Proceedings from the University of Washington
School of Oceanography Senior Thesis, Academic Year 2012-2013

Variation in phytoplankton abundance along a transect of the Kuroshio

Emma Wilson[1]

[1]*University of Washington, School of Oceanography,*
Box 355351, Seattle, Washington 98195
**emmaw5@uw.edu*
Received June 2013

NONTECHNICAL SUMMARY

Phytoplankton abundances and community composition in the form of size and species distributions are important for determining the productivity of the waters. They are primary producers in the ocean and are important because they are at the base of the food web. Understanding the abundance levels of phytoplankton in the Kuroshio is important because phytoplankton are an important component to the food web. Phytoplankton abundance along the Kuroshio is influenced by weather conditions that lead to mixing, amount of sunlight and nutrient concentrations. Their abundances can be controlled by bottom-up factors in that they are reliant on sunlight and nutrients in the water to survive. However, their abundance can also be regulated by top-down controls like grazing and mortality.

Phytoplankton size plays an important role in determining how much carbon is exported to the seafloor. Large phytoplankton take up more CO_2 and are more likely to sink, contributing to biological carbon export. The main factors that increase phytoplankton size are nutrient concentrations, sunlight and temperature. The conditions that were important in the wintertime are nutrients and temperature. I found that there were more nutrients in the north during the winter due to mixing even though the temperatures are colder than in the summer. Sunlight was not a mitigating factor in the winter because there was a lack of sunlight in both the subarctic and the subtropics during the winter. Through taking in CO_2 from the ocean, phytoplankton respire oxygen into the water which is an important factor in maintaining a balance in the biological carbon export. Nutrient conditions influence the types and sizes of phytoplankton that are present. More nutrients in the water typically result in a size increase. Mixing increased in the north which increased nutrient concentrations resulting in more of the larger size of phytoplankton. The nutrient concentrations were less in the south which was shown in the higher abundance of smaller phytoplankton. Along with the chlorophyll increases to the north, there were higher light levels in that area because chlorophyll concentrations result from light penetration which is another control for the phytoplankton abundances.

ABSTRACT

Phytoplankton abundance levels are an important factor in the world's oceans because they directly correlate to productivity as well as contribute to the global carbon export cycle. Phytoplankton abundance levels as well as chlorophyll concentrations vary along the Kuroshio in respect to area as well as season. There was an increase in chlorophyll and phytoplankton in the north along the Kuroshio due to the mixing increase and more nutrients at the surface levels. These measurements were taken with a CTD as well as net tows. The abundances were taken from different depths of 200 meters, 75 meters and the surface along the current from south to north and then back down. The limiting factors differ between seasons. In the summer the limitation is that there is less mixing as opposed to the winter where the limiting factor is sunlight. The increase in size and abundance of phytoplankton in the north resulted from increased mixing and nutrients which is a direct correlation to the productivity and positive function of the biological pump in the subarctic region.

The abundance of phytoplankton in the Kuroshio is the product of several factors that must be considered. The composition of the current influences the primary productivity of the water column and also attributes to better understanding of phytoplankton abundance. Abundance levels are limited by nutrient availability (Odate, 1994) and were compared by using chlorophyll concentrations. The chlorophyll maximum is the most nutrient rich area in the winter due to the mixing that occurs and the light penetration and is where the majority of phytoplankton lives and thrives. The winter conditions during the research cruise affected phytoplankton abundances because there was more mixing occurring in the winter. This deep mixing draws more nutrients into the euphotic zone which affected the size of phytoplankton (Jang et al). Water column instability causes mixing which increases nutrients (Odate, 1994). Availability of nitrate, phosphate, silicate and light levels in the photic zone are limited during the winter months in the subtropics area which results in the limitation of phytoplankton growth. However, in the subarctic area, nitrate, phosphate and silicate levels were higher due to the mixing and upwelling that occurred resulting in a larger size composition of the phytoplankton.

