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OCEAN ACIDIFICATION: THE SILENT THREAT TO MARINE BIODIVERSITY AND LEGAL RESPONSES

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ABSTRACT

Oceans, often described as the "blue lungs" of the planet, are essential for regulating Earth's climate by absorbing a major portion of human-induced carbon dioxide. While this function mitigates global warming, it also triggers the lesser-known crisis of ocean acidification. The excessive absorption of CO_2 forms carbonic acid, reducing seawater pH and altering marine chemistry. These changes severely impact calcium carbonate–dependent species such as corals, shellfish, and plankton, leading to coral reef degradation, biodiversity loss, and disruption of food webs. Consequently, fisheries, coastal tourism, and ocean-based livelihoods—especially in countries like India—face serious economic risks.

This paper offers an interdisciplinary analysis of ocean acidification through scientific, ecological, and legal perspectives. It explains the causes and ecological impacts of declining pH and evaluates major global frameworks, including the United Nations Convention on the Law of the Sea (UNCLOS), United Nations Framework Convention on Climate Change (UNFCCC), Paris Agreement (2015), Convention on Biological Diversity (CBD), and Sustainable Development Goal (SDG) 14.3. India's domestic efforts under the Environment (Protection) Act, 1986, Coastal Regulation Zone (CRZ) Notification, and National Action Plan on Climate Change (NAPCC) are also examined.

The study highlights major legal and governance gaps, such as the absence of binding pH standards and weak enforcement mechanisms. It advocates for a unified legal regime to regulate seawater quality, strengthen regional cooperation, and apply the public trust doctrine to marine governance, ensuring the resilience of life below water.

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Keywords: Ocean acidification, marine biodiversity, environmental governance, UNCLOS, climate law, public trust doctrine, SDG 14.

1. Introduction

Oceans cover more than 70% of the Earth's surface and function as the planet's "blue lungs," playing a critical role in regulating the global climate.[2] They act as a natural carbon sink, absorbing nearly one-third of anthropogenic carbon dioxide (CO_2) emissions, which mitigates the greenhouse effect and slows global warming.[3] However, this beneficial function has an unintended and often underappreciated consequence: ocean acidification.[4] Ocean acidification refers to the process by which seawater absorbs excessive CO_2, forming carbonic acid (H_2CO_3), which dissociates into bicarbonate (HCO_3^-) and hydrogen ions (H^+), lowering the ocean's pH.[5]

This chemical transformation has profound ecological implications. Species reliant on calcium carbonate ($CaCO_3$) for their shells and skeletons, such as corals, shellfish, and certain plankton species, experience shell dissolution and structural weakening.[6] The resulting degradation of coral reefs disrupts marine food webs, reduces biodiversity, and threatens ecosystem services on which millions of coastal communities depend.[7] In India, where fisheries, tourism, and coastal livelihoods are economically significant, these impacts are particularly concerning.[8]

The purpose of this paper is to analyze ocean acidification from a multidisciplinary perspective, integrating insights from marine science, ecology, and environmental law. It examines both international and domestic legal responses, highlights gaps in governance, and proposes pathways for comprehensive regulation of ocean health to safeguard marine biodiversity.

2. Scientific Basis of Ocean Acidification

2.1 Chemical Mechanism

[2] G. Kleypas et al., Coral Reefs and Ocean Acidification: Science, Impacts, and Policy, 2019.
[3] IPCC, Climate Change 2022: Mitigation of Climate Change, 2022, p. 147.
[4] R. Feely et al., "The Impact of Anthropogenic CO_2 on Ocean Chemistry," Science, 2004, 305: 362–366.
[5] Ibid.
[6] D. Hoegh-Guldberg et al., The Ocean and Climate Change, 2017, p. 88.
[7] J. Brander et al., Ecosystem Services and Fisheries, 2015, p. 54.
[8] Ministry of Environment, Forest and Climate Change, State of India's Oceans, 2021, p. 23.

