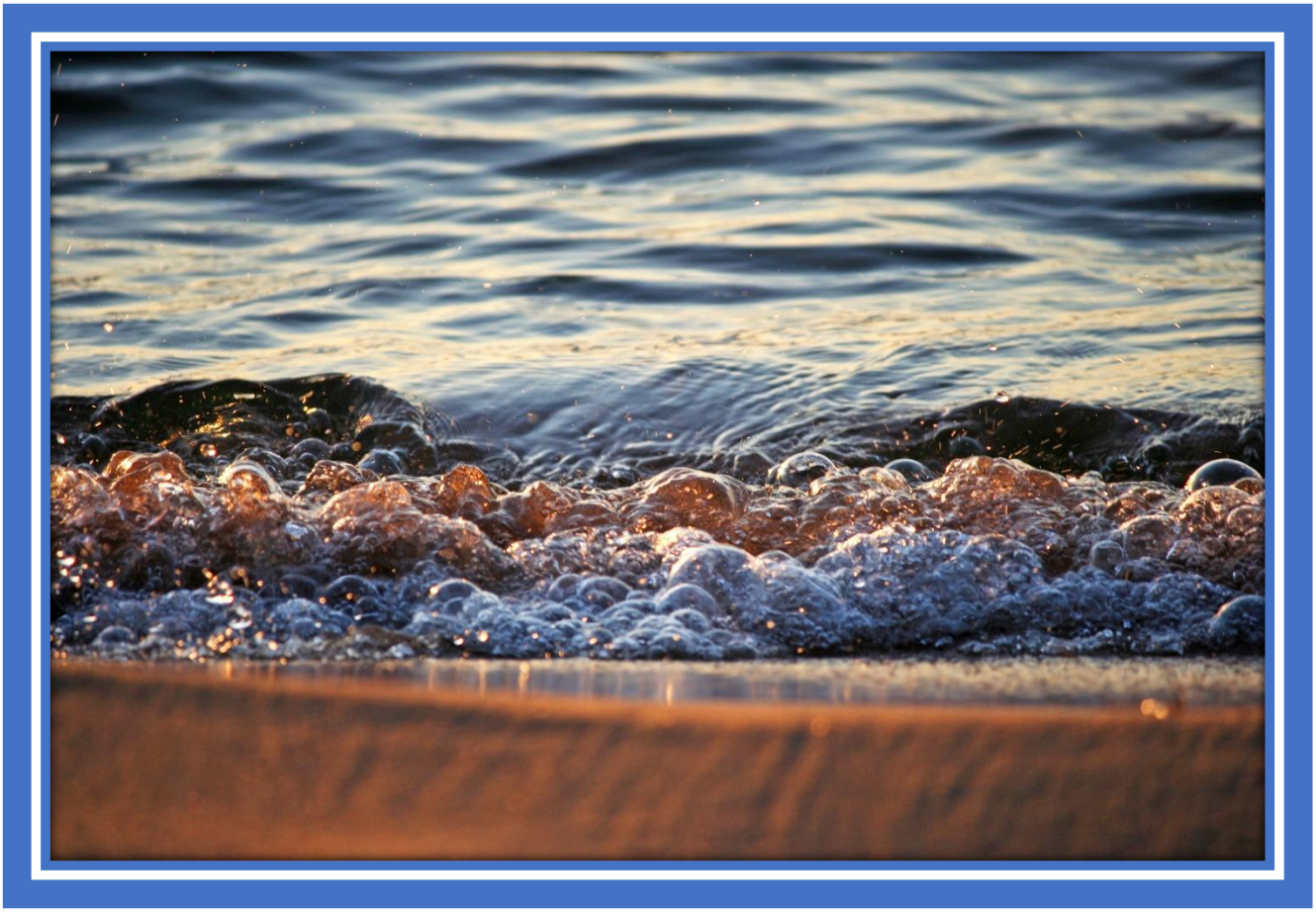
2021 Nearshore Monitoring in Wisconsin's Lake Superior Coast for Nutrient Conditions Leading to Harmful Algal Blooms



"Shore Bubbles" by Bill Carroll 2014 Great Lakes Photo Contest

Office of Great Waters -- Northern Region
Wisconsin Department of Natural Resources

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WISCONSIN DEPT. OF NATURAL RESOURCES

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Abstract:

There has been an increase in observed cyanobacterial blooms along the south shore of Lake Superior. These blooms have been identified as containing a potential toxin-producing species, *Dolichospermum lemmermannii.* Blooms could impact summer tourism, public health, and recreational users in nearshore areas. We do not currently understand conditions leading to bloom formation and where initial bloom formation occurs. Changing climate is thought to be a driver for the recently increased observations of blooms. The occurrence of these blooms is impacted by factors that happen on a wide spatial scale.

This project is one piece to a multi-agency Cooperative Science and Monitoring Initiative (CSMI) effort put together by members of the Lake Superior Algal Bloom subgroup to advance understanding of HABs in Lake Superior during the 2021 CSMI year. Our project objectives included 1) obtaining baseline surface water quality parameters associated with algal bloom formation in Wisconsin's shoreline of Lake Superior, 2) collecting water quality data before and during algal bloom events to characterize bloom supporting conditions, and 3) determining the spatial and temporal distribution of algal bloom events.

Throughout the field season a few occurrences of algal blooms occurred in Lake Superior and its connecting waters. A small algal bloom was reported on the south shore of Lake Superior on July 18th near the Meyers Beach sea cave area. Our research team responded the next day to collect samples, but wind and waves had dispersed the bloom and it was not present at the time of investigation. Another bloom was reported in the harbor of Lake Superior at the Barker's Island beach on September 9th . This bloom was sampled by researchers at the NERR and sample was analyzed for toxin concentrations. Microcystin was present at 8.7 µg/L, which is just over the EPA's swimming advisory level of 8 µg/L for beach closures. Saxitoxin was present at 0.022 µg/L, which is at the level of detection. Anatoxin-a was not detected. While it is concerning that waters connected with Lake Superior experienced these conditions, the algal bloom at Barker's Island was a different species composition that those previously detected in the nearshore of Lake Superior. The two additional species in that bloom may have been responsible for the toxin production, don't necessarily reflect the potential for nearshore *Dolichospermum* to produce toxins.

Summer air temperatures were extraordinarily warm for the season, but there was also an extreme lack of rain, which may have contributed to the lack of algal blooms. A similar study was conducted in 2019, in which no algal blooms were detected during that field season either. Even though the climatic conditions were similar, a statistical analysis determined that the water chemistry data sets were not from the same population.

Introduction:

While often thought of as pristine, Lake Superior has experienced cyanobacterial blooms in recent years that impact the beneficial uses of the nearshore area. Blooms were observed along the southern shore of Lake Superior in 2012, 2016, 2017, 2018, 2020, and 2021. A potential toxin-producing species, *Dolichospermum lemmermannii (*identified by Gina LaLiberte, Wisconsin Department of Natural Resources), was identified in the 2012, 2016, 2017, and 2018 bloom events. While toxins have not been detected in blooms along the south shore to date, these blooms are a concern to the

public due to their unprecedented nature, as well as their ability to potentially impact summer tourism, public health, and recreation.

We do not understand conditions leading to bloom formation on Lake Superior and where initial bloom formation occurs. Blooms are typically associated with increased loading of nutrients to nearshore environment (Lürling et al., 2018; Schindler, 1975; Steinberg and Hartman, 1988), particularly phosphorus, which is the limiting nutrient for Lake Superior. Changing climate is thought to be a driver for the recently increased observations of bloom formations. Extreme rain events and large fluxes of nutrients and sediment to the western arm of Lake Superior proceeded late summer algal blooms (Cooney et al., 2018 and Minor 2014). In Lake Superior, blooms were observed weeks after extreme storms; the lag times observed have ranged from 25 to 53 days (Sterner et al., 2020). The blooms generally occur from mid-July to the end of August (Sterner et al., 2020), likely because this is when the surface waters are warmest. Lake Superior has been warming at the fastest rate compared to the other Laurentian Great Lakes (Austin and Colman, 2007; O'Reilly et al., 2015), and these warming epilimnetic temperatures are thought to influence the increasing presence of cyanobacteria on Lake Superior (Konopka and Brock, 1978; Kosten et al., 2012; Paerl and Huisman, 2009; Robarts and Zohary, 1987).

The occurrence of these blooms is impacted by factors that happen on a wide spatial scale. It takes substantial resources (people, time, and money) to be able to answer the questions posed. Thus, it is fitting that this project was a part of the Cooperative Science Monitoring Initiative (CSMI). CSMI is a bi-national effort to coordinate science and monitoring activities in the Great Lakes. Its goal is to generate data and information for environmental management agencies. This project is one piece to a multi-agency proposal that was put together by members of the Lake Superior Algal Bloom and Nutrient Subgroup to advance understanding of HABs in Lake Superior during the CSMI year. Partners at USGS and EPA-GLTED conducted water quality sampling in tributaries, characterized in-stream sediment phosphorus removal potential, deployed autonomous gliders, and conducted a DNA metabarcoding study. These studies are a piece of the puzzle to determine drivers and conditions under which algal blooms form, which is a Lake Superior Lakewide Action Management Plan priority.

The goal of our project was to characterize water quality conditions before and during blooms in the Lake Superior nearshore. The collection of this information was a first step in understanding the blooms and developing management actions to minimize their occurrence and impact.

Methods:

Experimental design:

Sampling locations were chosen to replicate a previous study conducted in 2019, which focused on source tributary mouths and areas where previous blooms occurred. All SWIMS stations from 2019 are used for this study except for one (Block 9 Station 10052509) that was dropped, and a new location was chosen. This was done to align with our partners' sampling. These sites provide us with sufficient spatial distribution to understand where potential sources of nutrients, that may support blooms, are entering the lake. Surface water samples were collected at the 5 m contour (Figure 1, Table 1). In 2019 the Lake Superior algal sub-group determined that the 5 meters depth contour was most appropriate for sampling, as it balances interests in sampling the very nearshore (since that's

where blooms have been observed) and provides a broader scale perspective on the distribution of nutrients throughout the 55 miles of the south shore region.

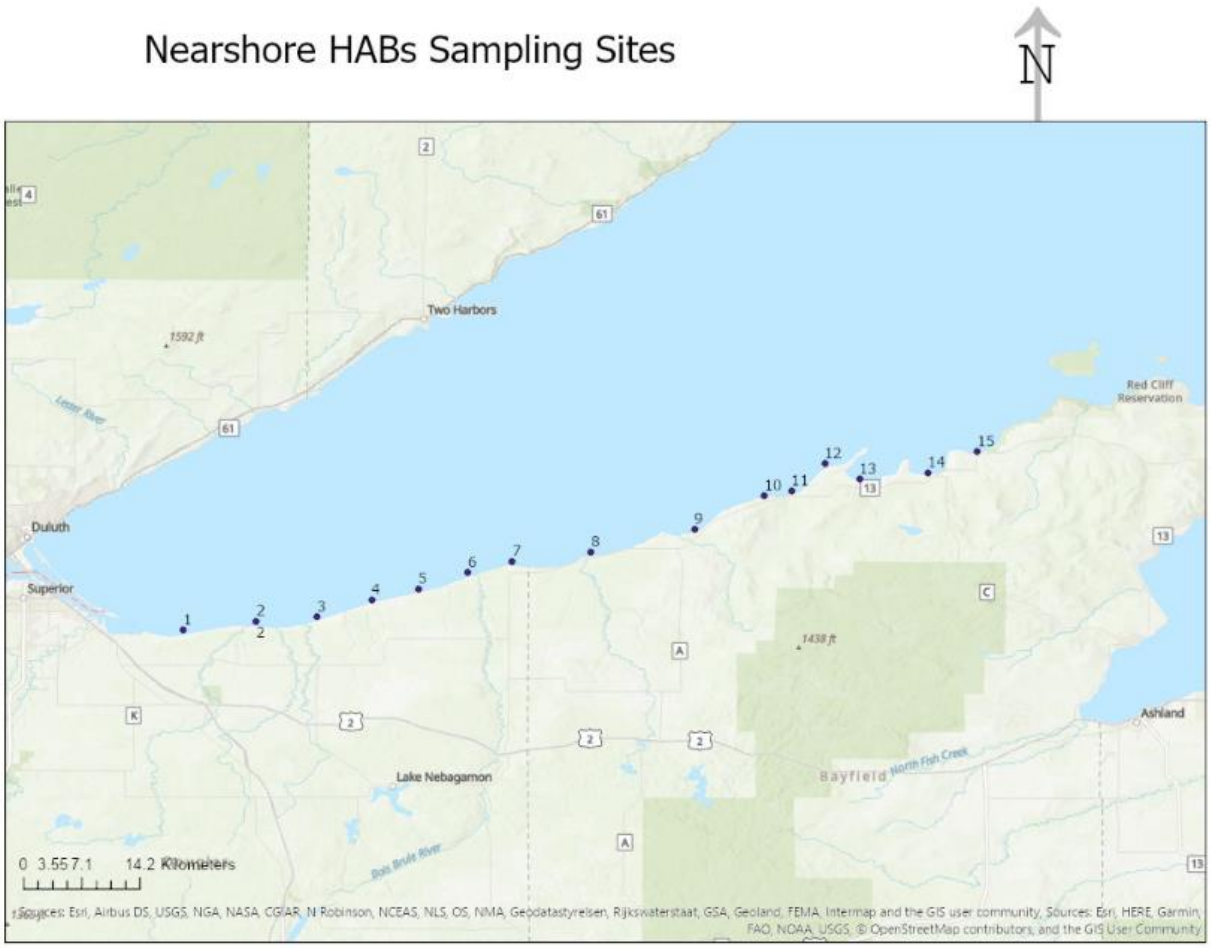


Figure 1 Map of Sampling sites. 15 sites spanning from Superior to Miwakuie bay

These sites were visited 7 times, approximately every other week mid- June through September. This time frame allowed us to capture water quality conditions throughout the potential growing season. The sampling frequency of every other week provides enough time points throughout the summer to determine how water quality changes in the nearshore. The collection of samples was generally split into two groups, 1-7 and 8-15, and done over two days to allow time for overnight shipping. When weather conditions restricted sampling, sites further east were prioritized, as these areas are where blooms have occurred in the past.

