ACIDIFICATION OF THE OCEAN AND THE BAY

By Gary Antonides

In the Spring 2019 issue of their newsletter, *Catalyst*, the Union of Concerned Scientists reported that the surface waters of our oceans are nearly 30 percent more acidic than they were in 1850. If we don't reduce carbon emissions, they could be more than twice as acidic in 2100 than they were in 2000. Of the three major effects of increased carbon emissions, *ocean acidification* occurs the most quickly by far, then *warming*, then *sea level rise*. If emissions decrease, ocean acidification will be the quickest to decrease.
(https://www.ucsusa.org/sites/default/files/attach/2019/05/Catalyst-Spring-2019.pdf)

As carbon dioxide (CO_2) dissolves into the ocean, it forms carbonic acid, decreasing the ocean's pH. This is the process of ocean acidification, and it deprives shell-forming marine organisms (shellfish, corals, etc.) of the carbonate ions they need to build their protective shells. Acidifying waters eat away at the bottom of the world's food chain. When our global food chain is at risk, so are those who make their livings from, or subsist on, seafood.

The International Union for Conservation of Nature (IUCN), in https://www.iucn.org/resources/issues-briefs/ocean-acidification, says to combat acidification, CO_2 emissions need to be cut significantly and immediately and that conservation, restoration and permanent protection of at least 30% of the oceans are urgently needed.

The ocean absorbs over 25% of all human generated emissions from the atmosphere each year. As CO_2 dissolves in sea water and forms carbonic acid, it does so in parallel with ocean warming and deoxygenation. Interaction between these is often cumulative or even multiplicative, resulting in combined effects more severe than the sum of their individual impacts.

Present ocean acidity change is unprecedented in magnitude, occurring at a rate approximately ten times faster than anything experienced during the last 300 million years. This rapid change is jeopardizing the ability of ocean systems to adapt to changes in CO_2, that naturally occur over millennia. Increases in ocean acidity will persist as long as concentrations of atmospheric CO_2 continue to rise. To avoid significant harm, IUCN says, atmospheric CO_2 levels need to get back to the 320-350 ppm range. A level of 400 ppm was exceeded in 2015.

Although more knowledge on the impacts of ocean acidification on marine life is needed, some predictions can be extrapolated from current knowledge. Some of the strongest evidence of the effects of ocean acidification comes from experiments on calcifying organisms. Increased sea water acidity has been shown to affect the formation and dissolution of calcium carbonate shells and skeletons in a number of marine species, including corals, oysters, mussels, and many phytoplankton and zooplankton species that form the base of marine food webs. Acidification can also cause changes in the growth and reproduction of marine species.

Increased ocean *temperatures* will also have direct effects on marine organisms and influence the geographical distribution of species. Some species such as reef-forming corals, are already living at their upper tolerance level, will have difficulty 'moving' fast enough to new areas. Changes in ocean temperature can also lead to coral bleaching, where corals expel the symbiotic algae living in their tissues, causing them to turn white.

The current emissions targets of the Intergovernmental Panel on Climate Change (IPCC) are to limit the global average temperature increase to less than 2°C. This is too much of a change to tackle the issue of ocean acidification. It will not reduce atmospheric CO_2 concentration to less than 400 ppm, and will significantly harm ocean life.

Another cause of ocean acidification is acid rain which contains nitrogen oxides and sulfur dioxide. They combine with atmospheric moisture to form acids. This is more concentrated near the coasts where the ocean is fed by rivers and runoff. (See "Acid Rain Has A Disproportionate Impact On Coastal Waters," Sept.15, 2007, Woods Hole Oceanographic Institution https://www.sciencedaily.com/releases/2007/09/070907175147.htm). They say that the release of sulfur and nitrogen into the atmosphere by power plants and agriculture plays a minor role in making the ocean more acidic on a global scale, but the impact is greatly amplified in coastal waters. Coastal waters are already some of the most heavily affected parts of the ocean due to pollution, over-fishing, and climate change. Woods Hole found that the change in acidity in coastal waters due to nitrogen and sulfur was as much as 50 percent of the total change caused by CO_2. The most heavily affected areas tend to be downwind of power plants (particularly coal-fired plants) and, in the U.S., predominantly on the East Coast.

