Limnology and Water Quality of the Rainbow Lake Chain:
Update on the 2024 Field Season

Paul Smith's College
Adirondack Watershed Institute

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Limnology and Water Quality of the Rainbow Lake Chain: Update on the 2024 Field Season

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Summary

First initiated in 1997, the Rainbow Lake Monitoring Program was specifically designed to describe the trophic status of Rainbow Lake and Clear Pond and to detect impacts from shoreline areas with dense concentrations of camps. Now 27 years later, the program represents an excellent example of long-term limnological monitoring in the Adirondacks. Long-term limnological data sets are essential for evaluating ecosystem response to disturbances, providing a baseline to evaluate change, or detecting response to management intervention. The objective of this report is to provide an update on the lake monitoring program by summarizing the results from the 2024 field season and describing historical trends in the key water quality indicators.

The water quality of the three lakes in the Rainbow Lake Chain (Rainbow Lake, Clear Pond, and Lake Kushaqua) remains good with no major concerns. When compared to lakes in the Adirondack Lake Assessment Program (ALAP), the overall water quality is average or in some cases slightly better (Laxson et al. 2019). All lakes show a significant decline in chlorophyll-a, which may be seen as an improvement in water quality. The driver of the decline in chlorophyll-a is not particularly clear based on the current analysis of the data. Typically, chlorophyll-a concentrations are closely tied to nutrient concentrations, which show no concurrent declines over the same period.

Major changes in the lakes observed are likely being driven by regional phenomenon, primarily a) recovery from acid rain and b) regional climate change (Driscoll et al. 2007). The pH of all three lakes show recent increases, which is consistent with regional recovery from acid rain. All three lakes also show evidence of summertime surface warming, consistent with patterns observed in other lakes in the region (Stager et al. 2022).

The Rainbow Lake Association's investment in the long-term monitoring of the lake chain is to be commended. The historical data, coupled with updates in trend analysis, allows for early detection of changes in water quality, which is critical to the effective management and protection of these important natural resources.

Changes to Data Analysis

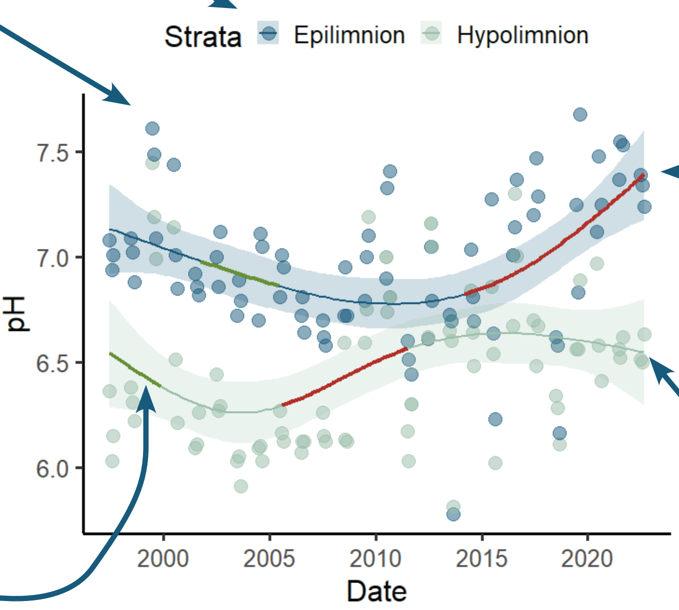
This report includes changes to the way data is analyzed and presented for the Rainbow Lake Chain. These changes are part of a broader effort at the Paul Smith's College Adirondack Watershed Institute to enable a more sensitive detection of changes in water quality in the lakes we monitor. Historically, we looked for long-term linear trends in data averaged by year. Trend analysis is now being conducted on all of the raw water quality data, rather than annual averages. We are using generalized additive models (GAMs) to characterize long-term patterns in the data and detect periods of change (Morton & Henderson 2008). These models allow for earlier detection of change in a parameter. The graphic below is provided to help the reader interpret the plots provided for each parameter.

We have also altered how the profile data is being reported. The profile plots now include all data from 2013 to 2024, allowing for a comparison over time. The full dataset of historical profile data will be included in future reports, allowing for a better understanding of how temperature and dissolved oxygen are changing in the Rainbow Lake Chain.

Point and line colors indicate which strata of the lake the data is from. The epilimnion is the warm upper layer of the lake and the hypolimnion is the cool bottom layer.

Red segments represent periods when the model indicates a significant increase in the parameter.

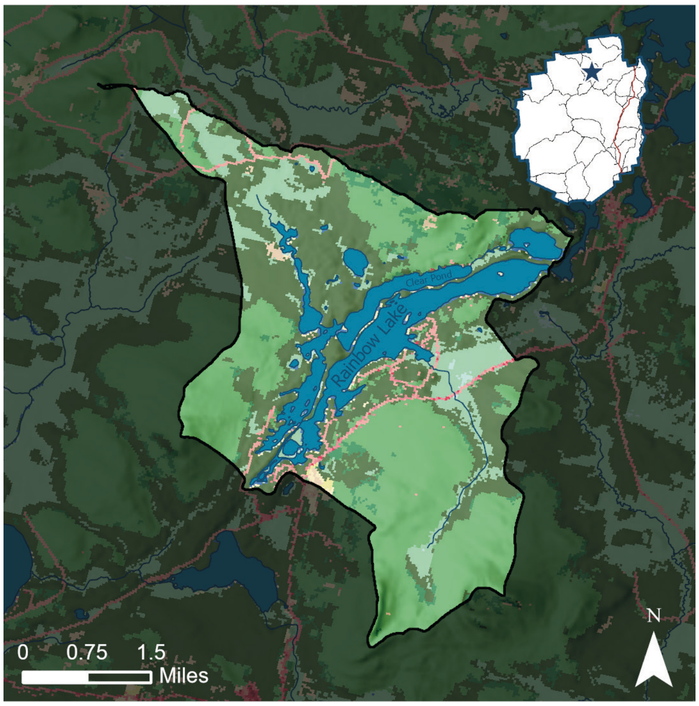
The points represent unique samples collected from the lake.



Green segments represent periods when the model indicates a significant decrease in the parameter.

The lines are fit using a 'generalized additive model' which is used to assess long-term trends and changes in the parameter. Shaded areas represent the 95% confidence interval for the fit model.

Rainbow Lake



- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Dwarf Scrub
- Grassland/Herbaceous
- Pasture/Hay
- Woody Wetlands
- Emergent Herbaceous Wetlands

Figure 1. A map of the Rainbow Lake watershed (highlighted area) depicting land cover classification.

