# Oyster Restoration Project in Nantucket, MA:
## Planning, Implementation, Monitoring, and Results

A technical paper submitted by: Leah Cabral
In partial fulfillment of the requirements for the degree of
Masters of Fisheries and Aquatic Sciences
University of Florida
Spring 2020
lcabral@ufl.edu

Along the northeastern Atlantic coast of the United States, an estimated 94% of historic *Crassostrea virginica* habitat has disappeared. These population declines have several drivers from over-harvesting to poor water quality. In response to larger-scale global declines of this species, scientists and conservation organizations have made significant efforts to restore oyster reefs and beds. The Town of Nantucket, located 30 miles off of the Massachusetts mainland, implemented it's first oyster restoration project in 2017 to enhance the habitat and population of *C. virginica,* as well as, collect data on physical and chemical parameters at the restoration site. Data has suggested that ecosystem services and habitat value have increased since restoration efforts were established. This document can serve as a resource for restoration scientists or organizations to use during the planning, permitting, implementation, and monitoring process for oyster restoration projects world-wide.

## Introduction

The eastern or American oyster, *Crassostrea virginica*, is found in estuaries, bays, tidal creeks, drowned river mouths, and behind barrier beaches along the east coast of North America from Canada to the Gulf of Mexico and from Mexico to Venezuela (Sellers and Stanly et al. 1984). Oysters in Massachusetts are found in brackish ponds and bays and are limited to sub-tidal environments due to ice scouring. Growth rates are limited by temperature, recruitment is periodic, and predators tend to have a large impact on survival (Kennedy et al. 1996).

World-wide oyster habitat and populations have declined by approximately 85% in the last 100 years (Beck et al. 2011; Figure 1). There has been an estimated 88% decline in oyster biomass in the United States, with oyster populations being strongly affected in estuaries along the Atlantic coast. According to Zu Ermgassen et al. (2012), the northeastern Atlantic coast has only 6% of historic *C.virginica* habitat left. These population declines have several drivers: over-harvesting, habitat loss, sedimentation, disease, and poor water quality (Wilberg et al. 2011). In response to global declines of this species, scientists and conservation organizations have made significant efforts to restore oyster reefs and beds. As a result, oyster restoration projects have been underway all over the coastal United States. In Massachusetts, restoration projects were established in Martha's Vineyard, Wellfleet, and Fairhaven with pending projects elsewhere in the state.

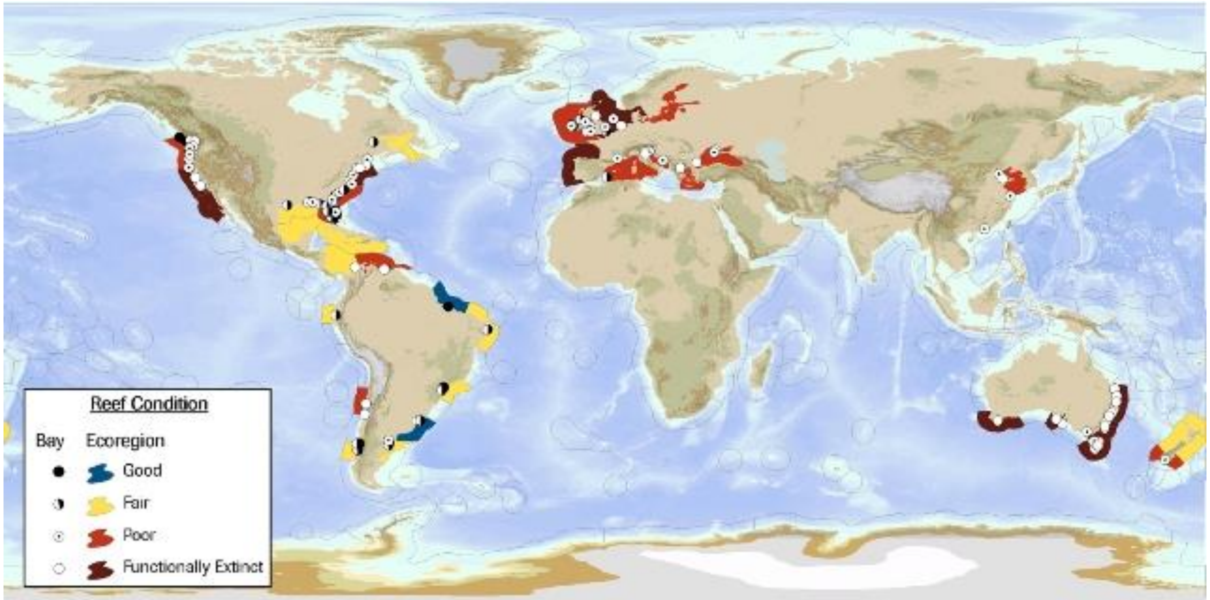


Figure 1. Global conditions comparing historic to current oyster reefs worldwide ranging from good (<50% loss) to functionally extinct (>99% lost) (Beck et al. 2009).

