Supplementary Material

Major changes in fish thermal habitat diversity in Canada's Arctic lakes due to climate change

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Supplementary Discussion

The following is a discussion of important issues to consider in future assessments of Arctic freshwater fish diversity.

Under-ice Winter Conditions and Oxygen Deficits

Our analyses focused on the fundamental aspects of lake thermal structure during the open-water season to project shifting Arctic fish community diversity under climate change. Although we did not attempt to explore the under-ice conditions of these lakes, it is important to consider the shortening of the ice-free season. A similar modelling approach has been used to characterize under-ice lake thermal conditions and could be applied to explore this interplay[1]. Other factors will have a role in how these systems change. Under-ice conditions and oxygen dynamics were not a focus in our study, and have implications for sustaining fish life year-round[2]. We defined barren lakes unable to support fish as those which had limited water due to thick lake ice, which supersedes the notion of limited oxygen. Conditions in lakes we did not classify as barren, however, may still be unable to support fish populations because of severe oxygen deficits[3]. Future research could account for these factors and expand the definition of barren lakes.

Freshwater Distribution Changes with Permafrost Melt

Our results project landscape-level changes in the thermal dynamics of Arctic lakes, given the current distribution of freshwater across the Arctic landscape. Warming-induced landscape-level terrestrial and geomorphic changes may affect this distribution and modify our results[4]. Permafrost conditions beneath Arctic lakes are of great importance to these ecosystems through interactions and feedback between lake ice and sediment thermal dynamics and may vary across lake size[5]. Permafrost thaw will alter the number, size, and distribution of lakes across the Arctic[6]. Arctic lakes and ponds are a substantial global source of natural greenhouse gas, and future permafrost thaw may lead to increased annual water body emissions of 20–54% by 2100 if ice-free seasons extend by 20 days[7]. Increasing permafrost melt and its implications for dissolved organic matter in lakes are also worth considering as this can affect the productivity of northern fish communities[8]. The network of Arctic lentic systems is changing with the climate, and trends vary by region, with both increases and decreases in lakes and ponds being documented[4,9,10]. Permafrost melt and subsequent slumping and draining opens up new habitat for fish species to colonize, including southerly invaders[11]. Future work on Arctic lakes and their ability to support different fish species will need to assess these changes in the distribution of freshwater across the northern landscape.

Thermal Diversity Within the Coldwater Guild

The thermal guild boundaries that we applied to our study were based on large assessments of fish species' thermal preferences across North America[12,13]. These studies did not focus on the thermal ecology of the Arctic. There is considerable thermal diversity within the coldwater guild, as defined in our analyses. For example, species with thermal preferences below 10 °C having been defined as an "Arctic guild" for freshwater fishes[14]. Further assessments of future Arctic lake thermal conditions should consider breaking the coldwater thermal guild into finer units to gain further insights on how climate change may affect ultra-cold-adapted fishes.

The Role of New Technologies in Future Monitoring

Future work could be bolstered by detailed regional surveys of thermal regimes in lakes of various sizes to further refine future projections. Environmental DNA sampling may also improve our knowledge of species distributions and lay the groundwork for the study of future changes[15].

Supplementary Methods

Lake Morphometry Assessment

Comparison with HydroLAKES

The Arctic GIS lake database was built to develop a lake morphometry dataset focused on the unique geographic qualities of the Canadian Arctic, which represents ~1/3 of global lakes ≥ 0.1 km^2 (~450,000 lakes)[16,17]. The original Arctic GIS lake database includes some lakes in northern Quebec and Ontario, along with some lake trout (*Salvelinus namaycush*) sampling lakes in prairie regions and Labrador. We focused on lakes with central coordinate latitudes ≥ 60°N. We also removed two lakes with spurious coordinates (i.e., they were located in Hudson's Bay), bringing the total of the full, original Arctic GIS lake database from 481,784 lakes, down to 481,782 lakes before filtering for latitude, and to 447,077 after filtering for lakes at least 60°N. Unless otherwise stated, our results are based on this subset of the Arctic GIS lake database. We omitted Great Bear Lake and Great Slave Lake from volume-days calculations, for a total of 447,075 lakes, and we state when this is the case.

We compared the Arctic GIS lake database's morphometry values to HydroLAKES, a widely used global lakes dataset[17] (Supplementary Table 10). The HydroLAKES dataset database was built using regression equations formulated with an extensive global training lakes dataset of training lakes, with the preferred mean depth model using lake area and average slope surrounding the 100 m buffer of the lake as predictors[17]. Both databases have estimates for lake morphometry/bathymetry and are based on the CanVec geospatial dataset (http://maps.canada.ca/czs/index-en.html). Lake counts are similar overall, by lake size, and ecozone (the top, most generalized, and largest level defined by the four-level National Ecological Framework for Canada) are similar for the Arctic dataset and HydroLAKES for both datasets, highlighting the fact that both databases were generated using the same CanVec waterbody area/location data (Supplementary Table 11). Differences between the Arctic dataset and HydroLAKES likely arise from slight contrasts in data processing procedures and value judgements on what constitutes a lake. For example, within the Canadian Arctic, HydroLAKES contains ~1.3% more lakes than the Arctic dataset.

Lake depth is a key morphometric variable used for estimating potential lake thermal resources. An advantage of the Arctic GIS lake database is that it has estimates for maximum depth, and although this metric has more uncertainty than mean depth, its use permits initial estimates of lake thermal habitat supply in lakes[16]. The training dataset that was used to estimate mean depth for HydroLAKES lacked Canadian Arctic empirical data[17]. The HydroLAKES model coefficients were derived for different lake size classes globally, so any regions that were not used in the HydroLAKES training dataset may be difficult to predict because these regional differences are not captured by the model. The HydroLAKES dataset also contains minimum mean depth boundaries for different lake size classes, and the mean depth model tends to overestimate these values[17]. Furthermore, mean depths < 1 m are never produced by the model despite lakes having these values[17]. This was not a key issue for the HydroLAKES dataset, as the main objective of the original study that presented HydroLAKES was to estimate global lake volume and water residence time, which is dominated by larger, generally more well-studied lakes, whereas the smallest lakes (mean depth < 1 m) were not of primary concern[17]. Producing accurate estimates for lakes of all depths is critical for our study, as shallow lakes that were formerly frozen to the bottom in winter may not be in the future due to climate change. Small lakes comprise a large portion of the Canadian Arctic by sheer numbers. Therefore, although small lakes comprise a small percentage of the total volume and thermal habitat supply, they comprise a large, connected hydrological network for coolwater and warmwater fish species to potentially invade and compete with coldwater residents.

Lake Morphometry Modelling Methods

For the original publication of the Arctic dataset, mean and maximum lake depths were estimated by modelling the surface topography digital elevation model along many transects for each lake across a distance of approximately one lake radius on each side, and splines were fit to the elevation data along transects to estimate lake depth[16]. This value was averaged with a value obtained from the single median slope value in the surrounding topography[16,18]. Analysis of known and estimated lake morphometry revealed no bias among the values[16]. In the original publication of the Arctic GIS lakes database, shallow lakes (maximum depth < 2.5 m, mean depth < 1.75 m) were excluded as they were likely to freeze to the bottom and probably would not support fish populations, a key focus of the initial analysis[16]. Lakes with estimated maximum depths less than 2.5 m or mean depths less than 1.75 m were excluded from the initial study as they were likely to freeze to the bottom and probably would not support fish populations, a key focus of the initial analysis[16]. In the present study, To include these lakes in our study, we used empirical relationships among ground-truthed Arctic lake morphometrics to estimate mean and maximum depths for these originally omitted shallow lakes. we used empirically derived relationships among ground-truthed Arctic lake morphometrics to estimate mean and maximum depths that fell below these minimum thresholds in the initial assembly of the Arctic dataset. We assessed regional trends in estimated lake depth using validated measures of Arctic lake morphometry sourced from previous studies, hereafter the "empirical morphometry database". We took lake surface area as a reliable measure of lake morphometry that is easy to measure compared to lake depth and should be relatively consistent across datasets regardless of their age. We compared relationships among mean depth, maximum depth, and surface area with the empirical morphometry dataset and subdivided the Arctic GIS lake database by ecozone to determine if regional patterns were apparent. We then overlaid the depth-area relationships of the Arctic GIS lake database and HydroLAKES for which the morphometric variables were available (HydroLAKES lacks a maximum depth estimate) to assess the correspondence of the relationships among ecozones. Although the empirical morphometry database is only a small sample of the total lakes in the Arctic, it provides a reasonable set of boundaries and a baseline with which to contextualize our results. Comparing mean depths from the Arctic and HydroLAKES datasets, we truncated both datasets at 1.5 m because the HydroLAKES model generally did not produce mean depth values in the 1–2 m range[17]. It is worth noting that ~1/3 of the Arctic GIS lake database lakes are omitted based on this filtering step as these lakes are estimated to be very shallow.

Lake Morphometry Modelling Results

Satisfactory models for predicting lake morphometry metrics (mean and maximum depths) were developed using regional inventories of lake resources and empirical datasets gathered across the region. The number of lakes for which empirical estimates were made for morphometry is summarized in Supplementary Table 12 (< 2% of all lakes). Where one or both depth metrics were missing, alternate estimates were developed using supplementary variables such as lake area and ecozone. Using the empirical morphometry dataset, mean depth was a very good predictor of maximum depth and vice versa ($R^2 = 0.89$, $p < 0.0001$, $N = 167$, Supplementary Figure 3, Supplementary Table 13). Lake area was a moderately strong predictor of both depths (mean depth $R^2 = 0.49$, $p < 0.0001$, $N = 167$; maximum depth $R^2 = 0.52$, $p < 0.0001$, $N = 167$, Supplementary Figure 5, Supplementary Table 13). Adding ecozone as a predictor improved all models significantly, but only in certain ecozones. Lakes from ecozones #6 (Boreal Shield) and #9 (Boreal Plains) were omitted from the analyses using ecozone as a predictor because they contained two and one lakes, respectively, which was insufficient to conduct the analysis. The above analysis was re-run without those three lakes so that ΔAIC comparison could be completed. ANOVA and ΔAIC results refer to a comparison of linear models without and with ecozone as a predictor. Although the predictions generated from these regression models are reliable, the small number of lakes in the dataset and their heterogeneous geographic distribution limits their applicability. Using ecozone as a predictor in the morphometry equations significantly improved the model fit for predicting maximum depth from mean depth (ΔAIC = 13.21, $R^2 = 0.91$, $p < 0.0001$, $N = 164$), predicting mean depth from maximum depth (ΔAIC = 53.54, $R^2 = 0.93$, $p < 0.0001$, $N = 164$), predicting mean depth from surface area (ΔAIC = 48.05, $R^2 = 0.63$, $p < 0.0001$), and predicting max depth from surface area (ΔAIC = 17.83, $R^2 = 0.56$, $p < 0.0001$); however, only ecozone #3 and #12 for mean depth from maximum depth, #12 for maximum depth from surface area, and #12 for mean depth from surface area was significant within their respective regression equations (Supplementary Table

14). The relationships between the estimated mean and maximum depths, as well as mean depth and surface area, for the Arctic GIS lake database conforms well to the relationships established with the empirical morphometry dataset across ecozones (Supplementary Figures 6 and 7). For example, in the ecozone where the empirical morphometry dataset contains the most lakes (Ecozone #3, n = 72) there is good agreement between the distribution of the Arctic GIS lake database's estimated mean depths and that of the empirical morphometry dataset. The empirical morphometry dataset contains many shallow lakes (n = 46 lakes ≤ 2 m, ~38% of the dataset), therefore, truncation at shallow depths is missing lots of existing lakes. By continuing to focus on the geographic region contained within the empirical morphometry dataset, the uncertainty is constrained.

Our lake morphometry assessment combined with the regional lakes numbers by size gives us a representation of the morphometry of all lakes across the region. Lakes > 10 ha in Canada at or north of 60° latitude cover approximately 401,723 km^2, ~10% of the region's total area. The perimeter of these lakes measures approximately 2,270,256 km in length, approximately nine times the entire marine coastline of Canada. The total volume of these lakes equals approximately 6,861 km^3 or approximately 3.7% of global lake volume[17]. The global HydroLAKES dataset[17] overall lake morphometry values for Arctic Canada are close to those presented here. Mean depths in the Arctic GIS lake database are generally lower than those in the global HydroLAKES dataset[17], as the estimated distribution of thermal resources partitioned by ecozone is more right-skewed for the Arctic GIS lake database compared to the HydroLAKES dataset (Supplementary Figure 8) and given the differences between the height of the bars in the more positive side of the histogram (Supplementary Figure 9). Furthermore, our reported surface area is 1.3% higher than HydroLAKES, shoreline length is 12.3% more, and volume is 7.9%

less. The top 10 lakes in terms of volume in both datasets have very similar volumes, with the sum of the values presented here being 0.57% greater than that of HydroLAKES. These lakes comprise 65.9% of the total lake volume in our dataset. Therefore, it is likely that the lower overall mean depth corresponding to the many thousands of small lakes in our dataset is driving the lower volume estimate (HydroLAKES mean depth: mean = 3.80 m, median = 3.40 m; Arctic mean depth: mean = 2.49, median = 1.77 m).

Comparison of Terrestrial Ecozones and Freshwater Ecoregions

We compared the degree to which terrestrial ecozones and freshwater ecoregions capture the variability in lake maximum depth and projected maximum lake surface water temperature[19,20]. We assigned each lake to its respective terrestrial ecozone and freshwater ecoregion. The number of lakes per terrestrial ecozone is reported in Supplementary Table 11. The number of lakes per freshwater ecoregion is reported in Supplementary Table 18. We conducted one-way ANOVA tests on the lake datasets to determine whether the means for maximum depth and lake temperature (tested separately) are significantly different under the terrestrial ecozone and freshwater ecoregion classification systems. We applied two post-hoc tests to further investigate whether means were significantly different using TukeyHSD and Least Significant Difference (LSD) with the Benjamini Hochberg false discovery rate applied. Means, medians, and standard deviations for maximum depth and lake temperature are summarized by the two systems in Supplementary Table 19. The metrics are visualized with boxplots in Supplementary Figure 13. The ANOVA shows that the group means are significantly different for both depth and temperature under either terrestrial ecozones or freshwater ecoregions (Supplementary Table 20). The fraction of the overall variation in both lake temperature and depth that is accounted for by the groupings, as indicated by the F-statistic, is approximately three times higher for terrestrial ecozones compared to freshwater ecoregions. The LSD test indicated that all means are significantly different for both metrics under both classification systems. For terrestrial ecozones, the TukeyHSD test indicated that all 28 pairwise comparisons of means are highly significant for both depth and lake temperature ($p < 0.0000001$). For maximum depth classified by freshwater ecoregions, the TukeyHSD test indicated that all but four out of the 36 pairwise comparisons of means are significant at $p < 0.0000001$. The remaining four are 113–112 ($p = 0.04$), 106–105 ($p = 0.01$), 113–102 ($p = 0.00003$), and 112–102 ($p = 0.009$). This is highlighted in Supplementary Figure 13 where the medians for 102, 105, 106, 112, and 113 appear to be relatively close in value. For lake temperature classified by freshwater ecoregions, the TukeyHSD test indicated that all but one pairwise comparison of means is significant. 103–101 was not significantly different ($p = 0.51$), whereas the rest of the comparisons were highly significantly different ($p < 0.0000001$).

This analysis indicates that terrestrial ecozones capture more variation across the dataset within the groups for both lake temperature and depth. All pairwise differences in means for the terrestrial ecozones were large and consistently highly significant. Pairwise differences in means for freshwater ecoregions were smaller, and some were not significantly different from zero. We also assessed the variation across group medians under both landscape classifications. Looking at the median values under terrestrial ecozones, the population variance is approximately two times greater for both lake temperature (terrestrial: $\sigma^2 = 18.3$, $N = 8$; freshwater: $\sigma^2 = 10.6$, $N = 9$) and depth (terrestrial: $\sigma^2 = 162.1$, $N = 8$; freshwater: $\sigma^2 = 74.4$, $N = 9$). This further shows that the terrestrial ecozone system separates the geographic, climactic, and limnetic variation on the landscape into regions where the between-region difference is greater than when regions are defined by the freshwater ecoregions system. Given this, it follows that the within group variance is smaller in the groups defined by terrestrial ecozones, shown by the residual sum of squares (Supplementary Table 20).

For the reader interested in a comparison between the two system, Supplementary Figure 14 recasts the results in the main text's Figure 7 (Ice-free volume-days associated with each thermal guild in 2100) in terms of freshwater ecoregions.

Supplementary Tables

Supplementary Table 1. Mean and standard deviation (in brackets) of lake thermal metrics by future climate scenario and ecozone. Max. LSWT represents the maximum surface water temperature.

