Ocean Acidification and the Effects on Aquaculture

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Introduction

From the Industrial Revolution onwards there has been an increase in the amount of carbon dioxide entering the atmosphere. Thirty percent of human-made carbon dioxide is absorbed into the ocean via the process of ocean acidification (OA).[1] This is damaging to the ocean food chain and alters the growth of certain invertebrates and calcifying animals. Ocean acidification negatively alters the ocean food chain by reducing the population of phytoplankton and zooplankton. Forage fish such as anchovies, sardines, and herring feed on phytoplankton and zooplankton and are used in the aquaculture industry to feed larger fish like salmon and tuna. Aquaculture is the harvesting of fish and other marine life for food and other products. Furthermore, when exposed to acidic water calcifying marine animals develop less dense biomineral exoskeletons, have smaller bodies, and fail to form complete shells. Because of this, ocean acidification is expected to damage the shellfish industry. Bivalves such as oysters and clams have been proven to be negatively affected at a young age, making it hard to grow the population. Finally, certain sea animals such as jellyfish are able to adapt and thrive in acidic water. Jellyfish can invade aquaculture farms and kill the inhabitants. Solutions to preventing ocean acidification include: educating consumers to become more knowledgeable on the various methods in which carbon dioxide emissions can be diminished, instituting policies that will call for the reduction of carbon dioxide, and developing new technology to increase the yield of sustainably raised aquaculture.

What is Ocean Acidification?

Ocean acidification (OA) is the change in the ocean chemistry and lowering of pH. This occurs due to the excess anthropogenic (human-made) carbon dioxide (CO_2) being absorbed into the ocean that combines with water molecules to make carbonic acids (H_2CO_3).[2] Carbon dioxide is a colorless and odorless gas.[3] It can be found in nature from plant and animal respiration, volcanic eruptions, forest fires and decomposition of organic matter.[4] However, since the Industrial Revolution anthropogenic carbon dioxide and emissions have been rising.[5] Carbonic acid dissolves into bicarbonate ions (HCO_3-) which results in the release of hydrogen ions. These excess hydrogen ions cause the ocean's pH to decrease which increases its acidity. Water is considered acidic when it has more free hydrogen ions (H+) than hydroxyl ions (OH^-).[6] Since the mid 1700's the ocean's pH value has decreased 0.1 to achieve a new level of 8.1.

Over the next century, however, it is expected to decrease at a rapid rate. By the year 2100 the ocean's pH is expected to decrease to the value of 7.67 due to the massive amounts of deforestation over the past 200 years.[7] There are currently fewer trees than before the Industrial Revolution to absorb the increased carbon dioxide emissions, as open land is being razed to make room for agriculture and new buildings.[2]

Ocean Acidification and the Food Chain

The ocean is expected to become less diverse and the abundance of different species will decline as the waters become more acidic.[8] This will negatively affect the food chain. Phytoplankton are microscopic single-cell plant organisms that convert sunlight and carbon dioxide into food using photosynthesis. They are at the bottom of the food chain and are essential to satiating the ocean, as many species of phytoplankton are consumed by a large number of animals such as krill, fish, and whales.[9] Phytoplankton experience a variety of changes due to OA. According to an analysis conducted by the MIT on many different phytoplankton species, some populations grew slower and disappeared while others experienced great population growth and survived, contributing to the species imbalance.[10] The analysis showed that as the oceans warm, phytoplankton in North Carolina will move to Boston's colder waters.[10] This will only provide temporary relief, however, as cold water has an increased rate of carbon absorption due to the fact that it holds more dissolved gases than warm water.[11] Ultimately, the phytoplankton will experience a similar fate due to OA as in warmer waters.

Similarly, a study performed on the foraminifera species of zooplankton showed that the population decreased significantly in acidic waters. Unlike phytoplankton which are plants, zooplankton are animals and feed on phytoplankton.[12] It is expected that the tropical foraminifera will go extinct as the water becomes more acidic.[13] This is problematic because this organism provides food for a vast amount of other marine life like sand dollars and tropical fish.[14] The variation of marine life will become off-balanced as those who eat the disappearing planktons will have escalated competition for food and resulting population decline.[10] In aquaculture, farm-raised fish, such as salmon and tuna, consume omega-3 fatty-acid packed fish fodder and oils made from forage fish that depend on phytoplankton and zooplankton.[15]

Ocean acidification places larger marine species at risk as well. Arctic cod is essential for supplying food to larger animals on the food chain like whales, seals, and seabirds[16] and

provides food for humans from wild catch and aquaculture.[17] It was observed in a study that the larvae of Arctic cod were twice as likely to die in their first 25 days of life when placed in waters replicating what the ocean's pH is expected to be in the year 2100.[18]

Calcifying Animals

As the ocean becomes acidic there will be more hydrogen ions (H+) present in the water. These excess hydrogen ions bond with carbonate ions (CO^{2-}_3) which diminishes their supply in the ocean. Calcifying animals such as pteropod zooplankton, bivalves (oysters, clams and scallops) and lobsters use carbonate ions to build their calcium carbonate shell. Calcifying animals that do not build their full shell are at a higher risk of being attacked by a predator, experience less reproduction and have increased rate of disease.[19] Studies conducted on pteropods or sea butterflies that have shells that are made of aragonite (a weak calcium carbonate), show that when exposed to acidic waters their shells dissolved significantly.[20]

