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OCEAN ACIDIFICATION: THE SILENT THREAT TO MARINE BIODIVERSITY

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Abstract

Ocean acidification (OA) is one of the quietest yet most profound changes unfolding in our seas. Caused mainly by the ocean's absorption of excess carbon dioxide from the atmosphere, it steadily lowers seawater pH and depletes carbonate ions — the essential building blocks for shells, skeletons, and coral reefs. These chemical shifts ripple through marine ecosystems, weakening coral structures, slowing the growth of shellfish, disrupting plankton communities, and ultimately destabilising the food webs that sustain biodiversity and human livelihoods. Although OA is recognised as a global problem, its effects are not uniform. Some regions, particularly the Indian Ocean and other tropical waters, remain poorly studied despite being home to rich biodiversity and millions of people whose lives depend on healthy coastal ecosystems. This paper focuses on OA as a "silent" driver of biodiversity loss and addresses two major gaps: the lack of strong policy and governance integration, and the scarcity of regional data for Indian and tropical waters. To explore how OA is framed in global agreements such as the United Nations Convention on the Law of the Sea (UNCLOS) and the Paris Agreement, and examine its treatment in India's environmental laws, including the Environment (Protection) Act, Coastal Regulation Zone rules, and the Biological Diversity Act. While these frameworks provide important protections, none directly target OA or mandate systematic monitoring. The shortage of long-term, high-resolution data on pH and carbonate chemistry in Indian waters makes it difficult to gauge the scale of the threat or design locally relevant solutions. The lack of species-specific studies in this region adds further uncertainty to impact predictions. This is mainly upon doctrinal studies. This study calls for integrating OA into national marine policies, creating dedicated monitoring networks in the Indian Ocean, and fostering interdisciplinary research that links chemical changes to ecological shifts and community livelihoods. Closing these gaps is vital not only for protecting marine biodiversity but also for ensuring food security and economic stability for coastal populations.

Keywords: Ocean Acidification, Marine Biodiversity, Carbondioxide, UNCLOS, Biodiversity

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Loss.

Introduction

The ocean has an important part in keeping our world's climate balanced. It absorbs nearly one-third of the carbon dioxide (co_2) that human activities do release so this decelerates the pace of global warming. The hidden cost of this service is a trade-off. Co_2 mixing into seawater changes the ocean's chemistry. The resulting in lower ph is in fact a process known as ocean acidification. It is a silent threat often called the "other co_2 problem," difficult to see, unfolding slowly, but with grave global effects.

Ocean acidification weakens corals, shellfish, as well as plankton since they form the very foundation of marine life. In contrast, macroalgae such as kelp may actually benefit, illustrating the uneven effects of these environmental changes.[1] Entire food chains are put at risk from these organisms' battle. Fisheries, biodiversity, and coastal communities' livelihoods are threatened by this. The risks are in particular alarming for countries that are around tropical waters also the Indian ocean, in which millions rely on the sea directly for both income with food. Coastal zone management is already complicated by competing interests, numerous stakeholders, and established sectoral institutions, making the integration of ocean acidification concerns even more challenging at present.

Ocean acidification remains under-studied within climate discussions. Despite clear scientific evidence of these consequences, ocean acidification remains largely absent from coastal zone management discussions. This is reminiscent of the broader disconnect between scientific understanding and policy action often observed with climate change. Especially for Indian and tropical waters limited regional data stands out and it is not well integrated into governance and policy frameworks. To address these gaps, the ecological and social impacts from ocean acidification are examined in this study. Laws that are stronger, policies that are better, and research that is more localized can also help to protect marine biodiversity and human well being.[2]

[1] Nathalie Hilmi et.al "Socio economic tools to mitigate the impacts of ocean acidification on economies and communities reliant on coral reefs a framework for prioritization" Regional Studies in Marine Science ISBN No. 2352-4855

[2] Ellycia R Harrould Kolieb "A governing framework for International ocean acidification Policy" Marine Policy

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Scientific Foundations of Ocean Acidification

When carbon dioxide (CO_2) is emitted into the atmosphere and diluted by seawater, it reacts to form carbonic acid. This process lowers the ocean's pH, making it more acidic, and reducescarbonate ions that are essential for many marine organisms to build shells and skeletons. Since the onset of the industrial era, ocean acidity has increased by approximately 30%, a rate unparalleled in the geological record for millions of years.

