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Research on the Principle of Ocean Acidification and its Impact on Marine Organisms

Yanchao Zhao

Northeast Yucai Foreign Language Middle School, Shenyang, China
CYDcola@163.com

Abstract: This paper investigates the mechanisms of ocean acidification and its effects on marine biota. Ocean acidification is where seawater absorbs too much carbon dioxide from the atmosphere, increasing acidity, measured by pH value. Its causes include human activities (fossil fuel burning, deforestation), climate activities (ocean warming, sea ice melting), and natural phenomena (volcanic eruptions, etc.). Historical PETM events and the end Permian mass extinction event indicate ocean acidification significantly impacts biodiversity. Ocean acidification may induce behavioral and physiological alterations in non-calcifying marine organisms, including modifications to the swimming patterns of clownfish and the foraging behaviors of planktonic fauna. For calcified microorganisms, it can hinder coral bone formation and shellfish shell formation, reducing juvenile survival rates. Overall, ocean acidification disrupts the marine food web, reduces biodiversity, damages ecosystem stability and adaptability, and requires in-depth exploration of its mechanisms and the development of response strategies.

Keywords: Ocean acidification, Marine organism, Physiology, Ecosystem

1. Introduction

Ocean acidification is the process by which the absorption of excessive atmospheric carbon dioxide by seawater results in a reduction in acidity. Acidity is usually represented by pH value, ranging from 0-14. The pH value is the negative logarithm of the concentration of hydrogen ions ([H^+]) in a solution (Formula 1), used to measure the strength of the acidity or alkalinity of the solution. The range is usually 0-14, with 7 being neutral, less than 7 being acidic, and greater than 7 being alkaline. Seawater should be weakly alkaline, and the ocean's pH value of surface water is about 8.2.

$$PH = -\log_{10}[H^+] \tag{1}$$

When carbon dioxide is absorbed by seawater, carbon dioxide molecules react with water molecules in seawater to produce car bonic acid (Formula 2 is a reverse reaction). Subsequently, carbonic acid dissociates in aqueous solution, yielding hydrogen ions and bicarbonate ions (Equation 3). Subsequently, bicarbonate ions undergo secondary ionization in water, generating hydrogen and carbonate ions (Formula 4). During this process, the ionized hydrogen ions cause a decrease in the pH value of the ocean.

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$$CO_2\,(aq) + H_2O \rightarrow H_2CO_3(aq) \tag{2}$$

$$H_2CO_3\,(aq) \rightarrow H^+ + HCO_3^-\,(aq) \tag{3}$$

$$HCO_3^-\,(aq) \rightarrow H^+ + CO_3^{2-}\,(aq) \tag{4}$$

This article explores ocean acidification principles and its impact on marine organisms through a comprehensive literature review. The research examines ocean acidification's direct and indirect effects on aquatic life, including changes in behavior, physiological processes, and ecosystem dynamics. The significance of this research lies in its contribution to understanding the complex mechanisms of ocean acidification and its consequences for marine biodiversity and ecosystem stability. This study highlights the potential long-term impacts of ocean acidification on marine ecosystems by analyzing historical events such as the Paleocene Eocene Thermal Maximum (PETM) and the end-Permian mass extinction. Furthermore, the findings provide valuable insights for developing strategies to mitigate and adapt to the ongoing changes in ocean chemistry, offering a scientific basis for conservation efforts and policy-making.

2. Causes of ocean acidification

2.1. Anthropic activity

Since the Industrial Revolution, humans have extensively used fossil fuels such as coal, oil, and natural gas, which release large amounts of carbon dioxide during combustion. Globally, the annual combustion of fossil fuels results in the emission of billions of tons of carbon dioxide. Oceanic absorption accounts for approximately 30% of these emissions, while the ocean absorbs about 23%.

Furthermore, extensive deforestation practices have resulted in an ongoing decline in forest cover, thereby diminishing the capacity of forests to sequester carbon dioxide. Consequently, a greater quantity of carbon dioxide persists within the atmosphere, ultimately leading to increased oceanic absorption. It is estimated that deforestation causes approximately 10% -15% of global greenhouse gas emissions annually.

2.2. Climate activity

The ocean warming and ice melting caused by climate change will indirectly exacerbate ocean acidification. Ocean warming is projected to induce significant shifts in the ocean's physical and chemical characteristics, thereby impacting the equilibrium of carbon dioxide sequestration and outgassing within the marine environment. The melting of sea ice dilutes seawater, affecting its chemical composition and acid-base balance.