Thermal Metric	Ecozone	Historical	RCP4.5 2050	RCP4.5 2100	RCP8.5 2050	RCP8.5 2100
Ice Break-up Date	01 - Arctic Cordillera	225.9 (17.8)	221.6 (18.5)	220 (19.4)	220.3 (18.5)	213.5 (22.4)
	02 - Northern Arctic	203.9 (11)	197.2 (11.2)	196.6 (11.3)	195.9 (11.5)	188.3 (10.8)
	03 - Southern Arctic	182.7 (7.9)	177.3 (7.4)	175.7 (7.5)	175.7 (7.1)	169.4 (6.6)
	04 - Taiga Plains	157.2 (7.5)	154.8 (6.5)	153.8 (7.1)	153.9 (6.8)	150.4 (6)
	05 - Taiga Shield	162.8 (7.6)	160.4 (6.7)	158 (6.4)	158.5 (6.6)	154.5 (5.8)
	09 - Boreal Plains	143.2 (1.7)	142.7 (1.5)	140.7 (1.6)	141 (1.3)	139.1 (1.3)
	11 - Taiga Cordillera	162.5 (5)	159.3 (4.5)	158.5 (4.4)	158.9 (4.6)	154.6 (4.3)

	12 - Boreal Cordillera	146.9 (5.6)	144.7 (5.2)	143.7 (5.1)	144.7 (5.2)	142.4 (4.8)
Ice-free Days	01 - Arctic Cordillera	52.5 (32.5)	69.1 (34.6)	73.8 (35)	73 (35.4)	102.7 (37.4)
	02 - Northern Arctic	77.4 (17.9)	95.1 (16)	98.8 (15.7)	98.4 (16.4)	123.1 (16.1)
	03 - Southern Arctic	106.8 (11.9)	119.2 (9.9)	122.5 (11.7)	121.9 (11.4)	143 (10.7)
	04 - Taiga Plains	136.7 (9.6)	145.2 (10.5)	148.3 (11.6)	147.4 (11.5)	162.1 (9.7)
	05 - Taiga Shield	133.9 (11.7)	144.2 (13.1)	150.7 (11.8)	150.8 (12.7)	165.7 (10.1)
	09 - Boreal Plains	160.1 (3.6)	170 (3.5)	173.9 (3.4)	175 (3.3)	184.2 (3.4)
	11 - Taiga Cordillera	128.3 (9.7)	136.1 (9.1)	137.4 (10)	137.7 (8.7)	149.8 (9.1)
	12 - Boreal Cordillera	155.9 (11.3)	167.4 (11.5)	172 (11.6)	167.3 (11.5)	181.1 (11.1)
	01 - Arctic Cordillera	286.2 (13)	296.9 (13.6)	299.5 (13.2)	299.4 (13.9)	317.3 (16.1)

Ice Freeze-up Date	02 - Northern Arctic	281.5 (9.2)	292.4 (7.6)	295.4 (7.2)	294.4 (8.2)	311.4 (9.4)
	03 - Southern Arctic	289.6 (5.4)	296.5 (5.4)	298.2 (5.9)	297.6 (6.3)	312.4 (6.1)
	04 - Taiga Plains	293.9 (4.9)	300 (5.5)	302.1 (6.1)	301.3 (6.3)	312.5 (5.7)
	05 - Taiga Shield	296.7 (5.8)	304.6 (7)	308.7 (6.3)	309.3 (6.8)	320.2 (5.4)
	09 - Boreal Plains	303.4 (3.2)	312.7 (3.3)	314.6 (3.3)	316 (3.4)	323.3 (3.7)
	11 - Taiga Cordillera	290.8 (8.2)	295.4 (8.8)	295.9 (9.6)	296.5 (8.6)	304.4 (8.7)
	12 - Boreal Cordillera	302.8 (8.8)	312.1 (9)	315.7 (9.3)	312 (9)	323.5 (9)
Max. LSWT	01 - Arctic Cordillera	8.3 (2.2)	9.9 (2.2)	10.2 (2.2)	10.5 (2.3)	14.6 (2.5)
	02 - Northern Arctic	11.1 (1.3)	13.5 (1.5)	13.6 (1.5)	13.9 (1.4)	18.1 (1.7)

	03 - Southern Arctic	14.1 (1.3)	16.6 (1.4)	16.7 (1.4)	16.7 (1.2)	20.8 (1.3)
	04 - Taiga Plains	19.3 (1.5)	21.6 (1.4)	22 (1.7)	21.7 (1.6)	25.5 (1.5)
	05 - Taiga Shield	17.9 (1.5)	20.1 (1.4)	20.6 (1.5)	20.3 (1.5)	24.3 (1.4)
	09 - Boreal Plains	21.4 (0.3)	23.4 (0.3)	24.5 (0.5)	24 (0.3)	28 (0.4)
	11 - Taiga Cordillera	16.9 (1.2)	19.5 (1.2)	20.1 (1.2)	19.6 (1.2)	23.2 (1.2)
	12 - Boreal Cordillera	18.2 (1.4)	20.6 (1.4)	21.4 (1.4)	21 (1.4)	24.3 (1.4)

Supplementary Table 2. Summary statistics for lakes by mixing class, climate scenario, overall (all lakes included at least 60°N latitude, N = 447,077).

Mixing class	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
Mixed	376,657 (84.2%)	346,434 (77.5%)	340,678 (76.2%)	357,992 (80.1%)	292,058 (65.3%)
Stratified	70,420 (15.8%)	100,643 (22.5%)	106,399 (23.8%)	89,085 (19.9%)	155,019 (34.7%)

Supplementary Table 3. Summary statistics for lakes by mixing class, climate scenario, and ecozone (all lakes included at least 60°N latitude, *N* = 447,077). Percentages are shown for each ecozone and scenario.

Ecozone	**Total**	**Mixing Class**	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
01 - Arctic Cordillera	3,062	Mixed	2,982 (97.4%)	2,961 (96.7%)	2,899 (94.7%)	2,930 (95.7%)	1,227 (40.1%)
		Stratified	80 (2.6%)	101 (3.3%)	163 (5.3%)	132 (4.3%)	1,835 (59.9%)
02 - Northern Arctic	165,018	Mixed	164,115 (99.5%)	157,959 (95.7%)	155,058 (94%)	151,481(91.8%)	116,980 (70.9%)
		Stratified	903 (0.5%)	7,059 (4.3%)	9,960 (6%)	13,537 (8.2%)	48,038 (29.1%)
03 - Southern Arctic	137,590	Mixed	126,777 (92.1%)	113,880 (82.8%)	112,925 (82.1%)	119,007 (86.5%)	103,112 (74.9%)
		Stratified	10,813 (7.9%)	23,710 (17.2%)	24,665 (17.9%)	18,583 (13.5%)	34,478 (25.1%)
04 - Taiga Plains	40,831	Mixed	28,117 (68.9%)	24,645 (60.4%)	24,239 (59.4%)	28,591 (70%)	24,838 (60.8%)
		Stratified	12,714 (31.1%)	16,186 (39.6%)	16,592 (40.6%)	12,240 (30%)	15,993 (39.2%)
	92,477	Mixed	51,759 (56%)	44,489 (48.1%)	43,159 (46.7%)	53,371 (57.7%)	43,524 (47.1%)

05 - Taiga Shield		Stratified	40,718 (44%)	47,988 (51.9%)	49,318 (53.3%)	39,106 (42.3%)	48,953 (52.9%)
09 - Boreal Plains	348	Mixed	322 (92.5%)	304 (87.4%)	295 (84.8%)	317 (91.1%)	295 (84.8%)
		Stratified	26 (7.5%)	44 (12.6%)	53 (15.2%)	31 (8.9%)	53 (15.2%)
11 - Taiga Cordillera	3,738	Mixed	2,017 (54%)	1,797 (48.1%)	1,776 (47.5%)	1,873 (50.1%)	1,766 (47.2%)
		Stratified	1,721 (46%)	1,941 (51.9%)	1,962 (52.5%)	1,865 (49.9%)	1,972 (52.8%)
12 - Boreal Cordillera	4,013	Mixed	568 (14.2%)	399 (9.9%)	327 (8.1%)	422 (10.5%)	316 (7.9%)
		Stratified	3,445 (85.8%)	3,614 (90.1%)	3,686 (91.9%)	3,591 (89.5%)	3,697 (92.1%)

Supplementary Table 4. Summary of the number of barren, thermally diverse, and thermally uniform lakes across the Canadian Arctic under different climate periods and scenarios.

Lake Class	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
Barren	232,377 (52%)	223,014 (49.9%)	219,906 (49.2%)	220,203 (49.3%)	205,165 (45.9%)
Thermally diverse	64,135 (14.3%)	90,590 (20.3%)	96,395 (21.6%)	84,137 (18.8%)	145,492 (32.5%)
Thermally uniform	150,565 (33.7%)	133,473 (29.9%)	130,776 (29.3%)	142,737 (31.9%)	96,420 (21.6%)

Supplementary Table 5. Summary of the total volume (km^3) of barren, thermally diverse, and thermally uniform lakes across the Canadian Arctic under different climate periods and scenarios (all lakes, including barren, included at least 60°N latitude except Great Bear Lake and Great Slave Lake, *N* = 447,075).

Lake Class	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
Barren	148.4 (5.2%)	133.3 (4.7%)	129.3 (4.6%)	129.5 (4.6%)	110.8 (3.9%)
Thermally diverse	1,505.5 (53%)	1,595.7 (56.2%)	1,609.8 (56.7%)	1,570.7 (55.3%)	1,827.1 (64.4%)
Thermally uniform	1,185.1 (41.7%)	1,110 (39.1%)	1,100 (38.7%)	1,138.8 (40.1%)	901.1 (31.7%)

Supplementary Table 6. Summary of the number and percentage of lakes that stayed in the same lake classification or switched between the historical climate scenario and each of the four future climate scenarios. The first lake classification is the historical one, and the second is the subsequent one under future climate change (e.g., "Barren → Thermally diverse" means that the lake was projected to be a barren lake under historical conditions and is subsequently projected to be a thermally diverse lake under climate change). Percentages express the proportion of lake numbers relative to the total of lakes analyzed (N = 447,077).

Lake Classification	RCP4.5 2050	RCP4.5 2100	RCP8.5 2050	RCP8.5 2100
Barren → Barren	223,014 (49.9%)	219,906 (49.2%)	220,203 (49.5%)	205,165 (45.9%)
Barren → Thermally diverse	1,410 (0.3%)	2,085 (0.5%)	1,106 (0.2%)	5,421 (1.2%)
Barren → Thermally uniform	7,953 (1.8%)	10,386 (2.3%)	11,068 (2.5%)	21,791 (4.9%)
Thermally diverse → Thermally diverse	64,135 (14.3%)	64,135 (14.3%)	61,805 (13.9%)	64,123 (14.3%)
Thermally uniform → Thermally diverse	25,045 (5.6%)	30,175 (6.7%)	21,226 (4.8%)	75,948 (17%)
Thermally uniform → Thermally uniform	125,520 (28.1%)	120,390 (26.9%)	129,339 (29.1%)	74,617 (16.7%)

Supplementary Table 7. Summary of ice-free volume-days corresponding to each thermal guild's temperature range by future climate scenario (all lakes, including barren, included at least 60°N latitude except Great Bear Lake and Great Slave Lake, N = 447,075).

Guild	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
Cold	3.09×10^{14} (96.2%)	2.92×10^{14} (84.7%)	3.05×10^{14} (84.1%)	2.98×10^{14} (84.2%)	2.50×10^{14} (61.1%)
Cool	1.21×10^{13} (3.8%)	5.25×10^{13} (15.2%)	5.55×10^{13} (15.3%)	5.46×10^{13} (15.4%)	1.21×10^{14} (29.5%)
Warm	0.00 (0%)	5.01×10^{11} (0.1%)	2.30×10^{12} (0.6%)	1.32×10^{12} (0.4%)	3.84×10^{13} (9.4%)

Supplementary Table 8. Summary of ice-free volume-days corresponding to each thermal guild's temperature range by future climate scenario and ecozone (all lakes, including barren, included at least 60°N latitude except Great Bear Lake and Great Slave Lake, N = 447,075).

Ecozone	**Guild**	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
01 - Arctic Cordillera	Cold	3.85×10^{12} (100%)	4.88×10^{12} (100%)	5.15×10^{12} (100%)	5.14×10^{12} (100%)	6.60×10^{12} (100%)
	Cool	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
	Warm	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
02 - Northern Arctic	Cold	8.35×10^{13} (100%)	9.94×10^{13} (100%)	1.04×10^{14} (100%)	1.03×10^{14} (100%)	8.89×10^{13} (92.1%)
	Cool	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	7.65×10^{12} (7.9%)
	Warm	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
03 - Southern Arctic	Cold	8.66×10^{13} (100%)	7.36×10^{13} (99%)	7.62×10^{13} (99%)	7.57×10^{13} (99.6%)	5.14×10^{13} (48.1%)
	Cool	0.00 (0%)	7.54×10^{11} (1%)	7.47×10^{11} (1%)	3.24×10^{11} (0.4%)	5.52×10^{13} (51.7%)
	Warm	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	2.68×10^{11} (0.3%)

04 - Taiga Plains	Cold	2.47×10^{13} (82.7%)	2.14×10^{13} (65.1%)	2.24×10^{13} (67.2%)	2.11×10^{13} (65.9%)	1.97×10^{13} (51.5%)
	Cool	5.18×10^{12} (17.3%)	1.12×10^{13} (34.1%)	9.48×10^{12} (28.4%)	1.02×10^{13} (31.8%)	1.05×10^{13} (27.4%)
	Warm	0.00 (0%)	2.67×10^{11} (0.8%)	1.47×10^{12} (4.4%)	7.45×10^{11} (2.3%)	8.08×10^{12} (21.1%)
05 - Taiga Shield	Cold	6.57×10^{13} (90.9%)	4.97×10^{13} (59.6%)	5.15×10^{13} (57%)	4.95×10^{13} (57.2%)	3.80×10^{13} (35.5%)
	Cool	6.61×10^{12} (9.1%)	3.35×10^{13} (40.2%)	3.81×10^{13} (42.1%)	3.65×10^{13} (42.1%)	4.25×10^{13} (39.8%)
	Warm	0.00 (0%)	2.30×10^{11} (0.3%)	7.82×10^{11} (0.9%)	5.61×10^{11} (0.6%)	2.63×10^{13} (24.6%)
09 - Boreal Plains	Cold	7.81×10^{9} (45.5%)	5.37×10^{9} (31.2%)	5.37×10^{9} (31.1%)	4.17×10^{9} (23.4%)	3.90×10^{9} (20.7%)
	Cool	9.37×10^{9} (54.5%)	7.46×10^{9} (43.3%)	5.75×10^{9} (33.3%)	7.06×10^{9} (39.7%)	4.75×10^{9} (25.2%)
	Warm	0.00 (0%)	4.38×10^{9} (25.4%)	6.16×10^{9} (35.7%)	6.57×10^{9} (36.9%)	1.02×10^{9} (54.2%)

11 - Taiga Cordillera	Cold	1.44×10^{12} (99.7%)	1.08×10^{12} (73.1%)	1.30×10^{12} (78%)	1.08×10^{12} (72.2%)	1.28×10^{12} (70.4%)
	Cool	4.47×10^{9} (0.3%)	3.97×10^{11} (26.9%)	3.66×10^{11} (21.9%)	4.16×10^{11} (27.8%)	4.08×10^{11} (22.6%)
	Warm	0.00 (0%)	0.00 (0%)	3.25×10^{8} (0%)	0.00 (0%)	1.27×10^{11} (7%)
12 - Boreal Cordillera	Cold	4.29×10^{13} (99.2%)	4.24×10^{13} (86.4%)	4.41×10^{13} (86.6%)	4.20×10^{13} (85.3%)	4.46×10^{13} (84.5%)
	Cool	3.30×10^{11} (0.8%)	6.65×10^{12} (13.6%)	6.76×10^{12} (13.3%)	7.24×10^{12} (14.7%)	4.58×10^{12} (8.7%)
	Warm	0.00 (0%)	1.53×10^{8} (0%)	3.50×10^{9} (0.1%)	6.08×10^{9} (0%)	3.63×10^{12} (6.9%)

Supplementary Table 9. Summary of thermal habitat volume-days according to lake classification type and climate scenario (all lakes, including barren, included at least 60°N latitude except Great Bear Lake and Great Slave Lake, *N* = 447,075).

Lake class	**Guild**	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
Barren	Cold	1.28×10^{13} (89.2%)	1.14×10^{13} (83.7%)	1.10×10^{13} (81%)	1.12×10^{13} (82.9%)	6.24×10^{12} (46.8%)
	Cool	1.55×10^{12} (10.8%)	2.13×10^{12} (15.7%)	2.17×10^{12} (15.9%)	1.98×10^{12} (14.6%)	5.64×10^{12} (42.2%)
	Warm	0.00 (0%)	8.45×10^{10} (0.6%)	4.24×10^{11} (3.1%)	3.28×10^{11} (2.4%)	1.47×10^{12} (11%)
Thermally diverse	Cold	1.81×10^{14} (95.9%)	1.78×10^{14} (83.6%)	1.90×10^{14} (84.8%)	1.80×10^{14} (84.4%)	1.92×10^{14} (68.2%)
	Cool	7.78×10^{12} (4.1%)	3.46×10^{13} (16.2%)	3.26×10^{13} (14.6%)	3.26×10^{13} (15.3%)	6.66×10^{13} (23.6%)
	Warm	0.00 × (0%)	3.48×10^{11} (0.2%)	1.44×10^{12} (0.6%)	6.21×10^{11} (0.3%)	2.30×10^{13} (8.2%)
Thermally uniform	Cold	1.15×10^{14} (97.6%)	1.03×10^{14} (86.6%)	1.03×10^{14} (83%)	1.06×10^{14} (83.9%)	5.19×10^{13} (45.4%)
	Cool	2.80×10^{12} (2.4%)	1.58×10^{13} (13.3%)	2.07×10^{13} (16.6%)	2.01×10^{13} (15.8%)	4.85×10^{13} (42.4%)
	Warm	0.00 × (0%)	6.83×10^{10} (0.1%)	4.33×10^{11} (0.3%)	3.70×10^{11} (0.3%)	1.39×10^{13} (12.2%)

Supplementary Table 10. Basic lake information for different Arctic lake GIS-derived bathymetry estimates.

Dataset	**Campana**	**HydroLAKES**
Coordinates	Yes	Yes (Pour point)
Lake area (km^2)	Yes	Yes
Perimeter (km)	Yes	Yes
Fetch (km)	Yes	No (could be estimated from surface area)
Shoreline development	No (could be calculated)	Yes
Volume (million cubic metres)	No (could be calculated)	Yes
Mean depth (m)	Yes	Yes (Volume/area)
Maximum depth (m)	Yes	No (could be estimated empirically)
Discharge (m^3 sec^{-1})	No	Yes
Residence time (days)	No	Yes
Elevation	Yes	Yes
Slope (degrees)	No	Yes
Watershed area	No	Yes

Supplementary Table 11. Number of lakes per ecozone in the Arctic GIS lake database[16], HydroLAKES[17], and empirical morphometry datasets.

Ecozone name	**Ecozone ID**	**Arctic**	**Arctic ≥ 60°N**	**HydroLAKES**	**Empirical morphometry**
Arctic Cordillera	1	4,859	3,062	2,942	0
Northern Arctic	2	165,018	165,018	167,723	12
Southern Arctic	3	159,819	137,590	141,244	76
Taiga Plains	4	40,831	40,831	38,211	12
Taiga Shield	5	102,603	92,477	96,005	20
Boreal Shield	6	2	0	0	2
Boreal Plains	9	349	348	95	1
Taiga Cordillera	11	3,738	3,738	2,984	0
Boreal Cordillera	12	4,016	4,013	3,723	44
Hudson Plains	15	547	0	0	0
	Total lakes	481,782	447,077	452,927	167

Supplementary Table 12. Number of lakes in the Arctic GIS lake database[16] that had their morphometry values predicted from empirical equations.

Variable predicted	Predictor variable	Number of lakes	Percent of lakes
Maximum depth	Mean depth	727	0.15%
Mean depth, Maximum depth	Area	5,233	1.09%
Mean depth	Maximum depth	3,113	0.65%
	No prediction required	472,709	98.12%
	Total lakes	481,782	100%

Supplementary Table 13. Results from the lake morphometry assessment linear regression equations.