The EPA is working on all three causes of acidification: CO_2 emissions, acid-rain and excess nutrients. The part of the US Executive Branch called the Subcommittee on Ocean Science and Technology administers the Interagency Working Group on Ocean Acidification, which includes 13 other agencies. The EPA collaborates with the National

Estuary Program (NEP) which is deploying monitoring systems in estuaries around the country (San Francisco Bay, Santa Monica Bay, Tampa Bay, Massachusetts Bay, Casco Bay, Barnegat Bay, Long Island Sound, Corpus Christi Bay and Tillamook, OR). EPA is also measuring acidification in the Mid-Atlantic ocean offshore of Chesapeake and Delaware Bays and collaborating with states to study the interactions between nutrients and coastal acidification, and with universities to study impacts on shellfish.

An article in National Geographic, "Carbon dioxide in the water puts shelled animals at risk," April 27, 2017 (https://www.nationalgeographic.com/environment/oceans/critical-issues-ocean-acidification/) says that for tens of millions of years, Earth's oceans have maintained a relatively stable acidity level, but that this ancient balance is being undone by the recent and rapid drop in surface pH, which could have devastating global consequences. Scientists know that about half of the man-made CO_2 generated since the early 1800s has been absorbed over time by the oceans. This has reduced climate change from what it would have been if the CO_2 had remained in the air. However, relatively new research is finding that the massive amounts of CO_2 in the oceans is affecting the life cycles of many marine organisms, particularly those at the lower end of the food chain.

The pH scale runs from 0 to 14, where solutions with low numbers are acidic and those with higher numbers are basic. Seven is neutral. As examples, lye has a pH of 13 and lemon juice has a pH of 2. Over the past 300 million years, the average ocean pH has been slightly basic (about 8.2). Today, it is around 8.1. A drop of 0.1 might not seem like a lot, but the pH scale is logarithmic and that drop amounts to about 25%. (pH 4 is ten times more acidic than pH 5) If we continue to add CO_2 at current rates, seawater pH may drop to 7.8 or 7.9 by the end of the century (an increase in acidity of *another* 60 to 100 percent), creating an ocean more acidic than it has been for the past 20 million years or more.

A Smithsonian website, https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification says it was once thought that ocean acidification might be a good thing because it leaves less CO_2 in the air. But in the past decade, we've realized that this has come at the cost of changing the ocean's chemistry. Also, scientists once assumed that rivers carried enough dissolved chemicals from rocks to the ocean to keep the ocean's pH stable (called "buffering.") But so much CO_2 is dissolving into the ocean that this natural buffering hasn't been able to keep up.

Scientists have been tracking ocean pH for more than 30 years, but biological studies really only started in 2003. Some organisms will survive or even thrive under more acidic conditions while others will struggle to adapt, or go extinct. Field studies are difficult because of other changes, like warming.

Living things can be very sensitive to small changes in pH. In humans, for example, normal blood pH is about 7.4. A drop in blood pH of 0.2-0.3 can cause seizures, comas, and even death. A small change in the pH of seawater can also impact communication, reproduction, and growth of marine life. The pH of the ocean fluctuates somewhat as a result of natural processes, and ocean organisms are able to survive these normal changes, but not the rapid recent changes. During the last great acidification event 55 million years ago, there were mass extinctions in some species including deep sea invertebrates. The rise in seawater acidity of 25 percent that we already have is already affecting some ocean organisms.

Oysters, Mussels, Urchins And Starfish - Generally, shelled animals, including mussels, clams, urchins and starfish, are going to have trouble building their shells in more acidic water. Mussels and oysters are expected to grow less shell by 25 percent and 10 percent respectively by the end of the century. Oyster larvae will fail to even begin growing their shells. Urchin and starfish shells dissolve even more quickly than corals.

A Yale report, "Northwest Oyster Die-offs Show Ocean Acidification Has Arrived," by Elizabeth Grossman, 11/21/11 (https://e360.yale.edu/features/northwest_oyster_die-offs_show_ocean_acidification_has_arrived) says that In Netarts Bay in Oregon, from 2006 to 2008, oyster larvae began dying, with losses of 70 to 80 percent. Burke Hales, from Oregon State University, determined that the cause was acidic seawater. Because of patterns of ocean circulation, colder, more acidic waters stream ashore in the fjords, bays, and estuaries of Oregon, Washington, and British Columbia. The corrosive waters prevented oyster larvae from forming shells. Oysters elsewhere in the Pacific Northwest have also experienced reproductive failure. Some of the largest operations are now buffering the water in which they grow their larvae, giving their tanks a dose of antacid in the form of sodium bicarbonate.

