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How Climate Change Affects Coral Reefs

Climate change is a very real phenomenon that currently affects many of the ecosystems on Earth. Climate change occurs on a global scale and can be very detrimental to different environments. This occurrence can cause ocean warming, sea level rise, ocean acidification, and increased storm intensity. According to the EPA, the ocean's temperature has increased 1.4^{o}F over the past century, and sea levels have risen 3.2 millimeters through the past 20 years.

Humans are a major driver of climate change because of all the emissions that are released through industrial processes, burning fossil fuels, deforestation, and agricultural processes (EPA 2013). The amount of CO_2 and other greenhouse gases in the atmosphere have increased at an unprecedented rate, and the current concentration of CO_2 in the atmosphere is higher than it has been at any point in the past 420,000 years (Ohki et al 2013). The increase of CO_2 in the atmosphere causes an increase of CO_2 in the oceans because the oceans are able to absorb approximately one fourth to one third of the anthropogenic CO_2 from the atmosphere (Maier et al 2013).

These changes to the oceans can greatly affect many of the ecosystems that reside in them. One of the main ecosystems that are being affected by climate change is the coral reef habitat. Coral reefs are very susceptible to shifts in their surroundings so it is important to examine and understand how global climate change will affect these reef systems. With climate change occurring so rapidly due to increased anthropogenic influences, humans must consider how these changes will affect the planet in general and the highly susceptible coral reef ecosystems in particular. Spillman et al (2011) found that due to the increase of carbon dioxide

in the Earth's atmosphere from the combustion of more fossil fuels, both the atmosphere and the oceans are warming and this rise in temperature is negatively affecting the coral reefs.

Coral reefs are some of the most productive and diverse ecosystems in the world. Many types of corals are found in the photic zone of the world's oceans because light is a very important factor in coral growth and survival. These corals have a symbiotic relationship with photosynthetic algae known as zooxanthellae; photosynthetic organisms that live in the walls of the corals. Zooxanthellae give the coral their bright colors. The coral host protects the zooxanthellae and also provides the algae with components they need for photosynthesis. In return, the zooxanthellae provide the corals with oxygen and nutrients from the photosynthesis they perform, and aid in waste removal. This closed relationship allows nutrients to be recycled and creates areas of high productivity in nutrient-poor waters.

Being in such shallow waters exposes the corals to many other factors that could potentially disrupt their habitat. Corals are very sensitive to fluctuations in their environment, so any small change could drastically alter their growth and survival. Increasing ocean temperatures are a major cause of stress to coral reefs. Berkelmans et al (2006) examined the role that zooxanthellae in coral play in thermal tolerance due to rising ocean temperatures. The authors predicted that the amount of tolerance a coral has to increased temperatures is based upon the type of zooxanthellae they possess in their structures. The author's hypothesis turned out to be correct because they found that the "type D" zooxanthellae had more of a tolerance to thermal stresses than corals with "type C" zooxanthellae (Berkelmans et al 2006). If corals do not possess the thermally tolerant "type D" zooxanthellae, then they will be less likely to tolerate thermal stresses. These corals will then become bleached from expelling their zooxanthellae which will lead to their death.

Sammarco and Strychar (2009) also examined how climate change and increasing ocean temperatures affect coral reefs. They found that in the symbiotic relationship between the host coral and zooxanthellae, the zooxanthellae are more susceptible to increasing sea temperatures than the coral species were. When the waters are too warm, the corals will expel their zooxanthellae. Sammarco and Strychar (2009) found that the corals are not dying because the temperature of the water is increasing; they're dying because they are losing their zooxanthellae. Zooxanthellae provide the nutrients and oxygen these corals need to survive, so without their zooxanthellae, the corals won't be able to function properly and will thus die.

Ocean acidification is another major stressor for coral reefs. Climate change is caused by increased carbon dioxide in the atmosphere. The increase of carbon in the atmosphere also causes more carbon dioxide ions to be absorbed into the ocean. More carbon dioxide ions in the ocean cause the pH of the ocean to decrease, making them more acidic. Also, the intake of more CO_2 decreases the oceanic concentration of carbonate. Corals need carbonate to calcify their hard exteriors.

