

# The Influence of Riverine Inputs and Nutrients on Plankton Abundance and Composition in the Pacific Northwest

## THE IMPORTANCE OF SILICATE AS A LIMITING NUTRIENT

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### Abstract

Silicate levels are important for many types of plankton; Diatoms, radiolarians, and silicoflagellates use the silicate to create shells and are the only species which fix silica. Silicate availability in the San Juan Channel has been changing from 2005 to 2022. Silica levels are heavily influenced by the Fraser River output. Silicate and phosphate have been decreasing. Nitrate has been increasing. Silicate: Nitrogen ratio has been decreasing but has not dropped below the 1:1 threshold to become silicate limited. Silicate levels are stable and a change in the plankton community is not expected due to the decrease in silicate.

### Background

The type of nutrients available to organisms can greatly influence the biodiversity of an ecosystem. In a marine or estuary environment, phosphate, nitrates, and ammonia are generally regarded as the three limiting nutrients. Previous studies have found that nitrogen is the limiting nutrient in many marine ecosystems. However, silicate levels are important for many types of plankton. Diatoms, radiolarians, and silicoflagellates use the silicate to create shells. Studies conducted in Asia and the Mississippi River have found that manipulating the Nitrogen: Phosphate: Silicate ratio can influence the secession of various plankton species, drastically altering the species diversity and evenness (Egge and Aksnes 1992). When the ratio of silicate to nitrate drops below 1:1, the system becomes silicate limited and is expected to have a subsequent decrease of diatoms and other glass shell based plankton (Officer and Ryther 1980). This is because diatoms incorporate silicate and nitrate in a 1:1 ratio.

In the Tamsui estuary in Taiwan, scientists found that nutrient levels fluctuated with the tidal cycle. The flood tides, which brought in saltwater from the Strait of Taiwan to the Tamsui River, has the lowest concentration of nutrients, with silicate being the limiting nutrient for primary growth. With this flux, the concentration of diatoms is lowest just before flooding when the ratio

of silica to nitrogen was 1:2. The addition of silicate to the estuary lead to a greater increase in primary productivity than the addition of nitrate or phosphate (Wu and Chou 2003).

Absolute nutrient levels vary seasonally but generally exists in the Redfield Ratio of Silicate: Nitrate: Phosphate, or 16:16:1 (Officer and Ryther 1980). These levels are controlled by plankton uptake and nutrient loading from runoff, weathering, anthropogenic inputs, etc.. Naturally, dissolved silicates originate from geological weathering and underwater volcanic activity, with much of the coastal silicate concentration originating from river discharge (Tréguer 2013). When silica-fixing phytoplankton die, their shells, or tests, sink to the bottom and accumulate as sediment. As the tests dissolve, the silica is released into the water, although this happens at a much slower rate than the recycling of nitrogen or phosphate. The estimated residence time of silica in the ocean is between 15,000 years to 17,000 years. Though little is currently known about how anthropogenic forces have impacted the marine silica cycle, it has become apparent in coastal zones that silica levels are sensitive to anthropogenic influences; Damming rivers, for instance, increases the residence time of water bodies resulting in a decrease of the dissolved silica concentrations downstream (Tréguer 2013).

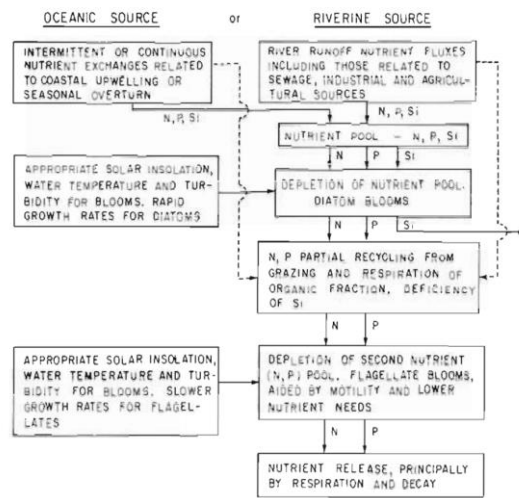


Figure 1: Estuary Nutrient Cycle, Officer and Ryther 1980

## Introduction

The Pelagic Ecosystems Function research apprenticeship at the University of Washington Friday Harbor Labs has been collecting data since 2005 for two stations, Station North near Yellow Island and Station South near Cattle Pass. The following oceanographic variables have been collected yearly from September to November for up to six weeks according to weather conditions and equipment availability: dissolved organic nitrogen ( $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ), dissolved organic phosphate ( $\text{PO}_4^{2-}$ ), dissolved organic silicate ( $\text{Si}(\text{OH})_4$ ), phytoplankton, zooplankton, fluorescence, chlorophyll, and phaeopigment. To date, no large scale statistical analysis has been conducted on the relationships between nutrients, hydrological conditions, and plankton.

Utilizing this long-term data, I was able to analyze the historical relationships between plankton abundance and the chemistry of the aquatic environment. Although my primary interest during this project is in the impact silica has on phytoplankton, I cannot ignore other essential nutrients. By analyzing the five collected nutrients, I am able to gain a more complete understanding of the conditions needed by plankton to thrive. In addition to analyzing how nutrients impact plankton, I also analyzed how riverine inputs to the San Juan Channel may be influencing the overall nutrient levels.

## Study Location

The San Juan Islands are located in the northern corner of Washington State. The Islands are surrounded by the Strait of Georgia to the north and the Strait of Juan de Fuca to the south. Between San Juan Island and Orcas Island is the San Juan Channel. Nearby is the Puget Sound, a brackish estuary near Seattle, WA, and the Fraser River in British Columbia, Canada (Figure 2).

Station North is located at  $48^{\circ}35.00'N$ ,  $123^{\circ}02.50'W$  (Figure 3). This station is marked by warm, fresher water from the Strait of Georgia and nutrient rich freshwater riverine inputs from the Fraser River in British Columbia.

Just south of Cattle Pass, Station South is categorized by cold saltwater inputs from the Puget Sound and warm freshwater output from the San Juan Channel. The station is located at  $48^{\circ}25.20'N$ ,  $122^{\circ}56.60'N$  (Figure 3).

