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Ocean Acidification and Its Consequences Upon the Environment

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Abstract **Review Article**

Ocean acidification describes the decline in pH of marine environments as the continue to absorb carbon dioxide (CO2). Research over the past ~15 years has reported the levels of ocean acidification forecasted for the end of the century (CO2 ~800-1000 µatm; pH ~7.6-7.7) This process alters the chemical balance of seawater, leading to significant ecological impacts on marine life, particularly those species that rely on calcium carbonate for shell and skeleton formation. This paper explores the causes, mechanisms, and consequences of ocean acidification, as well as its broader implications for marine ecosystems, biodiversity, fisheries, and human societies. It also highlights potential mitigation strategies to address this pressing environmental challenge, the aim of this study is finding a good strategies to decrease the ocean acidification and decreasing the amount of CO_2, also suggesting a suitable ways for protection the animals which effected by ocean acidification. Understanding these impacts is crucial to addressing one of the lesser-known but profoundly important aspects of global climate change.

Keywords: anthropogenic CO_2, calcification, ecosystem impacts, hypercapnia, ocean acidification, physiological effects.

INTRODUCTION

Animals at many levels of biological organization are being and will continue to be impacted by climate change. Although the majority of studies on how wildlife behaves in response to climate change have been on the consequences of rising [1]. The term "ocean acidification" refers to the decrease in marine pH brought on by the absorption of carbon dioxide (CO_2) from the atmosphere that is anthropogenic. From average preindustrial levels of ~280 µatm through to current levels of ~420µatm, the partial pressure of CO_2 (pCO_2) of the open ocean is expected to reach 800–1000 µatm by the end of the century if emissions remain unabated, resulting in a pH decline from current levels of~8.0 to ~7.6–7.7 [2]. Rising atmospheric carbon dioxide (CO_2) concentration is causing global warming and ocean acidification [3]. Over the past century, atmospheric carbon dioxide (CO_2) increased and the global oceans have absorbed approximately one-third of the CO_2 emissions from human activities, particularly fossil fuel combustion and deforestation [4], this increasing of CO_2 in atmosphere has been occurred faster than the natural increase [5]. Generally Industrial development has been changed the Earth's climate, which lead to change in natural systems that have increasingly inequitable outcomes for humans [6]. While this absorption mitigates the extent of atmospheric warming, it comes at a cost to ocean health. As CO_2 dissolves in seawater, it forms carbonic acid, which lowers the ocean's pH—a process known as ocean acidification. Ocean acidification may come to be understood as one of the most serious human-caused threats to endanger our ocean; a threat that, like climate change, is a result of ongoing burning of fossil fuels and emissions from land-use changes. As carbon dioxide levels (CO_2) in the atmosphere rise, increasing amounts of the gas are absorbed by the ocean, causing a profound change in its chemistry by making it more acidic [7]. Elevated partial pressure of CO_2 (pCO_2) in seawater (also known as hypercapnia) can impact marine organisms both via decreased calcium carbonate ($CaCO_3$) saturation, which affects calcification rates, and via disturbance to acid–base (metabolic) physiology. Recent work indicates that the oceanic uptake of anthropogenic CO_2 and the concomitant changes in seawater chemistry have adverse consequences for many calcifying organisms, and may result in changes to biodiversity, trophic interactions, and other ecosystem processes [8]. The inorganic carbon system is one of the most important chemical equilibria in the ocean and is largely responsible for controlling the pH of seawater, dissolved inorganic carbon (DIC) exists in seawater in three major forms: bicarbonate ion (HCO_3 2), carbonate ion (CO_3 22), and aqueous carbon dioxide

