2024 Nearshore Monitoring in Wisconsin's Lake Superior coast for nutrient conditions leading to Harmful Algal blooms (HABs)

"Dawn at Cave Point" by Michael Knaostein 2018 Great Lakes Photo Contest

Office of Great Waters -- Northern Region

Wisconsin Department of Natural Resources

Project Coordinators/Principal Investigators:
Ellen Coffman
WDNR, Lake Superior Sediment and Monitoring Coordinator
Superior, WI

Madeline Magee
WDNR, Monitoring Technical Lead - Bureau of Water Quality
Madison, WI

Acknowledgments:
Janae Widiker, DNR Natural Resource Research Technician

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Abstract

Since 2012 there has been an increase in cyanobacterial bloom observations along the south shore of Lake Superior. These blooms, defined as the rapid growth of cyanobacteria, can form surface accumulations and have the potential to produce toxins. The species most commonly found in nearshore bloom samples has been *Dolichospermum lemmermannii.* The potential for toxin production could impact summer tourism, public health, and recreational users in nearshore areas. While we are making progress in our understanding of where blooms tend to develop and under what weather and nutrient conditions, there are gaps in our understanding about how changes in nutrient dynamics influence bloom formation. Changes in precipitation regimes and warming lake surface temperatures are thought to be a driver of the recent increase in bloom observations.

Project objectives included 1) obtaining baseline surface water quality parameters associated with algal bloom formation in Wisconsin's Lake Superior shoreline, 2) collecting water quality data before and during algal bloom events, and 3) determining the spatial and temporal distribution of algal bloom events.

The dataset is captured during a year where an air-temperatures were consistent with the average conditions observed over the past five years (2020–2024), and precipitation patterns were characterized by elevated totals in May, June, and August but less than average amounts in July and September. We observed the maximum chlorophyl a concentration, 14.8 µg/L, at Flag River (site 9) occurring early in the sampling season (June). The sites furthest east (Miwakuie Bay to Bad River) experienced greater water clarity with deep Secchi depths and low total phosphorus concentrations when compared to sites further west (Schaffer Beach to Iron River). Looking across datasets collected within the last ten years in the nearshore of Lake Superior, 2024 showed to be one of the most productive in terms of nutrients and chla concentrations, but there were relatively few bloom occurrences recorded.

While no cyanobacteria blooms were observed at standard locations during sampling events, eight of the nine algal sites contained detectable cyanobacteria species at some point in the season, with Poplar River (site 3) being the only location without detections. In early October, cyanobacteria accounted for about half of the phytoplankton population in cell/mL. For many locations cyanobacteria represented a larger portion (45%) of the algal community towards the end of the sampling season (mid- August to early October 16-22 °C). There was no strong association observed between presence of cyanobacteria and current nutrient concentrations at sites.

Durning the 2024 bloom season algal blooms were detected within the nearshore Lake Superior and within the SLR estuary. In our area of study, a bloom in Little Sand Bay was recorded August 26 containing *Dolichospermum*, but no toxins were detected. Within the estuary blooms were observed from beginning of August till end of September, with *Aphanizomenon*, *Dolichospermum* and *microcystin*, all toxins detected were below recreational limits.

Introduction

Lake Superior is the largest freshwater lake on Earth by surface area and is often regarded as the least altered of the Laurentian Great Lakes. Its water quality supports diverse biological communities and provides critical ecosystem services, including fisheries, drinking water, and recreation, all of which depend on maintaining ecological integrity (Reinl et al., 2025). Despite its relatively undegraded status, Lake Superior has experienced notable ecological change in recent decades, including invasive species introductions, detection of harmful algal blooms, and accumulation of anthropogenic contaminants, with oligotrophic conditions making the system particularly sensitive to climate forcing (Reinl et al., 2025). These changes are most pronounced in the nearshore zone, where tributary

inputs, longshore transport, and localized meteorological forcing drive greater variability in temperature, nutrient concentrations, and water quality than in the offshore basin (Marcarelli et al., 2019). Because the nearshore region supports the majority of recreational use, fisheries, and drinking-water intakes, targeted monitoring of nutrient dynamics and nearshore conditions is essential for anticipating and mitigating ongoing and future environmental change.

Over the past decade, reported cyanobacterial accumulations along Lake Superior's shoreline have increased, raising concerns for recreational use and public health. While the environmental conditions that promote bloom formation and initiation zones in Lake Superior are not fully resolved, blooms in freshwater systems are commonly associated with elevated nutrient inputs, particularly phosphorus—the lake's limiting nutrient (Lürling et al., 2018; Schindler, 1975; Steinberg and Hartman, 1988). Climate-driven increases in precipitation intensity and surface-water warming are considered key drivers, with several late-summer blooms in the western arm of the lake (2012, 2016, 2018) occurring 25–53 days after extreme storm events that delivered large sediment and nutrient loads (Minor, 2014; Cooney et al., 2018; Sterner et al., 2020). These bloom initiation periods coincide with peak summer surface-water temperatures, and Lake Superior's rapid warming relative to the other Great Lakes likely further enhances cyanobacterial persistence (Austin and Colman, 2007; O'Reilly et al., 2015).

Since 2012, blooms have been documented along the southern shore, frequently following high-runoff events (2023 Lake Superior Bloom Bulletin). Many of these events have been dominated by *Dolichospermum lemmermannii*, a taxon capable of producing cyanotoxins (2023 Lake Superior Bloom Bulletin; ID by Gina LaLiberte, Wisconsin Department of Natural Resources). Bloom expression varies widely, from filamentous shoreline accumulations to surface scums, and cyanobacteria may also occur in the phytoplankton community without visible accumulation. Although toxin detections have been inconsistent, the increasing frequency of bloom observations raises concerns for public health, recreation, and tourism.

Since 2021 there has been an increased focused on connecting factors regarding bloom formation and toxin production. And while much has been learned regarding nearshore nutrient dynamics, blooms have not been frequent enough to have provide enough data to confidently provide mechanisms of formation or management actions.

Recent bloom activity has renewed attention on watershed-derived influences on nearshore biogeochemical processes. Tributary inputs of suspended sediment, particulate phosphorus, and cyanobacterial cells appear to play a key role in bloom development along the southwestern shore, particularly during high-flow events that mobilize phosphorus-rich sediments and increase bioavailable nutrient supply (Kreiling et al., 2025). Cyanobacteria, including toxin-producing strains, have been detected in tributary waters and bed sediments, suggesting that fluvial transport may seed nearshore blooms (Wood et al.,

2025). Although blooms remain spatially localized, their increasing occurrence highlights the need for proactive monitoring under a changing climate (Reinl et al., 2025).

Collectively, these observations indicate that cyanobacterial blooms in Lake Superior emerge from interactions between offshore oligotrophic conditions and dynamic nearshore processes. Rather than isolated surface phenomena, blooms are closely linked to tributary and sediment dynamics that regulate nutrient availability and cyanobacterial recruitment (Kreiling et al., 2025). While Lake Superior was historically considered resistant to algal blooms, recent evidence demonstrates that specialized cyanobacterial communities—often dominated by *Dolichospermum*—can persist and proliferate under these conditions (Sterner et al., 2020). This pattern mirrors broader Great Lakes trends, where climate change and altered nutrient loading are increasing bloom frequency and extent (Smith et al., 2024). High-resolution community analyses further show that while the genetic potential for toxin production is widespread, cyanotoxin expression is highly site-specific (Chaffin et al., 2024), underscoring the need to identify ecological controls governing the transition from biomass accumulation to toxigenic risk in Lake Superior's nearshore zone.

In 2024, cyanobacterial activity followed established seasonal patterns, with sparse reports in early summer giving way to an increase in bloom occurrences during August and September. These events were geographically widespread, appearing within the St. Louis River Estuary, along the Wisconsin south shore at Little Sand Bay, and extending to the north shore near Thunder Bay and Nipigon Bay. Taxonomically, these blooms were dominated by *Dolichospermum* and *Microcystis* species, including a notable 18.7% population abundance of *Dolichospermum lemmermannii* at Little Sand Bay in late August. Despite the physical presence of these accumulations, toxin detections remained low or absent across most nearshore sites; microcystin concentrations in the St. Louis River Estuary stayed below 0.10 µg/L, well under the US EPA recreational advisory threshold of 8 µg/L. However, the detection of both microcystin and cylindrospermopsin at Isle Royale National Park in late July confirmed that toxigenic conditions can materialize within the region. These 2024 observations underscore a persistent disconnect between cyanobacterial biomass and actual toxin production in Lake Superior's nearshore waters.

The objective of this study was to characterize water-quality conditions preceding and during cyanobacterial bloom activity in the Wisconsin nearshore of Lake Superior. This dataset provides a foundation for understanding bloom dynamics and supporting future management strategies aimed at reducing bloom frequency and mitigating their ecological and socioeconomic impacts. Field sampling was conducted at 20 nearshore sites across seven surveys spanning June through October.

Methods

Experimental Design

Sampling locations were chosen to replicate previous studies conducted in 2019, 2021, 2022, and 2023, which focused on source tributary mouths and areas where previous blooms have occurred. In addition to these standard locations, 5 additional sites were added to capture dynamics further east in the basin around the Bayfield Peninsula and Chequamegon bay area. These sites provide us with sufficient spatial distribution to understand where potential sources of nutrients leading to bloom conditions are entering the lake. Surface water samples were collected at the 5 m contour (F*igure 1*).

In 2019 the Lake Superior algal sub-group determined that the 5 m depth contour was most appropriate for sampling, as it balances interests in sampling the very nearshore (since that is where blooms have been observed) and provides a broader scale perspective of the distribution of nutrients throughout the 55 miles of the south shore region. This was confirmed by data analysis completed by University of Wisconsin data analyst that waters after 6m are more similar in nutrient conditions to offshore waters than nearshore waters.

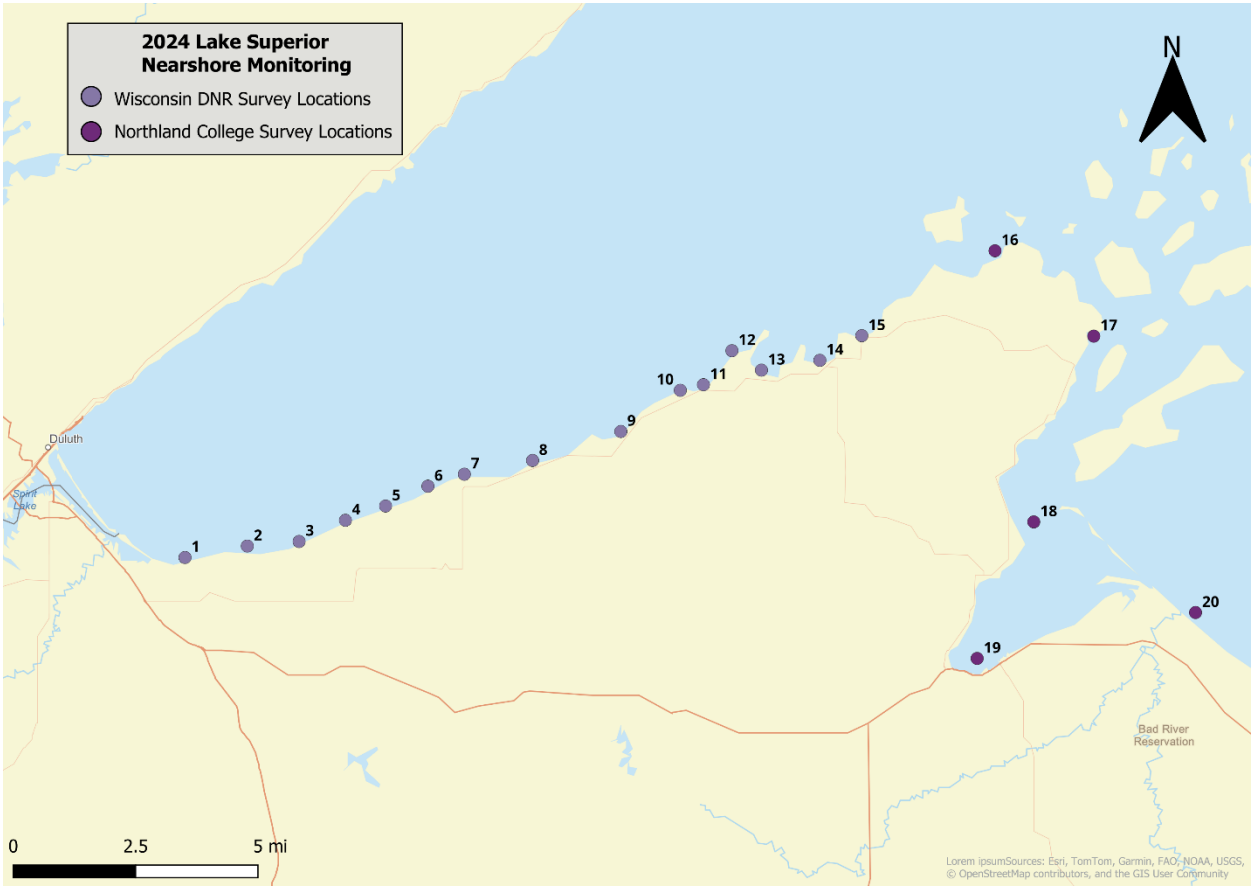

Figure 1: **WDNR and Northland College sampling sites from Superior to Bad River**. This map illustrates 20 nearshore monitoring locations spanning the Lake Superior south shore coastline. Sites are distinguished by the sampling organization: fifteen sites monitored by the Wisconsin Department of Natural Resources (WDNR; indicated

in light purple) and five sites monitored by Northland College (indicated in dark purple). These locations provide the spatial framework for the hydrodynamic and nutrient data analyzed throughout this report.

The sampling design was set up such that each site, would be visited 7 times approximately every week from mid- June through early October. This time frame allowed for the capture of water quality conditions throughout the potential growing season. The collection of samples was generally split into two groups, 1-7 and 8-15, and completed over two days to allow time for overnight shipping. Coordination with Northland College occurred to sample on the same days that WDNR was sampling, most rounds of sampling this method worked, but there were some rounds where Northland was able to collect when WDNR was unable to due to weather. When weather conditions restricted sampling, algal ID sites and sites further east (Siskiwit Bay to Bad River) were prioritized, as these areas are where historic blooms occurred.

Table 1: **Dates of sample collection by mobilization for WDNR and Northland College monitoring.** This table details the temporal range of each sampling round (mobilization) during the 2024 season. It outlines the specific start and end dates for the subsequent hydrodynamic and nutrient data collections.

Sampling Round	Date
1	June 10th and 11th
2	July 9th and 11th
3	July 22nd, 24th, and 25th
4	August 12th and 13th
5	August 26th
6	September 9th
7	September 30th, October 4th and 8th

Table 2: **Details of sampling locations by station including SWIMS identification and geographical coordinates.** This table provides a comprehensive reference for each monitoring site utilized during the 2024 season. It includes the station number, the Surface Water Integrated Monitoring System (SWIMS) station ID and names, as well as the precise latitude and longitude for each WDNR and Northland College sampling site.

Station	SWIMS Station ID	SWIMS Station Name	Latitude	Longitude
1	10040814	Lake Superior – Point off Schaffer Beach 3.6 m contour	46.68592	-91.929726
2	10052502	Lake Superior – W. of Amnicon	46.69601	-91.849785
3	101	Lake Superior – N.E. Poplar River	46.7	-91.78334
4	10052503	Lake Superior – W. of Bardon Cr	46.71865	-91.72388
5	10052504	Lake Superior – E. of Pearson Cr. Station	46.73117	-91.67240
6	103	Lake Superior – W. of Brule R.	46.7486	-91.618065
7	10052505	Lake Superior – W. of Douglas Co Line	46.75911	-91.571304
8	10052587	Lake Superior – E. Iron River	46.77119	-91.48382
9	10052510	Lake Superior – E. of Flag River Station	46.79663	-91.37061
10	10052511	Lake Superior – Block 11	46.83277	-91.29428
11	10052514	Lake Superior – Cranberry River	46.8377	-91.2646
12	10038057	Lake Superior – Bark Bay Point Clay Bluffs	46.8675	-91.22806
13	10052512	Lake Superior – Bark Bay W. of Bark R	46.85046	-91.1902
14	10052513	Lake Superior – Siskiwit Bay	46.85905	-91.115295
15	10054863	Lake Superior –Bay	46.88067	-91.0615
16	10058871	Lake Superior – Little Sand Bay	46.9550318	-90.8905818
17	10038061	Lake Superior – Red Cliff Bay	46.88028	-90.763885
18	10044196	NC Cheq Bay Site 10	46.71722	-90.84085
19	10044195	NC Cheq Bay Site 1	46.59708	-90.91349
20	115	Lake Superior at Bad River	46.6375	-90.63333

Sample Collection

Sample collection on Lake Superior is highly subject to weather conditions. During sampling weeks, the crew monitored weather conditions, and in the interest of crew safety, sampled on days where waves were less than 2 feet. Therefore, there are some gaps in site data due to unsafe weather conditions. Wind magnitude and direction can vary rapidly over the course of a day, which made it necessary to amend sampling plans in the field, leading to some sites not being sampled during a sampling event. To try to keep the timing consistent throughout the season, samples were only collected the weeks determined at the beginning of the season. Throughout those weeks, samples were collected on Mondays, Tuesdays, or Wednesdays. There was a shipping delay the second day of the first round that impacted hold times and temperatures of parameters. The dates sampled are shown in *Table 1*.

Time of arrival, weather conditions, latitude/longitude, and depth were recorded once the site was reached. Secchi depth was collected on the shaded side of the vessel. The depth at which the disk disappeared and reappeared was recorded. This measurement was completed by the same researcher in each sampling round to ensure consistency throughout the dataset.

Sonde profiles for WDNR were collected using a YSI ProDSS of dissolved oxygen (concentration and percent), temperature, specific conductance, pH, and turbidity at each site during each event. The sonde was calibrated to the standards of the manual. pH and conductivity were calibrated daily using standard solutions purchased from YSI. The pH probe did not pass its calibration checks at the beginning of the season and new probe was purchased and installed. After a few weeks of trouble shooting another probe was sent, but this did not occur until the end of the field season due to back log. No pH data was collected for the 2024 season for WDNR. Turbidity probe did not meet calibration standards and a new one was ordered as well. Northland College used Eureka Manta 30 multi-parameter sonde for collection of profile information.

Surface water samples were collected for chlorophyll-*a* (chl-*a*), total suspended sediment (TSS), orthophosphorus (ortho-P), total phosphorus (TP), total nitrogen (TN), and nitrate-nitrite (NO_3-NO_2). TP was run as low-level phosphorus (LLTP) with a lower detection method. Algal ID and enumeration samples were collected at Schaffer Beach, Poplar River, Brule River, Iron River, Flag River, Siskiwit Bay, Little Sand Bay, NC Cheq Bay Site 1, and Bad River (sites 1, 3, 6, 8, 9, 14, 16, 19, and 20, respectively), throughout the sampling season to gain a better understanding of how the algal community shifts within the nearshore.

Prior to collecting water samples, sampling bottles and lids were triple rinsed with site water to minimize contamination. All samples were taken approximately 6 inches below the surface of the water. Sampling containers were filled to the shoulder of the bottle unless stated below. 1 mL of 25% H_2SO_4 sulfuric acid was added to the sample for nutrients that contain TP, TN, and NO_3/NO_2, to preserve until analysis. When LLTP was sampled, a separate sampling bottle that was acid washed was filled and preserved. Algal ID samples were preserved with 2.5ml of Glutaraldehyde before shipment.

Ortho-P and chl-*a* were field filtered. Ortho-P filtrate was collected through 0.45 µm MCE filters. Chl-*a* filtrate was collected through 5.0 µm MCE filters and then both were stored on ice in the dark. The volume of water that passed through each Chl-*a* filter was recorded for each site and sampling event. Northland College used slightly different filter methods due to equipment and time constraints. For SRP a 0.45 µm membrane filters was placed into clean filter cartridges. The cartridges were attached via a Luer lock fitting to the end of a 60mL polypropylene syringe and approximately 50mL of lake water was filtered into the 60mL SRP bottles. For Chl-a, water was collected into 1-liter, brown HDPE bottles in the field, stored in a cooler for transport to the Northland College lab. Either the day of sample collection or the following morning, the volume of sample water was measured into a pre-rinsed, glass 1,000mL graduated cylinder. Water was filtered through the 47mm, 5.0 µm filters using a glass filter tower and side-arm flask. Filters were folded inward and placed in a 15 mL polypropylene centrifuge tube and covered with duct tape to block light.

Samples were collected into appropriate sampling containers (*Table 3, Table 4*) and placed on ice. After returning to the dock, samples were shipped to the Wisconsin State Lab of Hygiene for analysis.

