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SDG-14 Implementation: Scientific Assessment and CO_2 Reduction Strategies to Combat Ocean Acidification

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Abstract

Ocean acidification, a significant consequence of escalating atmospheric carbon dioxide (CO_2) concentrations, involves intricate changes in seawater chemistry with profound implications for marine ecosystems and offshore industries. Over the past three centuries, the mean atmospheric CO_2 level has risen from approximately 275 ppm in pre-industrial times to around 395 ppm, with the ocean absorbing a substantial portion of these emissions. This has led to a measurable decline in ocean pH, indicating increasing acidity. The process is primarily driven by the dissolution of CO_2 in seawater, forming carbonic acid and altering the carbonate chemistry critical to many marine organisms. If CO_2 emissions are not curtailed, the scope and impacts of ocean acidification are expected to escalate, posing severe challenges to marine biodiversity and dependent industries. For offshore engineering and technology, acidification presents unique challenges, including potential degradation of marine-based infrastructure, alteration of material performance, and impacts on operations reliant on healthy marine ecosystems, such as aquaculture and energy extraction. Furthermore, acidification may indirectly affect offshore industries by disrupting ecosystem services, including fisheries and natural carbon sequestration. This study highlights the importance of interdisciplinary strategies that integrate advancements in offshore technology with robust carbon management to mitigate acidification's impacts, protect marine ecosystems, and ensure the resilience of offshore industries in a changing ocean environment.

Keyword: Ocean acidification, seawater chemistry, atmospheric CO_2 concentration, marine life impact, global climate change

INTRODUCTION

Ocean acidification is a term used to describe the significant and unprecedented chemical changes occurring in the world's oceans due to the increased absorption of atmospheric carbon dioxide (CO_2). This phenomenon, primarily driven by anthropogenic activities, represents one of the most critical threats to marine ecosystems in the modern era. The oceans function as a natural carbon sink, taking in around 30% of the carbon dioxide emitted into the atmosphere from human activities, including fossil fuel combustion, deforestation, and industrial operations. However, while this absorption mitigates the effects of climate change to some extent, it comes at a cost. When CO_2 dissolves in seawater, it undergoes a series of chemical reactions, forming carbonic acid and leading to a reduction in the ocean's pH levels.

The increasing acidification of the oceans is causing significant disruptions to the chemical

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equilibrium of seawater, with extensive impacts on marine ecosystems and biodiversity. Since the onset of the Industrial Revolution, ocean acidity has risen by approximately 30%, a change that is both rapid and concerning. This accelerated rate of acidification poses a major challenge for marine organisms, as it progresses far more quickly than their natural capacity to adapt. Organisms that depend on calcium carbonate to build their shells and skeletons, such as corals, molluscs, and certain species of plankton, are particularly at risk. This threatens their survival and disrupts the delicate ecological balance within marine habitats. The weakening of these organisms not only endangers biodiversity but also threatens the integrity of marine food webs, which many species, including humans, depend on for sustenance and economic livelihoods.

The implications of ocean acidification extend well beyond the marine environment. It poses a significant risk to industries that rely on healthy and productive oceans, such as fisheries, aquaculture, and tourism, which are vital to the economies of many coastal communities worldwide. Additionally, the disruption of marine ecosystems can have cascading effects on global climate regulation, given the role oceans play in carbon cycling and heat absorption [1–4].

This multi-dimensional issue highlights the interconnectedness of ecological, economic, and social systems, emphasizing the urgent need for global action. Efforts to reduce CO_2 emissions, promote sustainable practices, and enhance public awareness are crucial to mitigating the adverse effects of ocean acidification and ensuring the preservation of marine ecosystems for future generations.

OCEAN ACIDIFICATION: GROWING GLOBAL CONCERN

Ocean acidification occurs when CO_2 from the atmosphere dissolves in seawater, triggering a series of chemical reactions that increase the concentration of hydrogen ions, thereby reducing seawater pH [2]. About ten times quicker than at any other point in the previous 50 million years, this fundamental shift in ocean chemistry has been occurring at an unparalleled rate [4]. Given that the pH scale is logarithmic, recent studies show that the pH of the surface ocean has already dropped from 8.2 to 8.1 during the pre-industrial era, signifying a 26% increase in acidity (Figures 1 and 2) [5–8]. The chemical process involves three primary steps.

