Climate Change Threatens Marine Ecosystems—
The Impact of Rising Sea Surface Temperature and Altered Nutrient Availability on the Abundance and Growth Behavior of the Phytoplankton Thalassiosira

i. Personal Statement

I have always enjoyed math and science, getting an early start by attending Invention Camp every summer during elementary school. However, my interest in environmental science came about when I was in 7th grade. I competed at our state science fair, AzSEF, with a project on the effects of acid rain and fertilizer run-off on *Spirogyra* algae. That was the first time I investigated problems relating to the environment, and I was eager to learn more. From that point on, I focused my scientific inquiries on issues impacting the environment: including, the study of water quality and contaminant removal using agricultural materials as alternative adsorption media; and the factors contributing to bleaching in coral reef ecosystems. I continued my interest in math and science, and will major in environmental science when I start college in the fall.

My 7th-grade science fair project did more than just spark my interest in environmental topics. At the AzSEF state fair, I won 1st place in the Environmental Science category and several special awards, including one from the Arizona Association for Women in Science. Part of that award included spending a day at Arizona State University where students listened to speakers, toured labs, and did hands-on science activities. I toured the Neuer lab where PhDs led a talk on microscopy, and allowed students to view phytoplankton. I told them all about my work with algae, and I think they were impressed by my enthusiasm for research because they gave me their business card. They mentioned that it may be possible for older students to do research in their lab, and I never forgot that. I held onto that card, and contacted Dr. Susanne Neuer at Arizona State University in my freshman year to introduce myself, and to ask about conducting a

research project in her lab. We arranged a meeting, and although she had not worked with high school students before, Dr. Neuer agreed to serve as my mentor and allow me to conduct independent research in her lab. I submitted a research proposal that she approved, and the project I submitted to Intel STS was born.

In doing this research project, I was exposed to advanced topics in oceanography, learned to apply the scientific method, and gained skills working hands-on in a lab. I got to do real science! I was rewarded with meaningful results, challenged when things seemed out of grasp, and motivated by discussing my work with experts in the field. My interests stemmed from a strong sense of wonder and depth of inquiry, but beyond scientific curiosity, I learned the necessary skills to design a successful experiment. Throughout my project, I used mathematics as a means to understand and enhance the science I was doing in the lab, and also to evaluate and present my results in a meaningful way to communicate science with others. As I was only a freshman when I started this project, my mathematics background was limited to algebra and geometry; but there was more math required for my project that I had not yet learned. I sought extra help from my geometry teacher to learn about logarithms and exponential functions, which was necessary to model the growth rate of my phytoplankton samples. Statistics is not offered at my school, but I wanted to better evaluate my data to demonstrate it was significant. So I taught myself how to do a Student's T-Test, even creating a program for it on my graphing calculator. I have always enjoyed mathematics, but being able to apply it to science was twice as rewarding.

Overall, this project has been an amazing experience for me, and I hope that by sharing my story it will encourage others to give it a try. It is always that first step that is most difficult—finding an idea or question that intrigues you. Read, investigate, and do not be afraid to try new things. When I began my project, I quickly realized that I did not have enough math experience

to fully understand the topics but I did not let that stand in my way. My advice is to get out there and try it! Put your passions about a topic into action through science and math.

ii. Abstract

Over the past fifty years, land temperatures have increased at a decadal rate almost twice that compared to the past 100 years. Warming Earth's atmosphere creates a rise in ocean heat content, and alters wind patterns and storm systems that impact surface layer mixing and ocean stratification, affecting nutrient availability. Changes in ocean temperatures and nutrient conditions are expected to impact many organisms including phytoplankton, the ocean's major producer. To evaluate how climate change threatens marine ecosystems, this project studied the impact of rising sea surface temperature and altered nutrient availability on the phytoplankton *Thalassiosira.* Cultures were grown under conditions of normal IMR saltwater media at ambient temperature 25ºC (control), elevated temperature 35ºC, and IMR with both elevated and depleted nitrate concentration (64%). Replicate samples were collected over the lifecycle (14 days) for multiple trials. Epifluorescence microscopy was used to count cells, *in vivo* fluorometry to quantify chlorophyll *a* production, and a Multisizer to measure cell size. Data analysis included peak magnitude, growth rate, peak bloom, fluorescence, and cell size. Results demonstrated significant reductions in magnitude for both nutrient groups (elevated reduced by 52%-depleted reduced 35%), while elevated temperature groups increased 164%; all experimental groups experienced a shortened lifecycle. Cell size was not significantly impacted. Understanding environmental influences on phytoplankton is important because disrupting their production severely impacts the ocean's food web causing loss of biodiversity, decreased human food source with economic consequences, and a reduction in phytoplankton's role in removing carbon from the Earth's atmosphere—further exacerbating climate change.

iii. Research Report

INTRODUCTION

Satellite observations and shipboard measurements document a significant downward trend in phytoplankton biomass noting, "… the average global phytoplankton concentration in the upper ocean currently declines by about 1% per year. Since 1950 alone, algal biomass decreased by around 40%, probably in response to ocean warming—and the decline has gathered pace in recent years [1]." Considering the important role of phytoplankton in the ocean's food web, and also its ability to process atmospheric CO_2, the greater concern is how harming phytoplankton communities may impact humans and the Earth overall.