Oysters and their habitat provide many ecological and economic benefits. Ecological services or ecosystem services refers to environmental processes that directly or indirectly contribute to the wellbeing of humans. This can be broken down further into four categories: provisioning (i.e. food, water), regulating (i.e. climate), supporting (i.e. nutrient cycles), and cultural (i.e. recreational benefits) (Ries et al. 2009). Nitrogen levels in the marine environment can be decreased by oysters' filtering ability. According to Kellogg et al. (2013), the denitrification process on an oyster reef starts when dissolved inorganic nitrogen is taken up by phytoplankton for growth. Oysters and other shellfish on the reef filter phytoplankton and other particulate organic matter from the water column. As a result, some of the associated nitrogen is incorporated into organisms and some is deposited on the surface of the sediments. A portion of the nitrogen in these biodeposits is transformed into nitrogen gas, which is released back into the atmosphere where it is no longer available for phytoplankton growth. Using oysters to reduce nitrogen loading in eutrophic bays, estuaries, and ponds is identified as an affordable option to supplement sewering projects. High nitrogen loads lead to algal blooms that block light. When the algae dies it is decomposed by bacteria in the sediment causing oxygen depletion. High nitrogen levels are thus detrimental to eelgrass, shellfish, crustaceans, and finfish. Three towns in Cape Cod, Massachusetts: Falmouth, Mashpee, and Wellfleet are restoring oysters with the goal of reducing their mandated Total Maximum Daily Load (TMDL) of nitrogen set forth by the United States Environmental Protection Agency.

Oysters are suspension feeders and can help improve water quality by removing floating particulate matter (phytoplankton containing chlorophyll a, bacteria, nutrients, and sediment) from the water column thus, reducing turbidity (Grabowski et al. 2012). This allows light to penetrate further down in the water column promoting eelgrass, *Zostera marina*, growth (Newell and Koch et al. 2004). This may be a cost effective strategy to restore eelgrass while removing stressors like excess nutrients. Depending on size and environmental condisitons, one oyster can filter between 30 and 50 gallons (113.5-189.3L) of water a day, helping improve water quality (Newell et al. 1996). Oysters in large densities may even help prevent harmful algae blooms such as red tide (Peabody and Griffin et al 2008).

An additional benefit is reducing ocean acidification on a local level by returning shell to the water during oyster restoration projects. Ocean acidification is a growing global concern and as carbon dioxide levels increase in the atmosphere, a portion of this gas is absorbed by the oceans, causing them to become acidic. According to Kelly et al. (2011) this process affects marine ecosystems in ways we are only beginning to understand. For instance, acidic waters impaire the ability of organisms to form shells or skeletons, alters food webs, and negatively affects economies dependent on services ranging from coral reef tourism to shellfish harvests. This is problematic because oysters remove carbon from the water column and use it to construct their calcium carbonate shells. Waldbusser et al. (2011) and Green et al. (2009) found that returning crushed shell to coastal habitats at densities found in healthy clam populations, can increase pH and mitigate localized acidification impacts. Oyster shells are made out of calcium carbonate, which in solution with marine water forms the basis of the ocean pH buffering system. As shells naturally deteriorate on oyster reefs this causes calcium carbonate to release back into the water column increasing the pH .

Oyster reefs can reduce shoreline erosion by acting as buffers between waves and the shore. According to Meyer et al. (1997) oyster reefs are often found seaward of marshes and mitigate erosive wave energies, stabilize sediments, and reduce marsh retreat. Oyster reefs are a living breakwater and promote sedimination on the landward side, which can counteract shoreline erosion and promote submerged aquatic vegetation growth.

In addition, oyster reefs diversify marine landscapes while providing habitat for an array of species including fish, invertebrates, epi-benthic fauna, and birds (Figure 2). Several studies indicate that three-dimensional oyster reefs attract greater numbers of resident and transient species when comparing sand or mud bottom habitats (Posey et al. 1999, Lenihan et al. 2001, Kingsley-Smith et al. 2013). A study by Mann and Harding et al. (1998), determined that oyster reefs serve as nursery and foraging grounds for small to intermediate fish and in turn this causes larger pelagic fish such as striped bass (*Morone saxotilis*), black sea bass (*Centropristis striata*), bluefish (*Pomatomus saltatrix*), and flounder (*Paralichthys dentatus*, *Pseudopleuronectes americanus*) to be found on or around oyster reefs. Additionally, oyster reefs serve as critical foraging habitat for endangered or threatened bird species such as the American oyster catcher (*Haematopus palliates*), and piping plover (*Charadrius melodus*) (Kingsley-Smith et al. 2015; Natural Heritage et al. 2016).

