FACTORS AFFECTING PHYTOPLANKTON POPULATIONS AND POSSIBLE SOLUTIONS TOWARDS PRESERVING THEM

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1 Abstract

Phytoplanktons are microscopic, photosynthetic algae that form the base of the marine food web. In this investigation, trends that reflected the phytoplankton populations were observed, along with the environmental factors affecting them. Recent experiments performed in oceanographic laboratories using small algal samples have shown that phytoplanktons have a relatively higher growth rate under warmer temperatures; however, with increasing global temperatures, there has been a worldwide decline in phytoplankton populations in the oceans (*see Figure 1*). With the help of this investigation, it was found that the increasing sea surface temperatures (SSTs) are a possible reason for the population decline. Water temperature is a key factor affecting phytoplankton bloom dynamics in waters, which in turn has the ability to change the entire food web and ecosystem services. Rapidly increasing surface temperatures deems ineffective in acting as the optimum living conditions for phytoplanktons, since the nutrients required by the phytoplanktons in order to thrive usually sink to the bottom of the ocean, thus depriving them of their nutrition. This phenomenon is known as thermal stratification. If there are not enough phytoplanktons to convert the atmospheric CO2 into breathable O2, the already high CO2 levels will skyrocket. Being a significant greenhouse gas, CO2 has undeniable after effects in the atmosphere such as increased pH levels of oceans, rapidly increasing SSTs, and increased trapping of the sun's heat. In the investigation, we will suggest ways of how to replenish the ocean nutrients in order to cope up with the thermal stratification caused due to warmer SSTs.

Keywords: phytoplankton, sea surface temperatures, nutrient-enrichment, algal blooms.

2 Introduction

Ocean phytoplankton generate almost half of global primary production, making it one of the supporting pillars of marine ecosystems.

In a balanced ecosystem, they provide food for a wide range of sea creatures including whales, shrimp, snails and jellyfish. However, the most significant contribution of these phytoplanktons is carbon fixation, and they fix between 30 and 50 billion metric tons of carbon annually, which is about 40 percent of the total. While it is difficult to confidently deduce changes in either phytoplankton biomass or photosynthetic rates on decadal time scales, time-series analysis of ocean transparency data suggest long-term trends have occurred in the oceans during the 20th century.

3 Materials and Methods

A wide range of data was used for the purpose of this investigation. The primary data sets used included the HadCRUT4 (provided gridded temperature anomalies across the world as well as averages for the hemispheres and the globe) and the HadSST4 (provided monthly SST anomalies on a 5x5 grid for 1850-present). In order to analyze the effect of nutrient enrichment on the phytoplanktons, data from the experiments conducted by the American Society of Limnolgy and Oceanography was used.

4 Discussion

In *Figure 1,* trends can be seen according to which there has been a general decline in the Chlorophyll-a (Chl-a) levels in the oceans. Chl-a fluorescence is commonly used as a proxy for phytoplankton biomass, and several studies have demonstrated that Chl-a in the oceans can be estimated from satellite remote sensing reflection.

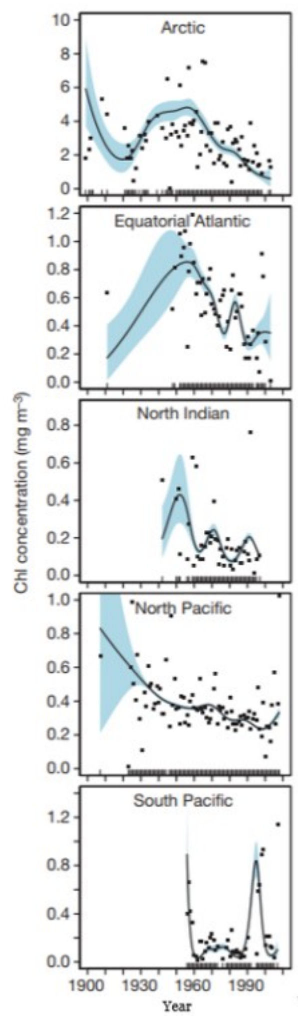

Figure 1: Chlorophyll concentrations (contained in the phytoplankton biomass) over the past years in several oceans over time

