Why are scientists talking about ocean acidification?

beaches without seashells, crabs without protection, and coral without color.

An Exploratory Essay on the Scientific Writing Process

Ocean acidification is one of those buzz words that people tend to associate with climate change, global warming, and (supposedly) our imminent doom. The definition of the term “ocean acidification” is seemingly straightforward: The pH of the ocean decreases. In order to actually grasp the implications of this, though, it is essential to understand what pH is and the role that it plays in chemistry. pH is a shorthand for “potential of hydrogen,” and it determines how much of a chemical constituent can be dissolved in the water and how much can be used by aquatic organisms (Water Science School 2019). It is a scale ranging from 0 to 14: a pH from 0-6 is acidic and a pH from 8-14 is basic. 7 is neutral — what we would consider to be “pure water.”

The ocean’s “potential of hydrogen” is heavily impacted by CO_2 emissions. Although the chemical changing of the ocean’s pH might not seem like a top priority when added to an already long list of problems created by the industrial revolution, its impacts are felt by marine life across the world’s oceans. The ocean absorbs around 30% of all of the CO_2 released into the atmosphere (“What Is Ocean Acidification?” 2012). In other words, the ocean plays a large part in sequestering carbon dioxide. As atmospheric CO_2 increases, so too does the amount of CO_2 that the ocean will absorb.

Although I am eager to connect how exactly CO_2 emissions affect the pH of the ocean, I have decided that first it is helpful to understand the chemical processes that occur between the seawater in the ocean and the carbon dioxide in the air. Displaying the chemical equations now will be a helpful reference for later when I discuss how and why atmospheric CO_2 impacts the ability of organisms to make calcium carbonate shells and skeletons. CO_2 is absorbed by the ocean through two mechanisms: photosynthesis by phytoplankton and chemistry (Riebeek [date unknown]). When CO_2 comes in contact with seawater, they react to form carbonic acid: $CO_2 + H_2O \longleftrightarrow H_2CO_3$ (Mitchell et al. 2009). The carbonic acid that is formed then dissociates to create a hydrogen ion and bicarbonate: $H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$ (Mitchell et al. 2009). Finally, bicarbonate is able to further dissociate into more hydrogen and carbonate: $HCO_3^- \longleftrightarrow H^+ + CO_3^{2-}$ (Mitchell et al. 2009). By transforming carbon dioxide into other chemical compounds, the CO_2 is trapped for a long period of time within the ocean, enabling the seawater to be a carbon sink. Most CO_2 is converted into bicarbonate, which accounts for about 92% of the carbon dioxide in the ocean (Webb [date unknown]).

In each of these reactions, the arrows are pointing in both directions. This is because these reactions help regulate the ocean's pH and can occur in either direction. If the pH rises, the chemical compound, bicarbonate, will dissolve into carbonate and release H^+ ions to help lower the pH (Webb [date unknown]). However, if the ocean's pH lowers, both bicarbonate and carbonate will react with H^+ ions to produce more carbonic acids and bicarbonate in order to lessen the amount of H^+ ions in the water. Therefore, increased CO_2 emissions result in a decrease in the ocean's pH because more hydrogen ions are created in the chemical reactions that result from the seawater absorbing carbon dioxide (Webb [date unknown]). Since a decrease in pH corresponds with an increase in acidity, CO_2 emissions cause the ocean to become more acidic — hence the term "ocean acidification."

While one source of carbonate in the ocean is the absorption of carbon dioxide and, ultimately, the dissociation of bicarbonate, another source is the limestone and other rocks. Thus, deeper waters are rich with carbonate that has dissolved into the water from the seafloor (Webb [date unknown]). Beyond being important for pH regulation, carbonate is also essential for some aquatic life. Carbonate ions react with calcium cations in the water to form calcium carbonate: $Ca^{2+} + CO_3^{2-} \longleftrightarrow CaCO_3$ (Mitchell et al. 2009). Calcium carbonate is used by many marine organisms to create their shells and skeletons. Ocean acidification threatens any species that rely on calcium carbonate because the chemical compound dissolves at lower pH levels. Further, a lower pH also means that there are fewer carbonate ions in the water because, as previously stated, carbonate will combine with H^+ ions to form bicarbonate in order to help raise the pH (Webb [date unknown]). This means that the shells and skeletons created by marine organisms not only start to dissolve in water with a lower pH, but there is also less carbonate available for these organisms to use to form their shells and skeletons in the first place.

