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Coupling Relationship Between Ocean Acidification in the Arctic Ocean and the Increase in Atmospheric CO_2

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Abstract. The actual reason behind ocean acidification is the drastic rise of CO_2 in the atmosphere, which has already become the process of the primary nature to alter the marine carbonate system and seawater chemistry. The paper investigates the relationship between the increase in CO_2 levels and the acidification of the ocean in the Arctic ocean. The greater the amount of CO_2 absorbed by seawater, the more the form carbonate the lower the PH value, and so the less carbonate ions are used. The Arctic Ocean is even more vulnerable since cold water is able to dissolve more CO_2, and the further melting of sea ice makes the process even more dramatic. This study also analyzes environmental factors. Moreover, the future direction and the potential mitigation measures, such as the reduction of the emissions of CO_2 and the creation of the solutions based on the oceans, are also studied in the paper. All in all, to anticipate the changes that may happen in the environment and safeguard the Arctic environment, it is important to be aware of the correlation between atmospheric CO_2 and ocean acidification as a whole.

Keywords: Environmental Science, Ocean acidification, Arctic Ocean, ecological friendly

1. Introduction

The most critical environmental problem in the modern world is climate change. The primary cause of climate change is in case of drastic growth of CO_2 in the atmosphere. Ever since the industrial revolution, human activities such as the burning of fossil fuels, industrial production, and transportation have been contributing greatly to the amount of CO_2 in the atmosphere [1-5]. This growth leads to global warming and disrupts ocean chemistry balance.

The ocean plays an important role in the absorption of CO_2 in the atmosphere. The world ocean has taken up about 25-30 percent of the human-generated CO_2 emissions, which are one of the significant sources of carbon sinks [6-10]. It is advantageous in that it reduces climate change [10]. Nonetheless, this absorption alters the seawater chemistry to produce a more acidic ocean. As the CO_2 is dissolved in the ocean it will react with the seawater to create carbonate which decreases the PH value of the seawater. This is the acidification of the ocean.

Ocean acidification is quite sensitive to the Arctic Ocean. The cold water has the capacity of absorbing a greater amount of CO_2 as compared to the warm water and the Arctic region is undergoing a very fast environmental change as temperatures increase and sea ice melts away. It has been found out that the Arctic Ocean is undergoing a high rate of environmental changes over the

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past decades [1]. As such, to forecast regional climate biogeochemical interactions, it is essential to demonstrate the coupling connection amid the rise in the CO_2 concentration in the atmosphere and ocean acidification.

2. Background

Ocean acidification refers to the gradual and long-term decline in the pH of sea water because of the absorption of man-made CO_2. The marine carbonate system controls this process and determines the pH and carbonate saturation. Arctic ocean is among the ones that is most susceptible to ocean acidification. Cold water takes in a greater amount of CO_2 and melting ice in the sea opens the ocean to the atmosphere where more CO_2 is released to the ocean [3]. Over the past few decades, the Arctic has emerged as a significant location of interest in climate change studies due to the fact that environmental changes are occurring at a faster pace than in most other locations globally.

This quick transformation is not merely in regard to temperature rise. With earlier and later ice retreats and formation, surface waters stay open longer, allowing more time to absorb CO_2. It also diminishes the natural protection capability of sea ice. Moreover, cold water enhances the solubility of gases, so that an equivalent volume of CO_2 can lead to a more significant decrease in pH than in warmer waters. Simultaneously, more freshwater inflow via melting glaciers and river outflow makes the seawater less alkaline, undermining the natural buffering capacity of the ocean. This complicates the ability of the system to counter acidity changes.

All of these processes cause a considerable reduction in the saturation state of carbonates and in particular the aragonite, which is a key component of the marine environment and needed by numerous marine species like pteropods and shell-forming planktons. At a saturation state lower than 1, these organisms start to undergo shell dissolution and slow down growth rates. In other areas of the Arctic, these undersaturated conditions already seasonally exist, sooner than anticipated in comparison with other areas.

