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March 26, 2025

TO: Highland Lake Watershed Association
ATTN: Candy Perez
FROM: Kendra Kilson, Research Scientist and George Knoecklein, PhD
Re: Highland Lake 2024 Water Quality Results

Discussion of 2024 Water Quality Results

This summary letter presents the results of 2024 Highland Lake water quality monitoring, including water clarity, dissolved oxygen and water temperature profiles, plankton samples, and nutrient chemistry. These data were collected from three stations located in the deepest water of the three large bays, North Bay, Center Bay, and South Bay (**Figure 1**). HLWA Volunteers visited the three stations monthly from May to October, NEAR visited the three stations in April. No sampling was conducted in November. Nutrient chemistry included total phosphorus from three depths at each station, and total nitrogen from two depths at each station.

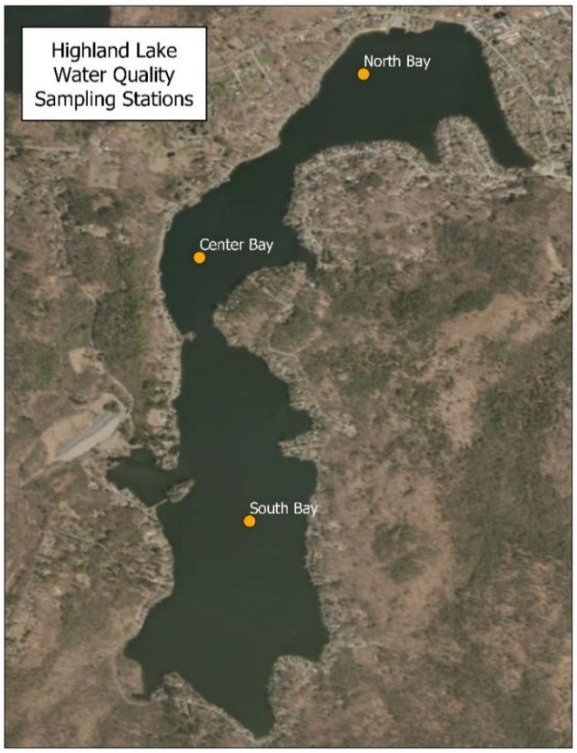


Figure 1. Highland Lake water quality sampling stations.

Water Clarity

The water clarity was poor across all stations in April but improved lake-wide through the season (**Table 1**). The best clarity in North Bay, 4.35m, and South Bay, 4.9m, were both observed in August. The best clarity in Center Bay, 6.4m, was observed in October. Water clarity in Highland Lake has remained within the same general range of values over the years. Data in **Figure 2** show each basin tends to have clarities between 3 and 5 meters, with Center Bay exhibiting maximum clarities of 6 meters. Values rarely exceed this limit, nor are there many values worse than 3 meters.

Table 1. 2024 Secchi disk depths (m) at each station.

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th
North Bay	2.45	3.8	3.95	3.8	4.35	3.5	4.3
Center Bay	2.6	4.0	3.9	3.9	5.45	4.5	6.4
South Bay	2.3	4.0	3.8	3.5	4.9	4.6	4.8

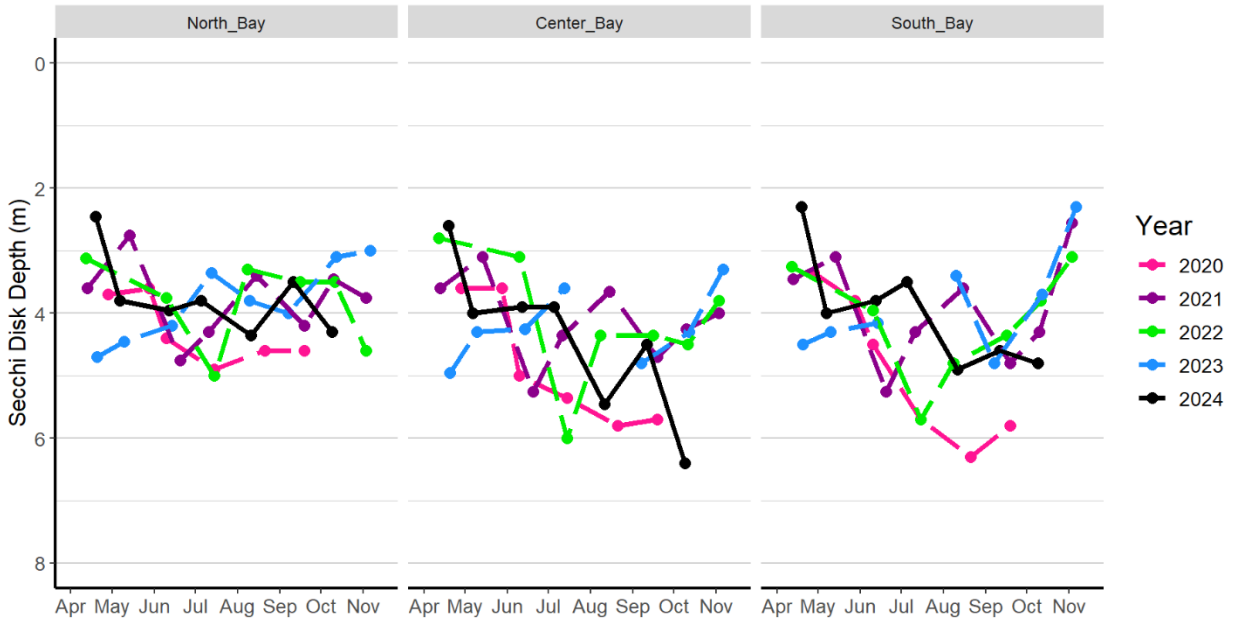


Figure 2. Secchi disk depths at all stations, 2020-2024.