Table 3: **Methods for algal sample handling requirements and WSLH laboratory protocols for field collection.** This table summarizes the necessary procedures for collecting and transporting samples to the Wisconsin State Laboratory of Hygiene (WSLH). It outlines specific parameters, lab codes, collection bottle types, and field filtration mandates, alongside preservation methods, shipping instructions, holding times, and limits of detection (LOD). Within this table, the designation "NA" indicates requirements that are not applicable to a specific parameter.

Parameter	Lab Code	Collection Bottle	Field Filter?	Preservation/Shipping	Hold time	LOD
Chlorophyll-*a* (Chl-*a*)	ICC25120	500 mL plastic quart bottle	Yes 47 mm, 5 um pore, no more than 6 inches of mercury (20kPa)	If filtered 15 mL polypropylene centrifuge tube wrapped in foil on ice. If not packed with ice in a dark cooler	48 hours (unfiltered); 3.5 weeks (filtered)	0.0578 µg/L
Microcystin	ETC47500	Glass of PETG 125 to 1000 mL	No	Half filed bottles frozen< -20 C if not to be analyzed within 24-48 hrs	5 days	0.10 µg/L
Saxitoxin	ETC47520	40 or 60 mL Amber glass with Teflon caps	No	Add preservative at a rate of 1 mL of 10X Concentrated Sample Diluent per 9 mL of Sample. Store sample in a dark & cool location at all times. Ship overnight on Ice.	5 days or frozen	0.022 µg/L
Algal ID/Enumeration	ETC47001	250 mL plastic bottle	No	Glutaraldehyde 1 mL of 25% glutaraldehyde for every 100 mL	Several years	NA

Table 4: **Methods for nutrient sample handling requirements and WSLH laboratory protocols for field collection.** This table summarizes the necessary procedures for collecting and transporting samples to the Wisconsin State Laboratory of Hygiene (WSLH). It outlines specific parameters, lab codes, collection bottle types, and field filtration mandates, alongside preservation methods, shipping instructions, holding times, and limits of detection (LOD). Within this table, the designation "NA" indicates requirements that are not applicable to a specific parameter.

Parameter	Lab Code	Collection Bottle	Field Filter?	Preservation/Shipping	Hold Time	LOD
Total Suspended Solids (TSS)	ICC65000	500mL plastic quart	No	Less than 6C	7 days	2
Orthophosphate (ORTHOP)	EPA 365.3	125mL polyethylene	Yes, 0.5 µm	Less than 6C, but not frozen	48 hours	0.0014
Low Level Total Phosphorus (TP)	ICC52010	250 mL plastic bottle	No	1mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.00190
Total Nitrogen (TN)	ICC46601	250mL plastic bottle	No	1mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.058
Nitrate/Nitrite (NO3/NO2)	ICC46000	250mL plastic bottle	No	1mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.055 mg NO3+NO2-N/L

Data Analysis

Lake Superior is an oligotrophic system; thus, it has low concentrations of nutrients. The values observed are at the lower limit of some of the methods used by the Wisconsin State Lab of Hygiene. There were many non-detects for TSS and ortho-P. LLTP dataset had values that were between the limit of quantification and the limit of detection. We acknowledge that we have a low degree of certainty for these values, but they are used in the analysis.

Data Visualization was completed using RStudio 2023.12.1.

For the summary statistics tables, non-detect values were replaced with half of the limit of detection. This provides a conservative estimate of average concentrations of parameters in the nearshore. For graphic visualization ND were not displayed.

For graphics and analysis of hydrologic information the depth of 0.5 m was used. This was done to pair values with surface water grabs for nutrients. When handling hydrodynamic data collected by Burke Center turbidity values that were designated <0.1 we treated as 0.1 in data analysis.

For full profile of water column view Appendix.

Results/Discussion

Gaps in the data are most likely due to sites not being sampled during a round of sampling. This was either caused by weather creating unsafe sampling conditions, or slow boating conditions such that a site had to be skipped to make it back in time to ship samples to the lab for analysis. The 2024 sampling season experienced some gaps due to weather, where we were unable to capture all sites. Sampling was distributed from mid-June to early October (*Table 1*). Only one rain/ runoff event was captured within the dataset after an early June rain (*Figure 2*).

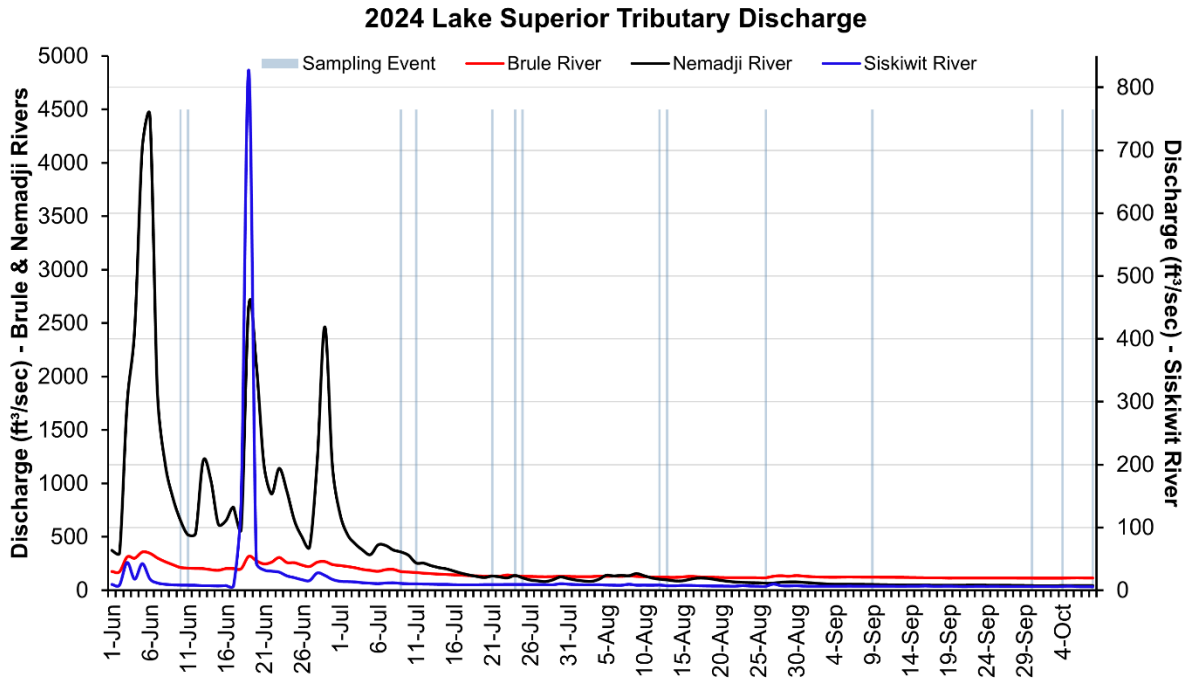

Figure 2: **Tributary discharge and sampling event timeline for the Brule, Nemadji, and Siskiwit Rivers.** The Figure displays daily discharge in cubic feet per second (ft3/sec) for three Lake Superior tributaries proximal to the monitoring sites. Discharge values are represented by red (Brule), black (Nemadji), and dark blue (Siskiwit) lines. To account for the significant difference in flow volumes, the Siskiwit River data is plotted on a secondary axis. Vertical light blue lines indicate the specific timing of 2024 sampling mobilizations, illustrating the hydrologic conditions present during each event.

Hydrodynamic Data

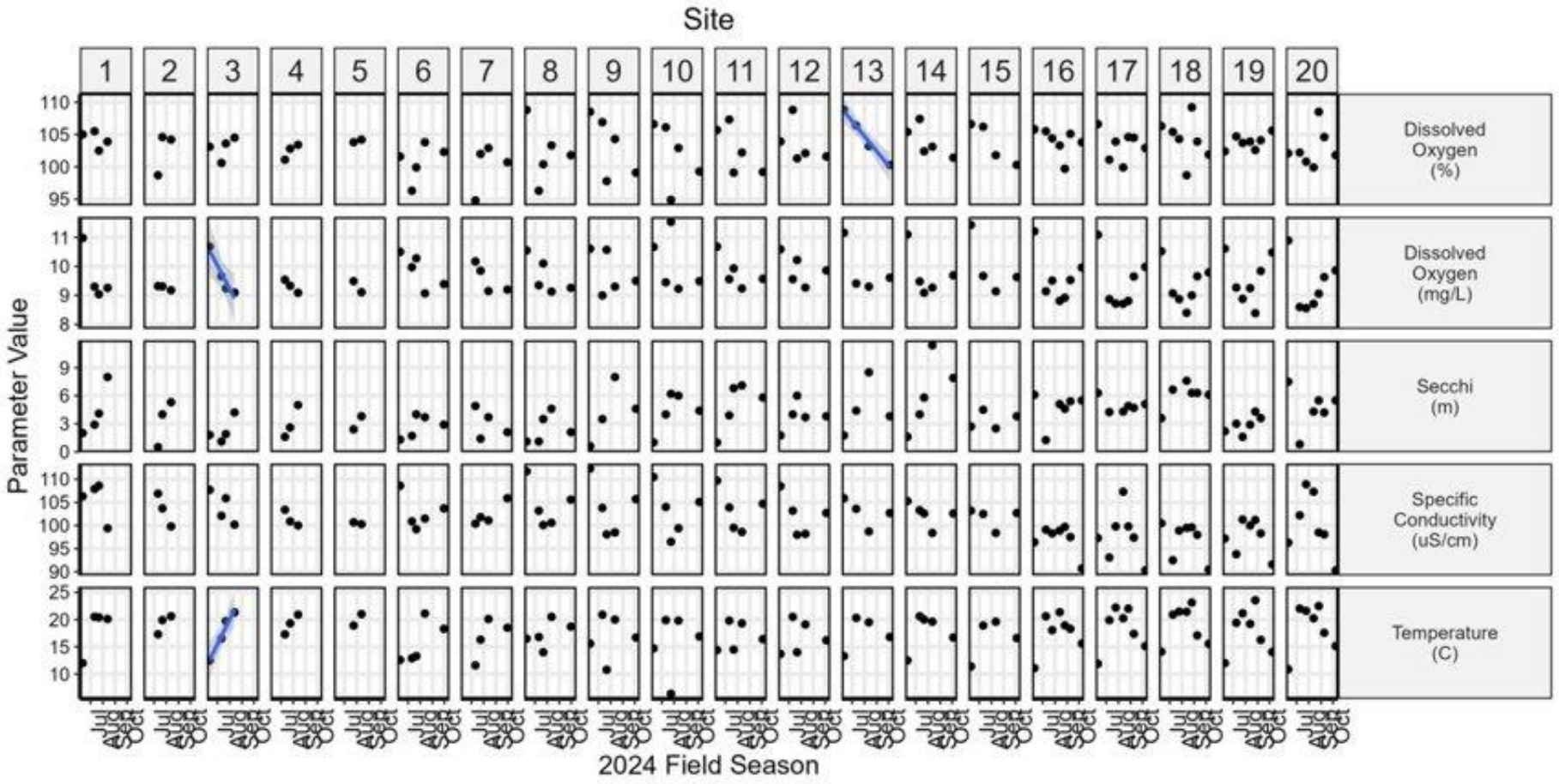

Figure 3: **Temporal trends in hydrodynamic parameters for each monitoring site at 0.5 m water depth for all sites and dates.** This figure illustrates the progression of measured parameters from June through October 2024, with site numbers indicated at the top of each column. Parameters are organized alphabetically, with black dots representing individual data points. Blue lines indicate linear regressions for significant trends ($p<0.05$), while grey shading represents the standard error of the model. Note that pH and turbidity data are omitted due to equipment malfunction; all other displayed data are from a consistent 0.5 m sampling depth.

Table 5: **Descriptive statistics for hydrodynamic measurements using sonde measurements at 0.5 m depth.** This table summarizes physical water characteristics collected across all 2024 monitoring sites. Statistics provided include the sample count (*n*), mean values, minimum and maximum ranges, and standard deviation (Stdev). All data represent measurements recorded at a consistent 0.5 m surface depth to characterize the surface water conditions of the Lake Superior nearshore region.

Hydrodynamic Parameter summaries averaged over sites and sampling rounds.

Parameter	Count	Mean	Min	Max	Stdev
Dissolved Oxygen (%)	99	102	96	108	3
Dissolved Oxygen (mg/L)	99	9.8	8.4	11.2	0.7
Secchi Depth (m)	99	4	0	12	2
Specific Conductivity (uS/cm)	99	100	90	110	5
Temperature (°C)	99	18	6	24	3

Temperature

Water temperature is a driving factor for if and when an algal bloom may occur (Calieri et al., 2014). Temperatures greater than 10 °C are considered to promote the growth of algal blooms (Sterner et al., 2020). The average surface temperature recorded for this field season was 17.6°C. While surface temperatures were warm enough to promote the growth of a bloom, there was no long-lasting or widespread bloom event during this sampling season. This indicates that factors other than water temperature are necessary to have algal bloom formation in Lake Superior's nearshore environment.

The maximum temperatures occurred at the end of July through the end of August (*Table 5*). An upwelling event was captured at the end of July, where sites experience cold water coming to the surface. Sites in the middle of the western arm, including Flag River, Block 11, and Cranberry River (sites 9, 10, and 11, respectively), experienced the most fluctuation of temperature during the upwelling event (*Figure 3*). In general, Poplar River (site 3) experienced a significant increase in temperature throughout the sampling season (*Figure 3*).

The first sampling round, which occurred in mid-June, showed the coldest water temperatures for the season at Bark Bay Point Clay Bluffs (site 12) at 6.4 °C (*Table 5*). Samples collected in early October fell within the middle of the temperature distribution for the sampling season (*Figure 3*). These sites profile data (Appendix A1-A4) shows minimal thermocline development, with a slight thermocline shown at NC Cheq Bay Site 10 (site 18) at the end of August.

Turbidity

The turbidity sensor was inoperable and unable to be replaced during the field season; therefore, data could not be collected. Secchi depth was recorded to measure water transparency and will be used for determining trends and conclusions for this season. The earliest sampling rounds, which occurred in mid-June and early-July, had the lowest water clarity. Values recorded in mid-August were generally high clarity values for the season. The greatest transparency of 11.4 meters was recorded at Siskiwit Bay (site 14) in mid-August. The site groupings Brule River to Iron River, Block 11 to Cranberry River, and

Bardon Creek & Brule River (sites 6-8, 10-11, and 4 & 6, respectively) each demonstrated similar Secchi depth patterns over the sampling season.

PH

The pH sensor was inoperable and unable to be replaced during the field season; thus, pH was not interpreted for this report. Burke Center did collect pH data with their sonde profiles, which is available in synthesized dataset in appendix.

Dissolved Oxygen (DO)

When analyzing results, it is suspected that the DO sensor may have experienced technical issues, as the percentage values seem inaccurate when compared to other in-situ values. However, the DO mg/L values seem accurate and will be interpreted to determine trends and conclusions for this season. The maximum DO values occurred at the end of July, which was the same time the upwelling event was observed (*Table 5*). Specifically, Block 11 (site 10) experienced a maximum value of 11.5 mg/L at this time. The minimum value of 8.4 mg/L was recorded at NC Cheq Bay Site 10 (site 18) in mid-August. In general, Poplar River (site 3) experienced a significant decrease in DO across the sampling season.

Nutrients

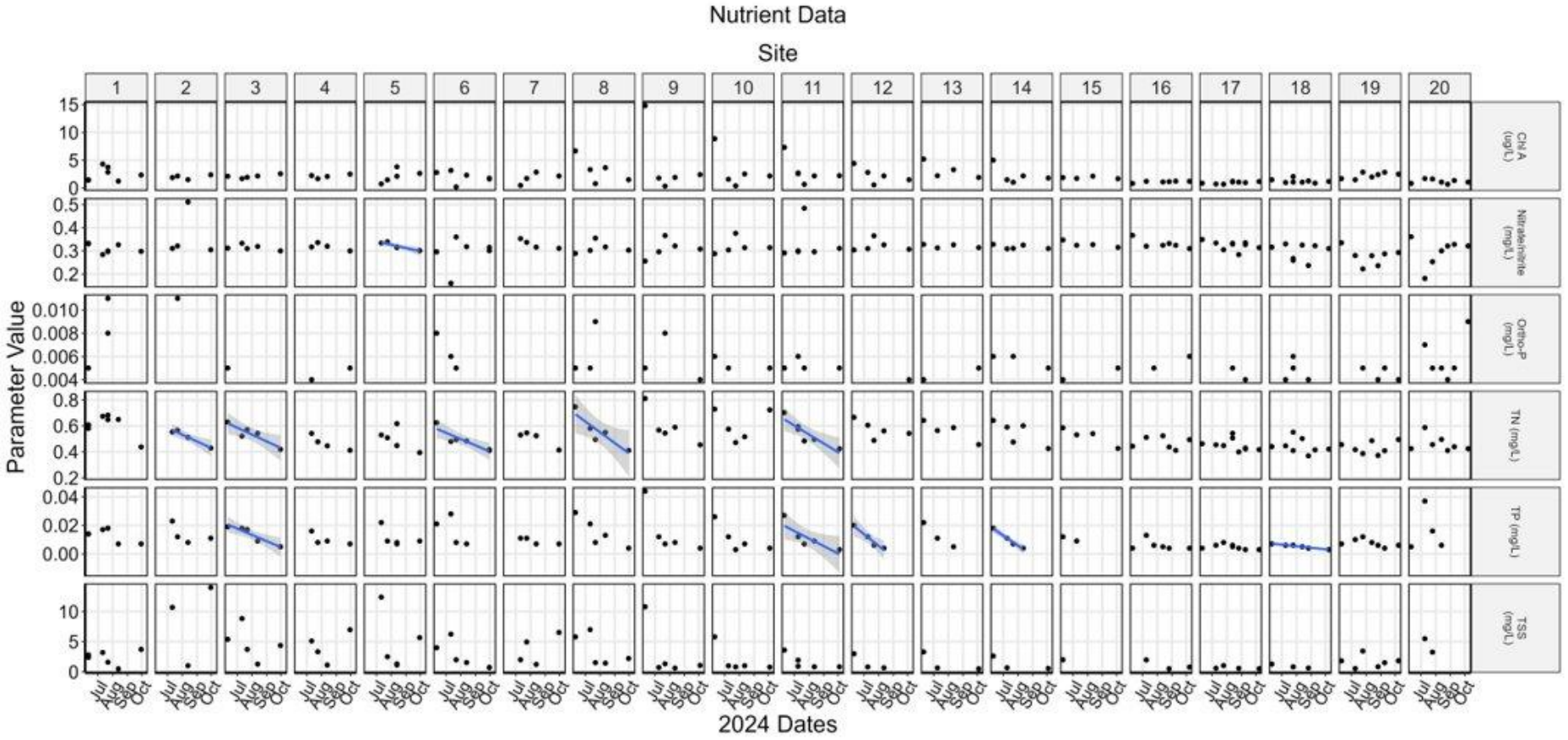

Figure 4: **Temporal trends in nutrient parameters for each monitoring site for all sites and dates.** This figure illustrates the progression of measured parameters from June through October 2024, with site numbers indicated at the top of each column. Parameters are organized alphabetically, with black dots representing individual data points. Blue lines indicate linear regressions for significant trends ($p<0.05$), while grey shading represents the standard error of the model.

Table 6: **Descriptive statistics for nutrient measurements using laboratory analysis of surface water samples.** This table summarizes the chemical nutrient concentrations across the study area for the 2024 season. It includes the sample count (*n*), mean concentrations, minimum and maximum ranges, and standard deviation (Stdev). These values are derived from surfaces water samples and provide a baseline for the nutrient status assessments discussed throughout this report.

Nutrient summaries averaged over sites and sampling rounds.

Parameter	Count	Mean	Min	Max	Stdev
Chlorphyll A (µg/L)	80	2	0	14	2
Nitrate + nitrite (mg/L)	80	0.28	0	0.49	0.07
OrthoP (mg/L)	80	0.003	0	0.012	0.003
TN (mg/L)	80	0.5	0	0.8	0.1
TP (mg/L)	80	0.008	0	0.048	0.008
TSS (mg/L)	80	2	0	12	2

Chlorophyll-*a* (Chl-*a)*

Chlorophyll-*a* (chl-*a*) can be used to measure the overall algal biomass in aquatic ecosystems. It is also a metric that details primary productivity within an aquatic ecosystem. Chl-*a* presence is a common response metric when there is an increase in phosphorus concentrations (WDNR WisCALM, 2020).

Most samples (59%) were below 2 µg/L of chlorophyll-*a*. Generally speaking, chl-*a* values tend to be highest at the beginning and end of the sampling season, with an observed decrease towards the middle of the season. The chl-*a* maximum occurred in mid-June at Flag River (site 9) with a recorded value of 14.8 µg/L. The timing of this corresponds to a large rain event that occurred early June, as shown by large discharge event in the Nemadji river (*Figure 2*).