"Temperatures a few degrees warmer might not sound like much, but even a 3°C (5.4°F) temperature rise will make the earth its warmest in 3 million years… [2]." Over the past 50 years, land temperatures have increased at a decadal rate almost twice that compared to the past 100 years [3]. These trends are also observed as a rise in ocean heat content. The Intergovernmental Panel on Climate Change (IPCC) predicts this pattern will continue and estimates an increase of ~6°C in sea surface temperature by the end of this century [3]. Rising sea surface temperatures may directly affect phytoplankton because their primary role is to perform photosynthesis and "… metabolic reactions proceed faster at higher temperatures… the rule of thumb is most reactions occur twice as fast with a 10˚C rise in temperature [2]." Mesocosm studies confirm that temperature and light impact phytoplankton response [4, 5, 6, 7].

Climate change also alters wind patterns and storm systems. These then affect ocean forces such as stratification and ventilation, with resultant consequences on nutrient availability. Warmer surface water temperature in the winter decreases the amount of overturn, an important process that provides the nutrients phytoplankton need for photosynthesis. When increased

frequency and intensity of storms create more mixing in the water column, phytoplankton lose access to sunlight, thereby affecting their growth and abundance. Changes in wind patterns, especially the trade winds, decrease the amount of upwelling, a necessary process to bring nutrients from the deep ocean up to the surface making them accessible to phytoplankton [2, 8, 9]. These changes disrupt the normal patterns of ventilation (when water is transferred from the surface-mixed layer to the interior ocean), and create greater ocean stratification, as well as cause a shift in the amount of time it takes for nutrient cycling to be completed [10, 11, 12]. These cumulative impacts on ocean forces could lead to zones of both elevated and depleted nutrient conditions; as confirmed by researchers [11, 13] who predict that nitrate levels will be affected at both ends of the range up to ~64% by the year 2100 due to changes in transit patterns.

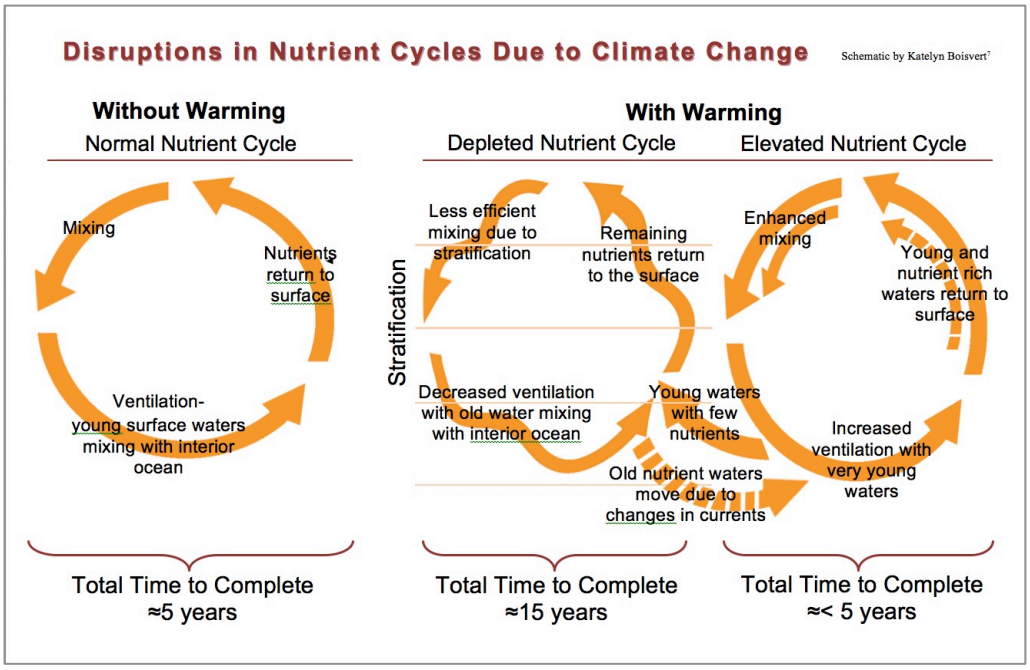

FIGURE 1. *Disruptions in Ocean Nutrient Cycles due to Climate Change.*
Diagram by Katelyn Boisvert from source information [2, 10, 11, 13, 14].

Others [12, 14] agree after examining changes in deep ocean currents resulting from global warming, finding that the age of water (referring to how mixed the water is and thus how many

nutrients are supplied to the surface) can be affected in two different ways: in some regions ocean age will increase due to stratification slowing the process of ventilation, resulting in fewer nutrients cycling to the surface and a longer time for the process to be completed in turn leading to depleted conditions; while in other areas, ocean age will decrease as a result of more efficient mixing allowing improved ventilation, thus refreshing surface nutrient supply more often and leading to elevated conditions. Figure 1 summarizes these impacts due to climate change.

Life in the Photic Zone

The surface layer of the ocean (~the first 100-200m/330-660ft) mixed by wind, waves and currents contains the photic zone, which is where all organisms that participate in photosynthesis live as it provides access to natural sunlight [2]. In this zone live mostly planktonic organisms, meaning that they do not swim but instead drift in the water carried by currents. Because phytoplankton do not have a means of mobility so cannot migrate, and are not able to regulate their own temperature, they are vulnerable to environmental influences being unable to adapt to changing water temperatures, currents, wind/storm patterns, and nutrient levels [16]. Phytoplankton are autotrophs and are the most important producers in marine ecosystems performing ~95% of the photosynthesis in oceans. Phytoplankton need CO_2, water, and sunlight to perform photosynthesis; but they also depend on nutrients especially nitrate, phosphate, silica, and iron [2].