Water Temperature

The water temperature in Highland Lake warmed from April to August, then cooled to October (**Figure 3**). In April, surface temperatures ranged between 10.6°C-10.9°C, and bottom temperatures ranged from 5.8°C-7.1°C, indicating the lake was no longer isothermal (similar temperature from surface to the bottom). The lake thermally stratified in June and remained so until the date of the last profile in October. The warmest temperatures, 24.5°C, were recorded on August 11th. The lake was still thermally stratified in October.

The lake developed a distinct epilimnion, or upper mixed layer, beginning in June, that persisted into October. The epilimnion is the top layer of water where the temperature is the same. The depth of the epilimnion was the same in each basin, from the surface to a depth of 4m in June and July, 5m in August, 7m in September, and 8m in October. Metalimnion thickness was slightly different in each basin. The metalimnion is the layer of water where the water temperature changes quickly with depth. In North Bay, the metalimnion extended to the bottom, in Center Bay the thermocline extended down to about 10 meters, in South Bay to about 8m. A hypolimnion existed in Cener Bay, below 10, and in South Bay, below 8m.

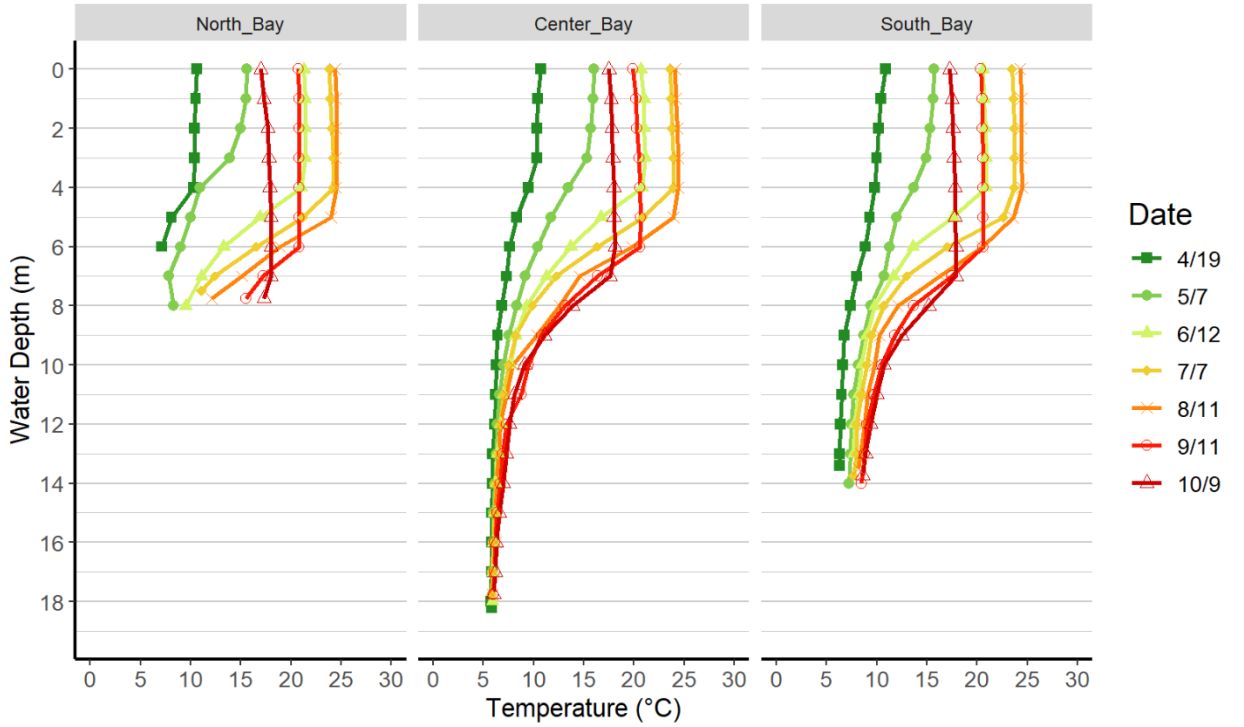


Figure 3. Temperature profiles at North, Center, and South Bays in 2024.

Dissolved Oxygen

The lake was fully oxygenated to the bottom in April and May, although dissolved oxygen (DO) concentration at the bottom of North Bay was <5 mg/L in May (**Figure 4**). Oddly, the DO in Center Bay decreased slightly in 5- and 6-meter water in July, dramatically in 6-meter water in August, and slightly in 7-meter water in September. In August, DO sharply declined from 6.3 mg/L at 5m to 1.5 mg/L at 6m, then increased to 4.6 mg/L at 7m. This loss is caused by colder anoxic water in North Bay spilling into Center Bay at the 6-meter depth. This occurs because a low lip of 6 meters separates the North and Center Basins. Water at 6m in North Bay tends to be colder than water at 6 meters in Center Bay. Once anoxia reaches the depth of the lip, ~6m, that colder, anoxic water will spill into Center Bay causing the DO decline observed in August.