Response	**Predictor(s)**	R^2	***F*-statistic**	**Degrees of freedom**	***p*-value**	**Intercept**	**Slope**	***n***
Mean depth	Maximum depth	0.89	1350	$F_{[1, 165]}$	< 0.0001	-0.90	0.93	167
Maximum depth	Mean depth	0.89	1350	$F_{[1, 165]}$	< 0.0001	1.17	0.96	167
Mean depth	Surface area	0.49	161	$F_{[1, 165]}$	< 0.0001	1.31	0.34	167
Maximum depth	Surface area	0.52	178	$F_{[1, 165]}$	< 0.0001	2.38	0.36	167

Supplementary Table 14. Results from the lake morphometry assessment linear regression comparisons with ecozone as a predictor. ANOVA and ΔAIC results refer to a comparison of linear models without and with terrestrial ecozone as a predictor.

Response	**Predictor(s)**	R^2	***F*-statistic**	**Degrees of freedom**	***p*-value**	**ΔAIC**	**ANOVA *F*-statistic**	**ANOVA *p*-value**	***n***
Maximum depth	Mean depth, Ecozone	0.91	313.2	$F_{[5, 158]}$	< 0.0001	13.21	5.61	0.0003	164
Mean depth	Maximum depth, Ecozone	0.93	409.3	$F_{[5, 158]}$	< 0.0001	53.54	18.18	< 0.0001	164
Maximum depth	Surface area, Ecozone	0.56	42.47	$F_{[5, 158]}$	< 0.0001	17.83	6.90	< 0.0001	164
Mean depth	Surface area, Ecozone	0.63	56.58	$F_{[5, 158]}$	< 0.0001	48.05	16.29	< 0.0001	164

Supplementary Table 15. Summary of fitted values for the shape (β) and scale (η) parameters of the Weibull distribution at different time scales (N = 109 sites).

Param	Hours	Min	1st Qu.	Median	Mean	3rd Qu.	Max
β	1	2.046	2.294	2.338	2.321	2.363	2.956
	8	2.172	2.494	2.531	2.564	2.653	3.406
	24	2.407	2.871	2.908	2.994	3.111	4.212
η	1	4.044	5.356	5.616	5.874	6.597	7.151
	8	4.030	5.360	5.612	5.873	6.600	7.153
	24	4.000	5.319	5.575	5.840	6.578	7.120

Supplementary Table 16. Summary statistics of summer storm wind strength (m s^{-1}) for historical conditions and our two climate change scenarios, as derived from the output from our sample (*n* = 9623 lakes).

Metric	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
n	9623	9623	9623	9623	9623
Missing	0	0	0	0	0
Mean	10.01	9.90	9.67	10.54	10.16
Minimum	5.56	5.19	5.05	5.68	5.44
1st Q	8.28	8.15	8.15	9.53	9.03
Median	10.49	10.35	10.10	10.83	10.45
3rd Q	11.38	11.51	10.92	11.64	11.11
Maximum	15.90	15.91	16.18	15.38	15.89
Skew	-0.19	-0.27	-0.02	-0.36	-0.07
Kurtosis	2.33	2.21	2.52	2.84	3.11

Supplementary Table 17. Summary statistics of thermocline depth (m) for historical conditions and our two climate change scenarios, as derived from the output from our sample (*n* = 9623 lakes).

Metric	**Historical**	**RCP4.5 2050**	**RCP4.5 2100**	**RCP8.5 2050**	**RCP8.5 2100**
n	1430	2068	2176	1839	3205
Missing	8193	7555	7447	7784	6418
Mean	4.91	4.72	4.84	5.78	5.14
Minimum	1.64	1.47	1.27	1.54	1.27
1st Q	3.20	2.86	2.93	3.57	3.38
Median	4.00	3.75	3.87	4.87	4.55
3rd Q	5.55	5.56	5.80	7.04	6.19
Maximum	20.00	20.00	20.00	20.00	20.00
Skew	2.87	2.43	2.28	1.86	2.00
Kurtosis	13.46	10.94	10.02	7.54	9.59

Supplementary Table 18. Number of lakes per freshwater ecoregion. Only lakes at least 60°N are shown.

Freshwater ecoregion name	**Freshwater ecoregion ID**	**Number of lakes**
Alaskan Coastal	101	862
Upper Yukon	102	5,504
Alaska and Canada Pacific Coastal	103	295
Upper Mackenzie	104	846
Lower Mackenzie	105	92,764
Central Arctic Coastal	106	97,351
Western Hudson Bay	111	121,400
Canadian Arctic Archipelago	112	114,143
Eastern Hudson Bay–Ungava	113	13,912
	Total lakes	447,077

Supplementary Table 19. Mean, median, and standard deviation (SD) of maximum depth and maximum lake surface water temperature (Max. LSWT; historical values). Lakes are classified according to terrestrial ecozones and freshwater ecoregions.

Metric	**Classification**	**Division**	**Mean**	**Median**	**SD**
Max. LSWT	Terrestrial Ecozones	01 - Arctic Cordillera	8.3	8.9	2.2
		02 - Northern Arctic	11.1	11.1	1.3
		03 - Southern Arctic	14.1	14.0	1.3
		04 - Taiga Plains	19.3	194	1.5
		05 - Taiga Shield	17.9	17.7	1.5
		09 - Boreal Plains	21.4	21.4	0.3
		11 - Taiga Cordillera	16.9	16.8	1.2
		12 - Boreal Cordillera	18.2	18.4	1.4
	Freshwater Ecoregions	101 - Alaskan Coastal	16.3	16.3	1.0
		102 - Upper Yukon	17.7	17.7	1.3
		103 - Alaska and Canada Pacific Coastal	16.5	16.8	1.1
		104 - Upper Mackenzie	21.3	21.3	0.4
		105 - Lower Mackenzie	18.5	18.7	1.8
		106 - Central Arctic Coastal	14.5	13.8	2.1
		111 - Western Hudson Bay	14.3	14.4	2.4
		112 - Canadian Arctic Archipelago	10.6	10.7	1.2

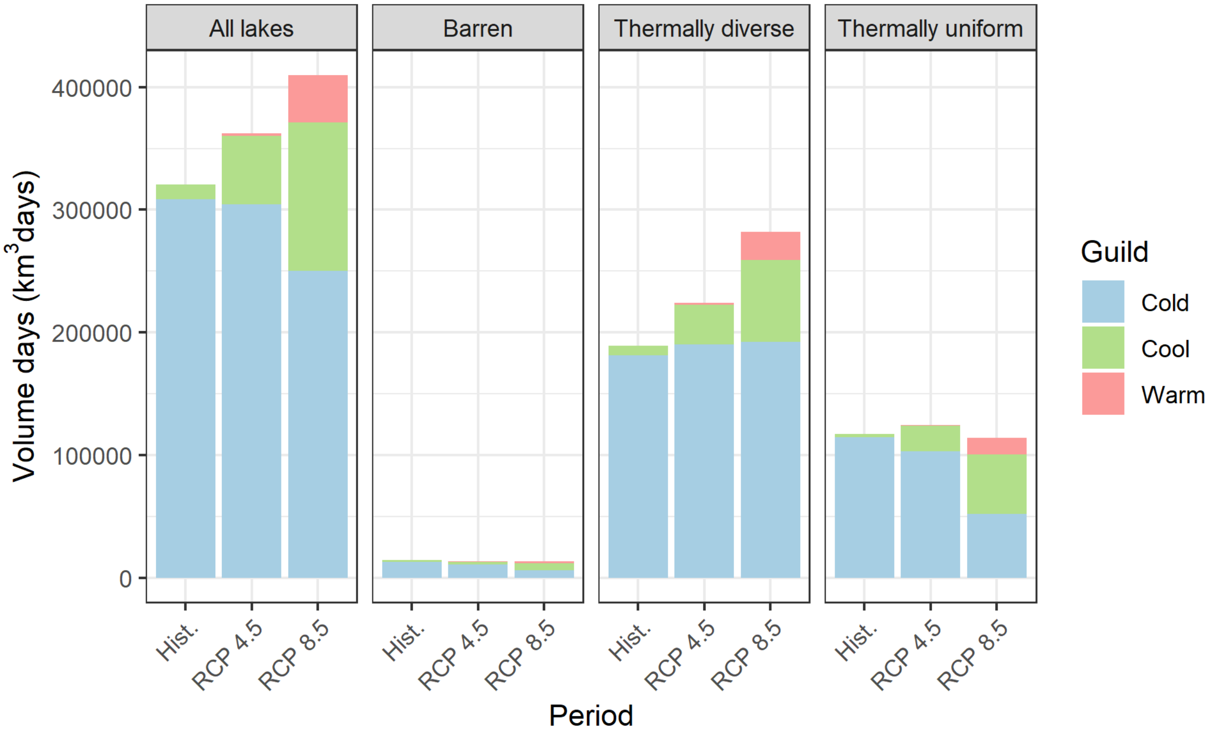
		113 - Eastern Hudson Bay–Ungava	12.6	12.7	0.8
Max. depth	Terrestrial Ecozones	01 - Arctic Cordillera	53.5	40.3	51.1
		02 - Northern Arctic	11.1	7.2	13.6
		03 - Southern Arctic	7.2	5.6	6.1
		04 - Taiga Plains	5.8	4.0	8.1
		05 - Taiga Shield	8.9	7.3	6.8
		09 - Boreal Plains	2.4	1.2	3.0
		11 - Taiga Cordillera	17.5	5.7	26.4
		12 - Boreal Cordillera	28.5	17.8	35.7
	Freshwater Ecoregions	101 - Alaskan Coastal	7.0	5.1	8.5
		102 - Upper Yukon	19.2	8.6	29.5
		103 - Alaska and Canada Pacific Coastal	48.5	31.2	61.0
		104 - Upper Mackenzie	2.5	1.4	3.8
		105 - Lower Mackenzie	9.0	7.1	9.1
		106 - Central Arctic Coastal	8.3	6.4	7.1
		111 - Western Hudson Bay	6.9	5.2	6.6

		112 - Canadian Arctic Archipelago	12.8	7.2	18. 5
		113 - Eastern Hudson Bay–Ungava	10.2	7.8	10. 5

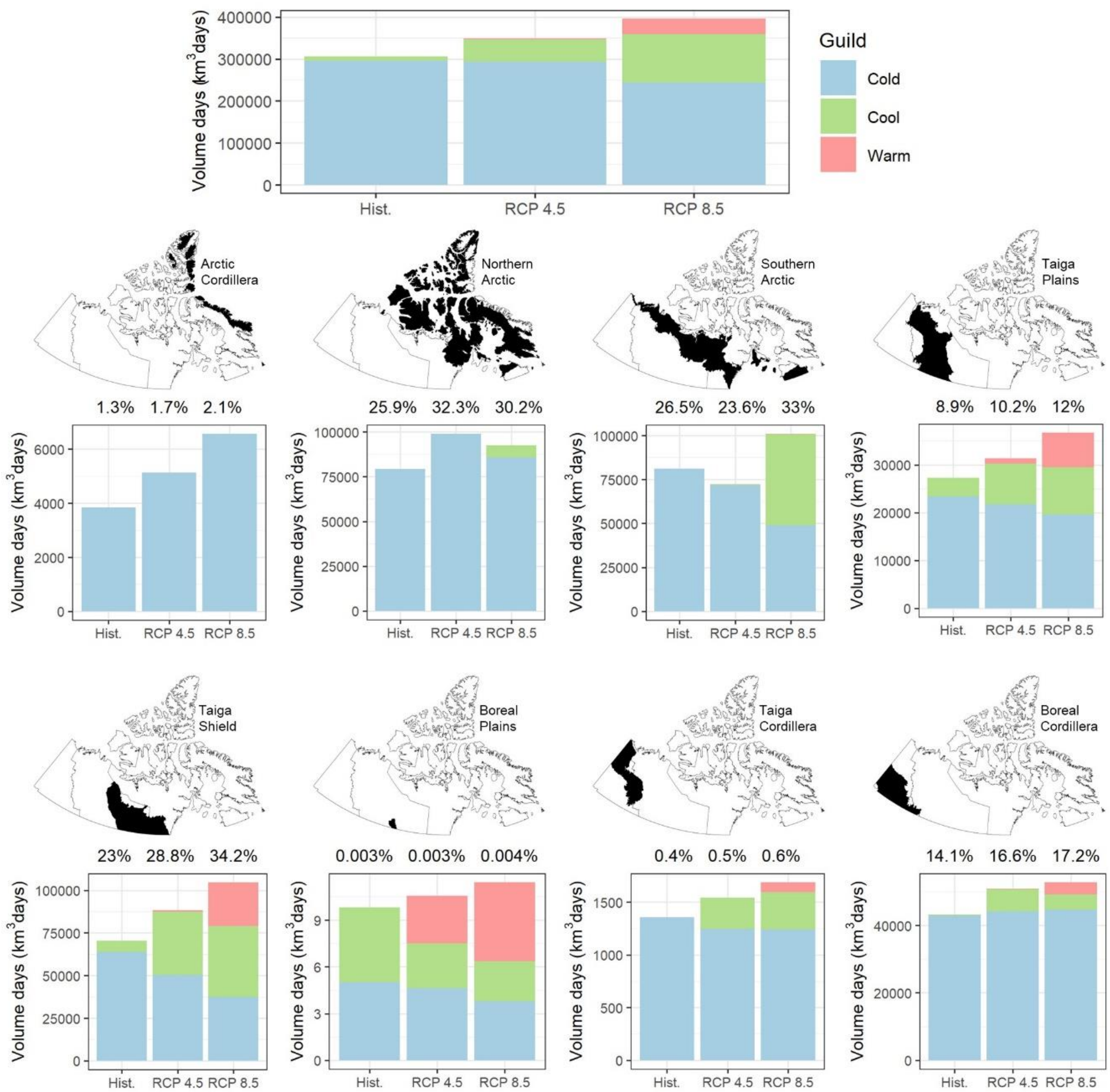
Supplementary Table 20. Results from the one-way ANOVA tests comparing the means of maximum depth and maximum lake surface water temperature (Max. LSWT) with terrestrial ecozones and freshwater ecoregions applied as the classification system or predictor.

Response	**Predictor**	***F*-statistic**	**Residual Sum of Squares**	**Degrees of freedom**	***p*-value**	***n***
Max. LWST	Terrestrial Ecozones	315,398	832,435	$F_{[7, 447,069}$	< 0.0001	447,077
	Freshwater Ecoregions	119,589	1,574,317	$F_{[7, 447,068]}$	< 0.0001	447,077
Maximum depth	Terrestrial Ecozones	6,150	68,209	$F_{[7, 447,069]}$	< 0.0001	447,077
	Freshwater Ecoregions	1,862	72,367	$F_{[7, 447,068]}$	< 0.0001	447,077

