The Effects of Climate Change on the Northern California Oyster Industry

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ABSTRACT

The increase in global temperatures and atmospheric carbon dioxide concentrations is proving to have alarming effects on ocean temperatures and pH in Northern California leading to negative implications on oyster populations and thus the oyster industry at large. Here we focus on Tomales Bay and Humboldt Bay, specifically the Hog Island Oyster Company hatchery located in Marshall, CA. The data was collected via CeNCOOS in Tomales Bay, while simultaneously focusing on industry survey literature centered around Humboldt Bay. Data and surveys were supplemented by an interview with Hog Island Oyster Company in order to identify strengths and weaknesses in companies' ability to adapt their processes and procedures to both protect their business and oyster health. Across a three year period from January 2020 to December 2022, it was proven that there was a decrease in ocean pH paralleled by an increase in ocean temperatures. Industry surveys showed that businesses are concerned about a decrease in oyster seed availability which is largely decreasing oyster abundance as the consequences of climate change overtake the hatcheries. Hog Island representative, Gary Fleener, added that farms are seeing large die off events largely caused by temperature or ocean acidification events. Moreover, the oyster industry is at risk for losing sufficient income as a result of the decrease in growable, harvestable, and sellable oysters across all life stages: larval, juvenile, and adult.

KEYWORDS

ocean acidification, ocean warming, water temperature, water pH

INTRODUCTION

As a result of increased carbon dioxide in the atmosphere, ocean acidification and ocean warming have sped up dramatically, impacting ocean health. Serving as the world's largest carbon sink, the ocean uptakes CO2 gas that dissolves in the water and triggers a chain of acid-base reactions changing the water chemistry (Feely et al. 2009). Ocean acidification is the process by which chemical bases in ocean water are reduced, thus increasing the quantity of H+ protons and therefore a decrease in ocean pH (Bates et al. 2014). Occurring parallel to ocean acidification, warming as a result of anthropogenic climate change can affect species distributions, particularly phytoplankton which play a large role in the sequestration of atmospheric carbon (Krumhardt et al. 2016). It is still unclear the complete extent to which organisms can adapt and adjust to these changes occurring in water temperature and chemistry.

As a calcifying organism, oysters rely on regulated calcium carbonate levels in the form of aragonite and moderate ocean temperatures for survival; climate change has heightened ocean acidification and ocean warming, harming oysters as a result. Oyster population dynamics have changed because a decrease in pH requires greater energy output by oysters for their survival, weakening the organisms due to the abundance of H+ ions in the water (Liu et al. 2020). Similarly, at higher water temperatures, oyster growth rates are significantly lower than at regular temperatures (Pereira et al. 2020). Climate change has and will continue to negatively impact oyster health and growth rates and in turn will affect the oyster industry.

Oyster companies and the economy revolving around the sale of oysters will be negatively impacted by the effects that climate change will have on commercially grown oysters. Commercial oyster farms are already seeing negative impacts of climate change with shorter harvesting seasons and more sensitive growing conditions. In an effort to mitigate the effects and increase their management efficiency, Hog Island Oyster Company in Tomales Bay has managed a wide variety of data in order to assess oyster viability and growth in the face of changing physical and chemical ocean properties. However, there are still methods to be observed that can increase the capacity of oyster growth and sales.

In my study, I will pose the question of how climate change is affecting oysters in Northern California. Due to the issue being as complex and multifaceted as it is, I will also be addressing (1) what impacts climate change, specifically ocean acidification and ocean warming,

have on oyster health, (2) how the effects of climate change have and will continue to impact the economic viability of oyster farms/the oyster industry, and (3) what has been done to help mitigate these issues and reinforce oyster longevity. In this study, I expect to find that (1) the impacts of the changing climate will reduce an oysters' ability to grow and thrive to their full biological ability by shortening their lifespan, (2) the oyster industry will see reduced growth rates and smaller harvests due to a lack of larval abundance, and (3) there will be transitions in the future to lab and farm grown oyster cultivation practices supplemented by a northward shift of farms to accommodate the changing climate. My data collection will focus on oyster survivability as a result of water chemistry and temperature, industry surveys from oyster farms as it relates to the health of oysters and annual harvest patterns, and the extent to which oyster farms--namely Hog Island Oyster Company--are taking action to prevent their oysters and their business suffering as a result of climate change.

