Limnology and Water Quality of the Rainbow Lake Chain: Update on the 2025 Field Season

Paul Smith's College
Adirondack Watershed Institute

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Cover photo by Brendan Wiltse

Limnology and Water Quality of the Rainbow Lake Chain: Update on the 2025 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 2025 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 (L'Hote et al. 2025). 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).

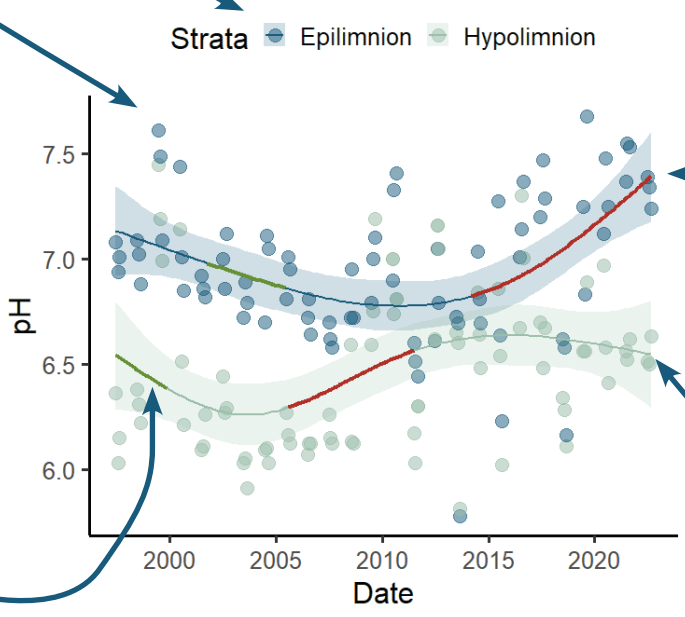
The Rainbow Lake Association's investment in the long-term monitoring of the lake chain is to be commended. The historical data, coupled with updates in trend analysis, allows for early detection of changes in water quality, which is critical to the effective management and protection of these important 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 2025, 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

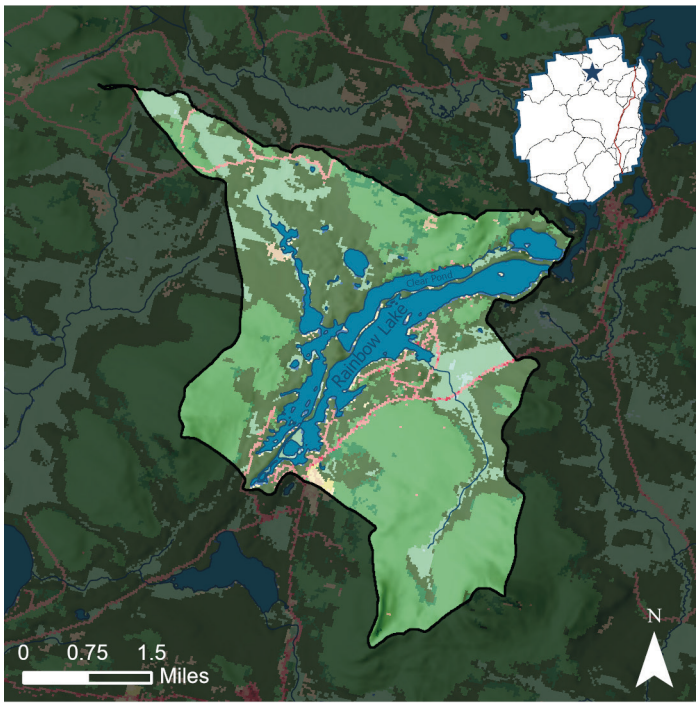


Figure 1. A map of the Rainbow Lake watershed (highlighted area) depicting land cover classification.