In tropical marine ecosystems, increasingly warming conditions may reduce the abundance and primary productivity of phytoplankton. This decrease results from enhanced stratification (refer to page ***), less vertical mixing and reduced nutrient supply to the euphotic zone. The tropical regions are characterized by a distinct winter phytoplankton bloom that occurs when colder atmospheric conditions contribute to significant heat loss over the region, and convective mixing (overturning) transports nutrients from deeper waters into the surface layers. These algal blooms are very important for the ecosystem, as not only do they paramount for zooplankton dynamics, but the increase population of phytoplanktons will perform carbon fixation at a higher rate, thus taking in the excess CO_2 in the atmosphere and converting it into breathable oxygen faster. In open oceans, increasing water temperature due to global warming changes the start and end timing of the blooms, and reduces their amplitude, affecting the survival and hatching time of commercially important species. Furthermore, experimental studies have shown that warmer conditions change the composition and trophic interactions of plankton communities, propagating the effects to higher trophic levels. Behrenfeld M. J. et al. describe how such fluctuations, especially in temperature, are connected to the productivity of phytoplankton in the world's oceans. Their analyses are based on nearly a decade of satellite data, and for much of the oceans they find that recent warmer surface temperatures correspond to lower oceanic biomass and productivity. Behrenfeld et al. argue that these patterns arise because climate-induced changes in ocean circulation reduce the supply of nutrients needed for photosynthesis.

4.1 Increasing SSTs Over the Past Decades

Observations of ocean temperatures have revealed that the ocean heat content has been increasing significantly over recent decades. This is something that has been predicted by climate models (and confirmed notably by Hansen et al, 2005), and has therefore been described as a 'smoking gun' for human caused greenhouse gases. In the figure below, the worldwide SST anomalies have been plotted, and it is clearly evident that there are rapid increases in the temperatures of the ocean surfaces.

The ultimate source of energy necessary to raise SSTs would be an increase in solar irradiance and excessive trapping of heat by the infamous greenhouse gases, regardless of whether the increase in solar irradiance resulted from variations in the solar cycle, or from changes in cloud cover, or from a reduction in stratospheric volcanic aerosols. Australia has told RTCC that as temperatures of oceans rise, they will become less able to absorb the carbon dioxide emitted by human activities.It is undeniable that the most significant cause for the increasing SSTs is the rapidly increasing quantities of CO_2 in the oceans.This is depicted by *Figure 3* where an increase in global temperatures can be seen with an increase in atmospheric CO_2 levels.

Currently, the oceans absorb between 35 to 40 percent of all CO2 emitted

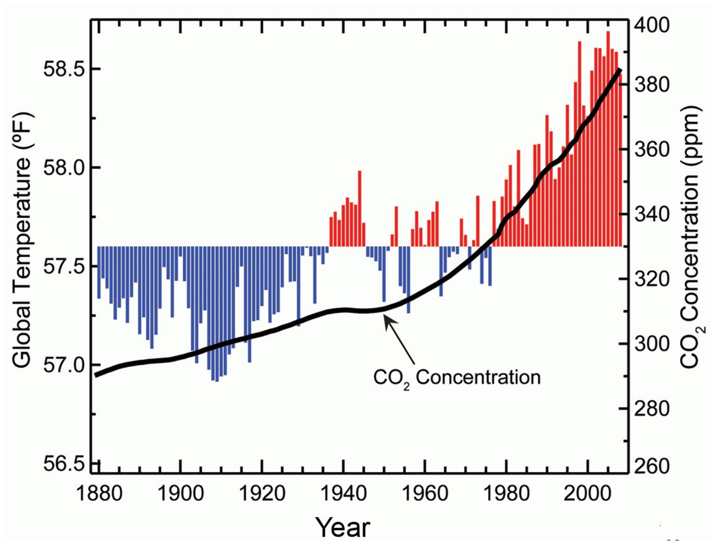

Figure 2: Relationship between global temperatures and increasing CO2 concentrations in the atmosphere. Data used: Karl, T. R., J. T. Melillo, and T. C. Peterson, 2009: Global Climate Change Impacts in the United States. T.R. Karl, J.T. Melillo, and T.C. Peterson, Eds. Cambridge University Press, 189 pp

