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The Impact of Climate Changes on Primary Producer of Aquatic Ecosystem (Phytoplankton) in the Ocean

The Impact of Climate Changes on Primary Producer of Aquatic Ecosystem (Phytoplankton) in the Ocean

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ABSTRACT

Aquatic ecosystems are very important for biodiversity and play a crucial role for the environment as well as for humans. Phytoplankton, the primary producers in this system, significantly contribute to oxygen production and CO_2 absorption, making them crucial for global climate regulation. However, climate change marked by rising temperatures and unpredictable weather patterns has negatively impacted the abundance and distribution of phytoplankton, thereby threatening marine biodiversity and the stability of ecosystems. This study focuses on analyzing the impact of climate change on the abundance of phytoplankton in the oceans and identifying strategies to address it, through literature review. The research results indicate a significant decline in phytoplankton abundance, influenced by significant temperature changes from year to year. Effective mitigation strategies, including efforts to reduce greenhouse gases, protect biodiversity, and educate the public, are essential for preserving aquatic ecosystems. This study emphasizes the need for immediate and sustained action to protect marine biodiversity and ensure ecological balance, by using literatures review.

Keywords*:* Climate change, Marine Biodiversity, Phytoplankton

INTRODUCTION

Aquatic ecosystems are critical components of the global environment. In addition to being essential contributors to biodiversity and ecological productivity. Aquatic ecosystems also provide variety of services for human populations, including water for drinking and irrigation, recreational opportunities, and habitat for economically important fisheries. However, aquatic ecosystems have been increasingly threatened, directly and indirectly, by anthropogenic activities that need to be minimize. Phytoplankton, an ecological group of unicellular or colonial photosynthetic organisms adapted to live in apparent suspension in water masses, is a

provider of many of the aforementioned services, in all the identified categories, to the ecosystems in which it lives and also to humankind (Prakash, 2021).

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The aim of this journal is to understand the causes and effects of climate change on the abundance of phytoplankton in the oceans. Because if we do not seek to understand the causes and effects of climate change, it will lead to damage to aquatic ecosystems. Global warming has become a hot issue for the past one hundred fifty years, since the industrial revolution, and has significantly increased the average temperature of the Earth by 0.76 ± 0.18ºC. This global warming is a tangible impact of the rising concentrations of CO_2 and other greenhouse gases as a result of uncontrolled human activities. This warming is causing instability in the Earth and making it increasingly difficult to predict the climate. (Sartimbul *et al.,* 2021).

REVIEW

The main energy source for all life on Earth is the sun, which emits its radiation that penetrates the Earth's atmosphere in the form of short waves. This radiation is reflected back into space in the form of long waves, some of which are absorbed by greenhouse gases, namely CO_2, CH_4, N_2O, HFCs, and SF6, present in the atmosphere. As a result, the long waves that have a thermal nature are trapped within the Earth's atmosphere. This event occurs repeatedly, causing the average temperature on the Earth's surface to rise. This phenomenon is known as global warming (Rahayu *et al*., 2018).

The most tangible impact of global warming to date is climate change. Global warming has increased the occurrence of droughts worldwide, heatwaves, and the frequency of tropical storms. The rise in global temperatures will lead to the melting of ice in the Arctic and Antarctic, resulting in the expansion of seawater and rising sea levels. Global warming will also cause shifts in seasons due to changes in rainfall patterns. Climate change results in high-intensity rainfall over short periods and prolonged dry seasons. Both events will have repercussions on several sectors. Ultimately, climate change leads to shifts in seasons and changes in rainfall patterns, which will affect national food security (Setyonegoro, 2015).

a. Climate Change

Climate change is a change in climate behavior patterns over a relatively long period, ranging from about 30 to thousands of years. This can happen due to natural effects, but the climate change currently occurring is a result of human activities. Climate change occurs due to the increase in air temperature, which affects the conditions of other climate parameters. Climate change includes changes in air pressure, temperature, wind direction and speed, and precipitation. Climate change causes alterations in seasonal patterns, making them difficult to predict. In some parts of the world, this increases the intensity of rainfall, potentially triggering floods and landslides. In other regions of the globe, climate change can lead to

prolonged dry seasons due to rising temperatures and decreasing humidity (Rahman *et al*., 2023).

Climate Change alters entire ecosystems along with the living ecosystems that are live there. Climate change has increasingly and profoundly threatened the global environment, biodiversity and sustainable human development, chiefly by altering global thermal regimes and the water cycle and causing acidification (Huang & Ge, 2021). Climate change is causing rising sea temperatures (about 1^{o}C) that significantly impact marine ecosystems. One of the affected groups is phytoplankton, microscopic organisms that form the foundation of the food chain in the oceans. As sea temperatures rise, phytoplankton growth is disrupted, which can affect the populations of other marine animals and threaten the overall balance of the ecosystem (Griggs & Reguero, 2021).

