Drew University College of Liberal Arts

Benefits of the Reintroduction of the Eastern Oyster *(Crassostrea virginica)* in New York State

A Thesis in Environmental Studies and Sustainability

By:

Kyle J Majid

Submitted in Partial Fulfillment of the Requirements for

the Degree of Bachelor in Arts

with Specialized Honors in Environmental Studies and Sustainability

May 2019

Abstract

The eastern oyster, *Crassostrea virginica*, was once abundant in the coastal regions of New York State during the 1800s. In fact, the vast amount of oysters located in and around New York City prompted the bivalves to become a main element of the local culture and cuisine during this period. Consequently, the city earned its nickname as the "Oyster Capital of the World." However, by the mid 1920s, the large oyster population crashed due to overharvesting and deteriorating water quality resulting from increasing pollution. Almost 100 years later, the water quality has improved dramatically, allowing for New York State's coastal regions to become a suitable habitat for *C. virginica* once again. This study aims to show that *C. virginica* is a prime candidate for reintroduction efforts in New York State. The reasoning behind my choice of focusing on *C. virginica* is because of its ability to provide large-scale environmental benefits, such as water filtration, flood control, and a habitat base in the water it inhabits. Additionally, the species is rooted deeply in the historical and current culture of the region, as well as, having the potential for being the basis of a growing food industry. Recent water quality data were accessed to better determine a plan of action for reintroduction. I theorized that a two-part plan, which divides the region into two major subsections, roughly corresponding to New York City and Long Island, would allow for a more comprehensive reintroduction effort.

Acknowledgments

I would like to start off by thanking everyone at Drew who has supported and encouraged me throughout my thesis process. I would like to especially thank my thesis committee, Professor Joshua Kavaloski for his crucial role in providing an outside perspective on the matter and Professor Tammy Windfelder for her invaluable knowledge, wisdom, and guidance throughout the whole procedure. I am inconceivably grateful to Professor Caroline Maier for her enthusiasm, hard work, and dedication not only as my thesis advisor but also as an academic advisor, mentor, and most importantly friend. You have seen something in me that I did not see in myself. For that, I cannot thank you enough for this thesis would not have come to fruition without you. Additionally, I would like to give a special mention to prior professors, Professor Sara Webb, Professor Paris Scarano, and Professor Phil Mundo, for it's through the demonstration of their passion in their fields of study that has inspired me to pursue the path I am on.

Finally, I would like to acknowledge my family, for their unyielding support of my academics, but also for bearing with my constant complaints, grumpy attitude, and late nights throughout my final semester at home. I reserve the most important acknowledgement for my mother Christine. The woman who has been at my side since the day I could walk and has single handedly worked so hard to provide me the opportunity to attend the university of my choice. I cannot put into words the gratitude I have for you and all that you have done. Simply put, thank you Mom.

Table of Contents

Introduction

The Eastern Oyster (*Crassostrea virginica*), an unassuming shellfish, has had large influence on New York, intertwining in the region's culture, economy, and environment. After a continual increase in popularity as a food source during 19th century, the oyster eventually faced large scale crashes in the mid 1920s (Nigro, 2011). Today, efforts are being made to bring oyster populations closer to their pre-crash abundance.

The growth in popularity of slow food and locally sourced goods has spread across lower New York State. Typically associated with agricultural products, the movement has shifted to include seafood as well. With oysters rising in popularity again, there is more emphasis on where these bivalves are farmed. As such, oyster farms are popping up across the Eastern Seaboard (Wolf, 2013).

These new farms have spurred an economic resurgence in the oyster industry. The center of oyster harvesting in New York has now shifted east from New York City to the more suburban Long Island. With higher water quality, the oyster industry is expected to continue to grow. To deter another potential crash, local governments have implemented environmental and business laws and restrictions to better manage the increasing number of oyster reefs in their waters.

The increasing abundance of oysters in New York State for harvesting has beneficial externalities. Water control and filtration and habitat rehabilitation are some of the environmental benefits stemming from oyster reintroduction. As a result, volunteer and governmental groups alike have begun reintroduction efforts for the environmental benefits alone with no intention of harvesting for profit.

The synthesis of these three elements (culture, economy, and environment) has provided support for oyster reintroduction efforts. This thesis will discuss in depth how these elements are reflected in the relationship between oysters and lower New York State. Additionally, I will outline a plan to better manage the increasing oyster reintroduction and harvesting efforts.

Crassostrea virginica

Crassostrea virginica, more commonly known as the eastern oyster, Atlantic oyster, or American oyster, is a "true oyster" species. True oysters belong to the scientific family Ostreidae. This means that the organism has a central abductor muscle that open and close the two shells. It is native to the coastal Atlantic waters of North America from New Nova Scotia to the Gulf of Mexico (See Appendix A). *C. virginica,* like most bivalves, is a sedentary benthic filter feeder at maturity. Filtering 1.5 to 10 liters of water each hour, they predominantly filter out plankton and other suspended particles larger than 5 μm when feeding (NOAA, Chesapeake Bay Office, n.d.; Riisgård, 1988). *C. virginica* are known to grow on almost any hard surface, even on top of other oysters. As such, they form extensive oyster reefs or beds in the waters they inhabit. Soft substrate such as sand and mud can hinder oyster growth and result in premature death if the organisms became covered by the substrate (NOAA, Chesapeake Bay Office, n.d.). Oysters prefer areas with constant water flow as these locations provide more food passing by in the current.

Though needing a hard substrate for attachment and a current rich in nutrients, *C. virginica* are quite robust. This species can survive in a wide range of temperature, salinity, and dissolved oxygen levels. Research conducted by NOAA suggests that adult eastern oysters can survive temperatures ranging from 35.6 – 96.8 °F (2 – 36°C). They can even survive short exposure to temperatures up to 120.2°F (49°C). Eastern oysters survive in a wide range of salinity as well, from 5 PSU to 40 PSU. The most impressive capability of these mollusks is their ability to survive in waters considered hypoxic by most other marine organisms. Most species need dissolved oxygen levels to be higher than 30%, however *Crassostrea virginica* can survive in water with as low as 20% dissolved oxygen (NOAA, Chesapeake Bay Office, n.d.).

The remarkable tolerance of eastern oysters allows them to be used for environmental restoration. Right now, the conditions of the Long Island Sound and New York Harbor are in the middle of the eastern oyster tolerance range for temperature and salinity. For example, the average salinity of Long Island Sound is about 23 PSU at its western end and 35 PSU at its eastern end (Long Island Sound Study n.d.). This means that if the salinity of Long Island Sound were to rise or drop by a moderate amount, the oysters would still be able to survive. This ability to survive in different salinities and temperatures, especially high salinity, is beneficial to help combat the sometimes unpredictable changes we could see in our coastal waters due to the ripple effects of global climate change. Similar to salinity, the Long Island Sound average temperatures are within the range of tolerance of the eastern oyster. On average the temperature of the Long Island Sound is 37°F (1.6°C) in winter and 69°F (20.5°C) in summer (Long Island Sound Study n.d.). With water temperatures expected to rise, the oyster's ability to survive up to 96.8°F will provide a buffer to the changing conditions that associated global climate change. This tolerance also allows reintroduction efforts to be theoretically more sound, as the initial effort would not be lost in the future due to gradual changes in the local ecosystems due to natural processes.

Benefits

The resilience of *C. virginica*, while an important aspect, is not the reason that a reintroduction effort should be initiated. The main reasons for reintroduction of *C. virginica* come down to three major points: turbidity, reefs, and economics.

The first major reason for reintroduction is the oyster's ability to reduce turbidity. One oyster can filter from 1.5 – 10 liters of water an hour (NOAA, Chesapeake Bay Office, n.d.). This equates to about 63.5 gallons of water a day. By filter feeding, oysters take particles out of the water column. They either consume plankton and microorganisms filtered from the water or they excrete these particles in the form of pseudofeces (NOAA, Chesapeake Bay Office, n.d.). By pulling particles out of the water column, oysters reduce the turbidity or cloudiness of the water around them, leading indirectly to a whole host of environmental benefits. Clear water allows for deeper light penetration into the water column. Since most of the nutrients in marine systems are located in the sediments of shallow littoral regions, the extra sunlight promotes additional plant growth. Aquatic plants are important components in marine ecosystems because they release dissolved oxygen into the surrounding water and take in the carbon dioxide given off by respiration of other organisms. Plants also process and recycle excess nutrients in ecosystems, helping reduce the possibility of large algal blooms and cultural eutrophication events. This is particularly important, as most coastal waters are flooded with excess nutrients from terrestrial activities. Because coastal waters are the prime habitat of oysters, and marine plant species, oyster beds and associated aquatic plant communities can be a barrier between nutrient run off and more open water in the estuaries. This barrier would reduce nutrient pollution and associated algal blooms, such as red tides, that cause both health and economic concerns.

The second major reason for reintroduction is the oyster's ability to form extensive reefs (See Appendix B). Similar to coral reefs, oyster reefs form complex 3D structural components that promote higher biodiversity levels (Meyer & Townsend, 2000). The 3D structure of oyster beds also provides a more direct benefit to humans. Oyster reefs act like living sea walls that can block or weaken waves and storm surges (Meyer & Townsend, 2000; Grabowski et al., 2012). Dense oyster reefs surrounding the coastal regions of New York can reduce the flooding and storm surge effects associated with events such as Hurricanes Sandy and Irene. Areas like Battery Park and lower Manhattan could benefit from the creation of artificial storm surge barriers, but these structures typically disrupt the local ecosystem, water patterns, and can be quite unaesthetic. Oyster reefs, in contrast, would provide a more seamless integration of seawall benefits without damaging local ecosystems or views. Additionally, man-made structures need almost constant maintenance and testing to confirm their durability, typically having a lifespan of about 20 years (Grabowski et al., 2012). Oysters would form a living wall that they themselves would be able to repair and maintain without much human intervention or capital input. 1 hectare (2.5 acres) of oyster reefs is estimated to provide a value of $85,988 per year in coastal protection alone. When compared to the lifespan of manmade structures, 1 hectare of oyster reefs will provide an estimated $1 million to just over $1.5 million in value in 20 years (Grabowski et al., 2012).

