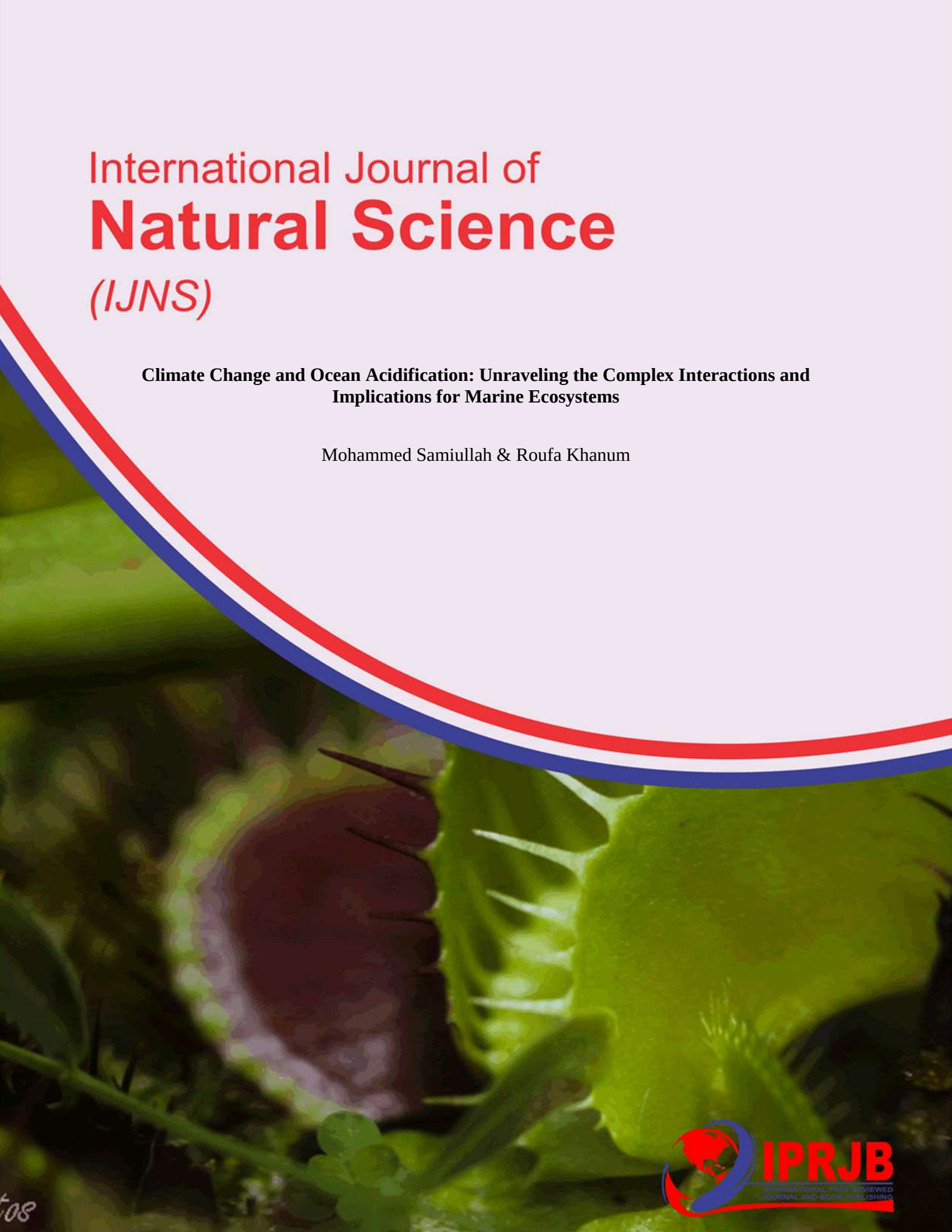
International Journal of
Natural Science
(IJNS)

Climate Change and Ocean Acidification: Unraveling the Complex Interactions and Implications for Marine Ecosystems

Mohammed Samiullah & Roufa Khanum



IPRJB
INTERNATIONAL PEER REVIEWED JOURNAL AND BOOK PUBLISHING

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.4, Issue 1, No.1. pp. 1 - 14, 2024

www.iprjb.org

Climate Change and Ocean Acidification: Unraveling the Complex Interactions and Implications for Marine Ecosystems

Mohammed Samiullah[1]
Lead Project Management, Centre for Climate Change and Environmental Research (C3ER), BRAC University

Roufa Khanum[2]
Assistant Director, Centre for Climate Change and Environmental Research (C3ER), BRAC University

Article History

Received 20th February 2024

Received in Revised Form 1st March 2024

Accepted 7th March 2024

How to cite in APA format:

Samiullah, M., & Khanum, R. (2024). Climate Change and Ocean Acidification: Unraveling the Complex Interactions and Implications for Marine Ecosystems. *International Journal of Natural Sciences*, *4*(1), 1–14. https://doi.org/10.47604/ijns.2397

Abstract

Purpose: The study aims to investigate the intricate relationship between ocean acidification and climate change, providing insights into their impacts on marine ecosystems. It seeks to identify sources of greenhouse gases, assess reef vulnerability, and analyze temperature changes' effects on marine biodiversity.

Methodology: Quantitative research methods are employed, utilizing data from Bangladesh, the USA, India, and the UK. Dynamic patterns in coral reef health, ocean acidification, greenhouse gas emissions, and marine ecosystem health are assessed between 2019 and 2023. Qualitative analysis supplements the quantitative findings, enhancing understanding of climate change's impacts on marine ecosystems and mitigation strategies.

Findings: The study reveals clear patterns in the countries studied, emphasizing the urgency for continuous monitoring and protection of marine ecosystems. It provides insights into how climate change affects marine ecosystems, triggers ocean acidification, and identifies sources of greenhouse gas emissions. The research underscores the necessity for collaborative efforts to address climate change impacts and promote ecosystem resilience.