There are many types of phytoplankton; one of the most common and well-studied is diatoms. They are found in temperate as well as polar waters, and live both near the coast and in the open ocean. Diatoms are unicellular, with a cell wall made mostly of silica having two halves fit together into a flat rounded shape, and chloroplasts located around the sides [2, 17]. Diatoms are good phytoplankton to study because they are sensitive to changes in their habitat but still

have good tolerance, so "… diatoms are used extensively in environmental assessment and monitoring [18]." Digital images from this project are in Results, and show the anatomy of the diatom *Thalassiosira* which is the phytoplankton studied here. All plankton go through the same phases of growth in their life cycle when a new culture is inoculated (Figure 2).

The first phase, the lag phase, is when cells slowly begin to grow. After multiplying for a few days, the growth rate increases very quickly during the exponential phase. Most growth occurs during this phase, reaching a maximum on the peak bloom day. The cells are then fairly constant in a stationary phase. After that is the die-off phase [19].

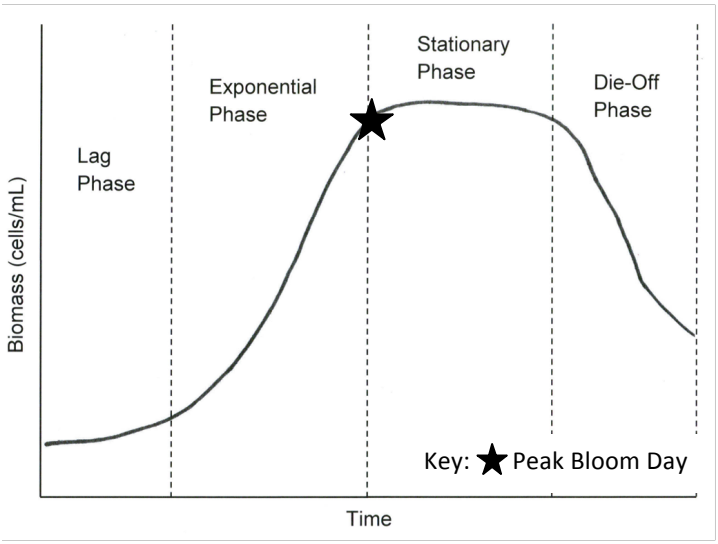

FIGURE 2. *Life cycle phases of phytoplankton growth*. Diagram by Katelyn Boisvert from source information [2, 15].

The growth and life cycle patterns of phytoplankton are important to understand because as the primary producers in marine ecosystems, the success of that entire food web depends on them; nd considering phytoplankton produce half of the world's oxygen and process CO_2 from our atmosphere, the Earth and all its inhabitants rely on their contribution. Studying environmental effects on phytoplankton helps us to understand how they will respond to changes in our world. The question this project investigates is, "Do the climate-driven issues of elevated sea surface temperature and altered nutrient availability affect the abundance and growth behavior of the marine phytoplankton *Thalassiosira*?" The hypotheses state: for Phase I, that exposure of *Thalassiosira* to increased temperature will affect its abundance and growth behavior, demonstrated by changes in growth rate, peak bloom, peak magnitude, and cell size;

and for Phase II, that exposure of *Thalassiosira* to both elevated and depleted nitrate nutrient levels will affect its abundance and growth behavior, demonstrated by changes in growth rate, peak magnitude, fluorescence, and cell size.

RESULTS

Qualitative evaluation by digital imaging of cells using the epifluorescence microscope was conducted to confirm that healthy, viable cultures were produced with the expected shape and size of cells and organelles, as well as adequate abundance to allow for experimentation. Slides were prepared from stock cultures of *Thalassiosira,* and epifluorescence microscopy was performed using an immersion lens with oil at 100X magnification. Figure 3 shows examples.

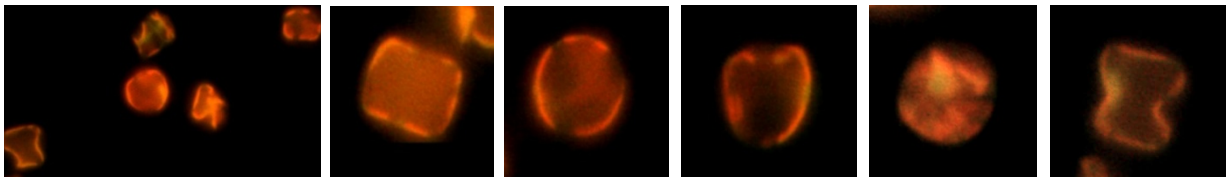

FIGURE 3. *Thalassiosira views and cell structures at 100X under epifluorescence microscope.* Left to right: cells in field; girdle view (side belt); valve view (top) showing cell wall; chloroplasts around outer edge of cell; nucleus at center of cell; dividing cell. Digital photos by Katelyn Boisvert

Phase I- Temperature Study: Abundance

Cultures of *Thalassiosira* were studied under conditions of elevated temperature (35˚C), selected based on the worse-case-scenario prediction for rise in sea surface temperature from the literature review; a control at ambient temperature (25˚C) was a comparative. Sampling was done at Day_0 to establish the starting values for initial cultures; and on Day_4, Day_7, Day_9, Day_{11}, and Day_{14} to evaluate the abundance and growth behavior of the phytoplankton. Data for the cell counts measured by epifluorecence microscopy was used to calculate the abundance of phytoplankton which is described as concentration (cells/ml). Figure 4 is a graph showing this data as peak magnitude, which describes the maximum change in abundance from Day_0 to the day of peak bloom. This graph represents the averaged data from multiple trials to summarize

growth of cultures for each testing condition. Results demonstrated 164% increase in abundance under the condition of elevated temperature as compared to the control, with results showing good reliability between the replicates. A Two-Tailed Student T-test was used to analyse data, and a statistically significant difference was shown between the control and elevated temperature group ($p=2.16X10^{-5}$) which was well below the set alpha of 0.01 demonstrating that abundance of *Thalassiosira* varies significantly with the temperature of the culturing environment.

