When the Tide is Out and the Ocean is Not Acidic, the Table is Set

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Abstract

In this paper, the issue of climate change causing our oceans to become more acidic is analyzed to show how it can be slowed and how we can adapt shellfish farming methods to counteract lowering pH. Shellfish rely on calcium carbonate ($CaCO_3$) in the surrounding water to precipitate into their shells, but increased carbon dioxide (CO_2) levels have made calcium carbonate less available for these organisms. One way we have found to try and mitigate effects on shellfish is to integrate kelp around shellfish farms. Kelp can be a very useful mitigation tool for ocean acidification because as it photosynthesizes it turns dissolved CO_2 into harmless oxygen, effectively raising the pH around where the kelp is planted. This effect is utilized in modified clam gardens where kelp is grown around a bed of shellfish to provide them with better growth conditions. Integrating these gardens into southeast Alaska could not only have a positive effect on commercial shellfish farms and Alaskan Natives who use shellfish for subsistence, but it could also raise pH in Alaskan waters. Overall, this research emphasizes the need for increased awareness and efforts toward ocean acidification and the effects it has on marine life, especially in vulnerable areas like the Pacific northwest.

Introduction

The Earth's climate has been changing rapidly in recent years due to increased anthropogenic carbon dioxide (CO_2) emissions from fossil fuels (NOAA, 2021). As the CO_2 levels in the atmosphere rise, so does the dissolved CO_2 concentration in oceans (NOAA, 2021). Because of the increasing dissolved CO_2 concentrations, more CO_2 will go through the series of reactions producing hydrogen ions that cause acidity in seawater.

Ocean acidification is a widespread problem across coastal communities, but colder marine ecosystems like southeast Alaska are particularly vulnerable to decreasing pH. It has been shown that factors such as Alaska's shallow waters and colder surface temperatures have more capacity for dissolved CO_2, leading to worse acidity problems (SEATOR, 2021). As seawater becomes more acidic, the carbonate ion (CO_3^{2-}) concentration will lower. This creates problems for calcifying organisms because carbonate ions are needed to create calcium carbonate ($CaCO_3$) which these organisms filter out of the water to create their shells, called precipitation (Gazeau et al., 2007).

Kelp could be the key to regulating CO_2 concentrations through its ability to photosynthesize which absorbs CO_2 from the surrounding water, thus reducing hydrogen ion concentration slightly, otherwise known as raising the pH or potential hydrogen. One way it has been suggested to integrate kelp into the Pacific northwest is through modified clam gardens. The benefits clams receive from surrounding kelp could be very important for people relying on clams for subsistence because kelp provides stability for clams by providing increased nutrients and decreased pollutants, including CO_2 (Falkenberg et al., 2012). It has also been suggested that shell hash, which is the broken-up bits of shells used as a substrate for clam gardens, can act as a pH buffer, providing more basic waters in those areas (van der Ven et al., 2020). These factors combined could make modified clam gardens an effective way of mitigating ocean acidification in Alaskan waters.

Climate Change and Ocean Acidification

For over 200 years, anthropogenic carbon dioxide has been dominating the atmosphere. This is and will continue to be a problem for many marine species because it can affect their habitat, food, and life production.

One way habitat is affected is by the decrease in the pH levels, which can benefit some organisms like seagrasses, but harm others like coral and shellfish. According to an article published by the Smithsonian, in just 200 years, the water has become 30 percent more acidic. Using the trajectory from figure one, we can predict that in 200 years our oceans will be 60 percent more acidic, possibly even more due to our exponentially increasing carbon footprint.

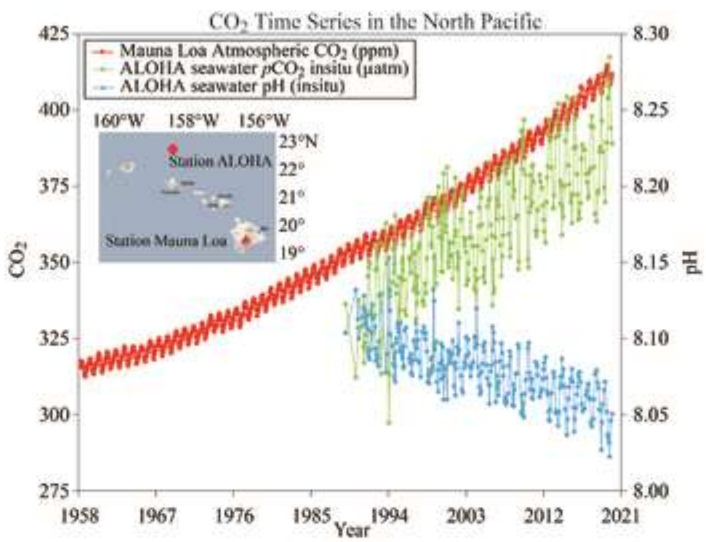

Figure 1. pH and CO_2 in Hawaii (NOAA, 2021)