Location

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

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

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

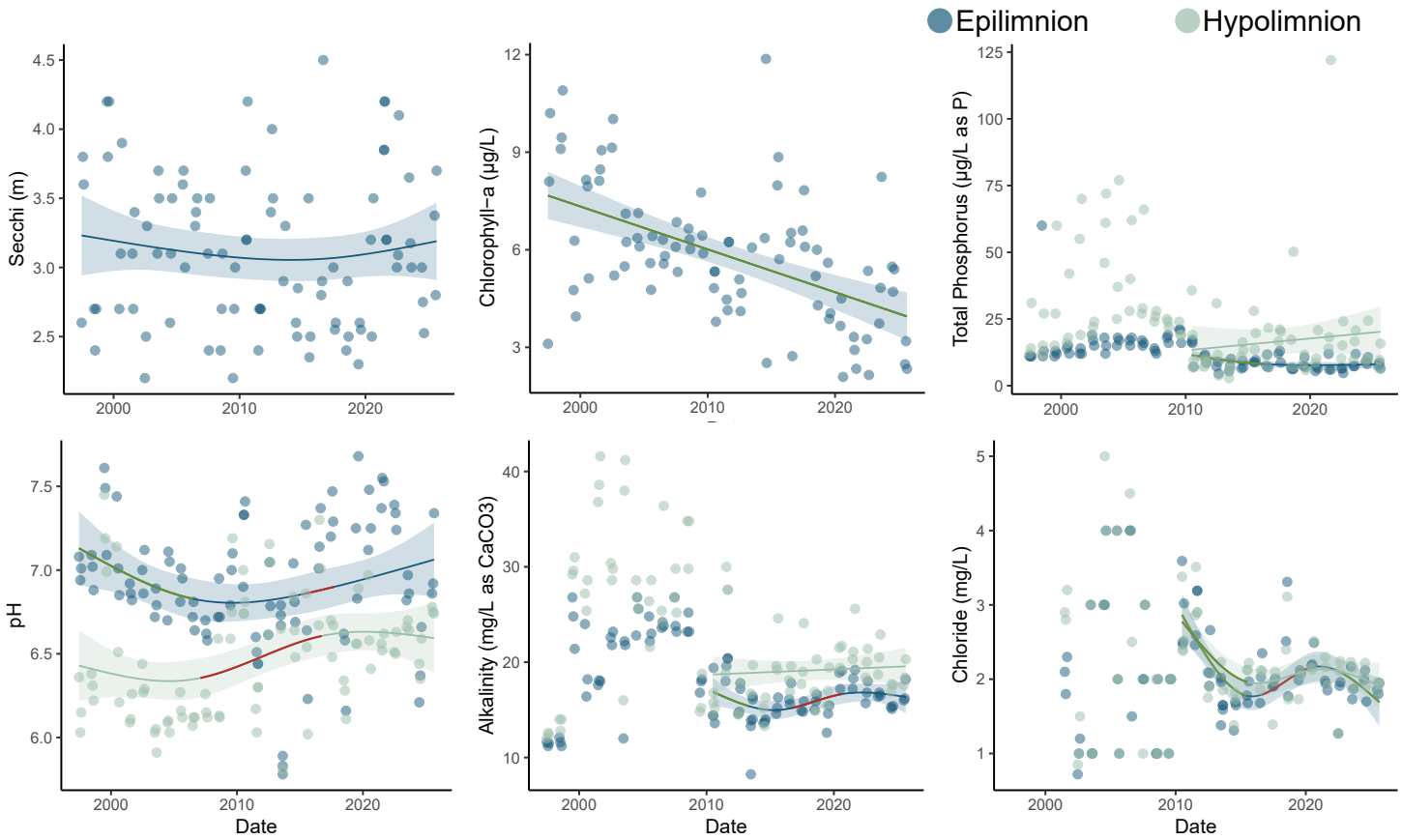


Figure 2. Data for key water quality indicators in Rainbow Lake, 1997-2025. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant increase, overlaid green lines represent periods with a statistically significant decrease. Areas with no red or green overlaid line represent periods with no statistically significant change. Data for total phosphorus, alkalinity, and chloride prior to 2010 is excluded from trend analysis to account for a shift in laboratory methods.

Rainbow Lake has moderate nutrient concentrations and is best classified as a mesotrophic lake. The water transparency in 2025 ranged from 2.8 to 3.7 meters with an average of 3.4 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 (L'Hote et. al 2025). 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 4.7 to 10.8 µg/L in 2025, 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 are circumneutral in terms of acidity, with an average pH of 7.0 and 6.8, respectively. These values are around average for lakes in ALAP. The alkalinity of the surface water averaged 16.8 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 1.9 and 2.0 mg/L, respectively. These values are marginally elevated above background concentrations for Adirondack Lakes (Kelting et al. 2012) but are below average for lakes in ALAP. 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 both June and July

were the highest on record since 2013 (Figure 4), consistent with warming observed on other lakes in the region. In August however, surface temperatures were around average for the record.

Rainbow Lake experiences significant oxygen depletion in the hypolimnion, which is a common phenomeneon in mesotrophic Adirondack lakes. The depletion was evident throughout the season, particularly in August, with waters below 10 m experiencing complete depletion, or "anoxia" (dissolved oxygen < 0.5 mg/L). Hypolimnion oxygen depletion may be exacerbated by prolonged thermal stratification and can lead to increased internal nutrient loading, or the release of nutrients stored in the sediments to the water column (Jane et al. 2022). There is an apparent long-term trend of declining oxygen in the hypolimnion, particularly in the late summer (Figures3-4), a pattern observed on many lakes across the planet and is likely driven by climate change.

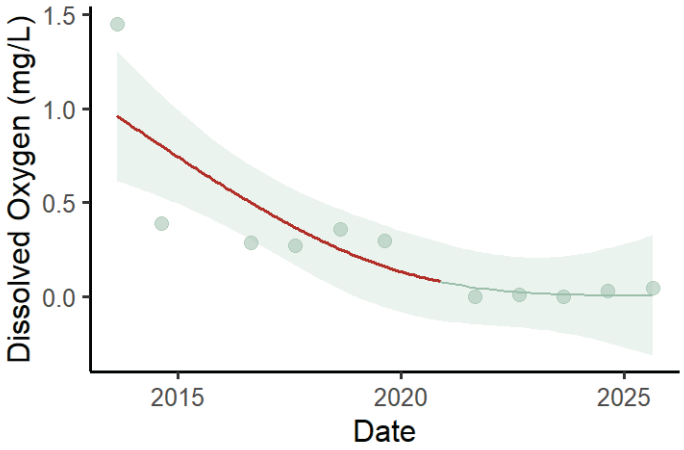


Figure 3. Near-bottom dissolved oxygen concentations (12 m) during late August profiles in Rainbow Lake. Data was filtered to only include profiles collected in the last ten days of August. The fit line is a generalized additive model with the shaded area representing the 95% confidence interval for the model. The overlaid red line represents a period with a statistically significant decrease in dissolved oxygen concentrations.