Table 1 Dates of sample collection for each CSMI mobilization

CSMI	DATE
1	June 22nd and 23rd 2021
2	July 8th and 9th 2021
3	July 19th 2021
4	August 10th and 11th 2021
5	August 23rd and 25th 2021
6	September 9th and 10th 2021
7	September 22nd and 23rd 2021

Table 2 Details of sampling locations

ID	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- Miwakuie Bay	46.88067	-91.0615

Sample collection:

The collection of samples on Lake Superior is highly subject to weather conditions. During sampling weeks, the crew monitored weather conditions and sampled on days where waves were less than 2 ft, for the safety of the crew. Therefore, some weeks there were gaps in data for sites when the weather was unsafe. Wind magnitude and direction can vary rapidly over the course of a day, which made it necessary to amend sampling plans on the fly, leading to some sites not being sampled during a giving sampling day.

Time of arrival, weather conditions, latitude/longitude, and depth were recorded once the site was reached. An anchor was deployed so that boat did not drift during sampling. Secchi depth was collected on the shaded side of the vessel. The depth at which the disk disappeared and reappeared was recorded 3 times. This measurement was completed by the same researcher in each sampling session to ensure consistency throughout the dataset.

At each site water quality data was collected via sonde and surface grab samples. The sonde (YSI ProDSS) collected vertical profiles of dissolved oxygen (concentration and percent), temperature, specific conductance, pH, and turbidity of the water column. The sonde was calibrated to the standards of the manual. pH and conductivity were calibrated daily using standard solutions purchased from YSI. Due to prior improper storage, the pH probe did not pass its calibration checks at the beginning of the season (mV readings were not within accepted values). A new pH probe was ordered but didn't arrive until CSMI 6. A LI-1500 Light Sensor logger was used to measure the Photoactive radiation (400 - 700nm) of the water column in both ambient and underwater conditions. A LI-190 quantum sensor was mounted on the top of the vessel, such that it was in direct sunlight. The in-situ profile was collected with the LI-192 sensor off the sunny side of the vessel.

Surface water samples were collected for chlorophyll a (chla), total suspended sediment (TSS), orthophosphate (OrthoP), total phosphorus (TP), ammonia-N (NH_3) total nitrogen (TN), nitrate-nitrite (NO_3-NO_2), dissolved organic carbon (DOC) and phycocyanin (phyco). Phyco samples were collected only during the bloom season (Late July-Late September), thus samples were not collected during CSMI 1 and 2 dates. Before collection of water, sampling bottles and lids were triple rinsed with site water to minimize contamination. All samples, except chla, and phyco, were taken approximately 6 inches below the surface of the water. Chla and phyco were collected at the water's surface. 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 contains (TP, TN, NO_3/NO_2, and NH_4) to preserve until analysis. DOC containers were filled to the top of the container and were sent to the lab unfiltered and unacidified.

OrthoP, chla, and phyco were field filtered. OrthoP was filtered through 0.45 µm MCE filters and the filtrate was collected. Chla was filtered through 5.0 µm MCE filters and phycocyanin was filtered through 0.22 µm PES membrane filters, and the filters were stored on ice in the dark. The volume of water that passed through each filter was recorded for each site and sampling event.

Samples were collected into appropriate sampling containers (Table 2) and placed on ice. After returning to the dock, samples were shipped to the Wisconsin State Lab of Hygiene for analysis, except for phycocyanin which was stored in the freezer until the end of the season and then sent to Dr. Todd Miller at the University of Wisconsin-Milwaukee.

Table 3. Details on Sample Handling NA stands for Not Applicable

Parameter	Lab Code	Collection Bottle	Field Filter?	Preservation/Shipping	Hold Time	LOD
Chlorophyll a (Chla)	ICC25120	Plastic Quart 500mL	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	if not filtered 48 hrs. If filtered 3.5 weeks	0.0578 µg/L
Microsystin	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
Saxotixin	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
Phycocyanin	Miller Laboratory SOP	4 L Polypropylene copolymer	yes	Filtered samples can be preserved at -20 C	Need to be filtered within 6 hours of collection	10 µg/L

Parameter	Lab Code	Collection Bottle	Field Filter?	Preservation/Shipping	Hold Time	LOD (mg/L)
Total Suspended Solids (TSS)	ICC65000	Plastic Quart 500mL	no	Less than 6C	7 days	2
Dissolved Organic Carbon (DOC)	OCC16621	1 L glass amber bottle	no	4C	48 hr	0.40 C
Orthophosphate (OrthoP)	ICC53000FF	60 mL polyethylene	Yes 0.45 um	Less than 6C, but not frozen	48 hours	0.004
Total Phosphorus (TP)	ICC52010	250 mL plastic bottle	no	1 mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.009
Total Nitrogen (TN)	ICC46601	250 mL plastic bottle	no	1 mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.058
Nitrate nitrite (NO_3/NO_2)	ICC46000	250 mL plastic bottle	no	1 mL of 25% H2SO4, Less than 6C, but not frozen	28 days	0.055 mg N
Ammonia (NH_3)	ICC440001	250 mL plastic bottle	no	1 mL of 25% H2SO4, Less than 6C, but not frozen	28 days	.012 N

Data Analysis:

Lake Superior is an oligotrophic system, thus it has low concentrations of nutrients. The values observed are at the lower limit of the methods used by the Wisconsin State Lab of Hygiene. There were many non-detects for TSS, NH_3, TP and OrthoP. TP, and OrthoP datasets had many 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.

For the summary 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.

Photosynthetically active radiation:

K_d is the vertical attenuation coefficient for downward irradiance. The K_d of Photosynthetic Active Radiation (PAR) is thought to be the best single parameter to characterize different water bodies with respect to the availability of photosynthetically useful radiant energy within them (Smith 1968). K_d of PAR is related to euphotic depth (When K_d(PAR) falls to 1%), which is a useful term to determine how deep photosynthetic light is available (Kirk 2002). This could potentially relate to where in the water column algal blooms are likely to occur. The larger the K_d value the quicker the light is absorbed in the water column, providing evidence for poorer water clarity.

Ambient and underwater PAR data was used to calculate PAR attenuation coefficients (K_d) in the water column following NCCA protocols (USEPA 2020). The underwater sensor, or the sensor that was lowered through the water column, measured PAR intensity (I_z) at depth z, and the ambient sensor measured incident PAR intensity (I_0). When normalized (I_z/I_0), the light intensity should decrease exponentially with depth (z) in accordance with Beer's law (Equation 1).

$$\frac{I_z}{I_0} = e^{-K_d * z} \qquad \text{Equation 1.}$$

K_d was calculated using a rearranged version of Equation 1 (Equation 2), where K_d is the negative slope of the regression of $\ln(I_z/I_0)$ vs. depth (z).

$$ln\frac{I_z}{I_0} = -K_d * z \qquad \text{Equation 2.}$$

The water clarity condition at each site (good, fair, or poor) was determined by %Trans @ 1 m values relative to benchmarks in

Euphotic depth was calculated by finding which depth PAR fell to 1% of its surface value.

$$z_{eu} = \frac{\ln(0.01)}{-K_d} \qquad \text{Equation 3}$$

Growing Degree Day:

Temperatures greater than 10 degrees Celsius are considered to promote the growth of algal blooms (Sterner et al., 2020). We calculated growing degree days (GDD) for the year as the cumulative sum of daily surface temperature > 10°C. UMD's Bark Point buoy (https://www.d.umn.edu/buoys/buoy_data_access.php) was used for surface temperature data. Daily growing degree days were calculated by taking the daily average surface water (0.06m) temperature and subtracting the base temperature of 10°C. These daily values were cumulatively added as the season progressed to obtain a growing curve. GDD analysis was modeled off analysis conducted in Sterner et al., 2020.

Results/Discussion:

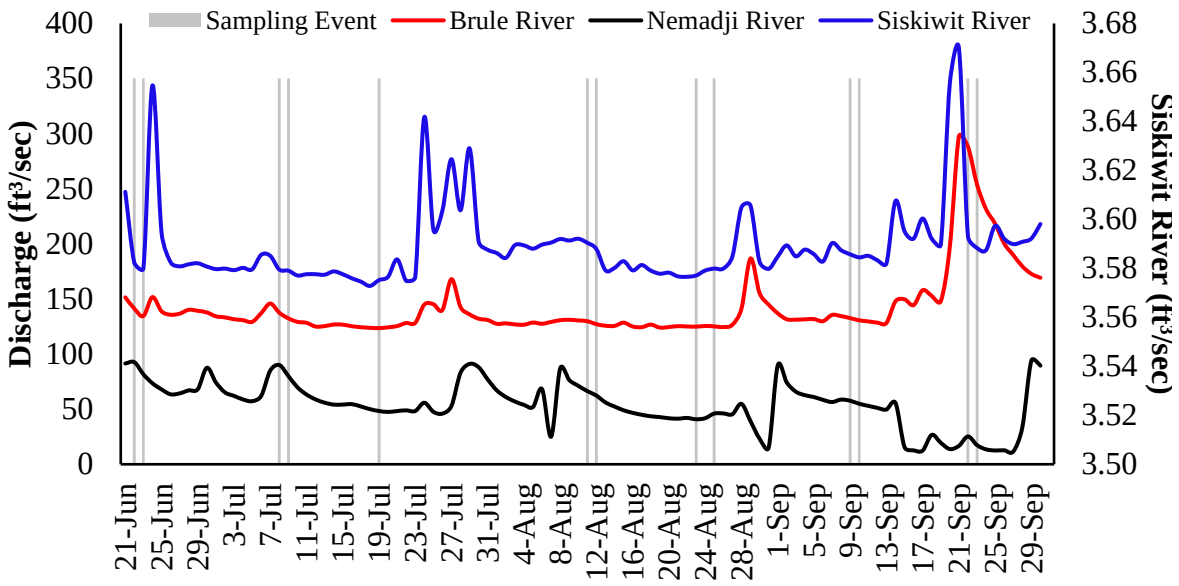


Figure 2 Depicts the discharge in ft³/sec for 3 Lake Superior tributaries that were near the sites sampled. Sampling events are depicted in grey vertical lines. Discharge values are depicted in red, black, and blue for Brule, Nemadji, and Siskiwit respectively. Siskiwit River had a much lower discharge, thus it is on its own axis.

Data collection relies heavily on good weather conditions for boating. We did not sample if the waves were predicted to be greater than 2 ft, to minimize risk to the sampling crew. To try to keep our timing consistent throughout the season, we only sampled the weeks determined at the beginning of the season. Throughout those weeks samples were collected; Mondays and Tuesdays were preferred, but sometimes due to weather samples were collected on a Thursday or Friday. These later-week samplings impacted our collection by exceeding the hold time on parameters that are less than 48 hrs. (DOC, OrthoP, and Chla). The dates sampled are shown in Table 2.

