METABOLIC RIFTS

Triple Crisis in the Anthropocene Ocean.

Part One: Corrosive Seas

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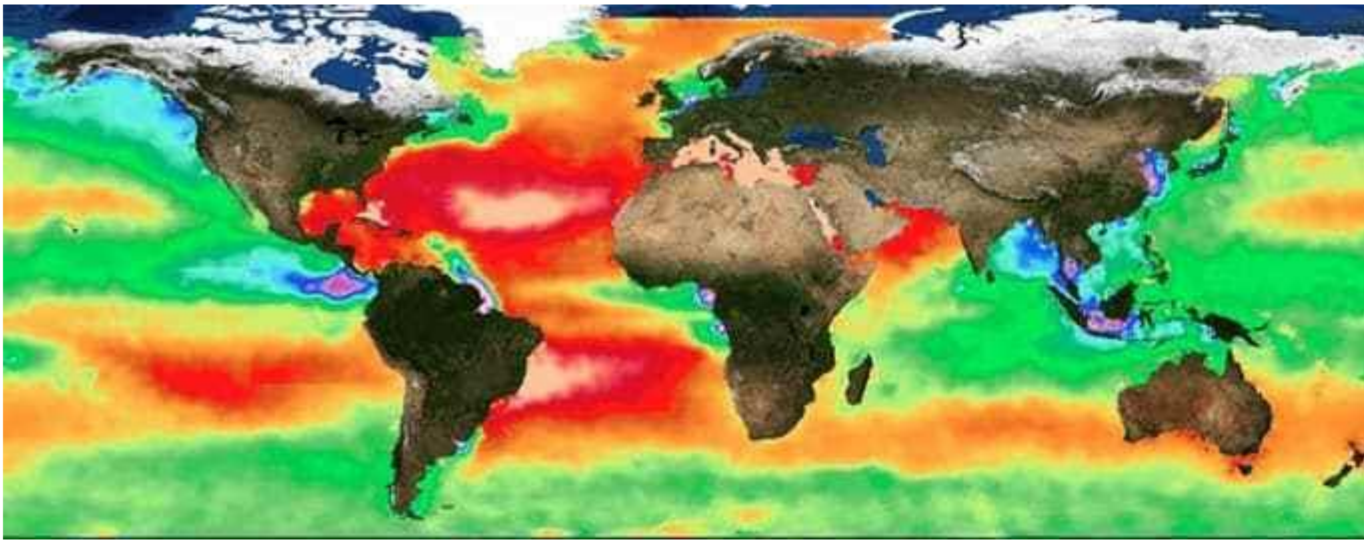
Scientists call them a 'deadly trio.' If acidification, oxygen loss, and overheating are not ended soon, a massive die-off of ocean life may be unstoppable.



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by Ian Angus

Introduction. It is impossible to overstate the importance of the ocean to life on Earth. Covering 71% of the planet's surface, it contains 97% of the world's surface water and is central to the great biogeochemical cycles that define the biosphere and make life possible. Marine plants generate half of the world's breathable oxygen.

Millions of species of animals live in the ocean. Seafood is a primary source of protein for three billion people, and hundreds of millions work in the fishing industry.

The ocean's metabolism — the constant flows and exchanges of energy and matter that have continued for hundreds of millions of years — is a vital part of the Earth System. As famed oceanographer Sylvia Earle writes, our fate and the ocean's are inextricably intertwined.

"Our lives depend on the living ocean — not just the rocks and water, but stable, resilient, diverse living systems that hold the world on a steady course favorable to humankind."[1]

"The *living ocean* drives planetary chemistry, governs climate and weather, and otherwise provides the cornerstone of the life-support system for all creatures on our planet, from deep-sea starfish to desert sagebrush. … If the sea is sick, we'll feel it. If it dies, we die. Our future and the state of the oceans are one."[2]

The living ocean is now being disrupted on a massive scale. It has changed before, but never, since an asteroid killed the dinosaurs, as rapidly as today. The changes are major elements of the planetary transition out of the conditions that have prevailed since the last ice age ended, towards a profoundly different biosphere — from the Holocene to the Anthropocene.

"We are entering an unknown territory of marine ecosystem change … the implications for the ocean, and thus for all humans, are huge."[3]

Most popular accounts of the relationship between the ocean and climate change focus on melting ice and rising sea levels, and indeed those are critical issues. Greenland alone loses over 280 billion metric tons of ice a year, enough to cause measurable changes in the strength of the island's gravity. At present rates, by 2100 the combination of global glacial melting and thermal water expansion will flood coastal areas where over 630 million people live today. Well over a billion people live in areas that will be hit by storm surges made bigger and more destructive by warmer seawater. Rapid action to slash greenhouse gas emissions would be fully justified even if rising seas were the only expected result of global warming.