The larger phytoplankton thrived due to an increase in nutrients from mixing (Odate 1994). The phytoplankton abundance and sizes can be understood from the nutrient concentrations. Abundance of large size class of phytoplankton coincides with a supply of nitrate while abundance of small size class dominates in nitrate-depleted waters (Odate, 1995). Along with mixing as an important factor in determining abundances, grazing by zooplankton also affected abundance levels. Knowing the abundances and effect of grazing are important for understanding how the composition of the water column affects the amount of phytoplankton, which also helps to gain an understanding of the productivity in the area that results from phytoplankton being the food supply for the higher trophic levels and the positive effect that they have on the biological carbon export. Sunlight is a final factor that affected phytoplankton in the winter because there was less sunlight which limits photosynthesis that needs to occur for phytoplankton growth. This all leads to the question of how phytoplankton abundance varied along the Kuroshio at the chlorophyll maximum and what were the size ratios along the current.

Based off the results from previous studies of phytoplankton abundance found at the chlorophyll maximums along the Kuroshio, there were higher abundance levels to the north along the current (Odate, 1994). This was because the chlorophyll concentrations increase to the north due to mixing. There also was a higher abundance of small and large phytoplankton than medium sized phytoplankton due to the weather conditions and the properties of the water during the winter (Odate, 1994).

METHODS

The cruise was conducted from 24FEB2013 to 17MAR2013. Samples were taken along a cruise track that went from 30°N to 40.9°N off the coast of Japan and crossing over the Kuroshio (Fig. 1). Duplicate samples were collected from 11 stations along the cruise track via CTD and net tows. One liter of water was collected from the CTD casts and four ounces of water was collected from the net tows. The water from the CTD cast was filtered on three filter sizes of 10µm, 5µm and .7µm. The water samples from the net tows settled in the jars were brought back to the lab where 2mL was used to identify species under the microscope.

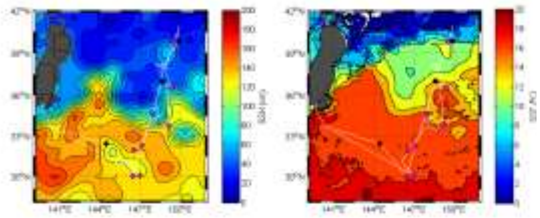

Figure 1: The cruise track from 30°N to 40.9°N. The left panel is Sea Surface Height in cm and the panel on the right is Sea Surface Temperature in °C. Diamonds are the southern stations and the circles are the northern stations. Stations that are pink are where the net tows were taken. The black dots were stations that net tows were not taken.

11 Stations along track

The samples were taken from 11 different stations along the cruise track. Five of the samples were taken along leg 2 at stations 1, 3, 5, 7 and 9 (Fig 1). The second set of five were taken along leg 3 at stations 11, 15, 17, 19, 21 and 23 (Fig 1).

This was so that there was a sample taken at every station because legs 2 and 3 were the same just traveling in opposite directions. Half of the samples were taken from every other station along leg 2 and on the way back along leg 3 the other half of the stations were sampled. The samples were taken at the surface, the chlorophyll maximum at approximately 75m, and 200m depth. The three depths gave variation throughout the water column. The different stations were chosen because they span along the current and resulted in a good representation of how the abundances varied along the current. These stations gave enough data to analyze, make a comparison between the stations and resulted in differences in abundance along the Kuroshio.

CTD cast

The conductivity, temperature and depth sensor (CTD) were attached to the rosette of Niskin bottles and was the method for determining the chlorophyll size fractionations at each sample station. The CTD was placed in the water column and as it was brought to the top, the individual Niskin bottles closed and took samples of the water column as the sensors are simultaneously recording the chlorophyll levels. There were water samples taken from the Niskin bottles on the CTD to measure the chlorophyll from the surface, down to 200 meters including the chlorophyll maximum. Through chlorophyll analysis, the samples then were run through a fluorometer to determine the actual amounts of chlorophyll present at those three depths. The chlorophyll size fractionations were used to determine the total chlorophyll abundance in the water and were determined using a stacked filtration system with three different sizes of filters that were, 0.8µm (GFF filter), 5µm and 10µm.

Net Tows

The net tows were taken along the cruise track at nine different stations. There were four net tows taken on leg 2 and five net tows taken on leg 3 (Fig 1). The net tows were taken using a 25 µm mesh net. The net was spooled out 10 meters, three to four times each tow. The depths that the net went down varied on the sea state. The tows were taken from the surface waters. It was attempted to take the tows from the shallow chlorophyll maximum but was not always accessible due to a change in the depth of the chlorophyll maximum and the ability to get the net down to said depths. The chlorophyll maximums at each station differed along the track due to the ship steaming from a subtropical gyre to a subarctic gyre. The samples from the net tows were taken at different times each day due to the time the ship was on station as well as a need for getting enough net tows for sufficient data and to compare with the stations where the chlorophyll data was taken.

