A Policy Brief

Eutrophication and Ocean Acidification

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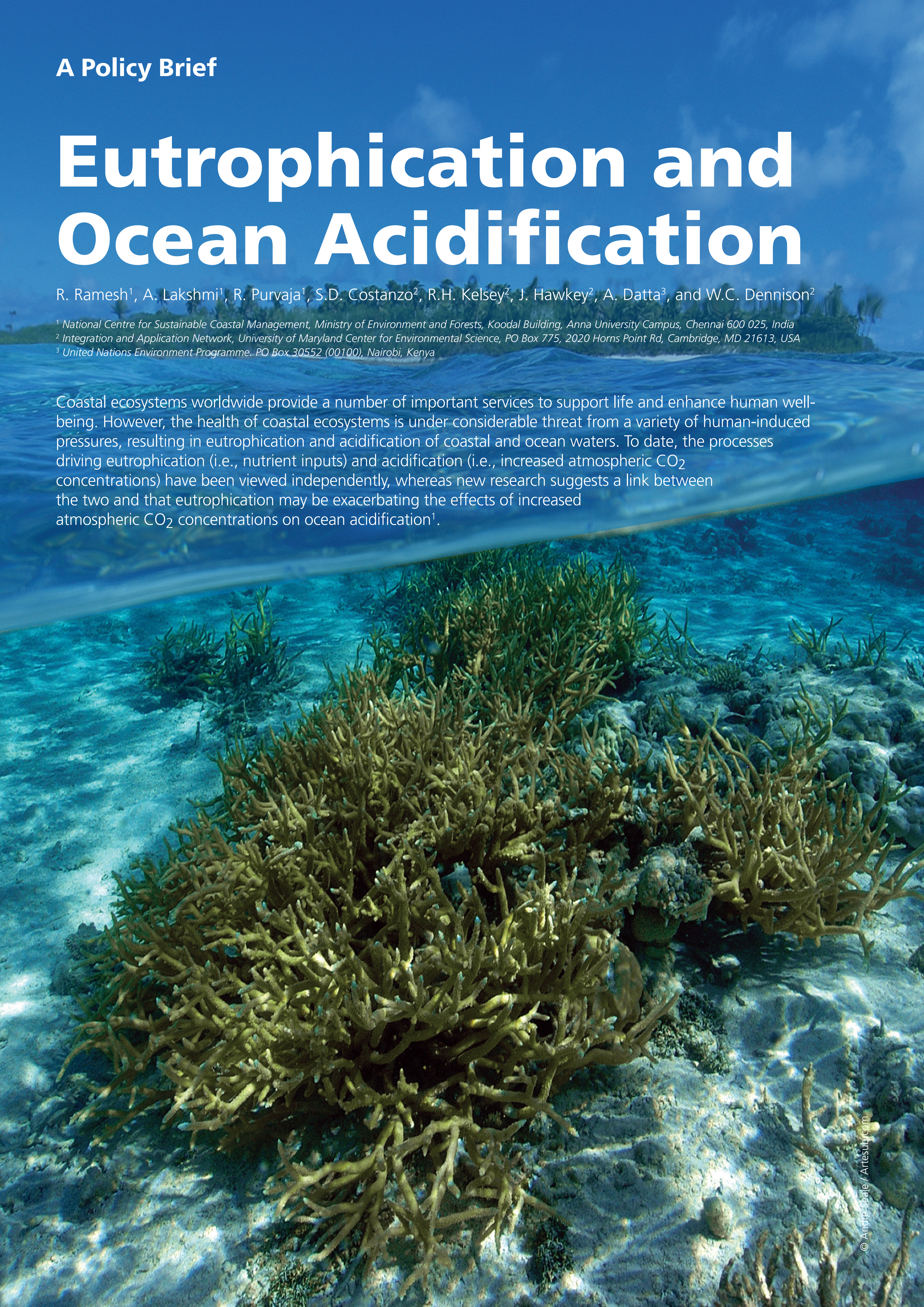
Coastal ecosystems worldwide provide a number of important services to support life and enhance human well-being. However, the health of coastal ecosystems is under considerable threat from a variety of human-induced pressures, resulting in eutrophication and acidification of coastal and ocean waters. To date, the processes driving eutrophication (i.e., nutrient inputs) and acidification (i.e., increased atmospheric CO_2 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 CO_2 concentrations on ocean acidification[1].



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Carbon dioxide and ocean acidification

Of the drivers associated with climate change, increasing carbon dioxide (CO_2) concentrations in the atmosphere are believed to be the most important[2]. The rise of atmospheric CO_2 concentrations has been shown to be moderated by the oceans which have taken up between 24-33% of anthropogenic CO_2 emissions during the last five decades, potentially reducing the severity of climate change to date[3]. However, this increased uptake of atmospheric CO_2 by the oceans has resulted in changes in seawater chemistry leading to ocean acidification.