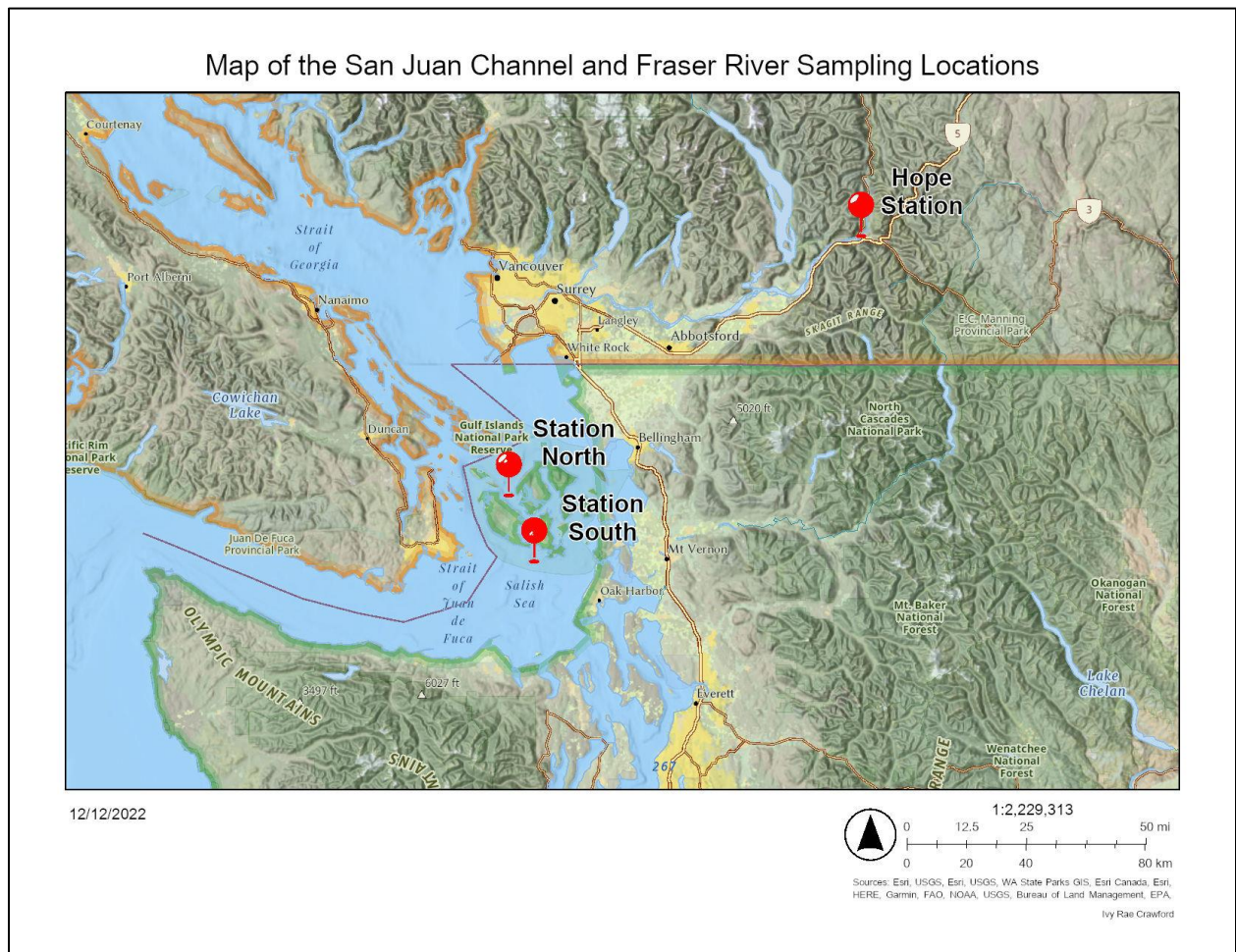


Figure 2: Map of Salish Sea and study locations



## Methodology

Water samples were collected using 2 liter Niskin bottles attached to a Conductivity Temperature and Depth machine, or CTD rosette. Chlorophyll and phaeopigment samples were collected in 60 mL opaque bottles and analyzed with a Turner Designs 10 fluorometer. Fluorescence was collected using a Seabird Electronics SBE19plus fluorometer attached to the CTD. This additional analysis was done as an accuracy assessment of the chlorophyll data. Fluorescence, chlorophyll, and phaeopigment were used as a proxy for plankton abundance. Phaeopigments, pheophytin and pheophorbide, are the degraded form of chlorophyll and are generated as algal species decompose.

Nutrient samples were filtered using a 0.5 micron filter and collected in translucent bottles which were later analyzed by the University of Washington Marine Chemistry Lab.

Plankton samples were collected using a plankton net lowered into the water and towed vertically back to the surface. Phytoplankton was collected using an 80 um net and zooplankton with a 153 um net. Zooplankton samples were preserved in 10% formalin.

Fraser River outflow data, measured in cubic meters per second, was collected from the Fraser River Environmental Watch Report, sponsored by the Government of Canada (cite). This data was recorded at the Hope station in British Columbia, Canada. Yearly Fraser River flow from June to September was compared against historical averages for relative flow. Fall flow during the first week of September and absolute maximum outflow was recorded to the nearest 500 m<sup>3</sup>/sec.

After collection, the data was analyzed using IBM SPSS. Data was sorted into two files by station: Station North and Station South. Three Analysis of Variance (ANOVA) tests were conducted per station to analyze the impact of dissolved organic nitrogen (nitrate + nitrite), dissolved ammonia, dissolved phosphate, and dissolved silicate on fluorescence in the photic zone (0 m – 30 m), deep water (30 m – bottom), and over the whole water column. Although a singular Multivariate ANOVA would have yielded a lower Type I error, conducting multiple ANOVA tests limits the impacts of multicollinearity. Due to the interrelated nature of nutrients, multicollinearity was a known risk. A Pearson Correlation was run to test the significance, strength, and directionality of the relationship between individual variable pairs.

The Fraser River relative flow, fall flow, and absolute maximum flow was compared against Station North fluorescence nutrient levels: dissolved organic nitrogen (nitrate + nitrite), dissolved phosphate, and dissolved organic silicate using paired t-tests. A Pearson Correlation was run to test the significance, strength, and directionality of the relationship between individual variable pairs.

## Results

### FRASER RIVER OUTFLOW

There is a statistically significant difference in fluorescence ( $t = 9.792$ ,  $p < 0.01$ ), phosphate ( $t = -7.752$ ,  $p < 0.01$ ), silicate ( $t = -217.426$ ,  $p < 0.01$ ), and nitrogen ( $t = -207.722$ ,  $p < 0.01$ ) levels and relative Fraser River outflow (Figure 4). There is a statistically significant correlation between silicate levels ( $0.300$ ,  $p < 0.01$ ) and nitrogen levels ( $-0.130$ ,  $p = 0.01$ ) and Fraser River relative outflow.

There is a statistically significant difference in fluorescence ( $t = 78.398$ ,  $p < 0.01$ ), phosphate ( $t = 80.420$ ,  $p < 0.01$ ), silicate ( $t = 79.044$ ,  $p < 0.01$ ), and nitrogen ( $t = 79.555$ ,  $p < 0.01$ ) levels and fall Fraser River outflow (Figure 5). There is a statistically significant correlation between silicate levels ( $0.397$ ,  $p < 0.01$ ) and fall Fraser River outflow.

There is a statistically significant difference in fluorescence ( $t = 91.419$ ,  $p < 0.01$ ), phosphate ( $t = 93.152$ ,  $p < 0.01$ ), silicate ( $t = 92.833$ ,  $p < 0.01$ ), and nitrogen ( $t = 93.152$ ,  $p < 0.01$ ) levels and maximum Fraser River outflow (Figure 6). There is a statistically significant correlation between fluorescence ( $0.136$ ,  $p = 0.01$ ), silicate levels ( $-0.341$ ,  $p < 0.01$ ) and phosphate levels ( $-0.285$ ,  $p < 0.01$ ) and maximum Fraser River outflow.

See Appendix A for full list of tables.

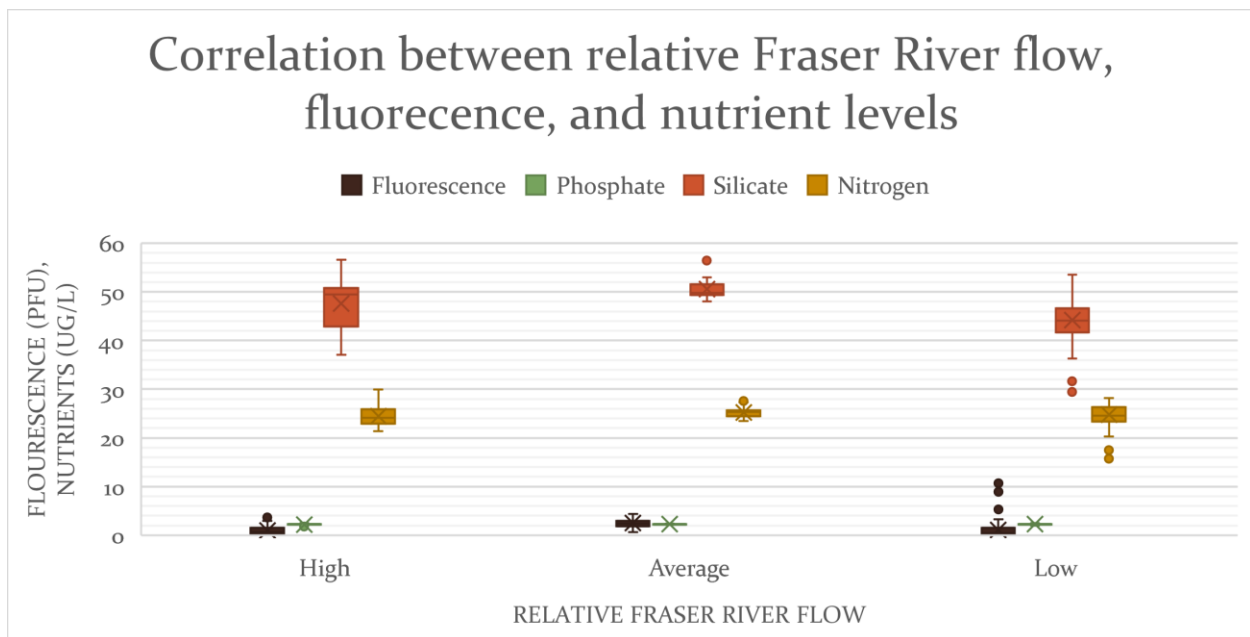


Figure 4: Correlation between Fraser River flow relative to historical means, fluorescence, and nutrient levels. Note the positive relationship between Fraser Flow and silicate levels.

