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For additional information, contact:

GPNM Secretariat
United Nations Environment Programme (UNEP)
UN Complex, Gigiri, NOF 2, South Block
Nairobi, Kenya
Tel: +254-20-7625276
Email: gpmn@unep.org
Website: www.nutrientchallenge.org; www.gpa.unep.org

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Jane Hawkey
Integration & Application Network
University of Maryland Center for Environmental Science



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A Policy Brief

Eutrophication and Ocean Acidification

R. Ramesh¹, A. Lakshmi¹, R. Purvaja¹, S.D. Costanzo², R.H. Kelsey²,
J. Hawkey², A. Datta³, and W.C. Dennison²

¹ National Centre for Sustainable Coastal Management, Ministry of Environment and Forests, Koodal Building, Anna University Campus, Chennai 600 025, India

² Integration and Application Network, University of Maryland Center for Environmental Science, PO Box 775, 2020 Horns Point Rd, Cambridge, MD 21613, USA

³ United Nations Environment Programme. PO Box 30552 (00100), Nairobi, Kenya

Coastal ecosystems worldwide provide a number of important services to support life and enhance human well-being. However, the health of coastal ecosystems is under considerable threat from a variety of human-induced pressures, resulting in eutrophication and acidification of coastal and ocean waters. To date, the processes driving eutrophication (i.e., nutrient inputs) and acidification (i.e., increased atmospheric CO₂ concentrations) have been viewed independently, whereas new research suggests a link between the two and that eutrophication may be exacerbating the effects of increased atmospheric CO₂ concentrations on ocean acidification¹.

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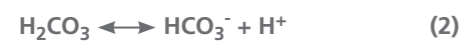
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Carbon dioxide and ocean acidification

Of the drivers associated with climate change, increasing carbon dioxide (CO₂) concentrations in the atmosphere are believed to be the most important². The rise of atmospheric CO₂ concentrations has been shown to be moderated by the oceans which have taken up between 24-33% of anthropogenic CO₂ emissions during the last five decades, potentially reducing the severity of climate change to date³. However, this increased uptake of atmospheric CO₂ by the oceans has resulted in changes in seawater chemistry leading to ocean acidification.

The process of ocean acidification begins when CO₂ in the atmosphere dissolves in water (CO_{2(aq)}) to form a weak carbonic acid (H₂CO₃) (Equation 1). Carbonic acid rapidly dissociates (splits apart) to produce bicarbonate ions (HCO₃⁻, Equation 2). In turn, bicarbonate ions can also dissociate into carbonate ions (CO₃²⁻, Equation 3). Note that the last two reactions also produce protons (H⁺) and therefore lower the pH of the solution, thereby increasing the acidity.



The reactions are slightly different when CO₂ dissolves in seawater. Carbon dioxide does not fully dissociate into carbonate ions and the number of hydrogen ions produced, and subsequent drop in pH, is therefore smaller than would be predicted in freshwater, e.g. This is due to the natural capacity of seawater to buffer against changes in pH due to the natural presence of CO₃²⁻ in seawater, as outlined in Equation 4, where CO₂ is effectively neutralized by the reaction with CO₃²⁻ to produce HCO₃⁻. The HCO₃⁻ produced by Equation 4 then partly dissociates (as per Equation 3), releasing protons and so decreasing the pH, but not to the extent that would be observed in an unbuffered situation. Also the ability of seawater to buffer changes in its pH as CO₂ is added depends on the concentration of CO₃²⁻ present. Hence, buffering capacity of seawater will decrease as more CO₂ is added and CO₃²⁻ is progressively consumed.



Figure 1 shows that the rising oceanic CO₂ levels are mirrored by falling pH levels in our oceans (pH has decreased by 30% over the past 200 years⁴). This change in ocean chemistry as a result of CO₂ absorption has been referred to as ocean

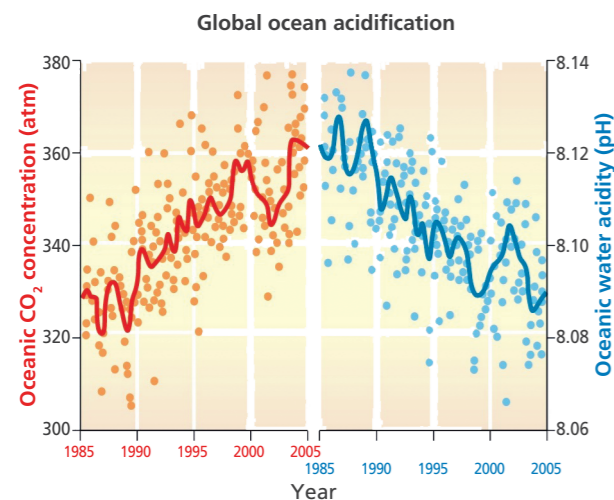


Figure 1. Global Ocean Acidification. Graphics: Riccardo Pravettoni, UNEP/GRID-Arendal (2009). Source: IPCC 2007.

acidification. Surface seawater pH is expected to continue to fall as atmospheric CO₂ rises⁵.