2.3. The impact of natural phenomena

In addition to human activities, some natural processes, such as volcanic eruptions, also release large amounts of carbon dioxide and other acidic gases, which have a certain impact on ocean acidification. In contrast to anthropogenic influences, the contribution of natural processes to ocean acidification is comparatively minor.

DOI: 10.54254/2753-8818/2025.LD25834

3. Related events in history

3.1. Palaeocene Eocene Extreme Heat Event (PETM)

PETM occurred approximately 56 million years ago and is one of Earth's most severe ocean acidification events. In this incident, the concentration of carbon dioxide in the Earth's atmosphere doubled, causing a temperature rise of 6 ℃ and resulting in the extinction of many species. The time scale of the PETM is 20000 years, while the concentration of carbon dioxide on Earth has increased by 30% in the past 100 years.

3.2. The end permian mass extinction event

About 250 million years ago, the Siberian volcano erupted violently, releasing much carbon dioxide and causing ocean acidification. The fossil record indicates that up to 96% of marine species and 70% of terrestrial species have perished, resulting in the extinction of 90% of marine life and two-thirds of terrestrial life on Earth. This is the largest of the five mass extinctions in Earth's history. The ocean did not recover vitality for nearly 5 million years after the extinction event.

4. The impact of the marine ecosystem under ocean acidification conditions

4.1. Impacts on non-calcified organisms' behavior

Some studies have found that ocean acidification can alter the swimming behavior of non-calcified marine organisms. For example, the swimming speed of juvenile clownfish in acidified seawater slows, and their perception of the surrounding environment decreases, affecting their ability to find food and avoid predators [1].

The acidification of the ocean can also affect the feeding behavior of non-calcifying organisms. Some planktonic animals may experience changes in their food preference in acidic environments, reducing their feeding on certain nutrient-rich phytoplankton and subsequently affecting their growth and reproduction [2].

Ocean acidification may alter some non-calcified algae's growth rate and biomass allocation, such as diatoms. In an acidic environment, the growth of some algae may be promoted or inhibited, depending on the type of algae and specific environmental conditions. Meanwhile, acidification may also affect the distribution pattern of algae, altering their distribution range in different water layers or sea areas [3].

Ocean acidification can affect physiological processes such as photosynthesis and respiration of algae. Some algae may increase or decrease their photosynthetic efficiency in acidified seawater, affecting their carbon fixation ability and energy metabolism. Furthermore, acidification may also modulate the interactions between algal species and other biota. such as plankton, affecting the feeding choices and efficiency of plankton towards algae, thereby altering the food chain structure of the entire marine ecosystem.

Non calcifying organisms are an essential component of the marine food web. If non-calcifying phytoplankton decrease due to ocean acidification, it may decrease the number of zooplanktons that feed on them, thereby affecting the energy flow and material cycling of the entire marine ecosystem .

Ocean acidification can threaten the survival of some non-calcifying species, leading to a decrease in population size or even extinction. This will disrupt marine ecosystems' biodiversity, reducing their stability and adaptability [4].

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4.2. Impacts on calcified organism's behavior

Ocean acidification makes it difficult for corals to build bones and slows their growth rate. Simultaneously, this phenomenon will impact coral larvae settlement behavior, diminishing their capacity to colonize secure habitats like seagrass beds, thereby influencing coral reproductive success and population dispersal. Related studies have shown that under high concentrations of carbon dioxide, the ability of coral larvae to attach to reefs decreases. For example, Munday et al. found that ocean acidification can alter clownfish's avoidance response to predator odors and affect their ability to locate in coral reef areas. Coral, as a habitat for clownfish, affects the attachment behavior of their larvae, which indirectly affects the survival and reproduction of fish and other organisms that rely on coral for survival

Ocean acidification slows the formation and growth rate of shellfish shells, and reduces the survival rate during the juvenile stage. Concurrently, shellfish filtration dynamics may be compromised, resulting in altered clearance rates. This, in turn, could impact nutrient acquisition efficiency, potentially influencing both feeding periodicity and habitat preference. As mentioned by Zhang Dong [5], research on aquatic animal behavior can be applied to aquaculture, and the impact of ocean acidification on the behavior of shellfish and other aquatic animals is also an important research topic [6].

Calcifying organisms are an important component of the marine food chain. Suppose calcified plankton decreases due to ocean acidification. In that case, it may decrease the number of planktonic animals that feed on them, thereby affecting the energy flow and material cycling of the entire marine ecosystem [7].

