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THE IMPACT OF CLIMATE CHANGE: AN IN-DEPTH ANALYSIS OF WARMING OCEAN WATER TEMPERATURES AND THE EFFECTS ON MAINE'S LOBSTERING INDUSTRY AND SUBSEQUENT EFFECT ON THE STATE ECONOMY

by

Bryce Nitchman

A Thesis Submitted in Partial Fulfillment
of the Requirements for a Degree with Honors
(Finance)

The Honors College

University of Maine

May 2020

Advisory Committee:
Stefano Tijerina, Lecturer in Management, Advisor
Melissa Ladenheim, Associate Dean of the Honors College
Julia McGuire, Lecturer in Biology
Ronald Roope, Cooperating Faculty in Finance
Richard Wahle, Research Professor of Marine Sciences

ABSTRACT

The effects of climate change are often not visible to the human eye and can, therefore, be hard to detect. As society has progressed since the industrial revolution, the effects of climate change are omnipresent in global, regional, and local air and water temperatures. This research aims to highlight the correlation between the effects of climate change on potentially rising ocean water temperatures in the Gulf of Maine, and the possible resulting adverse impacts on Maine's lobster industry and state economy. I will be using data compiled over the last several decades from the University of Maine's Climate Change Institute and Lobster Institute, and the National Oceanic and Atmospheric Administration (NOAA) to provide findings on price per pound, and annual landings, commercial fishing employment rates, and costs of supply chain management, all of which contribute to overall economic impact. I am interested in finding out if warming temperatures in the Gulf of Maine adversely affect the lobstering industry; and whether these effects have led or will lead to significant changes in Maine's Gross Domestic Product and economic growth. To test my hypothesis, I will be analyzing past and current data, as well as projections looking into the future to evaluate the implications of current or future threats to the Gulf of Maine's lobster stock and economy.

ACKNOWLEDGMENTS

I would like to thank my advisor, Professor Tijerina, for being so helpful and patient throughout this process. He was the one who helped me to narrow down my topic and help me find committee members who would provide expertise and insight into my paper.

I would also like to thank Professor Wahle and his incredible knowledge in the field. He helped me to narrow the focus of this thesis and find relevant information that was instrumental in finishing this paper.

To the rest of my committee, thank you for your patience and expertise. This was a very long and trying process. I lost track of how many times the focus of this paper and general outline changed, but every step of the way, my committee supported and reassured me.

DEDICATION

I dedicate this thesis to the biggest inspiration and light in my life, my mom. I would not be where I am today without her, and I am forever grateful for all of the times she was the sun in my world, even when it was storming in hers. I can only hope to be as successful as her one day.

To my grandparents, Judi and Chong, I would be so lost without them. They are two of the most selfless and caring people I know. I hope that one day I love what I do as much as they love what they do. They are two people who have never left and have always been there right when I needed them most.

I also want to thank my stepdad Jim, who has been a constant support over the past three years. I would not have gotten through the ups and downs of my academic career without him and his amazing professional advice. Helping me prepare for every interview, drafting every important email, reviewing every cover letter, and, most importantly, guiding me through the process of accepting my post-graduate job.

To Jillian, Brian, Ella, and Charlie, who have been nothing but supportive and positive. Their positivity has helped push me to the finish line.

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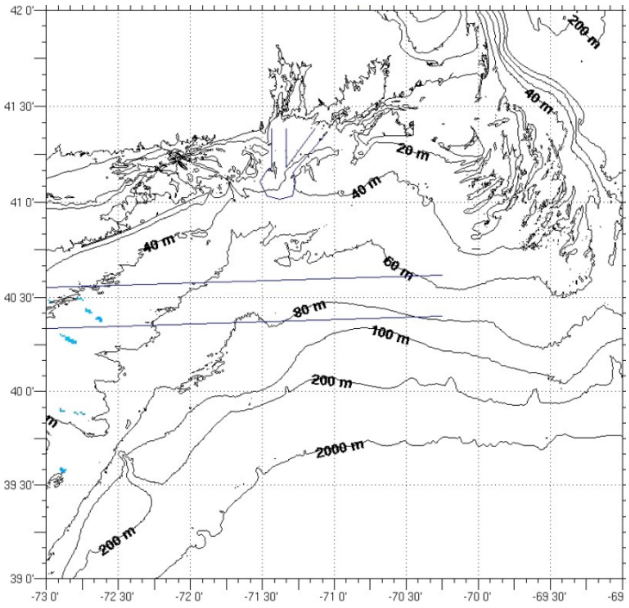
INTRODUCTION

For over a century, the American lobster stock in the Gulf of Maine has been extremely influential to the success of the Maine economy. Maine's coastal economy is reliant on a healthy lobster population for progress in the commercial fishing employment sector, competitive prices per pound, tourism, and the continuation of a prosperous "lobster culture." Additionally, the Gulf of Maine lobster fishery feeds the international and national markets.

Currently, the health of the American lobster stock in New England varies between southern New England (Fig.1) and the Gulf of Maine regions. (Fig.2)

Figure 1.

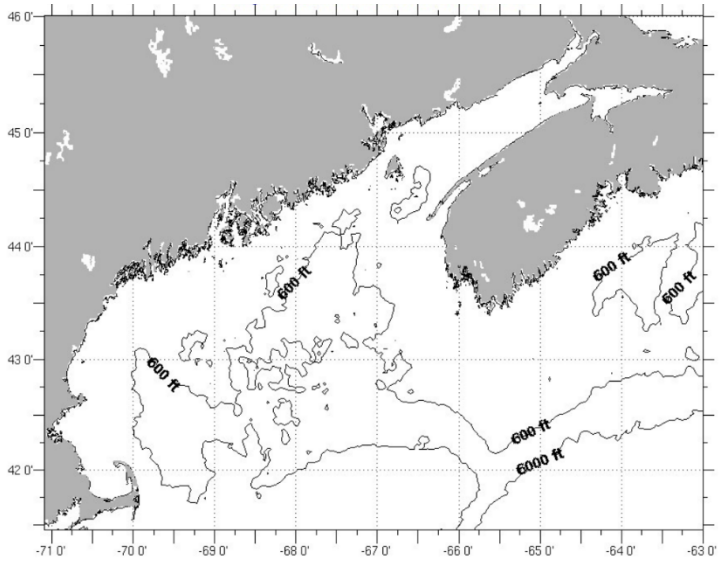
Bathymetry Chart of the Southern New England Region; South of Cape Cod



Note. From "NOAA 18 Sea Surface Temperature", by Rutgers Coastal Ocean Observation Lab, 2020, https://marine.rutgers.edu/cool/sat_data/show/?file=../../regions/maine/sst/noaa/2020/img/200422.113.1542.n18.jpg. Copyright 2020 by Rutgers, the State University of New Jersey.

Figure 2.

Bathymetry Chart of the Gulf of Maine Region

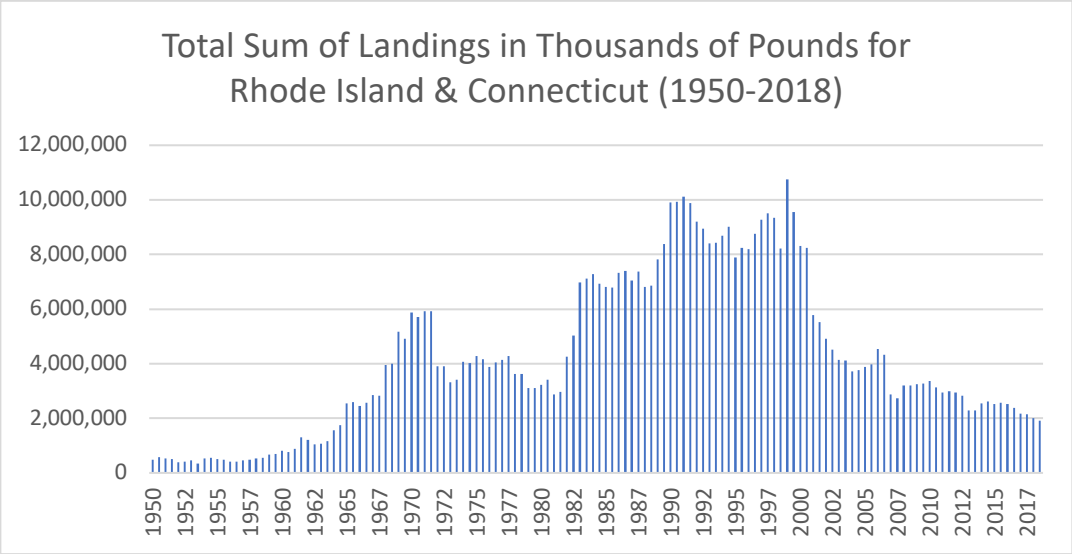


Note. From "NOAA 18 Sea Surface Temperature", by Rutgers Coastal Ocean Observation Lab, 2020, https://marine.rutgers.edu/cool/sat_data/show/?file=../../regions/maine/sst/noaa/2020/img/200422.113.1542.n18.jpg. Copyright 2020 by Rutgers, the State University of New Jersey.

