

GLOBAL WARMING, OCEAN ACIDIFICATION AND THE FUTURE OF THE PLANET . . .Connecting the Dots

By Bruce Steele

In the past 200 years the oceans have absorbed about 525 billion tons of carbon dioxide (CO₂), almost half of the amount produced by human activities. (Sabine and Feely, 2007). As CO₂ dissolves in seawater, it acts to make the ocean more acidic. The pH of global oceans has already dropped 0.1, on average, but this seemingly small change has increased acidity by about 30 percent. Ocean acidification amplifies the negative impacts caused by climate change – one condition exacerbates the other.

Seawater pH is a critical variable in the marine environment. Today's surface ocean is slightly alkaline, and it is saturated with calcium carbonate, an essential organic molecule for organisms such as corals, echinoderms, mollusks and crustaceans that make shells. As CO₂ reacts with seawater, it lowers the pH and releases hydrogen ions. These ions bind strongly with carbonate, preventing it from forming calcium carbonate molecules. If the pH of global oceans drops 0.4 by 2100, as predicted, the levels of calcium carbonate available for use by shellfish could decrease by some 45-50 percent. (Orr, 2005). To put this in historical perspective, surface ocean pH would decrease to a level not seen for more than 20 million years. (Feely et al, 2004).

The ocean has mechanisms to buffer surface acidification. In fact, physical mixing of ocean water and the biological process that transports calcite shells of surface dwelling animals to the ocean depths as they die have been responsible for balancing the acidifying effects of CO₂ for the last 750+ million years. (Knoll, 2003). Calcifiers span the food chain, including organisms such as echinoderms, crustaceans and mollusks.

Today calcium carbonate and silica leave the ocean largely as skeletons. (Knoll, 2003). However, due to the combustion of hydrocarbons since the beginning of the Industrial Revolution and the resultant increases of atmospheric CO₂, largely human-induced atmospheric changes have exceeded the ocean's ability to absorb the increasing CO₂ levels.

The world's oceans have experienced pH changes over the millennia due to cyclical increases in CO₂. “Since the beginning of the Industrial Revolution, carbon dioxide levels in the atmosphere and surface ocean have been rising, and they may be rising too fast for some skeleton formers to adapt. (The deleterious effects of environmental change nearly always hinge as much on rates as they do on magnitude.)” states Andrew H. Knoll, PhD, Fisher Professor of Natural History at Harvard University. “As Pco₂ continues its rapid rise, the physiological cost of carbonate precipitation may once again become prohibitively high, especially for poorly buffered organisms like benthic algae and cnidarians [anemones] – the same animals that suffered disproportionately at the end of the Permian Period. As they shed light on Earth's evolutionary past, then, experimental studies of growth in skeleton-forming organisms may illuminate the biological future that our grandchildren will inherit.” (Knoll, 2003)

Over the next 100 years, the predicted pH change will accelerate rapidly in the polar and sub-polar seas. Although average worldwide ocean pH has dropped 0.1 since the Industrial Revolution (Caldeira et al. 2003), the pH change in polar seas is larger due to colder waters (less transpiration) and fresh water runoff from the ice caps. Seawater pH ranges between 7.8 and 8.3 (standard pH units), but fresh water is much lower, around 7.0.

The changes in seawater chemistry that will occur in the next 100 years will likely negatively impact numerous species, including pteropods (Orr et al. 2005), sea urchins (Shirayama et al. 2005), mussels and oysters (Gazeau. 2007), corals (Gattuso et al. 1998), and others.

The effects will be the most severe in Arctic and Antarctic ocean waters, at least initially. Pteropods comprise the dominant form of zooplankton in the Ross Sea (Seibel et al. 2003) and account for the majority of the export to deep waters of both carbonate and organic carbon (Accornero et al. 2003; Collier et al. 2000). Experimental evidence suggests even the shells of live pteropods dissolve rapidly once surface waters have become undersaturated with respect to aragonite (Feely et al. 2004).

In fact, as Caspar Henderson wrote in an article entitled “Ocean Acidification: the *other* CO₂ problem” (New Scientist, August 2006):

“A few years ago, Victoria Fabry saw the future of the world's oceans in a plastic jar. She was aboard a research vessel in the frigid waters of the North Pacific, carrying out experiments on a species of pteropod called *Clio pyramidata* - frisky little molluscs with shells up to a centimetre long and flaps on their bodies that they use to swim in a way that resembles butterfly flight.

Something strange was happening in Fabry's jars. "The pteropods were still swimming like billy-o, but their shells were visibly dissolving," says Fabry, a biologist from California State University San Marcos. "I could see it with the naked eye."