WATER QUALITY INDICATOR	6/30/2025	7/28/2025	8/25/2025	AVERAGE
		Epilmnion (surface water)		
Transparency (m)	3.4	2.8	3.7	3.3
Total Phosphorus (µg/L)	8.2	10.8	4.7	7.9
Chlorophyll-a (µg/L)	2.5	3.2	2.3	2.7
Lab pH	6.9	6.9	7.3	7.0
Lab Cond (µS/cm@25 °C)	44.8	45.9	47.9	46.2
Apparent Color (Pt-Co)	40.2	37.1	27.8	35.0
Alkalinity (mg/L)	16.0	16.2	18.2	16.8
Total Nitrogen (µg/L)	248	297	261	269
Nitrate -N (µg/L)	<MDL	<MDL	<MDL	<MDL
Chloride (mg/L)	1.9	1.8	1.9	1.9
Sodium (mg/L)	1.8	2.0	2.1	2.0
		Hypolimnion (bottom water)		
Total Phosphorus (µg/L)	11.9	20.0	32.2	21.4
Lab pH	6.8	6.8	6.7	6.8
Lab Specific Cond (µS/cm@25C)	50.4	52.8	56.1	53.1
Apparent Color (Pt-Co)	71.1	117.5	173.1	120.6
Alkalinity (mg/L)	17.6	18.4	20.3	18.8
Total Nitrogen (µg/L)	432	461	390	402
Nitrate -N (µg/L)	235.0	187.0	39.8	153.9
Chloride (mg/L)	2.0	1.8	1.9	1.9
Sodium (mg/L)	1.8	2.0	2.1	2.0

Table 1. Water quality data for Rainbow Lake from the 2025 sampling season. <MDL denotes a value that is below the intsrument's detection limit.

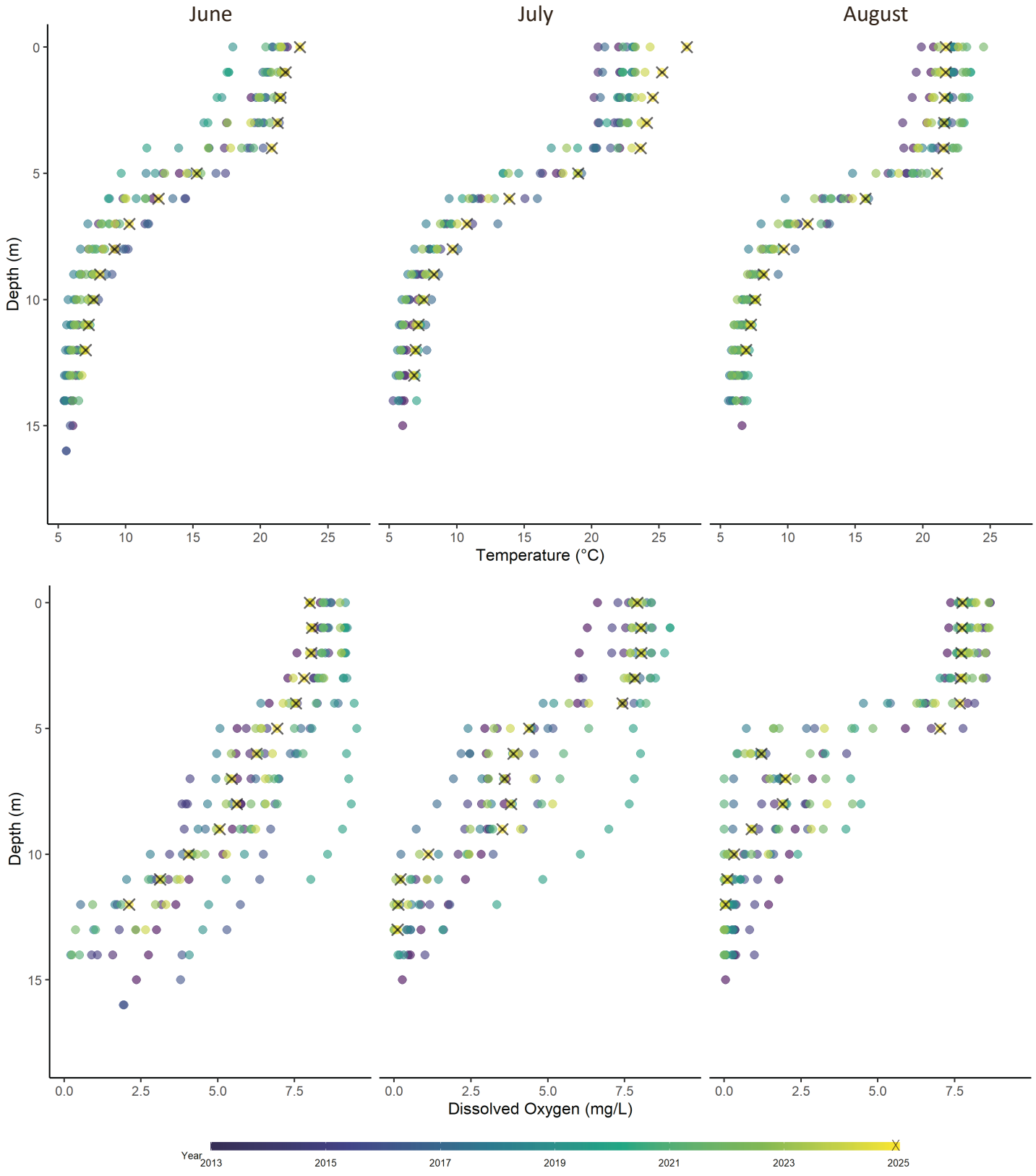
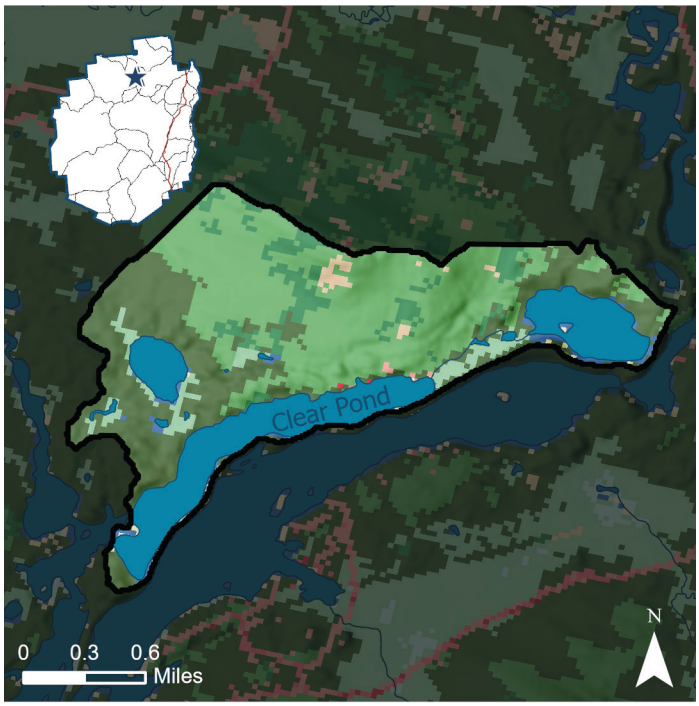


