

Relationship between phytoplankton abundance, available nitrate, ammonium, and temperature at Station ALOHA, and the R/V Roger Revelle Cruise RR1604.

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Abstract

The goal of the project was to assess the relationship between phytoplankton abundance, various available nutrient concentrations (NO_3 , NH_4) and temperature ($^{\circ}C$), based on data collected at station ALOHA, a time-series station located in the North Pacific subtropical gyre, and aboard the R/V Roger Revelle Cruise RR1604, conducted in a transect of the Indian Ocean. The cell counts, to gauge abundance, were deemed through a Flow Cytometer, and temperature was measured using a CTD sensor. Linear regression models were generated for the analysis process, thereby directly depicting the correlation between each of these factors and phytoplankton abundance. The overall relationship between phytoplankton abundance and the concentration of nitrate indicated a negative correlation between the two factors, for both diatom and dinoflagellate biomass. The overall relationship between phytoplankton abundance and the concentration of ammonium, conversely, showed a moderate, yet positive correlation between the two factors, for both diatom and dinoflagellate biomass. For temperature, there exists a positive relationship (directly proportional) between dinoflagellate (phytoplankton) abundance and sea – surface temperature. Under non-limiting nutrient conditions, an increase in water temperature usually correlates to an increase in phytoplankton nutrient uptake. In the data sets under study however, both these factors seem to have a drastic effect on abundance, not in correlation with each other (an increase in temperature does not necessarily lead to an increase in nutrient uptake, vice-versa). The differences in the derived correlations between phytoplankton abundance and the concentration of ammonium and nitrate, lead to the possibility that nitrate may be a limiting nutrient in the sampling environment, and is used by either class of phytoplankton at a time, but not together.

Based on the modeled data, it was determined that primarily, ammonium and sea-surface temperature play a role in phytoplankton persistence in the chosen sampling locations.

Plain Language Summary

The project examined the relationship between phytoplankton abundance, select nutrient concentrations (NO_3 , NH_4) and temperature ($^{\circ}C$). Data was collected from station ALOHA, a time-series station located in the North Pacific subtropical gyre, and aboard the R/V Roger Revelle Cruise RR1604, conducted in a transect of the Indian Ocean. The cell counts of phytoplankton were measured using a Flow Cytometer, and temperature was measured using a CTD sensor. In order to observe and analyze the relationship between phytoplankton and the above-mentioned factors, linear regression models were made. Upon analysis, the overall relationship between phytoplankton abundance and the concentration of nitrate resulted in a negative correlation between the two factors, for both diatom and dinoflagellate biomass. However, the overall relationship between phytoplankton abundance and the concentration of ammonium portrayed a positive correlation between the two factors, for both diatom and dinoflagellate biomass. This suggests that ammonium may have been in abundance as compared to nitrate, or is favored more. Sea-surface temperature also showed a positive correlation with phytoplankton abundance. When nutrients are sufficient, an increase in water temperature usually increases nutrient uptake, and in turn, phytoplankton abundance. But in the chosen data sets, an increase in temperature does not necessarily lead to an increase in nutrient uptake. The analyzed results between phytoplankton abundance and the concentration of ammonium and

nitrate, show that nitrate may be a limiting nutrient in the sampling environment, and could be used by either diatoms or dinoflagellates, but not together.

Introduction

Phytoplankton play a vital and crucial role in the marine environment, and are fundamental in comprehending numerous food webs, trophic energy flows, and the global carbon cycle, and hence, is the broad motivation for the study. They are “microscopic marine algae” and contain chlorophyll, requiring sunlight and other nutrients, inclusive of, but not limited to nitrates, phosphates, and sulfur, in order to grow.

The primary two categories of larger eukaryotic phytoplankton that play important roles in productivity, particularly in coastal environments, are diatoms, whose structure is rigid and rely on currents to move through the water, and dinoflagellates, who make use of a flagella to transport themselves through water. There also persist many other classes of eukaryotic phytoplankton such as the green algae, which tend to be very small and are mostly located in open ocean photic environments, thriving in warm, nutrient-rich waters, and the haptophytes, some of which may attain cell wall plates, made of calcium carbonate. Additionally, cyanobacteria also fall under the category of phytoplankton, but are prokaryotic instead, and get their name from their bluish green pigment (Domozych et al., 2012). They are also photosynthetic, and in gyres for example, these small cyanobacteria contribute significantly to primary productivity. Phytoplankton are thought of to be accountable for almost “half the global annual net primary production” (Field et al., 1998). Sewage discharges, and nutrient run-offs into

coastal waters lead to the occurrence of harmful algal blooms (HABs) (Burns et al., 2005), implicating excessive growths of algae, the release of toxic substances, and the depletion of oxygen, with HABs's decomposition (Laws et al., 2018). The cell counts of phytoplankton, to gauge abundance, were deemed through a Flow Cytometer, and temperature was measured using a CTD sensor. Linear regression models were generated for the analysis process that helped portray the correlation between nutrient concentration, temperature, and phytoplankton abundance.

The elemental stoichiometry (balance of chemical elements and mass, as and when resources are converted to waste products and consumer biomass) of both particulate, and dissolved matter in the sea, primarily the nitrogen-phosphorus ratio, is crucial in comprehending the nutrient control of plankton growth rates, as elemental concentrations may vary within different species, in different ecosystems. Furthermore, biogeochemical processes such as carbon sequestration may also be modeled based on consumption of nutrients and elemental stoichiometry, as the fate of carbon within organisms and ecosystems is largely regulated by the availability of certain key nutrient elements and mass-balance principles (Karl et al., 2001) (Sterner, 1995. In autotrophs, such as phytoplankton, nutrient limitation leads to less fixation of inorganic carbon, and excretion of organic carbon (Hessen et al., 2004). Fawcett et al., 2011, also portray the specific and absolute uptake rates of the nutrients and their importance, as a cell needs nutrients from external environments to support its activities. This would also help understand what amount of an uptake of a certain nutrient is needed by a particular class of phytoplankton for its growth/ photosynthesis. It can be represented, "based on the Michaelis-Menten equation (MM functional form for the uptake rate, $V = V_{\max}[S]/([S] + K_s)$) (Bonachela

et al., 2011).” $[S]$ refers to nutrient concentration, V_{\max} is a constant (the maximum uptake rate), and K_s is the half-saturation constant that associates with an organism having the ability to capture ions of nutrients at low concentrations of the nutrient itself (Bonachela et al., 2011).

Richard, W., 1972, shows that under non-limiting nutrient conditions, an increase in water temperature usually associates to an increase in phytoplankton growth, measured in doublings per day, and that different phytoplankton have different temperature optima. Data from the University of Hawai'i, has suggested that there persist “complex interactions” between the nitrogen and phosphorus pools, with rapid, unique microbial responses, over a period of time “(seasonal, interannual and decadal)” (Karl et al., 2001). In the broader context, analyzing temperature data with phytoplankton abundance allows for the determination of what seasons blooms are more likely to occur in. Climatic conditions and natural disasters may also have an impact over a longer period of time, which in turn may have an effect on growth rates and phytoplankton abundance. This may make it challenging to observe unique patterns over smaller time-scales, but may aid in investigating the relationship between nutrients (nitrogen and phosphorus particularly) and phytoplankton abundance in depth in the long term. The information from the databases (further addressed below) attains continuously-detected-activity data over a period of days, and so, a smaller transect will be analyzed, as compared to a seasonal/decadal timeframe, thereby allowing for the investigation of the relationship between certain nutrients, temperature, and phytoplankton abundance.

This project tested the hypothesis that phytoplankton growth strongly depends on the amount of available nutrient supply (NO_3 , NH_4) and temperature, with NH_4 being the most

important factor to their growth. The null hypothesis was that there is no relationship between phytoplankton abundance, available nutrient supply and temperature. A cell needs nutrients from external environments to support its activities, thereby leading to growth and abundance. An increase in temperature, as depicted by Richard, W., 1972, usually tends to increase the growth rates of phytoplankton, until their temperature optima. Striebel et al., 2016, deem that “phytoplankton responses to temperature increases are constrained by abiotic conditions and community composition”. In the larger context, these responses allow an insight into how global warming could affect ecosystem properties and processes, and also portrays the alternation of limitation to phytoplankton abundance between temperature and NH_4 in particular (from data sets).

To test the above mentioned hypothesis, correlations of data (from the University of Hawai'i, station ALOHA, and the R/V Roger Revelle Cruise RR1604) between various nutrient levels, phytoplankton abundance, and dissolved chlorophyll concentrations were analyzed through linear regression models, and what limits their abundance will be examined. Chlorophyll is used by phytoplankton during photosynthesis and primary productivity, and higher concentrations of chlorophyll correlate to a higher abundance of phytoplankton. This can also aid with diving deeper into the notion that the ocean is a carbon dioxide sink, due to the process of photosynthesis executed by phytoplankton. Carbon, in the form of CO_2 , is absorbed by their cells during photosynthesis and as and when plankton die or are consumed, the biological carbon pump transmits sinking particles of carbon from the surface to the deep ocean.

Data needed to investigate the hypothesis include cell counts for both diatoms and dinoflagellates (determined using a flow cytometer), against measurements of concentrations of available nutrient supply, and sea-surface temperature at depths ranging between 5 and 185 meters (Fox et al., 2020). The comparison of the data from the R/V Roger Revelle cruise RR1604 and station ALOHA was made as different factors limit phytoplankton abundance in both these areas, yet they are still similar in abundance, with similar chlorophyll *a* concentrations (Angel White Lab) (Lomas et al., 2021). This is beneficial as one may deem what factors in particular contribute to phytoplankton abundance, and the extent to which they in turn, have a role in the marine environment.

