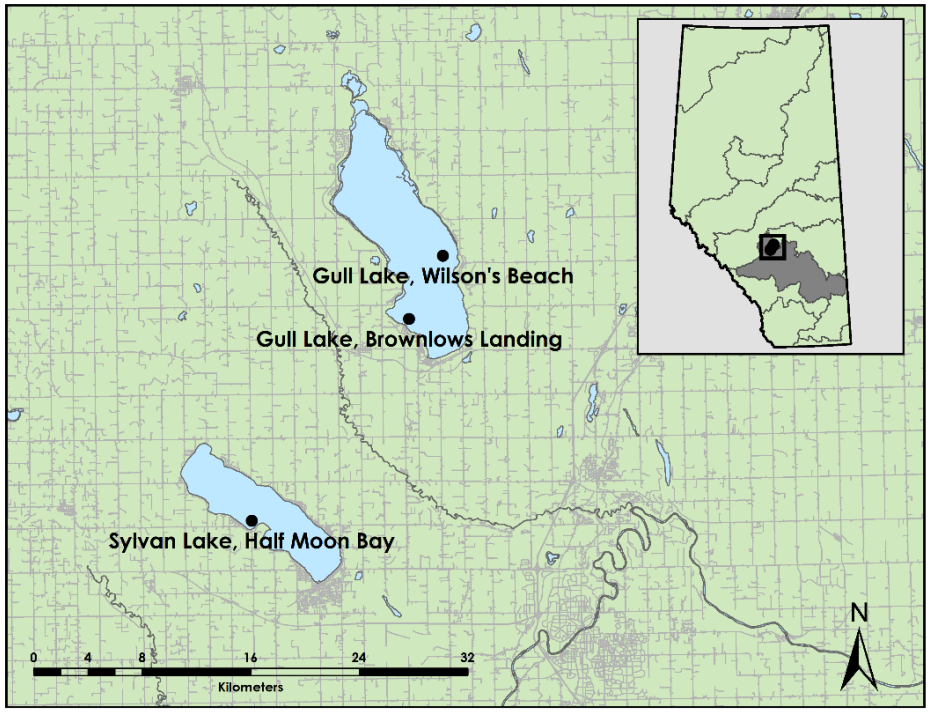
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Battle Lake, SE Butte	2021-02-19	0.8	25.0	17.0	8.8	10.0	440	7.98
Lacombe Lake, Profile	2021-01-24	1.7	10.0					
Lacombe Lake, Profile	2021-02-27	1.8	9.1	7.0	17.0	33.0	650	7.94
Lacombe Lake, Profile	2021-03-22	1.3	46.0					
Pigeon Lake, Grandview	2020-12-22	1.0	9.4	6.6	8.4	5.4	350	8.23
Pigeon Lake, Grandview	2021-01-18	1.0	6.9	6.1	7.6	5.9	370	8.27
Pigeon Lake, Grandview	2021-02-21	1.2	16.0	19.0	9.4	7.7	390	8.34
Pigeon Lake, Grandview	2021-03-18	1.0	9.9	5.4	8.2	5.4	350	8.27

Table 8b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Battle River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Battle Lake, SE Butte	2021-02-19	3	10	100	Clear	Colourless	No
Lacombe Lake, Profile	2021-01-24	-16	4	43	Opaque	Colourless	No
Lacombe Lake, Profile	2021-02-27	-8	18	56	Opaque	Colourless	No
Lacombe Lake, Profile	2021-03-22	2	0	41	Opaque	Colourless	Yes
Pigeon Lake, Grandview	2020-12-22	-6	5	43	Opaque	Colourless	No
Pigeon Lake, Grandview	2021-01-18	2	1	56	Opaque	Colourless	No
Pigeon Lake, Grandview	2021-02-21	7	8	81	Opaque	Colourless	No
Pigeon Lake, Grandview	2021-03-18	0	0	84	Opaque	Colourless	No

Red Deer River Watershed

Two lakes were sampled within the Red Deer River watershed in Winter LakeKeepers 2020-2021 (Map 7). Two sites at Gull Lake and one site at Sylvan Lake were sampled three times over the course the winter. All sites at both lakes had high DO levels in the first 4 m of the water column on all dates, but decreases below this depth were detected for both sites at Gull. (Figure 20). Over the season at Gull, water temperature gradually rose while DO gradually decreased at both sites, while at Sylvan both temperature and DO remained remarkably stable through the winter (Appendix Figure 4). TP levels were low at both lakes through the winter (Table 9a), and among the lowest of any lake across the province (Figure 1), but TKN levels were considerably lower at Sylvan, which displayed among the lowest TKN levels of any lake (Figure 3). TKN:TP ratios of both lakes were also among the highest of any lake in the winter (Figure 4).



Map 7. Sampling locations for Winter LakeKeepers 2020-2021, in the Red Deer River watershed. Red Deer River watershed highlighted in Alberta inset map.