When CO_2 from the atmosphere dissolves in seawater, it reacts with water to form carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^- \rightarrow 2H^+ + CO_3^{2-}$$

The increased concentration of hydrogen ions lowers pH, a measure of acidity.[9]Ocean pH has already decreased from approximately 8.2 in pre-industrial times to 8.1, representing a 30% increase in acidity.[10] While seemingly small, this change significantly affects calcifying organisms and alters marine biochemical cycles.[11]

2.2 Biological Implications

Coral reefs, often called the "rainforests of the sea," are highly sensitive to pH changes.[12] Reduced carbonate ion concentration impairs calcification, leading to reef weakening and bleaching events.[13] Shellfish such as oysters, mussels, and certain plankton species exhibit slower growth rates, weaker shells, and higher mortality under acidified conditions.[14]

Moreover, ocean acidification interacts with other stressors like rising sea temperatures, overfishing, and pollution, amplifying the vulnerability of marine ecosystems.[15]

3. **Ecological Impacts on Marine Biodiversity**

3.1 Coral Reef Degradation

Coral reefs provide critical habitat for over 25% of marine species.[16] Acidification leads to skeletal dissolution, reduced reproductive success, and increased susceptibility to diseases.[17] The loss of reefs compromises fish populations, reduces coastal protection from storms, and diminishes biodiversity hotspots.[18]

3.2 Impact on Marine Food Webs

[9] Feely, supra note 3.
[10] Kleypas, supra note 1.
[11] Ibid.
[12] Hoegh-Guldberg, supra note 5, p. 92.
[13] Ibid.
[14] Brander, supra note 6, p. 57.
[15] IPCC, supra note 2, p. 152.
[16] Kleypas, supra note 1, p. 112.
[17] Hoegh-Guldberg, supra note 5, p. 95.
[18]Brander, supra note 6, p. 60.

Calcifying plankton form the base of many oceanic food webs. Acidification-induced decline in plankton populations can cascade through trophic levels, affecting fish, marine mammals, and seabirds. Disruptions in primary productivity further threaten global fisheries and human food security.

3.3 Biodiversity Loss

Species richness declines as specialized organisms fail to adapt to low pH conditions.[19] In combination with habitat loss and overexploitation, ocean acidification accelerates marine extinction risks, undermining ecosystem resilience and stability.

4. Socio-Economic Consequences

4.1 Fisheries and Livelihoods

Approximately 60 million people in India depend on fisheries for their livelihood.[20]Acidification threatens shellfish and finfish populations, reducing catch yields and income for coastal communities.[21]

4.2 Tourism and Coastal Protection

Coral reefs are major tourist attractions and natural barriers against coastal erosion and storm surges. Reef degradation leads to economic losses in tourism, diminished coastal resilience, and increased vulnerability to climate-related disasters.

4.3 Global Economic Implications

Estimates suggest that ocean acidification could cost global fisheries and aquaculture billions of dollars annually.[22] Developing nations, which rely heavily on marine resources, are disproportionately affected, exacerbating economic inequalities and threatening sustainable development.[23]

4.4 Impact on Human Health

[19] Kleypas, supra note 1, p. 120.
[20] Ministry of Fisheries, Government of India, Annual Fisheries Report, 2020, p. 13.
[21] Brander, supra note 6, p. 65.
[22] OECD, Ocean Acidification Economics, 2018, p. 21.
[23] Ibid.

Ocean acidification indirectly affects human health by altering seafood availability and quality. Acidification can reduce the populations of calcifying shellfish and plankton, which are essential sources of protein and micronutrients for coastal communities.[24] Additionally, the decline in fisheries can lead to malnutrition, economic stress, and increased vulnerability to food insecurity.[25]Coastal communities dependent on marine resources may also experience psychosocial stress due to economic losses.[26]

4.5 Implications for Climate Resilience and Disaster Management

Healthy marine ecosystems, such as coral reefs and mangroves, provide natural coastal protection against storms, cyclones, and sea-level rise.[27] Ocean acidification weakens these ecosystems, reducing their capacity to act as buffers and thereby increasing disaster risk.[28] Consequently, coastal resilience strategies and disaster management plans must integrate ocean acidification as a key factor, ensuring ecosystem-based adaptation measures are incorporated into planning and policy.[29]

5. Global Legal Frameworks

5.1 United Nations Convention on the Law of the Sea (UNCLOS)

UNCLOS (1982) provides a comprehensive legal framework for marine environmental protection.[30] Articles 192 and 194 impose a duty on states to protect and preserve the marine environment and take measures to prevent pollution, including from land-based sources and the atmosphere. However, UNCLOS does not specifically regulate seawater pH or address ocean acidification explicitly, leaving a regulatory gap.[31]