Problems with ocean acidification are also starting to be seen on the U.S.'s Atlantic coast. Agricultural runoff and sewage already take a toll on the once-thriving oyster business in the Chesapeake Bay, and now rising ocean acidity is further exacerbating the problems. However, studies have found that, for some reason, crustaceans such as lobsters, crabs, and shrimp grow even stronger shells under higher acidity.

Zooplankton - Many species of zooplankton (tiny drifting animals) build shells, such as these sea butterflies in the Arctic. They are small, but almost all larger life eats zooplankton or other animals that eat zooplankton. These tiny organisms reproduce so quickly that they may be able to adapt to acidity better than slow-reproducing animals, but experiments have found that some of their shells do dissolve rapidly in acidic conditions.

Plants and Algae - Plants and many algae may thrive with acidic conditions. Seagrasses are nurseries for many larger fish, and can be home to thousands of different organisms. Unfortunately, they are in decline for a number of other reasons, especially pollution flowing into coastal seawater. It's unlikely that a boost in acidification will compensate entirely for that.

One major group of phytoplankton (single celled algae) grows shells. Early studies found that their shells weakened with increased acidity. But a longer-term study let them reproduce for 700 generations (taking about 12 months) in the warmer and more acidic conditions expected to become reality in 100 years, and they were able to adapt, growing strong shells.

Fish and Jellyfish - While fish don't have shells, acidification changes the pH of the fish's blood (acidosis). A small change in pH can make a huge difference in survival by affecting its catching and digestion of food, its growth, its avoidance of predators, and its reproduction. Clownfish can normally hear and avoid predators, but in more acidic water, they do not flee threatening noise. They also stray farther from home and have trouble getting back.

One big unknown is whether acidification will affect jellyfish. They compete with fish and other predators for food. If jellyfish thrive under warm and more acidic conditions while most other organisms suffer, it’s possible that jellies will dominate in some places, a problem already seen in parts of the ocean.

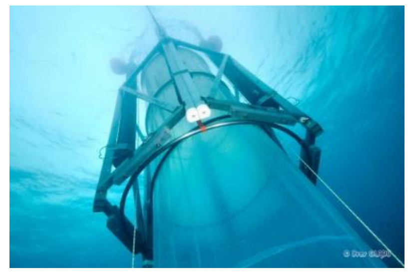
Coral Reefs - Acidification corrodes existing coral skeletons as well as slows the growth of new ones. A recent study predicts that by roughly 2080 ocean conditions will be so acidic that even otherwise healthy coral reefs will be eroding more quickly than they can rebuild. Acidification also impacts coral animals, but at this point only a few coral species have been studied.

Studying Acidification - Geologists study the potential effects of acidification by digging into Earth’s past when ocean CO_2 and temperature were similar to conditions found today. One way is to study cores, soil and rock samples taken from deep in the Earth’s crust, with layers that go back 65 million years. The chemical composition of fossils in cores from the deep ocean show that it’s been 35 million years since the Earth last experienced today’s high levels of atmospheric CO_2. But to predict what might happen by the end of the century, geologists have to look back another 20 million years. Some 55.8 million years ago, massive amounts of CO_2 were released into the atmosphere, and temperatures rose by about 9°F. We don’t know why, but, like today, the pH of the deep ocean dropped quickly, and so much of the shelled sea life disappeared that the sediment changed from primarily white calcium carbonate “chalk” to red-brown mud. Today, CO_2 levels are rising even faster than then.

Another way to study acidification is to perform controlled laboratory experiments, but other stressors such as warming and pollution have to be considered. Short-term studies might not uncover the potential for some species to adapt to decreasing ocean pH. For example, in one test, a deepwater coral showed a significant decline in its ability to maintain its skeleton during the first week of exposure to decreased pH, but after six months, the coral had adjusted and returned to a normal growth rate.