In the time frame from 1818 to 2018 carbon has been emitted at an exponential rate through the increased use of cars, trains, planes, and most importantly, factories, making it so since the industrial revolution, 525 tons of carbon dioxide have entered the oceans (NOAA, 2021).

According to the National Oceanic and Atmospheric Administration (NOAA), it is predicted that in 2100 the pH level will be about 7.67 as opposed to a pH of 8.1 which our oceans are at currently, which represents a large change because of pH being a logarithmic scale. As pH decreases, dissolved calcium carbonate levels in the ocean decrease as well. Shellfish, such as the pteropods and oysters shown in figures two and three, use this calcium carbonate to build and maintain their shells. Having thinner shells, these organisms would be more vulnerable to predators as well as not being able to sustain growth in their bodies if their shell never grows.

Figure 2. Images of shells acidification affected by ocean. Figure 3. Image of what acidic pH levels do to oyster shells

The decrease in the amount of calcium carbonate in the ocean also causes limitations in phytoplankton reproduction. Phytoplankton, also known as microalgae, are small waterborne plants that form the bottom of a wide range of aquatic food webs. Shellfish are one organism to feed on phytoplankton, making them an important part to consider when trying to farm shellfish. Overall, ocean acidification has a big impact on phytoplankton and shellfish, which could have significant effects on the marine food chain and human consumption of shellfish.

Cultural Significance of Bivalves

Shellfish, specifically bivalves, have had a major impact on the people of southeast Alaska for generations and have changed lifestyles for many people. Many Indigenous people in southeast Alaska use shellfish for food and artwork, as seen in Table 1. There are a variety of bivalves in the waters of southeast Alaska that can be used for subsistence or commercial harvest (SEATOR, 2020). Whether someone is a resident of a small Indigenous village or someone who lives in a larger community there is a tremendous amount of value that stems from the presence of bivalves.

Table 1. List of species of bivalves in southeast Alaska.

Species	Scientific Name
Horse Clam	Tresus nuttallii
Littleneck Clam	Protothaca staminea
Butter Clams	Saxidomus gigantea
Razor Clams	Siliqua patula
Cockles	Cerastoderma edule
Macoma Clams	Macoma nasuta
Blue Mussels	Mytilus edulis
Eastern Soft Shell Clams	*Mya arenaria*
Geoduck	*Panopea generosa*
Rock Scallops	Crassodoma gigantea
Pinks Scallops	Chlamys rubida

Clam gardens are important to Indigenous people for harvesting food. People harvest shellfish commercially so they don't have to worry about the dangers of paralytic shellfish poisoning (PSP) which is a neurotoxin poisoning that can cause tingling, numbness, paralysis, and even death in extreme cases (SEATOR, 2020). Local businesses rely a large amount on commercial shellfish for luxury dishes for people to enjoy without worrying about safety. Indigenous people also use shellfish for art and trinkets like necklaces and decorative artwork for pathways. There are a lot of traditional uses for shellfish such as ceremonies and traditional gatherings with the Indigenous people and even people who are not Indigenous use them every day. (Jackley et al., 2016; Hallman et al., 2009).

Ecology Of Bivalves

Bivalvia is a class of mollusks that have two shells; there are 20,000 species around the world; most live in saltwater but some have adapted to live in freshwater. Bivalves use their two shells as protection. Bivalves also use a soft muscular foot that extends from their shell to move around and dig underground and through the sand for shelter. The reproduction cycle of a bivalve is when they lay eggs they expel them out into the water then they hatch as larvae. They drift in the water and feed on whatever they can and eventually stick to the seafloor and become Bivalvia. (Rippley, 1998)