There may be concerns about the need to keep oysters beds clear of the shipping channels that crisscross the Port of New York and New Jersey. However, oysters are unable to survive in the deep water of these channels. Oysters typically grow in waters that are between 2 and 26 feet in depth (0.6 to 8 meters) (NOAA, Chesapeake Bay Office, n.d.). Most commercial shipping lanes are at least 30 feet (9 meters) in depth (US Army Corps of Engineers, n.d.). If any stray oysters do begin to grow in the channels, the constant dredging done to maintain the channels would remove any stray oysters that may try to form a foothold. So oysters could be used to protect the at-risk coastal regions without posing a threat to the shipping industry that brings approximately $100 billion into the New York Metro Region (Strauss-Wieder, 2017).

Oysters can also bring capital into the region as well. Oysters are a harvestable resource, not just a natural wall. Like many of the other fisheries in the United States, a thriving oyster fishery in New York State can provide thousands of jobs and bring more money to local communities. Because of the increased demand for seafood, The United States is now the number one importer of fish in the world (NOAA, Office of Aquaculture, 2019). Despite having an established aquaculture industry, the United States is considered a minor aquaculture nation (NOAA, Office of Aquaculture, 2019). Current domestic aquaculture cannot appease Americans' demands for seafood. This leads to a high dependency on foreign seafood imports.

The United States imports approximately 90% of its seafood (NOAA, Office of Aquaculture, 2019). Increasing the production of local oysters, especially near large population centers, would reduce The United States' dependency on foreign seafood. Without considering the environmental benefits, oyster aquaculture is a profitable industry. During 2016, oyster aquaculture generated approximately $192 million in the United States (NOAA, Office of Aquaculture, 2019). The profits are expected to grow since American aquaculture production has increased at a rate of 3% a year as of 2009 (NOAA, Office of Aquaculture, 2019). This rate can grow even faster if the US invests more in domestic aquaculture than in foreign productions.

Why Oysters?

Despite all the economic and environmental benefits of oysters in prior sections, one may still think why oysters? Why not choose some other type of shellfish? I originally chose to focus on *C. virginica* restoration not just for their ecological and environmental benefits, but also, importantly, for their place in New York culture. Oysters, and the food culture associated with them, have been present in New York since pre-Columbian times. Oysters are rooted deeply in the history of the state and continue to have a presence in mainstream New York food culture as well.

Historical Connection:

The oyster, while once abundant in the waters around New York State, is now a rare sight to see. This simple organism is one of the reasons New York City has risen to its current status. While one may think of New York's high rises and yellow taxi cabs, the oyster is more entwined with the history, making, and possibly the future of this urban metropolis. In the past, oysters had a much different connotation than they do today. In present times, we most often associate oysters with high end raw bars and fancy drinks, a dish often reserved for the more fortunate. However, in the past, oysters were so abundant and easily obtained that they were heavily relied upon by the poor. Historically oysters were used as street food and an inexpensive substitute to beef (See Appendix C)(Nigro, 2015). Oysters were everywhere in and around New York City, so much so that many places were named after the oysters themselves. Ellis and Liberty Island were once known as the Oyster Islands, Pearl Street in Manhattan was named for it water front location and was a center of oyster production, and Oyster Bay, New York was named by the Dutch for the vast amount of oysters located in the nearby waters (Nigro, 2015). Yet despite the oysters supporting the vast population of New York City and its surrounding population, the shellfish did have it limits. Expansive population growth, industrialization, and poor reef maintenance led to the collapse of most of the oyster beds in New York Harbor in the early 1920s. The few remaining beds were too contaminated to consume. In 1927, the last of New York City's oyster beds were closed. New York City lost its title of "Oyster Capital of the World" (Nigro, 2015).

In 1976, the US Government passed the Clean Water Act. While New York City's waters did improve as a result, they did not rebound enough to be deemed safe for shellfish consumption. One major concern is for bioaccumulation. Bioaccumulation is the process where organisms store toxic pollutants in their tissues instead of expelling them. While in small doses this accumulation is not threatening to the immediate organism it is detrimental to organisms higher on the It was found that heavy metals are often ingested and accumulate in the soft tissue of oyster leading to concerns of metal poisoning in humans if too may are consumed (Hedge, Knott, & Johnston, 2009). Nevertheless, the majority of waters east of the city, north and south of Long Island, have remained healthy enough according to New York State to still be harvestable.

Parents, relatives, and friends have told me about how, in the late 1970s and 1980s, you could scoop your hand into the waters around Long Island and pull out a whole host of shellfish ranging from clams to mussels, and most importantly, oysters. Every one of these shellfish was eaten raw, straight from the sea. Yet, my generation and those following have been denied this opportunity to partake in what seems to have been a universal component of the Long Island subculture. While most of my generation may have missed out on this component of a Long Island childhood, it is very plausible that future generations will be able to partake in this event again.

Current Connection:

Prior generations grew up on a Long Island community that was focused much more locally than today. People were tied to the sea and to the communities in which they were raised. During the early 1900s things changed. There was a rapid acceleration in technology, the expansion of the Long Island Railroad and the ever-expanding New York population spread onto Long Island. Throughout the mid 1900s, Long Island skyrocketed in population and changed quickly from an assortment of farming towns and remote fishing villages into a complex web of train lines, highways and suburban neighborhoods (Hofstra University Library Special Collection, n.d.). The expansion of transportation services in and out of the city attracted city workers to the newly formed suburbs and began the creation of many of the bedroom communities we see today. Yet, like any true Long Islander, we never forget where we come from and a sort of cultural renaissance is flourishing here. Local anything is a growing trend in Nassau and Suffolk Counties, especially in the food industry. Restaurants are spearheading the movement and have likely been influenced by the pioneering of the wine industry on the far east end of Suffolk County (See Appendix D)(Dooley, 2015). Once Long Islanders got a taste of locally sourced wine, the race was on to find other items we could self produce in the limited spaces between our cookie cutter suburbs. The east end of Long Island, especially the North Fork, is the epicenter of the movement of locally grown food due to its still rural nature and more abundant space. However the restaurants and eateries that provide a demand for locally sourced food have been spreading west into the densely populated villages and towns of western Suffolk and Nassau County (Brosky, 2017).

Despite the limitation of land, as of 2013, Suffolk County is still a top contender of agricultural production in the state of New York. The county is the largest producer of pumpkins, tomatoes, and cauliflower, and is third largest for other produce like peaches and grapes (Suffolk County of Department of Economic Development and Planning, 2015). Suffolk County is in a prime location for locally sourced products. The county contains 1.5 million inhabitants and is located just over the border from Nassau County with an estimated population of 1.3 million (US Census Bureau, n.d.). With such a high population located nearby and relative isolation from the rest of the nation, Eastern Suffolk can easily find local markets to sell its produce. This combination has allowed for just under 70% of all produce produced in Suffolk County to stay within its borders as of 2013 (Suffolk County of Department of Economic Development and Planning, 2015). Long Islanders are becoming acquainted with locally sourced food and the spread of Community Supported Agriculture (CSA) programs demonstrates this change in perspective.

The idea behind CSA is that community members interact directly with farmers, instead of buying produce at the local supermarket. The community members invest money upfront for the farmer in return for produce throughout the season. Due to the upfront payment, the risks associated with the farmer are also spread to community members, while providing the farmer with a more sustainable income (Brinson, Lee, Rountree, 2011). Because of this shared risk, it is in the community members' best interest to support farmers financially (up front payments) but also politically and culturally. In return for community support, farmers are more likely to reinvest into the local community with any additional profits (Brison et al., 2011). This sharing between the local community and the fishermen creates a form of positive feed back loop where both parties can feel the benefits.

With a still healthy agricultural sector, Long Island, specifically Eastern Suffolk, has taken advantage of this ideology. CSAs have been growing in numbers since at least 1990 (See Appendix E)(CSA Alliance of Long Island, n.d.). Yet, this is only the beginning of the true capabilities of the region. Long Island farmers have been cleverly utilizing as much land as possible despite constant urban sprawl. However, to truly take advantage of Long Island's greatest feature, Long Islanders should look to the large, shallow, nutrient rich estuaries that surround the island. Instead of just focusing on the CSA and terrestrial agriculture, Long Island can become part of a new trend of Community Sourced Fisheries (CSFs) that begun in 2007 (Brinson et al., 2011).

The Long Island Sound, Peconic Bay, and Great South Bay are all shallow estuaries that once boasted some of the greatest fisheries of the east coast, specifically shellfish. These estuaries were known for oysters and the shellfish they produced were shipped across the world (Brosky, 2018). Pollution, overharvesting, and changes in occupation and lifestyle limited the growth of the shellfishing industry. But with the trend of locally sourced goods and the improvement of local water quality, some individuals have begun introducing locally sourced oysters to go along with local vegetables and wine. During the mid 2000s, a small resurgence of oyster farming began off the waters of Long Island (Brosky, 2018). According to Chris Quartuccio, the movement has become a success (See Appendix F). His oysters are selling faster than he can harvest them for two reasons. The increased demand for local oysters reflects the trend of wineries beginning to serve them as a pairing. Most importantly, though, is the way in which oysters are being farmed today (Dooley, 2015).

Unlike years past, new laws such as the Bay Bottom Lease program in Islip and Specific Regulations for Protection and Taking of Shellfish in Brookhaven have made a barrier to big businesses owning and operating large commercial oyster beds in the south shore towns of Long Island (Brookhaven, n.d.; Town of Islip, n.d.).

Quartuccio states that just like the local movement on shore, oyster beds are also a new local business. This is because both the Townships of Islip and Brookhaven have limited the amount of acres and oysters one individual can lease or harvest (Dooley, 2015). So instead of having one business owning large tracts like in the past, most oyster beds are now small "family" run businesses. So many people are jumping at the opportunity of owning oyster beds that there is a waiting list to begin operating your own bed. As of March 2019, this list consisted of over 175 individuals in the Township of Islip alone (Town of Islip, n.d.).

The reason so many people are jumping on the opportunity to raise oysters is because there is money to be made in this industry. Just across the water in Connecticut where oyster fisheries are more established, the industry brought in over $6 million in 2008 (Boyle, 2015). This figure is expected to rise. According to NOAA, the United States' aquaculture industry steadily grew at just over 3% each year between 2006-2014. The growth is expected to increase along with Americans' demand for more seafood (NOAA, Office of Aquaculture, 2019). Oysters constituted the highest valued fishery in the United States and brought in $192 million in 2016 alone across the nation (NOAA, Office of Aquaculture, 2019).

Yet, with expectations for the aquaculture business continuing to rise, there are a few key concerns that should be addressed. The primary concern is whether water quality is currently suitable for new oyster farms to be established. The second major concern is the sustainability of the new oyster reefs as to prevent another crash.