Hoegh-Guldberg (2011) found that the calcifying abilities of corals depend on the concentration of carbonate ions in the water. The lower the concentration of carbonate ions in the water, the less the corals can calcify. Decreased calcification ability in corals causes them to become weak and easily damaged. Cohen and Fine (2012) looked deeper in to the issue of net and gross calcification rates of corals in more acidic conditions in the oceans. They found that after 16 months of incubation under high carbon dioxide concentration, the coral fragments continued to take up calcium and continued to survive. The specific coral Cohen and Fine (2012) studied was *Stylophora pistillata.* Since this coral was able to keep taking up $CaCO_3$, it appears that it has a high tolerance to increasing ocean acidification. The scientists concluded that *S.*

pistillata will be able to acclimate to increasing ocean acidification and maintain relatively normal calcification rates (Cohen, Fine 2012).

Ocean acidification not only impacts adult corals ability to calcify, but also the corals' developmental stages, larval settlement, sexual reproduction, algal symbiosis, metabolism and post-settlement (Albright 2011). Albright found that ocean acidification negatively affected all of these aspects of the corals lifespan. Decreasing pH altered the fertilization success of the corals' gametes and decreased spawning in female corals. More acidic waters also slowed the coral's metabolism. Slower metabolism in fully developed corals could lead to reduced growth, and decreased reproduction potential. In larval coral, slower metabolism affects motility during dispersal and settlement. Ocean acidification also changes the composition of the benthic substrate the coral needs to settle on (Albright 2011). This change affects the coral's ability to settle because the different substrate alters the settling clues the corals need to attach to the surface.

Climate change often increases the intensity of storms. Tropical storms need warm water to pick up their energy. With warmer ocean temperatures brought on by climate change, frequent strong storms and longer storm seasons are very likely (Storm Intensity). Increased storm intensity can cause major physical damage to corals on the coral reefs (Hoegh-Guldberg 2011). Madin et al (2012) specifically studied "the effects of changes in storm intensity and calcification rates on population growth of the ecologically dominant table coral *Acropora hyacinthus*, a pandemic reef-building species on wave-exposed Indo-Pacific reefs." They found that ocean acidification and increased storm intensity would impact the amount of coral cover and the resilience of the *Acropora hyacinthus* coral.

As the Earth's temperatures warm, the glaciers melt in to the ocean and cause global sea level to rise. According to the EPA, sea level has risen 3.2 millimeters over the past 20 years. Significant sea level rise can put the corals in water that is too deep for the sun to adequately reach them. Corals need to be in the photic zone of the ocean, because their symbiotic zooxanthellae need sunlight to drive their photosynthesis to produce nutrients for the corals. If the zooxanthellae cannot get sunlight to photosynthesize, the corals won't get the nutrients they need to survive.

Many scientists are curious as to whether or not corals could actually be resistant to climate change. McClanahan et al (2011) studied coral reef diversity to see if highly diverse reefs were associated with areas that had low to moderate climate stresses. They used a multivariate stress model to determine how much exposure to stress the corals experienced. The researchers also collected field data to determine the diversity of coral and the fish on the reef. Their data was weakly correlated due to the fact that it was hard to verify if the diversity of the reef was related to areas of low climate stress (McClanahan et al 2011).

Discovery Bay, Jamaica is home to a lot of important fringe and patch reefs. Crabbe (2010) looked at the stressors of the corals in Discovery Bay over time to see if the colonies were showing resilience during climate change stressors and anthropogenic stressors such as overfishing and land development. Crabbe measured diversity at five different sited over nine years and found that after a four year period, the coral colonies in the area actually recovered, beginning with many bleached colonies.