Although there were no significant trends overall, some observations could be made. Overall, Schaffer Beach (site 1) and the sites located in the middle western arm, especially Flag River, had the largest variation in chl-*a* concentrations. In contrast, the sites located further west (Schaffer Beach to Iron River) experienced the littlest change over time during this sampling season (Figure 2). The sampling at the end of July experienced the overall lowest chl-*a* values of any sampling round (Figure 2). Average concentrations for chl-*a* were greatest in the central south shore sampling region including Iron River to Siskiwit Bay (sites 8-14. respectively), with sites further east (Miwakuie Bay to Bad River) experiencing generally low chl-*a* concentrations (Figure 5).

Lake Winnipeg, a large freshwater lake in Manitoba Canada, uses 10 µg/L as an indicator of potential bloom conditions (Binding et al., 2018). During this sampling season, one sample reached 14.8 µg/L, indicating that there was a large amount of primary production occurring at the site (*Table 6*). Most likely a visible bloom would have occurred if wind and wave conditions were amenable.

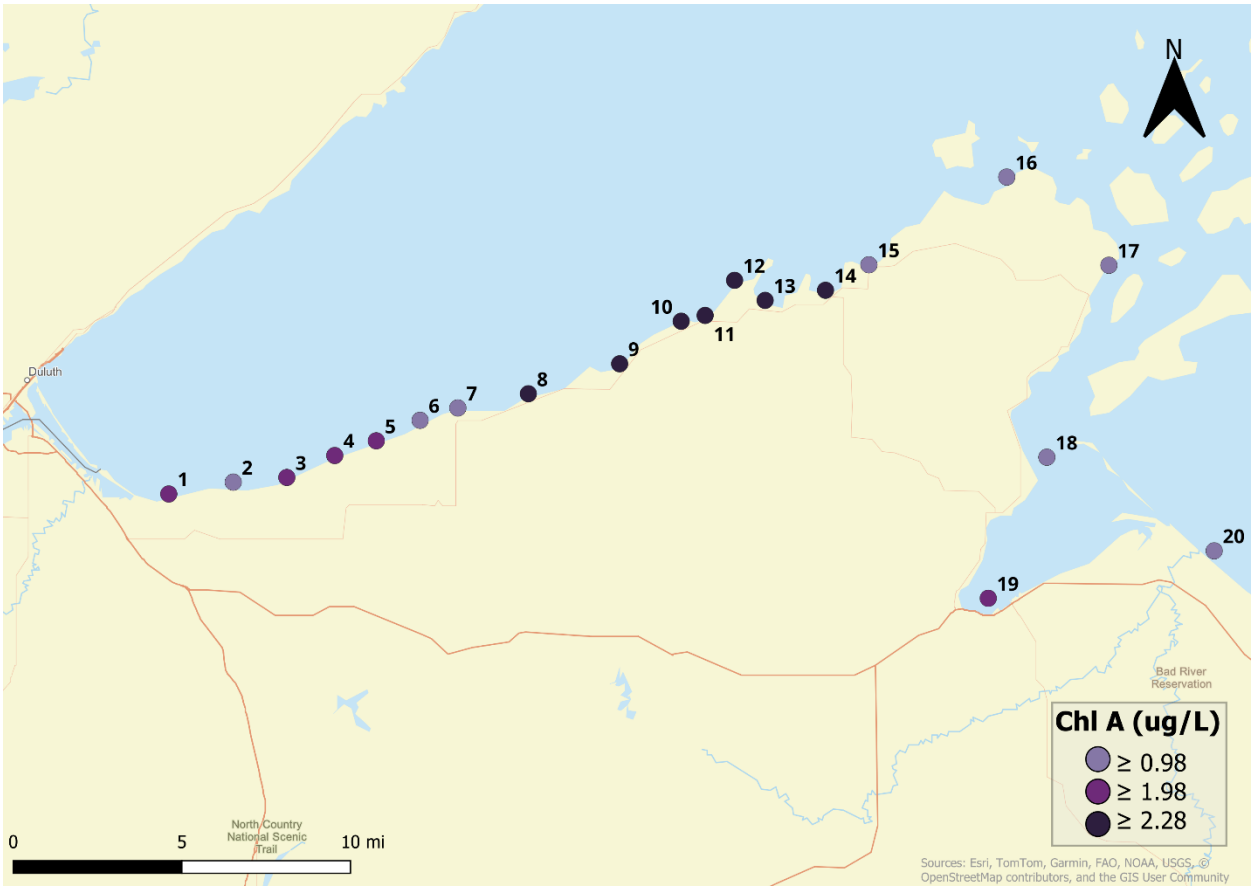

Figure 5: **Spatial distribution of average chlorophyll-*a* concentrations across the 2024 monitoring sites.** This map illustrates the mean chl-*a* values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of chl-*a* values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

Nitrate/Nitrite (NO3/NO2)

The eastern sites (Miwakuie Bay to Bad River) exhibited greater variability in concentrations compared with the western sites (Schaffer Beach to Iron River) (Figure 4). Brule River (site 6) in mid-July showed an unusually low value, whereas Amnicon (site 2) in mid-August displayed an abnormally high concentration and again recorded a pronounced peak in late-August (Figure 4). During late-July, which coincided with the upwelling event, the middle sites (Flag River to Siskiwit Bay) generally experienced elevated concentrations. In contrast, Pearson Creek (site 5) showed a marked decline over the course of the sampling season (Figure 5). Nitrate/Nitrite values trends vary drastically depending on sites locations, indicating that this nutrient is heavily influenced by tributary discharge and hydrodynamics of the area.

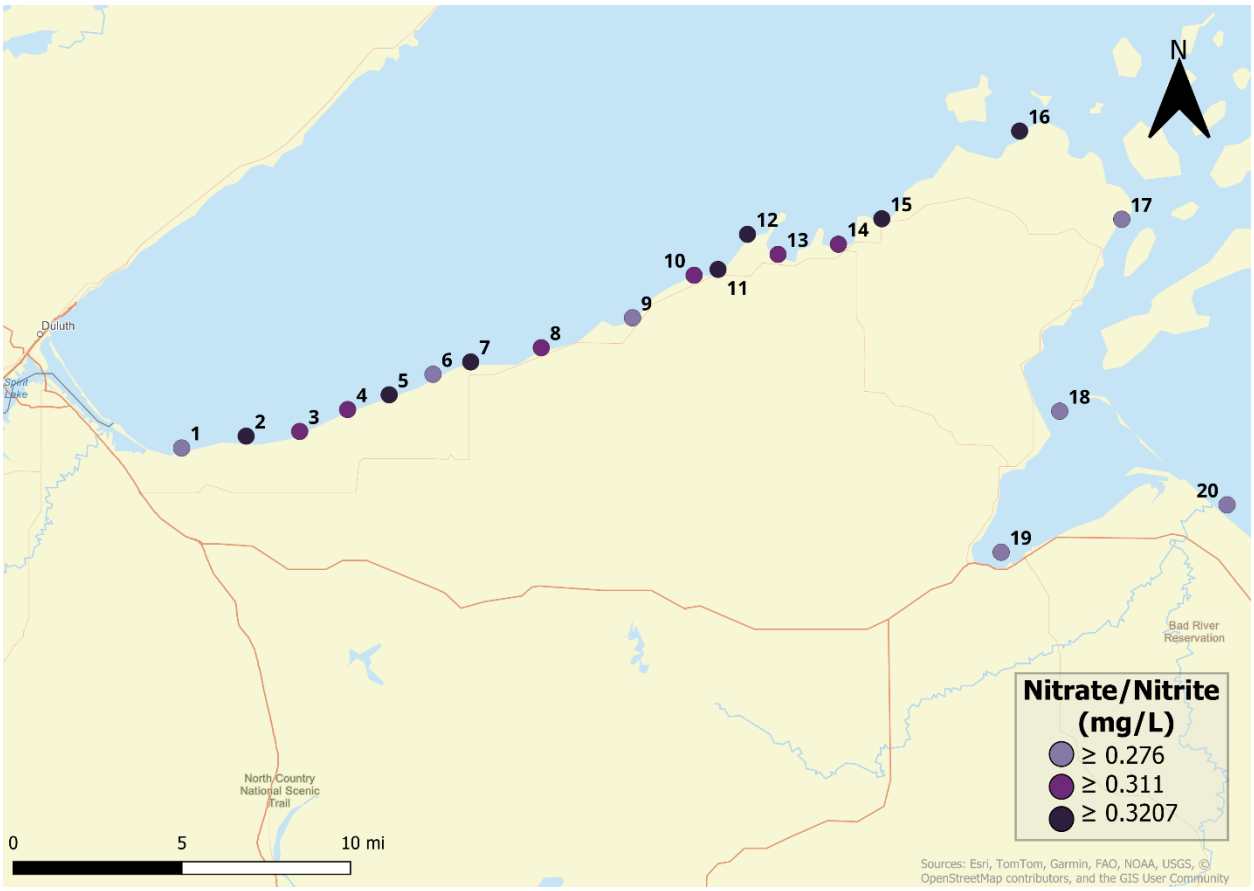

Figure 6: **Spatial distribution of average nitrate-nitrite concentrations across the 2024 monitoring sites.** This map illustrates the mean nitrate-nitrite values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of nitrate-nitrite values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

Ortho Phosphorus (Ortho-P)

In previous sampling seasons, Ortho-P values were typically below the limit of detection, whereas this year there were more detections. Variance in Ortho-P concentrations differed across the sites. The eastern sites (Miwakuie Bay to Bad River) showed a distinctly different pattern from the middle sites (Flag River to Siskiwit Bay), which had several non-detects, especially at Bark Bay Point Clay Bluffs, Little Sand Bay, and Red Cliff Bay (sites 12, 16, and 17, respectively) (Figure 4). Average concentrations across the sampling season shows that Ortho-P values were lowest in Bark Bay Point Clay bluffs, Bark Bay and Miwakuie Bay (Figure 7). Late July higher-than-average concentrations overall were recorded, and Ortho-P levels were generally higher at the western sites (Schaffer Beach to Iron River) compared with the eastern sites (Miwakuie Bay to Bad River) (Figure 4). Approximately 40% of the total samples were non-detects.

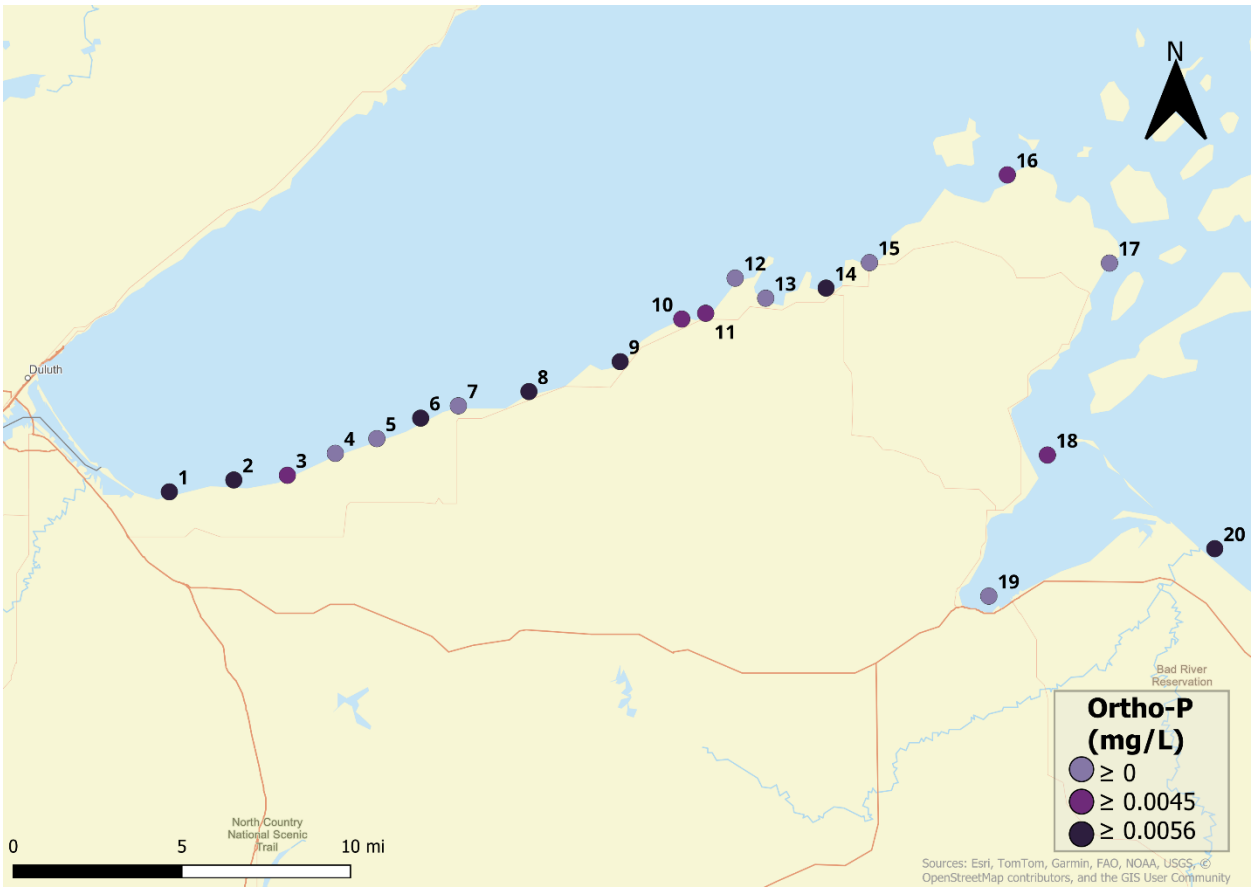

Figure 7: **Spatial distribution of average orthophosphorus (ortho-P) concentrations across the 2024 monitoring sites.** This map illustrates the mean ortho-P values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of ortho-P values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

Total Nitrogen (TN)

The majority of sites show similar values throughout the season, ranging from 0.07 to 0.81 mg/L. The overall maximum values occurred in mid-June, with the highest season value recorded at Flag River (site 9) (Figure 4). Throughout the sampling season there was a significant decrease in the values at Amnicon, Poplar River, Brule River, Iron River, and Cranberry River (sites 2, 3, 6, 8, and 11, respectively) (Figure 4). Samples collected in early October were fairly consistent as the lowest values of the season across all of the sites. In general, it can be observed that the means from Flag River to Bark Bay (sites 9-13, respectively) were higher than the sites oriented to the east (Miwakuie Bay to Bad River) or west (Schaffer Beach to Iron River) (Figure 8).

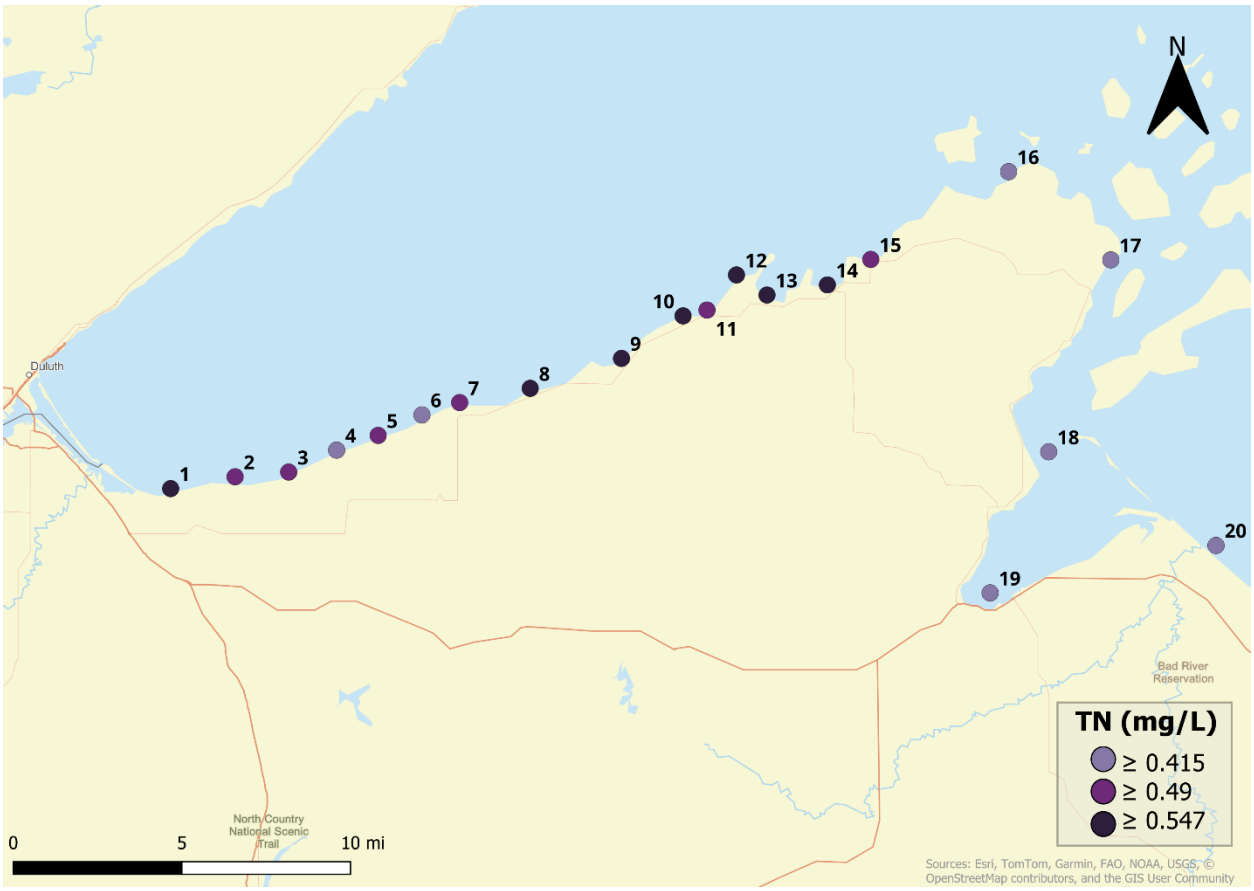

Figure 8: **Spatial distribution of average total nitrogen (TN) concentrations across the 2024 monitoring sites.** This map illustrates the mean TN values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of TN values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

Total Phosphorus (TP)

Phosphorus is an influential macronutrient that regulates the growth of algae within an aquatic ecosystem. Phosphorus in the nearshore could be from a variety of sources such as agricultural runoff, nearby wetlands, and the resuspension of sediments. Inputs from local tributaries with varying biological conditions may factor in as well. Phosphorus can bind to varying sediment types, such as iron (Fe) and rich clay, and when storm events occur, resuspension and redistribution of phosphorus in an aquatic system may occur (Bennington et al., 2010). The source of phosphorus in this area is not known, but it is important to think of what sources are potentially contributing when interpreting data.

Inland lakes and impoundments of Wisconsin have experienced algal blooms when concentrations of TP were 20 µg/L and 30 µg/L, respectively, or higher (WDNR Lakes). Typically, nearshore phosphorus concentrations are in the 5-10 µg/L range. Low concentrations of phosphorus in the nearshore likely limit growth of algal communities. On average, sites from this field season had a concentration of 8 µg/L, with a maximum value

of 48 µg/L (*Table 6*). This indicates that nearshore TP concentrations have a large variance and when determining if a location meets the phosphorus criteria, duration of elevated concentrations should be considered.

The low-level total phosphorus method was implemented for all rounds of sampling, this reduced the number of non-detects in the dataset compared to previous years. Only one non-detect was recorded at Miwakuie Bay (site 15) for the sampling season. Miwakuie to NC Cheq Bay Site 1 (sites 15-19, respectively) exhibited lower concentrations and variability in their observed concentrations than the other sites (Figure 4, Figure 9). In general, samples collected in mid-June, and mid-July had the higher values for the season (*Figure 4*). Douglas Co Line (site 7) was generally lower in value when compared to the rest of the western arm sites (Figure 9). Throughout the season a decreasing trend was observed at Poplar River, Cranberry River, Bark Bay Point Clay Bluffs, Siskiwit Bay, and NC Cheq Bay Site 10 (sites 3, 11, 12, 14, and 18, respectively) (Figure 4). The maximum value of 0.044 mg/L for TP for the season was reached during June at Flag River (site 9) (Table 6).