Water Quality

Four major bodies of water surround Long Island and New York City (See Appendix G). In the west lie New York City and its associated waters namely the East River, Hudson River, New York Bay and Jamaica Bay. On the Southern edge of Long Island, contained by the barrier islands, is the Great South Bay. To the north lies the Long Island Sound. Lying to the east of Long Island, between the two Forks, is Peconic Bay that opens into Gardiners Bay.

New York City:

New York City is the most populated city in the United States, with a population over 8.6 million (U.S. Census Bureau, n.d.). This number is expected to continue to rise in the future. Most of the City's water quality concerns stem from this large population combined with an aging infrastructure. New York City's waters are broken down into four main regions; The Inner Harbor, Jamaica Bay, Lower NY Bay, and Upper East River/ Western Long Island Sound (See Appendix H). To judge the quality of water, New York City Department of Environmental Protection (DEP) uses four main tests to rank the water's quality. The first test determines the concentration of dissolved oxygen. Higher dissolved oxygen often denotes higher quality water. The second test conducted calculates the water's turbidity, or the clarity. According to New York City Department of Environmental Protection, a transparency greater than 5 feet denotes clear water with little to no suspended pollutants (Sapienza & New York City Department of Environmental

Protection, 2017). The third test screens for fecal coliform bacteria. The presence of fecal coliform bacteria is an indicator for sewage contamination. The final test is for chlorophyll A. Chlorophyll A is naturally present in water, as it is a primary pigment used in photosynthesis by phytoplankton. However, an extremely high concentration of chlorophyll A suggests eutrophication due to nutrient loading, typically nitrogen. After considering the results of all four tests, the New York City Department of Environmental Protection classifies the water quality of an area using the standards set by the New York State Department of Environmental Conservation (See Appendix I).

New York City's waters have shown a slow increase in quality since the 1970s (Sapienza & New York City Department of Environmental Protection, 2017). Currently, the vast majority of New York City waters are classified as either I (safe for fishing and boating) or SB (safe for bathing and other recreation use). Only a small section, consisting of the waterways between Staten Island and New Jersey is seriously degraded. Both Arthur Kill and Kill van Kull are extremely degraded, with a classification of SD (suitable for fish survival only). Current and future restoration projects in and around New York City's waters should continue to increase the area's water quality.

One current project being conducted is the Jamaica Bay Wildlife Refuge Restoration. The effects of the project can be seen in the quality of the Bay's water. Since the project started in 2012, there has been a noticeable drop in nitrogen (Sapienza & New York City Department of Environmental Protection, 2017). Jamaica Bay's restoration is generally concentrated on the addition of native plant species, with emphasis on beach grasses and other salt tolerant plants (Jamaica Bay – Rockaway Park Conservation Inc., n.d.). The plants have filtered out nitrogen entering the bay and increased the amount of dissolved oxygen to the highest levels found in city waters (Sapienza & New York City Department of Environmental Protection, 2017). Now that dissolved oxygen levels have stabilized in the Bay, oysters are able to grow. The oysters would exploit the current benefits supplied by the plants along with supplying additional benefits to the Bay as well. The Billion Oyster Project, in connection with New York City Department of Environmental Protection, has introduced over 50,000 oysters into the Jamaica Bay to capitalize on this situation. While still too new of an installment to show drastic changes, the following five to ten years will provide further data on the benefit of oysters in urban environments.

Long Island:

Geographically, Long Island stretches from Brooklyn to Montauk. Colloquially, Long Island refers only to Nassau and Suffolk Counties. In this paper, the term "Long Island," refers just to these two counties (See Appendix J). Nassau and Suffolk have a growing population that is currently over 3 million (U.S. Census Bureau, n.d.). The waters off the coast of Long Island have generally high quality, with exceptions on the western edge closer to New York City (New York State Department of Environmental Conservation, n.d.). To better organize the vast number of harbors, bays, and inlets, New York State's Department of Environmental

Conservation has broken Long Island into a series of 12 watersheds (See Appendix K). To better manage the data, I have divided Long Island watersheds into five key regions for this thesis (See Appendix L). The North Shore consists of Long Island Sound West (LISW) and Long Island Sound East (LISE). The South Shore contains the watershed of Great South Bay East (GSBE) and Great South Bay West (GSBW). The bodies of water between the Forks are classified as Peconic.

The name for the two North Shore watersheds comes from the name of the major body of water in the region, The Long Island Sound. The division between LISE and LISW is the western town line of Oyster Bay. I divided the two North Shore watersheds along this line based off of the data provided by New York State. The harbors and inlets of LISW have generally lower water quality than those in LISE. Additionally, New York State does not support the waters in LISW for shellfish consumption due to the higher pollution levels and chance of contamination. As such the shellfishing areas have been closed (New York State Department of Environmental Conservation, n.d.). The reverse is true for LISE, where shellfishing is supported in the majority of these waters due to relatively lower levels of pollution than LISW (New York State Department of Environmental Conservation, n.d.). Exceptions to shellfish consumption occur mainly in the small tributaries to the larger bodies of water where water exchange is poor causing for lower levels of dissolved oxygen and higher levels of pollution (New York State Department of Environmental Conservation, n.d.). As a general trend, most of the tributaries that cannot produce consumable oysters have the word "creek" or "pond" as part of their name.

According to the New York State Department of Environmental Conservation, most of the pollution found in the Long Island Sound is derived from urban and storm water runoff. Combined sewer overflow contributes to a small percentage of pollution in both LISE and LISW with LISW experiencing higher levels. The LISW watershed is also at higher risk of pollution from the neighboring regions of New York City and Connecticut due to its closer proximity to these areas. New York City and Connecticut are known to contribute excess nutrients and possible pathogens from combined sewer overflow and municipal dumping (New York State Department of Environmental Conservation, n.d.).

The New York designated watershed of Oyster Bay – Huntington Bay makes up the western edge of LISE. While, as a whole, the watershed is classified as SA (suitable for shellfishing), the bays should be monitored more closely than those farther east in the LISE. This is because this watershed faces higher rates of nitrogen loading and periods of low dissolved oxygen in comparison to the other parts of the LISE. (New York State Department of Environmental Conservation, n.d.) These periods of lower water quality are caused by urban runoff and septic overflow (New York State Department of Environmental Conservation, n.d.). Due to the nonpoint source pollution, the Oyster Bay – Huntington Bay watershed section is under more stress than the eastern sections, especially during periods of high amounts of rain. As such this watershed shares some traits more typical of the LISW.

The South Shore can be split in a similar fashion as the North Shore. The division of the two southern watersheds is also the western town line of Oyster Bay. The pattern seen in these two watersheds is similar to the patterns seen in the north. The eastern half (GSBE) is generally approved for shellfishing. The excluded area is slightly larger than that of the LISE. While all the tributaries have water quality too poor for shellfish consumption, four other larger regions also cannot support shellfish consumption (New York State Department of Environmental Conservation, n.d.). The smaller bays that hug the coast of southwestern Suffolk County must be taken under careful consideration. These bays (Great Cove, Nicholl Bay, Patchogue Bay, Bellport Bay) are classified as SA (New York State Department of Environmental Conservation, n.d.). This usually translates to the ability to harvest shellfish. However, due to high levels of nutrients from run off, these regions of the Great South Bay are often affected by seasonal algal blooms, which could lead to contaminated shellfish (New York State Department of Environmental Conservation, n.d.). On the border of GSBE and GSBW, South Oyster Bay is among the top shellfish regions in New York State (New York State Department of Environmental Conservation, n.d.). As such this region is a confirmation that the western regions of Long Island have the potential to reach a water quality high enough for shellfish harvesting. Unlike the western half of GSBE, GSBW is mostly composed of smaller bays connected by a multitude of channels. The Bays are typically divided where clusters of marshland and barrier islands are formed. Because of this geography, water exchange in GSBW is reduced in comparison to

GSBE and pollutants are more likely to build up. Most of the pollution in the GSBW watershed is from algal growth due to high levels of nitrogen (New York State Department of Environmental Conservation, n.d.).

Unlike the majority of Long Island, which drains into either the Long Island Sound or the Great South Bay, the two eastern Forks mainly drain into the Peconic River and Bays. While typically included with the Great South Bay by New York State, I decided to give this region its own watershed. The reason I kept Peconic separate is because the region is socially and economically different than those in the GSBE and GSBW due to the higher levels of agriculture and generally lower population density. The water quality off the region reflects this higher agriculture nature. The Peconic River is highly degraded from nutrient overload a trait often seen in aquatic ecosystems bordering high agricultural areas (New York State Department of Environmental Conservation, n.d.). The entirety of the river displays characteristics of eutrophication, including high levels of algal growth and extremely low levels of dissolved oxygen (New York State Department of Environmental Conservation, n.d.). Unlike the smaller bays in the west, the large open bays of the Peconic watershed allow for greater dilution of these nutrients resulting in the majority of the watershed being clean enough to support shellfish consumption (New York State Department of Environmental Conservation, n.d.). Unlike the Great South Bay and Long Island Sound watersheds, the Peconic Bay includes some tributaries and minor bodies of water that can support shellfish consumption according to New York State Department of Environmental

Conservation. These tributaries and smaller bodies of water are concentrated in the remote eastern portion of the watershed, where they are closely connected to the Atlantic Ocean. Examples are Corey Creek, Cold Spring Pond, and Tobaccolot Pond (New York State Department of Environmental Conservation, n.d.). Since these bodies of water are closely connected to the Atlantic Ocean, water exchange is greater, allowing pollutants to be flushed out by the influx of cleaner ocean water.

High water quality alone does not determine successful oyster reintroduction. A few basic steps can be taken to ensure a more successful reintroduction of *C. virginica.*

Reintroduction Plan

A comparatively hardy species, *C. virginica* would benefit from some intervention, especially during the first couple of years before a sizeable population is established. The first part of this section discusses the general method of oyster reintroduction. The second part contains my own plan for reintroducing oysters across New York State.

Basic Reef Formation:

The successful introduction of oysters requires a few basic steps. The most basic requirement for their introduction is a place for oysters to latch onto while still in the juvenile phase. The base of an oyster reef needs a hard substrate such as rock, pilings, or even old oyster shells. Sand, gravel, mud, or anything too “soft” or small will not be able to support oyster growth since these substrates are moved easily with currents and have the potential to smother oysters from sedimentation (Colden, Latour, & Lipcius, 2017).