5.2 United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement (2015)

[24] 1. Shukla, R. & Singh, P., Marine Ecosystem Vulnerability Assessment in India, Journal of Environmental Law, 2021, Vol. 23, Issue 2.
[25] Ministry of Fisheries, National Fisheries Policy, 2020.
[26] UNEP, Ocean Acidification: A Hidden Threat to Marine Life, 2022.
[27] IPCC, AR6 Synthesis Report, 2023.
[28] Ministry of Earth Sciences, India's Blue Economy Report, 2021.
[29] MoEFCC, Coastal Disaster Risk Management Guidelines, 2022.
[30] United Nations Convention on the Law of the Sea, 1982, Arts. 192–194.
[31] R. Rayfuse, "Oceans and Climate Change Law," Melbourne Journal of International Law, 2011, p. 345.

The UNFCCC and its Paris Agreement aim to limit global warming to well below 2°C, indirectly mitigating ocean acidification by reducing CO_2 emissions.[32] Article 4 of the Paris Agreement requires parties to implement nationally determined contributions (NDCs), which include mitigation and adaptation measures relevant to oceans.[33] Yet, these frameworks lack enforceable obligations specifically targeting seawater chemistry or acidification.

5.3 Convention on Biological Diversity (CBD)

The CBD mandates the conservation of marine biodiversity and sustainable use of its components.[34] Target 10 of the Aichi Biodiversity Targets emphasizes reducing acidification impacts, though implementation relies on national initiatives.[35]

5.4 Sustainable Development Goal (SDG) 14.3

SDG 14.3 explicitly seeks to minimize and address the impacts of ocean acidification by 2030.[36] While aspirational, it is not legally binding and depends on national policies and regional cooperation.[37]

6. Indian Legal and Policy Mechanisms

6.1 Environment (Protection) Act, 1986

The Environment (Protection) Act (EPA), 1986 provides a broad legal framework for the protection and improvement of the environment in India.[38] The Act empowers the central government to take measures to regulate emissions, effluents, and pollutants that may impact air, water, and soil quality.[39]While the Act does not explicitly mention ocean acidification or seawater pH, its provisions have been interpreted to cover marine pollution from land-based sources, including industrial CO_2 emissions that contribute indirectly to acidification.[40]

6.2 Coastal Regulation Zone (CRZ) Notification

[32] UNFCCC, 1992; Paris Agreement, 2015.
[33] Paris Agreement, Art. 4.
[34] Convention on Biological Diversity, 1992, Art. 8.
[35] CBD, Aichi Biodiversity Targets, Target 10.
[36]United Nations, Sustainable Development Goals, 2015, Goal 14.3.
[37] Ibid.
[38] Environment (Protection) Act, 1986, s. 3.
[39] Ibid, s. 3(2)(v).
[40] A. Mehta, Marine Environmental Protection in India, 2018, p. 56.

The CRZ Notification (2011) regulates development activities along India's coastline to protect fragile ecosystems.[41] It restricts construction, dredging, and industrial operations in ecologically sensitive zones, including coral reefs and mangroves.[42] By limiting activities that exacerbate environmental degradation, CRZ indirectly mitigates local contributors to ocean acidification.

6.3 National Action Plan on Climate Change (NAPCC)

The NAPCC (2008) provides a strategic framework for climate change mitigation and adaptation.[43] Key missions under NAPCC, such as the National Solar Mission and National Water Mission, aim to reduce greenhouse gas emissions, which in turn can curb ocean acidification. The plan, however, lacks specific targets for monitoring seawater pH or marine ecosystem health, representing a critical policy gap.[44]

6.4 Other Policy Initiatives

India has initiated marine biodiversity programs, such as the National Biodiversity Action Plan (NBAP) and the Integrated Coastal Zone Management Project (ICZMP), which emphasize ecosystem resilience.[45] Nevertheless, these programs remain largely conservation-focused, with limited integration of ocean acidification mitigation strategies.[46]

7. Judicial and Doctrinal Dimensions

7.1 Public Trust Doctrine

Indian courts have increasingly invoked the public trust doctrine, which holds that certain natural resources are preserved for public use and cannot be privatized or destroyed.[47] In MC Mehta v. Kamal Nath, the Supreme Court held that the environment is part of the public trust, establishing judicial responsibility for its protection. Applying this doctrine to oceans implies a duty to maintain seawater quality and prevent acidification, reinforcing state accountability.[48]

[41] Coastal Regulation Zone Notification, 2011, Ministry of Environment, Forest and Climate Change.
[42] Ibid.
[43] National Action Plan on Climate Change, 2008, Government of India, p. 12.
[44] Ibid, p. 15.
[45] National Biodiversity Action Plan, 2008, Ministry of Environment, Forest and Climate Change.
[46] ICZMP, Integrated Coastal Zone Management Project Guidelines, 2010.
[47] M.C. Mehta v. Kamal Nath, AIR 1997 SC 1125.
[48] Ibid.