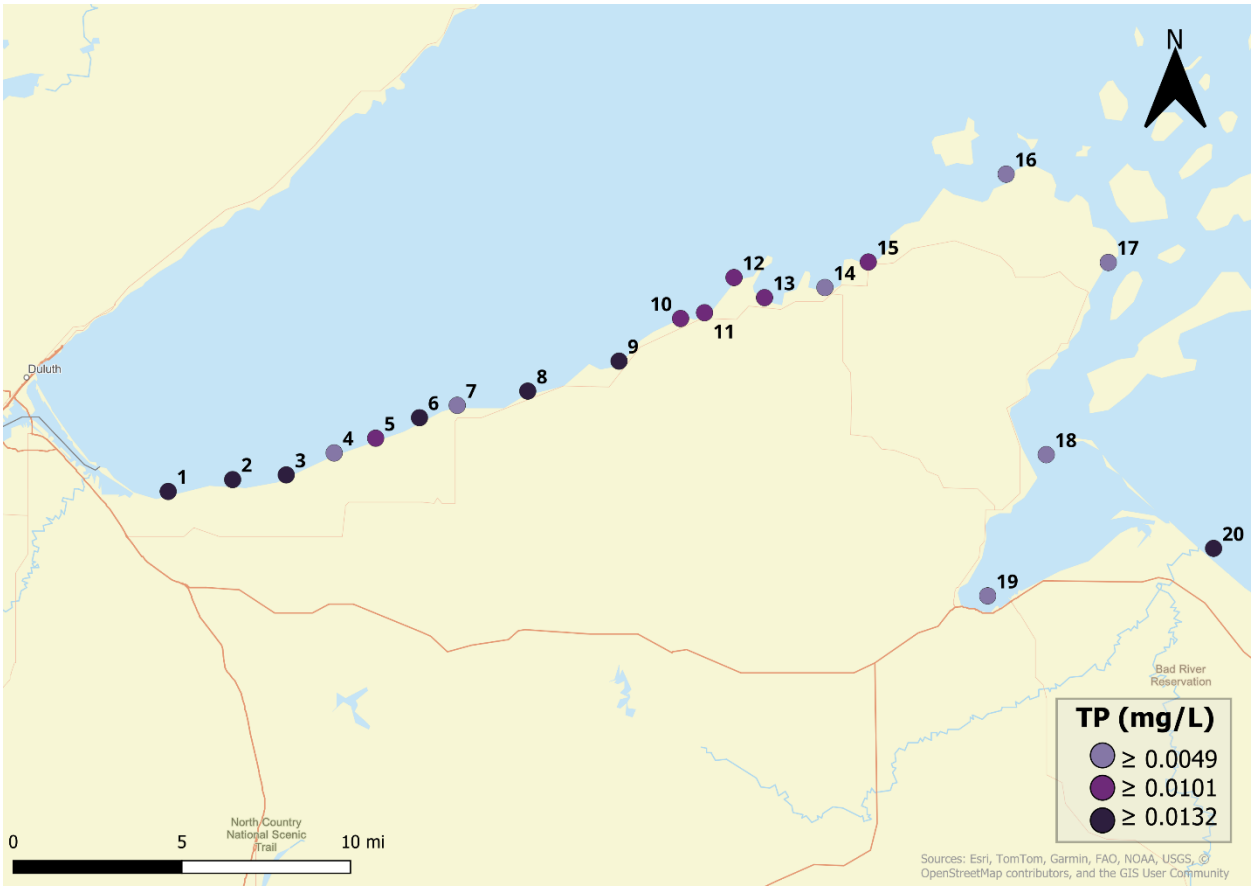

Figure 9: **Spatial distribution of average total phosphorus (TP) concentrations across the 2024 monitoring sites.** This map illustrates the mean TSS values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of TSS values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

Total Suspended Solids (TSS)

There were no significant trends for TSS values at any of the sites during the sampling season. There were more detections of TSS than previous years. Schaffer Beach to Iron River (sites 1-8, respectively) generally had higher TSS values than Flag River to Bad River (sites 9-20, respectively), while overall TSS values decreased in an eastward direction (Figure 10). The highest TSS values were collected during mid-June and early July, with a maximum value of 14.0 mg/L West of Amnicon (site 2). The season minimum value was 0.508 mg/L at Schaffer Beach (site 1) in mid-August.

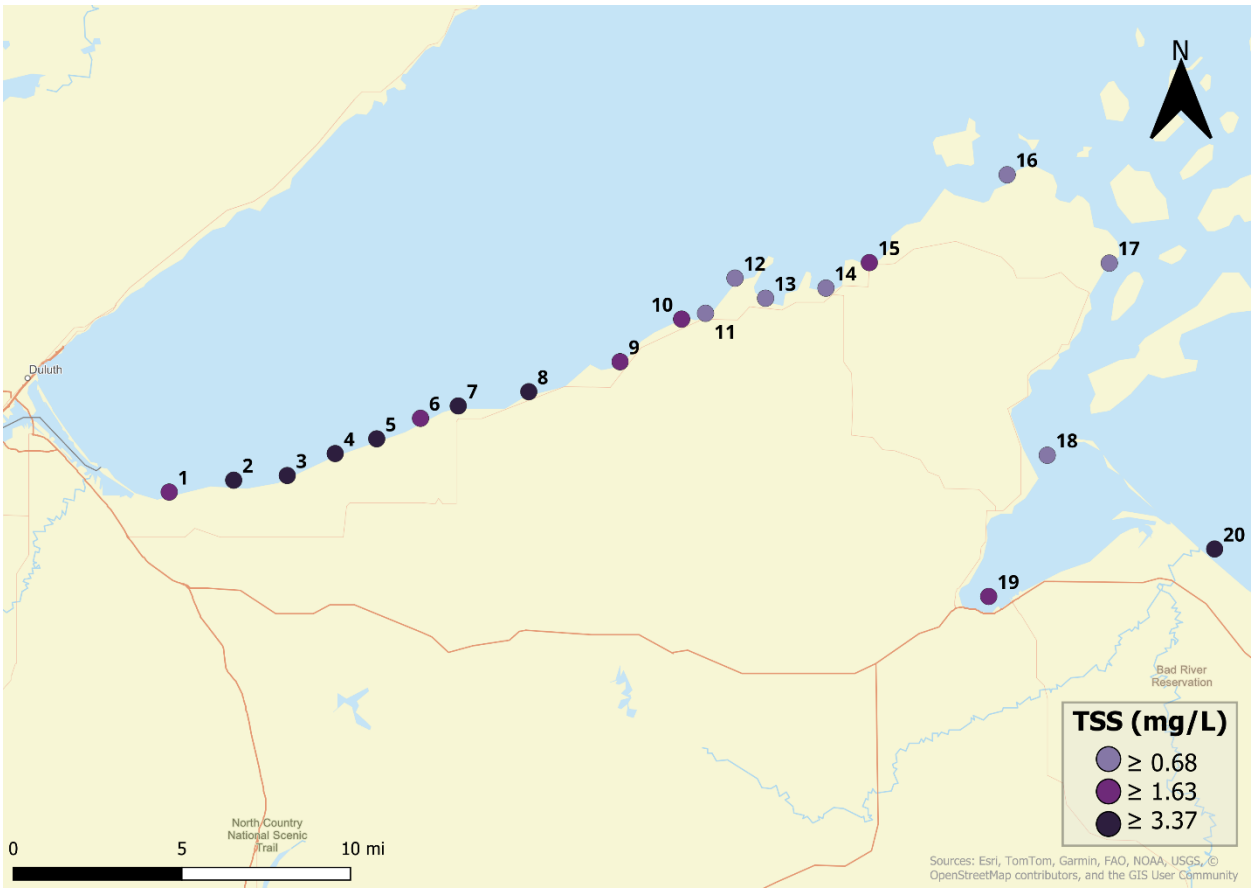

Figure 10: **Spatial distribution of average total suspended solids (TSS) concentrations across the 2024 monitoring sites.** This map illustrates the mean chl-*a* values derived from nutrient samples collected at each station throughout the sampling season. The color groupings are assigned based on the natural distribution of the observed data, allowing for a relative comparison of TSS values across the Lake Superior nearshore region. This visualization highlights localized hotspots and gradients within the specific context of the 2024 data range.

N:P Ratio

Table 7: **Redfield ratio interpretation of molar ratios derived from the calculation of total nitrogen to total phosphorus (TN:TP).** This figure evaluates the nutrient limitation status across the 2024 sampling sites by comparing observed molar concentrations to the standard Redfield ratio (16N:1P). Deviations from this ratio are used to indicate whether primary production in the nearshore region is potentially limited by nitrogen or phosphorus.

Molar Ratio Range	Limitation Status
< 20	N-limited
20 to 50	Co-limited
> 50	P-limited

To characterize nearshore nutrient dynamics in Lake Superior, molar ratios of total nitrogen to total phosphorus (TN:TP) were evaluated for the 2024 seasonal period (June-September). TN:TP ratios serve as a screening-level indicator to identify spatial patterns and relative nutrient balance rather than as a direct predictor of bloom occurrence (*Figure 11*). For this analysis, duplicate samples were averaged and non-detects were excluded. Site-specific seasonal means were then calculated by converting mass-based concentrations to molar concentrations using the atomic weights of nitrogen (14.01 g/mol) and phosphorus (30.97 g/mol):

$$TN{:}TP = \frac{TN(mg/L)/14.01}{TP(mg/L)/30.97}$$

Total Nitrogen to Total Phosphorus Molar Ratio

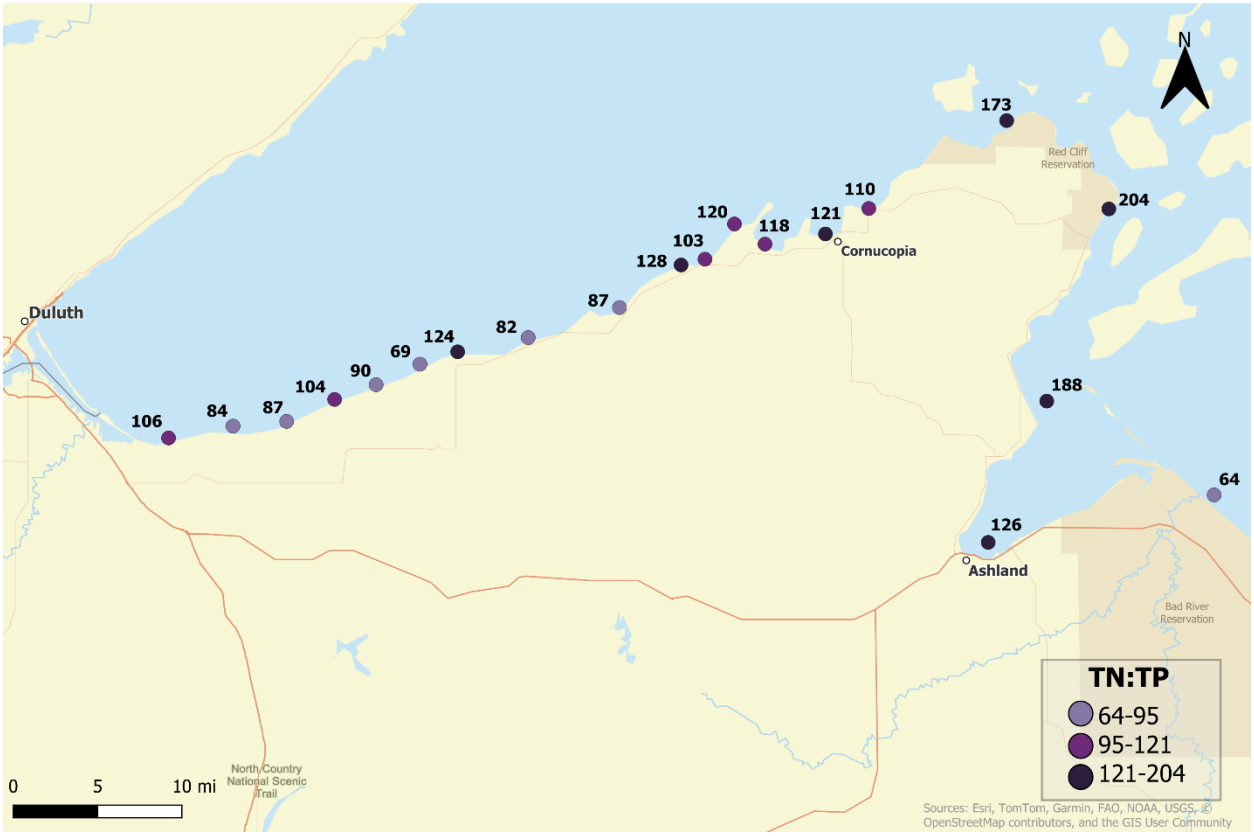

Figure 11: **Nitrogen to phosphorus molar ratio distribution per site for the 2024 sampling season.** This figure illustrates the stoichiometric relationship between total nitrogen (TN) and total phosphorus (TP) across the study area. Molar ratios were calculated by converting mass-based concentrations using the atomic weights of nitrogen

(14.01 g/mol) and phosphorus (30.97 g/mol). Color groupings are assigned based on the natural distribution of the observed data, providing a spatial representation of nutrient availability and potential limitation across the Lake Superior nearshore.

Across all sites, TN:TP ratios indicated phosphorus-limited conditions, with all values exceeding the Redfield Ratio of 16:1 and the regional p-limitation threshold of >50 (*Table 7*). While p-limitation was consistent across all sites, notable spatial variability existed (Figure 11). The Apostle Islands (sites 16-18) and the Bark Bay-Siskiwit region (sites 12-14) formed distinct high-ratio clusters; both areas have historically supported cyanobacterial blooms. In contrast, the Bad River site (site 20) exhibited the lowest TN:TP ratio in the study, driven by elevated tributary phosphorus inputs and slightly below-average total nitrogen. These patterns followed a spatial gradient where the highest TP values were concentrated in the western arm, and the highest TN occurred in the middle region (sites 8-15). Consequently, western arm sites averaged 102, which fell below the study wide mean of 114.

These spatial patterns likely reflect the combined influence of watershed characteristics, localized hydrodynamics, and varying nutrient sources. High TN:TP ratios in the Apostle Islands suggest a system shaped by limited nutrient inputs and the dilutive effects of mixing with offshore waters. Conversely, the lower ratios near the Bad River (site 20) indicate tributary-driven phosphorus enrichment. Overall, this descriptive analysis highlights shifts in nutrient balance across the nearshore and identifies regions of interest for focused monitoring, though it is important to recognize that TN:TP serve as a diagnostic indicated rather than a sole predictor of bloom drivers.

NCCA Eutrophication Index

The trophic condition of each nearshore site was evaluated by calculating a eutrophication index based on the framework established in the National Coastal Condition Assessment (NCCA) 2015 Technical Support Document. This approach prioritized indicators of nutrient enrichment because they represent a primary concern for nearshore habitats influenced by land-derived inputs over general chemical water quality. The index integrates four specific metrics including concentrations of total phosphorus and chlorophyll-a collected 0.5 m below the surface, water transparency via Secchi depth, and benthic dissolved oxygen recorded 0.5 m above the substrate. This combination of parameters captures both the presence of nutrients and the resulting biological response within the water column. For Lake Superior, the EPA established specific criteria to classify these data into "Good", "Fair", or "Poor" categories (*Table 8*).

Table 8: **Individual indicators for NCCA eutrophication classification based on established national water quality standards.** This figure breaks down the specific metrics used to determine the trophic status of each site, including total phosphorus, chlorophyll-*a*, dissolved oxygen, and Secchi depth. Each site is evaluated against the NCCA benchmarks to categorize sites into distinct tiers, providing a standardized assessment of eutrophication risk across the Lake Superior nearshore area.

Indicator	Good	Fair	Poor
TP (µg/L)	≤ 5	> 5 to ≤ 10	> 10
Chl-a (µg/L)	≤ 1.3	>1.3 to ≤ 2.6	> 2.6
DO (mg/L)	> 5	≤ 5 to > 2	≤ 2
Secchi (m)	> 8	≤ 8 to > 5.3	≤ 5.3

To determine the overall categorical rating for a site, these individual indicator ratings were synthesized using a standardized decision logic. A site was classified as "Good" if no indicators were rated poor and no more than one was rated fair. A "Fair" rating was assigned if one indicator was rated poor or if two or more indicators were rated fair. A site was designated "Poor" if two or more indicators were rated poor. In cases where data were insufficient, specifically if two or more indicators were missing and the available data did not already result in a fair or poor rating, the site was classified as "Missing".

Figure 12 shows that many South Shore sites were classified as "Poor" according to the EPA NCCA metrics. This characterization contrasts with the general ecological baseline and observations of resource managers. While short-term or localized increases in turbidity and chlorophyll-*a* were recorded, these conditions do not appear to be representative of the long-term state of the nearshore environment.

Discrepancies between these classifications and professional opinion likely reflect differences in sampling design and data integration rather than true degradation of ecological condition. In this study, values were averaged across the full sampling season at each site, whereas the NCCA classifications are intended to be derived from discrete, single-visit sampling events. Furthermore, the NCCA framework spans a broad depth range of approximately 2 to 30 m. In contrast, this project focused exclusively on the 5 m depth contour, a zone more directly influenced by tributary discharge and nearshore hydrodynamic processes.

The 2024 sampling season resulted in a greater proportion of sites being classified as "Poor" compared to the previous five years of monitoring (2019, 2021-2023 WDNR reports). This shift from "Good" or "Fair" to "Poor" condition was driven primarily by reduced Secchi depths (*Table 10*), which exerted a disproportionate influence on overall scores within the assessment framework. These reduced Secchi depths likely reflect increased turbidity from nearshore sediment resuspension and enhanced tributary inputs, potentially amplified by elevated stream discharge during the 2024 season. Such influences are more pronounced at the 5 m depth contour, where watershed and nearshore processes dominate. Consequently, the observed decline in condition classifications likely reflects heightened

sensitivity to event-driven nearshore conditions rather than a sustained deterioration in lake-wide water quality.

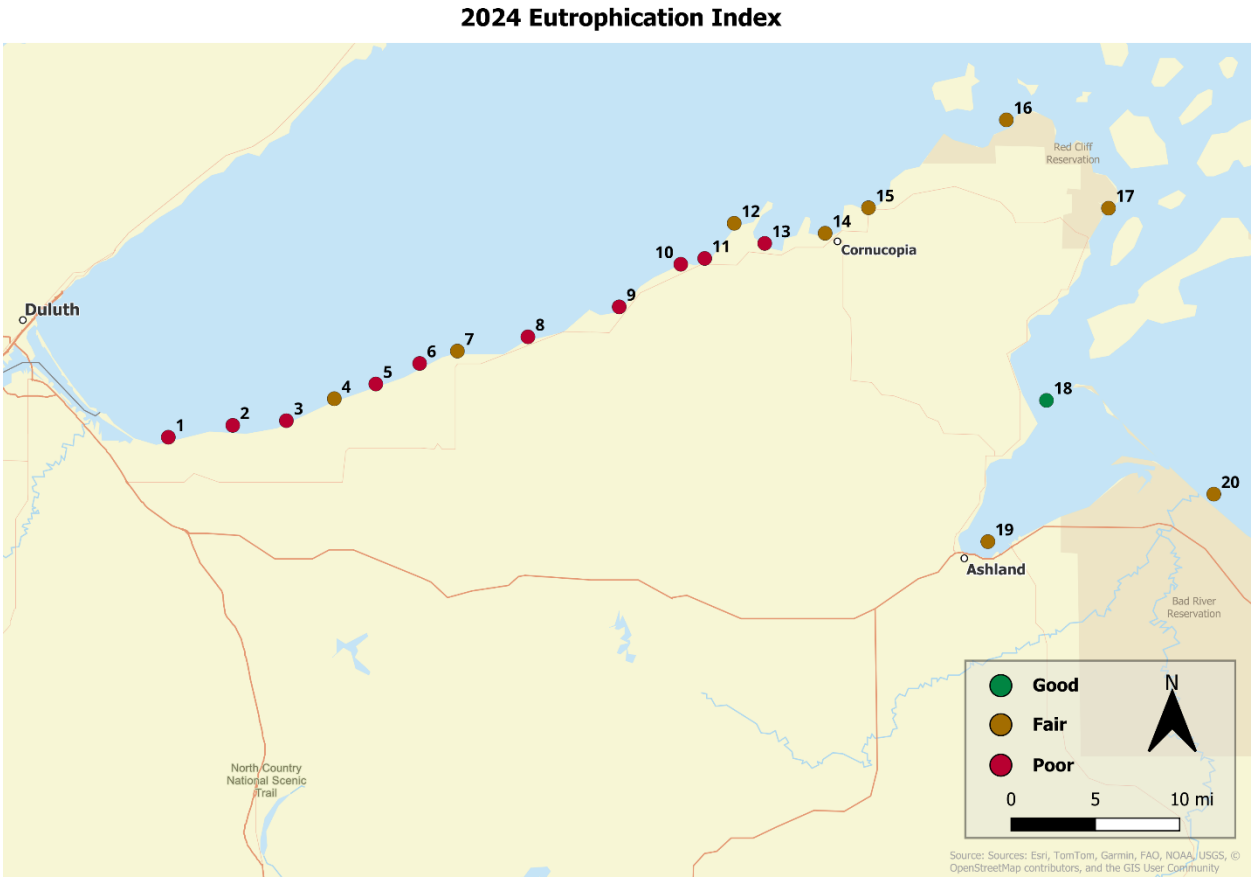

Figure 12: **2024 eutrophication index by site following National Coastal Condition Assessment (NCCA) parameters.** This map presents the final synthesized eutrophication rating for each site during the 2024 sampling season. The index integrates total phosphorus, chlorophyll-*a*, dissolved oxygen, and secchi depth values into a single categorical status. By applying the standardized NCCA framework, each site is classified as "Good," "Fair," or "Poor," providing a high-level summary of the coastal health and nutrient enrichment levels across the Lake Superior nearshore.