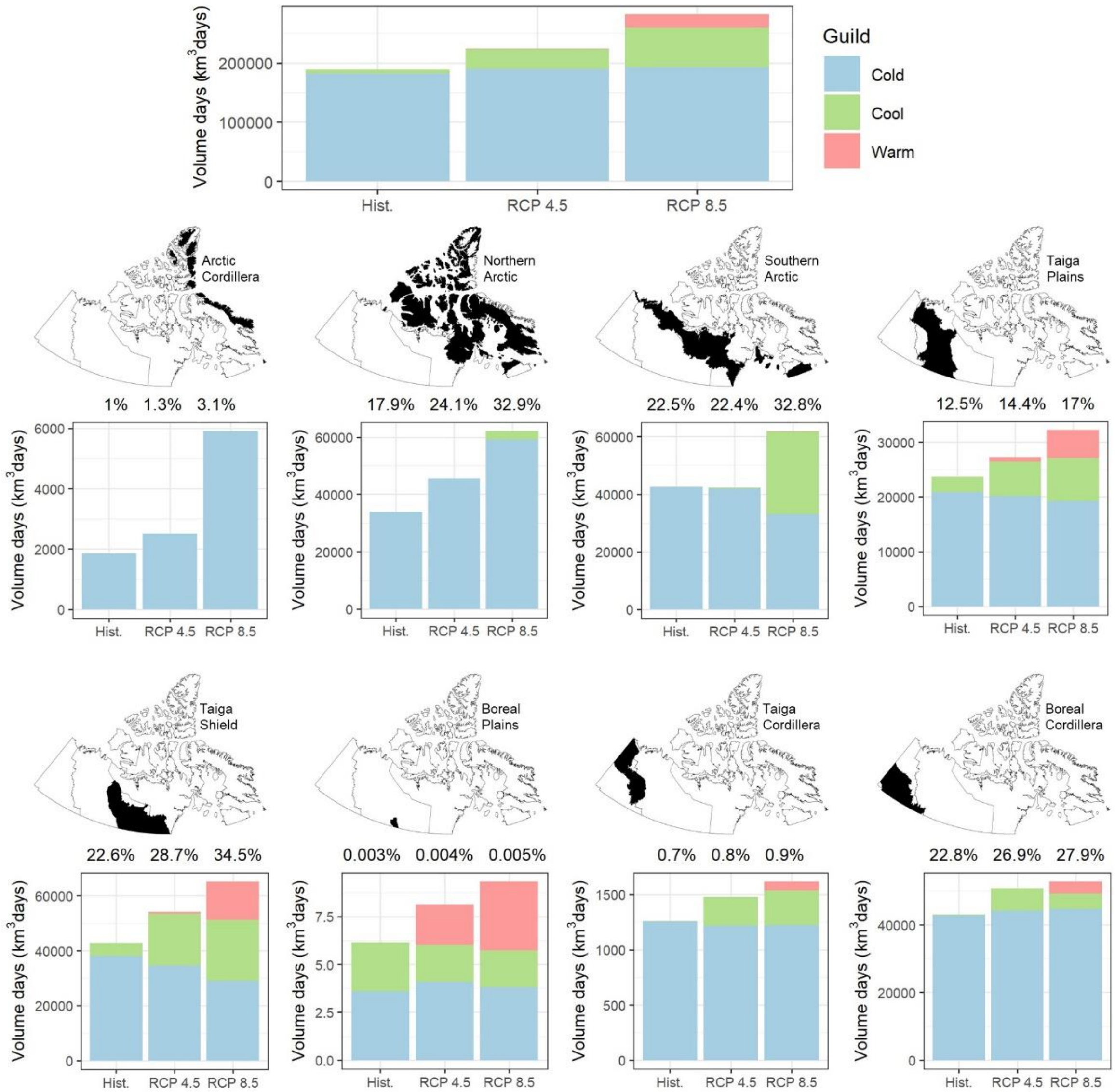
Supplementary Figures



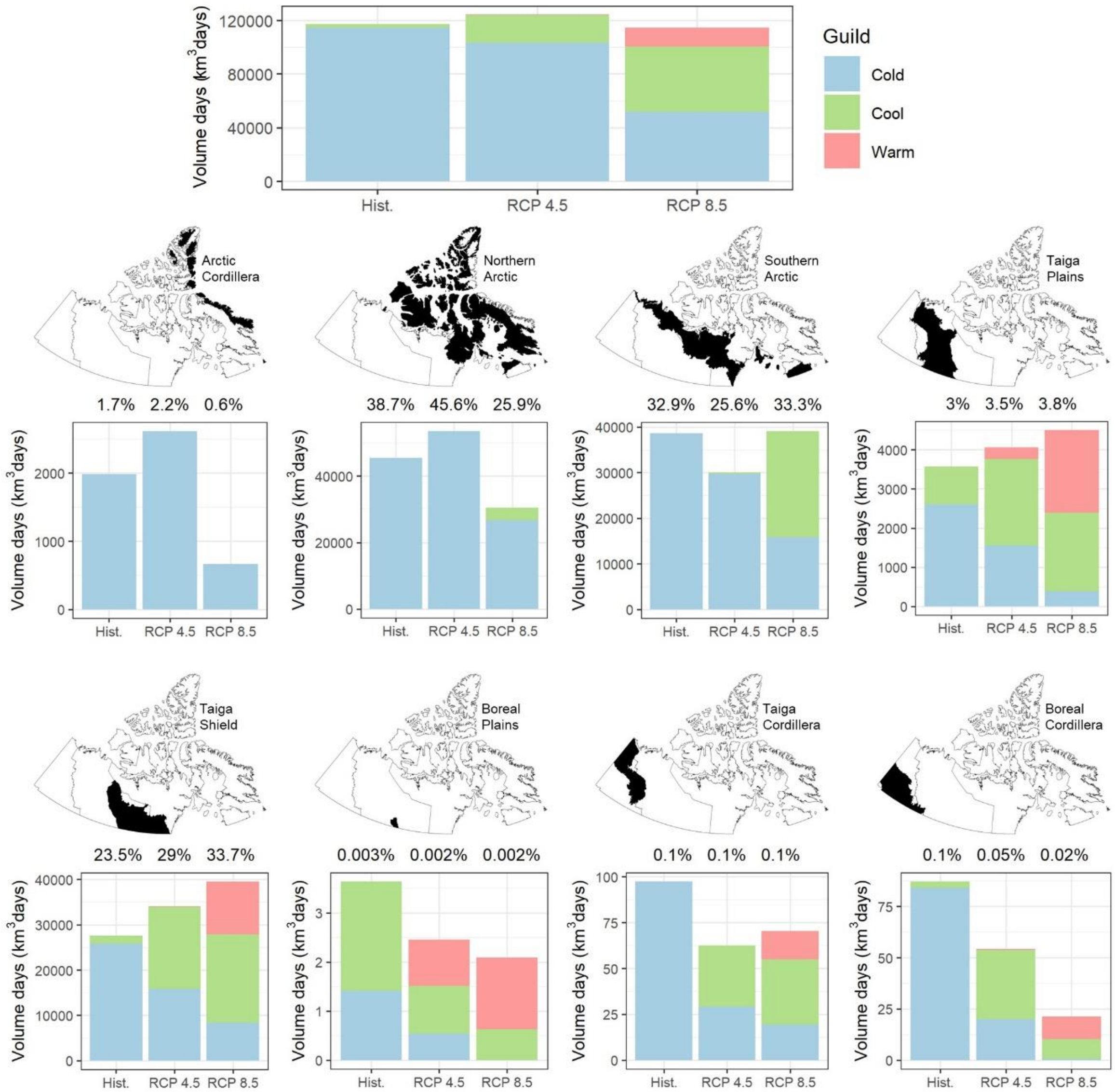
Supplementary Figure 1A. Ice-free volume-days across different climate scenarios and periods by thermal guild and lake status (all lakes, barren, thermally diverse, or thermally uniform). Great Bear Lake and Great Slave Lake were excluded. Barren lakes—which are excluded from other thermal habitat calculations—are included in the totals here and shown alongside the other two lake classes to illustrate their relatively minor contribution to the regional limnetic volume. A summary of ice-free volume-days for all lakes (left panel) across all five climate scenarios is in Supplementary Table 7.



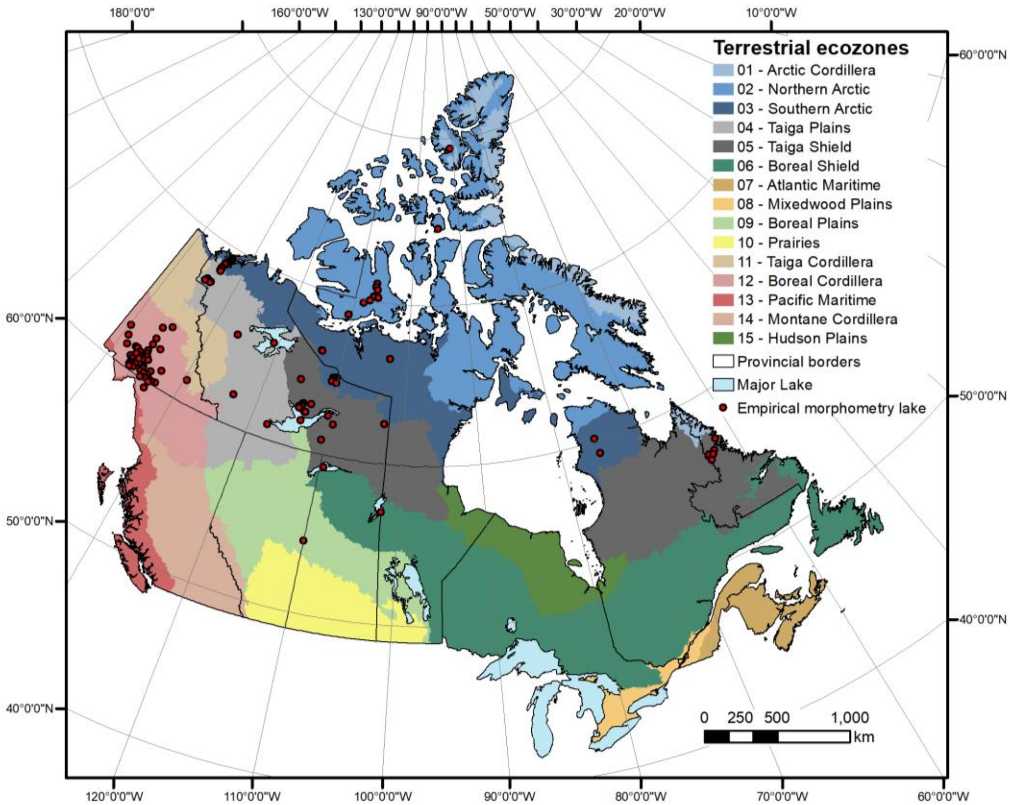
Supplementary Figure 1B. Ice-free volume-days associated with each thermal guild under historical and potential future climate change scenarios (RCP4.5 and RCP8.5 in 2100) for thermally diverse and thermally uniform lakes pooled (barren lakes excluded). The total is shown in the top panel, and by ecozone in the remaining panels (see Figures 4 and 5 for *n* by ecozone). Great Bear Lake and Great Slave Lake were excluded. The percentages above each bar represent the amount of thermal habitat that each ecozone comprises across the entire study area for that climate scenario.



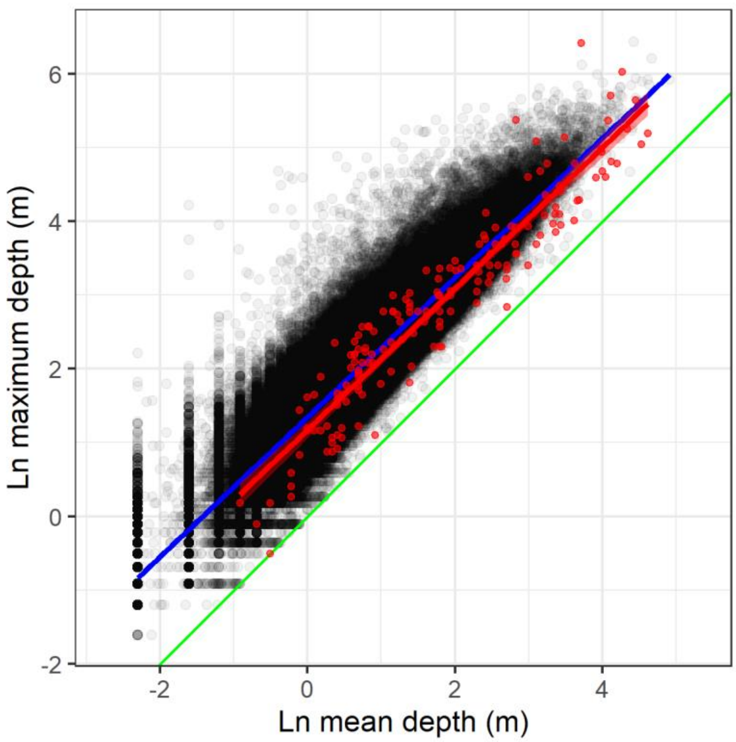
Supplementary Figure 1C. Ice-free volume-days associated with each thermal guild under historical and potential future climate change scenarios (RCP4.5 and RCP8.5 in 2100) for thermally diverse lakes only. The total is shown in the top panel, and by ecozone in the remaining panels (see Figures 4 and 5 for *n* by ecozone). Great Bear Lake and Great Slave Lake were excluded. The percentages above each bar represent the amount of thermal habitat that each ecozone comprises across the entire study area for that climate scenario. See Supplementary Table 9 for a summary including all five climate scenarios.



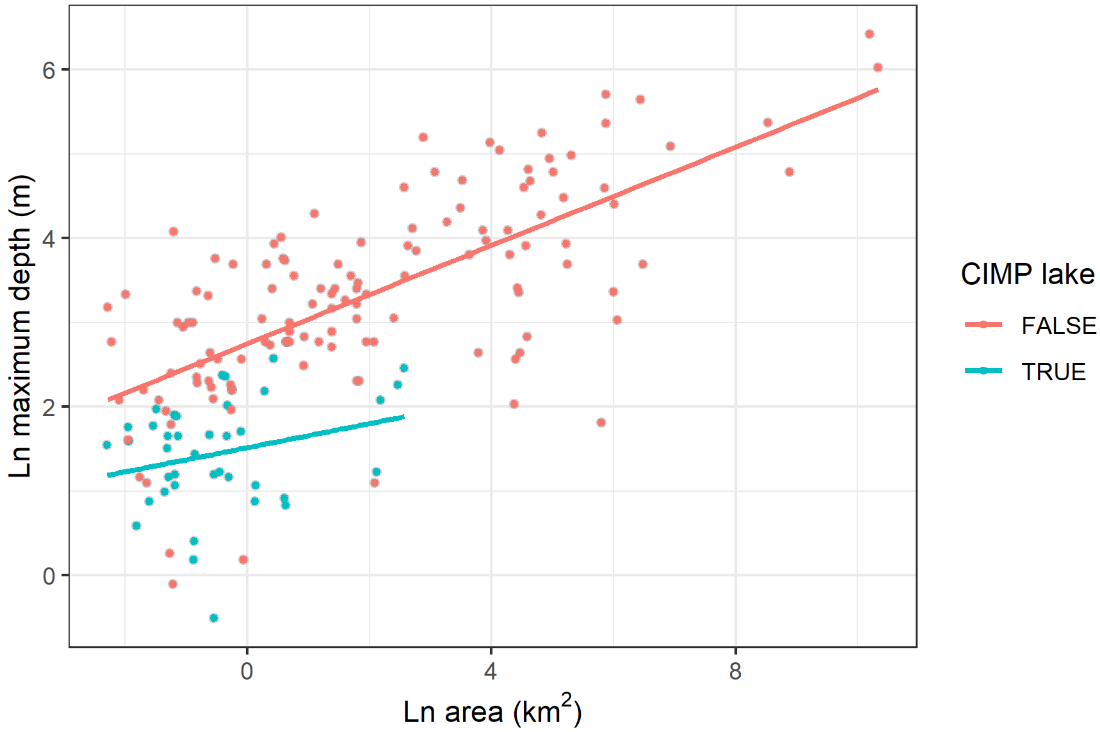
Supplementary Figure 1D. Ice-free volume-days associated with each thermal guild under historical and potential future climate change scenarios (RCP4.5 and RCP8.5 in 2100) for thermally uniform lakes only. The total is shown in the top panel, and by ecozone in the remaining panels (see Figures 4 and 5 for *n* by ecozone). Great Bear Lake and Great Slave Lake were excluded. The percentages above each bar represent the amount of thermal habitat that each ecozone comprises across the entire study area for that climate scenario. See Supplementary Table 9 for a summary including all five climate scenarios.



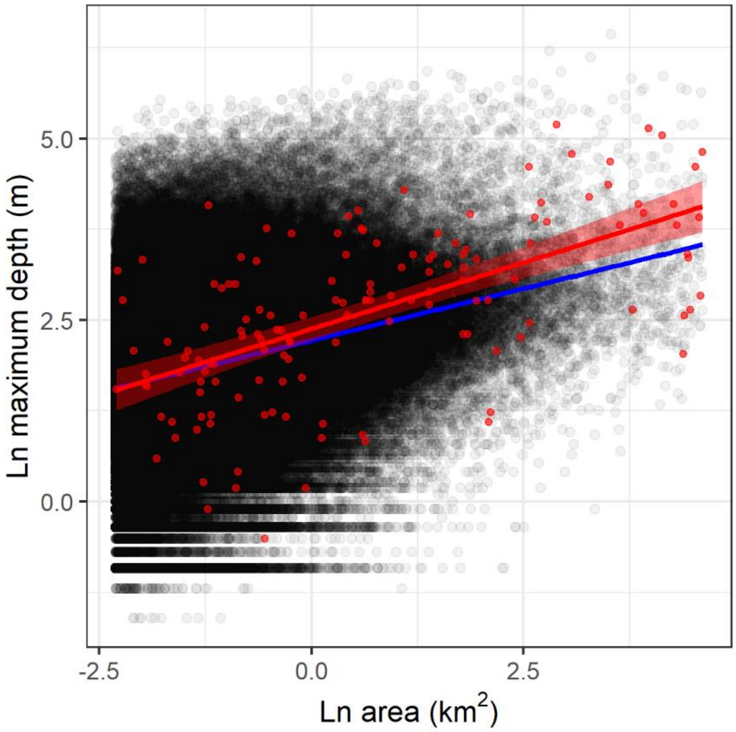
Supplementary Figure 2. Map showing the ecozones of Canada and the geographic locations of Canadian lakes for which we have ground-truthed morphometry estimates (*N* = 167). These lakes were used to inform the relationships for missing values in the Arctic GIS lake database. Lakes are coloured by Ecozone code.



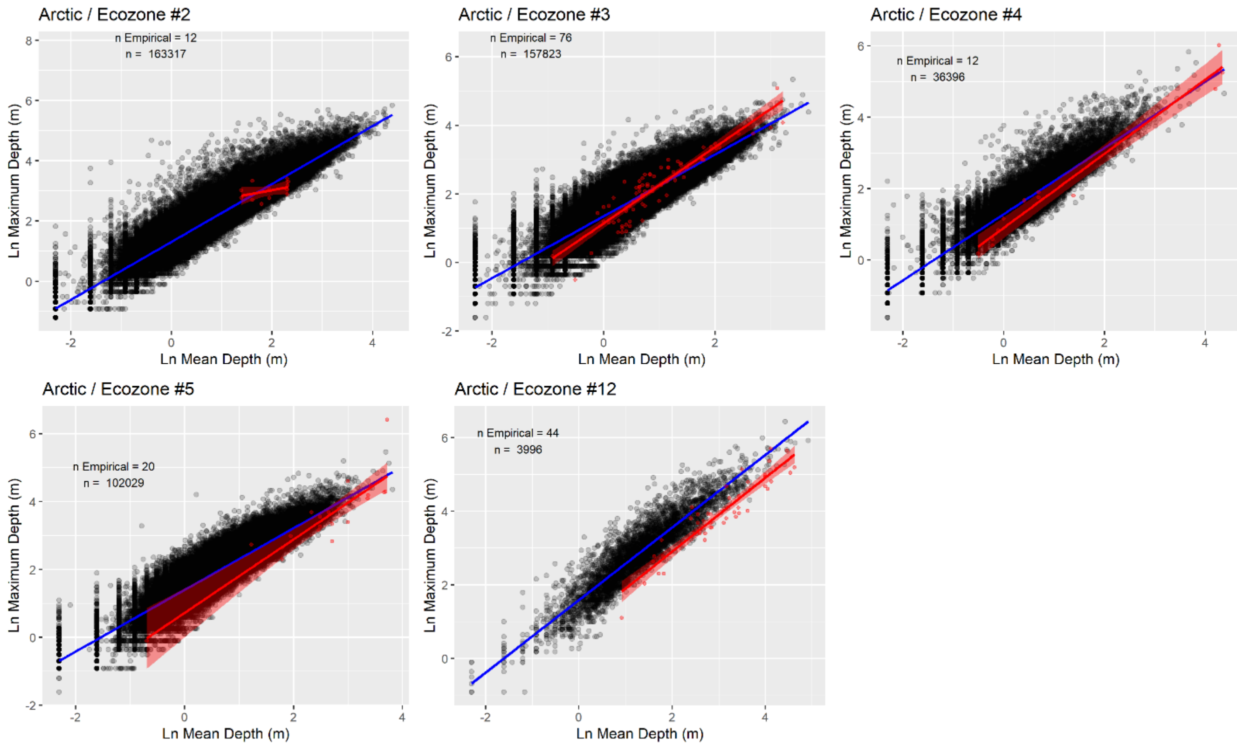
Supplementary Figure 3. Relationship between final mean and maximum depths in the Arctic GIS lake database[16] (n = 472,709) (black dots, blue regression line) with the empirical morphometry dataset overlaid in red (N = 167, red regression line). All values have been log-transformed (ln). The green line is the 1:1 line. Lakes from the Arctic GIS lake database with morphometry values predicted by the empirical equations have been left out of this figure (n = 9,073).