Global measurements indicate a consistent decline in oceanic pH, with projections suggesting that further reductions are likely if CO_2 emissions persist at current levels. This pattern of acidification is a worldwide phenomenon, transcending regional boundaries.[3]

The ecological ramifications are extensive. Coral reefs experience weakening and erosion; shell-making organisms such as mollusks and plankton face significant challenges to survival; and even fish exhibit altered behaviours, which can disrupt their ability to find food or evade predators. Given that plankton occupy the foundational tier of marine food webs, these disruptions can cascade through entire ecosystems.[4]

Socio-economic impacts are also considerable. The productivity of fisheries and aquaculture is undermined, leading to reduced yields. Coastal populations may face food insecurity, and livelihoods that depend on healthy marine environments are at heightened risk. In summary, ocean acidification represents a profound threat to both marine biodiversity and human societies reliant on ocean resources.

Global Legal and Policy Framework on Ocean Acidification

Ocean acidification (OA) is now widely acknowledged as one of the most pressing but least visible environmental challenges of our time. Unlike climate change, it does not yet have a dedicated international treaty to regulate it. Instead, OA is addressed indirectly through a patchwork of global agreements dealing with climate change, marine protection, and biodiversity. While this has brought the issue onto international agendas, it has also left important gaps in governance.

[3] Arianna Pansini et.al " Short Term and long term ocean acidification effects on seagrass performance: evidence from shallow CO2 vents" Environmental Research ISBN 0013-9351
[4] Tom Garrison and Robert Ellis "Oceanography- An invitation to Marine Science" Published by National Geographic Learning ISBN 13.978-1-305-10516-4=

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The starting point for any discussion is the United Nations Convention on the Law of the Sea (UNCLOS), often described as the "constitution for the oceans." Although it does not explicitly mention ocean acidification, its broad duty on states to protect and preserve the marine environment (Articles 192–194) can be interpreted to cover the harmful effects of excess carbon dioxide entering the ocean. In this sense, UNCLOS provides the legal foundation for addressing OA, even if it does so indirectly.

Another significant forum is the United Nations Framework Convention on Climate Change (UNFCCC) and, more recently, the Paris Agreement of 2015[5]. Since ocean acidification is caused primarily by rising atmospheric CO_2, any effort to cut emissions under these agreements also helps reduce OA. The Paris Agreement, with its commitment to limit global warming to 1.5°C or 2°C, is particularly important, though it does not specifically mention ocean chemistry.

The Convention on Biological Diversity (CBD)[6] has taken a more ecological approach by recognizing OA as a major driver of biodiversity loss. Through its decisions, the CBD encourages governments to integrate ocean acidification into their national biodiversity strategies and marine conservation programs.

The issue is also reflected in the Sustainable Development Goals (SDGs). Under SDG 14 ("Life Below Water")[7], Target 14.3 specifically calls for minimizing the impacts of ocean acidification through scientific cooperation, monitoring, and international collaboration. This is one of the few global policy commitments that directly names OA as a priority.

Beyond treaties, science-driven initiatives have been vital. The Intergovernmental Panel on Climate Change (IPCC)[8] now treats OA as a critical part of climate risk assessment. The Global Ocean Acidification Observing Network (GOA-ON)[9] provides countries with the tools and data needed to monitor changing ocean chemistry, while the UN Decade of Ocean Science

[5] Kyoto Protocol to the United Nations Framework Convention on Climate Change came into force on 16 February 2005
[6] Rio Earth Summit on June 5, 1992
[7] United Nations. (2025). *The Sustainable Development Goals Report 2025.*
[8] IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. doi:10.59327/IPCC/AR6-9789291691647.
[9] Tilbrook, B., et al. (2024): "The Global Ocean Acidification Observing Network: Data for Decisions." *Frontiers in Marine Science*.

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(2021-2030) has placed OA research high on its agenda.