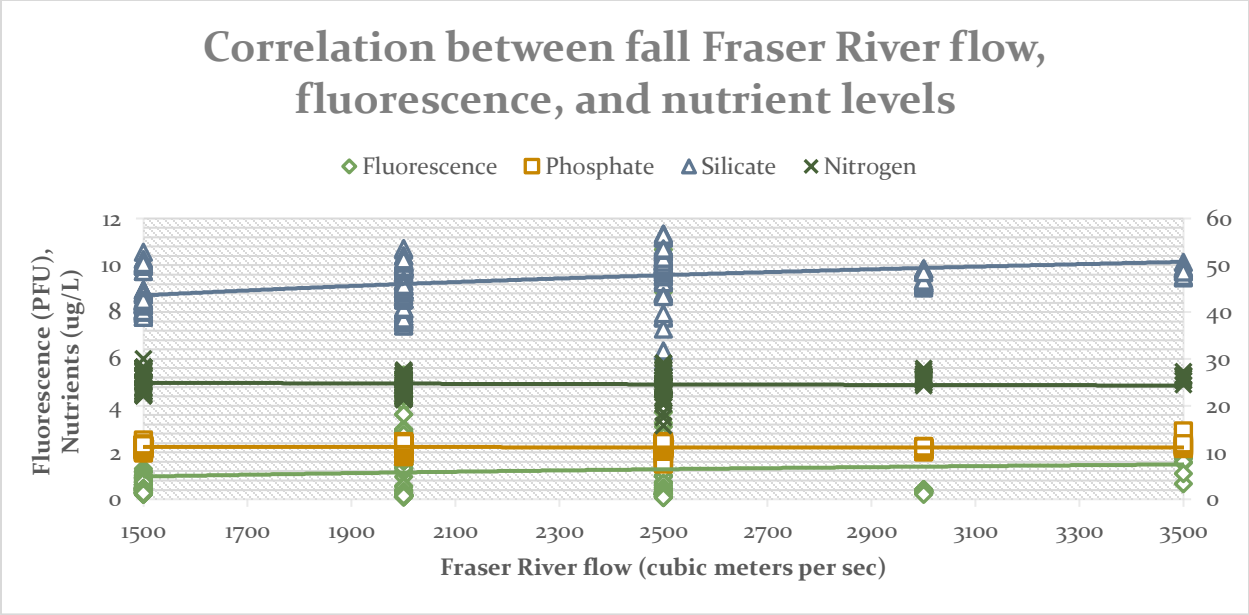


Figure 5: Correlation between fall Fraser River flow from the 1<sup>st</sup> week of September, fluorescence, and nutrient levels. Note the positive relationship between Fraser Flow and silicate levels.

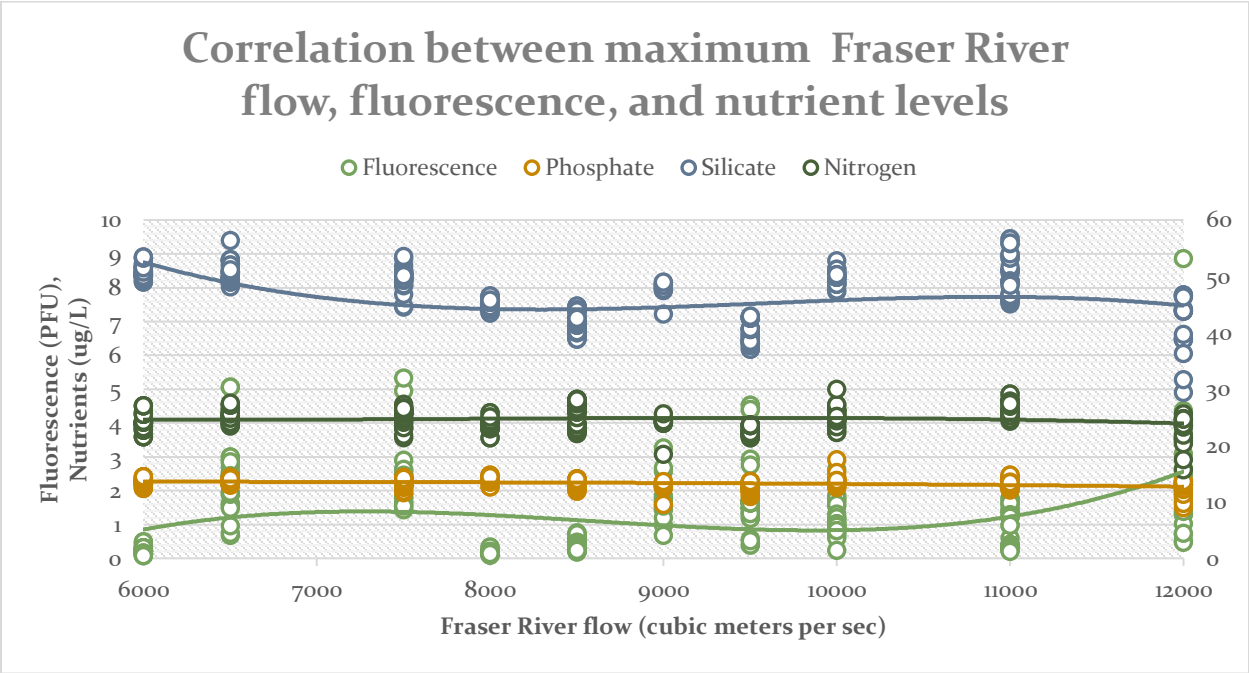


Figure 6: Correlation between maximum Fraser River flow, fluorescence, and nutrient levels. Note the bimodal relationship between Fraser Flow, fluorescence, and silicate levels.

## NORTH STATION FLUORESCENCE

Over the whole water column, silicate ( $-0.381$ ,  $p < 0.01$ ), phosphate ( $-0.160$ ,  $p < 0.01$ ), silicate: phosphate ( $-0.306$ ,  $p < 0.01$ ), and silicate: nitrate ( $-0.479$ ,  $p < 0.01$ ) have been decreasing. Nitrate ( $0.185$ ,  $p < 0.01$ ) and nitrate: phosphate ( $0.390$ ,  $p < 0.01$ ) have been increasing (Figure 7). Fluorescence is statistically significantly related to nitrate ( $-0.338$ ,  $p < 0.01$ ) (Figure 8), phosphate ( $-0.354$ ,  $p < 0.01$ ) (Figure 10), silicate ( $-0.115$ ,  $p = 0.02$ ) (Figure 11 **Error! Reference source not found.**), nitrate: phosphate ( $-0.105$ ,  $p = 0.04$ ), silicate: nitrate ( $0.138$ ,  $p < 0.01$ ), silicate: phosphate ( $0.109$ ,  $p = 0.03$ ).

