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Ocean Acidification: Impacts on Marine Ecosystem and Fisheries

Madhulika and Soibam Ngasotter*

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Corresponding Author
Soibam Ngasotter
e-mail: ngasotter@gmail.com

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Abstract

Ocean acidification occurs when environmental carbon dioxide dissolves in seawater, forming carbonic acid, which lowers the pH of the ocean. This phenomenon is majorly driven by human activities like the consumption of fuels and other land-based activities. Ocean acidification has been shown to have an impact on organisms' homeostasis and ecosystems, posing a risk to fisheries and aquaculture as well as several ecosystem services, coastal protection, and transportation. It is important to have awareness about the potential effects of ocean acidification on the oceanic environment and organisms so that possible prevention and control strategies such as periodical monitoring of carbonate chemistry, management of coastal wastes, limitation of wastes from main point sources and new marine water policies can be developed for the betterment of the marine environment and socioeconomic development of human communities that rely on them.

1. Introduction

High carbon dioxide (CO_2) concentration in the ocean, due to fossil fuel burning, deforestation, and agricultural and other industrial activities, are giving rise to significant increases in CO_2 and inorganic carbon levels. Atmospheric CO_2 levels have exceeded 417 ppm today (2021) that is nearly 50% higher than in the preindustrial period. The source of this excess CO_2 concentration is distinctly human-caused and reflects a combination of anthropogenic emissions. The oceans are the ultimate sink for many anthropogenic wastes, including CO_2 that is produced by land-based activities (Gruber et al., 2019). Increased CO_2 in the ocean is also known to cause changes in seawater acid-base chemistry, generating a shift towards more acidic conditions. CO_2 from the atmosphere dissolves in water due to physical exchange, resulting in a massive increase in inorganic carbon levels and CO_2 concentrations in seawater (Benway et al., 2019). Ocean acidification, in combination with other environmental stresses, especially elevated atmospheric CO_2 levels, has the potential to negatively impact many important ecosystem services provided by the ocean to human society, like fisheries, aquaculture, tourism, and so on. The effects of ocean acidification vary from changes in organism physiology and population dynamics to altered community

Author's Address

ICAR-Central Institute of Fisheries Education (CIFE), Mumbai, Maharashtra (400 061), India

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and ecosystems; it affects a wide range of physiological actions, including acid-base balance, basal metabolic rates, sensory perception to population and community, aerobic scope, oxygen intake, thermal tolerance, fertilization rates, and growth, among others. Ocean acidification impairs organisms' ability to construct and maintain calcium carbonate structures efficiently (e.g., coral reefs, oyster and mussel shells, coccolithophore exoskeletons) due to the under-saturation of calcium carbonate (Tai et al., 2018). The direct influence of ocean acidification on species abundance alteration will substantially impact competitive, facilitative, and trophic relationships. Ocean acidification and warming may negatively affect the production, quality, and safety of seafood by reducing marine species wellness (Lemasson et al., 2019). It impacts the ocean environment, aquaculture, and human societies that rely on the ocean, so we need to understand the overall impact of ocean acidification to develop appropriate adaptation strategies.

2. Chemical Reactions

Shifts in the concentration levels of dissolved ions are generated by the inclusion of CO_2 from natural and anthropogenic sources. In seawater acid-base chemistry, the inorganic carbon system and aqueous carbon dioxide [$CO_{2\ (aq.)}$] play significant roles. CO_2 added to seawater at a pH of (8.0) reacts with water to make bicarbonate (HCO_3^-) and hydrogen ions (H^+):

$$CO_2 + H_2O \longrightarrow (HCO_3^-) + (H^+)$$

The release of hydrogen ion increases acidity and lowers the pH of seawater, which is defined as the negative log of H^+ concentration:

$$pH = -\log_{10}[H^+],$$

and the concentrations of carbonate ions ($CO_3^{\ 2-}$) are decreased via:

$$(CO_3^{\ 2-}) + (H^+) \longrightarrow HCO_3$$

The effects of acidification will be determined by the responses of organisms towards various concurrent chemical changes. Many marine organisms are sensitive to acidification because their shells and skeletons are made of calcium carbonate ($CaCO_3$) minerals.

