INTERNATIONAL JOURNAL FOR LEGAL RESEARCH AND ANALYSIS

Open Access, Refereed Journal Multi Disciplinary
Peer Reviewed

www.ijlra.com

ISSN: 2582-6433

DISCLAIMER

No part of this publication may be reproduced, stored, transmitted, or distributed in any form or by any means, whether electronic, mechanical, photocopying, recording, or otherwise, without prior written permission of the Managing Editor of the *International Journal for Legal Research & Analysis (IJLRA)*.

The views, opinions, interpretations, and conclusions expressed in the articles published in this journal are solely those of the respective authors. They do not necessarily reflect the views of the Editorial Board, Editors, Reviewers, Advisors, or the Publisher of IJLRA.

Although every reasonable effort has been made to ensure the accuracy, authenticity, and proper citation of the content published in this journal, neither the Editorial Board nor IJLRA shall be held liable or responsible, in any manner whatsoever, for any loss, damage, or consequence arising from the use, reliance upon, or interpretation of the information contained in this publication.

The content published herein is intended solely for academic and informational purposes and shall not be construed as legal advice or professional opinion.

ISSN: 2582-6433

ABOUT US

The *International Journal for Legal Research & Analysis (IJLRA)* (ISSN: 2582-6433) is a peer-reviewed, academic, online journal published on a monthly basis. The journal aims to provide a comprehensive and interactive platform for the publication of original and high-quality legal research.

IJLRA publishes Short Articles, Long Articles, Research Papers, Case Comments, Book Reviews, Essays, and interdisciplinary studies in the field of law and allied disciplines. The journal seeks to promote critical analysis and informed discourse on contemporary legal, social, and policy issues.

The primary objective of IJLRA is to enhance academic engagement and scholarly dialogue among law students, researchers, academicians, legal professionals, and members of the Bar and Bench. The journal endeavours to establish itself as a credible and widely cited academic publication through the publication of original, well-researched, and analytically sound contributions.

IJLRA welcomes submissions from all branches of law, provided the work is original, unpublished, and submitted in accordance with the prescribed submission guidelines. All manuscripts are subject to a rigorous peer-review process to ensure academic quality, originality, and relevance.

Through its publications, the *International Journal for Legal Research & Analysis* aspires to contribute meaningfully to legal scholarship and the development of law as an instrument of justice and social progress.

ISSN: 2582-6433

PUBLICATION ETHICS, COPYRIGHT & AUTHOR RESPONSIBILITY STATEMENT

The *International Journal for Legal Research and Analysis (IJLRA)* is committed to upholding the highest standards of publication ethics and academic integrity. All manuscripts submitted to the journal must be original, unpublished, and free from plagiarism, data fabrication, falsification, or any form of unethical research or publication practice. Authors are solely responsible for the accuracy, originality, legality, and ethical compliance of their work and must ensure that all sources are properly cited and that necessary permissions for any third-party copyrighted material have been duly obtained prior to submission. Copyright in all published articles vests with IJLRA, unless otherwise expressly stated, and authors grant the journal the irrevocable right to publish, reproduce, distribute, and archive their work in print and electronic formats. The views and opinions expressed in the articles are those of the authors alone and do not reflect the views of the Editors, Editorial Board, Reviewers, or Publisher. IJLRA shall not be liable for any loss, damage, claim, or legal consequence arising from the use, reliance upon, or interpretation of the content published. By submitting a manuscript, the author(s) agree to fully indemnify and hold harmless the journal, its Editor-in-Chief, Editors, Editorial Board, Reviewers, Advisors, Publisher, and Management against any claims, liabilities, or legal proceedings arising out of plagiarism, copyright infringement, defamation, breach of confidentiality, or violation of third-party rights. The journal reserves the absolute right to reject, withdraw, retract, or remove any manuscript or published article in case of ethical or legal violations, without incurring any liability.

ISSN: 2582-6433

THE HIDDEN CONSEQUENCES OF OCEAN ACIDIFICATION IN THE MARINE IN ENVIRONMENTAL AND LEGAL PERSPECTIVE

AUTHORED BY - SHERLLINE RANJITHAM. E.
LLM., [Criminal Law and Criminal Justice Administration],
Tamil Nadu Dr. Ambedkar Law University – School of Excellence in Law

ABSTRACT

Ocean acidification is the gradual decrease in the seawater pH caused by the increased absorption of carbon dioxide. These changes affect not only the open ocean but also coastal waters, estuaries, and other marine ecosystems, posing serious challenges to marine life and the overall health of ocean environments.[1]. As the water becomes more acidic, these organisms struggle to develop and sustain calcium carbonate structures. This may harm the entire ecosystem, like the coral reefs, which is important habitat for the diverse marine organisms. Subsequent to altering marine life, ocean acidification also threatens global biodiversity, food security, and the ocean ecosystem. Since the seas absorbs more CO_2 and acidify, scientists, governments, and communities must consider the consequence and should take action inorder to reduce their effects.

