CARBON DIOXIDE AND OUR OCEAN LEGACY

By Richard A. Feely, Christopher L. Sabine, and Victoria J. Fabry

Global warming is increasing ocean temperatures and raising sea levels. New scientific research shows that ***our oceans are beginning to face yet another threat due to global warming-related emissions – their basic chemistry is changing because of the uptake of carbon dioxide released by human activities***.

When carbon dioxide is absorbed by the oceans it reacts with seawater to form carbonic acid. Ocean acidification, as the phenomenon is called, over time will create major negative impacts on corals and other marine life, with anticipated adverse consequences for fishing, tourism, and related economies.

Ocean acidification and climate change are both effects of excessive carbon dumping into the atmosphere. While climate change encompasses the varied impacts resulting from the greenhouse effect, ocean acidification is a straightforward chemical response to carbon dioxide emissions, and is measured and predicted with a high degree of certainty.

Over the past 200 years the oceans have absorbed 525 billion tons of carbon dioxide from the atmosphere, or nearly half of the fossil fuel carbon emissions over this period. This natural process of absorption has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and thus minimizing some impacts of global warming. However, the ocean's daily uptake of 22 million tons of carbon dioxide is starting to take its toll on the chemistry of seawater.

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About the Authors

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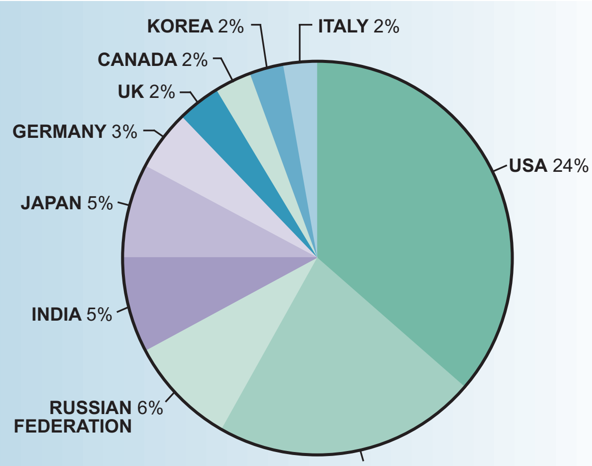
Carbon Dioxide: Our Role

The United States is the single largest contributor to global warming, responsible for nearly one-quarter of all human-made emissions. Every day the average American adds about 118 pounds of carbon dioxide to the atmosphere, due largely to energy-consuming activities that burn fossil fuels. On a yearly basis, the average American produces 22 tons of carbon dioxide, more than six times as much as the average person living outside of the United States. Together, Americans produced 6.5 billion of the 27.7 billion tons of carbon dioxide generated in 2003, and these numbers are growing every year.[3]

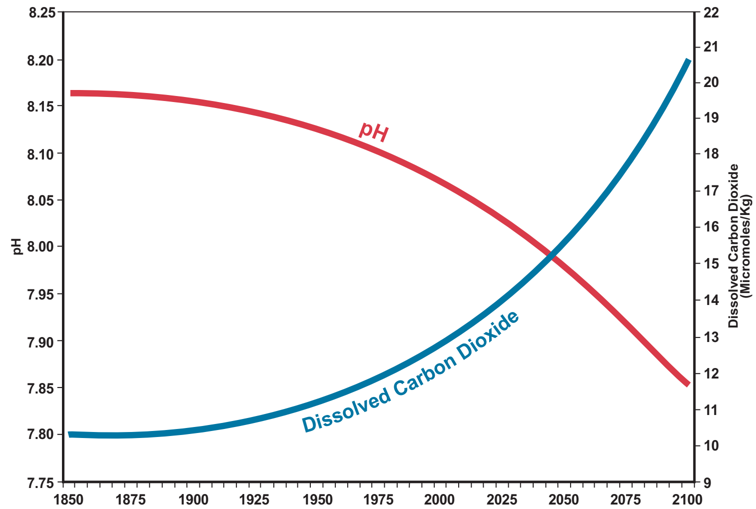


TOP 10 EMITTERS. SOURCE: U.S. DOE 2002

Changing Chemistry – Changing Oceans

Carbon dioxide does not sit idly in the oceans. Recent field and laboratory studies reveal that the chemical changes in seawater resulting from the absorption of carbon dioxide are lowering seawater pH. *(See box below.)* The pH decline then decreases the availability of chemical building blocks needed by organisms that produce shells and skeletons made of a mineral called calcium carbonate. Corals, as well as some free-floating plants and animals at the bottom of the food chain, have a more difficult time producing their shells, with potential consequences for other sea life that depend on the health and availability of these shelled organisms.

