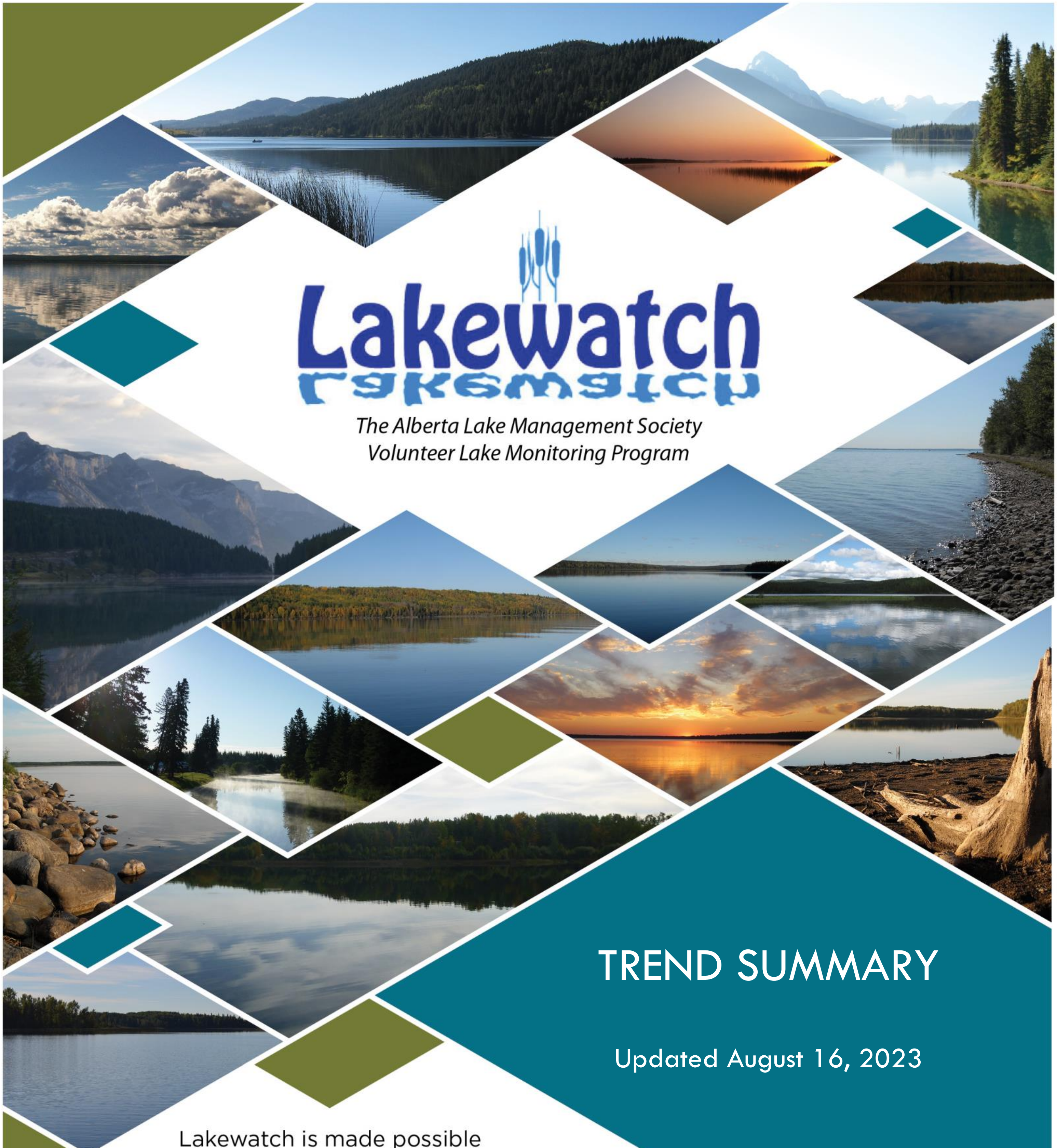

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

TREND SUMMARY

Updated August 16, 2023

Lakewatch is made possible with support from:

Alberta

Lac La Biche County
welcoming by nature.

LICA ENVIRONMENTAL STEWARDS

PIGEON LAKE WATERSHED ASSOCIATION

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

LakeWatch has several important 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. LakeWatch Reports are designed to summarize basic lake data in understandable terms for a lay audience and are not meant to be a complete synopsis of information about specific lakes. Additional information is available for many lakes that have been included in LakeWatch and readers requiring more information are encouraged to seek those sources.

ALMS would like to thank all who express interest in Alberta's aquatic environments and particularly those who have participated in the LakeWatch 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

The LakeWatch program is made possible through the dedication of its volunteers. Trend analysis is only possible with a large record of historical lake data, gathered by ALMS LakeWatch technicians, volunteers, and for some of the data used, Alberta Environment and Parks staff. Executive Director Bradley Peter and Program Manager Caleb Sinn were instrumental in planning and organizing the field program, and the ALMS trend analysis techniques were prepared by Laura Redmond. This report was prepared by Caleb Sinn and Bradley Peter.

INTRODUCTION

In 2018, the Alberta Lake Management Society, with support from Alberta Environment Protected Areas, established a methodology to conduct trend analysis for key lake water quality parameters. Lakes sampled through the 2017 LakeWatch season were the first to have trend analysis conducted. Since then, ALMS has conducted trend analysis for total phosphorus (TP), chlorophyll-*a* (ChlA), total dissolved solids (TDS), Secchi depth, and major ions on 27 lake basins in Alberta. Time periods range from 15 years to 43 years, with an average time span of 33 years, and from as far back as 1980 until 2022 (Figure 1). The reporting cycle for 2022 is the first to include additional trend analysis interpretation including visualizing the geographic distribution of the lakes by ChlA-derived trophic class and TDS-derived salinity class (Figure 2), the geographic distribution of trend results for TP, ChlA, TDS, and Secchi depth (Figure 4), bar graphs representing the number of lakes with each trend result direction split up by trophic and salinity classes (Figures 5 and 6), historical trajectory figures for TP, ChlA, TDS, and Secchi depth (Figure 7), and slope magnitude figures for major ions that contribute to TDS levels in lakes (Figures 12 and 13)

This trend summary is meant to be a continuously updating, "living" document that enables lake stewards and other interested parties to see how trends for key lake water quality parameters vary and compare across Alberta's lakes. If you would like to explore a specific lake's trend analysis data further, find the most recent LakeWatch report for that lake on the ALMS website, and view *ALMS Guide to Trend Analysis on Alberta Lakes* to learn more about ALMS trend analysis methods.

Beauvais Lake in the summer – photo by Klaus Exner

SUMMARY

- The lakes are dispersed throughout Alberta, located primarily in the northwest, central, central eastern, and south regions of the province. The lakes vary greatly in their trophic level (amount of primary productivity), as well as salinity.

- More lakes display decreasing levels of TP than increasing, but there are many lakes with no trend. Of the lakes with significant trends, lakes are increasing at a greater rate than the rate they are decreasing. More lakes in the north are increasing while more lakes in south are decreasing. High productivity lakes appear to be increasing in TP, while all lakes decreasing are lower productivity. In recent years there is greater variation in the trajectory of TP, and a divergence in rate change for lakes that are increasing compared with lakes that are decreasing.

- Most lakes have no significant trend in ChlA, but 8 have increasing trends, and only 2 have decreasing trends. The general rate of change between lakes increasing or decreasing is similar, but a few outlier lakes are increasing very quickly (Skeleton North, Laurier). Most lakes that are increasing are clustered in the central eastern region of the province. Of the lakes increasing, most of them are in a high productivity trophic class and are slightly higher in salinity.

- The case study of ChlA:TP trends describes that the trends of TP and ChlA being different for lakes may be due to trophic status, and other factors that influence overall ChlA yield. Most lakes have increased ChlA yield despite TP (increased ChlA:TP), and cluster geographically similar to lakes with increasing TDS. The overall trend across all lakes is a relatively sharp increase since the 2010s.

- Over 70% of lakes (19 of 26) have increasing TDS, while 5 lakes have decreasing TDS. Lakes are increasing and decreasing in TDS at a similar rate, but a few outliers have very high rates of change (Muriel, Alix, Laurier). TDS increases and decreases are seen in lakes throughout the province. Most of the lakes with increasing TDS are highly productive, but relatively low in salinity. The overall trend across all lakes is a steady and appreciable increase since the 1980s.

- Most of the ions that make up overall lake salinity are also increasing. Most lakes (22 of 26) have increasing chloride, at a relatively small but stable rate of change. Similar trends are observed for potassium and sodium but are not increasing as much in recent years. Hardness, alkalinity, and sulphate have been more variable over time, but across lakes are changing at greater rates than other ions.

- Most lakes have either decreasing or no change in Secchi, but a small number have increasing Secchi. Secchi is changing at greater rate for lakes with decreasing trends. Most lakes with decreasing trends are highly productive, and all lakes with increasing trends are low salinity. In recent years, only a couple lakes have an increasing rate of change in the increasing Secchi direction, but most lakes are slightly decreasing.

RESULTS

Total Phosphorus (TP): In total, 11 lakes have significant decreasing trends, 8 lakes have significant increasing trends, and 8 lakes have no statistically significant monotonic (unidirectional) trends (Table 2, Figure 4). The rate of change (slope) ranges from the greatest significant increase of 10.76 µg/L per year at Saskatoon, to the greatest significant decrease of -1.82 µg/L per year at Minnie. The median slopes for lakes with significant increasing trends is 2.01 µg/L per year (n = 8), and -0.71 µg/L per year (n = 11) for lakes with significant decreasing trends (Figure 11). The range of slopes for lakes with significantly increasing TP levels is proportionally much greater compared to the narrow range of slopes with significantly decreasing levels. Lakes with significant increasing trends are dispersed within the central, central eastern, or northwest regions of the province, while lakes with significant decreasing trends are also dispersed but located primarily in the central and southern regions of the province, with a few in the central eastern portion of the province (Figure 4). Classification of trophic levels are based on average historical chlorophyll-*a*, based on the classes from Nurnberg (1996)[1]. The classes can be seen in the appendix in Table 6, as well as for each lake in context of its average historical chlorophyll-*a* in Figure 14. All lakes with increasing trends are either eutrophic or hypereutrophic, while most lakes with decreasing trends are mesotrophic, but decreasing trends are occurring in lakes of all trophic classes (Figure 5). Classification of salinity levels are based on average historical total dissolved solids (TDS), based on salinity classes from Mitchell and Prepas (1990)[2]. The classes can be seen in the appendix in Table 6, as well as for each lake in context of its average historical TDS in Figure 15. The salinity class of the lake does not appear to be related to the trend results for TP (Figure 6). Based on the historical trajectory standardized trends of TP, within the past 10 years lakes appear to be diverging whether TP is increasing or decreasing, and that the slope in both of these directions is increasing – this has the effect on the overall LOESS trend of all lakes to have been relatively unchanged since the 1980s despite increasing change in the last decade (Figure 7).

Chlorophyll-*a* (ChlA): In total, 2 lakes have significant decreasing trends, 8 lakes have significant increasing trends, and 17 lakes have no statistically significant monotonic (unidirectional) trend (Table 3, Figure 4). The rate of change (slope) ranges from the greatest significant increase of 2.06 µg/L per year at Skeleton North, to the greatest significant decrease of 0.53 µg/L per year at Winagami. The median for lakes with significant increasing trends is 0.37 µg/L per year (n = 8), and -0.30 µg/L per year (n = 2) for lakes with significant decreasing trends (Figure 11). The range of slopes for lakes with significantly increasing ChlA levels is proportionally much greater compared to the narrow range of slopes with significantly decreasing levels. Lakes with significant increasing trends are clustered in the central eastern region of the province, within the Beaver River watershed, with two other lakes with increasing trends in the central part of the province (Pigeon and Pine; Figure 4). The two lakes with significant decreasing trends are in the northwest (Winagami), and the southwest (Beauvais). Half of the lakes with increasing trends are eutrophic, with the other half are split between mesotrophic and hypereutrophic classes (Figure 5). The two lakes with decreasing trends are mesotrophic (Beauvais), and hypereutrophic (Wingami). Both lakes with decreasing trends are in the low salinity class, while 5 out of the 8 lakes with increasing trends are either slight or moderate (Figure 6). Based on the historical trajectory standardized trends of ChlA, there doesn't appear to be much visual difference between the trajectory of the

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[1] 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.

[2] Mitchell, P. and E. Prepas 1990. Atlas of Alberta Lakes. University of Alberta Press, Edmonton, Alberta.

two lakes with decreasing trends, and no trends – this is likely due in part because the ChlA values of those two lakes were relatively higher in the 1980s but have decreasing appreciably since the 1990s (Figure 7). There is a subset of lakes with increasing trends that have increased with a high rate of change within the past 10 years. This has had the effect on the overall LOESS trend of all lakes that ChlA levels have increased since the early 2010s.

A case study within the Appendix section below describes the trends of the ratio of ChlA to TP (ChlA:TP), which is used to explore the dynamics of ChlA yield controlling for changes in TP over time.

