Ocean Acidification

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http://ccdatacenter.org/documents/ OceanAcidification.pdf

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The oceans have absorbed about 30 percent of the CO_2 emitted from all human activities (about 530 GTCO2 from 1750-2005), and this has increased the oceans' acidity about 30 percent[1,2].

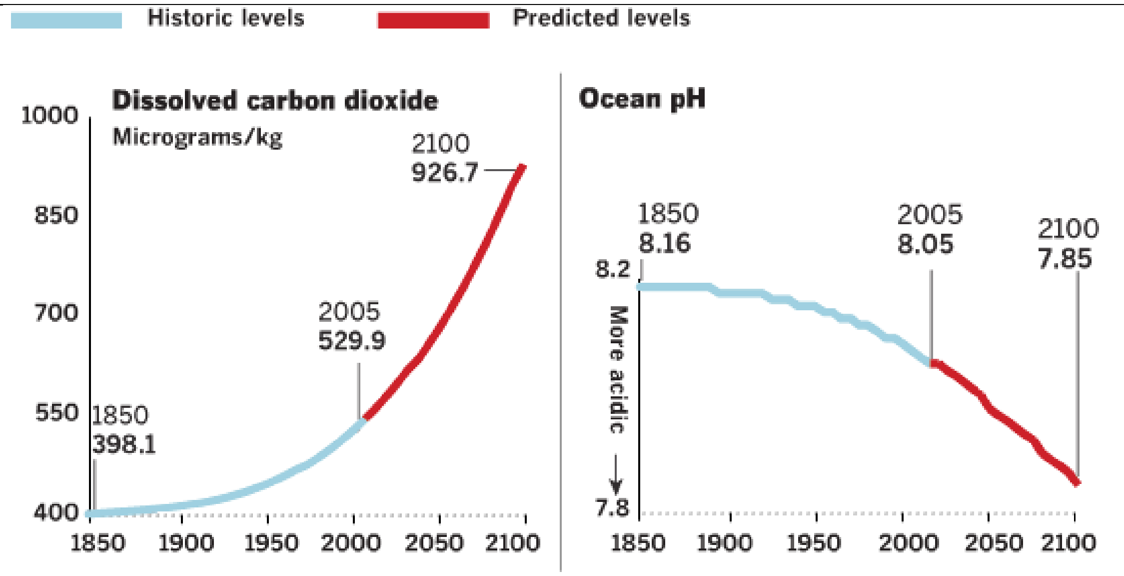
Because of increased ocean acidification, new shells end up being thinner and more fragile while existing shells become pitted and weak[1].

If CO_2 emissions continue at the current rate the ocean pH will likely drop another 0.3 to 0.4 pH units by2100, which would kill off most corals and shell fish[3].

For the Southern Ocean, the acidification tipping point is about 450-ppm atmospheric CO_2, which will be reached in less than 20 years at the current rate of increase (2.11PPM/Year from 2005-2015, while there was a 3% increase from 2015 to 2016)[3].

By 2050, live corals could become rare in tropical and sub-tropical reefs due to the combined effects of warmer water and increased ocean acidity[4].

OA1	**Effects of Changing the Carbon Cycle** About 30 percent of the carbon dioxide that people have put into the atmosphere has diffused into the ocean through the direct chemical exchange. Dissolving carbon dioxide in the ocean creates carbonic acid, which increases the acidity of the water. Or rather, a slightly alkaline ocean becomes a little less alkaline. Since 1750, the pH of the ocean’s surface has dropped by 0.1, a 30 percent change in acidity. Ocean acidification affects marine organisms in two ways. First, carbonic acid reacts with carbonate ions in the water to form bicarbonate. However, those same carbonate ions are what shell-building animals like coral need to create calcium carbonate shells. With less carbonate available, the animals need to expend more energy to build their shells. As a result, the shells end up being thinner and more fragile. Second, the more acidic water is, the better it dissolves calcium carbonate. In the long run, this reaction will allow the ocean to soak up excess carbon dioxide because more acidic water will dissolve more rock, release more carbonate ions, and increase the ocean’s capacity to absorb carbon dioxide. In the meantime, though, more acidic water will dissolve the carbonate shells of marine organisms, making them pitted and weak. Warmer oceans—a product of the greenhouse effect—could also decrease the abundance of phytoplankton, which grow better in cool, nutrient-rich waters. This could limit the ocean’s ability to take carbon from the atmosphere through the fast carbon cycle. On the other hand, carbon dioxide is essential for plant and phytoplankton growth. An increase in carbon dioxide could increase growth by fertilizing those few species of phytoplankton and ocean plants (like sea grasses) that take carbon dioxide directly from the water. However, most species are not helped by the increased availability of carbon dioxide. https://earthobservatory.nasa.gov/Features/CarbonCycle/page5.php