Over the Euphotic zone (0 m – 30 m), fluorescence is statistically significantly related to nitrate ( $-0.335$ ,  $p < 0.01$ ), phosphate ( $-0.365$ ,  $p < 0.01$ ), silicate ( $-0.143$ ,  $p = 0.04$ ). Over the deep zone (30 m – bottom), fluorescence is statistically significantly related to nitrate ( $-0.246$ ,  $p < 0.01$ ), phosphate ( $-0.156$ ,  $p = 0.03$ ), and nitrate: phosphate ( $-0.191$ ,  $p < 0.01$ ).

The relationships between fluorescence and nutrients are not linear. See Appendix B for full list of tables.

### Timeline of Fluorescence and Four Common Pelagic Nutrients, Station North 2005 - 2021

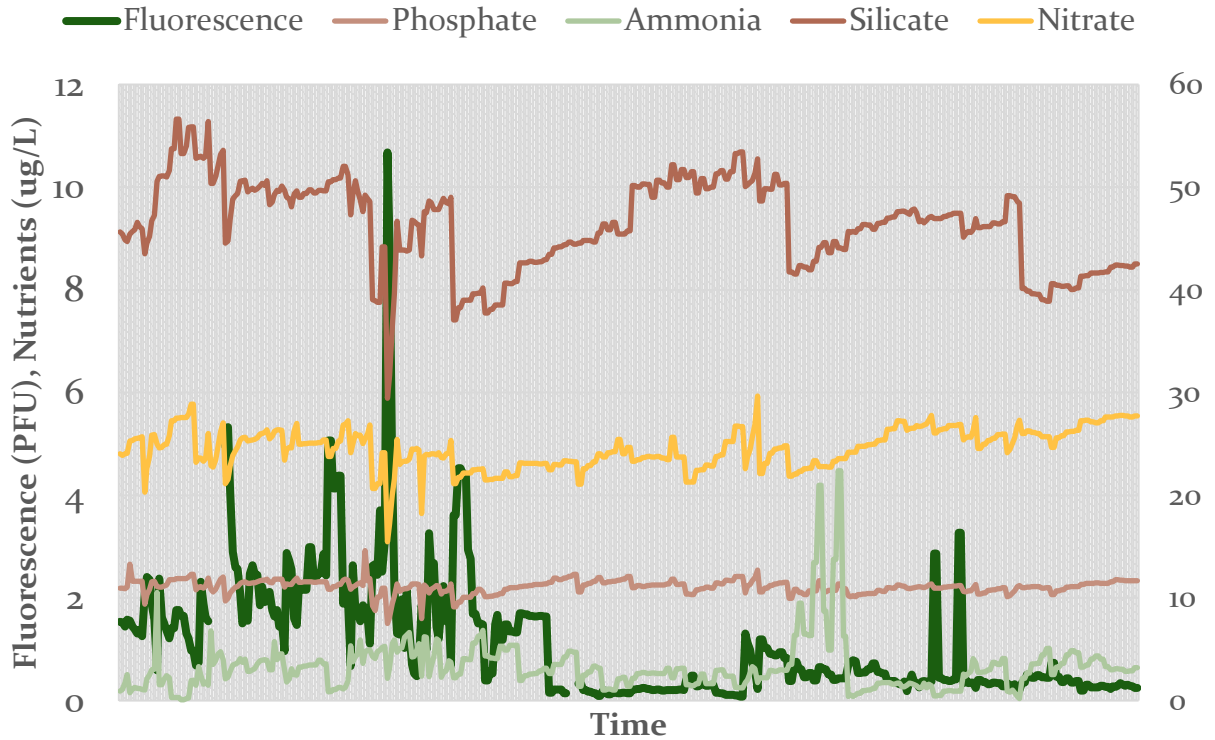


Figure 7: Timeline of fluorescence and nutrient levels at Station North from 2005 – 2021. Nitrate and silicate are on the secondary y axis. Note how the peaks in fluorescence correspond to a dip in nutrient levels.

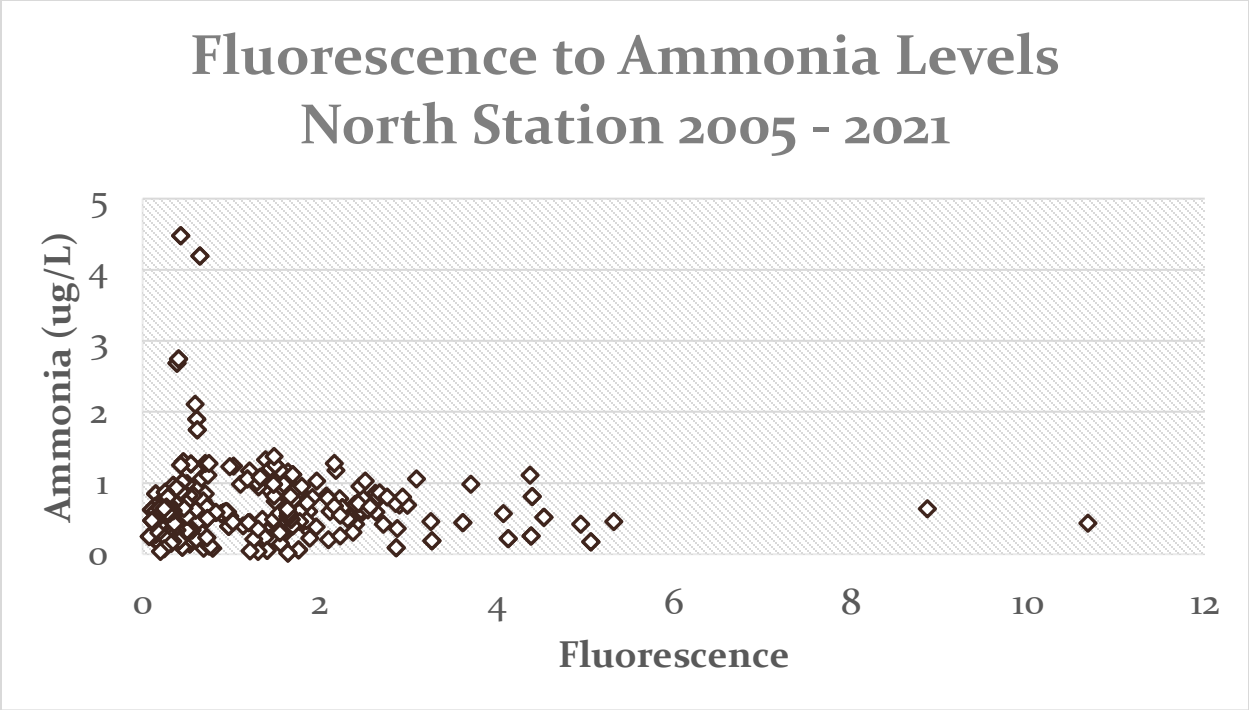


Figure 8: Correlation between ammonia levels and fluorescence over the whole water column at Station North. Note the spikes in ammonia when fluorescence is near zero.