Total dissolved solids (TDS): In total, five lakes have significant decreasing trends, 19 lakes have significant increasing trends, and two lakes display statistically insignificant monotonic (unidirectional) trends (Table 4, Figure 4). Note that there was insufficient data to perform trend analysis for TDS at Lac La Nonne, and was excluded from the TDS and major ions trend analyses. The rate of change (slope) ranges from the greatest significant increase of 21.75 mg/L per year at Muriel, to the greatest significant decrease of -10.00 mg/L per year at Laurier. The median for lakes with significant increasing trends is 1.94 mg/L per year (n = 19), and -2.04 mg/L per year (n = 5) for lakes with significant decreasing trends (Figure 11). In addition, the range of slopes for lakes with either significantly increasing or decreasing TDS is quite narrow, indicating that many lakes have comparable rates of increasing TDS. The ranges also may look minimal because of the presence of a few outliers, with Muriel and Alix as outliers for lakes with increasing trends, and Laurier being an outlier for lakes with decreasing trends. Lakes with significant increasing trends are present throughout the province, with clusters in the central and central eastern regions of the province (Figure 4). The five lakes with decreasing trends are also dispersed throughout the province. The number of lakes with increasing trends increases as trophic status indicates higher productivity with the eutrophic and hypereutrophic class lakes representing 13 out of the 19 lakes with increasing TDS (Figure 5). Lakes with decreasing trends are split through every trophic class, while lakes with no trends are only in the eutrophic and hypereutrophic classes. 14 out of the 19 lakes with increasing trends are in the low salinity class (Figure 6). Based on the historical trajectory standardized trends of TDS, only a couple of the lakes with decreasing trends are still trending down in recent years (Figure 7). The vast majority of other lakes show an appreciable increase relative to the beginning of their respective records, and has had the effect on the overall LOESS trend of all lakes that TDS levels have steadily increased in most of Alberta's lakes since the 1980s.

Trend analysis of ions influencing TDS levels in lakes indicates that most ions are also significantly increasing (Figures 9 and 10), which could be tied to processes which influence all ions (eg. precipitation and evaporation balance, or land use change through time). Lake specific changes may also influence specific ions levels, such as the influence of river diversions or addition of treated water into lakes. Note that alkalinity is a metric that can be used to evaluate changes in bicarbonate and carbonate over time, and hardness is a metric that can be used to evaluate calcium and magnesium over time (data for bicarbonate, carbonate, magnesium, and calcium is missing in many lakes). Chloride displays significant increasing trends and trajectories with the least oscillation over time in the greatest number of lakes (22) compared to other ions (Figure 9). The trajectories of potassium and sodium follow similar steady increases over time, but in slightly fewer lakes (21 and 18, respectively), and with trajectories flattening slightly relative to chloride. Hardness is also increasing in many lakes (17), and the magnitude of change has increased appreciably within the last 10 years. Trajectories of alkalinity and sulphate display the greatest spread of trend results, with high variation in trajectories over time. The number of outliers for slopes of ion trends is greatest and most different for alkalinity, sulphate and hardness (Figures 12 and 13). Their slope medians are also the greatest, at -2.14, -1.35, and -0.73 mg/L per year for hardness, alkalinity and sulphate, respectively, for lakes with decreasing trends, and 1.50, 0.76, and 0.68 mg/L per year for hardness, sulphate and alkalinity, respectively, for lakes with increasing trends. By contrast, the median slope for chloride is 0.31 mg/L. While the slope of chloride is steady over time, other ions display slopes of greater magnitude and variation over time.

Secchi depth (Secchi): In total, 10 lakes have significant decreasing trends, four lakes have significant increasing trends, and 13 lakes have no statistically significant monotonic (unidirectional) trends (Table 5, Figure 4). The rate of change (slope) ranges from the greatest significant increase of 0.04 m per year at Beauvais, to the greatest significant decrease of -0.20 m per year at Minnie. The median for lakes with significant increasing trends is 0.01 m per year (n = 4), and -0.03 m per year (n = 10) for lakes with significant decreasing trends (Figure 11). The range of slopes for lakes with significantly decreasing Secchi is proportionally much greater compared to the narrow range of slopes with significantly increasing levels. This corresponds with the range of slopes for ChlA in that increasing Secchi or water clarity would correspond with decreasing ChlA levels, and vice-versa. There are two outliers that are much lower than the bottom of the decreasing trend boxplot, and these are Minne and Skeleton North. Lakes with significant decreasing trends are dispersed within the central, central eastern, or northwest regions of the province, while lakes with significant increasing trends are also dispersed through the south, central, and northwestern regions of the province (Figure 4). Most of the lakes with decreasing trends are eutrophic, with the others split between mesotrophic and hypereutrophic classes (Figure 5). Lakes with increasing trends are dispersed through the meso-, eu-, and hypereu-trophic classes. Most lakes with no trend are within the hypereutrophic class. All lakes with increasing trends are in the low salinity class, while decreasing and no trend lakes are dispersed through all three classes, with many lakes with decreasing trends in the slight and moderate salinity classes (Figure 6). Based on the historical trajectory standardized trends of Secchi depth, levels across all lakes have not changed appreciably over time, based on the overall LOESS trend of all lakes (Figure 7). In recent years there are a couple of lakes with increasing trends that display an appreciably increasing slope, while there are also a few lakes with decreasing trends that also display an appreciably increasing slope magnitude in the negative direction.

Table 1. Summary of trend analyses results and direction of trend if significant for total phosphorus (TP), chlorophyll-*a* (ChlA), total dissolved solids (TDS), and Secchi Depth (Secchi) at lakes sampled through the LakeWatch program. An upwards green arrow denotes a significantly increasing trend, a downwards red arrow denotes a significantly decreasing trend, no significant trend is denoted by a blue dash, and "I.D." indicates there is insufficient data to perform trend analysis.

Lake	TP Trend	ChlA Trend	TDS Trend	Secchi Trend
Alix	–	–	↑	–
Beauvais	↓	↓	↓	↑
Buffalo	↓	–	↓	↓
Chestermere	↓	–	↑	–
Crane	↓	↑	↑	–
Gull	↓	–	↑	↓
Isle	↑	–	↑	–
Kehewin	–	–	↑	–
Lac La Nonne	↑	–	**I.D.**	–
Laurier	↑	↑	↓	↓
Marie	–	–	↓	–
McLeod	↑	–	–	↓
Minnie	↓	↑	↑	↓
Moonshine	↑	–	↓	↓
Moose	↑	↑	↑	↓
Muriel	–	↑	↑	↓
Pigeon	–	↑	↑	↑
Pine	–	↑	↑	↓
Saskatoon	↑	–	–	–
Skeleton North	↑	↑	↑	↓
Skeleton South	–	–	↑	–
Sturgeon	–	–	↑	–
Sylvan	↓	–	↑	–
Touchwood	↓	–	↑	–
Wabamun	↓	–	↑	↑
Winagami	↓	↓	↑	↑
Wizard	↓	–	↑	–

Table 2. Summary of trend analyses for total phosphorus (TP) at lakes sampled through the LakeWatch program. Tau = strength and direction of trend, Slope = rate of change of trend (µg/L per year), *p* = significance of trend (bolded indicates significance at $p < 0.05$), n = number of sampling events, Trend Test = either Seasonal Kendall (SK) or Mann Kendall (MK), Trend Range = range of years included in trend analysis. Table ordered by slope magnitude.

Lake	Tau	Slope (µg/L per year)	*p*	n	Trend Test	Trend Range
Saskatoon	0.30	10.76	**4.84E-04**	80	SK	1983-2022
Moonshine	0.39	4.40	**9.25E-07**	90	SK	1983-2022
Lac La Nonne	0.40	3.33	**0.001**	42	SK	1988-2022
Isle	0.28	2.58	**0.015**	46	SK	1983-2021
Laurier	0.49	1.44	**4.44E-08**	68	SK	1997-2022
Skeleton North	0.21	1.25	**0.041**	54	SK	2005-2022
Sturgeon	0.12	0.63	0.173	89	SK	1983-2022
Muriel	0.18	0.29	0.164	36	SK	1988-2022
Moose	0.14	0.23	**0.029**	118	SK	1983-2022
McLeod	0.17	0.18	**0.038**	93	SK	1984-2022
Pine	0.02	0.05	0.780	97	SK	1983-2021
Pigeon	-0.01	<0.01	0.904	106	MK	1983-2022
Wabamun	-0.16	-0.18	**0.007**	137	SK	1981-2022
Sylvan	-0.25	-0.21	**0.002**	82	SK	1983-2022
Touchwood	-0.33	-0.24	**0.004**	46	SK	1986-2022
Marie	-0.20	-0.29	0.130	39	SK	2003-2021
Beauvais	-0.37	-0.33	**1.11E-05**	75	SK	1984-2020
Alix	-0.12	-0.43	0.230	50	SK	1992-2020
Kehewin	-0.04	-0.56	0.800	30	SK	2003-2019
Skeleton South	-0.19	-0.57	0.051	57	SK	2005-2022
Chestermere	-0.56	-0.63	**3.53E-08**	55	SK	1983-2022
Gull	-0.47	-0.71	**2.96E-07**	67	SK	1983-2021
Wizard	-0.37	-0.82	**0.004**	38	SK	2006-2022
Buffalo	-0.36	-0.86	**5.22E-05**	68	SK	1984-2022
Crane	-0.53	-0.87	**2.62E-08**	60	SK	2005-2022
Winagami	-0.26	-1.79	**0.001**	89	SK	1983-2022
Minnie	-0.50	-1.82	**1.56E-06**	51	SK	2008-2022

Table 3. Summary of trend analysis for chlorophyll-*a* at lakes sampled through the LakeWatch program. Tau = strength and direction of trend, Slope = rate of change of trend (µg/L per year), *p* = significance of trend (bolded indicates significance at $p < 0.05$), n = number of sampling events, Trend Test = either Seasonal Kendall (SK) or Mann Kendall (MK), Trend Range = range of years included in trend analysis. Table ordered by Slope magnitude.

Lake	Tau	Slope (µg/L) per year	*p*	n	Trend Test	Trend Range
Skeleton North	0.50	2.06	**1.62E-06**	54	SK	2005-2022
Laurier	0.49	1.38	**2.97E-08**	68	SK	1997-2022
Kehewin	0.14	0.79	0.260	29	SK	2003-2019
Isle	0.13	0.45	0.290	45	SK	1983-2021
Pine	0.23	0.42	**0.001**	97	SK	1983-2021
Muriel	0.45	0.40	**0.002**	35	SK	1988-2022
Minnie	0.33	0.33	**0.003**	52	SK	2008-2022
Moose	0.23	0.28	**0.001**	118	SK	1983-2022
Moonshine	0.10	0.23	0.138	92	SK	1983-2022
Wizard	0.10	0.17	0.472	38	SK	2006-2022
Alix	0.12	0.17	0.280	50	SK	1992-2020
Skeleton South	0.14	0.16	0.193	58	SK	2005-2022
Pigeon	0.13	0.14	**0.048**	106	SK	1983-2022
Crane	0.26	0.11	**0.006**	60	SK	2005-2022
Buffalo	0.05	0.03	0.593	68	SK	1984-2022
Saskatoon	0.02	0.03	0.914	80	SK	1983-2022
Chestermere	0.12	0.03	0.275	54	SK	1983-2022
McLeod	0.04	0.02	0.503	96	SK	1984-2022
Touchwood	0.06	0.01	0.665	46	SK	1986-2022
Sylvan	-0.04	-0.01	0.677	83	SK	1983-2022
Gull	-0.05	-0.02	0.550	68	SK	1983-2021
Marie	-0.08	-0.03	0.520	39	SK	2003-2021
Wabamun	-0.10	-0.07	0.068	140	MK	1980-2022
Beauvais	-0.19	-0.08	**0.040**	74	SK	1984-2020
Lac La Nonne	-0.05	-0.12	0.743	42	SK	1988-2022
Sturgeon	-0.09	-0.17	0.230	90	SK	1983-2022
Winagami	-0.25	-0.53	**0.002**	88	SK	1983-2022

Table 4. Summary of trend analysis for total dissolved solids (TDS) at lakes sampled through the LakeWatch program. Tau = strength and direction of trend, Slope = rate of change of trend (mg/L per year), *p* = significance of trend (bolded indicates significance at $p < 0.05$), n = number of sampling events, Trend Test = either Seasonal Kendall (SK) or Mann Kendall (MK), Trend Range = range of years included in trend analysis. Table ordered by Slope magnitude. “I.D” indicates insufficient data to conduct trend analysis.

Lake	Tau	Slope (mg/L per year)	*p*	n	Trend Test	Trend Range
Lac La Nonne	-	-	**-**	-	I.D.	-
Muriel	0.45	21.75	**0.001**	35	SK	1988-2022
Alix	0.52	19.35	**1.11E-05**	43	SK	1996-2020
Minnie	0.33	5.80	**0.002**	45	SK	2008-2022
Moose	0.44	4.74	**2.07E-08**	85	SK	1983-2022
Wabamun	0.92	4.05	**3.30E-53**	136	SK	1980-2022
Skeleton North	0.63	3.19	**4.32E-09**	49	SK	2005-2022
Winagami	0.54	2.56	**8.13E-08**	57	SK	1983-2022
Skeleton South	0.69	2.42	**2.14E-10**	50	SK	2005-2022
Gull	0.48	2.36	**3.76E-06**	57	SK	1983-2021
Saskatoon	0.17	2.29	0.208	44	SK	1983-2022
Isle	0.74	1.94	**7.79E-10**	42	SK	1983-2021
Kehewin	0.46	1.80	**0.013**	23	SK	2003-2019
Chestermere	0.49	1.75	**2.39E-06**	52	SK	1983-2022
Crane	0.31	1.56	**0.003**	52	SK	2005-2022
Sturgeon	0.76	1.53	**6.84E-13**	51	SK	1983-2022
Pigeon	0.59	1.00	**5.31E-14**	85	SK	1983-2022
Pine	0.20	0.95	**0.012**	81	SK	1983-2021
Wizard	0.46	0.82	**0.001**	30	SK	2006-2022
Sylvan	0.45	0.75	**9.97E-06**	57	SK	1983-2022
Touchwood	0.52	0.26	**2.04E-04**	33	SK	1986-2022
McLeod	0.09	<0.01	0.352	53	MK	1984-2022
Marie	-0.26	-0.33	**0.035**	32	MK	2003-2021
Beauvais	-0.33	-0.57	**0.007**	42	SK	1984-2020
Moonshine	-0.31	-2.04	**0.006**	45	SK	1983-2022
Buffalo	-0.20	-2.90	**0.035**	63	SK	1984-2022
Laurier	-0.44	-10.00	**8.94E-05**	56	SK	1997-2022

Table 5. Summary of trend analysis for Secchi depth at lakes sampled through the LakeWatch program. Tau = strength and direction of trend, Slope = rate of change of trend (m per year), *p* = significance of trend (bolded indicates significance at $p < 0.05$), n = number of sampling events, Trend Test = either Seasonal Kendall (SK) or Mann Kendall (MK), Trend Range = range of years included in trend analysis. Table ordered by Slope magnitude.