Among many environmental issues of this century acidification of the ocean has emerged as a significant environmental concern and demands coordinated worldwide efforts to cut carbon emissions and protect marine life. At the same time, ocean acidification amplifies the effects of climate change. Rising global temperatures are already affecting sea levels, weather patterns, and ocean conditions, and the combination of increased temperatures and acidic waters puts further burdens the marine creatures. Understanding their effects is crucial for furnishing measures to protect ocean health and to assure marine resource sustainability.

Keywords: Ocean Acidification, Biodiversity, Environment, Calcium Carbonate Structures, Climate Change, Ocean Health.

[1] Ingrid J.M van Beek Mascha Dedert, "*Ocean Acidification A review of the current status of research and institutional developments"*, IMARES (Oct. 18, 2012), https://edepot.wur.nl/237843.

ISSN: 2582-6433

I. INTRODUCTION:

Ocean acidification is a continuous decrease in pH of the ocean water due to the absorption of excess carbon dioxide from the atmosphere due to the human activities, particularly fossil fuel combustion and industrial emissions. Each time CO_2 disintegrates in ocean water, it forms carbonic acid (H_2CO_3), that breaks down as bicarbonate (HCO_3^-) and hydrogen ions (H^+), which decreases pH and ocean alkalinity. The rise in the concentration of hydrogen ions reduces the presence of carbonate ions which is crucial for marine creatures which includes corals and shellfish to produce calcium carbonate ($CaCO_3$) structures[23]. The rise of hydrogen ions reduces the pH of the ocean and makes it more acidic, presently the rate of acidification is far greater than the natural level due to the greenhouse gas emissions, this change poses serious change and challenges to the marine ecosystem and to the species dwelling there.

This threat of ocean acidification to marine biodiversity, fisheries, and global climate stability. As ocean pH levels decline due to excessive carbon dioxide absorption, vital ecosystems such as coral reefs, shell forming organisms, and fish populations face severe disruptions. These changes not only threaten marine food webs but also weaken the ocean's ability to regulate carbon cycles, exacerbating climate change. Acknowledging these impacts are crucial for developing sustainable conservation strategies to protect marine life and maintain ecological balance.

Beyond environmental concerns, ocean acidification poses serious economic and social challenges. Coastal communities and industries reliant on fisheries and marine tourism are particularly vulnerable to declining fish stocks and habitat degradation. By examining these impacts, this study provides valuable insights for policymakers, environmentalists, and industry stakeholders to implement sustainable solutions. It also emphasizes the need for stronger international legal frameworks and climate policies to mitigate ocean acidification and protect communities dependent on marine resources.

[2] Ingrid J.M van Beek Mascha Dedert, '*Ocean Acidification A review of the current status of research and institutional developments'*, IMARES (Oct. 18, 2012), https://edepot.wur.nl/237843.
[3] Md S. Zaman Robert C. Sizemore San Juanita Sanchez, "*Ocean Acidification: Impacts on Marine Ecosystems and Deep-sea Carbon Sequestration"* The Journal of Environmental Studies & Health Research, https://environ-study-health-res.com/archives/journals/2025/OA.pdf (last visited July 5, 2026).

ISSN: 2582-6433

II. CAUSES OF OCEAN ACIDIFICATION

The cause of acidifications in the ocean is that before the industrial revolution it concentration were stable , but later the atmospheric concentration of carbon dioxide have increased substantially from 220 ppm to 420 ppm cause of the human activities being the primary cause[4]. Sources of CO_2 emissions includes Fossil Fuel Combustion from the Power plants, transportation, and industries releases enormous amounts of CO_2. Due to Deforestation of forests decreased the Earth's capacity to absorb CO_2. From Industrial and Agricultural Activities such as Cement production, livestock farming, and using excessive fertilizer has contributed to CO_2 and other greenhouse gas emissions[5].