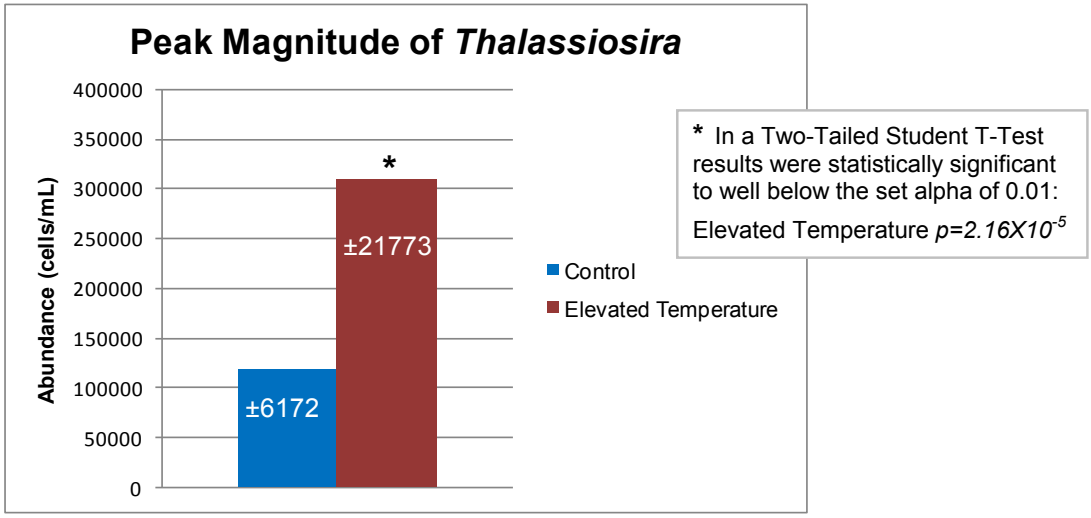

FIGURE 4. *Peak magnitude of Thalassiosira at elevated temperature (averaged trial data).*

Growth Behavior

Patterns of growth for *Thalassiosira* were also studied to understand the impact of temperature on the life cycle of the organism. Figure 5 describes cell abundance over the 14-day growing period to visually show life cycle phases. From the graph you can see that growth patterns for both testing conditions display the expected behavior of lag phase, exponential phase, stationary phase, and die-off (refer to Figure 2).

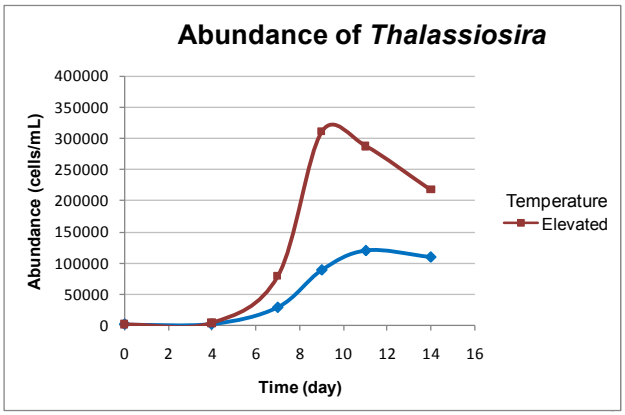

FIGURE 5. *Abundance of Thalassiosira at elevated temperature over lifecycle (averaged trial data).*

The growth rate describes the change in abundance during the phytoplankton's growth period (lag and exponential phases), and is calculated using the equation[15]:

$$K^1 = Ln(N_2/N_1)/(t_2-t_1)$$

where N=abundance (cells/ml) at two corresponding times t_1 and t_2 ; while t_1=Day_0 and t_2=peak day of bloom [Day_{11} for Control, Day_9 for experimental group]. Table 1 shows that growth rate accelerated 40% compared to the control. Results for overall growth rate show good reliability between the replicates; and a statistically significant difference was shown between the control and the elevated temperature group ($p=4.69X10^{-6}$) which was below the set alpha of 0.01, demonstrating that the growth rate of *Thalassiosira* varies significantly with the temperature of the culturing environment. Figure 6 presents this data as growth between sampling days to evaluate the peak day of bloom and compare patterns of growth between the testing conditions. This graph shows a faster growth rate for the elevated temperature group, at a consistently higher amount than the control during the entire growth phase Days 0-9. Maximum growth was reached earlier for cultures at elevated temperature, making the peak bloom time two days earlier (Day_9 versus Day_{11} for the control). The elevated temperature group displayed a very short stationary phase, and die-off began earlier and at a faster rate with a slightly shorter life cycle overall.