Lake	Tau	Slope (m per year)	*p*	n	Trend Test	Trend Range
Marie	0.18	0.04	0.180	39	SK	2003-2021
Beauvais	0.31	0.04	**2.80E-04**	77	SK	1984-2020
Touchwood	0.19	0.03	0.069	46	SK	1986-2022
Crane	0.10	0.02	0.338	60	SK	2005-2022
Winagami	0.18	0.02	**0.014**	90	SK	1983-2022
Pigeon	0.19	0.01	**0.009**	107	SK	1983-2022
Lac La Nonne	0.14	0.01	0.247	42	SK	1988-2022
Wizard	0.12	0.01	0.328	38	SK	2006-2022
Skeleton South	0.07	0.01	0.394	58	SK	2005-2022
Wabamun	0.15	0.01	**0.012**	141	SK	1980-2022
Saskatoon	-0.10	<0.01	0.184	81	SK	1983-2022
Sturgeon	<0.01	<0.01	0.958	90	SK	1983-2022
Sylvan	-0.01	<0.01	0.977	85	SK	1983-2022
Chestermere	-0.04	-0.01	0.626	52	SK	1983-2022
Isle	-0.22	-0.01	0.069	44	SK	1983-2021
Buffalo	-0.23	-0.01	**0.008**	70	SK	1984-2022
Moonshine	-0.22	-0.02	**0.004**	93	SK	1983-2022
Moose	-0.22	-0.02	**0.001**	120	SK	1983-2022
Alix	-0.14	-0.02	0.180	49	SK	1992-2020
Gull	-0.39	-0.03	**4.68E-06**	66	SK	1983-2021
Muriel	-0.37	-0.03	**0.009**	35	SK	1988-2022
Pine	-0.26	-0.03	**2.96E-04**	96	SK	1983-2021
McLeod	-0.26	-0.03	**3.68E-04**	96	SK	1984-2022
Laurier	-0.26	-0.04	**0.003**	69	SK	1997-2022
Kehewin	-0.16	-0.05	0.130	30	SK	2003-2019
Skeleton North	-0.55	-0.13	**6.76E-08**	54	SK	2005-2022
Minnie	-0.51	-0.20	**1.08E-06**	52	SK	2008-2022

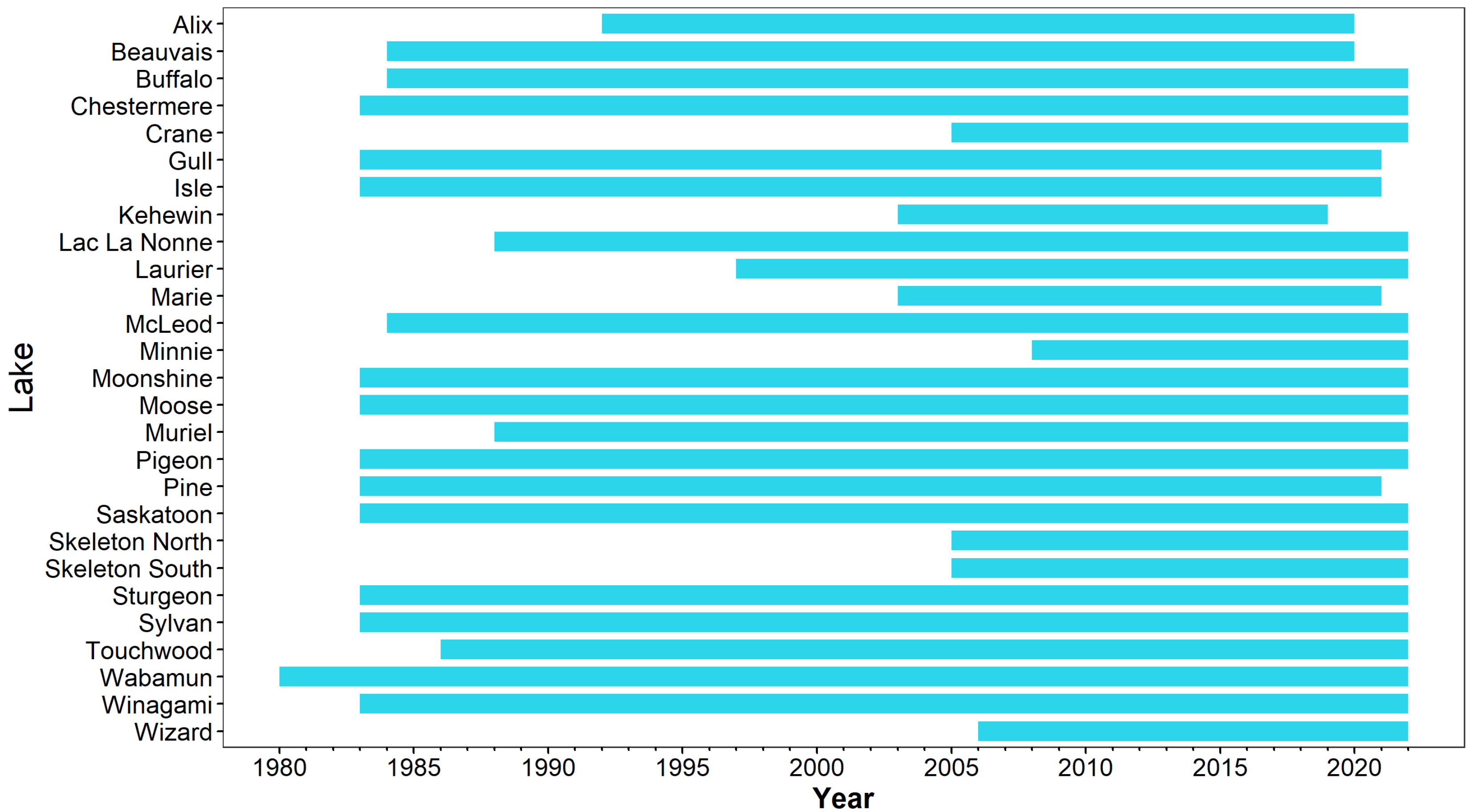

Figure 1. Range of years incorporated into trend analysis for each lake, with the trend analysis performed by ALMS. Note that some parameters may have shorter range dependant on historical sampling – refer to Tables 2, 3, 4 and 5 above to view range of years used specific to each parameter and lake.

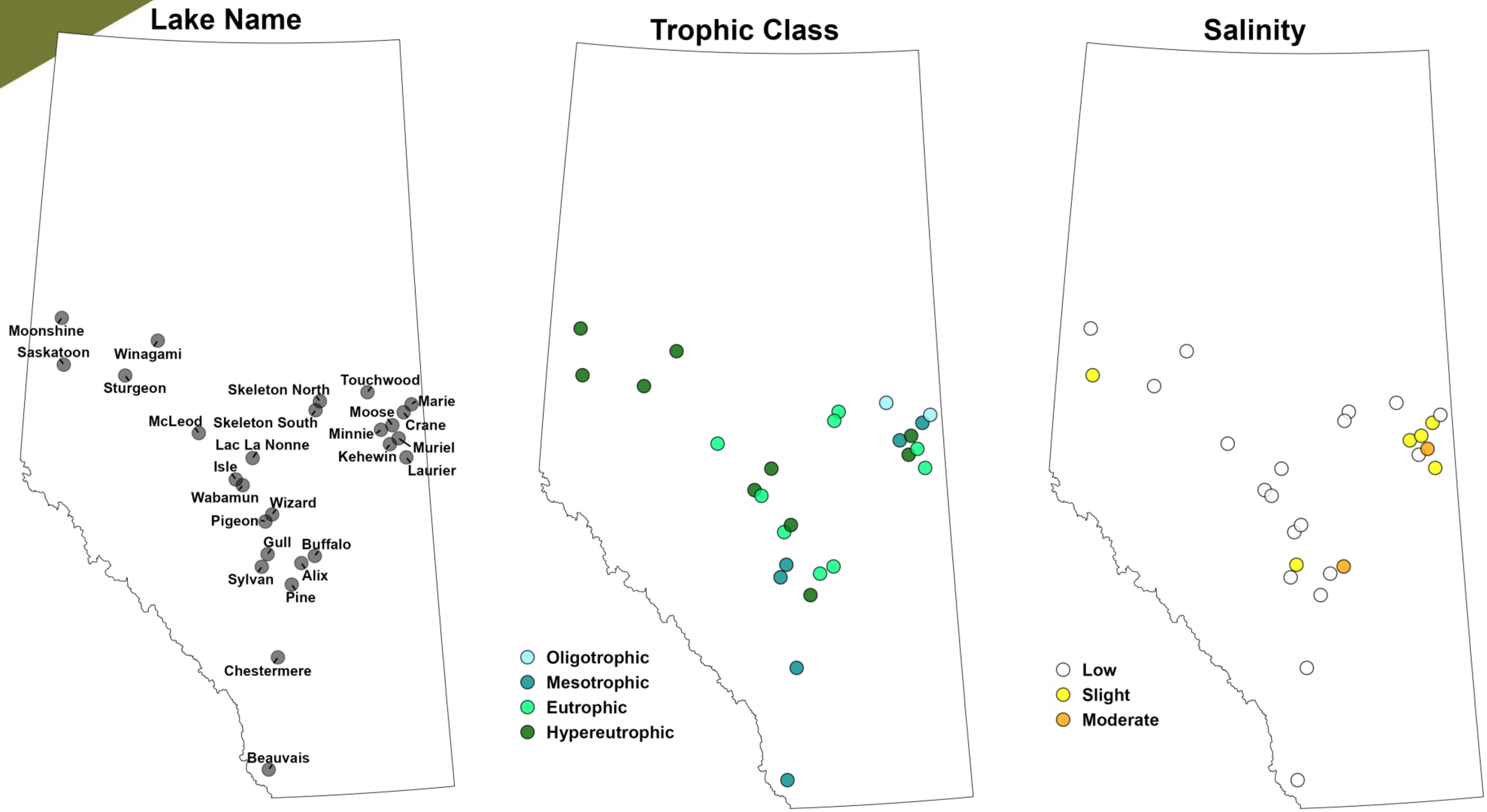

Figure 2. Geographic location in Alberta of the 27 lakes included in the trend analysis, including their name (left), trophic status as determined by each lake's historical chlorophyll-*a* average (center), using the trophic classes defined by Nurnberg (1996)[1], and salinity class as determined each lake's historical total dissolved solids (TDS) average (right), using the salinity classes defined by Mitchell and Prepas (1990)[2].