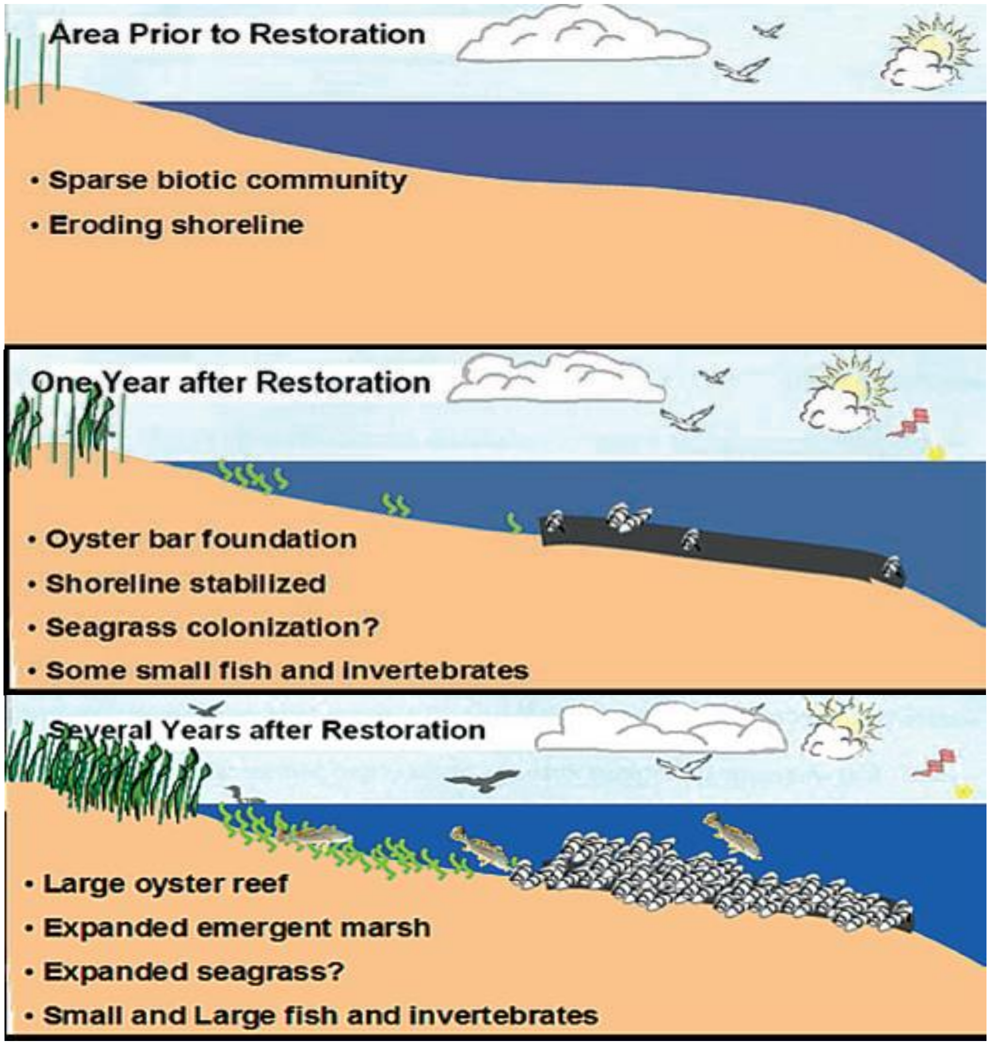



Figure 2. Possible effects of oyster restoration on habitats (Baggett et al. 2014).

Not only do oyster reefs provide habitat to an array of species, they provide critical habitat for their own species. Oyster larvae are free floating for 2 to 3 weeks until they develop a foot (Figure 3). At this time they are ready to attach to a suitable substrate and go through metamorphosis. If oyster larvae are substrate limited, they will attach to limestone, rock, concrete, and wooden pilings, but the preferred substrate and chemical attraction is to other oyster shell. If they do not find a suitable substrate then the larvae will not be able to complete their life cycle and will die. The chemical attraction to themselves helps increase the production of live oysters in and around the reef. Recruitment limitations can occur if there are not enough spawning stocks at the reef to produce enough offspring to overcome mortality rates. Oyster restoration addresses these two issues by adding suitable substrate and/or increasing spawning stock by bringing live oysters to the site if natural recruitment is limited.