The process of ocean acidification begins when CO_2 in the atmosphere dissolves in water ($CO_{2\ (aq)}$) to form a weak carbonic acid (H_2CO_3) (Equation 1). Carbonic acid rapidly dissociates (splits apart) to produce bicarbonate ions (HCO_3^-, Equation 2). In turn, bicarbonate ions can also dissociate into carbonate ions (CO_3^{2-}, Equation 3). Note that the last two reactions also produce protons (H+) and therefore lower the pH of the solution, thereby increasing the acidity.

$$CO_{2(aq)} + H_2O \longleftrightarrow H_2CO_3 \qquad (1)$$

$$H_2CO_3 \longleftrightarrow HCO_3^- + H^+ \qquad (2)$$

$$HCO_3^- \longleftrightarrow CO_3^{2-} + H^+ \qquad (3)$$

The reactions are slightly different when CO_2 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 CO_3^{2-} in seawater, as outlined in Equation 4, where CO_2 is effectively neutralized by the reaction with CO_3^{2-} to produce HCO_3^-. The HCO_3^- 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 CO_2 is added depends on the concentration of CO_3^{2-} present. Hence, buffering capacity of seawater will decrease as more CO_2 is added and CO_3^{2-} is progressively consumed.

$$CO_{2(aq)} + CO_3^{2-} + H_2O \longrightarrow 2HCO_3^- \qquad (4)$$

Figure 1 shows that the rising oceanic CO_2 levels are mirrored by falling pH levels in our oceans (pH has decreased by 30% over the past 200 years[4]). This change in ocean chemistry as a result of CO_2 absorption has been referred to as ocean acidification. Surface seawater pH is expected to continue to fall as atmospheric CO_2 rises[5].

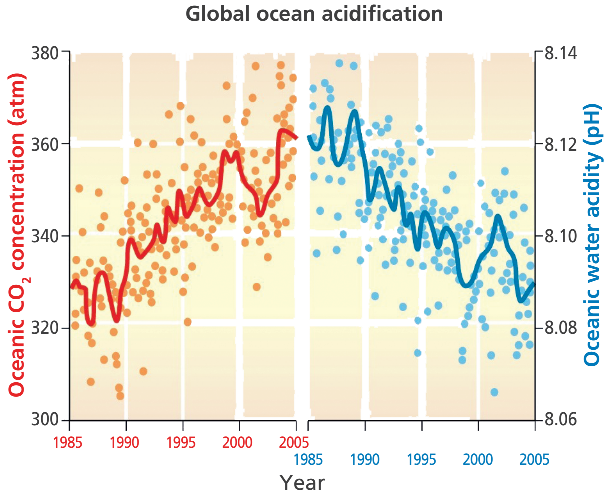


Figure 1. Global Ocean Acidification. Graphics: Riccardo Pravettoni, UNEP/GRID-Arendal (2009). Source: IPCC 2007.

However, the changes observed in oceanic pH may not be fully explained by changes in atmospheric CO_2 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 CO_2 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 waters[9], particularly in CO_2-supersaturated seawater[10]. Nutrient runoff and subsequent eutrophication of coastal waters is also a process that has been shown to contribute to ocean acidification[11].