Historical & Projected pH & Dissolved CO_2



As the ocean concentration of carbon dioxide increases, so does acidity (causing pH to decline).

At present, ocean chemistry is changing at least 100 times more rapidly than it has changed during the 650,000 years preceding our industrial era. And, ***if current carbon dioxide emission trends continue, computer models show that the ocean will continue to undergo acidification, to an extent and at rates that have not occurred for tens of millions of years.***

Nearly all marine life forms that build calcium carbonate shells and skeletons studied by scientists thus far have shown deterioration due to increasing carbon dioxide levels in seawater, and the resulting decline in pH. In experiments, when dissolved carbon dioxide was increased to two times pre-industrial levels (i.e., before the 1850s), the shell and skeleton-building rate of organisms studied declined by as much as 50%.

For example, increasing ocean acidification has been shown to significantly reduce the ability of reef-building corals to produce their skeletons, affecting growth of individual corals and making

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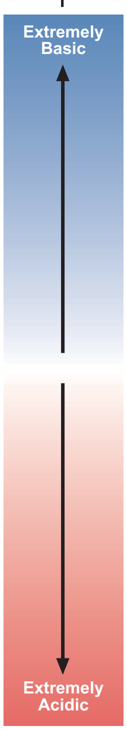
What is pH?



pH	
14	Sodium Hydroxide
13	Oven Cleaner
12	Household Bleach
11	Household Ammonia
10	Milk of Magnesia
9	Baking Soda
*8.16	SEA WATER (Historical)
7	Pure Water, Blood
6	Milk
5	Black Coffee
4	Wine, Tomatoes
3	Beer, Vinegar
2	Lemon Juice
1	Hydrochloric Acid
0	Battery Acid

pH is a measure of acidity. On the pH scale, 7.0 is neutral, with points higher on the scale being "basic" and points lower being "acidic."

The pH of our ocean surface waters has already fallen by about 0.1 units from about 8.16 to 8.05 since the beginning of the Industrial Revolution around 200 years ago,[4] and it may fall by as much as 0.4 units by 2100.[5]

The oceans have not seen a change in pH this abrupt and large for at least 650,000 years, and many sea creatures require stable conditions to survive.

Reefs at Risk

Healthy coral reefs are the foundation of many viable fisheries, as well as the source of jobs and businesses related to tourism and recreation. Approximately half of all federally managed fisheries depend on coral reefs and related habitats for a portion of their life cycles, and the National Marine Fisheries Service estimates the value of coral reefs to U.S. fish stocks at over $100 million.[7]

Local economies also receive billions of dollars from reef tourism. In the Florida Keys, for example, coral reefs generate more than $1.2 billion in tourism revenue annually. In Hawaii, reef-related tourism and fishing generate $360 million per year, and their overall worth has been estimated at close to $10 billion. Worldwide, coral reefs sustain a local tourism economy – including diving tours, recreational fishing trips, hotel and restaurant sales, and other related businesses – that makes up 10 percent of all jobs.[8] Plus, coral reefs provide vital protection to coastal areas that are vulnerable to storms and tidal surges.

At present, ocean chemistry is changing more rapidly than it has over the past 650,000 years.

the reef more vulnerable to erosion. ***By the middle of this century, coral reefs may well erode faster than they can be rebuilt.***[6] Lab results indicate that coral reefs cannot easily adapt to this changing seawater chemistry. While long-term consequences are unknown, this could affect the geographic range of corals and the life forms that depend on the reef habitat.

Cracks in the Food Chain

One type of free-swimming creature called a pteropod *(see photo below left)*, a small snail with a calcium carbonate shell, is eaten by animals ranging from tiny krill to giant whales. Pteropods can be an important food source for juvenile North Pacific salmon, and are also eaten by mackerel, herring, and cod.