(CO2(aq)), which here also includes carbonic acid (H2CO3), at a pH of 8.2, 88% of the carbon is in the form of HCO3 2, 11% in the form of CO3 22, and only 0.5% of the carbon is in the form of dissolved CO_2, when CO2 dissolves in seawater, H2CO3 is formed (Figure 1). Most of the H2CO3 quickly dissociates into a hydrogen ion (H+) and HCO_3. A hydrogen ion can react with a CO3 to form bicarbonate. Therefore, the net effect of adding CO2 to seawater is to increase the concentrations of H2CO3, HCO3, and H+, and decrease the concentration of CO_3 and lower pH (pH = 2log[H+]). These reactions are fully reversible, and the basic thermodynamics of these reactions in seawater are well known [9]. And without which atmospheric CO_2 would be approximately 450 ppmv today, a level of CO_2 that would have led to even greater climate change than witnessed today. Ocean CO_2 uptake, however, is not benign; it causes pH reductions and alterations in fundamental chemical balances that together are commonly referred to as ocean acidification. Because climate change and ocean acidification are both caused by increasing atmospheric CO_2, acidification is commonly referred to as the “other CO_2 problem [10]. This phenomenon has profound and widespread effects on marine ecosystems, particularly calcifying organisms such as corals, mollusks, and some plankton species [11, 12]. The world’s oceans play a critical role in regulating the Earth's climate, absorbing roughly one-third of the carbon dioxide (CO_2) emitted into the atmosphere by human activities. However, this process, while mitigating the effects of climate change, is not without consequences. Ocean acidification, often referred to as the "other CO2 problem," occurs when CO_2 dissolves in seawater, forming carbonic acid and lowering the ocean’s pH. Over the past 200 years, the oceans have become approximately 30% more acidic, a rate of change unprecedented in the last 300 million years [13, 14]. This rapid shift in ocean chemistry poses significant threats to marine ecosystems, particularly species that rely on calcium carbonate, such as corals, mollusks, and certain types of plankton. As the ocean becomes more acidic, these organisms struggle to build and maintain their shells and skeletons, leading to ripple effects throughout marine food webs. Beyond biological impacts, ocean acidification also threatens the livelihoods of millions of people who depend on marine resources for food and income [15, 16].

Causes of Ocean Acidification

First, when CO2 dissolves in seawater, most of it becomes carbonate ions and hydrogen ions (CO32 + H+). This increase in hydrogen ions (H+) decreases the pH, making the water more acidic. Secondly, the excess hydrogen ions combine with carbonate to form bicarbonate, decreasing the concentration of carbonate in the water. Carbonate ions are an important building block of structures such as sea shells and coral skeletons. Decreases in carbonate ions can make building and maintaining shells and other calcium carbonate ($CaCO_3$) structures difficult for calcifying organisms such as oysters, clams, sea urchins, shallow water corals, deep-sea corals, and calcareous plankton. Also, when too many hydrogen ions(H+) are present in seawater without a molecule to bond with, the calcium carbonate molecules ($CaCO_3$) will break apart, the carbonates will leave behind the calcium ions to form a bond with hydrogen ions (H+). This causes shells and structures made of calcium carbonate to dissolve. These changes in ocean chemistry can affect the behavior of non-calcifying organisms as well. The ability of some fish to detect predators is decreased in more acidic waters. When these organisms are at risk, the entire food web may also be at risk, ocean acidification is affecting the entire world’s oceans, including coastal estuaries and waterways. Many economies are dependent on fish and shellfish, and many people worldwide rely on food from the ocean as their primary source of protein [17, 18].

The Chemical Reactions of CO2 in the Ocean

First, CO_2 reacts with water to form carbonic acid (H2CO3-)

CO2 + H2O = H2CO3-

Carbonic Acid is a weak acid that rapidly breaks down into bicarbonate (HCO3-) plus hydrogen ion which then can lower pH