Rising sea surface temperatures (SST) due to global warming significantly impact phytoplankton abundance. Elevated SST can enhance water column stratification, reducing nutrient mixing from deeper layers to the surface. This nutrient limitation often leads to decreased phytoplankton biomass, as these microorganisms rely on nutrients like nitrate and phosphate for growth. A study in the Inner Oslofjorden observed a decline in phytoplankton abundance correlating with increased SST and reduced nutrient concentrations (Lundsør *et al.*, 2022).

Additionally, higher SST can alter phytoplankton community composition. Warmer temperatures may favor smaller phytoplankton species with higher thermal tolerances, potentially disrupting existing food webs and biogeochemical cycles. Research in the Yellow Sea demonstrated that increased temperature and CO_2 levels led to shifts in phytoplankton community structure, highlighting the complex interplay between warming and phytoplankton dynamics (Fu *et al.*, 2024).

b. Phytoplankton

In the field of fisheries, plankton plays an important role as a source of nutrients in aquatic environments. Plankton is classified into two based on its type, namely phytoplankton and zooplankton. The function of phytoplankton is as producers, providers of oxygen in water, indicators of pollution, and more. Phytoplankton can carry out their life activities by utilizing sunlight due to the presence of chlorophyll in their cells. The role of zooplankton is as primary consumers. Another role of plankton is as an indicator of water fertility based on the calculation of plankton abundance (Sudinno *et al*., 2015).

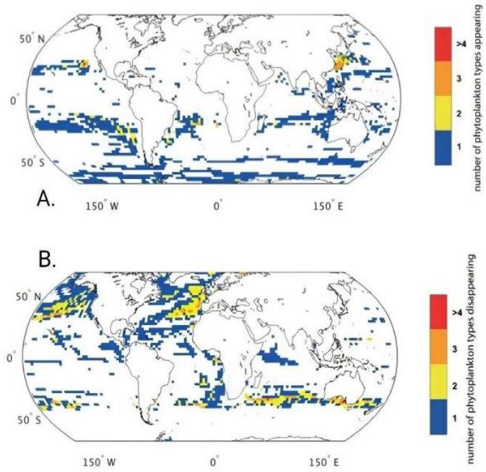
Phytoplankton group has a major influence on the marine carbon cycle and on the inorganic carbon pump, significantly contributing to the sequestration of large amount of CO_2 from the atmosphere and providing an important regulating effect not only to the ecosystems where they thrive but to the entire biosphere (Haunost et al., 2021). Altogether, a fraction ranging between 20% and 35% of global annual CO_2 emissions are directly sequestered by phytoplankton. On the whole, the amount of CO_2 captured yearly by phytoplankton has been estimated to be equivalent to that captured by 1.7 trillion trees, i.e., four Amazon forests' worth (Chami *et al*., 2019).

The presence of phytoplankton in a body of water can fluctuate due to the influence of salinity levels and other environmental factors that are constantly changing. One of the factors is the input load into the waters, which enriches the nutrients that support the growth of phytoplankton. (Sudinno *et al.,* 2015). In addition, the presence of phytoplankton is also influenced by several factors, namely temperature, currents, dissolved oxygen, and brightness. Local factors, such as

water quality, are generally considered the main drivers of variations in phytoplankton community structure. Overall, local factors such as water temperature, stream width and depth, flow velocity, and nutrient delivery are subject to seasonal variation, which significantly impacts the composition and abundance of the phytoplankton community (Tian *et al.,* 2021).

c. Case Study

Water temperature and primary production play critical roles in marine processes. Higher temperatures accelerate reaction rates, with consequences ranging from the molecular to ecosystem scale, while primary production provides the fundamental source of energy for almost all marine life. Climate change impacts on both water temperature and primary production will thus alter marine ecosystems in fundamental ways (Häder & Barnes, 2019). For example, a first-order expectation of these impacts is that accelerated metabolic rates will consume energy more quickly in a warmer ocean, all else being equal, so that less biomass could be supported by a given level of primary production. Ecosystem level effects emerge from individual level processes and interactions, which could lead to nonlinear effects and changes in ecosystem structure, while shifting thermal habitats may influence the distribution of species, transforming food webs to previously unknown states (Christensen *et al.*, 2020).