Data from the southern New England region will illustrate research conducted on historical variations of ocean water temperatures in Connecticut and Rhode Island. This data will determine how temperature changes resulting from climate change are affecting the American lobster stock, and impacting landings yielded, and if the industry is suffering as a result. (Fig.3)

Figure 3.

The Total Sum of Landings (in pounds) for Rhode Island and Connecticut (1950-2018)

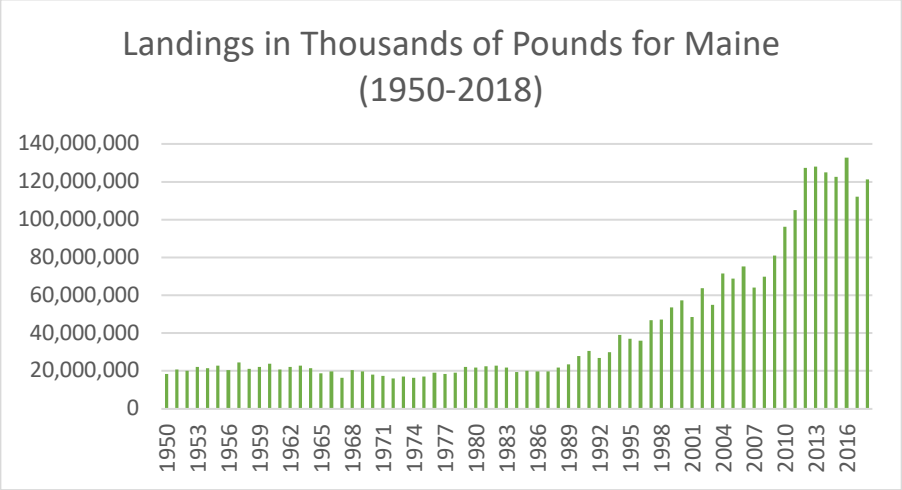


Note. : From "Commercial Fisheries Landings", by the Office of Science and Technologies, 2019, https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings. Copyright 2019 by the National Oceanic and Atmospheric Administration.

In comparison, total pounds landed from the Gulf of Maine have continued to increase. Additionally, the average price per pound of American lobster yielded from the Gulf of Maine has remained stable. This increase in landings has benefitted Maine's export sector and state economy. (Fig. 4)

Figure 4.

Landings in Millions of Pounds for Maine (1950-2018)



Note. : From "Commercial Fisheries Landings", by the Office of Science and Technologies, 2019, https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings. Copyright 2019 by the National Oceanic and Atmospheric Administration.

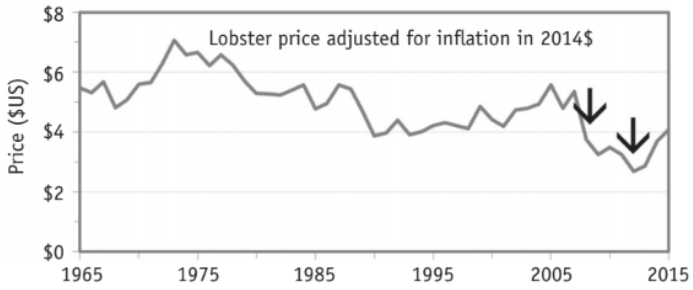
When comparing landings from the two regions, it is evident that the lobster industry in southern New England is experiencing a downturn that the Gulf of Maine region is not yet facing. This research will support the hypothesis that the effects of climate change are negatively impacting the American lobster stock in southern New England and how as climate change continues to progress, the Gulf of Maine could be experiencing similar challenges in the coming decades. For example, a decline in landings and a potential decrease in price per pound, resulting in a similar industry downturn to that of southern New England.

When looking at the historical price per pound of American lobster in Maine as adjusted for inflation, it is important to note that while the price has remained relatively constant, there are downturns in price as a result of changes in the demand for or supply of lobster, as can be seen by the arrows in figure 5. (Fig.5) In 2008, during the global

recession, the demand for lobster, a luxury food, decreased, resulting in a decline in price (Rheuban, Kavanaugh, and Doney, 2017). Following 2008, in 2012, prices fell again when an unusually warm season led to a climate-driven early-season surge in landings. The industry was not prepared to handle the excess supply with little increase in demand (Rheuban et al., 2017).

Figure 5.

Lobster Prices per Pound in Maine – Adjusted for Inflation in 2014 Dollars



Note. From *Lobster Fisheries,* by Wahle, Linnane & Harrington, 2020, Copyright 2020 by Oxford University Press.

While the effects of climate change on the ocean water temperature in the southern New England region have proven to be negative for the regional lobster industry, to date, climate change has proven to be positive in the Gulf of Maine. However, should these negative effects being seen in southern New England continue up the coast to the Gulf of Maine, the State of Maine could see drastic changes in the prosperity of the lobster industry, threatening the state's economy as well as national and international lobster markets.

In this study, I evaluated the economic impact of anthropogenic climate change on the American lobster (*Homarus americanus*) fishery in the United States. Several economic indicators were considered within the commercial "fish harvesting" sector of

Maine's economy, including the price per pound, landed lobsters, rates of employment, and a brief overview of the value of Maine's lobster distribution network. All these factors were combined to estimate the value of Maine's lobster fishing industry's overall output into the economy in terms of Gross Domestic Product (GDP). This paper evaluated the economic factors of the contribution of American lobster in the State's tourism industry as well. For example, employment levels associated with the commercial lobstering industry, lobsters' economic impact on the Maine restaurant industry, the price per pound, and volume of landings. In conclusion, I looked at whether the effects of climate change are currently posing a threat to the economic well-being of Maine's economy.

When studying the impact of anthropogenic climate change on the ocean water in the Gulf of Maine, the main goal is to determine if these environmental factors are detrimental to Maine's local lobster industry as well as any future threats to the national and international markets. The rise in global surface and water temperatures have had extensive effects on American lobster that are reaching through southern New England and up to the Gulf of Maine.[1] As the global surface temperature has risen, the State of Maine's annual air temperatures has risen by approximately 1.70°C from 1895-2014 (Fernandez, 2015). These changes in air temperature are affecting Maine's ocean temperatures in the Gulf of Maine; the major effect is that since 1982, the average sea surface temperature in the Gulf of Maine has increased at a rate of 0.03°C per year (Fernandez, 2015). This research will analyze the causes of the recent 'boom' in the Gulf of Maine's lobster population, why fisheries in the Gulf of Maine have reason to worry

[1] For further information about climate variation in southern New England refer to Chapter 3

about the future of the industry, and the importance of planning for adaptation to potential industry threats.

As Maine's climate continuously changes, it is important to know how the past data can illustrate future changes in the state's economy. Climate conditions in the future will alter the American lobster stock in the Gulf of Maine and determine the way commercial fishers conduct their business.

Factors other than climate also come into play and can either offset or exacerbate future effects of climate change. For example, tariffs imposed by the Trump Administration on China have negatively impacted the lobster industry in Maine, by reducing demand and price. A change in trade policy, such as a removal of tariffs, may reverse this outcome and Maine's coastal economy, therefore, becomes vulnerable to climate change impacts than policy or market-driven economics.

To develop the argument of the importance of American lobster to the state of Maine's economy and the potential impacts of climate change, this paper will first look at the history of the American lobster fishery and its economic importance to Maine's economy. This scope will then be broadened to look at the key role the lobster stock in the Gulf of Maine plays in feeding the national and international markets, and the economic importance of this for the state economy. The focus of this research will be on the local lobster market, looking at the current state of the lobster market in southern New England and how changes in climate have negatively altered the biological habitat of the lobster stock in those areas, therefore hurting the industry. Conclusions will be drawn from environmental and industry conditions in the southern New England Region to

show how the lobster industry in the state of Maine could soon start to feel the negative impacts of climate change.

I collected data centered around the effects of climate change on the biological habitat of the American lobster in the New England region and the problems presented to the lobstering industry in the New England region. Climate change is defined in the Intergovernmental Panel on Climate Change's 2012 Glossary of Terms as the following:

> A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" ("Glossary of Terms", 2012). According to the same report, climate change is influenced by both natural occurrences and human action. (p.557)

Data trends and patterns collected over the past several decades reveal the effects of climate change on the lobster industry in New England. Historical data of landings and value as compared to variations in air and water temperature within the different regions of New England will also help illustrate future projections in the Gulf of Maine

CHAPTER 1

THE AMERICAN LOBSTER MARKET

The State of Maine's economy is heavily reliant on a healthy lobster stock in the Gulf of Maine to feed the national and international lobster markets. Throughout history, American lobster has gone from lowly-regarded food for the poor, to a highly regarded commodity. From a cultural and economic standpoint, American lobster is of utmost importance to the state of Maine's Economy.

