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The Physiological and Ecological Effects between Ocean Acidification and Coral Reefs

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Abstract In recent decades, the concentration of CO_2 in the atmosphere has continued to rise, leading to global changes such as global warming and ocean acidification. The CO_2 in the atmosphere is dissolved in the ocean through water gas exchange to achieve water gas balance. The continuously increasing CO_2 concentration changes the marine hydrochemical system, especially breaking the original carbonate equilibrium system, reducing the pH value, carbonate ion concentration, and calcium carbonate saturation in seawater, leading to ocean acidification. A normal seawater hydrochloric acid system can promote the biological activity of coral reef ecosystems, while ocean acidification not only leads to a decrease in the calcification rate of calcified organisms in coral reef systems, but also leads to dissolution phenomena in coral reef systems. This review analyzes the phenomenon of ocean acidification, understands the ecological effects of coral reef systems in the process of ocean acidification, proposes corresponding protection measures, and hopes to strengthen the protection of the ocean and coral reef systems globally.

Keywords Ocean acidification; Coral reefs; Ecological effect

Coral reefs are one of the most precious and fragile ecosystems on Earth, known as the tropical rainforests of the ocean. They are composed of the calcareous skeletons of coral animals and the symbiotic microphytes (known as symbiotic algae). These wonderful underwater structures are not only beautiful natural landscapes, but also carry rich biodiversity and ecological functions. Coral reef ecosystems have enormous value for both humans and the Earth's environment. They are important fishing resources that provide food and economic resources for millions of people. Many fishing activities, such as fishing, aquaculture, and tourism, rely on the health and abundance of coral reefs; Coral reefs play an important protective role in mitigating coastal erosion and preventing natural disasters such as storm surges and waves from damaging coastal areas; In addition, coral reefs provide habitats and breeding grounds for many organisms, maintaining the balance of marine ecosystems (Figure 1).

Figure 1 Ecological environment of submarine coral reefs

Coral reefs are also one of the most abundant and diverse environments in the global marine ecosystem, providing shelter and food sources for countless marine species. However, in recent years, ocean acidification caused by global climate change has posed a serious threat to coral reefs and their ecosystems (Albright and Cooley, 2019). Ocean acidification is caused by an increase in the concentration of carbon dioxide in the atmosphere, which leads to changes in the acidity and alkalinity of seawater. This is because carbon dioxide dissolves in seawater, forming carbonate ions, causing the pH value of seawater to decrease and become more acidic. This has a direct impact on the physiological processes and bone formation of coral animals, slowing down the growth rate of corals and leading to bone dissolution. The climate change caused by greenhouse gas emissions leads to an increase in seawater temperature, leading to coral bleaching (Figure 2). Coral bleaching refers to the disorder of the relationship between corals and symbiotic algae, causing symbiotic algae to detach from the coral body and cause coral to turn white. This deprives corals of important sources of nutrients and makes them vulnerable to disease and death. The problems caused by climate change pose a huge threat to coral reef ecosystems. Research on a global scale indicates that many coral reefs are experiencing severe degradation and death, reduced biodiversity, and damaged ecological functions.

Figure 2 The impact of ocean acidification on coral bleaching phenomenon

Therefore, in order to protect and manage coral reef ecosystems, it is crucial to have a deep understanding of the impact of climate change on them. By studying the physiological and ecological effects of coral reefs, we can better understand their response mechanisms and adaptability to climate change. This research can involve the growth rate of corals, the process of bone formation, the interaction between corals and symbiotic algae, and the mechanism of coral bleaching. This paper aims to explore the physiological and ecological effects of ocean acidification on coral reefs and their ecosystems, provide scientific basis for the protection and management of coral reefs, and promote global attention and action on climate change and ocean acidification issues.

1 Overview of Coral Reef Ecosystems

1.1 Key components of coral reef ecosystems

The coral reef ecosystem is a complex and diverse ecosystem composed of coral animals, symbiotic algae, other biological populations, and abiotic environmental factors. Coral animals are the core elements of coral reefs, belonging to the class Anthozoa and mainly divided into two categories: hard corals (bony corals) and soft corals (cartilaginous corals). Coral animals have calcareous skeletons that gradually build coral reef structures by secreting calcium. There is an important symbiotic relationship between coral animals and symbiotic algae

(Zooxanthella). Symbiotic algae are a type of micro unicellular plants that live within the tissues of coral animals. They convert sunlight into energy through photosynthesis and produce organic matter, providing energy and nutrients for corals. At the same time, coral animals provide a suitable living environment and shelter for symbiotic algae, and this symbiotic relationship enables corals to survive and thrive in nutrient poor waters.