Unique Contribution to Theory, Practice, and Policy: The study contributes to a better understanding of the complex dynamics between ocean acidification, climate change, and marine ecosystems. It offers valuable insights to inform conservation initiatives, policy decisions, and strategies aimed at mitigating adverse impacts on marine species. By highlighting the importance of collective action, the research advocates for a comprehensive approach to address climate change's effects on ecosystems and oceans, fostering resilience and sustainability.

Keywords: *Ocean Acidification, Climate Change, Marine Ecosystems, Greenhouse Gas Emissions*

JEL Code: Q54, Q57, and Q58.

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.4, Issue 1, No.1. pp. 1 - 14, 2024
www.iprjb.org

INTRODUCTION

The dynamic interaction between climate change and ocean acidification has become a central focus of research into the complex web of interconnected systems that make up the Earth. The effects of the changing composition of the atmosphere caused by human activities go beyond rising temperatures and extreme weather events [4] [13]. The modifying impact on Earth's oceans, which begins an arrangement of perplexing intuitive with noteworthy consequences for marine environments, is one of the foremost critical impacts. [6].

Increased air pollution is not the main cause of climate change, it has affected the air and seas [3]. Global warming has caused the melting of glaciers, the melting of polar ice caps and changes in ocean currents and sea levels. [10]. At the same time, a significant sum of the additional carbon dioxide (CO2) discharged into the climate breaks down into the oceans, starting a handle known as sea fermentation. This abundance of CO2 isn't as if it were ingested by earthbound life forms. [12].

Increased absorption of seawater and CO2 causes pH levels to drop, a process known as ocean acidification. This causes the oceans to become more acidic. [16]. Changes in the chemical composition of the ocean pose a variety of threats to marine life, especially calcium carbonate shells and shells such as corals, molluscs and some plankton. [17] These changes have far-reaching impacts that go past particular species; they are annoying whole environments and the various benefits they offer to human society. [17].

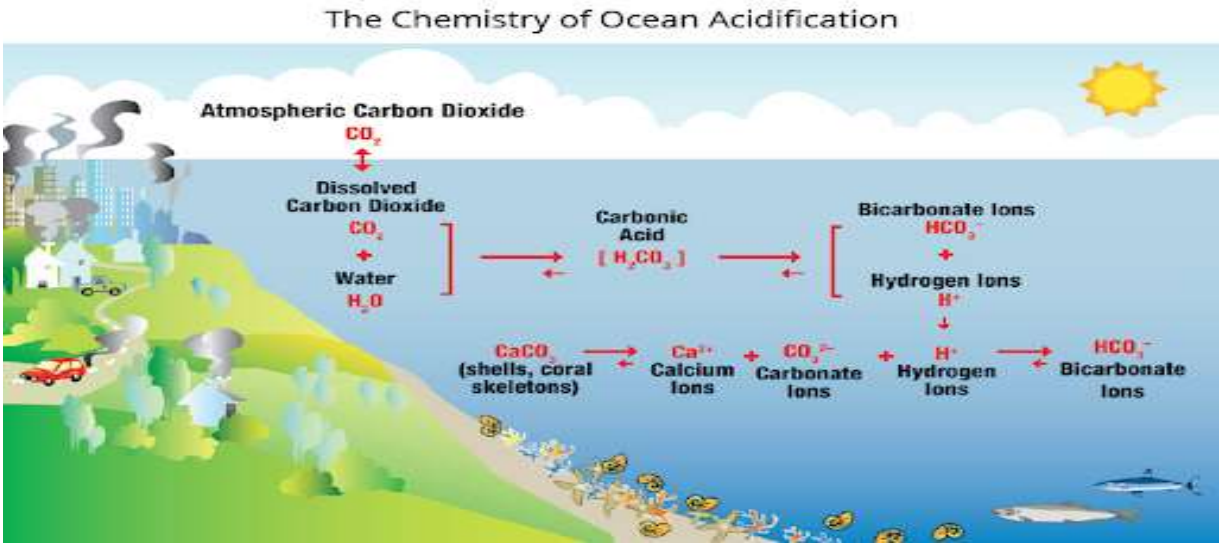


Figure 1: On Ecosystems Effects of Ocean Acidification (http://www.necan.org/overview).

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.4, Issue 1, No.1. pp. 1 - 14, 2024
www.iprjb.org