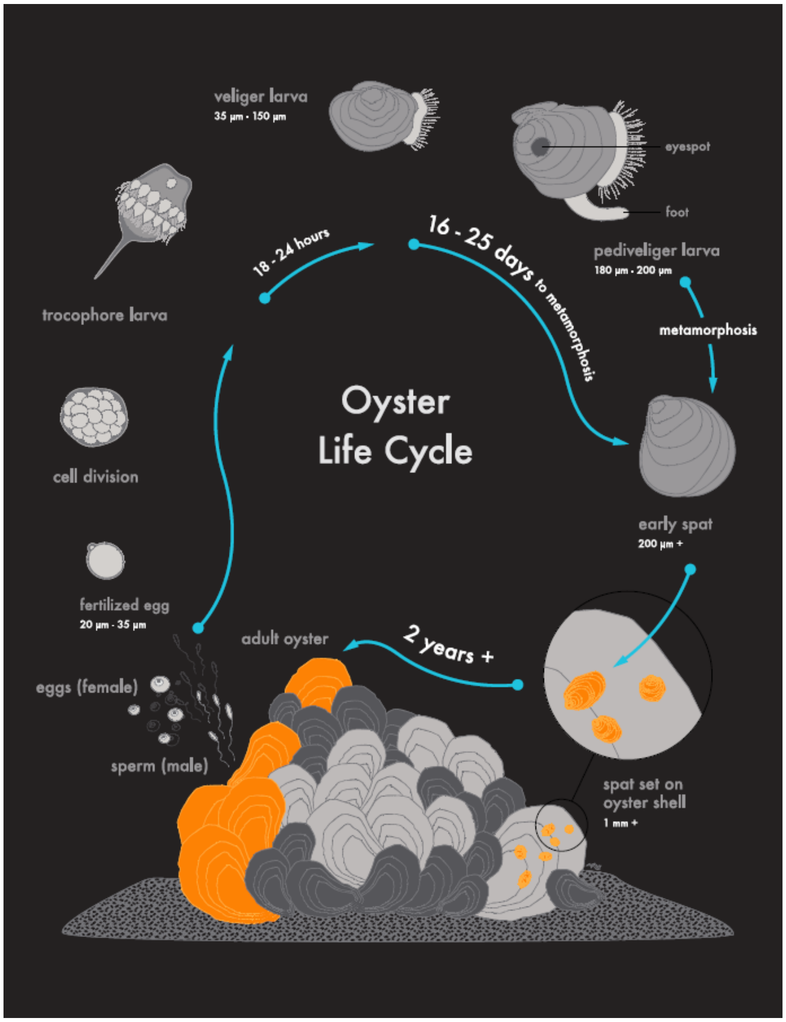



Figure 3. Oyster life cycle from spawning through to adulthood.

There are many different methods and materials used for oyster restoration projects. The prefered hard substrate is recycled, fossilized, or dredged oyster shell (Levine et al. 2016). Over the last 20 years, dredging buried oyster shell has been the source of substrate for restoration projects in the Chesapeake Bay (NOAA et al. 2019). According to Tamburri et al. (1992, 2008), oyster shell provides adequate area for oyster recruitment, settlement, retention and closely emulates the natural reef matrix and interstitial spaces. Another shell type that has been used for oyster restoration is surf clam but it is found to be less ideal as a substrate. Coen and Luckenbach et al. (2000) found that surf clam shells break easily, thus reducing interstitial space, and post-settlement mortality was higher than oyster shell. However, surf clam shell is cheap and usually donated to restoration organizations from shucking companies. The Nature Conservancy projects in Massachusetts (Fairhaven, Wellfleet, and Wareham) and in the Great Bay Estuary in New Hampshire used surf clam shell. There are two methods for deploying shell at a restoration site. The first broadcasts high densities of loose shell on the bottom. This method is largely used in the Chesapeake Bay, Massachusetts, and New Hampshire. The second option bags shell using mesh and orients it parrell to the shoreline, which is primarily used more often in the southern United States where many reefs are naturally intertidal (Figure 4). Intertidal shell bags are generally used in living shoreline projects because sediment accumumlates landward of the bags, which helps stabilize the shoreline and promote the growth of marsh grass.

Figure 4. South Carolina Aquarium SCORE reef building project in Charleston, SC where bags filled with oyster shells are placed along the shoreline (Thayer et al. 2005).

