Ecological effects of ocean acidification

by Lennart Nyman

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Introduction

Oceans cover some 71% of the Earth´s surface. Their importance for all life on Earth is vast. Oceans also play a major role in global climate dynamics. Oceans absorb some 93% of the heat accumulated in the atmosphere, which warms the oceans and directly and indirectly affects all global ecosystems, including the human one, in many ways. In addition to these natural temporal and spatial changes, man-made increases of the carbon dioxide levels (CO_2) in the atmosphere, mainly from burning of fossil fuels like oil, coal and gas, have caused an increase in ocean water acidification (Watson et al. 2009). By absorbing CO_2 the ocean is becoming more acidic, and this happens at a rate faster than during any other period in the past 300 million years (Wynne, 2012). Sea surface water has acidified by almost 30% since year 1900. Increased temperatures and acidification will amplify the impacts on biodiversity at large, overfishing, pollution and habitat destruction. Evaluating the scale of these threats it is suggested that ocean acidification is a driver for substantial change in ocean ecosystems potentially leading to long-term shifts in species composition (Wittmann, A.C and H-O Pörtner, 2013).

It has been estimated that from the start of the industrial era the ocean has absorbed some 525 billion tons of CO_2 from the atmosphere, currently some 22 million tons per day (The Ocean Portal Team, 2016).

Thus, increases in carbon dioxide in the atmosphere have made the oceans more acidic, thus leading to major shifts in global climate and mass destruction of species. Ocean acidification is a global stressor that constitutes a rapidly emerging problem for marine organisms, ecosystem functioning and services (Vargas et al., 2017). See more details below.

Changes in ocean chemistry

Basically, the issue of ocean chemistry is quite straightforward. Two important things happen when carbon dioxide dissolves in seawater. First, the pH gets lower as it becomes more acidic. Second, this process binds up carbonate ions and makes them less abundant. This process reduces the ability of many aquatic organisms to build their shells and skeletons.

Most life on earth, both terrestrial and aquatic, requires carbon dioxide – plants to grow and animals that exhale it when they breathe. Thanks to our burning of fossil fuels there is now an increasing amount of CO_2 in the atmosphere, and most of the carbon dioxide is retained creating a blanket around the Earth. Because the atmosphere absorbes heat from the sun this leads to increasing temperatures. Some 30% of this CO_2 is dissolved into seawater where chemical changes break down the CO_2 molecules and recombine them. When water and carbon dioxide mix, they form carbonic acid, which is a weak acid, but working like all acids it releases hydrogen ions which bond with other molecules. By definition, seawater containing more hydrogen ions is more acidic, i.e. having a lower pH. pH is the scale used to measure the concentration of H+ ions in a solution.

The lower the pH the more acidic the solution. Below (Fig. 1) the graphs show rising levels of carbon dioxide in the air (based on Keeling, 2017), rising CO_2 levels in the ocean, and decreasing pH in the water off the coast of Hawaii (reviewed by the Ocean Portal Team, 2016).