Bivalves are primary consumers as they feed on detritus, phytoplankton, and bacteria. Their predators are sea otters, sea stars and octopuses, and humans. Bivalve's major ecosystem service is that they are filter feeders and they are food to humans and animals. Bivalves are not keystone species. Bivalves can cause harm to the environment if their overpopulation is very dense in a small area. Their habitats are coral reefs or on shallow shores, they dig burrows in the sand. (Byron et al., 2011; Morton, 2020)

Some shellfish species are at risk of several disturbances; over-harvesting could make some shellfish species in that area go endangered that may affect their population. because of pollution from factories and overpopulation which is putting large amounts of pressure on our rivers and that also causes the fish population to decrease in the lakes which is vital for what mussels need to reproduce. A very large threat to shellfish is if the sea otter population is too high in that area the shellfish population there will decrease from the otters using them as the main food source. Overpopulation is a major threat to shellfish if their population is too high it will lead to a mass of dead shellfish from starvation. Ocean acidification is a major threat to shellfish because it destroys essential food sources minerals and chemicals for shellfish. (Ekstrom et al., 2015; Harley et al., 2020).

Mitigation Strategies Along the Pacific Coast

Ocean acidification is detrimental to the development of shellfish but proves to be beneficial to the growth of kelp. As kelp grows, it captures carbon from the water and produces oxygen, possibly removing enough carbon dioxide to help alleviate acidification and prove a possible mitigation plan against ocean acidification, an idea explored in Washington and California.

A 2.5-acre site north of the Hood Canal Bridge in Jefferson County, Washington, was leased by Hood Canal Mariculture to the Puget Sound Restoration Fund to investigate sugar kelp cultivation as a means of mitigation against ocean acidification through improved seawater conditions or providing shelter for sensitive species. In 2017, 6,364 kilograms of sugar kelp (wet weight) was harvested, which resulted in the removal of 130 kilograms of carbon and 18 kilograms of nitrogen from sea to land. In 2017, if kelp had been harvested at peak biomass, with 19,417 kg sugar kelp having been produced, approximately 395 kg of carbon and 55 kg of nitrogen would have been removed. In 2018, estimates for carbon and nitrogen contained in kelp grown averaged 21.54% for carbon and 1.99% for nitrogen. If kelp had been harvested at peak biomass in 2018, then over 22,000 kg would have been removed, representing 474 kg of carbon and 44 kg of nitrogen. Removal of carbon at peak biomass would be equivalent to the CO^2 emitted by 31–37% of one typical passenger vehicle in a year, and the amount of nitrogen removed at peak biomass would be equal to ten 43-lb bags of typical lawn fertilizer. Results from a small field study indicated the improved conditions for various calcifying organisms such as Pacific and Olympia oysters, bay mussels, and pteropods that were deployed in mesocosms inside and outside the kelp farm. Inside the kelp farm, results found reduced shell dissolution in all of the examined species. Results also showed that Pacific and Olympia's oysters showed faster growth inside the kelp farm. However, multiple factors may have helped in the improved benefits, such as more favorable carbonate chemistry conditions, food availability, and energy trade-offs (Peabody, 2019).

In Santa Monica Bay, researchers from the University of California at Los Angeles began investigating the impact of kelp forests on ocean acidification. Working specifically to monitor restored kelp forests off the coast of Palos Verdes, UCLA partnered with The Bay Foundation to evaluate the feasibility of kelp forests as a pH sanctuary for marine life from the harmful effects of ocean acidification by tracking seawater chemistry changes through time and measuring phytoplankton to see the effect they have on productivity. The research team went to Palos Verdes on four different field days and traveled to two different sampling locations. One was a restored kelp forest region, and the other was an open ocean region. After four field days, the research team had collected data from thirty-two conductivity, temperature and depth (CTD) casts, and collected 128 water samples to measure pH, and 384 chlorophyll filtrations.

As shown in this section, ocean acidification is able to be mitigated around the United States, but because Alaska has a higher risk for severe acidification, we will explore how these mitigation strategies could be applied in southeast Alaska.

Mitigation Strategy for Southeast Alaska

There are many ways of mitigating ocean acidification's impact on shellfish, one of which is the use of kelp to reduce the carbon emissions in the water (Mongin et al., 2016).

Because kelp uses photosynthesis, they produce energy by taking in CO_2, and output oxygen which is not a contributor to ocean acidification (Mongin et al., 2016). By removing anthropogenic CO_2 from the ocean, the pH of the surrounding seawater is raised, which supports the development of shells for organisms that build them. Because of this, kelp farms have been shown to be the most effective buffers against the changing ocean pH, meaning they resist lowering pH effectively slowing ocean acidification (Mongin et al., 2016).