In areas where erosion is prevalent from high wave energy or bottom sediment is soft, marine-friendly concrete structures called reef balls (i.e. oyster domes) or oyster castles are often employed (Figure 5). The domes provide three-dimensional structures for wave attenuation, sediment deposition, and habitat for both oysters and fish (Gedan et al. 2010). According to Gedan et al. (2010) living shoreline restorations of this type are appealing because they provide the service of hard coastal defense structures like breakwaters, bulkheads, or seawalls with the ecological benefits of restoration and, in addition, are self-maintaining. Hard structures such as reef balls promote sedimentation allowing restoration and expansion of coastal wetlands in high energy areas where traditional wetland restoration techniques may not be affective (Meyer et al.1997; Piazza et al. 2005). Reef balls and oyster castles are used in Florida, Chesapeake Bay, North and South Carolina and internationally to reduce erosion and provide habitat for oysters, fish, and other shellfish species.

Figure 5. Reef ball structures placed along a coast in Texas for erosion protection (Reef Innovations et al. 2013)

Interest in commercially farming oysters has significantly increased in Nantucket within the last 10 years. Currently there are six growers who use either bottom culture or floating cages to grow oyster seed (juvenile oysters) purchased from a State approved hatchery. Their leases encompass 90 acres at the Head of the Harbor which is in the Wauwinet region of Nantucket Harbor. Farmers grow gamete producing diploids and/or sterile triploids to sell commercially. In Nantucket, there are no recreational oyster harvest areas available due to recruitment and substrate limitations (SMP et al. 2014).

According to the Nantucket Shellfish Management Plan (SMP) adopted in October 2012, the Town of Nantucket purchased small oyster seed (19-30mm) for many years for grow-out purposes due to natural recruitment limitation. Seed is a term used in aquaculture to describe young oysters that are ready to be transplanted from a hatchery into the natural environment. When juvenile oysters are seeded they are planted in the natural environment. The seed was released in Nantucket Harbor to enhance natural broodstock populations and improve water quality. Additionally, oyster larvae were remotely set in a shellfish hatchery on bags filled with shell and then moved to Madaket Harbor for grow-out purposes. In the past five years, the Natural Resources Department (NRD) has expanded its shellfish production to include oysters during the winter and early spring (SMP High Priority: Goal 1, Objective 1, Recommendation 2). In the summers of 2014 and 2015, the Brant Point Shellfish Hatchery conducted a proof of concept study that included spawning oysters, rearing larvae, and remotely setting 3 million spat on recycled oyster shell (multiple juvenile oysters attached to a shell substrate). This study measured growth and settling rates as well as provided broodstock to use for future spawns. Subsequently, the Brant Point Shellfish Hatchery conducts about six annual oyster spawning events and all spat on shell is seeded at the Shimmo Creek restoration site.

In 2014, with the help from a local non-profit, the Nantucket Shellfish Association, the Town of Nantucket established a successful Shell Recycling Program: "Shuck It for Nantucket". Instituting a shell recycling program was a high priority in the SMP (Goal 1, Objective 3, Recommendation 2). Presently, oyster shells are a limiting resource for restoration due to their disposal in landfills, use as driveway material, or addition to chicken feed. According to Brumbaugh et al. (2009), shell recycling programs have become widespread to maximize the retention of shell for restoration projects in coastal areas. To date, Nantucket's shell recycling program has collected more than 125 tons of oyster and quahog shells from 30 local restaurants and raw bars. All shell must be cured on land for one year at the Department of Public Works under the Massachusetts Division of Marine Fisheries (MassDMF) Shellfish Planting Guidelines to prevent disease and pathogen transfer to Nantucket waters (Hickey et al. 2015). A portion of the reclaimed shell was used to establish Nantucket's first oyster restoration project in Shimmo Creek (SMP: Goal 1, Objective 1, Recommendation 3).

## Purpose

The long-term purpose of this restoration project was to enhance the population of a native shellfish species, *Crassostrea virginica*, in Nantucket waters to establish a healthy coastal ecosystem supporting an array of species. Nantucket's wild oyster populations were historically plentiful but presently functionally extinct and have followed the same trend as populations elsewhere in the region. Population declines were due to habitat degradation including poor water quality, overharvesting, and loss of suitable substrate. Small, wild populations can be found attached to rocks or bulkheads in Easy Street Basin and Sesachacha Pond. This project fulfilled fourteen recommendations in the SMP; six were high priority (Table 1).