With a solid reef base in place, it is possible to introduce young oysters and watch a reef form slowly over time. Reefs that are started at a depth less than 0.3m are more successful than reefs started in deeper waters (Colden et al. 2017). Starting a reef in shallow water reduces the chance of sedimentation smothering the young bed. Additionally, according to a study conducted by Colden and colleagues (2017), reefs started at less than 0.3m depth also tend to develop higher oyster density. A higher density of oysters accelerates the filtration of pollutants and provides more oysters for harvesting. Investing in a taller reef base for the reef at the beginning of cultivation, maximizes environmental and economic profits in a sustainable fashion.

Oyster bases do not have to be very expensive. As long as the base is "hard," oysters will be able to latch on and begin forming a reef. In my opinion using old oyster shells would be the best approach toward creating reef bases. An oyster reef base made of shells would be inexpensive, even free perhaps. As mentioned in the section "Why Oysters?," oysters are becoming popular in local cuisine. The oyster shells are used to serve the shellfish, yet are inedible. Instead of tossing these shells into landfills often located in the interior of our nation, they could be utilized for local environmental efforts. If restaurants are willing to donate back the shells, government organizations, non-for-profits, and even oyster farms could use them to create new reefs, increasing the number of reefs in local waters. With the current high demand for fresh oysters, it would be in a restaurant's best interest to donate the shells since more reefs would lead to more locally sourced oysters to meet demand. The Billion Oyster Project, an organization focused on cleaning up New York City through oysters, has demonstrated that the donation method is plausible. Currently, The Billion Oyster Project has over 70 restaurants willing to donate oyster shells. With New Yorkers consuming about half a million oysters per week, there are literally tons of shells that could potentially be collected (Billion Oyster Project, n.d.). To increase restaurants interested in donating their shells, they can be given a small kickback. One form of a kickback is that oyster farmers or environmental groups could buy back shells at a cheap price. While the restaurants would not regain the full price of each oyster, they would still gain a little money back, almost like a tax refund. Another alternative incentive could come in the form of tax breaks. Businesses, households, cars etc., earn tax breaks if they follow certain protocols. Recently, tax breaks have been given for pro environmental behavior. Perhaps this approach could be used on a local level with restaurants. If a restaurant donates "x" amount of shells, than the local government can reduce its taxes by a certain percentage. By using donated shells the cost of reestablishment is reduced since bases would not need to be constructed out of other materials. Using the shells also would eliminate the chance of pollution. An added benefit is that the shells would remain in the local vicinity, being moved between the bays to restaurants and then back to the bays to be recycled. In an environmental sense this is beneficial as it allows the nutrients released from the decaying shells to be cycled back into the local ecosystem and provides habitat for more reefs in the future.

Two Part Plan:

Long Island is geographically the largest island in the continental United States. It stretches 118 miles from New York Harbor in the west to Montauk in the east. The region of oyster introduction is even longer than this as it includes the coasts along the remaining portions of the City as well as outlying islands to the east, including Plum Island and Fisher's Island. To better manage such a large-scale project, I suggest two separate plans of action. The waters west of the westerntown line of the Town of Oyster Bay New York will be the first plan, which encompasses the City and the two western watersheds on Long Island (LISW and GSBW). The second, or eastern, plan is for the remainder of the watersheds east of the town line (See Appendix L).

The western restoration focuses on introduction of oysters solely for environmental purposes. The waters in this half of the region are too polluted to allow shellfish consumption. Therefore, the full effort of this half of the reintroduction plan is to raise water quality. The area included in this plan contains a host of shipping lanes that access the multiple ports around New York City. It was mentioned that oysters cannot naturally grow in the shipping lanes due to the lanes being too deep. However, this plan needs to ensure oysters do not provide obstacles toward shipping infrastructure close to shore, such as on pilings and around piers. Reintroduction efforts should focus on the peripheral bodies of water first to limit these possible obstacles. One example is Jamaica Bay, which already has ongoing restoration efforts. The harbors on the north shore of Long Island in the LISW watershed are also prime locations for the first wave of introduction. These peripheral bodies of water should also be planned to allow for future harvesting as well. The waters are currently too degraded for shellfish harvesting and consumption, yet locations like Jamaica Bay, Manhasset Harbor, and Hempstead Harbor all share characteristics with bays and harbors in the eastern plan. So instead of reintroducing oyster beds in a haphazard manner for immediate effects, oyster bed locations and layouts should be organized with the intent for potential future harvesting in these regions after a few generations. Regions like New York Harbor and the East River may not reach the potential of harvesting in the near future. However, both should be analyzed for locations to place small reefs on the shores to act as pollution barriers before entering the more open waters. Prime locations would be the southern shore of Staten Island and along the shore of the small islands dotting New York Harbor (Governors Hoffman, Ellis, etc). These small reefs would also provide additional protection from flooding.

The Eastern plan is focused on balancing harvesting oysters while allowing oyster populations to remain robust and healthy. Oyster farms should be given priority locations. While all the waters of the eastern plan can support oysters, not all are fit for consumption and harvesting as mentioned in prior sections. The area's tributaries should not be ignored. Although these regions are unfit for oyster consumption, they would make great locations for oyster nurseries. While long term plans should attempt to decrease pollution in the smaller tributaries, initially the pollution can be ironically beneficial. As discussed in the historical section, over harvesting became a large concern and one of the major downfalls for the oyster industry in the early 1900s. Oyster spawn had to be imported to keep up with demand. Instead of having to import spawn from other estuaries, the polluted tributaries and smaller inlets in The Great South Bay, Long Island Sound, and Peconic Bays can serve as an additional source of spawn for oyster farmers. Since oysters release millions of eggs into the water column, the tributaries' location near farms allows the chance for the spawn to naturally settle into the regions that will eventually be harvested, reducing the need for human intervention. One possible concern is that some of these tributaries and smaller inlets experience periods of low dissolved oxygen, and thus have hypoxic conditions (New York State Department of Environmental Conservation, n.d.). Although it was discussed that oysters can survive in lower levels of dissolved oxygen, they will die off if oxygen concentration drops too low. The restoration of native aquatic plant species, along with oyster restoration, will guarantee a more steady supply of dissolved oxygen in the water column and help the oysters sequester pollutants. The sequestration of pollutants in the tributaries, rather than in the open bays, reduces the risk of pollution and algal blooms in the region of harvesting. The farmed oyster beds would still provide all previously mentioned the environmental benefits, and the nursery/tributary beds would act as a buffer for these farms, providing more security for the economically profitable oysters.

Conclusion

While oyster abundance in New York State has severely decreased since its peak, a new wave of interest is beginning to spread across the region. Benefitting from the local culture of Long Island and a rising national demand in seafood, the reintroduction of oysters into New York State can be expected to garner strong support from a multitude of angles. Producing a highly in-demand item, oyster fisheries are among the most profitable fisheries in the United States. Yet, the economic benefits are only one benefit of oyster cultivation. The vast environmental benefits associated with oyster beds are gaining more attention among rehabilitation and restoration groups as a natural way to raise water quality. As attention continues to spread and reintroduction efforts persist, perhaps New York City can once again reclaim the title of "Oyster Capital of the World" and become a model for other maritime cities to follow suit.

Appendix A

Native Range Map for the Eastern Oyster (*Crassostrea virginica*)

Figure 1: map of the native range of *C. virginica*
(Team GeoNetwork, 2007)

Appendix B

Pictures of an Oyster Reefs

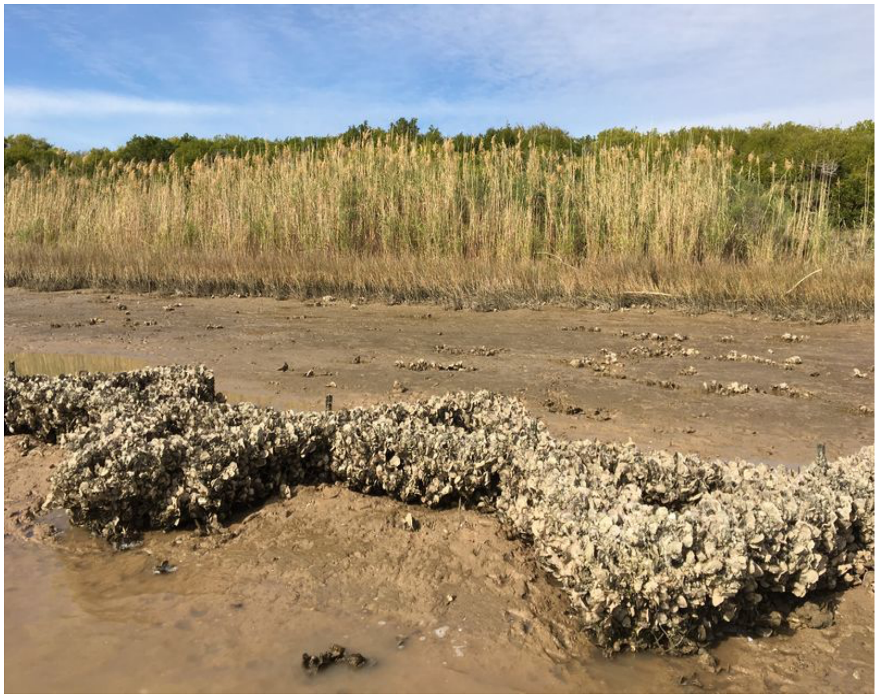


Figure 2A: image of oyster reef at low tide (Matchar, 2018)

Figure 2B: image of exposed oyster reef (Flynn, 2016)

Appendix C

Historical Images of Oysters in New York City

Figure 3A: Image of Oysters Houses in Lower New York City (Nigro, 2011)

Figure 3B: Image of Oyster Street Food Stand in New York City
(Oysters: From Rags to Riches, 2012)