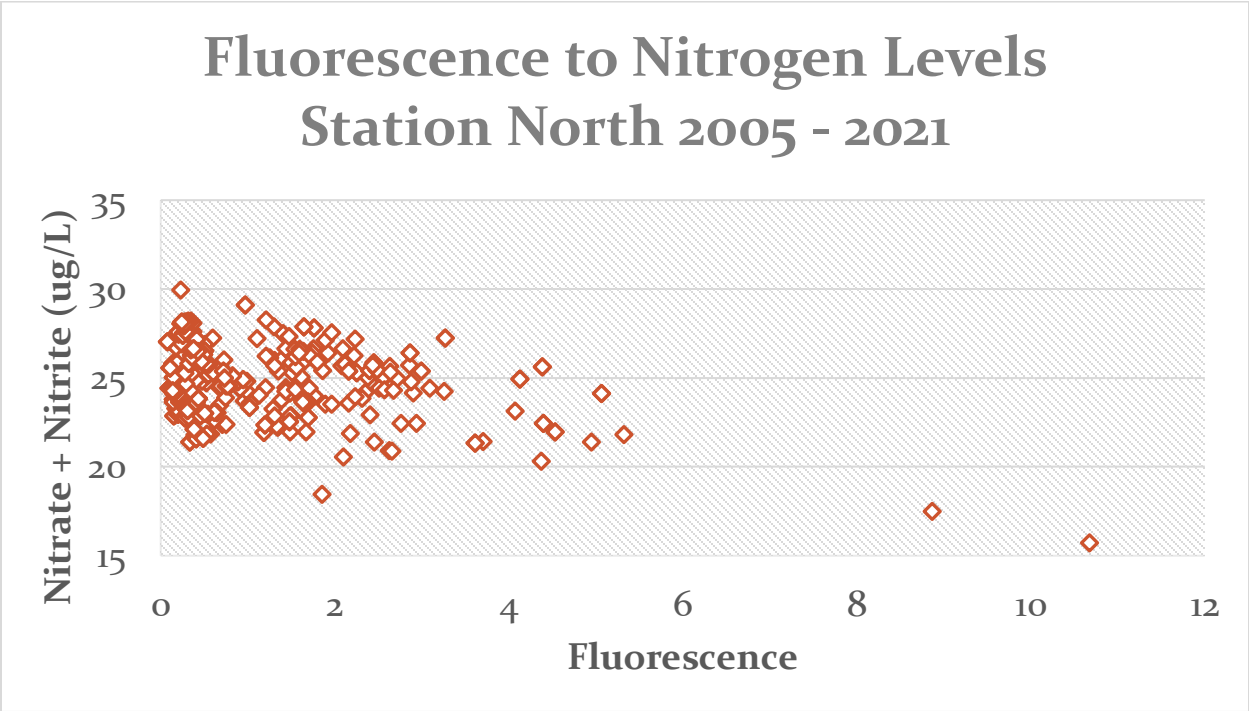


Figure 9: Correlation between nitrogen levels (nitrate and nitrite) and fluorescence over the whole water column at Station North. Note the negative relationship between nitrogen and fluorescence as well as the decline in nitrogen levels as fluorescence nears the fall maximum.

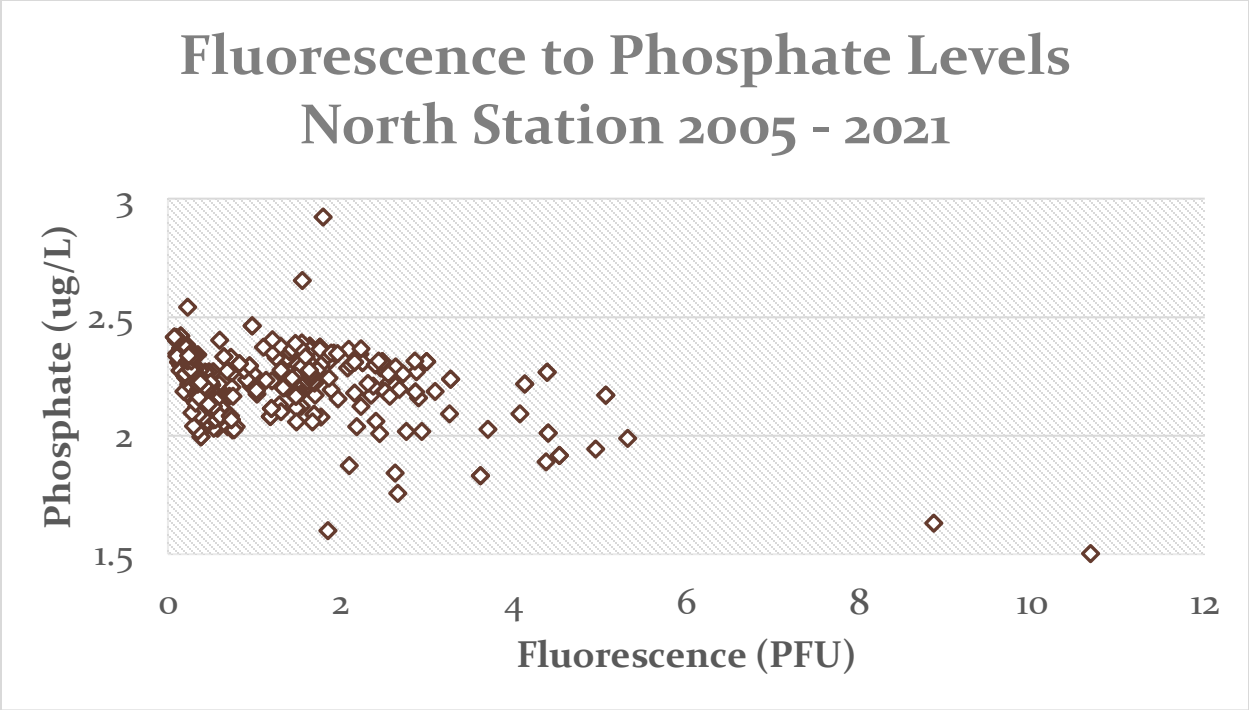


Figure 10: Correlation between phosphate levels and overall fluorescence at Station North. Note the negative relationship between phosphate levels and fluorescence as well as the decline in phosphate levels as fluorescence nears the fall maximum.

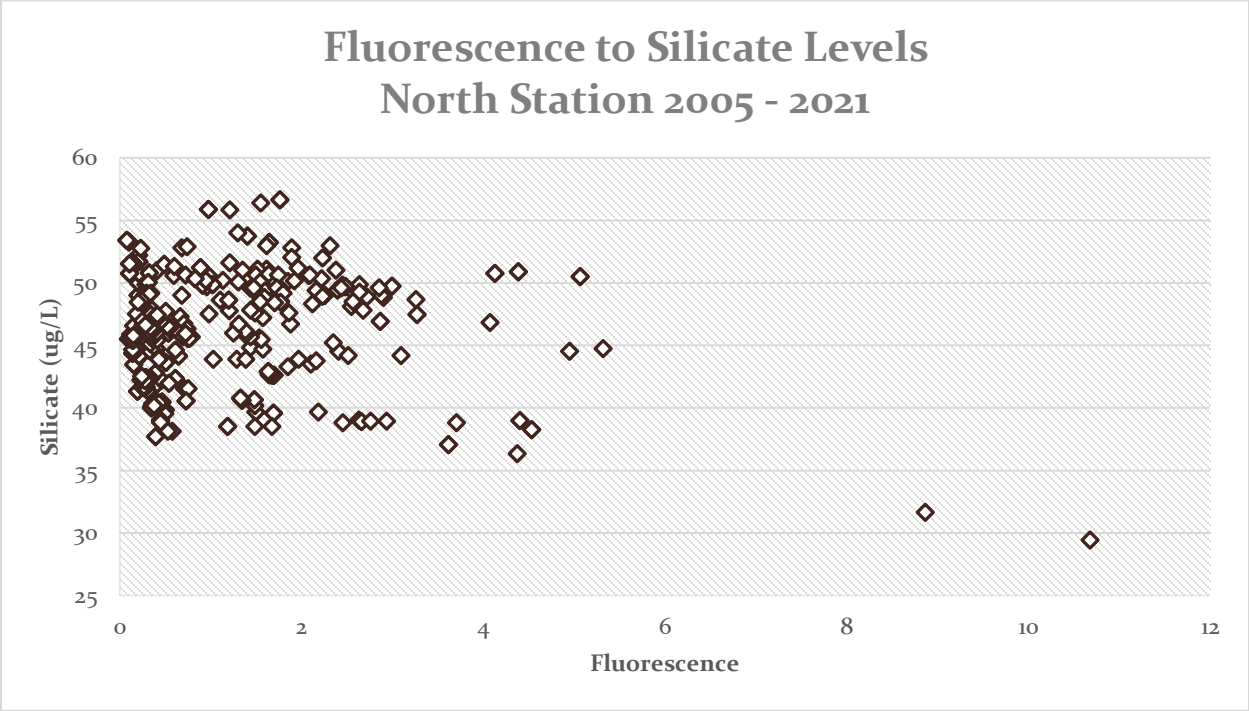


Figure 11: Correlation between silicate levels and fluorescence over the whole water column at Station North. Note the decline in silicate levels as fluorescence nears the fall maximum.