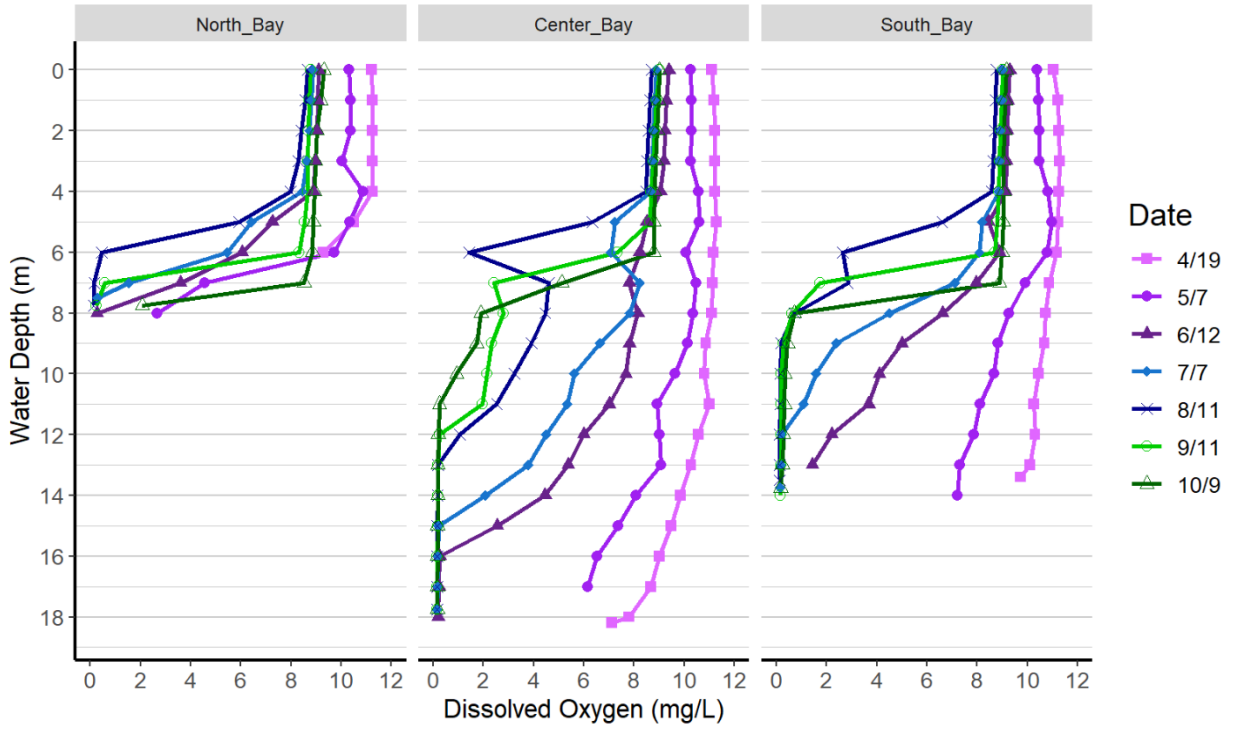


Figure 4. Dissolved oxygen profiles at North, Center, and South Bays in 2024.

Bottom Water Anoxia

The anoxic boundary, or the depth at which water has a dissolved oxygen concentration below 1 mg/L (termed 'anoxic'), should remain below the bottom of the thermocline in each basin.

In North Bay, the anoxic boundary remained at or below 6m in 2024 (**Figure 5**). The bottom water was hypoxic (<5 mg/L) in April and May. The anoxia boundary reached a maximum height of 5.9m (from the bottom) in August. In the past 5 years, the anoxic boundary has exhibited an erratic annual pattern of large changes in depth, sometimes as much as 2 meters. This suggests that this area of the lake may mix deeply during strong south winds events.

The bottom water was also oxygenated in April and May in Center Bay. The height of the anoxic boundary increased throughout the season, with the maximum height, 9.91m, recorded on October 9th, 2024. In 2021 and 2022, the anoxic boundary reached above 8 meters, in 2023 the anoxic boundary reached 9 meters. The loss rate appears to be the same for 2020 – 2023, that is the time it takes for the bottom to the maximum ascent depth. The loss rate appeared to be slower in 2024, that is, DO was lost from the water column at a slower rate than those prior years. The basin contained the largest volume of anoxic water on the date of the last sampling in October, similar to the last 4 years.

South Bay was fully oxygenated in April and May. The DO loss rate appeared to be similar to 2020, 2021, and 2022, the DO loss rate in 2023 was higher than all others. The anoxic boundary was stable at 8 meters through August, September, and October. The anoxic boundary has reached as high as 6 meters (2023) and 7 meters (2021).