OA2	 Note: 100 micrograms represents a 10,000th of one gram for each thousand grams of seawater. Based on "Ocean acidification due to atmospheric carbon dioxode, Altered Oceans: A Chemical Imbalance". See also "Ocean acidification due to increasing atmospheric carbon dioxide" (http://www.us-ocb.org/publications/Royal_Soc_OA.pdf)
OA3	If CO2 emissions continue at the current rate the ocean pH will likely drop another 0.3 to 0.4 pH units by2100, which would kill off most corals and shell fish. For the Southern Ocean, the acidification tipping point is about 450-ppm atmospheric CO2 (http://www.pnas.org/content/105/48/18860.long) , which will be reached in less than 20 years at the current rate of increase (2.11PPM/Year). Ocean Acidification will almost certainly be catastrophic (or at least very bad) based on any reasonable CO2 emissions mitigation scenario
OA4	**Plants, Animals, and Ecosystems** By 2050, live corals could become rare in tropical and sub-tropical reefs due to the combined effects of warmer water and increased ocean acidity caused by more carbon dioxide in the atmosphere. The loss of coral reefs will reduce habitats for many other sea creatures, and it will disrupt the food web that connects all the living things in the ocean. https://www3.epa.gov/climatechange//kids/impacts/effects/ecosystems.html
	Ocean acidification will likely have severe impacts before 2050
	FAQs about Ocean Acidification Thus, a 2°C increase in temperature results in about a 10% decrease in carbon uptake in surface waters. marine shellfish that have evolved in seawater with a higher and less variable pH are more susceptible to changes in pH Will ocean acidification kill all ocean life? No. However, many scientists think that ocean acidification will lead to important changes in marine ecosystems. In general, ocean life recovers from extinction episodes by adaptation and evolution of new species, but this takes roughly 10 million years to achieve pre-extinction levels of biodiversity.

	Today's rates of CO_2increase in the atmosphere are therefore approximately 100 times greater than most changes sustained over geologic time. It is within our technical and economic means to modify our energy and transportation systems and land-use practices to largely eliminate carbon dioxide emissions from our economies by mid-century. It is thought that the cost of doing this — perhaps 2% of the worldwide economic production — would be small, yet at present it has proven difficult for societies to decide to undertake this conversion. — Ken Caldeira, Senior Scientist, Carnegie Institution for Science, USA http://www.whoi.edu/page.do?pid=83380&tid=7342&cid=131410