## SOUTH STATION FLUORESCENCE

Over the whole water column, silicate ( $-0.465$ ,  $p < 0.01$ ), phosphate ( $-0.326$ ,  $p < 0.01$ ), silicate: phosphate ( $-0.304$ ,  $p < 0.01$ ), and silicate: nitrate ( $-0.416$ ,  $p < 0.01$ ) have been decreasing. Nitrate: phosphate ( $0.250$ ,  $p < 0.01$ ) has been increasing (Figure 12). Fluorescence is statistically significantly related to nitrate ( $-0.272$ ,  $p < 0.01$ ) (Figure 14), phosphate ( $-0.117$ ,  $p < 0.01$ ) (Figure 15), ammonia ( $0.143$ ,  $p < 0.01$ ) (Figure 13), nitrate: phosphate ( $-0.223$ ,  $p < 0.01$ ), silicate: nitrate ( $0.295$ ,  $p < 0.01$ ), silicate: phosphate ( $0.172$ ,  $p < 0.01$ ).

In the euphotic zone, fluorescence is statistically significantly related to nitrate ( $-0.155$ ,  $p = 0.03$ ), silicate: nitrate ( $0.222$ ,  $p < 0.01$ ), silicate: phosphate ( $0.154$ ,  $p = 0.03$ ). In the deep zone, fluorescence is statistically significantly related to nitrate ( $-0.212$ ,  $p = 0.01$ ), ammonia ( $0.232$ ,  $p < 0.01$ ), nitrate: phosphate ( $-0.217$ ,  $p = 0.01$ ), silicate: phosphate ( $0.248$ ,  $p < 0.01$ ).

The relationships between fluorescence and nutrients are not linear. See Appendix C for full list of tables.

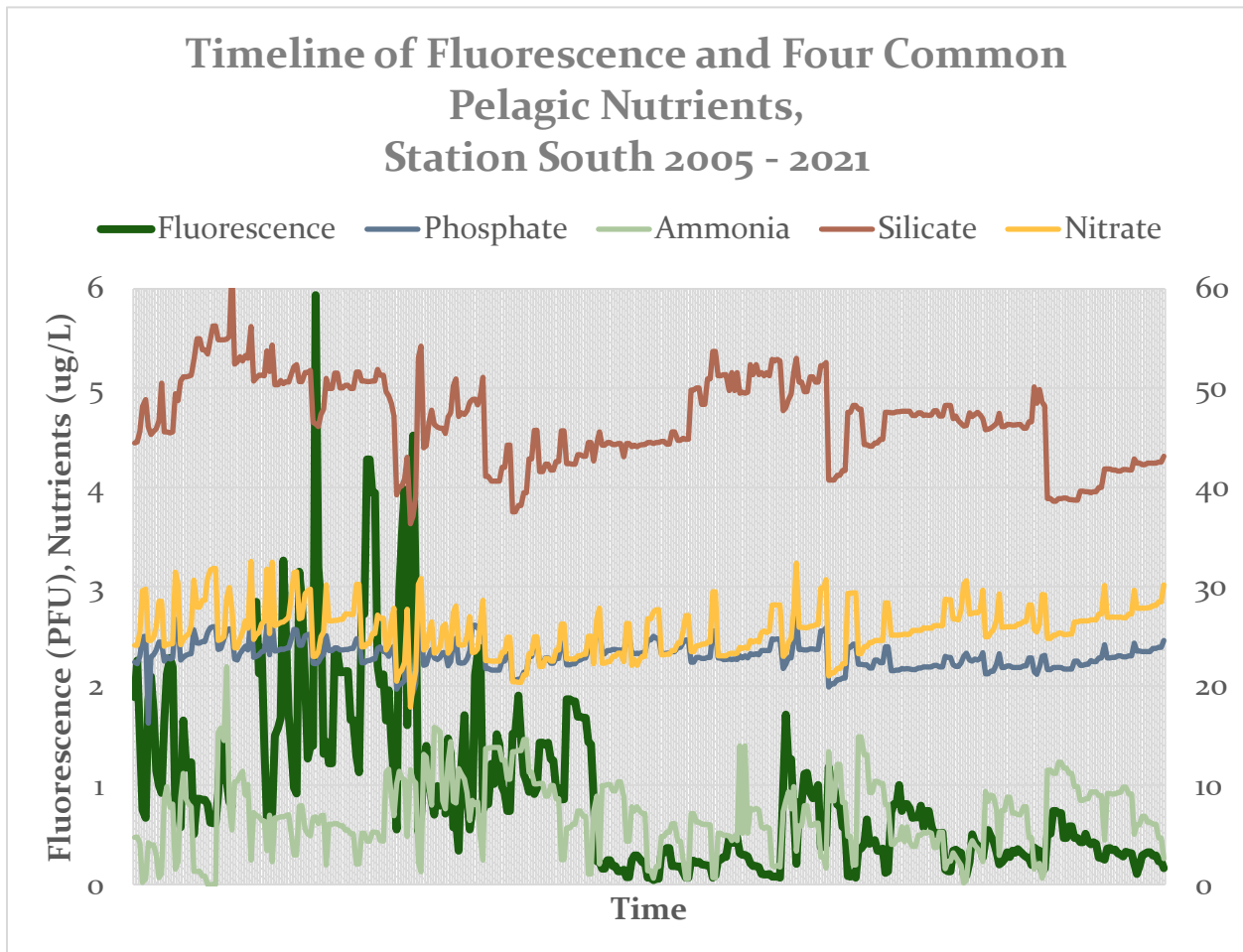


Figure 12: Timeline of fluorescence and nutrient levels at Station South from 2005 – 2021. Nitrate and silicate are on the secondary y axis. Note how the peaks in fluorescence correspond to a dip in nutrient levels.

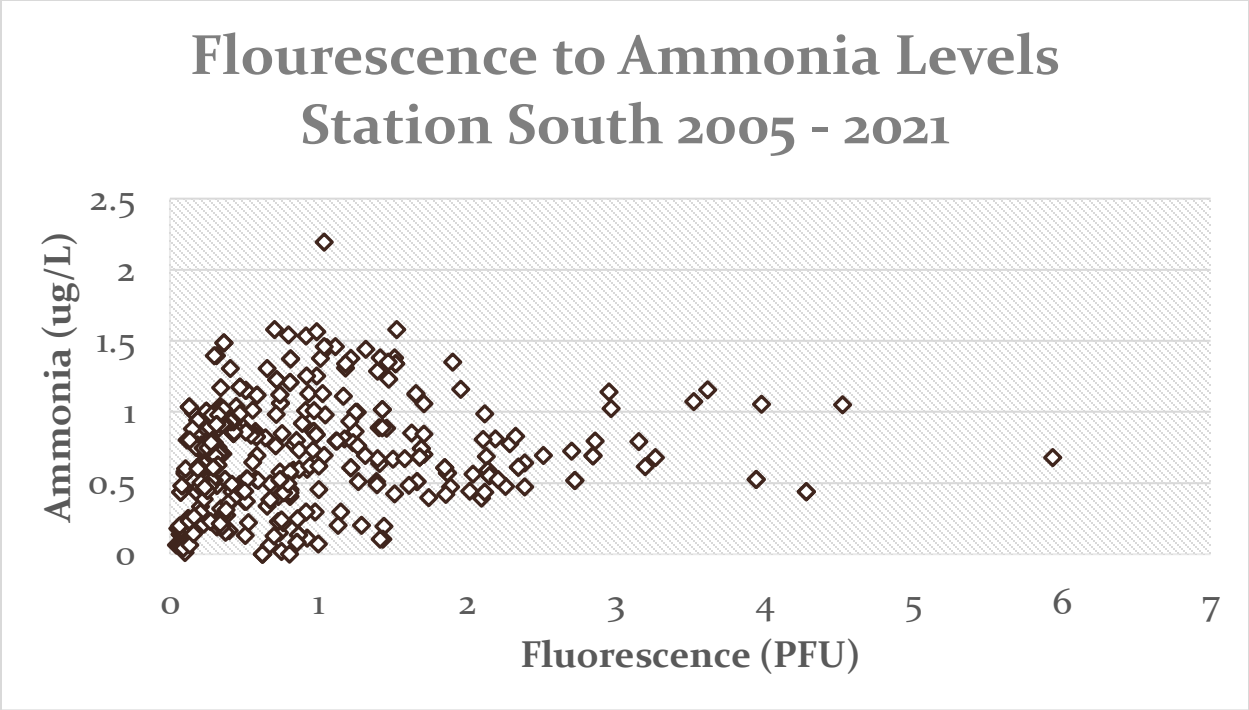


Figure 13: Correlation between ammonia and fluorescence over the whole water column at Station South. Note the spikes in ammonia as fluorescence nears zero.