The History of the Value of the Maine Lobster Industry

Today, the American lobster (*Homarus americanus)* is a highly sought-after commodity. With an increasing price per pound, it is served in high-end restaurants along the coasts and shipped around the world as a luxury food. However, this was not always the case. Beginning in the 1600s and well into the 1800s, people living along the coastal regions in New England regarded lobster as "cheap, low-status, even poorhouse fare" (Lewis, 1997). In many communities, lobster was donated with pity to widows and orphans. Into the 1800s, it was still regarded as "low status" and was used as pig feed, fertilizer, and fish bait (Lewis, 1997).

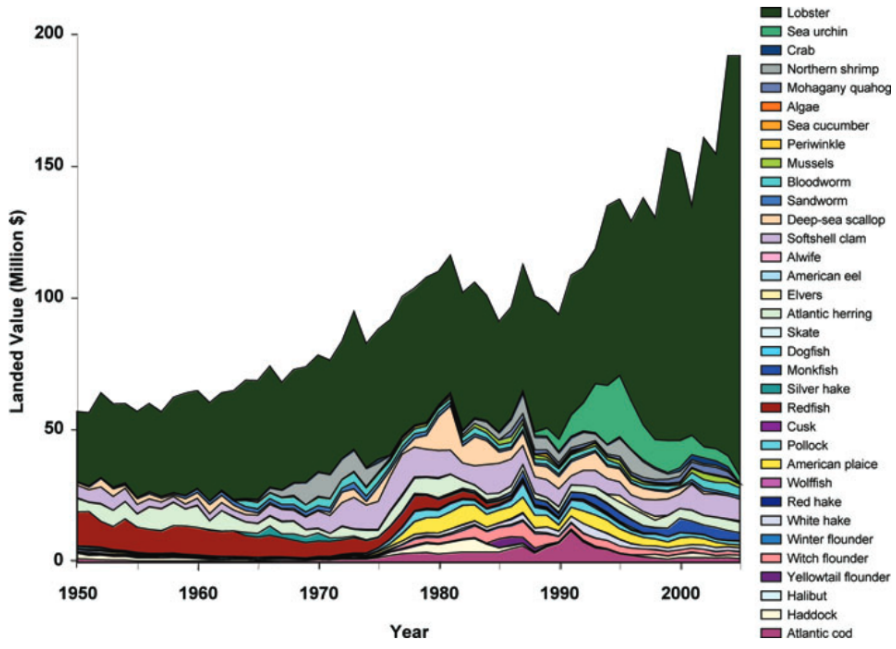
It was not until the end of the Civil War that lobster became a highly sought-after commodity. During the Civil War, the lobster populations of the coasts of Massachusetts and New York were nearly depleted from overfishing. Post-war Maine (around 1880) experienced an influx of wealthy vacationers from New York and Philadelphia looking to escape the summer heat of the city. Dining on lobster when residing at their summer cottages along Maine's coast became common for the wealthy. Once this started

happening, the American lobster became a staple of the Maine economy. From there, lobster became a "must-have" across sectors of the American market (Billings, 2014).

Over the past century, Maine's economy has become heavily reliant on the lobster industry, (Harold, 2008)-- important culturally and economically. (Fig.6)

Figure 6.

Dollar Value of the Top-landed Marine Species in Maine (1950-2005)



Note. "Creation of a Gilded Trap by the High Economic Value of the Maine Lobster Fishery", by Steneck et al., 2011, *Conservation Biology,* 25, copyright 2011 by Society for Conservation Biology.

Lobster also became central to tourism in Maine (Harold, 2008). Over the last thirty years, it became a valuable commodity nationally and internationally. The local market being tourist-dependent, and the national and international markets becoming export-dependent.

Local Market

When determining the value of the local lobster market within the State of Maine's economy, it is important to take multiple factors into account. The most important is the lobster culture. Maine's lobster culture comprises lobster cuisine, lobster fishing, and lobster fishing towns (Billings, 2014). According to a recent survey conducted by the Maine Office of Tourism, Maine's coastal regions account for 70% of the most frequently visited areas in Maine and eating lobster accounts for 43% of tourist experience (Billings, 2014).

There are two ways in which lobster contributes to the tourism experience and, therefore, the economy. One, lobster cuisine and two, the cultural experience. The cultural experience includes participating in lobster festivities like lobster boat races, shucking competitions, and lobster bakes. Throughout the summer, these events generate revenue for the Maine economy. For example, the annual Maine Lobster Festival in Rockland, ME, brings in approximately $1 million to the local economy (Billings, 2014). In recent years, as a way of adding to the cultural experience, numerous lobster fishers have started offering lobster boat tours. Tourists want the experience of not just eating lobster, but also being a part of the process that gets the lobster to the table. A lobster boat captain can obtain a demonstration license, which allows them to take six willing passengers out on the ocean. While on the boat, they can perform tasks such as stuffing bait bags or hauling traps over the side of the boat. With a demonstration license, caught lobsters must be returned to the ocean (Billings, 2014). Maine's economic success is heavily reliant on the tourism industry, and the tourism industry is dependent on the continued prosperity of Maine's lobster population.

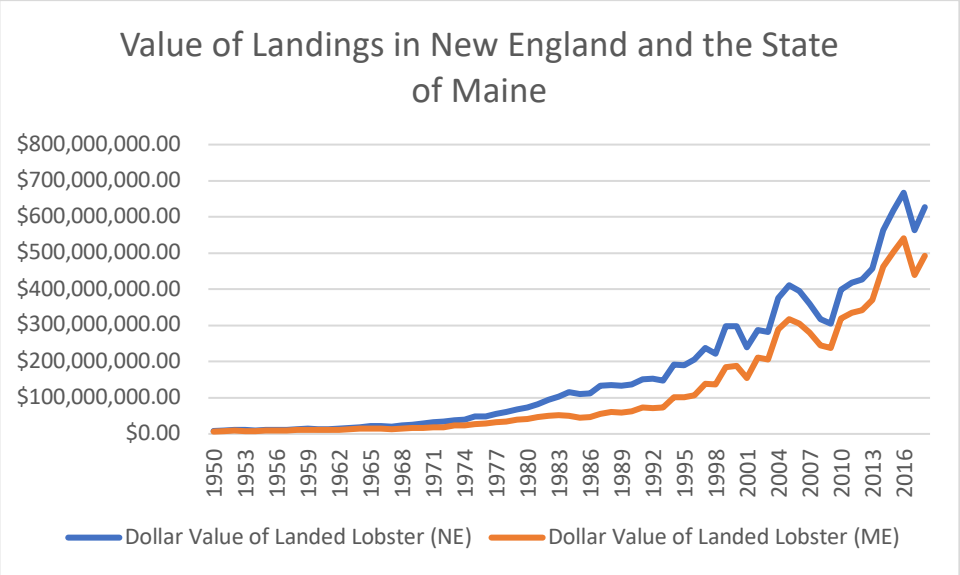
Economic Impact of the Local and Regional Market

Regionally, throughout New England and locally in the State of Maine, a sustainable American lobster harvest in the Gulf of Maine is imperative to the success of the economy. The commercial fishing sector in the State of Maine generates economic activity through employment and stimulating the local supply chain. The general order of the supply chain is; lobster fisher to lobster dealer or co-op, to the wholesaler, who then distributes to grocery stores, restaurants, food service companies and international/national exports. The National Oceanic and Atmospheric Administration (NOAA) measures specific economic impact through sales, income, value-added, and employment.

In 2015, the total landings revenue for the New England region totaled $1.2 billion, with American lobster accounting for $615 million of this total. This was a revenue increase of 55%, with an increase in landings of 54% and increased prices per pound of 101% since 2006 (NOAA, 2017). The State of Maine, on average, contributes 85-90% to the total American Lobster landings in New England. (NOAA, 2017). According to the same report, this increase in landings and landings revenue in New England was attributed to the exponential increase in the American lobster stock in the Gulf of Maine, which off-set the decreases in southern New England. (Fig.7)

Figure 7.

Dollar Value (not corrected for inflation) of Landings in New England and the State of Maine



Note. "Total Landings Revenue of American Lobster in the State of Maine and the New England Region," by the Office of Science and Technologies, 2019, https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings. Copyright 2019 by the National Oceanic and Atmospheric Administration.

The contribution of the commercial fishing sector to the vitality of Maine's economy is measured as the Commercial Fishing Location Quotient (CLFQ)[2]. According to NOAA, in 2014, the CLFQ for the state of Maine was 19.79 (NOAA, 2017). This statistic suggests that levels of employment associated with the commercial fishing industry in the state of Maine are nearly 20 times higher than the national level of employment within the commercial fishing industry. Lobstering in the State of Maine is crucial to supporting lobster fishers and their families, as well as stimulating the state economy. Employment levels and paid wages are examples of induced effects[3] impacting the economy. How these wages earned are spent (maintenance of equipment, crates, and

[2] The CLFQ is the ratio of the percentage of regional and state employment in the commercial fishing sector compared to the percentage of national employment in the commercial fishing sector

[3] The sum total of the multiplicative rounds of spending resulting from labor payments by lobster dealers

other supplies) represent the impacts of indirect effects[4] on the economy (Donihue, 2018).