Solubility of carbonate minerals:

$$CaCO_3(s) \longrightarrow (CO_3^{\ 2-}) + (Ca^{2+})$$

These equations explain the close relationship that exists between atmospheric CO_2, oceanic surface pH, and $CaCO_3$ saturation states.

3. Biological Impacts

Acidification has been linked to changes in cellular functioning, physiology of organisms, sensory perception, population dynamics, ecosystem, and biogeochemical dynamics. Even though some fish tend to be able to compensate for disruptions in acid-base balance under high CO_2 conditions, they display unprecedented sensitivity to current and near-future CO_2 levels in the growth of otoliths—calcium carbonate structures in fish ears that help in balance—mitochondrial function, metabolic rate, larval yolk intake, activity, neurosensory processes, and behavioral pattern. In high CO_2 environments, altered fish physiology may interrupt physiological functions associated with neurotransmitter gamma-aminobutyric acid (GABAA) (Tresguerres and Hamilton, 2017). GABAA is actively engaged in many sensory and behavioral pathways of animal nervous systems. The effects of disrupted GABAA signaling in fish in response to acidification are still being researched. *Coccolithophores* (calcium carbonate-plated phytoplankton), *Synechococcus,* and *Prochlorococcus,* like globally abundant picoplankton, have higher growth rates in elevated CO_2 conditions. In contrast, diatoms, dinoflagellates, diazotrophs, and other large phytoplankton, are shown to have reduced growth rates; there is a large variation in response within groups. Even though calcifying organisms are typically more sensitive to high CO_2 concentrations than noncalcifying organisms, this concept is not appropriate for every case, and the form of $CaCO_3$ produced by organisms (i.e., calcite, aragonite) is not closely related to species sensitivity. Amorphous $CaCO_3$, low-magnesium calcite, or a mixture of multiple $CaCO_3$ forms are among the minerals that are produced by marine organisms. Mollusks produce aragonite structures, whereas crustacea and echinoderms build calcite structures (Doney et al., 2020).

4. Impacts on Fisheries and Aquaculture

Commercial shellfish fisheries may face significant threats from ocean acidification. Ocean acidification has the potential to have direct biological consequences at both the molecular and cellular levels and might reduce the capability of calcifying organisms to build their shells and skeletons, in particular, species with a limited level of biological control over the calcification process are more affected. Ocean acidification and reducing concentrations of carbonate ions have a clear impact on organisms such as mollusks and crustaceans primarily because of reduced calcification rates (Mangi et al., 2018). Ocean acidification also affects the recruitment, growth, and larval survival of many fish and shellfish species. Responses of organisms to increased temperature and acidification vary between species; however, the effects of ocean acidification on species abundance are constant among species and generally decrease with increased acidity (Tai et al., 2018). The impact of ocean acidification on tiny free-swimming marine snails, called pteropods, is depicted in Figure 1.

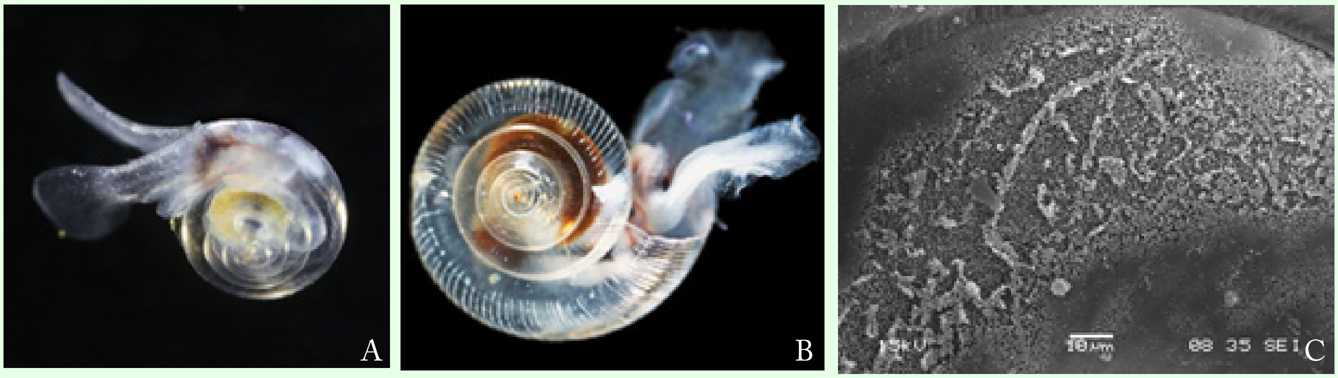

Figure 1: Impact of ocean acidification on a marine snail, pteropods. (a) A healthy pteropod (b) Pteropod with signs of dissolved shells (c) A scanning electron microscope image of dissolution on a pteropod shell (NOAA, 2014).