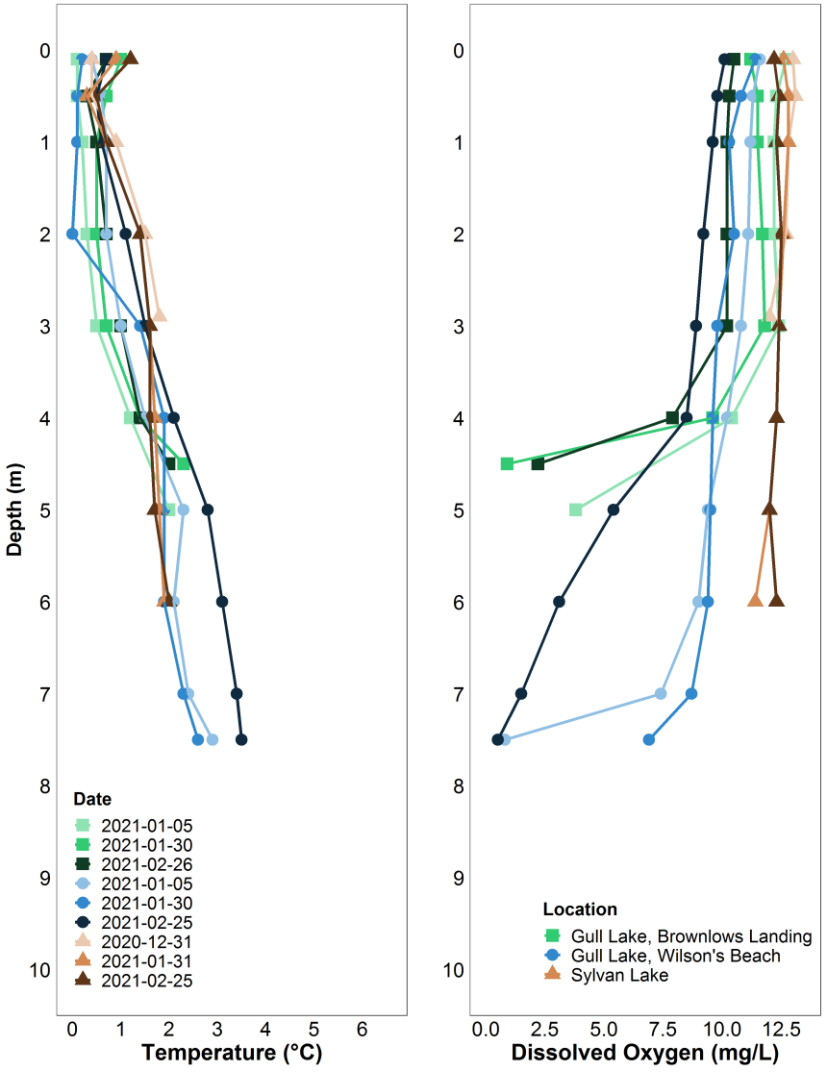


Figure 20. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in the Red Deer River watershed in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Red Deer River Watershed

Table 9a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

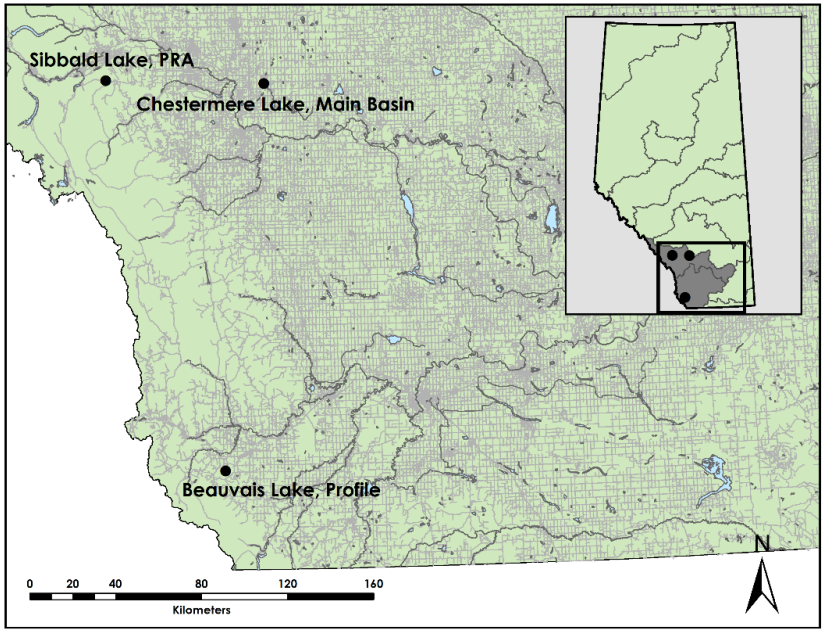
Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Gull Lake, Brownlows Landing	2021-01-05	2.0	9.1					
Gull Lake, Brownlows Landing	2021-01-30	1.8	12.0					
Gull Lake, Brownlows Landing	2021-02-26	2.0	9.3					
Gull Lake, Wilson's Beach	2021-01-05	2.0	10.0					
Gull Lake, Wilson's Beach	2021-01-30	1.8	9.9					
Gull Lake, Wilson's Beach	2021-02-25	2.0	15.0					
Sylvan Lake, Half Moon Bay	2020-12-31	0.8	7.4					
Sylvan Lake, Half Moon Bay	2021-01-31	0.6	7.6					
Sylvan Lake, Half Moon Bay	2021-02-25	0.8	5.1					

