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Ocean Acidification and the Shellfish Industry in Washington:
Analysis of Mitigation Efforts

Ocean acidification (OA) is a recently recognized product of climate change, wherein increased atmospheric CO2 leads to increased absorption of carbon dioxide by the ocean, resulting in decreased pH throughout the water. This absorption also decreases the saturation state of the carbonate minerals used by bivalves to create their shells (Gattuso and Hansson 2011), and has been linked to increased larval mortality among shellfish (Nerurkar 2020). The shellfish industry is incredibly influential in the state of Washington, creating thousands of jobs and an estimated $270 million in economic impact (Washington Sea Grant 2015).

In 2007, the Whiskey Creek Shellfish Hatchery in Washington noticed persistent and economically-damaging levels of larval mortality and seed shortages that sparked a conversation around ocean chemistry and its effects on shellfish production (Barton *et al.* 2015). Around the same time, Willapa Bay, an incredibly productive oyster estuary, saw a very dangerous decrease in natural recruitment of larvae from 2006-2012 (Dewey 2019). From these events, the people and state of Washington initiated an array of OA mitigation and adaptation strategies to protect the extremely valuable shellfish industry. This paper will analyze the success of these efforts.

Collaboration

According to Barton *et al.* (2015), the first response by the Whiskey Creek Shellfish Hatchery (WCSH), after ruling out pathogens as the reason for the unprecedented larval mortality in 2007, was to begin water quality monitoring. In 2009, the Pacific Coast Shellfish Growers Association (PCSGA) funded large-scale monitoring of water conditions and carbonate chemistry which both integrated the efforts of scientists and the shellfish industry and provided evidence that worsening OA contributes to shellfish decline (Barton *et al.* 2015). The WCSH found enough success as measured through larval survival that was attributable to water quality monitoring that more funding was requested from the National Oceanic and Atmospheric Administration (NOAA) to introduce the program in other shellfish hatcheries and at Oregon State University. This kick-started an industry-wide use of carbonate chemistry data to ensure successful shellfish harvests (Barton *et al.* 2015).

At the Ocean Acidification Impacts on Shellfish Workshop (2010) the efforts of three states, representatives from state and federal sectors, the shellfish industry, and scientists in relevant fields were brought together. During this workshop, much emphasis was placed on gaining a deeper understanding of ocean acidification, its ecological impacts, and the future preservation of the shellfish industry on the west coast. This group collaborated to create standardized methods for data collection, an accessible website to house the data, and an increased number of research sites along the coast (Dickson 2010). The California Current Acidification Network (C-CAN) was one of the results of this workshop. C-CAN is a program focused on ensuring a coordinated monitoring effort using set core scientific principles to be implemented on a large-scale (McLaughlin *et al.* 2015). The C-CAN program highlighted the need for data collection and monitoring at a global scale, as ocean acidification is a global issue (Feely 2010).The Governor of Washington also got involved around this time, creating an Executive Order addressing OA that became recognized internationally as one of the most preliminary efforts in OA mitigation. From these efforts, some tangible success was observed in oyster production (Dewey 2019).

The 2010 workshop, and the years of data collection it prompted, created a level of environmental stewardship that is rarely seen. Environmental advocates often pursue a cause for passion or admiration. Scientists pursue a cause for discovery and understanding of biological processes. Industries usually pursue a cause for monetary gain. This is an instance where all three parties could reach a happy ending through the same means, resulting in an amplified effort for an environmental issue. Environmental advocates care for the health and protection of our oceans. Scientists want to learn more about the ecology, reproduction, and development of shellfish. And the shellfish industry wants a healthy harvest to maintain the economies of the Pacific Northwest (PNW).

Industry and the general public are understandably the most difficult parties to get involved in environmental issues, but according to Miles *et al.* (2019), the Global Ocean Health (GOH) program knew how to bring them into the fold. The GOH, which specializes in involving stakeholders in environmental mitigation efforts, did significant fundraising in Washington in response to the shellfish crisis. This program played a fundamental role in involving everyday citizens whose lives depend on or are affected by the health of our oceans. The strategy of the GOH focuses on effective scientific communication with the public, wherein concepts full of complicated jargon are made accessible to increase "relatability" and relevance between scientists and a larger audience. Explaining to an everyday individual who might not even believe in climate change how a climate-related problem directly affects his livelihood in clear terms has proven highly successful with the GOH when trying to amass stakeholder interest in the issue at hand (Miles *et al.* 2019).

Outsourcing

A somewhat less notable solution to the shellfish crisis in the PNW was outsourcing hatcheries to new locations. According to Dewey 2019, it was noticed toward the beginning of the declines seen at Whiskey Creek Shellfish Hatchery and throughout Willapa Bay, that affiliated hatcheries in the state of Hawai'i did not observe the same losses. This prompted the opening of more hatcheries in Hawai'i under Washington companies. Although it was assumed that all ocean waters would eventually see the effects of OA, industry professionals saw this outsourcing as a palatable short-term answer to a pressing problem.

Research

Another significant effort in mitigation of OA effects was the consideration of genetics and selective breeding in the revitalization of the shellfish industry, and further discovery regarding shellfish adaptability and potential to withstand dramatic environmental changes. According to Zhang *et al.* (2012), who mapped the genome of the Pacific oyster, *Crassostrea gigas*, this species reserves a large part of its genetic code for response to environmental stressors. It was also discovered that oyster shell formation is incredibly complex. These conclusions provided some positivity that shellfish may be strong candidates for genetic manipulation in creating more OA-resistant individuals over generations (Zhang *et al.* 2012). Gurr *et al.* (2020) sought to observe how stress conditioning and epigenetics play a role in aquaculture of long-lived oysters. Their findings provide evidence for the potential benefits of early-life exposure to environmental stress in hatcheries to create healthier stocks come harvest.

The Molluscan Broodstock Program (MBP) was created to utilize genetics in the improvement of shellfish yields in the PNW. The MBP selected certain individuals for their success, using parameters like weight, yield, and survival. It was found over five generations that selective breeding may offer genetic improvement (Melo *et al.* 2016) to aid in oyster survival and harvest for the shellfish industry. Durland *et al.* (2021) also found great potential for adaptation under OA among selectively bred Pacific oysters. It should be noted that, across the board, strong differences were observed between wild and domesticated oysters.

Thoughts on Future Considerations

Even with all of the hope surrounding the potential for shellfish to adapt and survive, especially with human intervention, shellfish farmers and industry professionals will have to contend with a dilemma. The use of fossil fuels is fully intertwined with the industrial side of business in hatcheries and the transportation of goods to be sold (Troell *et al.* 2004). This means the shellfish industry is inadvertently feeding the problem they are trying to mitigate and negatively impacting their own source of income. This realization will hopefully spark a desire to get to the root of the issue that is climate change and create a demand for more sustainable aquaculture and fishery industries.

The mitigation efforts introduced and implemented by the state of Washington to combat the effects of OA have been efficient and appropriate. This is an example of the importance that should be placed on these pressing environmental issues. Washington should be recognized further for taking such quick and strong action in a crisis. Years of research and collaborative efforts between farmers and scientists have both expanded the general scientific knowledge of shellfish to be utilized across oceans globally, as well as helped to increase the yield of shellfish appropriate for markets in local economies throughout the PNW. Shellfish farmers are not the only stakeholders dependent on healthy oceans. With any luck, other marine industries will also invest their time and interest in further research to protect their own endeavors. The example Washington has set breeds hope that, as climate change continues to impact the earth and our natural resources, more quick and effective responses of this magnitude might be seen.

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