5. Impacts on Coral Reefs and Reef Fisheries

The coral reef ecosystem is a biological diversity hotspot that supports a wide variety of significant species for many countries' economic well-being. A decrease in the saturation level of biologically useable forms of $CaCO_3$, especially calcite and aragonite; their lower saturation states make it more difficult for many calcifying organisms, including coral reef organisms, to form their skeletons (Branch et al., 2013). Healthy coral reefs provide various ecosystem resources, including breeding grounds for many commercially significant fish species; the disappearance of reef fishes we are monitoring is expected to harm communities' financial well-being whose lives and livelihoods rely on reef fish (Speers et al., 2016). The observed effects of ocean acidification on the marine ecosystem, including coral reefs, food webs, etc., are depicted in Figure 2.

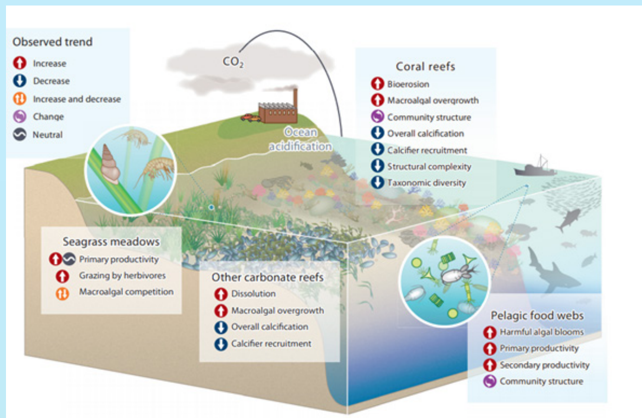

Figure 2: Observed effects of ocean acidification in a marine ecosystem (Doney et al., 2020)

6. Impact on Food Web

Predator-prey interactions help to shape the structure of marine communities and ecosystems. Several studies have found that increased CO_2 levels affect the response of prey and predators. Changes in the natural behavior of predators and prey might have a serious problem in the near future and may result in a disbalance in the trophic dynamics of the marine ecosystem. There is much evidence that elevated CO_2 alters the behavior patterns of organisms in this predator-prey relationship indicates that food web interactions and ecosystem function is becoming progressively difficult to anticipate as ocean acidification progresses over the near future (Watson et al., 2017).

7. Impact on Nutrient Composition of Seafood

Acidification and warming of seawater may threaten the production potential, quality, and safety of seafood. The possible effects of warming and ocean acidification on the quality of shellfish is still a vague topic of discussion. Under stress, a decrease in glycogen content is common; long-term exposure to ocean acidification can threaten the organism's long-term survival. Intensified ocean acidification may result in relatively low lipid, carbohydrate, and protein levels, as well as a higher concentration of Cu (Lemasson et al., 2019). After exhausting carbohydrate and lipid reserves, under chronic stress conditions, bivalves can catabolize proteins to gather energy. Furthermore, the altered biochemical composition of meat can influence its appearance, scent, taste, and texture (Lemasson et al., 2017). Therefore, alterations in biochemical composition caused by acidification and elevated temperature can reduce the market appeal and economic value of the seafood.

8. Conclusion

Ocean acidification is likely to endanger the world's fisheries, agricultural economy, and livelihood of people related to the fisheries sector without drastic reductions in CO_2 emissions. Aquaculture, fisheries, shoreline protection, and other crucial marine ecosystem resources are likely to be impacted by acidification, posing vulnerabilities and threats to human populations. Current management practices should include strategies like periodic monitoring of carbon dioxide concentration in marine water, management of coastal wastes, limitation of the pollution from major point sources, adoption of a new set of marine water policies and awareness programs to allow marine governance to remain flexible in the face of global and local challenges to reduce ocean acidification.

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