However, the changes observed in oceanic pH may not be fully explained by changes in atmospheric CO₂ concentrations alone. For example, increases in acidity in waters of the Gulf of Mexico and the East China Sea cannot be attributed to post-industrialization increases in CO₂ concentrations alone^{6,7,8}. Other gases such as SO_x and NO_x are gases that form acids when dissolved in seawater, and may consequently lower the pH of receiving waters⁹, particularly in CO₂-supersaturated seawater¹⁰. Nutrient runoff and subsequent eutrophication of coastal waters is also a process that has been shown to contribute to ocean acidification¹¹.

The remainder of this policy brief specifically explores the relationship between ocean acidification and eutrophication and includes recommendations on how the global community can respond to the challenge of ocean acidity through nutrient management options.

Eutrophication and ocean acidification

Eutrophication is the process of nutrient over-enrichment of waters that can lead to hypoxia (or oxygen depletion) and harmful algal blooms, which among others can destroy aquatic life in affected areas^{12,13}. Eutrophication of coastal waters is largely attributed to increased loadings from land-based sources containing nitrogen and phosphorus (e.g., sewage, chemical fertilizers) as well as micro-nutrients such as silica. While these nutrients are essential for plant growth, anthropogenic sources of these nutrients have resulted in near doubling of nitrogen and tripling of phosphorus inputs to the environment in comparison to natural values¹⁴. Of all the land based sources of pollution affecting coastal ecosystems, nutrient enrichment is considered a serious problem¹⁵ that needs to be addressed with immediate effect¹⁶. The concern is magnified by those findings from recent studies that show eutrophication can enhance ocean acidification^{17,18,19}. Excess organic matter production (e.g. algal blooms) in coastal and oceanic environments eventually undergoes microbial degradation, whereby O₂ is consumed and CO₂ is produced in the water column through microbial respiration which can result in a drop in pH (as explained earlier). This source of CO₂, in addition to inputs from the atmosphere, exacerbates the acidification problem and has been modeled, for example in the Gulf of Mexico and the Baltic Sea, to be more than additive in seawater at intermediate to higher temperatures resulting in decreased pH values of 0.25 - 1.1 units²⁰.

Impacts of acidification

Changes in ocean chemistry can have extensive direct and indirect effects on organisms and their habitats. The formation of HCO₃⁻ (as per Equation 4) results in the depletion of CO₃²⁻ in the water thereby hindering the capacity to precipitate calcium carbonate minerals (e.g., calcite and aragonite) by marine organisms whose protective shells or skeletons are composed of these minerals. Existing structures are vulnerable to dissolution unless the surrounding seawater contains saturating concentrations of CO₃²⁻. This reaction also consumes CO₂ generated from respiration so that waters with high CO₃²⁻ are buffered against increases in CO₂ and associated decrease in pH for a given respiratory input. However, eutrophic conditions may produce disproportional amounts of CO₂ from microbial breakdown and hypoxic conditions²¹.