1. CO_2 absorption at the ocean surface.
2. Carbonic acid formation (H_2CO_3).
3. Separation into bicarbonate (HCO_3^-) and hydrogen (H^+) ions.

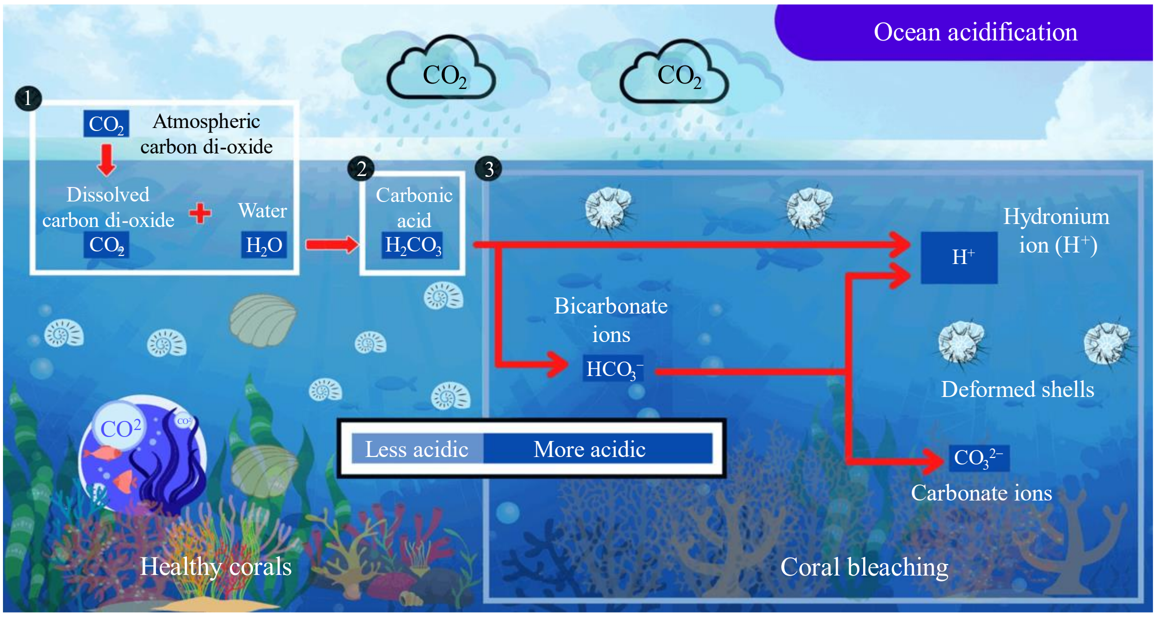

Figure 1. The process of ocean acidification through chemistry [7].

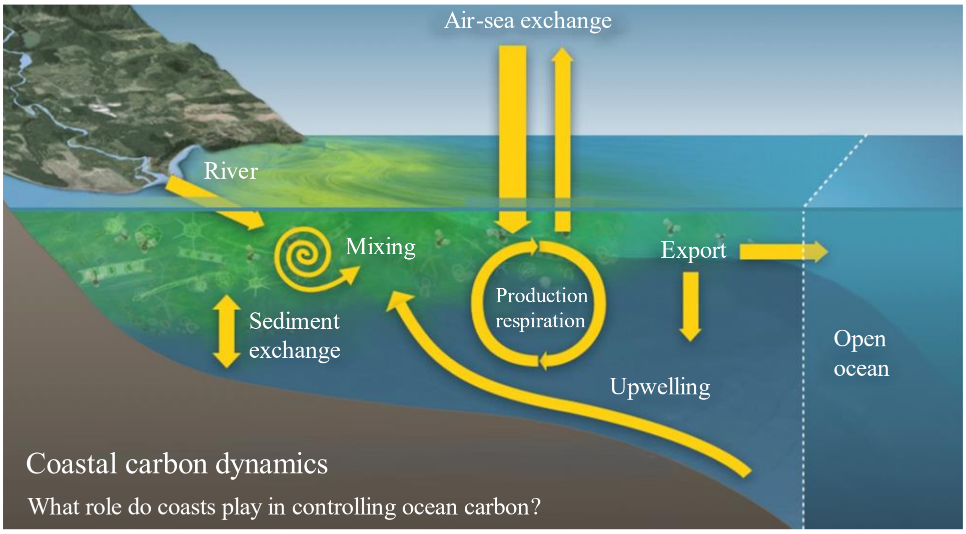

Figure 2. Coastal carbon dynamics (Borges).