Figure 4. Profiles of temperature and dissolved oxygen in Rainbow Lake from 2013 to 2025. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic.

Clear Pond



- 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
- Woody Wetlands
- Emergent Herbaceous Wetlands

Figure 5. 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

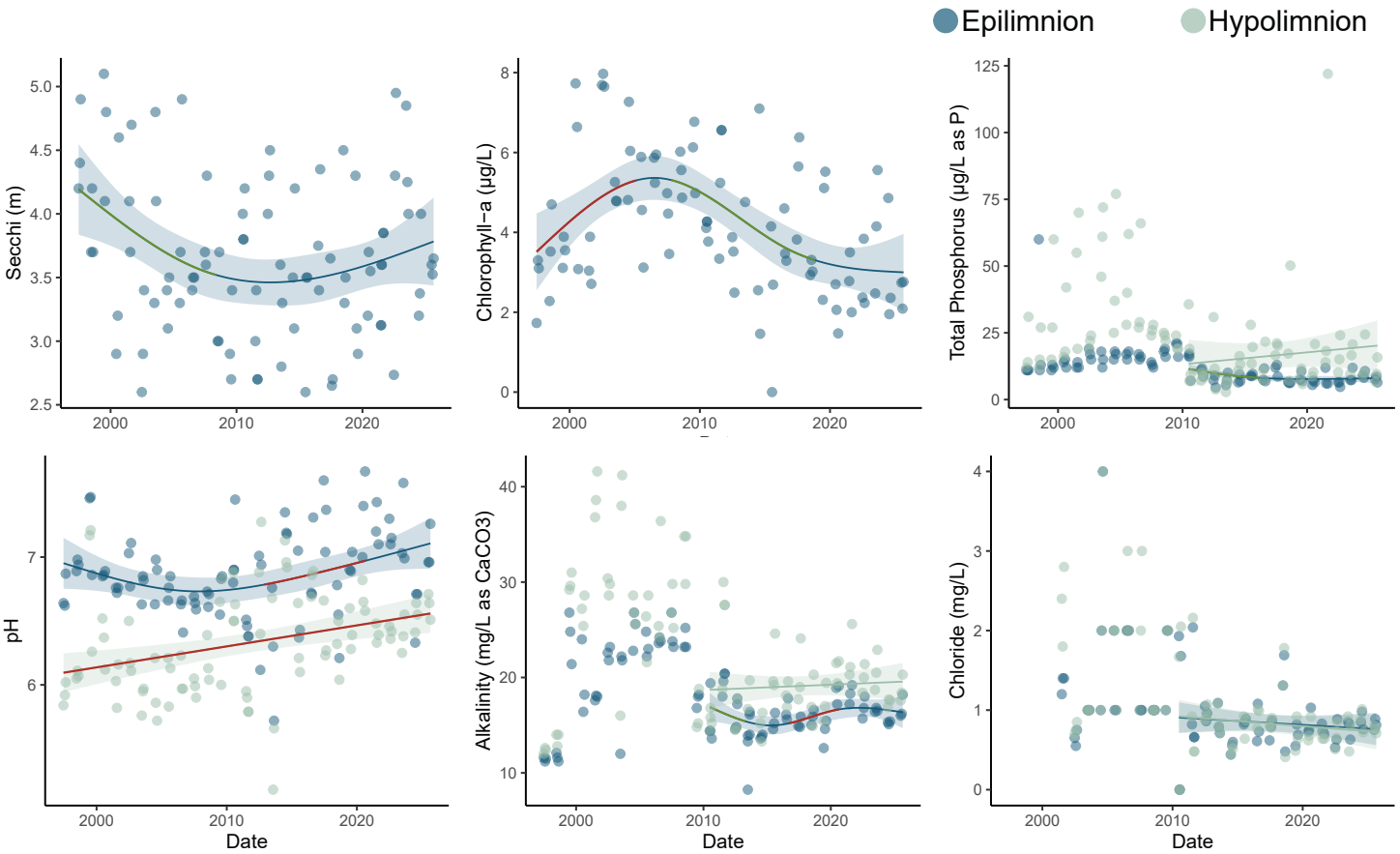


Figure 6. Data for key water quality indicators in Clear Pond, 1997-2025. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant increase, overlaid green lines represent periods with a statistically significant decrease. Areas with no red or green overlaid line represent periods with no statistically significant change. Data for total phosphorus, alkalinity, and chloride prior to 2010 is excluded from trend analysis to account for a shift in laboratory methods.