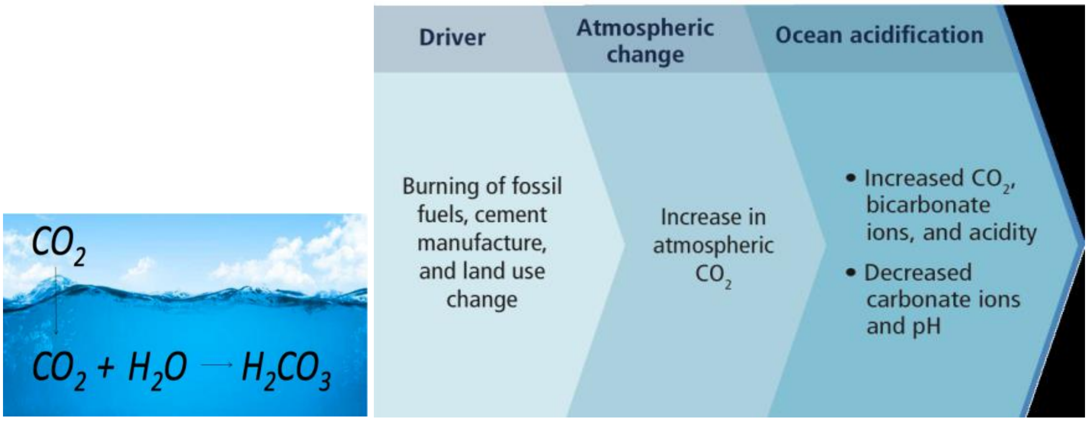
H2CO3- = H+ + HCO3-

Bicarbonate dissolves into carbonate ions (CO32-) and adds more hydrogen ions further drop of pH

HCO3- = H+ + CO32-

At first glance it may seem that ocean acidification is producing more carbonate ions; however, the chemical reactions can go in either direction. In fact, the chemical reactions does reverse, and with more CO2 creating more H+ ions and making the water more acidic, carbonate ions are very attracted to H+ and bond with the extra H+ ions to produce bicarbonate. This reduces the carbonate available to combine with calcium to create calcium carbonate structures used by marine organisms to make skeletal structures for life.

CO2 + H2O + CO32- = 2 HCO32-



Consequences of Ocean Acidification

1. **Impact on Calcifying Organisms:** Many marine organisms, such as corals, mollusks, and some plankton, rely on calcium carbonate to form their shells and skeletons. Ocean acidification reduces the concentration of carbonate ions, making it more difficult for these organisms to produce and maintain their structures. As a result, organisms like oysters, clams, and coral reefs are particularly vulnerable. Coral reefs, which are vital to marine biodiversity, are already experiencing significant damage from ocean acidification, leading to coral bleaching and reduced reef resilience. [19]
2. **Disruption of Marine Food Webs**: Ocean acidification affects not only individual species but also entire ecosystems. Many calcifying plankton species, such as pteropods and foraminifera, form the base of the marine food web. Their decline can ripple through the food chain, affecting fish populations and, subsequently, the predators that depend on them, including humans. As these foundational species struggle to survive in more acidic waters, the entire marine ecosystem becomes less stable and productive. [3]
3. **Behavioral and Physiological Changes in Marine Species:** In addition to its effects on calcifying organisms, ocean acidification can alter the behavior and physiology of marine species,
4. Scientists found that in more acidic conditions, young clownfish lost the ability to navigate home using their sense of smell. The fish also became attracted to odors they normally avoid, such as the scent of predators, and displayed uncharacteristically bold behaviors such as roaming far from their home reef. the marine species may experience reduced growth rates, compromised immune systems, and changes in reproductive success due to the altered chemical environment [20].
5. **Impact on Fisheries and Coastal Communities:** The economic implications of ocean acidification are profound, particularly for coastal communities that rely on fisheries and shellfish farming. Many commercially valuable species, such as crabs, lobsters, and oysters, are vulnerable to acidifying waters. As these species decline, the livelihoods of millions of people who depend on marine resources are at risk. The degradation of coral reefs, which provide critical habitat for many fish species, further exacerbates the impact on fisheries and marine biodiversity [19].