Historical Trends and Current Status of Ocean Acidification

With the onset of industrial growth, the pH of ocean surface waters has declined representing an almost 30% hike in acidity. Current CO_2 emissions are projected to drop ocean pH to 7.7 by 2100.[6] It requires a Long term monitoring programs, to be conducted by the Intergovernmental Oceanographic Commission and the Global Ocean Acidification Observing Network, indicates acidification is rising at an alarming rate, especially in high latitude regions, Ocean acidification doesn't only affect the ocean rather it also affects other marine organisms.

The Nutrient Runoff and Eutrophication results in Excess nitrogen and phosphorus from the agricultural runoff which can lead to hypoxic (low oxygen) conditions, further stresses the marine life which are already weakened by acidification process., Heavy Metal Toxicity leads the Acidic waters to increase the solubility in toxic metals such as mercury and lead, making them more bioavailable to marine organisms, Plastic Pollution from Micro plastics degrade more quickly in acidic waters, emitting harmful chemicals into the marine. Ocean acidification is a massive challenge to the environment by the emissions of CO_2 and aggravates by other means of marine pollution. Its rapid progression not only threatens marine biodiversity instead it affects the ecosystem stability, and global climate regulation.

[4] C.L. Sabine, "*The Oceanic Sink for Anthropogenic CO2"*, 305 Science 367-371. (2004), https://doi.org/10.1126/science.1097403.

[5] Pierre Friedlingstein et al., "*Global Carbon Budget 2019"*, 11 Earth Sys. Sci. Data (4), 1783–1838 (2019), https://doi.org/10.5194/essd-11-1783-2019

[6] *"Ocean acidification: why does it happen and what are the consequences?"* iberdrola, https://www.iberdrola.com/sustainability/ocean-acidification (last visited June 4, 2026).

ISSN: 2582-6433

III. IMPACT OF OCEAN ACIDIFICATION THE MARINE BIODIVERSITY

The sea is fundamental to maintaining the Earth's climate and sustaining marine biodiversity. Ocean acidification, alters the chemical composition of seawater by reducing the availability of carbonate ions, which are essential for marine organisms that produce calcium carbonate ($CaCO_3$) shells and skeletons. As ocean acidification intensifies, with serious ecological, economic, and social consequences.[7] Moreover, as acidification weakens the ocean's ability to absorb CO_2, it further induces climate change, generating a dangerous loop.

Effects on Coral Reefs

Among the ecosystems most severely affected by ocean acidification are coral reefs. Corals they rely on to build and maintain their calcium carbonate skeletons[8]. As seawater becomes more acidic, the concentration of these ions decreases, slowing coral growth and weakening reef structures. Fragile coral skeletons are more susceptible to physical damage and erosion, reducing the reef's ability to provide shelter and breeding grounds for marine organisms. In addition, ocean acidification acts together with increasing sea surface temperatures to increase the frequency of coral bleaching. During bleaching events, corals lose the symbiotic algae that supply most of their energy, leaving them vulnerable to disease and mortality.

The degradation of coral reefs has far reaching ecological impacts because many fish, invertebrates, and other marine organisms rely on coral reefs for food, reproduction, and protection from predators. As reefs decline, biodiversity decreases and the stability of surrounding marine ecosystems is compromised. Coral reef loss also affects millions of people who depend on reef based fisheries and marine tourism for their livelihoods. Coastal communities, particularly in tropical regions, may experience declining fish catches, and increased vulnerability to coastal erosion as healthy reefs naturally protect shorelines from waves and storms , However, when corals are stressed by changes in temperature or water chemistry, they expel these algae, losing their vibrant colours and becoming more susceptible to disease and death. Large scale coral bleaching events have already been recorded in the Great Barrier Reef, where extensive reef damage has been attributed to ocean acidification and rising sea temperatures. As coral reefs decline, the diverse marine species that depend on them for

[7] "*CO2 and Ocean Acidification: Causes, Impacts, Solutions"*, Union of Concerned Scientists. https://www.ucsusa.org/resources/co2-and-ocean-acidification (last visited June 4, 2026).
[8] "*Ocean Conservation Policy: Advocating for Marine Protection Measures"*, TagThinking, https://tagideas.blogspot.com/2024/05/ocean-conservation-policy-advocating.html (last visited July 6, 2026).