Table 1. *Overall growth rate of Thalassiosira (K^1) (Phase I)*

	K^1
Control	0.60 ±0.02
Elevated Temperature *	0.84 ±0.02

* In a Two-Tailed Student T-Test results were statistically significant to well below the set alpha of 0.01: Elevated Temperature $p=4.69X10^{-6}$

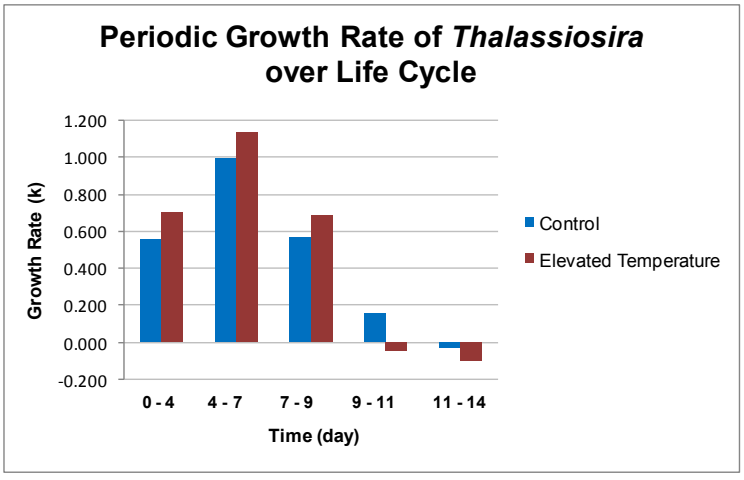

FIGURE 6. *Periodic growth rate of Thalassiosira at elevated temperature over the life cycle (representing averaged trial data).*

Data is presented for cell size of *Thalassiosira* (Figure 7) at initial culture on Day_0 and as a measure of average cell size over the life cycle. Data is represented as the percentage of cells that are <10µm and >10µm as viewed and sorted using the epifluorescence microscope. Results show that elevated temperature did affect cell size producing a higher percentage of smaller cells (<10µm), which represented a 5% increase as compared to the control group.

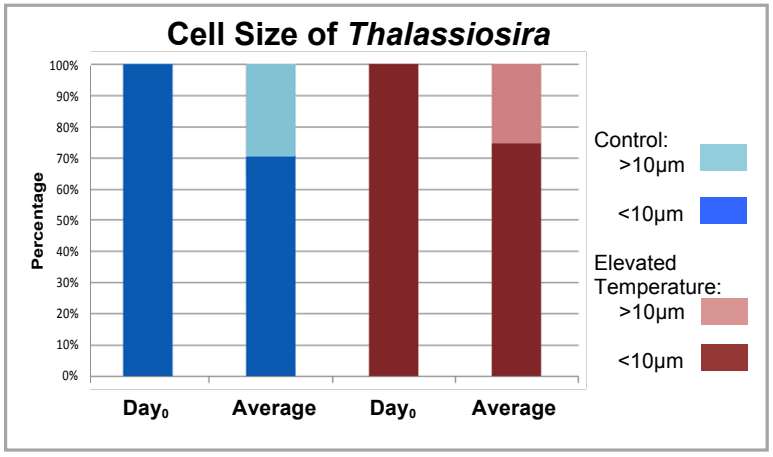

FIGURE 7. *Cell size of Thalassiosira at elevated temperature (representing initial culture and averaged over life cycle).*

Phase II- Nutrient Study: **Abundance**

Cultures of *Thalassiosira* were studied under conditions of altered nutrients at levels of 64% elevated nitrates and 64% depleted nitrates as compared to standard nutrient levels found in the IMR saltwater medium typically used for culture growth. These levels were selected based on the literature review, and a control of standard IMR was a comparative. Sampling was done at Day_0 and on subsequent days as previous. Cell counts were measured using a hemocytometer counting chamber under light microscopy; and this data was used to calculate the abundance of *Thalassiosira* described as concentration (cells/ml). Figure 8 displays peak magnitude describing maximum change in abundance from Day_0 to peak bloom (Day_9). This graph representing averaged trial data shows the highest abundance for the control and decreased abundance for

both altered nutrient conditions (elevated nutrients reduced 35% and depleted nutrients reduced 52%). Results for peak magnitude showed good reliability between the replicates; and a statistically significant difference was shown between the control and both the elevated nutrients group ($p=1.69X10^{-7}$) and depleted nutrients group ($p=1.33X10^{-8}$), which was well below the set alpha of 0.01 demonstrating that abundance of *Thalassiosira* varies significantly with the nutrient condition of the culturing environment.