into the atmosphere. They also absorb around 90 percent of the excess heat energy caused from rising greenhouse gases, which cause surface temperatures to rise. Since the atmosphere constantly interacts with the ocean surfaces as a result of winds and rain cycles, an increase in the global SSTs with respect to higher atmospheric temperatures can also be observed. Figure 3 represents the Avergae SST anomalies over the past couple of decades. It is observed that the SST anamolies (from Figure 3), atmospheric CO2 levels and global temperatures (from figure 2) are all directly proportional.

4.2 How higher SSTs Affect the Phytoplankton

As mentioned before, studies have shown that slightly warm temperatures make the perfect environment for phytoplankton growth. However, as seen in Figure 1, there his been a gradual decline in the biomass. Although warmer temperatures usually tend to increase cellular Chl-a, along comes irradiance and decreased nutrient availability which lowers the Chl-a levels produced by the phytoplankton. The positive effects of warm surface waters is overcompensated by the negative effects of decreased nutrients for the phytoplankton populations. Evidence for the inverse relationship between Chl-a levels and SSTs can be observed in Figure 4.

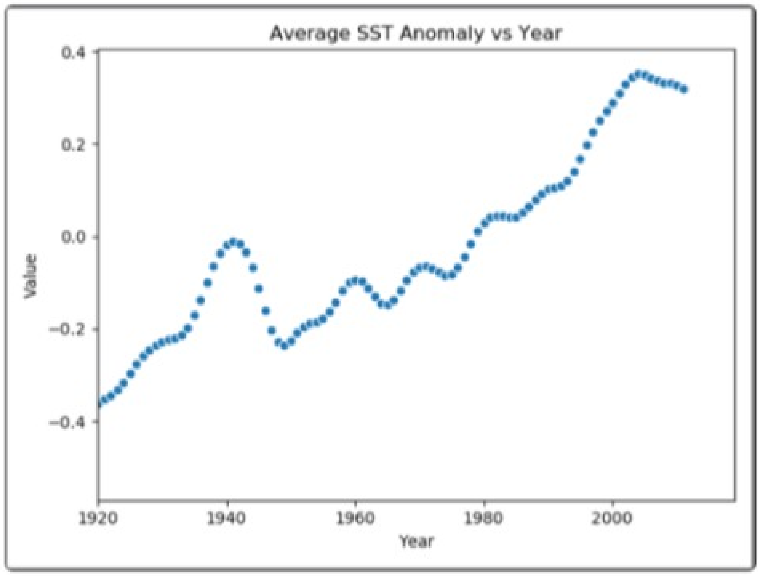

Figure 3: Average Sea Surface Temperatures Anomaly between 1920 and 2018. Data set used: HadCRUT4

From the figure above, it can be seen that every time there is an algal bloom, the SSTs are relatively low, and higher SSTs correspond to lower phytoplankton populations. But why do nutrients deplete with warmer surface waters? The answer is a phenomenon known as 'thermal stratification'.

4.3 What is Thermal Stratification?

Thermal stratification is the phenomenon in which water bodies develop two discrete layers of water of different temperatures: warm on top (epilimnion) and cold below (hypolimnion). Thermal stratification can be established during the warm seasons when the SSTs are comparatively higher than the layers below. Stratification is a natural occurrence in water bodies that are sufficiently deep (particularly lakes and oceans).