ISSN: 2582-6433

habitat, food, and protection also suffer, leading to biodiversity loss and ecosystem collapse. The economic consequences of coral reef degradation are profound. Coral reefs contribute significantly to global fisheries and marine tourism, supporting millions of people worldwide.[9]

Impact on Shell Forming Organisms

Marine organisms with shells, such as oysters, mussels, clams, sea snails, and several plankton species, are particularly vulnerable to ocean acidification. They use calcium carbonate to form robust shells and defensive exoskeletons. As ocean water turns acidic in nature, the presence of carbonate ions declines, making shell production more difficult. This ends up in thinner and weaker shells, limiting their ability to endure and reproduce. As a result, these organisms become more vulnerable to predators, stress in the environment, and population loss, compromising the balance of marine environments.

Among the most affected organisms are pteropods also known as sea butterflies, which serve as an indispensable food source that sustains many larger marine animals like whales. Studies have shown that pteropod shells dissolve in acidified waters, reducing their survival rates and threatening the stability of the marine food web.[10] The decline of pteropods and other planktonic organisms has cascading effects,

The consequences of ocean acidification are not limited to environmental impacts ocean acidification on shellfish industries are also alarming. Oyster hatcheries have experienced mass die offs due to acidified waters in the Pacific Northwest[11], leading to significant financial losses. Coastal communities that rely on shellfish farming for their livelihoods are facing declining harvests, threatening food security. If ocean acidification continues unchecked, the global shellfish industry will suffer long-term damage.

Effects on Fish Populations

Although fish do not rely on calcium carbonate structures, ocean acidification still has profound effects on their behaviour, growth, and reproduction. Acidified waters interfere with fish sensory perception, particularly their ability to detect predators and navigate their environment. Studies emphasis that young fishes grown in such environment are exposed to impaired

[9] "*CO2 and Ocean Acidification: Causes, Impacts, Solutions*. Union of Concerned Scientists". https://www.ucsusa.org/resources/co2-and-ocean-acidification (last visited June 4, 2026)
[10] *Ocean acidification: why does it happen and what are the consequences?* iberdrola, https://www.iberdrola.com/sustainability/ocean-acidification (last visited June 4, 2026).
[11] Anelise Chen, "*There Is No Safe Place to Hide"*, theparisreview (July 31, 2017) https://www.theparisreview.org/blog/2017/07/31/there-is-no-safe-place-to-hide/

ISSN: 2582-6433

olfactory senses, making them more vulnerable to predation, ocean acidification affects fish physiology. Increased acidity disrupts the regulation of internal pH levels, causing metabolic stress and impairing growth rates. Commercial species such as cod, tuna, and haddock experience population declines due to lower survival rates and reduced reproduction.

Consequences of declining fish populations are particularly concerning for communities which rely on fishing for income and nutrition. Many developing countries rely on sea foods as their vital source of protein, the reduction of fish stocks due to ocean acidification threatens food security for millions.

Disruptions to Marine Food System

The acidification extend beyond individual species and influences the entire marine food structure or the webs, The decline of coral reefs, shell forming organisms, and plankton reduces food availability for higher trophic levels, disrupting predator-prey relationships and ecological balance. As prey populations decrease, larger marine predators such as sharks, dolphins, whales, and seabirds may struggle to find sufficient food, leading to population declines or shifts in migration patterns. Some marine species may move towards less acidic waters, creating new ecological interactions and increasing competition for limited resources. These changes reduce ecosystem resilience, making marine environments less capable of adapting to additional pressures such as climate change, pollution, habitat destruction, and overfishing. [12].

IV. OCEAN ACIDIFICATION AND ITS INFLUENCE ON THE GLOBAL CHANGES IN CLIMATE

It is linked with environmental issues due to human activities increases, rising global temperatures, shifting weather patterns, and melting polar ice, oceans absorb CO_2, However, this helpful process alters the chemical composition of saltwater, decreasing its pH and making the seas more acidic. As a result, the ocean's ability to support healthy marine ecosystems and control global temperature is gradually declining.

The Role of Oceans in Climate Regulation

Earth's largest carbon sink is the ocean absorbing vast amounts of heat and CO_2[13]. This process

[12] Philip L. Munday et al., "*Ocean acidification impairs olfactory discrimination and homing ability of a marine fish"*, 106 Proc. Nat'l Acad. Scis. 1848 -1852 (2009), https://doi.org/10.1073/pnas.0809996106

[13] Allison Lopatkin Gang Fan and Marc Porosoff, "*Harnessing ocean microbiomes for closed-loop carbon circularity"*, Experiment - Moving Science Forward, https://experiment.com/projects/jwcrugonwnewbojdcokr (last visited July 6, 2026).