In addition to coral animals (Figure 3) and symbiotic algae, coral reef ecosystems also include other rich and diverse biological populations. Fish, shellfish, sea anemones, sponges, and marine plants, along with coral animals and symbiotic algae, form a complex food web. Fish find refuge, breeding grounds, and food sources in coral reefs (Alissa and Laura, 2023), while also helping to remove algae from corals and maintain their healthy state. The presence of other biological populations enriches the biodiversity of coral reefs and promotes the stability and function of ecosystems.

Figure 3 Underwater organisms on coral

Non biological environmental factors play an important regulatory role in the development and maintenance of coral reef ecosystems. The temperature of seawater is a key factor, and an appropriate temperature is conducive to the growth and reproduction of corals. Excessive temperature can lead to the breakdown of the symbiotic relationship between coral animals and symbiotic algae, known as coral bleaching. In severe cases, it may lead to coral death. Light levels also have a significant impact on coral reef ecosystems. Insufficient light can affect the photosynthetic efficiency of symbiotic algae, affecting the growth and health of corals. Changes in salinity can also have an impact on the adaptability of coral and other biological populations. However, global climate change has led to increased seawater temperature and ocean acidification, posing pressure and death risks to corals and symbiotic algae (Li and Yi, 2021). Overfishing, pollutant emissions, and human activities have also had serious impacts on coral reefs. Overfishing has disrupted the food chain and ecological balance of coral reefs, leading to a decrease in fish and other biological populations.

1.2 Ecological roles and functions of coral reefs

Coral reefs play an important role in marine ecosystems and provide multiple functions. Coral reefs are hotspots of biodiversity and treasure troves of species richness. They are home to numerous marine organisms, providing shelter and breeding grounds for various species, and are habitats for many organisms such as fish, shellfish, crustaceans, sea anemones, sponges, and marine plants. These organisms form complex food webs and ecosystem interactions in coral reefs (Michael and Philip, 2019), maintaining the stability and functionality of marine ecosystems.

Coral reefs also provide a source of food for many species. Coral animals and symbiotic algae in coral reefs produce organic matter through photosynthesis and provide energy and nutrients. These organic substances become a food source for other organisms, including plankton, small fish, crustaceans, etc. Fish rely on plankton and other small organisms in coral reefs to feed, forming a complex food chain (Josefin et al., 2019). The food chain of coral reefs not only nourishes the organisms within the coral reef ecosystem, but also provides important fishing resources for nearby fisheries.

In addition, coral reefs are of great significance for the protection of coastal areas. The structure of coral reefs can slow down the impact of waves and storms on coastal areas, forming a natural protective barrier. During storm surges and tsunamis, coral reefs can absorb and slow down energy, protecting coastal areas from damage. Especially for island countries and coastal communities that are frequently hit by storms and waves, the presence of coral reefs is crucial. They are in the ocean carbon cycle, where symbiotic algae absorb carbon dioxide through photosynthesis and convert it into organic matter. This helps to reduce carbon dioxide in the atmosphere and alleviate the effects of global warming. In addition, the bones of coral animals are rich in calcium. When they die, calcium can deposit on the seabed to form coral stones, which absorb a large amount of carbon dioxide during the formation process, helping to slow down global warming.

2 Background and Mechanism of Ocean Acidification

2.1 Greenhouse gas emissions and carbon cycling

During the process of ocean acidification, greenhouse gas emissions and carbon cycling have had a significant negative impact. Greenhouse gas emissions mainly refer to the emission of carbon dioxide (CO_2). Carbon dioxide is a greenhouse gas generated by human activities, such as burning fossil fuels, deforestation, and land use change. These activities result in a large amount of carbon dioxide being released into the atmosphere. A portion of carbon dioxide is absorbed by the atmosphere, forming carbonate ions that dissolve in seawater. As carbon dioxide increases, the concentration of carbonate ions in seawater also increases, leading to the process of ocean acidification.