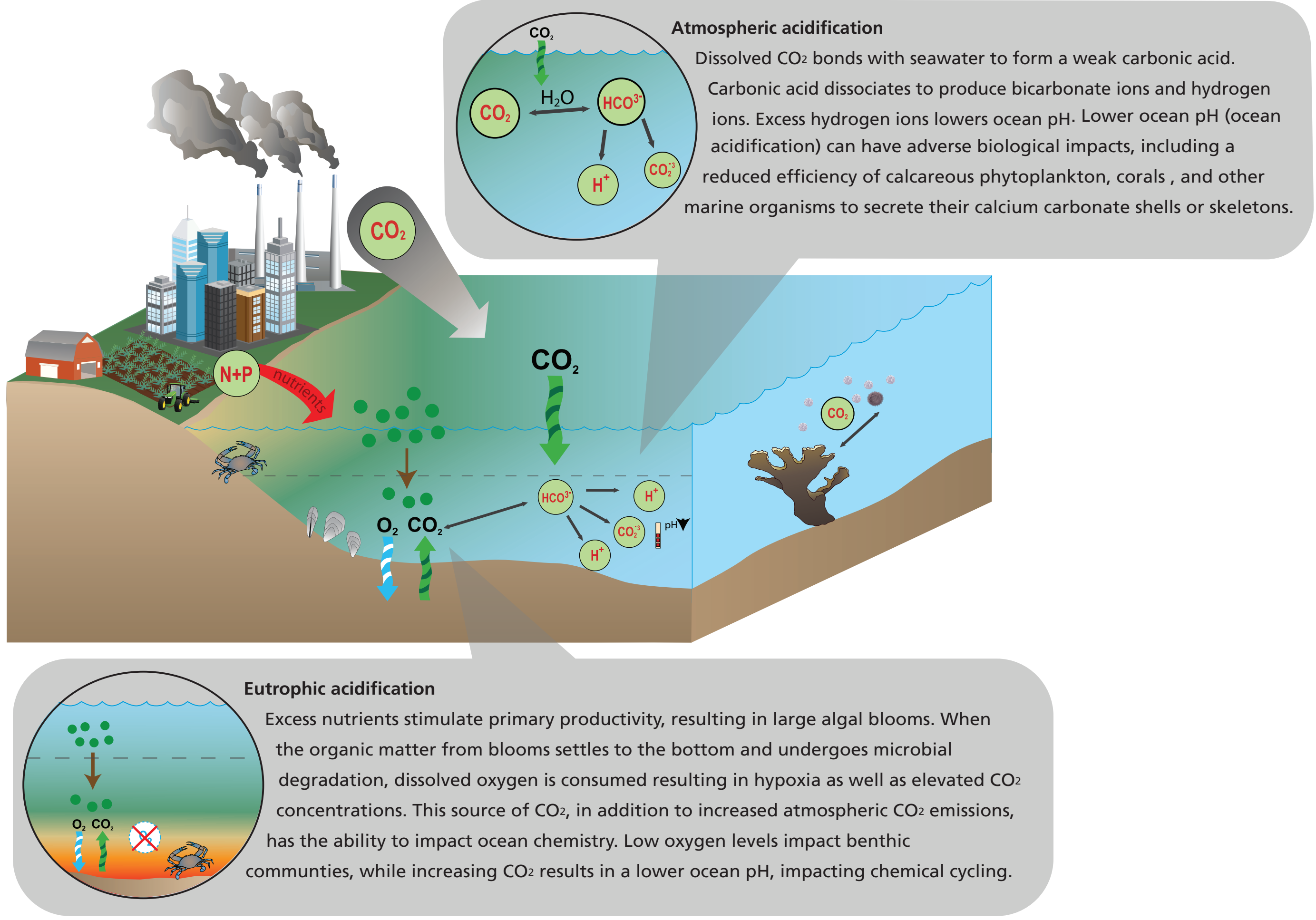
The remainder of this policy brief specifically explores the relationship between ocean acidification and eutrophication and includes recommendations on how the global community can respond to the challenge of ocean acidity though nutrient management options.

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 values[14]. Of all the land based sources of pollution affecting coastal ecosystems, nutrient enrichment is considered a serious problem[15] that needs to be addressed with immediate effect[16]. 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 O_2 is consumed and CO_2 is produced in the water column through microbial respiration which can result in a drop in pH (as explained earlier). This source of CO_2, 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 units[20].

Impacts of acidification

Changes in ocean chemistry can have extensive direct and indirect effects on organisms and their habitats. The formation of HCO_3^- (as per Equation 4) results in the depletion of CO_3^{2-} 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 CO_3^{2-}. This reaction also consumes CO_2 generated from respiration so that waters with high CO_3^{2-} are buffered against increases in CO_2 and associated decrease in pH for a given respiratory input. However, eutrophic conditions may produce disproportional amounts of CO_2 from microbial breakdown and hypoxic conditions[21].



Atmospheric acidification

Dissolved CO_2 bonds with seawater to form a weak carbonic acid. Carbonic acid dissociates to produce bicarbonate ions and hydrogen ions. Excess hydrogen ions lowers ocean pH. Lower ocean pH (ocean acidification) can have adverse biological impacts, including a reduced efficiency of calcareous phytoplankton, corals , and other marine organisms to secrete their calcium carbonate shells or skeletons.

Eutrophic acidification

Excess nutrients stimulate primary productivity, resulting in large algal blooms. When the organic matter from blooms settles to the bottom and undergoes microbial degradation, dissolved oxygen is consumed resulting in hypoxia as well as elevated CO_2 concentrations. This source of CO_2, in addition to increased atmospheric CO_2 emissions, has the ability to impact ocean chemistry. Low oxygen levels impact benthic communties, while increasing CO_2 results in a lower ocean pH, impacting chemical cycling.

Figure 2. Eutrophication-acidification link model, modified from Sunda and Cai 2012 [22].

Complexity of interactions

The biogeochemistry of coastal waters is complex with changes in carbonate chemistry providing either positive or negative feedback on increasing atmospheric CO_2 by modifying the flux of CO_2 between the ocean and the atmosphere[23]. The global coastal ocean thus can act as a sink or a source depending on the atmospheric CO_2 concentrations, but has increasingly become a sink with rising CO_2 concentrations[24]. Seasonal changes in CO_2 have also been found altered due to nutrient loading with increased CO_2 sequestration capacity in summer compared with autumn and winter[25]. The role played by ocean acidification in estuaries may be different from the open ocean[26].

Agricultural and industrial discharges are considered one of the causes of these recurrcing 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 acidification[29].

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 CO_2 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 follow into the coastal waters from agriculture and non-agricultural sources; and,
5. Raising awareness.

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