Devastating as sea level rise will be, however, more serious long-term damage to the Earth System is being driven by what biogeochemist Nicolas Gruber calls a "triple whammy" of stresses on the oceans, caused by the growing rift in Earth's carbon metabolism.

"In the coming decades and centuries, the ocean's biogeochemical cycles and ecosystems will become increasingly stressed by at least three independent factors. Rising temperatures, ocean acidification and ocean deoxygenation will cause substantial changes in the physical, chemical and biological environment, which will then affect the ocean's biogeochemical cycles and ecosystems in ways that we are only beginning to fathom. …

"Ocean warming, acidification and deoxygenation are virtually irreversible on the human time scale. This is because the primary driver for all three stressors, i.e. the emission of CO_2 into the atmosphere, will cause global changes that will be with us for many hundreds, if not thousands, of years."[4]
Other marine ecologists have described ocean warming, acidification and oxygen loss as a "deadly trio," because when they have occurred together in the past, mass extinctions of animal and plant life have followed.[5]
We will consider the elements of the deadly trio separately, but it is important to bear in mind that they are closely related, have the same causes, and frequently reinforce each other.

Part One:
CORROSIVE SEAS

"Ocean acidification … is a slow but accelerating impact that will overshadow all the oil spills that have ever occurred put together." —Sylvia Earle[6]

Ocean acidification has been called global warming's equally evil twin. Both are caused by the radical increase in atmospheric CO_2, and both are undermining Earth's life support systems.
There is always a constant interchange of gas molecules across the air-sea interface, between atmosphere and ocean. CO_2 from the air dissolves in the water; CO_2 from the water bubbles into the air. Until recently, the two flows were roughly balanced: the amount of carbon dioxide in each element has not changed much for hundreds of thousands of years. But now, when atmospheric CO_2 has risen 50%, the flow is out of balance. More carbon dioxide is entering the sea than leaving it.
That's been good news for the climate. The ocean has absorbed about 25% of anthropogenic CO_2 emissions and over 90% of the additional solar heat,

half of that since 1997. If it hadn't done so, global warming would already have reached catastrophic levels. As Rachel Carson wrote years ago, "for the globe as a whole, the ocean is the great regulator, the great stabilizer of temperatures…. Without the ocean, our world would be visited by unthinkably harsh extremes of temperature."[7]

But there is a price to be paid for that service. Adding CO_2 is changing the ocean's chemistry. The formula is very simple:

$$\mathbf{H_2O + CO_2 \rightarrow H_2CO_3}$$

Water plus carbon dioxide makes carbonic acid.

Adding CO2 makes seawater more acidic.

Over the past century, the ocean's pH level has fallen from 8.2 to 8.1. That doesn't sound like much, but the pH scale is logarithmic, so a drop of 0.1 means that *the oceans are now about 30% more acidic than they used to be*.[8] That's a global average — the top 250 meters or so are generally more acidic than the deeps, and acidification is more severe in high latitudes, because CO_2 dissolves more easily in colder water.

The present rate of acidification is a hundred times faster than any natural change in at least 55 million years. If it continues, ocean acidity will reach three times the pre-industrial level by the end of this century.

Impact

Surprisingly, given that scientific concern about CO_2 emissions started in the 1950s, little attention was paid to ocean acidification until recently. It was first named and described in a brief article in *Nature* in September 2003, and first discussed in detail in a 2005 Royal Society report that concluded acidification would soon go "beyond the range of current natural variability and probably to a level not experienced for at least hundreds of thousands of years and possibly much longer."[9]

Those wake-up calls triggered the launch of hundreds of research projects seeking to quantify acidification more precisely, and to determine its effects. While there are still big gaps in scientific knowledge, there is now no doubt that ocean acidification is a major threat to the stability of the Earth System, one that is pushing towards a sixth mass extinction of life on our planet.[10]

Though formally correct, the word "acidification" is misleading, since the oceans are actually slightly alkaline, and the shift now underway only makes them a little less so. Even in the most extreme scenario, a thousand liters of seawater would still contain less carbonic acid than a small glass of cola.

However, just as raising the atmospheric concentration of carbon dioxide to 0.041 percent is causing global climate change, so a small increase in the amount of CO_2 in seawater poses major threats to the organisms that live in that water. Reduced pH has already significantly changed the habitats that marine plants and animals depend on: a further reduction could be deadly for many of them.