Total abundance (sizes)

The relative abundance of phytoplankton was comprised of the amounts of the different sized organisms. Net tows were used to determine the relative abundance of large and small phytoplankton. These samples were placed in 4oz jars and then fixed with formaldehyde. Once the samples settled in the jars, 0.1mL was pipetted out of the bottom of the jars onto a slide and then counted using a microscope. The abundances were determined from the density of phytoplankton versus the volume of water sampled. The different sized organisms were compared between stations. This method of phytoplankton abundance answers the question of how the sizes of phytoplankton change along the current and if there is much diversity in the identification of phytoplankton species.

The second way the phytoplankton were collected for species identification was from the Niskin bottles on the CTD at the surface, the chlorophyll maximum and 200m depths. 250mL of water was taken from the bottles and then placed into a Hoefer filtration box with a filter size of 0.8µm. These samples then were stained with a 4'6-diamidino-2 – phenylindole (DAPI) solution, placed on slides, refrigerated and analyzed under an epifluorescent microscope back at the lab. This collection method was used to determine the total abundance of the smallest species of phytoplankton, cyanobacteria, which were seen on the 0.8µm filter and their contribution to the abundance levels; this species was also too small to be caught in the net tows. Together, these sampling methods helped to answer the question of how phytoplankton abundance varied along the Kuroshio in that both of the procedures result in quantities and identification of phytoplankton.

RESULTS

There was a significant change in phytoplankton abundance along the cruise track from the southern stations to the northern stations. There was not, however, a change in the total chlorophyll concentrations from the subtropics to the subarctic (Fig. 2).

The Kuroshio was located at approximately 36°N (Fig. 1). There was a clear distinction in change from high to low sea surface height (SSH) as well as a decrease in sea surface temperature (SST) as the cruise crossed the current. The cruise track went from low SSH to high SSH across the Kuroshio and then back south from high SSH to low SSH. Similarly, the cruise path was from high SST of approximately 17°C to low SST of approximately 9°C and then back south to the higher SST. Six stations were sampled south of the current and six stations were sampled north of the current. There were eight stations where net tows were taken (Fig. 1). This gives an equal representation for comparison of the different locations north and south of the current to further analyze the differences in the ocean's properties.

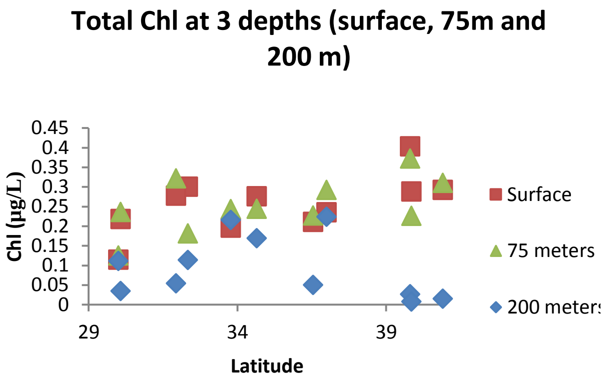

Figure 2: Total chlorophyll concentrations found at three depths: surface (squares), 75 meters (triangles) and 200 meters (diamonds). This was data was found from the southernmost stations to the northernmost stations.

The total amount of chlorophyll along the cruise track did not change significantly (Fig. 2). The surface depth along with 75 meters had similar concentrations. There were two sets of data taken at each degree of latitude. There were 13 stations sampled from the subtropics to the subarctic and 13 stations sampled from the subarctic to the subtropics. These stations were as close to each other as possible for duplicate data. The surface and 75 meter depth concentrations showed no clear change along the track. The samples taken from 200 meters depth also showed no clear change along the cruise track. This lack of abundance changes are broken down in the size fractionation data that show clear increases of specific species sizes which contribute to the total chlorophyll concentrations (Fig. 5).