This photo shows CO_2 bubbles from volcanic vents in the reef off the coast of Papua New Guinea. One effect of these CO_2 seeps_ was that large boulder corals replaced complex branching forms and, in some places, the corals disappeared entirely.

There are places scattered throughout the ocean where CO_2-rich water from vents like these lower the pH in surrounding waters. Scientists study these for clues as to what an acidified ocean will look like. Researchers working off the Italian coast compared the ability of 79 species of bottom-dwelling invertebrates to settle in areas at different distances from CO_2 vents. For most species, including worms, mollusks, and crustaceans, the closer to the vent, the fewer individuals were able to colonize or survive. Reef-building corals, snails, barnacles, sea urchins, and coralline algae were absent or much less abundant in the acidified water, which was dominated by dense stands of sea grass and brown algae.



This photo shows a test tube that is 60-feet deep and holds almost 15,000 gallons of water. Extra CO_2 can be added, making the water inside more acidic. Studies with these "mesocosms" can include many other effects beyond acidification, such as warming, pollution, and overfishing. Scientists from five European countries built ten of these and placed them in a Swedish fjord. After letting plankton and other tiny organisms drift or swim in, they sealed the test tubes and decreased the pH to 7.8, the expected acidity for 2100, in half of them to see if and how the organisms adapt. They have not yet completed the experiment, but, if successful, it can be repeated in different ocean areas around the world.

Chesapeake Bay - "Growing acidification of the Chesapeake Bay threatens crabs, oysters, other life," by Scott Dance, Baltimore Sun, Oct. 5, 2017 reports that, during recent summers, researchers aboard a University of Delaware research vessel collected water samples from the mouth of the Susquehanna River to Solomons Island in order to find out when and where the waters of the Chesapeake Bay were turning most acidic. One finding was that acidification is likely to come faster to the Bay than to our oceans. Researchers are beginning to realize that acidification will compound the ecological challenges already affecting the bay.

Experiments are showing that blue crabs, marsh grasses and algae could theoretically thrive in the conditions expected to develop over the next century. But the acidification is a threat to other bay species, such as oysters, which are a key source of food for crabs. Scientists say acidification could dramatically alter the delicate balances in the bay ecosystem. With so many things affecting bay creatures (acidity, warming, pollution), research is complicated.

The University of Delaware research found a zone of increasing acidity at depths of about 30 to 50 feet across the Bay. While surface waters hover around the pH norm of 8.2, the deeper waters registered almost one point lower (10 times more acidic). The researchers believe it's not only the global effects of CO_2 emissions, but also the dead zones of low or no oxygen that are created when nitrogen and phosphorus runoff from farms and lawns, and fertilize large algae blooms. Microbes strip oxygen from the water when they die and decompose, and release more CO_2 in the process. When the water is already stripped of oxygen, and organic matter decomposes, the bacteria use up other compounds in the water which produce hydrogen sulfide, which makes the muck in the bay smell like rotten eggs.

Others are testing what could happen to the Bay's crabs and oysters. For her dissertation, UMCES doctoral candidate Hillary Glandon exposed blue crabs to both warmer and more acidic waters and found that acidification alone didn't affect them, but when coupled with warmer waters, crabs grew faster, and ate more food. While crabs could thrive in warmer and more acidic water, the oysters and mussels they eat could be struggling.

Looking to the Future - When CO_2 in the atmosphere passed 400 parts per million (ppm) in 2015**,** it became higher than at any time in the last one million years (maybe even 25 million years). The "safe" level is around 350 ppm, a milestone we passed in 1988. Without ocean absorption, atmospheric CO_2 would be closer to 475 ppm. The most realistic way to lower this number or to keep it from getting astronomically higher would be to reduce our carbon emissions by burning less fossil fuels and finding more carbon sinks, such as growing mangroves, seagrasses, and marshes. If we did this, it would still take over hundreds of thousands of years for CO_2 in the atmosphere and ocean to stabilize again. Even if we stopped emitting all carbon right now, ocean acidification would not end immediately because there would be a lag before we see the effects. The climate would continue to change, the atmosphere would continue to warm and the ocean would continue to acidify. The main effect of increasing CO_2 that weighs on people's minds is global warming. Some proposals suggest we reflect sunlight back into space from the atmosphere. However, this solution does not remove CO_2 from the atmosphere, or keep it from dissolving into the ocean.