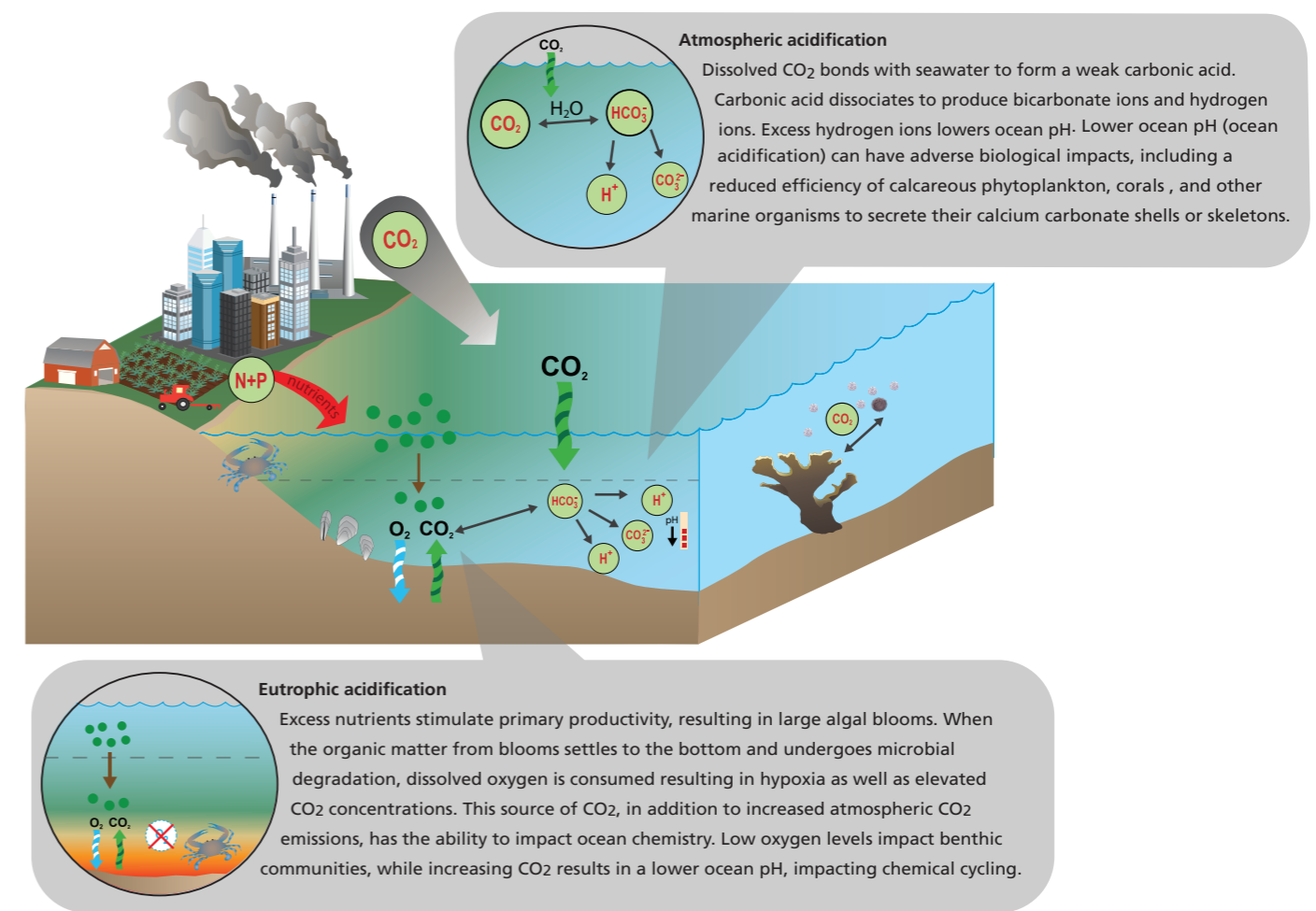


Figure 2. Eutrophication-acidification link model, modified from Sunda and Cai 2012²².

Complexity of interactions

The biogeochemistry of coastal waters is complex with changes in carbonate chemistry providing either positive or negative feedback on increasing atmospheric CO₂ by modifying the flux of CO₂ between the ocean and the atmosphere²³. The global coastal ocean thus can act as a sink or a source depending on the atmospheric CO₂ concentrations, but has increasingly become a sink with rising CO₂ concentrations²⁴. Seasonal changes in CO₂ have also been found altered due to nutrient loading with increased CO₂ sequestration capacity in summer compared with autumn and winter²⁵. The role played by ocean acidification in estuaries may be different from the open ocean²⁶.



Agricultural and industrial discharges are considered one of the causes of these recurring massive algal bloom (*Enteromorpha prolifera*) in China.

Responding to the challenge

From the above discussion, it is clear that the combination of eutrophication and ocean acidification is likely to have greater adverse effects on coastal ecosystems. Hence, this needs to be urgently addressed. It is well known that nitrogen is the primary cause of eutrophication in many coastal ecosystems. Therefore, optimal management of coastal eutrophication suggests controlling both N and P, in part because P can limit primary production in some systems^{27,28}. However, there are also studies indicating that in highly productive near-shore coastal marine environments, the effect of eutrophication on carbon cycling can counter the effect of ocean acidification on the carbonate chemistry of surface waters; hence, changes in river nutrient delivery due to management regulation policies can lead to stronger changes in carbonate chemistry than ocean acidification²⁹.

The ocean-acidification—eutrophication challenge needs to be addressed in multiple ways and at various levels. Some of these include:

1. International action on mitigating CO₂ emissions;
2. Reduction in nutrient loading into coastal waters through control of chemical fertilizers run-off from agriculture as well as discharge of untreated sewage containing high concentrations of nutrients;
3. Further research in multiple ecosystems on understanding better the temperature-salinity-nutrient linkages;
4. Improving capacities in developing countries to monitor and design policies to reduce nutrients flow into the coastal waters from agriculture and non-agricultural sources; and,
5. Raising awareness about ocean acidification and eutrophication.