# Mapping Future Scenarios of Oyster Farming in Waquoit Bay, Massachusetts to Decrease Nitrogen Loading

# Mapping Future Scenarios of Oyster Farming in Waquoit Bay, Massachusetts to Decrease Nitrogen Loading

Sarah Thompson Hansen

A Thesis in the Field of Sustainability

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

November 2017

Abstract

Excessive nitrogen loads in saltwater bodies along the East Coast of the U.S. are causing significant eutrophication of the water leading to species loss and water quality issues. These impacts have led to calls for significantly reducing nitrogen loading. Many ideas have been put forward to decrease nitrogen loads, from lower fertilizer use, to more green roofs, and even to the use of new technologies such as urine separating toilets. One method that has been touted as particularly cost effective and environmentally friendly is the use of shellfish, particularly oysters from oyster farming. A call to use this method in Waquoit Bay in Massachusetts compelled me to use spatial analysis to examine how oyster farming at a large enough scale to effect nitrogen loads will impact the rest of the environment and other uses of the Bay. I hypothesized that spatial analysis of oyster farming in the Bay, taking into account environmental impacts, areas of nitrogen loading, current water uses, and economic benefits, would give a clear picture of how much oyster farming can be done while balancing the needs of other species and other human uses.

To complete the spatial analysis I collected data from a number of local, state, federal and private sources to make multiple maps using GIS to show the uses of Waquoit Bay which would affect oyster farming. The uses included recreational, commercial, and other wildlife habitats. I also completed a map showing what areas would be suitable habitat for oyster farming. These maps were compared to the percentage of the Bay that would be required to be farmed to decrease the nitrogen load to acceptable levels.

The results indicated that very large percentages of the Bay would have to be farmed in order to lower nitrogen levels by the required amount. This amount of farming would definitely disrupt the current uses of the Bay; however, the extent and type of disruption would be up to local officials. Also, some of the areas where farming would be most efficient for nitrogen reduction are areas that are not suitable for oyster farming, resulting in either less total nitrogen removal or the need for more area for farming.

The spatial analysis and accompanying economic analysis should be useful to local officials and residents in deciding how much to rely on oyster farming for nitrogen reduction versus other methods. An analysis like this could be used in other areas looking at large scale shellfish farming.

Acknowledgments

I thank Scott Horsley and Mark Leighton for their inspiration and guidance in composing and completing this project. Their expertise, both during this project, and during my time in the Extension program has been key to my success.

To the other students in my thesis class, and all of my Harvard classes, your encouragement, questions and struggles have inspired me and kept me going. Just the smallest words of encouragement kept me headed in the right direction through this entire project.

Finally, and most importantly my family. Shawn, I could not have done this without you and know that we will continue to encourage and inspire each other for years to come. Jack, I hope that you are inspired by both of your parents and find your passion as you grow and explore.

Table of Contents

List of Figures

# Chapter I

## Introduction

Excessive nitrogen loads have been drastically increasing along the East Coast of the U.S. in salt-water bodies leading to eutrophication. The poor water quality that is a result of eutrophication contributes to habitat degradation and species loss. The problem of eutrophication exists in water bodies up and down the East Coast for reasons ranging from excessive fertilizer use to septic system designs. This is a significant problem on Cape Cod where a large population in a relatively small area results in large nitrogen loads from septic systems, fertilizers, and storm water run off.

There are many solutions to high nitrogen levels but they are often expensive, complicated, and only address nitrogen at the source of the contamination and do not address the nitrogen already in the ground water. One possible solution, which does combat the problem in the water body and is affordable for taxpayers, is shellfish farming. Shellfish farming, oyster farming in particular, can remove large amounts of nitrogen by introducing species that are native to the waters and do not have a large construction time or cost for supporting infrastructure (Woods Hole Group, 2012). However, there are significant impacts that need to be addressed when contemplating the use of shellfish farming. These include effects on other species in the area, land uses, and economic effects. To effectively plan a shellfish farming strategy in waters with heavy nitrogen loads, it is necessary to map these impacts so a successful farming approach might be accepted by all stakeholders in the area.

Research Significance and Objectives

A model that maps all consequences of farming, while showing the amount of oysters necessary to reduce the nitrogen load will give stakeholders a good tool for deciding the proper use of this nitrogen reduction technique. Giving local communities a picture of the impacts, both negative and positive, will allow them to make an informed decision on whether oyster farming should be part of their solution to reduce nitrogen. If this decision is made without all of the consequences taken into consideration it is more likely that this type of program will fail. This research will allow communities to make sound decisions and increase the chances of a positive outcome when using oyster farming to help control nitrogen levels.

My objectives were:

- To examine the role that shellfish farming could play in ecosystem restoration
- To design a spatial planning model of where shell fishing would be the most beneficial for the entire community using a variety of parameters
- To look at a natural solution to an environmental problem, which could be a case study for other similar methods

## Background

Loss of species and poor water quality have been contributed to significant eutrophication of saltwater bodies all over the world, particularly in the U.S. Many ideas have been put forward as methods to reduce nitrogen loads but one popular method is shellfish farming (Carmichael, Walton, & Clark, 2012). Shellfish farming could be an effective approach to this issue but it is important to consider other social, economic, and environmental consequences.

## Eutrophication

Eutrophication is caused by the accumulation of excessive amounts of phosphorous and nitrogen in a water body (Nixon, 1995). A eutrophic water body has excessive phytoplankton growth, which leads to an imbalance in the primary and secondary productivity of the ecosystem (Khan and Ansari, 2005). This causes an accumulation of organic matter leading to murky water that reduces the amount of light able to penetrate the water, causing a reduction in photosynthesis by plants in the system (Yang, Wu, Hao, & He, 2008; Rabalais, Turner, Diaz, & Justic, 2009). It can also cause a significant reduction in the amount of dissolved oxygen in the water, greatly harming aquatic life (Yang et al., 2008). These effects of excessive nutrient loading cause water bodies to lose their primary functions and can result in species loss, algae blooms and even dead zones (Yang et al., 2008; Conley et al., 2009). Nitrogen is usually the causative factor in coastal waters, and therefore the most important nutrient in limiting eutrophication in these waters (Bowen & Valiela, 2001).

Eutrophication in marine bodies has been recognized as a growing problem since around 1970 when the Environmental Protection Agency held the first International Symposium on the Effects of Nutrient Enrichment in Estuaries (Nixon, 1995). Since that time eutrophication has been recognized as one of the most challenging and important problems facing coastal marine waters (Yang et al., 2008; Bowen & Valiela, 2001). The significant increase in eutrophication in a short period of time can be attributed to the rapid urbanization of coastal land in the U.S., which has occurred largely without a plan to address this issue (Bowen & Valiela, 2001).

The causes of eutrophication are varied. The most significant sources of nitrogen are atmospheric deposition, fertilizer applications that run off from storms and watering into the water system, and human waste inputs from both point source discharges from sewer plants and septic systems that leach nitrogen into groundwater (Bowen & Valiela, 2001). Atmospheric deposition can not be controlled at the local level so in determining local solutions to decrease nitrogen loading fertilizers, run off and sewage disposal are generally the focus. The location of the water body determines the significant sources of nitrogen and therefore the solutions put in place to reduce the nitrogen load. For instance, eutrophication in the Gulf of Mexico is caused mostly by run off from fertilizers used in farming along the Mississippi River (Conley et al., 2009). Along the highly residential East Coast, particularly on Cape Cod, most of the nitrogen causing eutrophication is coming from septic systems (Howes et al., 2009). The solutions in these two places could be significantly different because of the types of sources that are contributing to the nitrogen loads.

## Solutions to Nitrogen Loading

There are a wide range of differing types of solutions to the issue of large nitrogen loads in coastal water bodies. Most of these solutions focus on decreasing the amount of nitrogen that is initially released or the amount that is able to actually make its way into the water system. These solutions include, but are not limited to, more sophisticated water treatment plants, innovative septic systems, permeable reactive barriers, decreases in fertilizer usage, green roofs, and even toilets that collect urine to be treated separately from the rest of residential waste. These all target the pollution at or near to the source, however a solution that has been studied and is being championed as a great natural solution is the use of shellfish to remove nitrogen once it has reached the water body (Sebastiano, Levinton, Doall, Kamath, 2015).

## Shellfish Aquaculture

Shellfish are filter feeders, pulling in large amounts of water containing nutrients and contaminants. They consume these in the form of phytoplankton, detritus, and bacteria (Sebastiano et al., 2015).  This process allows them to sequester large amounts of nitrogen in their soft tissue and shells as they grow (Woods Hole Group, 2012). This nitrogen can then be removed from the system by harvesting shellfish. Shellfish can also directly remove nitrogen by biodepositing the nitrogen in the seabed (Carmichael. Walton, Clark., 2012). Microbes that are nitrifers and denitrifiers then use these biodeposits as a source of nitrogen in the nitrification/denitrification process (Woods Hole Group, 2012).

The idea of shellfish aquaculture as a solution to nitrogen loads has grown in popularity. However, there are a number of considerations that have to be accounted for when focusing on this as a solution to significant nitrogen loading. First, the actual amount of nitrogen removal by shellfish is uncertain, varying across more than thirty studies from less than 1% to 15% of the annual nitrogen load depending on the amount of shellfish, type, and location (Carmichael et al., 2012). Therefore, to realistically determine the amount of nitrogen removal in any given water body, a study must be done first. Also, different species of shellfish sequester different amounts of nitrogen and have other characteristics, which make them more or less suitable for large scale aquaculture

(Woods Hole Group, 2012). Even when the type of shellfish and possible amount of nitrogen removal has been determined the potential habitat, other land and water uses in the area, and other ecological effects must be taken into consideration (Carmichael et al., 2012; Leavitt, 2003).

Oyster restoration and oyster aquaculture are particularly promising solutions and oysters are studied as a species that can be used for restoration of water bodies (Cerco and Noel, 2007; Woods Hole Group, 2012). The focus of this paper will be on the aquaculture of the oyster, *Crassostrea virginica*, due to it's relatively high nitrogen removal rate and suitability to grow in the area being studied, as well as it's popularity as a gourmet food (Woods Hole Group, 2012).

## Case Study: Waquoit Bay

Waquoit Bay (Figure 1) is a water body on the southern coast of Cape Cod in Massachusetts, which, like much of southern Cape Cod, has a significant nitrogen loading issue (Howes et al., 2009). The Bay is part of a 13,268 acre watershed and is mostly fed by groundwater inputs from the inland area of Cape Cod. The total water flow into the bay is approximately 3.5 million ft^3 a day, bringing in a significant amount of nitrogen (Howes et al., 2009).