Factors such as solar radiation and heat trapped by the surface CO2 warm the water at the surface of the oceans and lakes, due to which this layer becomes lighter and less dense. This epilimnion thus floats on top of the cooler, denser and nutrient-rich water below. This is directly linked to the increasing SSTs, since with an increase in the surface temperatures, there are more frequent and long-term thermal stratification periods. During winters, lake turnover is experienced where the layers mix with each other due to insignificant temperature and density differences between the layers. However, if the SSTs remain high to an extent where the temperature differences between the epilimnion

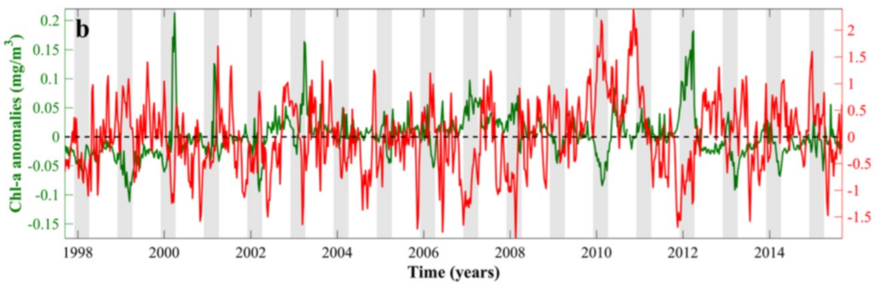

Figure 4: Time series of satellite-derived Chl-a concentration and sea surface temperatures (8-day averages) for the Northern Red Sea (1998-2015). The grey shaded areas represent the bloom periods (usually occur between December and April)

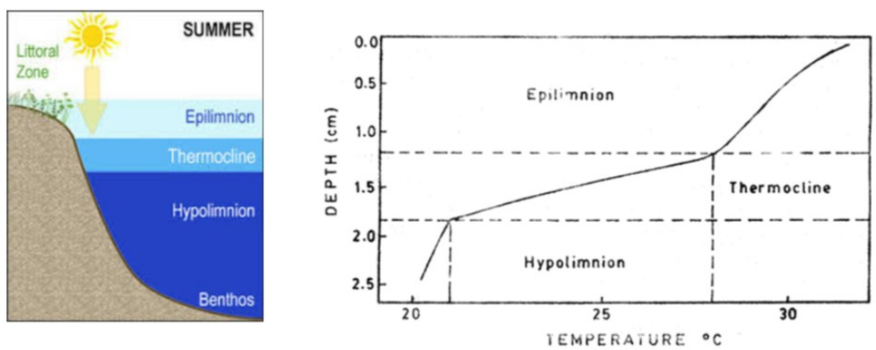

Figure 5: The image on the left shows the different layers formed during thermal stratification. The image on the right shows the temperature of the layers

and hypolimnion is so large that wind and waves can no longer mix the layers, the phytoplankton population will continue to thrive. This is mainly because the epilimnion will be nutrient-deficit for prolonged periods, thus depleting the phytoplankton populations.

A study performed by Jiangqi Qu in 2018 [Jiangqi Qu et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 121 032023] concluded that the content of total iron, nitrogen and phosphorus increased with the water depth during months of thermal stratification, as seen in Figure 7. This suggests that some of the most vital nutrients required by the phytoplankton sink to the bottom of the ocean (hypolimnion and metalimnion) when the SSTs are high, due to which they struggle to thrive.

Nutrient exhaustion offers a general explanation for bloom termination, but detail on which nutrients and their relative influence on phytoplankton productivity, community structure, and physiology is lacking.