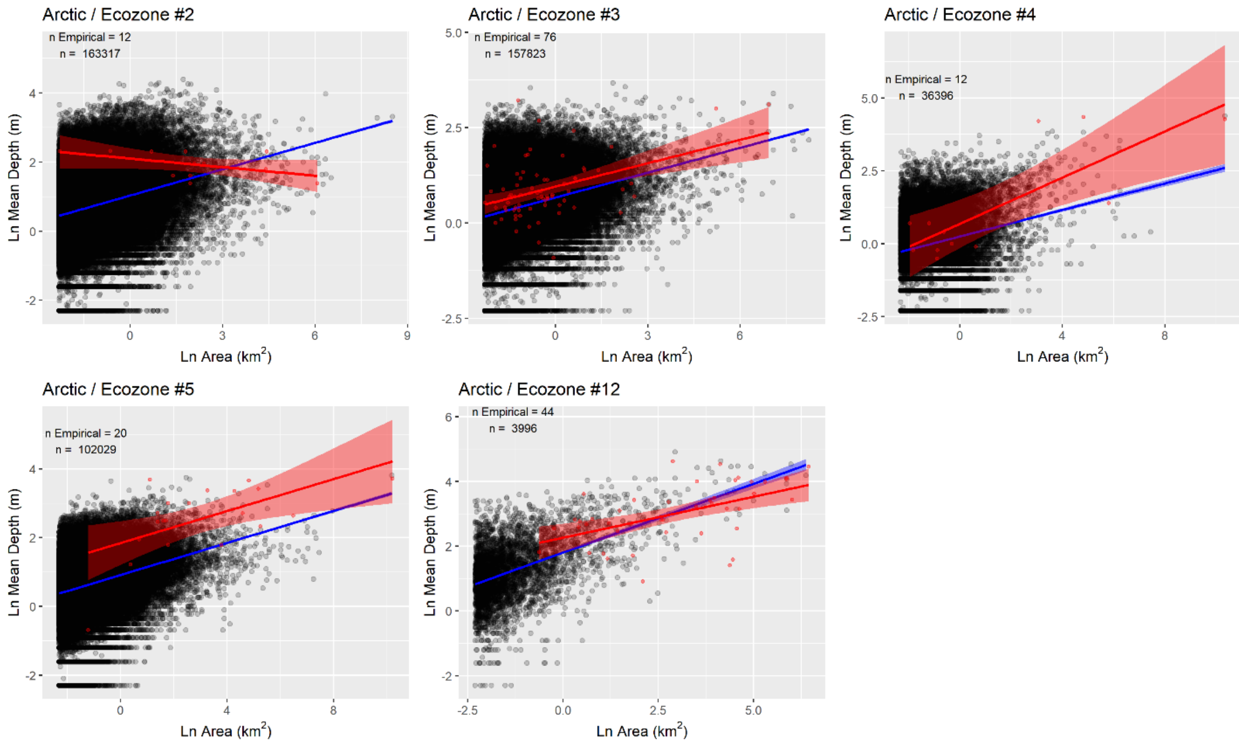
Supplementary Figure 4. The relationship between lake maximum depth and surface area for our empirically measured lakes database (*N* = 167). Lakes that are part of the Cumulative Impact Monitoring Program (CIMP) lake dataset are identified (*n* = 39).



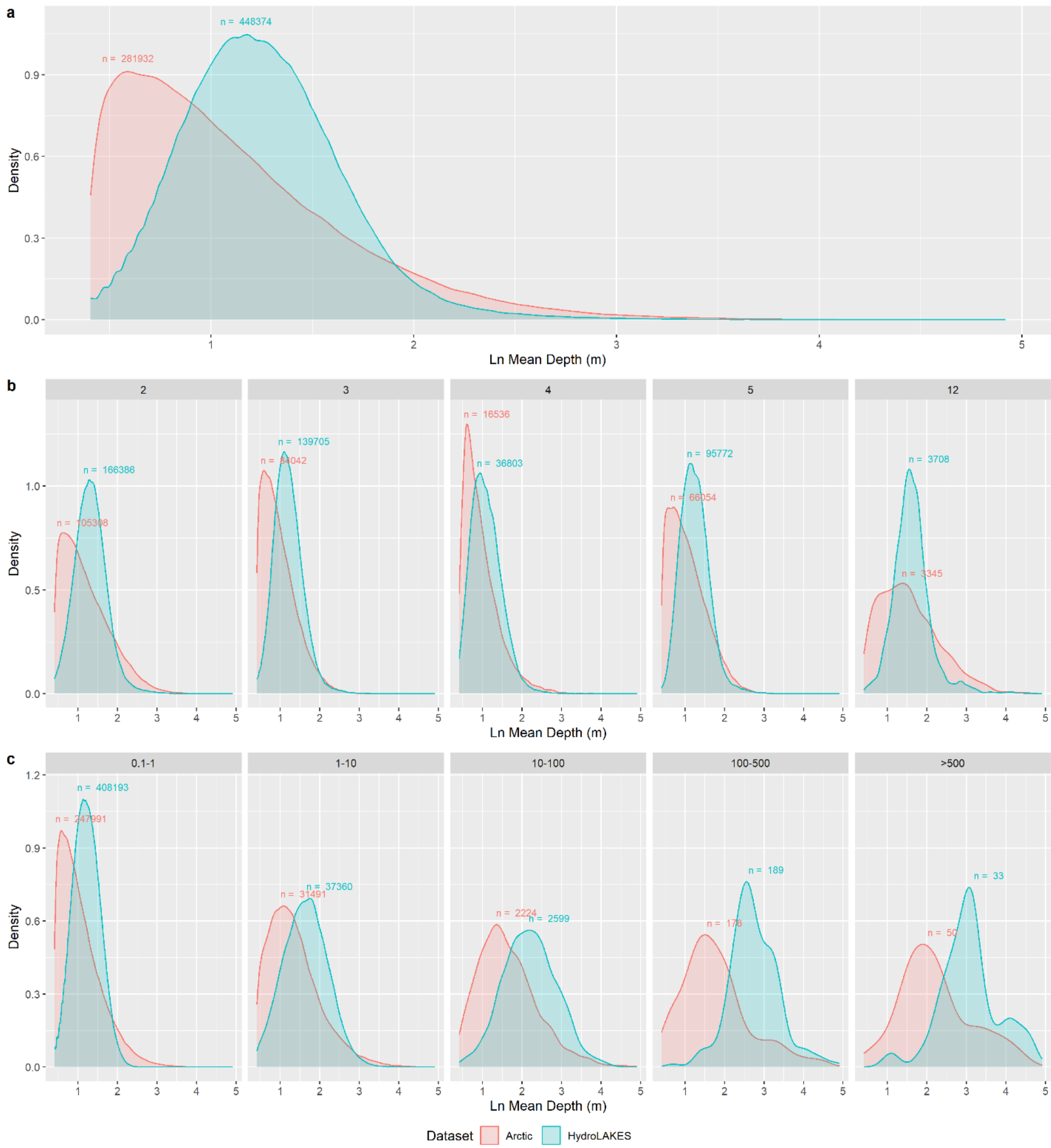
Supplementary Figure 5. Relationship between area and final maximum depths in the Arctic GIS lake database[16] (*n* = 472,475) (black dots, blue regression line) with the empirical morphometry dataset overlaid in red (*n* = 144, red regression line). All values have been log-transformed (ln). This plot includes lakes with surface areas between 0.1 and 100 km^2 which is why the full 167 empirical morphometry lakes are not included. Lakes from the Arctic GIS lake database with morphometry values predicted by the empirical equations have been left out of this figure (*n* = 9,071).



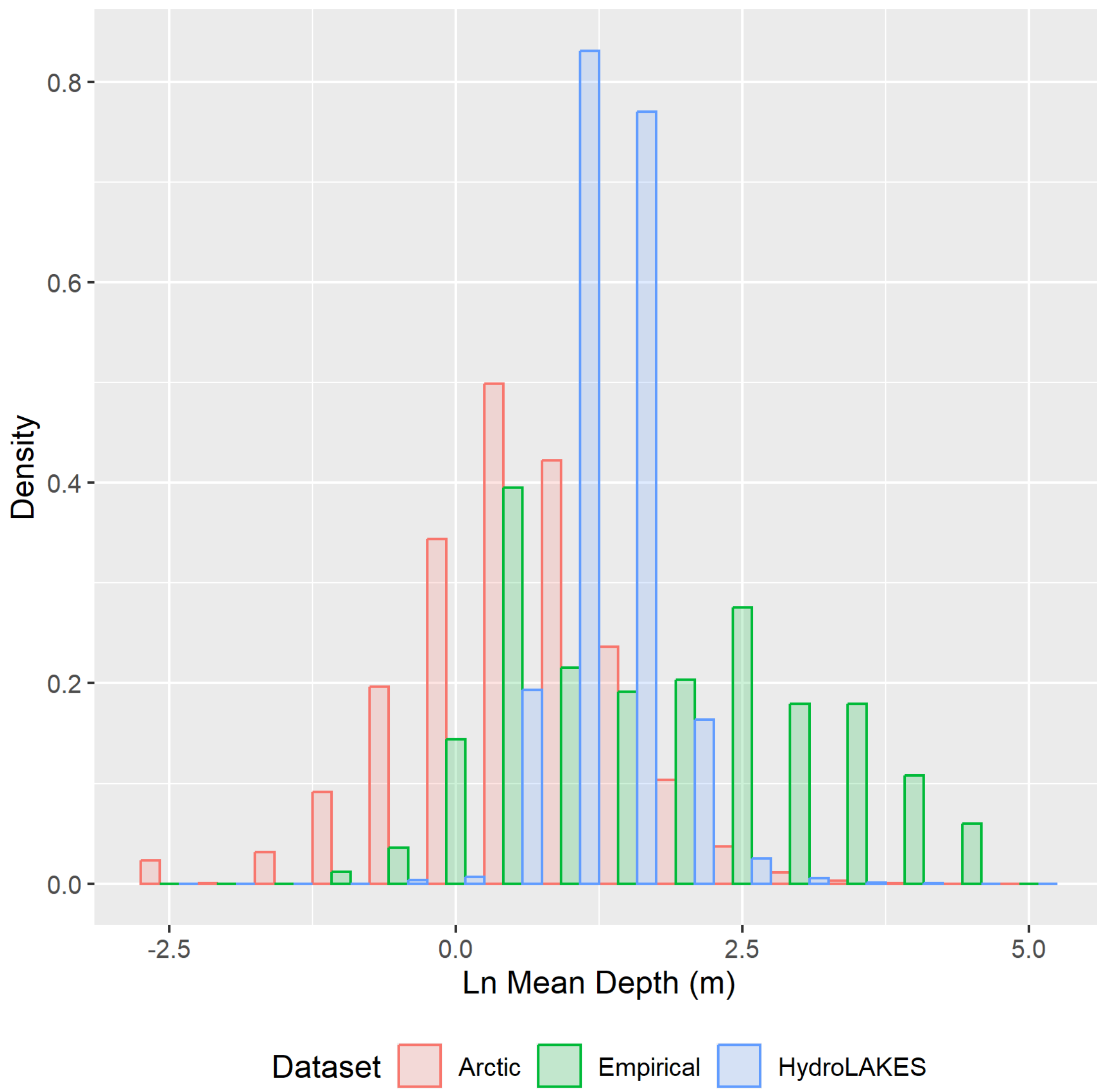
Supplementary Figure 6. Relationship between final mean and maximum depths in the Arctic GIS lake database[16] (black dots, blue regression line) with the empirical morphometry dataset overlaid in red (red regression line) for the five ecozones with the greatest numbers of empirically validated lakes. The number of lakes for each dataset is indicated on the plots. All values have been log-transformed (ln). Lakes from the Arctic GIS lake database with morphometry values predicted by the empirical equations have been left out of this figure.



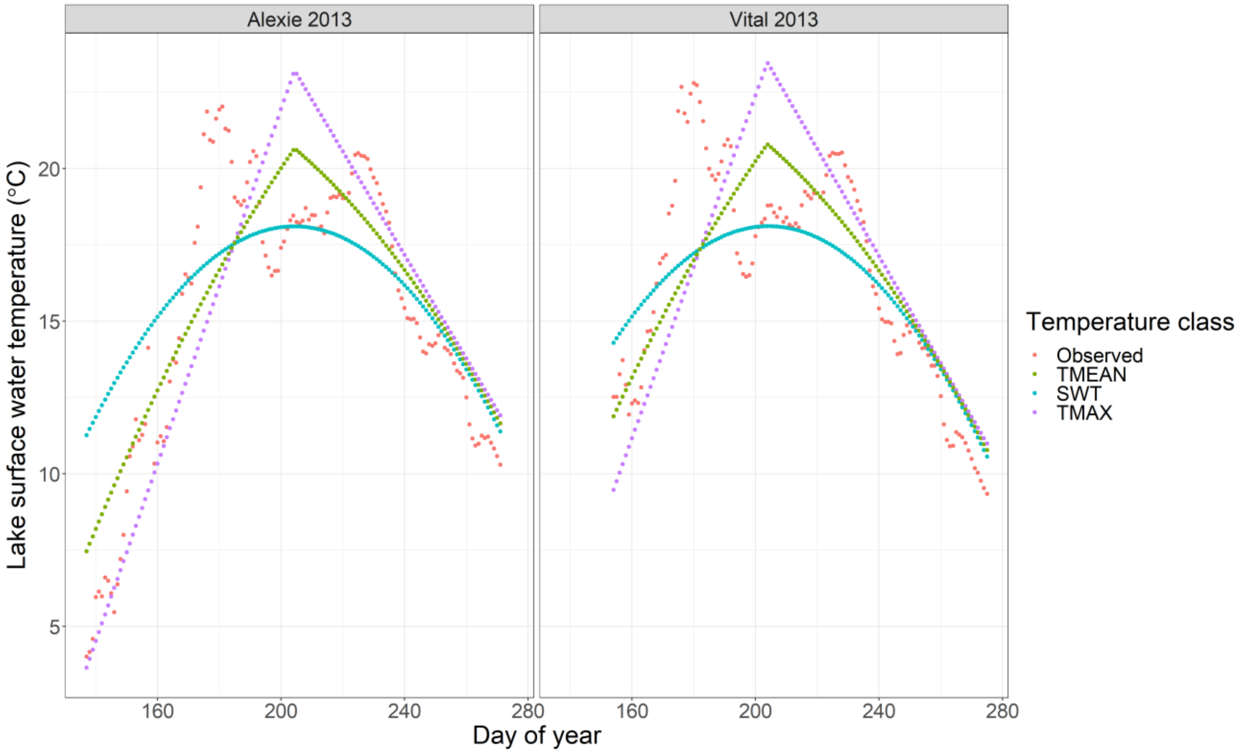
Supplementary Figure 7. Relationship between area and final mean depths in the Arctic GIS lake database[16] (black dots, blue regression line) with the empirical morphometry dataset overlaid in red (red regression line) for the five ecozones with the greatest numbers of empirically validated lakes. The number of lakes for each dataset is indicated on the plots. All values have been log-transformed (ln). All values have been log-transformed (ln). Lakes from the Arctic GIS lake database with morphometry values predicted by the empirical equations have been left out of this figure.



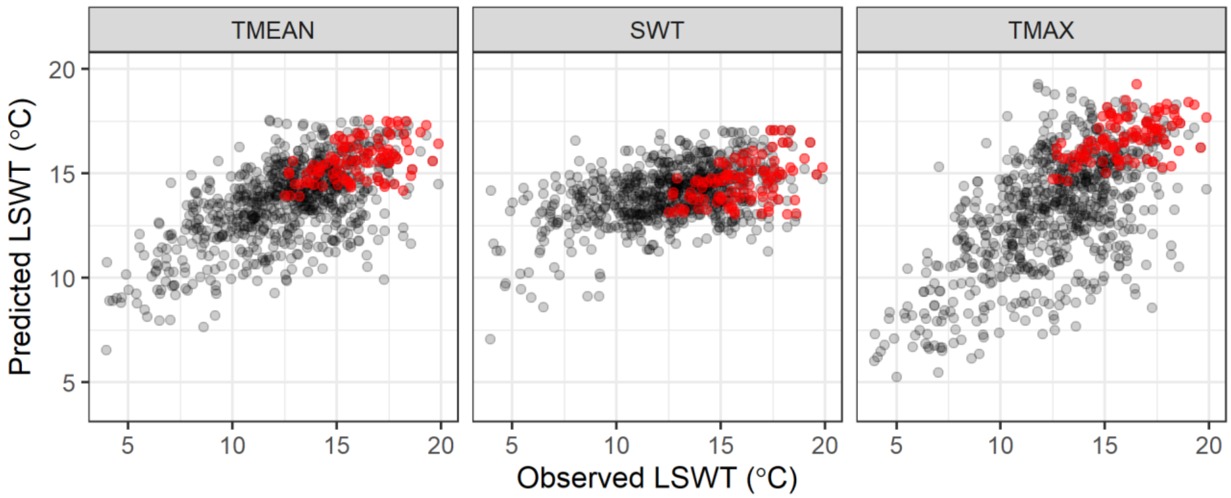
Supplementary Figure 8. Distribution of mean depth values (log-transformed) among datasets (a), ecozones (b), and lake size classes (km^2) (c). Sample sizes listed above maximum density plot values. Lakes with mean depths less than 1.5 m have been omitted from this figure.



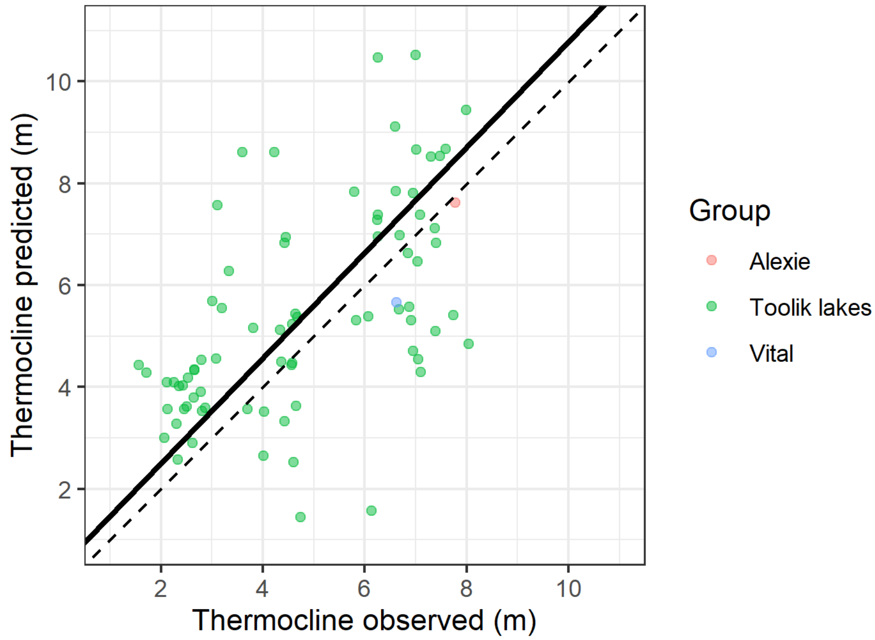
Supplementary Figure 9. Distribution of mean depth values (log-transformed) for the Arctic (*n* = 472,709), HydroLAKES (*n* = 452,927), and empirical morphometry datasets (*n* = 167). All mean depth values were included in this figure, except for Arctic GIS lake database lakes with morphometry values predicted from equations derived using the empirical morphometry dataset. All ecoregions are included.