Watershed Characteristics

Watershed Area (ha):	2,114.9
Open Water (%):	12.62
Developed, Open Space (%):	2.09
Developed, Low Intensity (%):	0.57
Developed, Medium Intensity (%):	0.11
Developed, High Intensity (%):	0.00
Barren Land (%):	0.00
Deciduous Forest (%):	37.11
Evergreen Forest (%):	31.65
Mixed Forest (%):	2.76
Dwarf Shrub (%):	0.46
Grassland/Herbaceous (%):	0.74
Pasture/Hay (%):	0.11
Cultivated Crops (%):	0.00
Woody Wetlands (%):	10.76
Emergent Herbaceous Wetlands (%):	1.00

Lake Characteristics

Surface Area (ha):	149.6
Shoreline Length (km):	19.0
Max Depth (m):	17.7
Mean Depth (m):	4.6
Volume (m^3):	6,535,932
Flushing Rate (times/year):	1.7

Location

Latitude:	44.4844
Longitude:	-74.1571
County:	Franklin
Towns:	Brighton, Franklin
Watershed:	North Branch Saranac River

Harmful Algal Bloom Reports

None

Aquatic Invasive Species Detections

None

Trophic Status	Acidity	Acid Neutralizing Capacity	Road Salt Influence	Aquatic Invasive Species	Harmful Algal Blooms
Mesotrophic	Circumneutral	Adequate	Low	Not Present	None Reported

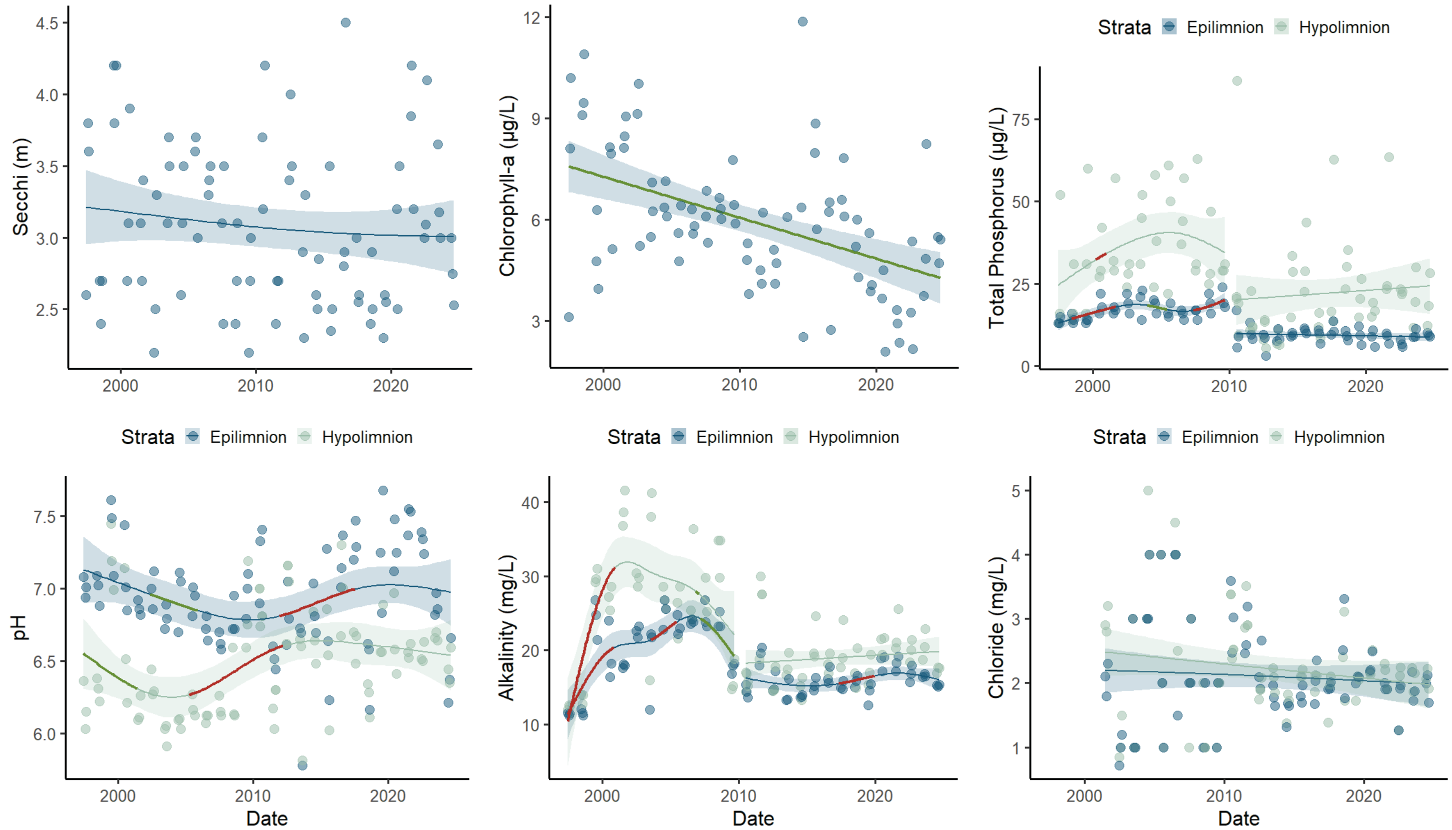


Figure 2. Data for key water quality indicators in Rainbow Lake, 1997-2024. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant increase, overlaid green lines represent periods with a statistically significant decrease. Areas with no red or green overlaid line represent periods with no statistically significant change. Total phosphorus and alkalinity have a break in the fit models to account for an improvement in laboratory methods.

Rainbow Lake has moderate nutrient concentrations and is best classified as a mesotrophic lake. The water transparency in 2024 ranged from 2.5 to 3.0 meters. Historically, annual average transparency has fluctuated between 2.2 and 4.5 meters with no significant trend. These values are around the average for lakes in ALAP (Laxson et al. 2019). Chlorophyll-a concentrations are declining, but despite the decline in chlorophyll, transparency has not been increasing. Further investigation is needed to determine if the lack of change in transparency in the face of declining chlorophyll is due to lake browning driven by recovery from acid rain. The total phosphorus concentration in the epilimnion ranged from 9.0 to 10.2 µg/L in 2024, around average for lakes in ALAP. Phosphorus concentrations in the epilimnion and hypolimnion of the lake have been stable since 2010, with hypolimnion concentrations generally being higher.

The epilimnion and hypolimnion of the lake is circumneutral in terms of its acidity, with an average pH of 6.4 and 6.5, respectively. These values are around average for lakes in ALAP. A long-term increase in epilimnion pH has occurred since around 2015. The alkalinity of the surface water averaged 15.3 mg/L, indicating that the lake has adequate buffering ability, and is not currently sensitive to changes in pH due to acid deposition. There was a short period of increasing alkalinity from 2019 to 2021.

