



*Marine Science 201*

# Ocean Acidification: Cause, Effect, and Potential Mitigation Approaches

*Joanna M. Norton*

The accumulation of carbon dioxide in Earth's atmosphere is mirrored by an increase in dissolved carbonic acid in the oceans. Carbon dioxide dissolves easily into liquid, so the surface layers of the ocean are always in equilibrium with atmospheric pressures of the gas and provide a massive sink. Some of the dissolved carbon dioxide remains as carbonic acid, some breaks down further to form carbonate ion, but most is present in the form of bicarbonate ( $\text{HCO}_3^-$ ); these are the components of the ocean's buffering system to guard against pH changes. However, the buffer can be overwhelmed by continued inputs of carbon dioxide and lose its buffering capacity. The addition of carbon dioxide to the ocean is already causing a rise in acidity, which will have an increasingly negative effect on ocean ecosystems and processes if left unchecked (Jeffree, 2009). Researchers have begun investigating not only the effects of this acidification but also methods of potentially neutralizing it. Because rising levels of carbon dioxide are always equilibrating with ocean levels, and any changes made to individual ocean areas will eventually affect the entire ocean, mitigation efforts will involve massive alteration of ocean chemistry. Predicted effects of ocean acidification and proposed methods for its mitigation are examined here.

The lowering of oceanic pH levels has begun, and preliminary research indicates that the effect on marine organisms will be dire. Organisms that form shells or tests out of

calcium carbonate could be among the first victims of acidification, as more acidic waters pull carbonate out of calcium carbonate structures and back into solution. Current pH levels of the ocean are 0.1 unit lower than in preindustrial times, and modeling based upon the business-as-usual emissions predictions made by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations indicate that the Southern Ocean could become undersaturated for aragonite (a form of calcium carbonate) by the year 2050 (Orr et al., 2005). Furthermore, Caldiera and Wickett (2003) predict that this same emission regime will result in pH levels decreasing by 0.7 units within the next few centuries. This pH change is greater than any on geological record for the last 300 million years. Needless to say, no population alive in the ocean today has had a chance to evolve coping mechanisms for a pH shift that large, so the extent of potential ecosystem disturbance is entirely unknown. Researchers have simulated predicted levels of ocean acidity in experimental tanks to begin to address this question. Orr et al. (2005) found that after two days in a tank with carbon dioxide added to approximate levels in the year 2050, live high-latitude pteropods experienced substantial shell dissolution. The research team questions whether any high latitude pteropods could survive this environment. In some Antarctic regions pteropods account for a majority of all carbon export from the surface, so an extinction of this type would upset the whole base of the food web in these areas, as well as eliminate the carbon sequestration that is done by these species. Experimental evidence indicates that low-latitude corals and phytoplankton that form calcite tests would also be negatively affected by pH changes of this magnitude (Orr et al., 2005). Jeffree (2009) finds that reproductive success in animals that do not form shells, such as cuttlefish and seabream, also decreases with acidification.

One mitigation approach suggested by researchers involves sequestering carbon on the ocean floor by fertilizing certain ocean regions with iron, which can be a limiting nutrient in these areas. Pollard et al examined an area of the Southern Ocean with high nutrients and low chlorophyll (HNLC) and found that influxes of terrestrial iron led to rises in primary productivity (Pollard et al 2009). The resulting phytoplankton blooms produce more carbon-containing molecules that then travel through carbon flux and sink down to be sequestered on the sea floor. The observation of this phenomenon has led to proposals from private industry to utilize iron fertilization as a carbon offset on a global carbon market. A review of this plan's effects and side effects is therefore of timely importance (Cullen & Boyd 2008). Cullen and Boyd enumerate the main points of iron fertilization: it will increase primary productivity in areas of the ocean where large amount of macronutrients are currently unused, and thus send more organically-formed carbon-containing molecules down into the depths of the ocean where they are sequestered as particulates. Along with this intended result, these will also occur: macronutrients will be collected in the deep ocean with carbon, and become unavailable downstream in the nutrient flow from the site of iron fertilization; and oxygen levels at mid-level depths will decrease as heightened levels of organic material decompose, and release CO<sub>2</sub>. Iron fertilization could have negative feedbacks that lessen some of the carbon capture, and could negatively effect ocean ecosystem functioning (Cullen and Boyd 2008).