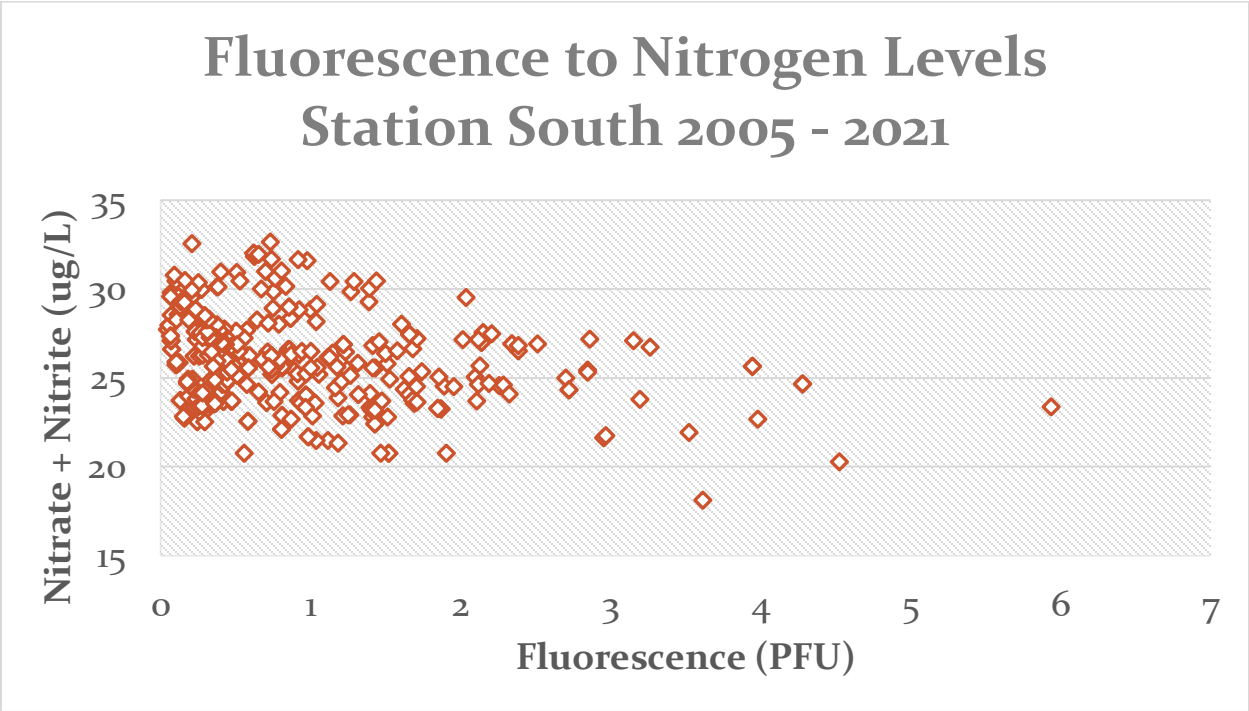


Figure 14: Correlation between nitrogen (nitrate and nitrite) and fluorescence over the whole water column at Station South. Note the negative relationship between nitrogen and fluorescence.

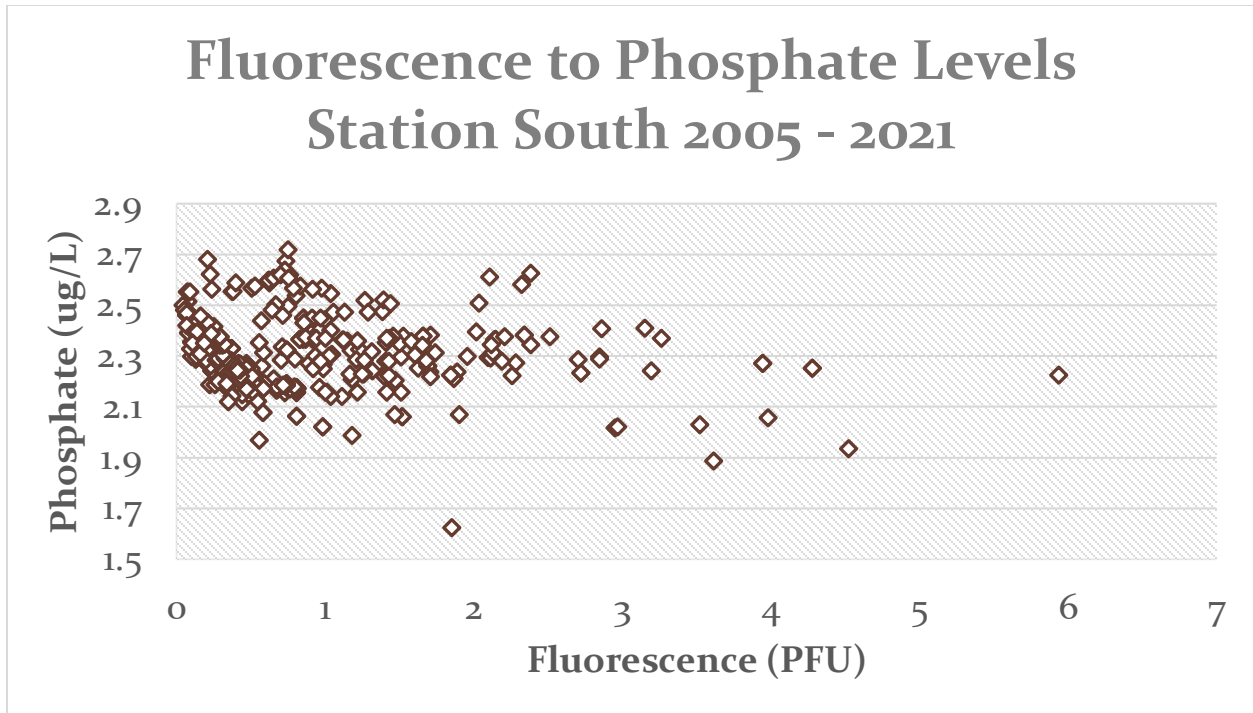


Figure 15: Correlation between phosphate and fluorescence over the whole water column at Station South. Note the negative relationship between phosphate and fluorescence.