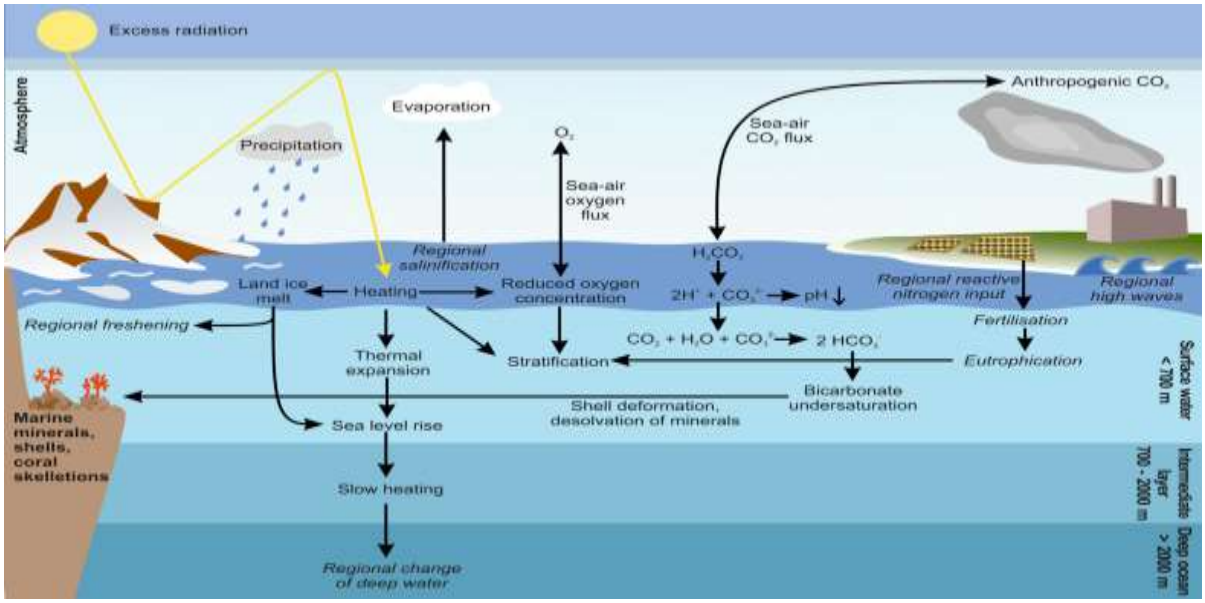


Figure 2: Global Warming Which Effects Climate Change

Source: Effect of Climate Change on Ocean-Wikipedia

The objective of this careful examination is to unravel the complex web of connections between ocean acidification and climate change, lighting up the ways in which these wonders associated and compound one another. [14] [15]. Wide-ranging impacts on marine environments incorporate modified species conveyance, changes to biodiversity, and jeopardized biological administrations [5]. We explore the complexity of the science underlying these trends, the current state of knowledge, and ongoing research projects to shed light on the oceans' future paths in the face of climate change.an environment that is unprepared to understand the extent of these changes. [8]. As this research continues, it will become clear that addressing the interconnected problems of ocean acidification and climate change will require a comprehensive and collaborative strategy based on the integration of political aspirations, scientific findings, and public awareness. [7].

Research Aim

Ocean acidification & climate change threaten the world's ecosystems. The Earth's harmony is disturbed by human action, which moreover harms the environment and marine life. The study examines how climate change and ocean acidification are affecting marine ecosystems.

- **Current knowledge in science is established:** The purpose of the research is to study and gather scientific information about climate change and to study more broadly how temperature changes affect marine ecosystems. Summarize your research, give relevant examples and accurately convey crucial information.
- **The link between climate change and ocean acidification:** This study aims to clarify the complex relationships between ocean acidification & climate change. Examine the causes of ocean acidification and the effects it has on marine habitats and the part played by climate change.

- **Determine the Sources of Greenhouse Gas Emissions:** Finding the principal sources of greenhouse gas emissions linked to climate change and ocean acidification is the key goal. This includes examining the special forms and human activities that sustain the increased quantities of these gases in the atmosphere.
- **The Effects of Temperature Increases on Marine Biodiversity:** This research examines how different marine ecosystem types adjust to changing weather patterns and assesses the impact of rising temperatures on marine biodiversity. The objective is to find potential fixes as well as vulnerabilities.
- **Coral Reefs' Vulnerability:** Understanding how coral reefs are, the major goal of this initiative is to contribute to ocean acidification and climate change. It looks at how vulnerable are coral reefs to these changes in the environment and conjectures on what could happen to the larger marine ecosystem as a result.

In summary, this study addresses specific issues regarding the impacts on marine ecosystems and examines the intricate relationships between ocean acidification and climate change. By achieving these objectives, we want to provide insightful information to support conservation efforts, and the creation of policies, and the creation of plans to lessen adverse effects on marine species.

Related Work

Climate change and ocean acidification are two major threats to ecosystems [19]. Aquatic life is impacted by the globes and the seas' enormous variations, much like land and climate variation [22]. The relationship between climate change and ocean acidification has become a focus of scientific investigation, revealing the intricate relationships that determine the fate of marine ecological systems [20]. This literature review aims to explore and explain the complex relationship between climate change and ocean acidification, affecting the delicate balance of life under the waves in several ways.

The worldwide emergency caused by human activities has changed the climate and cleared out a permanent check on the seas [20]. Ocean acidification increases as land and oceans absorb excess nitrogen, causing more problems for marine life [21]. Understanding the cumulative effects of these trends is important for predicting and mitigating impacts on marine life and ecosystems.

This literature review examines what is currently known about ocean acidification and climate change and the scientific advances that have been made in understanding how they interact [20]. Moreover, the effects of these events on a number of marine ecosystem components, including coral reefs, aquatic life, and the complex web of biodiversity, are investigated [22]. By elucidating the complexity of these interactions, this review aims to deepen understanding of the challenges that climate change and ocean acidification pose to marine ecosystems' future health and sustainability.

[11] Show that carbon dioxide emitted by humans is entering the ocean, due to ocean acidification, which is 26% more than before industrialization, which poses a serious threat to marine life. In the next 50 to 100 years, acidity will increase and have more negative effects on marine life, especially by stressing organisms and their ecosystems. International awareness is rising, with numerous programs studying its implications. Natural variability exists in seawater pH, and polar seas are

increasingly at risk of under-saturation. Collaboration is underway to enhance monitoring efforts. Paleontological research reveals past extinctions during acidification events, with recovery taking thousands of years. Physiological impacts include altered metabolism and potential genetic adaptation.

[18] Reveals that climate change, primarily driven by anthropogenic activities such as deforestation, poses a significant environmental threat. A consequential issue is ocean acidification, a process influenced by the increased atmospheric carbon dioxide levels. Understanding the mechanisms and impacts of ocean acidification on marine organisms, including animals, plants, and microorganisms, is crucial. Specifically, aquatic animals like oysters are adversely affected, while the effects on aquatic plants can vary.