### Nitrogen Loading in Waquoit Bay

Nitrogen (N) loading in Waquoit Bay has been continuously increasing over time with a doubling of the nitrogen load between 1938 and 1990 (Bowen & Valiela, 2001). As of 2009 the total attenuated nitrogen load of the watershed was estimated at 40,223 kg


Figure 1. Waquoit Bay and surrounding land and tributaries (ESRI, 2017).

N/yr and the unattenuated load was 48,319 kg N/yr (Howes et al., 2009). The attenuated load is lower than the unattenuated load because it assumes that some of the nitrogen is attenuated in the fresh water sources, streams and ponds, before it reaches the bay. The natural tides that bring water in and out of the bay result in nitrogen concentrations, which are lowest at the mouth of the bay and slowly increase as you move farther inland (Figure 2) (Howes et al., 2009).

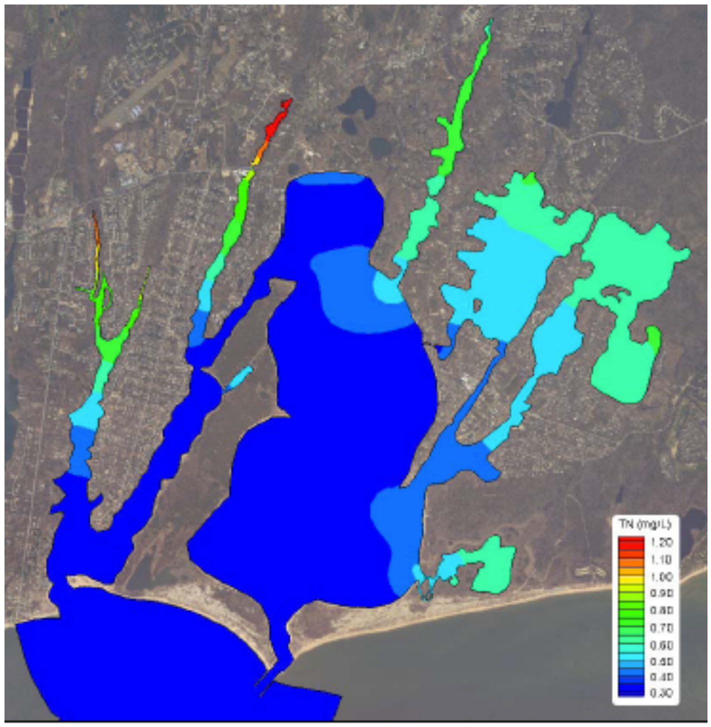


Figure 2. Average nitrogen loading concentrations in Waquoit Bay (Howes et al., 2009).

However, this only represents the loading of the Bay as of 2009. With more build out, particularly of residential areas, the nitrogen loading will increase even further if nothing is done. Approximately 11% of the watershed is still available for development, and if fully developed, would increase the nitrogen load for the watershed to 68,164 kg N/yr of unattenuated load, or 57,426 kg N/yr of attenuated load (Howes et al., 2009). This is a significant increase, which will continue to further degrade the water and ecosystem quality in the Bay.

By far the largest contributor to the nitrogen load in Waquoit Bay is wastewater (75%), followed by impervious surfaces (13%) and fertilizers (12%) (Howes et al., 2009) (Figure 3). In contrast, the local control loads are the loads that can be changed by things done in the local area (Figure 3). It is extremely important to understand where the excess nitrogen is coming from as this will determine what is used to combat the problem.

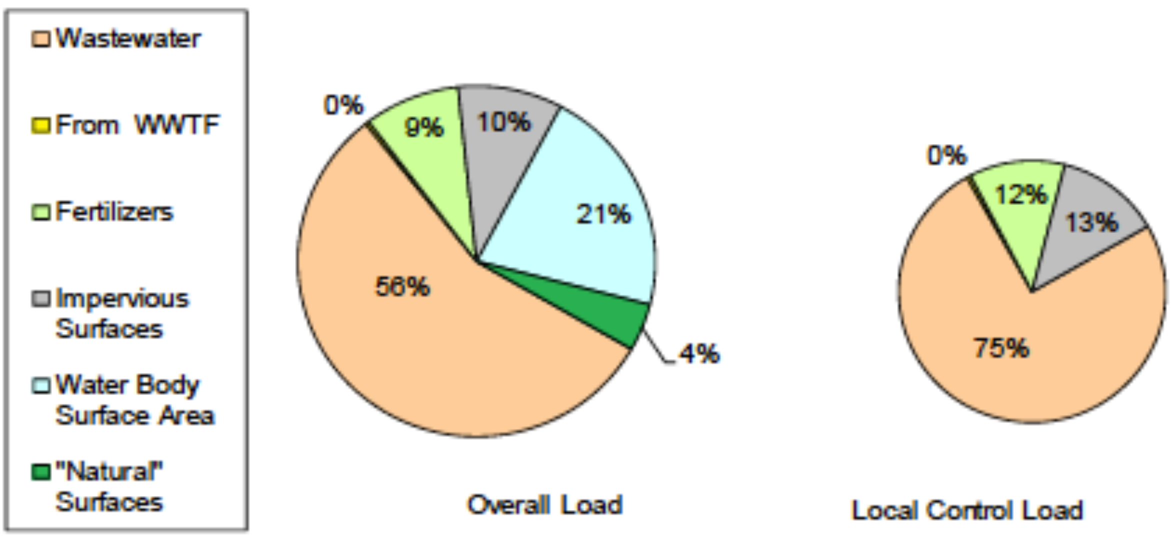


Figure 3. Waquoit Bay nitrogen load by source (Howes et al., 2009).

Impacts from Nitrogen Loading

The largest impact seen from the nitrogen loading in the Bay is significant species decline caused by eutrophication. In particular, eelgrass beds have declined as the eelgrass competes for light and nutrients in waters made murky from algae blooms due to eutrophication (Bowen & Valiela, 2001). The eelgrass coverage was already decreasing before 1970 and saw a large further decrease in the late 1980s and 1990s as residential construction rapidly increased (Bowen & Valiela, 2001; Short and Burdick, 1996). Between 1987 and 1992 the loss of eelgrass in the area was significant and was correlated with the number of houses in the area (Short and Burdick, 1996). Eelgrass, and seagrass in general, is an important species in the ecosystem as it provides a habitat for shellfish and fin fish species (Bowen & Valiela, 2001). The bay scallop, *Argopecten irradians*, which uses eelgrass as its habitat, saw a tenfold decline in harvest from 100,000 lb/yr in 1960 to 10,000 lb/yr in 1977 (Bowen & Valiela, 2001). Eelgrass and sea scallops are just two of the species negatively affected by the eutrophication of the Bay.

## Nitrogen Loading Reduction

The Massachusetts Estuary Project (MEP) calculated the necessary reduction of nitrogen loading in Waquoit Bay to help bring back the ecosystem and get rid of the eutrophication problem in the water body (Howes et al., 2009). The loading limits were determined by looking at sediment characteristics, nutrient water quality information (especially dissolved oxygen and chlorophyll-a), and key habitat parameters of in fauna and eelgrass. The survivability of eelgrass was used as a parameter because of its importance in the ecosystem of the bay. The conclusion from the MEP report was that the nitrogen loading needed to be reduced by 53% from the 2009 loads (Howes et al., 2009). This would bring the nitrogen level down to approximately 0.38 mg/l total nitrogen (TN) across the watershed (Howes et al., 2009).

## Solutions to Nitrogen Loading in Waquoit Bay

Many potential solutions have been investigated for reducing the nitrogen load in the Bay, from installing sewage systems with treatment plants to decreasing run off and using lower nitrogen emitting septic systems. However, all of these have drawbacks, including significant costs to the towns and to local residents, long lead times, and some are experimental in nature. The solution of using oyster agriculture and farming the oyster, *Crassostrea virginica*, has been advertised as a low cost solution, or even a net positive benefit, and a natural solution to the problem. The other advantage that shellfish aquaculture has in comparison to other solutions is that nitrogen is removed after it has already been deposited in the water. Other solutions stop nitrogen at the source, which over time will be able to greatly decrease the nitrogen load in the water, but it does not affect the current situation. Much of the nitrogen in Waquoit Bay comes from groundwater polluted by septic systems releasing nitrogen (Howes et al., 2009). Some of the groundwater in the watershed originates from many miles away and will not get to the Bay until ten years after it enters the system (Howes et al., 2012). This means that even if all added nitrogen was stopped tomorrow, excessive amounts would still be reaching the bay for at least ten years. This issue can be solved by removing the nitrogen after it has entered the Bay, which is where oyster farming could be particularly useful.

Oyster Farming

A lot of research has been done on oyster farming, including research in Waquoit Bay. Growing oysters over approximately 0.5%-1% of the area of the bay was able to remove about 15% of land -derived nitrogen and 1% of phytoplankton nitrogen (Carmichael et al., 2012). This proves that oyster farming could have a positive impact on the nitrogen loading of the bay. However, this study also pointed out that the use of oyster farming needs to be considered in conjunction with other ecological factors, current water uses, and available space. Currently in Waquoit Bay there is one commercial oyster farm operating under an aquaculture grant that has been in existence since 1877 (Washburn Island Oysters), and a couple of other small farms that have come into existence in the last few years. There is also recreational shell fishing done in the area, mostly focused on quahogs. However, to reduce the nitrogen load in the Bay the amount of oyster farming will have to be significantly increased. Determining the best places and areas available to farm oysters is the important next step in ensuring that oyster farming in Waquoit Bay succeeds at a level that will reduce the nitrogen load, reduce eutrophication, and restore the ecosystem.

## Research Question, Hypothesis and Specific Aims

My overarching research goal was to map Waquoit Bay to determine good areas for oyster farming, while taking into account environmental, social and economic factors. A number of nitrogen reduction scenarios were explored to determine the amount of oyster farming acreage required in the Bay to meet those targets. My major research question was therefore: In proposing a map of shellfish farming in the bay, where do other environmental, economic, and social factors outweigh the benefits of using oyster farming for nitrogen removal?

To help address these questions, I examined the following hypotheses:

1) Waquoit Bay can support enough oyster farming to remove the amount of nitrogen necessary to bring nitrogen loading to acceptable levels;
2) The amount of farming necessary will not be able to be achieved without major impacts on other uses of the area.

Specific Aims

Addressing these questions and hypotheses required these specific steps:

1. Map the areas of Waquoit Bay, which are best suited to oyster farming using information including shellfish suitability and town open areas.
2. Use local maps, town regulations, and interviews with town officials to map areas of high recreational/commercial use. This is necessary to determine what areas in the Bay might be off limits to oyster farming and what areas might be less socially acceptable for oyster farming.
3. Determine environmentally sensitive areas in the Bay where oyster farming would disturb the environment or local species.
4. Overlay layers for the nitrogen loading of the bay, successful oyster farming parameters, environmentally sensitive areas, and current social/economic uses to determine the best areas for oyster farming in Waquoit bay, given scenarios of different amounts of oysters that correspond to different nitrogen loading reduction levels.
5. Calculate the economic savings of using oyster farming as a solution to the nitrogen loading problem instead of a traditional installed water treatment system.