Hydrodynamics

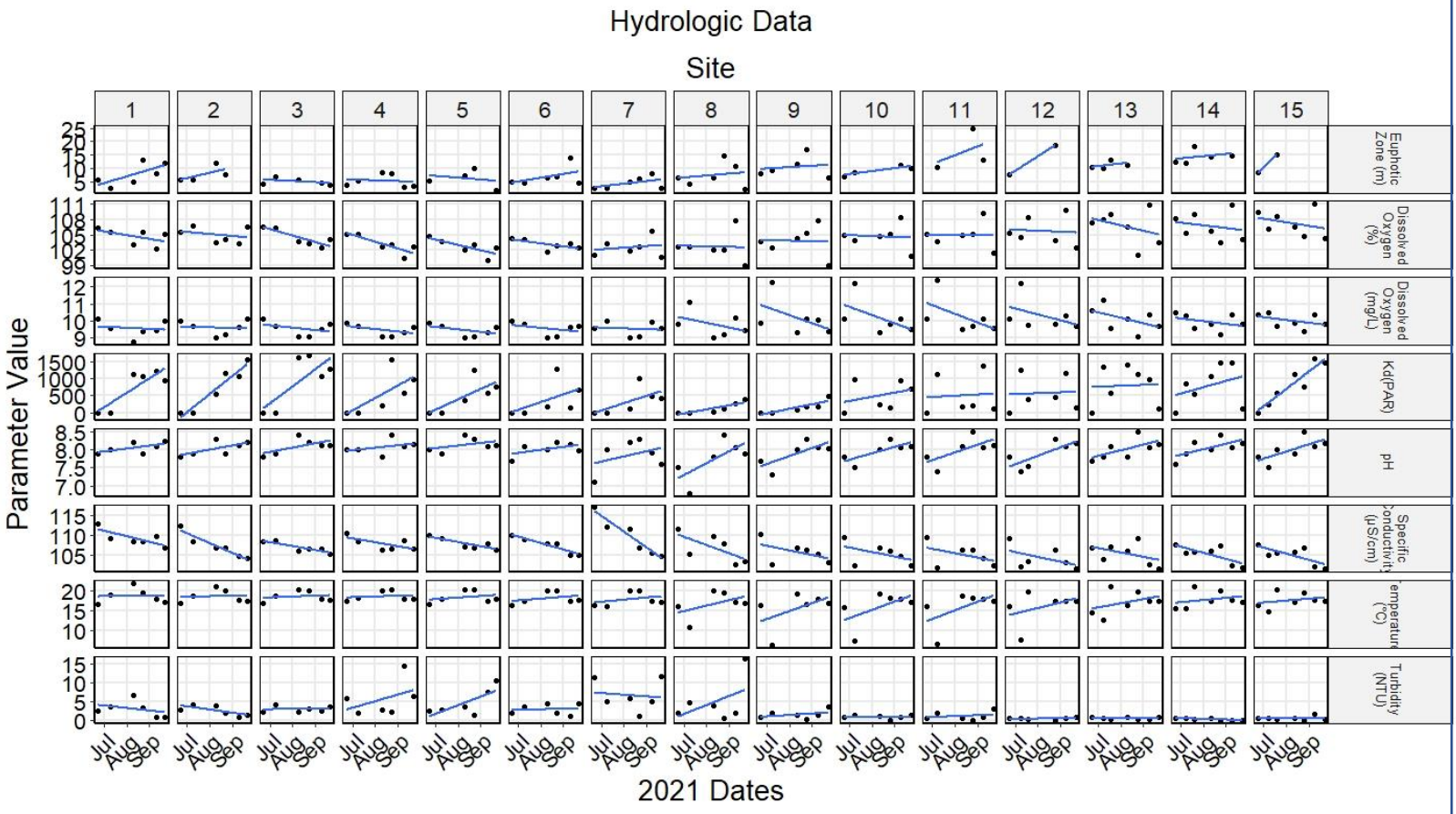


Figure 3 Trends in data for each parameter measured through time and by site. Numbers on top represent the site number. For each column, the cell moves through the sampling season from June to September. Parameters are arranged in alphabetical order. Black dots are data points, The Blue line is linear regression depicting trends for each site, and parameters through time. Data displayed is from 0.5 m water depth for all sites and times

Table 4 Descriptive statistics for overall sampling effort. N is the number of samples in our dataset, Min is the minimum value, Mean is the average value, Max is Maximum value, SD is Standard deviation of values. The count is lower for Euphotic Zone due to sites with R^2 values lower than 0.90 being removed.

Hydrodynamic Parameters summaries averaged over sites and sampling rounds.

Parameter	Count	Mean	Min	Max	Stdev	NDs
DO %	93	105	99	111	3	0
DO (mg/L)	93	9.8	9.1	12.6	0.7	0
Euphotic Zone(m)	79	10	0	25	5	0
Kd (PAR)	93	500	0	1500	500	0
pH	93	8.1	6.9	8.4	0.3	0
Specific Conductivity (uS/cm)	93	108	102	117	3	0
Temp (C)	93	18	6	21	3	0
Turbidity (NTU)	93	3	0	15	3	0

Temperature

Water temperature is a driving factor for if an algal bloom may occur (Calieri et al., 2014). Temperatures greater than 10 degrees Celsius are considered to promote the growth of algal blooms (Sterner et al., 2020). The average surface temperature recorded for this field season was 17.1 °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 temperatures play a role in algal bloom formation in Lake Superior's nearshore environment.

Similar temperature trends were observed in sites 1-7, where the maximum temperatures occurred in mid-August (Figure 3). When examining the water column profile data there is not a large variation of the temperatures from surface to depth. The second sampling session, which occurred in early July, showed the coldest water temperatures for the season in sites 8-11 at 6.6 °C. Sites 12-15 experienced a large variation of temperatures between surface and depth measurements when compared to the other sites.

Profile data (**Appendix**) shows minimal thermocline development. The slight thermocline shown at site 9 is most likely influenced by river water intrusion.

Turbidity

Turbidity for the area was overall low values, especially at sites 9-15 (Figure 3). Site 1 showed a peak during the second sampling session, which was driven by 2-5 m depths. Sites 2-8 exhibit peaks during CSMI 7, again this is driven by depths greater than 2 m deep, except for site 8 where all depths are much more turbid than previous sampling dates.

pH

The pH Probe was not calibrated properly for most of the season. It was not registering the correct millivolt reading for pH 4, 7, and 10. It was typically about 70-90 mV less than the accepted value. Due to supply chain issues, we were not able to obtain a new probe until 8/31/2021. Once installed, it calibrated to accepted values.

Euphotic Zone

Euphotic Zone increased slightly as the sampling season progressed, especially in sites 10-15 (Figure 3). Sites 1-9 values held more stable throughout the season. There is more variability in sites 10-12 than in the other group of sites. Knowing how the photic zone varies across the nearshore allows us to make science-informed decisions regarding future sample collection plans.

Cyanobacteria are well adapted to thrive in a wide variety of light conditions (Dokulik & Teubner, 2000). They have exoplasmic phycobilisomoes as a part of their photosynthetic apparatus that allow them to absorb light in the green to orange part of the electromagnetic spectrum that most eukaryotic algae are not able to access (Kirk 1994). Cyanobacteria also have a protein structure that allows them to use light in the far-red spectrum, allowing them to grow in restricted light conditions (Kirk 1994). They can effectively adapt to low irradiance depths (<1% of incident light), which helps to explain the occurrence of deep chlorophyll maxima in oligotrophic lakes (Hamre et al., 2018; Scofield et al., 2017; Reinl et al., 2020).

Nutrients

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 to ship samples to the lab for analysis. There are a few data points missing where there were issues with bottles breaking or lab slips being unclear with the analysis requested.

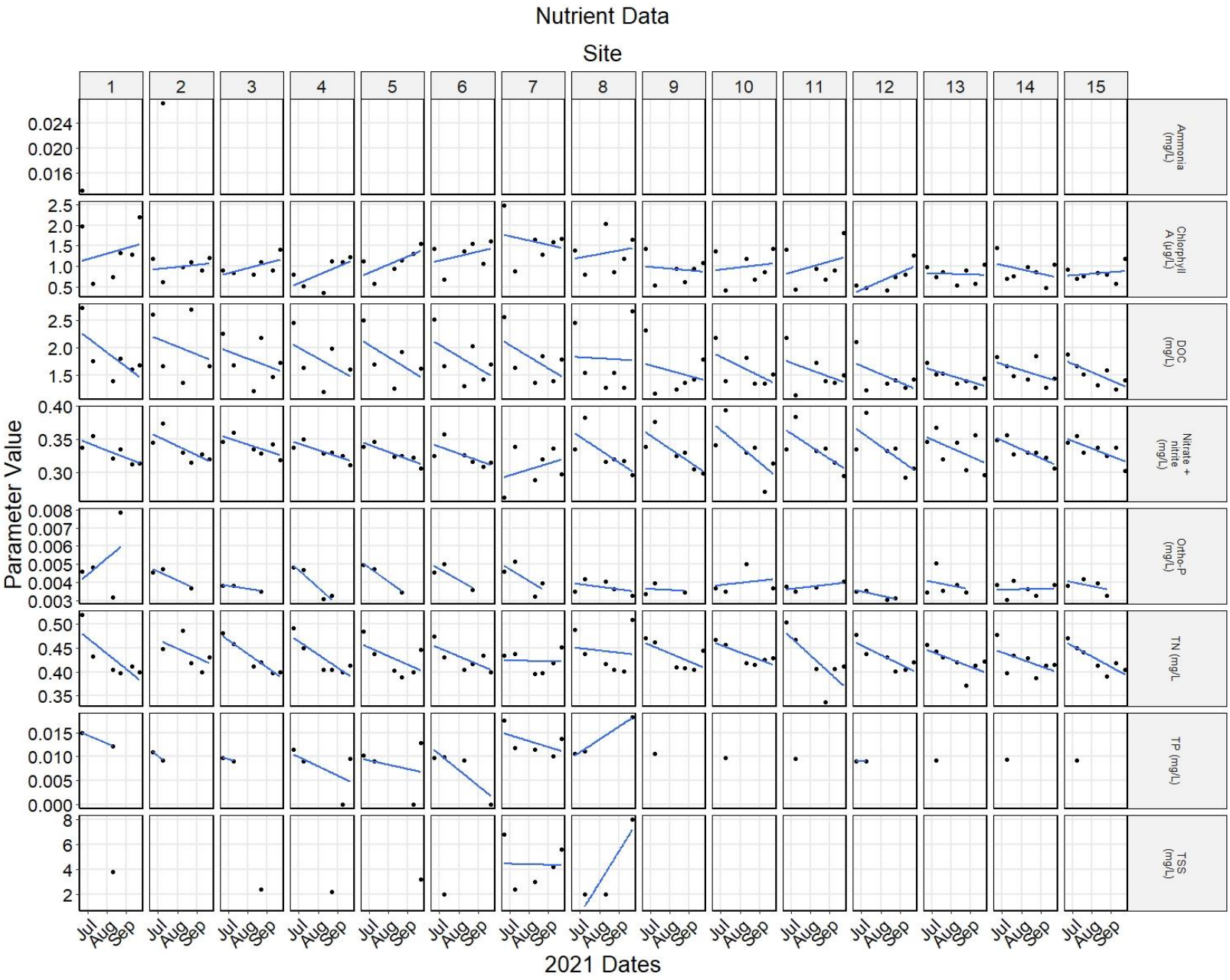


Figure 4 Trends for each parameter measured through time and by site. Numbers on top represent the site number. For each column, the cell moves through the sampling season from June to September. Parameters are arranged in alphabetical order. Black dots are data points, Blue line is linear regression depicting trends for each site, parameters through time.,

NH_3

Ammonia values for Lake Superior are below the detection limit for the method used, thus we were only able to collect values for two data points throughout the field season.

Table 5 Descriptive statistics for overall sampling effort. N is the number of samples in our dataset, Min is the minimum value, Mean is the average value, Max is Maximum value, SD is Standard deviation of values. The count is lower for TSS and DOC due to shipping and/or lab issues. Missing Data we sampled: TSS and DOC (CSMI 6, Site 2, 4,5), Blank information for CSMI 1 Site 2

Nutrient summaries averaged over sites and sampling rounds.

Parameter	Count	Mean	Min	Max	Stdev	NDs
Chl A (ug/L)	93	1.2	0.4	2.4	0.4	0
DOC (ppm)	90	1.6	1.2	2.8	0.4	0
NH3 (mg/L)	93	0.006	0.006	0.028	0.002	91
Nitrate/nitrite (mg/L)	93	0.34	0.26	0.4	0.02	0
Ortho-P (mg/L)	93	0.003	0.001	0.008	0.001	34
TN (mg/L)	93	0.45	0.05	0.5	0.05	1
TP (mg/L)	93	0.009	0.006	0.018	0.003	59
TSS (mg/L)	86	1	1	8	1	73

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 grab samples were below 3 µg/L of Chlorophyll *a*. Generally speaking, there are higher Chl *a* values at the beginning of our sampling season, low in the middle, and increasing towards the end of the season. The timing for the Chl *a* minimum was at the 2nd to 3rd round sampling. The maximum chla concentration, 2.47 µg/L, for the sampling season occurred at site 7 in the first round of sampling (Table 7 of Appendix). Sites 1-5 exhibit a trend through the season where concentrations start high, fall rapidly, then recover to similar or higher values than the start of the season. Sites 9-11 show a similar pattern to 1-5, but with less variation in concentrations. Sites 12-15 exhibited stable concentrations throughout the season and show a much smaller confidence interval around the trend line than other sites (Figure 8 in appendix). All chlorophyll values are above the LOQ.

Lake Winnipeg, a large freshwater lake, uses 10 µg/L as an indicator of potential bloom conditions (Binding et al., 2018). From this sampling endeavor, none of the samples reached this concentration.

DOC

Western sites (1-8) experienced a decrease in DOC mid-season, the lowest concentrations were observed during sampling round 4. Eastern sites seem to have a muted response, where there is less of a decrease. Minimum values across sites had a small range of 1.2 to 1.5 mg/L. The bottles for CSMI 6 sites 2, 4, and 5 were broken in the mail and the lab was not able to provide results for these data points. Sites 13-15 have a tight confidence interval around the trendline, compared to other sites indicating more stable conditions (Figure 7 in Appendix).