Table 9: **Summary of eutrophication indicators percent of sites per classification according to NCCA standards.** This table provides an overview of the 2024 results, displaying the proportion of monitoring locations that fall into "Good," "Fair," "Poor," or "Missing" categories for each measured parameter. By calculating the percentage of sites within each tier, this summary highlights which specific indicators are most frequently meeting or exceeding water quality benchmarks across the study area.

Condition	TP (mg/L)	Chlorophyll-*a* (mg/L)	Secchi Depth	DO (mg/L)	Overall Condition Eutrophication
% Good	10	20	0	100	5
% Fair	45	50	10	0	45
% Poor	45	30	90	0	50
% Missing	0	0	0	0	0

WisCALM

To provide an additional line of evidence for evaluating nearshore water-quality conditions, an informational assessment was conducted using Wisconsin's Consolidated Assessment and Listing Methodology (WisCALM). This framework provides standardized guidance for comparing water-quality data to surface water quality standards for Clean Water Act reporting. This analysis utilized a multi-year dataset spanning 2019 to 2024, specifically including sites with at least five years of available data. To ensure data integrity, blank and duplicate sample values were excluded from the dataset, and any non-detect values were adjusted to a value representing 50% of the limit of detection. To align with state assessment protocols, total phosphorus (TP) data were restricted to samples collected between June 1st and September 15th, while chlorophyll-*a* (chl-*a*) data were limited to the July 15th to September 15th period. Although WisCALM does not include assessment criteria tailored specifically to Lake Superior's nearshore environments, its framework offers a consistent approach for a comparative baseline analysis. In the absence of nearshore-specific criteria for Lake Superior, the two-story (epilimnetic) lake criteria for total phosphorus (15 µg/L) and chlorophyll-*a* (8 µg/L) were applied. This assessment followed a specific assessment logic to determine the final site condition. Monthly means were first calculated for each site; in instances where multiple samples were collected within a single month, a monthly average was determined for that period. A mean of monthly averages was then calculated from these values to represent the overall site condition.

To determine the assessment category, an 80% confidence interval (CI) was calculated to account for the variation in the monthly data per site. Each monitoring site was treated as an independent assessment area to preserve spatial variability and to identify localized patterns rather than evaluating the lake as a whole. The final classification of a site, ranging from "Clearly Meets" to "Clearly Exceeds", was determined by where the applicable criterion fell relative to this 80% CI. If the criterion falls within the CI range, the site is designated as either "May Meet" or "May Exceed". Conversely, a criterion falling entirely outside the CI range results in a "Clearly Meets" or "Clearly Exceeds" designation. This analysis is intended to provide broader context for observed nearshore conditions and does not represent a formal impairment or listing determination.

Results indicate that chlorophyll-*a* concentrations at all 15 nearshore sites were classified as "Clearly Meets*"* the applicable criterion, suggesting consistently low algal biomass relative to the threshold. Total phosphorus levels were similarly low across the study area, with 13 of 15 sites designated as "Clearly Meets*"* the criterion. Two sites, West of Amnicon (site 2) and Northeast of Poplar River (site 3), fell within the "May Meet" category for total phosphorus. This designation indicates that mean concentrations were near the criterion, with variability overlapping the threshold, though no clear evidence of exceedance was observed (*Table 11*). Notably, no sites were classified as "May Exceed*"* or "Clearly Exceeds" for either parameter. Under the WisCALM framework, "May Meet*"* represents an

intermediate statistical category and does not constitute an exceedance or impairment determination.

Table 10: **Summary of WisCALM analysis results for sites 1–15 compared to total phosphorus (TP) and chlorophyll-*a* (chl-*a*) thresholds.** This table provides a standardized assessment of water quality based on the Wisconsin Consolidated Assessment and Listing Methodology (WisCALM). It compares 2024 data against established regulatory thresholds to determine the attainment status for each site. Note that only sites 1-15 are included in this specific analysis; sites 16-20 were established in 2024 and currently lack the multi-year historical data required for a formal WisCALM evaluation.

Site	TP Assessment (15 µg/L criterion)	Chl-*a* Assessment (8 µg/L criterion)
1	Clearly Meets	Clearly Meets
2	May Meet	Clearly Meets
3	May Meet	Clearly Meets
4	Clearly Meets	Clearly Meets
5	Clearly Meets	Clearly Meets
6	Clearly Meets	Clearly Meets
7	Clearly Meets	Clearly Meets
8	Clearly Meets	Clearly Meets
9	Clearly Meets	Clearly Meets
10	Clearly Meets	Clearly Meets
11	Clearly Meets	Clearly Meets
12	Clearly Meets	Clearly Meets
13	Clearly Meets	Clearly Meets
14	Clearly Meets	Clearly Meets
15	Clearly Meets	Clearly Meets

The slightly elevated total phosphorus concentrations observed West of Amnicon (site 2) and Northeast of Poplar River (site 3) are likely influenced by local watershed characteristics. Both sites are situated near tributary inputs from the Amnicon and Poplar rivers and are influenced by runoff from red clay plains, which are known to contribute higher particulate-bound phosphorus loads to the nearshore. At Northeast of Poplar River (site 3), the "May Meet" classification was driven primarily by a single monthly average with elevated concentrations, while values during the remainder of the study period remained well below the criterion. At West of Amnicon (site 2), several months exhibited higher total phosphorus values, though concentrations in the remaining months were moderate. These

patterns suggest that episodic hydrologic or runoff-driven events, rather than sustained loading, are the primary drivers of total phosphorus levels at these locations.

Nearshore Phytoplankton Trends

Algal ID Enumeration

Algal ID and Enumeration was conducted throughout the field season for 9 sites; Schaffer Beach, Poplar River, Brule River, Iron River, Flag River, Siskiwit Bay, Little Sand Bay, NC Cheq Bay Site 1, and Bad River (sites 1, 3, 6, 8, 9, 14, 16, 19 and 20, respectively). These sites were selected to capture a wide distribution of geographical locations, with focus on tributary inputs or bay areas. There was also a preference for areas where partners were collecting data upstream to capitalize on synergies. This allowed us to track how the community shifted throughout the season.

Cyanobacteria, or the phylum *Cyanophyta*, were detected at all sites, except for near the Poplar River (site 3). They were seen to be a large part (>50%) of the phytoplankton population at Bad River (site 20) and greater than >45% of the population at Siskiwit Bay (site 14), especially during the late-season transition in October (Figure 13). The occurrence of *Cyanophyta* in the phytoplankton population was not marked by any discernable pattern in water chemistry data that occurred concurrently. This lack of a local chemical signal suggests the community might be responding to broader shifts in Lake Superior where an increase in cyanobacteria has been noted since 2001 (Reavie et al., 2014). Researchers suggest these subtle changes are potentially a result of lake warming and shifts in water quality rather than isolated nutrient spikes.

In our observations, *Heterokontophyta* showed a mid-season peak, with their abundance generally declining when *Cyanophyta* increased (Figure 13). This shift aligns with recent reports of higher nitrites, turbidity, and the deepening of the warm upper water layer which may be favoring certain species that can exploit the changing physical environment over traditional summer diatoms (Reavie et al., 2014). *Heterokontophyta* are typically larger in size and more influential in the ecosystem when considering light penetration and nutrient uptake, even when *Cyanophyta* are more prevalent, using the metric of cell density (Reavie et al., 2014). *Cryptista* remained relatively stable at the beginning and end of the season, except at Poplar River and Brule River (sites 3 and 6, respectively), where their patterns differed (Figure 13). By late August to early September, *Cyanophyta* contributed a notable portion of the overall algal community. See Appendix *Table A4-A12* for counts of phyla for each site. for counts of phyla for each site.

Blooms of cyanobacteria were detected in the St. Louis River Estuary and the Wisconsin south shore of Lake Superior. Blooms are considered visible accumulation of cyanobacteria, they can look like grass clippings or paint spills depending on species presence. Cyanobacteria can be present in the phytoplankton community without being considered a bloom if there is not visual evidence of an accumulation of cells. Reports of

algal blooms were sparse in late June and again in late July; however, bloom occurrences increased substantially during August and into September. Samples collected during blooms within the St. Louis River Estuary were dominated by *Dolichospermum and Microcystis*, while the blooms along the south shore (Little Sand Bay near site 16) were dominated by *Dolichospermum*. Blooms within the estuary consistently included the species *Dolichospermum*, *Microcystis*, and *Aphanizomenon*, with some events also containing other cyanobacterial species.

Toxin data is not available for all blooms observed. Three of the St. Louis River Estuary blooms that were analyzed for algal toxins had microcystin toxin concentrations of <0.10 µg/L, which is below the US EPA Recreation Advisory level of 8 µg/L.

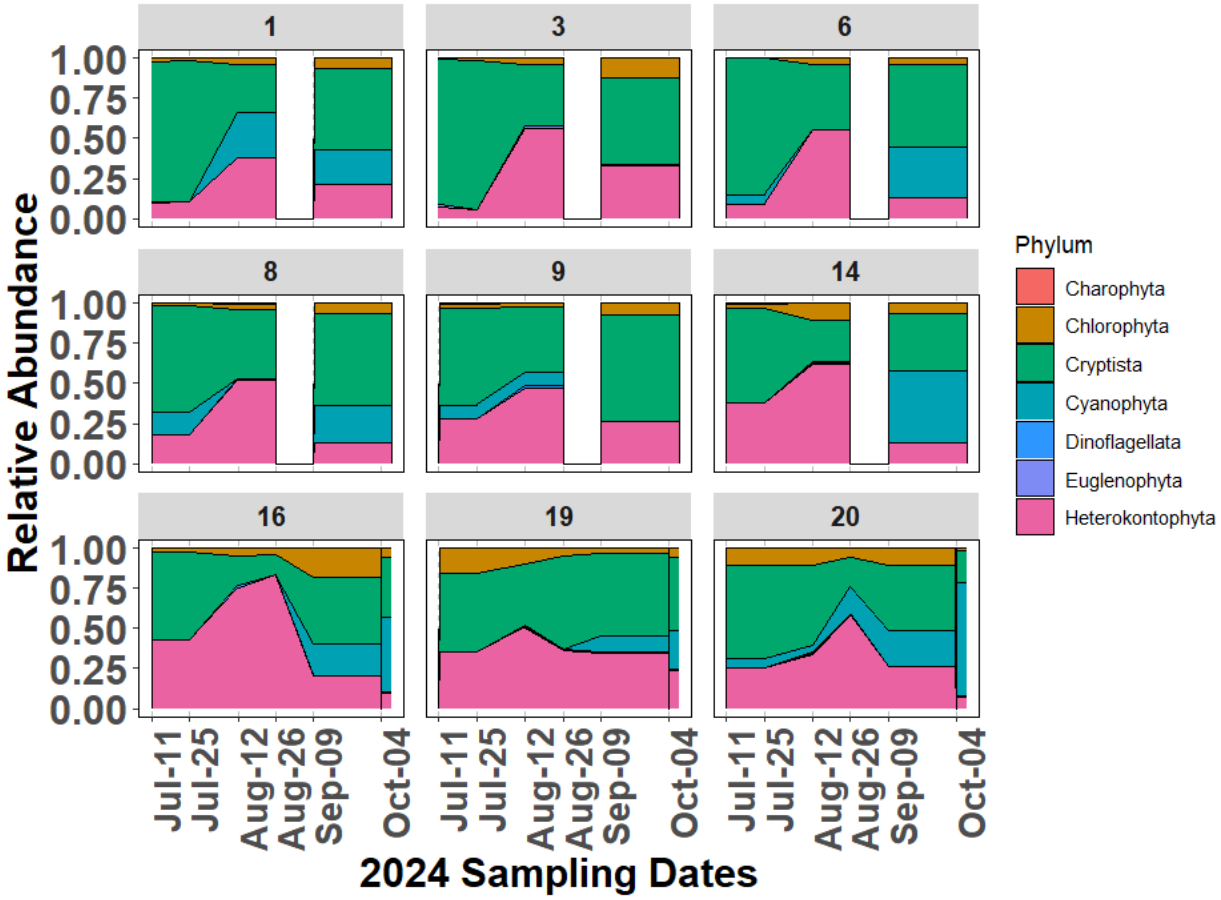

Figure 13: **Results from algal ID enumeration by phyla for nine representative monitoring sites across the sampling season.** This figure illustrates the relative abundance of phytoplankton communities at sites 1, 3, 6, 8, 9, 14, 16, 19, and 20. The x-axis tracks the date of sample collection, while the y-axis represents the percentage of total cell counts attributed to specific phyla. Color groupings distinguish the various taxonomic groups, providing a visual breakdown of community composition and successional shifts throughout 2024.

2024 Lake Superior Bloom Frequency

The 2024 Lake Superior Bloom Bulletin provides a comprehensive overview of the season's observations. During the 2024 season, monitoring of known bloom-prone areas across the Lake Superior basin documented several high-abundance cyanobacterial bloom events

(*Table 12*; Lafrancois & Reinl, 2025). Notably, dominant taxa included *Dolichospermum* and *Microcystis* in the St. Louis River Estuary (SLRE) and along the North Shore of Lake Superior. At Little Sand Bay, a significant population of *Dolichospermum lemmermannii* was recorded. Despite these occurrences, analytical testing showed a consistent lack of correlation between biomass and toxicity; concentrations of microcystin, anatoxin, and cylindrospermopsin remained below detection limits at these locations. The primary exception was a single detection of saxitoxin (1.607 µg/L) on the North Shore in late August (Lafrancois & Reinl, 2025). While trace amounts of various cyanotoxins were detectable throughout the season at most locations, the 2024 data confirms that cyanobacterial presence and abundance are not reliable standalone indicators of toxicological risk.

Table 11: **Summary of observed algal bloom locations and characteristics in the Lake Superior nearshore during the 2024 season.** This table documents specific bloom events, noting the geographic coordinates and site numbers where sightings occurred. It includes qualitative and quantitative characteristics such as bloom intensity, duration, and surface coverage. These observations provide a field-verified record of localized algal activity to complement the nutrient and chlorophyll-*a* data presented in this report.

Location	Date(s)	Relative Size	Dominant Taxa	Toxins Detected?	Notes
Lake Nipigon	26-Aug	Car	*Dolichopermum sp., Cryptomonas*	Unknown/not tested	NA
Little Sand Bay	26-Aug	Car	*Dolichospermum lemmermannii*	No	NA
LS North Shore	14-Aug 25-Aug 26-Aug	Car	*Dolichospermum sp., Woronichinia, Microcystis*	Yes	Saxitoxin at 1.607 µg/L on 25-Aug
Headwater Lake	22-Jun	Tennis court	*Dolichospermum sp., Microcystis sp., Woronichinia*	Yes	Below recreational limits
Isle Royale NP	30-Jul	Tennis court	*Woronichinia sp.*	Yes	Unknown toxin concentrations
SLRE	6-Aug 7-Aug 21-Aug 26-Aug 11-Sep 26-Sep 28-Sep	Football field	*Aphanizomenon sp., Dolichospermum sp., Microcystis sp.*	Yes	Below recreational limits

Climate Influence

According to data collected from 2024, with the exception of September, air temperatures fall within the mid-range conditions observed over the past five years (2020-2024). Precipitation varied throughout the year and did not follow a clear trend compared to previous years. Precipitation patterns showed higher totals in May, June, and August, with noticeably lower amounts in July and September. A late-July Lake water upwelling event aligned with several notable shifts in the seasonal climate data (*Figure 14*). July experienced the warmest air temperatures of the season, while precipitation amounts dropped sharply to below average conditions, after an above average June. Air temperatures slightly decreased into August, though not to unseasonal able lows.

The current thought regarding algal bloom formation is that they tend to occur in warmer and higher flow years. While this may be true, we have also observed blooms in lower flow and cooler temperature years. It is anticipated that climate change will increase the precipitation the area of study will receive, regarding total amount and frequency of rain events, thus we anticipate that blooms will become more prevalent (Walsh et al., 2014).

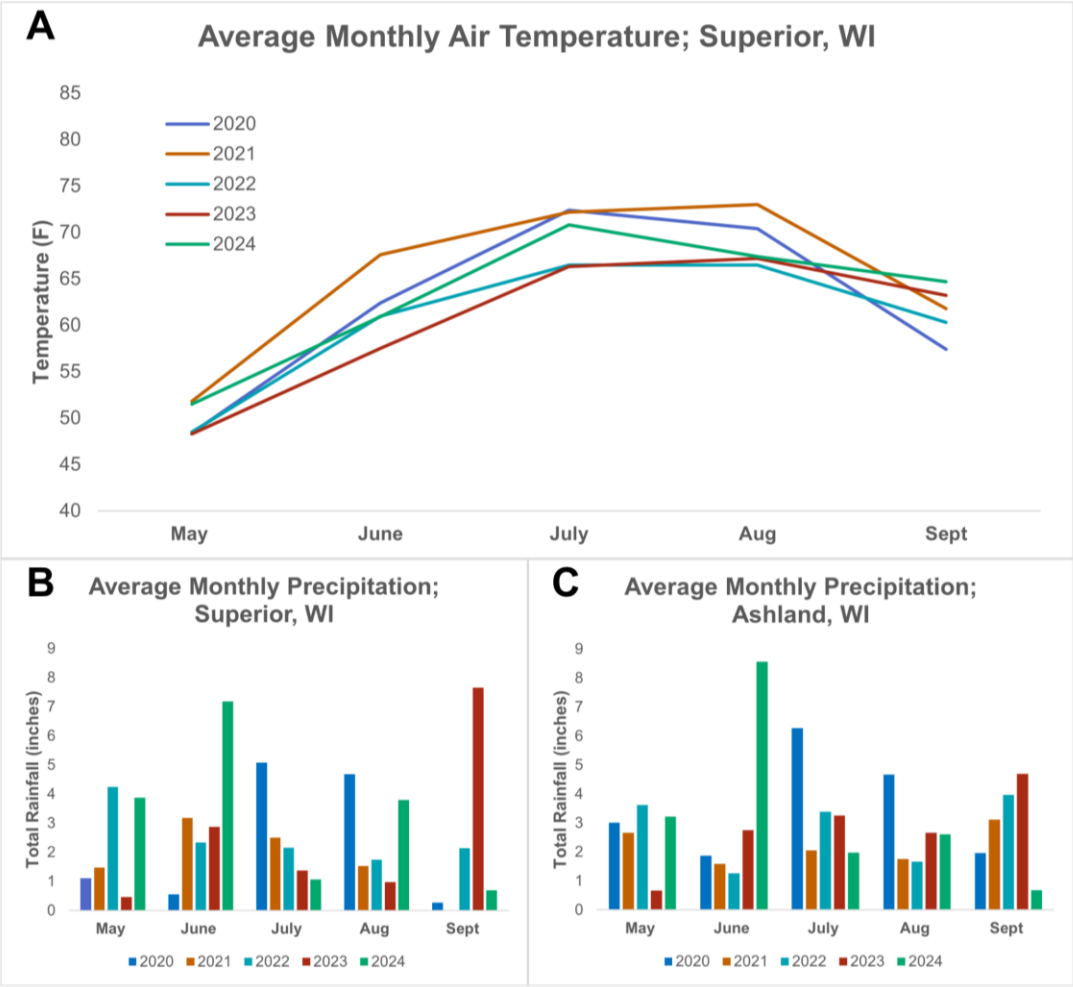

Figure 14: **Summer 2024 climatology for Superior and Ashland WI.** (A) Monthly average air temperature for Superior, WI (representative of regional trends for both Superior and Ashland); (B) monthly precipitation totals for Superior, WI; and (C) monthly precipitation totals for Ashland, WI. These meteorological data provide essential environmental context for the hydrologic and biological trends observed in Lake Superior tributaries and nearshore sites during the 2024 sampling period.