The lobster supply chain network in the state of Maine is responsible for the distribution, processing, and sales of American lobster locally in the State of Maine and New England region, as well as the national market. In the State of Maine, lobster fishers go through either a dealer or a co-op to get their lobsters from the boat to the market. Dealers often have the same group of lobster fishermen from year to year to whom they supply bait and fuel. At the end of each week, the dealer, having recorded the total landings (in pounds) each day, will settle upon a payment (Billings, 2014). The other option for lobster fishers is to be part of a cooperative. The idea behind the co-op is to allow local lobster fishers to come together and form their own "dealership," splitting the costs and profits, maximizing their profits and cutting the dealer out. Because many lobster fishers lack the expertise and time required to market and sell their product, managers are often hired to get the lobster fishers the maximum profit they can. (Billings, 2014) As stated by Dr. James Acheson, an emeritus anthropologist at the University of Maine, when asked about the benefits of a co-op, he replied,

> "The formation of cooperatives has lifted the veil of secrecy from prices and markets. Since it is common knowledge that the cooperative managers try to get as high a price as possible for their members, the cooperative prices have become the benchmark used by all fishermen in Maine…" (Billings, 2014).

In effect, the co-op prices have become the "benchmark" for other lobster fishers to assess whether or not they are being treated fairly by their dealer. This dynamic between

[4] The business-to-business made by the lobster dealer or lobster fisher that have a multiplicative effect on the state and regional economy

lobster fisher and dealer, and lobster fisher and co-op has become important in the supply chain management of the American lobster market in the State of Maine.

Once the dealer buys the lobster, it is put on a truck or sent to a holding pound and is typically sold to a second-tier dealer or wholesaler (Billings, 2014). Once the lobster is in the hands of the wholesaler, it is sold and shipped to national and international importers such as China and Canada, food service companies, restaurants or supermarkets (Billings, 2014). All of these different parts make up the complex lobster supply chain within the State of Maine and across the national and international markets. To measure the economic impact of the lobster supply chain in the state of Maine, the direct effects[5] were measured in a study conducted by Colby College called, "Lobsters to Dollars" (Donihue, 2018). The study found that dealers surveyed spent a total of $84,575,388 on goods and services in 2016, which resulted in an estimated economic output totaling $36,212,514 of indirect economic activity. The total economic output resulting from the lobster supply chain (sum of the direct, indirect, and induced effects) in 2016 amounted to $967,675,313. The supply chain also supported a total of 5,586 jobs associated with "dealer operations". According to the U.S. Bureau of Economic Analysis, in 2016, the state of Maine's total GDP was $59,753,900,000, meaning the lobster supply chain alone contributed nearly $1 billion to this overall figure. The lobster supply chain within Maine is only a part of the economic impact that lobstering has on the State economy. Exports to national and international markets also play a key role in determining economic impact.

National Market

[5] Direct effects in an economic impact analysis include labor services and indirect effects include business-to-business transactions

American lobster took off in the national market in the 1930s when Canada's Emile Paturel began freezing lobster, allowing it to be shipped across the country by train. By the 1950s, lobster was nationally considered a luxury food. It became the food of Hollywood and Las Vegas movie stars. Vacationers looked at lobster as a luxury after the influential Rockefeller family was noted to enjoy lobster, serving it at parties and consuming it at dinner parties and special functions (Billings, 2014). The lobster market in the United States is the most valuable commercial fishery in the United States, with a landed value in 2015 of $620 million. The state of Maine accounts for 80% of the total landings in the United States that contribute to this value (Mills, Pershing & Hernandez, 2017). As the lobster industry in the Gulf of Maine has such a significant contribution to the national market throughout the United States, its continued prosperity is imperative for the future success of the Maine economy.

Economic Impact of the National Market

Across the United States, American lobster has become a popular commodity being served in restaurants from the local McDonald's throughout New England to high-end restaurants such as Street & Co in downtown Portland, Maine. Over the decades, American lobster has become readily available to Americans, at all price ranges. Throughout New England, at select McDonald's locations in the summertime, one can walk in and buy a lobster roll, also known as a "McLobster" for only $9 (Bowerman, 2016). In contrast, a higher-end restaurant, such as Street & Co, serves a grilled lobster dinner in butter and garlic at $41 (Design, 2019). As a result of an increase in landings yielded from the Gulf of Maine in recent years, the lobster industry in the United States has worked to increase demand within restaurants. Lobster is made available and

affordable to the average consumer through incorporation into simple dishes such as soups, pasta dishes, salads, etc., (Billings, 2014). The recent lobster population boom in the Gulf of Maine has contributed to the exponential increase of lobster landings, and increased revenue yielded in the national market (NOAA, 2017).

Although an overall positive trend is evident in the national market, the regional nurseries in southern New England are currently facing the adverse effects of climate change. The consequences of these effects are widespread through the health of the lobster stock and local economies in the region. Any negative changes within the regional economy of southern New England impact the state of Maine's economy and lobster stock.

American Lobster is currently the most valuable single-species fishery in North America valued at $1,670,000,000 (Goode, Brady, Steneck & Wahle, 2019), with the state of Maine controlling a large portion of this national market, and much of the international market. Over the last several decades, the state of Maine has been a leading contributor to the national lobster market, accounting for the highest landings in the United States for the last 36 years (NOAA, 2017).

The International Market

The international market for American lobster was first recognized in the 1950s when frozen lobsters were shipped across the world on planes (Billings, 2014). Since this time, over the last several decades, the international market demand for American Lobster has been consistently high. Ranging in location from Canada to Asia, people demand lobster, both live and frozen. In 2017 alone, the United States exported 35.2 million pounds with a value of $287.0 million to Eastern and Southern Asia (NOAA,

2016). Over the last several years, China has ranked as one of the top five importers of American Lobster since 2014 (US Census Bureau, 2020). Most recently, media attention is drawn to the trade war between the United States and the United Nations and China. These recent tensions have led to tariffs that China's government placed on the importation of American Lobster. Though this political factor is significantly influencing the economies of the United States and Maine specifically, this paper will be focusing less on economic policy, and more on the environmental factors potentially influencing the international lobster market and the state of Maine.

Economic Impact of the International Market

For several decades, the success of the state of Maine's economy has been reliant on exports to the international lobster market, that is, the demand from other countries for American Lobster from the Gulf of Maine. The world's top lobster importers are Canada, China, and Australia. ("Trade war affecting the local lobster market", 2018). Beginning in 2010, China became one of the leading importers of American Lobster from the United States and specifically, Maine. According to an article published by CNBC, the recent boom in Chinese demand for American Lobsters is attributed to the growth of the middle class. Lobster is viewed as an "affordable luxury", making it a more affordable option than other Chinese seafood ("Lobster-crazy China sets Record", 2017).

In 2014, the state of Maine exported approximately $265,635,694 worth of lobster around the world. China consumed $16,834,797 of that total ("Maine's Export Overachievers", n.d.). Since 2014, as the lobster stock in the Gulf of Maine has boomed, high rates of trade have continued as well. In 2017, Maine exported approximately $128,600,000 worth of American Lobster to China (Valigra, 2018). As the trend

continued, in the first three months of 2018, the United States exported around 7,000 tons of American Lobster, and China imported 59.6% of this ("Trade war affecting the local lobster market", 2018). As tariffs have taken over exports from the United States of American Lobster to China, the United States has turned to Canada to export the stock abundance.

In July of 2018, the state of Maine exported $43.72 million worth of American Lobster to Canada, which was a 100% increase from the previous year (Valigra, 2018). Following the trade tariff of 25% imposed by China against the United States on July 5, 2019, Maine dealers began shipping lobster to Canada, allowing them to export directly to China, thereby avoiding the Chinese tariff (Valigra, 2018). As a result, the state of Maine's exportation of American Lobster from the Gulf of Maine to China decreased, and Canadian exports of live lobster to China increased by 58% between July of 2017 and July of 2018 (Valigra, 2018).

Currently, tariffs imposed on the United States are the biggest threat to the national and local economy when looking at the upcoming season. However, in looking at long-term economic projections of the state of Maine's economy, climate change could have a much more severe and detrimental effect in the long-term. The impact of climate change will be far-reaching, affecting ocean water temperatures in the Gulf of Maine, the health of the American Lobster stock in the region, and the future of the industry. As stated in the 2013 State of the Gulf of Maine Report: Commercial Fisheries: "The health of fishery resources in the Gulf of Maine and economic well-being of fish harvesters and fishing communities depend on the overall health of the ecosystem." (Gulf of Maine, 2013) A collapse of the fishery would be detrimental to the state of Maine's economy.