The Ocean's Critical Role in Climate Regulation

The oceans serve as Earth's primary climate regulator through multiple mechanisms.

Heat Absorption and Distribution

- Absorbs approximately 93% of excess heat from greenhouse gas warming.
- Regulates global temperature through oceanic circulation patterns.
- Influences weather patterns and climate systems worldwide.

Carbon Sequestration

- Acts as the largest active carbon sink on Earth.
- Stores roughly 50 times more CO_2 than the atmosphere.
- Maintains critical carbon cycle balance.

Biological Pump

- Encourages marine photosynthesis, which generates half of the oxygen in the atmosphere.
- Uses biological mechanisms to help transfer carbon to the deep ocean.
- Sustains the productivity of marine ecosystems.

THREATS TO MARINE LIFE AND ECOSYSTEMS

Ocean acidification has a wide-ranging and getting worse effect on marine ecosystems (Figure 1) [6].

Calcifying Organisms

- Reduced ability to form calcium carbonate shells and skeletons.
- Increased energy requirements for shell maintenance.
- Vulnerability in early life stages.

Ecosystem Disruption

- Alterations to food web dynamics.
- Changes in species distribution and abundance.
- Potential loss of biodiversity.

Socioeconomic Implications

- Threats to fisheries and aquaculture.
- Impacts on coastal communities.
- Potential disruption of global food security.

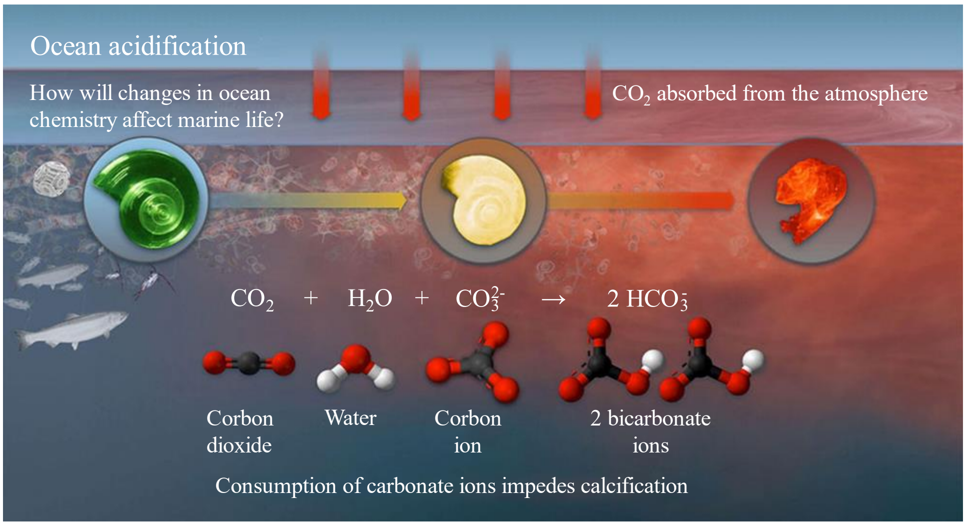

Figure 3. Osteoporosis of the sea.

Table 1. Year and pH level of the Ocean.

Year	pH level
1990–1995	8.11
1995–2000	8.1
2000–2005	8.1
2005–2010	8.09

Table 2. Rates of increasing acidity in different marine regions.

Location	Period	Data source	Year of publication
Coral Sea	1700–1990	Proxy reconstruction	2005
Iceland	1984–2009	Direct measurements	2009
Hawaii (HOT)	1989–2007	Direct measurements	2009
Canary (ESTOC)	1995–2004	Direct measurements	2010
Bermuda (BATS)	1984–2012	Direct measurements	2012
Eastern Mediterranean	1964–2005	Proxy reconstruction	2016

To capture changes in ocean acidification, sustained ocean time-series are essential, as shown in Figure 3 and Tables 1 and 2.