Growing Degree Day (GDD)

Water temperatures exceeding 10°C are considered to promote the development of algal blooms in Lake Superior (Sterner et al., 2020). To quantify the thermal energy available for bloom formation in 2024, growing degree days (GDD) were calculated as the cumulative

sum of daily mean surface temperatures above a 10°C base. Surface temperature data (1 m depth) were obtained from the University of Minnesota Duluth (UMD) McQuade Harbor offshore buoy (**46.814 N 91.829 W).** Data was only available until mid-August for the 2024 sampling year. Following the modeling approach of Sterner et al. (2020) daily values were determined by subtracting the 10°C base from the daily average temperature, with results cumulatively summed throughout the season to characterize the thermal trajectory. Progressed to obtain a growing curve. GDD analysis was modeled from analysis conducted in Sterner et al., 2020.

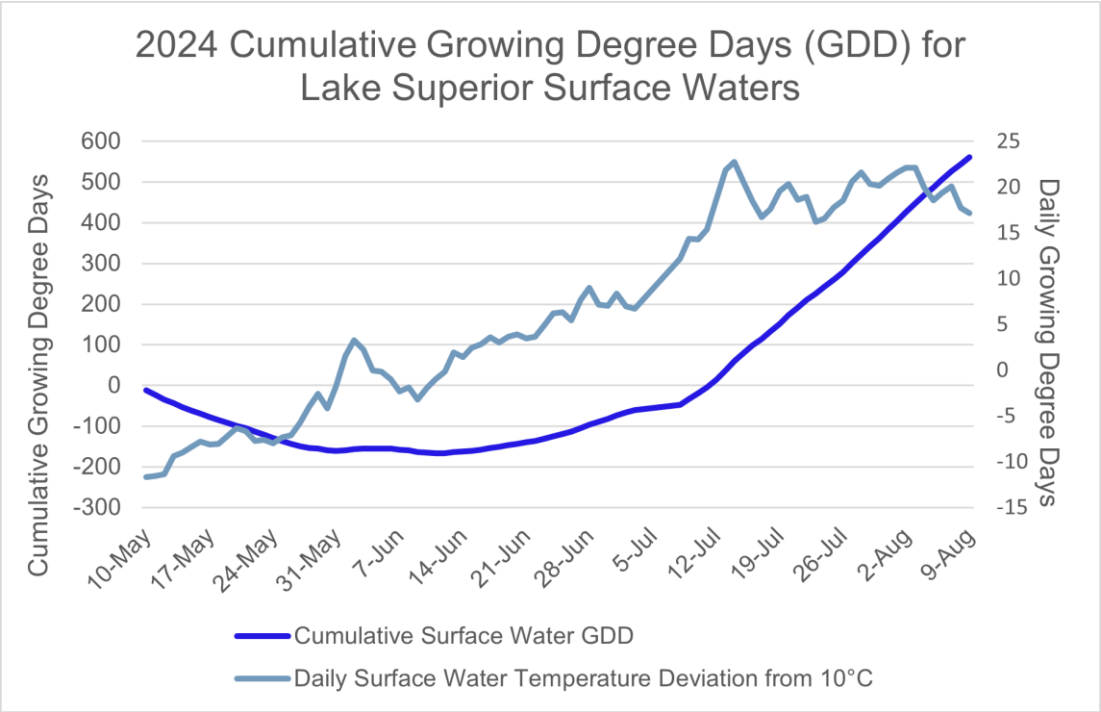

Figure 15: **Growing degree days (GDD) trends in Lake Superior surface waters calculated from May 10 to August 9, 2024.** The net cumulative surface water GDD (dark blue curve) represents the running sum of temperature units relative to a 10°C base. The initial negative trajectory (May to June) illustrates a thermal deficit where average surface temperatures remained below 10°C. The daily surface water temperature deviation (light blue line) shows the daily difference between the observed surface temperature and the 10°C threshold. The shift to a positive slope in early July identifies the onset of sustained surface warming, creating the thermal conditions necessary for the development of algal blooms in the region.

In previous years, cyanobacterial blooms in Lake Superior have occurred when cumulative thermal energy reached an average of 750-1000 GDD (Sterner et al., 2020). By the conclusion of the 2024 sampling effort, cumulative GDD values were only beginning to approach the lower end of this range. Without surface water temperature data for the remaining portion of the season, it is difficult to determine how the remaining part of the season would have progressed, but this suggests that the thermal trajectory for 2024 did not reach the optimal window usually associated with sustaining a bloom (*Figure 15*). It is important to note that these results deviate from prior years' monitoring because the Bark Point buoy was not maintained. Consequently, data were derived from an offshore North

Shore buoy at a collection depth of 1m rather than the 0.6 m depth utilized in previous reports. These methodological differences, specifically the geographic shift and the increased sensor depth, introduced variables that complicate direct longitudinal comparison with historical GDD datasets.

Conclusion

Over the past five years, this monitoring program has addressed its core objectives by characterizing baseline nearshore water-quality conditions associated with algal bloom formation and describing the spatial and temporal distribution of cyanobacteria along Wisconsin's Lake Superior shoreline. Although no active harmful algal blooms were captured at fixed monitoring sites, the dataset provides a strong foundation for understanding nearshore conditions relevant to bloom development.

Cyanobacteria were observed at 8 of 9 algal sampling locations, indicating that bloom-forming taxa are a common component of the nearshore phytoplankton community. However, five years of data reveal a significant ecological data gap; while nearshore waters consistently reached temperatures favorable for growth large-scale blooms did not develop at fixed sites. This suggests that temperature alone is insufficient and that additional drivers are required. The lack of a consistent relationship between concurrent nutrient concentrations and cyanobacteria occurrence underscores the complexity of these dynamics, pointing instead toward the critical influence of nutrient timing, chemical speciation, and hydrodynamic processes.

The 2024 regional season further reinforced these findings, demonstrating that cyanobacterial presence and abundance are not reliable indicators of toxicological risk. Observations from the St. Louis River Estuary, the North Shore, and Little Sand Bay showed that even high-biomass blooms dominated by *Dolichospermum* and *Microcystis* were largely associated with toxin levels below detection limits. A single detection of saxitoxin (1.607 µg/L) on the North Shore stands as a notable exception, yet the broader regional trend supports the program's conclusion: while bloom forming taxa are now a common component of the nearshore community the specific triggers for widespread toxicity remain episodic and geographically isolated.

Collectively, five years of monitoring have improved characterization of nearshore baseline conditions across the sampled sites. While conditions remain highly dynamic, the dataset supports identification of typical ranges and spatial patterns rather than a single fixed baseline. Analysis conducted by the UW-Madison Collaboration grant data analyst, including clustering of water-quality and biological data, identified groups of sites with similar nearshore dynamics. This analysis demonstrated that fewer sites are needed to characterize nearshore conditions without loss of critical information. As a result, the monitoring network will be reduced from 20 to 13 sites, improving cost efficiency while maintaining coverage of key spatial gradients and process domains.

Future monitoring will focus on these optimized sites and continue at a frequency of three out of every four weeks to better resolve short-term variability and evaluate potential lags between nutrient inputs and bloom development. Low-level total phosphorus methods remain necessary for detecting trends in this region, particularly at eastern sites, and orthophosphorus analysis will continue at the Wisconsin State Laboratory of Hygiene to ensure analytical consistency. Algal identification will remain focused on six sites to track spatial variability in nearshore phytoplankton communities.

This effort is supported through collaboration with basin partners, including WDNR, NPS, the Burke Center for Freshwater Innovation, and the Lake Superior Estuarine Research Reserve. In 2025, continued collaboration with the Burke Center will support expanded monitoring in the eastern portion of the basin to better capture nearshore dynamics along the Wisconsin shoreline. Partner datasets will continue to be synthesized to refine and adapt the monitoring framework, with improvements incorporated into the 2025 monitoring strategy. These collaborations are critical for maintaining an efficient, scientifically defensible, and cost-effective long-term nearshore monitoring program.

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Appendix

Sonde Profile Data 2024

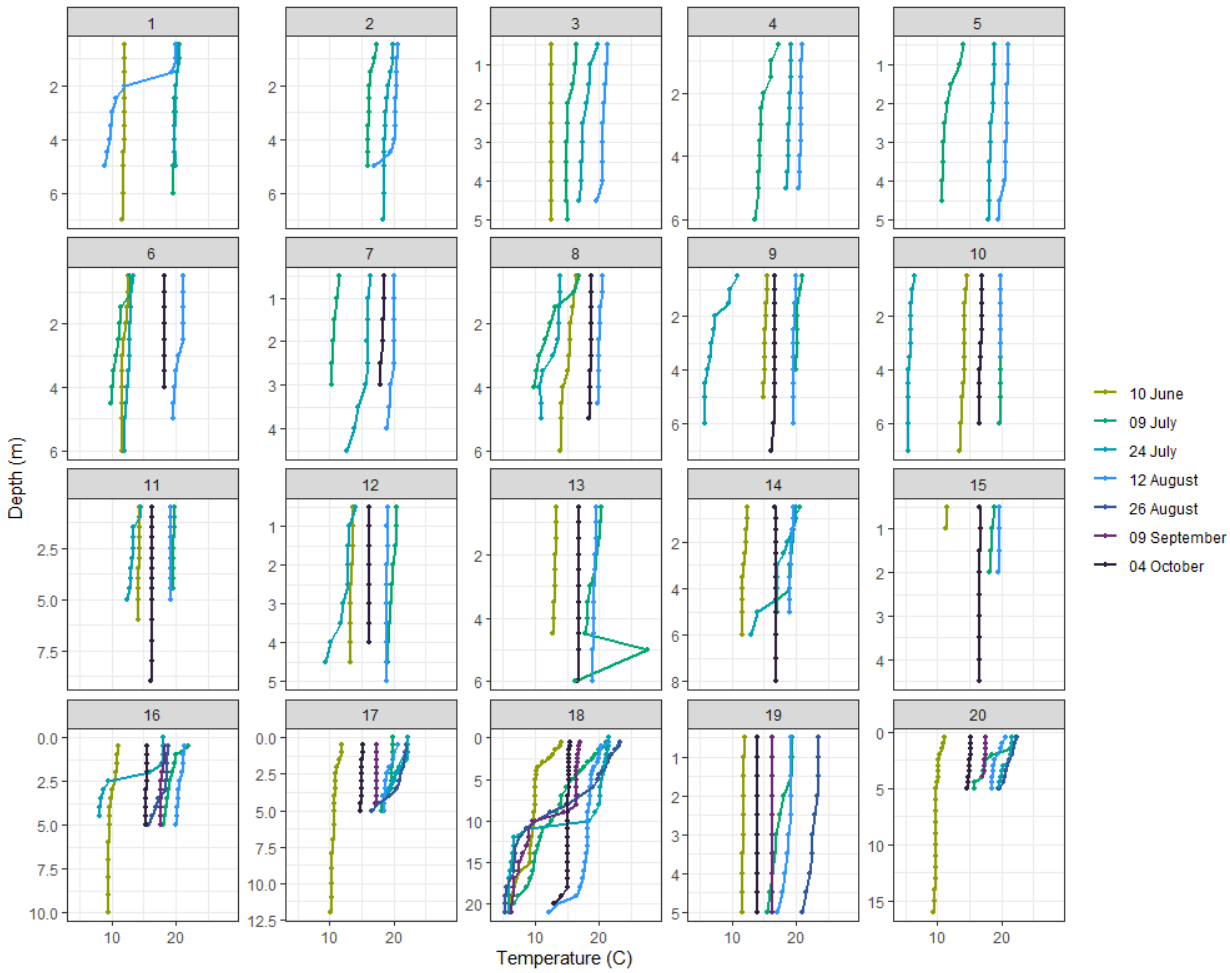

Figure A1: **Temperature data from YSI ProDSS measurements collected throughout the 2024 sampling season.** This figure illustrates the thermal profile of the study area, with values recorded in degrees Celsius (°C). These measurements provide a baseline for physical water conditions, which influence the biological and chemical processes discussed in this report.

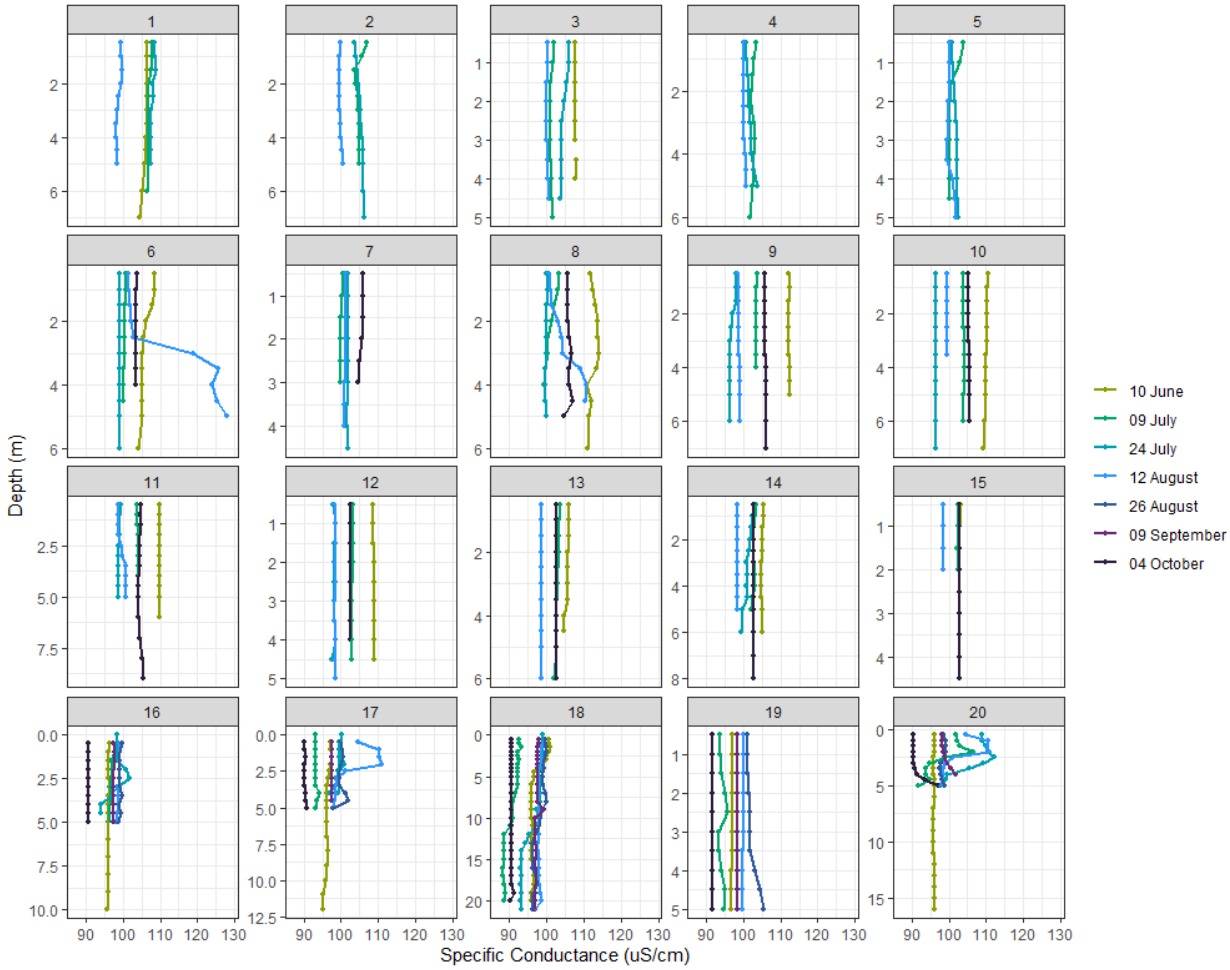

Figure A2: **Specific conductance data from YSI ProDSS measurements collected in 2024.** This figure illustrates the electrical conductivity of the water, normalized to 25°C and recorded in microsiemens per centimeter (uS/cm). These values serve as a proxy for total dissolved solids and help identify different water masses or tributary plumes within the Lake Superior nearshore environment.

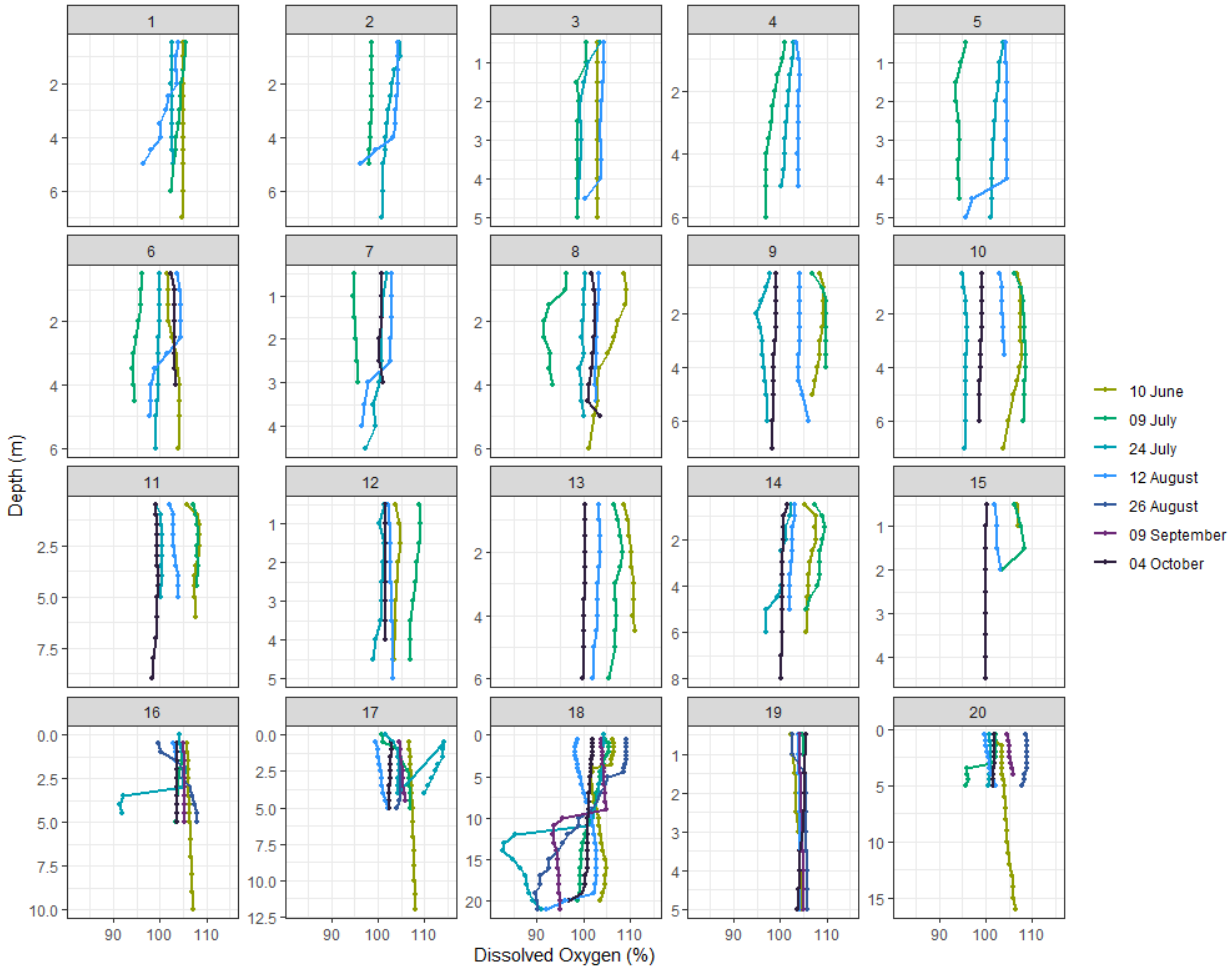

Figure A3: **Dissolved oxygen saturation data from YSI ProDSS measurements collected in 2024.** This figure displays dissolved oxygen in percent saturation (%). These metrics characterize the oxygen availability for aquatic life and help identify areas of high biological productivity or physical mixing throughout the sampling season.