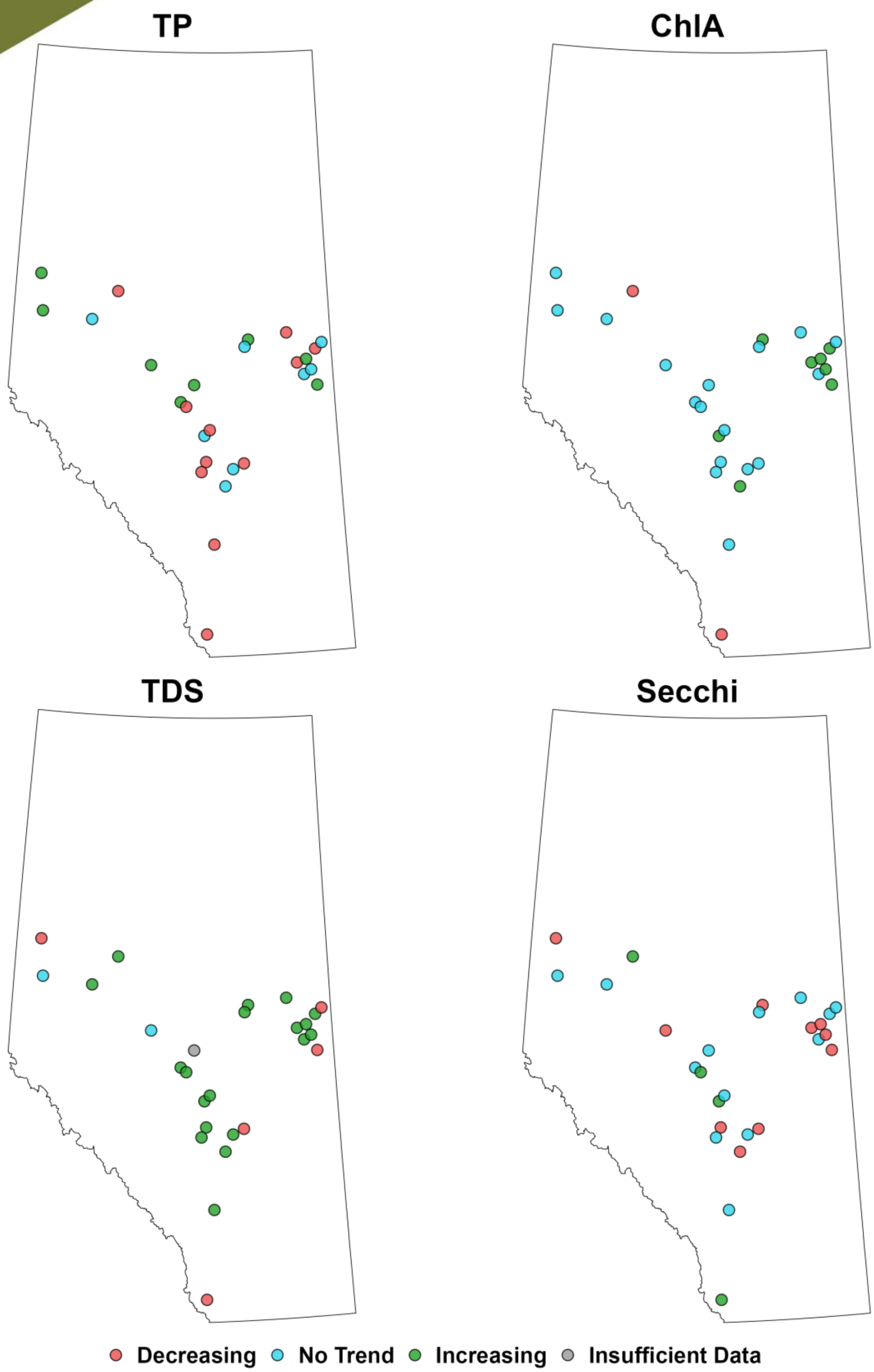

Figure 3. Geographic location in Alberta of the 27 lakes included in the trend analysis, organized by lake water quality parameter (TP = total phosphorus, ChlA = chlorophyll-*a*, TDS = total dissolved solids, Secchi = Secchi depth), with statistically decreasing (red), no trend (blue), or statistically increasing (green) trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis. Where there is insufficient data to perform trend analysis, the lake is colored gray.

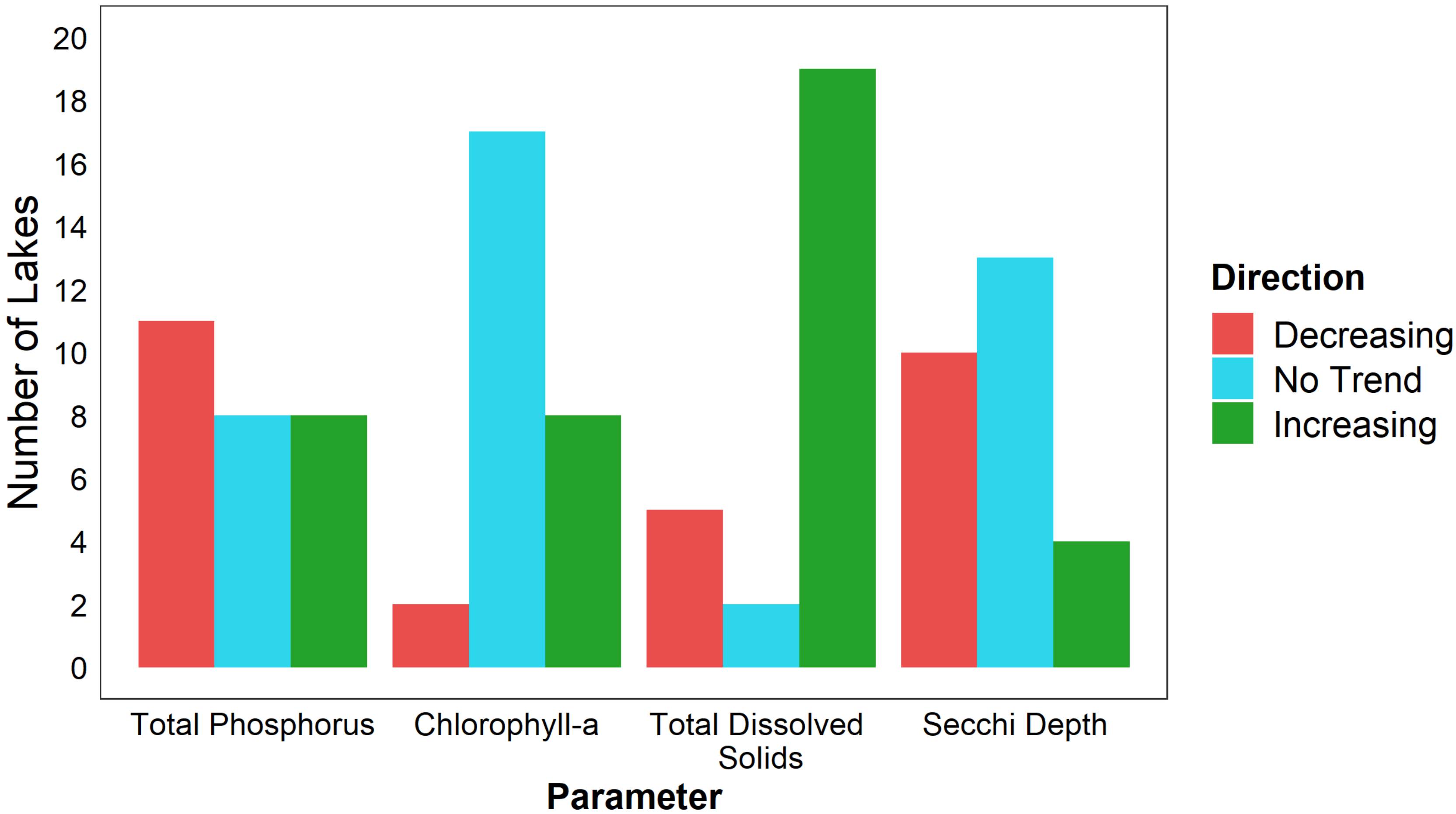

Figure 4. Number of lakes organized by lake water quality parameter (total phosphorus, chlorophyll-*a*, total dissolved solids, and Secchi depth), with statistically decreasing (red), no trend (blue), or statistically increasing (green) trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis. Note that there was insufficient data to perform trend analysis for TDS at Lac La Nonne, and is excluded from the TDS section of the figure.

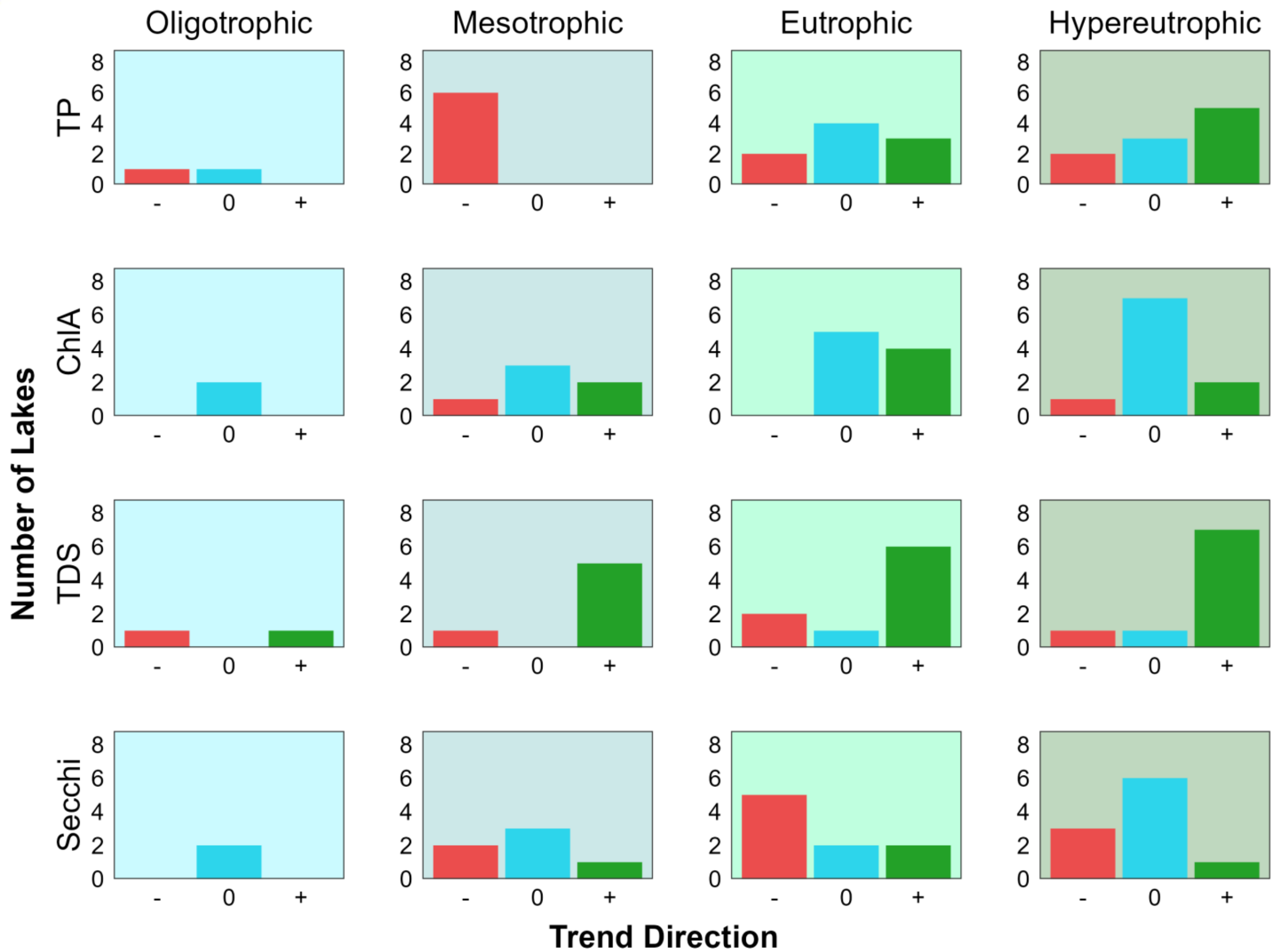

Figure 5. Number of lakes organized by lake water quality parameter (TP = total phosphorus, ChlA = chlorophyll-*a*, TDS = total dissolved solids, Secchi = Secchi depth), and split into each lake's trophic classification based on historical average chlorophyll-*a* as defined by Nurnberg (1996)[1], with statistically significant statistically decreasing (red, "-"), no trend (blue, "0"), or statistically increasing (green, "+") trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis. Note that there is insufficient data to perform trend analysis for TDS at Lac La Nonne, and is excluded from the TDS section of the figure.

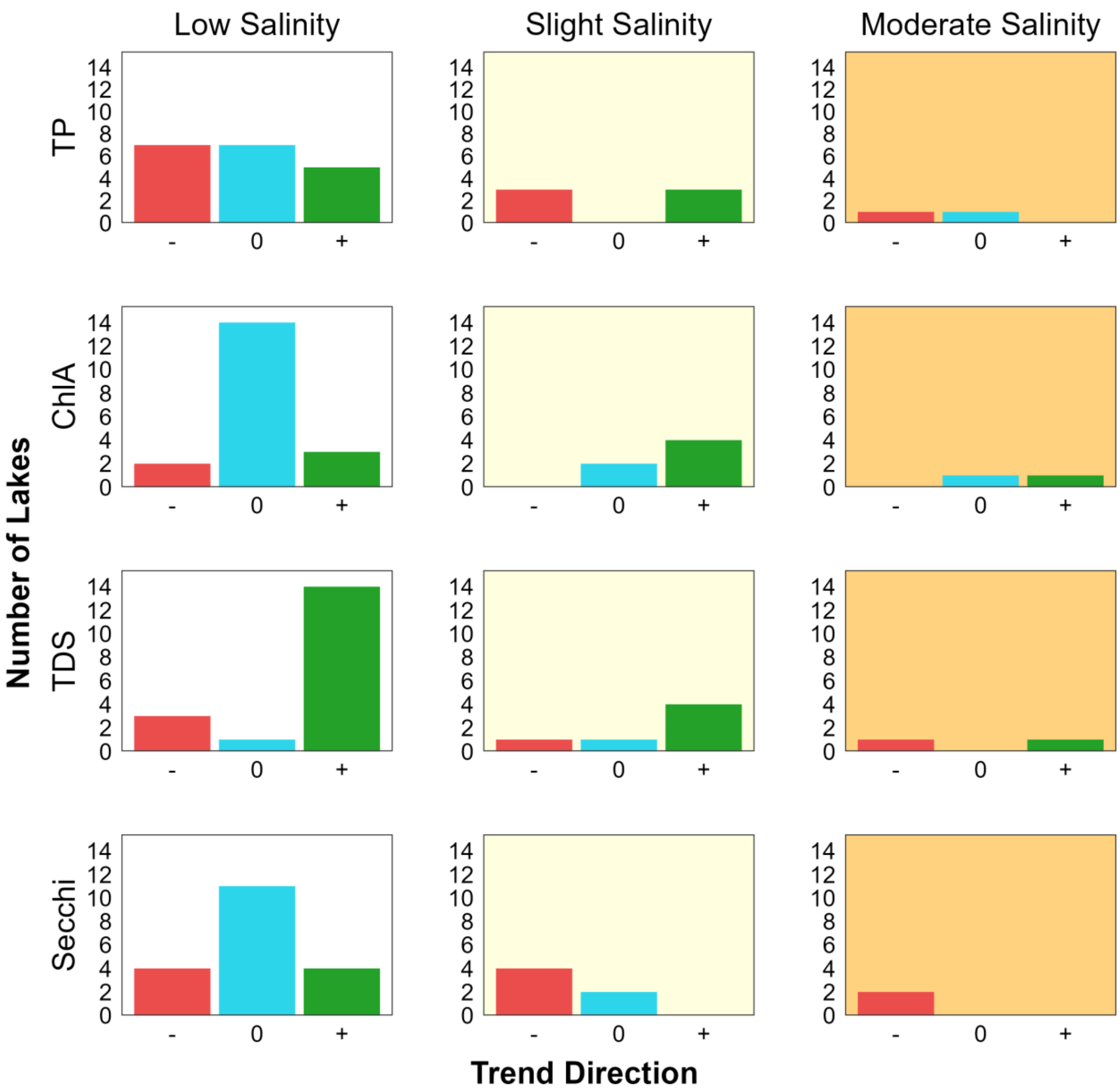

Figure 6. Number of lakes organized by lake water quality parameter (TP = total phosphorus, ChlA = chlorophyll-*a*, TDS = total dissolved solids, Secchi = Secchi depth), and split into each lake's salinity class based on historical average total dissolved solids as defined by Mitchell and Prepas (1990)[2], with statistically significant statistically decreasing (red, "-"), no trend (blue, "0"), or statistically increasing (green, "+") trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis. Note that there is insufficient data to perform trend analysis for TDS at Lac La Nonne, and is excluded from the TDS section of the figure.