The chloride and sodium concentrations in the surface water averaged 1.9 and 1.6 mg/L, respectively. These values are marginally elevated above background concentrations for Adirondack Lakes but are below average for lakes in ALAP (Kelting et al. 2012). A portion of these ions may be from road salt runoff from the 6.6 km of roads in the watershed.

Rainbow Lake is a thermally stratified dimictic lake, meaning it turns over or mixes twice per year, once in the fall and once in the spring. Surface temperatures in July were the highest on record since 2013, consistent with warming observed on other lakes in the region. In August however, surface temperatures were cooler than the average for the record, likely caused by a period of cold and windy weather prior to the sampling trip in August of 2024.

Rainbow Lake experiences significant oxygen depletion in the hypolimnion. The depletion was evident throughout the season, particularly in August. Hypolimnion oxygen depletion may be exacerbated by prolonged thermal stratification and can lead to increased internal nutrient loading (Jane et al. 2022). There is an apparent long-term trend of declining oxygen in the hypolimnion, a pattern observed on many lakes across the planet and is likely driven by climate change. Further investigation is needed to assess the impact of these changes on the health of Rainbow Lake.

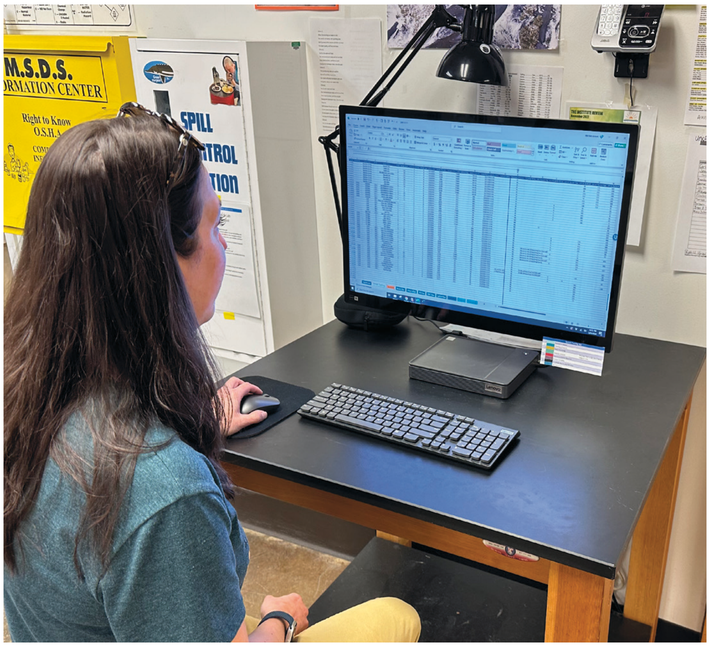


Table 1. Water quality data for Rainbow Lake from the 2024 sampling season. <MDL denotes a value that is below the intsrument's detection limit.

WATER QUALITY INDICATOR	6/24/2024	7/23/2024	8/26/2024	AVERAGE
		EPILMNION (SURFACE WATER)		
Transparency (m)	3.0	2.8	2.5	2.8
Total Phosphorus (μg/L)	10.2	9.4	9.0	11.8
Chlorophyll-a (μg/L)	5.5	4.7	5.4	5.2
Lab pH	6.2	6.4	6.7	6.4
Lab Cond (μS/cm@25 °C)	44.1	43.5	43.6	43.7
Apparent Color (Pt-Co)	39.4	68.2	50.4	55.1
Alkalinity (mg/L)	15.3	15.1	15.4	15.3
Total Nitrogen (μg/L)	277	288	254	273
Nitrate -N (μg/L)	<MDL	<MDL	<MDL	<MDL
Chloride (mg/L)	2.0	2.1	1.7	1.9
Sodium (mg/L)	1.8	1.7	1.5	1.6
		HYPOLIMNION (BOTTOM WATER)		
Total Phosphorus (μg/L)	12.3	18.2	28.3	19.6
Lab pH	6.4	6.4	6.6	6.5
Lab Specific Cond (μS/cm@25C)	49.1	51.4	55.5	52.0
Apparent Color (Pt-Co)	82.5	154.4	288.4	175.1
Alkalinity (mg/L)	16.9	17.7	17.6	17.4
Total Nitrogen (μg/L)	423	454	330	402
Nitrate -N (μg/L)	216.1	205.0	15.3	145.4
Chloride (mg/L)	2.1	2.2	1.9	2.1
Sodium (mg/L)	1.8	1.7	1.6	1.7