The most-studied casualties of ocean acidification are *calcifiers*, the many organisms that take carbonate from the surrounding water to build their shells and skeletons. In seawater, carbonic acid quickly combines with available carbonate, making it unavailable for shell and skeleton building. Water with less than a certain concentration of carbonate becomes corrosive, and existing shells and skeletons start to dissolve.

As marine conservation biologist Callum Roberts writes, lower pH is already weakening coral reefs, and the problem will get much worse if CO_2 emissions aren't radically reduced soon.

"The skeletons of corals on Australia's Great Barrier Reef have weakened measurably in the last twenty-five years and now contain 14 percent less carbonate by volume than they did before.… Ocean acidification has been dubbed 'osteoporosis for reefs' because of this skeletal weakening. …

"If carbon dioxide in the atmosphere doubles from its current level, all of the world's coral reefs will shift from a state of construction to erosion. They will literally begin to crumble and dissolve, as erosion and dissolution of carbonates outpaces deposition. What is most worrying is that this level of carbon dioxide will be reached by 2100 under a *low*-emission scenario of the Intergovernmental Panel on Climate Change."[11]

About 25% of all fish depend on coral reefs for food and shelter from predators, so the shift that Roberts describes would be disastrous for marine biodiversity.

Other calcifiers weakened by ocean acidification include oysters, mussels, crabs, and starfish. Of particular concern are tiny shelled animals near the bottom of the food chain: if their numbers decline, many fish and marine mammals will starve. In particular:

- Single-celled *Foraminifera* are abundant in all parts of the ocean, and are directly or indirectly consumed by a wide variety of animals. A recent study compared present day foraminifera with samples collected 150 years ago in the Pacific by the famous *Challenger* expedition. The researchers found that "without exception, all modern foraminifera specimens had measurably thinner shells than their historical counterparts." In some types of foraminifera, shell thickness is now 76% less than in the 1800s.[12]
- Pea-sized *Pteropods*, sometimes called sea butterflies, live mainly in cold water. An article in the journal *Nature Geoscience* reports "severe levels of shell dissolution" in live pteropods captured in the ocean near Antarctica, resulting in "increased vulnerability to predation and infection."[13] Since pteropods are food for just about every larger marine animal from krill to whales, "their loss would have tremendous consequences for polar marine ecosystems."[14]

Interference with shell and skeleton formation may not be the most deadly effect of ocean acidification. The metabolic systems of all organisms function best when the pH level of their internal fluids stays within a narrow range. This is particularly problematic for marine animals, including fish, whose blood pH tends to match the surrounding water. For some species, even a small reduction in blood pH can cause severe health and reproduction problems, even death.[15] A growing body of research suggests that ocean acidification alone will decimate some species of fish in this century, causing the collapse of major fisheries.[16]

Only long-term studies can determine exactly how acidification will affect global fish populations, but waiting for certainty is dangerous, because once acidification occurs, we are stuck with it. A recent study confirmed that "once the ocean is severely affected by high CO_2, it is virtually impossible to undo these alterations on a human-generation timescale." Even if some unknown (and probably impossible) geoengineering system rapidly returns atmospheric CO_2 to the pre-industrial level, "a substantial legacy of anthropogenic CO_2 emissions would persist in the oceans far into the future."[17]

Warnings ignored

In 2008, 155 scientists from 26 countries signed a declaration "based on irrefutable scientific findings" about "recent, rapid changes in ocean chemistry and their potential, within decades, to severely affect marine organisms, food webs, biodiversity, and fisheries."

“To avoid severe and widespread damages, all of which are ultimately driven by increasing concentrations of atmospheric carbon dioxide (CO_2), we call for policymakers to act quickly to incorporate these concerns into plans to stabilize atmospheric CO_2 at a safe level to avoid not only dangerous climate change but also dangerous ocean acidification. …

“Policymakers need to realize that ocean acidification is not a peripheral issue. It is *the other CO_2 problem* that must be grappled with alongside climate change. Reining in this double threat, caused by our dependence on fossil fuels, is the challenge of the century. …”[18]

In 2009, twenty-nine leading Earth System scientists identified the level of ocean acidification as one of nine Planetary Boundaries — “non-negotiable planetary preconditions that humanity needs to respect in order to avoid the risk of deleterious or even catastrophic environmental change at continental to global scales.”[19]

In 2013, the always-cautious Intergovernmental Panel on Climate Change (IPCC) expressed *high confidence* that absorption of carbon dioxide is “fundamentally changing ocean carbonate chemistry in all ocean sub-regions, particularly at high latitudes.”