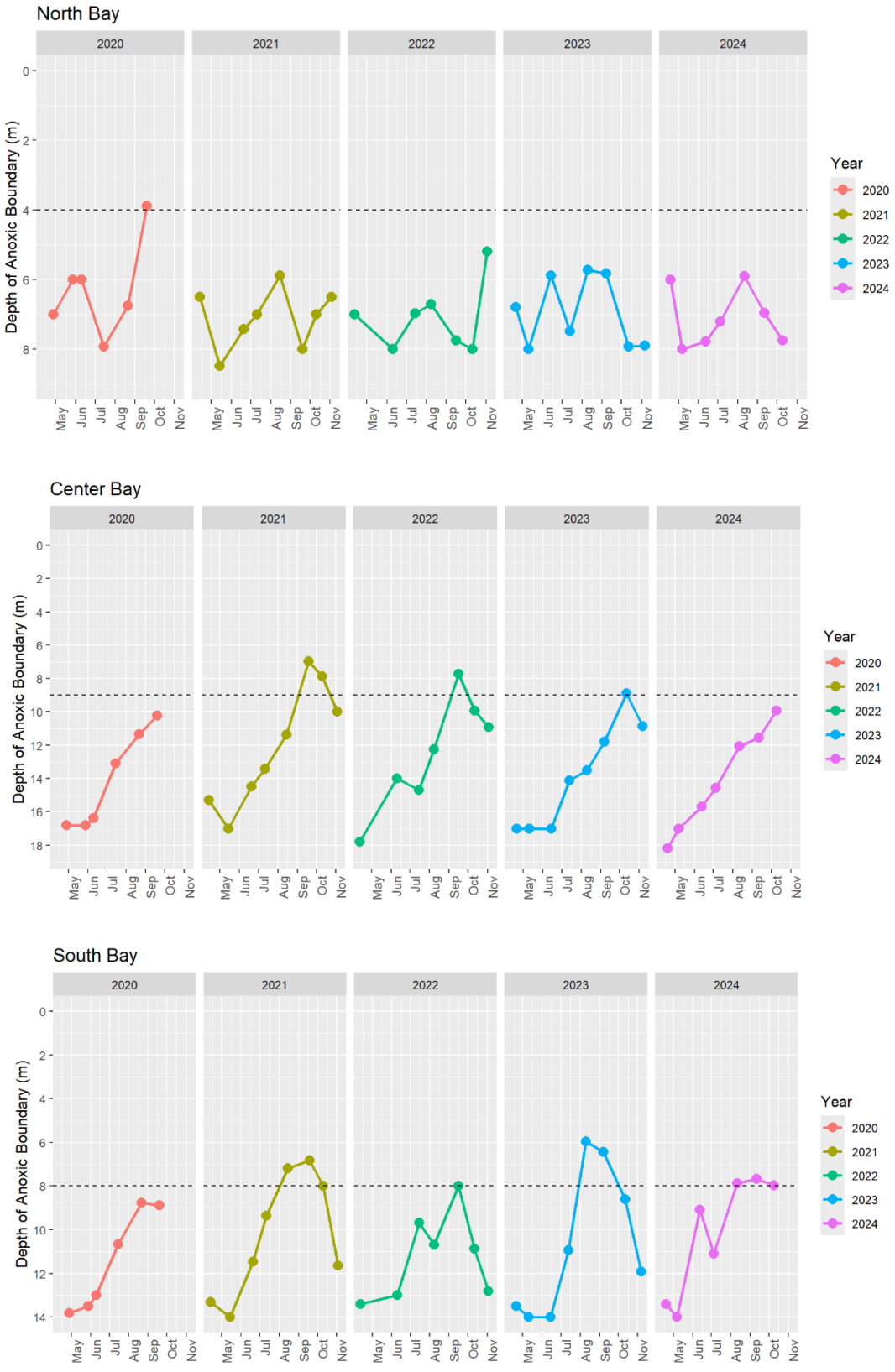


Figure 5. Anoxic boundaries in North, Center, and South Bays, 2020-2024.

Nutrients

Total Phosphorus

Total phosphorus (TP) concentrations in the top (1m) waters were excellent in Highland Lake during 2024, ranging from 2ppb to 14ppb (**Table 2**). In middle waters, TP ranged from 3ppb to 22ppb (**Table 3**). Bottom water TP concentrations were highest at Center and South Bays on October 9th, with concentrations of 64ppb and 61ppb respectively (**Table 4**). Table 1

Table 2. 2024 top-water (1m) total phosphorus concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th	Avg
North Bay	3	2	14	7	9	13	7	8
Center Bay	10	4	9	9	9	10	6	8
South Bay	5	2	8	9	7	9	7	7

Table 3. 2024 middle-water total phosphorus concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th	Avg
North Bay	3	7	8	8	10	11	22	10
Center Bay	6	7	12	12	10	10	8	9
South Bay	5	4	10	13	10	9	7	8

Table 4. 2024 bottom-water total phosphorus concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th	Avg
North Bay	5	11	9	10	17	18	7	11
Center Bay	5	6	11	15	12	40	64	22
South Bay	5	7	10	10	24	37	61	22

Total Nitrogen

Total nitrogen (TN) concentrations were low, ranging from 187ppb-265ppb in the top (1m) waters (**Table 5**). TN concentrations ranged from 183ppb-714ppb in the bottom waters (**Table 6**).

Table 5. 2024 top -water (1m) total nitrogen concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th
North Bay	197	211	222	193	206	204	187
Center Bay	241	199	215	201	212	209	188
South Bay	215	189	232	225	251	265	202

Table 6. 2024 bottom-water total nitrogen concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th
North Bay	206	226	183	191	234	276	189
Center Bay	234	359	337	274	493	435	714
South Bay	222	252	401	296	373	515	667

Ammonia Nitrogen

Bottom water ammonia nitrogen concentrations were slightly elevated in Center and South Bays in June, August, September, and October (**Table 7**). Bottom water ammonia nitrogen was also slightly elevated at Center Bay in May. These concentrations indicate some minor release from sediments; only the 454ppb on the bottom in October approaches a high value for anoxic water. In North Bay, ammonia nitrogen was always low, ranging from 2ppb to 14ppb.