Carbon cycle refers to the cycling process of carbon elements between different environments on Earth. Carbon can exist in various forms, including carbon dioxide in the atmosphere, carbonate ions dissolved in seawater, organic matter on land, and organisms. The carbon cycle involves the absorption, release, and transformation of carbon elements. The ocean is one of the largest carbon reservoirs on Earth, with carbonate ions in seawater playing an important role. The ocean absorbs approximately 25% of anthropogenic carbon dioxide emissions and stores them through carbon cycling processes.

There is a close relationship between greenhouse gas emissions and carbon cycling during ocean acidification. Greenhouse gas emissions lead to an increase in the concentration of carbon dioxide in the atmosphere, and a portion of carbon dioxide is dissolved in seawater to form carbonate ions. As carbon dioxide increases, the concentration of carbonate ions in seawater also increases, leading to an increase in seawater acidity, known as ocean acidification. This acidic environment has had a negative impact on marine life and ecosystems, especially posing a threat to the growth and development of calcareous organisms such as coral reefs. The carbon cycle also involves other important processes, such as biological absorption and release of carbon, deposition and dissolution of carbon. Plants and plankton in the ocean absorb carbon dioxide through photosynthesis, convert it into organic matter, and release oxygen. These organic compounds can become the foundation of the food chain, absorbed and utilized by other organisms. On the other hand, the decomposition of organic matter and biological death will release carbon dioxide into seawater.

2.2 Chemical processes of acid-base balance and ocean acidification

Ocean acidification refers to the increase in acidity in seawater, mainly caused by an increase in carbon dioxide in the atmosphere. The carbon dioxide (CO_2) generated by human activities is released into the atmosphere. Carbon dioxide has the ability to dissolve in water, including seawater, through an equilibrium process of material exchange. Between the atmosphere and the ocean, carbon dioxide can be absorbed through the $CO_2+H_2O \rightleftharpoons H_2CO_3$ reaction, which converts carbon dioxide into carbonic acid (H_2CO_3) and begins the process of ocean acidification (Figure 4). Carbonic acid can further dissociate into carbonate ions (HCO^{3-}) and hydrogen ions (H^+), which are important components of ocean acid-base equilibrium. In seawater, the concentration of carbonate ions and hydrogen ions increases with the increase of carbon dioxide, which leads to an increase in acidity.