METHODS

Study Site

In order to analyze how increasing ocean temperature and decreasing ocean pH are impacting Northern California oysters, I will be obtaining data from the Central and Northern California Ocean Observing System, specifically from a censor deployed in Marshall, CA situated in Tomales Bay. Located in Marshall is Hog Island Oyster Company; Hog Island has a 160 acre farm where they grow 6 different kinds of oysters and other shellfish. Similar to the rest of the Bay Area, Tomales Bay experiences moderate weather with cool winters and warm summers. The temperate climate of the Bay Area allows for better predictions about climate change as well as changes in weather events over time. We have observed that carbon dioxide concentrations in the atmosphere are steadily increasing and are projected to worsen in the distant and near future (Buchwitz et al., 2018). Knowing this, we can interpret information about the study site in a more holistic manner.

Temperature and pH data acquisition

To obtain data regarding the temperature and pH I contacted a representative from Hog Island and was directed to the Central and Northern California Ocean Observing System (CenCOOS). In order to answer the question of what impacts climate change (ocean warming and ocean acidification) have on oyster health in our specific area, I had to filter the results first to Tomales Bay and then was able to select the sensor deployed at the Hog Island hatchery. I acquired temperature and pH measurements, and also available were aragonite, CO2, and salinity measurements. In order to align the time frames of the different data sets, I chose the period from January 2020 to December 2022. The objective of this data collection was to interpret how oysters are impacted by decreased pH and increased ocean temperatures over time, and specifically how this has changed in the recent past.

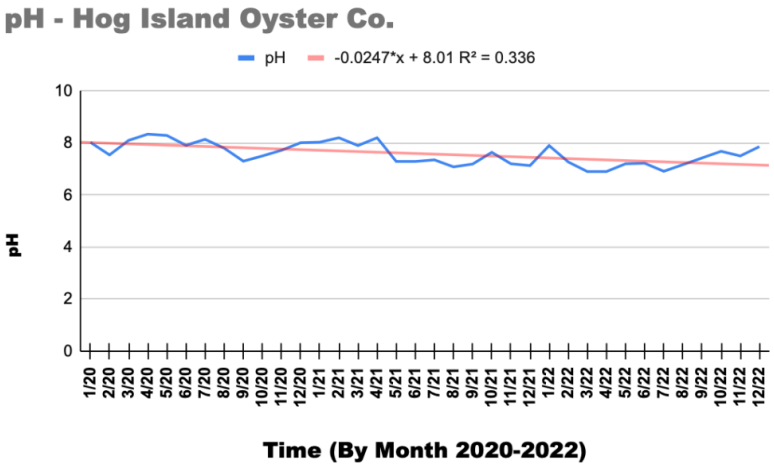
Data analysis

In order to analyze the data from CenCOOS, I compared different graphs and applied lines of best fit to see the overall trends in the data. In a small time frame, I compared data from January 2020 to December 2022 and put the data into tables in order to make a visual comparison/correlation between the different effects of climate change over time. I reviewed a summary report published by NOAA that surveyed shellfish mariculture business that assesses the impacts of climate change. The survey was conducted in Humboldt Bay and surveyed 6 different businesses regarding the state of the industry in the face of changing ocean conditions. The 6 businesses cover over 385 acres of farmland and all use a variety of business models (Richmond et al., 2018). To supplement this survey, I conducted an interview with Gary Fleener from Hog Island Oyster Company to inquire about the current issues being addressed. Due to the speed in which the global climate is changing, it is important to get recent information to understand what is occurring at oyster farms. In my interview I asked the following questions: (1) in recent decades there have been large changes in the climate, have there been any outstanding occurrences at Hog Island that have had a large negative impact on harvests and what was done to help the farm recover, (2) are there any procedures in place at Hog Island related to climate change that were not in place 20-30 years ago and what was the turning point for implementing these changes, and (3) does Hog Island have any current or future plans for protecting the company from the impacts of climate change.