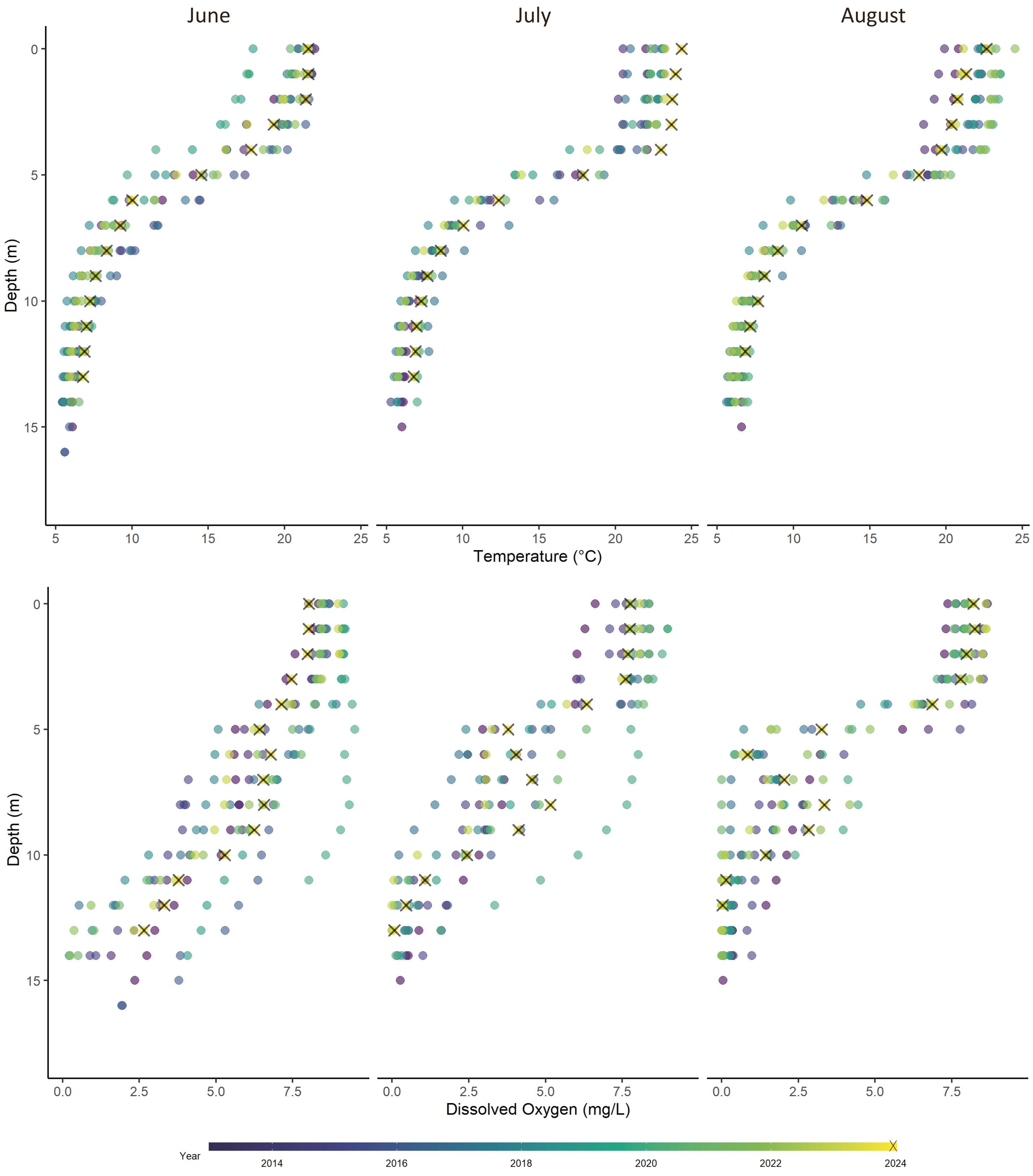


Figure 3. Profiles of temperature and dissolved oxygen in Rainbow Lake from 2013 to 2024. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic.

Clear Pond

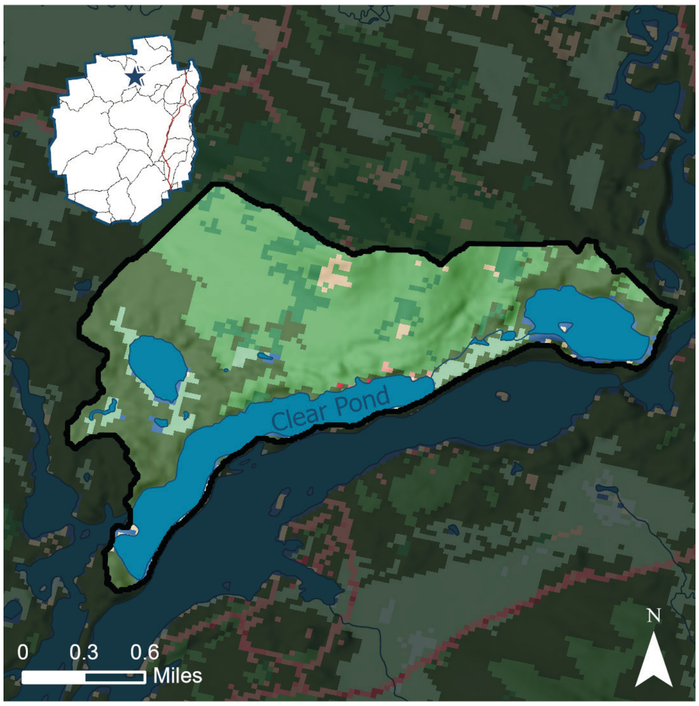


Figure 4. A map of the Clear Pond watershed (highlighted area) depicting land cover classification.

Location

Latitude:	44.4866
Longitude:	-74.1607
County:	Franklin
Towns:	Brighton, Franklin
Watershed:	North Branch Saranac River

Watershed Characteristics

Watershed Area (ha):	329.0
Open Water (%):	20.80
Developed, Open Space (%):	0.19
Developed, Low Intensity (%):	0.11
Developed, Medium Intensity (%):	0.05
Developed, High Intensity (%):	0.00
Barren Land (%):	0.00
Deciduous Forest (%):	37.06
Evergreen Forest (%):	29.91
Mixed Forest (%):	6.13
Dwarf Shrub (%):	0.90
Grassland/Herbaceous (%):	0.68
Pasture/Hay (%):	0.00
Cultivated Crops (%):	0.00
Woody Wetlands (%):	3.89
Emergent Herbaceous Wetlands (%):	0.27

Lake Characteristics

Surface Area (ha):	42.1
Shoreline Length (km):	5.1
Max Depth (m):	16.8
Mean Depth (m):	7.3
Volume (m^3):	2,840,976
Flushing Rate (times/year):	0.7

Harmful Algal Bloom Reports

None

Aquatic Invasive Species Detections

None

Trophic Status	Acidity	Acid Neutralizing Capacity	Road Salt Influence	Aquatic Invasive Species	Harmful Algal Blooms
Mesotrophic	Circumneutral	Adequate	None	Not Present	None Reported