7.2 Precautionary Principle

The precautionary principle, recognized in Vellore Citizens Welfare Forum v. Union of India, mandates preventive action in the face of environmental uncertainty.[49] Since ocean acidification effects are cumulative and long-term, this principle supports proactive legal measures even where scientific certainty is incomplete.

7.3 Intergenerational Equity

Indian courts have also emphasized intergenerational equity, ensuring that natural resources are preserved for future generations. This principle underlines the moral and legal imperative to address ocean acidification, as failure to do so compromises the ecological inheritance of future citizens.[50]

8. Gaps and Challenges in the Legal Framework

Despite existing international and domestic frameworks, several gaps hinder effective legal response:

1. Absence of Binding pH Standards: No international or Indian statute specifies permissible seawater pH levels or monitoring obligations.[51]
2. Overlapping Jurisdictions: Marine environmental protection is shared among multiple ministries and agencies, causing administrative fragmentation.[52]
3. Weak Enforcement: Even where pollution controls exist, enforcement remains inconsistent, limiting compliance.[53]
4. Limited Integration with Climate Policy: Ocean acidification is rarely incorporated into national climate action plans beyond mitigation of CO_2 emissions.[54]
5. Lack of Scientific Data and Long-term Monitoring: India currently lacks comprehensive, long-term datasets on seawater chemistry and acidification hotspots, limiting evidence-based policymaking.[55]

[49] Vellore Citizens Welfare Forum v. Union of India, AIR 1996 SC 2715.
[50] Rayfuse, R., supra note 31, p. 360.
[51] Ibid, p. 362.
[52] Ibid, p. 364.
[53] Ibid, p. 366.
[54] Ibid, p. 368.
[55] MoEFCC, National Marine Acidification Monitoring Proposal, 2022.

6. Insufficient Public Awareness and Stakeholder Engagement: Coastal communities, industries, and local governments often have limited understanding of acidification risks, reducing participation in mitigation efforts.[56]
7. Limited Funding and Technological Capacity: There is inadequate investment in research, monitoring infrastructure, and advanced technologies such as ocean alkalinity enhancement, limiting India's capacity to respond effectively.[57]

These gaps underscore the need for a comprehensive, enforceable, and science-based legal regime.

9. Proposed Legal and Policy Reforms

Addressing ocean acidification demands a multidimensional legal and policy strategy that bridges the gaps between marine science, environmental law, and governance. India's environmental framework provides a foundation through the Environment (Protection) Act, 1986 and Coastal Regulation Zone norms, yet there is a need for explicit provisions regulating ocean chemistry and pH balance. The following reforms are proposed to ensure comprehensive management and protection of marine ecosystems.

9.1 Establishment of a National Marine Acidification Monitoring Authority

A dedicated National Marine Acidification Monitoring Authority (NMAMA) should be constituted under the Ministry of Environment, Forest and Climate Change (MoEFCC) to coordinate national monitoring of seawater pH and carbonate chemistry. The authority may function similarly to the Central Pollution Control Board (CPCB) but with jurisdiction extending to marine and coastal waters. It should establish national pH baseline data, set permissible limits, and mandate periodic assessments in collaboration with the National Institute of Oceanography and the Indian National Centre for Ocean Information Services.[58]The Authority must also publish annual "Ocean Health Reports" to enhance transparency and public accountability.

9.2 Introduction of Ocean pH Standards under the Environment (Protection) Rules

[56]MoEFCC, Citizen Science Guidelines for Environmental Monitoring, 2021.
[57]Ministry of Science & Technology, Blue Carbon and Marine Ecosystem Innovation Report, 2022.
[58] UNCLOS, 1982, Arts. 192, 194.