Picture 1. The Abundance of Phytoplankton from 2005-2024 (Christensen *et al.*, 2020)

The image above shows the changes in the abundance levels of the phytoplankton that occurred over the period from 2005 to 2024. In image A, it shows the occurrence level of the phytoplankton. The dominant occurrence value is at level one. Meanwhile, image B illustrates the decreasing level of phytoplankton. It can be seen that in image B, the yellow to red colors (levels 2 to 4) are increasing, indicating that the level of phytoplankton that have disappeared is greater than the occurrence value. This can be influenced by several factors, namely climate change, where temperatures are rising over time. Long-term temperature changes have been shown to affect the distribution and abundance of marine resources such as small pelagic fish, as well as other marine organisms, like plankton (Sartimbul *et al.,* 2021).

Climate change is one of the factors that can affect the biodiversity of phytoplankton through several mechanisms, one of which is the increase in temperature. Some phytoplankton thrive better in cooler temperatures. The increase in temperature will cause a decrease in dissolved oxygen concentration, thereby affecting the growth of living organism (Prakash, 2021). The average air temperature of the Earth has increased by about 0.74°C over the last 100 years. Many experts estimate that the average temperature will rise by between 1.4°C and 5.8°C by the year 2100. Meanwhile, the Intergovernmental Panel on Climate Change (IPCC) predicts that global temperatures are likely to increase by 1.1°C to 6.4°C over the next 90 years. This is known as Global Warming, which

indicates the increase in the Earth's average temperature. The rise in temperature affects the biodiversity of aquatic organisms (Setyonegoro, 2015).

Climate change, largely driven by global warming due to increased greenhouse gas emissions, significantly impacts the diversity, productivity, and environmental conditions of aquatic ecosystems. Global warming causes ocean temperatures to rise and alters nutrient distribution patterns, triggering a reorganization of plankton communities. This increase in temperature also reduces primary productivity, where warmer seasons hinder phytoplankton blooms (Armengol *et al.,* 2020). In waters with moderate temperatures, phytoplankton diversity thrives, supporting a robust food (Celewicz & Gołdyn, 2021), but global warming is pushing oligotrophic systems to higher temperatures, which decreases diversity and productivity, as well as triggering a shift to less desirable plankton communities. This impact highlights the need for better management efforts to reduce global warming and minimize damage to aquatic ecosystems (Henson *et a*l., 2021).

d. How to Minimize Climate Change

The Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) mention several pieces of evidence and dangers caused by climate change, including changes in rainfall patterns, rising air temperatures, increasing water levels, and increasingly extreme weather conditions. That condition has indeed been felt by all the inhabitants of the Earth. The direct impact also includes changes in the hydrological cycle, as well as changes in the quantity and quality of water on Earth. Humans are a significant factor in climate change and global warming. The damage that has occurred has been catastrophic, with impacts affecting health, social aspects, the economy, and the entire ecosystem on Earth (Murgan & Ganiyu, 2021).

Awareness and behavioral change are needed to address the issue (Mustangin, 2017). States that community involvement and awareness of the threats posed by climate change are necessary through education for the public in order to successfully implement mitigation and adaptation actions for climate change. There is a great need for knowledge and understanding among the public regarding the impacts of climate change. Where adaptation and the readiness of the community are needed to face extremely unpredictable weather situations and conditions. With awareness, the community will be more selective in the use of fossil fuels, reducing, managing, and utilizing household waste, especially plastic materials (Malihah, 2022).

In addition to the need for awareness and understanding, there are four types of actions to reduce the scale and impacts of climate change that are considered: (1) reduction of atmospheric greenhouse gas concentrations, (2) solar radiation management, (3) protection of biota and ecosystems, and (4) manipulation of biological and ecological adaptation. The actions in the first two categories (hereafter referred to as global actions, although some forms of solar radiation management could be local) aim to either reduce the primary cause of climate change on a global scale (mainly the rise in atmospheric CO_2 concentration) or to mitigate warming by increasing albedo in the atmosphere or at the Earth's surface, thus enhancing the proportion of solar radiation that is reflected back into space (Bates *et al*., 2017).

CONCLUSION

The changes in ocean temperatures driven by climate change are having a profound impact on aquatic ecosystems, particularly on phytoplankton populations. As primary producers in the marine food chain, phytoplankton are sensitive to

temperature shifts, which can alter their overall abundance, distribution, and growth rates. Warmer ocean temperatures can lead to decreased nutrient availability in surface waters, reducing phytoplankton productivity and affecting the entire marine food web, including fish populations and other marine life that depend on them. These disruptions not only threaten marine biodiversity but also undermine the ocean's ability to sequester CO_2, contributing to a feedback loop that exacerbates global warming. To address these issues, it is essential to mitigate climate change through reducing greenhouse gas emissions and adopting sustainable practices to maintain the health and stability of ocean ecosystems.

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