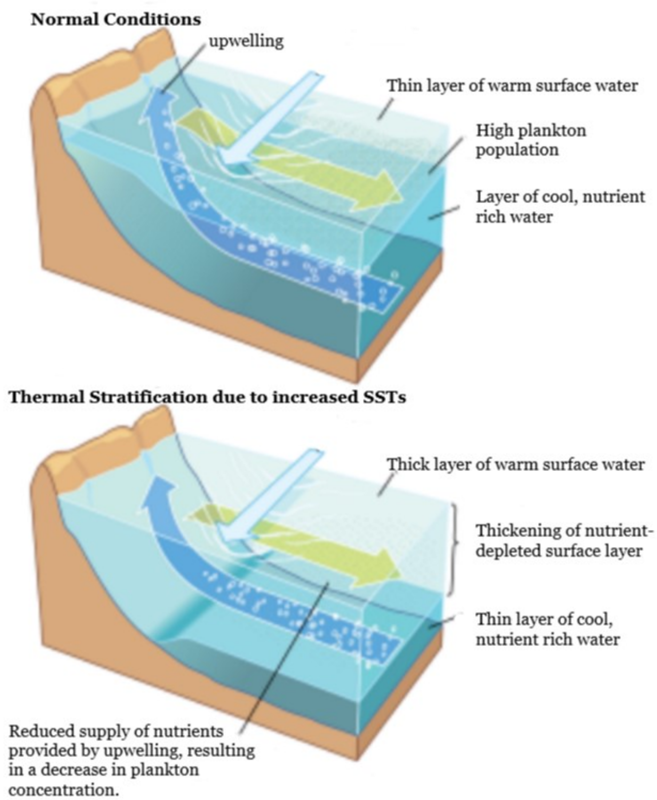

Figure 6: Time series of satellite-derived Chl-a concentration and sea surface temperatures (8-day averages) for the Northern Red Sea (1998-2015). The grey shaded areas represent the bloom periods (usually occur between December and April)

5 Conclusion

5.1 Possible Solutions to Prevent Phytoplankton Depletion

With constantly increasing SSTs, it becomes of an even higher priority to add and circulate the depleting ocean nutrients. Given the fact that phytoplanktons in the ocean fix close to 40 percent of the total CO2, some researchers suggest that if we are able to induce several algal blooms in the near future, the destructive effects of global warming and climate change can be reduced.

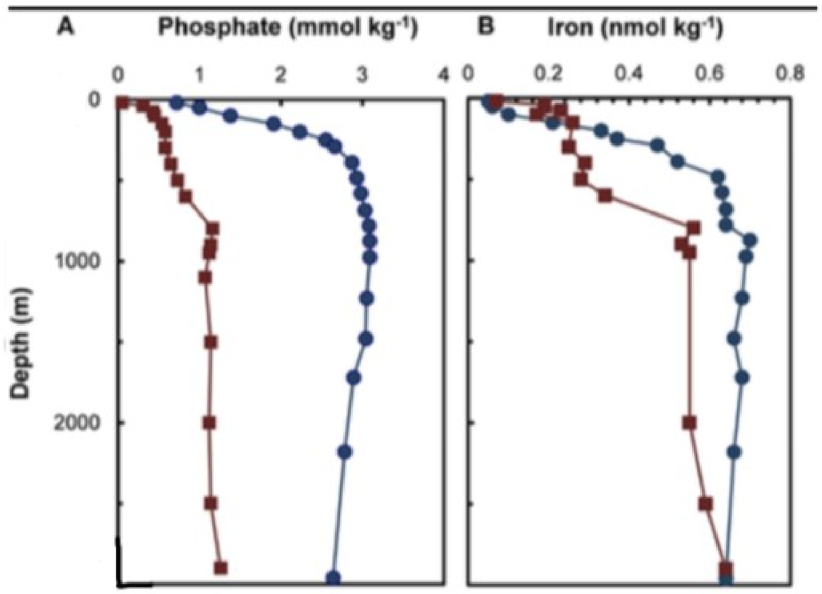

Figure 7: This image shows how nutrients are scarce in the upper layers of the water bodies during thermal stratification

Ocean Circulation

To avoid the phenomenon of thermal stratification, one possible solution is 'ocean circulation'. It is the large scale movement of waters in the ocean basin, that reduces the effects of thermal stratification by circulating the lower nutrient-rich water layers and bringing it to the epilimnion. One type of aeration is known as 'destratification systems' uses compressed air to cause vertical water movement and mixing of the water column. Winds and ocean currents act as a natural destratification methods that allow the cooling and sinking of the warmer surface waters which in turn circulated the nutrients to the upper layers.