Nitrate/Nitrite
All sites exhibit a peak in concentration at sampling rounds 2-3. Concentrations decline as the season progresses, except for site 7 which shows a slight increase. Sites 8-12 show similar patterns where concentrations increase at the beginning of the season, fall dramatically by 3rd round of sampling and continue decreasing as the season progresses.

OrthoP
The majority of data are between LOD and LOQ, this should be considered when looking at trends in Figure 4. The maximum value of 0.009 mg/L occurred at site 1, at the sampling session 5.

TN
The majority of sites show a similar trend of decreasing most at beginning of the season and a slower decrease after 4th sampling session, with a slight increase at the 7th sampling session. Sites 7 and 8 exhibit a more stable trend than other sites.

TP
Phosphorus is an influential macronutrient that regulates algae growth 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 be factors as well. Phosphorus can bind to varying sediment types, such as iron (Fe) 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.

The majority of data are between LOD and LOQ, this should be considered when looking at trends in Figure 4. The highest concentration, 0.018 mg/L, was observed during the 1st sampling round at site 7. This peak aligns with the peak of TSS and Chl *a* at round 1.

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). These concentrations were not reached in this monitoring project. Low concentrations of phosphorus in the nearshore likely limit growth of algal communities. The National Coastal Condition Assessment (NCCA) established that concentrations of less than 5 µg/L TP are good water quality, and concentrations greater than 10 µg/L are considered poor. Very seldomly did this data set exceed 10 µg/L (Table 3).

Table 6: Indicators for National Coastal Condition Assessment Eutrophication Indicator

NCCA INDICATORS	GOOD	FAIR	POOR
TP (µg/L)	<5	5 to 10	>10
CHLA (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

TSS

Most samples came back as non-detects, thus we are unable to establish trends in data. Concentrations above the LOD were most consistently observed at sites 7 and 8. These sites are east of the Brule River and Iron River, respectively, which is most likely influencing these values. We see a rise in TSS and TP concentrations after a September rain event (Figure 2) at site 8, which is just east of the Brule River outlet. Chl *a* showed a muted response to this event.

Phycocyanin

Phycocyanin samples were collected to investigate the correlation between phycocyanin and algal bloom occurrence. There were no detections of phycocyanin in any of the samples taken.

Carlson analysis

The trophic state index (TSI) can be calculated using Chl *a* and TP and the simplified equations derived from Carlson (1977). The output of the equation determines which category a waterbody falls into: Oligotrophic (0-40), Mesotrophic (40-50), and Eutrophic (50+). TSI can help assess the biological condition of a lake. Oligotrophic systems typically have fewer available nutrients, less algal growth, and tend to have increased water clarity, mesotrophic systems have moderate water clarity and a moderate amount of available nutrients, and eutrophic systems have a high amount of available nutrients, decreased water clarity, and increased algal growth (Chapra and Dobson, 1981).

$$TSI\ (Chla) = 9.8 * \ln(Chla) + 30.6$$
$$TSI\ (TP) = 14.42 * \ln(TP) + 4.15$$
$$TSI = (TSI\ (Chla) + TSI\ (TP))/2$$

Equation 4: Trophic State Index Calculations. WisCALM 2018, Units for Chla and TP are µg/L

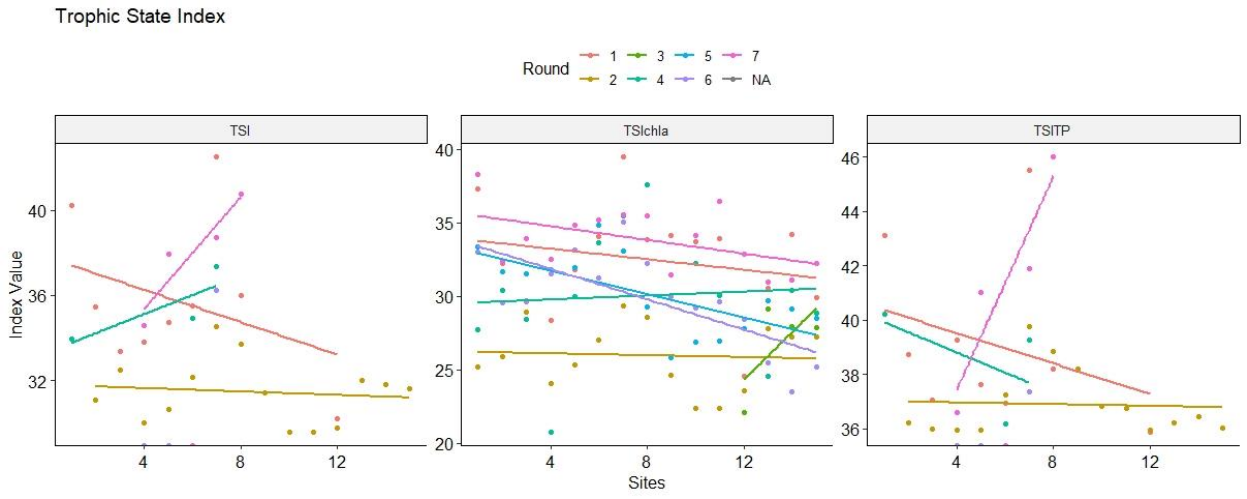


Figure 5 Trophic State Index summary. Graph A shows the overall Index, B shows the chlorophyll a contribution and C shows the TP contribution. Linear regression shows trends for each round of sampling.

Almost all sampling points fall in the oligotrophic range. Round 2 of sampling shows consistent TSI across all sites, indicating that all sites are experiencing similar nutrient conditions. The trophic state for the 7th round of sampling seems to trend toward mesotrophic (Figure 5). Total Phosphorus concentrations seem to be the driver of this trend, not chl *a*. Chl *a* indicator tends to decrease as you move toward further east sites, which correlates to an increase in water clarity.

Comparison to 2019:

For a more thorough examination of the 2019 data look at the SWIMS document: 2019 Lake Superior Nearshore Monitoring Final Report

Here the parameters that were measured in both studies were compared using an F-Test for Variance and a T-Test for means over all sampling time and sites. It was found that concentrations in 2019 of Chl *a*, Nitrate, OrthoP, and TN were significantly different from those in 2021 (Figure 6, Table 7). Chl *a* , OrthoP and TN were considered significantly higher concentrations while Nitrate was significantly lower. These trends seem to be drive by 1-2 outliers for the 2019 data, which are associated with sampling after a rain event. For TP and TSS there was not enough evidence to reject the null hypothesis that these were from the same population. This is driven by the fact that there were few sampling points above non-detect for these parameters, which provided the analysis little power to distinguish between the groups. Both datasets were collected in lower flow years where a nearshore bloom did not occur, thus it is surprising to see how many parameters were significantly different. This provides evidence of how much influence spatial and temporal variability of the climate and flow has on the nearshore nutrient dynamics.

Table 7 Summary Statistics for Comparison between 2019 and 2021 datasets. F-test for variance, T- test for means. Using 0.05 as a measure of significance. Welch's Two samples tests used for the T-Test. Bolded values are significantly different parameters.

Parameter	**F-test p-value**	**T-test p-value**	**Mean 2019**	**Mean 2021**	**N Samples 2019**	**N Samples 2021**
Chla	1.20E-12	**0.01258**	1.24	0.96	78	80
Nitrate	0.03	**0.04187**	0.326	0.334	84	80
OrtoP	2.49E-09	**9.52E-06**	0.005	0.004	70	61
TN	0.009	**3.33E-05**	0.457	0.43	80	79
TP	2.20E-16	0.1436	0.016	0.011	39	29
TSS	5.20E-10	0.079	11.7	3.1	29	10

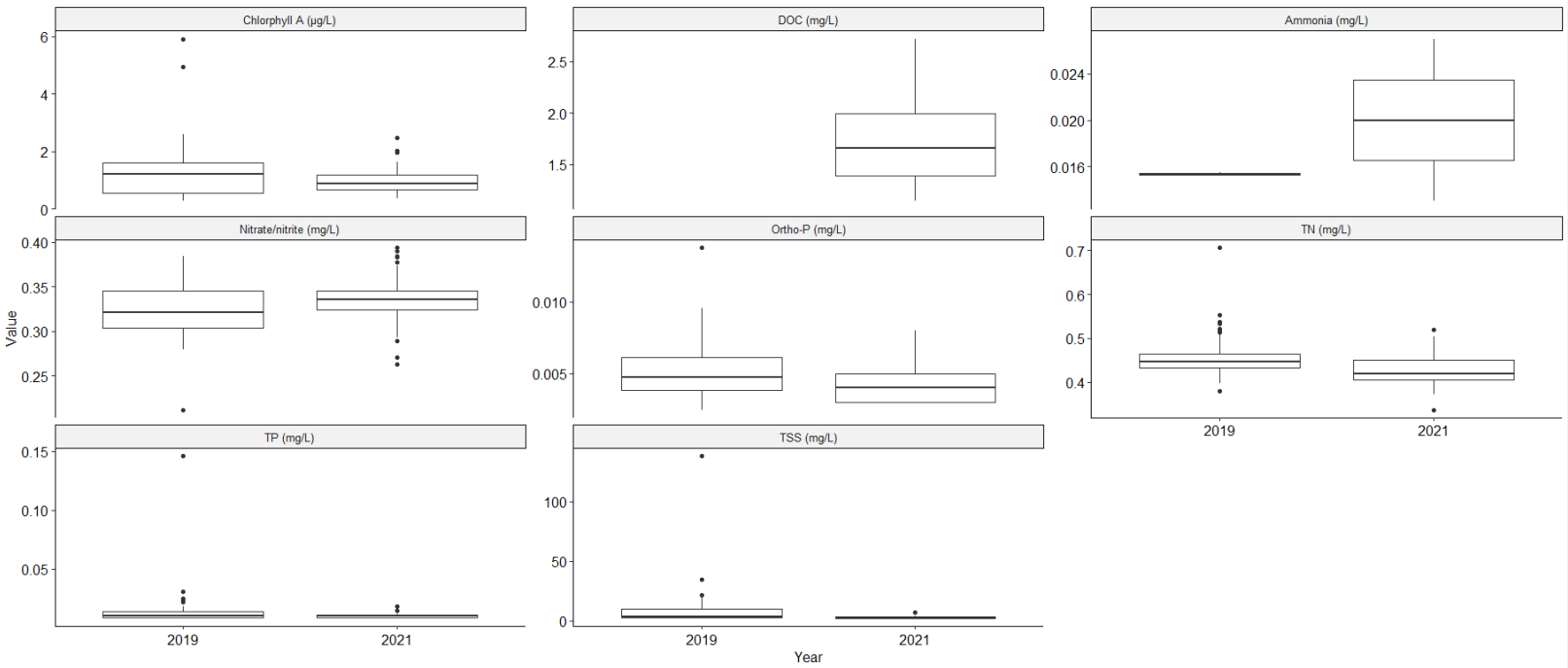
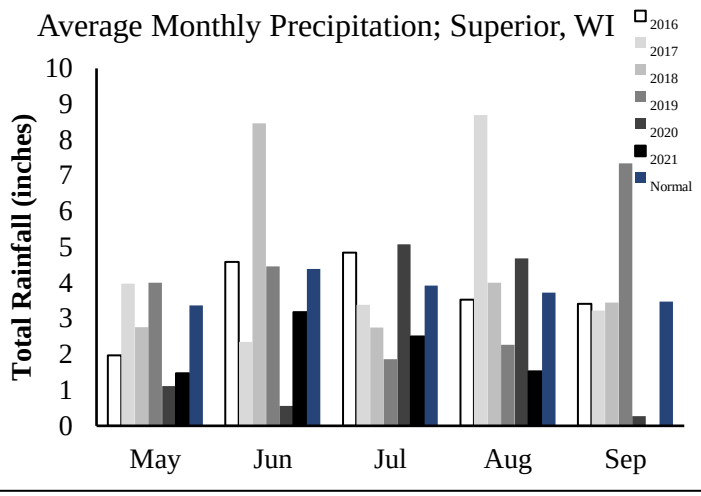


Figure 6 Nutrient boxplot comparison for 2019 and 2021. All nutrients are statistically significantly different between years, expect for TP and TSS.

Climate Influence:

After examining the local climate data, we see that the discharge of the Brule River in 2021 is one of the lowest flows in the last 5 years (Figure 2, Figure 7). 2019, the other year that we collected data in the nearshore, was also a low-flow year. Based off anecdotal evidence, algal blooms tend to occur in higher flow years, thus it is not surprising that neither of these data sets captured bloom formation data. The small peak that was observed at the end of September occurred too late in the season to result in an algal bloom.

This summer (June through August) was the hottest on record through August 16 for Duluth. The average temperature of 67.7 degrees bests the previous mark of 67.5 degrees set back in 2012 (https://www.mprnews.org/story/2021/08/17/hottest-summer-on-record-for-duluth-more-90s-ahead).