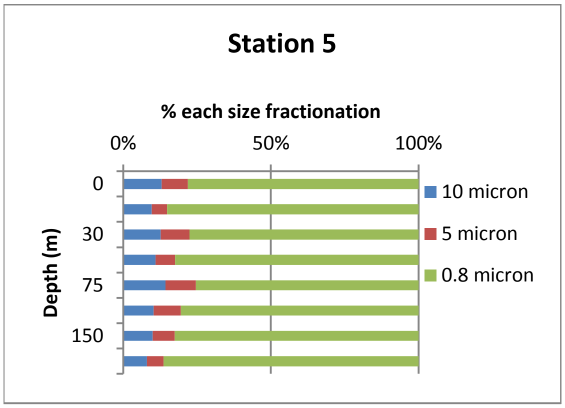

Figure 3: Size fractionated chlorophyll versus depth amounts from the representation of the Southern stations, station 5.

Station 5 is representative of all stations south of 36°N (Fig. 3). The total concentrations were higher at the surface depths above 100 meters. They started to decrease at depths deeper than 100 meters. The chlorophyll concentrations were typically between 0.2 µg/L and 0.3µg/L and decreased with depth. Between the surface and 100 meters depth, there was not a clear trend of increase or decrease in concentrations with depth. The size fractionations help define the total amounts of chlorophyll but also don't show a clear trend (Fig. 3). All through the water column, species that were filtered and collected on the 0.8µm filter contributed the most to the total abundance. The large phytoplankton collected on the 10 µm filter had the next largest values of contribution to the total chlorophyll concentrations. Breaking down the total chlorophyll concentrations into size fractionations present an understanding as to which species and species sizes are contributing to the total concentrations.

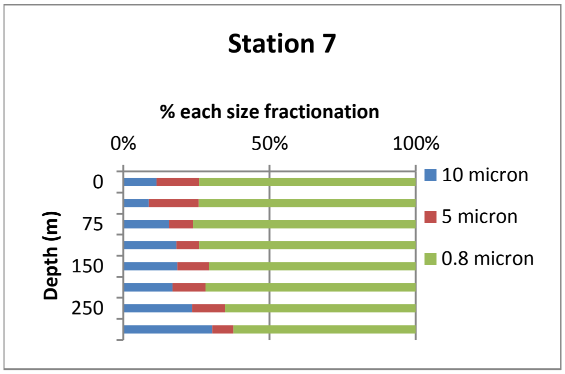

Figure 4: Size fractionation chlorophyll versus depth concentrations from the representation of the Northern stations, station 7.

Station 7 is representative of all stations north of 36°N (Fig. 4). The concentrations at this station were between 0.2µg/L and 0.3µg/L. There was a slight increase in concentration at 100 meters depth and then the concentrations decreased further down in the water column. There was a clearer pattern with depth at the northern stations (Fig. 4) than in the southern stations (Fig. 3). Once broken down into size fractionations, there is a clearer picture as to which sizes of phytoplankton are contributing to the total chlorophyll. There also is a trend seen in the size fractionations (Fig. 4). Overall there is the greatest abundance of the smallest size fraction of 0.8 µm. From the surface to depth, there is an increase of contribution from the large phytoplankton species of 10 µm in contrast to the decrease of smallest phytoplankton sizes with depth.

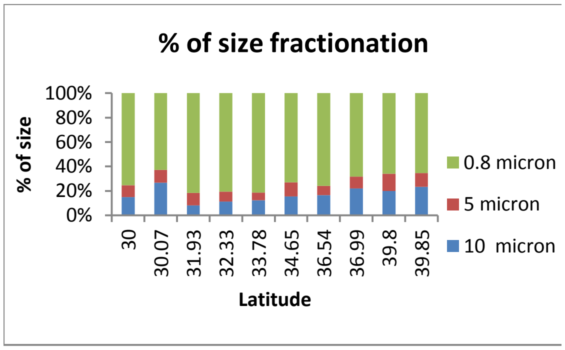

Figure 5: The amounts of each size fractionation that were found at each station along the cruise track. A positive linear progression in all size fractionations from the southern latitudes to the northern latitudes.

There was an increase in percent of each size fractionation of chlorophyll that was filtered (Fig.