Experimental evidence suggests that sea urchins, as echinoderms, may also suffer in ocean waters with decreasing pH levels. Because urchins utilize high magnesium calcite in shell formation, changing seawater chemistry may place them in harm's way. High magnesium calcite goes into solution even before aragonite. (Shirayama et al. 2005). When seawater magnesium/calcium (Mg/Ca) molar ratios reach 5.5, high magnesium calcite reaches undersaturation. Because current molar ratios are already around 5.2, echinoderms, crustose and articulated corraline red algae, gorgonia and other life forms utilizing high Mg/Ca may be some of the first life forms to suffer in our new ocean paradigm. Indeed, sea urchins may begin to suffer physiological effects even in temperate seas.

The pronounced deleterious effect on the biological pump and the concurrent snowball effect caused by the loss of carbon transport in the polar and subpolar seas are likely to exacerbate problems extending 100-300 years from the present. Connecting the dots: global warming to increased CO₂ ... to increased ocean acidification ... the consequences are truly life threatening for our planet – at least to life as we know it.

Depending on assumptions regarding business-as-usual growth projections in fossil fuel use over the next few decades, models predict that the changes discussed in this paper will begin within the next 50 to 100 years. However, it seems to me as a lay person and sea urchin diver, the scientific papers that I've found to date have described these changes in sealife and ocean chemistry in a manner that appears to be both ultra-conservative and even myopic in scale and time frame.

If one accepts these profound changes to begin in the next 100 years, I believe it behooves us to take the next step and make the logical mental extension to consider the impact these changes will have on the oceans: both in the ocean's declining ability to absorb CO₂ and the cascading effects of that failure as entire ecosystems begin to collapse and cease to function as carbon sinks.

As a fisherman who has spent the last 35+ years (my adult life) on and in the ocean, I believe even the possibility that this problem could cascade into a replication of the Permian extinction within the next 100-300 years should resonate as a loud wake-up call. According to Knoll (2003), "More than half of all invertebrate families, and perhaps 90 percent or more of existing species perished in the oceans (Raup, 1979, Erwin et al. 2002), and both tetrapods and vascular plants suffered substantial losses on land. (Maxwell. 1972, Looy. 2001)." Knoll acknowledged that debate still continues on both the physical triggers for the extinction and the physiological mechanisms that induced mortality on such a large scale.

That said, this issue should not be relegated to the back burner for more scientific debate first, before taking direct and immediate action to change our habits. This is not a debate about sea-level rise or the extinction of polar bears, this is a debate about life itself.

Everyone on this fragile planet needs to wake up to the threat that humanity poses if we continue on our current course.

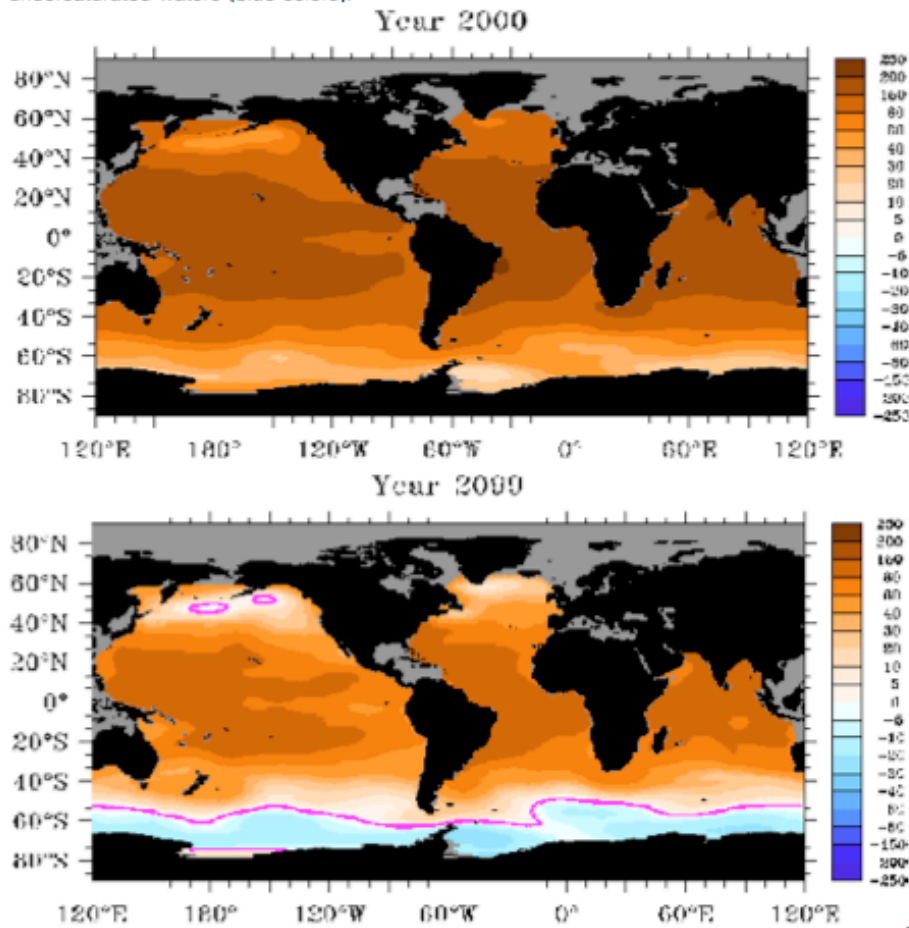
[Nature paper](#) | [Press reports](#) | [Projected Saturation State](#) | [Pteropods](#) | [Cold-Water Corals](#) | [Links](#)