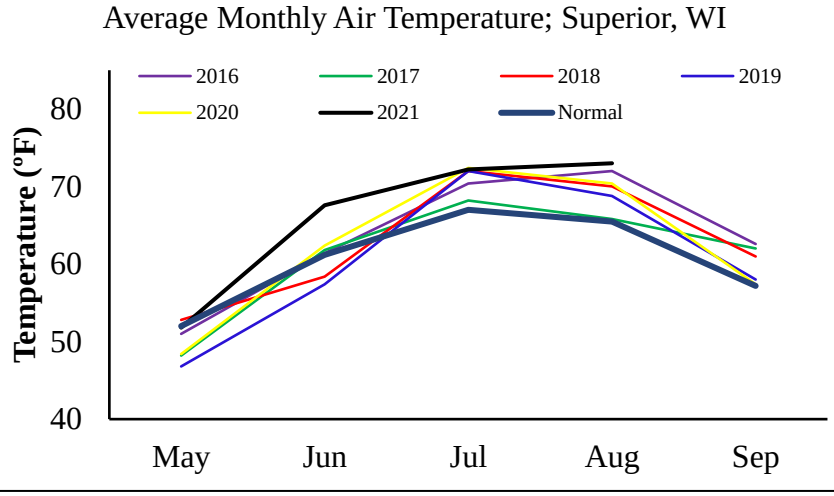


Figure 7 Left panel Average Monthly Precipitation in Superior WI for summer season. A typical year being represented by the navy-blue bar on the far right of each month, Right Panel Average Monthly Air Temperature for Superior WI in the summer season.

Based on the information gathered from the nearshore of Lake Superior this summer, warm weather is not enough to drive the formation of harmful algal blooms, it seems that nutrient and sediment inputs from the streams are required for growth.

Growing Degree Days:

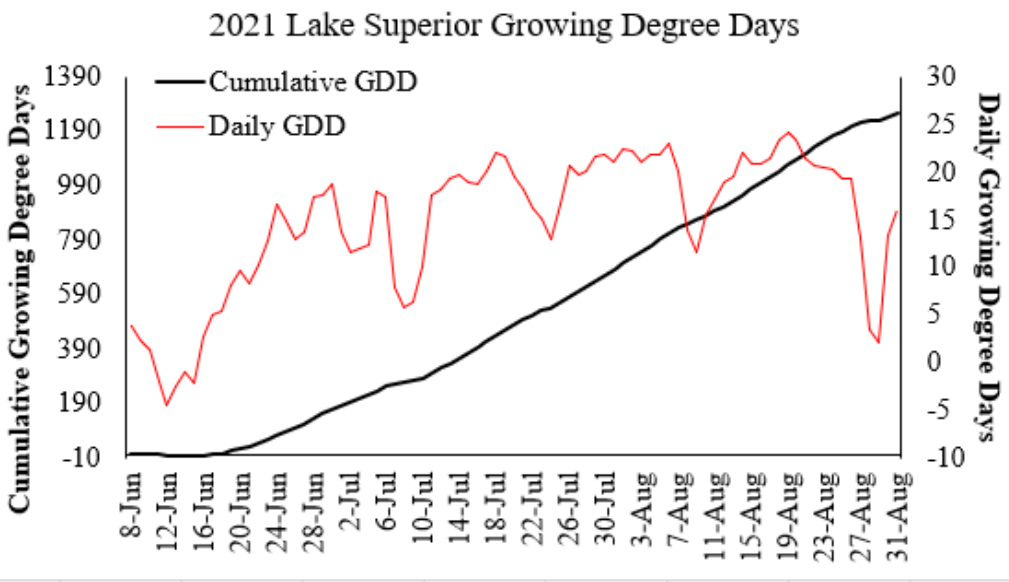


Figure 8 Growing Degrees days (> 10 C) for 2021. The Red line shows Daily GDD, the Black line shows the Cumulative GDD.

Temperatures greater than 10 °C are considered to promote the growth of algal blooms (Sterner et al., 2020). We calculated growing degree days (GDD) for the year as the cumulative sum of daily surface

temperature > 10°C. These daily values were cumulatively added as the season progressed to obtain a growing curve. GDD analysis was modeled off analysis conducted in Sterner et al., 2020.
In previous years blooms have occurred with an average of ~750-1000 growing days in the bloom season (Sterner et al., 2020). In 2021 we determined that the average GDD was 834 (Figure 8). This indicates that the water was warm enough to support bloom growth. This aligns with our conclusions that surface temperature of the water is not the only factor needed to produce an algal bloom.

Conclusion

To improve this work in the future we suggest sampling the same locations as this will increase our understanding of how these nearshore conditions change year to year. DOC samples were collected because partners were collecting that parameter. However, there was little additional information gained from this data set. Thus, in future studies this parameter will not be collected as a part of the standard set. Many of the ammonia results were below the detection limit for the method. At this point in time the WSLH does not offer a method with a lower detection limit. Ammonia will be dropped in the next field season. Recently the WSLH did add a method for low-level total phosphorus, which will be used in future studies. The new detection level of this method is 0.00190 mg/L compared to 0.009 mg/L that was used in this current study. This will allow us to determine more nuanced changes in the low concentrations of TP. We will not have the instrumentation available to use next field season to measure PAR for future studies.

No algal blooms were captured in this dataset, but it will be useful as baseline data for future research into what the driving factors may be for algal blooms within Lake Superior. Our dataset also provides insights into how hydrodynamics and nutrients vary spatially across the nearshore and may inform us as to why blooms occur where they do. The nearshore warmed to temperatures that are thought to support bloom growth, but was potentially missing another important factor necessary to form a bloom.

