Chronicle of Aquatic Science

TYPE: Mini-review Article
PUBLISHED: 31 August, 2023
ISSUE: Volume 1, Issue 3
ARTICLE ID: CoAS_V1IS3_08

EDITED BY
Ankures Bhattacharya
West Bengal University of
Animal and Fishery Sciences

REVIEWED BY
Dr. Golam Ziauddin
West Bengal University of
Animal and Fishery Sciences

Mr. Devarshi Ranjan
ICAR-NBFGR

*CORRESPONDENCE
Ponmani M.
ponmanimuthu1998@gmail.com

RECEIVED 5 August 2023
ACCEPTED 23 August 2023
PUBLISHED 31 August 2023

CITATION
Ponmani, M., Manimekalai, D., Padmavathy, P., Rani, V., and Manickavasagam, S. (2023). Ocean Acidification and its Impacts on Marine Biota. ***Chronicle of Aquatic Science*** 1(3): 47-55

Ocean Acidification and its Impacts on Marine Biota

Ponmani. M[1*], Manimekalai. D[1], Padmavathy. P[1], Rani. V[1], Manickavasagam. S[1]

[1]Fisheries College and Research Institute-Thoothukudi, Tamil Nadu Dr. J. Jayalalithaa Fisheries University

The carbonate system of the world's oceans is quickly altering as a result of ocean acidification. Ocean acidification has been connected to previous mass extinction events, and the current rate of change in seawater chemistry is unparalleled. According to the available data, these alterations will likely have a considerable impact on marine taxa, especially those that produce biogenic calcium carbonate, shells, and skeletons. Though research into the long-term ecosystem effects of ocean acidification is still in its infancy, it is possible that changes in species distributions and abundances could spread through numerous trophic levels of marine food webs. Since the end of the pre-industrial period, the ocean has absorbed around 29 percent of the world's CO2 emissions. The combustion of fossil fuels and changes in land use have resulted in an annual emission of around 40 gigatons of heat-trapping gases into the atmosphere over the past ten years (from 2008 to 2017), which is the same as 252 million blue whales.

Keywords

Ocean, marine organisms, food web, trophic structure, acidification, carbon dioxide

Introduction

Ocean acidification is rapidly affecting the world's carbonate system and it is one of the negative effects of climate change on marine ecosystems. It is primarily caused by carbon dioxide absorption from the atmosphere. Due to human activity atmospheric carbon dioxide has been increased, which dissolves in sea water to form carbonic acid, making the ocean more acidic. Ocean acidification has been linked to prior mass extinction events, and the current rate of change in seawater chemistry is unparalleled. Based on the evidence, these changes will have a significant impact on marine taxa, mainly those that build skeletons, shells, and tests of biogenic calcium carbonate (Riebesell et al., 2007). Though research into the long-term ecosystem impacts of ocean acidification is in its early phases, potential changes in species distributions and abundances could propagate through multiple trophic levels of marine food webs. According to the National Oceanic and Atmospheric Administration (NOAA), the ocean absorbs approximately 30% of the carbon dioxide released into the atmosphere. As a result, the high concentration of CO_2 and the resulting acidification pose a serious threat to marine ecosystems. Indeed, ocean acidification is frequently referred to as "climate change's evil twin". One-third of the carbon dioxide emitted by humans has been absorbed by the oceans. This has slowed the rate of global warming, but it has also triggered chemical reactions that will lower the pH of the ocean.

What is ocean acidification?

Ocean acidification is defined as a reduction in the pH of the ocean over a long period of time, typically decades or longer and it is caused primarily by the uptake of carbon dioxide from the atmosphere but also by other chemical inclusions or deductions from the ocean. Carbonate, a key building block in seawater, is depleted as a result of ocean acidification.

$$\mathbf{CO_2 + H_2O \longrightarrow H^+ + HCO_3^-}$$

What causes ocean acidification?