Data Collection and Methods

a. Source of Data

The uptake rates of NH_4 and NO_3 were measured using a mass spectrometer in nanomoles per liter per hour ($nmol\ N\ L^{-1}h^{-1}$), and the concentrations in $\mu mol/ kg$. The nanoeukaryotic and picoeukaryote cell content was measured using a flow cytometer in cells/mL and $\mu g\ C/ L$. Additionally, chlorophyll *a* concentrations were deemed using a spectrophotometer in mg/ m^3 . Lastly, temperature, across various depths, was measured using a *conductivity, temperature, and depth* (CTD) sensor in $^{\circ}C$. (Angel White Lab) (Lomas et al., 2021).

Both the data sets were accessed through simonscmap.com with the following URLs, and data sources:

Data source	URL
Angel White Lab, University of Hawaii at Manoa	https://simonscmap.com/catalog/datasets/HOLELegacy2A_KM1513_MicrozooplanktonAbundance
GO-SHIP 109, Bigelow Laboratory for Ocean Sciences, Lomas Lab	https://simonscmap.com/catalog/datasets/RR1604_flow_cytometry_mass_spec

The collected data from the University of Hawai'i, station ALOHA, and from the RR1604 cruise, along the GO-SHIP IO9 were explored and studied to deem whether or not there is a correlation between various nutrients, temperature and phytoplankton abundance, as different limiting factors are evident at each of the sites. Absolute and specific uptakes by various phytoplankton cells, alongside carbon content, and availability of NO_3 and NH_4 were provided in the data sets. Values in the data set, titled "microzooplankton abundance, from the Legacy 2A cruise aboard the R/V Kilo Moana (cruise KM1513) in the north Pacific subtropical gyre" were obtained by first transferring a 1 L volume of the water sample, from a depth range of 5 to 45 meters into a 2 L amber bottle, and then, fixing these samples using a 5% mix of "Acid Lugols and 37% formaldehyde (to toughen cell walls)" (Angel White Lab). Post this, filtration was performed using a black polycarbonate filter ("with a polyester drain disk as a backing filter"), measuring 25 millimeters in diameter, and a pore size of 8 microns (Angel White Lab). Next, the samples were stowed away at $-20^{\circ}C$ and counted within 30 days of storage. Lastly,

they were made room temperature and counted again, using a “Nikon Diaphot 200 inverted microscope, equipped with a drawing tube and cell measuring capabilities via the Pax Microbiota software” (Angel White Lab).

b. Methods of Analysis

With the provided data from station ALOHA’s database, and the University of Hawai’i, linear regression models were generated through Microsoft Excel, that directly depict the correlation between available nutrient supply, temperature, and phytoplankton abundance.

If the provided data tends to have a strong linear correlation between phytoplankton abundance, specific nutrient supply, and temperature, it is evident that the hypothesis that phytoplankton abundance strongly depends on the amount of available nutrient supply, and temperature is true and accurate. If there tend to be weakly correlated data, the relationship may not be true for all classes of phytoplankton and one or the other factors may be limiting. There may also be other external factors involved (such as wind, and seasonal changes) that may have an effect on the modeled results from the data set. If there is no evident relationship (correlation) between the classes of phytoplankton in the data sets, temperature, and nutrient supply, the null hypothesis is supported. However, each day of sampling aboard the cruises weathered different environmental conditions (such as changes in sea-surface temperature), and so, it would not be an accurate representation if all the data were grouped together in the same figure for an analysis. Hence, the provided data were broken down into figures that would help analyze day to day information, over smaller periods of time (three to five day segments). To further lessen the

chance for inaccuracy, the data was also broken down into figures based on regions of sampling/ sampling locations, as the cruise was long and had moved through very different regions, each having different environmental conditions.

Results

The transects of the sampling locations can be seen in figures 1 and 2, respectively.

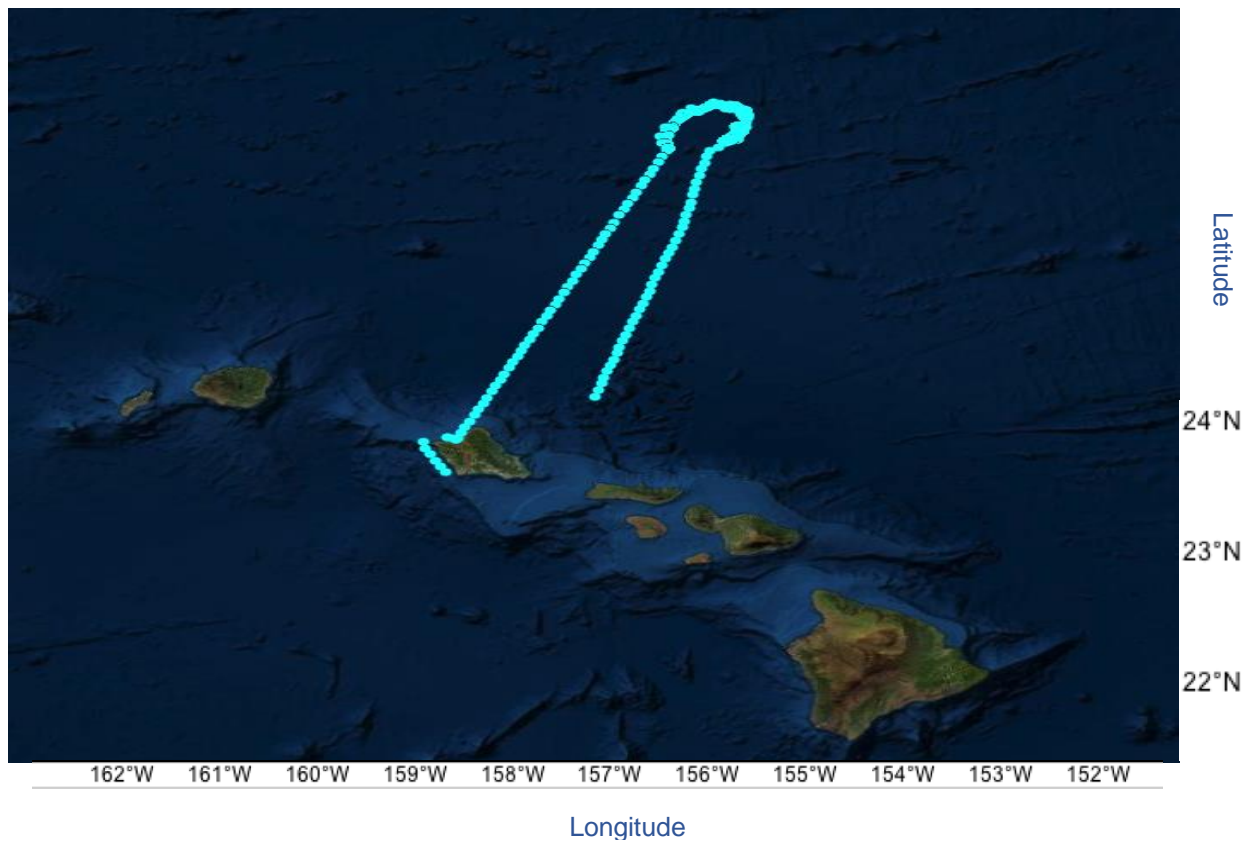


Figure 1. Transect of latitude and longitude on the KM1513 Cruise where measurements were taken and samples were collected. (Angel White Lab).

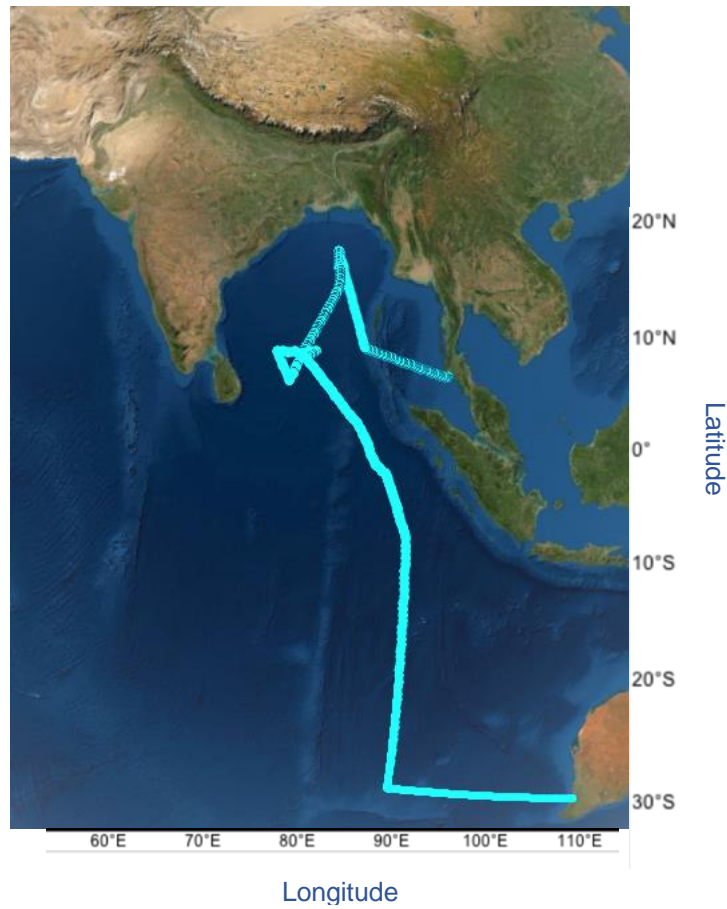


Figure 2. Transect of latitude and longitude on the RR1604 Cruise where measurements were taken and samples were collected. (Lomas et al., 2021).

The overall relationship between phytoplankton abundance and the concentration of nitrate, as seen in figures 3 and 4, from the RR1604 cruise indicated a negative correlation between the two factors, for both diatom and dinoflagellate biomass.

