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To catch a fallen sea angel: A mighty mollusk detects ocean acidification

By Kevin Zelnio | Nov 5, 2010 10:05 AM | 8

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"What's *more*," snapped the Lorax. (His dander was up.)

"Let me say a few words about Gluppity-Glupp.

Your machine chugs on, day and night without stop

making Gluppity-Glupp. Also Schloppity-Schlopp.

And what do you do with this leftover goo?...

I'll show you. You dirty old Once-ler man, you!

"You're glumping the pond where the Humming-Fish hummed!

No more can they hum, for their gills are all gummed.

So I'm sending them off. Oh, their future is dreary.

They'll walk on their fins and get woefully weary

in search of some water that isn't so smeary."

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) concluded "the response of organisms to ocean acidification is poorly known and could cause further changes in the marine carbon cycle with consequences that are difficult to estimate" (Bindoff et al., 2007). In the intervening three years since its publication, ocean acidification has risen to become a major research area in marine

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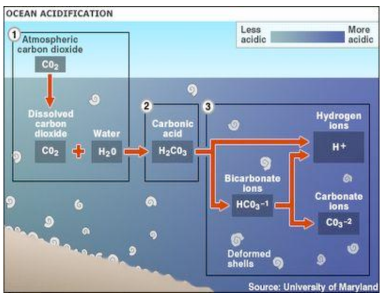
science. While the oceans buffer the planet against rising CO2 concentrations, it does so a cost to its own chemistry.

In case you have yet to noticed the ocean is REALLY big, 1.3 billion cubic kilometers (312 million cubic miles) big in fact. The oceans hover near a pH around 8.1. Since the ocean is HUGE, it takes A LOT to move the pH up or down. At a pH of 8.1, the carbonate system is composed of 90% bicarbonate, 9% carbonate, and only 1% as dissolved CO2. While we put our Gluppity-Glupp and Schloppity-Schlopp into the atmosphere, the ocean does its best to buffer the planet by balancing its chemistry with the air. As a consequence the acid balance is tilted lower because while the concentration of each component of the carbonate system increases, the increase in hydrogen ions comes at a cost to carbonate ions, which is what marine calcifiers need to create shells (Doney et al., 2009).



The fate of carbon dioxide in the ocean.

Calcifying organisms exist in all regions of the ocean from the deep seafloor to the pelagic open waters, from near-shore to far offshore, and at a wide range of depths. Carbonate dissolves faster at shallower depths where most of the carbonate-secreting animals live, such as corals and bivalve mollusks. Carbonates also dissolve a greater rate in frigid polar waters, which are home to large populations of the planktonic calcifiers like pteropod mollusks and formaniferans. Calcium carbonate exists as two forms when utilized by organisms – calcite and aragonite. The chemical differences may be subtle, but the results are dramatic. Aragonite dissolves at a much shallower depth, depending on where in the ocean you are 0.5 to 3 kilometers deep, while calcite dissolves between 4.2 and 5 kilometers deep. It is the aragonitic form that used by many animals, such as mollusks and corals. The IPCC's "business as usual" CO2 emissions model projects that high latitude waters will be undersaturated with respect to aragonite near the end of the century (Orr et al., 2005). This model assumes that we do not change our emissions behavior and lessen our current rate of CO2 input to the atmosphere.

To grasp how our input of CO2 feeds back upon polar foods webs we can use the unassuming pteropod mollusk, commonly called the sea angel because of its modified wing-like (ptero-) foot (-pod), as a case study. Pteropod mollusks are particularly susceptible to ocean acidification because their carbonate shells are very thin and composed of aragonite, which is 50% more soluble in seawater than calcite, the other form of calcium carbonate. Hence, they are considered a "canary" in the climate change coal mine. Orr and colleagues (2005) examined the fate of the pteropod's fragile shell under "business as usual" CO2 emissions. After 48 hours, shells edges were already acid-pitted (Orr et al., 2005). Calcification is a physiological process and organisms exert some degree of control over the enzymatic constituents, but it is an energetically expensive process (reviewed in Fabry et al., 2008). When shells get damaged, animals must exert even more precious energy to repair the damage.