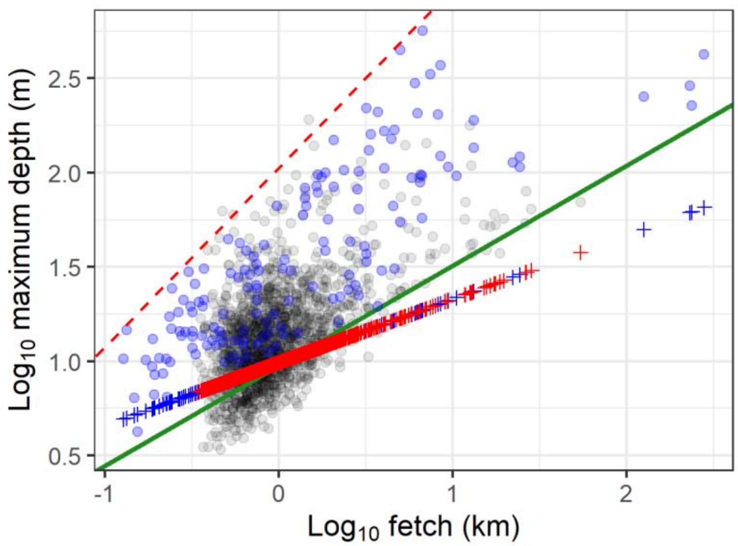
Supplementary Figure 10A. Observed and modelled open-water daily lake surface water temperatures for two Arctic lakes: Alexie Lake (n = 135 days) and Vital Lake (n = 122 days). T_{MAX} predictions were produced using the model from Gillis et al. 2021[21], and the SWT predictions were produced using the model from Sharma et al. 2007[22]. T_{MEAN} shows the average of these two values.



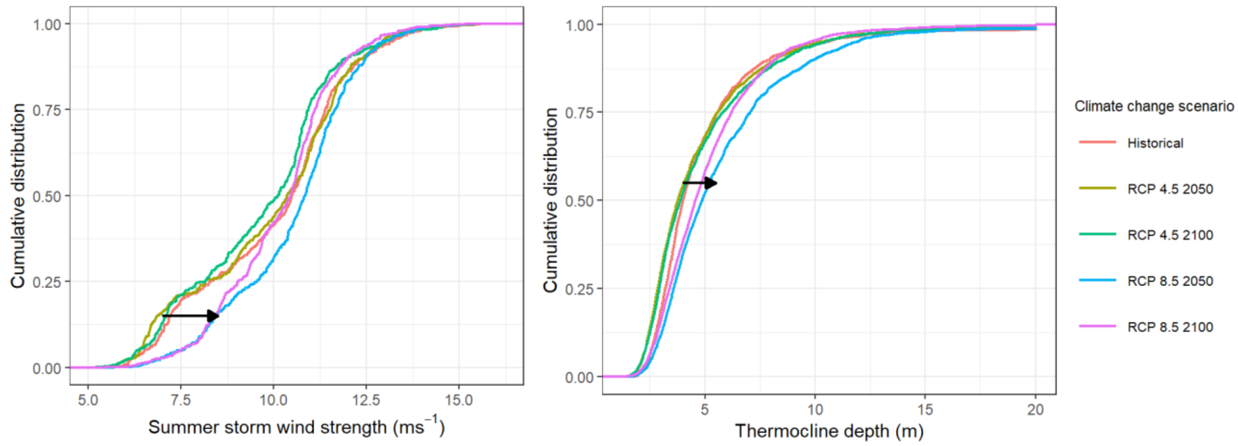
Supplementary Figure 10B. Observed and predicted lake surface water temperature (LSWT) for eleven Alaska lakes at the Toolik Field Station (n = 770 pairwise comparisons per panel). T_{MAX} predictions were produced using the model from Gillis et al. 2021[21], and the SWT predictions were produced using the model from Sharma et al. 2007[22]. T_{MEAN} shows the average of these two values. Black circles represent comparisons between observed and predicted LSWT for each lake on specific dates. Red circles represent comparisons between observed and predicted yearly maximum LSWT for each lake (n = 96 pairwise comparisons per panel), which may not necessarily fall on the same date.



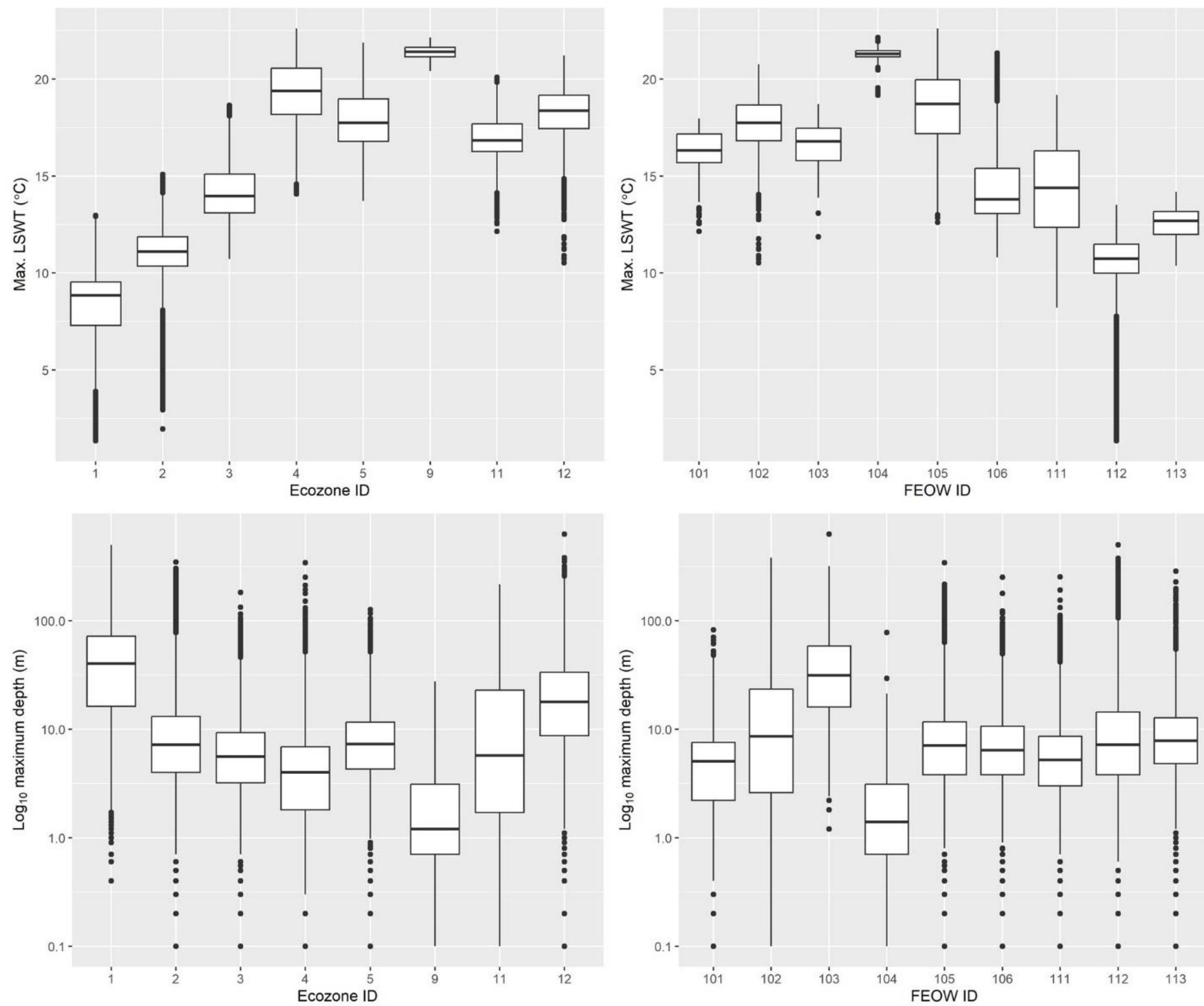
Supplementary Figure 10C. Comparisons of observed and predicted lake thermocline depth on the date of maximum heat content (*n* = 70). Only lakes for which thermocline presence was accurately predicted are shown (i.e., lakes predicted to be mixed but observed to be stratified are not shown because a pairwise comparison cannot be made). The 1:1 ratio line is shown as a dashed line. The reduced major axis regression line of best fit through the points is shown as a solid line. We chose the latter metric for comparing observed and predicted values because error is inherent in both the predicted values on the y-axis and the observed values on the x-axis.



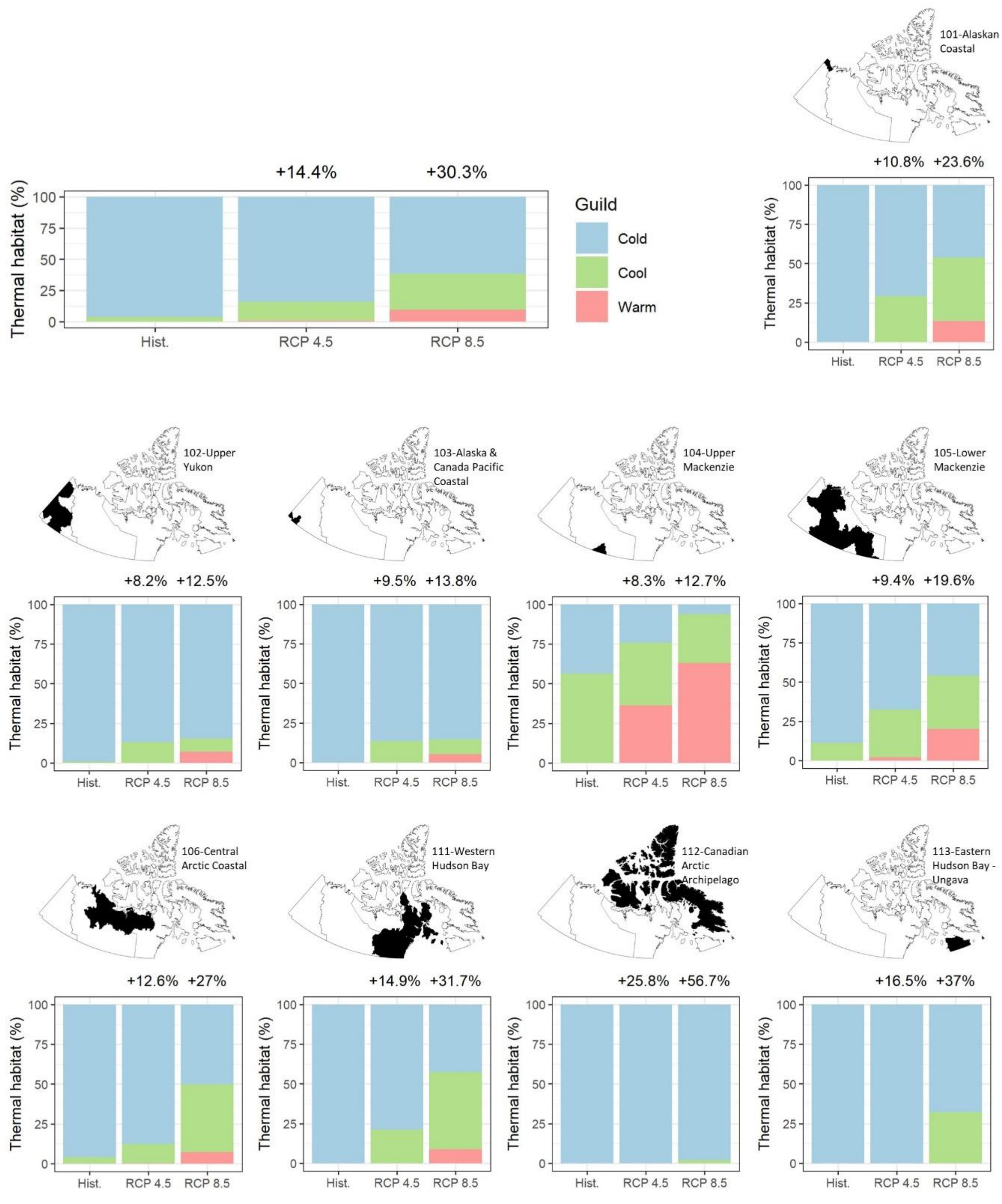
Supplementary Figure 11. The relationship between $\log_{10}$ fetch (km) and $\log_{10}$ maximum depth (m) for stratified lakes featured in Gorham and Boyce 1989[23] (blue circles) (N = 152) and the Arctic lakes (black circles) (N = 1430) predicted to stratify under wind conditions derived from a Weibull distribution with the following parameters: Weibull shape parameter (β) = 2.338, percentile 99.9999. The Arctic lakes shown are those predicted to stratify from the evenly sampled 9623 lakes within the Arctic GIS lake database (~2% of the dataset). The crosses define the 'Hanna Line' derived by multiplying 1.7 by the thermocline depth predicted using the equation from Hanna (1990)[24]. The multiplication factor of 1.7 is specified by the model from Gorham and Boyce (1989)[23]. Red crosses correspond to Arctic lakes and blue crosses correspond to Gorham and Boyce lakes. Most blue circles lie above this theoretical boundary. The green solid line represents the first quartile regressions of $\log_{10}$ fetch and $\log_{10}$ maximum depth for the 1430 stratified Arctic Lakes. The red dotted line defines the upper bound for the distribution of maximum depths in the first figure of Gorham and Boyce (1989)[23] ($\log_{10}$ maximum depth (m) = $2.03 + 0.95 \times \log_{10}$ fetch (km)). These Weibull parameters were chosen for subsequent analysis because, out of the other Weibull parameter values assessed, the first quartile regression line derived from these parameters had the greatest overlap with the theoretical ‘Hanna’ boundary.



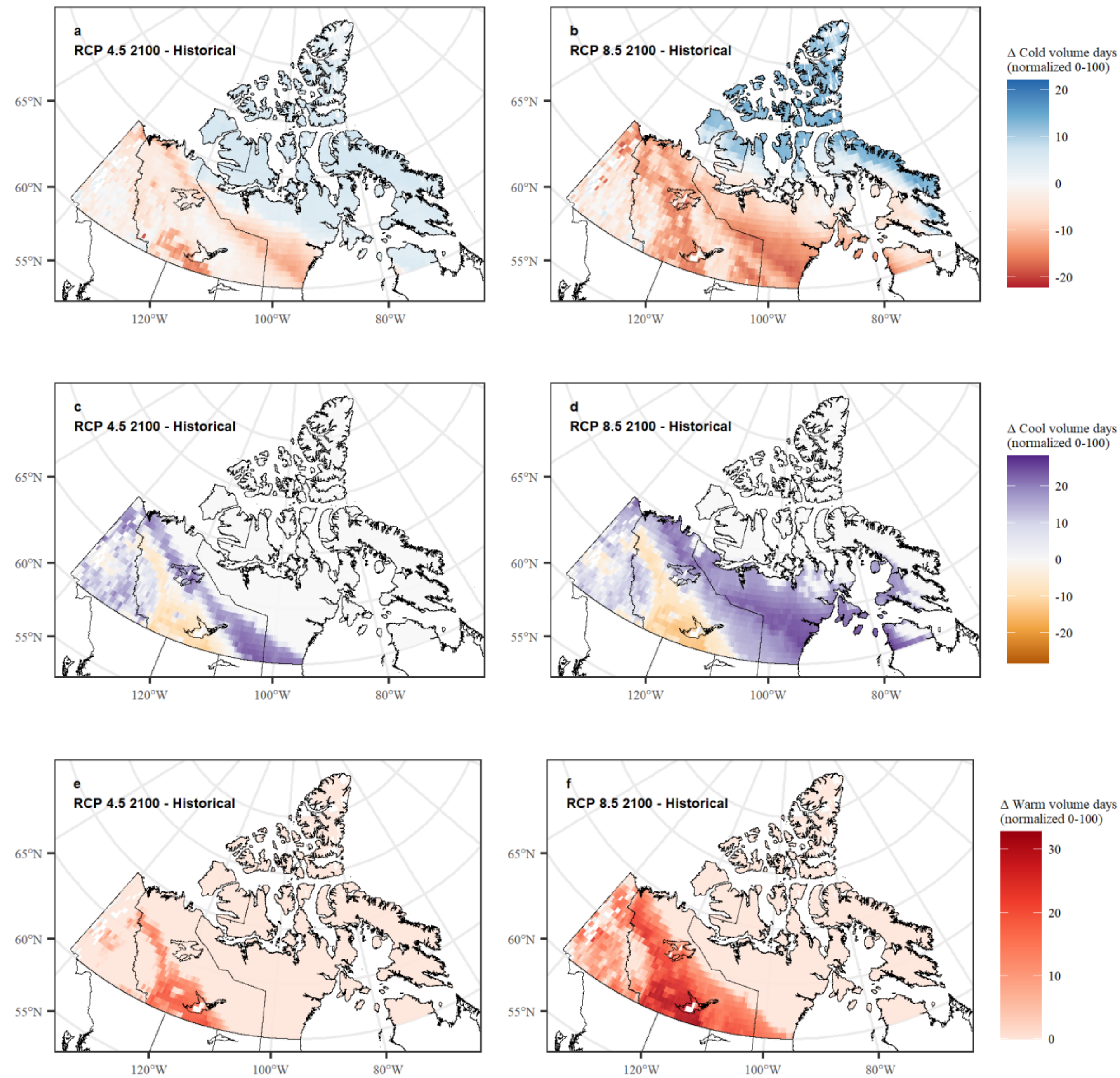
Supplementary Figure 12. Cumulative distribution for summer storm wind strength and thermocline depth. Parallel projections for increases in both summer storm wind strength and thermocline depth are evident for RCP8.5 (as indicated by the arrows) over and above the projections for both historical climate conditions and RCP4.5.