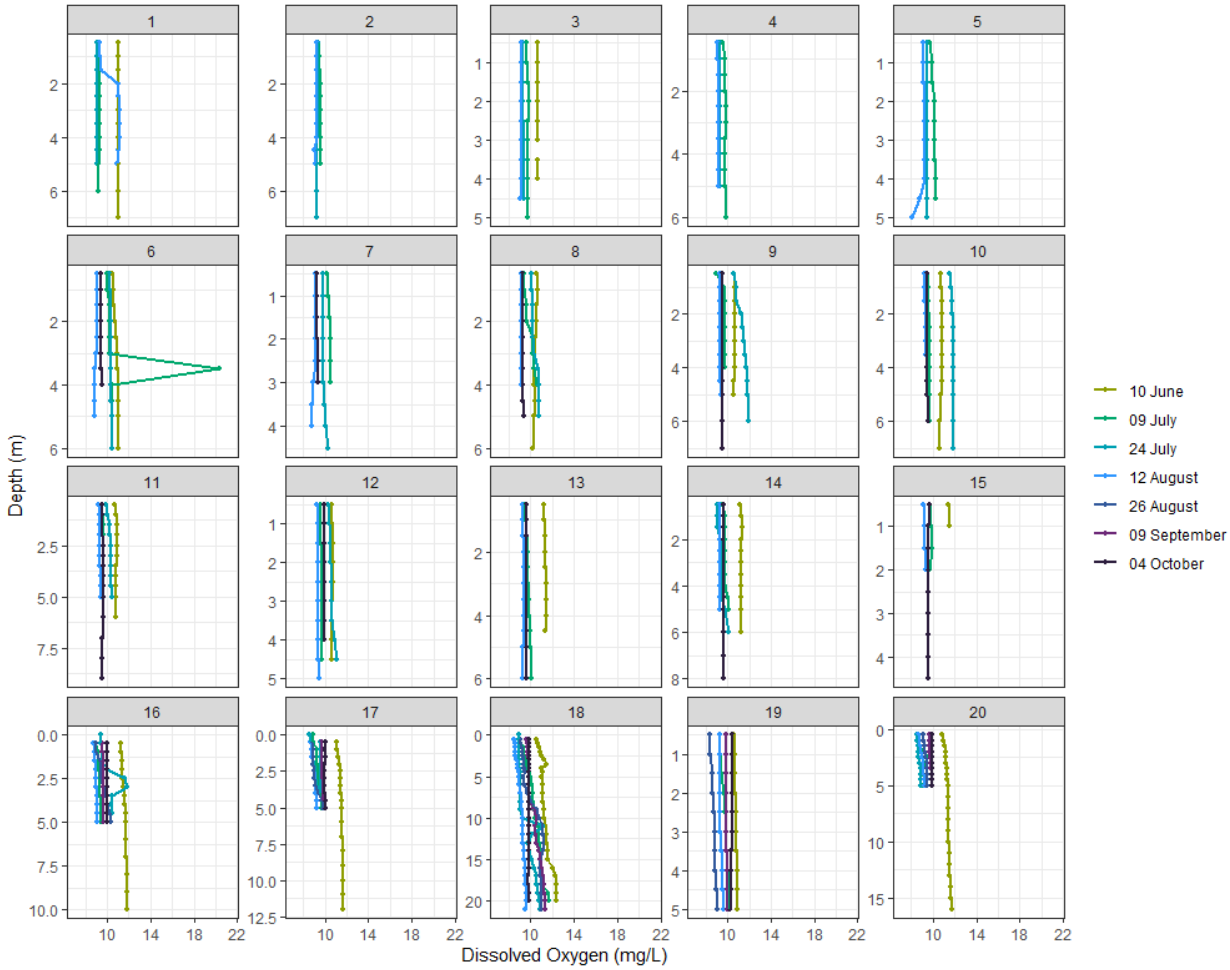

Figure A4: **Dissolved oxygen concentration data from YSI ProDSS measurements collected in 2024.** This figure displays dissolved oxygen in concentration (mg/L). These metrics characterize the oxygen availability for aquatic life and help identify areas of high biological productivity or physical mixing throughout the sampling season.

Maps of Nutrient Data

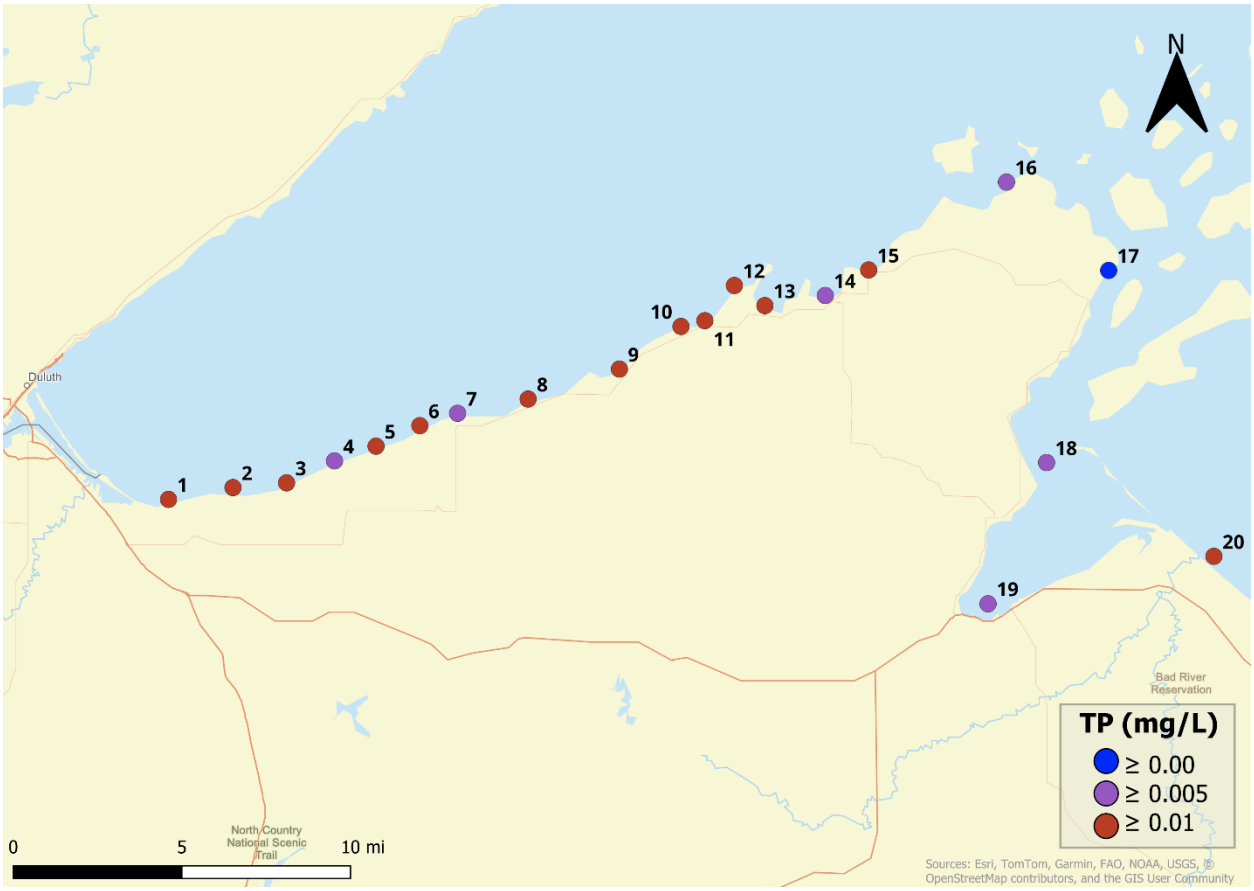

Figure A5: **Action threshold total phosphorus status map for the 2024 monitoring sites.** This figure categorizes each site based on whether total phosphorus (TP) concentrations meet or exceed established regulatory action thresholds. Unlike the data distribution maps, this visualization uses a fixed "tier-based" color scheme to highlight areas where nutrient levels may trigger management concerns. This spatial assessment identifies specific locations that deviate from water quality targets within the Lake Superior nearshore.

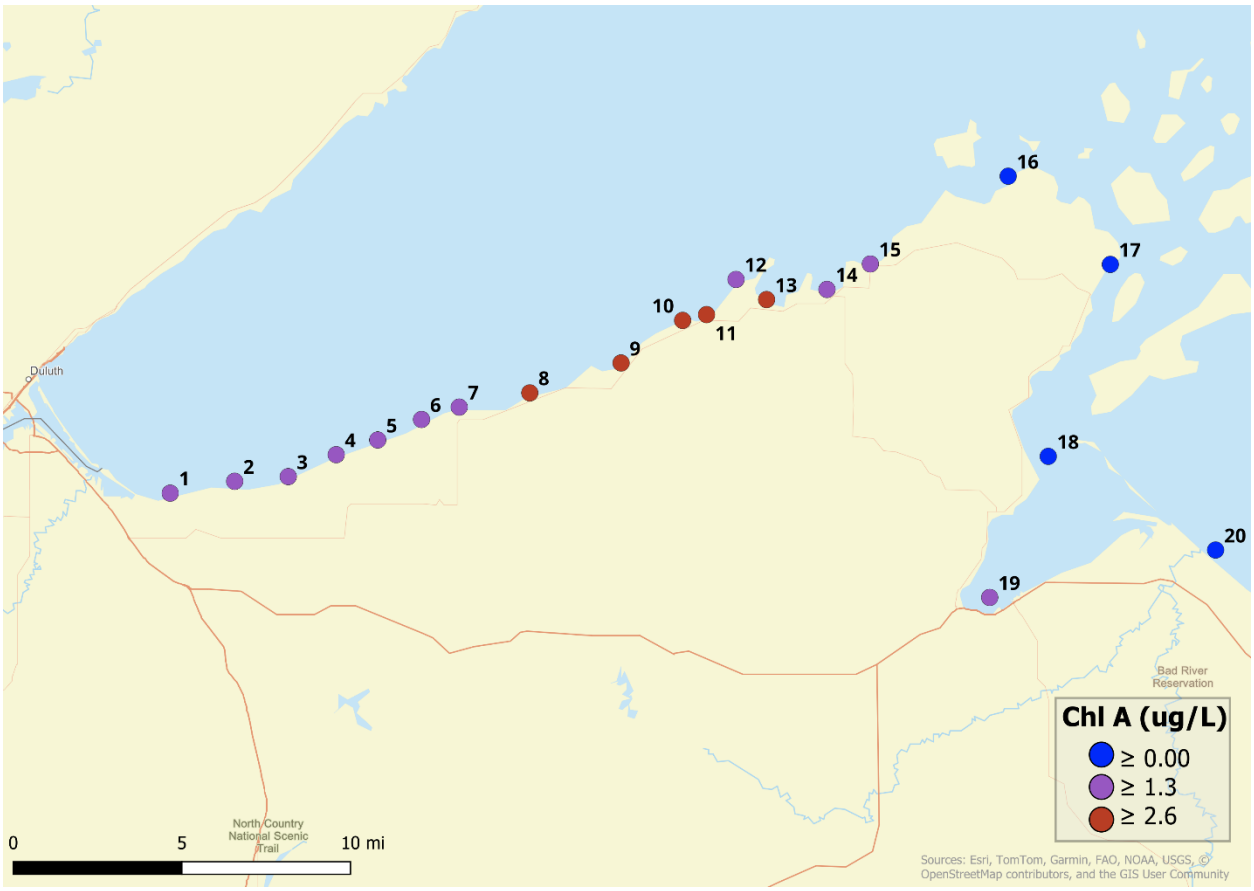

Figure A6: **Action threshold chlorophyll-*a* status map for the 2024 monitoring sites.** This figure categorizes each site based on whether chlorophyll-*a* (chl-*a*) concentrations meet or exceed established regulatory action thresholds. Unlike the data distribution maps, this visualization uses a fixed "tier-based" color scheme to highlight areas where nutrient levels may trigger management concerns. This spatial assessment identifies specific locations that deviate from water quality targets within the Lake Superior nearshore.

Summary Table Data

Table A1: Summaries of 2024 nutrient data grouped by sampling round.

Nutrient summaries grouped by sampling round.

Round	Parameter	Count	Mean	Min	Max	Stdev	NDs
1	Chlorphyll A (µg/L)	16	4	0	16	4	0
1	Nitrate + nitrite (mg/L)	16	0.33	0.27	0.36	0.03	0
1	OrthoP (mg/L)	16	0.003	0	0.009	0.003	NA
1	TN (mg/L)	16	0.6	0.4	0.8	0.1	0
1	TP (mg/L)	16	0.02	0	0.04	0.01	0
1	TSS (mg/L)	16	3	0	12	3	3
2	Chlorphyll A (µg/L)	20	2	0	4	1	0
2	Nitrate + nitrite (mg/L)	20	0.3	0.15	0.35	0.05	0
2	OrthoP (mg/L)	20	0.002	0	0.008	0.002	14
2	TN (mg/L)	20	0.54	0.42	0.66	0.06	0
2	TP (mg/L)	20	0.016	0.008	0.04	0.008	0
2	TSS (mg/L)	20	4	0	12	4	2
3	Chlorphyll A (µg/L)	20	1	0	4	1	NA
3	Nitrate + nitrite (mg/L)	20	0.3	0	0.5	0.1	NA
3	OrthoP (mg/L)	20	0.004	0	0.012	0.004	NA
3	TN (mg/L)	20	0.4	0	0.6	0.2	NA
3	TP (mg/L)	20	0.008	0.004	0.016	0.004	NA
3	TSS (mg/L)	20	2	1	5	1	NA
4	Chlorphyll A (µg/L)	20	2.1	1.4	3.5	0.7	0
4	Nitrate + nitrite (mg/L)	20	0.35	0.3	0.5	0.05	0
4	OrthoP (mg/L)	20	0.001	0.001	0.005	0.001	18
4	TN (mg/L)	20	0.55	0.45	0.65	0.05	0
4	TP (mg/L)	20	0.006	0.004	0.012	0.002	1
4	TSS (mg/L)	20	0.9	0.6	1.5	0.3	8
5	Chlorphyll A (µg/L)	4	1.2	1.2	2.4	0.6	0
5	Nitrate + nitrite (mg/L)	4	0.25	0.25	0.35	0.05	0
5	OrthoP (mg/L)	4	0.002	0	0.004	0.002	2
5	TN (mg/L)	4	0.39	0.36	0.45	0.03	0
5	TP (mg/L)	4	0.004	0.004	0.006	0.001	0
5	TSS (mg/L)	4	0.6	0.5	0.8	0.1	0

Table A2: Hydrodynamic parameter 2024 data summaries grouped by round.

Hydrodynamic Parameter summaries grouped by round.

Round	Parameter	Count	Mean	Min	Max	Stdev
1	Dissolved Oxygen (%)	16	106	102	108	2
1	Dissolved Oxygen (mg/L)	16	10.8	10.5	11.4	0.3
1	Secchi Depth (m)	16	2	0	8	2
1	Specific Conductivity (uS/cm)	16	102	96	114	6
1	Temperature (°C)	16	14	12	16	2
2	Dissolved Oxygen (%)	20	104	96	108	4
2	Dissolved Oxygen (mg/L)	20	9.2	8.4	10	0.4
2	Secchi Depth (m)	20	2	0	6	2
2	Specific Conductivity (uS/cm)	20	100	92	108	4
2	Temperature (°C)	20	18	12	21	3
3	Dissolved Oxygen (%)	18	102	96	105	3
3	Dissolved Oxygen (mg/L)	18	9.8	8.4	11.2	0.7
3	Secchi Depth (m)	18	4	2	6	2
3	Specific Conductivity (uS/cm)	18	100	96	108	4
3	Temperature (°C)	18	16	8	24	4
4	Dissolved Oxygen (%)	20	102	98	104	2
4	Dissolved Oxygen (mg/L)	20	9	8.4	9.3	0.3
4	Secchi Depth (m)	20	6	2	12	2
4	Specific Conductivity (uS/cm)	20	100	98	104	2
4	Temperature (°C)	20	20	19.2	21.6	0.8
5	Dissolved Oxygen (%)	5	104	100	108	4
5	Dissolved Oxygen (mg/L)	5	8.7	8.4	9	0.3
5	Secchi Depth (m)	5	4.8	4	6.4	0.8
5	Specific Conductivity (uS/cm)	5	99.9	98.1	100.8	0.9
5	Temperature (°C)	5	22	18	24	2
6	Dissolved Oxygen (%)	5	104.5	104	105	0.5
6	Dissolved Oxygen (mg/L)	5	9.7	9.5	9.8	0.1
6	Secchi Depth (m)	5	5	4	6	1
6	Specific Conductivity (uS/cm)	5	98	97.6	98.4	0.4
6	Temperature (°C)	5	17.5	16.1	18.2	0.7
7	Dissolved Oxygen (%)	15	102	100	106	2
7	Dissolved Oxygen (mg/L)	15	9.6	9.3	10.5	0.3
7	Secchi Depth (m)	15	4	2	8	2
7	Specific Conductivity (uS/cm)	15	98	91	105	7
7	Temperature (°C)	15	16	14	19	1

Hydrodynamic Parameter summaries grouped by site.

Parameter	Site	Count	Mean	Min	Max	Stdev
Dissolved Oxygen (%)	1	4	104	102	106	1
Dissolved Oxygen (%)	2	3	102	99	105	3
Dissolved Oxygen (%)	3	4	102	100	104	2
Dissolved Oxygen (%)	4	3	102	101	103	1
Dissolved Oxygen (%)	5	3	100	95	105	5
Dissolved Oxygen (%)	6	5	102	96	105	3
Dissolved Oxygen (%)	7	4	100	96	104	4
Dissolved Oxygen (%)	8	5	100	95	110	5
Dissolved Oxygen (%)	9	5	105	100	110	5
Dissolved Oxygen (%)	10	5	100	95	105	5
Dissolved Oxygen (%)	11	5	104	100	108	4
Dissolved Oxygen (%)	12	5	105	102	108	3
Dissolved Oxygen (%)	13	4	104	100	108	4
Dissolved Oxygen (%)	14	5	104	102	108	2
Dissolved Oxygen (%)	15	4	105	99	108	3
Dissolved Oxygen (%)	16	7	104	100	106	2
Dissolved Oxygen (%)	17	7	104	100	106	2
Dissolved Oxygen (%)	18	7	105	99	108	3
Dissolved Oxygen (%)	19	7	104	102	106	1
Dissolved Oxygen (%)	20	7	102	99	108	3
Dissolved Oxygen (mg/L)	1	4	9.9	9	10.8	0.9
Dissolved Oxygen (mg/L)	2	3	9.28	9.2	9.28	0.08
Dissolved Oxygen (mg/L)	3	4	9.8	9.1	10.5	0.7
Dissolved Oxygen (mg/L)	4	3	9.4	9	9.6	0.2
Dissolved Oxygen (mg/L)	5	3	9.3	9	9.6	0.3
Dissolved Oxygen (mg/L)	6	5	9.6	9	10.8	0.6
Dissolved Oxygen (mg/L)	7	4	9.5	9	10	0.5
Dissolved Oxygen (mg/L)	8	5	9.6	9	10.8	0.6
Dissolved Oxygen (mg/L)	9	5	9.8	9.1	10.5	0.7
Dissolved Oxygen (mg/L)	10	5	10	9	12	1
Dissolved Oxygen (mg/L)	11	5	9.6	9	10.8	0.6
Dissolved Oxygen (mg/L)	12	5	10	9.5	10.5	0.5
Dissolved Oxygen (mg/L)	13	4	9.9	9	10.8	0.9
Dissolved Oxygen (mg/L)	14	5	9.6	8.8	11.2	0.8
Dissolved Oxygen (mg/L)	15	4	10	9	11	1
Dissolved Oxygen (mg/L)	16	7	9.9	9	10.8	0.9
Dissolved Oxygen (mg/L)	17	7	9	9	10.8	0.9
Dissolved Oxygen (mg/L)	18	7	9.1	8.4	10.5	0.7
Dissolved Oxygen (mg/L)	19	7	9.6	8	10.4	0.8
Dissolved Oxygen (mg/L)	20	7	9	9	10.8	0.9

Secchi Depth (m)	1	4	3	3	9	3
Secchi Depth (m)	2	3	4	0	6	2
Secchi Depth (m)	3	4	2	1	4	1
Secchi Depth (m)	4	3	4	2	4	2
Secchi Depth (m)	5	3	2	0	4	2
Secchi Depth (m)	6	5	3	1	4	1
Secchi Depth (m)	7	4	4	2	4	2
Secchi Depth (m)	8	5	2	2	4	2
Secchi Depth (m)	9	5	3	0	9	3
Secchi Depth (m)	10	5	4	0	6	2
Secchi Depth (m)	11	5	6	0	6	3
Secchi Depth (m)	12	5	4	2	6	2
Secchi Depth (m)	13	4	6	3	9	3
Secchi Depth (m)	14	5	8	0	12	4
Secchi Depth (m)	15	4	3.6	2.7	4.5	0.9
Secchi Depth (m)	16	7	4	2	6	2
Secchi Depth (m)	17	7	4.8	4	6.4	0.8
Secchi Depth (m)	18	7	6	4	8	1
Secchi Depth (m)	19	7	3	2	4	1
Secchi Depth (m)	20	7	4	0	8	2
Specific Conductivity (uS/cm)	1	4	104	100	108	4
Specific Conductivity (uS/cm)	2	3	104	100	108	4
Specific Conductivity (uS/cm)	3	4	105	99	108	3
Specific Conductivity (uS/cm)	4	3	102	100	104	2
Specific Conductivity (uS/cm)	5	3	102	100	104	2
Specific Conductivity (uS/cm)	6	5	104	100	108	4
Specific Conductivity (uS/cm)	7	4	102	100	106	2
Specific Conductivity (uS/cm)	8	5	105	100	110	5
Specific Conductivity (uS/cm)	9	5	102	96	114	6
Specific Conductivity (uS/cm)	10	5	105	95	110	5
Specific Conductivity (uS/cm)	11	5	104	100	108	4
Specific Conductivity (uS/cm)	12	5	104	96	108	4
Specific Conductivity (uS/cm)	13	4	102	99	105	3
Specific Conductivity (uS/cm)	14	5	102	99	105	3
Specific Conductivity (uS/cm)	15	4	102	98	104	2
Specific Conductivity (uS/cm)	16	7	96	90	99	3
Specific Conductivity (uS/cm)	17	7	95	90	105	5
Specific Conductivity (uS/cm)	18	7	96	92	100	4
Specific Conductivity (uS/cm)	19	7	96	92	100	4
Specific Conductivity (uS/cm)	20	7	102	90	108	6
Temperature (°C)	1	4	20	12	20	4
Temperature (°C)	2	3	20	18	20	2
Temperature (°C)	3	4	16	12	20	4
Temperature (°C)	4	3	20	18	20	2
Temperature (°C)	5	3	16	16	20	4
Temperature (°C)	6	5	16	12	20	4
Temperature (°C)	7	4	16	12	20	4
Temperature (°C)	8	5	18	14	20	2
Temperature (°C)	9	5	16	12	20	4
Temperature (°C)	10	5	18	6	18	6
Temperature (°C)	11	5	18	15	21	3
Temperature (°C)	12	5	18	15	21	3
Temperature (°C)	13	4	18	12	21	3
Temperature (°C)	14	5	18	12	21	3
Temperature (°C)	15	4	16	12	20	4
Temperature (°C)	16	7	16	12	24	4
Temperature (°C)	17	7	20	12	24	4
Temperature (°C)	18	7	18	15	24	3
Temperature (°C)	19	7	16	12	24	4
Temperature (°C)	20	7	20	12	24	4

Table A3: Nutrient parameter 2024 data summaries grouped by site and parameter.