Clear Pond is classified as a mesotrophic lake with moderate nutrient concentration. The water transparency in 2025 ranged from 3.5 to 3.6 meters. Historically, annual average transparency has fluctuated between 2.5 and 5.0 meters, which is near the average for lakes in ALAP (L'Hote et. al 2025). 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. The total phosphorus concentration in the epilimnion ranged from 6.4 to 8.6 µg/L in 2025, near the 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 are circumneutral in terms of acidity, with an average pH of 7.1 and 6.6, 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 12.8 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 1.2 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 around average for the record.

Clear Pond experiences significant oxygen depletion in the hypolimnion. The depletion is particularly evident in August, with waters below 13 m experiencing complete depletion, or “anoxia” (dissolved oxygen < 0.5 mg/L) . 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 (Figures 7-8), a pattern observed on many lakes across the planet and is likely driven by climate change (Jane et al. 2022).

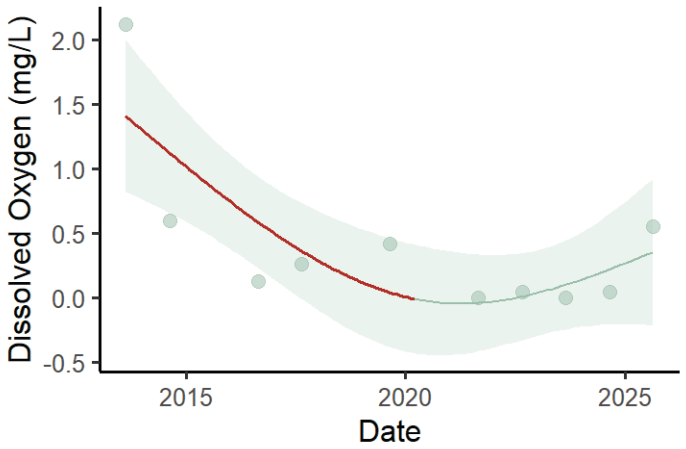


Figure 7. Near-bottom dissolved oxygen concentations (15 m) during late August profiles in Clear Pond. Data was filtered to only include profiles collected in the last ten days of August. The fit line is a generalized additive model with the shaded area representing the 95% confidence interval for the model. The overlaid red line represents a period with a statistically significant decrease in dissolved oxygen concentrations.

WATER QUALITY INDICATOR	6/30/2025	7/28/2025	8/25/2025	AVERAGE
		Epilmnion (surface water)		
Transparency (m)	3.6	3.5	3.6	3.6
Total Phosphorus (µg/L)	7.5	8.6	6.4	7.5
Chlorophyll-a (µg/L)	2.7	2.1	2.8	2.5
Lab pH	7.0	7.0	7.3	7.1
Lab Cond (µS/cm@25 °C)	32.6	33.4	34.9	33.6
Apparent Color (Pt-Co)	34.0	24.7	30.9	29.9
Alkalinity (mg/L)	11.9	12.5	13.9	12.8
Total Nitrogen (µg/L)	224	231	243	233
Nitrate -N (µg/L)	<MDL	<MDL	<MDL	<MDL
Chloride (mg/L)	0.8	0.9	0.8	0.9
Sodium (mg/L)	1.1	1.2	1.3	1.2
		Hypolimnion (bottom water)		
Total Phosphorus (µg/L)	6.7	9.6	15.8	10.7
Lab pH	6.7	6.6	6.5	6.6
Lab Specific Cond (µS/cm@25C)	35.2	35.9	38.1	36.4
Apparent Color (Pt-Co)	49.5	92.7	219.5	120.6
Alkalinity (mg/L)	12.2	12.3	11.6	12.0
Total Nitrogen (µg/L)	336	376	421	378
Nitrate -N (µg/L)	157.0	145.0	83.3	128.4
Chloride (mg/L)	0.8	.8	0.7	0.8
Sodium (mg/L)	1.1	1.1	1.2	1.1

Table 2. Water quality data for Clear Pond from the 2025 sampling season. <MDL denotes a value that is below the intsrument’s detection limit.