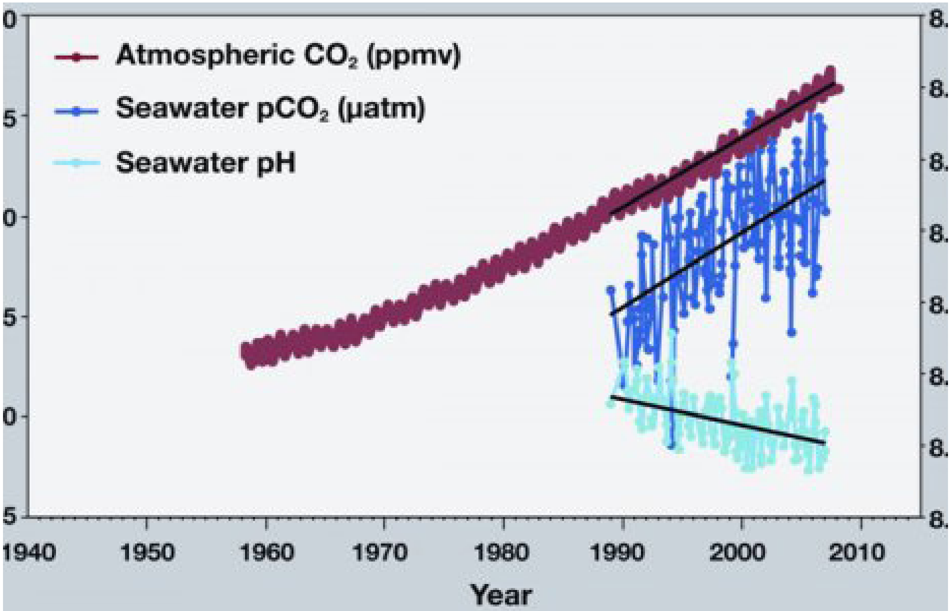

Fig. 1 A More Acidic Ocean. This graph shows the level of carbon dioxide in the air, rising CO_2 levels in the ocean, and decreasing pH in the ocean off the coast of Hawaii (NOAA PMEL Carbon Program, 2017).

So far, ocean pH has dropped from 8.2 to 8.1 (an increase in acidity of some 26%) since the start of the industrial era, and it is expected to fall by another 0.3-0.4 pH units by the end of the 21st century (The Ocean Portal Team, 2016). A drop in pH of 0.1 pH units might not seem so large, but the pH scale is logarithmic. pH 4 is thus 100 times more acidic than pH 6. An increase in emission of carbon dioxide at current rates would, by the end of this century, make the ocean more acidic than it has been during at least the past 20 million years.

Such a quick change in ocean chemistry will not give marine life much time to evolve and adapt. The shells of some animals are already dissolving in the more acidic seawater, and it is expected that acidification will have mostly negative impacts on ocean ecosystems. When two hydrogen ions bond with carbonate they form a bicarbonate ion (2HCO3) (Fig. 2). Shellbuilding organisms cannot extract the carbonate ion they need from bicarbonate, and this prevents them from growing new shells and skeletons. Even though some animals are able to build shells or skeletons in more acidic water they will spend more energy doing so, which will obstruct using resources for other activities like reproduction. This process thus makes carbonate ions less abundant for aquatic organisms that need to build up shells and/or skeletons.

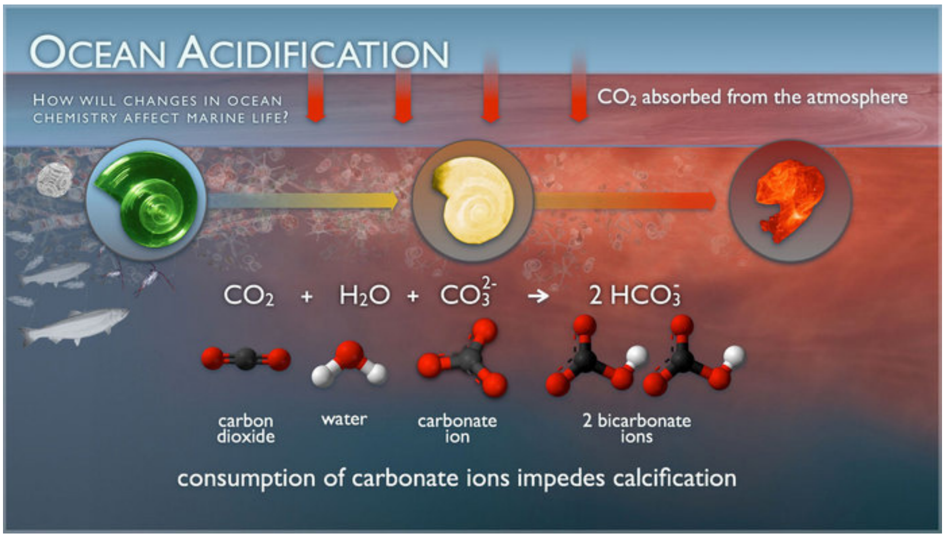

Fig. 2 The chemical pathway to increased ocean acidification. (NOAA PMEL Carbon Program., 2017).

Plants, algae and coral reefs

Many plants and algae may thrive under more acidic conditions. Some species of algae will actually grow better when faced with increasing levels of carbon dioxide, but algae responsible for building coral reefs will fare less well. In acidifying conditions it was found that coralline algae covered 92% less area than normal, making space for non-calcifying algae (Kuffner et al., 2008). Also, acidification may limit coral growth by corroding existing coral skeletons and the weaker reefs that result will be more vulnerable to erosion (Stephens, 2013). However, some species of coral can use bicarbonate instead of carbonate ions to build their skeletons (Graber, 2012). Other species can handle a wide pH range. In the next century some common species of coral will shift, even though we do not know for sure what the change will look like. However, these changes will affect thousands of species that live on the reefs, also in unpredictable ways.