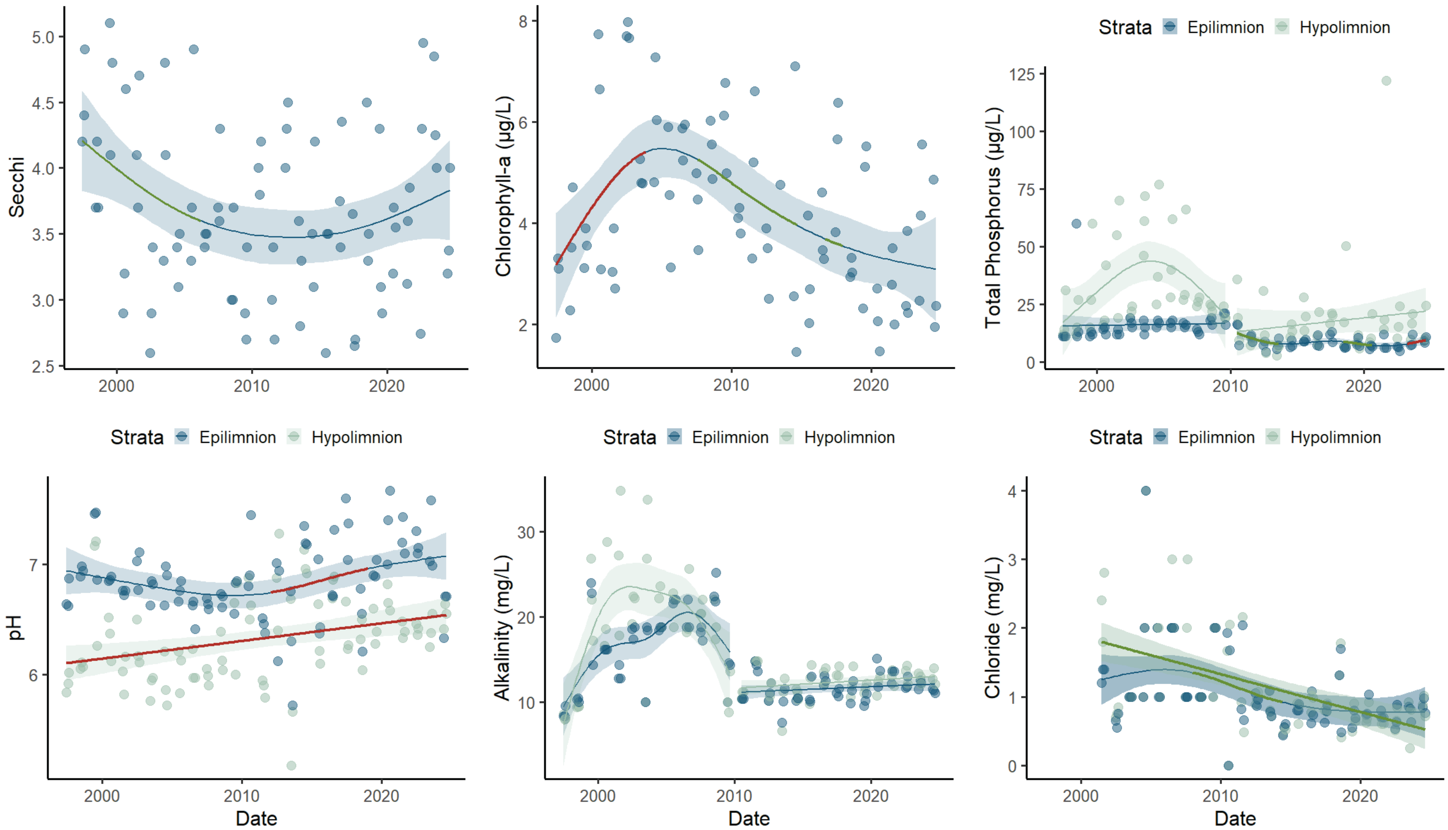


Figure 5. Data for key water quality indicators in Clear Pond, 1997-2024. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant increase, overlaid green lines represent periods with a statistically significant decrease. Areas with no red or green overlaid line represent periods with no statistically significant change. Total phosphorus and alkalinity have a break in the fit models to account for an improvement in laboratory methods.

Clear Pond is best classified as a mesotrophic lake with moderate nutrient concentration. The water transparency in 2024 ranged from 3.2 to 4.0 meters. Historically, annual average transparency has fluctuated between 2.5 and 5.0 meters, which is average for lakes in ALAP (Laxson et al. 2019). A significant decline in transparency occurred from 1997 to 2005, which corresponds with a significant increase in chlorophyll. Chlorophyll has been declining since 2007, with no significant change in transparency during this time. As with Rainbow Lake, further investigation into the dynamics between transparency and chlorophyll would be beneficial. The total phosphorus concentration in the epilimnion ranged from 8.2 to 10.7 µg/L in 2024, average for lakes in ALAP. Phosphorus concentrations in the epilimnion and hypolimnion of the lake have been stable since 2010, with hypolimnion concentrations generally being higher.

The epilimnion and hypolimnion of the lake is circumneutral in terms of its acidity, with an average pH of 6.6 and 6.5, respectively. These values are about average for lakes in ALAP. A long-term increase in epilimnion pH has occurred since 2013, and hypolimnion pH since 1997. The alkalinity of the surface water averaged 11.3 mg/L, indicating that the lake has adequate buffering ability, and is not currently sensitive to changes in pH due to acid deposition.

The chloride and sodium concentration in the surface water averaged 0.9 and 1.0 mg/L, respectively. These values are within the background concentrations for Adirondack Lakes, indicating that Clear Pond has no influence from road salt (Kelting et al. 2012).

Clear Pond is a thermally stratified dimictic lake, meaning it turns over or mixes twice per year, once in the fall and once in the spring. Surface temperatures in July were the highest on record since 2013, consistent with warming observed on other lakes in the region. In August however, surface temperatures were cooler than the average for the record, likely caused by a period of cold and windy weather prior to the sampling trip in August of 2024.

Clear Pond experiences significant oxygen depletion in the hypolimnion. The depletion is particularly evident in August. Hypolimnion oxygen depletion may be exacerbated by prolonged thermal stratification and can lead to increased internal nutrient loading. There is a less apparent long-term trend of declining oxygen in the hypolimnion compared to Rainbow Lake, a pattern observed on many lakes across the planet and is likely driven by climate change (Jane et al. 2022). Further investigation is needed to assess the impact of these changes on the health of Clear Pond.

Table 2. Water quality data for Clear Pond from the 2024 sampling season. <MDL denotes a value that is below the intsrument's detection limit.

WATER QUALITY INDICATOR	6/24/2024	7/23/2024	8/26/2024	AVERAGE
		EPILMNION (SURFACE WATER)		
Transparency (m)	3.2	3.4	4.0	3.5
Total Phosphorus (µg/L)	9.1	8.2	10.7	9.3
Chlorophyll-a (µg/L)	4.9	2.0	2.4	3.1
Lab pH	6.3	6.7	6.7	6.6
Lab Cond (µS/cm@25 °C)	32.0	31.5	31.7	31.7
Apparent Color (Pt-Co)	35.8	43.0	24.6	34.5
Alkalinity (mg/L)	11.5	11.4	11.1	11.3
Total Nitrogen (µg/L)	308	263	252	274
Nitrate -N (µg/L)	<MDL	<MDL	<MDL	<MDL
Chloride (mg/L)	0.9	1.0	0.8	0.9
Sodium (mg/L)	1.1	1.0	0.9	1.0
		HYPOLIMNION (BOTTOM WATER)		
Total Phosphorus (µg/L)	9.0	10.1	24.4	14.5
Lab pH	6.4	6.4	6.6	6.5
Lab Specific Cond (µS/cm@25C)	34.5	35.8	39.1	36.5
Apparent Color (Pt-Co)	57.4	96.9	259.5	137.9
Alkalinity (mg/L)	12.7	14.0	12.1	12.9
Total Nitrogen (µg/L)	306	283	400	329.7
Nitrate -N (µg/L)	122.0	80.0	8.5	70.1
Chloride (mg/L)	0.9	1.0	0.7	0.9
Sodium (mg/L)	1.0	1.0	1.1	1.1