1. Raised Carbon IV oxide Concentration in the Ocean
2. Raised Carbon IV oxide Concentration in the atmosphere
3. Higher Concentration of Hydrogen ions in the Water
4. Burning Fossil Fuels
5. Waste Disposal
6. Improper Land Management
7. Industrialization

Effects of ocean acidification

- Increase in the Carbon dioxide Concentration in the Ocean
- Loss of Aquatic Life
- Food Shortage
- Food Web Interference
- Impact on Human Health
- Impact on the Reefs
- Impact on the Open Ocean Planktonic Ecosystems
- Coastal Ecosystems are impacted
- Ocean at high Latitude are at risk

Effect of ocean acidification in Marine biota

- Calcification and dissolution response
- Physiological response
- Community impacts

The organism that are mainly affected by the effect of ocean acidification are as follows,

- Calcifying macroalgae
- Corraline algae
- Halimeda
- Cold water corals

- Benthic mollusk, bryozoans and echinoderms
- Coccolithophores, foraminifera and pteropods
- Fishes and other photosynthetic organisms

Calcification and dissolution response

Hermatypic coral (zooxanthellate)

Coral reef ecosystems has the ability to grow depends on their capacity to accrete at rates that are greater than the rates at which erosional processes can degrade them. A reduction in calcification of this magnitude could fundamentally alter the current structure and function of Coral reef ecosystems. Reef accretion will become more important in the coming decades as sea levels rise and corals in the deepest parts of the photic zone experience a reduction in available light for photosynthesis. At double preindustrial CO2 concentrations (pCO_2 around 560 ppm), tropical reef-building coral calcification rates will be reduced by 20-60%. The rate of coral calcification and the development of their skeletons will be significantly impacted by a significant drop in the amount of carbonate ions present in seawater. Slower growth rates may also reduce corals ability to compete for space and light. Weaker coral skeletons will likely result from a reduction in carbonate ions, allowing erosional processes to occur at much faster rates than they have in the past.

Fig.1: Hermatypic coral (Ouedraogo et al., 2023)

Calcifying macroalgae

Coralline algae

Reef-calcifying organisms other than Scleractinia corals are also sensitive to dwindling saturation states. Crustose coralline algae (CCA) are an essential component of the ecology of coral reef systems because they provide the "cement" that keeps reefs stable, contribute significantly to the sediment in these systems, and serve as a significant source of food for sea urchins, parrotfish, and other organisms. These species of coralline algae are particularly sensitive to decreasing carbonate saturation states because they produce calcium carbonate in the form of high-magnesium calcite, which is a more soluble form of calcium carbonate than either calcite or aragonite. Kuffner *et al*. (2008) conducted a mesocosm experiment exposed to pCO_2 by using CCA algae in that 40% less growth, 78% less recruitment, 92% less total area and 52% more non-calcifying algae were observed

Fig.2: Coralline algae (Borowitzka and Larkum 1986)

In contrast to changes in coral growth, the combined effects of decreased carbonate production and diminished stabilisation (cementation) of coasts and shallow seafloors by encrusting calcifiers are likely to cause erosion and ecosystem transitions (macro algal takeover) to occur more quickly.

Halimeda

In some parts of the world's oceans, the green, calcifying macroalgae genus Halimeda grows in large beds. Their three-dimensional structures offer vital habitat for adult fish and may act as nurseries for young fish and invertebrates. These calcifying macroalgae produce biogenic calcium carbonate in three forms; They are

- High-magnesium calcite,
- Aragonite
- calcite

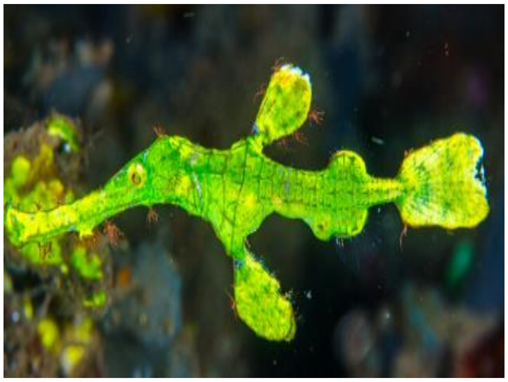

Fig.3: Halimeda (Wetzel and Wourms 1995)