RESULTS

I found that there was a consistent pattern of decreasing water pH paralleled by increasing water temperatures. The pH of ocean water within the deployed area has been seen to decrease steadily across the study period with periodic fluctuations (figure 1a). It was seen that there is an indirect relationship between the increase in water temperature (figure 1b) and the decrease in pH. The trendline of the water pH has a slope of -0.0247 meaning that over time the water of the Hog Island farm is becoming more acidic. The decrease in pH is consistent with the increase in water temperature which has a positive slope of 0.0401, showing an overall increase during the January 2020 to December 2022 period.

(a)



(b)

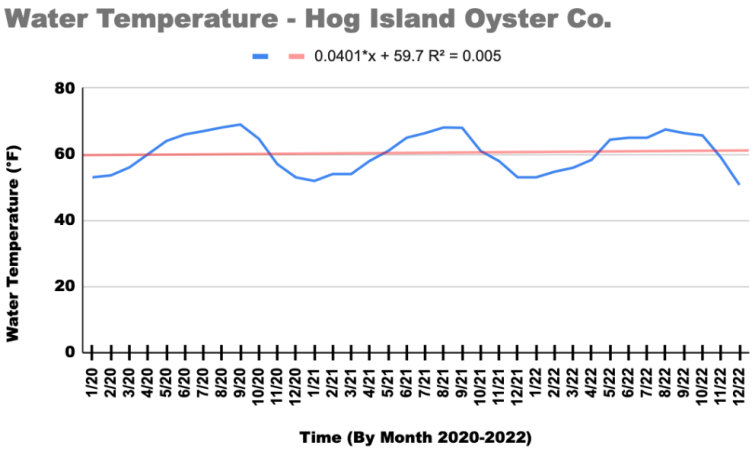


Figure 1. **Temperature and pH data of Hog Island Oyster Company.** The hatchery data was recorded by a sensor located in Marshall, CA. Data was collected from January 2020 to December 2022: (a) ocean pH (b) ocean temperature.

In my analysis of the Humboldt Bay industry survey I found that there are multiple key concerns as it relates to the security and longevity of the oyster industry. The first main concern is the industry-wide shortage of oyster seed/larvae that are available to the oyster farms. The survey revealed that a lack of seed availability has been a recurring challenge for the businesses. In order to counteract this shortage, businesses are aiming to increase the production of shellfish seed and larvae in hopes to find greater financial security (i.e. revenue and operational costs). The main overall concerns are as follows: tideland availability, water quality and regulatory changes. Regulatory changes include changing pH and water temperature (Richmond et al., 2018).

In the interview with Gary Fleener of Hog Island, I asked three questions. The first investigated climate events that have impacted harvests and what was done at the farm in order to recover. He described warming events across the last ten years that have "triggered large scale oyster mortality." While the causes are a bit more nuanced, the warmer temps have largely contributed to these large die-offs. In response to what was done to recover, he described new breeding of more temperature tolerant oysters and investigating different genetic aspects that impact the oysters' tolerance. Second, I addressed new climate related procedures being put into place and what triggered these changes. It was revealed to me that Hog Island actually invested in a hatchery in Humboldt Bay around 10 years ago which allowed for greater control over genetics and seed availability. Unfortunately, this change was "driven by a large ocean acidification driven mortality event in Oregon about 15 years ago. Lastly, I asked what the future plans of Hog Island look like in order to protect their business. The Humboldt hatchery is a huge part of their plan to protect the company and the oysters; they plan on diversifying their shellfish species and harvesting more oysters in Humboldt Bay with the goal of greater diversification. Throughout the interview, diversification was a large motivating factor for the growth and longevity of Hog Island.

DISCUSSION

The complex relationship between ocean water pH and temperature have distinct effects on oyster survivability and quality of harvests. Due to the nature of these relationships, the negative effects on oyster health caused by pH and temperature directly affect the productivity of harvests and thus the success of oyster farms. Companies within the Northern California oyster industry have had no choice but to make a variety of changes varying in significance in order to better protect their oysters, and thus their individual farms, from the effects of climate change. These changes, while substantial, are not effective enough as climate change continues to worsen and ocean temperature increase and ocean acidification are occurring rapidly.