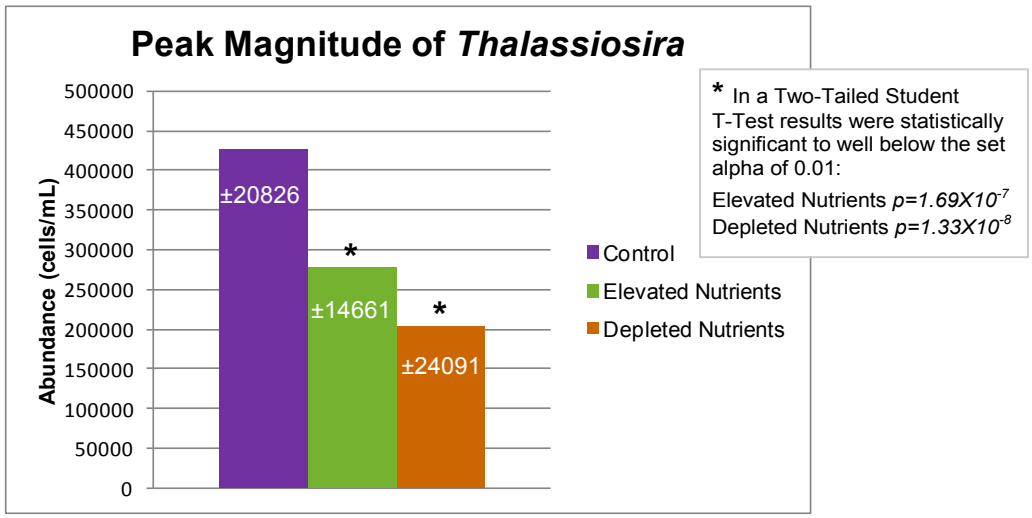

FIGURE 8. *Peak magnitude of Thalassiosira under altered nutrient conditions (averaged trial data).*

Figure 9 represents the averaged data for fluorescence of *Thalassiosira*. This graph describes chlorophyll *a* production over the 14-day life cycle, which correlates directly with the amount of phytoplankton present [20]. This measure is a supporting documentation of abundance, and reflects the amount of photosynthetic activity by the cells. The depleted nutrient group demonstrated the greatest loss of photosynthetic activity.

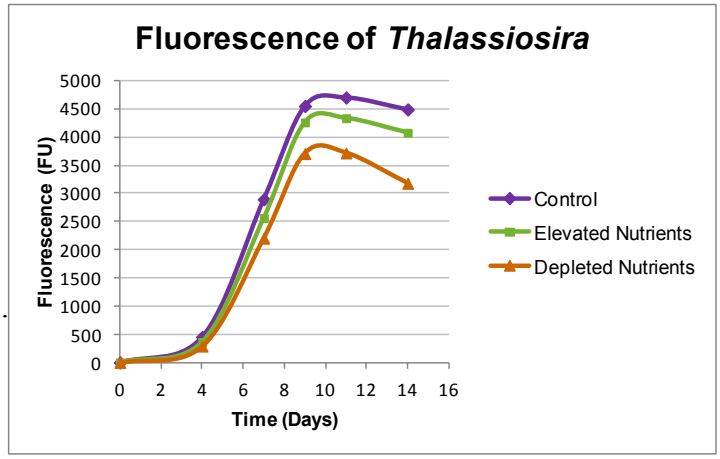

FIGURE 9. *Fluorescence of Thalassiosira under altered nutrient conditions (representing averaged trial data).*

Growth Behavior

Patterns of growth for *Thalassiosira* were studied to understand the impact of altered nutrients on its life cycle. Figure 10 describes cell abundance over the 14-day period. From the graph you can see that the growth pattern for all three testing conditions displays the expected behavior of lag phase, exponential phase, stationary phase, and die-off as in Figure 1. Growth during the exponential phase showed a steady increase for all testing conditions.

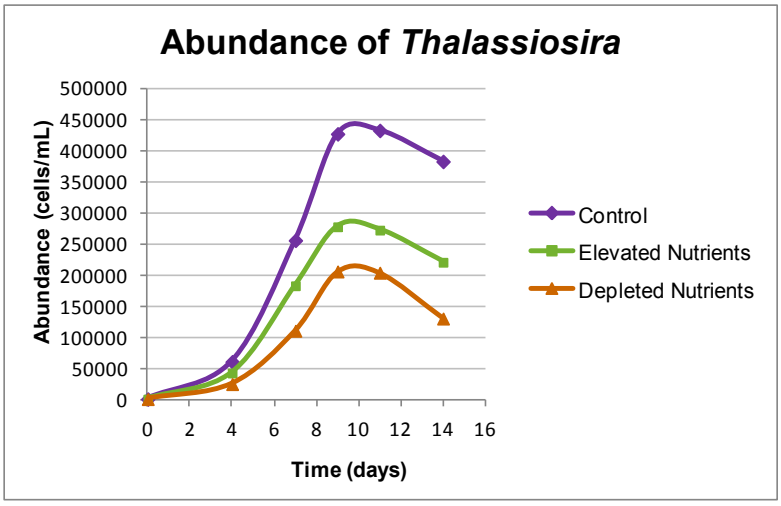

FIGURE 10. *Abundance of Thalassiosira under altered nutrient conditions over the life cycle (averaged trial data).*

The growth rate describing the changein abundance during the phytoplankton's lag and exponential phases was again calculated using the equation:

$$K^1 = \mathrm{Ln}(N_2/N_1)/(t_2-t_1)$$

Peak day of bloom (t_2) is Day_9 in this experiment. Table 2 shows that growth rate is reduced compared to the control, with the elevated nutrients group reduced 7% and the depleted nutrients group by 12%. Results for overall growth rate show good reliability between the replicates; and a statistically significant difference was shown between the control and both the elevated nutrients group ($p=0.007$) and the depleted nutrients group ($p=0.0002$) which was below the set alpha of 0.01 demonstrating that the growth rate of *Thalassiosira* varies significantly with the nutrient

condition of the culturing environment. Figure 11 presents this data as a periodic look at *Thalassiosira* growth patterns during its life cycle. This graph shows a faster growth rate for the control Days 0-4, but even rate between the three groups during Days 4-7. The depleted nutrients group shows a delayed growth response with higher rates for Days 4-7 and 7-9; and also died off faster than the other groups Days 11-14. The peak bloom day was calculated as Day_9 from abundance data; but periodic growth rate suggests that peak bloom may be half a day earlier for the elevated nutrient group, and half a day later for the depleted group.