Table 7. 2024 bottom water ammonia concentrations (ppb).

	Apr 19th	May 7th	Jun 12th	Jul 5th	Aug 11th	Sep 11th	Oct 9th
North Bay	3	14	11	8	8	2	14
Center Bay	34	132	145	86	270	252	454
South Bay	5	43	134	82	132	265	360

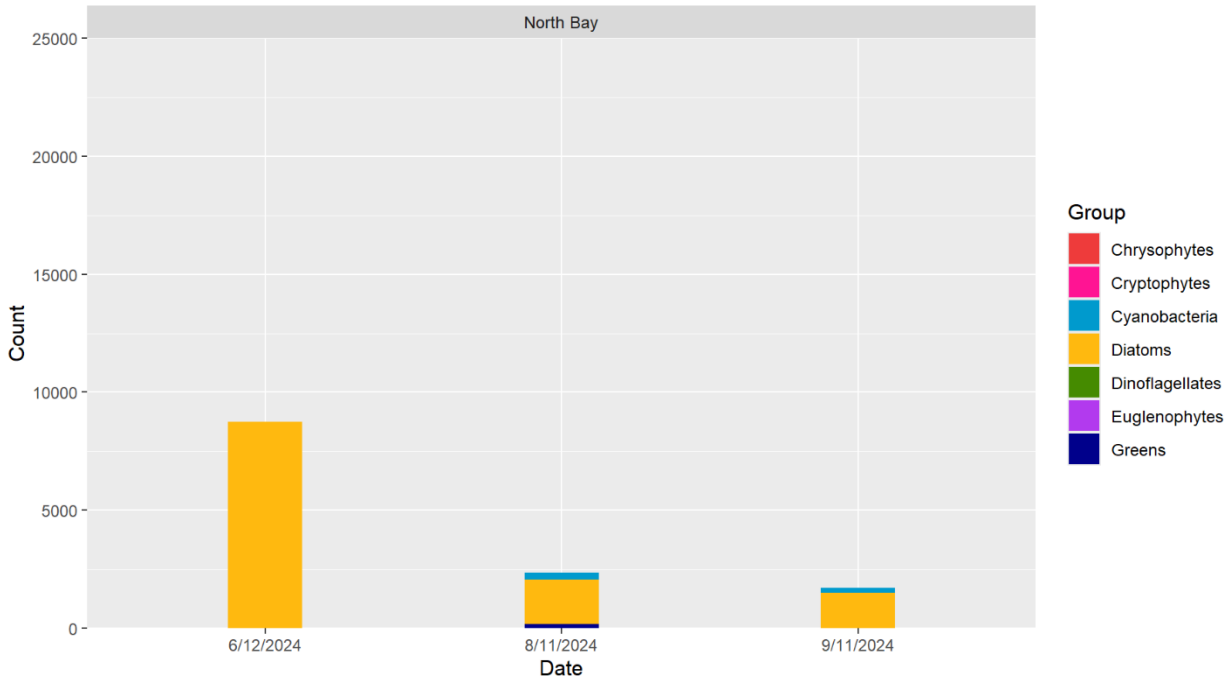
Phytoplankton

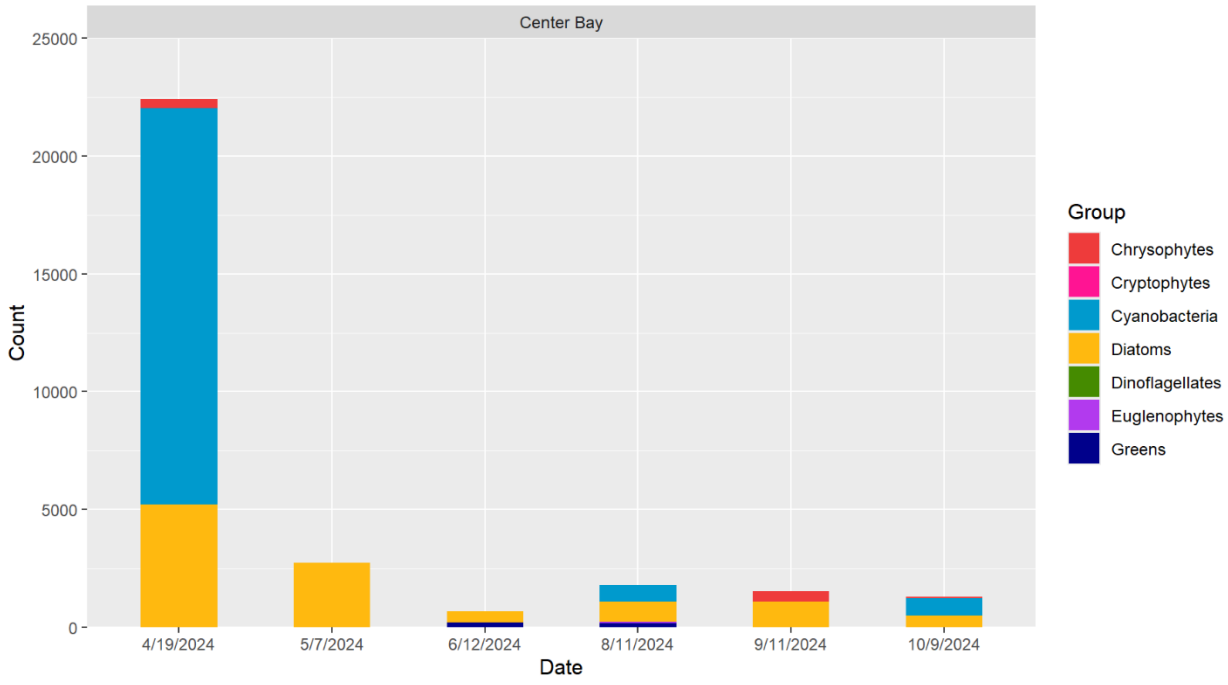
Phytoplankton samples were identified and enumerated at all three monitoring stations in June, August, and September (**Figure 6**). Additional samples were identified and enumerated at Center Bay in April, May, and October.