# Chapter II

# Methods

Data from a number of sources were collected and then compiled into maps using ArcGIS Pro to represent the best areas for shellfish farming and the conflicts within these areas. Nitrogen maps from the MEP report were also evaluated to show which areas have the highest nitrogen loads. A basic analysis of economic impacts was done using recent fisheries data; however, this data was not presented in a map format.

Data gathered from these various sources were then imported into GIS. Some of the files were already GIS capable files and some data had to be hand drawn into the program. The hand drawn data is more likely to have errors because it was transcribed, often from a PDF with little detail. However, this was carefully done using the best data available so as to minimize possible errors on the maps.

## Data Sources

Data were collected from towns, Massachusetts' government sites and studies, and local surveys of the area. The most significant source of varied types of data was the Massachusetts Office of Geographic Information, also known as MassGIS. This office provides a trove of information ranging from permitted shellfishing areas to locations of public boat ramps. These data were already formatted for GIS use and inserted directly into the maps created for the project. Each type of data was identified by its layer name and by a descriptive name.

Water Use Data

A NOAA chart was used to determine the land and water areas along with depths throughout the Bay. Also on the NOAA chart were channels and other Aids to Navigation that would preclude an area from being farmed. The chartlet used is a portion of NOAA chart 13229. This chart was imported from MassGIS and was last updated in December, 2004 (MassGIS, 2017).

To represent some of the social conflicts a MassGIS source was added entitled Fishing and Boating Access Sites (OFBA_PT), with data representing ramps and water access sites open to the public along Massachusetts shores, last updated in June, 2017 (MassGIS, 2017). It was gathered by the Office of Fishing and Boating Access within the Massachusetts Department of Fish and Game (MassGIS, 2017). However, there could be other private boat ramps not represented in this data. To identify other boat ramps and mooring fields missing from this map, I surveyed the watershed by boat. This added one boat ramp and several current mooring fields along with approximate locations. The only official mooring field data showed most of the Bay as possible mooring fields depending on the town and the year. This survey was conducted in June and again in July, 2017.

Other critical water use data was added by a survey of the area. Areas used for recreational purposes including swimming, boating, and windsurfing were added as a layer. This survey was done over multiple occasions in May, June, and July 2017 to include the most complete representation of the recreational areas most used in the watershed.

Shellfish Suitability Data

A number of MassGIS data sources were compiled to represent suitable shellfishing areas, including a Shellfish Sampling Stations (SHLFSHST_PT) layer. This layer consists of 2700 points statewide that represent sites for collecting water quality, shellfish and marine biotoxin samples as well as areas such as mooring fields and marinas. These data were compiled by the Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement's Division of Marine Fisheries. This was last updated in October, 2000 (MassGIS, 2017).

A Shellfish Suitability Areas (SHELLFISHSUIT_POLY) data layer from MassGIS, which was last updated in May, 2011, was added. This layer represents areas deemed suitable habitat for growing ten different types of shellfish. These data were compiled using input from the Massachusetts Division of Marine Fisheries, local shellfish constables, local fishermen, and information from maps and studies of shellfish in the areas (MassGIS, 2017). However, this layer does not necessarily represent areas where shellfish are currently growing. It also does not necessarily represent all of the areas where shellfish could grow, as there could be suitable shellfish habitat that is not represented in this layer.

Another added data source was Designated Shellfish Growing Areas (DSGA_POLY), last updated April, 2017 (MassGIS, 2017). These data were compiled by the Massachusetts Department of Fisheries and Game and is available from MassGIS. This data source lists all 304 shellfish growing areas in Massachusetts and their classifications. Five state classification categories are identified: Approved, Conditionally Approved, Restricted, Conditionally Restricted, and Prohibited.

Other sources of data also proved significantly important. The Town of Falmouth and the Town of Mashpee provided maps or descriptions of shell fishing areas in their jurisdictions and what these areas can be used for, whether commercial or recreational shellfishing. They also provided information on areas closed to shellfishing due to contamination.

The Mashpee map was a handrawn map that identified four types of areas that are already restricted to shellfishing in some form: No Shellfishing Contaminated, No Shellfishing May 1-October 31, Family Area No Commercial Shellfishing and Shellfish Farm No Shellfishing (Town of Mashpee, 2017). The handrawn map was redrawn in GIS and added as a separate layer. This map was last updated July, 2017 (Town of Mashpee, 2017).

The Falmouth shellfish areas were described in a PDF document. The written descriptions were used to draw out the areas unavailable to shellfishing in the Waquoit Bay system. The PDF lists all the open areas and areas open with restrictions. Any other area is closed (Town of Falmouth, 2017). The closed and restricted areas were plotted. Some areas were only open for some methods of shellfishing. These areas were assumed to be available for shellfish farming and added to the map of suitable areas in the Bay. These areas were current as of May, 2017.

## Environmental Concerns

To represent areas of environmental concern a MassGIS layer entitled NHESP Estimated Habitats of Rare Wildlife (ESTHAB_POLY) was consulted. This layer represents areas where rare wetland wildlife has been observed in the last 25 years with occurrences documented in the Natural

Heritage & Endangered Species Program (NHESP). This layer only represents rare wildlife, and was updated as of August, 2017 (MassGIS, 2017).

## Nitrogen Data

The primary data that began this project was the nitrogen loading data for the watershed. This data and the maps portraying it come from the Massachusetts Estuaries Projects (MEP) report (Howes et al., 2009). Unfortunately the data are almost ten years old, dating from the late 2000s. Since that time there has been more residential growth on Cape Cod, which may have resulted in more nitrogen loading than in the MEP report. However, there is no reason to believe that this data does not still portray a good approximation of current conditions.

One very important decision in examining these data was the amount of nitrogen that could be removed by the oysters. Data vary widely in regards to how much nitrogen is actually removed by the biomass of different types of shellfish. The most accurate numbers come from studies to determine how much nitrogen certain shellfish can remove from a particular body of water. In this case an analysis of Mashpee oysters was completed by Boston University (York, 2016). They concluded that these oysters had a 0.5% nitrogen content in live weight, shell and tissue included. This means that for every 100 grams of oysters harvested, 0.5 grams of nitrogen is removed from the system (York, 2016). This may be an underestimation and simplification of the amount of nitrogen removed, but it is the most accurate measure available, and is used by the town when making decisions about oyster farming.

The amount of nitrogen removed by the oysters by volume was then used to calculate how much biomass of oysters would be required to remove enough nitrogen from the water to bring it back to an acceptable level, as determined from the Massachusetts Estuary Project report. This benchmark of nitrogen removal would allow the water to return to a state where natural species would thrive and the Bay would become a healthy habitat.

Different types of oyster farming were looked at to determine how much of the watershed would need to be farmed in order to create the necessary biomass. Types of farming are split into two categories, on the bottom and off the bottom methods. The most common type of oyster farming uses cages with bags inside, which float right around the surface of the water. This method is currently being used in the area. These bags and oysters are routinely shaken to keep growth off the oysters. A number of assumptions were made to determine the average number of oysters produced per acre.

## Economic Data

The economics behind a large increase in oyster farming are not as easy to see in a map format. The 2015 and 2016 Department of Marine Fisheries Annual Reports were examined to determine the reported value of oyster farming and how many oysters were farmed in the last years. This report breaks down the results by town, so Mashpee and Falmouth were the focus. These numbers were compared to a recent report on Maine's aquaculture (Hale, 2016)  to get a good comparison of shellfish farming in another similar area to Cape Cod.

An economic comparison to other ways of removing nitrogen or keeping nitrogen out of the system was also conducted. The Town of Mashpee's mitigation plan lays out costs associated with different methods of nitrogen removal/nitrogen mitigation. The costs of other methods, such as reducing fertilizer use and treating sewage discharge at sewer plants, were compared.

It was also important to look at whether the recommended amount of shellfish farming could have a negative impact on other aspects of the economy, including tourism and commercial fishing. This was a much more difficult analysis as impacts are uncertain, depending on where the farms are actually set up in Waquoit Bay. Therefore, some newspaper articles and other sources of local concerns were consulted, but no hard numbers were determined for this part of the analysis.

## Eelgrass Data

Finally, a map was constructed of the distribution and amount of eelgrass in Waquoit Bay. A large commitment to an environmental problem, such as adding a significant amount of oyster farming, needs to be able to be tracked for progress. In addition to direct water testing, an indirect way to monitor if the Bay is in fact reducing its nitrogen levels is to track the amount of eelgrass, as it serves as a bioindicator. Eelgrass has been reduced greatly over the last half a century in the area, largely due to nitrification (Short, 1996). Tracking the spread of eelgrass also tracks the health of the water and ecosystems. Studies of eelgrass have been done numerous times over this period and maps of some of these years were available from MassGIS. The most recent data for the areas is from 2010 on a MassGIS layer entitled EELGRASSPOLY2010_POLY. Also included on the map is the oldest data layer from 1995 entitled EELGRASS1995_PLOY. The data is collected via aerial images and confirmed on the ground by surveys done by boat (MassGIS, 2017). Eelgrass will continue to be tracked to hopefully indicate water quality improvements and give the local community a visual indication of habitat improvements.

# Chapter III

# Results

A number of maps were produced to assist local communities in deciding whether or not to use oyster farming as part or all of their nitrogen loading reduction plan. These maps show results of how much nitrogen needs to be reduced overall, and the significant amount of acreage necessary for this reduction, as well as impacts on other aspects of Waquoit Bay.

## Nitrogen

The amount of nitrogen necessary to be removed is crucial to determining how much of the Bay would need to be farmed. The current nitrogen levels were mapped to show areas of more concentrated nitrogen.

### Nitrogen Removal

In Waquoit Bay for every 100 grams of oysters harvested, 0.5 grams of nitrogen would be removed on average (York, 2016). Most of this nitrogen, about 66%, is found in the meat of oysters with the rest in the shell (Reitsma, 2016). These mean values are for oysters that are grown at the surface of the water, the preferred method for most oyster farmers. The average weight of oysters grown in this way is about 60 grams (Reitsma, 2016). These numbers are similar to studies done in Chesepeake Bay and New York, but were calculated for Waquoit Bay oysters specifically. The nitrogen rate does vary somewhat seasonally and by oyster size; however, for this study the average nitrogen was used.