DISSOLUTION OF CARBONATE

Anomalies in seawater total alkalinity and calcium concentration normalized to a given salinity can be used to infer the dissolution of carbonate minerals. The main mechanisms influencing the overall alkalinity of seawater under aerobic circumstances and constant salinity are precipitation reactions and carbonate dissolution [9–14].

Ocean acidification's effects on human health

- Malnutrition and poisoning via altered food quantity and quality.
- Respiratory issues via impaired air quality.
- Mental health impacts via modification of natural spaces (Figures 4 and 5).

RESULTS AND DISCUSSION

The findings of this study underscore the urgent need for scientific investigation and decisive policy measures to address the growing threat of ocean acidification. This phenomenon, primarily driven by increased atmospheric CO_2 emissions, leads to a reduction in ocean pH levels, creating a cascade of negative impacts on marine biodiversity, ecosystem services, and human societies.

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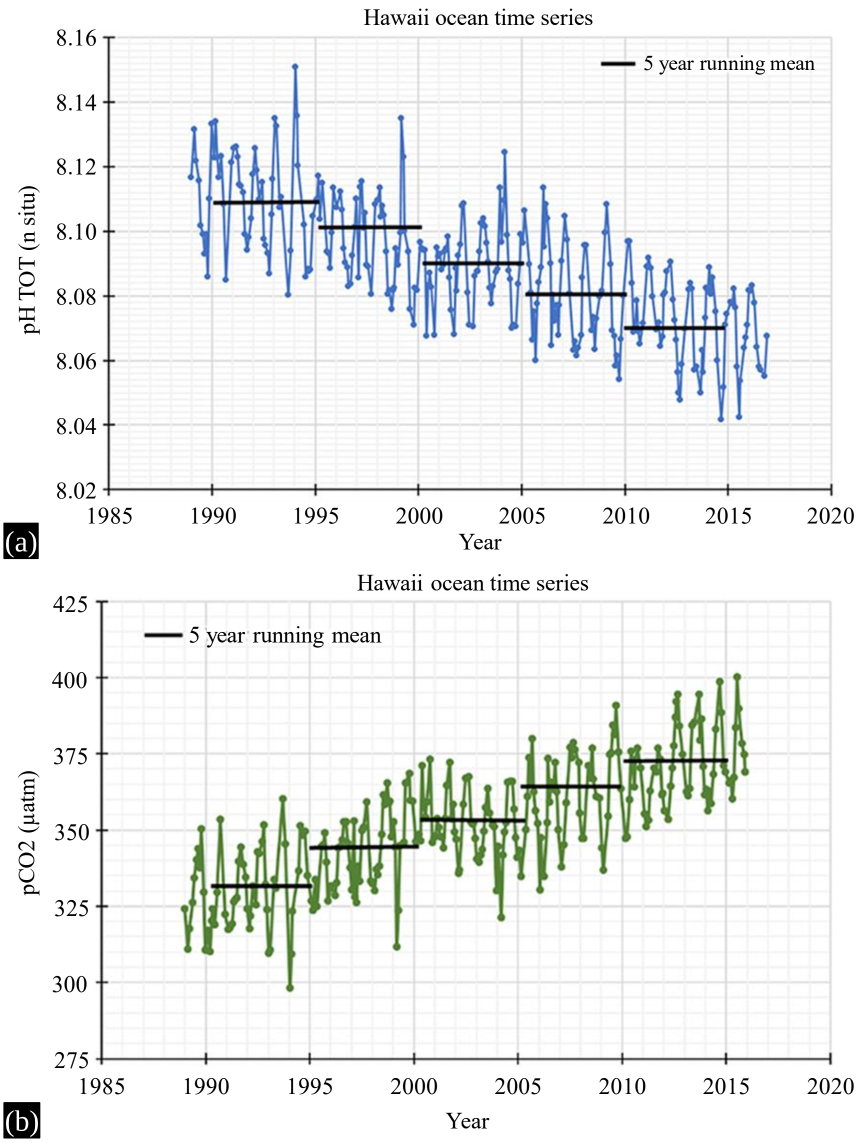

Figure 4. Ocean's year and (a) pH level (b) pCO2 level.