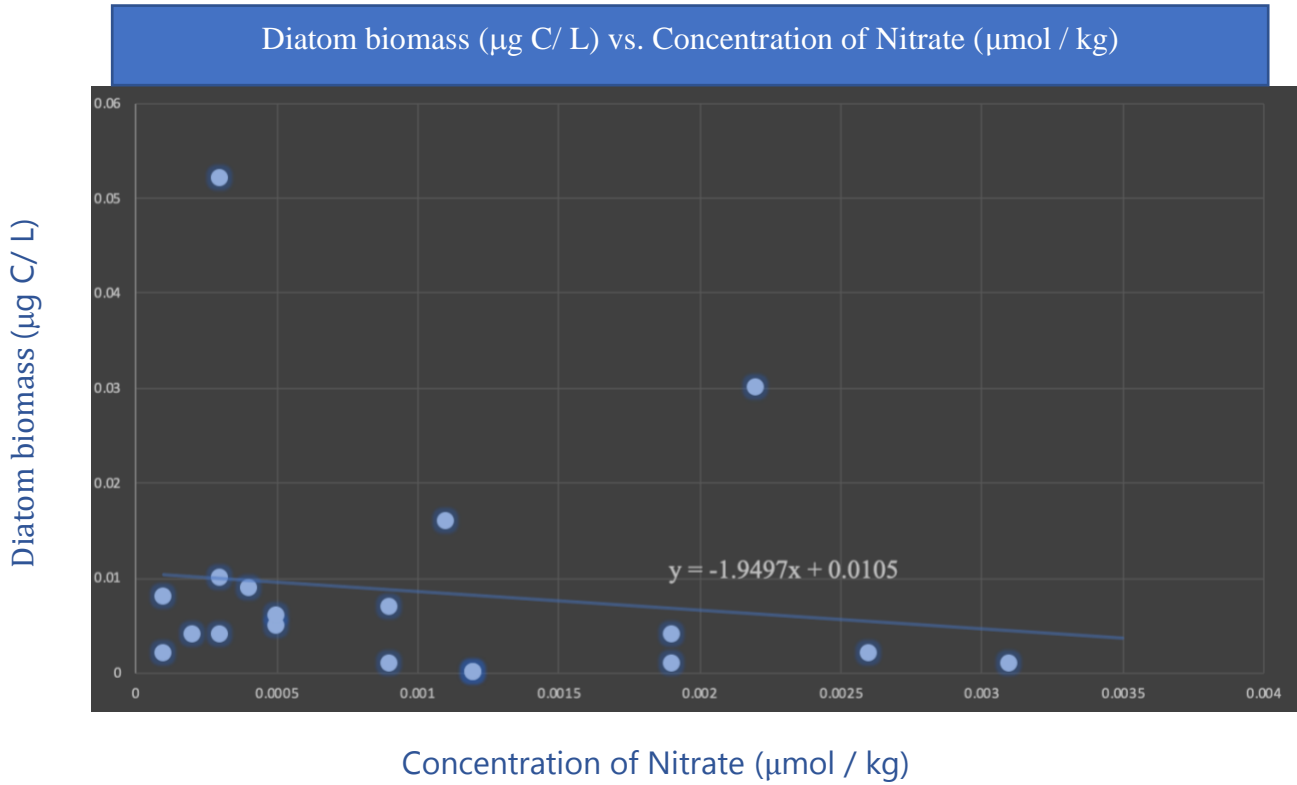
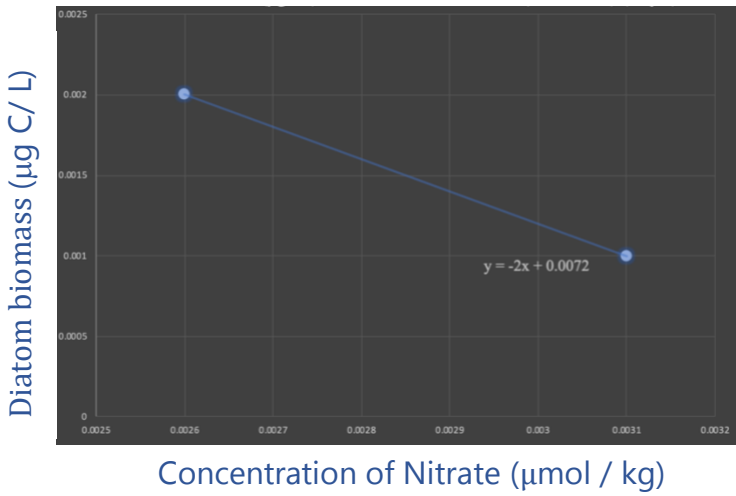
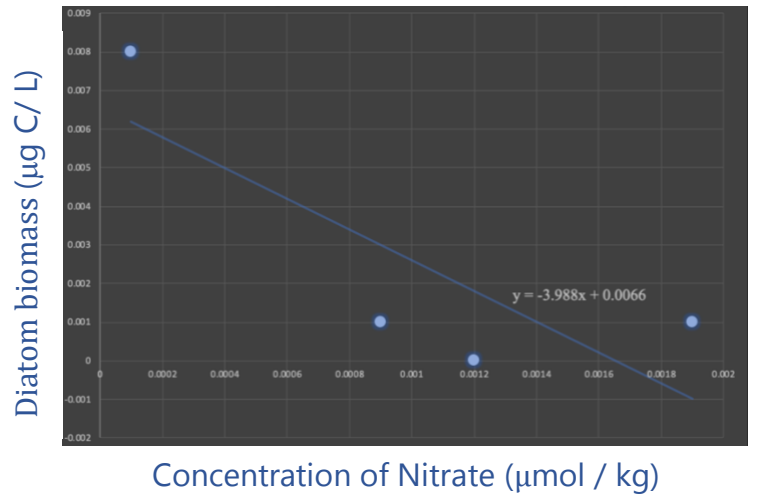


Figure 3. Diatom biomass ($\mu\text{g C/L}$) against nitrate concentration ($\mu\text{mol / kg}$) from sampling aboard the R/V Roger Revelle RR1604 Cruise. The blue trend line portrays the overall relationship. (Lomas et al., 2021).

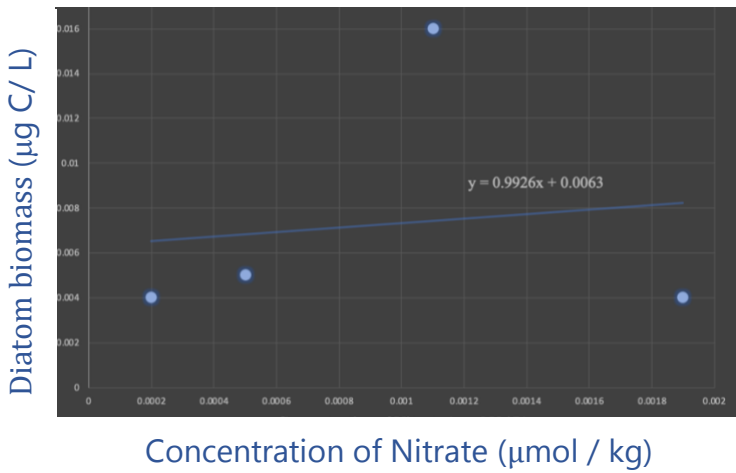
DAY 1



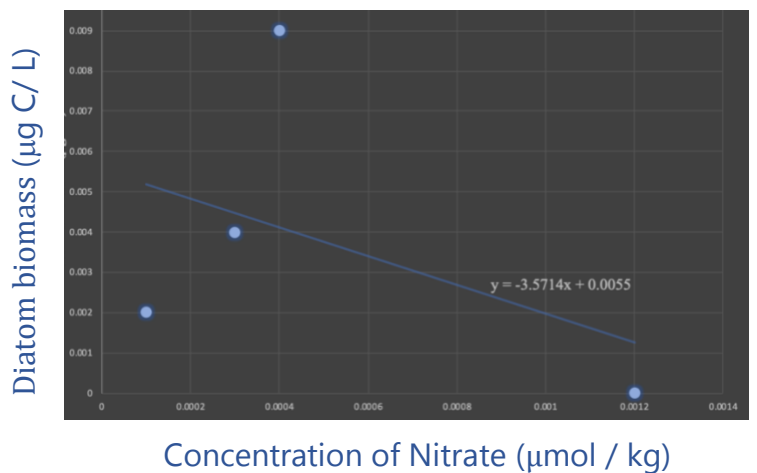
DAYS 6-9



DAYS 10-14



DAYS 15-18



DAYS 19-23

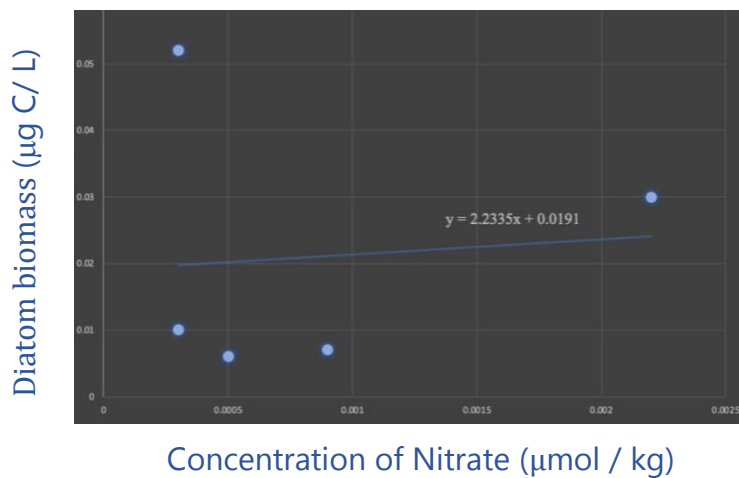
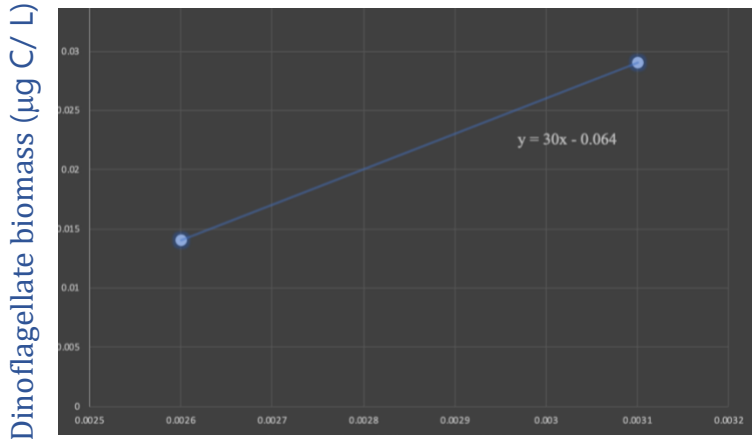


Figure 5. Diatom biomass ($\mu\text{g C/L}$) against nitrate concentration ($\mu\text{mol / kg}$) from sampling aboard the R/V Roger Revelle RR1604 Cruise, across periods of days. The blue trend line portrays the relationship.