CHAPTER 2

CLIMATE CHANGE IN NEW ENGLAND

Climate change, a term often interchangeable with "global warming", is defined as the long-term change in the average weather patterns that define Earth's local, regional and global climate (Shaftel, 2019). Beginning in the industrial period (~1880), Earth's global temperature began to rise from human activities such as the burning of fossil fuels, leading to increases in greenhouse gas in Earth's atmosphere (Lindsey, 2020). Consequently, the Earth's oceans have absorbed approximately one-third of the human-produced carbon dioxide (Hoegh-Guldberg, 2010). As a result of the rise in greenhouse gas emissions, studies have shown that global temperatures have risen by approximately 0.2°C per decade over the last 30 years (Hoegh-Guldberg, 2010). Though these increases in global temperature are having detrimental impacts on habitats around the world, this research will focus primarily on the inherent negative effects that climate change is having on the habitat of the American Lobster in the Gulf of Maine.

Climate Change on a Global Scale

Research has shown that dating back to the industrial revolution (~1880), Earth's global climate has been rising as a result of an increase in greenhouse gas emissions. There are many different causes behind climate change, the most prominent being anthropogenic CO_2, which has presented as a rise in global temperature (Islam and Khan, 2019). Since 1880, the combined global ocean and the land temperature has increased at approximately 0.07°C per decade (Lindsey and Dahlman, 2020). According to the same study, the incremental increase of global ocean and land temperatures since 1981 has

been 0.18°C, indicating that Earth's warming process has been exponentially speeding up since 1880. As a result of the rise in air temperatures and greenhouse gas emissions, global ocean water temperatures have also risen.

The rise in Earth's climate has resulted in a subsequent rise in the temperature of the world's oceans. According to Doney and Rosenberg (2014), the ocean helps to regulate climate by having such a high heat-storing capacity. This factor has contributed to the rise in global ocean temperatures. Over the last 100 years, the upper layers of Earth's oceans have warmed by 0.6°C (Hoegh-Guldberg & Bruno, 2010). As cited in the same study, the rises in Earth's ocean temperature are ongoing. For example, in January 2010, Earth's ocean surface temperatures were the second warmest on record. As this trend of warming continues, the effects will be far-reaching, as can already be seen in New England ocean water temperatures.

Increases in Earth's ocean water temperatures are not the only problem. As cited in Doney and Rosenburg (2014), atmospheric levels of carbon dioxide have risen by ~40% when compared to pre-industrial levels. According to Hoegh-Guldberg and Bruno (2010), the world's oceans have absorbed approximately one-third of the carbon dioxide produced by humans. The resulting changes being in ocean pH and an overall increase in acidity. To be specific, over the past 30 years, the surface layers of Earth's oceans have experienced a decrease of 0.02 pH units, resulting in an overall decrease of 0.1 pH units since the pre-industrial period (Hoegh-Guldberg and Bruno, 2010). By the end of this century, the pH of the global ocean is predicted to decrease by an additional 0.3-0.4 units (Keppel, Scrosati, and Courtenay, 2012). The effects of a more acidic ocean are overall detrimental to most marine life and will likely reduce the growth and survival of shellfish

stocks in all regions (Doney and Rosenburg 2014). Lobster is the state of Maine's most valuable shellfish, and as such, assessing the risks of a warming and more acidic global ocean to American lobster is imperative to the future success of the industry in the Gulf of Maine.

Climate Change in the Gulf of Maine

The state of Maine has been subject to rising land and water temperatures over the last two centuries, with the rate of temperature increases beginning in 1960 (Fernandez, 2020). While the effects of climate change are felt state-wide, the effects of the Earth's rising land and water temperatures are magnified regionally in the Gulf of Maine. The Gulf of Maine is a semi-enclosed portion of the Atlantic Ocean spanning 36,000 square miles of deep basins and shallow bank and is currently home to around 3,000 sea creatures (Gulf of Maine Association, n.d.). Naturally occurring variations in water temperature are the result of cold currents from the north, mixing with warmer currents from the south, compounded with warmer air temperatures in the summer, and cooler air temperatures in the winter (Fernandez, 2015). Trends in ocean water temperature increases in the Gulf of Maine were noticed in the early 1980s, with the effects of this temperature increase also documented.

Just how fast has the ocean water temperature been rising? Between the years of 1982 and 2013, the surface level temperature in the Gulf of Maine rose at a rate of approximately 0.03°C per year, (Pershing, 2015) compared to an increase of 0.01°C of the global ocean (Fernandez, 2020). As cited by Fernandez (2015), since 2004, the rate of warming in the Gulf of Maine rose to 0.23°C per year, which is a rate faster than 99% of the world's oceans. These increases in temperature are documented to be related to

human activity since the industrial revolution that has led to the consistent increase of atmospheric greenhouse gas concentrations (Fernandez, 2020). Additionally, atmospheric warming affects the rate of ocean warming, and in turn, ocean circulation (Fernandez, 2015). For example; the effects of increased levels of greenhouse gas on the Atlantic Meridional Overturning Circulation (AMOC)[6]. Changes in climate conditions that continue affecting the Gulf of Maine's temperature will have important implications for the future survival of the American lobster.

There have been several studies conducted projecting future ocean water conditions in the Gulf of Maine should current climate conditions in the State of Maine continue. Most recently, Kleisner et al., (2017) predicts that under a continuation of current climate conditions, the bottom ocean water temperature in the Gulf of Maine could increase by as much as 3.9°C within the next 80 years. Implications of this temperature increase suggest that the lobster population and landings may start declining in the short-term (Rheuban, Kavanaugh & Doney, 2017; Le Bris et al. 2018, Oppenheim et al. 2019). With these current projections, the state of Maine must prepare for the progressing changes to the biological conditions in the Gulf of Maine to protect the commercial lobster industry and economy.

[6] The Atlantic Meridional Overturning Circulation (AMOC) is an ocean circulation system that is characterized by the northward flow of warmer salty water to the top layers of the Atlantic and the southward flow of cooler salty water to the deeper layers of the Atlantic (Delworth et al., 2008).

CHAPTER 3

THE IMPACTS OF CLIMATE CHANGE ON THE LOBSTER FISHERIES

While the temperature increases outside the Gulf of Maine in southern New England are closely associated with collapsing lobster fisheries in Connecticut and Rhode Island, they have thus far had positive impacts on the lobster population in the Gulf of Maine. While lobster landings have significantly decreased in southern New England over the last several years, lobster landings in the Gulf of Maine have dramatically increased, making the Gulf of Maine lobster fishery the most valuable single-species fishery in the United States (NOAA 2017, Goode, Brady, Steneck & Wahle, 2019).

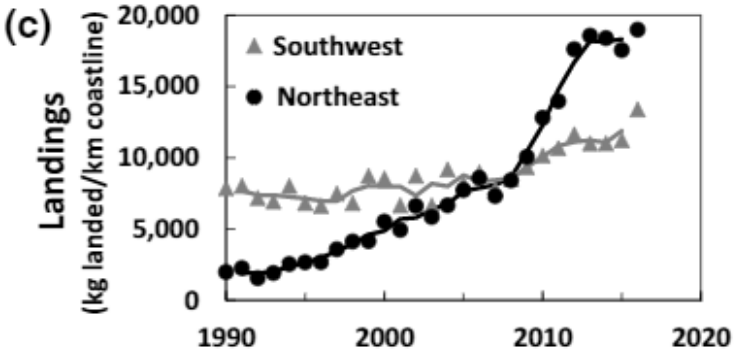
Current State of American Lobster in the Gulf of Maine

In Goode et al., (2019), trajectories of lobster landings in the Gulf of Maine were split into two periods; linear growth (~1989-2008) and geometric growth (~2007-2015). The study found that the northeastern region of Maine's "summer maxima" temperature ranges from 11-13°C, while in the southwestern region of the Gulf of Maine, the summer maxima ranges from 16-18°C. The differences in temperature ranges between the two regions in the Gulf of Maine, resulted in the recorded landings in the northeastern region being 80% higher per unit length of coastline than those in the southwest (Goode et al., 2019). These data prove that the differences in the distribution of American lobster as a result of a contrast in environmental temperatures have led to a northeastward shift in landings. Goode et.al., (2019) cites that the overall warming of the ocean water temperatures in the northeast region of the Gulf of Maine has made a more extensive range of depths fit the ideal thermal conditions than the southwestern regions, attributing

to the swell of landings in the northeastern region over the southwest region. (Fig.8) Although climate change is not yet negatively impacting the Gulf of Maine's lobster stock as it has in southern New England, the question remains whether a future downturn is on the horizon.

Figure 8.