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Appendix

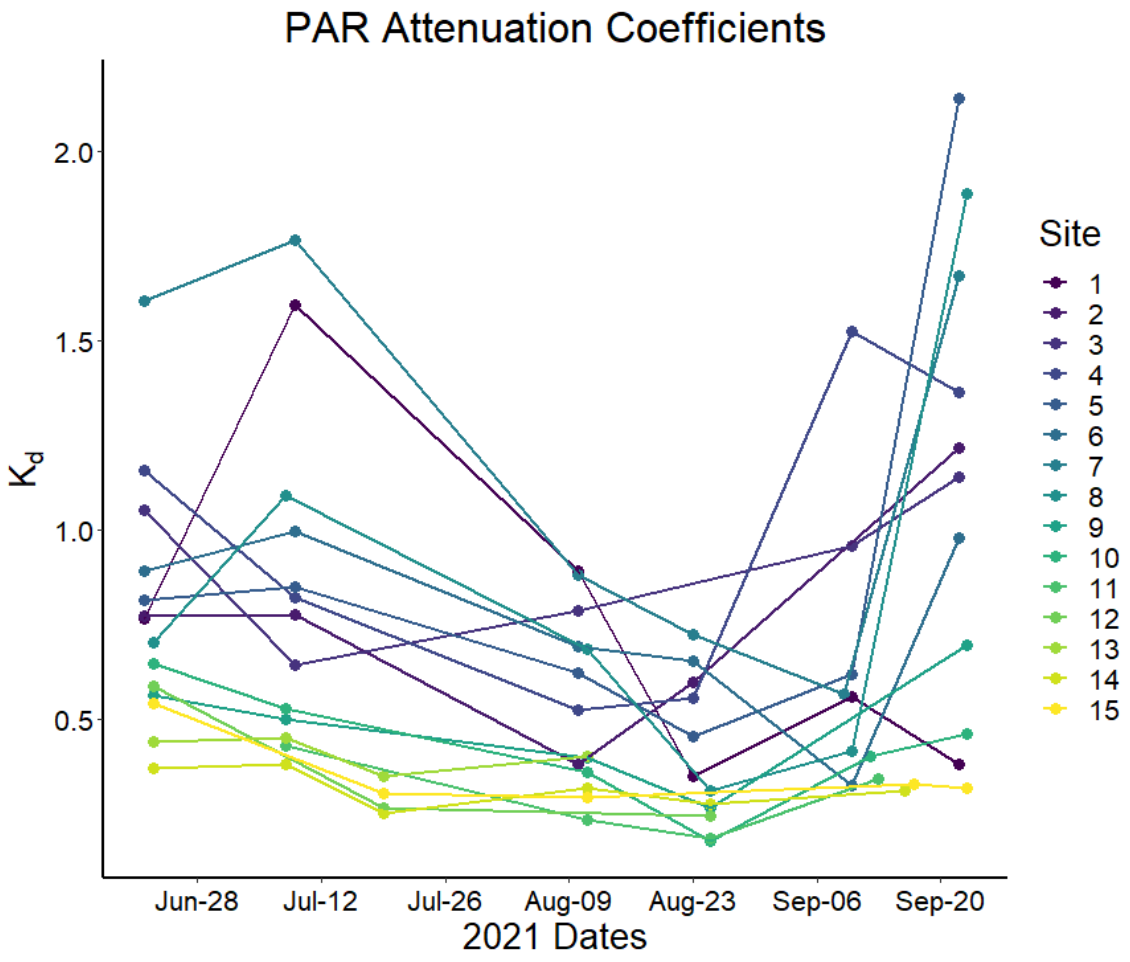

Figure1

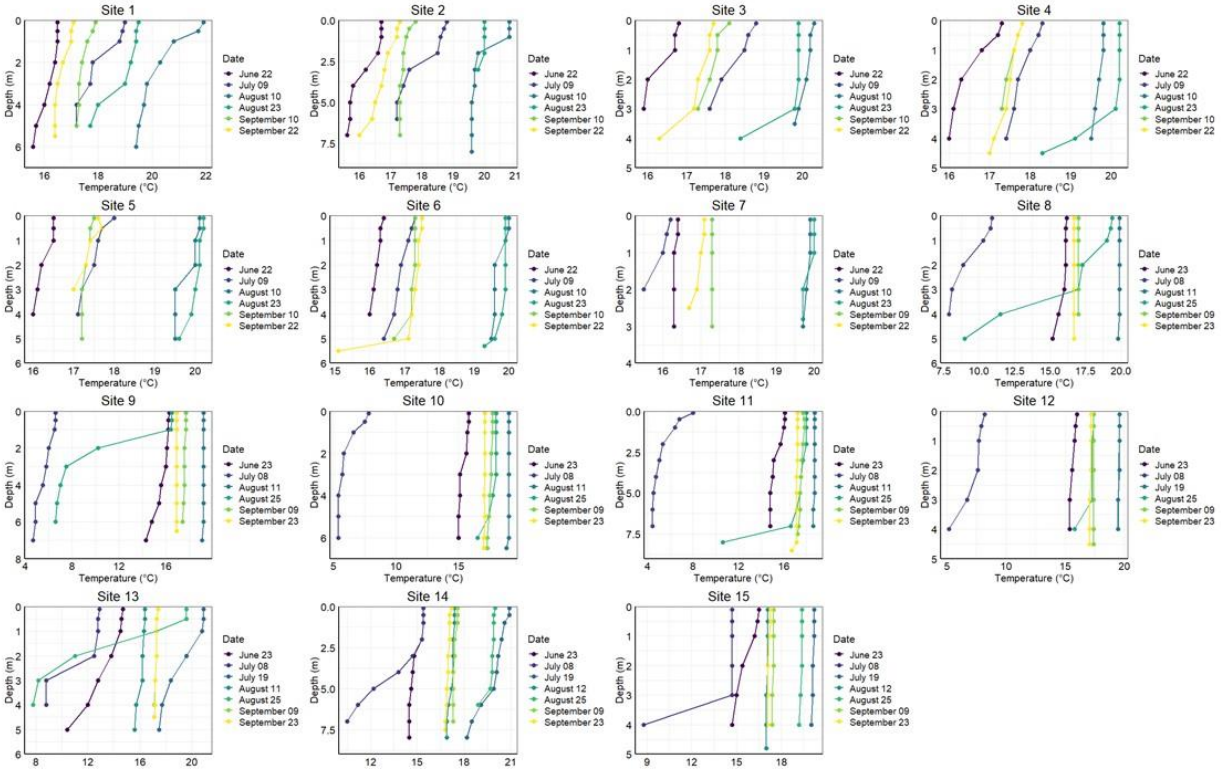

Figure 2

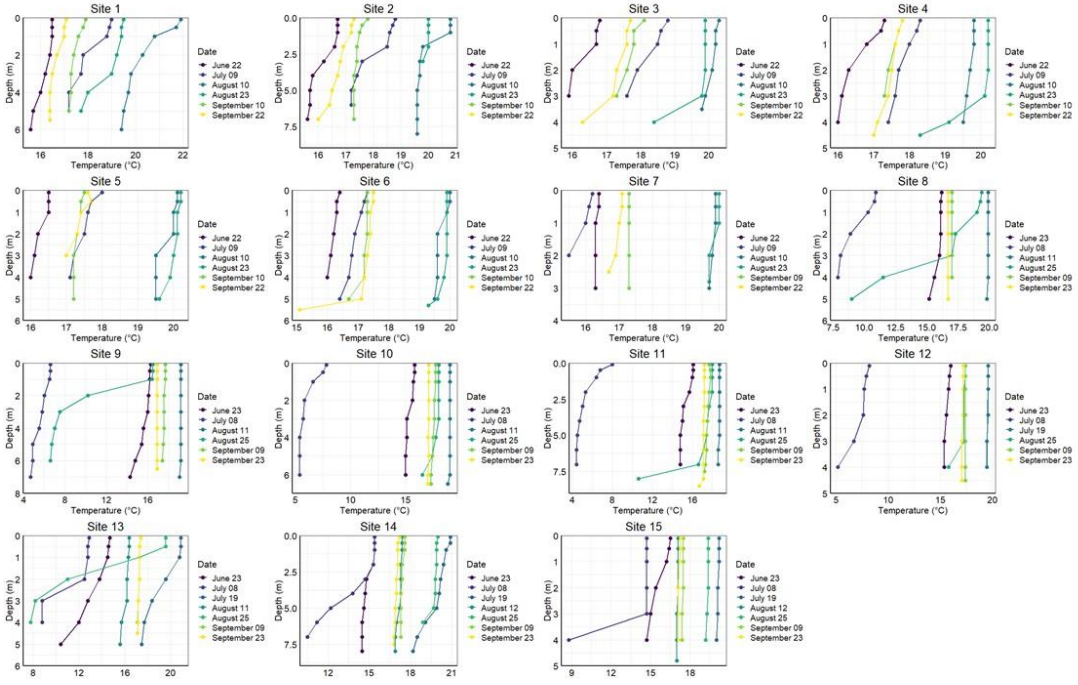

Figure 3

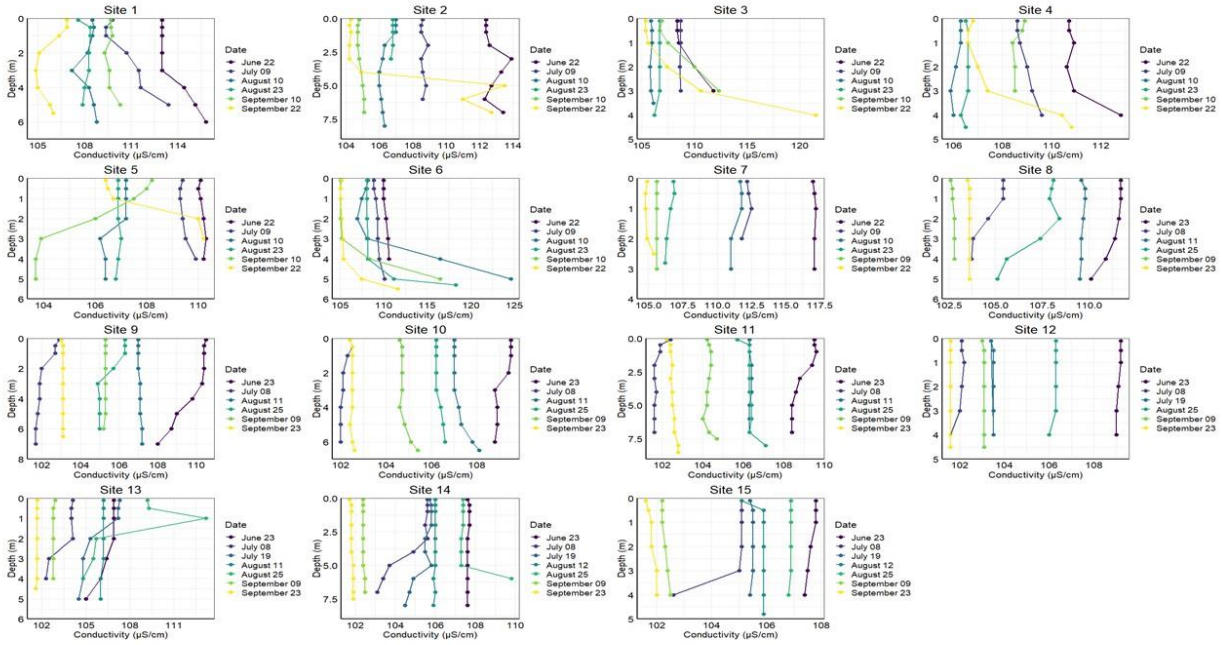

Figure 4

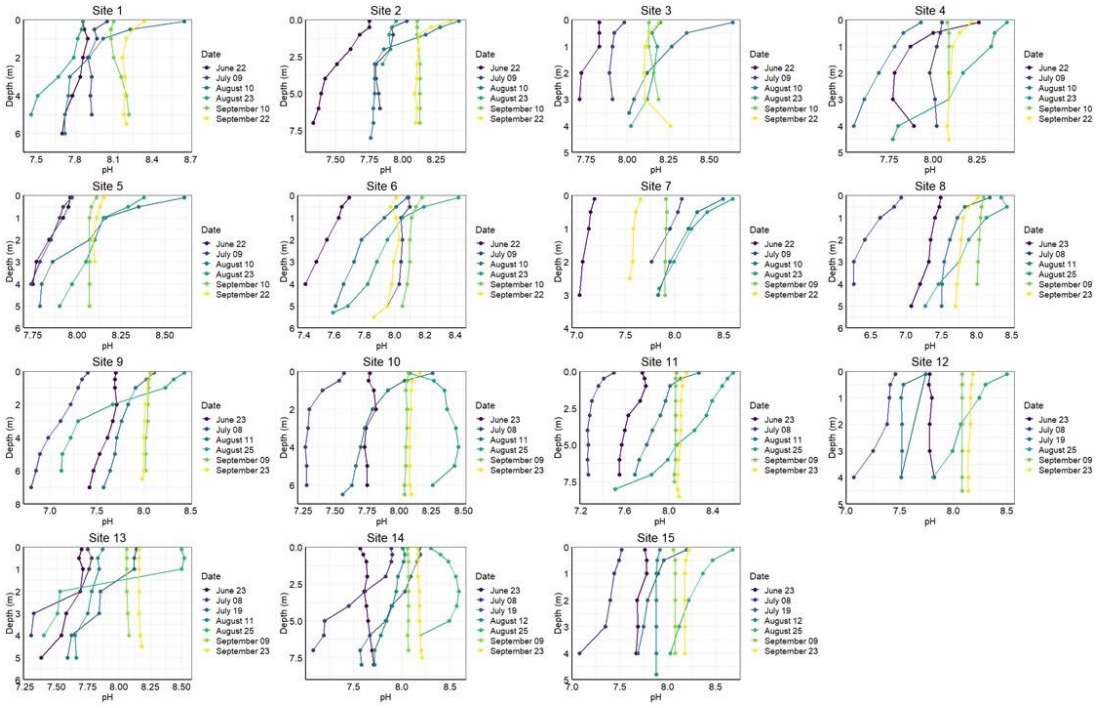

Figure 5

Table 3 Descriptive statistics for overall sampling effort. N is number of samples in our dataset, Min is the minimum value, Mean is the average value, Max is Maximum value, SD is Standard deviation of values, NDs indicate number of non-detects. OrthoP that was past hold time 7 from Round 1, 6 from round 2, all from round 4, 7 round 5, 4 round 6,

Nutrient summaries grouped by sampling round.

Round	Parameter	Count	Mean	Min	Max	Stdev	NDs
1	Chl A (ug/L)	15	1.5	0.5	2.5	0.5	0
1	DOC (ppm)	15	2.4	1.8	2.7	0.3	0
1	NH3 (mg/L)	15	0.006	0.006	0.014	0.002	14
1	Nitrate/nitrite (mg/L)	15	0.34	0.26	0.34	0.02	0
1	Ortho-P (mg/L)	15	0.0042	0.0036	0.0048	6e-04	0
1	TN (mg/L)	15	0.4	0	0.5	0.1	1
1	TP (mg/L)	15	0.008	0.008	0.016	0.004	6
1	TSS (mg/L)	15	1	1	7	1	14
2	Chl A (ug/L)	15	0.6	0.4	0.9	0.1	0
2	DOC (ppm)	15	1.6	1.2	1.8	0.2	0
2	NH3 (mg/L)	15	0.005	0.005	0.025	0.005	14
2	Nitrate/nitrite (mg/L)	15	0.36	0.34	0.4	0.02	0
2	Ortho-P (mg/L)	15	0.004	0.001	0.005	0.001	1
2	TN (mg/L)	15	0.44	0.4	0.46	0.02	0
2	TP (mg/L)	15	0.009	0.006	0.012	0.001	1
2	TSS (mg/L)	15	1	1	2.5	0.5	12
3	Chl A (ug/L)	4	0.6	0.4	0.8	0.2	0
3	DOC (ppm)	4	1.44	1.36	1.52	0.08	0
3	NH3 (mg/L)	4	NaN	NaN	NaN	0	4
3	Nitrate/nitrite (mg/L)	4	0.33	0.32	0.335	0.005	0
3	Ortho-P (mg/L)	4	0.0035	0.003	0.004	5e-04	0
3	TN (mg/L)	4	0.435	0.43	0.44	0.005	0
3	TP (mg/L)	4	NaN	NaN	NaN	0	4
3	TSS (mg/L)	4	NaN	NaN	NaN	0	4
4	Chl A (ug/L)	14	1.2	0.4	2	0.4	0
4	DOC (ppm)	14	1.4	1.2	1.8	0.2	0
4	NH3 (mg/L)	14	NaN	NaN	NaN	0	14
4	Nitrate/nitrite (mg/L)	14	0.33	0.29	0.34	0.01	0
4	Ortho-P (mg/L)	14	0.003	0.001	0.005	0.001	5
4	TN (mg/L)	14	0.42	0.4	0.48	0.02	0
4	TP (mg/L)	14	0.008	0.006	0.012	0.002	11
4	TSS (mg/L)	13	1.8	0.9	3.6	0.9	10
5	Chl A (ug/L)	15	0.9	0.6	1.5	0.3	0
5	DOC (ppm)	15	1.6	1.2	2.8	0.4	0
5	NH3 (mg/L)	15	NaN	NaN	NaN	0	15
5	Nitrate/nitrite (mg/L)	15	0.33	0.3	0.34	0.01	0
5	Ortho-P (mg/L)	15	0.003	0.001	0.008	0.001	2
5	TN (mg/L)	15	0.4	0.34	0.42	0.02	0
5	TP (mg/L)	15	NaN	NaN	NaN	0	15
5	TSS (mg/L)	15	1	1	2.5	0.5	13
6	Chl A (ug/L)	15	0.9	0.6	1.5	0.3	0
6	DOC (ppm)	12	1.4	1.2	1.6	0.1	0
6	NH3 (mg/L)	15	NaN	NaN	NaN	0	15
6	Nitrate/nitrite (mg/L)	15	0.32	0.28	0.36	0.02	0
6	Ortho-P (mg/L)	15	NaN	NaN	NaN	0	15
6	TN (mg/L)	15	0.41	0.4	0.44	0.01	0
6	TP (mg/L)	15	0.008	0.006	0.014	0.002	12
6	TSS (mg/L)	9	1	1	4	1	8
7	Chl A (ug/L)	15	1.5	0.9	2.1	0.3	0
7	DOC (ppm)	15	1.8	1.5	2.7	0.3	0
7	NH3 (mg/L)	15	NaN	NaN	NaN	0	15
7	Nitrate/nitrite (mg/L)	15	0.306	0.297	0.324	0.009	0
7	Ortho-P (mg/L)	15	0.002	0.001	0.004	0.001	11
7	TN (mg/L)	15	0.42	0.42	0.51	0.03	0
7	TP (mg/L)	15	0.008	0.008	0.02	0.004	10
7	TSS (mg/L)	15	2	0	8	2	12