| Section | Goal | Objective | Recommendation | Description | Priority | Addressed by Oyster Reef |
|---|---|---|---|---|---|---|
| Habitat Management | 1 | 1 | 5 | Conduct and/or support studies to investigate the role that environmental changes may have in altering shellfish populations on Nantucket, including sea level rise, ocean acidification, and climate change. As part of this, continue,and where appropriate, enhance efforts to record water temperature, changes in pH, and details about when the Harbors freeze over. | Medium | Water quality devices (HOBO and SONDE) will be deployed pre and post reef construction to give real time water quality data |

| | | | | | | |
|---|---|---|---|---|---|---|
| Habitat Management | 1 | 2 | 3 | Develop and implement a cost effective strategy to protect/restore eelgrass in locations of significance to shellfish resource—both within?and outside Nantucket and Madaket Harbors. This strategy should take into consideration options such as propagating eelgrass, reseeding areas, and removing stressors (e.g., moorings,excess nutrients) to existing and potential eelgrass habitats. | Medium | Oyster's filtration abilities reduce suspended sediments and phytoplankton concentrations increasing light penetration through the water column aiding in eelgrass establishent and growth (Newell et al. 2004). |
| Habitat Management | 1 | 3 | 2 | Work with the Nantucket Department of Public Works to institute a shell recycling program where most, if not all, shells are returned to the Harbors for pH buffering and settlement substrate purposes (potentially with assistance from fishermen). Ensure that the deposition of shells does not harm existing habitat features (such as eelgrass beds) or create new habitat dominated by predators. Adhere to DMF's Shellfish Planting Guidelines for placing shells in the water: "Oyster, quahog and softshell clam shell used as cultch shall be aged on land for a minimum of one year. Shell from other species of bivalves such as surf clam, ocean quahog, scallops and mussels may be used without limitations. All issues regarding approved shell cultch must be addressed by Marine Fisheries prior to placement into coastal waters." (Hickey et al., 2012). Conduct research to identify the most appropriate locations for returning the shells and monitor the deposition sites to better understand the impacts of such activities. | High | Shells reclaimed from this program will be used to construct the oyster reef. Research has been conducted to locate an appropriate site for the reef and the reef will be thoroughly monitored. |
| Habitat Management | 1 | 3 | 3 | Continue to monitor dissolved oxygen in benthic areas of the Harbors, and expand monitoring to include monitoring of sediment acidity. | Medium | Water quality devices (HOBO and SONDE) will be deployed pre and post reef construction to give real time dissolved oxygen data. |
| Habitat Management | 1 | 3 | 4 | Continue monitoring spat settlement throughout the waters of Nantucket by way of spat collection and enumeration. | Medium | Oyster spat collectors will be deployed in Shimmo Creek to monitor natural sets. |
| Habitat Management | 1 | 3 | 5 | Conduct collaborative annual surveys of juvenile shellfish stocks to assess the areas of spatfall to aid in management decision making. | High | Annual surveys will be conducted on the reef to monitor shellfish stocks. |
| Shellfish Resources | 1 | 1 | 1 | Develop and implement a strategy to track the effectiveness of propagation activities in terms of supplementing the commercial and recreational harvests. As part of this, identify locations best suited for larval release (e.g., areas with larval retention), examine the timing of larval release in terms of survival, and conduct post set release and associated monitoring for survivability. | High | The reef will be supplemented with hatchery grown oysters until it becomes self-sustaining. Annual surveys will monitor post-set release survivability. |
| Shellfish Resources | 1 | 1 | 2 | Continue current propagation efforts such as the larval release program and, based on the results of the study of propagation effectiveness, consider pursuing opportunities to expand propagation activities, including expansion to different species (i.e., oysters). | High | In 2014, propagation has expanded to oysters. Oysters were spawned, larvae reared, and remotely set on recycled oyster shell provided by the Shell Recycling Program. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Shellfish Resources | 1 | 3 | 1 | Continue to develop spawning sanctuaries, through the use of spawning cages, to increase larval supply, and monitor impacts of sanctuaries. Particular focus should be on utilizing areas with high larval retention and evaluating the manipulation of water flow for larval retention. | High | The reef will be a spawning sanctuary which means no recreational or commercial oyster harvesting. Oyster larvae from the reef will aid in stocking other areas in the Harbor. |
| Shellfish Resources | 1 | 3 | 2 | Institute new steps—and continue existing efforts—to identify spawning events and monitor spat levels in the Harbors such as by the strategic placement of spat bags strategically around the Harbors. | Medium | Oyster spat collectors will be deployed in Shimmo Creek to monitor spawning events and natural sets. |
| Shellfish Resources | 1 | 3 | 3 | Continue larval release at various locations throughout Nantucket waters and evaluate its effectiveness in terms of localized recruitment of spat. Investigate whether or not the timing of the releases affects their effectiveness at enhancing local populations. | High | The reef will be supplemented with hatchery grown larvae/spat until it becomes self-sustaining. Annual surveys will determine its effectiveness on local populations. |
| Shellfish Resources | 2 | 1 | 1 | Measure and monitor predator abundance in Nantucket waters (in part through a survey of by ? catch) and measure impacts on shellfish resources during the various life stages for each species. Understand the impacts of native versus non ? native predators and implement a predator management protocol as appropriate, perhaps based on the identification of an “over ? abundance” (which would need to be defined) of predators in the ecosystem. As part of the protocol, conduct research to understand the impacts of predator removal—both on the harvested resources and on the biological communities in the Harbors. Specifically look at the impacts of the mud blister worm (Polydora). | Low | Predator pilot project was deployed in Fall of 2015 on a "mini reef" and will continue to be monitored for 1 year. Predators will be monitored through dive surveys, time-lapse cameras, and seine nets. |
| Shellfish Resources | 3 | 1 | 2 | Better understand and define the biological traits of and stressors to bay scallops, quahogs, conch, oysters, softshelled clams, and other harvested shellfish. Use that knowledge to make informed management decisions. Specific topics of interest include (1) the relationship between spat recruitment and post ? set spat survival as it relates to the overall abundance of shellfish, and (2) the genetic variability among harvested shellfish. | Medium | Physical and biological stressors will be monitored on the oyster reef as well as spat recruitment and post-set spat survival. |
| Support Commericial Fishery | 1 | 1 | 3 | Develop marketing strategies to enhance the value of Nantucket shellfish by ? products (e.g., shells as a buffering source for restoration projects, viscera as a protein source, guts as bait or food, gonads as food). | Low | Addressed by "Shuck It for Nantucket": oyster and quahog Shell Recycling Program |