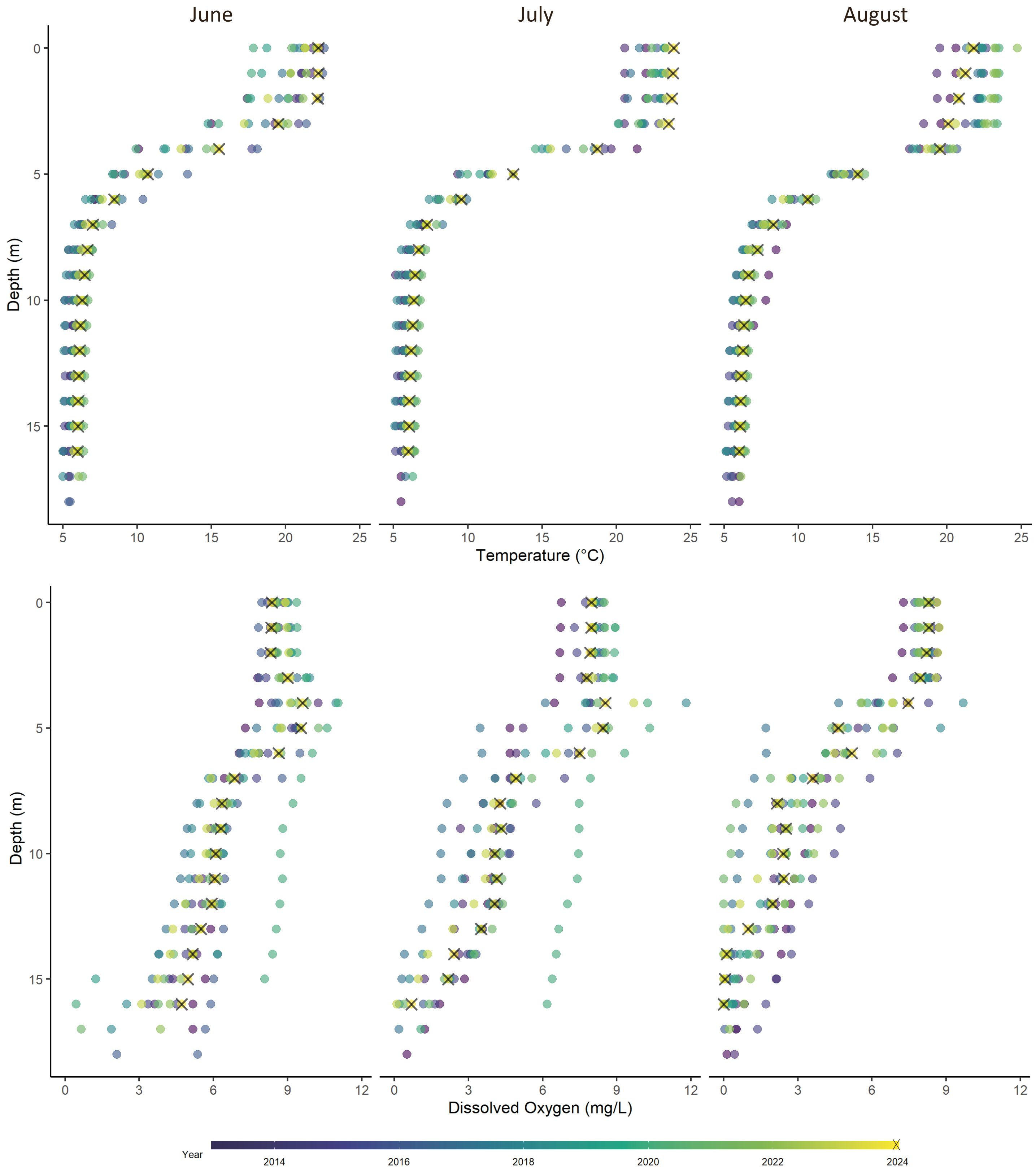
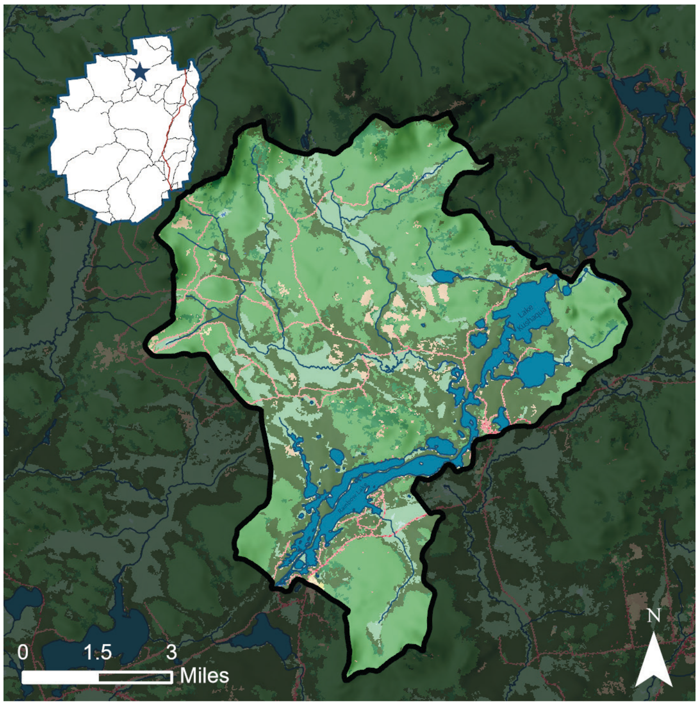


Figure 6. Profiles of temperature and dissolved oxygen in Clear Pond from 2013 to 2024. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic.

Lake Kushaqua



- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Dwarf Scrub
- Grassland/Herbaceous
- Pasture/Hay
- Woody Wetlands
- Emergent Herbaceous Wetlands

Figure 7. A map of the Lake Kushaqua watershed (highlighted area) depicting land cover classification.