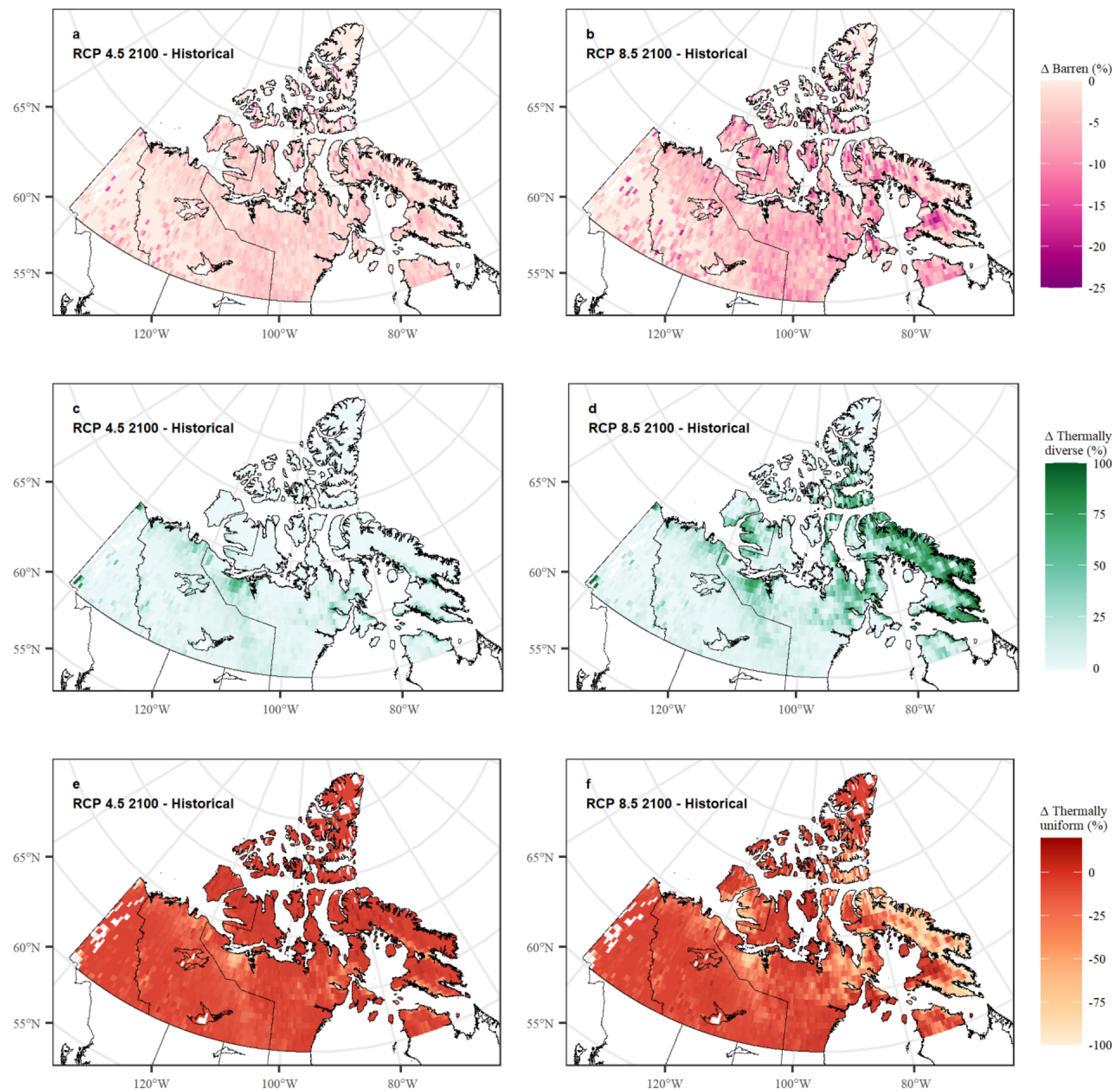
Supplementary Figure 13. Boxplots showing the distribution of maximum lake surface water temperature (Max. LSWT) and maximum depth values with lakes classified by terrestrial ecozone and freshwater ecoregion (FEOW). The box height represents the interquartile range (IQR) between the 25th and 75th percentiles. The black line inside the box represents the median. The tails on either side of the box represent either the maximum/minimum value in the data, or the 25th/75th percentile plus 1.5 times the IQR. Outliers are shown as black circles. See Supplementary Table 11 and Supplementary Table 18 for names of terrestrial ecozones and freshwater ecoregions by ID, respectively.



Supplementary Figure 14. Ice-free volume-days associated with each thermal guild as a percentage of total ice-free thermal habitat under historical and potential future climate change scenarios (RCP4.5 and RCP8.5 in 2100) for thermally diverse and thermally uniform lakes (barren lakes excluded). The total overall change is shown in the top panel, and by freshwater ecoregion in the remaining panels (see Supplementary Table 18 for *n* by freshwater ecoregion). Great Bear Lake and Great Slave Lake are excluded from volume-days calculations, including the Supplementary Tables. They comprise ~59% of the limnetic volume in the region and as large lakes are subject to complex physical forces, which would skew our results. Barren lakes under each scenario are excluded from these summaries as they are assumed to not support fish. Lakes that transition to thermally uniform or thermally diverse from barren under climate change are included in those scenario's summaries. There are four main groupings of ecozones according to their trends in ice-free volume-days: 1) the Canadian Arctic Archipelago and Eastern Hudson Bay–Ungava remain mostly coldwater (except for the Eastern Hudson Bay–Ungava under RCP8.5, which becomes approximately one third coolwater), 2) Alaskan Coastal, Lower Mackenzie, Central Arctic Coastal, and Western Hudson Bay represent the greatest increases in coolwater and warmwater, 3) the southwesterly Upper Yukon and Alaska & Canada Pacific Coastal show small increases coolwater and warmwater, and 4) Upper Mackenzie becomes warmwater dominant under RCP8.5. An overall summary (top) of thermal habitat volume-days broken down by lake class and for all five climate scenarios is in Supplementary Table 9.

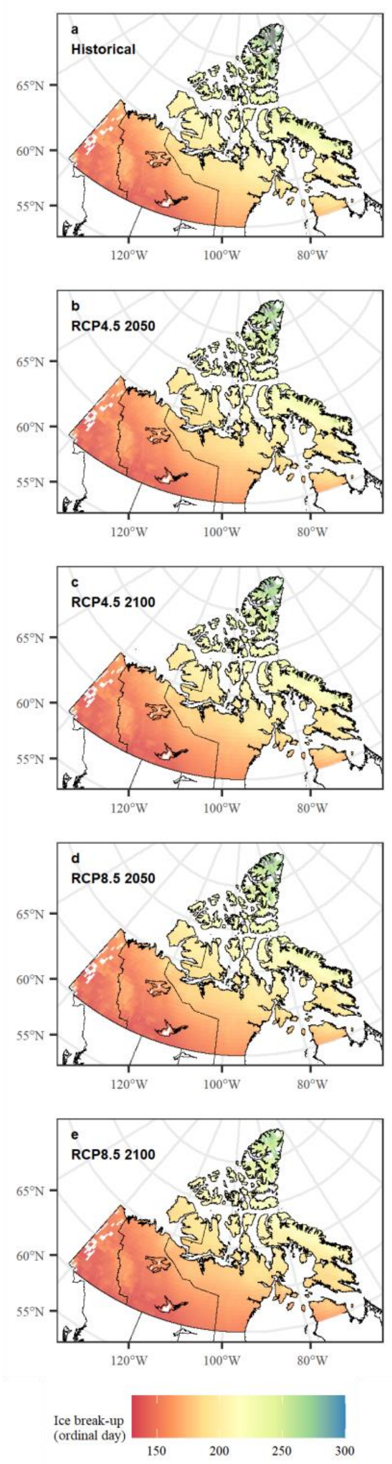


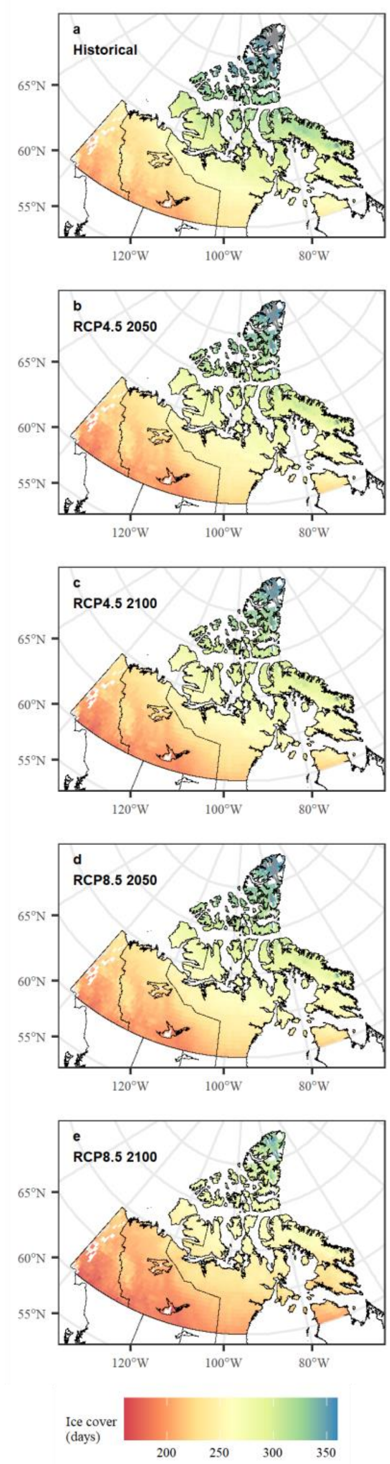
Supplementary Figure 15. Difference between (Δ) historical and potential future climate scenarios in 2100 for cold-, cool-, and warmwater thermal habitat. Regional averages are represented by 0.5° grid cells. Results are shown for coldwater (a, b), coolwater (c, d), and warmwater (e, f) fishes, and for the RCP4.5 (a, c, e) and RCP8.5 (b, d, f) climate scenarios.



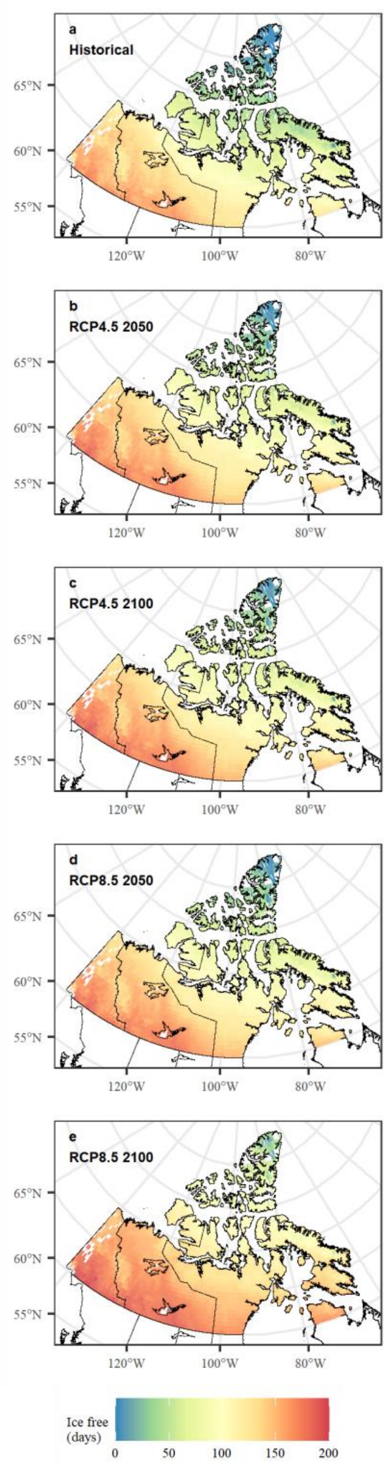
Supplementary Figure 16. Percent change (Δ) of lakes belonging to different lake classes: barren (a, b), thermally diverse (c, d), and thermally uniform (e, f) represented by 0.5° grid cell averages. Outliers for barren and thermally uniform lakes are shown in dark gray and the colour scales are adjusted such that the extremes are set according to the data without those outliers, affording more emphasis on most of the data. These outliers were defined as below the 1%

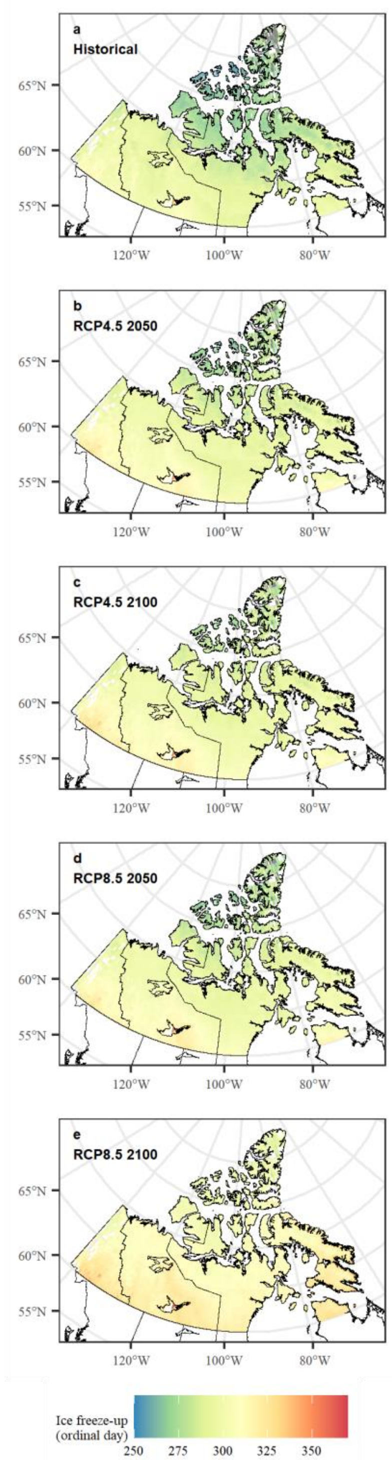
extreme negative value for barren and above the 1% extreme positive value for thermally uniform.



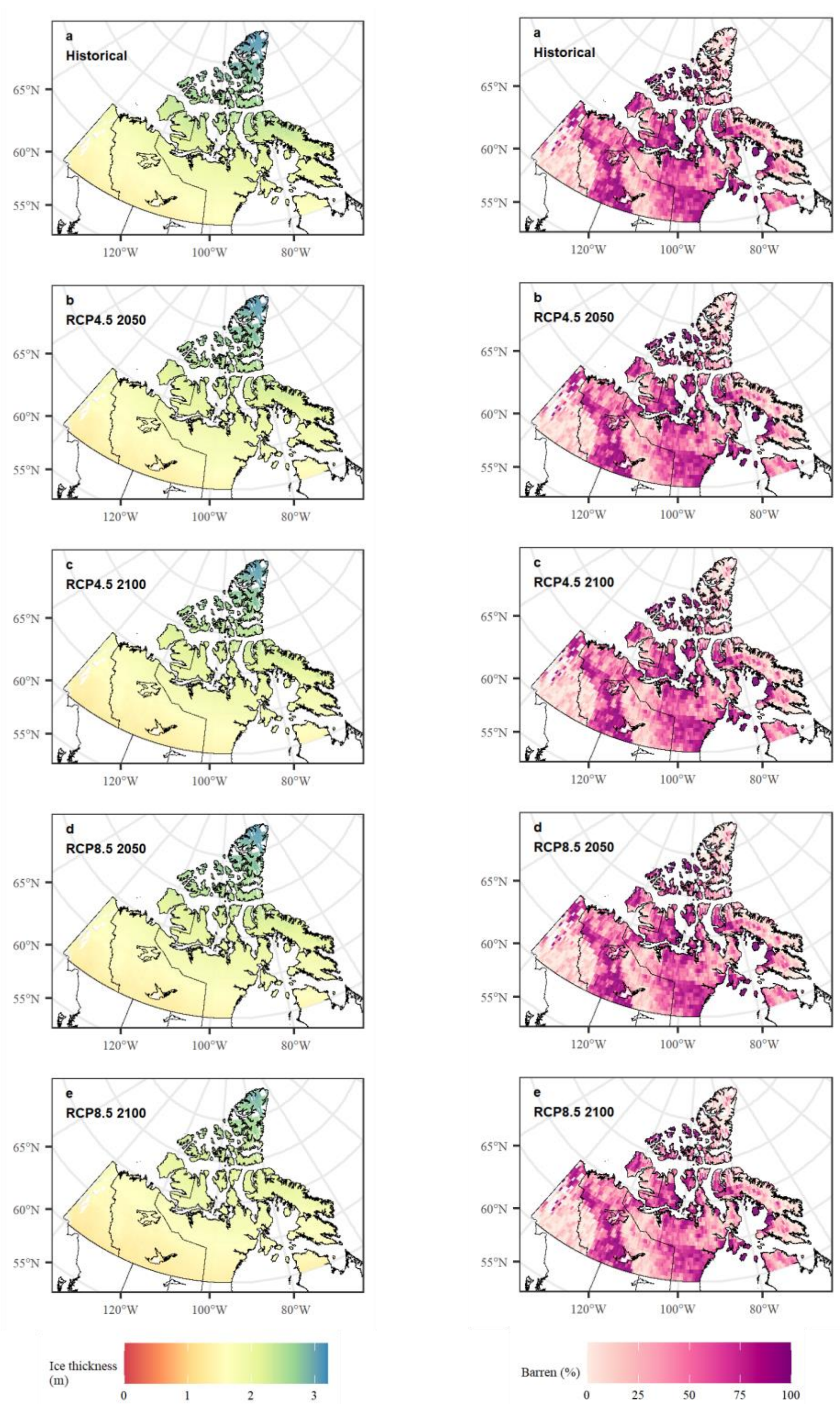


Supplementary Figures 17 and 18. Ice break-up dates and ice cover days represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).