Appendix D

Long Island Wineries

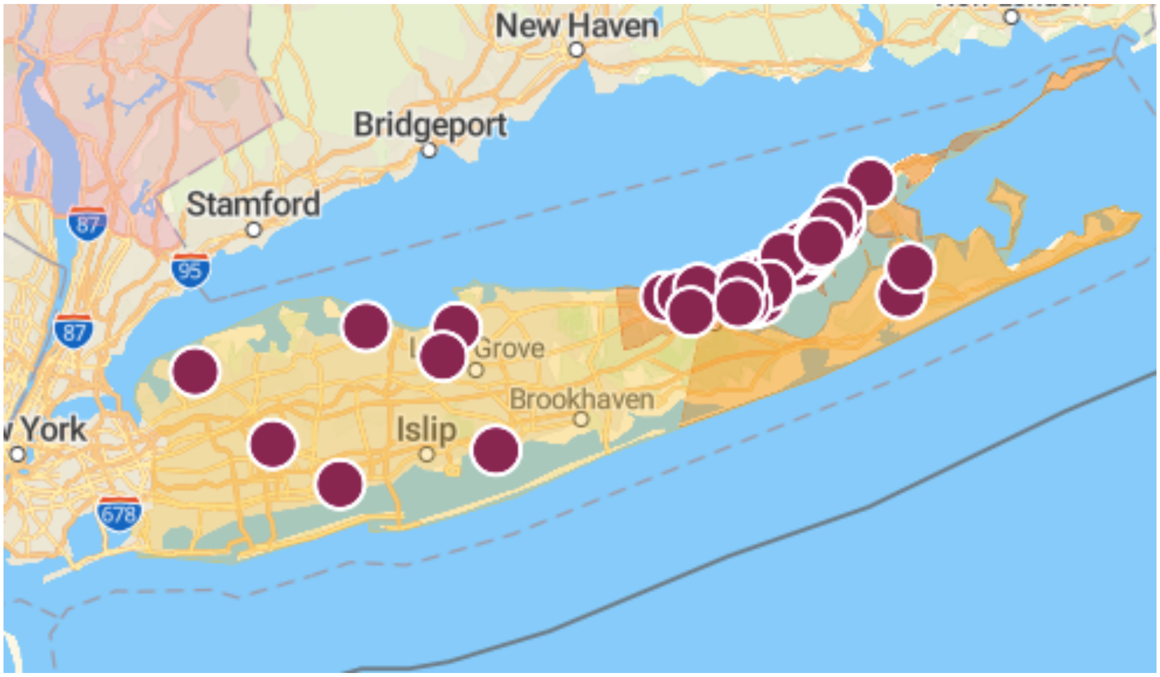


Figure 4: Image of the 56 currently registered wineries on Long Island in New York State (AtWineries, n.d.)

Appendix E

Community Supported Agriculture

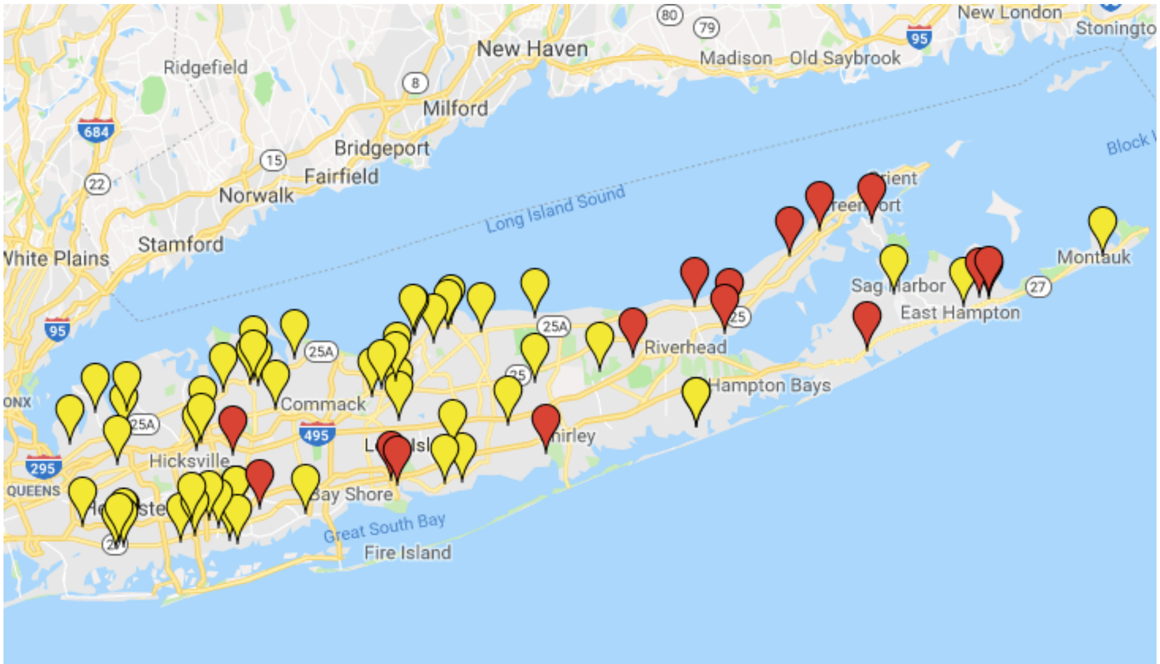


Figure 5: A map displaying the CSA Locations on Long Island; Red indicates farm location, yellow indicates pick up locations for produce
(CSA Alliance of Long Island, n.d.)

Appendix F

Oyster Farms

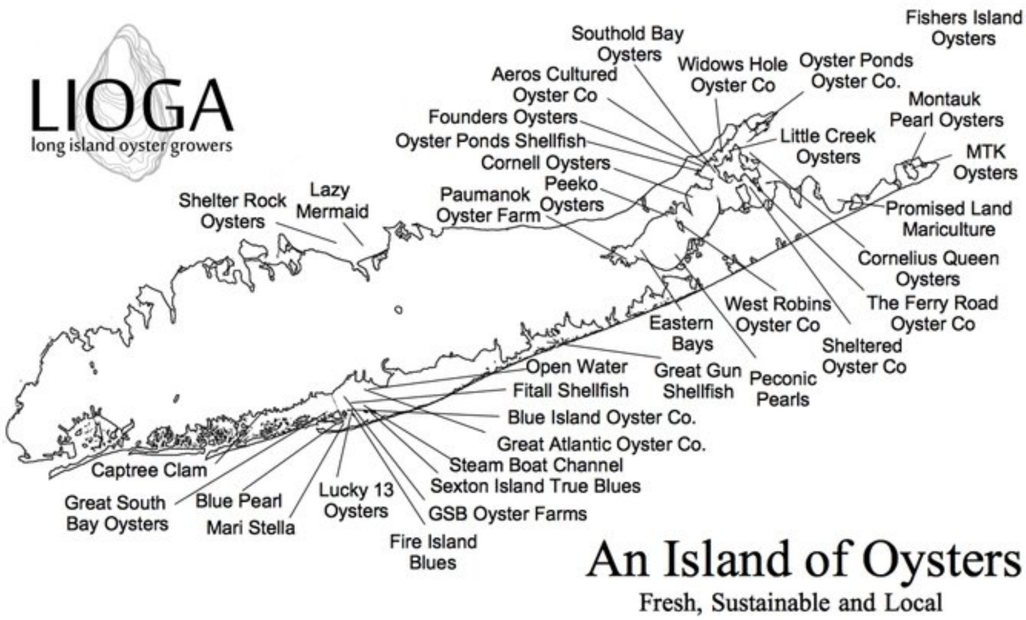


Figure 6: Map displaying locations of multiple oyster farms currently operating off the coast of Long Island in New York State (LIOGA, n.d.)

Appendix G

Long Island Bodies of Water

Figure 7: Map of the four main bodies of water surrounding Long Island in New York State (image background sourced - Reclaim New York, 2017)

Appendix H

New York City Waterways

Figure 8: Map of New York City's waters divided into sub sections by the New York City Department of Environmental Protection

(Sapienza, V., P.E., & New York City Department of Environmental Protection, n.d.)

Appendix I

Water Quality Standards

COMMON WATER USE AND NYSDEC STANDARDS FOR SALINE WATERS				
Class	**Best Usage of Waters**	**Fecal Coliform**	**Dissolved Oxygen (never-less-than)**	**Enterococcus**
SA	Shellfishing and all other recreational use	No standard	5.0 mg/L	N/A
SB	Bathing and other recreational use	Monthly geometric mean less than or equal to 200 cells/100 mL from 5 or more samples	5.0 mg/L	(monthly geometric mean) - < 35 Cells / 100mL (single sample) - Max 104 Cells / 100mL
I	Fishing and Boating	Monthly geometric mean less than or equal to 2,000 cells/100 mL from 5 or more samples	4.0 mg/L	N/A
SD	Fish survival	No standard	3.0 mg/L	N/A

Figure 9 - New York State Department of Environmental Conservation water quality standards based on coliform and dissolved oxygen levels

(Sapienza & New York City Department of Environmental Protection, 2017)

Appendix J

Counties and Boroughs of Lower New York State

Figure 10: Map displaying the Boroughs of New York City and the two eastern counties of Nassau and Suffolk that compose the colloquial term of Long Island (Long Island, 2019).