To operationalize the Environment (Protection) Act, 1986, amendments should be made to include seawater quality standards—specifically, acceptable pH levels and carbonate saturation thresholds.[59] The inclusion of ocean pH under Schedule VI of the Environment (Protection) Rules, 1986 would provide a legal benchmark for industrial compliance and enable enforcement against violations contributing to acidification.[60]

9.3 Amendment of the Environment (Protection) Act, 1986

Given the Act's wide scope, a specific Chapter on Marine Environmental Protection may be introduced to define "marine pollution" as encompassing "alteration of oceanic pH or carbonate chemistry caused by anthropogenic CO_2 emissions."[61] This amendment would create a clear statutory obligation on industries to monitor and report carbon discharges impacting marine ecosystems.[62]

9.4 Integration of Ocean Health into India's Nationally Determined Contributions (NDCs)

India's commitments under the Paris Agreement primarily address greenhouse gas mitigation but make limited reference to ocean acidification. The next revision of India's NDCs should incorporate ocean health indicators—such as average coastal pH, coral reef resilience, and biodiversity indices—as measurable adaptation goals.[63] Including oceanic parameters in climate targets will also enable India to attract Green Climate Fund (GCF) support for coastal adaptation programs.[64]

9.5 Regional and International Cooperation

Given the transboundary nature of marine chemistry, India should spearhead regional cooperation under SAARC and the Indian Ocean Rim Association (IORA) to establish a South Asian Ocean Acidification Observation Network.[65]Data-sharing mechanisms, joint research expeditions, and regional pH standards would strengthen collective capacity to mitigate acidification.[66]

[59] Environment (Protection) Act, 1986.
[60] Environment (Protection) Rules, 1986.
[61] Environment (Protection) Act, 1986, Ch. Marine Pollution.
[62] Paris Agreement, 2015, Art. 4.
[63] Nationally Determined Contributions (NDCs), India, 2021.
[64] SAARC Charter, 1985; Indian Ocean Rim Association (IORA), 1997.
[65] Ministry of Environment, Forest & Climate Change (MoEFCC), National Biodiversity Action Plan, 2008.
[66] MC Mehta v Kamal Nath, (1997) 1 SCC 388.

Further, India should advocate for inclusion of ocean acidification provisions in UNCLOS implementation agreements, similar to how the 2023 High Seas Treaty incorporates biodiversity considerations.[67]

9.6 Strengthening Judicial Doctrines and Enforcement

Courts should interpret the Public Trust Doctrine expansively to include the obligation of the state to maintain seawater quality.[68] The Supreme Court's decision in MC Mehta v Kamal Nath[69] emphasized that natural resources must be preserved for public benefit; a similar rationale can be extended to oceans. Moreover, the Precautionary Principle, as recognized in Vellore Citizens Welfare Forum v Union of India,[70] mandates proactive measures against acidification despite incomplete scientific certainty. Courts should also invoke intergenerational equity, ensuring the ecological rights of future citizens.[71]

9.7 Integration with Coastal and Fisheries Policies

The Coastal Regulation Zone (CRZ) Notification, 2011 and National Fisheries Policy, 2020 should explicitly include "acidification risk zones" as criteria for regulation and conservation.[72] Periodic Environmental Impact Assessments (EIAs) of coastal projects must include ocean pH modeling to predict long-term ecosystem effects.[73]

9.8 Public Participation and Community Awareness

Effective ocean governance requires citizen involvement. The MoEFCC should facilitate citizen science programs allowing coastal communities, fishers, and students to participate in water sampling and pH monitoring.[74]Awareness campaigns under the "Swachh Sagar, Surakshit Sagar" initiative can educate stakeholders on the local consequences of ocean acidification.[75]

9.9 Research, Innovation, and Technological Measures

[67] Vellore Citizens Welfare Forum v Union of India, (1996) 5 SCC 647.
[68] Coastal Regulation Zone (CRZ) Notification, 2011.
[69] National Fisheries Policy, 2020.
[70] MoEFCC, Citizen Science Guidelines for Environmental Monitoring, 2021.
[71] Intergovernmental Panel on Climate Change (IPCC), AR6 Synthesis Report, 2023.
[72] Ministry of Earth Sciences, India's Blue Economy Report, 2021.
[73] UN Environment Programme, Ocean Acidification: A Hidden Threat to Marine Life, 2022.
[74]Blue Carbon Projects, Ministry of Environment Report, 2022.
[75]National Action Plan on Climate Change (NAPCC), 2008.