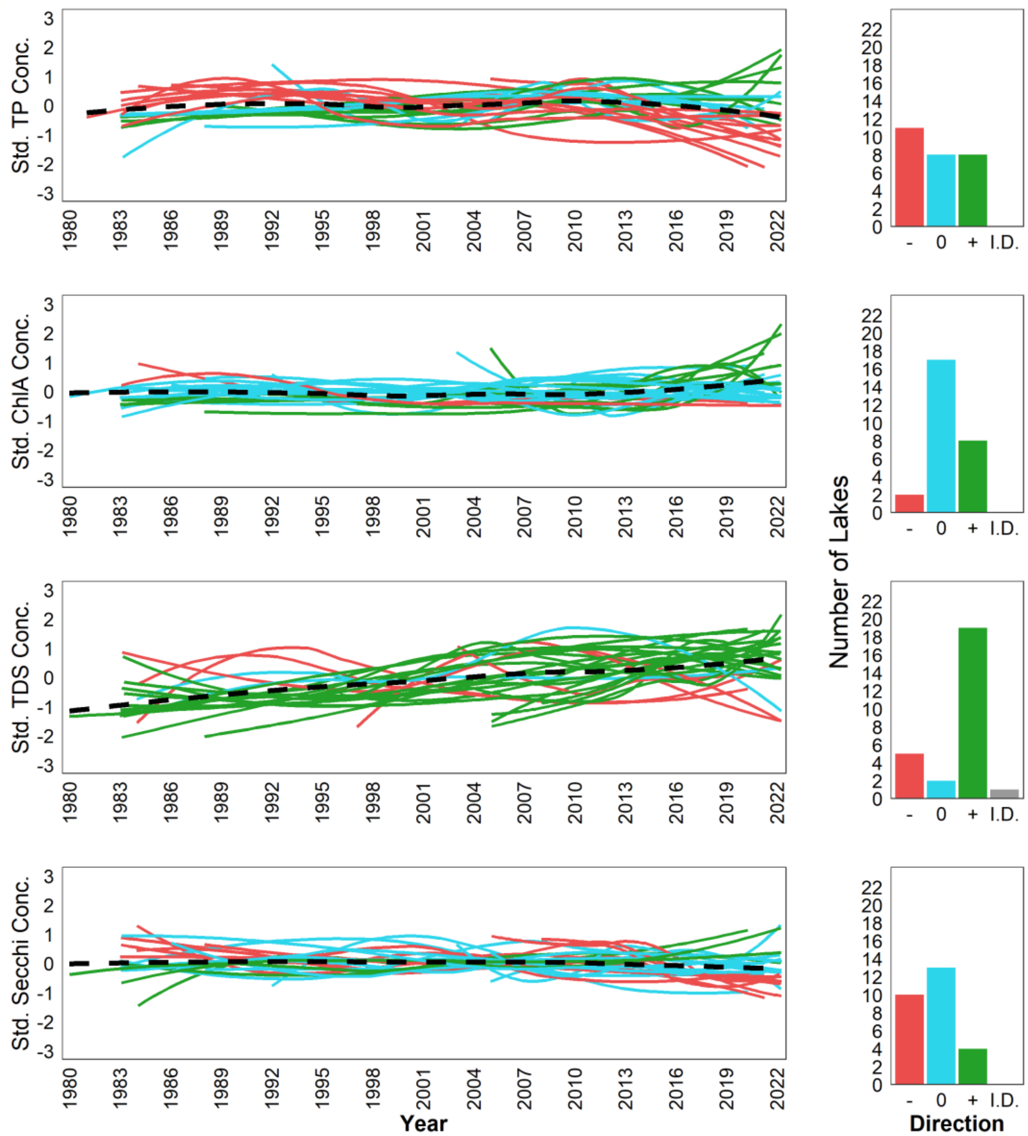

Figure 7. Left) Standardized (Std.) concentrations (Conc.) of total phosphorus (TP), chlorophyll-*a* (ChlA), total dissolved solids (TDS), and Secchi Depth (Secchi) fitted by a LOESS trend line for each lake, from lakes measured monthly between 1980 and 2022. A LOESS trend is also fitted to all data for each parameter (black dashed line). Data was standardized to improve inter-lake trend comparison by rescaling each lake's data set to mean = 0, and standard deviation = 1. Monotonic trend results are represented by line color for each parameter. Test used is either Mann Kendall or Seasonal Kendall, and if significant at $p < 0.05$, then increasing trends are represented by green, decreasing trends by red, and insignificant trends by blue. If parameter has insufficient data for trend analysis, the LOESS trend line is not plotted. Data and test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Individual LakeWatch reports available at https://alms.ca/reports/ present raw data figures and results of trend results for each lake eligible for trend analysis (currently for lakes sampled up to 2022, only). Right) The number of lakes with either a significantly decreasing trend (red, "-"), insignificant trend (blue, "0"), significantly increasing trend (green, "+"), or number of lakes where data is insufficient for trend analysis (black, "I.D."). Historical trend visualization and data standardization follows method of Dugan *et al.* (2017).[3]

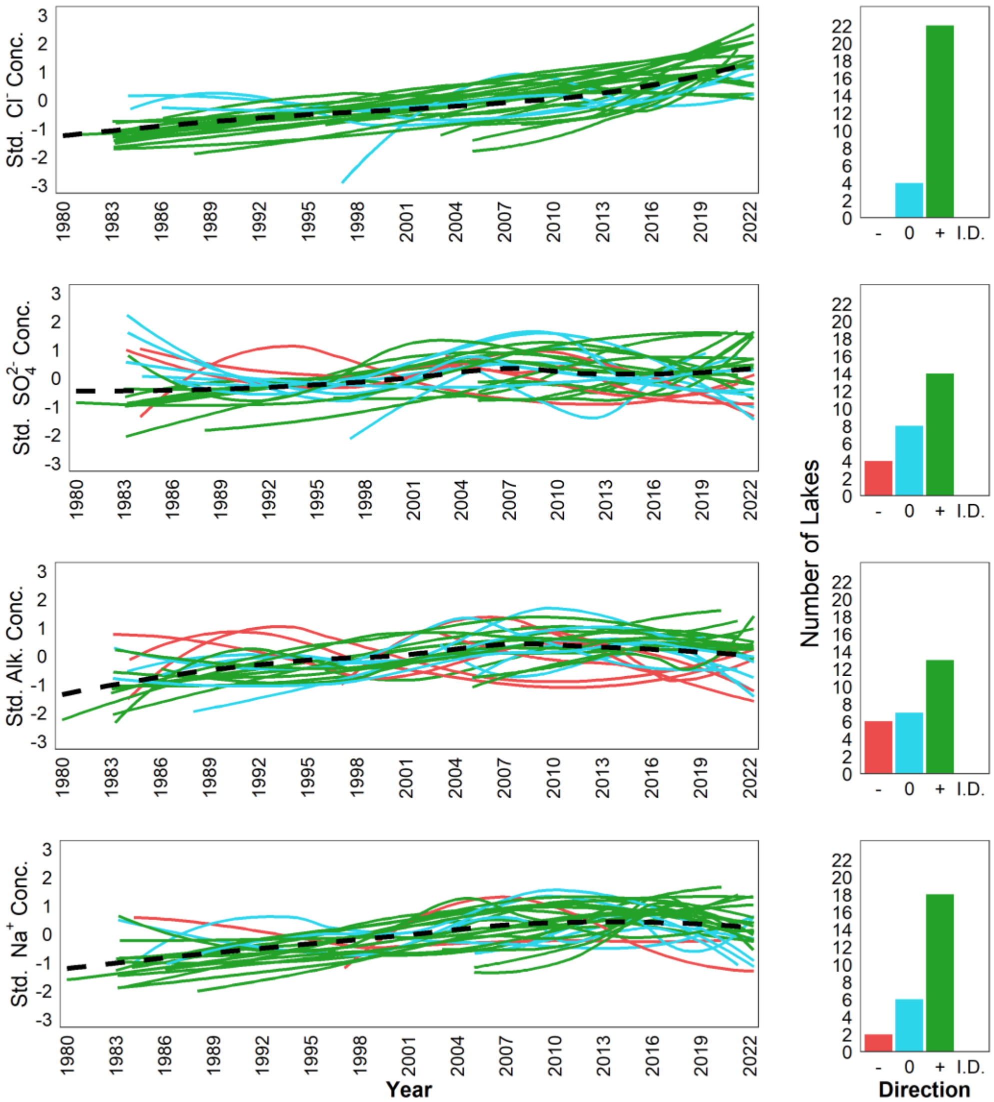

Figure 9. Left) Standardized (Std.) concentrations (Conc.) of major ions (chloride = Cl^-, sulphate = SO_4^{2-}, sodium = Na^+) and total alkalinity (Alk., as mg/L $CaCO_3$) fitted by a LOESS trend line for each lake, from lakes measured monthly between 1980 and 2022. A LOESS trend is also fitted to all data for each parameter (black dashed line). Data was standardized to improve inter-lake trend comparison by rescaling each lake's data set to mean = 0, and standard deviation = 1. Monotonic trend results are represented by line color for each parameter. Test used is either Mann Kendall or Seasonal Kendall, and if significant at $p < 0.05$, then increasing trends are represented by green, decreasing trends by red, and insignificant trends by blue. If parameter has insufficient data for trend analysis, the LOESS trend line is not plotted. Data and test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Individual LakeWatch reports available at https://alms.ca/reports/ present raw data figures and results of trend results for each lake eligible for trend analysis (currently for lakes sampled up to 2022, only). Right) The number of lakes with either a significantly decreasing trend (red, "-"), insignificant trend (blue, "0"), significantly increasing trend (green, "+"), or number of lakes where data is insufficient for trend analysis (black, "I.D."). Historical trend visualization and data standardization follows method of Dugan *et al.* (2017).[3] Note that since there is insufficient data to perform trend analysis for TDS at Lac La Nonne, it is excluded from this figure.