Despite these advances, international law still lacks a binding mechanism dedicated to ocean acidification. Current efforts depend on broader climate and biodiversity agreements, which vary in strength and enforcement. To truly address this "silent threat," stronger global coordination, binding commitments, and long-term monitoring frameworks will be essential.

Indian Legal and Policy Framework on Ocean Acidification

In India, there is currently no single law that directly addresses ocean acidification. Instead, the issue is dealt with indirectly through a combination of environmental, climate, and marine protection measures. This mirrors the global situation, where OA is acknowledged as a pressing challenge but remains largely embedded within broader legal frameworks.

The Environment (Protection) Act, 1986[10] provides the central government with wide-ranging powers to safeguard environmental quality. Although ocean acidification is not explicitly mentioned, the Act serves as the backbone for controlling activities that increase carbon emissions and marine pollution—two drivers linked to changes in ocean chemistry. Alongside this, the Water Act of 1974[11] and the Air Act of 1981[12] regulate pollutants that ultimately contribute to CO_2 buildup in the atmosphere and, by extension, in the oceans.

The Coastal Regulation Zone (CRZ) Notification of 2011[13], framed under the Environment Act, is also significant. It restricts construction and industrial projects in ecologically sensitive coastal areas, thereby offering some protection to habitats such as coral reefs, mangroves, and estuaries. These ecosystems are particularly at risk from acidification and related stressors.

On the climate front, India's participation in the Paris Agreement has shaped national responses to CO_2 emissions. Domestic initiatives like the National Action Plan on Climate Change (NAPCC)[14] and various State Action Plans promote renewable energy, energy efficiency, and sustainable practices. While designed to combat climate change, these measures

[10] Act No. 29, Acts of Parliament, 1986 (India).
[11] Act No. 6 of 1974.
[12] Act No. 14 of 1981
[13] Ministry of Environment and Forests, Coastal Regulation Zone Notification, S.O. 19(E), Gazette of India, (Jan. 6, 2011).
[14] Prime Minister's Council on Climate Change. (2008). *National Action Plan on Climate Change*. Government of India.

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also help slow the progression of ocean acidification by limiting carbon output.

Biodiversity protection adds another layer to this framework. The Biological Diversity Act, 2002[15] emphasizes the conservation of marine and coastal species, while the National Marine Fisheries Policy (2017) underscores the importance of healthy ecosystems for livelihoods and food security. Local conservation efforts, including coral reef management programs in the Lakshadweep Islands and the Andaman & Nicobar region, further strengthen India's compliance with its obligations under the Convention on Biological Diversity (CBD).

Despite these measures, significant gaps remain. Ocean acidification is not explicitly recognized in Indian law, and monitoring efforts are fragmented and limited. Long-term, region-specific data for Indian and tropical waters is scarce, leaving policymakers with an incomplete picture of the risks. Considering that millions of Indians rely on fisheries and coastal ecosystems, this lack of focus represents a major governance challenge.

Moving forward, India would benefit from expanding its marine monitoring capacity, explicitly incorporating OA into national climate and biodiversity strategies, and fostering regional cooperation within the Indian Ocean. Such steps would transform ocean acidification from an overlooked issue into a clear policy priority, ensuring greater protection for both ecosystems and communities.

Case Study: The Vanishing Atolls of Lakshadweep

The Lakshadweep archipelago serves as a stark legal laboratory for the inadequacies of the Biological Diversity Act, 2002. While the Union Territory has utilized Section 37 to designate sensitive zones, these protections are strictly 'Spatial and Physical.' They regulate who can walk on the reef, but they do not regulate the 'pH' of the water surrounding it.

As CO_2 levels rise, the carbonate saturation state of the Laccadive Sea is reaching a critical threshold. This study finds that the Biodiversity Management Committees (BMCs) in Lakshadweep are legally 'blind' to ocean acidification. Their People's Biodiversity Registers (PBRs) record the presence of coral species but fail to record the chemical baseline of the water. To move from a reactive to a proactive legal framework, the BDA must be amended to

[15] Act No. 18 of 2003

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recognize 'Chemical Integrity' as a mandatory component of biodiversity conservation.