Limacina helicina—a pteropod mollusc *Image used with permission by Russ Hopcroft, University of Alaska Fairbanks. More at* Arctic Ocean Diversity

Unfortunately, baseline data among pteropod species are lacking and it is difficult to track the effects of ocean acidification at the population level in the field. Polar pteropods are adapted for metabolic activity in cold waters, but by trading off locomotor capabilities for increased aerobic capacity, they are even more vulnerable to changes in their environment (Rosenthal et al., 2009). Because pteropods are limited to the much more soluble aragonite for shell production, it is predicted their range will be severely limited over a short time – as little as 50-100 generations – vertically in the water column and then latitudinally as they are forced towards lower latitudes (Fabry et al., 2008). Even if they are able to adapt to warmer waters with lower aragonite-saturation depths they will necessarily be exposed to new planktonic communities, entering into new competitive interactions, and be displaced from their preferred prey.

The loss of the tiny pteropod is not without major repercussions in the polar food web. As a major food source in polar open waters (Pakhomov et al., 1997), decreased pteropod abundance will adversely affect the structure of food web (Seibel & Dierssen 2003). Some of the better-known predators of pteropods are whales, fish and seabirds. Pteropods located in northwest Pacific salmon fishing grounds can make up over 60% of juvenile salmon diets (Armstrong et al., 2005, Turley et al., 2010). There are few pteropod specialists. In Japanese waters a deep-water myctophid fish, *Centrobrachus brevirostris*, exclusively eats pteropods (Watanabe et al., 2002). Ironically, the most fierce-some predators that the thin-shelled pteropods have to be wary of are other larger, shell-less pteropods (Seibel et al., 2007). While few specialize on pteropods, they are an important, abundant, and high protein food source for a whole community of generalist predators. The disappearance of pteropods may cause these generalist predators to prey upon larvae of economically important fishery stocks, such as juvenile salmon, more frequently.

Pteropods are also the dominant grazers of polar phytoplankton, out-consuming copepods by up to 33% (Bernard & Froneman 2009) with ingestion rates at the upper end for zooplankton in general (Hunt et al., 2008). Fewer pteropods may relieve pressure on phytoplankton, though, and drive a small negative climate feedback by taking up and sequestering more CO2 in the polar latitudes. While lower pteropod abundances decrease export of carbon, via carcasses, fecal pellets and carbonate, to deep sea, marine snow will still accumulate to some extent because of the increased phytoplankton biomass.

This case study of the pteropod is but a small window into the effects of ocean acidification as a result of human input of CO2 into the atmosphere. While under high CO2 emissions scenarios in the lab, pteropods were still able to precipitate calcium carbonate for their shells, but shell production was highly contingent upon pH (Comeau et al., 2010). It is still unclear whether rate that new shells is created is equal to or greater than the rate at which older shell is dissolved as a net process operating at lower pH or high CO2 emissions (Comeau et al., 2010). Other calcifying organisms such as foraminferans, coccolithophores, other mollusks, shallow and deep-water corals, echinoderms, fish, crustaceans, coralline algae, and seagrasses are all physiologically susceptible to acidification (Doney et al., 2009). Pteropods appear to be most vulnerable species to ocean acidification, but the effects to economically important bivalve and corals, which often provide habitat for commercial fisheries, will likely be among the most severe socioeconomic and environmental outcomes.

Can we catch a fallen sea angel from the brink of decimation? That will be up to us to decide. If the old Once-ler can realize the errors of his ways, albeit nearly too late, perhaps we too can learn a lesson from The Lorax.