The second important number is how much nitrogen needs to be removed to bring nitrogen levels back to an ecologically sustainable level. This number was determined using research done by the Massachusetts Estuaries Project. Overall the amount of nitrogen loading in the watershed needs to be reduced by 53.4% from the present load of 91 kg/day to a total maximum daily load (TMDL) of 42 kg/day, a reduction of 48 kg/day (Howes et. al., 2009). To reduce the nitrogen load to this extent using oyster farming as the sole method of nitrogen reduction, approximately 35.55 million average oysters would need to be harvested yearly from the Waquoit Bay watershed. This is a huge number but it is very unlikely that aquaculture would be looked at as the only part of a nitrogen reduction plan. The current town plans, and probably future plans, would have many other facets, including sewer plants, fertilizer run off reduction, and technologies such as green roofs and permeable pavement.

To determine the amount of space this would take up in the water, typical off-the-bottom oyster farming was assumed. A floating oyster cage typically holds six bags that produce about 200 oysters each. About 100 cages can be placed on one acre of useable water, resulting in about 120,000 oysters per acre (Morse, n.d.). To produce enough oysters to lower nitrogen levels in the watershed to the recommended level, approximately 296 acres of Waquoit Bay and its estuaries would need to be used for shellfish farming. There are approximately 1,227 acres of open water in Waquoit Bay (Howes et al., 2009). Therefore, to farm the oysters needed to reduce the nitrogen to recommended levels, almost 25% of the open water in the bay would need to be farmed.

This estimate could be lower depending on how the oysters are farmed. If more oysters are in each cage or more cages are placed per acre, the required number of oysters could be farmed on less water surface.

## Nitrogen Mapping

Nitrogen concentration levels vary across the Bay (Figure 4), with some highly concentrated areas and areas that are much closer to safe loading levels. The areas with

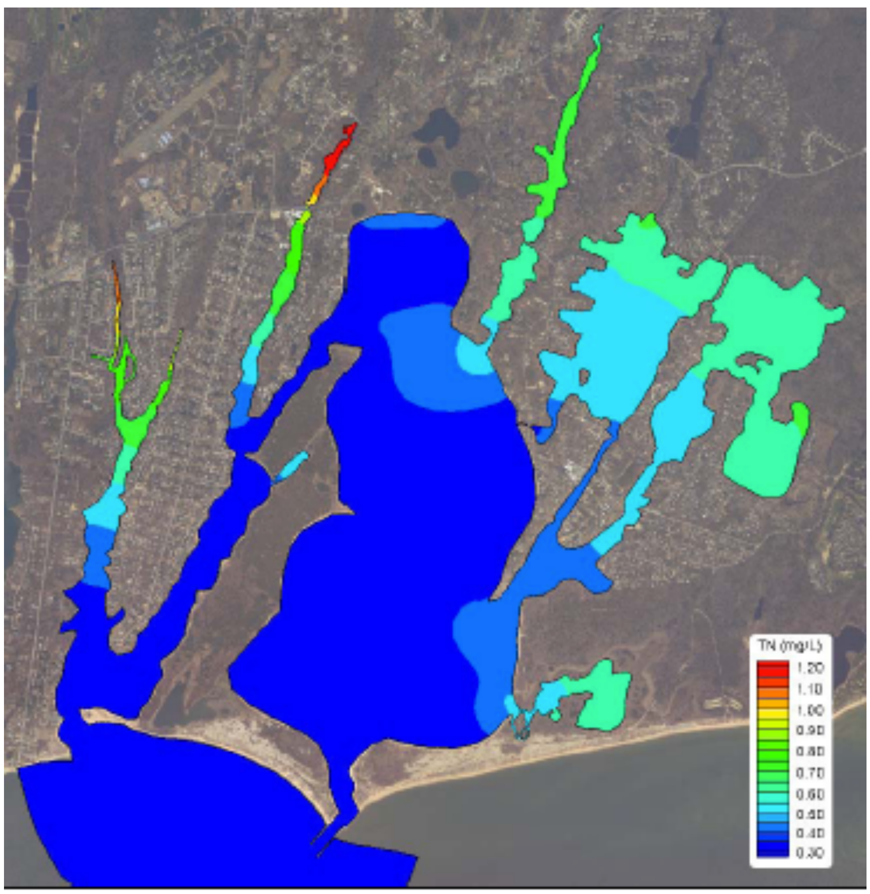


Figure 4. Current distribution of nitrogen in Waquoit Bay (Howes et al., 2009).

the highest concentrations are in the upper rivers where most of the groundwater is feeding into the system. In the lower area of the Bay there is a much lower nitrogen concentration because of constant water change out due to tides. The areas where shellfish farming for the purpose of removing nitrogen makes the most sense is in the upper rivers where the concentration is the highest.

Under a scenario where more of the area is built out, with added septic systems, fertilizers, and run off to the system, nitrogen loading throughout the Bay increases (Howes et al., 2009) (Figure 5). This is not unrealistic; since the report was written ten years ago, a significant amount of build out has occurred in the watershed.

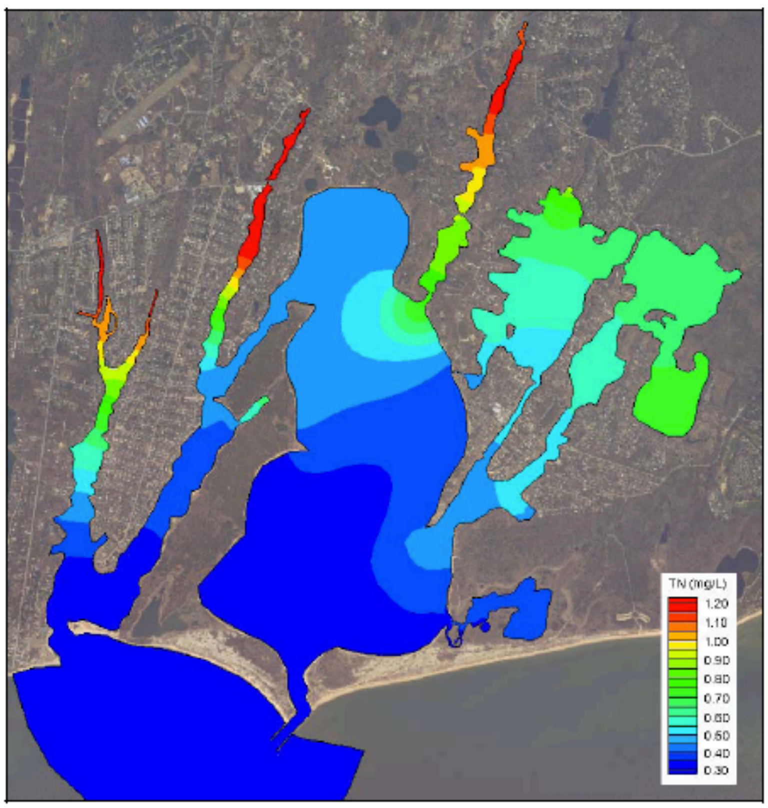


Figure 5. Forecasted full build out nitrogen concentrations in Waquoit Bay. This assumes the area reaches full build out of businesses and homes (Howes et al., 2009).

## GIS Maps

The actual map layers represent many different things that affect the suitability of oyster farming in Waquoit Bay. For ease of readability six maps were created. The first map has areas suitable for shellfish growing and the shellfish monitoring stations. The second map has State Designated Shellfish growing areas, Mashpee shellfishing areas, and Falmouth shellfishing areas. The third is a NOAA chart outlining buoys and channels. The fourth map shows recreational uses for the bay including popular boating areas, mooring fields and boat launches. The fifth map shows habitat of rare wildlife. Finally, the sixth map is one that should be updated over time to show the change in eelgrass area over time. All these layers can also be placed on a map and toggled on and off to highlight different areas and all the elements affecting those areas.

### Farming Suitability

The farming suitability map (Figure 6) represents areas where the habitat is conducive to shellfish surviving and growing. The first layer in this map is Shellfish Suitability, which represents if the habitat has been determined to be suitable for growing oysters in the area. Much of Waquoit Bay and its tributaries have been determined to be suitable habitat by the Massachusetts Division of Marine Fisheries. However, sections of the Bay that have not been determined to be suitable (blue areas, Figure 6) may nonetheless be grown in that area. This needs to be taken into consideration when using this data layer.

A shellfish sampling station layer is also included in this map to show locations where data is collected to make determinations on whether certain areas should be open or closed because of water conditions. These do not have any impact on whether shellfishing can occur in these areas, but they do give a good representation of how many sampling stations there are for the data that makes these decisions.

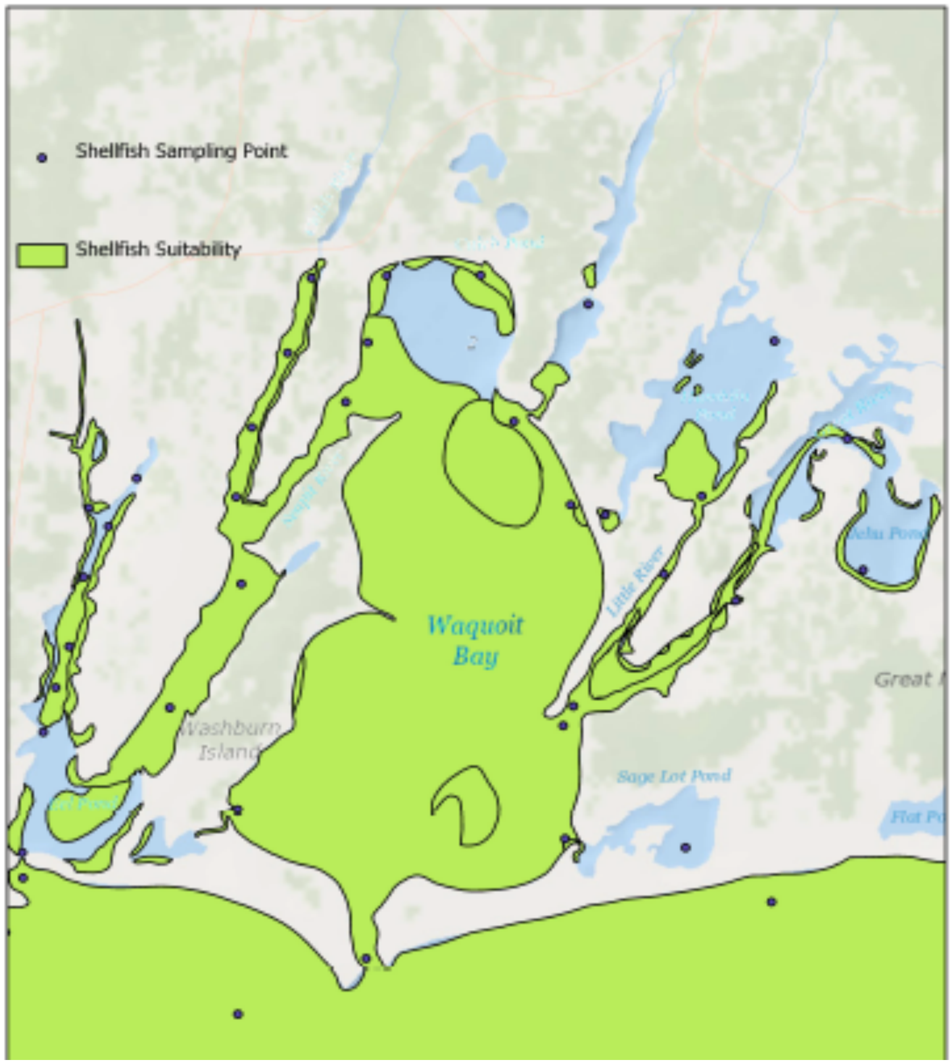


Figure 6. Locations suitable for shellfish and water sampling stations in Waquoit Bay.