Ocean acidification can threaten the survival of some calcified organisms, leading to a decrease in population size or even extinction. This will destroy marine ecosystems' biodiversity, reducing their stability and adaptability [8].

5. Ocean acidification's physiological effects on marine organisms

5.1. Effects on non-calcified animals

Research has shown ocean acidification can interfere with non-calcified organisms' respiration and metabolic processes. Taking the eel as an example, its gills are the main site of gas exchange. Acidizing seawater can affect the gills' ion regulation and acid base balance, leading to an increase in CO_2 content and a decrease in pH value in the blood, which in turn affects oxygen transport and metabolic processes [9].

The decrease in seawater pH also weakens the immune defense of non-calcified organisms. For example, the expression of immune-related genes in the acidified environment of sea cucumber is inhibited, making them more vulnerable to the invasion of pathogens, and the incidence rate and mortality are significantly increased [10].

5.2. Effects on calcified animals

Ocean acidification reduces calcium carbonate saturation in seawater, decreasing the amount of calcium carbonate available to calcifying organisms, thereby slowing down their calcification rate and quality. For example, under acidic conditions, the calcification rate of corals significantly decreases, and their skeletal structure becomes fragile and susceptible to physical damage [11].

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Calcified organisms in an acidic environment may have their metabolic activities affected, which could lead to an imbalance in energy allocation within the organism. In acidified seawater, shellfish must expend additional metabolic energy to maintain acid-base equilibrium, which subsequently reduces the energy available for somatic growth and reproductive output [12].

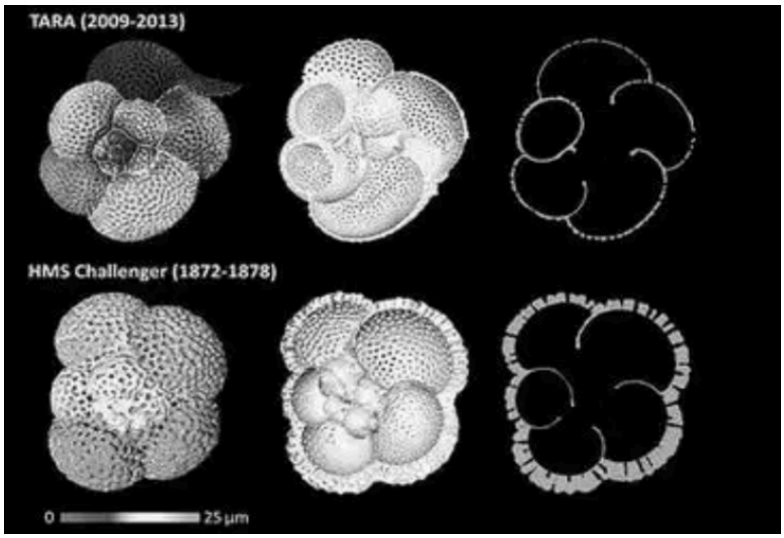


Figure 1. Climate change and ocean acidification: changes in the skeletons of marine organisms over the past century.

Figure 1 shows the skeletal structures of two groups of organisms, each from two different time spans: the sample from the "TARA (2009-2013)" period at the top and the sample from the "HMS Challenger (1872-1878)" period at the bottom. Analysis of the image sets reveals a significant reduction in the thickness of calcified organism exoskeletons following a century of ocean acidification.

6. Ocean acidification's impact on marine organisms' metabolism and growth

6.1. The impact on metabolism

Ocean acidification increases the energy expenditure of marine organisms for acid-base homeostasis. For example, shellfish require additional energy to regulate their acid-base balance in acidified seawater, decreasing energy used for growth and reproduction. Ocean acidification mainly inhibits the embryonic development, energy metabolism, basic biological processes, and calcium ion conduction-related genes and pathways of Fujian oysters, leading to delayed larvae growth [13].

What's more, ocean acidification can affect the nutritional composition of microalgae, such as a possible decrease in the content of polyunsaturated fatty acids (PUFA) in diatoms. In contrast, the proportion of PUFA in microalgae increases under long-term acidification conditions. In addition, short-term acidification can stimulate microalgae to synthesize more proteins and soluble carbohydrates. Still, long-term acidification can lead to a decrease in their content and an increase in the C/N ratio, affecting the efficiency of nutrient transfer in the food chain.