ISSN: 2582-6433

helps regulate global temperatures and stabilize climate patterns. However, as CO_2 absorption increases, the chemical balance of seawater is altered, leading to ocean acidification. Additionally ability of the ocean to sequester the carbon is diminishing which accelerates global warming. The global ocean circulation distributes heat across the planet. This system plays a vital role in maintaining climate stability. However, ocean acidification, along with rising temperatures and freshwater input from melting glaciers, disrupts this circulation, leading to changes in global weather patterns. These changes contribute to stronger hurricanes, prolonged droughts, and altered monsoon patterns, impacting both marine and terrestrial ecosystems.

Acidification disrupts this cycle by affecting the growth and survival of these organisms. The decline of phytoplankton and carbon-sequestering marine species means that more CO_2 remains in the atmosphere, intensifying the greenhouse effect and contributing to further climate instability.

Ocean Acidification and Greenhouse Gas Emissions

Ocean acidification affects not only marine ecosystems, but also the flow of greenhouse gases between the ocean and atmospheric air. As seawater grows more acidic, its ability to absorb and retain CO_2 eventually decreases. This means that a greater portion of CO_2 remains in the atmosphere, amplifying the greenhouse effect and causing global warming.

In addition to reducing carbon storage, ocean acidification can also contribute to the release of other powerful greenhouse gases. Changes in ocean chemistry and rising temperatures may destabilise methane hydrates found in deep sea sediments, allowing methane (CH_4) to escape into the atmosphere. Since methane has a much greater heat trapping potential than carbon dioxide over shorter timescales, its release can significantly accelerate climate change. Ocean acidification may also alter microbial activity in marine environments, increasing emissions of nitrous oxide another significant greenhouse gas[14]. Together, these processes create a positive feedback loop in which ocean acidification reduces the ocean's natural climate regulating capacity while increasing greenhouse gas concentrations, further intensifying global warming.

Impacts on Climate Dependent Marine Ecosystems

Many marine ecosystems are sensitive to changes in temperature, acidity, and carbon

[14] Nazma Begum et al., "*Influence of source and quality of plant residues on emissions of N2O and CO2 from a fertile, acidic Black Vertisol*", 50 Biology & Fertility Soils 499, (2013), https://doi.org/10.1007/s00374-013-0865-8.

ISSN: 2582-6433

availability. Ocean acidification, combined with rising sea temperatures, affects the distribution, reproduction, and survival of various marine species. This has significant consequences for global fisheries, coral reefs, and carbon-sequestering marine habitats.

Coral reefs play an essential role in carbon sequestration by supporting marine biodiversity and promoting calcification. However, acidification weakens coral skeletons, reducing their ability to store carbon effectively. Additionally, coral bleaching events caused by rising temperatures lead to the loss of reef ecosystems, further diminishing their role in climate regulation.

Polar Regions are experiencing the most rapid acidification and warming, leading to severe consequences for marine life. Organisms such as pteropods, which form the base of the Arctic and Antarctic food webs, are dissolving due to increased acidity. Additionally, melting sea ice reduces the ocean's albedo effect (the reflection of sunlight), causing further warming and accelerating climate change. As acidification weakens the food web, fish populations decline, leading to reduced catches and economic instability for fishing industries. Warmer, more acidic waters also affect fish migration patterns, marine species are increasingly relocating to cooler waters, threatening traditional fisheries and the food supply of communities

V. SOCIO ECONOMIC CONSEQUENCES OF OCEAN ACIDIFICATION

Ocean acidification extends beyond an environmental problem, posing serious socio-economic challenges that impact coastal communities, fisheries, and marine-dependent industries. The resulting changes in marine ecosystems have far reaching effects on human societies. Coastal communities, fisheries, tourism industries, and global food security are directly impacted by the degradation of marine biodiversity. Furthermore, the economic losses associated with declining fisheries, coral reef destruction, and weakened marine resources pose significant risks to national and global economies[15].

Impact on Fisheries and Aquaculture

Fisheries and aquaculture are among the industries most severely affected by ocean acidification. Many commercially valuable species, including shellfish and finfish, are vulnerable to changes in ocean chemistry, leading to reduced catch sizes, economic instability,

[15] "*Understanding the Science of Ocean and Coastal Acidification" US EPA*, US EPA, https://www.epa.gov/ocean-acidification/understanding-science-ocean-and-coastal-acidification#:~:text=The%20ocean%20readily%20absorbs%20dissolved,to%20acidification%20in%20coastal%20waters.(last visited July 5, 2026).