> "But now," says the Once-ler,
>
> "Now that you're here,
>
> the word of the Lorax seems perfectly clear.
>
> **UNLESS** someone like you cares a whole awful lot,
>
> nothing is going to get better, Its not." – Dr. Seuss, *The Lorax*

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About the author: Kevin Zelnio is a doctoral student at University of North Carolina, Wilmington, received his MSc at Penn State studying community of hydrothermal vents, and got his BSc in Evolution and Ecology at University of California, Davis. He studies the geographic extent of hybrid populations, molecular ecology of marine invertebrates and is a published taxonomist of hydrothermal vent invertebrates. He has described one new species of shrimp and 4 new species of anemones. Kevin is the Assistant Editor and Webmaster for

Deep Sea News where he writes extensively about marine science. To learn more about him visit his homepage, where he occasionally writes about non-marine evolutionary ecology, and follow him on Twitter: @kzelnio. [Image used with permission by Anna Linda Photography]

The views expressed are those of the author and are not necessarily those of Scientific American.

Tags: Carbon Cycle, Fish, Marine Biology, Climate Change, Climate, CO2, Ocean Acidification, IPCC, Arctic

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8 Comments

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1. fthoma
03:29 PM 11/5/10

The ocean ph varies all over the lot, naturally. See "The Electric Oceanic Acid Test" at http://wattsupwiththat.com/2010/06/19/the-electric-oceanic-acid-test/ and additional information at http://wattsupwiththat.com/2010/11/01/scientists-plead-for-15-billion-ocean-acidification-monitoring-system/

I think I'm going to let my SciAm subscription lapse. Sadly, because I've been reading the mag for over 50 years, but this studied bias on AGW is really not in keeping with its historic accuracy in its reporting on science.

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2. ElOceanografo
05:53 PM 11/5/10

The fact that something is variable in space or time is not mean there is not a long-term trend as well. These things are not mutually exclusive. The fact that some change or variance is natural doesn't really say anything about whether some other change or variance is man-made.

Ocean acidification is basic diffusion and carbonate chemistry. It isn't scientifically surprising or controversial. There's a lot of uncertainty when it comes to the ecological consequences, but it's a safe bet that animals like pteropods won't be doing so well in the future.

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3. fthoma
07:53 PM 11/5/10

"but it's a safe bet that animals like pteropods won't be doing so well in the future" Why do you say that? Did you look at my reference? It includes a section on our contribution to the CO2 content of the ocean, and, not demanding of a belief system, it is inconsequential. Whatever happens in the ocean has very little to do with out <4% of the total annual contribution to the

CO_2 content of the atmosphere.Humans are not the final arbiters of whether a species lives or dies.

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4. ElOceanografo
08:53 PM 11/5/10

Well, there's the paper referenced in the wattsupwiththat blog post, for one: http://www.agu.org/journals/gl/gl1002/2009GL040999/

A total pH decrease of -0.08 over 15 years doesn't look like much, but it means (assuming I didn't screw up my logarithms) that the actual concentration of hydrogen ions increased by 20% over that time period, with almost half of that change (48%) attributed to human-generated CO_2. And they say that contribution will get bigger in the future:

"On multidecadal time scales, pH changes attributable to anthropogenic CO_2 can be expected to eventually dominate the signal. CO_2 produced by respiration in the subsurface ocean (diagnosed from O_2 measurements) can be expected to show positive and negative variations [Deutsch et al., 2006; Whitney et al., 2007; Mecking et al., 2008]. In contrast, anthropogenic CO_2 in seawater should steadily increase as atmospheric levels continue to rise."

They also speculate on the possible consequences of acidification:

"One outcome of the observed widespread pH declines (Figures 2 and 4) is an increasingly inhospitable environment for calcifying marine plankton, such as pteropods, forams, and coccolithophorids. Decreasing pH translates directly to decreasing carbonate saturation states. The physiological status of these pelagic calcifying organisms currently abundant in the North Pacific is therefore likely to be adversely impacted [Feely et al., 2004, 2008; Fabry et al., 2008]. Many other chemical, physiological, and ecological processes are affected as well (e.g., trace metal speciation, photosynthesis, nitrogen fixation), to an extent that is not well characterized [Doney et al., 2009]."