Table 2. *Overall growth rate of Thalassiosira (K^1) (Phase II)*

	K^1
Control	0.68 ±0.03
Elevated Nutrients *	0.63 ±0.02
Depleted Nutrients *	0.60 ±0.02

* In a Two-Tailed Student T-Test results were statistically significant to well below the set alpha of 0.01:

Elevated Nutrients *p=0.007*
Depleted Nutrients *p=0.0002*

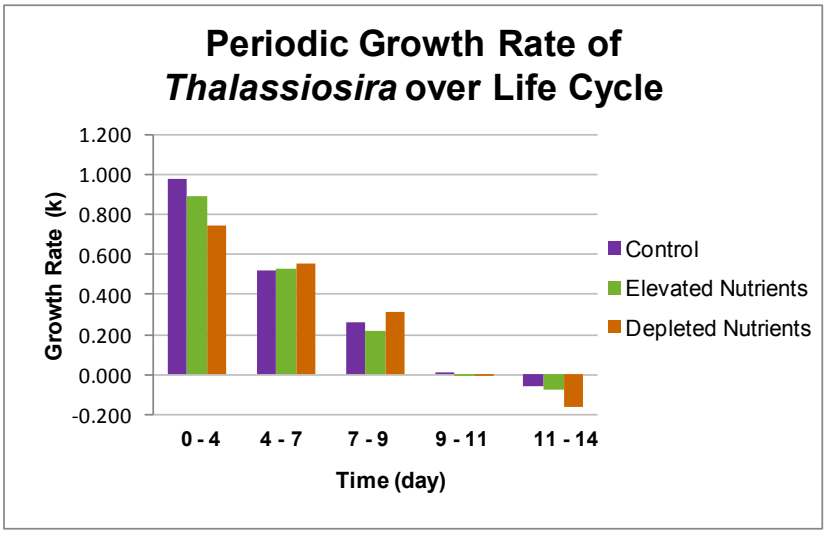

FIGURE 11. *Periodic growth rate of Thalassiosira under altered nutrient conditions over the life cycle (averaged trial data).*

Figure 12 describes the distribution of cell size from the Multisizer data. The range (6.961µm to 10.47µm) was selected based on known *Thalassiosira* size; the same range was used for all samples. Table 3 displays the mean cell size with standard deviations for averaged trial data. Results show that samples are similar in size, with elevated nutrient samples having slightly larger cells (increased by 0.9%), and depleted samples having slightly smaller cells (0.6%). The mean cell size showed variability between the replicates; results were not statistically significant between the nutrient-altered conditions.

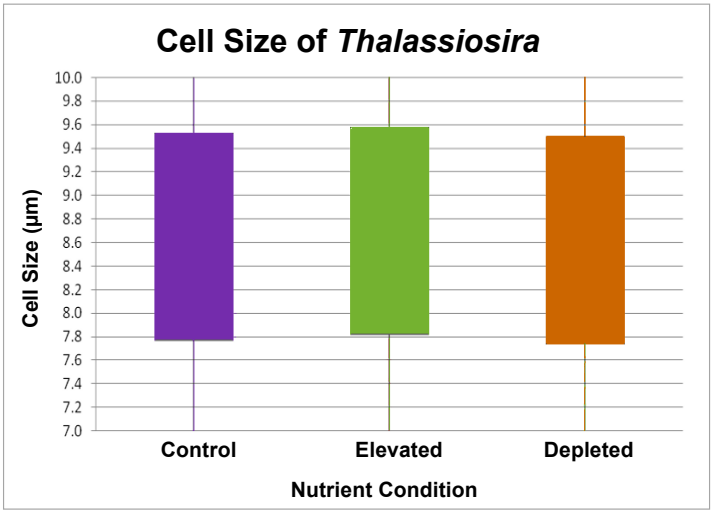

FIGURE 12. *Distribution of Thalassiosira cell size under altered nutrient conditions (representing averaged trial data).*

Table 3. *Mean cell size (µm) of Thalassiosira (averaged trial data)*

	Mean
Control	8.61 ±0.09
Elevated ^ Nutrients	8.69 ±0.22
Depleted ^ Nutrients	8.56 ±0.10

^ In a Two-Tailed Student T-Test results were not statistically significant with an alpha level of 0.01:

Elevated Nutrients *p=0.45*
Depleted Nutrients *p=0.35*

DISCUSSION

The spring bloom of phytoplankton, triggered by increased light and nutrients and lasting until the end of summer, provides the food source for zooplankton who are their direct consumers [2]. This food source is essential for zooplankton to properly reproduce; and that goes all the way up the food chain. Therefore, the timing and abundance of the spring bloom is very important. Metabolic processes occur more quickly in higher temperatures, and with the expected rise in sea surface temperatures, reaction times for photosynthesis will be faster. The growth rate of phytoplankton will increase and abundance will be higher, as demonstrated by elevated temperature conditions in this project. The faster rate caused the peak bloom time to occur earlier in the life cycle (Day_9 versus Day_{11}), which would mean an earlier spring bloom for a phytoplankton community. In this scenario, nutrients are used up quickly and the phytoplankton soon reach their carrying capacity. Being unable to maintain that accelerated growth, they die-off faster demonstrating a shorter life cycle as observed in the data. In this

project, because only one life cycle was studied, elevated temperature stimulated faster growth and greater abundance; but with additional generations of phytoplankton and the cumulative effect of a shorter life cycle, I expect abundance would reduce overall.