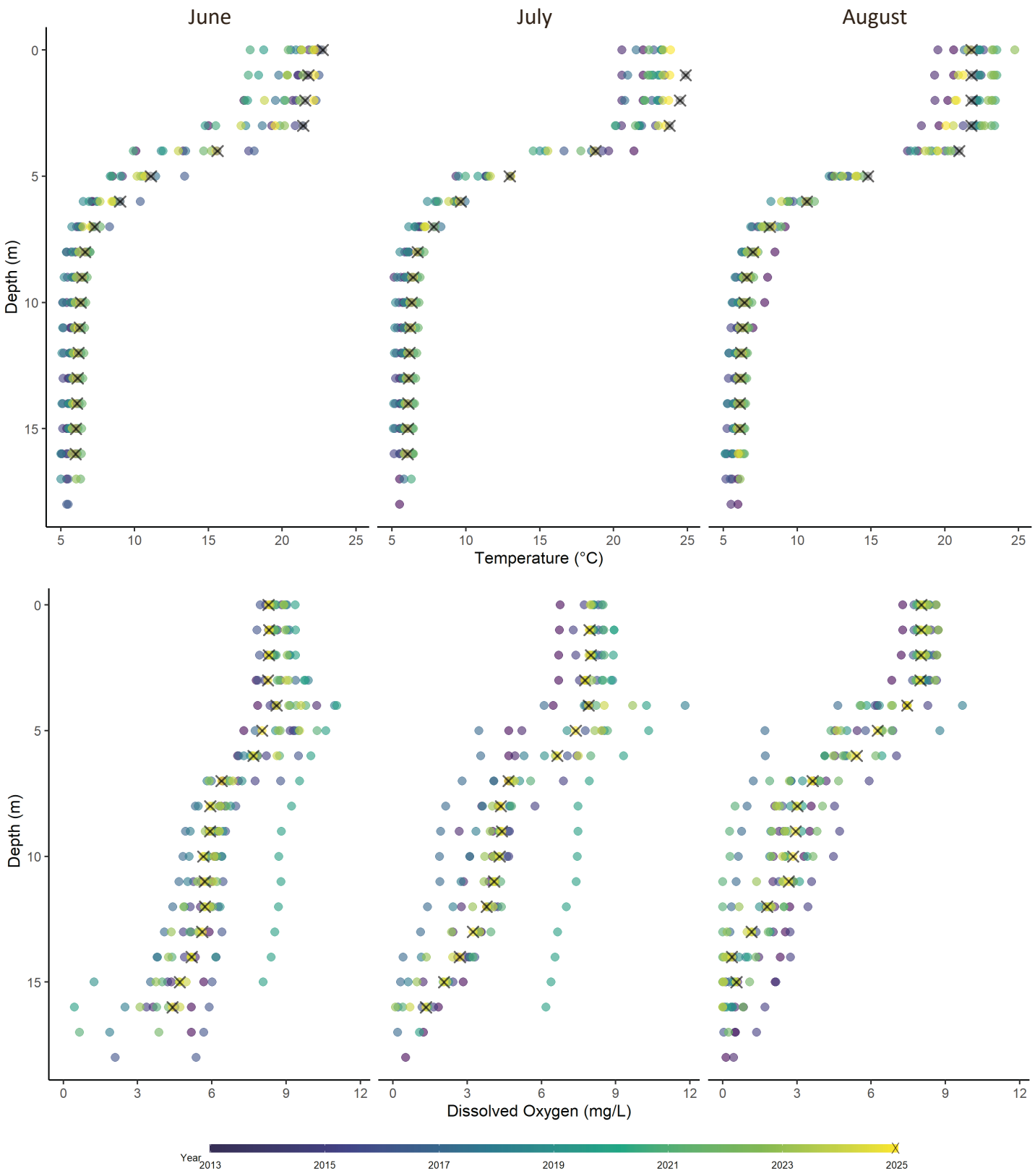
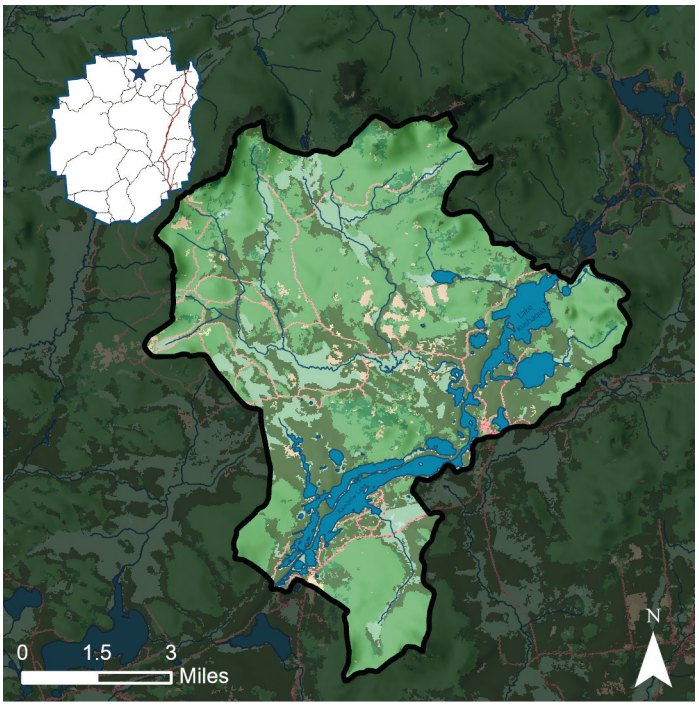


Figure 8. Profiles of temperature and dissolved oxygen in Clear Pond from 2013 to 2025. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic.