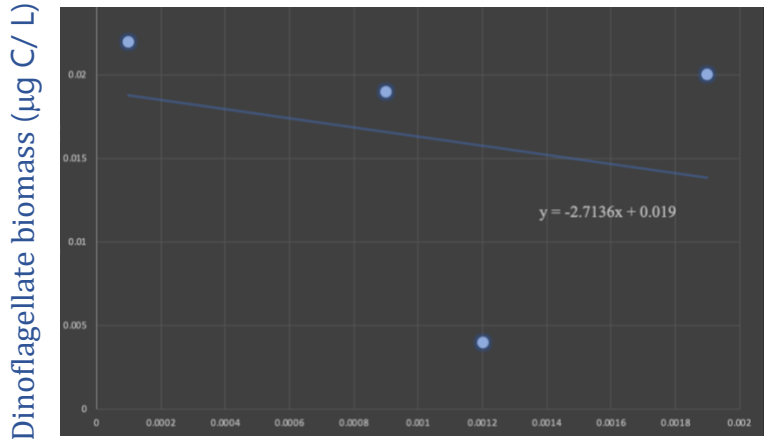
(Lomas et al., 2021).

DAY 1-5



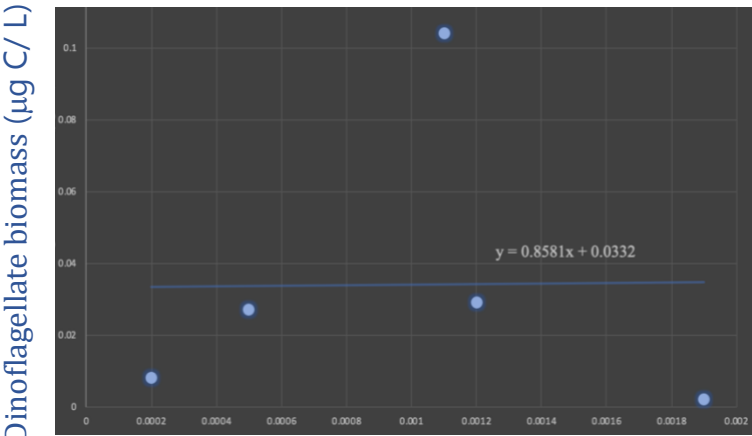
Concentration of Nitrate ($\mu\text{mol} / \text{kg}$)

DAYS 6-10



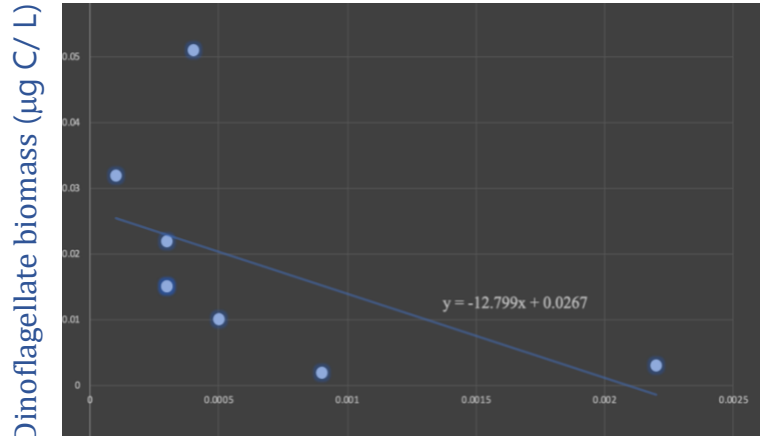
Concentration of Nitrate ($\mu\text{mol} / \text{kg}$)

DAYS 11-15



Concentration of Nitrate ($\mu\text{mol} / \text{kg}$)

DAYS 16-23



Concentration of Nitrate ($\mu\text{mol} / \text{kg}$)

Figure 6. Dinoflagellate biomass ($\mu\text{g C} / \text{L}$) against nitrate concentration ($\mu\text{mol} / \text{kg}$) from sampling aboard the R/V Roger Revelle RR1604 Cruise, across periods of days. The blue trend line portrays the relationship. (Lomas et al., 2021).

The overall relationship between phytoplankton abundance and the concentration of ammonium, conversely, as seen in figures 7 and 8, from the RR1604 cruise indicated a moderate, yet positive correlation between the two factors, for both diatom and dinoflagellate biomass.

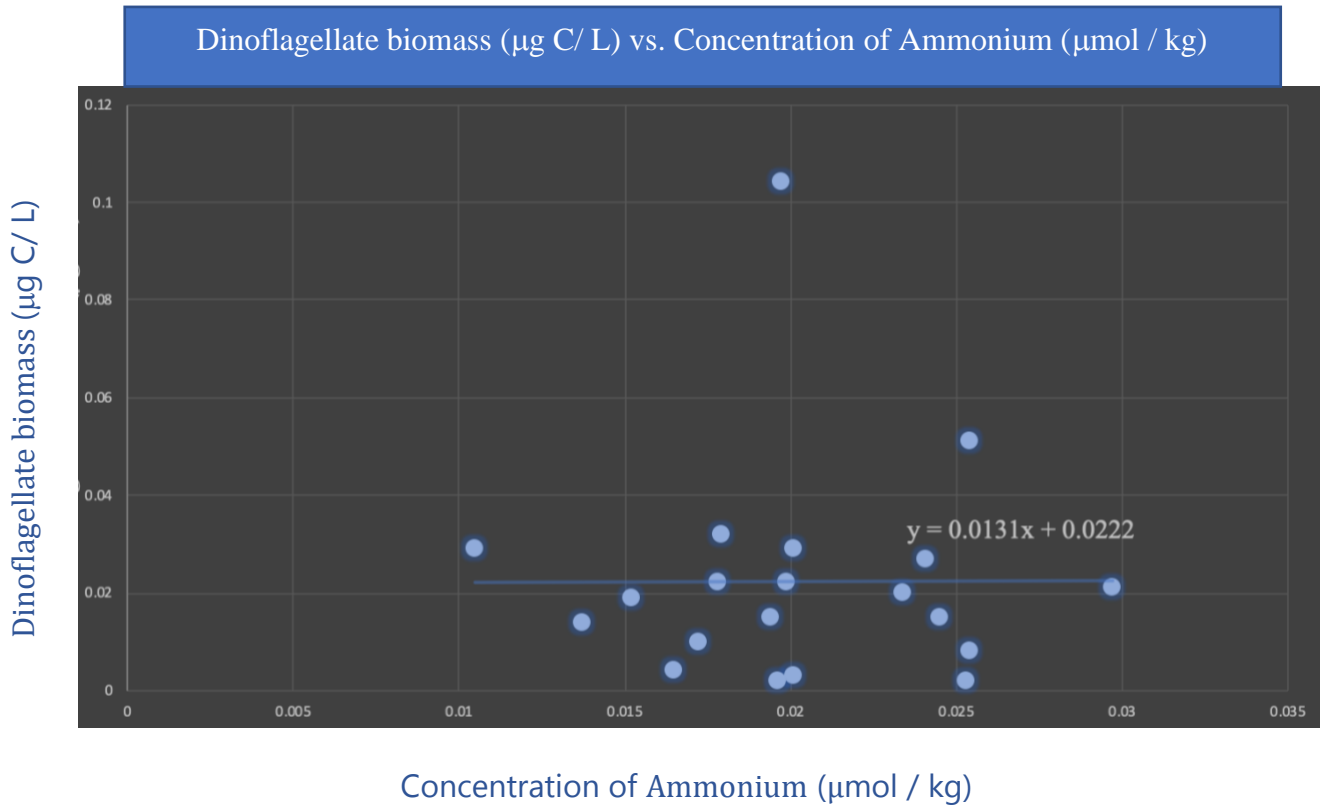


Figure 7. Dinoflagellate biomass (µg C/L) against ammonium concentration (µmol / kg) from sampling aboard the R/V Roger Revelle RR1604 Cruise. The blue trend line portrays the relationship. (Lomas et al., 2021).