Table 9b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Red Deer River watershed in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Gull Lake, Brownlows Landing	2021-01-05	-4	8	70	Clear	Colourless	No
Gull Lake, Brownlows Landing	2021-01-30	-18	8	77	Clear	Colourless	No
Gull Lake, Brownlows Landing	2021-02-26	3	11	74	Clear	Colourless	No
Gull Lake, Wilson's Beach	2021-01-05	-6	10	70	Clear	Colourless	No
Gull Lake, Wilson's Beach	2021-01-30	-20	12	74	Clear	Colourless	No
Gull Lake, Wilson's Beach	2021-02-25	-3	12	75	Clear	Colourless	No
Sylvan Lake, Half Moon Bay	2020-12-31	-6	10	36	Opaque	Colourless	No
Sylvan Lake, Half Moon Bay	2021-01-31	-10	10	68	Clear	Colourless	No
Sylvan Lake, Half Moon Bay	2021-02-25	5	10	69	Clear	Colourless	No

Bow & Oldman River Watersheds

Three lakes were sampled across the Bow and Oldman River watersheds in Winter LakeKeepers 2020-2021 (Map 8). Chestermere Lake, in the Bow River watershed, was the only reservoir sampled in the 2020-2021 season, and was sampled three times through the winter. Beauvais Lake was the only lake to be sampled five times, including a unique sampling event on April 12th, 6 days after ice-out. Chestermere and Beauvais both displayed trends of decreasing dissolved oxygen (DO) throughout the season (Figure 21, Appendix Figure 5), and the build-up of hypoxia (Appendix Table 1a). Sibbald Lake displayed very low DO during the single March sampling event. Beauvais had the warmest winter temperatures recorded of any lake. Temperatures between 6 - 6.5 °C were recorded down to 3 m depth on March 21st, which corresponded to decreased ice thickness compared to March 1st, as well as changes in conductivity, TKN, DOC, and Cl (Tables 10a & 10b). Chestermere displayed among the highest levels of Cl of any lake in the province (Figure 7), as well as the lowest levels of DOC (Figure 6). Sibbald and Beauvais had some of the lowest levels of Cl across all lakes (Figure 7).



Map 8. Sampling locations for Winter LakeKeepers 2020-2021, in the Bow and Oldman River watersheds. Bow and Oldman River watersheds highlighted in Alberta inset map.

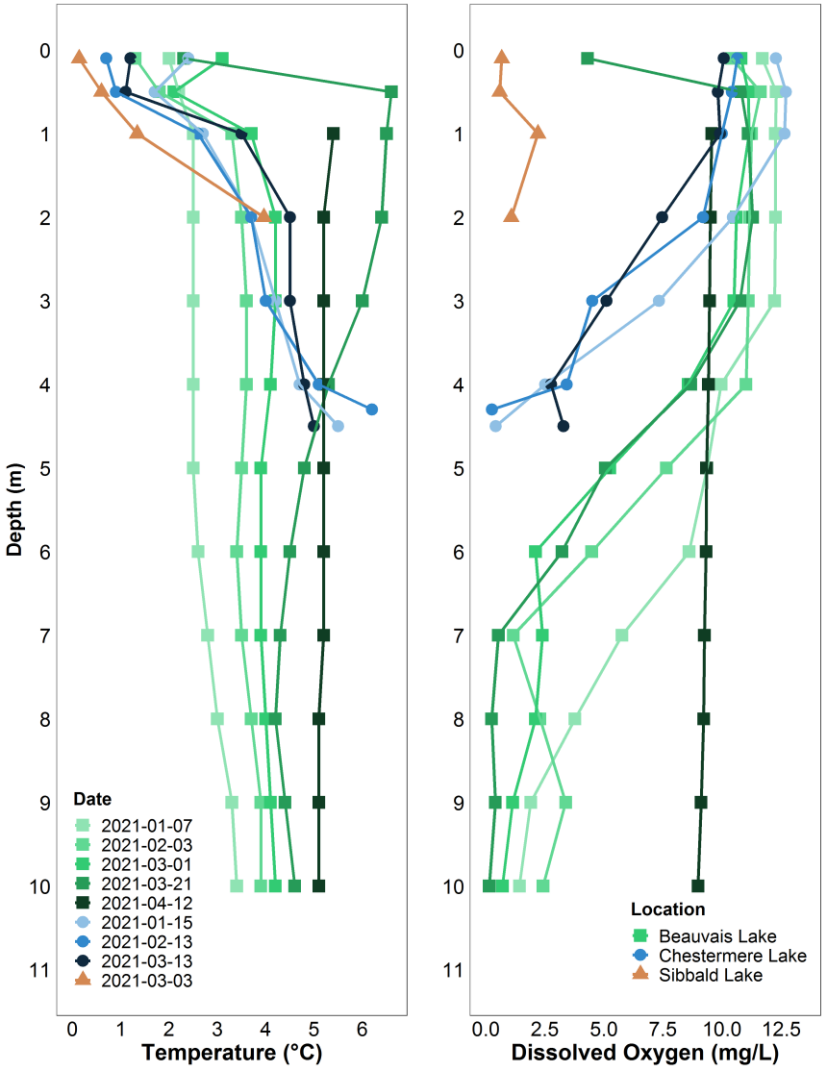


Figure 21. Temperature (°C) and dissolved oxygen (mg/L) measurements recorded at lakes in Bow and Oldman River watersheds in Winter 2020-2021. Measurements were taken at 0.1m and 0.5m, then every meter starting at 1 meter from water surface, until lake bottom.