State and Town Areas

The next important aspect is whether the state and local governments allow shellfish harvesting in the area, which is represented in the State and Town Restrictions

Map (Figure 7). The Designated Shellfish Growing Areas layer is compiled by the Massachusetts Department of Fisheries and Game. This delineates areas of shellfish habitat that are monitored and put into five categories. In the Waquoit Bay area three of the five categories are represented: Approved, Conditionally Approved, and Prohibited.

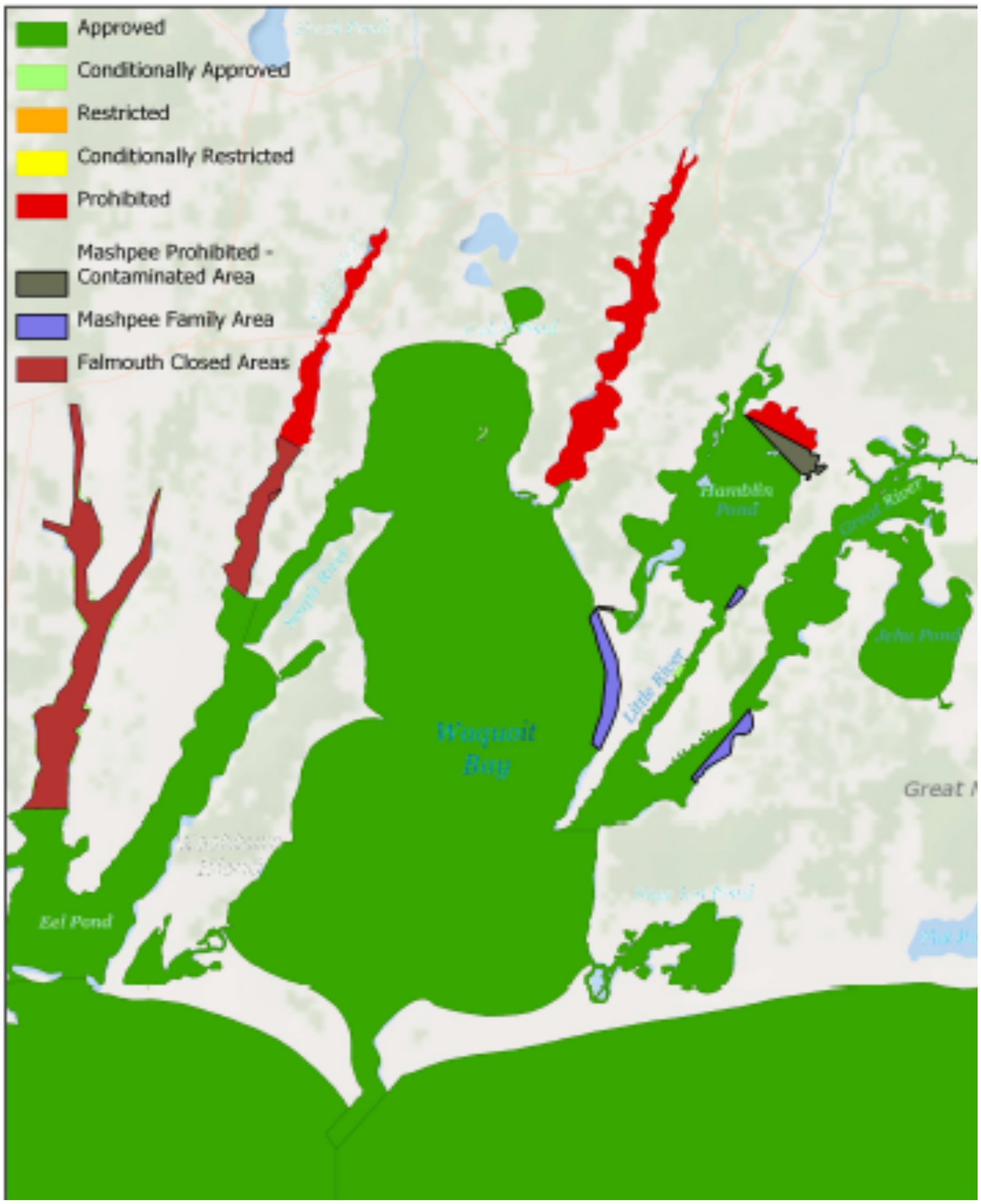


Figure 7. Areas of the Bay closed or restricted to shellfish farming or harvesting for various reasons.

Approved areas are areas where shellfish may be harvested for direct human consumption. Conditionally Approved areas are locations where shellfish may be harvested for direct human consumption as long as some conditions are met in a management plan. Prohibited areas are locations where no shellfish harvesting is allowed (MassGIS, 2017). Most of Waquoit Bay is in the Approved category for shellfishing (Figure 7). There is an area in the northernmost area of Hamblin Pond and most of the Mashpee River where shellfish harvest is prohibited. There is also an area of Childs River which is classified as Conditionally Approved.

Besides state areas, the local towns of Mashpee and Falmouth both also have a say in what areas are open for shellfishing and what type of shellfishing. These areas are also represented on this map. Mashpee enlarged the area in the northern section of Hamblin Pond that the state already identified as prohibited for shellfishing  and added an area near Seconsett Island. They also identified one small area where no shellfishing is allowed from May 1 to October 31, not shown on the map. A couple of Family Areas that are not open to commercial shellfishing are also identified on Great River, Hamblin Pond, and off of Seconsett Island. These areas were classified as areas where shellfish farming could not take place. There were also a few small areas where shellfish farming is already occurring, and so were counted towards the total acreage of shellfish farming.

Most of the Falmouth areas were marked as open. Closed areas were on the Quashnet River, an area already closed by the state and areas on the northern parts of the Eel River (Figure 7). These areas had been marked as conditionally approved by the state so closure by the town overruled the state marking. A small area by Seconsett Island was also marked as closed but this area is also marked by the town of Mashpee.

Areas that were identified as closed by both a town and the state are marked as red by the state GIS layer. Areas that the state marked as open but had restrictions placed on it by the town were marked at the higher classification the town required. In sum, approximately 21 acres of the Bay, mostly in the upper river areas, are closed to shellfishing by either the state or either town. A little bit less than two acres of area is reserved for family shellfishing in Mashpee, with commercial shellfishing prohibited.

## Commercial and Recreational Use

The next two maps represent other commercial and recreational uses in Waquoit Bay besides shellfishing. These range from boating to swimming to other types of fishing and recreation.

A portion of NOAA chart 13229 (Figure 8) shows the channels, buoys and other hazards to navigation. These are all areas where shellfishing would not be possible because of current boat traffic or navigational aids.

Another layer added was of public boat ramps identified by Massachusetts. These boat ramps would have significant traffic in the area making it difficult to grow shellfish conventionally in close proximity. Only two public boat ramps were identified using the Massachusetts data in the northern area of Waquoit Bay. Another public boat ramp was identified in Mashpee after a local survey of the area.

There were other mooring locations in the Bay but the ones represented on the map had the highest concentrations of vessels, which would make it difficult to farm in these areas. Exact mooring locations can change from year to year and most boats are

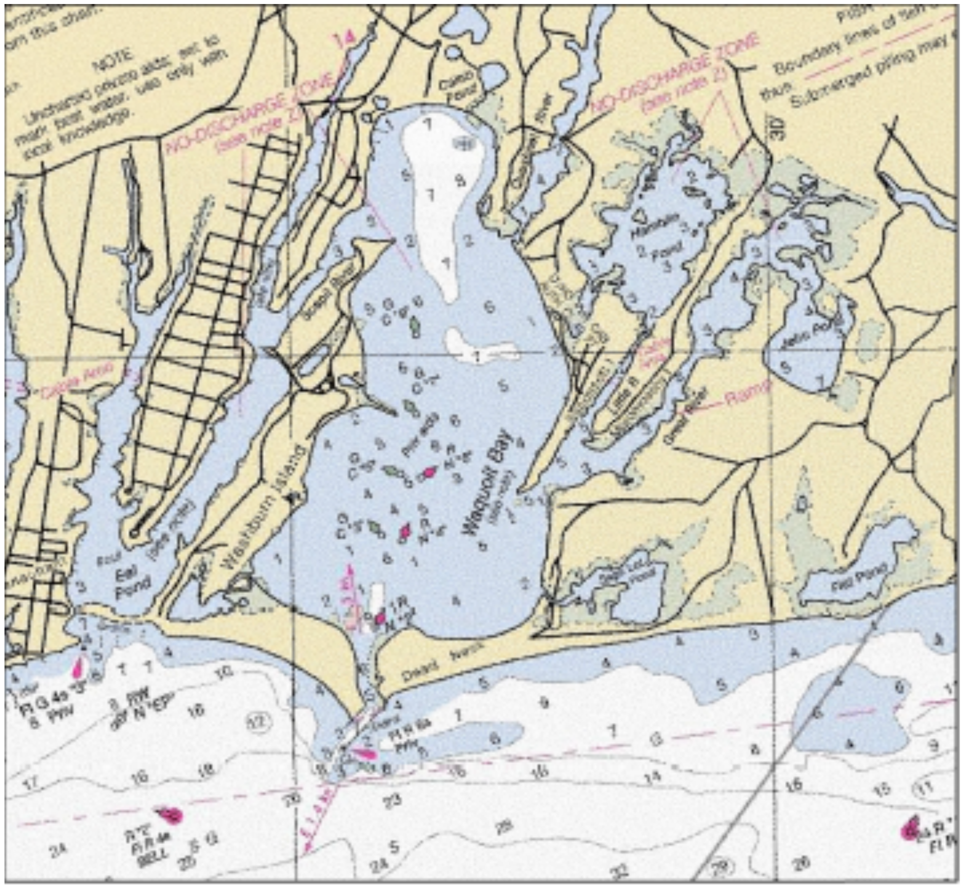


Figure 8. Portion of NOAA Chart 13229 - Waquoit Bay portion of NOAA chart to show channels and Aids to Navigation.

taken out of the water from October thru April. The areas of mooring fields should also be assumed to be high boat traffic areas. The largest mooring fields identified were along the rivers, in the northern part of Waquoit Bay, and along the West side of Seconsett Island. The mooring field areas would not necessarily be off limits to oyster farming but these areas are heavily trafficked. This would need to be considered if a request was put in to farm in these areas.