Adding Fe and B12 to Ocean Nutrients to Enrich Phytoplankton Populations

Primary productions in the Ross Sea has previously been shown to be seasonally limited by iron. In two of three bottle incubation experiments conducted by the American Society of Limnology and Oceanography, significantly higher Chl-a concentrations were measured upon the addition of iron and B12, relative to iron additions alone. This is consistent with the hypothesis that during month of thermal stratification, phytoplankton slow down in growth due to the scarcity of nutrients in the top oceanic layer. Other nutrients including Cobalt and Zinc were also added to the bottle incubations; however a significant increase in phytoplankton growth was not seen.

	Initial phytoplankton	Final phytoplankton (after Fe addition)	Final phytoplankton (after B12Fe addition)
Experiment 1	1.4 x 10^4 +- 0.1 x 10^4	7.08 x 10^4 +- 0.1 x 10^4	18.0 x 10^4 +- 0.1 x 10^4
Experiment 2	0.4 x 10^4 +- 0.1 x 10^4	3.45 x 10^4 +- 0.1 x 10^4	3.35 x 10^4 +- 0.1 x 10^4
Experiment 3	0.2 x 10^4 +- 0.1 x 10^4	7.32 x 10^4 +- 0.1 x 10^4	8.94 x 10^4 +- 0.1 x 10^4

Figure 8: Initial and Final phytoplankton populations after experiments conducted by the American Society of Limnology and Oceanography. Column 2 is the initial population of the phytoplanktons in all three experiments. Column 3 is the final population of the phytoplankton after Iron was added to the BOD. Column 4 is the final population after both, Iron and B12 was added.

There were statistically significant increases in Chl-a concentrations, nearly doubling in experiment 1 and over 20 percent higher in experiment 3 relative to iron treatments. One particular species - P. Subcurvata, increased from 73 percent of the population to over 92 percent in experiment 1, and from 59 percent to 74 percent in experiment 3.

These results indicate that combined B12 and Fe additions can influence the growth rates of phytoplankton as well as alter the phytoplankton species composition relative to iron-only additions and unamended controls. All in all, adding vital nutrients to smaller water bodies (such as lakes), if not oceans, can raise the phytoplankton populations to a significant extent.

5.2 Ethical Issues of Phytoplankton Enrichment

The external enrichment of phytoplanktons can often lead to detrimental algal blooms which is a result of the overgrowth of harmful organisms. Some produce dangerous toxins in fresh or marine water but even nontoxic blooms in an excessive amount can hurt the environment and local economies.

In other cases, HABs (harmful algal blooms) may be linked to 'overfeeding.' This occurs when nutrients (mainly phosphorus, nitrogen, and carbon) from sources such as lawns and farmlands flow downriver to the sea and build up at a rate that 'overfeeds' the algae that exist normally in the environment.

HABs can also be costly in economic terms as well. At present, HABs cause about 82 million dollars in economic losses to the seafood, restaurant, and tourism industries each year. HABs reduce tourism, close beaches and shellfish beds, and decrease the catch from both recreational and commercial fisheries.

Harmful algal blooms can:
- Produce extremely dangerous toxins that can sicken or kill people and animals
- Create dead zones in the water
- Raise treatment costs for drinking water
- Hurt industries that depend on clean water

It is thus of utmost importance to work towards phytoplankton-enrichment in a limited amount, while keeping in mind what nutrients are the least harmful while being the most effective. Nutrient pollution from human activities makes the problem worse, leading to more severe blooms that occur more often. Therefore, more research and experiments need to be performed in order to calculate the right amount of nutrients to be added in the water bodies for the most effective and harmless blooms. One possible way is to artificially populate the harmless phytoplanktons in optimum amounts in laboratories by nutrient enrichment, and then releasing them into the oceans. Other wide range of treatments that can be used to control HABs is to aerate the water, add clays to the water bodies, and use only selective nutrients for the enrichment-process (phosphorus and nitrates are some of the most harmful nutrients). This, however, would require lots of funding, time and resources.

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