Cold Ocean Acidification

A [new study](#) by an international team of oceanographers published in *Nature* on September 29, 2005 reports that ocean acidification could result in [corrosive chemical conditions](#) that would be reached much sooner than previously thought. Within 50 to 100 years, there could be severe consequences for marine calcifying organisms, which build their external skeletal material out of calcium carbonate, the basic building block of limestone. Most threatened are cold-water calcifying organisms, including sea urchins, [cold-water corals](#), coralline algae, and plankton known as [pteropods](#)--winged snails that swim through surface waters. Below you will find photographs of some of these organisms.

Chemical Saturation State:

Projections for the "chemical state" of the surface ocean for years 2000 (top) and 2009 (bottom) given as the median of 10 ocean models. The magenta colored line (seen only in 2009) separates saturated waters (orange colors) from undersaturated waters (blue colors).



References:

- Accornero, A.; Manno, C.; Esposito, F.; and Gambi, M.C. (2003). "The vertical flux of particulate matter in the polyna of Terra Nova Bay". Part II. Biological components. *Antarct. Sci.* **15**, 175-188.
- Collier, R.; Dymond, J.; Susumu Honjo., S.M.; Francois, R.; and Dunbar, R. (2000). "The vertical flux of biogenic and lithogenic material in the Ross Sea moored sediment trap observations 1996-1998. *Deep-Sea Res. II* **47**. 3491-3520.
- Caldeira, K., and M.E. Wickett (2003). "Anthropogenic carbon and ocean pH". *Nature* **425** (6956): 365-365. DOI: 10.1038/425365a. ISSN 0028-0836
- Feely, R.A.; Sabine, Christopher L.; Lee, Kitack; Berelson, Will; Kleypas, Joanie; Fabry, Victoria J.; Millero, Frank J. (2004). "Impact of Anthropogenic CO₂ on the CaCO₃ System in the Oceans". *Science* **305** (5682): 362-366. DOI: 10.1126/science. 1097329. ISSN 0036-8075.
- Gattuso, J.P; Frankignoulle, M.; Bourge, I.; Romaine, S. and Buddemeier, R.W. (1998). "Effect of calcium carbonate saturation of seawater on coral calcification". *Global and Planetary Change* **18** (1-2): 37-46. DOI: 10.1016/S0921-8181(98)99935-6. ISSN 0921-8181
- Gazeau, F.; Quiblier, C.; Jansen, J.M.; Gattuso, J.P.; Middleburg, J.J. and Heip, C.H.R. (2007). "Impact of elevated CO₂ on shellfish calcification". *Geophysical Research Letters* **34**: L07603. DOI: 10.1029/2006GL028554. ISSN 0094-8276.
- Knoll, A.H.; Bambach, R.; Canfield, D.; Grotzinger J.P. (1996). "Comparative Earth history and late Permian mass extinction". *Science* **273** : 452-457.
- Knoll, A.H. (2003). "Biomineralization and Evolutionary History", *Reviews in Minerology and Geochemistry*. V.54; 1; p 329-356. DOI: 10.2113/0540329
- Orr, J.C., S. Pantoja, and H.O. Portner (2005). Introduction to special section: "The Ocean in a High CO₂ World". *J. Geophys. Res.*, 110, C09S01, DOI: 10.1029/2005JC003086.
- Orr, James C.; Victoria J. Fabry; Olivier Aumont; Laurent Bopp; Scott C. Doney; Richard A. Feely; Anand Gnanadesikan; Nicolas Gruber; Akio Ishida; Fortuat Joos; Robert M. Key; Keith Lindsay; Ernst Maier-Reimer; Richard Matear; Patrick Monfray; Anne Mouchet; Raymond G. Najjar; Gian-Kasper Plattner; Keith B. Rodgers; Christopher L. Sabine; Jorge L. Sarmiento; Reiner Schlitzer; Richard D. Slater; Ian J. Totterdell; Marie-France Weirig; Yasuhiro Yamanaka and Andrew Yool. (2005). "Anthropogenic ocean acidification over the 21st century and its impact on calcifying organisms." *Nature* **437** 29 September 2005. DOI: 10.1038/nature 04095
- Seibel, B.A. and H.M. Dierssen (2003). "Tip of the iceberg: Cascading trophic impacts of reduced biomass in the Ross Sea, Antarctica". *Biological Bulletin* **202**, 93-97
- Shirayama, Y., and H. Thornton (2005). "Effect of increased atmospheric CO₂ on shallow water marine benthos". *J. Geophys. Res.*, 110, C09508, DOI: 10.1029/2004JC002618