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

Location

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

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

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

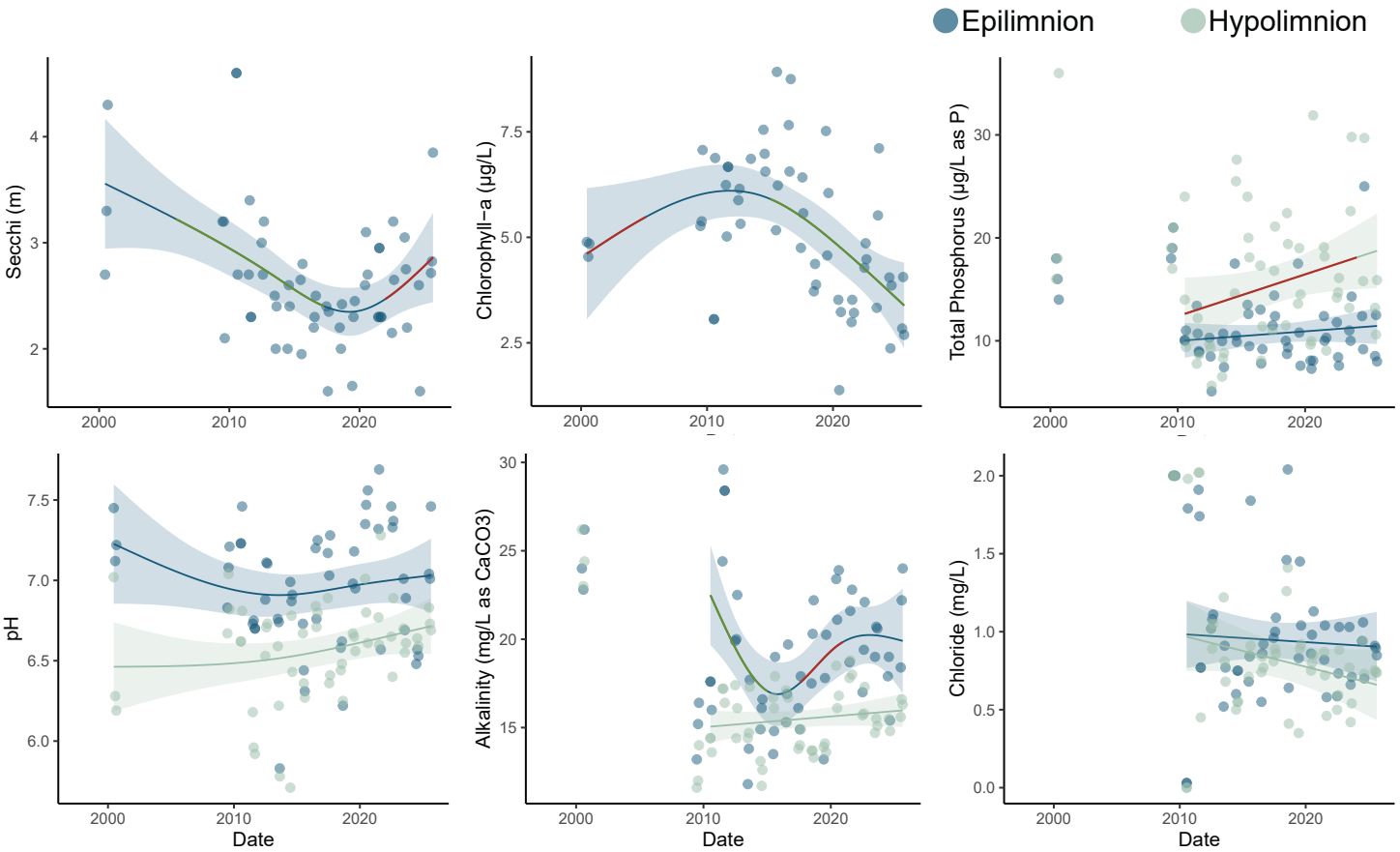


Figure 10. Data for key water quality indicators in Lake Kushaqua, 2001-2025. Regular long-term monitoring began in 2009. Fit lines are generalized additive models with shaded areas representing the 95% confidence interval for the model. Overlaid red lines represent periods with a statistically significant 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. Data for total phosphorus, alkalinity, and chloride prior to 2010 is excluded from trend analysis to account for a shift in laboratory methods.

The water transparency of Lake Kushaqua is the lowest in the lake chain, and averaged 2.1 meters in 2025. This is below average for lakes in ALAP (L'Hote et. al 2025). 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 concentrations have 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 8.0 to 12.5 µg/L in 2025. 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 acidity, with an average pH of 7.2 and 6.8, respectively. These values are about average for lakes in ALAP. The alkalinity of the surface water averaged 21.5 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 1.6

mg/L, respectively. These values are within the background concentrations for Adirondack Lakes, indicating that Lake Kushaqua has little 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.

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 in the late-summer (Figures 11-12) which is in contrast to Rainbow Lake and Clear Pond.

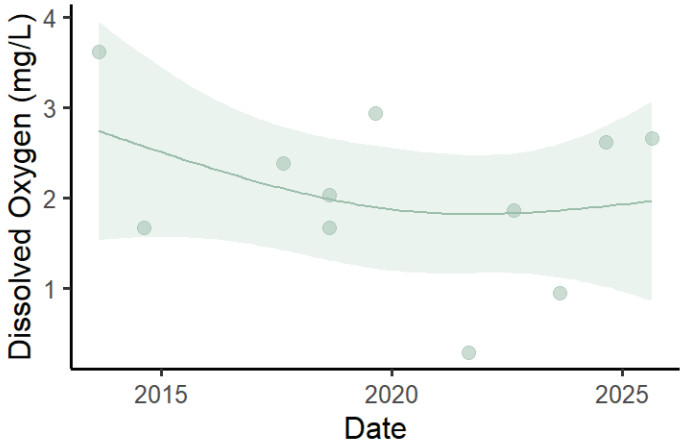


Figure 11. Near-bottom dissolved oxygen concentations (22 m) during late August profiles in Lake Kushaqua. Data was filtered to only include profiles collected in the last ten days of August. The fit line is a generalized additive model with the shaded area representing the 95% confidence interval for the model.