6.2. The impact on juvenile development

Many marine organisms exhibit developmental abnormalities in their larvae when exposed to acidic seawater. The juveniles of sea snakes exhibit developmental abnormalities when exposed to

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seawater with a pH decrease of 0.2-0.4 units. The juveniles of shellfish, conches and other shellfish die prematurely due to their inability to form shells [14].

Research indicates that a 0.4-unit reduction in seawater pH correlates with a 16% decrease in sea urchin sperm swimming speed, a 12% reduction in swimming velocity, and a 25% decline in fertilization success. These findings predict a population reduction to 10% of the initial size after eight generations.

Due to various factors mentioned above, ocean acidification can decrease the survival rate of marine organisms' juveniles. The larvae of shellfish such as oysters die in acidified seawater due to the inability to form shells properly, decreasing their population size. Under 1500 ppm pCO_2, Fujian oyster larvae did not show significant effects. Still, under 3000 ppm pCO_2, the larvae were smaller, the shell growth was slow, and the deformity rate increased.

7. Conclusion

In conclusion, ocean acidification is a significant environmental issue that negatively impacts marine organisms. This research has provided a comprehensive overview of the principles of ocean acidification and its effects on marine life. The key findings include understanding how anthropogenic activities, climate change, and natural phenomena contribute to ocean acidification. Ocean acidification, as evidenced by past events like the Paleocene-Eocene Thermal Maximum and the Permian-Triassic extinction, poses significant threats. This study examines the effects of ocean acidification on marine organisms, including calcified and non-calcified species, their behavior, and ecosystem dynamics. Results show reduced growth, impaired calcification, behavioral changes, and decreased survival rates. These findings underscore the need for further research into mitigation and adaptation strategies. This study offers a general overview but lacks in-depth mechanistic analysis. Future research should focus on the long-term effects of ocean acidification on marine ecosystems and potential mitigation strategies.

References

[1] Munday, P. L., Donelson, J. M., Dixson, D. L., & Endler, J. A. (2009). Effects of ocean acidification on the early life history of coral reef fishes. Coral Reefs, 28(3), 511-519.
[2] Lohbeck, K. T., Riebesell, U., & Reusch, T. B. H. (2012). Reduced grazing under ocean acidification: zooplankton feeding preferences and phytoplankton nutritional quality. Marine Ecology Progress Series, 458, 13-24.
[3] Boyd, P. W., Riebesell, U., & Armstrong, R. A. (2010). A mesocosm study of the effects of ocean acidification on plankton dynamics and biogeochemistry. Limnology and Oceanography, 55(4), 1542-1559.
[4] Zhou Liantao (2014) Research progress on ocean acidification and its impact on marine organisms (Doctoral dissertation). Shandong University
[5] Fleming, A. J., & Smith, M. D. (2016). Ocean acidification affects shell formation but not growth or lipid content in a marine bivalve, Mytilus galloprovincialis. Marine Environmental Research, 115, 1-7.
[6] Zhang Dong (2013) New progress and applications in the study of aquatic animal behavior. Aquatic Science, 2, 132-136
[7] Fabry, V. J., Seibel, B. A., Feely, R. A., & Orr, J. C. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science, 65(3), 414-432.
[8] Guinotte, J. M., & Fabry, V. J. (2008). Ocean acidification and its potential effects on marine ecosystems. Annual Review of Environment and Resources, 33, 321-348.
[9] Heuer, R., & Grosell, M. (2014). Acid-base regulation in fish: cellular and molecular mechanisms. Journal of Experimental Biology, 217(12), 2193-2202.
[10] Melzner, F., Sturzenbaum, S. R., & Käse, R. (2013). Marine invertebrate immune systems: evolutionary ecology meets environmental chemistry. Marine Genomics, 9, 55-64.
[11] Kline, D. I., C. J. (2012). Ocean acidification and calcifying organisms: a snapshot of key mechanisms and interactions. Marine Genomics, 5(2), 79-87.

DOI: 10.54254/2753-8818/2025.LD25834

[12] Waldbusser, G. G., & Salisbury, J. E. (2014). Ocean acidification: the bigger picture for estuarine and coastal marine ecosystems. *Marine Ecology Progress Series*, 504, 291-296.
[13] Zou, H., Zhang, Y., Zhang, H., et al. (2019). Transgenerational exposure to elevated CO_2 affects larval development and associated transcriptomic profiles in the Pacific oyster (Crassostrea gigas)—Journal of Marine Science and Engineering, 7(12), 432.
[14] Kroeker, K. J., Kordas, R. L., Crim, R., & Singh, G. G. (2010). Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecology Letters, 13(11), 1419-1434.