5). The filter sizes that were used were 10µm, 5µm and 0.8µm. From the subtropics to the subarctic latitudes the highest abundances were found on the 0.8µm filter. This was the smallest size of filter that was used. The species that was found on this filter was cyanobacteria. There was a positive linear progression from the southern stations (south of 36°N) to the northern station (north of 36°N). The filter size that had the second highest abundances was the 10µm filter. This was the filter that had the largest size of phytoplankton on it as well. The 5µm filter had a relatively constant abundance level from the south to the north. There was not as noticeable of a change in the concentration of phytoplankton on this filter.

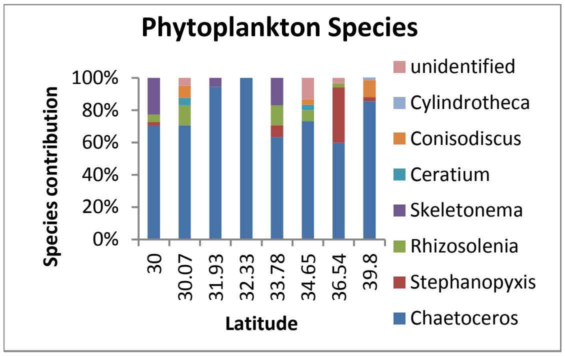

Figure 6: The different species of phytoplankton that were found along the cruise track. Species differences from south (30) to northern (39.8) stations. A progression of the types of species that were collected.

The phytoplankton species that were found in the most abundance at a majority of the stations were *Chaetoceros* and *Stephanopyxis*. Overall there was a higher percentage of *Chaetoceros* all along the cruise track at all of the stations (Fig. 6). The latitudes that show the most diversity with different species were 30.07°N, 33.78°N and 34.65°N. All of these stations were in the southern region of the cruise. There was over 50% contribution of *Chaetoceros* at each station and was therefore the most abundant species that was seen overall.

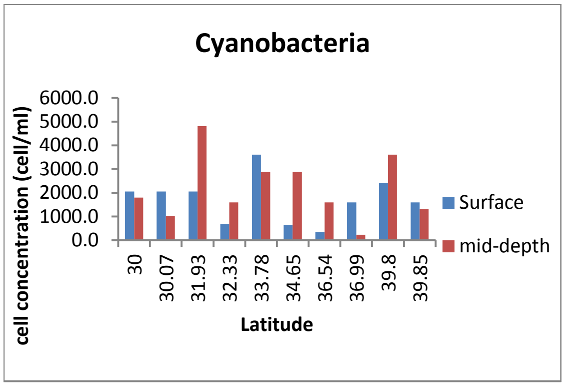

Figure 7: Concentration of cyanobacteria versus latitude traveling from southern to northern areas. Values collected and analyzed from water samples. Representative of smallest phytoplankton size found on 0.8 µm filter.

There was not a clear trend in the cyanobacteria concentrations along the cruise track (Fig. 7). There was variation in whether or not the surface or mid-depth latitudes contained higher concentrations. There is not a clear distinction as to which depth had the greatest impact on total cyanobacteria concentrations. These values were found from the slides that were made from water samples and the counts represent the smallest size of phytoplankton species found on the 0.8µm filter. The lack of trend shows that cyanobacteria were a contributor all along the cruise track and define the reasoning for the high levels of 0.8µm filtered phytoplankton.

There was an increase in nutrient concentrations from 30°N to 40.9°N (Fig. 8). The total concentrations were below 5µmole/L in the stations south of 36°N. The nutrient concentrations increased continually in the stations north of 36°N. The highest concentrations of nutrients were found at 40.9°N which was the northernmost station. The surface nutrients showed these increasing trends (Fig. 8).

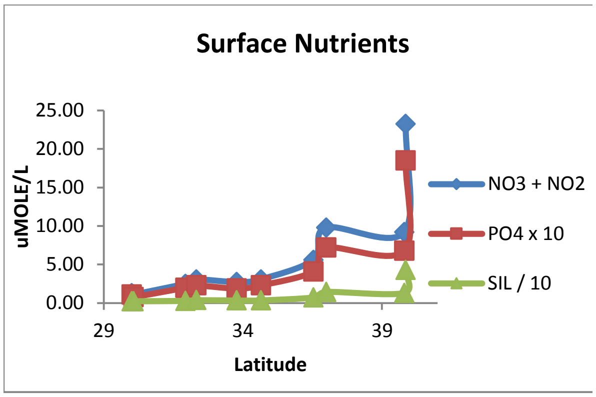

Figure 8: Surface nutrients found along the cruse track. Three different nutrients were evaluated: NO3 + NO2 (diamonds), PO4 x 10 (squares) and SIL /10 (triangles). Nutrient values increase from the southern stations at the lower latitudes to the northern stations at higher latitudes.