All of these forms are vulnerable to the adverse effects of decreasing carbonate saturation states. The lab experiment conducted by Borowitzka & Larkum (1986) observed that some species of Halimeda from the Great Barrier Reef mainly the Halimeda tuna, showed a negative calcification response when exposed to high pCO2 and a pH drop of 0.5 units (8 to 7.5)

Cold Water Corals (Azooxanthellate)

The world's oceans are covered in cold-water corals and the ecologically diverse bioherms they create. As azooxanthellate organisms, cold-water corals are not restricted to the photic zone because they do not contain photosynthetic algae. Most cold-water corals are found between 200 and 1000 metres under the surface. There are six different azooxanthellate scleractinian coral species that all form aragonite calcium carbonate skeletons. Cold-water coral reefs support a wide variety of deep-sea organisms, including several fish species with significant economic importance, and have an incredibly high level of biodiversity.

Fig.4: Scleractinian coral (Lane et al., 2013)

There are other organisms that create azooxanthellate habitats besides scleractinian cold-water corals. Though the scleractinian are the cold-water coral their abundance is very less in north pacific because of the shallow depth of the aragonite saturation horizon and high dissolution rates throughout the region Cold-water corals live in cold, deep waters with high CO2 concentrations (global average Ω_{arag} = 2). They are able to grow and calcify at rates that are an order of magnitude slower than those of tropical zooxanthellate corals due to the low carbonate saturation state environment in which they reside (global average Ω_{arag} = 4).

Benthic Mollusks, Bryozoans, and Echinoderms

The physiological and ecological effects of rising pCO_2 on benthic mollusks, bryozoans, and echinoderms are poorly understood and only a few manipulative experiments have been conducted to determine sensitivity to elevated pCO_2.By the end of the century, the calcification rates of the Pacific oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*) are predicted to decline linearly with rising pCO_2 by 25% and 10%, respectively, according to research by Gazeau et al., (2007). Both species contribute significantly to global aquaculture production and are significant coastal ecosystem engineers. Coastal estuarine-dwelling bivalves might be especially susceptible to anthropogenic ocean acidification. These organisms naturally undergo extremely high mortality rates (>98%) in the transition from larvae to benthic juveniles, and any increase in juvenile mortality as a result of ocean acidification could have detrimental effects on estuarine bivalve populations.

Fig.5: Benthic Mollusks, Bryozoans, and Echinoderms (Mastrototaro et al., 2010)

- Increased pCO_2 in seawater has a severe impact on the early development of the oyster (*Crassostrea gigas*) emphasizing the importance of acidification effects on marine calcifier larval development stages. Because most benthic calcifiers have planktonic larval stages and early life stages appear to be more sensitive to environmental disturbance than adults, fluctuations in larval stages due to high mortality rates may have a significant impact on the population size of adults.
- The effects of increased pCO2 on the fertilization rate and larval morphology of two species of sea urchin embryos (*Hemicentrotuspulcherrimus* and *Echinometramathaei*) were studied, and it was discovered that the fertilization rate of both species decreased as CO2 concentration increased (Gazeau et al., 2007). Furthermore, the size of pluteus larvae decreased with increasing CO2 concentration, and malformed skeletogenesis was observed in both species' larval stages.
- Bibby et al., (2007) studied the intertidal gastropod *Littorina littorea* behavioral, metabolic, and morphological responses to acidified seawater (pH=6.6). In control experiments, this marine snail produced thicker shells when exposed to predation (crab) cues, but this defensive response was disrupted when pH was decreased. The snails also demonstrated decreased metabolic rates and increased avoidance behaviour, both of which could have significant ecosystem implications through organism interactions, energy requirements, and predator-prey relationships.

Coccolithophores, Foraminifera, and Pteropods

The major planktonic producers of $CaCO_3$ are

- Coccolithophores (single-celled algae),
- Foraminifera (protists)
- Euthecosomatous pteropods (planktonic snails).