Damage to oyster health

At the core of this research is the impacts of climate change on oysters and how they are, in a multitude of ways, affected by ocean acidification and ocean warming. To address the question of what impacts climate change has on oyster health, I compared the water temperature and water pH data over a three year period (January 2020-December 2022). The data showed that there is an indirect correlation between increasing water temperatures and decreasing pH. When exposed to lower ocean temperature at a younger life cycle, namely the larval stage, oysters' survival as juveniles and into the adult life stages is reduced dramatically. Simultaneously, oysters growth rates were stunted dramatically through the juvenile and adult stages when they were exposed to low pH as larvae, showing long-term effects of early exposure (Hettinger et al., 2013). Ocean warming and ocean acidification are affecting oysters at an increasing rate and these issues are revealing themself in the form of decreasing pH and increasing water temperatures. However, there may be other significant factors that I did not study that are playing a role in oyster health. Issues such as low oxygen rates could have similar or more serious implications on oyster growth and health as well.

Implications on broader industry

Due to the decrease in harvestability on oyster farms (decreasing seed availability and changing climate related concerns) the oyster industry is facing a potential oncoming crisis. To examine the economic viability of oyster farms as climate change continues to impact oysters, I

reviewed a summary report of an industry survey conducted in Humboldt Bay. When comparing information related to industry concerns, I found that the largest concerns were related to water quality and regulatory changes. These factors reveal that there is a growing concern on oyster farms in Northern California, mainly about the success of businesses rather than the actual organismal impact. While these go hand in hand, the priority is the business not the protection of the organisms. This study does not account for all oyster farms or areas in Northern California as I acquired information just for Humboldt Bay and Tomales Bay. However, the implications of this data reveal a negative impact on oyster farms, especially as the impacts of climate change increase in severity.

Effect on the industry

A prominent cornerstone in the shellfish industry, oyster farms must continue in their efforts to make changes in the cultivation and growth of oysters. To help uncover what has been done to mitigate these issues and reinforce oyster longevity I conducted a primary research review and an interview with a representative from Hog Island Oyster Company. By asking questions regarding mass die off events HIOC has experienced, processes/procedures in place related to climate change, and future plans to protect the business from these effects, I found that there is indeed a large effort being made to ensure oyster health and business longevity. This data led me to believe that actions are being taken regionally to help combat climate change more broadly and the effects on oysters more specifically. However, more changes should be implemented in both the short and long term. The opinions and stances of one individual or one company does not mean that all companies and individuals in the oyster industry believe or take these to be true. Ultimately, greater action needs to be taken by oyster farms or else the negative effects will increase marginally if management does not become more meticulous and strategic.

Limitations

In an effort to address problems across the broader Northern California oyster industry, this project mainly addresses the statistics and data in only Humboldt Bay and Tomales Bay due to my resources. I had a difficult time collecting data, as it was hard coordinating via email with

the representative from Hog Island Oyster Company. Ultimately, I faced some complications and had to pivot to using different data sets which ended up aligning very closely to my original project. I was unfortunately not able to collect data myself so had to rely on these broader resources to collect the data I needed.

As a student, it was difficult to do the research to the extent at which I had originally imagined. Because of the restrictions of data and my ability to do fieldwork, I used two of the most common data variables for ocean water: temperature and pH. To get a broader understanding, I would incorporate other factors such as oxygen concentration, breeding patterns, as well as farm specific tactics that would affect oyster growth.

Implications and future management

The main focus of this research is to investigate the impacts of climate change (ocean acidification and ocean warming) that are altering the viability of oyster farms in Northern California--to what extent and what is being done about these changes. Moving forward, investigating a wider variety of oyster farms and areas within Northern California as well as investigating other factors that are altering oyster life cycles. Similarly, investigating the impacts of climate change on other shellfish and their relationship to oysters. This study reveals that greater action needs to be taken by oyster farms or else future implications will increase marginally. As far as management, meticulous research and planning by oyster farms should be furthered in order to change farm conditions and cultivate healthier oyster lifecycles and therefore oyster success.

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