Seagrasses that serve as shallow-water nurseries for many species of fish in coastal ecosystems (Fig. 3) supporting thousands of different species may reproduce better and grow taller under acidic lab conditions (Rosier, 2016). On the other hand this ecosystem is in decline because of e.g. pollution, and it is unlikely that increased acidification will compensate for other stressors.

Fig. 3 A seagrass (Posidonia oceanica) of the Mediterranean protecing fish and other animals (Rosier, G., 2016/ Credit: Marine Photobank).

Effects on zooplankton

Two major types of zooplankton (and shelled phytoplankton like coccolithophores) build shells made of calcium carbonate – foraminifera and pteropods. They are extremely important in marine food webs, as almost all larger marine animals eat these zooplankton directly or indirectly. These zooplankton are also critical to the global carbon cycle, which describes how carbon moves between air, land and sea.

Foraminifera are sensitive to increased acidity, as their shells dissolve, and some species from tropical waters may become extinct by the end of this century.

The same fate seems to affect certain pteropods the shells of which are already starting to dissolve in the Southern Ocean (Fig. 4) (Littschwager, 2016). Like the situation with foraminifera some species may actually become extinct by the end of this century.

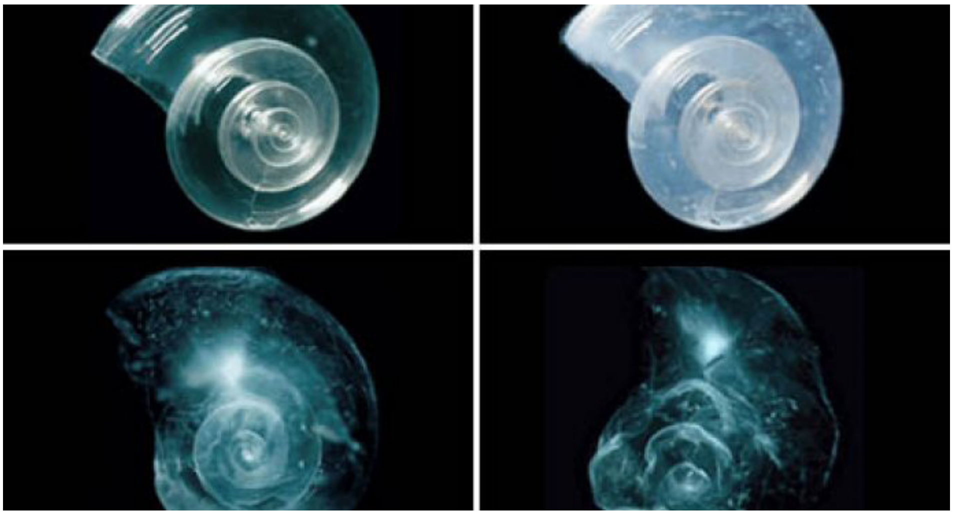

Fig. 4 Dissolution of pteropod shells in seawater with increased acidity over 40 days (Littschwager,

Effects on other benthic shelled organisms

Like corals, numerous benthic shelled animals, like mussels, clams, starfish and urchins may have trouble building shells in more acidic water (Ries, 2010). Some mussel and oyster species will grow less shell, by 25 and 10 percent, respectively, by the end of this century. We know less about the fate of urchins and starfish, but they build their skeletons from a type of calcium carbonate that dissolves even more quickly in acidic water than the type corals use (Mah, 2013). Oyster larvae may fail to grow their shells in more acidic water which has already caused very high death rate in oysters off the Pacific Northwest of U.S.A. (Grossman, 2011).

The problems refered to above are not universal in all benthic invertebrates, however, because species groups like shrimps, crabs and lobsters may grow even stronger shells under higher acidity (Ries, 2010).