Research Gaps and Challenges

Ocean acidification (OA) is becoming more widely acknowledged as a global issue, but in the Indian context, a Lack of Region-Specific Data number of gaps and difficulties prevent an effective response:

- Lack of Region-Specific Data

  There are still few scientific studies on OA in tropical waters and India. Understanding of localised impacts on fisheries and biodiversity is limited because the majority of available data is extrapolated from temperate regions.

- Policy Integration Deficit

  India's policies on marine biodiversity and climate change are not well integrated with OA, leading to disjointed approaches. In contrast to marine pollution or carbon emissions, OA is not specifically acknowledged in national frameworks.

- Institutional and Infrastructure Limitations

  Inadequate marine research infrastructure and limited institutional capacity plague India, especially when it comes to specialised ocean chemistry studies and long-term monitoring. This limits the capacity to produce trustworthy, superior datasets.

- Community-Level Awareness

  Fishermen and coastal communities are not well informed or involved. Adaptive strategies remain top-down and are less practical if local knowledge is not disseminated.

- Comparative Disadvantage

  In terms of systematic monitoring, policy integration, and public engagement, India lags behind nations such as the United States, Australia, and Pacific Island nations. India can learn from these nations' strong OA observatories, legal recognition, and community adaptation models.

  In order to establish an efficient OA governance model in India, these gaps underscore the pressing need for region-specific research, policy mainstreaming, and improved

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institutional community ties.

Findings And Discussions

According to the study, marine biodiversity is increasingly at risk from ocean acidification (OA). It weakens molluscs, coral reefs, and other calcifying species by changing the chemistry of the ocean, which destabilises entire ecosystems. The direct effects of this decline on India's fisheries, coastal livelihoods, and food security are significant ramifications. Millions of people rely on marine resources for both income and nutrition, especially in coastal states. These socioeconomic lifelines are in danger of being disrupted by OA, which would exacerbate preexisting vulnerabilities like overfishing and climate change.

The Indian legal system has an OA gap at the governance level. Because OA is not specifically recognised or regulated by current environmental and marine biodiversity laws and policies, serious ecological and social risks go unchecked. These results highlight how crucial it is to combine science, law, and policy in order to create a cogent regional and national response. Without this kind of integration, scientific understanding will continue to be divorced from legally binding regulations. Lastly, the study emphasises the necessity of multi-stakeholder and cross-disciplinary approaches. To create solutions that are both socially just and scientifically sound, cooperation between scientists, legal professionals, legislators, coastal communities, and international networks is crucial.

Recommendations

Addressing ocean acidification requires multi-level and integrated responses:

1. Policy-Level
    - Explicitly include ocean acidification (OA) in climate change and marine biodiversity policies.
    - Improve monitoring and data collection, focusing on Indian waters to create a strong national database.

2. Legal Reforms
    - Add OA parameters as markers of the health of marine ecosystems to the Environment Protection Rules.
    - To guarantee accountability, include OA-specific pledges in India's

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National Biodiversity Targets.

3. Institutional Measures
    - Create regional research centres to produce accurate and localised scientific data, such as an Indian Ocean OA Observatory.
    - Boost cooperation with international networks for technical assistance and knowledge exchange, such as the Global Ocean Acidification Observing Network (GOA-ON).

4. Societal Interventions
    - Increase the ability of fishermen and coastal communities, who are among the first impacted, to adapt.
    - Run campaigns to raise awareness of the effects of OA in order to encourage community involvement and behavioural change.

5. Academic and Research Initiatives
    - Establish long-term OA monitoring initiatives, particularly in coastal waters in India and the tropics.
    - Encourage multidisciplinary research that combines policy, marine science, and law to create practical solutions.

Conclusion

Ocean acidification is a serious and urgent threat to marine biodiversity. It disrupts the ecological balance and harms the livelihoods that rely on healthy oceans. While this issue is mostly scientific, its wide-ranging effects require prompt legal, policy, and scientific actions on both global and regional levels. To effectively tackle this crisis, we must address the current research gaps. This includes improving policy integration and gathering more data that is specific to different regions. If we don't address these gaps, our responses will remain scattered and inadequate. What we need is a fair and sustainable governance model. This model should balance environmental protection with social fairness and economic strength. Only with this approach can we protect ocean health for today and future generations.