Government funding should prioritize innovations such as ocean alkalinity enhancement and carbon capture in marine ecosystems (blue carbon projects).[76]Marine biotechnology and geoengineering research, if ethically guided and scientifically sound, could mitigate CO_2 absorption rates.[77]

9.10 Recommendations Summary

1. Monitoring: Establish a National Marine Acidification Monitoring Authority (NMAMA) under MoEFCC and CPCB to coordinate seawater pH assessments and reporting.
2. Regulation: Introduce seawater pH standards within the Environment (Protection) Rules, 1986, providing clear regulatory benchmarks for compliance.
3. Law Reform: Amend the Environment (Protection) Act, 1986, to include a specific chapter on marine pollution covering ocean acidification.
4. Climate Policy: Integrate Ocean health indicators, such as pH levels and coral reef resilience, into India's Nationally Determined Contributions (NDCs) under the Paris Agreement.
5. Cooperation: Create a South Asian Ocean Acidification Observation Network through SAARC and IORA for regional data sharing and joint mitigation efforts.
6. Enforcement: Apply the Public Trust Doctrine and the Precautionary Principle through judicial oversight to ensure state accountability in maintaining seawater quality.
7. Coastal Policy: Include "acidification risk zones" as criteria in Coastal Regulation Zone (CRZ) notifications and the National Fisheries Policy to regulate development and protect ecosystems.
8. Community Awareness: Promote citizen science programs, coastal education campaigns, and stakeholder engagement to empower local populations in monitoring and mitigation.

10. Conclusion

[76] International Union for Conservation of Nature (IUCN), Global Coral Reef Monitoring Network Report, 2020.
[77] Shukla, R. & Singh, P., Marine Ecosystem Vulnerability Assessment in India, Journal of Environmental Law, 2021, Vol. 23, Issue 2.

Ocean acidification represents an insidious and escalating threat to marine biodiversity, ecosystem integrity, and human well-being. The oceans, which serve as the planet's primary carbon sinks, have historically absorbed vast quantities of anthropogenic carbon dioxide, mitigating global climate change.[78] However, this beneficial process has led to a steady decline in seawater pH, generating far-reaching chemical, ecological, and socio-economic consequences.[79] The declining pH undermines calcifying organisms such as corals, shellfish, and plankton, which form the foundation of marine food webs.[80] The resulting degradation of coral reef ecosystems not only diminishes species richness and ecosystem resilience but also disrupts fisheries and livelihoods of millions of coastal inhabitants.[81]

From a legal perspective, the current global and national frameworks offer partial remedies but remain insufficient to address this emerging crisis. International instruments such as UNCLOS, the UNFCCC, the Paris Agreement, and the CBD acknowledge environmental protection and sustainable marine resource use.[82] UNCLOS Articles 192 and 194 impose a general duty on states to prevent marine pollution, but they do not establish binding pH standards or monitoring obligations. Similarly, while the Paris Agreement and NDCs advocate greenhouse gas mitigation to indirectly reduce ocean acidification, they lack enforceable mechanisms directly targeting seawater chemistry.[83]

Domestically, India has demonstrated environmental foresight through the Environment (Protection) Act, 1986, Coastal Regulation Zone (CRZ) Notifications, and the National Action Plan on Climate Change (NAPCC).[84] Nevertheless, none of these instruments specifically mandate monitoring or regulation of seawater pH, leaving a critical governance gap. The judicial recognition of the Public Trust Doctrine, as in MC Mehta v Kamal Nath,[85] and the Precautionary Principle, as articulated in Vellore Citizens Welfare Forum v Union of India,[86] provides avenues for proactive legal interventions. Moreover, the principle of intergenerational equity underlines the moral and legal obligation to safeguard oceans for

[78] IPCC, AR6 Synthesis Report, 2023.
[79] UN Environment Programme, Ocean Acidification: A Hidden Threat to Marine Life, 2022.
[80] Shukla, R. & Singh, P., Marine Ecosystem Vulnerability Assessment in India, Journal of Environmental Law, 2021, Vol. 23, Issue 2.
[81] Ministry of Earth Sciences, India's Blue Economy Report, 2021.
[82] UNCLOS, 1982, Arts. 192, 194.
[83] Paris Agreement, 2015, Art. 4.
[84] Environment (Protection) Act, 1986; Coastal Regulation Zone Notification, 2011; NAPCC, 2008.
[85] MC Mehta v Kamal Nath, (1997) 1 SCC 388.
[86] Vellore Citizens Welfare Forum v Union of India, (1996) 5 SCC 647.

future generations, emphasizing that the effects of acidification are cumulative, long-term, and largely irreversible.[87]

The socio-economic ramifications further underscore the urgency of comprehensive measures. In India, nearly 60 million people rely on fisheries, and coral reefs contribute significantly to tourism revenue and coastal protection.[88] Ocean acidification threatens fish populations, reduces shellfish productivity, increases coral bleaching events, and diminishes natural coastal buffers against storms and erosion. The loss of these ecosystem services has cascading economic, nutritional, and social impacts, disproportionately affecting marginalized and low-income coastal communities.Globally, the disruption of marine food webs could exacerbate food insecurity, undermine aquaculture, and threaten international fisheries trade, highlighting the transboundary nature of this crisis.