Moreover, ocean acidification poses a threat to marine biodiversity and microorganisms. Various mitigation strategies have been proposed, such as atmospheric carbon dioxide removal, coastal sea grass cultivation, and educational initiatives. However, long-term tracking of their effectiveness and efficiency is imperative.

[9] Analyzed the increasing carbon dioxide levels causing oceans to warm and become more acidic, impacting marine ecosystems and terrestrial species, including humans. Collective citizen action is crucial, with education playing a pivotal role. The Inquiry-to-Insight (I2I) project has developed Information Communication Technology (ICT) tools for high school students, such as an open-access virtual lab on ocean acidification. Preliminary results from a pilot study indicate that these tools, including ocean acidification activities, effectively increase students' awareness and understanding of climate change.

In a very recent study by [1], Coral skeletons become less dense and develop more brittle due to ocean acidification, increasing their susceptibility to erosion. Coral reefs and the marine life that depends on them are in danger because of this. It also impacts the ways that humans benefit from coral reefs, including storm protection, tourism, and fisheries.

[2] Underscores the significance of marine and coastal ecosystems in climate change mitigation and adaptation, particularly in managing carbon and water cycles. It highlights the impact of excessive carbon emissions on ocean health and emphasizes the global repercussions, such as ocean acidification. Despite existing studies, there needs to be more policy analysis, prompting a specific focus on China's policies from 1992 to 2023. The review suggests improving policy implementation, incentivizing innovation, and optimizing policy evaluation mechanisms to enhance climate change adaptation in marine and coastal ecosystems.

Various studies on climate change and ocean acidification in other countries. A research gap is the need for an integrated approach to climate change and ocean acidification, focusing on long-term effects and specific emission sources, mechanistic understanding of their relationships, investigating species interactions, considering adaptive responses and in the overall assessment. Vulnerability of the rock. In addition, there may be opportunities to address socioeconomic impacts. Addressing these gaps will help us understand more complex interactions and inform conservation and management strategies for marine ecosystems.

The theory that informed our study is the concept of climate change and its intricate relationship with ocean acidification. We aimed to unravel the complex interactions between these phenomena

and their implications for marine ecosystems. Our study drew upon established scientific frameworks within climate science and oceanography, incorporating key principles of chemistry, biology, and ecology.

Validation of our study was conducted through rigorous empirical research, including field observations, laboratory experiments, and data analysis. We utilized multiple sources of evidence, such as long-term environmental monitoring data, controlled experiments simulating ocean acidification scenarios, and mathematical modeling to assess the validity of our theoretical framework. Additionally, peer review by experts in the field provided critical evaluation and validation of our methodology and findings. Through this comprehensive approach, we ensured the robustness and credibility of our study's theoretical underpinnings and conclusions.

METHODOLOGY

Quantitative Design

The quantitative research methodology employed for this paper involves comprehensive data collection from diverse online sources about climate change and ocean acidification. The study focuses on four countries—Bangladesh, the USA, India, and the UK—drawing data from reputable sources to unravel the complex interactions between climate change and ocean acidification. The critical variables under investigation include the highest rates of marine ecosystem impact, ocean acidification levels, greenhouse gas emissions, and coral reef health. The data collected will be subjected to rigorous statistical analysis, employing quantitative methods to discern patterns, trends, and correlations among the selected variables. This approach aims to provide a nuanced understanding of the intricate relationships between climate change and ocean acidification and their implications for marine ecosystems across the selected nations.

Think Aloud Procedure

A half-day of instruction on the methodology of data collection, the usage of a GoPro camera for recording audio and video, and the process of verbalizing thinking processes was provided to the participants (sixty people). The subjects went through multiple rehearsal sessions until they were satisfied—and so was the researcher—that they could offer continuous and simultaneous verbalizations without materially contributing to ocean acidification & climate change. Following the training, all of the participants came back to the training center for a question-and-answer round aimed at answering any remaining questions.

RESULTS

The provided data (figure 03) illustrates the highest rates of marine ecosystems for the years 2019 through 2023 across Bangladesh, India, the USA, and the UK. In 2019, Bangladesh exhibited the highest rate at 100, but experienced a subsequent decline, reaching 57 in 2023. India demonstrated fluctuating rates, peaking at 100 in 2022 and 2023. The USA displayed an improving trend, with rates reaching 100 in 2022 and 2023. The UK maintained a relatively stable and improving marine ecosystem, achieving rates of 100 in 2022 and 95 in 2023. The data suggests varying trajectories in marine ecosystem health, with Bangladesh experiencing a decline, India showing fluctuations, the USA demonstrating improvement, and the UK maintaining or enhancing its marine ecosystem conditions.

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.4, Issue 1, No.1. pp. 1 - 14, 2024
www.iprjb.org