Bow & Oldman Rivers Watersheds

Table 10a. Water chemistry (TKN = total Kjeldahl nitrogen in mg/L, TP = total phosphorus in µg/L, TDP = total dissolved phosphorus 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 2020-2021. All samples taken at approximately 0.1 m depth.

Site	Date	TKN (mg/L)	TP (µg/L)	TDP (µg/L)	DOC (mg/L)	Cl- (mg/L)	Cond. (µS/cm)	pH
Beauvais Lake, Profile	2021-01-07	0.5	7.6	5.0	5.6	1.4	290	7.47
Beauvais Lake, Profile	2021-02-03	0.5	8.6	11.0	5.5	1.1	280	8.27
Beauvais Lake, Profile	2021-03-01	0.5	7.1	3.8	5.6	1.2	310	8.10
Beauvais Lake, Profile	2021-03-21	0.2	6.1	3.7	3.6	2.8	160	7.93
Beauvais Lake, Profile	2021-04-12	0.5	15.0	7.0	5.1	1.7	280	8.23
Chestermere Lake, Main Basin	2021-01-15	1.4	19.0	5.5	3.0	26.0	670	8.13
Chestermere Lake, Main Basin	2021-02-13	0.6	23.0	19.0	3.3	29.0	710	8.02
Chestermere Lake, Main Basin	2021-03-13	0.4	7.2	1.5	2.9	28.0	680	8.26
Sibbald Lake, PRA	2021-03-03	1.1	28.0	6.6	12.0	1.1	370	7.90

Table 10b. Environmental measurements (Air Temp. = air temperature in °C), and observations recorded at lakes in the Bow River and Oldman River watersheds in Winter 2020-2021.

Site	Date	Air Temp. (°C)	Snow Depth (cm)	Ice Thickness (cm)	Ice Colour	Water Colour	Particles?
Beauvais Lake, Profile	2021-01-07	2	8	18	Opaque	Colourless	No
Beauvais Lake, Profile	2021-02-03	-5	5	41	Opaque	Colourless	No
Beauvais Lake, Profile	2021-03-01	3	8	46	Opaque	Colourless	No
Beauvais Lake, Profile	2021-03-21	-3	0	23		Colourless	No
Beauvais Lake, Profile	2021-04-12	0	0	0		Colourless	No
Chestermere Lake, Main Basin	2021-01-15	7	5	42	Clear	Colourless	No
Chestermere Lake, Main Basin	2021-02-13	-21	16	62	Clear	Colourless	No
Chestermere Lake, Main Basin	2021-03-13	7	0	61	Opaque	Colourless	No
Sibbald Lake, PRA	2021-03-03		7	57	Opaque	Colourless	No

Appendix

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 2020-2021 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Battle Lake, SE Butte	2021-02-19	92	13.0
Beauvais Lake, Profile	2021-01-07	33	10.5
Beauvais Lake, Profile	2021-02-03	40	10.0
Beauvais Lake, Profile	2021-03-01	50	10.0
Beauvais Lake, Profile	2021-03-21	50	10.0
Beauvais Lake, Profile	2021-04-12	0	10.0
Calling Lake, Cardinal Drive	2021-03-06	0	7.0
Chestermere Lake, Main Basin	2021-01-15	15	4.7
Chestermere Lake, Main Basin	2021-02-13	33	4.5
Chestermere Lake, Main Basin	2021-03-13	36	4.7
Chickakoo Lake, Profile	2021-03-07	71	6.8
Gerharts Lake, Profile	2021-03-06	84	18.4
Gull Lake, Brownlows Landing	2021-01-05	0	5.0
Gull Lake, Brownlows Landing	2021-01-30	0	4.5
Gull Lake, Brownlows Landing	2021-02-26	0	4.5
Gull Lake, Wilson's Beach	2021-01-05	0	7.5
Gull Lake, Wilson's Beach	2021-01-30	0	7.5
Gull Lake, Wilson's Beach	2021-02-25	33	7.5
Half Moon Lake, East Central	2020-12-14	47	7.5
Half Moon Lake, East Central	2021-01-06	100	7.2
Half Moon Lake, East Central	2021-02-16	100	7.5
Half Moon Lake, East Central	2021-03-16	73	7.5

Appendix

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 2020-2021 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Iosegun Lake, East Boat Launch	2021-02-15	0	2.2
Isle Lake, Silver Sands	2020-12-30	51	6.1
Lac Cardinal, Queen Elizabeth	2021-03-11	100	4.8
Lacombe Lake, Profile	2021-01-24	43	3.5
Lacombe Lake, Profile	2021-02-27	85	3.3
Lessard Lake, Boat Launch	2020-12-27	6	3.2
Little Mere West Lake, Profile	2021-03-07	100	7.2
Mayatan Lake East, Profile	2021-02-17	100	6.3
Mayatan Lake West, Profile	2021-02-17	100	22.0
Muriel Lake, SE Corner	2021-03-02	100	4.6
Pigeon Lake, Grandview	2020-12-22	14	9.3
Pigeon Lake, Grandview	2021-01-18	23	9.1
Pigeon Lake, Grandview	2021-02-21	23	9.1
Pigeon Lake, Grandview	2021-03-18	2	9.1
PL1 Lake, Profile	2021-03-06	100	11.3
PL10 Lake, Profile	2021-03-14	100	6.5
PL11 Lake, Profile	2021-03-14	60	7.5
PL12 Lake, Profile	2021-03-14	94	8.4
PL2 Lake, Profile	2021-03-06	92	6.5
PL3 Lake, Profile	2021-03-07	100	6.5
PL4 Lake, Profile	2021-03-06	100	9.5
PL5 Lake, Profile	2021-03-06	100	15.6