In April, cyanobacteria dominated at Center Bay, particularly *Planktolyngbya sp*. Cyanobacteria remained low at all three stations during the remainder of the sampling period. At South Bay in September, cyanobacteria counts were slightly below 10,000 cells/mL. Diatoms were the dominant group found in North Bay, though counts were equal to or less than ~8,764 cells/mL.

In late October 2024, HLWA volunteers and residents reported to NEAR a lake-wide cyanobacteria bloom, with concentrated scums along shorelines (i.e. state boat launch) (**Photo 1**). We advised residents to collect a sample and send it to our office. Additionally, NEAR staff stopped by the lake on October 22nd and collected a sample from the boat launch. NEAR looked at the samples under the microscope and determined it was *Dolichospermum*, a known toxin producer. Late-season blooms are not uncommon, as the lake begins fall turnover and nutrients from the bottom of the lake are stirred up in the water column.

The World Health Organization (WHO) and Environmental Protection Agency (EPA) outlines recommended thresholds for cyanobacteria exposure (**Table 8**). One cannot always tell from looking at cyanobacteria blooms or scum if it is toxic and cell counts are not available immediately upon collection, so it is generally encouraged to minimize exposure for both humans and pets if there is a bloom in the lake.


North Bay
25000
20000
15000
10000
5000
0
Count
6/12/2024
8/11/2024
9/11/2024
Date
Group
Chrysophytes
Cryptophytes
Cyanobacteria
Diatoms
Dinoflagellates
Euglenophytes
Greens


Center Bay
25000
20000
15000
10000
5000
0
Count
4/19/2024
5/7/2024
6/12/2024
8/11/2024
9/11/2024
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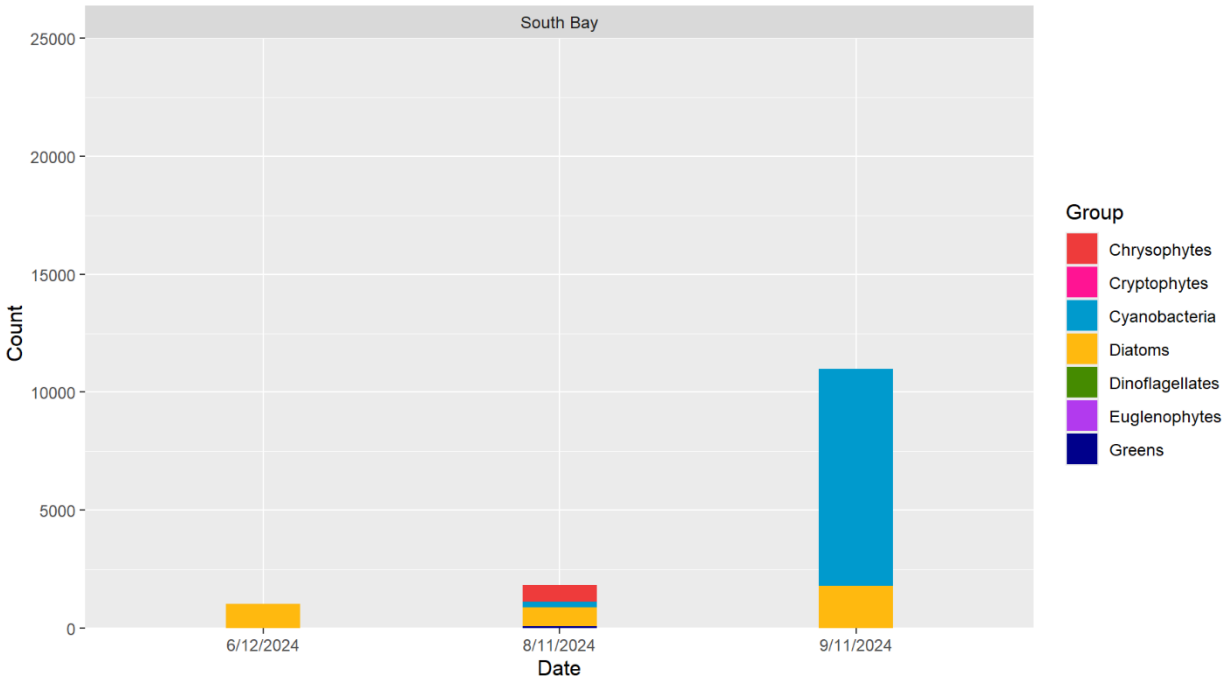

Figure 6. Phytoplankton counts (cells/mL) at North, Center, and South Bays in 2024.