The Trajectory of Landings per Unit Length of Coastline in the Southwest and Northeast Regions of the Gulf of Maine



Note. "The Brighter Side of Climate Change: How local oceanography amplified a lobster boom in the Gulf of Maine", by Global Change Biology, 2019, https://onlinelibrary-wiley-com.wv-o-ursus-proxy02.ursus.maine.edu/doi/epdf/10.1111/gcb.14778. Copyright 2019 by The Authors.

Current rates of rapid warming in the Gulf of Maine pose future threats to the State of Maine's most valuable marine species, the American lobster. While current conditions in the Gulf of Maine remain suitable for the American lobster, changes in the ocean's pH levels and the continued rise in ocean water temperature are negatively impacting the lobster population in southern New England. As climate change progresses throughout the coming decades, the environment and health of the American lobster in Maine will change.

The Future of Maine's Lobster Fisheries

In reading popular press, one could easily come away with the impression that changing environmental conditions are having only detrimental effects on the American lobster stock in the Gulf of Maine. Literature citing negative factors such as increased ocean acidification and warming ocean water may be misleading in evaluating the current state of the American Lobster stock in the Gulf of Maine. The information presented will aim to take a deeper dive into the primary scientific literature that more fully and accurately depicts the current knowledge of the effects of climate change on the Gulf of Maine and its lobster industry. Additionally, this information will assess how current conditions in southern New England are adversely affecting the lobster stock, and how continued warming could create potential problems in the future for lobster fisheries in the Gulf of Maine.

While the lobster stock in southern New England has dwindled over the last decade, essentially wiping out the lobster industry in that region, the population of American Lobster in the Gulf of Maine has exponentially increased. Although the Gulf of Maine population seems to be thriving in current conditions, there are suggestions of potential future threats to the industry. These threats include but are not limited to, increased rates of shell disease as a result of warming temperatures. As these threats begin to affect the lobster stock in the Gulf of Maine, will the scale of these environmental impacts have a detrimental effect on the economy?

Temperature Increase

Steady increases in ocean water temperature have had a significant negative impact on the lobster stock in southern New England, but positive effects in the Gulf of Maine. In southern New England, the temperature has adversely impacted larval settlement, disease prevalence, and northward migration. These factors have all led to the slow destruction of the lobster industry in southern New England over the past several decades. Wahle, Dellinger, Olszewski & Jekielek (2015) cite that summer water temperatures in southern New England now exceed the 20°C thermal threshold frequently, resulting in decreased larval settlement and subsequent migration away from nurseries in southern New England and northward to cooler waters in the Gulf of Maine. According to the same study, this decline of larval settlement in Rhode Island coincided with a summer temperature rise of 0.09°C per year since 1990. Additionally, this rise in temperature pushed the thermally favorable habitat of the lobster stock northward to cooler waters (Wahle et al., 2015). The implications of these results for nurseries in the Gulf of Maine remain unclear and raise the question of whether they will soon face the same problems.

Although ocean water warming has largely had a positive effect on the lobster fishery in the Gulf of Maine, the effects of future warming are less clear. There are implications that by the end of this century in the southwestern portion of the Gulf of Maine, levels of warming may be high enough to be stressful for the American lobster stock (Le Bris et al., 2018). Ocean water temperatures in the Gulf of Maine have increased at a rate of 0.03°C per year since 1982, which is three times the global rate (Kleisner et al., 2017). In 2004, the warming rate accelerated to 0.23°C per year.

(Kleisner et al., 2017) Despite this accelerated rate of warming, Rheuban, Kavanaugh & Doney (2017), found that maximum monthly bottom temperatures in the Gulf of Maine have so far remained below that 20°C threshold. However, future projections warn of advanced warming in the Gulf of Maine that could result in an increase in days above the 20°C threshold throughout inshore areas. By 2050, the historical mean of bottom ocean water temperature could increase by 1.2-1.4°C (Rheuban et al., 2017) and 3.9°C by the end of this century. (Kleisner et al., 2017) When looking at future projections, the Gulf of Maine has the most intense warming potential. (Rheuban et al., 2017) Given these projections, for American lobster to remain in a sustainable thermal habitat, the stock will be forced to move out of the inshore areas, to the boundaries of the Gulf of Maine or northward towards Canada.

Shell Disease

As water temperatures continue to rise in Connecticut and Rhode Island, Epizootic Shell Disease (ESD) has been an influential factor in the increase in mortality rates among the American Lobster population in southern New England. Shell disease is an epizootic disease found on the shells of lobsters. It is believed to be primarily caused by the bacterium, *Aquamarina,* as well as a lobsters' increased susceptibility as a result of warming ocean water temperatures (Kircun, 2019). The disease is distinguishable by visible, circular lesions on the top of the carapace. The few weeks when a lobster molts its outer shell, and the new shell is still soft, is when they are most susceptible to shell disease (Kircun, 2019). Shell disease increasingly became a problem for the lobster stock in southern New England throughout the 1990s, originating in the inshore areas of Connecticut and Rhode Island (Gomez-Chiarri and Cobb, 2012). Since that time, shell

disease has affected up to 30% of observed animals varying from year to year (Atlantic States Marine Fisheries Commission, 2015). Shell disease is mainly brought on by environmental stressors that lead to an unsuitable thermal environment and is most prevalent in egg-bearing females (Atlantic States Marine Fisheries Commission, 2015). Females are particularly at risk because they do not molt their shells while carrying eggs, which may delay the molting process for up to 6 months, allowing the disease a greater time to enter the bloodstream. Strong and healthy females are necessary for sustaining the stock population (Kircun, 2019).

When ocean water temperatures exceed the ideal thermal threshold, lobsters are put under biological stress resulting in an increased prevalence of shell disease (Le Bris et al., 2018). As found by Howell (2012), the number of days with ocean water temperatures exceeding 20°C was "significantly correlated" to the prevalence of lobsters exhibiting signs of shell disease. These conclusions were drawn from Stevens (2009), a study in which 55 shell-diseased lobsters were monitored for one year. By the end of the study, 24% died of shell disease-related causes (Howell, 2012).

While shell disease has been a significant problem in southern New England, according to the American Lobster Stock Assessment Report, shell disease was first reported in Maine in April of 2003, with less than 0.5% of the lobster stock being affected between 2003 and 2004. Between the years of 2005 and 2012, it was reported that between 0.2 and 0.6% of the annual lobster catch was infected with shell-disease. In looking at this report, it is clear that shell disease is not yet a critical problem in the state of Maine.

Both the northward shift and increased rates of mortality due to the prevalence of shell disease in southern New England have resulted in the population decrease and fall in the number of commercial landings within the industry. Although nurseries in the Gulf of Maine are not yet facing these problems, analyzing the current conditions in southern New England will guide future research in projecting the potential problems associated with shell disease in the Gulf of Maine in the future.

Ocean Acidification

Shell disease is not the only potential threat to the lobster industry in the state of Maine. Although shell disease is currently only affecting a relatively small fraction of the lobster stock in the Gulf of Maine compared to nurseries in southern New England, several studies indicate that the level of pCO_2 predicted by the end of the century could have adverse effects on the future lobster stock in the Gulf of Maine.

As ocean waters around the world rise, the ocean's pH levels are changing as well. According to the Intergovernmental Panel on Climate Change, ocean acidification has led to an overall decrease in seawater pH by 0.1 units since the Industrial Revolution, and a further decrease of 0.3-0.4 units is predicted by the end of this century (2100).

Research on the effects of ocean acidification on the American lobster is in its early stages. Keppel et al., (2010), evaluated how reductions in ocean pH affect the growth and development of American lobster. The study found that in each of the first three stages of development in the larvae's life, the length of the carapace was negatively affected in water with a higher level of acidification. A smaller carapace can lead to complications with the larvae's overall growth and development. When it came time for the lobster to molt its shell, in the higher acidification, it took more than twice the amount of time than

in the control tank with current pH levels. At stage II of development, it took the larvae 7.3 days to molt to stage III, whereas it took five days in the control tank. Molting times continued on average to be slower in the water with an elevated pH as opposed to the control tank. Mortality rates were also elevated in the water with an increased acidity level. In conclusion, lobster larvae have exhibited decreased "performance" in ocean water with elevated levels of acidity (Keppel, Scrosati & Courtenay, 2012). Should changes in ocean pH continue throughout the end of this century, the lobster stock in the Gulf of Maine and the state's industry will face new challenges. One of these challenges being a shift of the population searching for a more biologically suitable habitat.

As the American lobster population recedes from southern New England in the face of climate change, it has been increasing in a northeastward direction and across a greater range of depths in the Gulf of Maine (Good et al. 2019). Kleisner et al., (2017) proposes that future projections indicate that there will be consistent increases in the distance between a suitable environmental habitat and fishing ports in the Gulf of Maine.