“Warming temperatures, and declining pH and carbonate ion concentrations, represent risks to the productivity of fisheries and aquaculture, and the security of regional livelihoods given the direct and indirect effects of these variables on physiological processes (e.g., skeleton formation, gas exchange, reproduction, growth, and neural function) and ecosystem processes (e.g., primary productivity, reef building and erosion).”[20]

The IPCC’s *Special Report on the Ocean and Cryosphere*, published in 2019, concludes that “the ocean is continuing to acidify in response to ongoing ocean carbon uptake,” that “it is very likely that over 95% of the near surface open ocean has already been affected,” and that “the survival of some keystone ecosystems (e.g., coral reefs) are at risk.”[21]

Despite overwhelming scientific evidence that acidification is a major threat to the world’s largest ecosystem, the governments of the world’s richest countries remain silent. The word *oceans* only appeared once in their Paris Agreement and *acidification* wasn’t mentioned at all. It remains to be seen whether the next UN Climate Change Conference, which has been postponed to December 2021, will respond appropriately — if it responds at all.

Part Two of "Triple Crisis in the Anthropocene Ocean," will be published in mid-September.
This article continues my series on metabolic rifts. As always, I welcome your comments, corrections and constructive criticism.—IA

Notes

[1] Sylvia A. Earle, *The World Is Blue: How Our Fate and the Oceans Are One* (Washington, DC: National Geographic, 2010), 20.

[2] Sylvia A. Earle, *Sea Change: A Message of the Oceans* (New York: Ballantine Books, 1995), xii.

[3] Jelle Bijma et al., "Summary of 'Climate Change and the Oceans.'"

[4] Nicolas Gruber, "Warming Up, Turning Sour, Losing Breath: Ocean Biogeochemistry Under Global Change," *Philosophical Transactions of the Royal Society A,* May 2011, 1980, 1992.

[5] Jelle D. Bijma et al., "Climate Change and the Oceans — What Does the Future Hold?" *Marine Pollution Bulletin* Sept., 2013.

[6] Interviewed in John Collins Rudolf, "Q. and A.: For Oceans, Another Big Headache." *New York Times,* May 5, 2010.

[7] Rachel L. Carson, *The Sea Around Us* (New York: Oxford University Press, 2018 [1950]), 163-4.

[8] More precisely, there are 30% more hydrogen (H+) ions.

[9] Ken Caldeira and Michael E. Wickett, "Anthropogenic Carbon and Ocean pH," *Nature*, Sept. 25, 2003, 365; Royal Society, *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide* (London: Royal Society, 2005), 39.

[10] Some argue that a mass extinction has already begun.

[11] Callum Roberts, *The Ocean of Life: The Fate of Man and the Sea* (New York: Penguin, 2013), 108,110.

[12] Lyndsey Fox et al., "Quantifying the Effect of Anthropogenic Climate Change on Calcifying Plankton," *Scientific Reports*, January 31, 2020.

[13] N. Bednaršek et al., "Extensive Dissolution of Live Pteropods in the Southern Ocean," *Nature Geoscience*, (December 2012) 881, 883.

[14] Matthias Hofmann and Hans Joachim Schellnhuber, "Ocean Acidification: A Millennial Challenge," *Energy & Environmental Science* (September 2010), 1888-89

[15] This is also true of humans. Our normal blood pH is 7.4: a drop of 0.2 can be fatal.

[16] See, for example, Martin C. Hänsel et al., "Ocean Warming and Acidification May Drag down the Commercial Arctic Cod Fishery by 2100," *PLOS ONE*, April 22, 2020. For a summary of research on biological and other effects of ocean acidification, see *An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity*, published by the Secretariat of the Convention on Biological Diversity.
[17] Sabine Mathesius et al., "Long-term Response of Oceans to CO2 Removal from the Atmosphere," *Nature Climate Change*, December 03, 2015, 1107-14.
[18] "Monaco Declaration," proceedings of Second International Symposium on the Ocean in a High-CO2 World (Unesco, 2008).
[19] Johan Rockström et al., "Planetary Boundaries: Exploring the Safe Operating Space for Humanity," *Ecology and Society* 14, no. 2 (2009)
[20] Ove Hoegh-Guldberg et al., "The Ocean," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. (Cambridge University Press, 2014), 1658.
[21] IPCC, *Special Report on the Ocean and Cryosphere in a Changing Climate* (2019), 59, 66.