If climate-driven changes in available nutrients are considered, there are additional impacts on phytoplankton. Conditions of both elevated and depleted nitrates, the most limiting nutrient for growth, resulted in significantly reduced abundance. At first it may be expected that abundance of *Thalassiosira* under elevated nutrient conditions would be greater than the control, as in eutrophication and cases of problematic algal blooms. However, the observed abundance of elevated nutrient samples was lower than the control. Eutrophication is usually seen along coastline areas caused by nitrogen-based fertilizer runoff which is enhanced additionally with phosphates and iron both of which stimulate phytoplankton growth. Because the fertilizer runoff is "charged" it causes the wild increase in growth associated with algal blooms. This project investigates fluxes in nitrate concentration from environmentally-influenced changes in ocean systems (ex. upwelling and overturn), and considers how increased ocean stratification is affecting nutrient levels. These effects will vary regionally based on climate and ocean factors.

Nutrient availability has a definite impact on phytoplankton abundance, and also significantly affects the rate at which they grow. Overall growth rate was significantly different between experimental groups caused by changes in nitrate concentration. Nutrient availability can stress the cells, and growth can be slowed when cells are under stress caused by changes in their typical environment[23]. Whether due to an elevated or depleted supply of nutrients, phytoplankton will conserve resources when under this stressed condition; consequently, cell growth rate is slower than average, and the ability to achieve maximum abundanceis reduced because the carrying capacity of the phytoplankton is diminished.

The cell size of *Thalassiosira* was only slightly influenced by temperature and nutrient conditions, and differences were not significant. Diatoms display a natural reduction in size during asexual cell division when they split their two valves apart to produce daughter cells [16]. The slight differences observed may have been due to how silica was utilized by the phytoplankton, as that is an essential nutrient to build its cell wall. The cell size of the depleted nutrients group was slightly smaller than the control, maybe because silica could not be well utilized without sufficient nitrates available. As higher temperatures increased growth rate, more cell divisions would occur which explains the higher percentage of smaller cells observed for elevated temperature samples. Although results did not support significant change in cell size, over many generations a more substantial reduction in cell size may occur or smaller-sized diatom species may be favored over others; as noted by other researchers [6, 7].

When climate-driven issues of elevated sea surface temperature and altered nutrient availability are considered together in a real-world case rather than individual laboratory experiments, threats to phytoplankton sustainability are intensified as disruptions occur to both abundance and growth behavior. Based on this research, the collective impact on phytoplankton due to the environmental conditions of rising sea surface temperature and altered nutrient availability are a loss of abundance, reduced growth rate, earlier peak bloom with a shortened lifecycle, and a possible reduction in cell size which further reduces biomass.

Relevance

Phytoplankton are the primary producers forming the base of the entire marine food web. Because they do not have any means of mobility and are unable to regulate their own temperature, they are not able to adapt well to rising sea temperatures, nor can they migrate to areas of best temperature or nutrient conditions. Research by Doney [8] and many others report

that if climate change patterns continue, primary productivity will be affected to the point that it will disrupt the "… geographical boundaries that separate specific marine ecosystems (the ocean equivalents of forests, grasslands, and so on)" with resultant effects on all marine species. If phytoplankton abundance and growth are harmed, the major food source of the ocean would be reduced and this would decrease the biodiversity of all organisms above them in the food chain, including marine mammals and sea birds. Consequently, decreased fish production would limit a food source for humans, and create economic difficulty as well.

Carbon dioxide (CO_2) from the atmosphere is taken into the ocean as part of the global carbon cycle. In photosynthesis, primary producers like phytoplankton convert CO_2 into organic matter used as building blocks for consumers. "These microorganisms use light, carbon dioxide, and nutrients to grow. Although phytoplankton are small, they flourish in every ocean, consuming about half of the carbon dioxide emitted into the atmosphere… But warming oceans may significantly limit their growth and diversity, with far-reaching implications for the global carbon cycle [26]." Maintaining abundance and diversity of phytoplankton helps to maintain balance in the carbon cycle. Reductions in phytoplankton may stress a system already burdened by increasing atmospheric carbon levels. Without the benefit of a large phytoplankton community, the condition of our atmosphere may significantly worsen [14, 24, 25].

The observations stressed in this research support the importance of studying abundance and growth behavior of phytoplankton because they serve not only a valuable role in marine ecosystems, but on Earth as a whole, including having an impact on human life.

CONCLUSIONS

1. *Thalassiosira* growth demonstrates expected life cycle stages during a 14-day culture period.
2. Altered environmental conditions affect the abundance and growth behavior of *Thalassiosira:*

such that, both elevated and depleted nutrient availability significantly reduce peak magnitude and growth rate; while elevated temperature creates a significant surge in peak magnitude and growth rate.

3. Peak bloom time occurs earlier when *Thalassiosira* is exposed to conditions of elevated temperature, while nutrient availability does not stimulate a significant advance in bloom time.
4. *Thalassiosira* demonstrates a shorter life cycle due to the altered environmental conditions of elevated temperature and depleted nutrient availability.
5. Cell size of *Thalassiosira* is minimally affected by elevated temperature and altered nutrient conditions.

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