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Carbon Emissions and Acidification

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Avoiding environmental damage from ocean acidification requires reductions in carbon dioxide emissions regardless of climate change.

Much of the scientific and public focus on anthropogenic carbon dioxide (CO₂) emissions has been on climate impacts. Emission targets have been suggested based primarily on arguments for preventing climate from shifting significantly from its preindustrial state. However, recent studies underline a second major impact of carbon emissions: ocean acidification. Over the past 200 years, the oceans have taken up ~40% of the anthropogenic CO₂ emissions. This uptake slows the rise in atmospheric CO₂ considerably, thus alleviating climate change caused by anthropogenic greenhouse gas emissions. But it also alters ocean chemistry, with potentially serious consequences for marine life (1).

Oceanic uptake of anthropogenic CO₂ leads to a decrease in seawater pH and thus lowers the saturation state for carbonate minerals such as calcite and aragonite (CaCO₃). This process, termed ocean acidification, is expected to have detrimental consequences for a variety of marine organisms (2, 3). For example, a decline in carbonate saturation state will affect the stability and likely production rates of CaCO₃ minerals, which are the building blocks of coral reefs and form the shells and skeletons of other marine calcifying species. Independent of climatic considerations, carbon emissions must be reduced to avoid these consequences.

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References

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The range of tolerable pH changes (where “tolerable” means “without substantial detriment to organism fitness”) is as yet unknown for many marine organisms. In laboratory and mesocosm studies, a decrease of 0.2 to 0.3 units in seawater pH inhibits or slows calcification in many marine organisms, including corals (4), foraminifera (5), and some calcareous plankton (6, 7). A drop of 0.3 pH units corresponds to a doubling of the hydrogen ion concentration [H\(^+\)], because pH is expressed on a logarithmic scale as pH = −log([H\(^+\)]).

Compared with preindustrial levels, average surface ocean pH has already decreased by ~0.1 units (2). If future increases in seawater acidity affect calcification in coral reefs, such that erosion outweights accretion, then the reefs could lose structural stability, with further negative implications for reef communities and for shore protection (3). Reduced calcification in shellfish such as oysters and mussels would impact worldwide commercial aquaculture production (8). Effects of ocean acidification on noncalcifying organisms such as viruses and bacteria are largely unknown, as are potential consequences for marine food webs.

Thus, although the response of different organisms is expected to be inhomogeneous (9), current evidence suggests that large and rapid changes in ocean pH will have adverse effects on a number of marine organisms. Yet, environmental standards for tolerable pH changes have not been updated in decades. For example, the seawater quality criteria of the U.S. Environmental Protection Agency date back to 1976 and state that for marine aquatic life, pH should not be changed by more than 0.2 units outside of the normally occurring range (10). These standards must be reevaluated based on the latest research on pH effects on marine organisms. Once new ranges of tolerable pH are adopted, CO\(_2\) emission targets must be established to meet those requirements in terms of future seawater chemistry changes.

The key variables that will determine the extent of future seawater chemistry changes—and therefore the impact on marine life—is the magnitude and time scale of the anthropogenic carbon release. For specific CO\(_2\) emission scenarios, changes in atmospheric CO\(_2\), surface ocean pH, and carbonate mineral saturation state have been calculated with different carbon cycle models (1, 11–13). Fortunately, and in contrast to climate model predictions, such future ocean chemistry projections are largely model-independent on a time scale of a few centuries, mainly because the chemistry of CO\(_2\) in seawater is well known (14) and changes in surface ocean carbonate chemistry closely track changes in atmospheric CO\(_2\). Predicted changes in surface ocean pH for given total emissions and release time of anthropogenic carbon are thus similar among different types of models over the next few centuries [see supporting online material and (1, 11–13)].

Projected changes in ocean carbonate chemistry should serve as a guideline for policy protocols that identify CO\(_2\) emission targets to reduce the effects of human-made ocean acidification. For example, to avoid a surface ocean pH decline by more than 0.2 units (10), total emission targets would have to range from ~700 Pg C over 200 years to ~1200 Pg C over 1000 years (see the figure). Such scenarios would be difficult to achieve, however, because they require immediate reductions in global emissions. If emissions can be reduced after the year 2050 and capped at 1500 Pg C, surface ocean pH would decline by ~0.35 units relative to preindustrial levels. The aragonite saturation state in the warm surface ocean would drop from ~3.5 to ~2.1 under this scenario (see supporting online material). Substantial reductions in coral calcification have been reported over this range (2–4).

Predictions of changes in calcification rates and other physiological responses in marine organisms to ocean acidification are hampered by a lack of adequate experimental data and field observations. Most studies indicate reduced calcification rates at high CO\(_2\) (2–8, 11), but some find little change or increasing calcification rates (9, 15). The key is to understand the response of the functional groups that drive marine biogeochemical cycles. For instance, very few studies have examined foraminifera (5), which are major contributors to the production and deposition of calcium carbonate in the ocean. Also, long-term experiments are necessary with different calcifying and non-calcifying groups to test their ability to adapt to a high–CO\(_2\) world.

To monitor and quantify future changes in ocean chemistry and biogeochemical fluxes, intensified global ocean carbon dioxide surveys in combination with carbon-cycle modeling will be necessary. Awareness must be raised among the public and policy-makers of the effects of ocean acidification and the steps required to control it. Ocean chemistry changes, and not only climate effects, should be taken into consideration when determining CO\(_2\) emission targets; such consideration is likely to weigh in favor of lower emission targets.

References
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Supporting Online Material
www.sciencemag.org/cgi/content/full/321/5885/51/DC1
Figs. S1 and S2

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