The addition of powdered limestone to ocean water to react with carbon dioxide and form bicarbonate has also been proposed (Rau and Caldiera 1999; Harvey 2007). This would neutralize the acidity of the added carbon dioxide, as well as push the oceanic carbon equation towards carbonic acid and allow for more calcium carbonate to stay undissolved in the shells of marine life. The

ocean has a large, untapped ability to hold dissolved bicarbonate, if enough calcium carbonate (limestone) is made available for the reaction (Rau et al 2006). This process would essentially increase the buffering capacity of the ocean, by adding carbonate ion to offset the carbon dioxide absorbed by the ocean. Rau et al (2006) calculate that the ocean could hold enough bicarbonate that all the carbon in existing fossil fuel stores could be sequestered. In fact, this is how past rises in atmospheric carbon were eventually modulated, gradually, over millennia. They suggest accelerated weathering of limestone at locations of CO<sub>2</sub> production. Harvey (2007) investigates adding powdered limestone to areas that would carry it in upwelling current. This method could be especially cheap and effective, and no negative side effects have been found, but these issues have not been thoroughly examined.

Just as ocean acidification has implications for primary and secondary ocean productivity, so do the mitigation ideas mentioned above. Doing nothing to reverse carbon acidification of the ocean will alter productivity, with decreases in some species experimentally shown (Orr et al 2005, Jeffrey 2009). Addition of iron changes levels of primary productivity at the site of introduction, and could possibly lead to a massive increase in total ocean productivity (Pollard et al 2009). Addition of limestone might protect productivity of biota that build calcium and aragonite shells (Rau and Caldiera 1999). Secondary effects on the ecosystems where productivity decreases are entirely unknown, and nutrients left unconsumed will eventually be found by species that can exploit the new situation. An interesting secondary effect of heightened levels of carbon has been found by Riebesell et al(2007): not only do elevated levels of carbon raise overall photosynthetic activity, but carbon is utilized up to 39% more while consumption of other nutrients remains even. The researchers conclude that this flexibility of primary producers has already mitigated about 10% of the effects of the rise

of carbon dioxide.

More than one way to mitigate the build-up of acidifying carbon dioxide in the world's oceans has been proposed. Addition of limestone or iron fertilization might prove to be appropriate responses; however, the global nature of the problem means that potential solutions must also be global, and will have profound effects on ocean chemistry and biology. This inspires caution, although some researchers ask how much caution is merited in regards to mitigation proposals when the predicted accumulation of oceanic carbon is poised to set off such drastic alterations in marine ecosystems (Jeffree 2009 ). Whether mitigating efforts are undertaken or not, ocean chemistry is changing.

## **Bibliography**

- Caldiera K, Wickett ME (2003) Anthropogenic carbon and ocean pH. *Nature* Sept 425:365
- Cullen JJ, Boyd PW (2008) Predicting and verifying the intended and unintended consequences of large-scale ocean iron fertilization. *Mar Ecol Prog Ser* Jul 364:295-301
- Harvey, LDD (2007) Mitigating the atmospheric CO<sub>2</sub> increase and ocean acidification by adding limestone powder to upwelling regions. *J. Geophys Res* 113:C04028
- Jeffree RA (2009) Ocean acidification: a prognosis and treatment for this eclipsing issue in marine ecotoxicology. *Integ Env Assess Mgmt* Nov 5:173-175
- Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely FA, Gnanadesikan A, Gruber M, Ishida A, Joos F, Key RM, Lindsay K, Maier-Reimer E, Matear R, Monfray P, Mouchet A, Najjar RG, Plattner G, Rodgers KB, Sabine CL, Sarmiento JL, Schlitzer R, Slater RD, Totterdell IJ, Weirig M, Yamanaka Y, Yool A (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* Sept 437:681-686
- Pollard RT, Salter I, Sanders RJ, Lucas MI, Moore MC, Mills RA, Statham PJ, Allen JT, Baker AR, Bakker DCE, Charette MA, Fielding S, Fones GR, French M, Hickman AE, Holland RJ, Hughes AJ, Jickells TD, Lampitt RS, Morris PJ, Nedelec FH, Nielsdottir M, Planquette H, Popova EE, Poulton AJ, Read JF, Seevave S, Smith T, Stinchcombe M, Taylor S, Thomalla S, Venables HJ, Williamson R, Zubkov MV (2009) Southern ocean deep-water carbon export enhanced by natural iron fertilization. *Nature* Jan 457:577-580
- Rau GH, Caldiera K (1999) Enhanced carbonate dissolution: a means of sequestering waste CO<sub>2</sub> as ocean bicarbonate. *Energy Conv and Mgmt* Nov 40:1803-1813
- Rau GH, Knauss KG, Caldiera K, Friedmann J (2006) Opportunities for low-cost CO<sub>2</sub> mitigation in electricity, oil, and cement production. *Proc Greenhouse Gas Tech Conf* 8:1-4
- Riebesell U, Schulz KG, Bellerby FGJ, Botros M, Fritsche P, Meyerhofer M, Neill C, Nondal G, Oschlies A, Wohlers J, Zollner E (2007) Enhanced biological carbon consumption in a high CO<sub>2</sub> ocean. *Nature* 450:545-548