After elaborating upon the chemical compounds and delving into calcium carbonate, I determined that there was one more important piece of information necessary to comprehending how ocean acidification generally works: ocean currents. There is constantly an exchange of gases, water, and heat happening between the ocean and the atmosphere ("Marine Currents, the Regulators of the Climate" 2023). Marine currents then distribute these throughout the world's oceans. The cold waters of high latitudes primarily absorb the CO_2 that is then carried towards the seafloor ("What Is Ocean Acidification?" 2012). At the equator, the ocean absorbs solar energy to warm the water and uses evaporation to lower its temperature — water has a high thermal inertia, so the oceans store a lot of heat and take a while to adjust their temperature

(“Marine Currents, the Regulators of the Climate” 2023). As currents push water between the equator and the polar zones, heat from the tropics helps to warm the polar regions (“Marine Currents, the Regulators of the Climate” 2023). Meanwhile, the cold and salty water of the poles is dense and sinks to the bottom. Eventually these cold waters move towards the equator, become warmer, and rise to the surface. Furthermore, upwelling of these waters “restocks the carbonate” in the shallower water (Webb [date unknown]), which also aids in the regulation of the ocean’s pH. This general understanding of how temperature and salinity impact the movement of water is all that is necessary to inform how CO_2 is moved through the ocean. Although I could go into greater detail about the different streams and currents that have been identified and named, I do not think that it will impact how well ocean acidification is understood. I wanted to discuss currents briefly in order to provide some background about what impacts how ocean water moves between different depths and regions, since that will be affected by the continued increase in CO_2 emissions.

Now that I have addressed the key scientific terms, processes, and chemical compounds that are involved in ocean acidification, I will switch my focus to the effects that acidification has on marine life and their ecosystems. I decided to make this switch because learning about ocean acidification felt incomplete if I did not also have an in-depth understanding of its impacts. Similarly, I did light research into the causes of acidification, but ultimately they are simply anything that causes CO_2 to be emitted into the atmosphere, furthering the heating of the planet. Since there was not a more niche or specific reason for ocean acidification, I determined that my research would be better spent on the explicit impacts of acidification.

As mentioned before, many plants and animals rely on carbonate to build their shells and skeletons. These "calcifying organisms" are facing "decreased carbonate availability and increased acidity" ("Effects of Ocean and Coastal Acidification on Marine Life" 2023). Organisms, such as soft-bodied mollusks, snails, calms, and oysters, require a shell for survival — it is their protection from predators. At this point in the research process, I contemplated whether or not to include an explanation of how calcium carbonate forms their shells. I decided that, since I had already delved into how calcium carbonate is created, it would be interesting to also understand how it is used by marine life. However, I was wary to not go into too much detail — I wanted the description to be thorough but easily comprehensible: The outermost layer of tissue of mollusks is called the mantle. Specialized cells in the mantle secrete proteins and minerals into the space outside of the cells. The proteins provide structural support to grow the shell and then calcium carbonate fills in the space around the proteins ("How Are Seashells Made?" 2022). Calcium carbonate then forms crystals called calcite and aragonite to make the shell. The shell has different layers that occur as it is created, and the animal adds to the outer edges of its shell as it grows so that the shell can be altered to fit the organism ("How Are Seashells Made?" 2022). Eventually, when the animal dies, its shell begins to drift in the currents, likely to be ultimately broken down against the rocks and eroded by the water.