The resilience of coral reefs is also dependent on the types of fish that live on the reef. Large herbivorous fish play a large role in keeping the reefs healthy. If these fish were reduced in

population or removed from this ecosystem entirely, then there could potentially be a phase shift from a coral dominated reef to an algal dominated reef (Hughes et al 2007). Without herbivorous fish on the reef, the macroalgae would grow more abundant and would soon come to overrun the reefs. Algal dominated reefs ultimately reduce the corals ability to be resilient to climate change. Local impacts on corals can also affect their resilience (Knowlton 2008). Factors such as resource extraction and poor water quality can lead to disease in corals and overgrowth of algae on the reefs. This shift to an algal dominated reef can affect the trophic structure, and biodiversity of the reef environment.

Humans, however, also play a large role in protecting coral reefs and combating climate change. Improving the water quality around the reefs could decrease the affect climate change has on the ecosystem (Wooldridge and Done 2009). Wooldridge and Done suggested that if the quality of the water that the corals inhabit is improved, then it could in turn increase the resistance the corals have to climate change. Their hypothesis was proven correct because they found that both high nutrients and warmer water temperatures have a negative effect on the resistance of coral reefs.

Since fish are so crucial to the health of the reef, it is important for fishermen to know how their fishing gear affects the reef fish. Cinner et al (2009) examined how each type of fishing gear affected each variety of fish in order to possibly help manage the coral reefs better by restricting the gear that can be used to catch important reef fish. After examining fish caught by many different gear types, the authors found that there were only a small proportion of strong coral associated fish being caught by fisheries. Implementing marine protected areas (MAPs) in the oceans are considered an effective management approach to protecting coral reefs (Keller et

al 2009). Marine protected areas should also be in conjunction with management strategies like fisheries regulations and reduction of pollutants in order to further protect the reefs.

Maynard et al (2009) provided three ways to effectively respond to coral bleaching as a way to ultimately protect the coral reef environment. The responses included giving the public an early warning about the bleaching event, assessing and monitoring the extent of the bleaching, and effectively communicating to the public what is going on with the coral reefs. To make sure that the response plan to coral bleaching is implemented effectively, the coral reef managers must be able to clearly communicate to the public, the stakeholders, and the senior decision makers what needs to be done.

Many scientists have found that climate change negatively affects the health and survival of the coral reefs. Climate change causes the corals to expel their symbiotic zooxanthellae, which, in turn, causes them to become bleached and die. The increased CO_2 in the oceans cause the coral to be unable to calcify, which weakens their structure and makes them more susceptible to breaking in rough waters. Even though climate change has the ability to destroy many coral reef ecosystems, scientists have found that corals are sometimes able to respond to and resist the effects of climate change. Scientists believe that humans need to do something to try to prevent climate change from wiping out our Earth's coral reefs so they will be able to both survive and thrive.

Since human are a major driver of climate change, I think that it is the public's responsibility to try to preserve and protect these coral reef ecosystems. Coral reefs bring in a lot of money to countries that utilize them for tourist purposes. Many small islands and towns, especially in the Caribbean, rely on the tourists to come visit their coral reefs in order to make

their living. If these coral reefs disappear, the tourism of the areas where these reefs are located will decline, and the country will see a detrimental decline to their economy.

Stricter laws and policies need to be implemented to decrease carbon emissions, and ultimately combat global climate change. Carbon taxes are becoming a popular topic in reducing emissions. This tax would make companies pay a certain price for the amount of carbon they emit. The point of these taxes is to try to encourage companies to switch to "greener" sources of energy so they will be producing less carbon dioxide. Unfortunately, legislators are reluctant to pass these taxes because they fear that it would anger the voters since they are already disgruntled about high gas prices (How Carbon Tax Works).

Even though these new policies may be met with resistance from some companies and countries, there are many smaller things people can do to reduce their impact on the environment. I think some of the easiest ways for individuals to reduce their emissions are by being energy efficient; turning off lights when you leave a room, unplugging electronic devices, switching from compact fluorescent light bulbs to LED light bulbs, and buying appliances that are energy efficient.

Humans need to realize that what we do, no matter how big or small, affects this planet that we live on. If we don't start changing the way we are living our lives, we can detrimentally affect the Earth. Global climate change is a real concern for Earth's coral reefs. If humans can work to try to reverse these changes to our environment, then there is a chance that the coral reefs can be saved. If things do not change, however, coral reefs face the serious reality of disappearing altogether.

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