[3] Dugan, H.A. *et al.* (2017). Salting our freshwater lakes. Proceedings of the National Academy of Sciences (PNAS), U.S.A. 114, 4453-4458. https://doi.org/10.1073/pnas.1620211114

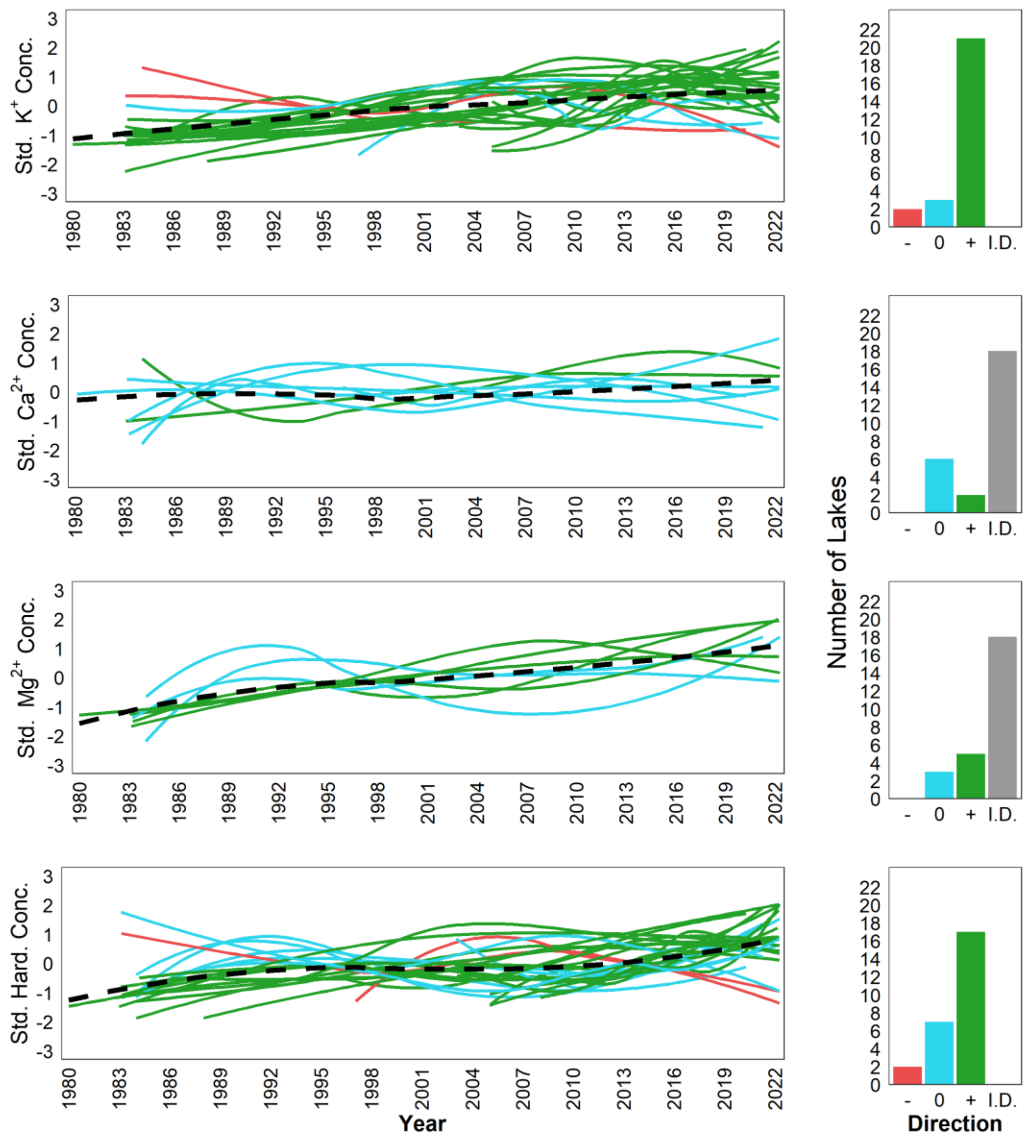

Figure 10. Left) Standardized (Std.) concentrations (Conc.) of major ions (potassium = K^+, calcium = Ca^{2+}, magnesium = Mg^{2+}) and total hardness (Hard., as mg/L $CaCO_3$) fitted by a LOESS trend line for each lake, from lakes measured monthly between 1980 and 2022. A LOESS trend is also fitted to all data for each parameter (black dashed line).Data was standardized to improve inter-lake trend comparison by rescaling each lake's data set to mean = 0, and standard deviation = 1. Monotonic trend results are represented by line color for each parameter. The test used is either Mann Kendall or Seasonal Kendall, and if significant at $p < 0.05$, then increasing trends are represented by green, decreasing trends by red, and insignificant trends by blue. If a parameter has insufficient data for trend analysis, the LOESS trend line is not plotted. Data and test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Individual LakeWatch reports available at https://alms.ca/reports/ present raw data figures and results of trend results for each lake eligible for trend analysis (currently for lakes sampled up to 2022, only). Right) The number of lakes with either a significantly decreasing trend (red, "-"), insignificant trend (blue, "0"), significantly increasing trend (green, "+"), or number of lakes where data is insufficient for trend analysis (black, "I.D."). Historical trend visualization and data standardization follows method of Dugan *et al.* (2017).[3] Note that since there is insufficient data to perform trend analysis for TDS at Lac La Nonne, it is excluded from this figure.

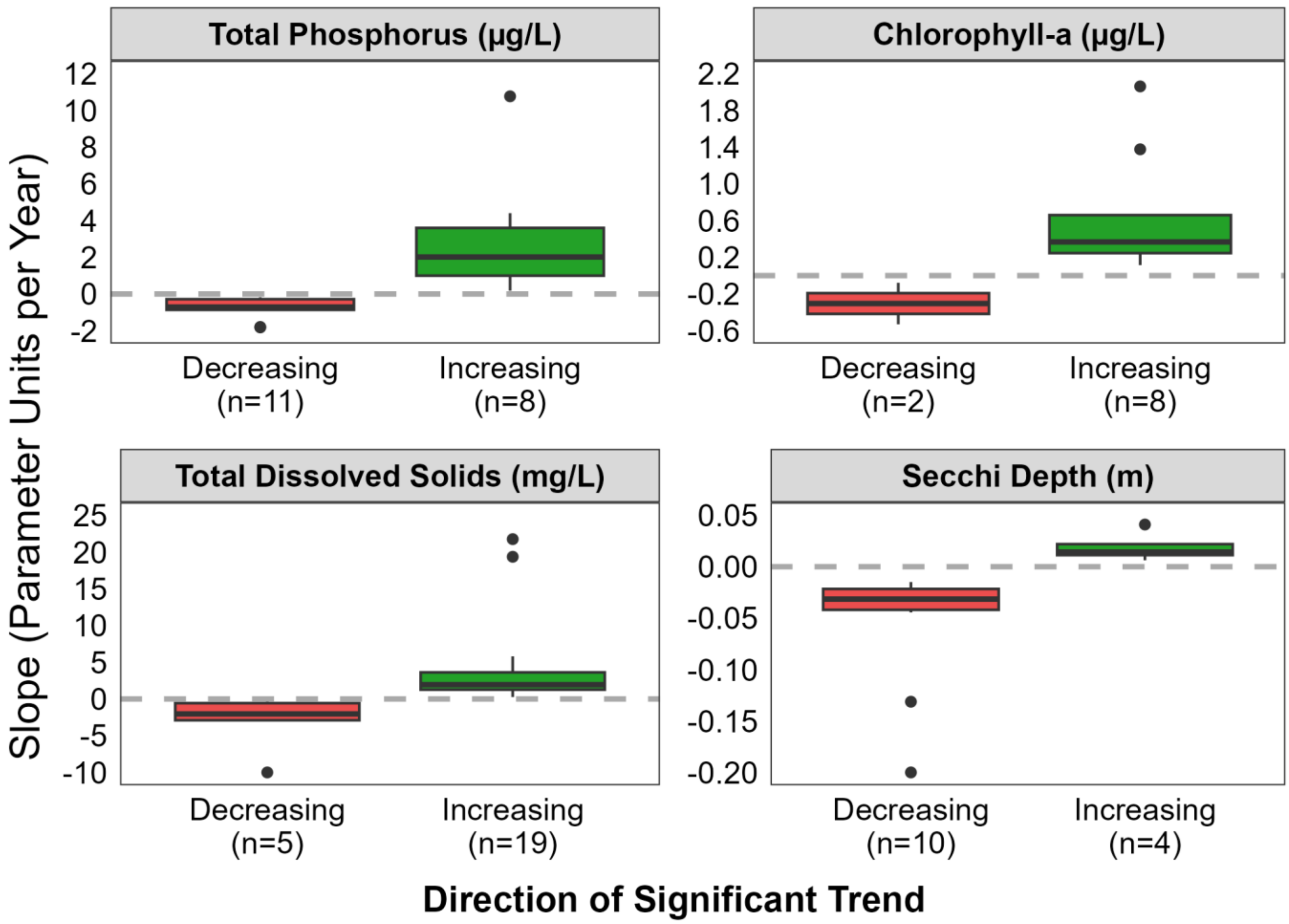

Figure 11. Boxplot of slopes of statistically significant increasing or decreasing trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis, organized by lake water quality parameter (total phosphorus, chlorophyll-*a*, total dissolved solids, and Secchi depth). Refer to the Appendix for boxplot figure interpretation.

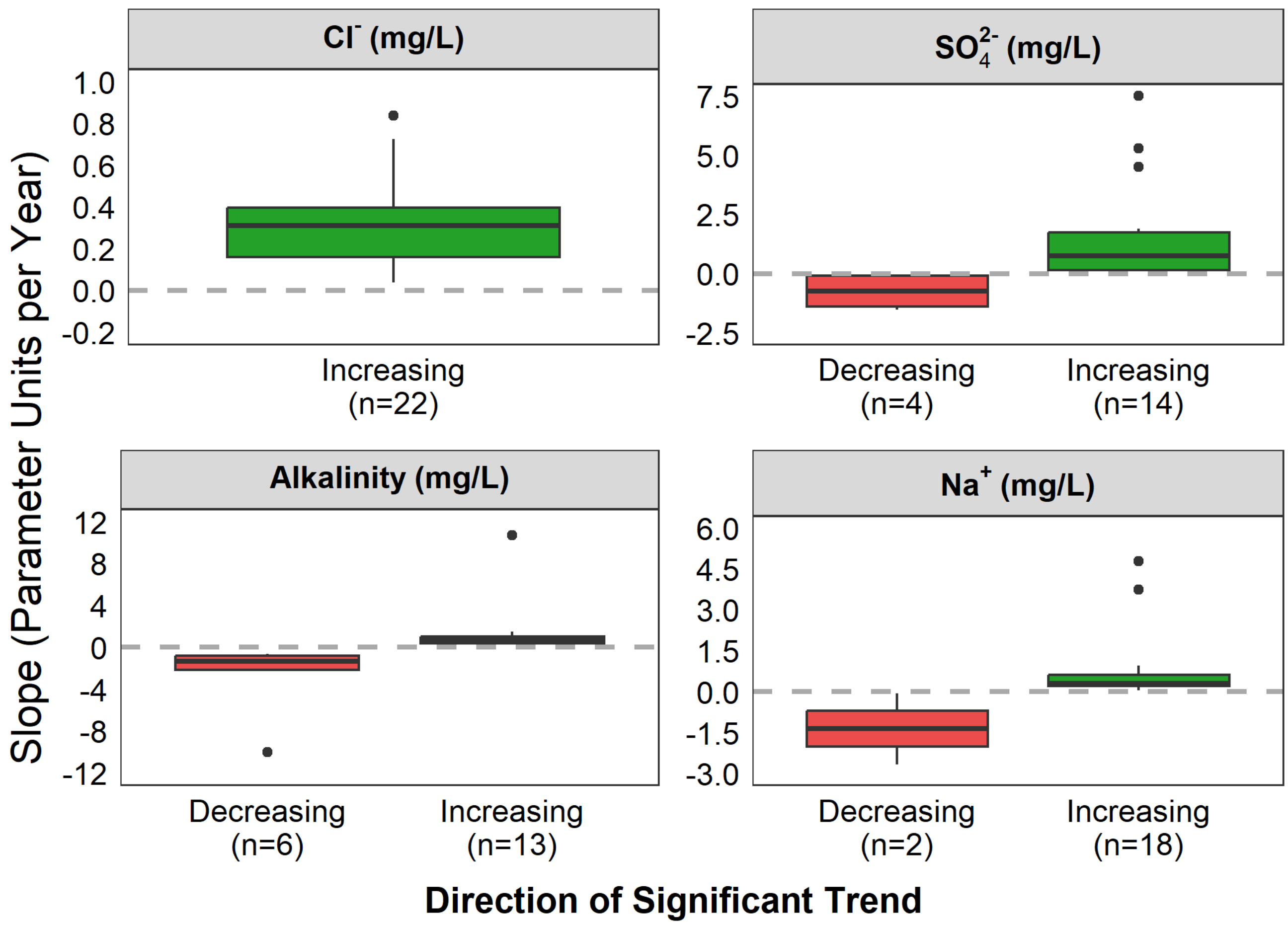

Figure 12. Boxplot of slopes of statistically significant increasing or decreasing trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis, organized by lake water quality parameter (chloride = Cl^-, sulphate = SO_4^{2-}, sodium = Na^+, Alkalinity = total alkalinity as mg/L $CaCO_3$). Refer to Appendix for boxplot figure interpretation.