Appendix

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 2020-2021 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
PL6 Lake, Profile	2021-03-07	100	5.2
PL7 Lake, Profile	2021-03-11	94	16.3
PL8 Lake, Profile	2021-02-17	100	10.7
PL9 Lake, Profile	2021-03-10	100	18.3
Sauer Lake, Profile	2021-03-07	100	9.4
Sibbald Lake, PRA	2021-03-03	63	2.7
Skeleton Lake North, Profile	2021-01-11	57	16.1
Skeleton Lake North, Profile	2021-02-04	50	16.0
Skeleton Lake North, Profile	2021-03-10	69	16.0
Skeleton Lake South, Center	2021-03-10	30	8.6
Snipe Lake, Resort	2021-01-19	33	4.5
Snipe Lake, Resort	2021-02-23	41	5.1
Snipe Lake, Resort	2021-03-20	38	4.8
Spring Lake, South of Island	2021-01-02	100	6.1
Sylvan Lake, Half Moon Bay	2020-12-31	0	2.9
Sylvan Lake, Half Moon Bay	2021-01-31	0	6.0
Sylvan Lake, Half Moon Bay	2021-02-25	0	6.0
Twin Lake West, Center	2021-03-14	90	30.4
Wabamun Lake, Rich's Point	2020-12-23	0	4.4
Wabamun Lake, Rich's Point	2021-01-21	0	4.5
Wabamun Lake, Rich's Point	2021-02-24	0	5.5
Wabamun Lake, Rich's Point	2021-03-18	0	5.0