Moreover, there is also an influence on biological processes. Trophic cascades can cause shifts in the nutrient cycles, species composition, and productivity of phytoplankton, potentially changing the whole marine food web. As most of the species in the Arctic are highly specialized and adapted to stable environments, they might not be able to adapt to a swift change in chemicals. This poses a threat of imbalance in the ecosystem and loss of biodiversity. These effects can impact world ocean systems as well, as they accumulate, underscoring the expanded significance of studying and managing Arctic ocean acidification.

Moreover, the effects of ocean acidification in the Arctic can be combined with other environmental stress factors, including increasing temperatures and a low oxygen supply. All of these pressures may cause further decreased survival and adaptation of the marine life. As an example, already stressed species by warming water might be more pH sensitive. Meanwhile, changes in the distribution of species could take place, whereby some species would be relocated to the new locations and others reduced. This may interfere with the existing ecological associations and make the stability of the ecosystem to be uncertain. Thus, the acidification of oceans cannot be regarded as a single problem, but it is a component of a bigger system of environmental changes occurring in the Arctic.

In addition, the issue of ocean acidification in the Arctic is particularly worrying since its impact may be long-lasting. The ocean does not rapidly recuperate to its initial chemical balance even when there are lowered levels of CO_2 emissions in the future. What this implies is that the effects on the marine life and ecosystems might be experienced over decades or even longer. Consequently, long-term scientific surveillance and studies are extremely significant. Constant data is required by the

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scientists to know the rate of change, the vulnerable species and anticipate the future. In this meaning, the Arctic serves as an early warning system to the entire world oceans. The events occurring in this area can bring valuable information on the possibility of ocean acidification progressing globally.

3. Thesis statement

The rise in the concentration of CO_2 in the atmosphere aids in increasing the acidity of the ocean within the Arctic Ocean by depositing seawater pH and carbonate ion concentrations. This activity disrupts the marine ecosystem and the calcifying in particular and is further boosted by the environment specific to the Arctic environmental change. Some of the mitigation strategies that can counter these impacts include carbon emission reduction and ocean-based measures.

This process is especially pronounced in the Arctic due to several interacting physical and chemical feedbacks. Lower temperatures increase CO_2 solubility, while the rapid loss of sea ice enhances air-sea gas exchange and exposes surface waters to prolonged atmospheric uptake. The resulting decline in carbonate saturation states directly affects calcifying taxa such as pteropods, foraminifera, and bivalves, which play key roles in the polar food web. Furthermore, freshwater influx from melting ice and increased river runoff reduces alkalinity buffering capacity, amplifying pH variability. In light of these region-specific vulnerabilities, mitigation efforts must address both global carbon dioxide reductions and localized interventions, including alkalinity enhancement and ecosystem-based management.

4. Result

4.1. Direct impacts of ocean acidification on the Arctic Ocean chemistry

Ocean acidification is a phenomenon that interferes with the chemical structure of the Kodak Ocean by reducing the pH of the seawater and reducing the amount of carbonate ions. The seawater in the Arctic dissolves more CO_2 and the balance in carbonates is disturbed which results in visible declines in pH [1]. The process also lowers the saturation of the ionic form of carbonates and decreases the concentration of carbonate ions which inhibit biomineralization of the marine organisms. The studies that have been done on the basis of the observations have noted that the Arctic ocean has undergone a sharp acidification process in the period between 1994 and 2020 with a downward trend in the pH on the long run [2]. Even though these chemical changes are well documented, more worrying is their environmental impacts.

4.2. Biological impact on the Arctic sea life

The adverse impacts of ocean acidification on the Arctic marine ecosystems include a change in microbial processes and organism physiology. Experimental and field studies have shown that acidification alters microbial functional potential with ramifications on nutrient cycling and whole ecosystem stability [3]. Reduced supply of carbonate ions leads to low calcification rate and physiological stress in shell-forming organisms. It is stated that, based on the evidence of the past events, such as the Palaeocene-Eocene Thermal Maximum, parallel changes in ocean chemistry took place, which were characterized by reduced carbonate saturation and enormous restructuring of the ecological system [4]. Other than these biological reactions, there are other biological reactions of the Arctic environment that promote aggravation of acidification.