Table 4

Parameter	Site	Count	Mean	Min	Max	Stdev	NDs
Chl A (ug/L)	1	6	1.4	0.7	2.1	0.7	0
Chl A (ug/L)	2	6	1	0.6	1.2	0.2	0
Chl A (ug/L)	3	6	1	0.8	1.4	0.2	0
Chl A (ug/L)	4	6	0.8	0.4	1.2	0.4	0
Chl A (ug/L)	5	6	1.2	0.6	1.5	0.3	0
Chl A (ug/L)	6	6	1.2	0.6	1.5	0.3	0
Chl A (ug/L)	7	6	1.5	1	2.5	0.5	0
Chl A (ug/L)	8	6	1.5	1	2	0.5	0
Chl A (ug/L)	9	6	0.9	0.6	1.5	0.3	0
Chl A (ug/L)	10	6	0.8	0.4	1.6	0.4	0
Chl A (ug/L)	11	6	1	0.5	2	0.5	0
Chl A (ug/L)	12	6	0.6	0.3	1.2	0.3	0
Chl A (ug/L)	13	7	0.8	0.6	1	0.2	0
Chl A (ug/L)	14	7	0.9	0.6	1.5	0.3	0
Chl A (ug/L)	15	7	0.8	0.6	1.2	0.2	0
DOC (ppm)	1	6	2	1.5	2.5	0.5	0
DOC (ppm)	2	5	1.8	1.2	2.4	0.6	0
DOC (ppm)	3	6	1.6	1.2	2.4	0.4	0
DOC (ppm)	4	5	2	1	2.5	0.5	0
DOC (ppm)	5	5	2	1.5	2.5	0.5	0
DOC (ppm)	6	6	1.6	1.2	2.4	0.4	0
DOC (ppm)	7	6	1.6	1.2	2.4	0.4	0
DOC (ppm)	8	6	1.8	1.2	2.4	0.6	0
DOC (ppm)	9	6	1.6	1.2	2.4	0.4	0
DOC (ppm)	10	6	1.5	1.5	2.1	0.3	0
DOC (ppm)	11	6	1.6	1.2	2	0.4	0
DOC (ppm)	12	6	1.5	1.2	2.1	0.3	0
DOC (ppm)	13	7	1.5	1.3	1.7	0.1	0
DOC (ppm)	14	7	1.6	1.2	1.8	0.2	0
DOC (ppm)	15	7	1.6	1.2	1.8	0.2	0
NH3 (mg/L)	1	6	0.006	0.006	0.012	0.003	5
NH3 (mg/L)	2	6	0.009	0.009	0.027	0.009	5
Nitrate/nitrite (mg/L)	1	6	0.32	0.32	0.36	0.02	0
Nitrate/nitrite (mg/L)	2	6	0.34	0.32	0.38	0.02	0
Nitrate/nitrite (mg/L)	3	6	0.34	0.32	0.36	0.01	0
Nitrate/nitrite (mg/L)	4	6	0.33	0.31	0.35	0.01	0
Nitrate/nitrite (mg/L)	5	6	0.33	0.31	0.35	0.01	0
Nitrate/nitrite (mg/L)	6	6	0.32	0.3	0.36	0.02	0
Nitrate/nitrite (mg/L)	7	6	0.3	0.27	0.33	0.03	0
Nitrate/nitrite (mg/L)	8	6	0.33	0.3	0.39	0.03	0
Nitrate/nitrite (mg/L)	9	6	0.33	0.3	0.39	0.03	0
Nitrate/nitrite (mg/L)	10	6	0.32	0.28	0.4	0.04	0
Nitrate/nitrite (mg/L)	11	6	0.33	0.3	0.39	0.03	0
Nitrate/nitrite (mg/L)	12	6	0.33	0.3	0.39	0.03	0
Nitrate/nitrite (mg/L)	13	7	0.33	0.3	0.36	0.03	0
Nitrate/nitrite (mg/L)	14	7	0.34	0.3	0.36	0.02	0
Nitrate/nitrite (mg/L)	15	7	0.34	0.3	0.36	0.02	0
Ortho-P (mg/L)	1	6	0.003	0	0.009	0.003	2
Ortho-P (mg/L)	2	6	0.002	0.002	0.004	0.002	3
Ortho-P (mg/L)	3	6	0.002	0.001	0.004	0.001	3
Ortho-P (mg/L)	4	6	0.004	0.002	0.004	0.002	2
Ortho-P (mg/L)	5	6	0.002	0.002	0.004	0.002	3
Ortho-P (mg/L)	6	6	0.002	0.002	0.006	0.002	3
Ortho-P (mg/L)	7	6	0.004	0.002	0.006	0.002	2
Ortho-P (mg/L)	8	6	0.003	0.001	0.004	0.001	1
Ortho-P (mg/L)	9	6	0.002	0.001	0.004	0.001	3
Ortho-P (mg/L)	10	6	0.004	0.002	0.004	0.002	2
Ortho-P (mg/L)	11	6	0.003	0.001	0.004	0.001	2
Ortho-P (mg/L)	12	6	0.003	0.001	0.004	0.001	2
Ortho-P (mg/L)	13	7	0.003	0.001	0.005	0.001	2
Ortho-P (mg/L)	14	7	0.003	0.001	0.004	0.001	1
Ortho-P (mg/L)	15	7	0.003	0.001	0.004	0.001	3
TN (mg/L)	1	6	0.44	0.4	0.52	0.04	0
TN (mg/L)	2	6	0.4	0	0.4	0.2	1
TN (mg/L)	3	6	0.42	0.39	0.48	0.03	0
TN (mg/L)	4	6	0.42	0.39	0.48	0.03	0
TN (mg/L)	5	6	0.42	0.39	0.48	0.03	0
TN (mg/L)	6	6	0.44	0.4	0.48	0.02	0
TN (mg/L)	7	6	0.42	0.4	0.46	0.02	0
TN (mg/L)	8	6	0.45	0.4	0.5	0.05	0
TN (mg/L)	9	6	0.42	0.39	0.48	0.03	0
TN (mg/L)	10	6	0.44	0.42	0.46	0.02	0
TN (mg/L)	11	6	0.42	0.36	0.48	0.06	0
TN (mg/L)	12	6	0.42	0.39	0.48	0.03	0
TN (mg/L)	13	7	0.42	0.36	0.45	0.03	0
TN (mg/L)	14	7	0.42	0.39	0.48	0.03	0
TN (mg/L)	15	7	0.42	0.39	0.48	0.03	0
TP (mg/L)	1	6	0.008	0.008	0.016	0.004	4
TP (mg/L)	2	6	0.008	0.006	0.012	0.002	4
TP (mg/L)	3	6	0.008	0.006	0.01	0.002	4
TP (mg/L)	4	6	0.009	0.006	0.015	0.003	2
TP (mg/L)	5	6	0.009	0.006	0.012	0.003	2
TP (mg/L)	6	6	0.008	0.006	0.01	0.002	2
TP (mg/L)	7	6	0.012	0.008	0.016	0.004	1
TP (mg/L)	8	6	0.01	0.005	0.02	0.005	3
TP (mg/L)	9	6	0.006	0.006	0.01	0.002	5
TP (mg/L)	10	6	0.007	0.006	0.01	0.001	5
TP (mg/L)	11	6	0.007	0.006	0.01	0.001	5
TP (mg/L)	12	6	0.008	0.006	0.01	0.002	4
TP (mg/L)	13	7	0.006	0.006	0.009	0.001	6
TP (mg/L)	14	7	0.006	0.006	0.009	0.001	6
TP (mg/L)	15	7	0.006	0.006	0.009	0.001	6
TSS (mg/L)	1	5	2	1	4	1	4
TSS (mg/L)	3	5	1.2	1.2	2.4	0.6	4
TSS (mg/L)	4	5	1	1	2	0.5	4
TSS (mg/L)	5	5	1	1	3	1	4
TSS (mg/L)	6	5	1.2	0.8	2	0.4	4
TSS (mg/L)	7	6	4	0	6	2	1
TSS (mg/L)	8	6	3	0	9	3	3