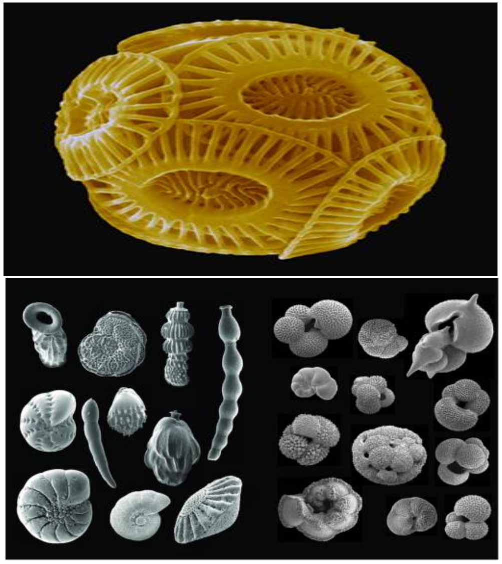

Fig.6: Coccolithophores, Foraminifera, and Pteropods (Jannasch 1985)

- Coccolithophores and foraminifera secrete calcite, whereas pteropods secrete aragonite shells, which are about 50% more soluble in seawater than calcite. Only in a few species has the calcification response of coccolithophores, foraminifera, and pteropods to ocean acidification been studied. When pCO2 is increased to 560-840 ppm, bloom-forming coccolithophores (*Emilianiahuxleyi* and *Geophyrocapsaoceanica*) exhibit decreased calcification rates ranging from 25 to 66%.
- When exposed to seawater chemistry equivalent to pCO2 values of 560 and 740 ppm, the shell mass of the foraminifera *Orbulinauniversa* and *Globigerinoidessacculifer* decreased by 4-8% and 6-14%, respectively, when compared to the shell mass secreted at preindustrial pCO2 levels.
- Most of the research shows that most calcareous plankton exhibit reduced calcification in response to decreased carbonate ion concentrations, suggesting that the response of planktonic calcifying organisms to elevated pCO2 may not be consistent across species or over time.
- Calcareous plankton growth and reproductive success may be complicated by chronic exposure to elevated pCO2, or they may result in adaptations that are not seen in short-term experiments.

Physiological Reponses

Fishes

The physiology of water-breathing animals will be impacted by elevated CO_2 partial pressures (hypercapnia) because they cause acidosis in the tissues and bodily fluids of marine organisms, including fish.

- The organism's pH, bicarbonate, and CO_2 levels change, which has long-term effects on its metabolism, growth, and reproduction and could all be detrimental to populations and species.
- The acid-base status, respiration, blood circulation, and nervous system functions of fish are altered in the short term by elevated CO2, while the growth rate and reproduction of fish are slowed down in the long term.
- The majority of the experiments were carried out by adjusting pH to values that would be present if CO2 were to be directly injected into the seafloor pH between 5.8 and 6.2 (Riebesell et al.,2007) Many studies have demonstrated the harmful effects of seawater acidification on fish at all stages of development (eggs, larvae, juveniles, and adults).
- Fish in early developmental stages are more sensitive to environmental change than adults and a limited number of studies have shown this to be true when fish eggs, larvae, and juveniles were exposed to elevated CO_2

Photosynthetic Organisms

Phytoplankton and Cyanobacteria

The majority of marine phytoplankton species have carbon-concentrating mechanisms that allow them to store inorganic carbon as CO_2, HCO_3 or both.

- Most marine phytoplankton tested in single-species lab experiments or natural community perturbation experiments show either no change or small increases (generally 10%) in photosynthetic rates when grown under high pCO_2 conditions equivalent to about 760 micro atmospheres. This is largely due to their carbon-acquisition mechanisms and efficiencies.

