

Impact of Ocean Acidification on Plankton – A Short Review

Ishita Sharma, Dipanwita Das*, Sayantika Mukherjee and Amrita Saha

Amity Institute of Environmental Sciences, Amity University, Kolkata, West Bengal – 700156, India

✉ ddas@kol.amity.edu

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Abstract: “Ocean acidification” (OA) is a result of global warming, which describes a long-term drop in the pH of the ocean, mostly due to the ocean’s absorption of carbon dioxide (CO₂) from the atmosphere. Plankton, a diverse collection of tiny organisms, are decisive in supporting marine and freshwater food webs living at and beneath the surface of lakes, rivers, ponds, and oceans across the planet. Recently this vital community has been severely affected due to ocean acidification, which has forced it to either die or they are migrating significantly as OA intensifies. This review provides a concise overview of the impacts of ocean acidification (OA) and other environmental factors on plankton communities thereby highlighting the necessity of conducting comprehensive assessments to provide insights into the impacts of climate change on marine ecosystems.

Keywords: Ocean acidification; Plankton; Global warming.

Introduction

Anthropogenic emissions of carbon dioxide (CO₂) and its absorption by the sea surface have led to significant changes in the chemical composition of marine carbonate chemistry, resulting in acidification of seawater and a decrease in the saturation state with calcium carbonate. Due to CO₂ intrusion, the pH of the modern sea surface has decreased by an average of 0.1 units compared with pre-industrial times. According to forecasts by the Intergovernmental Panel on Climate Change (IPCC), the atmospheric CO₂ partial pressure (pCO₂) is expected to continue to rise, from about 390 µatm to about 760 µatm. This increase was estimated to result in a decrease in the mean oceanic surface pH by 0.3 to 0.4 units by the beginning of the 22nd century, following a ‘business-as-usual scenario’. This shift in carbonate chemistry, known as Ocean Acidification (OA), was believed to primarily impact calcifying organisms that construct their shells and skeletons from

calcium carbonate. The biological effects of OA on non-califiers were noted to be diverse and often highly species-specific.

Current understanding of the potential impacts of OA is largely limited to the responses of individual species. However, the consequences of OA on food web interactions are still poorly understood. Indirect effects due to trophic interactions were expected as OA has the potential to alter the biochemical composition and metabolism of primary producers, thereby affecting the nutritional index of foods for consumers. Increasing CO₂ levels can stimulate carbon fixation by photosynthetic organisms, thereby reducing nutrient density relative to carbon. This in turn determined the quality of the herbivores’ diet. The imbalance between phytoplankton stoichiometric composition and consumer nutrient demand for somatic growth could be exacerbated under elevated CO₂ conditions. In addition to elemental stoichiometry, the fatty acid (FA) content was a critical factor in regulating energy transfer between

*Corresponding Author

primary producers and consumers. Essential long-chain polyunsaturated FAs (PUFAs) played a crucial role in the growth, development, and reproductive success of heterotrophs. OA had the potential to impact phytoplankton FA synthesis, as environmental pH was known to influence various intracellular physiological parameters affecting its enzyme activity.

The classic diatom-copepod-fish link in the ocean supports some of the world's most productive ecosystems and provides highly nutrient-dense food at higher trophic levels. Experimental studies suggested a weakened sensitivity of primary producers to CO_2 and no noticeable direct effects on copepod growth and reproduction success at CO_2 levels expected by the end of the century. However, CO_2 levels could indirectly influence zooplankton growth through its potential effect on the nutritional quality of phytoplankton which is their primary food source. To test this hypothesis, the researchers independently manipulated CO_2 concentrations in diatoms used as food algae and in copepod cultures and examined the effects of the OA diet on copepod growth and reproduction. The resulting FA composition of both algae and copepods, as well as copepod development and reproduction, were determined. The experiments demonstrated that increased CO_2 levels affected the biochemical composition of the diatom, resulting in constrained copepod growth performance. A marine ecosystem model was also calibrated with the results of the meta-analysis to understand the changes in community structure, while mentions of the inclusion of a CONTROL simulation and additional experiments are discussed (Dutkiewicz et al., 2015).

Ocean Acidification Altered Microbial Functional Potential in the Arctic Ocean

In this study, the researchers employed highly precise functional gene microarray technology, specifically GeoChip 4, to delve into the functional gene structure and diversity of bacterioplankton in the Arctic Ocean mesocosm experiment. GeoChip 4 demonstrated several advantages, including its ability to comprehensively analyse microbial functional genes, shedding light on their diversity and potential roles in ecological and biogeochemical processes. The technology facilitated the identification and quantification of specific genes participating in key metabolic processes, such as carbon degradation and methane oxidation, among others. Its simultaneous analysis of a multitude of genes provided a detailed understanding of bacterioplankton

communities' functional potential with high sensitivity and accuracy. The experiment's inferences revealed that ocean acidification (OA) significantly impacted the metabolism potential of bacterioplankton in the Arctic Ocean. Elevated pCO_2 levels, simulating future OA conditions, led to a higher evenness of microbial functional genes and a more stable community structure. Molecular ecological networks exhibited increased complexity and stability under elevated pCO_2 , supporting the notion that complexity fosters stability in ecological systems. Moreover, increased abundances were observed for genes involved in key metabolic processes under elevated pCO_2 , suggesting that OA could alter the metabolic potential of bacterioplankton and potentially impact biogeochemical cycling in the ocean. Ultimately, the study underscores the importance of understanding bacterioplankton communities' response to OA for predicting the future trajectory of biogeochemical processes in the ocean (Dörner et al., 2020).