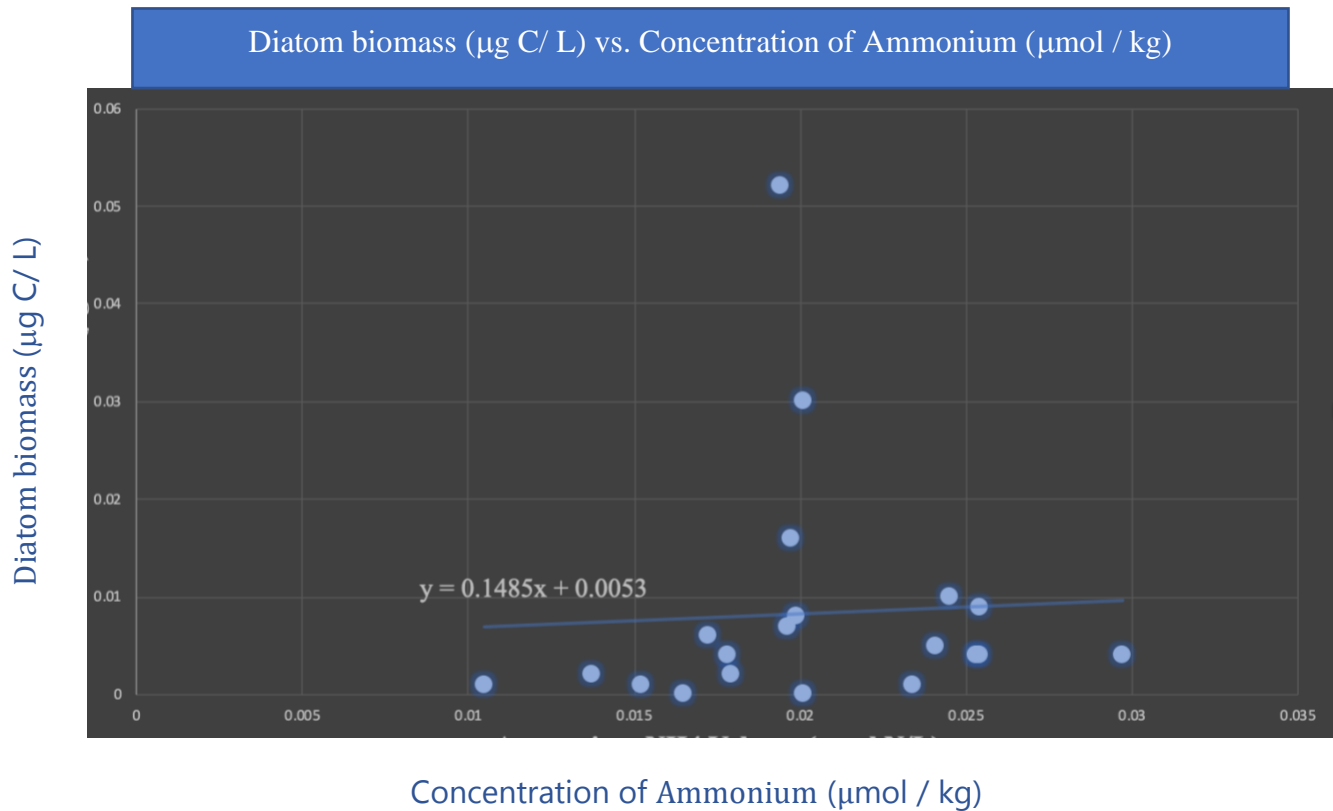
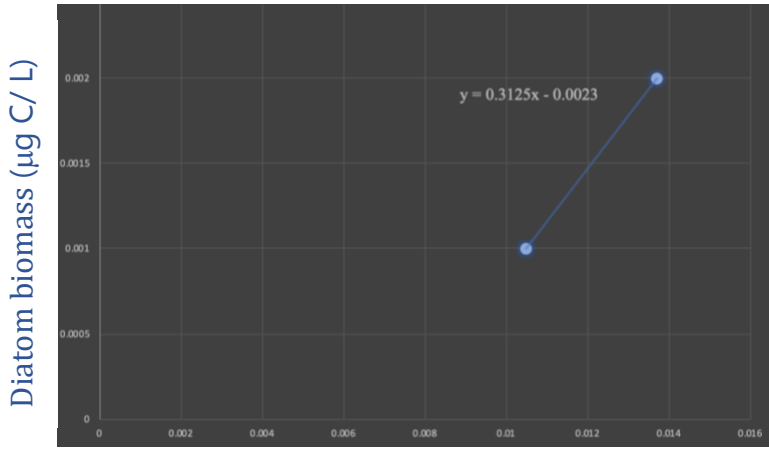


Figure 8. Diatom biomass (µg C/L) against ammonium concentration (µmol / kg) from sampling aboard the R/V Roger Revelle RR1604 Cruise. The blue trend line portrays the relationship. (Lomas et al., 2021).

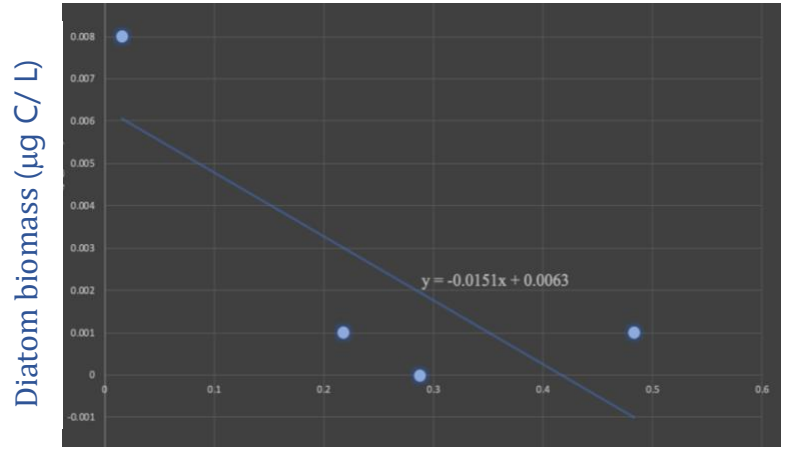
Days 1 – 5, and 16 - 23 had very strong, positive correlations between diatom abundance and the concentration of available ammonium, yet, days 6 – 10, and 11 – 15 had negative correlations, and can be observed in figure 9.

DAYS 1-5



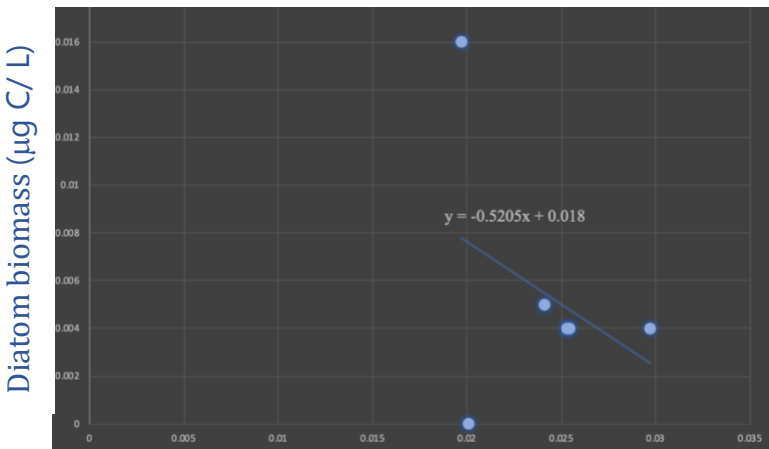
Concentration of Ammonium ($\mu\text{mol / kg}$)

DAYS 6-10



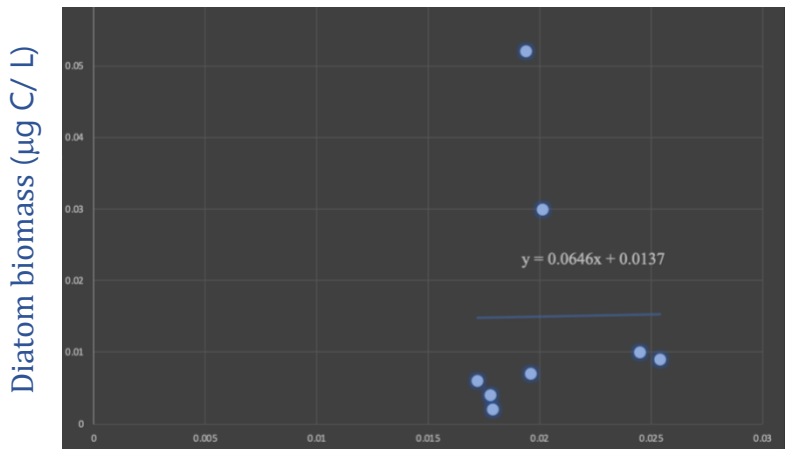
Concentration of Ammonium ($\mu\text{mol / kg}$)

DAYS 11-15



Concentration of Ammonium ($\mu\text{mol / kg}$)

DAYS 16-23



Concentration of Ammonium ($\mu\text{mol / kg}$)

Figure 9. Diatom biomass ($\mu\text{g C/L}$) against ammonium concentration ($\mu\text{mol / kg}$) from sampling aboard the R/V Roger Revelle RR1604 Cruise, across periods of days. The blue trend line portrays the relationship. (Lomas et al., 2021).

However, in terms of dinoflagellate abundance against the concentration of available ammonium, days 6 – 10, and 16 – 23 of sampling had strong positive correlations, as compared to days 1 – 5, and 11 – 15 (as seen in figure 10).