Appendix K

Long Island Watershed Boundaries

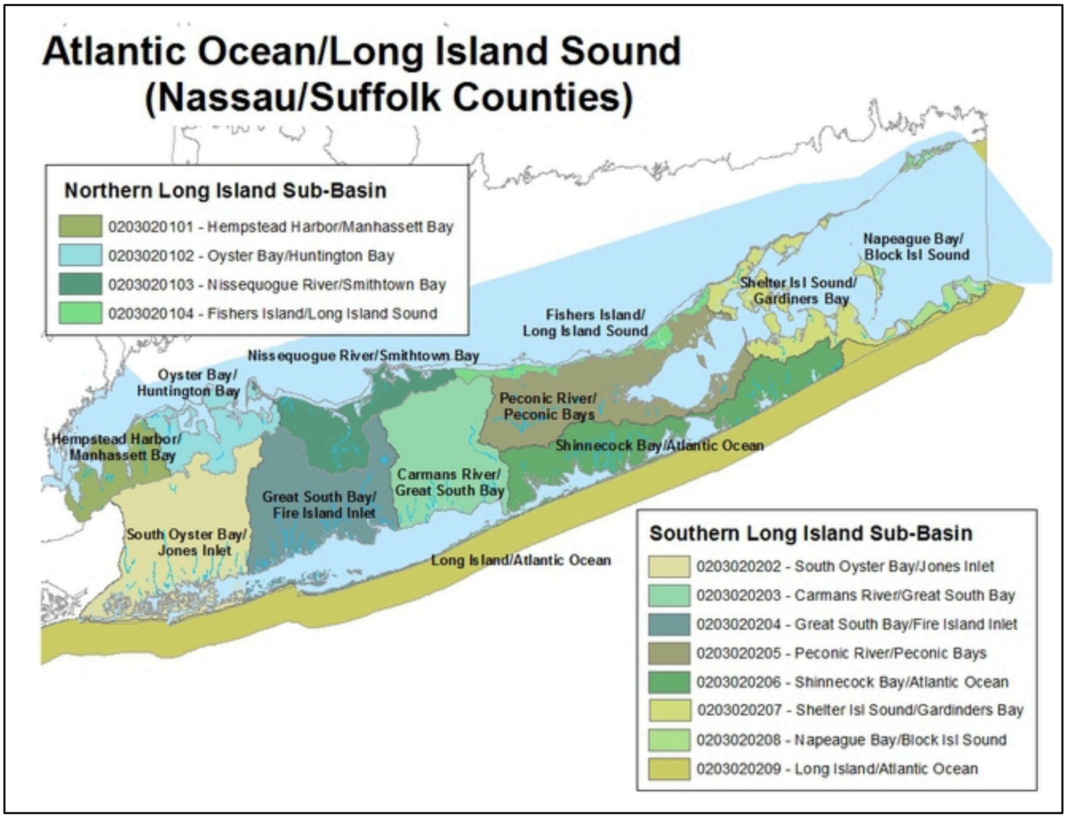
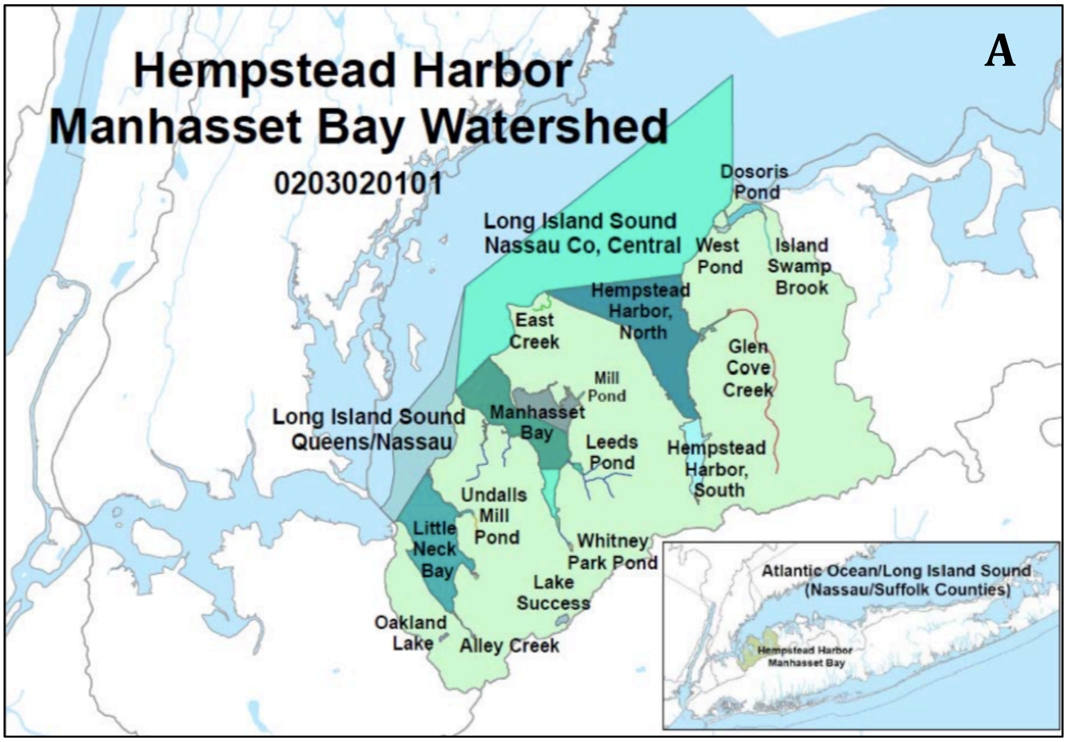
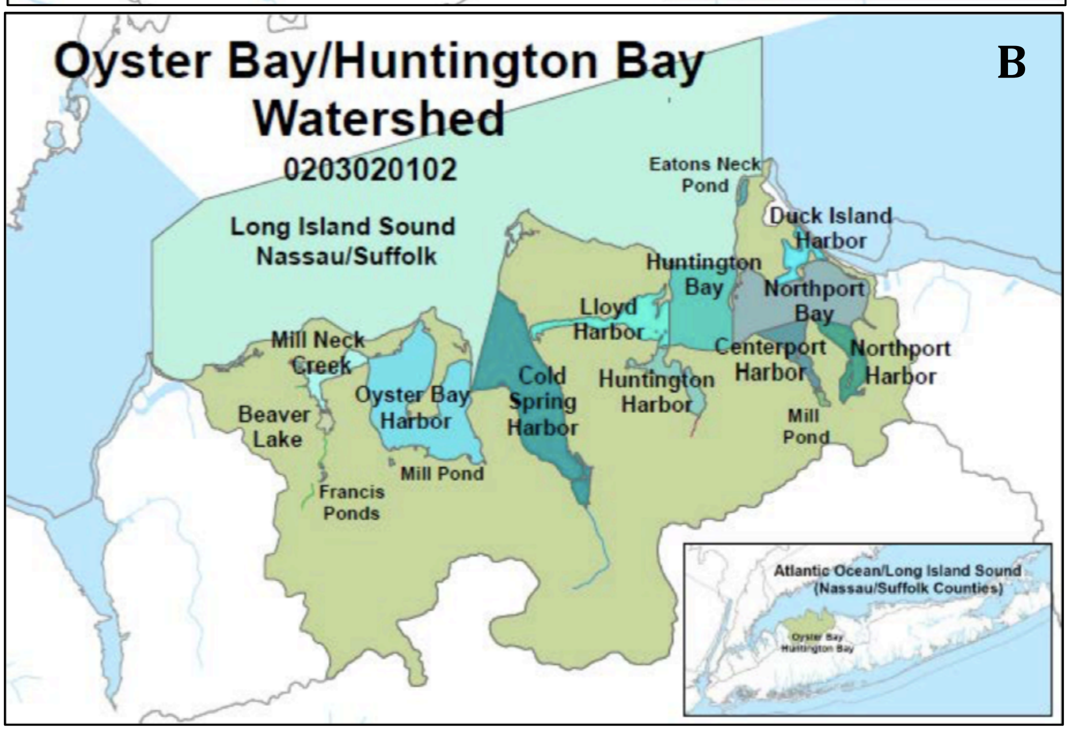


Figure 11: Map of the 12 watersheds of Long Island according to the New York State Department of Environmental Conservation

(New York State Department of Environmental Conservation, n.d.)

Long Island North Shore Watersheds:





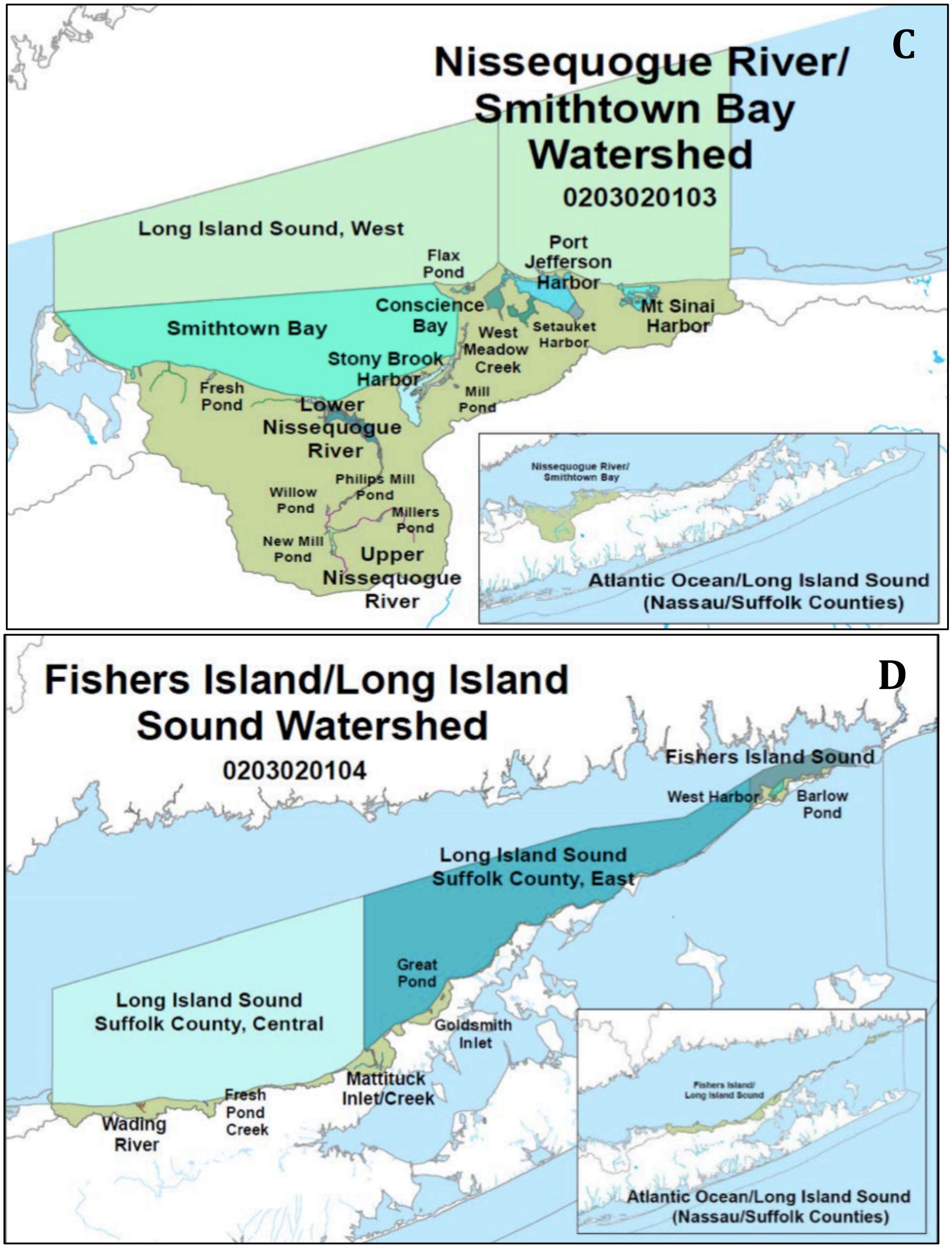
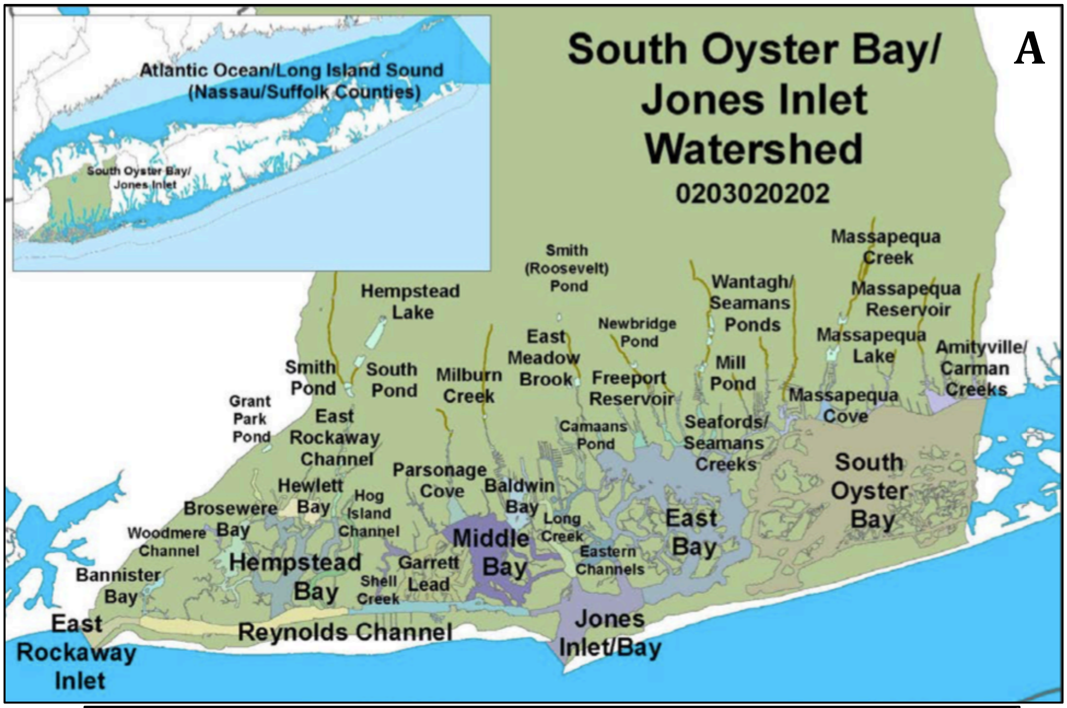