Corals are another species that are hugely impacted by ocean acidification. While coral polyps are animals, they often are participating in a mutualistic relationship with zooxanthellae, specialized algal cells that live within the coral. In this relationship, the zooxanthellae take in the carbon dioxide and water that is produced by the coral polyps to carry out photosynthesis ("Polyps Up Close" 2013). The products of this, sugars, lipids, and oxygen, are then used by the coral to grow and continue cellular respiration. Thus, the productivity of coral reefs is heavily reliant on the "tight recycling of products between the polyp cells and the zooxanthellae" ("Polyps Up Close" 2013). However, if the coral becomes stressed, due to warmer temperatures for example, the polyps may expel the zooxanthellae in an attempt to survive ("Coral Bleaching and Ocean Acidification…" 2011). When the coral is struggling to sustain its own life, it will no longer be able to also help sustain the zooxanthellae. Yet, in order for the coral to survive long-term, it requires the mutual benefit that the zooxanthellae provides. When the algae leaves the coral, the polyps turn white — hence the term "coral bleaching" — because the algae give coral their color ("Coral Bleaching and Ocean Acidification…" 2011). Furthermore, coral reefs also require calcium carbonate to grow, so the chemical compound must be supplied "at a rate that is faster than the reef is being eroded" ("Coral Bleaching and Ocean Acidification…" 2011). Since ocean acidification impacts carbonate availability, it decreases the growth rate of coral reefs.

Calcifying organisms are not the only marine life threatened by ocean acidification — it also harms various species of larvae. For example, sea urchin and oyster larvae will not develop properly in an environment with increased acidity; similarly, fish larvae may lose their ability to smell and avoid predation ("Effects of Ocean and Coastal Acidification on Marine Life" 2023). If fish larvae are killed off by acidification, less fish offspring will reach adulthood and be able to reproduce ("Effects of Ocean and Coastal Acidification on Marine Life" 2023). This could cause a positive feedback loop that may result in the extinction of numerous fish species overtime. The Industrial Revolution and high gas emissions may have triggered the start of a feedback loop in which no one wins. If fish larvae do not reach adulthood due to greater acidity, then less fish will be able to reproduce. Then, the more that CO_2 is emitted, the fewer individuals with access to food, especially in coastal communities.

Finally, theories and predictions began to materialize through my searches to answer the following question: If the pH continues to decrease, what impacts will be seen first? Before industrialization, the CO_2 concentration in the ocean was 280 parts per million (ppm). Now, the concentration is nearing 400 ppm and its growth rate is only accelerating. Scientists predict that CO_2 levels could reach 500 ppm by 2050 and even 800 ppm by the end of the century ("Ocean Acidification" 2019). This data represents the cause of ocean acidification: As the ocean struggles to exponentially increase its CO_2 absorption, it is experiencing a severe decrease in pH. Over the last century, pH has declined from 8.2 to 8.1 which represents a 30% increase in acidity (Webb [date unknown]).

Similarly to everything else in ecology, from every cause there is a domino effect of results. In other words, when one species is directly impacted by ocean acidification, numerous other species across the food web will also be affected indirectly — including humans.

As the atmosphere continues to change, polar ice will melt. Thus, the salinity of the ocean water will decrease, while the temperature simultaneously increases. These two factors play large roles in dictating the density of water, which is what causes ocean currents. If water density begins to change, ocean currents may also change, resulting first and foremost in an increase in severe storms (Riebeek [date unknown]). The ocean will take in carbon dioxide until global warming slows down ocean circulation so much so that the ocean is forced to slow its carbon uptake

(Riebeek [date unknown]). This is yet another example of a feedback loop: As CO_2 emissions increase, warming increases, which will cause slower currents, the ocean will take up less CO_2, which will leave more CO_2 in the atmosphere, resulting in more warming.

If ocean acidification continues due to global warming, many ecosystem services that humans rely on will be destroyed. Coral reefs, for example, provide multiple services that our infrastructure and livelihoods depend upon. From giving habitats and nurseries to the fish that we need for food to providing storm protection and medicine, the reef ecosystem provides society with more than just eco-tourism.

Through the course of writing this essay, I went down multiple rabbit holes, but I now understand ocean acidification at a chemical level. I could explain in-depth the role that ocean currents play in dictating the temperature and salinity of the ocean. I learned about what exactly pH is and how it impacts marine life. I uncovered multiple positive feedback loops that our environment is currently trapped within. Finally, I inquired about what this means for our future only to learn about the negative effects that acidification will have on all life, unless we urgently create policies to stop CO_2 emissions.

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