Watershed Characteristics

Watershed Area (ha):	7,406.4
Open Water (%):	7.54
Developed, Open Space (%):	2.59
Developed, Low Intensity (%):	0.35
Developed, Medium Intensity (%):	0.08
Developed, High Intensity (%):	0.00
Barren Land (%):	0.00
Deciduous Forest (%):	45.75
Evergreen Forest (%):	26.18
Mixed Forest (%):	4.47
Dwarf Shrub (%):	1.95
Grassland/Herbaceous (%):	0.45
Pasture/Hay (%):	0.03
Cultivated Crops (%):	0.00
Woody Wetlands (%):	10.10
Emergent Herbaceous Wetlands (%):	0.51

Lake Characteristics

Surface Area (ha):	153.9
Shoreline Length (km):	13.7
Max Depth (m):	27.4
Mean Depth (m):	13.4
Volume (m^3):	NA
Flushing Rate (times/year):	NA

Location

Latitude:	44.5208
Longitude:	-74.1123
County:	Franklin
Towns:	Franklin
Watershed:	North Branch Saranac River

Harmful Algal Bloom Reports

None

Aquatic Invasive Species Detections

None

Trophic Status	Acidity	Acid Neutralizing Capacity	Road Salt Influence	Aquatic Invasive Species	Harmful Algal Blooms
Mesotrophic	Circumneutral	Adequate	None	Not Present	None Reported

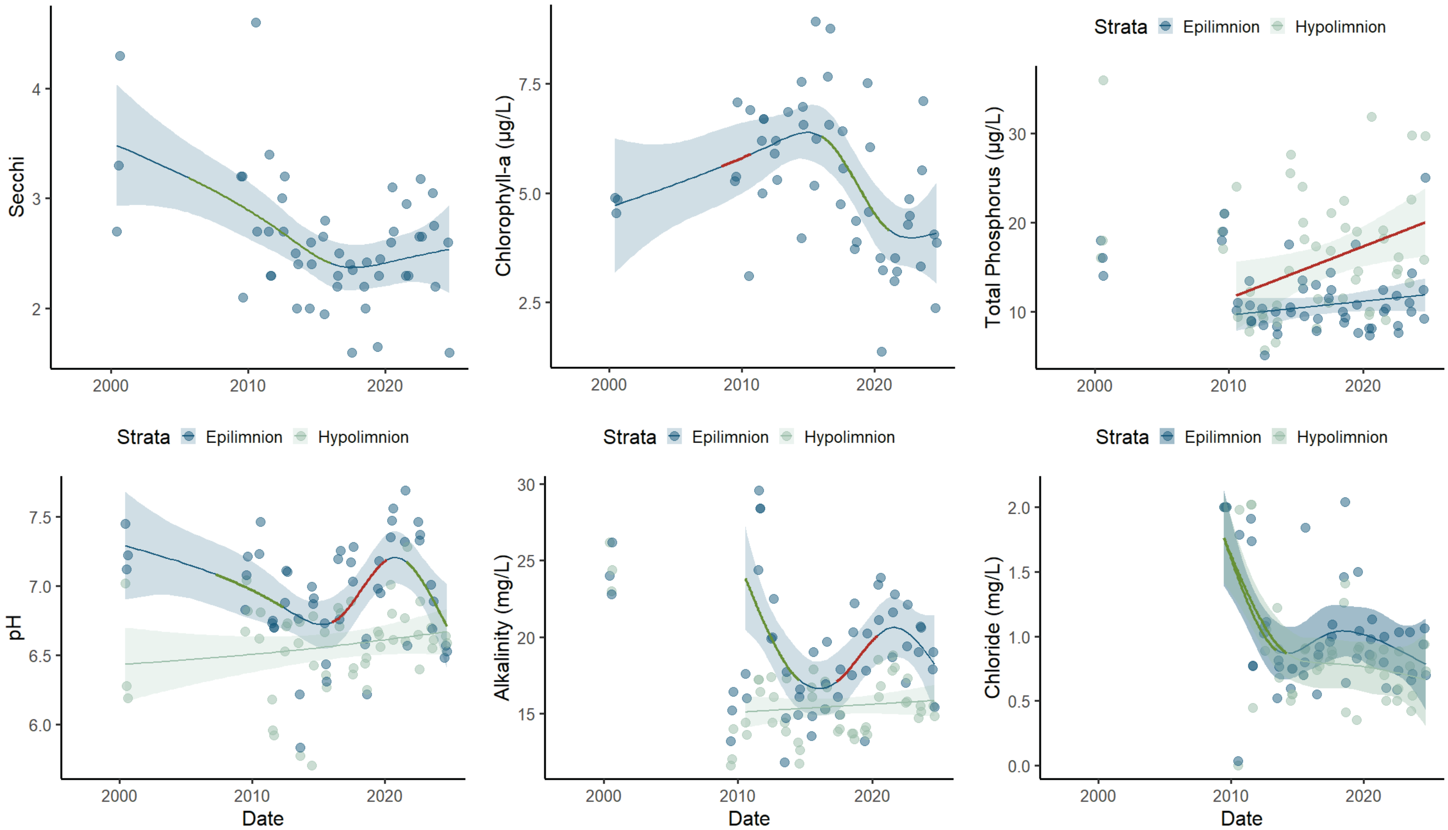


Figure 8. Data for key water quality indicators in Lake Kushaqua, 2001-2024. Regular long-term monitoring began in 2009. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant increase, overlaid green lines represent periods with a statistically significant decrease. Areas with no red or green overlaid line represent periods with no statistically significant change. Total phosphorus and alkalinity have a break in the fit models to account for an improvement in laboratory methods.

The water transparency of Lake Kushaqua is the lowest in the lake chain, and averaged 2.1 meters in 2024. This is below average for lakes in ALAP (Laxson et al. 2019). We detected a significant downward trend in transparency from 2006 to 2016. The reduction in transparency is likely a part of a regional phenomenon. We have observed reduced transparency trends in several of our study lakes. Current research suggests that increased dissolved organic carbon (DOC) is responsible for the transparency changes. Increased DOC in lakes is likely the result of a combination of recovery from acid deposition as well as increased precipitation (Walter et al. 2023). This mechanism is likely the driver of changes in transparency in Clear Pond as well. Apparent color is a useful surrogate measure for DOC. The color of Lake Kushaqua was greater than 90% of the lakes in the AWI dataset.

Chlorophyll had a period of increase around 2010 and has been declining since 2015. This is generally consistent with patterns in chlorophyll in both Rainbow Lake and Clear Pond. The total phosphorus concentration in the epilimnion ranged from 12.4 to 25.0 µg/L in 2024. This is about average for lakes in ALAP. Phosphorus concentrations in the epilimnion of the lake have been stable since 2010. Hypolimnion phosphorous concentrations are generally higher and show an increase over this time period.

The epilimnion and hypolimnion of the lake is circumneutral in terms of its acidity, with an average pH of 6.5 and 6.6, respectively. These values are about average for lakes in ALAP. A long-term increase in epilimnion pH has occurred since 2016. The alkalinity of the surface water averaged 17.4 mg/L, indicating that the lake has adequate buffering ability, and is not currently sensitive to changes in pH due to acid deposition.

The chloride and sodium concentrations in the surface water averaged 0.9 and 1.3 mg/L, respectively. These values are within the background concentrations for Adirondack Lakes, indicating that Lake Kushaqua has no influence from road salt (Kelting et al. 2015).