Figure 12: Displays the North Shore watersheds from west to east and their associated subsections according to New York State (New York State Department of Environmental Conservation, n.d.)

Long Island South Shore Watersheds:



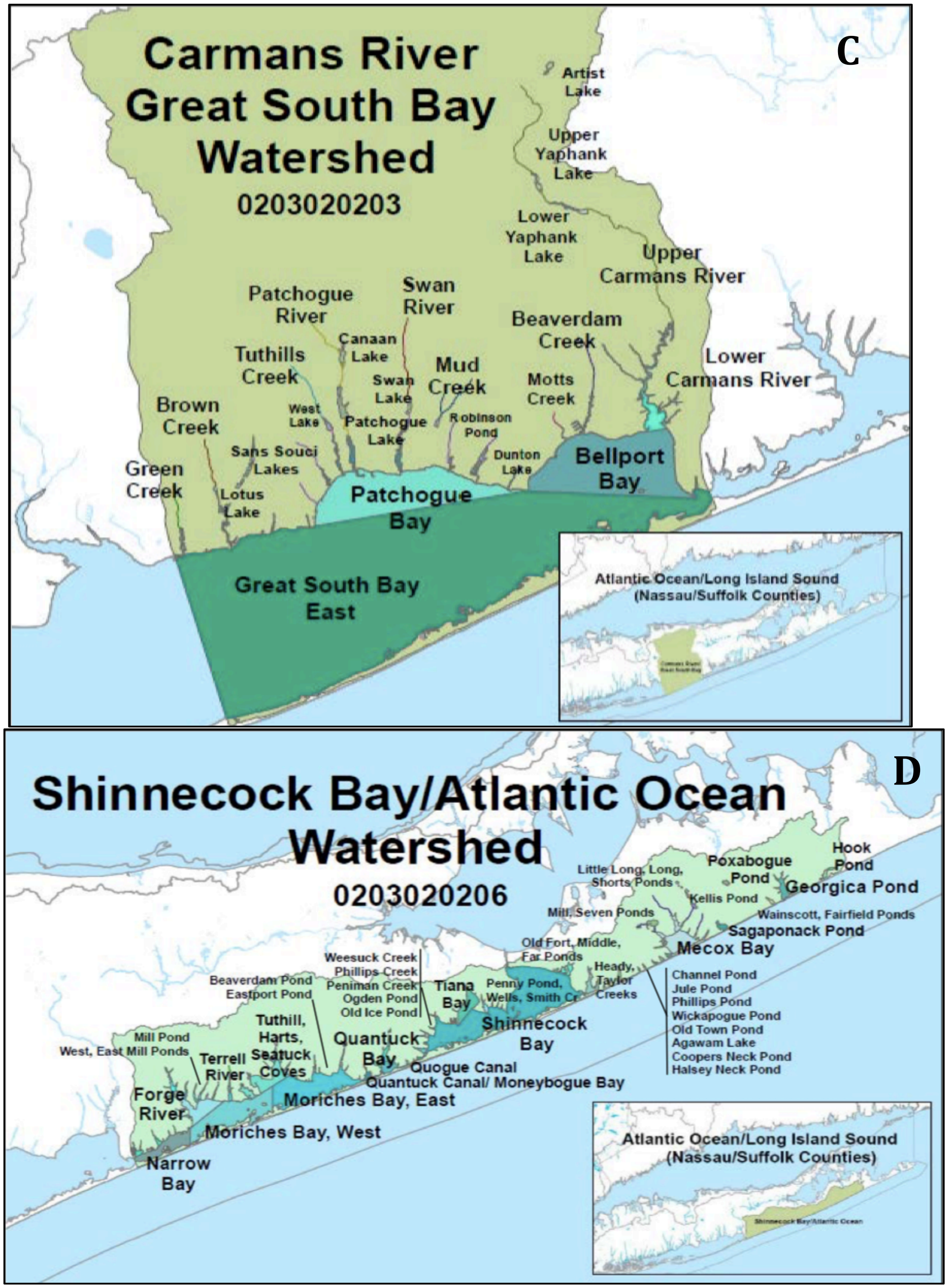


Figure 13: Display the South Shore watersheds from west to east and their associated subsections according to New York State (New York State Department of Environmental Conservation, n.d.)

Peconic Watersheds:

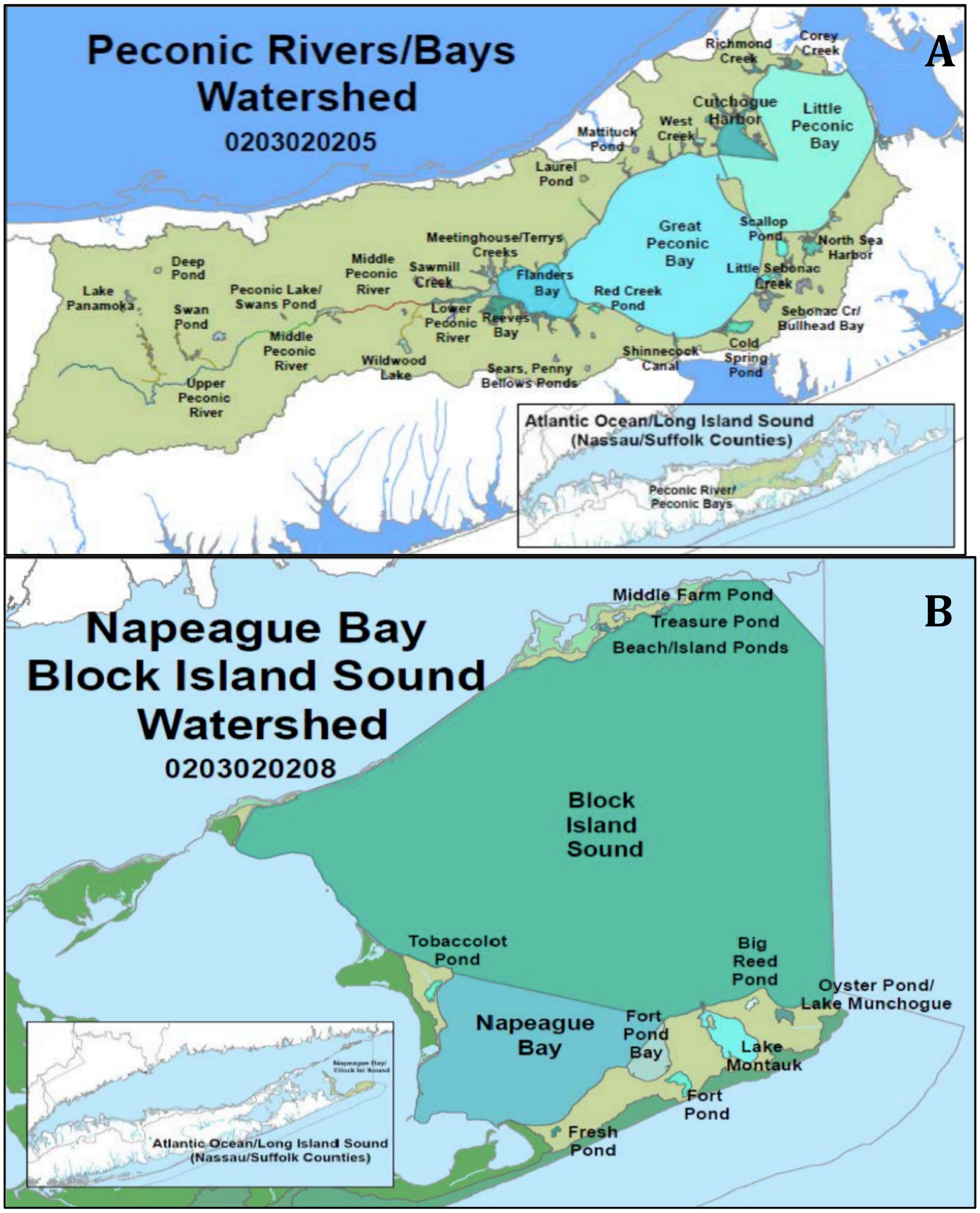


Figure 14: Display the Peconic watersheds from west to east and their associated subsections according to New York State (New York State Department of Environmental Conservation, n.d.)