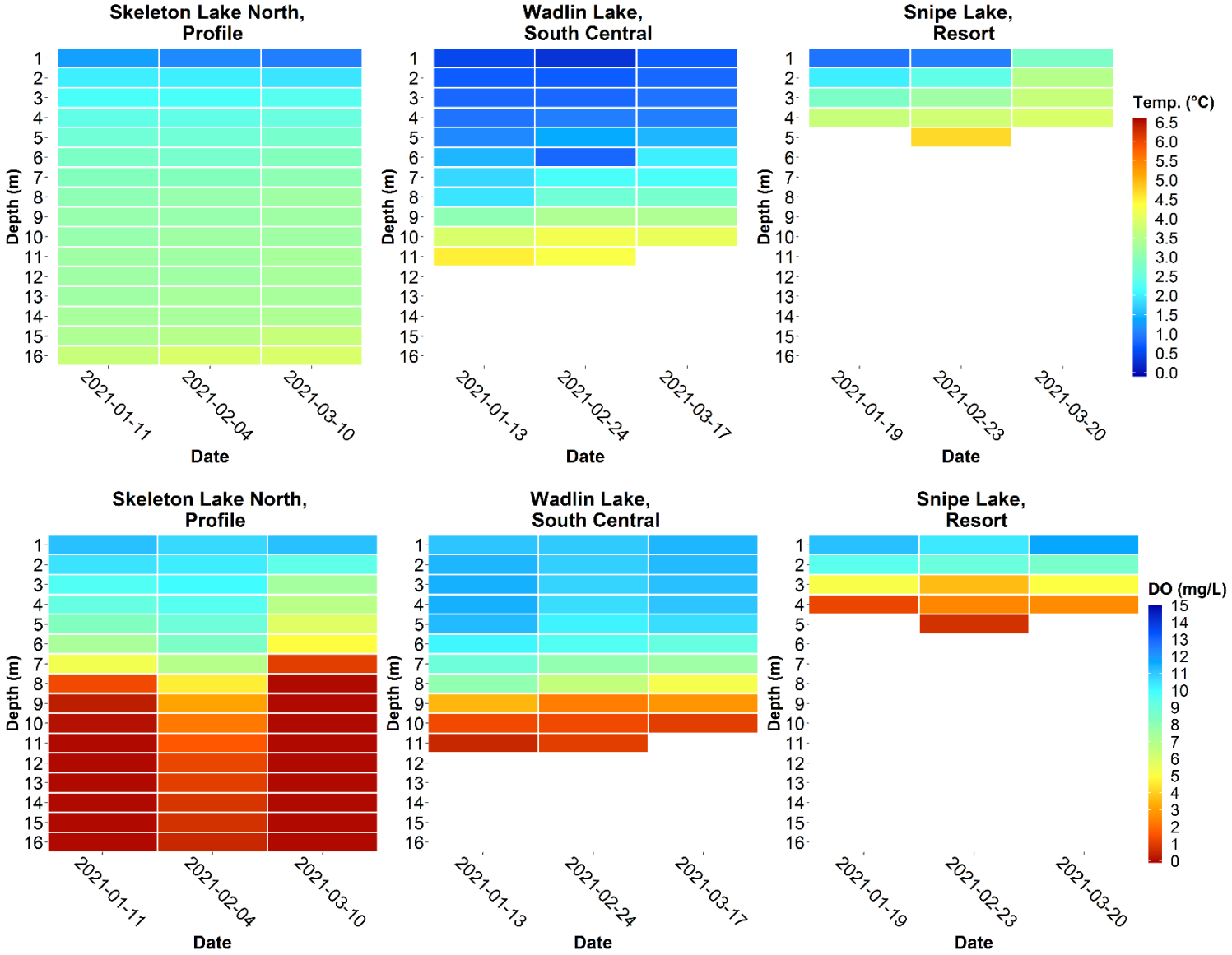
Appendix

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 2020-2021 season. Site bottom depth also listed for reference.

Site	Date	Water Column Hypoxia (%)	Site Bottom Depth (m)
Wabamun Lake, Seba Beach	2020-12-23	0	9.0
Wabamun Lake, Seba Beach	2021-01-21	0	7.0
Wabamun Lake, Seba Beach	2021-02-24	29	8.5
Wabamun Lake, Seba Beach	2021-03-18	33	7.5
Wabamun Lake, Water's Edge	2020-12-23	0	2.0
Wabamun Lake, Water's Edge	2021-01-21	0	2.1
Wabamun Lake, Water's Edge	2021-02-24	0	2.0
Wabamun Lake, Water's Edge	2021-03-18	0	2.0
Wabamun Lake, Whitewood Sands	2020-12-23	0	6.7
Wabamun Lake, Whitewood Sands	2021-01-21	0	5.0
Wabamun Lake, Whitewood Sands	2021-02-24	7	7.5
Wabamun Lake, Whitewood Sands	2021-03-18	38	6.5
Wadlin Lake, South Central	2021-01-13	22	11.5
Wadlin Lake, South Central	2021-02-24	18	11.0
Wadlin Lake, South Central	2021-03-17	24	10.5
Wizard Lake, Jubilee	2020-12-27	0	5.5
Wizard Lake, Jubilee	2021-01-17	19	6.2
Wizard Lake, Jubilee	2021-02-21	0	6.0
Wizard Lake, Jubilee	2021-03-14	0	5.5
Wizard Lake, West Basin	2020-12-27	0	2.5
Wizard Lake, West Basin	2021-01-17	0	2.9
Wizard Lake, West Basin	2021-02-21	0	3.0
Wizard Lake, West Basin	2021-03-14	0	2.5