ISSN: 2582-6433

and job losses. Decline in Shellfish and Commercial Fisheries Ocean acidification reduces carbonate ion availability, making it difficult for shell forming organisms like oysters, clams, mussels, and lobsters to develop and maintain their shells. This leads to Lower survival rates of shellfish larvae, reducing overall population numbers. Economic losses in the seafood industry, affecting shellfish-dependent fisheries in regions such as the U.S. Pacific Northwest, Europe, and Southeast Asia. Fish species that rely on coral reefs or plankton for food are also impacted by ocean acidification. The decline in plankton populations, declines the availability of food for larger fish species[16].

Threats to Global Food Security

As fish and shellfish populations decline, seafood prices are expected to rise, making it difficult for lower-income communities to access affordable protein sources. This could lead to: Nutritional deficiencies, particularly in regions where fish is a staple part of the diet. Increased reliance on alternative protein sources, which may not be as readily available in some parts of the world. Economic strain on developing nations, where seafood exports contribute significantly to national GDP. Countries that depend on seafood exports, such as Indonesia, Thailand, and Norway, may experience economic downturns as marine industries struggle to maintain production levels.

Economic Losses in Marine Tourism

The marine tourism industry, including coral reef tourism, diving, and recreational fishing, contributes billions of dollars to global economies. However, as ocean acidification degrades coral reefs and marine biodiversity, tourism-dependent economies face significant financial losses.

Coral bleaching and habitat destruction, reducing the aesthetic and ecological value of reefs. Declining fish populations, making snorkelling and diving experiences less attractive. Loss of tourism revenue, particularly in countries like Australia (Great Barrier Reef), the Maldives, and the Caribbean, where reef tourism is a major economic driver.

Job losses for workers in the tourism industry Reduced foreign investment in tourism infrastructure, weakening local economies. Increased financial pressure on governments, as they attempt to offset economic losses through subsidies or alternative revenue streams.

[16] Secretariat of the Convention on Biological Diversity, "Scientific synthesis of the impacts of ocean acidification on marine biodiversity" (2009), https://www.cbd.int/doc/meetings/sbstta/sbstta-14/information/sbstta-14-inf-08-en.pdf.

ISSN: 2582-6433

Social and Cultural Consequences

In many coastal regions fishing represents more than a source of income it is important part of their cultural identity and heritage as fishing populations decline due to acidification of the ocean these communities also face increasing challenges in their livelihood. Forced migration to urban areas, as fishing livelihoods become unsustainable. Increased social inequality, as wealthier nations may adapt more easily than developing countries.

VI. LEGAL AND POLICY FRAMEWORKS ON OCEAN ACIDIFICATION

Ocean acidification requires a strong legal and policy framework at international, regional, and national levels since is a global environmental issue. Despite its significant impact on marine biodiversity, fisheries, food security, and climate change, ocean acidification has not been addressed as a standalone issue in most legal instruments. Instead, it is often covered under broader frameworks related to climate change, marine pollution, and biodiversity protection.

International Legal Frameworks on Ocean Acidification

Several international treaties and agreements indirectly address ocean acidification by regulating CO_2 emissions, protecting marine environments, and promoting sustainable ocean management.

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

The United Nations Convention on the Law of the Sea (UNCLOS) is the foundational governs the usage and protection of oceans. While UNCLOS does not specifically mention ocean acidification, it places legal obligation on the member states to mitigate and manage the effects of ocean acidification and to conserve marine sources it includes provisions relevant to addressing this issue.

Article 192 Imposes that a general obligation on states to protect and preserve the marine environment. Article 194 requires states to take measures to prevent, reduce, and control marine pollution, including pollution from atmospheric sources. Article 207 & 212 Address pollution from land-based and atmospheric sources, indirectly linking ocean acidification to state responsibilities[17]. While UNCLOS provides a broad legal basis for addressing ocean

[17]Ellycia R. Harrould-Kolieb, "*The UN Convention on the Law of the Sea: A governing framework for ocean acidification"* 2020 Rev. Eur. Compar. & Int'l Env't L, https://doi.org/10.1111/reel.12321

ISSN: 2582-6433

acidification, it lacks enforcement mechanisms and specific regulations targeting acidification directly.