Broader Ecological and Environmental Impacts

1. **Coral Reef Degradation:** Coral reefs are among the most bio-divers ecosystems on the planet, providing habitat for thousands of marine species. Ocean acidification weakens coral skeletons, making them more susceptible to breakage and erosion. Additionally, acidified waters hinder the ability of corals to recover from bleaching events caused by rising sea temperatures. As coral reefs decline, so does the biodiversity they support, leading to a cascade of ecological consequences [21].
2. **Loss of Biodiversity:** The combined effects of acidification, warming, and other human-induced stressors are driving biodiversity loss in the oceans. Many marine species are already struggling to adapt to the rapidly changing environment. The loss of biodiversity threatens the stability and functioning of marine ecosystems, reducing their resilience to further environmental changes [22].
3. **Ocean Deoxygenation and "Dead Zones":** Ocean acidification, combined with global warming, contributes to ocean deoxygenation, creating hypoxic "dead zones" where oxygen levels are too low to support most marine life. These dead zones are expanding, further threatening marine ecosystems and exacerbating the decline of biodiversity [23]

Mitigation Strategies

Addressing ocean acidification requires global efforts to reduce CO_2 emissions and limit other human impacts on the ocean. Key mitigation strategies include:

1. **Reducing Carbon Emissions:** The most effective way to slow ocean acidification is to reduce the amount of CO_2 entering the atmosphere. This can be achieved through the transition to renewable energy sources, energy efficiency measures, and reforestation efforts.

One mitigation approach suggested by researchers involves sequestering carbon on the ocean floor by fertilizing certain ocean regions with iron, which can be a limiting nutrient in these areas. Pollard et al examined an area of the Southern Ocean with high nutrients and low chlorophyll (HNLC) and found that influxes of terrestrial iron led to rises in primary productivity [17]. The resulting phytoplankton blooms produce more carbon-containing molecules that then travel through carbon flux and sink down to be sequestered on the sea floor. The observation of this phenomenon has led to proposals from private industry to utilize iron fertilization as a carbon offset on a global carbon market. A review of this plan's effects and side effects is therefore of timely importance [18]. Cullen and Boyd enumerate the main points of iron fertilization: it will increase primary productivity in areas of the ocean where large amount of macronutrients are currently unused, and thus send more organically formed carbon-containing molecules down into the depths of the ocean where they are sequestered as particulates. Along with this intended result, these will also occur: macronutrients will be collected in the deep ocean with carbon, and become unavailable downstream in the nutrient flow from the site of iron fertilization; and oxygen levels at midlevel depths will decrease as heightened levels of organic material decompose, and release CO2. Iron fertilization could have negative feedbacks that lessen some of the carbon capture, and could negatively effect ocean ecosystem functioning [18].

2. **Marine Protected Areas:** Establishing marine protected areas (MPAs) can help safeguard vulnerable ecosystems and species from additional human pressures, such as overfishing and pollution. MPAs can also serve as refuges for species that may be more resilient to acidification. [24].
3. **Restoration of Coastal Ecosystems:** Protecting and restoring coastal ecosystems like mangroves, sea grasses, and salt marshes can enhance natural carbon sequestration and provide buffer zones against ocean acidification. These ecosystems act as carbon sinks, absorbing CO_2 and mitigating its effects on marine environments.
4. **Research and Monitoring** Continued research into the effects of ocean acidification and its interaction with other climate-related stressors is crucial for developing effective adaptation and mitigation strategies. Monitoring changes in ocean chemistry and its biological impacts can help inform policy decisions and conservation efforts.

CONCLUSION

Ocean acidification is one of the most significant consequences of anthropogenic CO_2 emissions, with far-reaching effects on marine ecosystems, biodiversity, and human societies. The consequences of acidification are already being felt in vulnerable marine species and habitats, and the situation is likely to worsen if global CO_2 emissions are not curbed. Collaborative international efforts to reduce emissions, protect marine ecosystems, and advance scientific understanding are essential to mitigate the impacts of ocean acidification and preserve the health of the world's oceans for future generations.

More than one way to mitigate the build-up of acidifying carbon dioxide in the world's oceans has been proposed. Addition of limestone or iron fertilization might prove to be appropriate responses; however, the global nature of the problem means that potential solutions must also be global, and will have profound effects on ocean chemistry and biology. This inspires caution, although some researchers ask how much caution is merited in regards to mitigation proposals when the predicted accumulation of oceanic carbon is poised to set off such drastic alterations in marine ecosystems [25]. Whether mitigating efforts are undertaken or not, ocean chemistry is changing.

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