- In a recent study on mesocosm CO_2 manipulation, Riebesell et al., (2007) reported that CO_2 uptake by a phytoplankton community (primarily diatoms and coccolithophores) in experimental pCO_2 treatments of 700 and 1050 atm was 27% and 39% higher, respectively, than the pCO_2 treatment of 350 atm.
- In large oceanic swaths, ocean acidification will be accompanied by climate warming. Higher sea surface temperatures have been associated with observed declines in phytoplankton biomass and productivity, especially at low and mid latitudes, as they increase thermal stratification of the upper ocean and decrease the vertical mixing of nutrients with surface waters.
- Under elevated pCO_2, nitrogen and carbon fixation rates in nitrogen-fixing cyanobacteria of the genus *Trichodesmium*, which support a significant portion of primary productivity in such low-nutrient regions of the world's oceans, increase.
- Some coastal marine phytoplankton species can tolerate a wide range of pH values, while others experience drastic growth rate changes over a 0.5 to 1.0 pH unit change.
- Small variations in the pH of ambient seawater have been found to have an impact on the succession, abundance, and growth rates of various species in coastal phytoplankton communities.
- In tandem, eutrophication and ocean acidification may increase the pH range found in coastal habitats, which may increase the frequency of blooms of species that can tolerate extremely high pH levels.

Community Impacts

Seagrasses, Coral Reefs, and Fishes

Mangroves and seagrass meadows serve as crucial fish nidification sites for young fish, many of which migrate to coral reefs as adults, increasing fish diversity and abundance on coral reefs nearby these ecosystems.

- If the water quality and clarity (low suspended sediment) are good enough for photosynthesis to occur, the net effect of increasing CO_2 on seagrass ecosystems will likely be increased seagrass biomass and productivity.

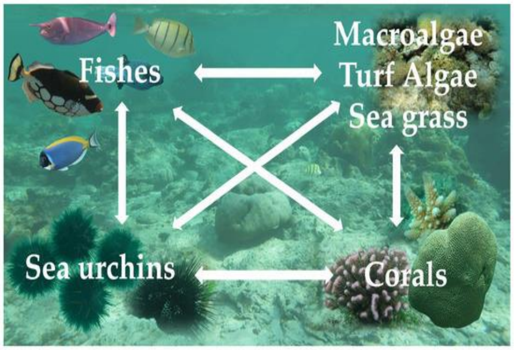

Fig.7: Community relationship of Seagrasses, Coral Reefs, and Fishes (Ditzel et al., 2022)

- Under these circumstances, an increase in the total area of seagrass is likely to result in a more favourable habitat and environment for associated invertebrate and fish species. However, the combined effects of rising sea surface temperatures (coral bleaching) and declining carbonate saturation states of surface waters in the coming decades will likely have a significant negative impact on many reef-building marine calcifiers, making the overall impact of ocean acidification on coral reef ecosystems likely to be negative (Bibby et al., 2007)

- It is challenging to predict the magnitude of ecosystem responses to ocean acidification and other environmental changes acting in concert, as well as the overall effects on fish diversity and abundance.
- The abundance of unknowns surrounding the long-term effects of rising CO2 on fish physiology, metabolism, and potential range shifts as a result of warming oceans makes it even more difficult to predict the net effects on fish populations.

Conclusion

The biological effects of ocean acidification are still poorly understood from a scientific standpoint, and it is only possible to speculate on the long-term effects of altered seawater chemistry on marine ecosystems. The calcification response of shallow-water scleractinian corals is well understood. When ocean acidification causes net calcification rates to be lower than net dissolution rates in coral reef systems, certain data sets enable the identification of "tipping points" or "thresholds" of seawater carbonate chemistry. Through pH-dependent speciation of nutrients and metals, ocean acidification may also have an impact on primary productivity in coastal and open ocean environments. If we limit our global warming emissions, and we limit future warming, we can significantly reduce the harm to marine ecosystems. Information about ocean acidification should be included in existing ecosystem models (like Ecopath and Ecosim) that aim to forecast how alterations in the environment will affect marine populations and ecosystem structure. Making accurate predictions about how future ocean acidification will affect marine ecosystems and helping managers make decisions will depend on the development of these tools. It is urgently necessary to conduct research on the interactions between ocean acidification and other human-caused environmental changes (such as rising sea temperatures) on marine food webs and the potentially transformative effects these changes may have on marine ecosystems. Avoiding the most harmful effects of human-induced climate change requires international cooperation, political will, and significant investments in clean energy technologies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Conflict of interest

The authors declare that the manuscript was formulated in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Reference

Bibby, R., Cleall-Harding, P., Rundle, S., Widdicombe, S. and Spicer, J., 2007. Ocean acidification disrupts induced defences in the intertidal gastropod Littorina littorea. *Biology letters*, *3*(6), pp.699-701.