Scientists believe that under conditions of increased ocean acidification the weakened pteropod shells will compromise the health and success of these organisms, which could allow competing species to take over. This could mean ***substantial changes in the biodiversity of our oceans***, though more research is needed to identify large-scale ecosystem impacts. Other species – like snails, sea urchins, starfish, lobster, and bivalves such as oysters, clams, mussels, and scallops – also construct their shells or skeletons in the same way and could be jeopardized.

Furthermore, it is suspected that higher marine life forms, including even some fish, may be affected by declining pH through a process called ***acidosis***, or carbonic acid buildup in body fluids. Acidosis can lead to lowered immune response, metabolic decline, and reproductive or respiratory difficulties.[9] Combined with coral and other ecosystem impacts, acidosis could spell trouble for fishing and tourism-dependent economies and communities.

One region of special concern is the northern Pacific Ocean, including the Bering Sea between Alaska and Russia. The climate and ecosystem of the region have changed dramatically over the last 50 years, representing a transition from primarily cold and icy Arctic ecosystems earlier in the 20th century to warmer, sub-Arctic conditions today. Already vulnerable, the region – holding one-half of all U.S. fish and shellfish landings – is expected to be impacted most immediately by our changing ocean chemistry.

Fish – It's What's For Dinner

Any threat to marine ecosystems, such as ocean acidification, will reverberate through our economy and food supply. The United States is the third largest seafood consumer in the world. Americans ate a record of nearly 17 pounds of seafood per person in 2004, while total consumer spending for fish and shellfish topped $62 billion. In that year alone, coastal and marine commercial fishing generated $32 billion for the economy and employed over 67,000 people.[10]

Where Do We Go From Here?

The impacts of ocean acidification on shelled organisms and other animals could negatively affect marine food webs, and, when combined with other climatic changes, could substantially alter the number, variety, and health of ocean wildlife. As humans continue to send more and more carbon dioxide into the oceans, the impacts on marine ecosystems will be direct and profound.

Today's carbon dioxide emissions will continue to affect global ocean chemistry for many hundreds of years to come, but a significant effort to curb our emissions will help slow the rate of change, allowing ecosystems a better chance to adapt and decreasing our ultimate negative impact on the environment. While our understanding of how the web of sea life will respond to ocean acidification is still in its early stages, initial findings from studying ocean chemistry show cause for great concern. ***The message is clear: excessive carbon dioxide poses a threat to the health of our oceans.***

Summary Points

- Human activities are changing the ocean's chemistry at a significant rate.
- The pH changes are predicted with a high degree of certainty.
- These changes have a negative impact on corals and other sea life, especially at the base of the food chain, with potential adverse economic consequences.
- Curbing carbon dioxide emissions will help slow the rate of change, reduce the human impact on the environment, and allow ecosystems a better chance to adapt.

ENDNOTES

1 Organizational affiliation is provided for reference only. The findings and conclusions in this science brief are those of the authors and do not necessarily represent the views of the National Oceanic and Atmospheric Administration or the California State University.

2 This brief is adapted largely from Feely et al. (2004), Sabine et al. (2004), and Orr et al. (2005). Feely, R.A., C.L. Sabine, K. Lee, W. Berelson, J. Kleypas, V.J. Fabry, and F.J. Millero (2004): Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. Science, 305(5682), 362-366.

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3 EIA, U.S. DOE (December 2005). Emissions of Greenhouse Gases in the United States 2004, Washington, D.C.

4 The Royal Society (2005). Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide, The Clyvedon Press Ltd., Cardiff, UK.

5 IOCCP. Please see http://ioc.unesco.org/ioccp/ $HighCO_2$ /$HighCO_2$ world.htm.

6 Hood, Maria (October-November 2004). A carbon sink that can no longer cope? A World of Science, 2(4), 2-5.

7 NOAA Coral Reef Conservation Program. Please see http://www.coralreef.noaa.gov/outreach/protect supp_ income.html.

8 *Ibid*.

9 Hood, Maria, *op. cit.* (2004).

10 NOAA Fisheries Office of Science and Technology. Please see http://www.st.nmfs.gov/st1/fus/fus04/ index.html.

www.cleartheair.org

www.oceanlegacy.org

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