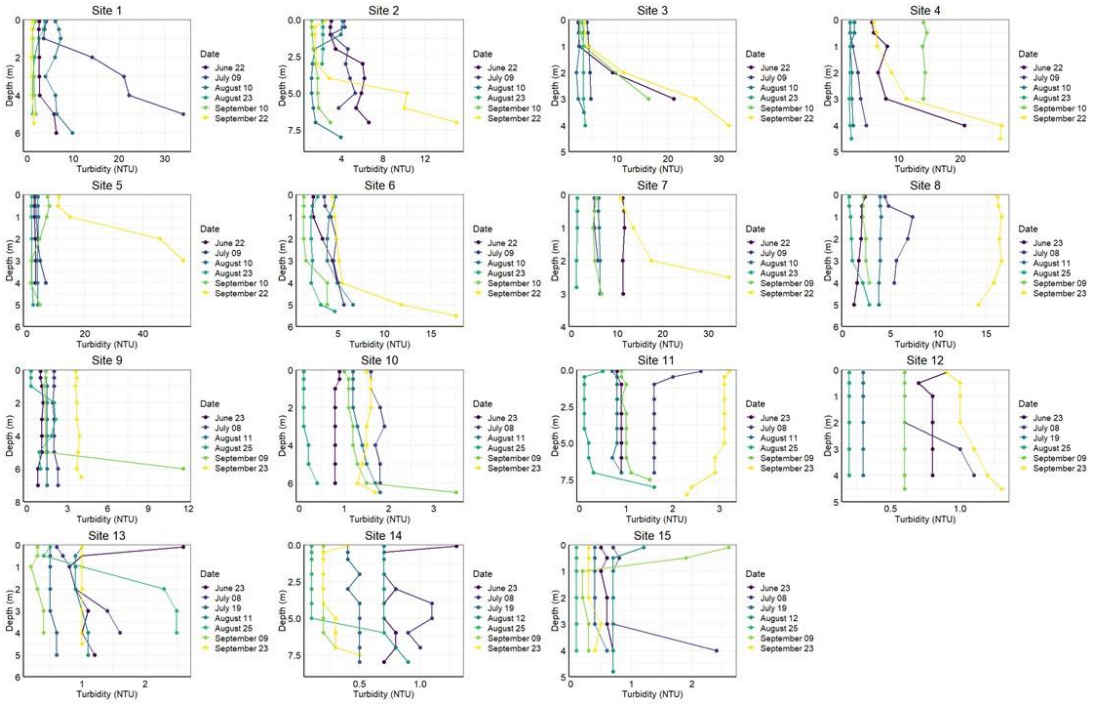

Figure 6

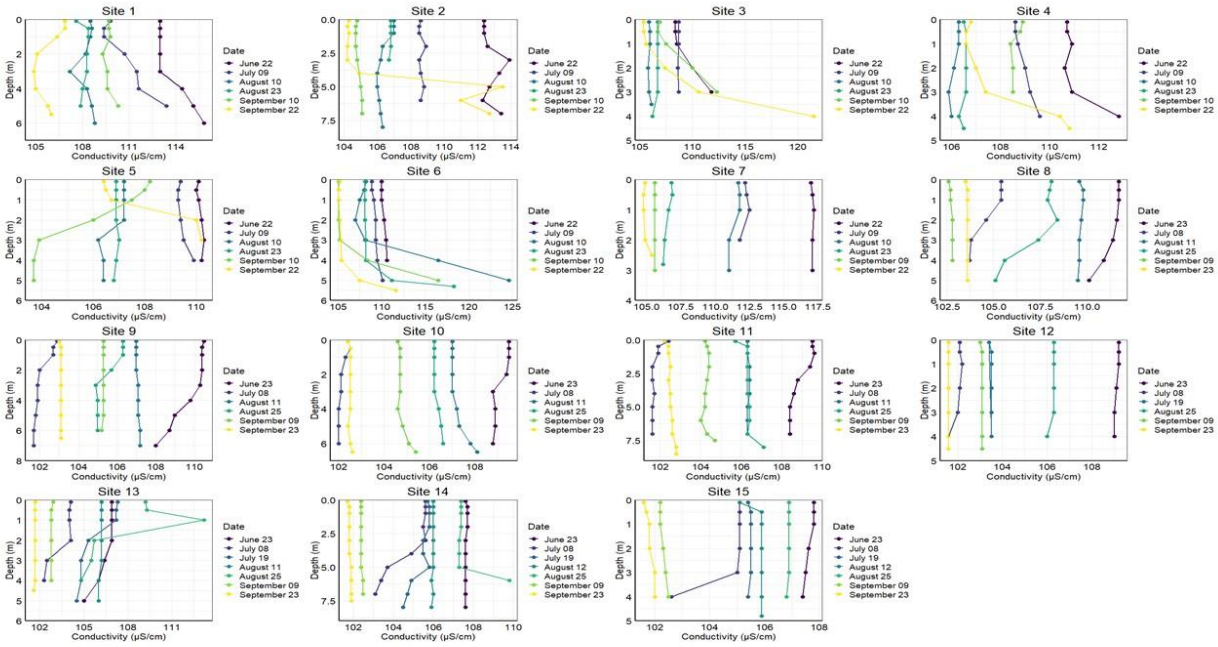

Figure 7

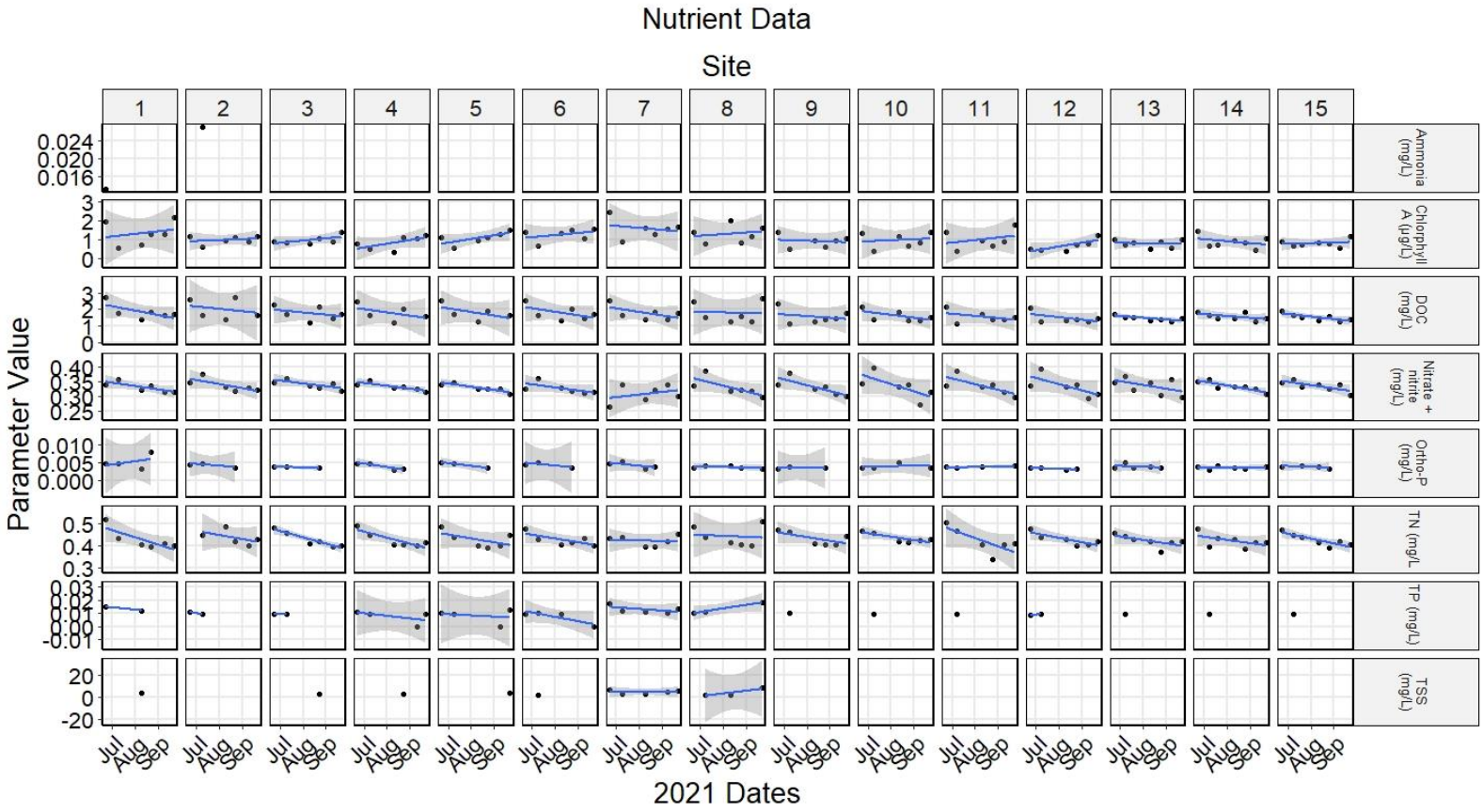
Nutrient Data
Site
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Ammonia (mg/L)
Chlorphyll A (ug/L)
DOC (mg/L)
Nitrate + nitrite (mg/L)
Ortho-P (mg/L)
TN (mg/L
TP (mg/L)
TSS (mg/L)
Parameter Value
Jul
Aug
Sep
2021 Dates

Figure 8

Table 5

Parameter	Site	Count	Mean	Min	Max	Stdev	NDs
DO %	1	6	104	102	106	2	0
DO %	2	6	104	104	106	2	0
DO %	3	6	104	102	106	2	0
DO %	4	6	104	100	106	2	0
DO %	5	6	102	100	104	2	0
DO %	6	6	103	102	104	1	0
DO %	7	6	102	100	106	2	0
DO %	8	6	102	99	108	3	0
DO %	9	6	105	99	108	3	0
DO %	10	6	104	100	108	2	0
DO %	11	6	105	102	108	3	0
DO %	12	6	105	102	111	3	0
DO %	13	7	108	102	111	3	0
DO %	14	7	108	102	111	3	0
DO %	15	7	108	104	110	2	0
DO (mg/L)	1	6	9.5	9	10	0.5	0
DO (mg/L)	2	6	9.6	8.8	10	0.4	0
DO (mg/L)	3	6	9.6	9.2	10	0.4	0
DO (mg/L)	4	6	9.6	9	9.9	0.3	0
DO (mg/L)	5	6	9.6	8.8	10	0.4	0
DO (mg/L)	6	6	9.6	8.8	10	0.4	0
DO (mg/L)	7	6	9.6	8.8	10	0.4	0
DO (mg/L)	8	6	9.6	8.8	11.2	0.8	0
DO (mg/L)	9	6	10	9	12	1	0
DO (mg/L)	10	6	10	9	12	1	0
DO (mg/L)	11	6	10	10	12	1	0
DO (mg/L)	12	6	10	10	12	1	0
DO (mg/L)	13	7	9.8	9.1	11.2	0.7	0
DO (mg/L)	14	7	10	9	10.5	0.5	0
DO (mg/L)	15	7	10	9.6	10.4	0.4	0
Euphotic Zone(m)	1	6	8	4	12	4	0
Euphotic Zone(m)	2	5	6	3	12	3	0
Euphotic Zone(m)	3	5	5	4	7	1	0
Euphotic Zone(m)	4	6	6	2	8	2	0
Euphotic Zone(m)	5	6	6	2	10	2	0
Euphotic Zone(m)	6	6	6	3	12	3	0
Euphotic Zone(m)	7	6	4	2	8	2	0
Euphotic Zone(m)	8	6	8	4	12	4	0
Euphotic Zone(m)	9	5	12	8	16	4	0
Euphotic Zone(m)	10	6	14	7	28	7	0
Euphotic Zone(m)	11	4	18	12	24	6	0
Euphotic Zone(m)	12	3	12	6	18	6	0
Euphotic Zone(m)	13	4	11	10	12	1	0
Euphotic Zone(m)	14	6	15	12	18	3	0
Euphotic Zone(m)	15	5	12	9	15	3	0
Kd (PAR)	1	6	600	0	1200	600	0
Kd (PAR)	2	6	600	0	1800	600	0
Kd (PAR)	3	6	800	0	1600	800	0
Kd (PAR)	4	6	600	0	1800	600	0
Kd (PAR)	5	6	500	0	1000	500	0
Kd (PAR)	6	6	500	0	1500	500	0
Kd (PAR)	7	6	400	0	800	400	0
Kd (PAR)	8	6	200	0	400	200	0
Kd (PAR)	9	6	200	0	400	200	0
Kd (PAR)	10	6	400	0	800	400	0
Kd (PAR)	11	6	600	0	1200	600	0
Kd (PAR)	12	6	500	0	1000	500	0
Kd (PAR)	13	7	600	0	1200	600	0
Kd (PAR)	14	7	600	0	1200	600	0
Kd (PAR)	15	7	600	0	1800	600	0

Parameter	Site	Count	Mean	Min	Max	Stdev	NDs
pH	1	6	8.1	7.9	8.2	0.1	0
pH	2	6	8	7.8	8.4	0.2	0
pH	3	6	8	7.8	8.4	0.2	0
pH	4	6	8	7.8	8.4	0.2	0
pH	5	6	8.2	8	8.4	0.2	0
pH	6	6	8	7.6	8.2	0.2	0
pH	7	6	8	7.2	8.4	0.4	0
pH	8	6	7.5	7	8.5	0.5	0
pH	9	6	7.8	7.2	8.4	0.3	0
pH	10	6	8.1	7.5	8.4	0.3	0
pH	11	6	8	7.2	8.4	0.4	0
pH	12	6	8	7.2	8.4	0.4	0
pH	13	7	8.1	7.8	8.4	0.3	0
pH	14	7	8.1	7.5	8.4	0.3	0
pH	15	7	8.1	7.5	8.4	0.3	0
Specific Conductivity (uS/cm)	1	6	110	106	112	2	0
Specific Conductivity (uS/cm)	2	6	108	105	111	3	0
Specific Conductivity (uS/cm)	3	6	107	105	109	1	0
Specific Conductivity (uS/cm)	4	6	108	106	110	2	0
Specific Conductivity (uS/cm)	5	6	108	106	110	1	0
Specific Conductivity (uS/cm)	6	6	108	106	110	2	0
Specific Conductivity (uS/cm)	7	6	110	105	115	5	0
Specific Conductivity (uS/cm)	8	6	108	104	112	4	0
Specific Conductivity (uS/cm)	9	6	105	102	111	3	0
Specific Conductivity (uS/cm)	10	6	105	102	108	3	0
Specific Conductivity (uS/cm)	11	6	105	102	108	3	0
Specific Conductivity (uS/cm)	12	6	105	102	108	3	0
Specific Conductivity (uS/cm)	13	7	105	102	108	3	0
Specific Conductivity (uS/cm)	14	7	106	102	108	2	0
Specific Conductivity (uS/cm)	15	7	106	102	108	2	0
Temp (C)	1	6	18	16	22	2	0
Temp (C)	2	6	18	16	20	2	0
Temp (C)	3	6	18	17	20	1	0
Temp (C)	4	6	18	17	20	1	0
Temp (C)	5	6	18	16	20	2	0
Temp (C)	6	6	18	16	20	2	0
Temp (C)	7	6	18	16	20	2	0
Temp (C)	8	6	18	12	21	3	0
Temp (C)	9	6	16	8	20	4	0
Temp (C)	10	6	16	8	20	4	0
Temp (C)	11	6	16	8	20	4	0
Temp (C)	12	6	16	8	20	4	0
Temp (C)	13	7	18	12	21	3	0
Temp (C)	14	7	18	16	20	2	0
Temp (C)	15	7	18	14	20	2	0
Turbidity (NTU)	1	6	4	0	6	2	0
Turbidity (NTU)	2	6	3	1	4	1	0
Turbidity (NTU)	3	6	2.8	2.1	4.2	0.7	0
Turbidity (NTU)	4	6	5	0	15	5	0
Turbidity (NTU)	5	6	4	0	12	4	0
Turbidity (NTU)	6	6	3	1	4	1	0
Turbidity (NTU)	7	6	8	0	12	4	0
Turbidity (NTU)	8	6	6	0	18	6	0
Turbidity (NTU)	9	6	2	0	4	1	0
Turbidity (NTU)	10	6	1.2	0	1.8	0.6	0
Turbidity (NTU)	11	6	1	0	3	1	0
Turbidity (NTU)	12	6	0.6	0.3	0.9	0.3	0
Turbidity (NTU)	13	7	0.6	0.3	0.9	0.3	0
Turbidity (NTU)	14	7	0.3	0	0.6	0.3	0
Turbidity (NTU)	15	7	0.6	0	1.8	0.6	0

Table 6

Hydrodynamic Parameter summaries grouped by sampling round.

Round	Parameter	Count	Mean	Min	Max	Stdev	NDs
1	DO %	15	106	102	110	2	0
1	DO (mg/L)	15	10.2	9.6	10.5	0.3	0
1	Euphotic Zone(m)	14	6	2	12	2	0
1	Kd (PAR)	15	0.6	0	2.4	0.6	0
1	pH	15	7.8	7	8	0.2	0
1	Specific Conductivity (uS/cm)	15	111	108	117	3	0
1	Temp (C)	15	16.2	14.4	17.4	0.6	0
1	Turbidity (NTU)	15	3	0	12	3	0
2	DO %	15	104	102	108	2	0
2	DO (mg/L)	15	11	10	12	1	0
2	Euphotic Zone(m)	13	6	3	12	3	0
2	Kd (PAR)	15	500	0	1500	500	0
2	pH	15	7.6	6.8	8	0.4	0
2	Specific Conductivity (uS/cm)	15	105	102	111	3	0
2	Temp (C)	15	15	5	20	5	0
2	Turbidity (NTU)	15	2	0	4	2	0
3	DO %	4	108.6	108.3	108.9	0.3	0
3	DO (mg/L)	4	9.68	9.6	9.76	0.08	0
3	Euphotic Zone(m)	4	16	12	18	2	0
3	Kd (PAR)	4	540	360	540	90	0
3	pH	4	8.1	7.5	8.1	0.3	0
3	Specific Conductivity (uS/cm)	4	106	104	108	2	0
3	Temp (C)	4	20.4	19.8	21	0.6	0
3	Turbidity (NTU)	4	0.4	0.32	0.48	0.08	0
4	DO %	14	104	102	106	2	0
4	DO (mg/L)	14	9.2	8.8	10	0.4	0
4	Euphotic Zone(m)	14	8	4	16	4	0
4	Kd (PAR)	14	500	0	1500	500	0
4	pH	14	8	7.8	8.4	0.2	0
4	Specific Conductivity (uS/cm)	14	108	106	112	2	0
4	Temp (C)	14	19	16	22	1	0
4	Turbidity (NTU)	14	2	0	6	2	0
5	DO %	15	104	101	106	1	0
5	DO (mg/L)	15	9.3	9	10.2	0.3	0
5	Euphotic Zone(m)	12	12	6	24	6	0
5	Kd (PAR)	15	1000	0	1500	500	0
5	pH	15	8.2	8	8.4	0.2	0
5	Specific Conductivity (uS/cm)	15	107.1	106.2	108.9	0.9	0
5	Temp (C)	15	19	16	20	1	0
5	Turbidity (NTU)	15	1	0	4	1	0
6	DO %	15	108	100	112	4	0
6	DO (mg/L)	15	10	9.2	10.4	0.4	0
6	Euphotic Zone(m)	11	8	4	16	4	0
6	Kd (PAR)	15	1000	0	1500	500	0
6	pH	15	8.05	7.9	8.15	0.05	0
6	Specific Conductivity (uS/cm)	15	106	102	110	2	0
6	Temp (C)	15	17.6	17	17.8	0.2	0
6	Turbidity (NTU)	15	4	0	16	4	0
7	DO %	15	102	100	106	2	0
7	DO (mg/L)	15	9.6	9.4	10	0.2	0
7	Euphotic Zone(m)	11	4	4	12	4	0
7	Kd (PAR)	15	500	0	1500	500	0
7	pH	15	8	7.6	8.2	0.2	0
7	Specific Conductivity (uS/cm)	15	104	102	106	2	0
7	Temp (C)	15	17.1	16.8	17.7	0.3	0
7	Turbidity (NTU)	15	5	0	15	5	0