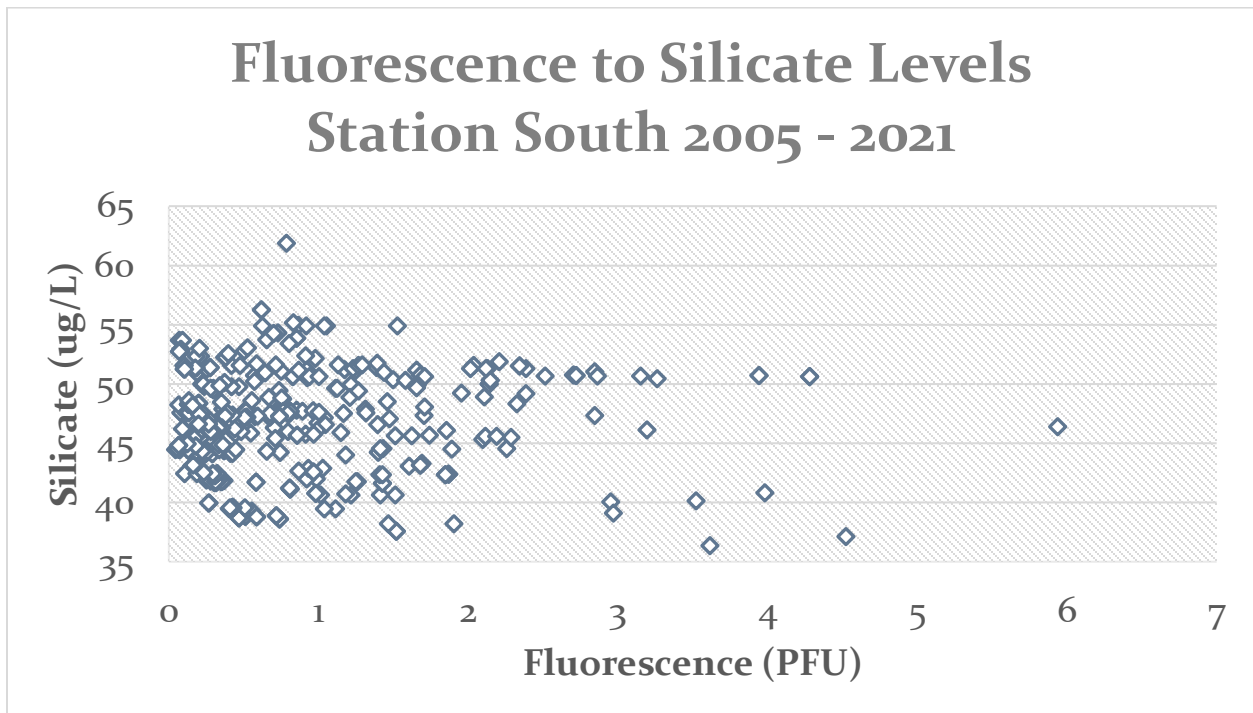


Figure 16: Correlation between silicate and fluorescence over the whole water column at Station South. Note the near zero slope of the fit line and statistical insignificance.

## Discussion

At Station North, which was anticipated to have a stronger relationship between nutrients and plankton, had on average stronger Pearson correlations to nutrient levels than Station South. This was expected given the geographic proximity to the Fraser River, which supplies the San Juan Channel with inland nutrients from agriculture, weathering, etc. Pawlowicz et. al noted that nitrate levels begin to drop about April when the spring bloom starts but before the peak Fraser River flow. Therefore, the flow of nitrogen from the Fraser isn't as important because of the plethora of sources of nitrogen. Silicate, however, is vastly more limited to natural, or non-anthropogenic, sources and the silicate levels at Station North are positively correlated to the output from the Fraser River. Neither fluorescence nor phosphate levels were correlated to the Fraser output.

Fluorescence dropped sharply after The Blob – a marine heat wave event which occurred in the Pacific Ocean from 2013 to 2016 – but has been slowly recovering. When or if fluorescence will return to “Pre-Blob” levels is uncertain. Given that the relative nutrient ratios have been holding steady around the Redfield ratio since 2005, it is likely that the culprits for the plankton's slow recovery is the overall increasing sea surface temperature.

Over time, silicate and phosphate levels have been decreasing while nitrate levels have been increasing. This result agrees with a study conducted in the Puget Sound which found that the silicon-to-nitrate ratio has been decreasing with a decline in silicate concentration of 8  $\mu\text{M}$  from 2005 to 2019 (Krembs et. al 2019). Krembs stated that the decline appeared to be driven by decreases in silicate concentration, suggesting that there is either an increased uptake by siliceous diatoms or a lower silicate supply. Although the Fraser River, which supplies much of the northern end of the San Juan Channel with nutrients, is not dammed, there have been numerous projects which could alter nutrient discharge, including dikes, channel training structures, and dredging of the river. It would be interesting to discover if the past and ongoing projects along the Fraser River have impacted the input of silicate into the estuary waters. Another possibility for the changing silicate levels is the altered snowmelt patterns which feed the Fraser River. The peak outflow for the river varies year to year, with the strength and timing of the peak dependent on the snowmelt from the Rocky Mountains.

After analyzing the residuals from the linear regressions, I was able to determine that the relationships between nutrients and fluorescence were not linear. However, due to time constraints, I was not able to determine to what power the relationship was. My assumption is the relationships are logarithmic or exponential.

As previously established, phosphate and nitrate have a moderate correlation between overall fluorescence and nutrient levels. Although I had expected this correlation to be stronger given the understood importance of phosphate and nitrate as essential nutrients, it is reasonable to assume that the collinearity between nutrients, E. G. plankton abundances are related to all four nutrients simultaneously, limited the power of statistical analyses.

Silicate alone was only significantly correlated with fluorescence at Station North, whereas silicate ratios were significantly correlated at both stations. This result agrees with studies by Turner et. al, Mochamadkar et. al, and Wu and Chou, which found that manipulating the silicate ratio, and not the nutrient levels themselves, is what triggers a successional change. Silicate: Nitrate is negatively correlated to fluorescence whereas silicate: phosphate is positively correlated, suggesting that silicate and nitrate are the limiting nutrients for plankton.

Ammonia and its corresponding nutrient ratios are not significantly correlated to fluorescence. Ammonia is a nutrient associated with degradation and regenerated nitrogen and thus more likely to be related to phaeopigment. Unfortunately for my study, it was discovered that the chlorophyll and phaeopigment data was unusable due to human error or inaccurate calibrations; The data was tabled until it could be discovered what caused the unusual data and a means to correct it, if any. The CTD fluorometer data, however, was deemed accurate and thus became the sole focus of my study. This lack of data did not allow me to study the relationships between nutrients and phaeopigment, which is a degraded form of chlorophyll and a proxy for dead or consumed phytoplankton.

Given the variety of counting and recording methods for phyto- and zooplankton, there was a limited comparable data set available for plankton. When limiting for the dates which had nutrient, phytoplankton, and zooplankton data, there were less than 20 data points available, and even these were of questionable integrity. Because of this, I was not able to draw statistically significant conclusions regarding how silica levels may be impacting plankton communities. However, the ratio of diatoms to zooplankton appears to be increasing. If the general trend of decreasing silicate: nitrate and increasing phytoplankton: zooplankton continues, this may be an indicator of eutrophication and a potential shift in planktonic community composition.

## Conclusion

Just as carbonate is important for the survival of crabs and mollusks, so too is silicate for diatoms. Further studies may be able to determine the resiliency of diatoms to silicate changes. Fortunately for these microscopic organisms, the ratio of silicate to nitrate in the San Juan archipelago has been consistently well above the 1:1 limit and likely will not drop below the threshold within the century. However, if the anthropogenic alterations to the ecosystem are not monitored and abated, this may not continue to hold true. Since 2005, silicate: nitrate levels have been slowly but steadily decreasing. If the nutrient supply continues to change for diatoms that are already pH and temperature stressed, we may see a drastic change in the composition of plankton communities and subsequently, the entire pelagic ecosystem.

## Acknowledgements

I would like to thank the Mary Gates Endowment Scholarship for their generous support of the Friday Harbor Laboratories. Without their generous scholarship, I would not have been able to take part in this apprenticeship. To the crews of the R/V Kittiwake and the R/V Rachel Carson,

thank you for the time and effort you put into collecting the data we needed for this course. To Rebecca and Matt, thank you for your support and feedback. Thank you, Jan, for all of your help and insight throughout this project; There were many speedbumps in this project, and you helped me handle them with grace and navigate around some of the larger potholes to create something I could be proud of.

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