Population Growth Factors

One of the biggest questions facing Maine's lobster industry today is how the lobster stock in the Gulf of Maine is booming, as the lobster stock in southern New England is collapsing. As stated by Dave Cousens, former president of the Maine Lobstermen's Association, when asked about the effects of climate change on the state of Maine's lobster industry, "Climate change really helped us for the last 20 years…but, climate change is going to kill us, in probably the next 20." (Albeck-ripka, 2018). A few factors have contributed to the recent boom. As cited in Le Bris et al., (2018), the recent

warming of the ocean water in the northwest Atlantic have had a significant role in the population boom in the Gulf of Maine and subsequent collapse in southern New England.

Another factor contributing to the population boom of the American lobster in the Gulf of Maine is predation pressure. A predator that at one time posed the greatest threat to the American Lobster, the Atlantic cod. In recent years, the cod fishery in the Gulf of Maine has been virtually depleted from overfishing and warming ocean water temperatures that made for an unsuitable environment (Wahle, Brown & Hovel 2013, Le Bris, et al., 2018). The depletion of cod and other predatory groundfish that prey on juvenile lobsters in the Gulf of Maine has been a decisive factor in the growth of the population. However, as favorable environmental conditions pass, it will take more than depleted groundfish populations to keep the lobster stock in the Gulf of Maine productive.

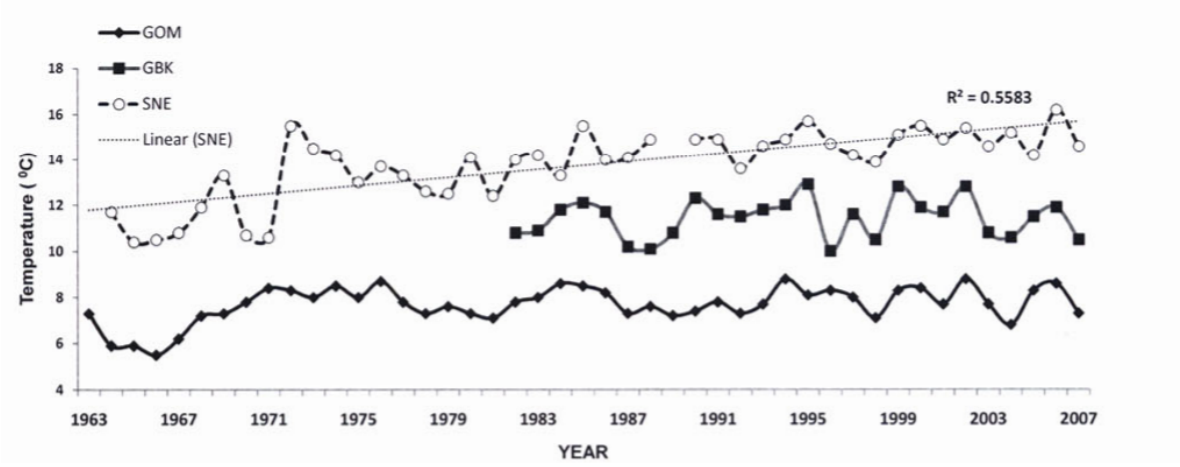
Problems presented by the current environmental conditions have resulted in a negative economic outlook for the region. Specifically, the index of growth and decline of the industry in southern New England. As the environment changes the biological habitat of the American lobster in southern New England, the number of landings will continue to decline, and new economic challenges will be presented. This trend is important for the state of Maine to observe. As stated in the State of the Gulf of Maine Report on Commercial Fisheries, “The health of fishery resources in the Gulf of Maine and economic well-being of fish harvesters and fishing communities depend on the overall health of the ecosystem.” (Lapointe, G., 2013).

Trajectories of the Lobster Stocks in Southern New England

In 2016, American lobster fishery in the United States had a combined value of more than $1.67 billion (Goode et at., 2019). This valuable shellfish thrives in a narrow range of ocean water temperatures, with ideal thermal conditions being between 12°C and 18°C (Rheuban et al., 2017). According to Goode et al., (2019), 12°C is the low of the temperature threshold because at any temperature lower, irregular respiration and heartbeat occurs, which is lethal to the lobster. If the lobster should inhibit ocean waters with a temperature higher than 20°C, it will start to exhibit signs of "biological stress" (Rheuban et al., 2017). These temperature thresholds are being threatened due to rising ocean water temperatures in Southern New England. When looking at the historic average bottom ocean water temperatures between southern New England and the Gulf of Maine, it is evident that climate conditions between the two regions greatly differ. (Fig.9)

Figure 9.

Average Bottom Ocean Water Temperatures in Southern New England, Georges Bank and the Gulf of Maine (1963-2007)



Note. "The Status of the Southern New England Lobster Stock", by Howell, 2012, *Journal of Shellfish Research*, 31, p.578, Copyright 2010 by the National Shellfisheries Association, Inc.

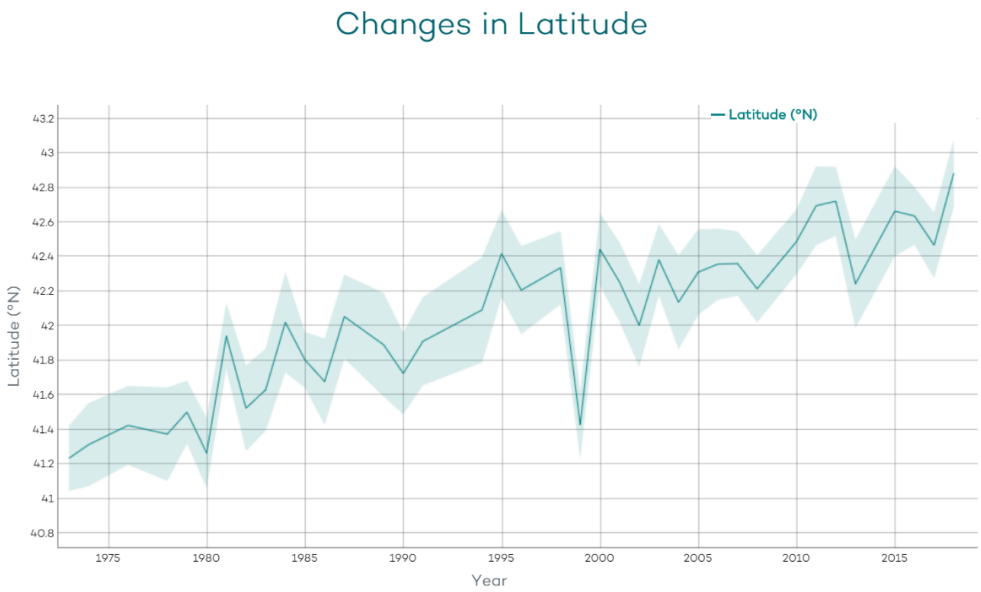
Historically, the ocean water temperatures in southern New England states have conformed to the ideal range of 12°C-18°C. Over the last decade, the increase in the ocean water temperatures of southern New England states has led to nurseries becoming inhospitable to the American lobster (Rheuban et al., 2017). These temperature increases have led to the "poleward shift" of American lobster, a species important to the economic success of the commercial fisheries (Oppenheim, Wahle, Brady, Goode and Perishing, 2019). Current ocean water temperature indexes exhibit noticeable differences in bottom temperatures between Southern New England ocean waters and the Gulf of Maine. Kleisner et al. (2017) showed the average change in bottom ocean water temperature in the Northern (Gulf of Maine) and Southern (Mid-Atlantic Bight/Georges Bank) regions, in the Fall and Spring seasons of the U.S. Northeast Continental Shelf between 1968-2013. The study concluded that in the fall, bottom ocean water temperatures have risen by ~0.8°C in the northern U.S. Northeast Continental Shelf and ~2.1°C in the southern regions. Results from this study were used to construct a projection looking at bottom ocean water temperatures over the next 80 years. The projections show that if current climate conditions continue, the bottom ocean water temperature in the southern regions may increase by as much as ~5.0°C (Kleisner et al., 2017). A temperature increase this drastic would be detrimental to the habitat of the American Lobster in southern New England, indicating that by the end of the century, nearshore fisheries in Southern New England states may not be viable at any point in the year (Rheuban et al., 2017).

The frequency with which these warmer ocean water temperature days occur every year also factors into the northward migration of the lobster population in southern New England. Future climate scenarios not only look at seasonal average temperature

increases, but at the number of the days that a geographic region will experience a day with ocean water temperatures at or exceeding the 20°C, and the frequency with which these days occur. According to Rheuban et al., (2017), studies on future climate projections indicate that if climate change conditions progress at the current rate, nearshore areas in Southern New England could experience an increase of days >20°C by 20-80 days by the end of the century. Locations such as Georges Bank could experience not only an increase of days above >20°C, but an overall rise in temperature, resulting in a yearly mean bottom ocean temperature of >12°C in 2020 (Rheuban et al., 2017). The resulting conclusion being that under current warming conditions, marine species will continue to be forced to migrate northward to colder, more hospitable waters in the Gulf of Maine. (Fig.10)

Figure 10.