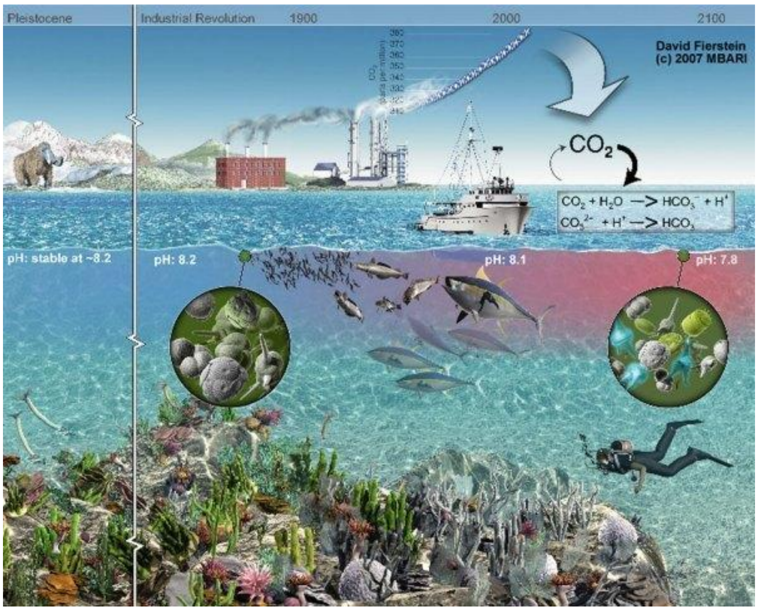

Figure 4 Process of ocean acidification

The acid-base balance in the ocean plays a role in many chemical reactions, where carbonate ions and hydrogen ions react with calcium ions (Ca^{2+}) to form calcium carbonate ($CaCO_3$), which is an important process for corals and other marine invertebrates to form bones and shells. Carbonate ions and hydrogen ions react with boric acid (H_3BO_3) to form quaternary salt ions ($B(OH)^{4-}$), which are crucial for the cycling of boron in the ocean and the metabolic processes of organisms. Carbonate ions and hydrogen ions react with iron ions (Fe^{3+}) to form iron carbonate, helping the iron cycle in the ocean and the growth and development of organisms. PH value is an indicator of the acidity and alkalinity of a solution. Ocean acidification causes an increase in the concentration of hydrogen ions in seawater, leading to a decrease in pH value (Luan et al., 2023). The pH value of normal seawater is approximately 8.1~8.3, while in areas affected by ocean acidification, the pH value may decrease to 7.8 or lower (Chen et al., 2016).

3 Physiological Effects of Ocean Acidification on Corals

3.1 The impact of ocean acidification on coral growth and bone formation

Ocean acidification leads to a decrease in the concentration of carbonate ions (CO_3^{2-}) in seawater, and corals utilize the carbonate ions and calcium ions (Ca^{2+}) in seawater to form their skeletal structures. However, due to acidification and the scarcity of carbonate ions, corals face a shortage of calcium ion supply, which limits the formation and growth of bones (Morgado et al., 2022). In acidic environments, the calcium content in coral bones decreases and the quality of the bones weakens, making the structure of corals fragile and susceptible to external pressure and damage, such as storms, waves, and physical damage, and directly affecting the growth rate of corals. In an acidic environment, corals require more energy to absorb and utilize the scarce carbonate and calcium ions in seawater, slowing down the growth process of corals and resulting in a slower overall growth rate. Weakening the immune system of coral makes it difficult to resist attacks from pathogens and other stress factors, making it more susceptible to disease and infection, increasing the risk of coral disease and death. The limited growth and decreased bone mass of corals pose a threat to the overall health and stability of coral reefs. The reduction of corals can lead to a decrease in the biodiversity of coral reef ecosystems, affecting the survival and reproduction of many species that rely on coral reefs.

3.2 Impact of ocean acidification on nutrient uptake and metabolism of corals

Corals are the cornerstone of coral reef ecosystems, providing habitats and food sources for other organisms. Ocean acidification has a negative impact on the survival and growth of corals, leading to a decrease in coral coverage and degradation of coral reef structures. Ocean acidification may affect coral's ability to absorb nutrients such as nitrogen and phosphorus. Under such conditions, the permeability of coral cell membranes may change, affecting the entry of nutrients into the cells, which may lead to limited nutrient uptake by coral and affect its growth and metabolism. A portion of coral's energy comes from symbiotic algae (called coralline algae), which produce organic matter through photosynthesis. However, ocean acidification may affect the photosynthetic efficiency of coral algae. Coral algae are subjected to stress in acidic environments, which may lead to weakened photosynthesis and a decrease in the quality of nutrients provided to corals. Corals require more energy to maintain normal physiological functions and cope with environmental pressures. This may lead to an increase in coral's metabolic rate, making it more prone to energy deficiency and growth limitations. Corals require additional energy consumption and increase their sensitivity to other stress factors.

4 Summary and Outlook

Ocean acidification has had a profound impact on the calcification process, survival and reproductive ability of corals, as well as the diversity and stability of ecosystems. Despite some research results on the impact of ocean acidification on coral reefs (Suman et al., 2023), there are still many aspects that need further exploration. Australia is one of the largest coral reef systems in the world, with the famous Great Barrier Reef (Figure 5). In order to protect and maintain the ecosystem of the Great Barrier Reef, the Australian government has taken multiple conservation measures. In 1981, the Australian government established the Great Barrier Reef Marine Park, which is one of the largest marine parks in the world with an area of approximately 345 400 km^2. There are various protection and management areas within the Ocean Park to protect coral reefs and their ecosystems. The management agency of Ocean Park is responsible for monitoring and managing activities within the park to ensure its sustainable development.