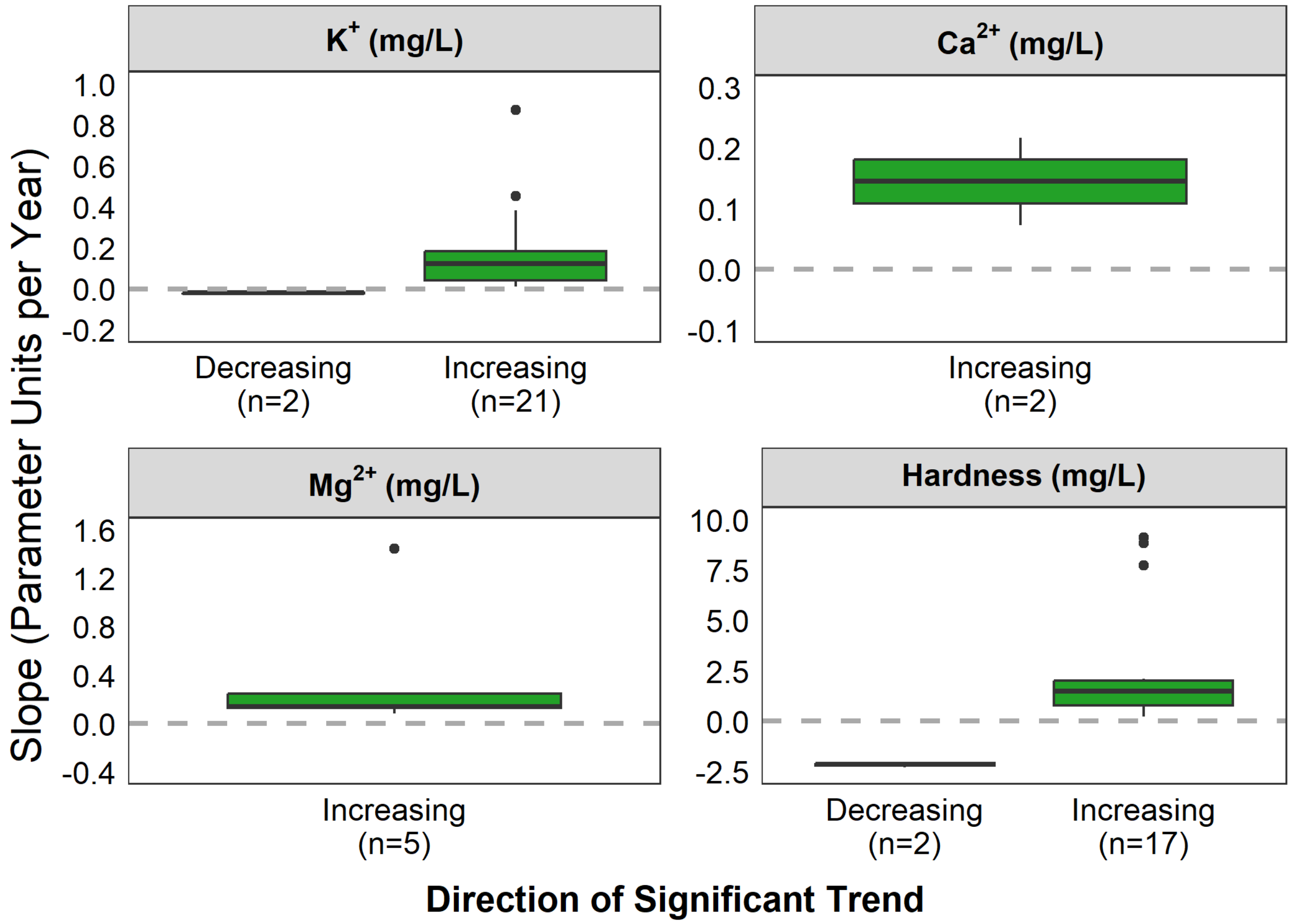

Figure 13. Boxplot of slopes of statistically significant increasing or decreasing trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis, organized by lake water quality parameter (potassium = K^+, calcium = Ca^{2+}, magnesium = Mg^{2+}, Hardness = total hardness as mg/L $CaCO_3$). Refer to Appendix for boxplot figure interpretation.

APPENDIX

Definitions:

Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

Box and Whisker Plot: a box-and-whisker plot, or boxplot, is a way of displaying all of our annual data. The median splits the data in half. The 75th percentile is the upper quartile of the data, and the 25th percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.

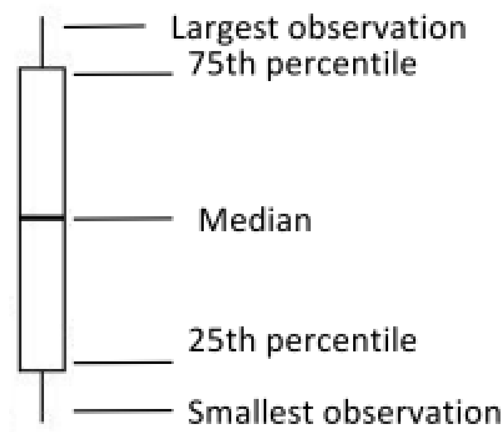

Table 6. Classifications for trophic class as determined by each lake's historical chlorophyll-*a* average using the trophic classes defined by Nurnberg (1996)[1], and salinity class as determined each lake's historical total dissolved solids (TDS) average, using the salinity classes defined by Mitchell and Prepas (1990)[2].

Trophic Class	Average Chlorophyll-*a* (µg/L)	Salinity Class	Average Total Dissolved Solids (mg/L)
Oligotrophic	< 3.5	Low	< 500
Mesotrophic	3.5 – 9	Slight	500 – 1000
Eutrophic	9 – 25	Moderate	1000 – 5000
Hypereutrophic	> 25	High	> 5000

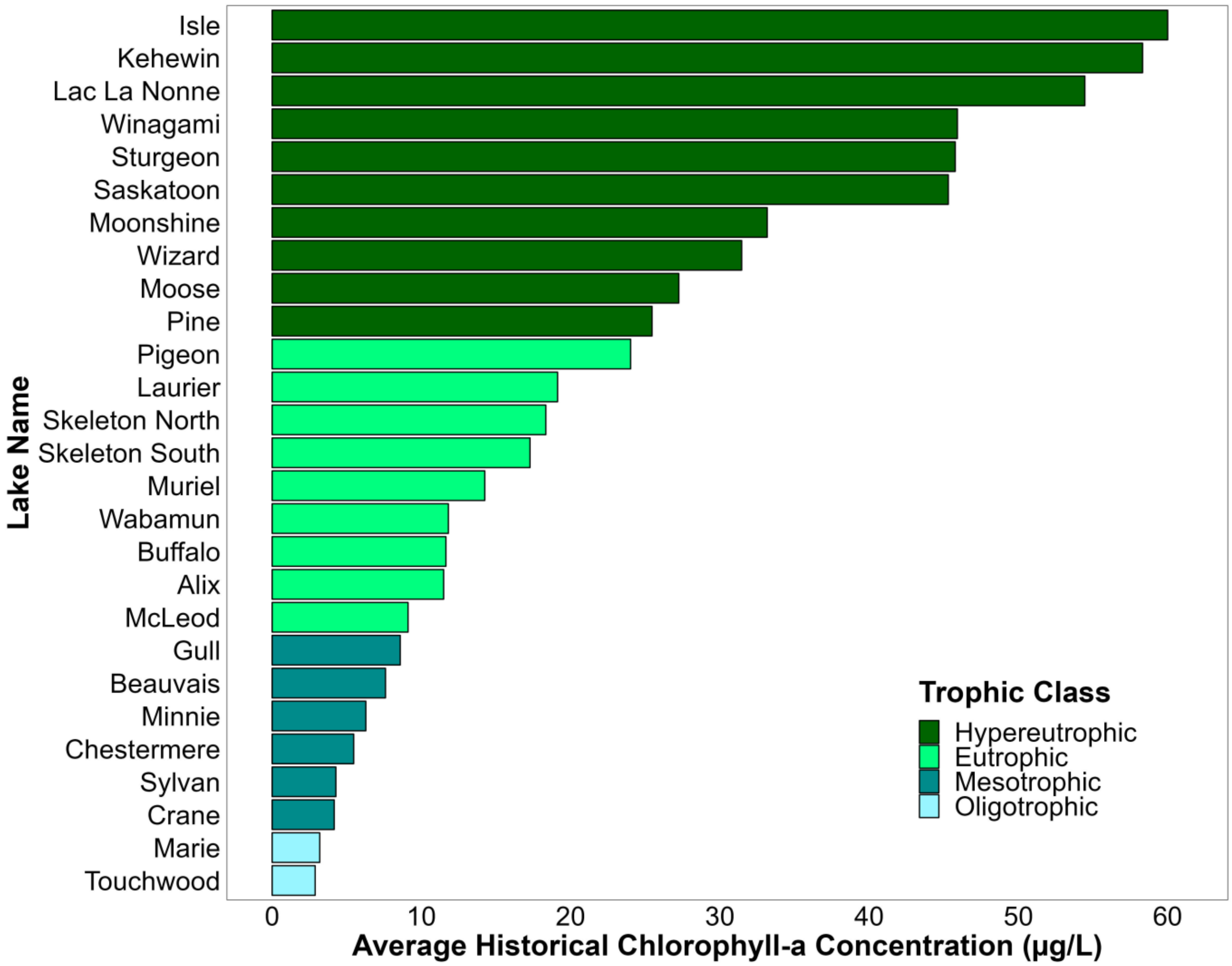

Figure 14. Average historical chlorophyll-*a* concentrations (µg/L) measured from 27 lakes, and colored by trophic class based on the classification by Nurnberg (1996)[1].

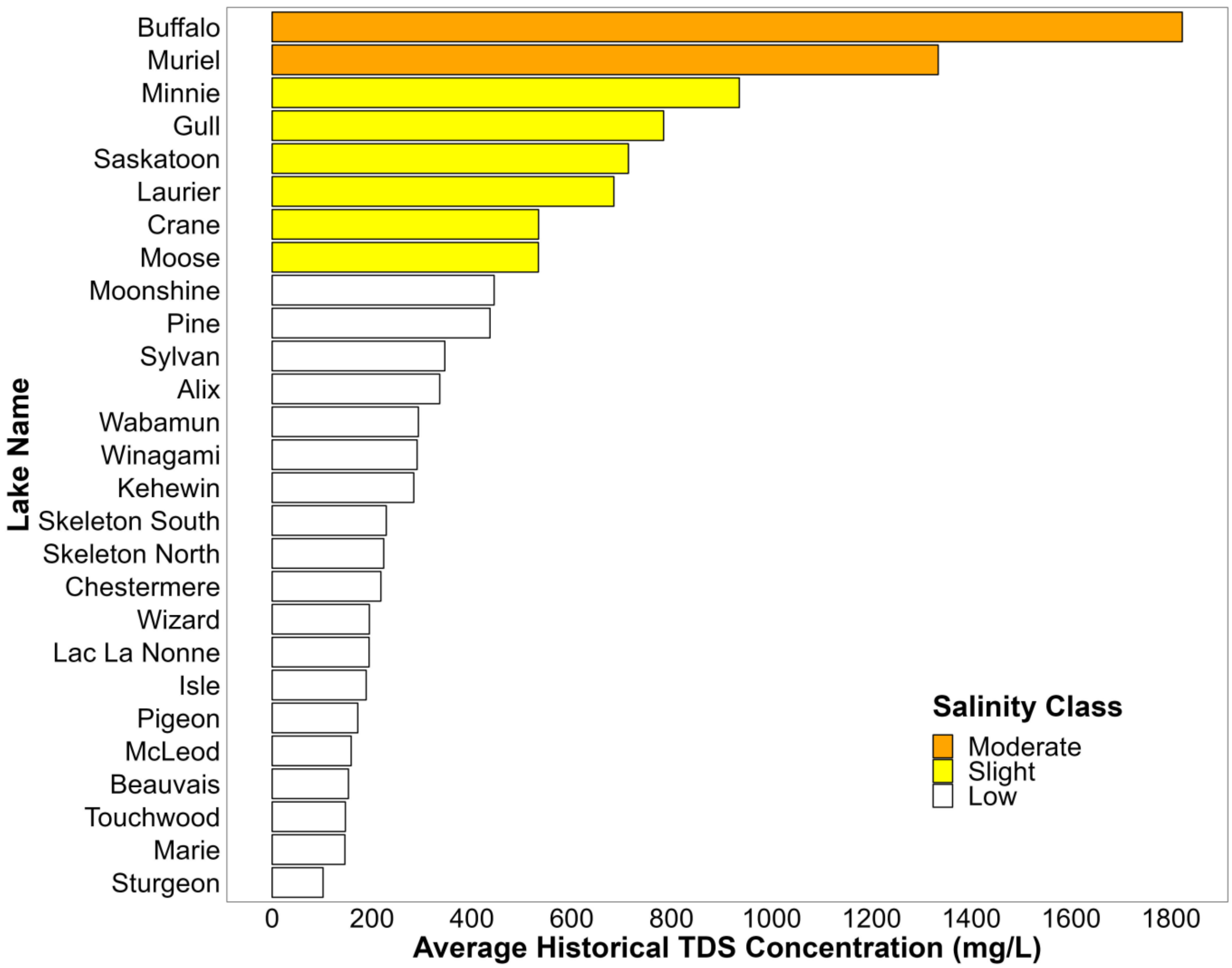

Figure 15. Average historical total dissolved solids (TDS; mg/L) measured from 27 lakes, and colored by salinity class based on the classification by Mitchell and Prepas (1990)[2].

CASE STUDY: Investigating ChlA:TP

While it is widely recognized that total phosphorus (TP) is the primary limiting factor to the potential growth of algae and cyanobacteria, it is an interesting observation from the trend analysis results that there are only 2 lakes (Beauvais and Winagami) where there were significant decreasing trends for both TP and chlorophyll-*a* (ChlA), and only 3 lakes (Skeleton North, Moose, Laurier) where there were significant increasing trends for both TP and ChlA. While additional analysis would be needed to confirm how correlated TP and ChlA are for each of these lakes, this suggests TP may be driving the corresponding ChlA, or algae and cyanobacteria growth in these lakes. There are also 5 lakes where no significant trends are observed for both TP and ChlA. How then can the significant increasing trends in ChlA at five other lakes be explained, especially considering TP is significantly decreasing in nine other lakes as well? Many factors can influence the relationship between ChlA and TP, such as lake depth, nitrogen-phosphorus ratios, grazing, watershed characteristics, light, climate, and bioavailability of phosphorus within the TP pool (Yuan and Jones, 2020)[4]. While this trend report does not investigate these relationships, one way to explore how ChlA is changing despite counter-intuitive trends in TP is to control for TP by analyzing the ratio of ChlA to TP. This is a method of describing the extent to which TP is related to ChlA yield. If the ratio is relatively consistent over time, either parameter isn't changing appreciably over time or the ChlA yield is changing proportionally to the amount of TP within the lake. If the ratio decreases over time, higher proportions of TP with the lake are not translating into increased ChlA – this may occur in highly saline lakes or lakes with very high levels of TP. If the ratio increases over time, then it could be inferred that factors other than TP abundance are maintaining or increasing the yield of ChlA.