Lake Kushaqua is a thermally stratified dimictic lake, meaning it turns over or mixes twice per year, once in the fall and once in the spring. Surface temperatures in July were the highest on record since 2013, consistent with warming observed on other lakes in the region. In August however, surface temperatures were cooler than the average for the record, likely caused by a period of cold and windy weather prior to the sampling trip in August of 2024.

Lake Kushaqua does not experience significant oxygen depletion in the hypolimnion. The oxygen profile is characterized as negative heterograde with a dip in oxygen around the thermocline. There is no apparent long-term trend of declining oxygen in the hypolimnion which is in contrast to Rainbow Lake and Clear Pond.

Table 3. Water quality data for Lake Kushaqua from the 2024 sampling season. <MDL denotes a value that is below the intsrument's detection limit. When used to calculate an average, <MDL is represented as 1/2 the value of the minimum detection limit. Note- in June, we were unable to collect a hypolimnion sample or measure transparency due to adverse weather conditions.

WATER QUALITY INDICATOR	6/24/2024	7/23/2024	8/26/2024	AVERAGE
		Epilmnion (surface water)		
Transparency (m)	-	2.6	1.6	2.1
Total Phosphorus (µg/L)	12.4	9.2	25.0	15.5
Chlorophyll-a (µg/L)	4.0	2.4	3.4	3.4
Lab pH	6.5	6.6	6.5	6.5
Lab Cond (µS/cm@25 °C)	44.5	44.6	41.0	43.4
Apparent Color (Pt-Co)	68.1	79.0	105.1	77.0
Alkalinity (mg/L)	17.9	19.0	15.4	17.4
Total Nitrogen (µg/L)	315	293	320	309
Nitrate -N (µg/L)	10.4	<MDL	<MDL	5.1
Chloride (mg/L)	0.9	1.0	0.7	0.9
Sodium (mg/L)	1.4	1.3	1.3	1.3
		Hypolimnion (bottom water)		
Total Phosphorus (µg/L)	-	15.8	29.7	22.8
Lab pH	-	6.6	6.6	6.6
Lab Specific Cond (µS/cm@25C)	-	41.8	43.4	42.6
Apparent Color (Pt-Co)	-	118.5	130.8	124.7
Alkalinity (mg/L)	-	15.5	14.8	15.2
Total Nitrogen (µg/L)	-	447	466	456
Nitrate -N (µg/L)	-	252.0	236.0	244.0
Chloride (mg/L)	-	0.9	0.7	0.8
Sodium (mg/L)	-	1.1	1.2	1.2

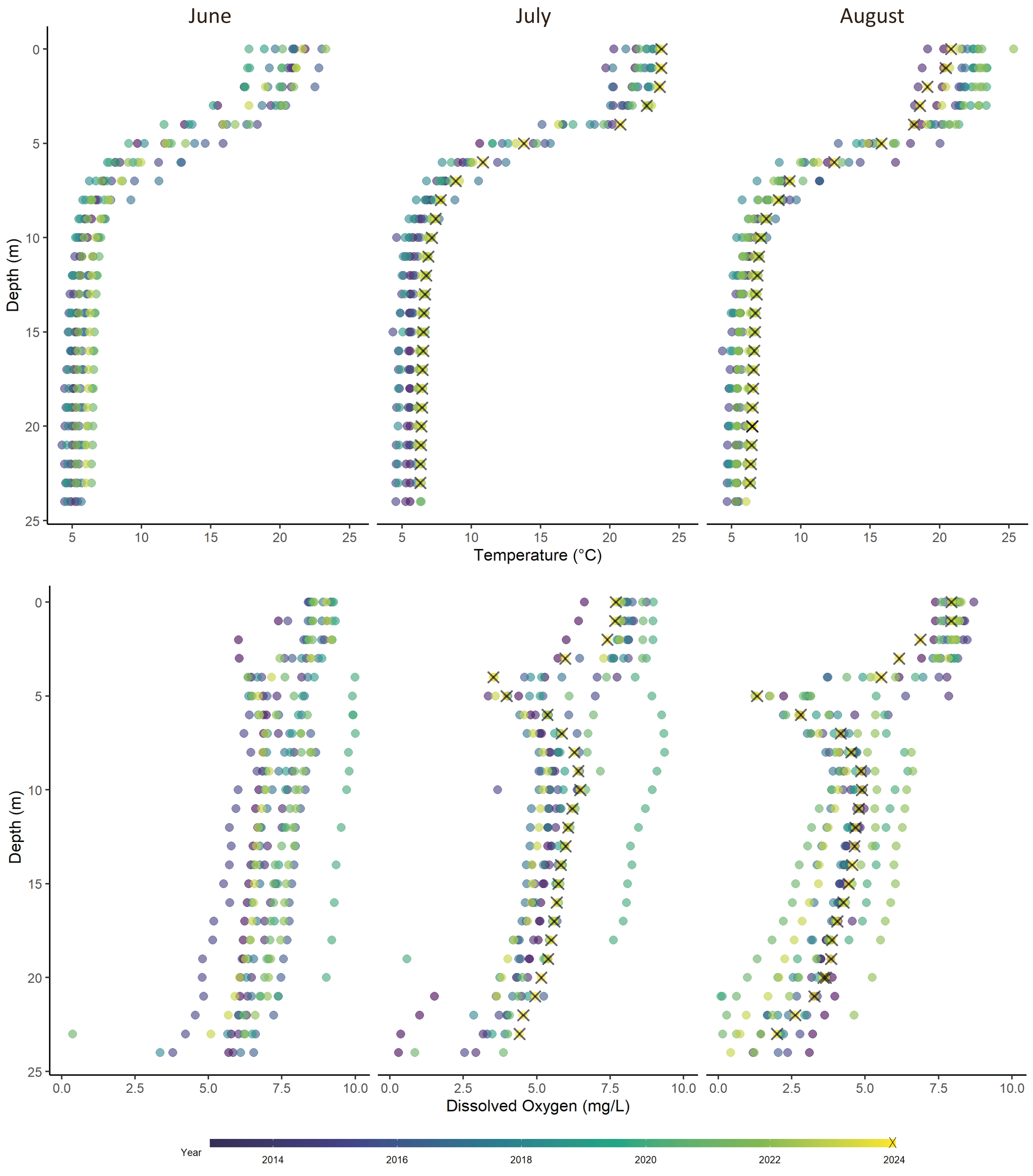


Figure 9. Profiles of temperature and dissolved oxygen in Lake Kushaqua from 2013 to 2024. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic. Note: no data was collected in June of 2024 due to adverse weather conditions.

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