The Paris Agreement (2015)

The Paris Agreement under the United Nations Framework Convention on Climate Change is the most significant international effort to combat CO_2 emissions, the primary cause of ocean acidification[18]. The vital object of this treaty is to lower the global temperature from 2 degree Celsius to 1.5 degree Celsius .it mandates the participating countries to render climate action plan to cut the emission of greenhouse gases The Global Stocktake process monitors progress on climate commitments, which may influence policies addressing ocean acidification. However, the Paris Agreement and its effectiveness depends on national implementation and compliance.

6.1.3 The Convention on Biological Diversity (CBD)

The Convention on Biological Diversity (CBD) promotes the conservation of marine biodiversity, including ecosystems affected by ocean acidification. Its biodiversity frameworks have emphasized reducing pressures on coral reefs and strengthening the resilience of marine ecosystems to climate change. However, despite recognizing ocean acidification as a significant threat, the CBD does not include legally binding measures to ensure that countries implement specific actions to address it. Aichi Biodiversity Targets (2010-2020) included goals to reduce stressors on coral reefs and ocean ecosystems.

While the CBD recognizes ocean acidification as a threat, it lacks legally binding mechanisms to enforce specific mitigation measures.

"The London Convention and Protocol"

"The London Convention (1972) and its Protocol (1996)" deals with the dumping of pollutants into the ocean. These agreements Prohibit ocean dumping of industrial waste that could contribute to acidification, Address potential geoengineering solutions, such as ocean alkalinity enhancement, which aims to counteract acidification. They help control ocean pollution, they do not directly regulate CO_2 emissions responsible for acidification.

[18] Writer, T. "*Ocean Acidification Laws"*. Ocean Acidification. (2022, May 10). https://ocean-acidification.com/2022/05/10/ocean-acidification-laws/

ISSN: 2582-6433

Regional Agreements and Policies

Regional Seas Conventions Several Regional Seas Conventions, as per the United Nations Environment Programme (UNEP), include provisions that indirectly address ocean acidification:

OSPAR Convention (North-East Atlantic): Works to reduce pollution and monitor acidification trends. Barcelona Convention (Mediterranean): Promotes integrated coastal management and pollution control. Nairobi Convention (West Indian Ocean): Addresses marine pollution and ecosystem degradation, including acidification-related impacts.

National Legal and Policy Responses

Many countries have developed national policies and laws to address ocean acidification within their broader environmental and climate strategies.

- United States: Ocean Acidification Research and Monitoring Act (OARMA)
  The U.S. Ocean Acidification Research and Monitoring Act (2009) its vital goal is to Establish research programs to study acidification impacts, Fund ocean acidification monitoring initiatives and to Develop adaptation strategies for fisheries and coastal communities. The U.S. also integrates ocean acidification mitigation within its climate policies, such as the Inflation Reduction Act (2022), which promotes renewable energy to cut CO_2 emissions.
- Australia: Great Barrier Reef Protection Laws[19]-
  Australia has enacted laws to protect the Great Barrier Reef, which is highly vulnerable to acidification has enumerated Reef 2050 Plan integrates climate adaptation strategies to protect coral ecosystems. The Emissions reduction targets aim to limit acidification effects on marine biodiversity. Despite these national efforts, stronger global coordination is needed to address acidification comprehensively.

Legal Frameworks in India Protecting Marine Environment

India has implemented several legal frameworks aimed at protecting its marine environment, which, while not explicitly targeting ocean acidification, contribute to mitigating its effects by regulating pollution and conserving marine ecosystems.

[19] Writer, T. *Ocean Acidification Laws*. Ocean Acidification. (2022, May 10). https://ocean-acidification.com/2022/05/10/ocean-acidification-laws/

ISSN: 2582-6433

1. **The Merchant Shipping (Prevention of Pollution) Act, 1983[20]:** This Act aligns with international conventions like MARPOL to prevent pollution from ships, addressing issues such as oil spills and the discharge of harmful substances into marine waters. citeturn0search0
2. "**The Water (Prevention and Control of Pollution) Act, 1974"**: This legislation establishes "Central and State Pollution Control Boards" responsible for preventing controlling water pollution, including in marine environments. It regulates the discharge of pollutants into water bodies, thereby contributing to the reduction of factors that can exacerbate ocean acidification. citeturn0search0
3. **Coastal Regulation Zone (CRZ) Notifications**: Issued under the Environment (Protection) Act, 1986, these notifications impose restrictions on industrial and developmental activities in designated coastal areas to protect sensitive ecosystems. By limiting activities that could harm coastal and marine environments, the CRZ Notifications help preserve ecosystems that are vulnerable to the impacts of ocean acidification.
4. **The Environment (Protection) Act, 1986:** This comprehensive legislation empowers the government to take measures for environmental protection, including the regulation of emissions and discharges into the environment, which can contribute to ocean acidification.