Borowitzka, M.A. and Larkum, A.W.D., 1986. Reef algae. *Oceanus*, *29*, pp.49-54.

Buddemeier, R.W., Jokiel, P.L., Zimmerman, K.M., Lane, D.R., Carey, J.M., Bohling, G.C. and Martinich, J.A., 2008. A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry. *Limnology and Oceanography: Methods*, *6*(9), pp.395-411.

Ditzel, P., König, S., Musembi, P. and Peters, M.K., 2022, January. Correlation between coral reef condition and the diversity and abundance of fishes and sea urchins on an East African coral reef. In *Oceans* (Vol. 3, No. 1, pp. 1-14). MDPI.

Gazeau, F., Quiblier, C., Jansen, J.M., Gattuso, J.P., Middelburg, J.J. and Heip, C.H., 2007. Impact of elevated CO2 on shellfish calcification. *Geophysical research letters*, *34*(7).

Jannasch, H.W., 1985. Review Lecture-The chemosynthetic support of life and the microbial diversity at deep-sea hydrothermal vents. *Proceedings of the Royal society of London. Series B. Biological sciences*, *225*(1240), pp.277-297.

Kuffner, I.B., Rodgers, K.S., Jokiel, P.L., Andersson, A.J., Cox, E.F. and Mackenzie, F.T., 2008. Ocean acidification and calcifying reef organisms: a mesocosm investigation. *Coral reefs*, *27*, pp.473-483.

Kuffner, I.B., Andersson, A.J., Jokiel, P.L., Rodgers, K.U.S. and Mackenzie, F.T., 2008. Decreased abundance of crustose coralline algae due to ocean acidification. *Nature geoscience*, *1*(2), pp.114-117.

Lane, D.R., Ready, R.C., Buddemeier, R.W., Martinich, J.A., Shouse, K.C. and Wobus, C.W., 2013. Quantifying and valuing potential climate change impacts on coral reefs in the United States: Comparison of two scenarios. *PloS one*, *8*(12), p.e 82579.

Mastrototaro, F., D'Onghia, G., Corriero, G., Matarrese, A., Maiorano, P., Panetta, P., Gherardi, M., Longo, C., Rosso, A., Sciuto, F. and Sanfilippo, R., 2010. Biodiversity of the white coral bank off Cape Santa Maria di Leuca (Mediterranean Sea): An update. *Deep Sea Research Part II: Topical Studies in Oceanography*, *57*(5-6), pp.412-430.

Ouédraogo, D.Y., Mell, H., Perceval, O., Burga, K., Domart-Coulon, I., Hédouin, L., Delaunay, M., Guillaume, M.M., Castelin, M., Calvayrac, C. and Kerkhof, O., 2023. What are the toxicity thresholds of chemical pollutants for tropical reef-building corals? A systematic review. *Environmental Evidence*, *12*(1), pp.1-38.

Riebesell, U., Schulz, K.G., Bellerby, R.G.J., Botros, M., Fritsche, P., Meyerhöfer, M., Neill, C., Nondal, G., Oschlies, A., Wohlers, J. and Zöllner, E., 2007. Enhanced biological carbon consumption in a high CO2 ocean. *Nature*, *450* (7169), pp.545-548.

Wetzel, J. and Wourms, J.P., 1995. Adaptations for reproduction and development in the skin-brooding ghost pipefishes, Solenostomus. *Environmental biology of fishes*, *44*, pp.363-384.