WATER QUALITY INDICATOR	6/30/2025	7/28/2025	8/25/2025	AVERAGE
		Epilmnion (surface water)		
Transparency (m)	3.1	2.7	3.8	3.1
Total Phosphorus (µg/L)	8.5	12.5	8.0	9.7
Chlorophyll-a (µg/L)	2.8	4.1	2.7	3.2
Lab pH	7.0	7.0	7.5	7.2
Lab Cond (µS/cm@25 °C)	46.9	50.1	53.5	50.2
Apparent Color (Pt-Co)	43.3	43.3	34.0	40.2
Alkalinity (mg/L)	18.4	22.2	24.0	21.5
Total Nitrogen (µg/L)	258	269	268	265
Nitrate -N (µg/L)	<MDL	<MDL	<MDL	<MDL
Chloride (mg/L)	0.9	0.9	0.8	0.9
Sodium (mg/L)	1.4	1.6	1.8	1.6
		Hypolimnion (bottom water)		
Total Phosphorus (µg/L)	13.2	10.6	15.9	13.2
Lab pH	6.8	6.7	6.7	6.8
Lab Specific Cond (µS/cm@25C)	42.1	42.2	44.2	42.8
Apparent Color (Pt-Co)	85.3	68.0	89.7	80.4
Alkalinity (mg/L)	15.6	16.6	16.3	15.2
Total Nitrogen (µg/L)	457	458	485	467
Nitrate -N (µg/L)	223.0	245.0	259.0	242.3
Chloride (mg/L)	0.8	0.7	0.7	0.7
Sodium (mg/L)	1.2	1.3	1.4	1.3

Table 3. Water quality data for Lake Kushaqua from the 2025 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.

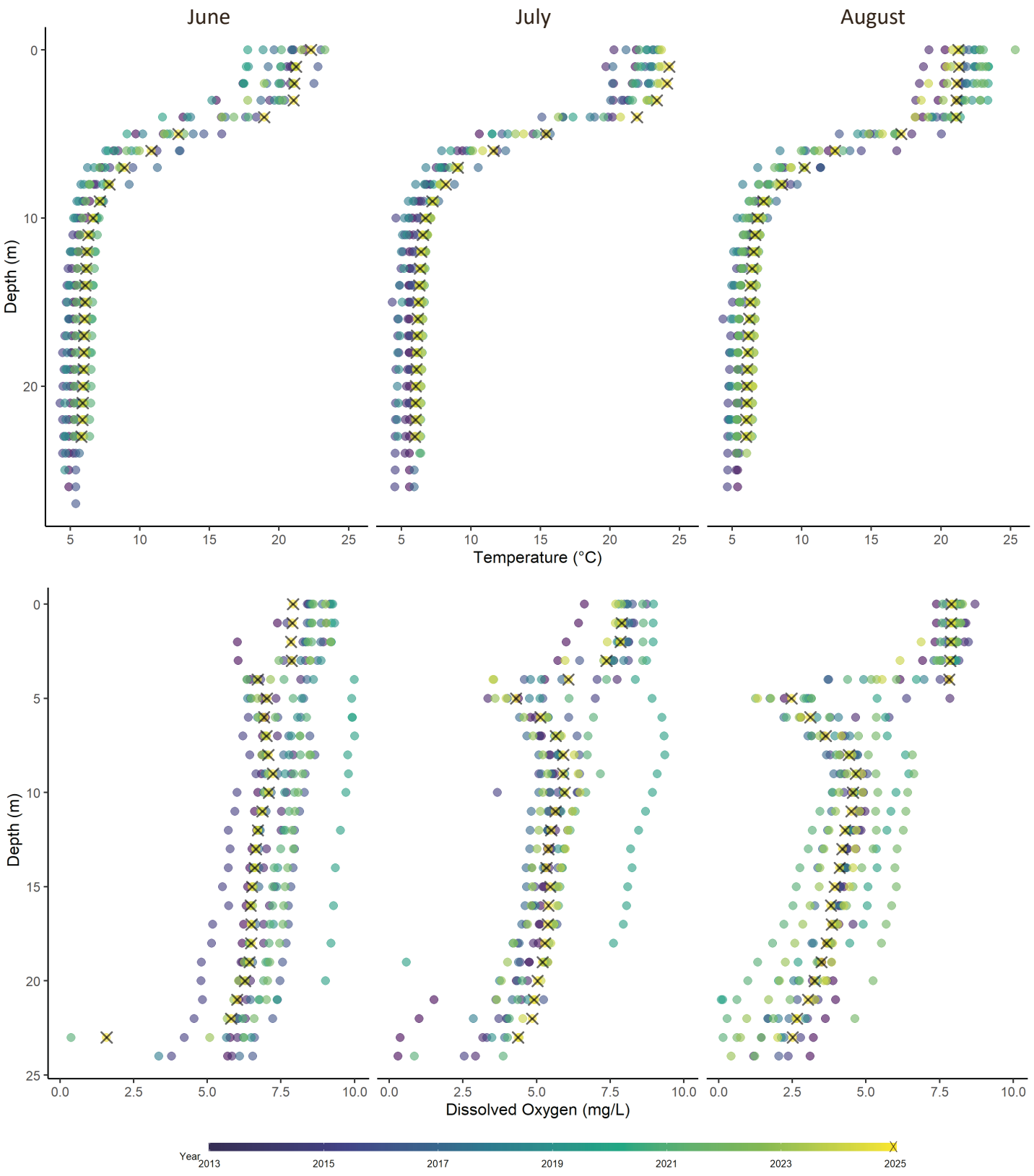


Figure 12. Profiles of temperature and dissolved oxygen in Lake Kushaqua from 2013 to 2025. Point color represents the year in which the profile data was collected. Dissolved oxygen concentrations less than 2 mg/L are considered hypoxic and less than 0.5 mg/L are considered anoxic.

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