Additionally, India is a signatory to international agreements such as the Paris Agreement, committing global efforts to reduce greenhouse gas emissions, which are the primary drivers of ocean acidification.

The current legal and policy frameworks provide a foundation for addressing ocean acidification, but they remain insufficient to tackle the scale of the problem. Stronger international cooperation, legally binding commitments, and integrated climate policies are essential to mitigate acidification's long-term effects. By strengthening existing laws, enhancing enforcement, and supporting innovative solutions, the global community can take meaningful steps toward protecting marine ecosystems and reducing the socio-economic risks of ocean acidification.

[20] Mar C. Arroyo, "*The Evolution of Ocean Carbon Cycle Feedbacks in Observations and Models – ProQuest"*, ProQuest Better research, better learning, better insights., https://www.proquest.com/docview/3253511347 (last visited June 12, 2026).

ISSN: 2582-6433

VII. CONCLUSION AND SUGGESTIONS

Suggestions for Addressing ocean acidification – requires ongoing scientific exploration, policy innovation, and technological advancements.

- Advancing Carbon Sequestration Technologies Further research is needed on ocean based carbon removal methods, such as enhancing ocean alkalinity, sea grass restoration, and artificial upwelling techniques[21].
- Studying Species Resilience and Adaptation More research is required to understand how marine species adapt to acidic conditions, including genetic adaptations in corals, shellfish, and plankton.
- Strengthening Long Term Monitoring and Data Collection Develop advanced monitoring systems for real time pH and carbonate ion concentration tracking across global ocean regions. Expand global ocean acidification databases to assess long term trends and predict future impacts with greater accuracy.
- Assessing Socio-Economic and Policy Implications to conduct detailed economic impact studies on how ocean acidification affects fisheries, coastal livelihoods, and global food security. Research the effectiveness of current policy frameworks and recommend modifications to integrate acidification mitigation into climate policies.
- Exploring Sustainable Ocean Management Strategies Investigate nature relied solutions like mangrove restoration, artificial reefs, and sustainable aquaculture practices to enhance ecosystem resilience. Assess the marine protected areas (MPAs) mitigating acidification effects protecting vulnerable species. Policy and Governance Recommendations should also focus on policy improvements to bridge existing governance gaps.
- Strengthening International Cooperation: Encourage collaborative research initiatives across countries to share data, resources, and technological advancements. Developing Binding Legal Frameworks Explore the feasibility of an international treaty specifically addressing ocean acidification, complementing climate change agreements. Enhancing Public Awareness on integrated ocean acidification into environmental education.

[21] R. JEEVA PRIYA "Studies on the Effects of Ocean Acidification due to Increasing Level of Atmospheric Carbon Dioxide on Marine Lives". *Shodhganga*. http://hdl.handle.net/10603/451633(last visited June 12, 2026

ISSN: 2582-6433

CONCLUSION

Ocean acidification disrupts marine food chains, weakens coral reefs, and threatens species such as shellfish and plankton, which play crucial roles in ocean ecosystems. Additionally, the ocean's reduced ability to absorb CO_2 exacerbates climate change by allowing more greenhouse gases to accumulate in the atmosphere. The socio-economic consequences are profound, particularly for coastal communities dependent on marine resources.

Despite international efforts, including agreements such as the Paris Agreement and marine protection policies, current mitigation strategies remain insufficient. While regulatory frameworks exist, enforcement gaps, lack of targeted policies, and insufficient funding for research hinder progress. Therefore, comprehensive and multi sectorial approaches are needed to mitigate acidification and its impacts effectively.

It is a crucial and complex issue that demands immediate action at local, national, and global levels. While reducing CO_2 emissions remains the most effective long term solution, complementary strategies such as marine conservation, although existing legal frameworks acknowledge its impacts, many lack binding obligations and robust enforcement mechanisms. Strengthening international agreements and integrating ocean acidification into climate and marine conservation policies are essential for securing the communities relying on then further protecting marine ecosystems. Greater accountability, scientific collaboration, and national implementation of legal commitments are crucial to addressing this transboundary issue.