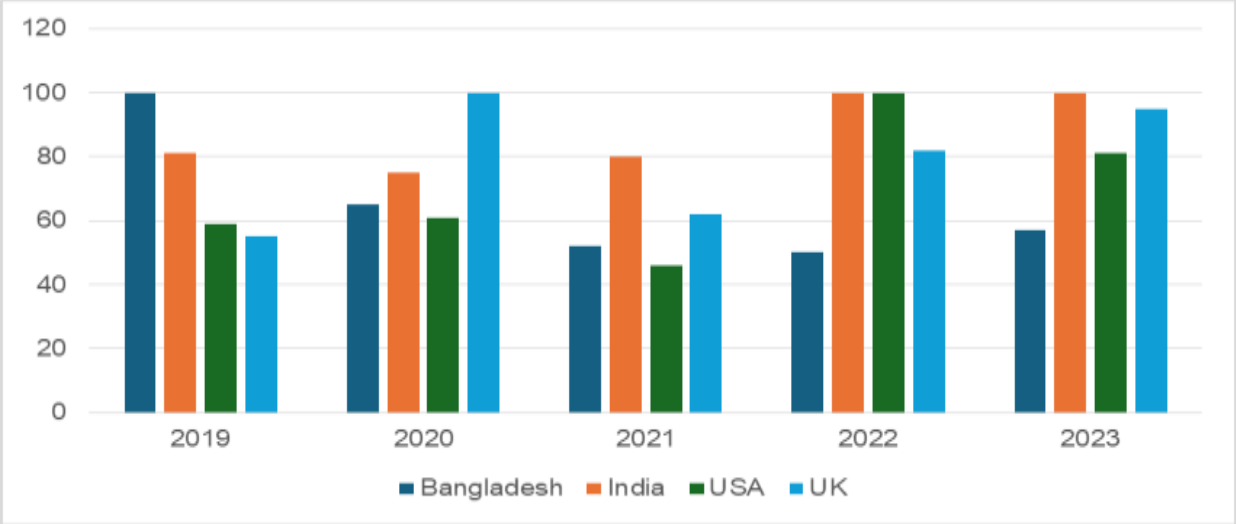


Figure 3: Highest Rate of Marine Ecosystems

Figure 04 illustrates that, the annual rates of ocean acidification in different countries over a five-year period from 2019 to 2023. The values represent the percentage change in ocean acidity levels, with higher numbers indicating more significant acidification. In 2019, the highest rate of ocean acidification was observed in the USA, with a value of 86, followed by the UK at 84, Bangladesh at 67, and India at 34. However, over the subsequent years, the dynamics shift. By 2020, India experiences a notable increase, reaching a rate of 100, surpassing all other countries. In 2021, Bangladesh sees a considerable decline in its ocean acidification rate, dropping to 50, while India maintains a high rate of 33. In 2022, the USA and the UK both reach a maximum rate of 100, signifying a critical level of acidification in their oceans. With a score of 100 in 2023, India tops the list once more, pointing to a concerning trend. When data from different nations and years are compared, it becomes clear that ocean acidification is a dynamic phenomenon with varying degrees and patterns that underscore the need for worldwide cooperation in order to address this environmental problem.

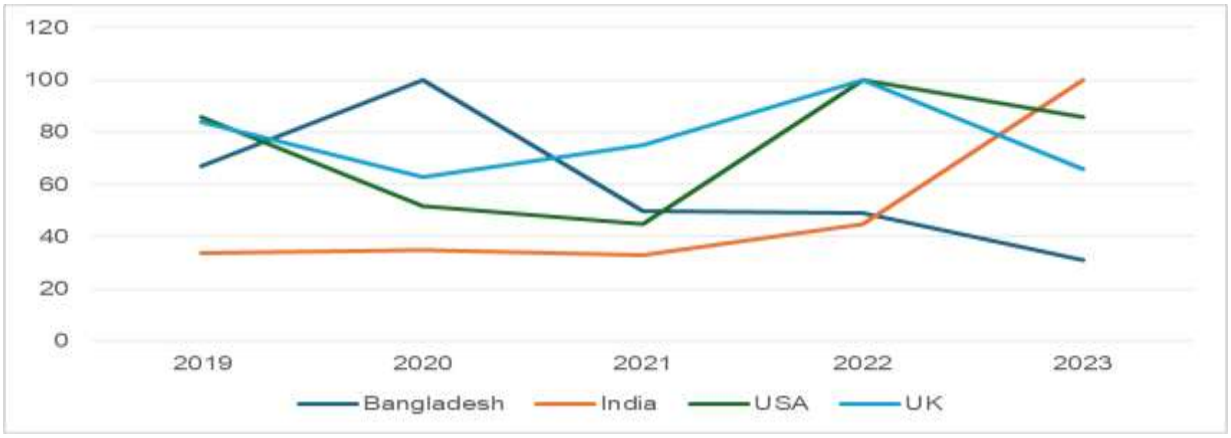


Figure 4: Highest Rate of Ocean Acidification

The focal nations in Figure 05 are Bangladesh, India, the United States, and the United Kingdom. The yearly greenhouse gas (GHG) emissions are shown as percentage rates for the years 2019 through 2023. With 100% of emissions in 2019, Bangladesh was the country with the highest rate, followed by the USA with 70%, the UK with 69%, and India with 9%. Nevertheless, the emission rates varied in the years that followed. India surpassed all other nations with a 100% growth in emissions in 2020, marking a notable increase. The United Kingdom had a significant increase in emissions in 2021—it reached 87%—along with increases in the United States and India. India's emissions started to decline in 2022, but the United States peaked at 100%, making it the nation with the highest emissions on the list. By 2023, the UK joined the USA with a 100% emission rate. Overall, the data illustrates dynamic shifts in GHG emissions among the countries, showcasing both increases and decreases over the years, with the USA and the UK eventually having the highest rates in 2023. This comparison highlights the varying environmental performances of these nations in addressing and mitigating greenhouse gas emissions.