Table 1. Objectives that the Shimmo Creek oyster restoration project and Shell Recycling Program fulfill for the Town’s Shellfish Management Plan. The highlighted sections are high priority (SMP et al. 2014).

## Project Goal

The ultimate project goal is to restore populations of the native oyster species, *Crassostrea virginica*, in Nantucket waters to establish a healthy coastal ecosystem that provides habitat to support an array of species. Specific objectives of the project are outlined below.

## Project Objectives

1. Stock oyster spat on shell and broodstock for several years to supplement natural recruitment until the reef persists as self-sustaining with multi–year age classes.
2. Establish an educational platform for local and visiting scientists, students, and the community to study the ecological benefits of a small-scale oyster reef. Topics may include but are not limited to water quality, species biodiversity, and shoreline stabilization in one of Nantucket Harbor's sub-embayments.
3. Long-term monitoring of the oyster reef including oyster size-frequency distribution, oyster densities, reef height, and sex ratio will provide information about growth, recruitment, survival of cohorts, and reef success.
4. Gain public support and volunteer interest about the importance of shell recycling and oyster restoration.

## Site Selection

Shimmo sub-embayment is located between Pimney's Point and Abram's Point on the southern shore of Nantucket Harbor. It is tidally influenced with a high and low tide moving twice a day through a narrow channel that opens to the Harbor. Shimmo consists of two water bodies that are partially divided by land and connected by a single, shallow channel. It comprises a barrier beach, salt marsh, and two freshwater sources that are located at the head of the embayment (Figure 6). The restoration project is in the embayment closest to the harbor, which is 4.26 acres (1.72 ha) in extent, but the reef only comprises only 1.14 acres (0.46 ha).

Many factors are taken into consideration when determining if a site is ideal for oyster restoration. Some factors are mandated by both local and state government and include but are not limited to:

1. <u>Sediment type</u>: Shimmo's bottom type consists of sand and anoxic soft sediment with little to no habitat value.
2. <u>Void of eelgrass pre-construction:</u> Yes
3. <u>Void of shellfish species pre-construction:</u> Yes
4. <u>Water depth:</u> It has relatively shallow water (1.5m at high tide), which simplified cultch deployment, monitoring, and maintenance but is vulnerable to silt accumulation during storm events.
5. <u>Vulnerability to storm events:</u> The barrier beach helps block strong winter storms from the Northeast.
6. <u>Accessibility:</u> Shimmo is easily accessible by both boat and foot and out of the way of most harbor users.
7. <u>Water quality parameters:</u> see below
8. <u>Predator and pest presence and density:</u> Predators at the site include oyster drills, crabs, and jellyfish. Pests include mud blister worms and boring sponge.
9. <u>Disease prevalence:</u> None

10. Suitability for growing oysters: MassGIS depicts this area as suitable for growing *C. virginica*.
11. History of oyster populations at or close to the site: There is a Native American oyster shell midden pile located in the woods adjacent to the site.
12. Approved by MassDMF for shellfishing: According to MassDMF guidelines, Shimmo qualifies as an acceptable site for aquaculture or shellfish restoration because it was in an approved area for shellfish propagation (now closed to shellfishing) at the time of construction.