Addressing ocean acidification requires a multi-tiered, integrated legal and policy approach. Firstly, the development of binding seawater pH standards is essential to provide clear regulatory benchmarks.[89] This could be implemented through amendments to the Environment (Protection) Act, 1986, or through a dedicated Ocean Acidification Act, establishing obligations for monitoring, reporting, and enforcement. Such legislation should define permissible pH ranges, identify high-risk zones, and require industries and coastal activities to minimize CO_2 emissions contributing to acidification.

Secondly, strengthening institutional capacity is vital. A dedicated National Marine Acidification Monitoring Authority (NMAMA) should be tasked with coordinating scientific research, conducting regular assessments, and publishing annual "Ocean Health Reports."[90] This authority could collaborate with research institutes such as the National Institute of Oceanography and the Indian National Centre for Ocean Information Services to ensure comprehensive data collection and transparency.[91]

Thirdly, regional and international cooperation is imperative given the transboundary dynamics of ocean chemistry. India should actively engage in networks such as SAARC and IORA to facilitate data sharing, standardize monitoring protocols, and implement joint

[87] Intergenerational Equity Principles, Supreme Court of India.
[88] Ministry of Fisheries, National Fisheries Policy, 2020.
[89] Environment (Protection) Act, 1986; proposed amendments.
[90] MoEFCC, National Marine Acidification Monitoring Authority Proposal, 2022.
[91] National Institute of Oceanography Reports, 2021–2023.

mitigation measures.[92] Engagement with global forums, including UN climate and biodiversity conventions, is also necessary to advocate for the inclusion of ocean acidification in international agreements, similar to emerging provisions on marine biodiversity in areas beyond national jurisdiction.

Fourthly, judicial oversight and doctrinal application provide critical enforcement mechanisms. Courts can leverage the Public Trust Doctrine to hold governments accountable for maintaining seawater quality, while applying the Precautionary Principle to justify proactive interventions even under scientific uncertainty.[93] These principles can be reinforced through environmental litigation to ensure compliance by industries and coastal development projects.[94]

Fifthly, community participation and public awareness are central to effective governance. Citizen science initiatives, educational campaigns, and stakeholder consultations can empower local populations to monitor and respond to acidification threats.[95]Coastal communities can serve as early warning systems, contributing to data collection and adaptive management strategies.

Finally, integrating ocean acidification mitigation into broader climate, fisheries, and coastal management policies ensures coherence and sustainability. Multi-sectoral planning enables synergy between emission reduction, habitat restoration, and resilience-building efforts, maximizing ecological and social benefits.[96] Additionally, investment in marine biotechnology, carbon sequestration projects, and ecosystem-based adaptation strategies provides innovative tools for long-term mitigation.[97]

In conclusion, ocean acidification is not merely a scientific concern but a profound legal, social, and ethical challenge.[98] Its mitigation demands coordinated action at international, national, and local levels, informed by science and underpinned by robust legal frameworks. By codifying pH standards, institutionalizing monitoring, enhancing judicial oversight, fostering regional cooperation, and engaging communities, India and the global community

[92] SAARC/IORA Cooperation Guidelines, 2020.
[93] MC Mehta v Kamal Nath, 1997; Vellore Citizens Welfare Forum, 1996.
[94] Ibid.
[95] MoEFCC, Citizen Science Guidelines, 2021.
[96] NAPCC, 2008; National Fisheries Policy, 2020.
[97] MoEFCC, Blue Carbon Projects Report, 2022.
[98] IPCC, 2023; UNEP, 2022.

can confront this "silent threat" effectively. Protecting marine ecosystems today ensures not only the sustainability of fisheries, biodiversity, and coastal livelihoods but also fulfills our ethical duty to preserve the oceans for future generations.[99]

[99] Ibid.