	The Ocean Is Acidifying The ocean absorbs about 30 percent of the CO_2 emitted from human activities. When the ocean absorbs CO_2, it converts the gas into carbonic acid. Until the Industrial Revolution, there wasn't enough carbonic acid in the water to unbalance the ecosystem. But after more than a century of unchecked carbon emissions, the ecosystem has been measurably upended. The pH level of surface waters has dropped from 8.18 to 8.07, an unprecedented shift in the last 300 million years of the fossil record. [a change of 0.11 in pH corresponds to an increase of about 30% in the hydrogen ion concentration. - https://www.pmel.noaa.gov/co2/story/A+primer+on+pH)] it means less calcium carbonate. This mineral is a key ingredient in the shells of several marine species, and without it, fewer shellfish are surviving to adulthood. One oyster farm in Washington state reported that their oyster production declined by 42 percent in just 10 years. The tiny shellfish that feed Alaska's salmon stocks are also in danger, to say nothing of the state's lucrative crab fishery. Carbonic acid not only dissolves calcium carbonate, it also dissolves limestone, which makes it more difficult for coral to grow. Combine that with the reduction of pteropods and other zooplankton at the bottom of the food chain and the impacts to marine life are potentially catastrophic. Life above sea level will also be impacted. Investigations of carbon upwelling zones along the West Coast suggest that lower pH levels make it more difficult for certain phytoplankton to absorb nutrients, rendering them vulnerable to disease and toxins. And that's a problem, because healthy phytoplankton produce about 60 percent of the oxygen on Earth. Like the disappearance of microscopic pteropods, losing coral has a major ripple effect across the marine food chain. Though they cover less than one percent of the ocean floor, coral reefs support a quarter of all marine life. https://www.huffingtonpost.com/pierce-nahigyan/ocean-acidification-is-ba_b_8952240.html
	Ocean Acidification Assuming a "business-as-usual" IPCC CO_2emission scenario, predictive models of ocean biogeochemistry project that surface waters of the Arctic and Southern Oceans will become undersaturated with aragonite (a more soluble form of calcium carbonate) within a few decades, meaning that these waters will become highly corrosive to the shells and skeletons of aragonite-producing marine calcifiers like planktonic marine snails known as pteropods. http://www.whoi.edu/ocean-acidification/

Ocean pH vs Atmospheric CO2 PPM

	Pre-industrial	Today	2 × pre-industrial	3 × pre-industrial	4 × pre-industrial	5 × pre-industrial	6 × pre-industrial
Atmospheric concentration of CO_2	280 ppm	380 ppm	560 ppm	840 ppm	1120 ppm	1400 ppm	1680 ppm
H_2CO_3 (mol/kg)	9	13	19	28	38	47	56
HCO_3^- (mol/kg)	1768	1867	1976	2070	2123	2160	2183
CO_3^{2-} (mol/kg)	225	185	141	103	81	67	57
Total dissolved inorganic carbon (mol/kg)	2003	2065	2136	2201	2242	2272	2296
Average pH of surface oceans	8.18	8.07	7.92	7.77	7.65	7.56	7.49
Calcite saturation	5.3	4.4	3.3	2.4	1.9	1.6	1.3
Aragonite saturation	3.4	2.8	2.1	1.6	1.2	1.0	0.9

Table 1. Changes to ocean chemistry and pH estimated using the OCMIP3 models calculated from surface ocean measurements and our understanding of ocean chemistry. Note that the concentration of bicarbonate ion (HCO3 –) and carbonic acid (H2CO3) increase with rising atmospheric concentration of CO2 while carbonate ion (CO3 2–) decreases. The average pH of the surface ocean waters decreases with increasing atmospheric CO2 concentration. (Assumptions used in model: Total alkalinity = 2324 mol/kg, temperature = 18° C. All other assumptions as per OCMIP3 (Institut Pierre Simon Laplace 2005). Aragonite and calcite saturation calculated as per Mucci & Morse (1990). Physical oceanographic modelling is based on Bryan (1969) and Cox (1984).

If CO2 emissions continue on current trends, this could result in the average pH of the surface oceans decreasing by 0.5 units below the level in pre-industrial times, by 2100. This is beyond the range of natural variability and represents a level probably not experienced for at least hundreds of thousands of years and possibly much longer (Caldeira & Wickett 2003). Critically, the rate of change is also at least 100 times higher than the maximum rate observed during this time period. These changes are so rapid that they will significantly reduce the buffering capacity of the natural processes that have moderated changes in ocean chemistry over most of geological time.

Royal Society - http://www.us-ocb.org/publications/Royal_Soc_OA.pdf

Good source for ocean acidification information: http://news-oceanacidification-icc.org/