A recreational use layer added areas that were frequently used for boating, swimming, and windsurfing (Figure 9). These areas would not necessarily be off limits to shellfish farming but need to be considered when permitting. It may be more difficult to put oyster farms in these areas because people are attached to them for recreational purposes. They are identified as a layer in this map although they are superseded by any other use that would make shellfishing unsuitable in the area.  All of these layers combined make up the Recreational Uses Map (Figure 9).

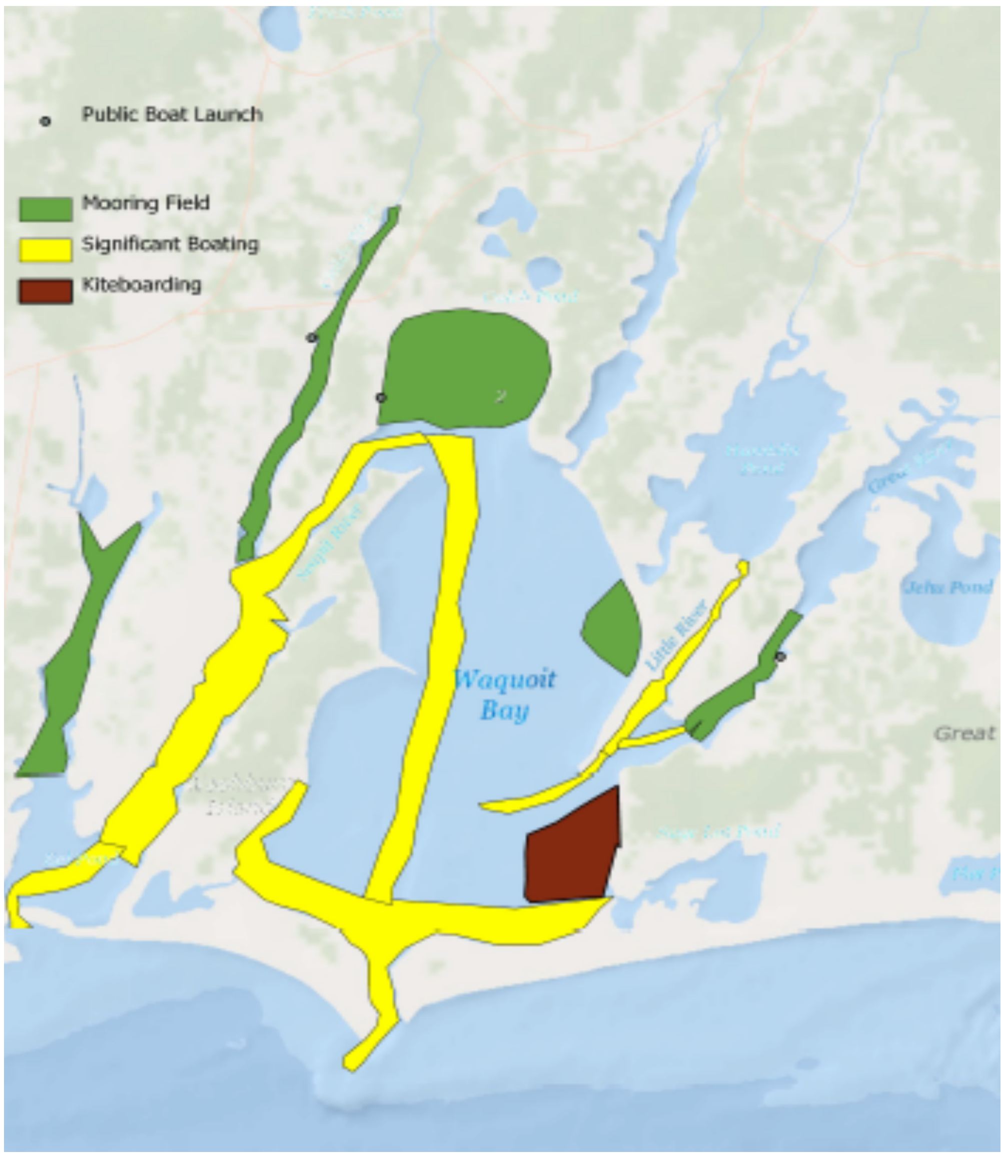


Figure 9. Heaviest used areas of the Bay for recreational pursuits.

Other Environmental Factors

There is no evidence that oyster farming would have any significant negative impact on the environment or other species in the Bay. The most significant impact could be just the habitat and area that the farming occupies. However, this does not seem to be a big concern. To show the possible wildlife impacts, the Habitats of Rare Wildlife Map (Figure 10) was created to show Estimated Habitats of Rare Wildlife in the area. Much of the Bay is covered by this category so it is something that needs to be taken into account

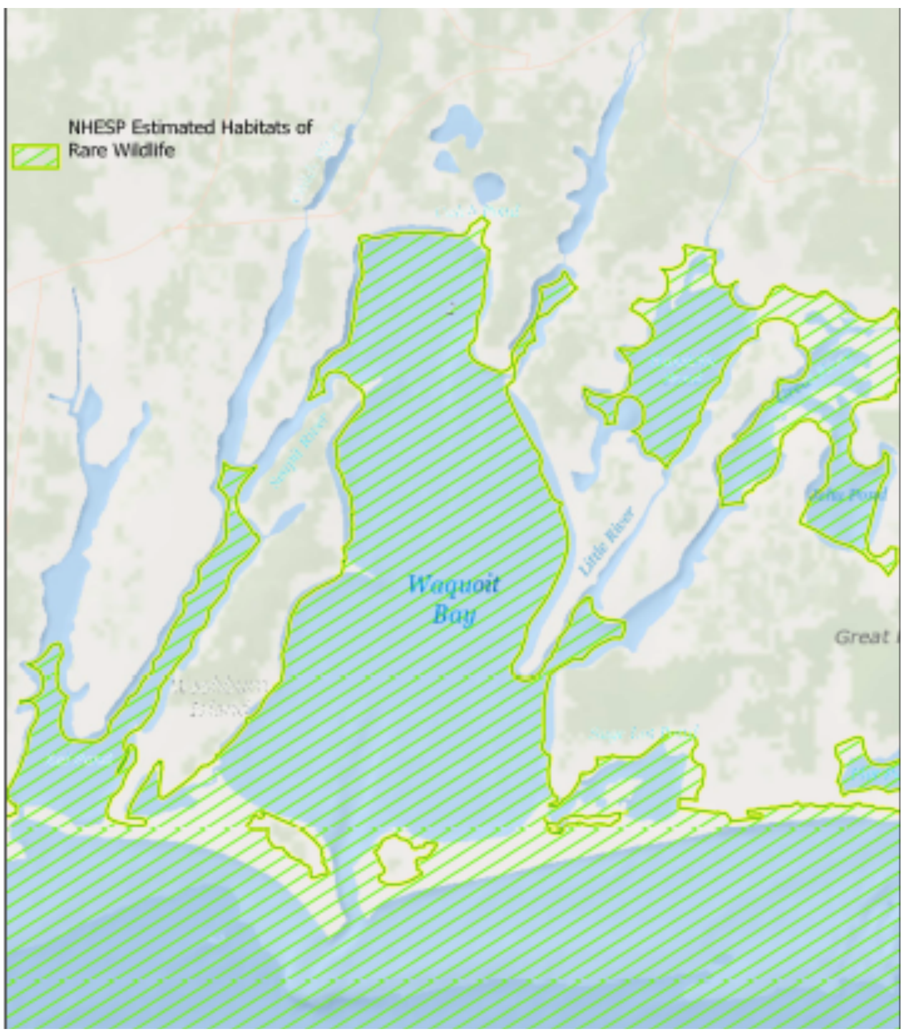


Figure 10. Area identified as habitats of rare wildlife by the NHESP.

when planning an oyster farm. A study of the specific site would need to be done to ensure the disturbance from farming would not impact any rare species in the area.

Finally Figure 11 shows the decline in eelgrass coverage from 1995 to the most recent survey in 2010. Eelgrass coverage is a good indicator of the health of the habitat and has been declining since the mid 1900s.

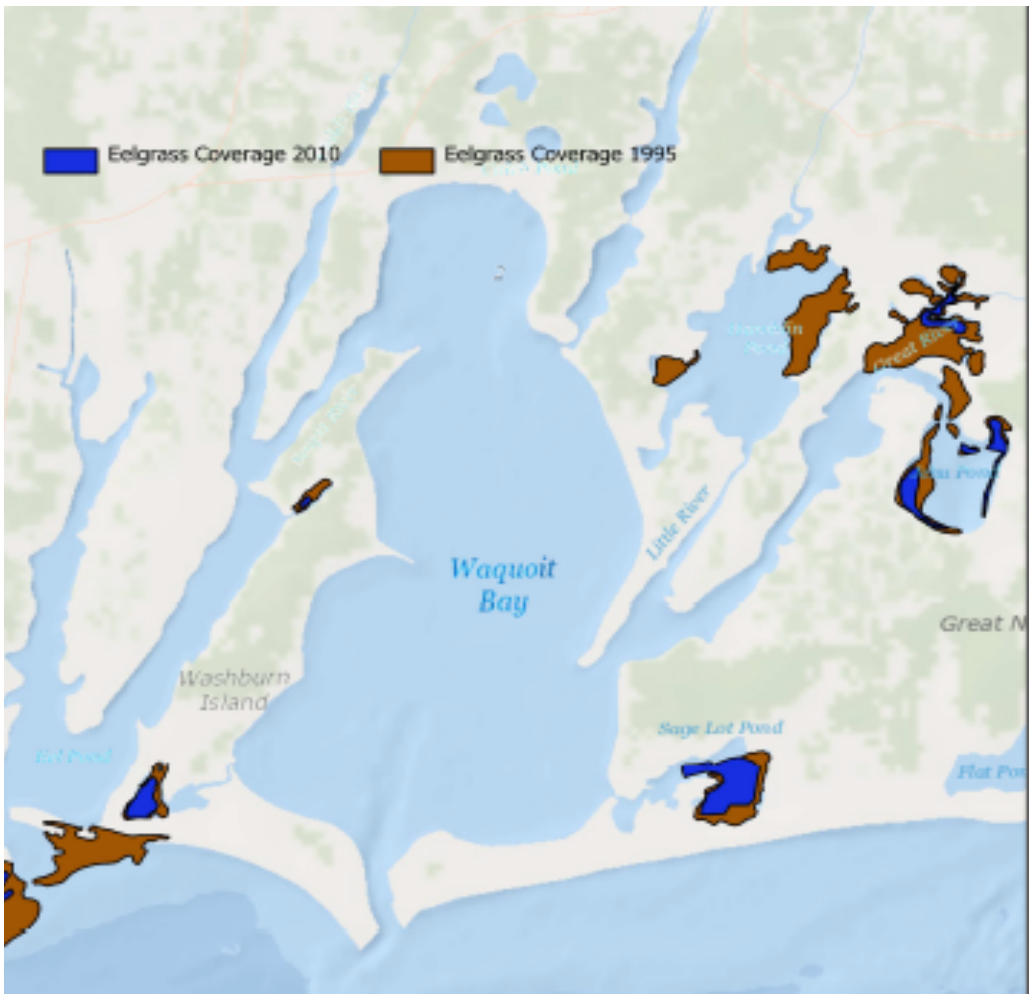


Figure 11. Areas covered by eelgrass in 1995 and 2010.