Figure 5. Ocean acidification's effects on human health.

Ocean acidification poses significant risks to calcifying species, including corals, shellfish, and certain plankton types, which rely on calcium carbonate to form their shells and skeletons. The weakening of these organisms disrupts marine food webs, threatening the survival of fish species and other marine life that depend on them for sustenance. Coral reefs, often referred to as the "rainforests of the sea", are particularly vulnerable. As acidification progresses, the structural integrity of coral reefs deteriorates, compromising their role as critical habitats for diverse marine species and their ability to protect coastal regions from storm surges and erosion.

The socioeconomic implications of these changes are profound. Global fisheries and aquaculture industries, which provide essential nutrition and livelihoods for millions of people worldwide, face significant challenges. Reduced fish stocks, declining shellfish populations, and the loss of coral reef habitats jeopardize food security, particularly in coastal and developing regions that depend heavily on marine resources. Additionally, the degradation of marine ecosystems adversely impacts tourism industries, which rely on vibrant coral reefs and healthy ocean environments to attract visitors.

Ocean acidification has far-reaching effects on global climate regulation. The oceans are vital in the carbon cycle, absorbing carbon dioxide from the atmosphere and storing it as dissolved inorganic carbon. However, as acidification intensifies, their ability to function as an effective carbon sink could diminish, potentially worsening global warming and its impacts on weather patterns, rising sea levels, and ecosystems. To address these challenges, immediate action is necessary. Mitigating the effects of ocean acidification requires reducing greenhouse gas emissions through a global transition to renewable energy sources, improved carbon capture technologies, and sustainable land-use practices. Additionally, targeted conservation efforts, such as the establishment of marine protected areas, can help safeguard vulnerable ecosystems and promote biodiversity resilience. Raising public awareness and fostering international collaboration are essential for mobilizing resources and implementing impactful strategies [14].

Furthermore, adaptive measures should focus on supporting communities and industries affected by ocean acidification. These include fostering sustainable aquaculture practices, developing resilient fishery management systems, and investing in research to explore potential solutions, such as artificial alkalinity enhancement to offset acidification locally. Collaborative efforts between scientists, policymakers, and stakeholders are essential to ensuring that mitigation and adaptation strategies are comprehensive and inclusive.

Ocean acidification is a pressing environmental challenge with significant implications for marine ecosystems, human communities, and the planet's overall well-being. Addressing this challenge requires urgent and coordinated global efforts to reduce CO_2 emissions, protect marine ecosystems, and promote adaptive strategies that will sustain ocean health for future generations. Through scientific innovation, policy intervention, and community engagement, it is possible to mitigate the impacts of ocean acidification and preserve the invaluable resources and services provided by our oceans.

CONCLUSION

Ocean acidification is a critical environmental issue driven by rising CO_2 emissions, which significantly impacts marine ecosystems, global biodiversity, and human societies reliant on ocean resources. The reduction in ocean pH levels disrupts the natural balance of marine environments, leading to the degradation of coral reefs, the decline of calcifying species, and the weakening of marine food webs. These changes pose a direct threat to global fisheries, aquaculture, and coastal economies while also diminishing the ocean's capacity to act as a carbon sink, thereby exacerbating climate change.

Addressing ocean acidification requires immediate, coordinated, and sustained global efforts. Reducing greenhouse gas emissions through a transition to renewable energy sources, advancing carbon capture technologies, and implementing sustainable land-use practices are critical steps. In parallel, conservation measures such as marine protected areas and community-based management strategies can help safeguard vulnerable ecosystems.

Furthermore, adaptive approaches must be developed to support communities and industries most affected by ocean acidification. Research into innovative solutions, such as localized alkalinity enhancement and sustainable aquaculture techniques, can contribute to mitigating its effects. Public awareness campaigns and international collaboration are essential to drive meaningful policy changes and foster a shared commitment to protecting our oceans.

In conclusion, ocean acidification is not only an environmental challenge but also a global societal concern with wide-reaching implications. By acting decisively and collaboratively, we can mitigate its impacts, protect marine ecosystems, and ensure the sustainable use of ocean resources for generations to come. Preserving ocean health is fundamental to securing the planet's environmental, economic, and social well-being.

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