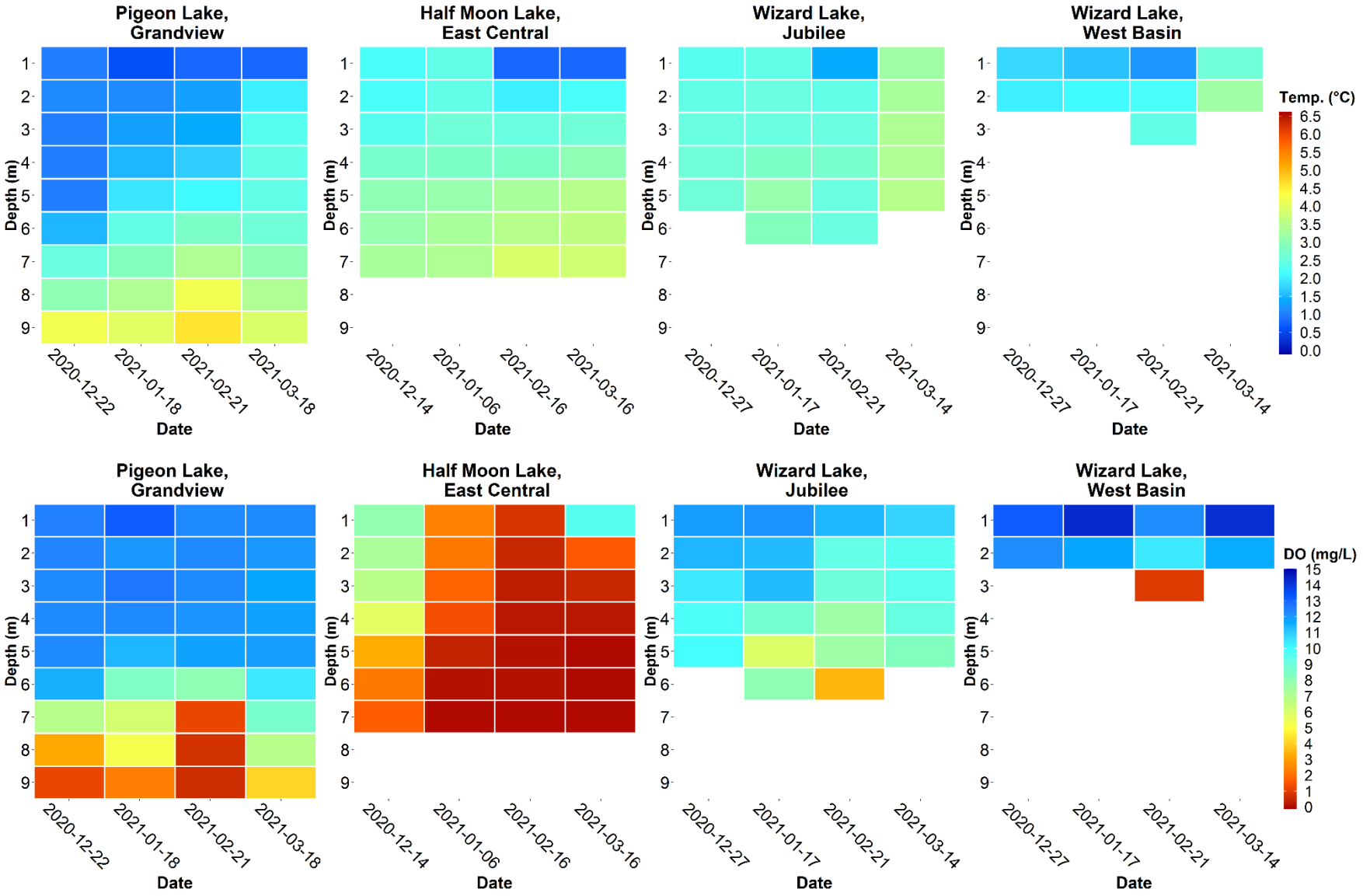
Appendix

Appendix Figure 1. Heat maps for temperature (°C) and dissolved oxygen (mg/L) (Temp., DO) measurements recorded at sites on Skeleton Lake, Wadlin Lake, and Snipe Lake, from Winter 2020-2021. Measurements represented are 1m until the deepest whole depth available.



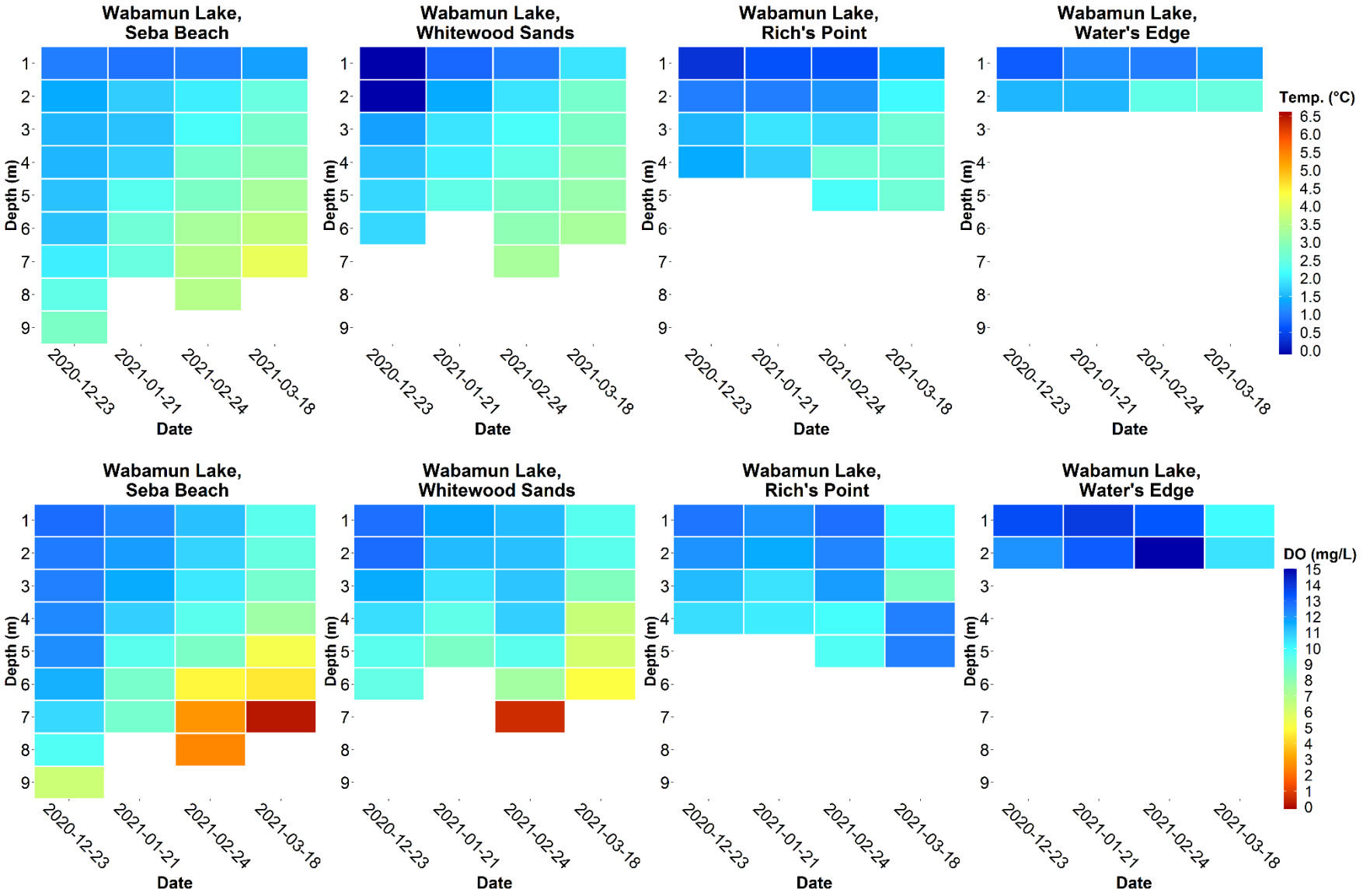
Appendix

Appendix Figure 2. Heat maps for temperature (°C) and dissolved oxygen (mg/L) (Temp., DO) measurements recorded at sites on Pigeon Lake, Half Moon Lake, and Wizard Lake, from Winter 2020-2021. Measurements represented are 1m until the deepest whole depth available.