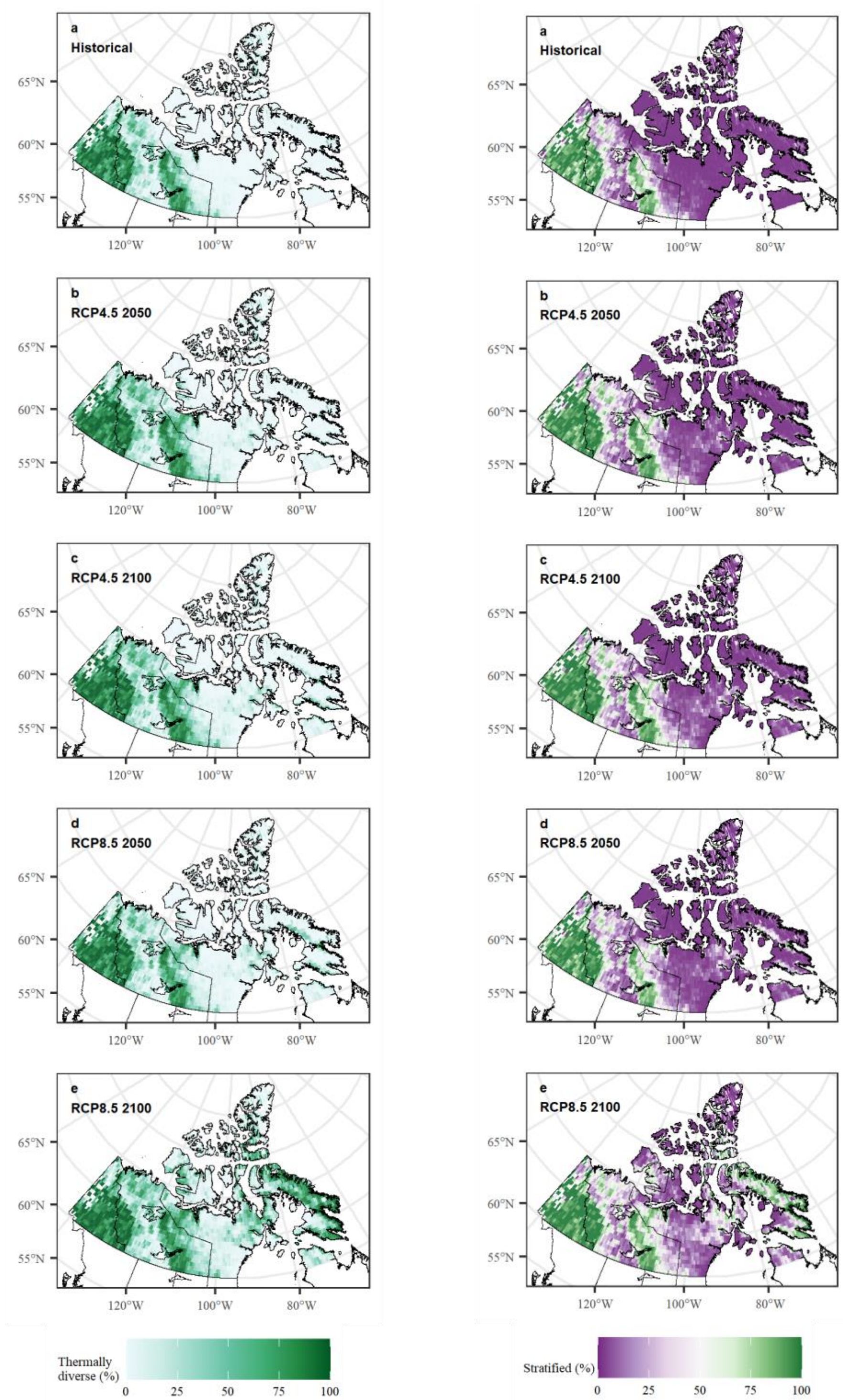




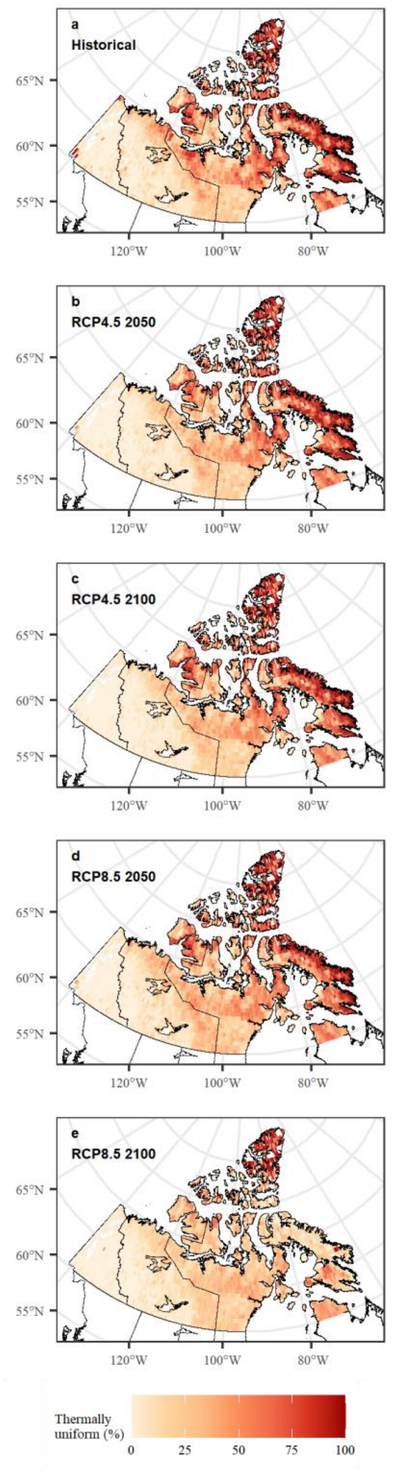
Supplementary Figures 19 and 20. Ice-free days and ice freeze-up dates represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).

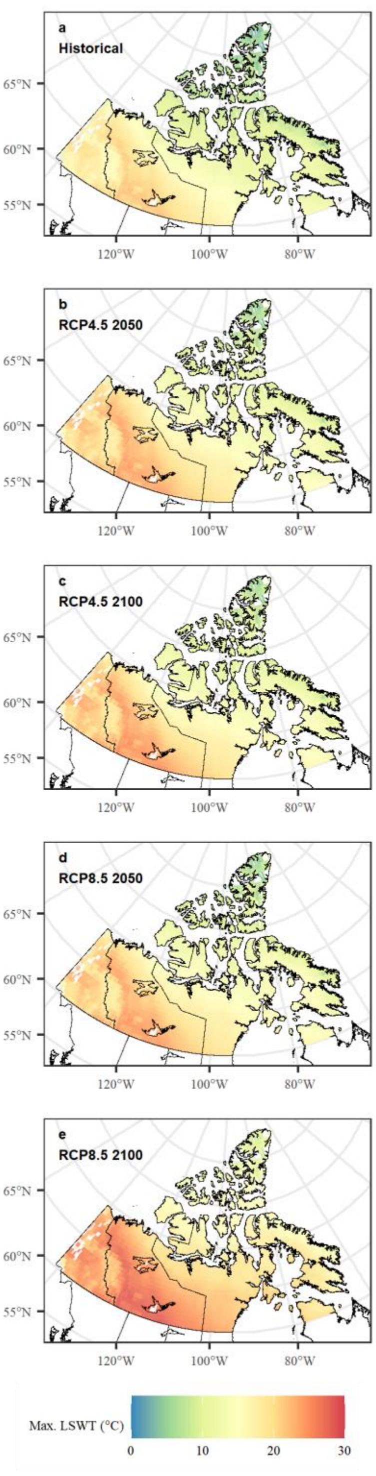


Supplementary Figures 21 and 22. Ice thickness and percentage of barren lakes represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).

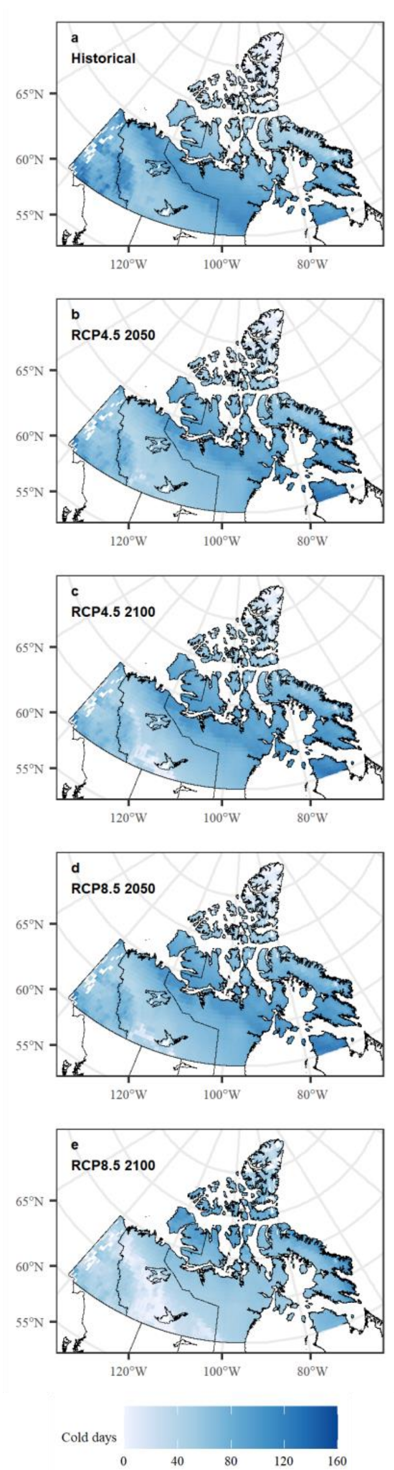


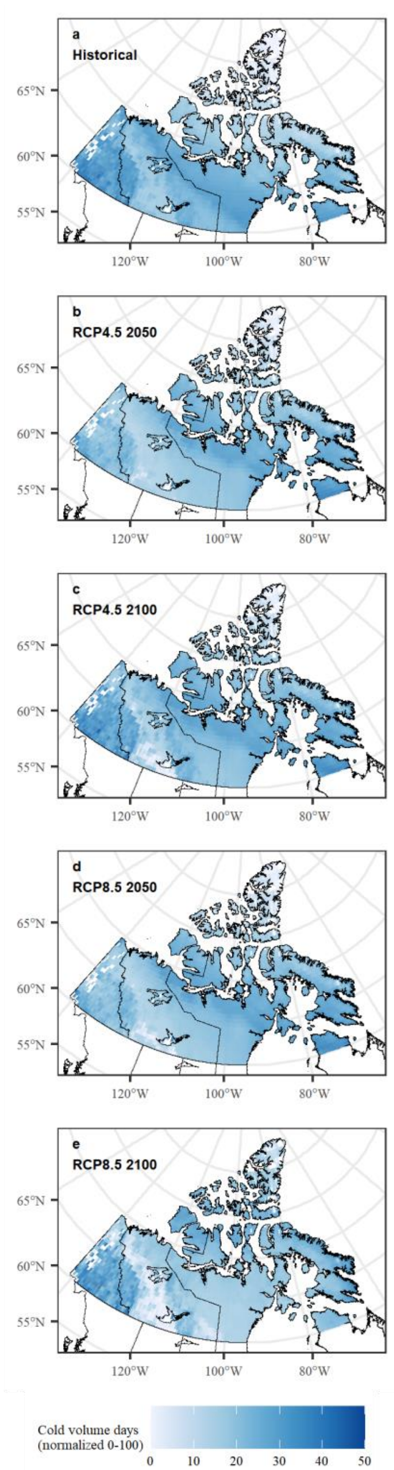
Supplementary Figures 23 and 24. Percentage of thermally diverse lakes and the proportion of stratified lakes represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).



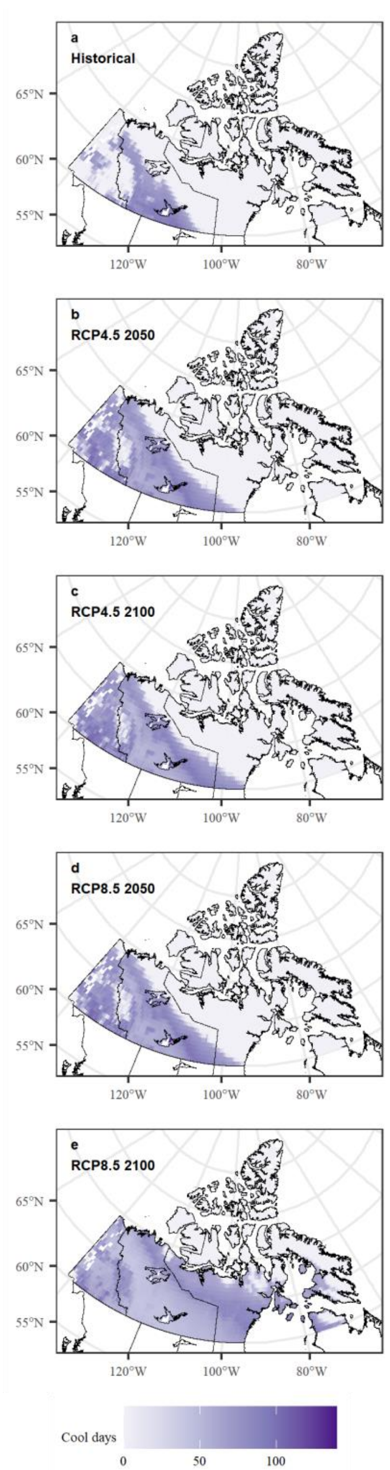


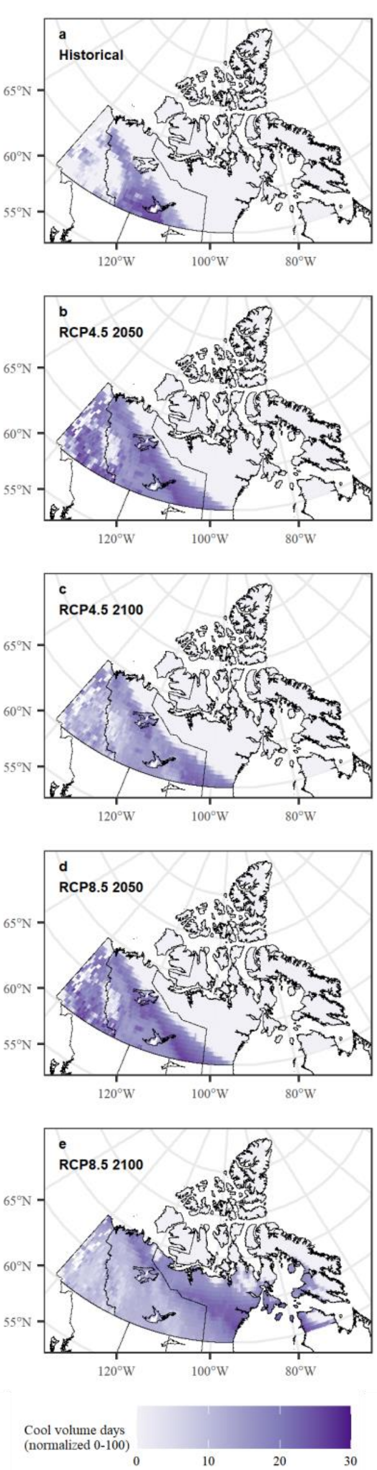
Supplementary Figures 25 and 26. Percentage of thermally uniform lakes and maximum surface water temperature represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).



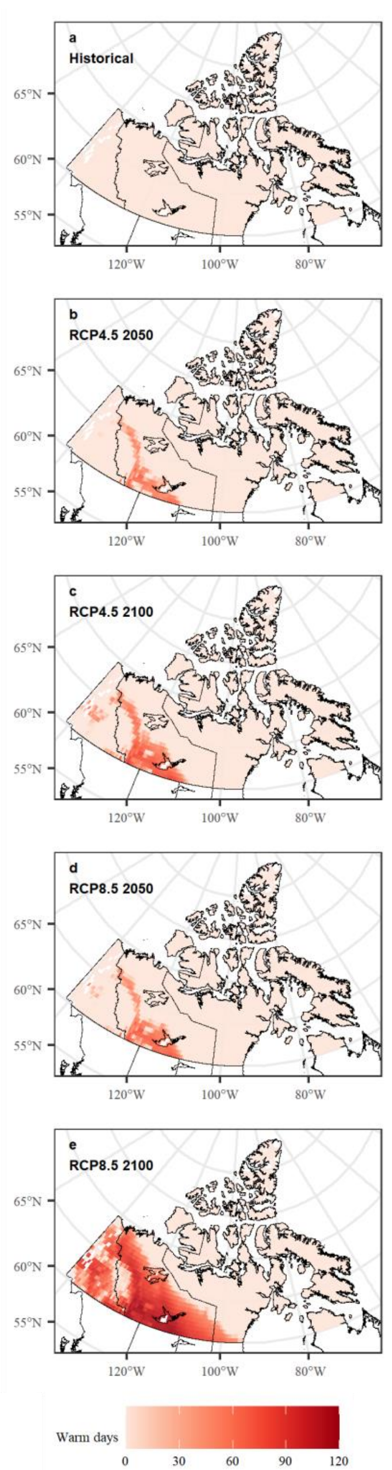


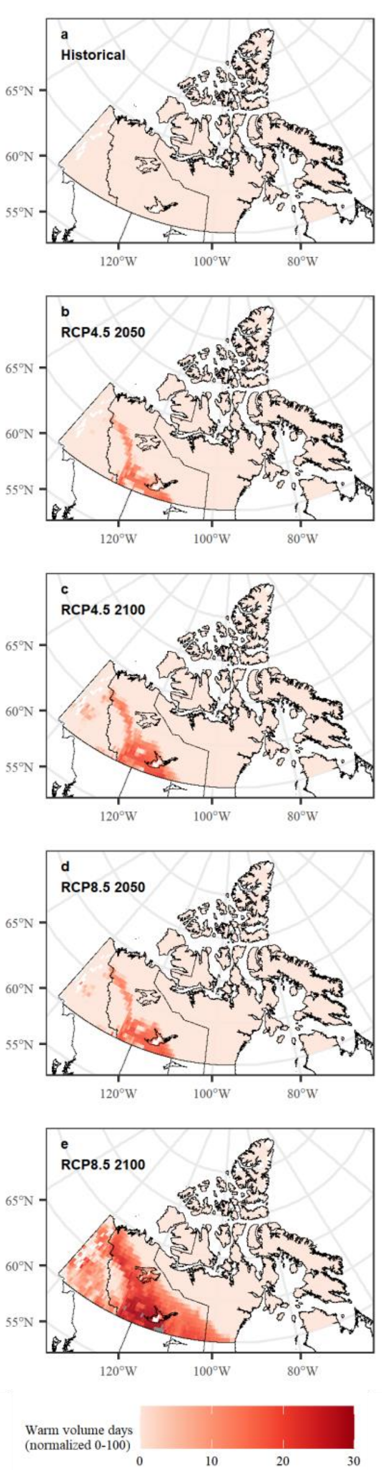
Supplementary Figures 27 and 28. Cold days and cold volume-days represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).





Supplementary Figures 29 and 30. Cool days and cool volume-days represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).





Supplementary Figures 31 and 32. Warm days and warm volume-days represented by 0.5° grid cell averages for historical (a) and potential future climates under RCP4.5 (b, c) and RCP8.5 (d, e) for 2050 (b, d) and 2100 (c, e).

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