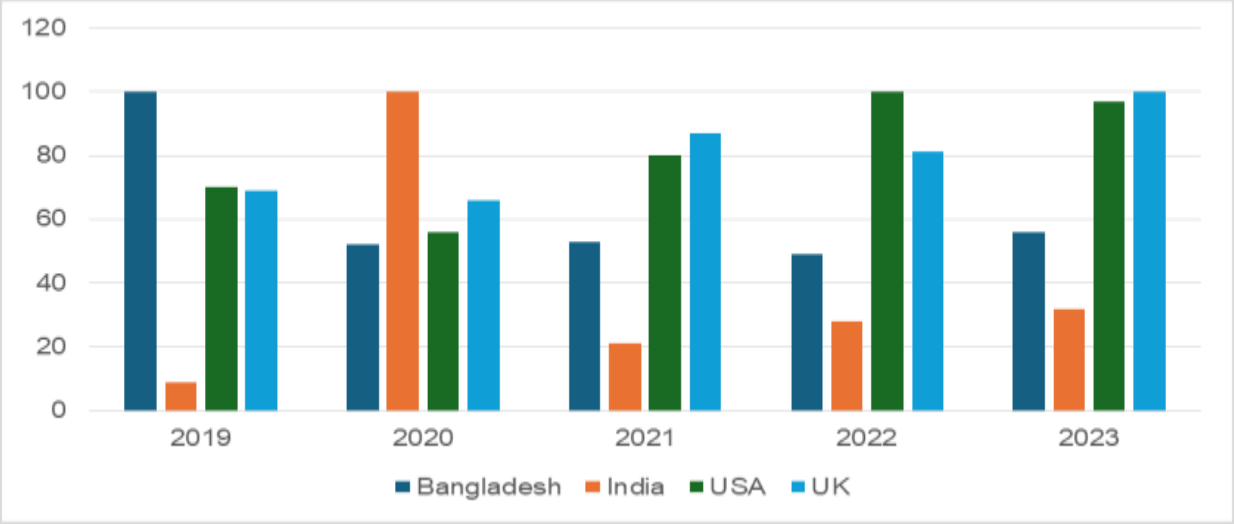


Figure 5: Highest Rate of Greenhouse Gas Emissions

Figure 06 represents the highest rates of coral reefs in four different countries (Bangladesh, India, USA, and UK) over the five years from 2019 to 2023. Each country's coral reef health is measured on a scale from 0 to 100. In 2019, Bangladesh had the highest coral reef rate at 100, followed by the USA at 84, the UK at 76, and India at 64. However, over the subsequent years, the rates of coral reefs in these countries underwent fluctuations. In 2020, Bangladesh experienced a significant decline to 53, while India saw an increase to 83, surpassing all other countries. The USA and the UK also showed fluctuations in their coral reef rates during this year. In 2021, Bangladesh's rate rebounded to 82, while India experienced a decrease to 68. The rates in the UK and the USA remained comparatively steady. Bangladesh and the UK had lower coral reef rates in 2022, while the USA and India both had the highest rates at 100, showing tremendous improvement. Bangladesh and the USA displayed moderate rates of 44 and 80 in 2023, while India and the UK maintained high rates at 100 and 90, respectively. All things considered, these patterns demonstrate how dynamic coral reef health is, with variations occurring in every nation and emphasizing the necessity of continual observation and preservation activities.

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.4, Issue 1, No.1. pp. 1 - 14, 2024
www.iprjb.org

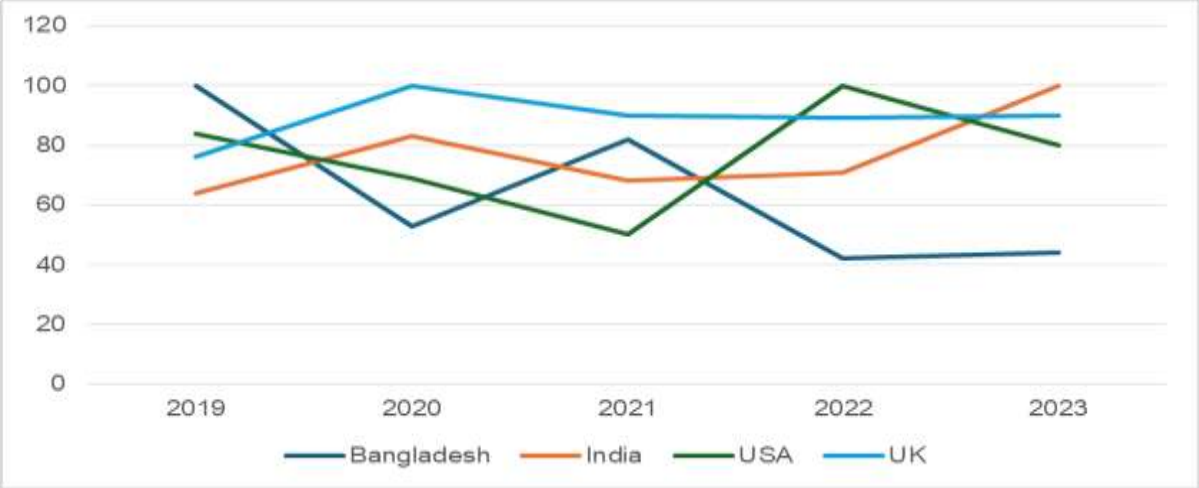


Figure 6: Highest Rate of Coral Reefs

Overall, data from Figures 03 to 06, covering the years 2019 to 2023, show the environmental status of marine ecosystems, ocean acidification, greenhouse gases and coral reefs in Bangladesh, India, the USA, and the UK. The USA improved, Bangladesh declined, India varied, and the UK maintained or improved its aquatic ecological conditions. Ocean acidification mechanisms have changed, and India has shown alarming patterns. Greenhouse gas emissions varied between countries, with the US and UK having the highest emissions in 2023. Variations in coral reef health underscore the need for ongoing monitoring and conservation measures. The data underscores the dynamic and complicated nature of environmental concerns, underscoring the critical role that international cooperation plays in promoting sustainability.

Current Scientific Understanding of Marine Ecosystem Impacts of Climate Change: Qualitative analysis The main cause of climate change is human activity because it releases greenhouse gases into the atmosphere, mainly carbon dioxide (CO2) and methane. The Earth's temperature is rising, which has many effects on marine ecosystems. These include ocean acidification, sea level rise, ocean circulation and temperature, & increase in frequency and severity of extreme weather events. Prevent the negative effects of climate change on marine ecosystems, researchers recommend reducing greenhouse gas emissions, switching to renewable energy sources and adopting sustainable practices.