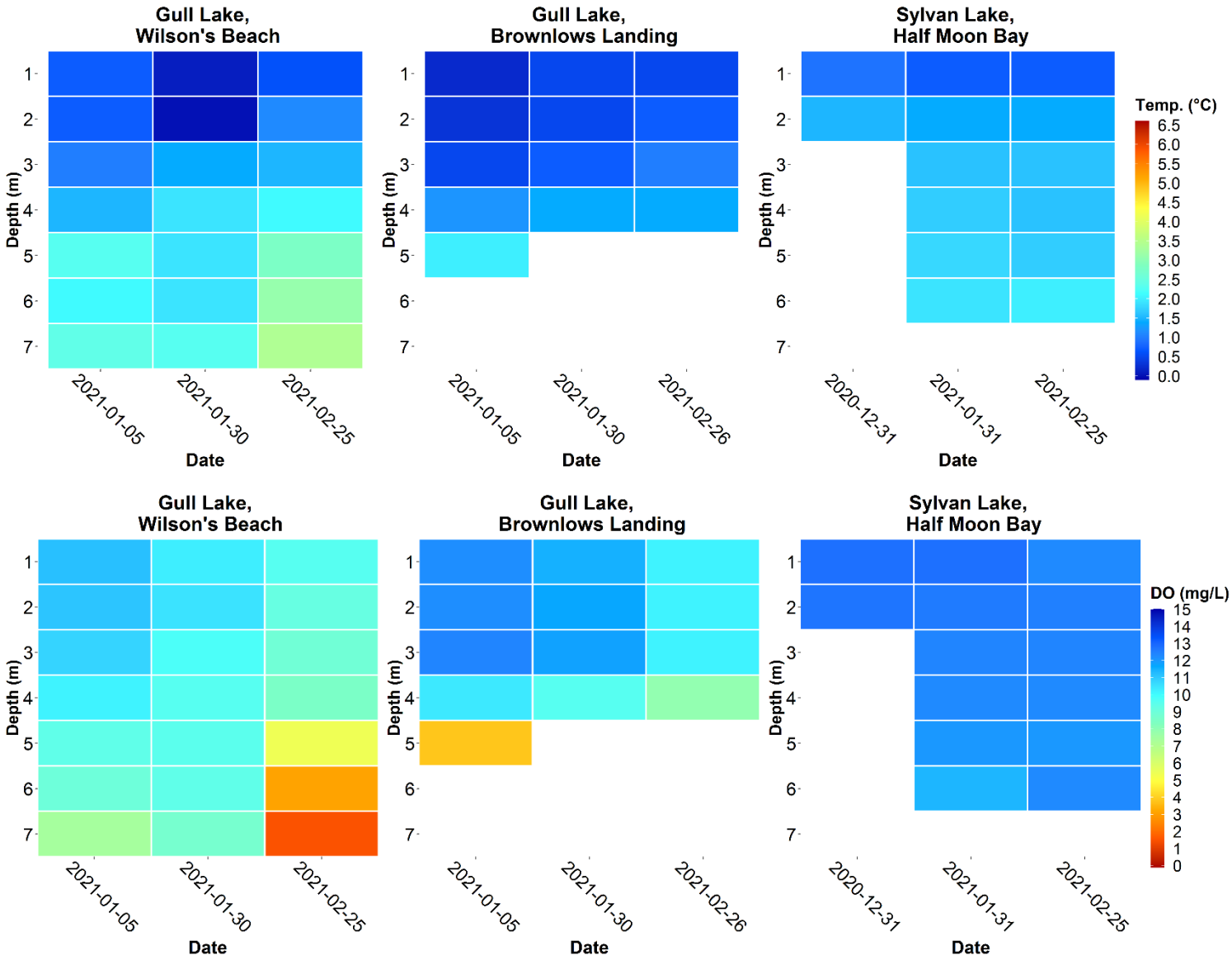
Appendix

Appendix Figure 3. Heat maps for temperature (°C) and dissolved oxygen (mg/L) (Temp., DO) measurements recorded at sites on Wabamun Lake, from Winter 2020-2021. Measurements represented are 1m until the deepest whole depth available.



Appendix

Appendix Figure 4. Heat maps for temperature (°C) and dissolved oxygen (mg/L) (Temp., DO) measurements recorded at sites on Gull Lake, and Sylvan Lake, from Winter 2020-2021. Measurements represented are 1m until the deepest whole depth available.



Appendix

Appendix Figure 5. Heat maps for temperature (°C) and dissolved oxygen (mg/L) (Temp., DO) measurements recorded at sites on Beauvais Lake, and Chestermere Lake, from Winter 2020-2021. Measurements represented are 1m until the deepest whole depth available.