Effects on fish

Fish have no shells, but they feel effects of acidification. Although fish are in balance with their environment, when the water surrounding fish have a lower pH, some chemical reactions change the pH of fish blood. This is called acidosis. Even though most marine fish are in harmony with their environment, certain chemical reactions that normally take place in their bodies are altered, and even small changes in pH can make huge difference in survival. In humans a drop in blood pH of 0.2 to 0.3 can even cause death. Likewise, fish are also sensitive to pH and need to burn more energy to put their bodies back to normal. Even a slight change in pH reduces the energy a fish has to digest food, escape predators, reproduce and grow. Clownfish were found to have impaired hearing in water slightly more acidic than normal (Richard, 2011). This can seriously impact survival in the long run because it decreases their ability to react to the presence of prey and predators. More acidic oceans will affect all sea life. Infant sea creatures will be expecially harmed. According to results from the BIOACID Project (see below) the number of young cod growing to adulthood could fall to a quarter or even a 12th of today´s number (Harrabin 2017).

The worst problem for fish in future is however indirect, when ecosystem changes involve availability of prey, and new plankton and benthic organisms may replace those present today with incalculable consequences.

Summary

An acidified ocean will be very different from the present one. Some species will continue to thrive while others will decrease in number and distribution or go extinct. These changes will very likely change ocean food webs, and also decrease biodiversity, and thus make ecosystems less stable. Scientific research must focus not only on direct effects of acidification, but also on global warming, pollution, habitat degradation and overfishing. Field experiments are absolutely necessary, like the present study on Biological Impacts of Ocean Acidification (BIOACID) (www.bioacid.de). Aquiring an evolutionary perspective on how marine life will respond to future global changes will help us identify which conservation efforts will be most needed and most effective (Calosi et al., 2016).

If the present level of carbon dioxide in the atmosphere stabilizes neutralizing will occur eventually, pH will decrease to "normal" conditions. However, pH is now dropping so quickly that buffering will take thousands of years, i.e. too long for the ocean organisms affected now or in the near future to adapt. It can be stated that ocean acidification already has a very serious impact on ocean ecosystems. "If the outlook for marine life was already looking bleak- torrents of plastic that can suffocate and starve fish, overfishing, diverse forms of human pollution that create dead zones, the effects of global warming which is bleaching coral reefs and threatening coldwater species – another threat is quietly adding to the toxic soup" (Harvey 2017).

In 2013 carbon dioxide in the air exceeded 400 parts per million – higher than at any time in the past tens of millions of years (Leen, 2016). A "safe" level of carbon dioxide was set at 350 ppm, a concentration we passed already in 1988 (The Keeling Curve, 2017).

What can we do? In short, cut carbon emissions. Also, create more carbon sinks, like mangroves, seagrass beds, and marshes. Even if we stopped emitting all carbon dioxide right now it would take a long time before ocean acidification came to a halt. The climate will continue to change and the ocean will continue to acidify. Carbon dioxide will remain in the atmosphere for hundreds of years and more acidic waters will carry on mixing with deep water over a cycle of hundreds of years. On a human time scale this may seem like forever, especially if we do not try to stop the emissions right away. Finally, a thought on a video called "New animation of Keeling curve available" - "The Holocene is over. And no we´re not now in the Anthropocene. We are now in the Hellocene: the fires of Hell - of our own creation - be upon us" (Mole, 2017).

The most comprehensive overview of the impacts of ocean acidification on marine biodiversity so far was presented by the secretariat of the Convention on Biological Diversity (CBD) in cooperation with UNEP (CBD and UNEP, 2014). Another and more recent major contribution to our knowledge of the impacts of acidification on ocean life is the termination (?) of the German-led BIOACID Project (Bach et al. 2017), which is based on the synthesis of more than 350 publications by more than 250 scientists. Some important results of the project are:

1. Many organisms are able to withstand ocean acidification, but many lose this ability if also exposed to other stressors such as warming, excess nutrients, loss of oxygen, reduced salinity or pollution.
2. Even small alterations at the base of the food web can have knock-on effects for higher trophic levels.
3. Marine life is able to adapt to ocean change through evolution and can partly compensate for negative effects. But, since ocean acidification happens extremely fast compared to natural processes, only organisms with short generation times, such as microorganisms, are able to keep up.
4. Climate change alters the availability of prey for fish and as a consequence may affect their growth and reproduction.
5. Ocean acidification and warming reduce the survival rates of early life stages of some fish species. This will likely reduce recruitment of fish stocks and ultimately fisheries yields.
6. The distribution and abundance of fish species will change. This will have a significant impact on economic activities such as small-scale coastal fisheries and tourism.
7. It is crucial to consider ocean acidification and warming in the management of fish stocks and marine areas.
8. Following the precautionary principle is the best way to act when considering potential risks to the environment and humankind, including future generations.

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