Appendix L

Division of East and West Plan

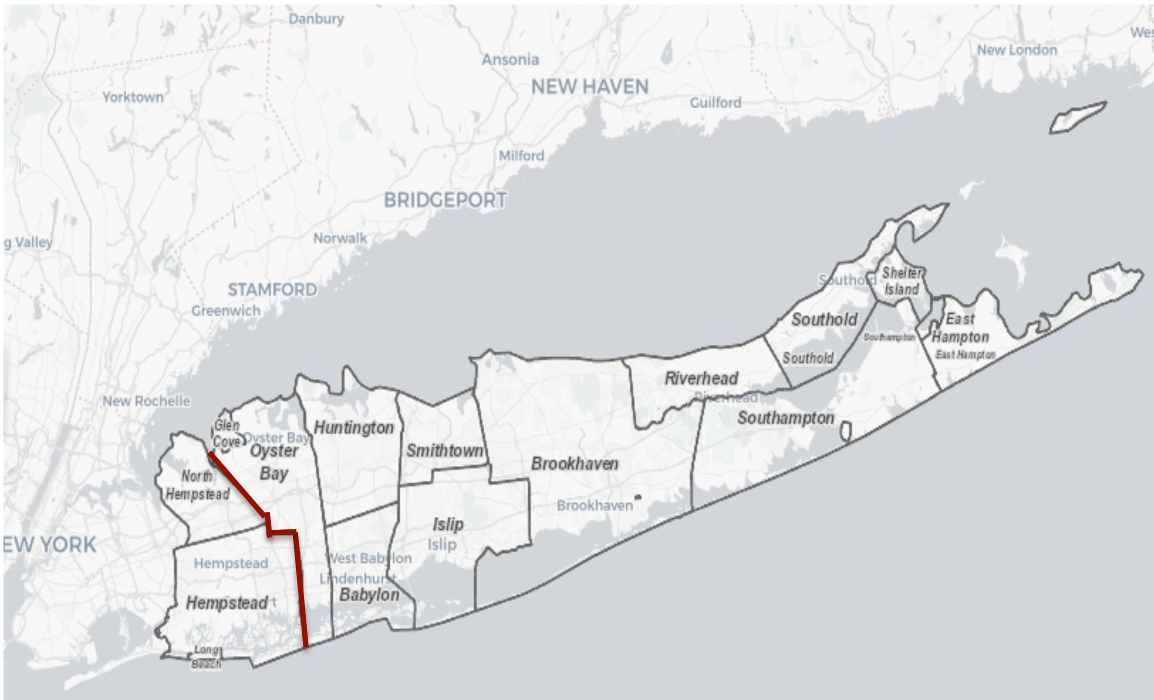


Figure 15: The red line marks the western town line of the Town of Oyster Bay and divides the region into the western and eastern halves (Long Island Index: Interactive Map, n.d).

Works Cited

AtWineries. (n.d.) Explore 56 Wineries and Vineyards in Long Island. Retrieved April, 2019, from https://www.atwineries.com/map/united-states/new york/long-island/

Billion Oyster Project. (n.d.) Retrieved February, 2019, from https://billionoysterproject.org

Boyle, D. (2015, August 27). Oystering in Connecticut, from Colonial Times to the 21st Century. Retrieved February, 2019, from https://connecticuthistory.org/oystering-in-connecticut-from-colonial -times-to-today/

Brinson, A., Lee, M.Y., Rountree, R. (2011). Direct Marketing Strategies: The Rise in Community Supported Fishery Programs. Retrieved May, 2019, from http://localiahawaii.com/files/1-s2.0-S0308597X11000157-main.pdf

Brookhaven, NY | Official Website. (n.d.). Retrieved February, 2019, from https://www.brookhavenny.gov

Brookhaven, NY : Oysters (Crassostrea virginica). (2015, February). Retrieved February, 2019, from https://ecode360.com/8594035

Brosky, K.F. (2017, August 17). Looking for Farm to Table Cuisine On Long Island? There is an App for That. Retrieved January 2019, from https://www.ediblelongisland.com/2017/08/17/aura-rating-farm-to-table -app-launches-on-long-island/

Brosky, K.F. (2018, February 26). How a Briny Bivalve Spawned an Industry on Long Island. Retrieved January, 2019, from https://www.ediblelongisland.com/2018/03/06/our-oystering-heritage/

Colden, A., Latour, R., & Lipcius, R. (2017). Reef height drives threshold dynamics of restored oyster reefs. *Marine Ecology Progress Series*, 582, 1-13. doi: 10.3354/meps12362

CSA Alliance of Long Island. (n.d.) Long Island CSA Directory. Retrieved February, 2019, from https://www.longislandcsa.com/longislandcsa

Dooley, C. (2015, October 25). Why Long Island's Commercial Oyster Industry is Booming. Retrieved November, 2018, from http://lipulse.com/2015/10/25/why-long-island-oysters/

Flynn, R. (2016, January 22). Oh Where, Oh Where Should This Oyster Reef Go?. Retrieved April, 2019, from https://oceanbites.org/oyster_reef_restoration/

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F., Keeler, A.G., Opaluch, J.J., Peterson, C.H., . . . , Smyth, A.R. (2012, October 10). Economic Valuation of Ecosystem Services Provided by Oyster Reefs. Retrieved April, 2019, from https://academic.oup.com/bioscience/article/62/10/900/238172

Hedge, L.H., Knott, N.A., Johnston, E.J. (2009). Dredging Related Metal Bioaccumulation in Oysters. Retrieved May, 2019, from https://www.sciencedirect.com/science/article/pii/S0025326X09000472

Hofstra University Library Special Collections. (n.d.). Long Island: From Sea Shells to Suburbia. Retrieved February, 2019, from https://www.hofstra.edu/pdf /library/libspc-oe-lisi-sea-shells-suburbia.pdf

Jamaica Bay – Rockaway Parks Conservation Inc. (n.d.). Jamaica Bay – Rockaway Parks Conservancy. Retrieved March, 2019, from http://www.jbrpc.org

LIOGA. (n.d.) LIOGA – Long Island Oyster Growers Association. Retrieved April, 2019, from https://www.liogany.org

Long Island. (2019, May 01). Retrieved May, 2019, from https://en.wikipedia.org/wiki/Long_Island

Long Island Index: Interactive Map. (n.d.) Retrieved April 8, 2019, from http://www.longislandindexmaps.org

Long Island Sound Study. (n.d.) Long Island Sound – By the Numbers. Retrieved January, 2019, from http://longislandsoundstudy.net/ about-the-sound/by-the-numbers/

Meyer, D.L., & Townsend, E. C. (2000). Faunal Utilization of Created Intertidal Eastern Oyster (Crassostrea virginica) Reefs in the Southeastern United States. *Estuaries*, 23(1), 34. doi: 10.2307/1353223

New York State Department of Environmental Conservation. (n.d.) Atlantic Ocean/ Long Island Sound WI/PWL. Retrieved March, 2019, from https://www.dec.ny.gov/chemical/36748.html

Nigro, C. (2015, April 15). History on the Half-Shell: The Story of New York City and Its Oysters. Retrieved October, 2018, from https://www.nypl.org/blog/2011/06/01/history-half-shell-intertwined -story-new-york-city-and-its-oysters

NOAA, Chesapeake Bay Office. (n.d.). Oysters – Fish Facts. Retrieved November, 2018, from https://chesapeakebay.noaa.gov/fish-facts/oysters

NOAA, Office of Aquaculture. (2019, January 30). U.S. Aquaculture. Retrieved January, 2019, from https://www.fisheries.noaa.gov/national/ aquaculture/us-aquaculture

Oysters: From Rags to Riches. (2012, October 16). Retrieved April, 2019, from https://blog.mcny.org/2012/10/16/oysters-from-rags-to-riches/

Reclaim New York. (2017, July 25). Start-Up NY's Downward Spiral on Long Island. Retrieved May, 2019, from https://www.reclaimnewyork.org/2017/07/25/start-up-nys-downward spiral-on-long-island/

Riisgård, H. (1988). Efficiency of particle retention and filtration rate in 6 species of Northeast American bivalves. *Marine Ecology Progress Series,* 45, 217-223. doi: 10.3354/meps045217

Sapienza, V., P.E., & New York City Department of Environmental Protection (n.d.). 2017 New York Harbor Water Quality Report. Retrieved February, 2019, from https://www1.nyc.gov/html/dep/html/harborwater/ harborwater_quality_survey.shtml

Strauss-Weider, A. (2017). The Economic Impact of the New York – New Jersey Port Industry. Retrieved January, 2019, from http://www.nysanet.org/ association-publications/

Suffolk County Department of Economic and Development Planning. (2015, December). Suffolk County Agricultural and Farmland Protection Plan – 2015. Retrieved February, 2019, from https://www.suffolkcountyny.gov/ Departments/Economic-Development-and-Planning/Planning-and-Environment/Open-Space-and-Farmland/Farmland-Preservation

Team GeoNetwork. (2007, July 02). GeoNetwork opensource portal to spatial data and information. Retrieved from April, 2019, from http://www.fao.org/ geonetwork/srv/en/main.home?uuid=fao-species-map-oya

Town of Islip. (n.d.). Bay Bottom Leasing Program. Retrieved March, 2019, from https://www.townofislip-ny.gov/departments/environmental-control/shellfish-hatchery

U.S. Army Corps of Engineers. (n.d.). Controlling Depth Reports and Surveys. Retrieved January, 2019, from https://www.nan.usace.army.mil/Missions/Navigation/Controlling-Depth-Reports/

U.S. Census Bureau (n.d.) QuickFacts: Kings County (Brooklyn Borough), New York; Queens County (Queens Borough), New York; Nassau County, New York; Suffolk County, New York. Retrieved January 2019, from https://www.census.gov/quickfacts/fact/table/kingscountybrooklynboroughnewyork,queenscountyqueensboroughnewyork,nassaucountynewyork,suffolkcountynewyork/PST045218

Wolf, B. (2013, January 27). Oysters Rebound In Popularity With Man Made Bounty. Retrieved December, 2018, fromhttps://www.npr.org/2013/01/27/170376271/oysters-rebound-in-popularity-with-man-made-bounty