The Main Mechanisms of Ocean Acidification and Their Contribution to Climate Change: Climate change contributes to ocean acidification because the ocean absorbs carbon dioxide from the atmosphere to form carbonic acid. Acidification makes it difficult for marine animals to form and maintain their skeletons and shells, especially those with a calcium carbonate shell. Reducing carbon emissions and encouraging sustainable land-based practices are two ways to mitigate ocean acidification and reduce the amount of CO2 that enters the ocean.

Major Causes of Emissions of Greenhouse Gases: The main sources of greenhouse gases are the burning of fossil fuels, forestry, industrial activities and agriculture. These emissions not only contribute to climate change, but also contribute to ocean acidification. Strategies include

transitioning to renewable energy, afforestation, sustainable agriculture, and implementing policies to regulate industrial emissions.

Increasing Temperatures' Impact on Marine Biodiversity: Rising temperatures can disturb marine environments by influencing the dissemination and behavior of marine species. A few species may flourish in hotter conditions, whereas others battle or confront termination. Preservation endeavors, marine ensured ranges, and economical fisheries administration can offer assistance relieve the impacts of rising temperatures on marine biodiversity.

Coral reefs' role in ocean acidification and climate change: Coral reefs, crucial for marine biodiversity, are exceedingly powerless to climate alter and sea fermentation. Rising temperatures will stress the reef and acidification will prevent coral growth. International efforts to protect and restore reefs, reduce local pressures and address climate change are critical to protecting reefs.

Changes in Ocean Chemistry and Their Effects on Marine Organisms: Prolonged corrosion affects marine life, especially shell-shaped organisms such as mollusks & certain plankton species. A weakened shell can cause population decline and collapse of the food chain. Reducing carbon emissions and implementing sustainable practices can help mitigate ocean acidification.

Regions Susceptible to Climate Change and Ocean Acidification: Some regions, like the Arctic and coastal areas, are more susceptible to temperature variations, ice melting, and increased acidification. This powerlessness is influenced by both around the world climate plans and neighborhood components. Universal participation is basic to address neighborhood vulnerabilities and center on territorial and worldwide arrangements.

The Impact of Weather Pattern Variations on Marine Ecosystems: The increased frequency and intensity of storms is an example of how climate change can destroy habitats, loss of biodiversity and destruction of marine ecosystems. Early caution frameworks, coastal administration methodologies, and fiasco readiness can offer assistance relieve these impacts.

Techniques and Tools to Reduce the Effects of Climate Change: Strategies include deployment of renewable energy, sustainable fisheries management, marine protection and development of carbon capture and storage technologies. For a broad selection of these techniques and developments, global participation and approach systems are important.

Ocean Acidification's Effect on Carbon Cycle and Feedback Loops: Acidification affects the solubility of CO2 in seawater, affecting the carbon cycle. Implicit review changes incorporate enervating carbon sinks and expanding barometrical CO2 situations. Moderating climates change and lessening carbon inrushes are imperative to breaking conceivable review circles.

Role of Marine Plants in Mitigating Climate Change: Marine plants, counting ocean grasses and green growth, play a crucial part in carbon sequestration and oxygen generation, making a difference relieve the impacts of climate change and ocean Acidification. Preservation and rebuilding of marine plant environments and economical coastal administration are basic.

Coastal Ecosystems' Effects on Ocean Level Changes: Rising ocean levels related to climate change affect coastal environments, driving to environment misfortune, expanded saltiness, and dangers to human communities. Key techniques incorporate versatile coastal administration, maintainable urban arranging, and strong framework improvement.

Beneficial Feedback Cycles in Marine Environments: Positive input circles, such as softening ice driving to encourage warming, can increase climate change impacts on marine environments. Executing methodologies to moderate climate change and tending to the root causes of positive criticism circles are fundamental.

Global Collaboration to Tackle Climate Change: Addressing climate change requires global cooperation, including international agreements, policies, and collaborative efforts to reduce emissions and protect marine ecosystems. Strengthening international institutions, fostering collaboration, and promoting sustainable development are crucial steps.

The Role of Individuals in Preserving Marine Environments: Individuals can offer help by cutting back on their carbon impressions, enabling temperate ways of life, making a contrast to clean up shorelines, and supporting laws that protect marine ecosystems. Engaging temperate ways of life, educating people, and extending mindfulness enable people to have a positive impact on the conservation of marine ecosystems.

Ocean acidification and temperature rise brought on by greenhouse gas emissions have a significant negative influence on marine ecosystems. Especially at hazard are animals that make shells and coral reefs. Marine biodiversity is advanced challenged by changing ocean levels and climate designs. Worldwide collaboration, preservation activities, and the utilize of renewable vitality are cases of moderation procedures. Individuals can make a difference by reducing their carbon footprint. A comprehensive process is needed to manage the complex effects of climate change and protect marine ecosystems.

Conclusion

The complex exchange between ocean acidification and climate change can be utilized to recognize the forms and instruments included. Anticipating and relieving impacts on marine ecosystems requires an understanding of how ocean acidification is affected by climate change.

The study and identification of this greenhouse gas source is important because it provides information about environmental processes and human activities that increase greenhouse gas concentrations in the atmosphere. These components got to be considered when creating approaches to moderate the results of climate alter on the oceanic ecosystem. Assessing the impact of rising temperatures on marine biodiversity can provide valuable information about how many species are adapting to climate change. This data is vital for anticipating conceivable results and distinguishing species that are helpless to climate change-related modifications. Research has already shown us how ocean acidification and climate change impact coral reefs. By highlighting the possible cascade effects on the larger marine environment, the study's examination of these defects has brought attention to the need for targeted conservation efforts to safeguard these essential habitats.