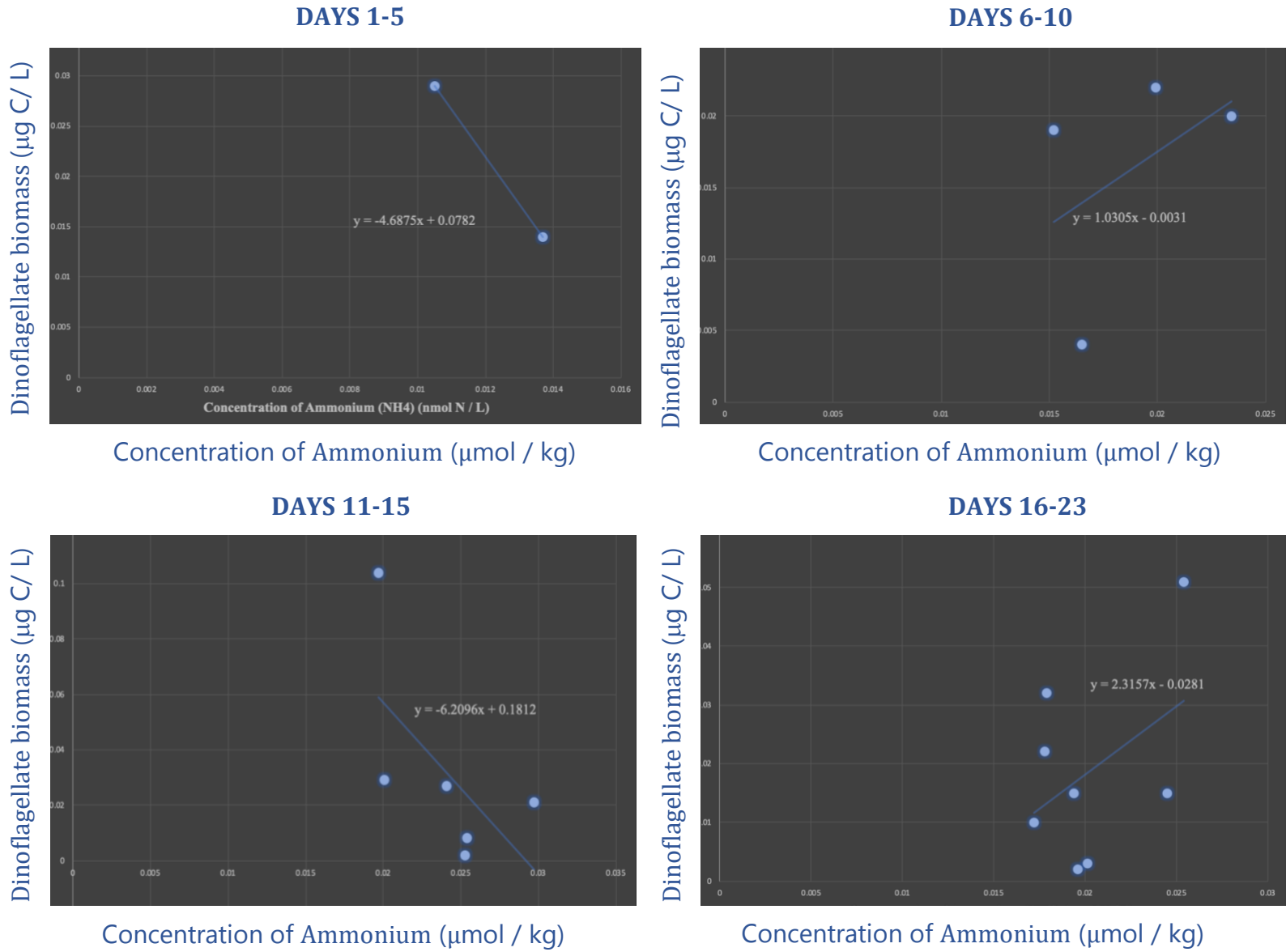


Figure 10. Dinoflagellate biomass ($\mu\text{g C/L}$) against ammonium concentration ($\mu\text{mol/kg}$) from sampling aboard the R/V Roger Revelle RR1604 Cruise, across periods of days. The blue trend line portrays the relationship. (Lomas et al., 2021).

In addition, for the below relationships, station ALOHA data was used. It can be observed in figures 11 and 12 that there exists a positive relationship (directly proportional) between dinoflagellate (phytoplankton) abundance and sea – surface temperature.

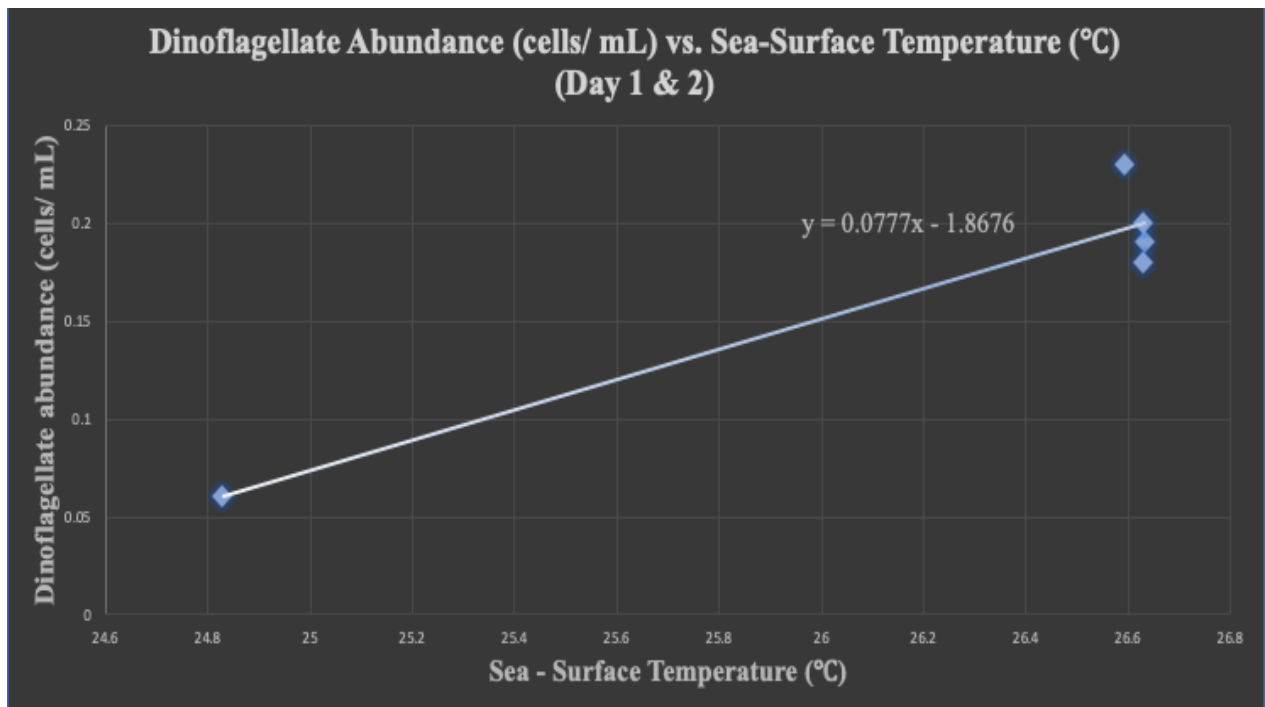


Figure 11. Dinoflagellate abundance (cells / mL) against Sea-Surface Temperature (°C) on days 1 and 2 of sampling aboard the KM1513. The blueish white trend line portrays the relationship.

(Angel White Lab).

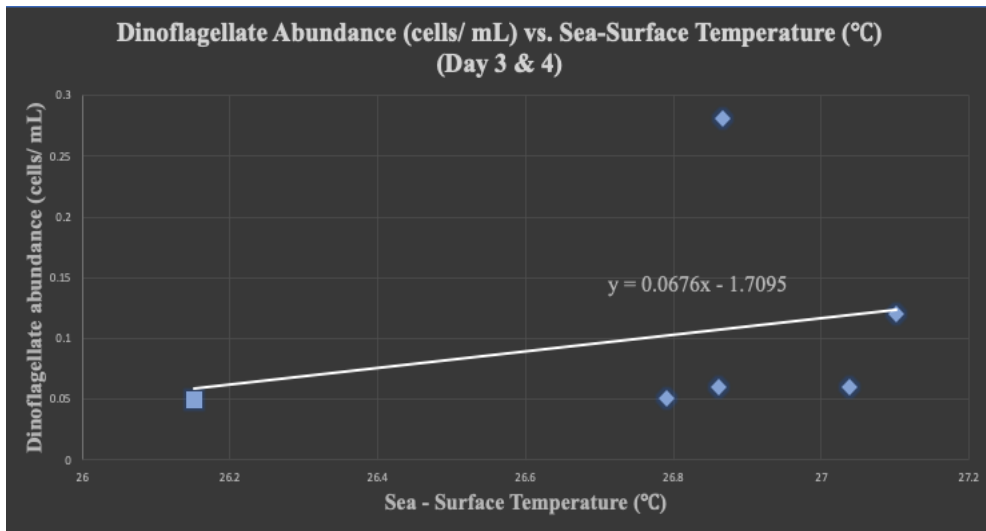
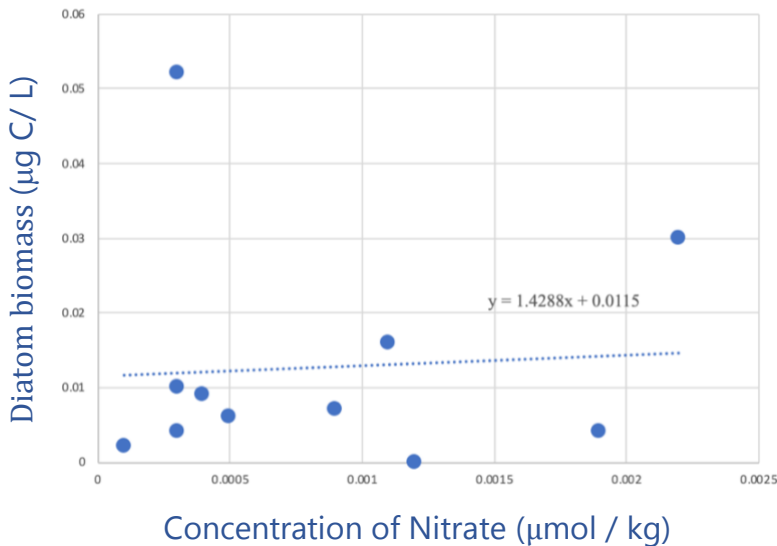


Figure 12. Dinoflagellate abundance (cells / mL) against Sea-Surface Temperature (°C) on days 3 and 4 of sampling aboard the KM1513. The blueish white trend line portrays the relationship. (Angel White Lab).

Figure 13 depicts a positive correlation between diatom abundance and the concentration of nitrate for the regions of sampling between 87.07° E to 93.65° E, but a negative correlation for the regions of sampling between 94.13° E to 95° E. However, the overall concentration of nitrate was higher at the latter, as opposed to between 87.07° E and 93.65° E.