Before going into the full mitigation plan, clam gardens will first be introduced for a deeper understanding. Clam gardens are a creation by indigenous of southeast Alaska peoples to optimize clam habitats. They are made by constructing rock walls at the low tide lines on bays and inlets (Groesbeck et al., 2014). An example of what a clam garden looks like in southeast Alaska is shown in figure 4. Clam gardens are mainly used in Canada by the First Nations of British Columbia, but also by indigenous people from Washington and Alaska. These indigenous populations have relied on clam gardens for subsistence purposes for at least 5000 years, making shellfish a staple food source for Northwest Coast First Nations (Groesbeck et al., 2014). Clam gardens are so important to these people, that traditional knowledge about how to tend to clam gardens is ingrained into their community, and is passed down through stories, practice, and even in music (Groesbeck et al., 2014).

Figure 4. Image shows the layout of a clam garden.

By putting these two parts together, we have come to the idea of modifying clam gardens to support kelp growth. It has been shown that in kelp-dominated areas, mussels will grow approximately twice as fast in the subtidal zone and four times as fast in the intertidal zone as opposed to mussels in areas with space kelp growth (Duggins et al., 2007). This effect is made possible not only by the increase in pH caused by kelp photosynthesising, but also the nutrients provided by kelp biomass (Duggins et al., 2007). As kelp grows or decomposes, it releases large amounts of organic carbon into the water. The organic carbon is then consumed by surrounding suspension feeders like clams contributing to their growth as shown in figure 5 (Duggins et al., 2007). So by growing kelp alongside with clams in modified clam gardens, indingenos people and commercial fisheries alike can farm clams with less worry about acidity ruining their harvest.

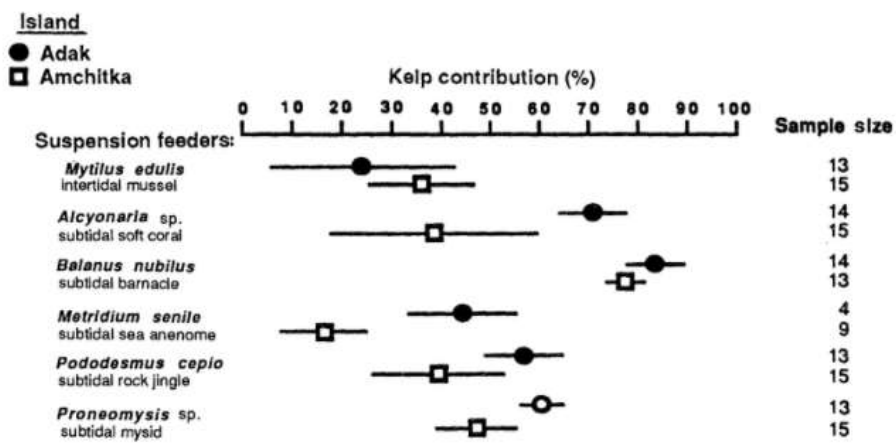

Figure 5. Percentage of kelp organic carbon found in the tissue of suspension feeders at islands in Alaska with extensive kelp growth

Conclusion

While ocean acidification impacts nearly all marine life, shell-building organisms are particularly sensitive to the pH changes in the surrounding water (Gazeau et al., 2007). As dissolved carbon dioxide levels increase, it will go through a series of chemical reactions that eventually lower the amount of calcium carbonate available in the water (NOAA, 2021). Without enough calcium carbonate, shellfish will grow smaller and have thinner shells. This becomes an issue for commercial fisheries and indigenous people who need shellfish to feed themselves alike, as now harvests contain less overall weight of shellfish (Jackley et al., 2016).

Kelp has been studied recently as a possible solution to slowing down ocean acidification because of its ability to absorb dissolved carbon dioxide through photosynthesis. This could be used to create areas around kelp forests where organisms sensitive to low pH could thrive. One way to apply this has been the use of clam gardens, which were used by Pacific Northwest natives to propagate shellfish. The design would be altered to also support various species of kelp to help regulate pH and nutrients, creating a better environment for developing shellfish.

But, the only way to make these strategies work is if word is spread and action is taken. If kelp gardens and clam gardens are brought to attention and funded, the Pacific Northwest will likely see not only healthier shellfish, but a healthier and more stable ecosystem overall.

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