Photo 1. Late October 2024 bloom, photos taken and provided by HLWA members and residents.

Table 8. WHO guidance values for the relative probability of health effects resulting from exposure to cyanobacteria.

Relative Probability of Acute Health Effects	Cyanobacteria Density (Cells/mL)
Low	< 20,000
Moderate	20,000-100,000
High	100,000-10,000,000
Very High	> 10,000,000

Zooplankton

Highland Lake was stocked with alewife many years ago as a forage base for trout. However, alewife are zooplanktivores so they have heavily grazed the natural population of zooplankton. Zooplankton samples were collected from Center Bay every month from April through October. The most abundant group of zooplankton in April, June, and October were rotifers (**Figure 7**). No Calanoids were observed in any of the samples. Some moderately sized Daphnia and copepods were present in the spring Moderately sized Daphnia were present in small- to medium-sized body forms at other times of the year, no large bodied (>1mm) forms were observed (**Figure 8**). Rotifers (small-bodied organisms <0.4mm) were generally the most numerous. Copepods and cyclopoids remained below 10 animals per liter all season.

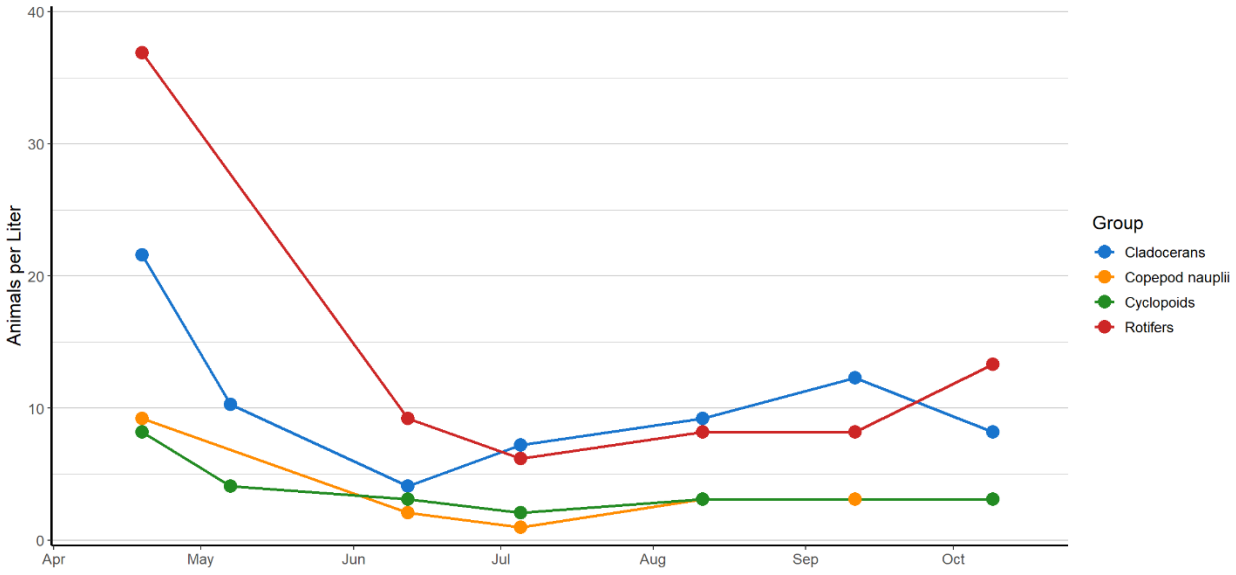

Figure 7. Zooplankton counts at Center Bay in 2024.