87.07° to 93.65°



94.13° to 95°

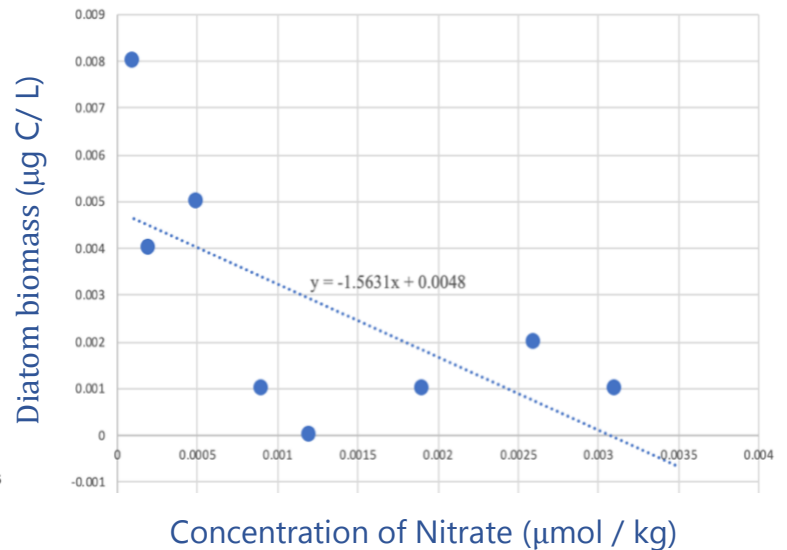


Figure 13. Diatom abundance ($\mu\text{g C/L}$) against nitrate concentration ($\mu\text{mol / kg}$) at regions from 87.07° E to 93.65° E and 94.13° E to 95° E of sampling aboard the KM1513. The blue trend line portrays the relationship. (Lomas et al., 2021).

Figure 14 depicts a negative correlation between dinoflagellate abundance and the concentration of nitrate for the regions of sampling between 87.07° E to 93.65° E , but a positive correlation for the regions of sampling between 94.13° E to 95° E .

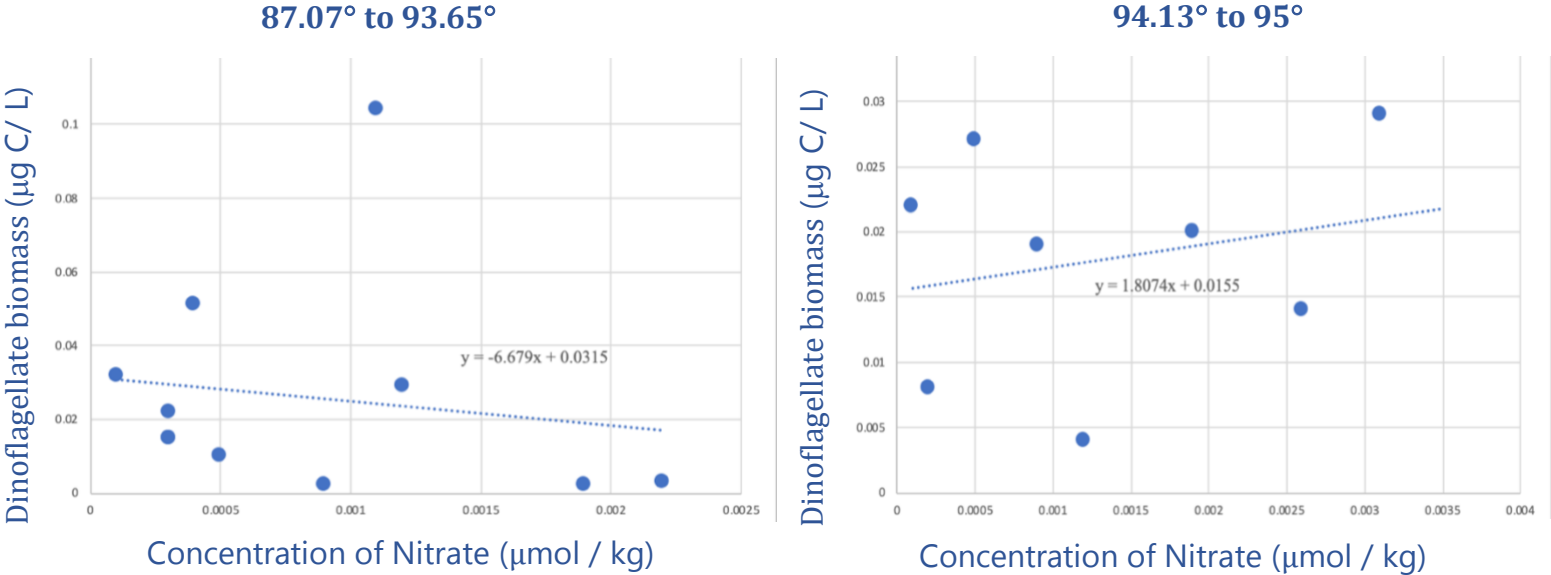


Figure 14. Dinoflagellate abundance ($\mu\text{g C/L}$) against nitrate concentration ($\mu\text{mol / kg}$) at regions from 87.07° E to 93.65° E and 94.13° E to 95° E of sampling aboard the KM1513. The blue trend line portrays the relationship. (Lomas et al., 2021).

Similarly, figure 15 depicts a negative correlation between diatom abundance and the concentration of ammonium for the regions of sampling between 87.07° E to 93.65° E , but a positive correlation for the regions of sampling between 94.13° E to 95° E .

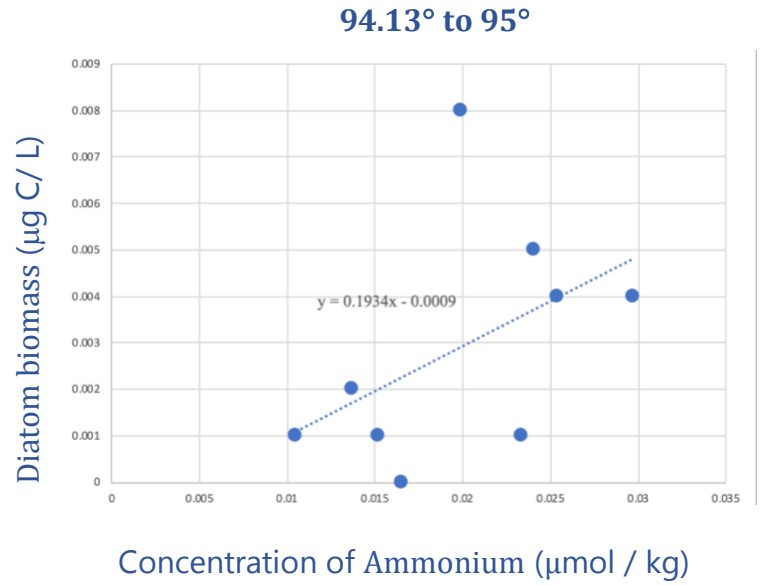
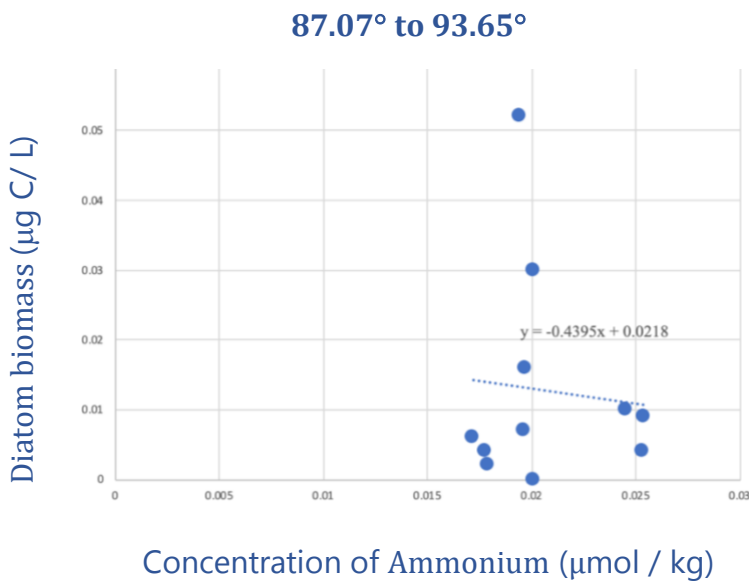


Figure 15. Diatom abundance ($\mu\text{g} \text{C} / \text{L}$) against ammonium concentration ($\mu\text{mol} / \text{kg}$) at regions from 87.07° E to 93.65° E and 94.13° E to 95° E of sampling aboard the KM1513. The blue trend line portrays the relationship. (Lomas et al., 2021).

Lastly, figure 16 depicts a negative correlation between dinoflagellate abundance and the concentration of nitrate for both the regions of sampling between 87.07° E to 93.65° E, and 94.13° E to 95° E.