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4.3. Certain Arctic drivers and rapid changes

Certain environmental conditions in the Arctic Ocean enhance the rate of the occurrence of ocean acidification. Low temperatures also enhance CO_2 solubility making the gaseous exchange between the air and the sea more effective and the uptake of CO_2 easier [5]. Simultaneously, the melting sea ice expands the open ocean space, which enhances the additional absorption of CO_2. The variations in ocean circulation dictate the distribution of dissolved inorganic carbon and alkalinity which contributes to spatial variation in patterns of acidification [5]. Based on the long-term reconstructions, although the world has experienced the higher levels of ocean acidification since the pre-industrial period, Arctic is changing at a relatively higher pace [1]. Such dynamics demonstrate the necessity to consider risks in future when the environment continues its evolution.

4.4. Preventive and future projections

Despite the fact that the ocean acidification is progressively developing, there are mitigation measures that can reduce its impact in the long term. This will cause a reduction in the rate of acidification since the amount of CO_2 in the atmosphere will reduce [6]. Joins applied to the ocean e.g. alkalinity stimulation can increase the buffering capacity and partially offset the pH decrease [7]. Due to the central role of the ocean in global carbon cycle, there is the necessity of further adopting the combined approaches in managing carbon [8]. Even though there are still questions as to who causes what feedbacks, there are very strong indications that anthropogenic CO_2 emission is the primary cause of ocean acidification [9]. These considerations indicate that mitigation and region-specific adaptation initiatives are necessary to address the issue of Arctic Ocean acidification on a global scale..

5. Conclusion

To sum up, the issue of acidification of the Arctic Ocean is a critical ecological issue that is directly linked to the increase in the level of atmospheric CO_2. The higher the level of CO_2 in the ocean, the higher the level of carbonic acid that is formed by reacting with the seawater and hence decreasing the pH of the water. Such a chemical transformation increases the level of acidity in the ocean and impacts a variety of marine organisms, in particular, shellfish, plankton, and corals that cannot live without calcium carbonate. In cases where these organisms are troubled or failing, the impacts may be transmitted in the food web affecting fish, marine mammals, and even human communities that rely on these resources.

A particularly sensitive area is the Arctic region due to its natural conditions. Cold water takes in more CO_2 than warm water, hence, acidification occurs rapidly in polar regions. Meanwhile, melting sea ice opens an even greater surface of the ocean to absorb yet more CO_2. The melting ice also alters the salinity and chemistry of the sea water, which complicates the adaptation of organisms in the sea. A combination of all these factors leads to a scenario in which the Arctic ecosystem is highly stressed and might transform faster than other areas.

The effects of these changes are not just environmental, but social and economic as well. Numerous Arctic communities of the Indigenous population depend on the sea creatures as their food, culture, and their livelihood. It may impact food security and traditional ways of life, in case key species are on the decline. Moreover, the world fisheries and biodiversity can be also affected by the alteration of the Arctic ecosystems, demonstrating that it is not merely a local problem, but a global one.

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Although the issue is severe, it is not without means to react. Reduction of CO_2 emissions in the world is the most significant solution, as it is the primary cause of acidification of the oceans. Reduction of carbon emission by use of cleaner energy and sustainable practices is done by governments, industries and individuals. Simultaneously, researchers will have an opportunity to come up with solutions based on the ocean, including the protection of marine ecosystems, restoration of habitats, and enhancement of carbon storage in oceans. More efficient monitoring systems are also required to monitor changes and enable scientists to make more precise predictions.

Lastly, inter-country collaboration is needed to resolve this problem. Arctic belongs to numerous nations and its future is in unity. Nations should collaborate to develop policies, exchange scientific information and fund research in the long term. Ocean acidification can be reduced by taking global actions and local measures to save the Arctic environment. Further focus on this matter will aid in making sure that the problems of the Arctic Ocean will be better perceived and dealt with by the next generations.

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