When exposed to acidic water bivalves develop smaller bodies and brittle shells. Mussels have an organ known as byssal threads that stick to rocks. Healthy mussels can use this sticky organ to keep themselves safe from being pulled by a strong surf. In acidic waters they lose their stickiness and fail to attach to rocks. In aquaculture mussels fail to latch onto the ropes used for harvesting them and cannot be retrieved when they fall to the seafloor. Mussel farmers place a platter below the rope to catch them when their byssal threads do not stick to the line.[21] During an oyster's first 24-48 hours of life they go through a major growth spurt and develop 70% of their aragonite shell. Once the shell is partially generated they can start developing tissue. Analysis on farms in the Pacific Northwest showed that the low amounts of calcium carbonate present in acidic waters made it difficult for oysters to build their shells. Some oyster larvae are failing to build their shells in this stage, resulting in their death and a decrease in the oyster population.[22] The oysters that are successful in have a shell that is brittle and can fracture upon harvesting.[23] Many Americans on the East Coast, West Coast, Alaska and in the South depend on the bivalve aquaculture industry.[24] Additionally, harvesting bivalves provide food and jobs for many people around the world. The demand for bivalves has increased and is expected to continue to increase to feed the growing global population.[25]

Oysters and other bivalves help ocean marine life and the finfish aquaculture industry. They are filter feeders which prevent nitrogen and phosphorus levels from becoming too concentrated.[26] A body of water that is too concentrated in nitrogen and phosphorus is at risk of having toxic

algal blooms. Toxic algal blooms are expected to occur more frequently as the ocean's temperature increases.[27] This is damaging to aquaculture because the blooms deplete the oxygen present in the water by consuming oxygen to grow and killing aquatic plants by blocking sunlight.[28] Wild fish are able to migrate to oxygenated water, however aquaculture-raised inhabitants cannot due to the pens they are kept in, so they ultimately die. Toxic algal blooms can also set forth diseases on farmed fish and shellfish that are transmittable and harmful to humans.[29] In May of 2019 eight million farm-raised salmon in Norway died due to this occurrence.[30] In April of 2020, 10,000 salmon on a farm in Chile also died due to a toxic algal bloom.[31] The aquaculture industry has experienced tremendous losses over the span of many years due to a variety of different species of algal blooms.

Lobsters and the lobster industry are being harmed by ocean acidification. In acidic waters lobsters develop health problems. A study conducted on lobsters shows that organisms living in acidic waters developed a decrease in heart function and fewer infection-fighting cells which increases their risk of mortality.[32] The number of young lobsters is also declining because the zooplankton copepods that lobsters feed on are failing to grow normal-sized bodies in warm waters. Studies show that when lobsters from the Gulf of Maine are exposed to acidic waters, they respirated more and required more energy through food. However, there is less food available so they conserve energy by not reproducing.[33]

In the West Coast the Dungeness crabs' shells are dissolving in acidic water. A study conducted on the crabs noted that the exoskeleton surrounding their body, legs and mechanoreceptors broke down significantly.[34] The dissolution of their shells and mechanoreceptors is leading to a decrease in vital sensory functions which limits mobility, increases their risk of being attacked by a predator and reduces their efficiency when hunting.[35]

Both the Maine lobster and West Coast crab industries are negatively affected by ocean acidification, as each is dependent on the crustaceans for their income. Ocean acidification is expected to damage the shellfish industry by hampering the crustaceans' development and shortening the life expectancy of various calcifying animals.

Resistant Sea Creatures

Jellyfish are predicted to become more dominant as the oceans lower in pH. These tentacled creatures have been discovered living in volcanic seeps in the Mediterranean.[36] Volcanic seeps

have an increased level of carbon dioxide and a low pH due to the CO_2 bubbles they release.[37] The jellyfish do not seem to be impacted by the acidic environment of these volcanic seeps. Furthermore, an experiment was conducted on Australian spotted jellyfish polyps that involved subjecting the polyps to water that had been adjusted to the pH level expected in the year 2100. The results showed that the jellyfish polyps proved to be resistant to the acidic water at that pH level.[38]Jellyfish have swarmed fish farms and killed a significant number of the fish present. At a farm in Northern Ireland in 2007, 100,000 salmon died due to a jellyfish invasion.[39] Seven years later in November 2014 at a farm in North Uist, Scotland, a massive collection of jellyfish killed 300,000 of the salmon occupants.[40]

Ways to reduce carbon dioxide emissions

Ocean acidification is caused in part by the excess carbon dioxide released by human activity. These activities include the burning of fossil fuels for energy, deforestation, car transportation and using heat or air conditioning. The ocean can only absorb a certain amount of carbon dioxide. Scientists fear that as the ocean reaches its absorption limit, more carbon dioxide will enter the atmosphere. The carbon dioxide collects heat from the sun and warms the earth in a process known as the greenhouse gas effect, causing the water's temperature to rise.[7] This event causes problems like rising sea levels, stronger storms, melting sea ice, and more.[41] There are many different actions that can be done to reduce an individual's CO_2 emissions, such as:

- Eating less meat- The meat industry produces carbon dioxide as forests are being cut down and burned to make room for cattle and livestock. Healthy trees absorb carbon dioxide and release oxygen but when they are set ablaze extra CO_2 is released. Brazil is the largest exporter of beef products in the world.[42] The cattle ranching industry is a large component as to why the Amazon rainforest is currently being deforested at an alarming rate.[43]A secondary consequence is that the deforested land needs to be ignited every few years to allow the grass to re-sprout after the nutrition in the soil is depleted by the continuous grazing from cattle.[44]
- Green shopping- for clothing items it is recommended that consumers donate or sell old clothes, purchase second-hand items and avoid buying trendy "fast fashion" products to prevent the vast amount of clothing that ends up in landfills.[45] The clothing and fashion industry produces 10% of the globe's carbon dioxide emissions.[46]
- Unplugging vampire outlets- Another way to reduce carbon emission is to unplug devices that are fully charged or not in use. Energy "vampires" include phone chargers,

electronic hair styling tools like dryers and curling irons, cable boxes, coffee makers and more. These electronics continue to use energy when plugged in even when turned off. By not unplugging these devices an extra 44 million tons of anthropogenic carbon dioxide are emitted per year in the United States.[47] This energy-saving practice will not only save the oceans but it will also save money over a long period of time.[48]

- Using less plastic- According to a study both the production and decomposition of plastics produces excess carbon dioxide. Plastic is made of petroleum which emits carbon dioxide upon extraction, distillation and processing. The incineration and dumping of plastics also releases carbon dioxide. Recycling would lower the carbon dioxide emission but 90.5 percent of the world's plastics are not recycled.[49] Scientists have developed bioplastics made of either sugarcane or corn which are carbon neutral. This is because as the plants grow they absorb CO_2 that will later be released as the plastic decomposes.[50] Not only will this help protect the oceans by reducing carbon emissions resulting in ocean acidification, but also by reducing the amount of plastics that harm fish and other marine creatures.
- Conserving water- Pumping and heating water requires energy. The less water someone uses the less energy needed to retrieve and heat it.[51] There are many ways to lower water usage, from sealing pipes to reducing water use when gardening.

Some of these lifestyle changes might not work for everyone due to economic stability, health and available resources. However, if everyone does what they are able to do to reduce their carbon emissions it will make a big difference. This approach gives everyone power over the future of the ocean.

Engaging with the government

One way to reduce carbon dioxide emissions is to engage with the government to instate policies and laws that promote the protection of the environment. Politicians have created these laws with input from individuals who are passionate about going green. The plastic straw ban movement began when a nine-year old child initiated an anti-straw campaign. Over the course of a few years the movement began to expand and politicians took notice.[52] In 2018 California passed a law that banned the distribution of plastic straws at sit-down restaurants unless requested by the customer.[53] In another instance, in 2008 New York passed a bill that banned large chain stores from keeping their doors open in the summer months after numerous people sent letters to their local councilperson. In 2015 the bill was amended so all stores and

restaurants are required to close their doors when the air conditioning is on.[54] It is estimated that one 10,000 square foot building that keeps its doors open during the summer would release an extra 2.5 tons of carbon dioxide a season.[55] These are examples of a group of people contacting their government officials and encouraging action. It is important for people no matter what age to advocate for change.

Solutions for the Bivalve Industry

Scientists have been selectively breeding bivalves to withstand ocean acidification. As stated bivalves have been annihilated due to the lack of calcium carbonate in the water leaving their shells underdeveloped. This is resulting in a deleterious effect on the oyster population. However, a study from Australia published in 2019 on the estuary-raised Sydney rock oyster proved that it is possible to successfully selectively breed oysters. The oysters were bred to have larger bodies and be resistant to diseases. The oysters that were selectively bred experienced an alteration in their calcite crystal biomineralization and were able to build a stronger and thicker shell.[56] At the University of Washington, researchers have also successfully bred Pacific oysters to be resistant to OA.[57]

Other organizations are inventing creative ways to grow oysters that can withstand the impacts of ocean acidification. One organization collects used oyster shells from restaurants, which are already fully formed, and proceeds to place them in a hatchery with oyster larvae. The goal of this method is for the larvae to attach to a fully developed shell. Once the larvae grow to a certain size in their new shell, they are placed into the oyster reefs in the ocean where they continue to live for the rest of their lives.[58]

Conclusion

Ocean acidification is a threat to marine life and the irreversible damage to the oceans has taken a toll on the aquaculture industry. Scientists have already developed and are continuing to create solutions to promote the longevity of bivalves. Additionally, there are many ways for individuals to prevent further damage by reducing excess carbon dioxide emissions. As these levels are reduced, the worsening effects of ocean acidification will also decline.

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