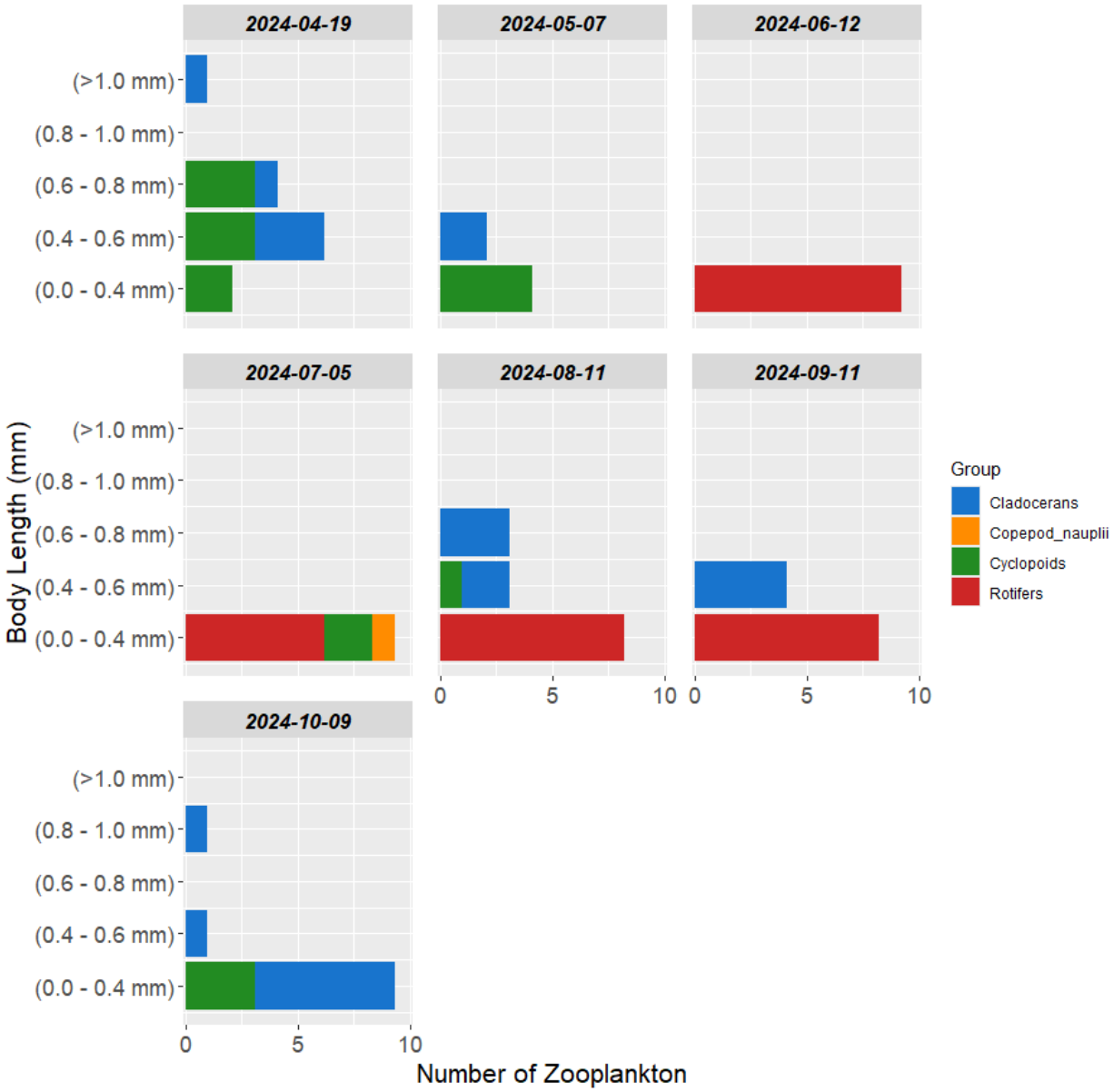

Figure 8. Zooplankton body lengths at Center Bay in 2024.

Conclusions / Recommendations

The water clarity of Highland Lake waters has remained relatively consistent over the long-term. Secchi disk depths have varied between 3 and 5-6 meters each year since monitoring began. Occasionally, the lake has had water clarity of less than 3 meters, but there have been only two readings less than 2 meters since monitoring started in 2005. The best clarity in North Bay is typically 5 meters, while the best clarity in Center and South Bay is ~6 meters. Measurements in 2024 were for the most part within the ranges established by the long-term data, between 3 and 5-6 meters. The exception was Center Bay water clarity in October, which was 6.4 meters, better than all prior measurements at Highland Lake.

The anoxic boundary in the Center and South Bays followed the same general trend of beginning in late-May and steadily progressing upward through the summer to reach maximum ascent depth in late fall. However, the rate of ascent was slower in 2024 than in the last few years. In 2024, the maximum ascent depth in Center Bay occurred in October, as opposed to September as in recent years. The maximum ascent depth in each basin is likely governed by the morphometry of each basin, however this has not been investigated. Anoxia in North Bay appears to be closely linked to wind as the boundary can fluctuate by a couple of meters between visits.

The total phosphorus concentration in the upper waters rarely exceeds 20ppb and is generally below 15ppb. In 2024, upper water total phosphorus was 10ppb or less, better than most recent years when total phosphorus was 15ppb or less. Average TP in middle and bottom water was slightly higher than last year.

The zooplankton community remains modest, composed mostly of small, bodied organisms, (<0.4mm).

Phytoplankton numbers were generally low. High numbers of cyanobacteria occurred in Center Bay in April and South Bay in September. A lake-wide cyanobacteria bloom was documented in late October.

Global warming has affected lakes by lengthening the lake season, going from 7 months (April to October) to 9 months (March to November). The lake monitoring plan was developed to obtain data at ice-out, through the spring summer heating period, the fall cooling and the establishment of fall mixing prior to freezing. Ice-out, if it occurs at all, happens in early to mid-March, and fall mixing doesn't happen until November.

- We recommend beginning sampling in March and extending through at least November, possibly December. One of the goals of early- and late-season sampling is to capture isothermal conditions. Increasingly in the region, we are noticing this occurs in March, rather than April, and again later in the season. The lake was stratified during the April and October visits in 2024.

There are very few zooplankton in the lake generally so any differences between stations will be slight.

- At this time, continued zooplankton collection from only Center Bay is sufficient.

Phytoplankton numbers and Groups varied considerably between basins, however for the most part numbers remained low.

- To reduce phytoplankton analyses, it is sufficient to only collect phytoplankton when the clarity falls below 3 meters.

The lake would benefit from a long-term data review, building upon the report produced by NEAR in 2020, to continue to monitor the trajectory of lake condition, assess any improvements within the watershed in the past 5 years based on our 2020 recommendations, and re-assess remaining recommendations for improvement.