Figure 5 Australia's Great Barrier Reef

In order to protect marine life in the coral reef ecosystem, the Australian government has restricted fishing and hunting activities in the waters surrounding the Great Barrier Reef. This includes measures such as establishing prohibited fishing areas, limiting fishing quantities and methods, and implementing fishery quota management (Allemand and Osborn, 2019) to maintain the sustainable utilization of fishery resources. By managing agricultural and urban sewage discharge, controlling the use of fertilizers and pesticides. Helps to reduce the input of agricultural and urban pollutants into the ocean. Helps to reduce the concentration of nutrients in water bodies and reduce the risk of stress and eutrophication on coral reefs. Actively promote coral regeneration and restoration projects to increase coral coverage and diversity. For example, projects such as coral seedling cultivation, establishment of artificial skeletons, and transplantation of coral fragments. Through these efforts, the growth and reproduction of coral can be promoted, and the resilience of coral reefs can be increased.

The Australian government also works closely with partners such as international organizations, research institutions, civil society, and indigenous peoples to protect the Great Barrier Reef. Promote public education and awareness raising, promote sustainable tourism and fishing practices, and strengthen the management and law enforcement of marine protected areas. Continuous research and action can provide a more comprehensive understanding of the impact of ocean acidification on coral reefs and their ecosystems, and provide scientific basis and feasible solutions for the protection and management of this precious natural resource.

Authors' Contributions

WJN is the main author of this review and has completed the first draft of the paper; XXY participated in the organization and revision of paper materials; WLM is the conceptualizer and leader of the project, participating in paper analysis and guiding paper writing. All authors read and approved the final manuscript.

References

Albright R., and Cooley S., 2019, A review of interventions proposed to abate impacts of ocean acidification on coral reefs, Reg. Stud. Mar. Sci., 29: 100612-100612.
https://doi.org/10.1016/j.rsma.2019.100612

Alissa B.V., and Laura F.J., 2023, Contrasting behavioural responses to ocean acidification and warming have the potential to disrupt herbivory, Climate Change Ecology, 5: 1-8.
https://doi.org/10.1016/j.ecochg.2023.100068

Allemand D., and Osborn D., 2019, Ocean acidification impacts on coral reefs: From sciences to solutions, Reg. Stud. Mar. Sci., 28: 100558-100558.
https://doi.org/10.1016/j.rsma.2019.100558

Chen X.F., Wei G.J., Deng W.F., and Zou J.Q., 2016, Changes in pH of coral reef seawater and their significance for ocean acidification, Redai Dili (Tropical Geography), 36(1): 41-47.

Josefin S., Mirjam A., Fernando M.G., Graham R.D., and Timothy C.D., 2019, Long-term acclimation to near-future ocean acidification has negligible effects on energetic attributes in a juvenile coral reef fish, Oecologia, 190(3): 689-702.
https://doi.org/10.1007/s00442-019-04430-z

Li Y.D., and Yi L., 2021, Research progress on the ecological response of coral reefs under the background of global warming and ocean acidification, Haiyang Dizhi yu Disiji Dizhi (Marine Geology & Quaternary Geology), 41(1): 33-41.

Luan W.Y., Li H., Zhang L.T., and Liu J.G., 2023, Enhalus acoroides efficiently alleviate ocean acidification by shifting modes of inorganic carbon uptake and increasing photosynthesis when pH drops, Mar. Environ. Res., 186: 105896.
https://doi.org/10.1016/j.marenvres.2023.105896

Michael J.D., and Philip M.L., 2019, Diel CO2 cycles and parental effects have similar benefits to growth of a coral reef fish under ocean acidification, Biology Letters, 15(2): 20180724.
https://doi.org/10.1098/rsbl.2018.0724

Morgado E.A., Pires S.T., Cunha S.V.D., Fabricio M.T., and Parreira S.P.G.D., 2022, Effects of the ocean acidification on the functional structure of coral reef nematodes, Coral Reefs, 41(5): 1481-1494.
https://doi.org/10.1007/s00338-022-02296-x

Suman N., Ashna S., Bhusan N.B., Shashi B., and Karankumar R., 2023, Impacts of marine debris on coral reef ecosystem: A review for conservation and ecological monitoring of the coral reef ecosystem, Mar. Pollut. Bull., 189: 114755.
https://doi.org/10.1016/j.marpolbul.2023.114755