Nutrient summaries grouped by site.

Parameter	Site	Count	Mean	Min	Max	Stdev	NDs
Chlorphyll A (µg/L)	1	4	2	2	4	2	0
Chlorphyll A (µg/L)	2	3	1.8	1.5	2.1	0.3	0
Chlorphyll A (µg/L)	3	4	2	1.6	2.2	0.2	0
Chlorphyll A (µg/L)	4	3	2.1	1.8	2.1	0.3	0
Chlorphyll A (µg/L)	5	3	1.4	0.7	2.1	0.7	0
Chlorphyll A (µg/L)	6	4	2	0	3	1	0
Chlorphyll A (µg/L)	7	3	2	0	3	1	0
Chlorphyll A (µg/L)	8	4	4	0	6	2	0
Chlorphyll A (µg/L)	9	4	7	0	14	7	0
Chlorphyll A (µg/L)	10	4	4	0	8	4	0
Chlorphyll A (µg/L)	11	4	3	0	6	3	0
Chlorphyll A (µg/L)	12	4	2	0	4	2	0
Chlorphyll A (µg/L)	13	4	2	0	6	2	0
Chlorphyll A (µg/L)	14	4	2	2	6	2	0
Chlorphyll A (µg/L)	15	4	1	0	2	1	0
Chlorphyll A (µg/L)	16	5	1	0	1	0.5	1
Chlorphyll A (µg/L)	17	5	1	0.6	1.2	0.2	0
Chlorphyll A (µg/L)	18	5	1.2	1	1.4	0.2	0
Chlorphyll A (µg/L)	19	5	2	1.5	3	0.5	0
Chlorphyll A (µg/L)	20	4	1.2	0.8	1.6	0.4	0
Nitrate + nitrite (mg/L)	1	4	0.32	0.28	0.34	0.02	0
Nitrate + nitrite (mg/L)	2	3	0.4	0.3	0.5	0.1	0
Nitrate + nitrite (mg/L)	3	4	0.32	0.31	0.33	0.01	0
Nitrate + nitrite (mg/L)	4	3	0.32	0.32	0.34	0.01	0
Nitrate + nitrite (mg/L)	5	3	0.33	0.32	0.34	0.01	0
Nitrate + nitrite (mg/L)	6	4	0.27	0.18	0.36	0.09	0
Nitrate + nitrite (mg/L)	7	3	0.34	0.32	0.36	0.02	0
Nitrate + nitrite (mg/L)	8	4	0.33	0.3	0.36	0.03	0
Nitrate + nitrite (mg/L)	9	4	0.3	0.25	0.35	0.05	0
Nitrate + nitrite (mg/L)	10	4	0.32	0.28	0.36	0.04	0
Nitrate + nitrite (mg/L)	11	4	0.36	0.27	0.45	0.09	0
Nitrate + nitrite (mg/L)	12	4	0.33	0.3	0.36	0.03	0
Nitrate + nitrite (mg/L)	13	4	0.2	0	0.3	0.1	0
Nitrate + nitrite (mg/L)	14	4	0.32	0.31	0.33	0.01	0
Nitrate + nitrite (mg/L)	15	4	0.2	0	0.4	0.2	0
Nitrate + nitrite (mg/L)	16	5	0.3	0	0.4	0.1	0
Nitrate + nitrite (mg/L)	17	5	0.33	0.27	0.36	0.03	0
Nitrate + nitrite (mg/L)	18	5	0.28	0.24	0.32	0.04	0
Nitrate + nitrite (mg/L)	19	5	0.28	0.24	0.32	0.04	0
Nitrate + nitrite (mg/L)	20	4	0.24	0.16	0.4	0.08	0
OrthoP (mg/L)	1	4	0.005	0	0.01	0.005	3
OrthoP (mg/L)	2	3	0.006	0	0.012	0.006	2
OrthoP (mg/L)	3	4	0.002	0	0.004	0.002	3
OrthoP (mg/L)	4	3	0.002	0	0.004	0.002	2
OrthoP (mg/L)	5	3	0.001	0.001	0.001	0	3
OrthoP (mg/L)	6	4	0.006	0	0.009	0.003	1
OrthoP (mg/L)	7	3	0.001	0.001	0.001	0	3
OrthoP (mg/L)	8	4	0.006	0	0.009	0.003	1
OrthoP (mg/L)	9	4	0.004	0	0.008	0.004	2
OrthoP (mg/L)	10	4	0.003	0	0.006	0.003	2
OrthoP (mg/L)	11	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	12	4	0.001	0.001	0.001	0	4
OrthoP (mg/L)	13	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	14	4	0.003	0	0.006	0.003	2
OrthoP (mg/L)	15	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	16	5	0.002	0	0.004	0.002	3
OrthoP (mg/L)	17	5	0.002	0	0.004	0.002	3
OrthoP (mg/L)	18	5	0.004	0	0.006	0.002	1
OrthoP (mg/L)	19	5	0.002	0	0.004	0.002	2
OrthoP (mg/L)	20	4	0.003	0	0.006	0.003	0

OrthoP (mg/L)	1	4	0.005	0	0.01	0.005	3
OrthoP (mg/L)	2	3	0.006	0	0.012	0.006	2
OrthoP (mg/L)	3	4	0.002	0	0.004	0.002	3
OrthoP (mg/L)	4	3	0.002	0	0.004	0.002	2
OrthoP (mg/L)	5	3	0.001	0.001	0.001	0	3
OrthoP (mg/L)	6	4	0.006	0	0.009	0.003	1
OrthoP (mg/L)	7	3	0.001	0.001	0.001	0	3
OrthoP (mg/L)	8	4	0.006	0	0.009	0.003	1
OrthoP (mg/L)	9	4	0.004	0	0.008	0.004	2
OrthoP (mg/L)	10	4	0.003	0	0.006	0.003	2
OrthoP (mg/L)	11	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	12	4	0.001	0.001	0.001	0	4
OrthoP (mg/L)	13	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	14	4	0.003	0	0.006	0.003	2
OrthoP (mg/L)	15	4	0.002	0	0.004	0.002	2
OrthoP (mg/L)	16	5	0.002	0	0.004	0.002	3
OrthoP (mg/L)	17	5	0.002	0	0.004	0.002	3
OrthoP (mg/L)	18	5	0.004	0	0.006	0.002	1
OrthoP (mg/L)	19	5	0.002	0	0.004	0.002	2
OrthoP (mg/L)	20	4	0.003	0	0.006	0.003	0
TN (mg/L)	1	4	0.63	0.6	0.66	0.03	0
TN (mg/L)	2	3	0.54	0.51	0.57	0.03	0
TN (mg/L)	3	4	0.55	0.5	0.65	0.05	0
TN (mg/L)	4	3	0.5	0.45	0.55	0.05	0
TN (mg/L)	5	3	0.54	0.48	0.6	0.06	0
TN (mg/L)	6	4	0.49	0.49	0.63	0.07	0
TN (mg/L)	7	3	0.53	0.52	0.55	0.01	0
TN (mg/L)	8	4	0.6	0.5	0.7	0.1	0
TN (mg/L)	9	4	0.6	0.5	0.8	0.1	0
TN (mg/L)	10	4	0.6	0.5	0.7	0.1	0
TN (mg/L)	11	4	0.6	0.5	0.7	0.1	0
TN (mg/L)	12	4	0.56	0.49	0.7	0.07	0
TN (mg/L)	13	4	0.6	0	0.6	0.3	0
TN (mg/L)	14	4	0.56	0.49	0.63	0.07	0
TN (mg/L)	15	4	0.3	0	0.6	0.3	0
TN (mg/L)	16	5	0.4	0	0.6	0.2	0
TN (mg/L)	17	5	0.44	0.4	0.52	0.04	0
TN (mg/L)	18	5	0.45	0.35	0.5	0.05	0
TN (mg/L)	19	5	0.4	0.35	0.5	0.05	0
TN (mg/L)	20	4	0.49	0.42	0.56	0.07	0
TP (mg/L)	1	4	0.015	0.005	0.02	0.005	0
TP (mg/L)	2	3	0.016	0.008	0.024	0.008	0
TP (mg/L)	3	4	0.015	0.01	0.02	0.005	0
TP (mg/L)	4	3	0.012	0.008	0.016	0.004	0
TP (mg/L)	5	3	0.016	0.008	0.024	0.008	0
TP (mg/L)	6	4	0.02	0.01	0.03	0.01	0
TP (mg/L)	7	3	0.01	0.008	0.012	0.002	0
TP (mg/L)	8	4	0.018	0.009	0.027	0.009	0
TP (mg/L)	9	4	0.02	0	0.04	0.02	0
TP (mg/L)	10	4	0.01	0	0.03	0.01	0
TP (mg/L)	11	4	0.018	0.009	0.027	0.009	0
TP (mg/L)	12	4	0.014	0.007	0.021	0.007	0
TP (mg/L)	13	4	0.008	0.008	0.024	0.008	0
TP (mg/L)	14	4	0.012	0.006	0.018	0.006	0
TP (mg/L)	15	4	0.008	0.004	0.012	0.004	1
TP (mg/L)	16	5	0.008	0.004	0.012	0.004	0
TP (mg/L)	17	5	0.006	0.004	0.008	0.002	0
TP (mg/L)	18	5	0.006	0.004	0.007	0.001	0
TP (mg/L)	19	5	0.008	0.006	0.012	0.002	0
TP (mg/L)	20	4	0.02	0	0.04	0.01	0
TSS (mg/L)	1	4	2	1	3	1	1
TSS (mg/L)	2	3	6	0	12	6	1
TSS (mg/L)	3	4	6	0	9	3	0
TSS (mg/L)	4	3	4	2	6	2	0
TSS (mg/L)	5	3	6	0	12	6	0
TSS (mg/L)	6	4	4	2	6	2	0
TSS (mg/L)	7	3	2	2	4	2	0
TSS (mg/L)	8	4	3	0	6	3	0
TSS (mg/L)	9	4	5	0	10	5	0
TSS (mg/L)	10	4	2	0	6	2	0
TSS (mg/L)	11	4	2	1	4	1	1
TSS (mg/L)	12	4	1	1	3	1	1
TSS (mg/L)	13	4	1	1	3	1	1
TSS (mg/L)	14	4	0.9	0.9	2.7	0.9	2
TSS (mg/L)	15	4	1	1	2	0.5	2
TSS (mg/L)	16	5	1	0.5	2	0.5	3
TSS (mg/L)	17	5	0.8	0.6	1	0.2	2
TSS (mg/L)	18	5	1	0.6	1.2	0.2	2
TSS (mg/L)	19	5	2	1	3	1	1
TSS (mg/L)	20	4	2	0	6	2	2

Table A4: **Algal ID/enumeration of Schaffer Beach (site 1) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Schaffer Beach, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/11	*Chlorophyta*	44	1.9
	Cryptista	2028	88.1
	Euglenophyta	13	0.6
	Heterokontophyta	218	9.5
7/22	*Chlorophyta*	27	1.1
	Cryptista	2125	88.1
	Heterokontophyta	259	10.7
8/12	*Chlorophyta*	48	3.7
	Cryptista	391	30.2
	Cyanophyta	**363**	**28.0**
	Euglenophyta	3	0.2
	Heterokontophyta	490	37.8
10/4	Chlorophyta	108	6.5
	Cryptista	834	50.2
	Cyanophyta	**359**	**21.6**
	Euglenophyta	4	0.2
	Heterokontophyta	355	21.4

Table A5: **Algal ID/enumeration of Poplar River (site 3) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Poplar River, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/11	*Chlorophyta*	8	0.7
	Cryptista	1106	90.8
	Euglenophyta	20	1.6
	Heterokontophyta	84	6.9
7/22	*Chlorophyta*	16	1.7
	Cryptista	890	93.1
	Heterokontophyta	50	5.2
8/12	*Chlorophyta*	36	3.5
	Cryptista	343	33.0
	Euglenophyta	15	1.4

	Heterokontophyta	507	48.8
10/4	*Chlorophyta*	137	14.3
	Cryptista	617	64.5
	Dinoflagellata	6	0.6
	Euglenophyta	3	0.3
	Heterokontophyta	373	39.0

Table A6: **Algal ID/enumeration of Brule River (site 6) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Brule River, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Cryptista*	812	85.3
	Cyanophyta	**53**	**5.6**
	Heterokontophyta	87	9.1
8/12	*Chlorophyta*	86	4.1
	Cryptista	837	40.4
	Heterokontophyta	1151	55.5
10/4	Chlorophyta	83	4.2
	Cryptista	1028	51.4
	Cyanophyta	**624**	**31.2**
	Heterokontophyta	264	13.2

Table A7: **Algal ID/enumeration of Iron River (site 8) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Iron River, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Chlorophyta*	12	1.1
	Cryptista	717	67.1
	Cyanophyta	**148**	**13.9**
	Heterokontophyta	191	17.9
8/12	*Charophyta*	4	0.3
	Chlorophyta	50	3.8
	Cryptista	574	43.1
	Dinoflagellata	4	0.3
	Euglenophyta	8	0.6
	Heterokontophyta	693	52.0

10/4	Chlorophyta	76	6.3
	Cryptista	690	57.5
	Cyanophyta	**279**	**23.3**
	Dinoflagellata	3	0.3
	Heterokontophyta	151	12.6

Table A8: **Algal ID/enumeration of Flag River (site 9) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Flag River, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Charophyta*	3	0.5
	Chlorophyta	16	2.7
	Cryptista	360	60.3
	Cyanophyta	**52**	**8.7**
	Heterokontophyta	166	27.8
8/12	*Chlorophyta*	25	2.7
	Cryptista	373	40.6
	Cyanophyta	**74**	**8.1**
	Dinoflagellata	14	1.5
	Heterokontophyta	433	47.1
10/4	Chlorophyta	65	7.1
	Cryptista	612	66.4
	Heterokontophyta	244	26.5

Table A9: **Algal ID/enumeration of Siskiwit Bay (site 14) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Siskiwit Bay, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Charophyta*	9	0.9
	Chlorophyta	22	2.2
	Cryptista	583	58.9
	Heterokontophyta	375	37.9
8/12	*Chlorophyta*	91	10.7
	Cryptista	222	26.1
	Dinoflagellata	5	0.6
	Euglenophyta	5	0.6

	Heterokontophyta	529	62.1
10/4	Chlorophyta	89	6.5
	Cryptista	480	35.3
	Cyanophyta	**613**	**45.1**
	Heterokontophyta	177	13.0

Table A10: **Algal ID/enumeration of Little Sand Bay (site 16) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Little Sand Bay, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Chlorophyta*	14	2.7
	Cryptista	283	54.7
	Heterokontophyta	220	42.6
8/12	*Chlorophyta*	79	5.2
	Cryptista	273	17.9
	Dinoflagellata	30	2.0
	Heterokontophyta	1144	75.0
8/26	*Chlorophyta*	75	4.2
	Cryptista	226	12.6
	Heterokontophyta	1491	83.2
9/9	*Chlorophyta*	287	18.3
	Cryptista	651	41.5
	Cyanophyta	**308**	**19.6**
	Euglenophyta	7	0.4
	Heterokontophyta	316	20.1
10/4	Chlorophyta	54	5.5
	Cryptista	374	37.8
	Cyanophyta	**455**	**46.0**
	Dinoflagellata	8	0.8
	Heterokontophyta	98	9.9

Table A11: **Algal ID/enumeration of NC Cheq Bay Site 1 (site 19) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at NC Cheq Bay Site 1, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Charophyta*	6	0.3

	Chlorophyta	517	22.9
	Cryptista	1014	44.8
	Heterokontophyta	724	32.0
8/12	*Chlorophyta*	141	9.7
	Cryptista	559	38.6
	Dinoflagellata	9	0.6
	Euglenophyta	5	0.3
	Heterokontophyta	736	50.8
8/26	*Chlorophyta*	122	5.1
	Cryptista	1385	58.3
	Dinoflagellata	8	0.3
	Heterokontophyta	862	36.3
9/9	*Chlorophyta*	53	3.0
	Cryptista	886	51.8
	Cyanophyta	**169**	**9.9**
	Euglenophyta	13	0.8
	Heterokontophyta	592	34.6
10/4	Chlorophyta	80	5.5
	Cryptista	671	45.9
	Cyanophyta	**355**	**24.3**
	Euglenophyta	4	0.3
	Heterokontophyta	352	24.1

Table A12: **Algal ID/enumeration of Bad River (site 20) for the 2024 sampling season.** This table provides a detailed taxonomic breakdown of the phytoplankton community at this specific location. It includes the collection date, identified phyla, raw cell counts, and the relative percentage of each group within the total sample. These metrics characterize the successional changes and community structure at Bad River, offering a highly descriptive look at algal population dynamics over time.

Date	Phyla	Count	Percent Population
7/22	*Charophyta*	3	0.3
	Chlorophyta	119	10.8
	Cryptista	640	58.1
	Cyanophyta	**58**	**5.3**
	Euglenophyta	3	0.3
	Heterokontophyta	279	25.3
8/12	*Chlorophyta*	112	11.0
	Cryptista	507	49.6
	Cyanophyta	**45**	**4.4**
	Dinoflagellata	6	0.6
	Euglenophyta	6	0.6

	Heterokontophyta	346	33.9
8/26	*Chlorophyta*	63	5.4
	Cryptista	216	18.7
	Cyanophyta	**200**	**17.3**
	Dinoflagellata	9	0.8
	Heterokontophyta	668	57.8
9/9	*Chlorophyta*	229	10.7
	Cryptista	876	40.8
	Cyanophyta	**477**	**22.2**
	Heterokontophyta	564	26.3
10/4	Chlorophyta	25	2.0
	Cryptista	248	19.5
	Cyanophyta	**899**	**70.8**
	Euglenophyta	5	0.4
	Heterokontophyta	93	7.3

Table A13: **Summary of average TSI for individual sites during the 2024 sampling season.** This table presents the calculated trophic state index (TSI) for each monitoring location, integrating chlorophyll-*a* and nutrient data. For quality assurance, duplicate samples collected at specific sites were included in the calculation of the final site average. These index values allow for a comparative assessment of productivity levels across the study area, identifying the trophic classification of each nearshore station.

Site	Average	(n)
1	39.7	7
2	38.9	4
3	39.0	5
4	37.2	4
5	37.1	5
6	37.9	4
7	35.0	4
8	39.8	5
9	37.9	5
10	35.4	5
11	36.3	4
12	36.3	4
13	40.4	3
14	36.4	4
15	37.2	2
16	29.8	5
17	28.2	8
18	30.3	7

19	35.4	7
20	36.1	4