The trend analysis of ChlA:TP in the 27 lakes indicates 15 lakes display increasing trends, 2 lakes display decreasing trends, and 10 lakes display no significant trend (Figure 17). The two lakes that display decreasing trends are Lac La Nonne and Sturgeon (Figure 16), which are both classified as hypereutrophic (Figures 14, 18). For Lac La Nonne, increases in TP are significant while ChlA hasn't significantly changed over time. Sturgeon displays non-significant trends in both ChlA and TP, but the slope of ChlA is negative and TP is positive (Tables 2 and 3). This suggests a decoupling of the phosphorus-mediated ChlA yield, perhaps due to the trophic status of these lakes being hypereutrophic. For lakes with increasing ChlA:TP, half are within the eutrophic category, and the rest are split between the other trophic categories, while most lakes with no trend are hypereutrophic, but also split between the remaining categories. All but one of the lakes with no trend in ChlA:TP are in the low salinity class, while both lakes that are decreasing are also low salinity (Figure 18). While most lakes with an increasing trend are in the low salinity class, a high proportion are considered slightly saline. Lakes with increasing ChlA:TP are clustered within the central eastern and central regions of the province (Figure 16), in clustering that is similar for lakes with increasing TDS (Figure 3). The overall trajectory of ChlA:TP trends is a sharp increase, beginning in the early 2010s (Figure 17).

In summary, ChlA:TP trends describes that many lakes are displaying higher yields of ChlA despite levels of TP, indicating that factors other than TP abundance may be driving the abundance of algae and cyanobacteria and particularly the increased ChlA yield over the past decade. The similarity of lakes with increasing ChlA:TP and TDS suggest that the same lakes may be sensitive to similar drivers of increasing salinity and ChlA yield, but the particular drivers and associated dynamics require further investigation.

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[4] Yuan LL, Jones JR. Rethinking phosphorus-chlorophyll relationships in lakes. Limnol Oceanogr. 2020 Mar 16;9999:1-11. doi: 10.1002/lno.11422.

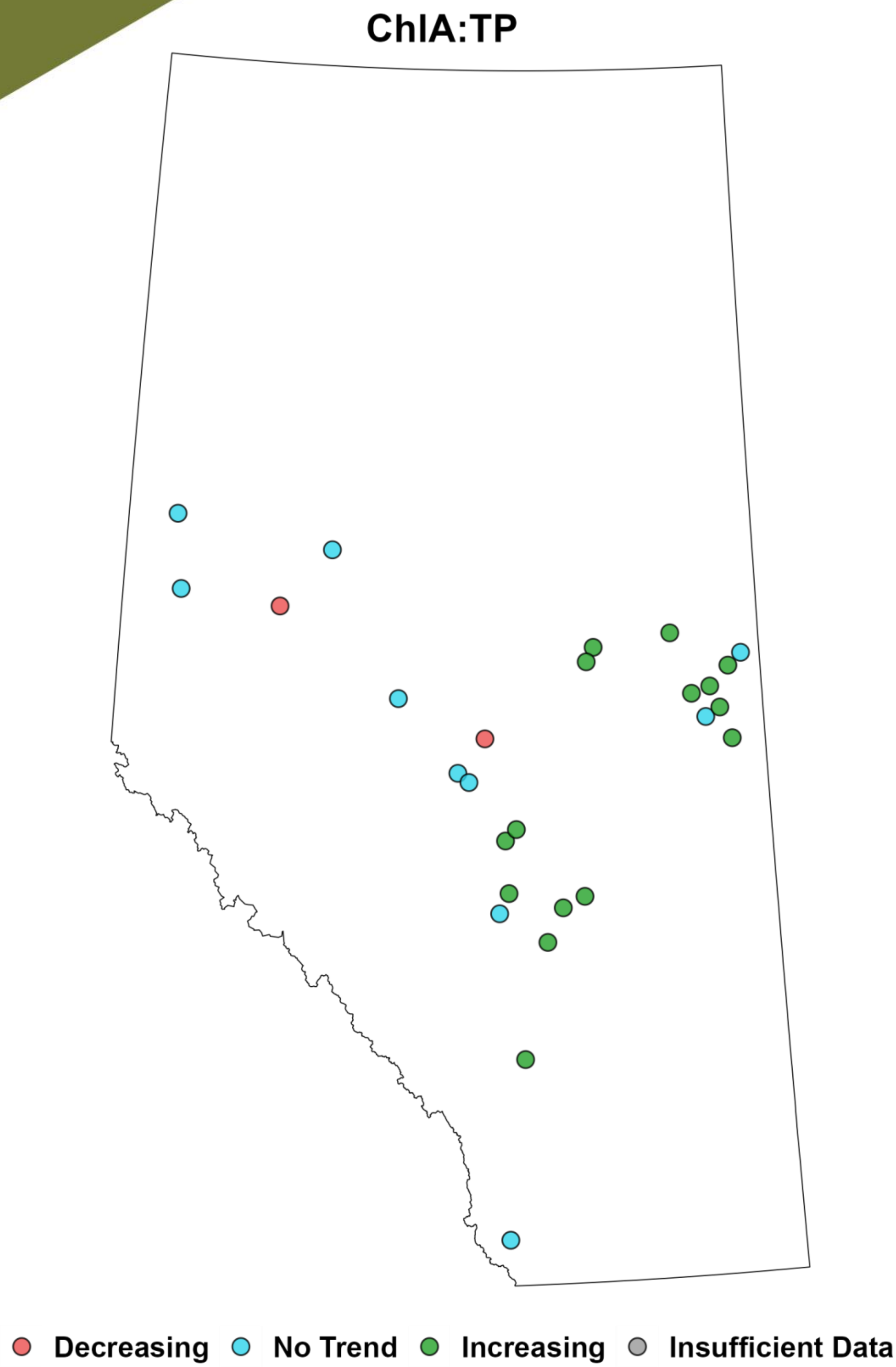

Figure 16. Geographic location in Alberta of the 27 lakes included in the trend analysis of the ratio of chlorophyll-*a* to total phosphorus (ChlA:TP) with statistically decreasing (red), no trend (blue), or statistically increasing (green) trends through either Mann Kendall or Seasonal Kendall ALMS trend analysis.

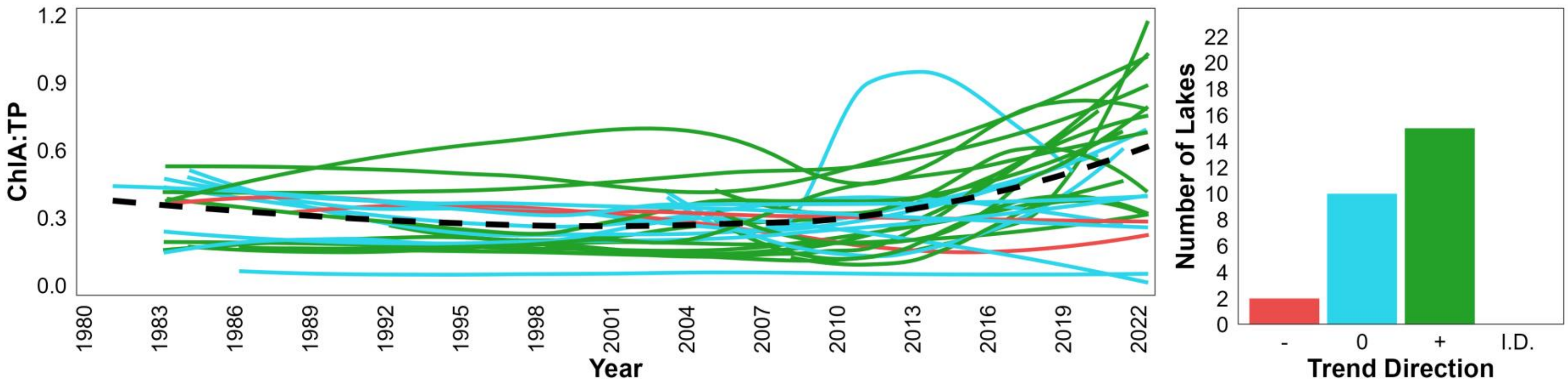

Figure 17. Left) Ratio of chlorophyll-*a* to total phosphorus (ChlA:TP) fitted by a LOESS trend line for each lake, from lakes measured monthly between 1980 and 2022. A LOESS trend is also fitted to all data for each parameter (black dashed line). Monotonic trend results are represented by line color for each parameter. The test used is either Mann Kendall or Seasonal Kendall, and if significant at $p < 0.05$, then increasing trends are represented by green, decreasing trends by red, and insignificant trends by blue. If a parameter has insufficient data for trend analysis, the LOESS trend line is not plotted. Data and test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Individual LakeWatch reports available at https://alms.ca/reports/ present raw data figures and results of trend results for each lake eligible for trend analysis (currently for lakes sampled up to 2022, only). Right) The number of lakes with either a significantly decreasing trend (red, "-"), insignificant trend (blue, "0"), significantly increasing trend (green, "+"), or number of lakes where data is insufficient for trend analysis (black, "I.D."). Historical trend visualization and data standardization follows method of Dugan *et al.* (2017).[3]

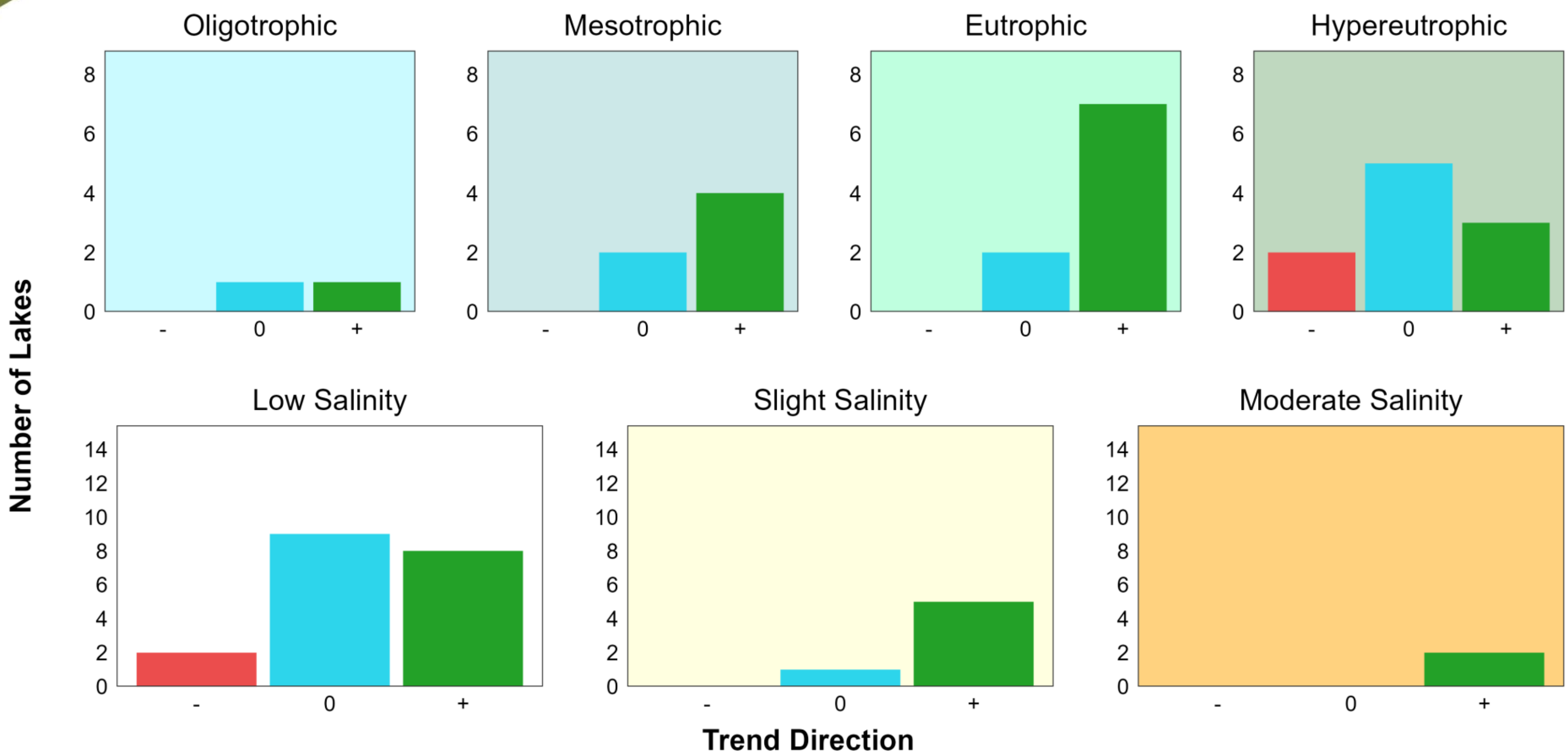

Figure 18. Top) Number of lakes with statistically significant statistically decreasing (red, "-"), no trend (blue, "0"), or statistically increasing (green, "+") trends of the ratio of chlorophyll-*a* to total phosphorus (ChlA:TP) through either Mann Kendall or Seasonal Kendall ALMS trend analysis, split into each lake's trophic classification based on historical average chlorophyll-*a* as defined by Nurnberg (1996)[1]. Bottom) Number of lakes with statistically significant statistically decreasing (red, "-"), no trend (blue, "0"), or statistically increasing (green, "+") trends of the ratio of chlorophyll-*a* to total phosphorus (ChlA:TP) through either Mann Kendall or Seasonal Kendall ALMS trend analysis, split into each lake's salinity class based on historical average total dissolved solids as defined by Mitchell and Prepas (1990)[2].