DISCUSSION

The main reason there was a higher abundance level of the larger phytoplankton species in the north is that there were more nutrients (Fig. 7). With more nutrients, the larger phytoplankton thrive and are more sustainable (Odate, 1994). In addition, the smaller phytoplankton species such as cyanobacteria that were seen on the smallest chlorophyll filter were most abundant in the southern, subtropics area because they thrive off of fewer nutrients (Odate, 1996). Smaller phytoplankton have a larger surface area ratio and do not need as many nutrients because of their smaller size, the ratios between that size and the amount they can take up from the nutrients. The larger phytoplankton thrive off of more nutrients because they dominate over the smaller phytoplankton species and use up the nutrients and are more competitive because they are sustained. In another study conducted in the Antarctic polar region, in nutrient depleted waters there were higher abundances of smaller phytoplankton species as well as higher larger phytoplankton species in the nutrient abundant waters (Patil et. al, 2013). This contributes to the idea that even in another water source, there are still similar results because of the constant factors that affect phytoplankton abundances.

Another source of nutrients along with mixing is decomposition of organisms throughout the water column (Jang et al., 2013). *Chaetoceros* was the main species seen in abundance along the cruise track (Fig. 6). This species is dominant when there are low nutrient concentrations (Jang et al. 2013). Although in abundance for the duration of the cruise at all of the stations, there was a higher concentration of *Chaetoceros* in the southern stations (Fig. 6).

As well as having more nutrients in the northern stations, there possibly could have been more sinking of the larger organisms that occurred (Fig. 4). This would result in the larger values of phytoplankton that were found in the net tows as well as on the 10μm filter. There were limited light levels all along the cruise track but especially in the north due to the time of the cruise being in the winter (Fig. 3). With light not being as significant of a limiting factor, the larger phytoplankton species could have been seen in the sinking (Odate, 1994). Due to their size, the larger species sink quicker in the water column (Holland, 2010). and were seen in larger amounts in the size fractionated chlorophyll at depths on the larger filter size.

There was not an obvious change in the chlorophyll concentrations along the cruise track (Fig. 2). This did not determine the phytoplankton community though. When further analyzed, there was seen a change in the size fractionated chlorophyll concentrations even though there was not a change in the total chlorophyll (Fig. 5). There was a great change in the phytoplankton abundances and contributions of different sizes and species to the total concentrations. There was a higher abundance of the larger phytoplankton species and lower abundance of cyanobacteria, the species that was seen on the smallest filter, north of 36°N contrasting to the lower abundance of large phytoplankton species and higher abundance of cyanobacteria south of 36°N (Fig. 5). These changes in phytoplankton sizes and species along the cruise track can lead to understanding the differences seen in the size fractionations of chlorophyll but can't determine the reasoning behind the static total chlorophyll concentrations.

The abundance levels of phytoplankton play an important role in understanding the productivity of an area as well as the water composition (Odate, 1996). Phytoplankton play a major role in the biological pump (Hogg et al., 2009). As they die and sink to the bottom, they take the CO_2 down into the deep waters with them. This helps with the carbon cycle and export of carbon from the atmosphere into the oceans. Seeing as how an explanation for the abundances being higher in the subarctic is from the sinking of larger phytoplankton, this is a direct correlation to the contribution of those organisms to the biological pump and taking the carbon down with them as they are sinking. In addition, the larger species sink quicker than the smaller ones due to their weight; therefore they contribute more to the biological pump.