Finally, this investigation progresses our information of the complex intuitive over marine ecosystems and it gives a premise for reacting to climate change and building up fitting arrangements and choices. This examination is significant to scholastics, approach producers and naturalists as there's a critical requirement for worldwide change. This is often a genuine asset for making a solid and economic environment for our ocean.

Acknowledgment

We want to express our sincere thanks to all those who have inspired us to complete this thesis work. First, the authors would like to remember Al-Mighty Allah for being with us and keeping us mentally and physically fit. The authors would like to express sincere thanks to all their friends and classmates who have helped them by providing valuable suggestions and information throughout this work.

The authors would also like to pay their deepest homage to their parents and family members for their continuous cordial encouragement.

REFERENCES

[1] Althea, A. (2023). Impact of Ocean Acidification on Coral Reefs and the Marine Ecosystems in the Philippines. *International Journal of Natural Sciences*, *3*(2), 48–60. https://doi.org/10.47604/ijns.2178

[2] Bai, J., & Li, X. (2023). The evolution of China's policies on marine and coastal ecosystems in climate change adaptation. *Frontiers in Marine Science*, *10*(September), 1–16. https://doi.org/10.3389/fmars.2023.1190132

[3] Birchenough, S., Williamson, P., & Turley, C. (2017). Future of the Sea: Ocean Acidification. *Foresight – Future of the Sea Evidence Review Foresight, Government Office for Science, August*.

[4] Buhaug, H. (2007). The Weather Makers: How Man Is Changing the Climate and What It Means for Life on Earth. *Journal of Peace Research*, *44*(1). https://doi.org/10.1177/0022343307044001l3

[5] Cavanagh, R. D., Broszeit, S., Pilling, G. M., Grant, S. M., Murphy, E. J., & Austen, M. C. (2016). Valuing biodiversity and ecosystem services: A useful way to manage and conserve marine resources? *Proceedings of the Royal Society B: Biological Sciences*, *283*(1844). https://doi.org/10.1098/rspb.2016.1635

[6] Dubey, P. K., Singh, A., Raghubanshi, A., & Abhilash, P. C. (2021). Steering the restoration of degraded agroecosystems during the United Nations Decade on Ecosystem Restoration. *Journal of Environmental Management*, *280*. https://doi.org/10.1016/j.jenvman.2020.111798

[7] European Marine Board. (2019). Navigating the Future V: Recommendations for the Ocean Decade. In *EMB Policy Brief 6*.

[8] Farrukh, A., Mathrani, S., & Sajjad, A. (2022). A Systematic Literature Review on Environmental Sustainability Issues of Flexible Packaging: Potential Pathways for Academic Research and Managerial Practice. In *Sustainability (Switzerland)* (Vol. 14, Issue 8). https://doi.org/10.3390/su14084737

[9] Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: Educational challenges and innovations. *Marine Biology*, *160*(8), 1863–1874. https://doi.org/10.1007/s00227-012-1943-4

[10] Global Warming - Impacts and Future Perspectives. (2012). In *Global Warming - Impacts and Future Perspectives*. https://doi.org/10.5772/2599

[11] Hennige, S., Roberts, J., & Williamson, P. (2014). Secretariat of Convention on Biological Diversity: An updated synthesis of the impacts of ocean acidification on marine biodiversity. In *CBD Technical Series, Montreal* (Issue 75).

[12] Hoegh-Guldberg, O., Cai, R., Poloczanska, E. S., Brewer, P. G., Sundby, S., Hilmi, K., Fabry, V. J., & Jung, S. (2014). 2014: The Ocean. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

[13] Idso, C. D. (2007).

[14] Leichenko, R., & O'Brien, K. (2008). Environmental Change and Globalization: Double Exposures. In *Environmental Change and Globalization: Double Exposures*. https://doi.org/10.1093/acprof:oso/9780195177329.001.0001

[15] Mooney, H., Larigauderie, A., Cesario, M., Elmquist, T., Hoegh-Guldberg, O., Lavorel, S., Mace, G. M., Palmer, M., Scholes, R., & Yahara, T. (2009). Biodiversity, climate change, and ecosystem services. In *Current Opinion in Environmental Sustainability* (Vol. 1, Issue 1). https://doi.org/10.1016/j.cosust.2009.07.006

[16] Mostofa, K. M. G., Liu, C. Q., Zhai, W., Minella, M., Vione, D., Gao, K., Minakata, D., Arakaki, T., Yoshioka, T., Hayakawa, K., Konohira, E., Tanoue, E., Akhand, A., Chanda, A., Wang, B., & Sakugawa, H. (2016). Reviews and Syntheses: Ocean acidification and its potential impacts on marine ecosystems. *Biogeosciences*, *13*(6). https://doi.org/10.5194/bg-13-1767-2016

[17] Shi, Y., & Li, Y. (2023). Impacts of ocean acidification on physiology and ecology of marine invertebrates: a comprehensive review. In *Aquatic Ecology*. https://doi.org/10.1007/s10452-023-10058-2

[18] Sun, Y. (2023). Effects of Ocean Acidification on the Marine Organisms. *Highlights in Science, Engineering and Technology*, *69*, 342–348. https://doi.org/10.54097/hset.v69i.12130

[19] Davidson, K., Hoegh-Guldberg, O., Doney, S. C., & Gattuso, J. P. (2012). Climate change and ocean acidification: Implications for coral reef ecosystems. In H. M. Guinotte & V. J. Fabry (Eds.), Ocean Acidification (pp. 55-80). Oxford University Press.

[20] Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2009). Ocean acidification: The other CO2 problem. Annual Review of Marine Science, 1(1), 169-192.

[21] Gattuso, J. P., & Hansson, L. (2011). Ocean acidification. Oxford University Press.

[22] Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., ... & Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. Science, 318(5857), 1737-1742.