Graph of the Latitudinal Shift of the Center of the American lobster Population



Note. "Changes in Latitude", by Rutgers Ocean Adapt: Institute of Earth, Ocean, and Atmospheric Sciences, 2018, https://oceanadapt.rutgers.edu/. Copyright 2018 by Rutgers, the State University of New Jersey

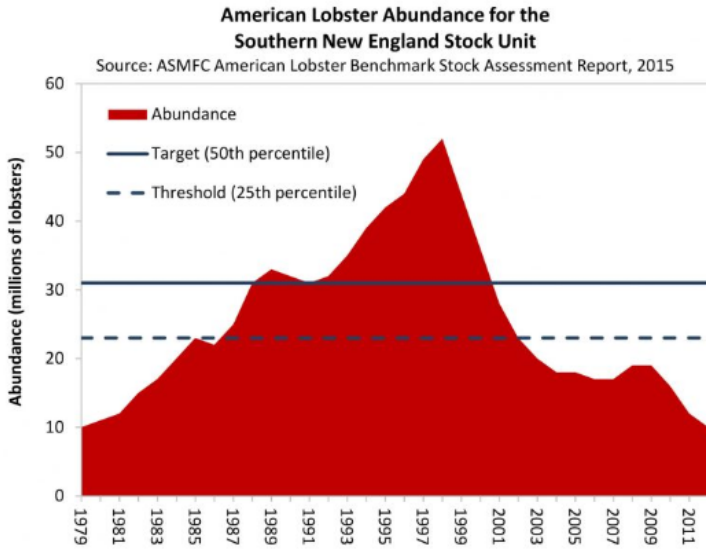
The rise in ocean water temperature in southern New England has led to the northward shift of the lobster population, which is, in part, the result of an increase in mortality rates driven by Epizootic Shell Disease at the southern point of the species' range. Both northward migration and increased rates of mortality due to the prevalence of shell disease in southern New England have resulted in the population decrease and fall in the number of commercial landings within the industry.

Changes in Landings Trajectory

The change in the biological habitat of nurseries in southern New England and the resulting northward shift and increased mortality of the lobster population in the south have had tremendous effects on the number of commercial landings in the region. Historically, fisheries in southern New England accounted for approximately 22% of U.S. landings (American Lobster Stock Assessment Report, 2015). In recent years, the trajectory of landed lobsters in the Southern New England States of Rhode Island and Connecticut have exhibited a sharp decline (NOAA, 2017). According to Howell (2012), the lobster industry in southern New England began to experience a significant decrease in landings starting between 2003 and 2007, with environmental conditions greatly contributing. One method used to determine the state of American lobster fisheries in southern New England is to compare the total number of commercial landings recorded in a year to target and threshold numbers that the Atlantic States Marine Fisheries Commission set as bench markers. In Southern New England, for the abundance of the American Lobster stock to be considered "favorable," the target abundance should be at around 30 million pounds, with the threshold being a little greater than 20 million pounds. (Fig.11)

Figure 11.

American Lobster Stock Abundance in Southern New England



Note. "American Lobster", by Atlantic States Marine Fisheries Commission, 2015, http://www.asmfc.org/species/american-lobster. Copyright 2020 by Atlantic States Marine Fisheries Commission.

As can be seen in Fig. 11, the American lobster abundance in southern New England has consistently fallen below this threshold. According to the 2015 American Lobster Stock Assessment Report, the recorded landings in southern New England fell below the 25% threshold for twelve years straight, and should current climate conditions continue, show little promise of recovering to the point of reaching industry standards (Atlantic States Marine Fisheries Commission, 2015). As the lobster stock in southern New England continues to decline, the number of landings in the state of Rhode Island and Connecticut have been gradually declining. The decrease in American lobster stock and total landings have resulted in the lobster stock in southern New England to be "critically depleted" as deemed by the 2009 Atlantic States Marine Fisheries Commission stock assessment.

As southern New England is experiencing a collapse in the stock of American lobster nurseries primarily due to increasing ocean water temperatures, the Gulf of Maine has experienced an exponential increase and northward expansion (Goode et al. 2019; Oppenheim et al., 2006). Within the past decade, there have been both positive and negative outcomes for the state of Maine's lobster industry as a result of this population surge. The rising temperatures have led to the declines of lobster populations in southern New England and an increase in the Gulf of Maine. The model-estimated mean abundance of the Gulf of Maine stock increased by 515% between the years of 1985 and 2014 but decreased in southern New England by (Le Bris et al., 2018). Economically, although the population increase led to an unprecedented high volume of landings in the state of Maine, in 2012, an unseasonably warm spring that year led to an early molt, leaving the state's supply chain unprepared, resulting in a price collapse (Mills, Pershing, and Hernández, 2017). Seeing how the success of Maine's economy and social identity are so heavily reliant on the lobster industry, it is imperative to evaluate future climate projections to anticipate potential effects on the American Lobster stock in the Gulf of Maine and prevent economic instability within the industry.

CHAPTER 4

CONCLUSION

As climate change has progressed, the effects have proven to be both positive and detrimental to American lobster stocks depending on where the stock is situated along the steep north-south thermal gradient from southern New England to the northern end of the Gulf of Maine. In southern New England, climate change has negatively affected the biological habitat and health of American lobster, for example, by causing increased rates of shell disease and mortality rates. In the southern New England region, larval settlement has been steadily declining over the past several years, due to a rising ocean water temperature and an increase of thermal stress. As warming patterns continue, egg-bearing females will be pushed out of coastal nursery habitats, resulting in the continued reduction of larval settlement and recruitment (Rheuban et al., 2017). Climate change has so greatly affected the American lobster stocks in the southern New England region, that projections show near-shore fisheries to not be viable by the end of this century (Rheuban et al., 2017). As climate change is projected to continue throughout the coming decades, the environment and health of the American lobster in Maine will change. As stated in Oppenheim et al.,(2019), should current climate conditions in New England follow current projections, the lobster abundance the region is currently experiencing will pass as favorable environmental conditions shift northward to the Scotian Shelf in Canada. This northward shift would be problematic for the state of Maine from economic and socio-cultural standpoints.

By contrast, as a result of warming temperatures, the Gulf of Maine has experienced a considerable boom in lobster production. Still, the future of the fishery remains unclear and will depend on the trajectory of future climate warming. In recent years, the state of Maine has accounted for approximately 85-90% of the nation's total American lobster landings, and 79% of total landings revenue since 2006 (NOAA, 2017). The Gulf of Maine lobster stock is crucial to the regional and national success of the commercial fishing industry, as well as the state economy. The value of the American lobster to the State of Maine's economy is far-reaching beyond the supply chain. Other industries in the state such as the restaurant and tourism industry, are also economically dependent on a healthy lobster population to contribute to the state's GDP. Currently, the state of Maine's total GDP ranks at number 44 in the nation ("Annual GDP by State", 2020). Given the state's poor economic performance, it is fair to conclude that a decline in the commercial fishery industry would be detrimental to the future of Maine's economy. A decline in the stock of American lobster in the Gulf of Maine will negatively impact employment rates and the supply chain.

In the current global economic climate, the outlook for the American lobster industry is grim. The spread of Coronavirus is dominating the global market, driving demand for lobster down (Martinez, 2020). With stay-at-home orders throughout the country and lockdowns around the world, lobster fishers are having a hard time getting wholesalers to buy their stock. According to a recent report, wholesale lobster prices hit $1.25/pound, which is a 33% decrease from March of 2018 (Press, 2020). One of the main reasons for demand decreases is the closure of restaurants and cancelation of events. For example, under the state of Maine's stay-at-home order, restaurants are unable to

open to the public, the business has been reduced to take-out only, decreasing the need for fresh lobster. With many of Maine's lobster fishers struggling to maintain equipment and keep staff aboard, it will take a significant turnaround and a great deal of time for the industry to recover.

Data Limitations

There were several data limitations throughout the process of writing this thesis. In looking at projections of the future, it is nearly impossible to predict how climate change will progress and whether American lobster will have the ability to adapt to their changing environment exactly. Changes in policy could slow the effects of climate change, while a lack of policy implementation could accelerate the effects. Additionally, had there been more time to complete the thesis, it would have been possible to research the impacts of current world events, such as the Coronavirus, on the lobster market and local economy. Recommendations for future research would be to wait until more research on future projections is published. There are a few research papers in the process of being written; however, they are not yet copyrighted, so a citation was no possible.

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AUTHOR'S BIOGRAPHY

Bryce Nitchman was born in Washington, D.C., and moved to Scarborough, Maine, at age 2. She graduated from Scarborough High School in 2016 and attended the University of Maine to study Finance and Economics. While at the University of Maine, Bryce was a member of the Class of 2020 Class Council, Alpha Phi, and Order of Omega.

Upon graduation, Bryce is moving to Chicago for her first rotation in CVS/Aetna Health's 3-year Financial Leadership Development Program. She will be working with their Internal Audit and Compliance team. In the future, she hopes to continue her education and obtain her MBA.