For others, check out the references listed at the end of this piece, especially Orr et al. 2005. They use a number of different models to try to predict more CO_2 in the atmosphere will affect pH in the ocean.

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5. Kevin Z
11:32 PM 11/5/10

Hi fthoma, thank you for comment. I am sorry that you felt my article was reason to stop subscribing to Scientific American. I am very concerned about why you think "studied bias on AGW is really not in keeping with its historic accuracy in its reporting on science." I am reporting results of several studies on the effects of anthropogenic forcing of CO_2 in the atmosphere on ocean life.

The experiments and observations documented here and elsewhere show that for most of the aragonitic calcifying animals studied so far there are detrimental effects. My post discussed only the effects on shell production really, but there is also literature on physiology and blood pH as well.

Finally, there needn't be a belief system here for global warming. Scientists are all skeptics by the nature of the profession. Several decades of data have been collected mounting a very convincing argument. New data may tell us something different, we await that with open arms as well.

The problem is really with feedbacks. Because our input of CO2 into the atmosphere is an external driver to the Earth climate system, something needs to compensate. The oceans absorb CO2 to maintain an equilibrium with the atmosphere, this is purely by physical processes alone. The more CO2 in the atmosphere, the more the oceans will take in till it comes into equilibrium. The CO2 does not leave the ocean though, this is a long term gain. Bicarbonate and carbonate increase too because an equilibrium must be maintained between the chemical species of the carbonate system. So more CO2 in the ocean, produces more carbonic acid which disassociates into carbonate and hydrogen ions. The hydrogen ions accumulate which lowers pH.

Small changes in pH have a devastating effect because it is a concentration that is on a log-scale. Therefore a 1 unit shift in pH is an order of magnitude change in concentration of hydrogen ions. Smaller organisms are very susceptible to any change.

A topic for another post, and I am about reaching my character limit for commenting here, but there are lots of mechanisms by which CO2 accumulates and gets held up in near the surface waters where most of the primary production and resulting food web biology occurs. What happens is less mixing over large scales of the ocean, which concentrates CO2 in the biologically interesting area near surface waters. So shallow waters are particularly susceptible to decreasing pH.

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6. sunnystrobe
03:36 AM 11/9/10

Bravo, Sci Am! Brave New World, that has such people in it as Kevin Z! It's truly interactive , first class 'live'journalism to witness the learned author personally replying to a 'doubting Thoma'..
Though I come from a different angle of interest in evolution myself, namely, the quaint & quirky fast-food feeding habits of Mr/Mrs Homo S.S., which result in no less damage to his and especially- her- calcium balance-/bone density in the long run, due to mainly machine-made , condensed & heat-damaged non-plant food intake leading to a higher pH level . This ill befits our 'chimp-de-luxe' chassis; leading to high body stress, but is blithely ignored by most conventionally trained medicos.
(They have more interest in the pH level of their swimming pools than in that of their own system; but why is this so I wonder.
Perhaps it can be explained with our neotony, eolutionary

baby status?)
It seems too hard to realize that our own body cells are bathed in an briny milieu, too, where the same biochemistry rules still apply..

For more on the theme of species-specific human nutrition, please visit youthevity.com

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7. Le Spaz d'Argent
01:46 PM 11/9/10

Fthoma - Speaking of bias please see http://www.science20.com/chatter_box/weird_world_weather for a review of James Watts' approach to climate science. Factual, if a bit tart...

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8. BUZZINGSTREET
12:35 AM 11/15/10

Dear Visitor,
Market is showing some good move. Nifty traders are now confused if they should go short in Nifty from current level of 5400 or should go further long. NSE and BSE are the two major stock exchanges of Indian stock market. Keeping in mind that many investors and traders are very much confused with the current market move, we have stared posting " title="technical research reports"> technical research reports These reports are highly accurate and are available for free.

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Nifty is on its peak now and is turning volatile. Investors are suggested to book long delivery positions soon. As after some more upmove we can see profit booking in the market soon. Investors are suggested to grab quality stocks at lower level again.

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