## Areas to Farm Oysters

To decrease nitrogen levels the best places to farm oysters would be in the areas with the highest concentration of nitrogen. These are the areas where the most nitrogen could be pulled out of the water before entering the rest of the Bay. However, the areas with the highest nitrogen concentrations are in the ponds and up the rivers of the estuary. Those are the areas with the most acreage closed to shellfishing, mostly because of contamination, which makes it unsafe to harvest oysters in those areas. These include the Moonakis River, Eel River, Childs River, and the northern part of Hamblin Pond. Beyond the environmental pollution in these areas, this is also where the highest amount of boat traffic is and where the highest concentrations of homes are. Finally, some of the pond areas include habitat not considered suitable for shellfish farming.

Even with the difficulties faced by oyster farmers in the ponds and rivers, other open areas still available for farming would have a significant impact. Jehu Pond and the open parts of Hamblin Pond would be particularly good areas for oyster farming if the habitat is suitable. There is quite a bit of traffic in some of these areas but farms that are set up towards the shoreline and with markers could avoid issues with recreational boaters.

Other areas of the Bay could also be farmed successfully and reduce nitrogen levels, although not as efficiently as the areas with high nitrogen concentrations. Good markings would make it possible to farm in Waquoit Bay itself, particularly if farms were close to shore to avoid high speed boat traffic. Even areas that are highly trafficked can be used if the farms are kept compact and to the outside of channels.

## Economic Effects of Expended Oyster Farming

The maps created give a good idea of the impact of oyster farming on the environmental and social aspects of sustainability. However, it was more difficult to map the economic impacts of oyster farming. To measure these impacts previous research was used to determine the basic positive economic impacts of oyster farming on Cape Cod. This was then extrapolated to the impacts on Waquoit Bay.

### Harvest Yields

In 2016 four new shellfish farming sites in Mashpee and Falmouth, totaling 11 acres, were issued permits by the state to operate. This brought the total between the two towns to 14 sites equaling 71 acres (Mass DEP, 2017). These sites grew both oysters and quahogs. In 2016, 410,504 oysters were harvested from the Falmouth farms for a total reported value of $260,116. No harvest was reported from Mashpee (Mass DEP, 2017), The 2016 harvaest was almost half that reported in 2015 for the same area. That year 958,802 oysters were harvested in Falmouth for a value of $550,585 and 147,471 oysters were harvested in Mashpee for a total of $84,303 (Mass DEP, 2016). The oyster harvests were reported directly from the growers and the value was based off of reported values from the growers or if that data was unavailable, the average unit price was used (Mass DEP, 2017).

From the numbers above 2016 yielded a per oyster value of $.63 for Falmouth growers and 2015 was a per unit value of $.57 for both Mashpee and Falmouth growers. This per unit value is how much they received per oyster and does not take into account costs of growing the oysters. In total for all of Massachusetts, 38.3 million oysters were commercially grown in 2016 at a value of $21.7 million and in 2015, 37 million were grown at a value of about $21.5 million (Mass DEP, 2016 & 2017).

It was calculated earlier that to use only oysters to reduce the nitrogen load to recommended levels it would take 35.55 million oysters a year harvested from Waquoit Bay. Using the average price from 2016 this would result in a value of $22.4 million. That would be over 10% of the 2015 U.S. oyster market, which was valued at almost $215 million (Hale, 2016). However, this calculation is just the raw numbers and does not take into account any other market pressures that could result from the increase in oysters.

# Chapter IV

# Discussion

The impacts of oyster farming on Waquoit Bay would be significant, particularly if oyster farming is to be used as a major solution to reducing nitrogen. There are also other considerations, including natural disaster and disease impacts on oysters, and seeding natural oysters instead of farming that should be considered. These all need to be discussed by all stake holders before making any decisions on using oyster farming for nitrogen removal.

## Impacts

The impacts of oyster farming go well beyond the anticipated nitrogen removal. Environmental, social and economic impacts all need to be considered when planning large scale oyster farming. There are varying degrees of consequences but even something that seems like a small impact compared to the good provided by the farming can become a road block.

### Environmental Impacts

The numbers used for calculating the amount of nitrogen removed from the Bay by a single oyster only account for the nitrogen contained in that oyster and removed from the system. It does not take into account other nitrogen reducing benefits that may be occurring due to the oyster's natural cycles. However, if oysters are taking nitrogen out of the system and then depositing it in another form, that nitrogen is still staying in the water. It is debatable whether this process of biodepositing nitrogen actually removes nitrogen from the system. That is why only the amount of nitrogen removed by actually harvesting the oysters was considered, as this was the most conservative way to measure nitrogen removal.

Oyster aquaculture could have a big positive impact on nitrogen removal and cleaning of the watershed. To have a significant impact a relatively small amount of water area would need to be farmed. There were not significant negative environmental impacts found with large increases in oyster farming. However, it is important to look at every site to ensure no other species would be affected but on a large scale oyster farming seems to have only positive environmental consequences.

## Social Impacts

The maps created for this project cover the impacts of oyster farming on recreational activities such as fishing, boating, and wind surfing. However, they do not do a good job of representing the aesthetic factor that has been an issue in the past due to shellfish farming. Floating shellfish farms are sometimes considered to be an eyesore, particularly for homeowners who have paid a premium for land with an ocean view. For instance, in 2010 a Mashpee oyster farmer wanted to expand his farm by 1.9 acres in Popponessett Bay. A group of wealthy residents opposed the farm and his permit was tied up in hearings and courts for five years (Spillane, 2015). One of the reasons given by the mostly wealthy homeowners was the appearance of the cages in the water, which they would see when looking at the view that they spent a lot of money to see (O'Sullivan, 2014).

The likelihood and extent of opposition will depend on homeowners and location. Many people like the local aspect of the farms but others see it as an eyesore. Others like the idea of eating local oysters but do not want it to ruin the view in front of their home, the not in my backyard argument. This is something that has to be dealt with by individual towns and farmers on a case by case basis.

The other major social impacts are to recreational fisherman and boaters of all kinds. Smart placement of oyster farms would reduce these impacts. Smart placement could mean anything from picking another area of the watershed to just making sure that farms are along the edges of marshes and channels and are well marked.

## Economic Impacts

One of the reasons that oyster farming is touted as a great solution to nitrogen loading is the bonus economic additions to the economy. If Waquoit Bay was farmed to reduce nitrogen levels to what are recommended about 35 million oysters per year would be harvested at a value of around $22 million. This would create a significant number of jobs and add a lot to the local economy.

Most shellfish farms are small businesses with only a few employees (Washburn Island Oysters, 2013). Some of these employees are also only seasonal employees, which requires them to either get another job or have some other source of income for the year. Oyster farms, just like any small business does add jobs to the economy but they may be jobs that only last part of the year.

This can also be a volatile industry as seen in the significant differences between the 2015 and 2016 harvest. The Falmouth harvest in 2016 was less than half the harvest in 2015. This could be disastrous for small farms struggling to survive. This also has an impact on the local economy as it could mean fewer people working the farms, and therefore more of a strain on these people and their local economy.

There is also the worry of flooding the market with oysters, which could drive prices down. The value per oyster is high and it is considered a delicacy around the country. Oysters are also advertised as a local, sustainable food so people are often excited to get oysters from the area they are from or are visiting. Filling the market with local oysters could drive prices down in the immediate area or even farther through the country.

There are definitely worries with the economic side of oyster farming due to the risk farmers take to farm and what would occur if the number of oysters harvested in Massachusetts quickly doubled. However, the shellfish farming industry, and aquaculture industry in general are steadily growing industries. It is an industry that has been predicted to keep growing, particularly as people demand local and sustainable foods.

## Dangers of Relying on Oyster Farming

There are different types of solutions that have been suggested to reduce nitrogen loading on Cape Cod and particularly in Waquoit Bay. They range from installing sewage systems throughout Cape Cod to using innovative septic systems to oyster farming. All of these different solutions are being used and considered in some form or another. They all also have advantages and disadvantages.

Oyster farming has the distinct disadvantage of being very vulnerable to natural effects. Large storms and disease are two things that could prove easily and quickly disastrous to oyster farms. In 2016 all oyster harvesting in Wellfleet, MA was shutdown because of an outbreak of norovirus linked to oysters. At the same time most shellfishing in the Nantucket Sound area was closed because of a phytoplankton bloom that could produce a deadly toxin (Fraser, 2016). These were unrelated natural events that shut down significant amounts of shellfish harvesting at the same time. This type of event not only means that the oysters may not be harvested, and therefore not as much nitrogen may be removed, but a large loss of income may result for farmers. For farms that do not have a large profit margin to begin with, one season of loss could close the farm.

Warming waters could affect oyster farms in two ways--- first, more major storms fueled by warm waters are expected, and secondly, warming waters are leading to an increase in the bacteria *Vibrio* (McKenna, 2016). This is a particularly dangerous bacteria found in oysters and has been increasingly found as waters warm in the northeast. In 27% of human *Vibrio* cases the person had to be hospitalized making this a very serious risk (McKenna, 2016). An outbreak of this disease could make consumers think twice about consuming raw oysters. This is just another danger that could shut down oyster farms and cause farmers to lose their businesses if it continues to spread with the changing climate.