Effect of Ocean Acidification on Future Plankton Communities

Due to the combined effect of ocean acidification and changing climate, the plankton diversity has seen a significant decrease. Plankton are delicate organisms that are not viable for changes in the environment, thus they struggle to adapt to conditions of high acidity. The plankton metabolism is unable to access the dissolved CaCO_3 present in the water thus ending up losing their body structure and important nutrients. Due to increased competition and harsh environments, it is natural that various taxa of plankton will either go extinct, adapt themselves or change their genetic nature. However, it has been noticed that while there might be significant changes in the genetic types, their functional diversity is not much affected. Nutrient limitation of growth was determined by the most limiting resource and genetic diversity changes were observed depending on the parameterisation of genetic differences (Wang et al., 2023).

Inferior Plankton Leading to Disturbed Copepod Reproduction

Ocean acidification (OA) is predicted to cause a decrease in ocean pH, which can have direct effects on calcifying species and non-calcifying organisms. Copepods play critical roles in marine ecosystems and their response to OA could have significant consequences for ecosystem

functioning. Previous studies have shown that copepods may be resilient to high $p\text{CO}_2$ levels, but the long-term impact on copepod populations is not well understood. OA can alter the nutritional quality of phytoplankton, which is an important food source for copepods. Changes in phytoplankton species composition and size distribution under high $p\text{CO}_2$ conditions can affect copepod feeding and nutrition. The nutritional quality of phytoplankton, specifically the fatty acid composition, can impact the reproductive success of copepods and higher trophic levels. The copepods studied showed impaired reproductive ability when on a diet of $p\text{CO}_2$ rich phytoplankton with reduced essential fatty acids (EFA) and polyunsaturated fatty acids (PUFA), indicating that future ocean acidification (OA) conditions may decrease copepod fecundity. Changes in the nutritional quality of phytoplankton, specifically the EFA content, can have cascading effects throughout the food web, affecting copepod reproduction and the availability of essential macromolecules for copepod diets. The effects of OA on the nutritional quality of phytoplankton, such as their cellular FA composition, were modified by the level of nitrogen deficiency. The reproductive response of copepods was negatively affected by OA-induced changes in the availability of EFAs in their planktonic diets. While previous studies have found copepods to be resilient to future-predicted OA conditions, this study demonstrated that copepods can be indirectly affected by OA through changes in the availability of EFAs in their diets (Meyers et al., 2019).

Effect of Ocean Warming and Nutrient Limitation on Plankton

Recent research on the effects of ocean acidification (OA) on planktonic communities has highlighted the importance of in situ mesocosm experiments. These experiments provide valuable information about the effects of OA on natural plankton communities and how these are affected by changes in nutrient availability. By synthesising findings from in situ mesocosm studies conducted in arctic and temperate waters, researchers identified general patterns of plankton community change in response to OA. A notable result is the increased abundance of phytoplankton under simulated OA conditions, particularly for smaller taxa. However, the response of primary heterotrophic consumers varied depending on the availability of inorganic nutrients. Under nutrient-limiting conditions, bacteria and micro-heterotrophs benefited, while larger heterotrophs showed inconsistent responses. In contrast, heterotrophs

were generally negatively affected during times of nutrient abundance, although some mesozooplankton life stages, such as B. copepods, recorded an increase. The observed changes in plankton community dynamics suggest that changes in phytoplankton size distribution and composition may play a key role in triggering these responses. Furthermore, the study highlights the complex interaction between OA and nutrient availability in the formation of marine food webs. In addition to OA, ocean warming has also become an important factor affecting plankton biomass. Previous research has linked physical and biological mechanisms to this phenomenon, but the relative importance of these mechanisms remains unclear. To fill this gap, researchers integrated the predictions of a global circulation model into a mesocosm experiment to study the effects of warming on the multitrophic plankton community. The results showed that although the warming treatments had a direct positive effect on phytoplankton biomass, this effect was counteracted by a reduction in nutrient input. As a result, the zooplankton changed their feeding habits from phytoplankton to cilia feeding. These results contrast with previous experiments conducted under nutrient-rich conditions, where warming indirectly reduced phytoplankton biomass by increasing zooplankton grazing. Overall, the study highlights the complex connection between ocean warming, nutrient availability and plankton community dynamics. By providing a mechanistic understanding of these interactions, researchers aim to improve predictions about the future impacts of climate change on marine ecosystems (Alvarez-Fernandez et al., 2018; Lewandowska et al., 2014).

Conclusion

Ocean acidification, promotes acidification of the oceans, negatively impacting marine organisms and ecosystems. Calcifying plankton, such as foraminifera, are particularly vulnerable to ocean acidification, with potential consequences for marine carbon cycling and the use of foraminifera as palaeoceanographic indicators. Ocean acidification poses a major threat to coral reefs, fisheries, and the blue economies of coastal nations and small islands. Studies have shown that ocean acidification negatively affects the biomass of zooplankton species, including dinoflagellates and other important primary producers. The effects of ocean acidification on plankton communities are species-specific and can lead to deterioration in the quality and quantity of food available, with potential

consequences for the transfer of matter and energy via biomagnification to higher trophic levels. Plankton populations in the oceans are of great importance and should be conserved. Plankton serve as the base of marine food webs, providing food for other marine organisms such as fish and corals. They also play a crucial role in climate change by contributing to primary production and the export of carbon to the deep ocean. The decline of plankton populations can have significant impacts on marine ecosystems, fisheries, and other marine life. It is important to understand and study plankton to inform policy and management decisions for the conservation and sustainable use of marine resources. Efforts should be made to monitor and protect plankton populations on a global scale, using cost-effective methods such as the Continuous Plankton Recorder survey.

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