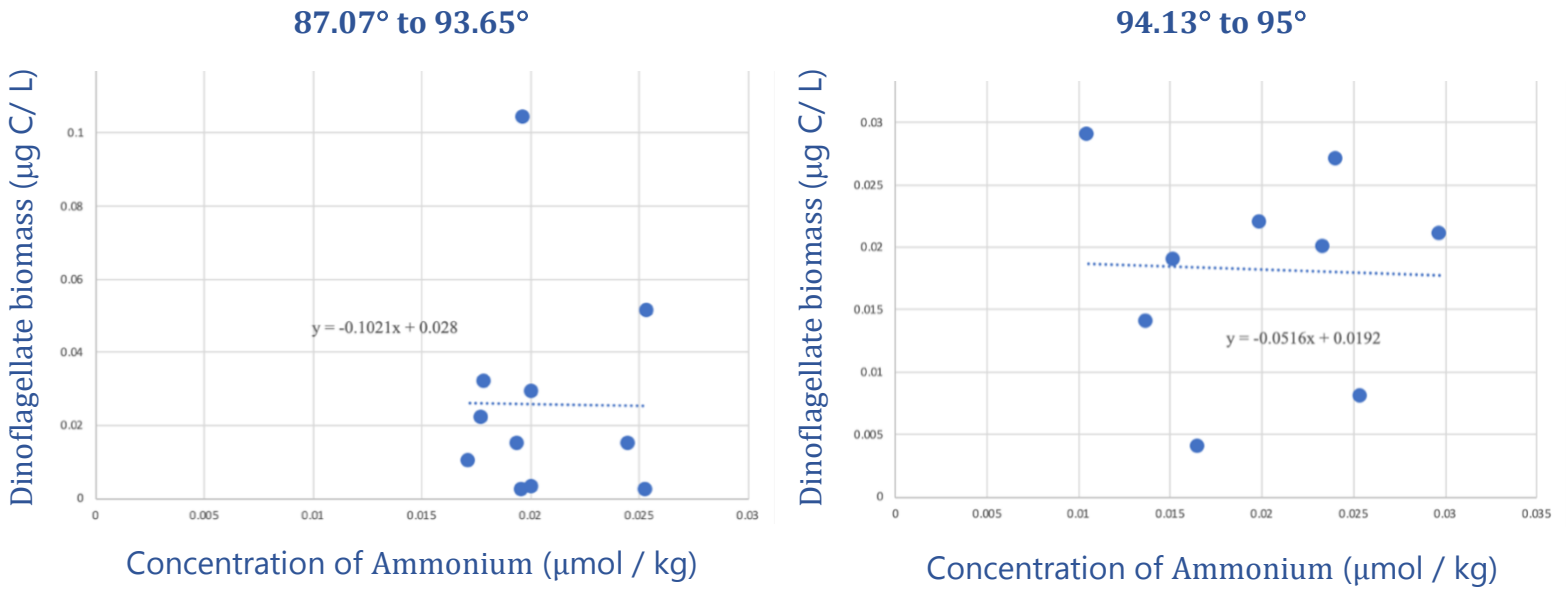


Figure 16. Dinoflagellate abundance ($\mu\text{g C/L}$) against ammonium concentration ($\mu\text{mol / kg}$) at regions from 87.07° E to 93.65° E and 94.13° E to 95° E of sampling aboard the KM1513. The blue trend line portrays the relationship. (Lomas et al., 2021).

Discussion

Sampling aboard the RR1604 cruise was conducted over a span of twenty – three days, and over a period of four days for the KM1513 cruise (Angel White Lab). The RR1604 cruise data set does not depict temperature data, but the KM1513 cruise data set does. The same goes for nitrate and ammonium concentrations, wherein the RR1604 cruise data set does display them, but the KM1513 cruise data set does not. In addition, only dinoflagellate data is depicted (for phytoplankton) in the KM1513 (station ALOHA) cruise data set. In order to take into account all the conditions affecting the anticipated results, inclusive of errors and changing environmental conditions, data was broken down and analyzed into figures that illustrate results based on

periodic segments (every 5 days) and sampling regions (data between 87.07° E to 93.65° E, and 94.13° E to 95° E, as there is more data present for the latter). However, days 1 -5, from all the figures, attained only two data points and so, was not considered for the analysis as it is not valid to compare a slope from only two points.

a. Phytoplankton abundance and the concentration of nitrate

The derived negative correlation between phytoplankton abundance and the concentration of nitrate, does not align with the hypothesis that phytoplankton abundance strongly depends on nitrate for growth, and its reasoning could be that nitrogen is likely a limiting nutrient and/or there may have been some errors with the collected data whilst sampling. Hecky, R. E et al., 1988, depict that phytoplankton could possibly become limited by the availability of nutrients, predominantly because they consume it, when temperature and light are sufficient and loss rates are not excessive. Another possibility is that each day of sampling weathered different environmental conditions (such as changes in sea-surface temperature), and so, it would not be an accurate representation if all the data were grouped together in the same figure for an analysis. Hence, the figures were broken down over a short span of days for both diatom and dinoflagellate abundance against the concentration of nitrate, as seen in figures 5 and 6. With the broken down figures, the r^2 values for the negative correlations in both the sets of figures (5 and 6), were far greater than the r^2 values for the positive correlations, showing that nitrate is probably a limiting nutrient that is quickly consumed when temperature and light are sufficient, and there are no excessive loss rates. The overall relationship between diatom and dinoflagellate abundance against the concentration of nitrate over twenty-three days (figures 3

and 4) mainly also have negative correlations (Lomas et al., 2021). However, as seen in figure 13, a positive correlation is depicted between diatom abundance and the concentration of nitrate for the regions of sampling between 87.07° E to 93.65° E, but a negative correlation for the regions of sampling between 94.13° E to 95° E, thereby differing from the results obtained based on the time-period analysis. This is probably because there are certain locations with higher biomass of phytoplankton than others, and also higher nutrient concentrations, and can be tested by how quickly phytoplankton uptake nitrate. The opposite is true for dinoflagellate abundance (figure 14), which leads to the possibility that nitrate may be used by either diatoms or dinoflagellates based on the location, but not together at the same time. Sampling conducted closer to 95° E may also attain a higher dinoflagellate abundance than regions between 87.07° E to 93.65° E, which may attain a higher diatom abundance.

b. Phytoplankton abundance and the concentration of ammonium

The resulting positive correlation between phytoplankton abundance and the concentration of ammonium data supports the hypothesis that phytoplankton abundance strongly depends on ammonium for growth, as seen in figures 7 and 8. Irrespective of the results, the provided data were once again, broken down into figures that would help analyze day to day information due to changes in environmental conditions, over smaller periods of time (five day segments), and can be seen in figures 9 and 10. This 'breaking down' of the figures once again, allows for smaller errors to also be noticed whilst making an overall assumption on the relationship between phytoplankton abundance (for both classes) and the concentration of ammonium. The difference between the positive correlations on days 16-23 (as seen in Fig. 9),

and the negative correlations on days 6-10 and 11-15 (as seen in Fig. 10), allows for further exploration on whether there pertains a relationship between both diatoms and dinoflagellates, and how they utilize available nutrients (Lomas et al., 2021), as they do not consume them together, at the same time. Similar to figure 14, figure 15 depicts a negative correlation between diatom abundance and the concentration of ammonium for the regions of sampling between 87.07° E to 93.65° E, but a positive correlation for the regions of sampling between 94.13° E to 95° E. In addition, figure 16 depicts a negative correlation between dinoflagellate abundance and the concentration of nitrate for both the regions of sampling between 87.07° E to 93.65° E, and 94.13° E to 95° E. This leads to the possibility that ammonium may be a limiting nutrient, or is favored more by diatoms, as compared to dinoflagellates at these sampling regions. It could also mean that ammonium was in lower quantity as compared to nitrate closer to 95° E, but was in abundance between 87.07° E to 93.65° E, and so, diatom were able to consume it. This could be tested by how investigating how quickly phytoplankton uptake nutrients, relative to each other.

c. Phytoplankton abundance and sea – surface temperature

Sea – surface temperatures varied every day at station ALOHA (KM1513 cruise), and with depth – the deeper the water, the cooler the water temperature, but after spawning both the figures, it can be observed in figures 11 and 12 that there exists a positive relationship (directly proportional) between dinoflagellate (phytoplankton) abundance and sea – surface temperature. This resulting positive correlation also supports the hypothesis that phytoplankton abundance also strongly depends on temperature for growth (Angel White Lab). The figures for this dataset

were also broken down into smaller periods of time (2 day segments), even though the entire duration of the sampling itself was four days long, to account for all resultant data.

In addition, it may be intriguing to research how concentrations of various nutrients and phytoplankton abundance vary across seasons and extended periods of time. Past papers have deemed that climatic conditions/ natural disasters may have an effect on some regions, thereby attaining higher, or lower concentrations than the average measurements at the same locations (Wilson, S.T., et al., 2019). Another study, led by researchers at the University of Hawaii, and Southern California, that depicts the relationship between nutrient supply and phytoplankton growth is the eruption of the Kilauea Volcano in 2018. With its eruption, millions of cubic feet of lava was infused into waters that were poor in nutrients, off Hawaii, thereby stimulating phytoplankton growth vastly, also detectable by a satellite. High concentrations of nitrate were brought to the ocean's surface, due to the heat from the basaltic lava that was injected, thereby allowing for other nutrient-rich deep waters to rise (Wilson, S.T., et al., 2019). Such conditions may have a drastic impact on formulating and modeling the results, and could also be taken into consideration whilst analyzing the provided data.

Conclusion

The aim of this project was to test the hypothesis that phytoplankton growth strongly depends on the amount of available nutrient supply (NO_3 , NH_4) and temperature. The null hypothesis was that there is no relationship between phytoplankton abundance, available nutrient

supply and temperature, and is not supported by any of the derived results. Phytoplankton play a vital and crucial role in the marine environment, and are fundamental in comprehending numerous food webs, trophic energy flows, and the global carbon cycle, and hence, was the broad motivation for the study. It is known that a cell needs nutrients from external environments to support its activities, and that that under non-limiting nutrient conditions, an increase in water temperature usually associates to an increase in phytoplankton growth. Accordingly so, the expected results were that phytoplankton abundance would yield a positive correlation against the concentration of nitrate and ammonium, and temperature. However, the overall relationship between phytoplankton abundance and the concentration of nitrate, illustrated negative correlations between the two factors, for both diatom and dinoflagellate biomass. This consequent negative correlation does not support the hypothesis that phytoplankton abundance strongly depends on nitrate for growth, but shows the possibility that nitrate may be a limiting nutrient. The overall relationship between phytoplankton abundance and the concentration of ammonium portray a moderately strong positive correlation between the two factors, for both diatom and dinoflagellate biomass. This derived positive correlation supports the hypothesis that phytoplankton abundance strongly depends on ammonium for growth. Lastly, it was also observed that there exists a positive relationship between dinoflagellate (phytoplankton) abundance and sea – surface temperature, again supporting the hypothesis that temperature is needed for phytoplankton growth. The variations between the relationships in the broken data however, suggest insight and allows for further study that there may exist a relationship between diatoms and dinoflagellates, and how they utilize available nutrients. Furthermore, climatic conditions and natural disasters may have impacts on pH levels over a longer period of time, which in turn may have an effect on phytoplankton abundance and growth rates. This may make

it challenging to observe unique patterns over smaller time-scales. Therefore, investigating and analyzing patterns that take into consideration climatic conditions, natural disasters, and pH levels over smaller and longer timescales could be another follow up to this study.

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