One last hypothesis that can be made for the differences in phytoplankton sizes and abundances from the subtropics to the subarctic is grazing (Odate, 1994). There were significantly more copepods seen in the southern stations than in the northern stations. Previous studies of this area in the summertime had data that showed grazing as one of the major factors in limiting phytoplankton abundances (Odate, 1994). Copepods graze on phytoplankton and contribute to the lower abundance levels in the south. Copepods also graze more so on the larger phytoplankton species which shows in the differences of the size fractionations from the south to the north (Jang et al., 2013). Copepod abundances were not calculated or analyzed, but they were seen when doing phytoplankton counts and were easily seen in the samples with the naked eye. Grazing had an equal effect on large and small sized phytoplankton species because there wasn’t a change in the chlorophyll concentrations (Patil et al., 2013). Grazing was the top-down control that limited the phytoplankton whereas nutrients and partial light levels were the bottom-up controls (Odate, 1996). Larger zooplankton such as copepods graze on phytoplankton whereas the smaller grazers have less of an effect on the top-down controls in the phytoplankton community (Lacerot et al., 2013).

CONCLUSIONS

There is an increase in phytoplankton to the north along the current as well as an increase in size fractionated chlorophyll concentrations. The phytoplankton increases are a result of the increased nutrients towards the subarctic in the winter because there is more mixing and upwelling that brings the nutrients to the surface. The lack of sunlight in the winter has an effect on the abundance levels compared to the summer, but does not account for the abundance level differences from the southern subtropics to the northern subarctic. There is less abundance in the subtropics because there is less mixing that occurs and therefore fewer nutrients. The sunlight is not a mitigating factor in the winter because it is lacking all along the Kuroshio. The smaller phytoplankton species thrive more on less nutrients due to their surface area ratio and therefore are more abundant in the south as opposed to the larger species higher abundances in the north resulting from higher nutrient levels. Finally, grazing played a role in the abundance levels but the impact from grazing was not quantitatively accounted for.

ACKNOWLEDGEMENTS

I would like to thank Kathy Newell for allowing me to use her lab and supplies. I would also like to thank her for the extensive assistance she gave me on my project while at sea and back at the University of Washington doing analysis. I would like to thank Hilary Palevsky for her assistance, guidance and help to make me into a better writer and analyst. Thank you to the crew of R/V *Melville* for their time and hard work on the cruise as well as Steve Emerson and Steve Reiser for funding the trip with their grant money. Finally, I would like to thank all who assisted me in taking my net tows and collecting water samples for chlorophyll data.

REFERENCE LIST

Caruso, M., Beardsley, R., Gawarkiewicz, G., 2004. Interannual variability of the Kuroshio Current intrusion in the South China Sea. Phys. Res. Lett. 68, 91-95, 2004 ISSN 0717-652X.

Chu, P., Kuo, Y., 2009. Biophysical variability in the Kuroshio extension from altimeter and SeaWiFS. IEE/MTS oceans 09. 1001-1008.

Holland, D. Sinking rates of phytoplankton filaments orientated at different angles: theory and physical model. 2010. Journal of Plankton Research. 32:9, 1327-1336.

Imawaki, S., Uchida, H., Ichikawa, H., Fukasawa, M., Umatani S., ASUKA group, 2001. Satellite altimeter monitoring the Kuroshio transport south of Japan. Geophys. Res. Lett. 28, 17-20.

Jang, P-G., Shin, HH., Baek, SH., Jang, MC., Lee, TS., Shin, K. 2013. Nutrient distribution and effects on phytoplankton assemblages in the western Korea/Tsushima Strait. New Zealand Journal of Marine and Freshwater Research. 47, 21-36.

Jayne, S., Hogg, N., Waterman, S., Rainville, L., Donhue, K., Watts, D., Tracey, K., McClean, J., Maltrud, M., Q, B., Chen, S., Hacker, P., 2009. The Kuroshio extension and its recirculation gyres. Deep-sea. Res. 56. 2088-2099.

Lacerot, G., Krik, C., Lurling, M., Scheffer, M. 2013. The role of subtropical zooplankton as grazers of phytoplankton under different predation levels. Freshwater Bio. 58, 494-503.

Odate, T, 1996. Abundance size composition of the summer phytoplankton communities in the western North Pacific Ocean, the Bearing Sea, and the Gulf of Alaska. Oceanogr., 335-351.

Odate, T, 1994. Plankton abundance and size structure in the northern North Pacific Ocean in early summer. Fish. Oceanogr, 3:4, 267-278.

Patil, S., Mohan, R., Shetye, S., Gazi, S. 2013. Phytoplankton abundance and community structure in the Antarctic polar frontal region during austral summer of 2009. Chinese hournal of Oceanology and Limnology. 31, 21-30.