The other consequence of climate change on oyster farms could be increasingly powerful storms. A large storm, like a hurricane or powerful Noreaster could wreak havoc on the farms. Most of them are in well protected areas, but even these areas could be devastated by a direct hit from a large storm. The threat of rising sea levels and warming waters could bring stronger storms to the area as well as change the habitat suitability. Stronger and more frequent storms could make shellfish farming more and more difficult, particularly as something that could be sustained over a long period of time.

Finally, predation is always something that has to be worried about in any type of shellfish farming. Natural predators of oysters exist in Waquoit Bay and could significantly reduce any year's harvest. This is something that farmers plan for but could still have a significant impact.

Storms, disease, and predators are all things that could significantly impact any single year's harvest, or could even, in extreme cases, affect multiple years. Not only would this be an issue for the year or two of the harvest decline but it could be farther reaching if it causes farms to shut down. If a large scale shut down occurs this could lead to a quick, significant increase in nitrogen levels. To successfully implement this as a major part of the nitrogen solution a program that helps farmers get through tough times due to natural causes, much like crop insurance for other types of farmers, would be a significant help to current farmers and those thinking about joining the business.

## Current Nitrogen Removal Plans

The Town of Mashpee, which contributes significant amounts of nitrogen to Waquoit Bay, has been working on a nitrogen mitigation plan since 1999. The final report was completed in 2015 (GHD, 2015). The report's final recommendations rely heavily on shellfish aquaculture to reduce nitrogen loading. A limited sewer system, as well as fertilizer run off reduction, are also big parts of the plan. Other innovative solutions are mentioned as well, although they are not key parts of the plan (GHD, 2015).

According to the town plan the cost of the entire plan at build out with shellfish aquaculture will be $160 million. This grows to $250 million without shellfish aquaculture (GHD, 2015). Most of this money would have to be spent to increase sewage infrastructure in the town. That is an incredible amount of money that the town would have to make up if shellfish aquaculture is not successful.

The Town of Falmouth completed a Wastewater Management Plan in 2010. Their plan focused significantly greater resources and planning on upgraded sewer systems throughout the town. They are relying much more on sewer and man made treatment options for lowering nitrogen levels. However, their report does still mention aquaculture and other alternative nitrogen reducing technologies and systems (Town of Falmouth, 2010).

The reliance on shellfish aquaculture is not surprising as it is a relatively cheap alternative to sewers and it is popular because of its natural appeal. However, the recommendations also delve into what the alternatives will be if the aquaculture does not take hold as well as it is predicted or hoped to, a concern explored in this thesis.

## Research Limitation of Nitrogen Loading Data

One significant limitation of this research is the age of the data used to calculate the nitrogen loading throughout the watershed. The data was collected in the mid to late 2000s. This calls into question its validity at least ten years later. This has been a known issue for that entire time period, with people working on solutions to lower nitrogen levels. This could mean that current nitrogen levels are below that used for this research. However, continued development of the area also means the levels could be higher, even significantly higher than the data used for this research. Either way it is an important factor to consider, especially for those making decisions based on this data. More recent and more accurate data are always best when applying scientific research; however, at some point it is also important that decision makers use what is available and act on that information--- in this case, to improve the water quality in the watershed.

## Oyster Seeding

Another topic brought up during this research that needs further exploration is the potential of seeding efforts to increase the non-farmed amount of shellfish in the area. This seeding would allow oysters, and other shellfish, to take root and grow naturally in the bay. This would then allow for them to run their course as a part of the ecosystem. These oysters could also be harvested under commercial fishing permits or by recreational fisherman. The seeding and subsequent encouragement of these natural areas to grow could in the long run be more sustainable within the ecosystem.

Mashpee started a seeding program in 2004 that by 2008 had helped to reestablish the fishery. In 2008 520,000 oysters were harvested, providing a significant nitrogen load reduction in the area (York, Town of Mashpee). This had successfully led to an uptick of the number of wild shellfish. Not only does this help remove nitrogen from the water but it encourages the land and water to return to a more natural ecosystem. The shellfish create and use habitat that in turn makes it easier for other plants and animals to grow as they would have previously. This return to a more natural ecosystem is a more sustainable solution that would be interesting to compare to the impacts of oyster farming.

## Conclusion

Oyster farming can be a significant part of a good nitrogen reduction plan for areas where shellfish farming is suitable. The natural process by which oysters remove nitrogen has benefits both environmental and economic. The reduction in eutrophication in Waquoit Bay could lead to the return of first eel grass and then many other species to make Waquoit Bay a much healthier environment. However, oyster farming does have to be done carefully to ensure that other pressures, including environmental and social, do not significantly impede on the ability to make this a long term solution. Farming has to be done carefully so that it can be a successful pursuit for the farmers and the towns that are hoping to use this as a solution to nitrogen loading. The areas in Waquoit Bay where oyster farming is best suited strike a balance between reducing nitrogen loads, producing safe oysters, and allowing for other uses of the Bay to continue.

References


Barnes, M., Lescault, A., Augusto, K., & Holmes, G. (2015). Massachusetts Shellfish Aquaculture Economic Impact Study. Retrieved from http://web.whoi.edu/seagrant/wp-content/uploads/sites/24/2015/01/MA-Aquaculture-Economic-Impact-Study-2015.pdf

Bowen, J. L, & Valiela, I. (2001). The ecological effects of urbanization of coastal watersheds: historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries. *Canadian Journal of Fisheries and Aquatic Science, 58*, 1489-1500.

Carmichael, R.H., Walton, W., & Clark, H. (2012). Bivalve-enhanced nitrogen removal from coastal estuaries. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*, 1131-1149.

Cerco, C.F. & Noel, M.R. (2007). Can oyster restoration reverse cultural eutrophication in Chesapeake Bay? *Estuaries and Coasts*, *30*, 331-343.

Conley D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Havens, K.E., Lancelot, C., & Likens, G.E. (2009). Controlling eutrohpication: nitrogen and phosphorus. *Science*, 323(597), 1014-1015.

ESRI. (2017). Satellite Imagery with Titles. ArcMapPro 2015. Redlands, CA. Environmental Systems Research Institute.

Fraser, Doug. (2016). Wellfleet closed to shellfishing; no raw oysters at oysterfest. *Cape Cod Times.*

GHD Inc. prepared for Town of Mashpee Sewer Commission (2015). Final Recommended Plan/Final Environmental Impact Report. Retrieved from http://www.mashpeewaters.com/documents/FinalRecommendedPlan-FinalEnvironmentalImpactReport-May2015.pdf

Hale Group. (2016). Maine farmed shellfish market analysis. The Gulf of Maine Research Institute.

Howes, B.,, Samimy, R., Schlezinger, D., Eichner, E., Kelly, S., Ramsey, J., & Detjens, P. 2009). Linked watershed embayment approach to determine critical nitrogen loading thresholds for the Waquoit Bay and Eel Pond embayment system Towns of Falmouth and Mashpee, Massachusetts. Massachusetts Estuaries Project.

Khan, F.A. & Ansari, A.A. (2005). Eutrophication: An ecological vision. *The Botanical Review*, *71*, 449-482.

Leavitt, D.F. (2003). Best management practices for the shellfish culture industry in Southeastern Massachusetts Version 09-04a. Southeastern Massachusetts Aquaculture Center.

Massachusetts Department of Fish and Game (2017). Massachusetts Division of Marine Fisheries 2016 Annual Report. Retrieved from http://www.mass.gov/eea/docs/dfg/dmf/publications/2016-dmf-annual-report.pdf

Massachusetts Department of Fish and Game (2016). Massachusetts Division of Marine Fisheries 2015 Annual Report. Retrieved from http://www.mass.gov/eea/docs/dfg/dmf/publications/2015-dmf-annual-report.pdf

Massachusetts Office of Energy and Environmental Affairs (2017). Waquoit Bay Area of Critical Environmental Concern. Retrieved from http://www.mass.gov/eea/agencies/dcr/conservation/ecology-acec/waquoit-bay.html.

Massachusetts Office of Geographic Information (MassGIS). 2017. MassGIS Data Layers. Retrieved from http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/

McKenna, M. (2016). Climate change may make shellfish (and us) sick. *National Geographic.* Retrieved from https://www.nationalgeographic.com/people-and-culture/food/the-plate/2016/08/climate-change-vibrio-warming-oysters-foodborne-infection/

Morse, D.L. (n.d.). Eastern oyster oroduction in Maine: A basic review. *Maine Sea Grant.* Retrieved from https://www.seagrant.umaine.edu/files/Dana%20Morse/Oyster%20Prod%20Overview%20FINAL.pdf

Nixon, S.W. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia*. 41, 199-219.

O'Sullivan, J. (2014). Appeals court rules for Mashpee oysterman. *Boston Globe.*

Rabalais, N.N., Turner, R.E., Diaz, R.J. & Justic, D. (2009). Global change and eutrophication of coastal waters. *ICES Journal of Marine Science*. 66, 1528-1537.

Reitsma, J., Murphy, D., Archer, A. & York, R. (2016). Nitrogen extraction potential of wild and cultured bivalves harvested from nearshore waters of Cape Cod, USA. *Marine Pollution Bulletin, 116*, 175-181.

Sebastiano, D., Levinton, J.S., Doall, M. & Kamath, S. (2015). Using a shellfish harvest strategy to extract high nitrogen inputs in urban and suburban coastal bays:

practical and economic implications. *Journal of Shellfish Research*, *34,* 573-583. Doi: 01.2983/035.034.0242

Short, F.T. & Burdick, D.M. (1996). Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. *Estuaries, 19,* 730-739.

Spillane, Geoff. (2015). Aquaculture license issued for Mashpee oyster farm. *The Mashpee Enterprise.*

Town of Falmouth. (2017). Town of Falmouth Shellfish Areas Effective May 1, 2017. Retrieved from http://www.falmouthmass.us/DocumentCenter/Home/View/3323

Town of Mashpee. (2017). Mashpee Shellfishing Map Waquoit Bay Area July 12, 2017. Retrieved from https://www.mashpeema.gov/system/files/uploads/shellfishing_maps_071217.pdf

Washburn Island Oysters. (2013). Retrieved from http://washburnislandoysters.com/the-arm/oyster-roots/

Woods Hole Group. (2012). Shellfish Propagation Demonstration Project Technical Memorandum II.

Yang, X., Wu, X., Hao, H. & He, Z. (2008). Mechanisms and assessment of water eutrophication. *Journal of Zhejiang University Science B, 9,* 197-209.

York, R. RE: [Town of Mashpee] Waquoit Bay Oyster Farming. Received by Sarah Thompson, July 7, 2016.

York, R. Town of Mashpee Website: Shellfish: Oyster Propagation and Mitigation. Retrieved from https://www.mashpeema.gov/shellfish