Figure 6. Aerial view of Shimmo Creek. Yellow pin indicates the middle of the restoration site and red pins indicate freshwater inputs.

Additionally, oysters can survive a wide range of habitat conditions. According to Shumway et al. (1996), the range and optimal conditions for *C. virginica* in the northeastern United States are the following:

**Depth:**

Range: 0-11 meters
Optimal: 0.6- 5 meters (MacKenzie et al. 1996)

**Salinity:**

Range: larvae (10-27.5 ppt), adults (5-40ppt)
Optimal: 12-28 ppt

**Temperature:**

Range: -2ºC to 36ºC (28.4ºF to 96.8ºF)
Optimal: larvae (14 ºC -28ºC; 57.2ºfF- 82.4ºF), adults (20-30 ºC; 68ºF- 82.4ºF)

**Substrate:**

Optimal: larvae prefer clean oyster shell; adults can tolerate various substrates including mud

**pH:**

Optimal: larvae (6.75-8.75)

**Dissolved Oxygen (D.O.):**

Range: 3mg/L or above. Depending on D.O. levels and temperature, oysters can close their shells and survive for several hours. (NOAA)

**Hydrographic circulation:**

Light enough to keep larvae near existing reefs but with enough exchange to maintain a good food supply and near neutral silt balance on the oyster reefs (Lenihan et al. 1999).

According to the optimal conditions described above by Shumway et al. (1996), Shimmo's depth, temperature, dissolved oxygen, and substrate are in optimal range for oysters (see below). The salinity level is not optimal for oyster survival due to increased prevalence of marine predators at high salinities.

**Shimmo's range for oysters:**

**Depth:** Low tide**:** 0.8m High tide: 1.5m
**Salinity:** 31.6ppt
**Average temperature in July-August:** 24.14 ºC
**Substrate:** Reclaimed, cured oyster and quahog shells
**pH:** To be determined
**Average dissolved Oxygen (Winkler):** 5.91 mg/L
**Bottom Type:** Sand and anaerobic soft sediment
**Hydrographic circulation:** To be determined

## Permitting

Permits for oyster restoration were acquired from federal, state, and local agencies. The permitting process for this project took about 200 hours to submit and a little under a year to obtain all permits from the varying agencies before restoration began.

### Local Permitting:

Locally, a Notice of Intent was granted by the Nantucket Conservation Commission which reviewed the impacts of the project on the state Wetland Protection Act as well as the Nantucket Wetlands bylaw. The project gained support from the Nantucket Harbor and Shellfish Advisory Board before it was presented to the Board of Selectman for approval. At the town level, public hearings were held for the community to voice any concerns.

### State Permitting:

A full review of Chapter 91 Public Waterways License was granted by the Massachusetts Department of Environmental Protection because cultch is considered fill in Massachusetts. For this permit, engineered project plans were required as well as an Order of Conditions, project descriptions and maps. An Environmental Notification Form was granted by the Department of Environmental Protection and published in the Environmental Monitor as well as published in the local newspaper for public comment. The 401 Water Quality Certification from the Massachusetts Department of Environmental Protection Bureau of Water Resources was granted. The project was sent to Coastal Zone Management for a Federal Consistency Review to make sure that there were no conflicts between federal and state approvals for the project. A permit was not necessary from the Division of Marine Fisheries, but their approval must be granted indicating that they don't feel the project will harm existing shellfish or other benthic resources. For this project, Natural Resources employees conducted a dive survey using DMF's protocol to assess shellfish populations and eelgrass at the project site. The area was void of eelgrass and shellfish, so they gave project approval. In addition, copies of the application materials were sent to the Natural Heritage and Endangered Species Program (NHESP) and/or the Massachusetts Historical Commission and Underwater Archaeology Board. A data release form was filed with NHESP to determine whether the project site was in Priority Habitat or Estimated Habitat of Rare Species. Shimmo Creek fell under Priority Habitat for Winter Flounder, so no silt-producing work could be done from January 15 to May 31.

**Federal Permitting:**

The last permit in this process was granted by the United States Army Corp of Engineers and was a Self-Verification Form.

## Project Scope

The Town of Nantucket Natural Resources Department collaborated with several restoration experts, including Dr. Anamarija Frankic (UMASS Boston), Jon Kachmar and Matthew Pelikan (The Nature Conservancy) and Dr. Jon Grabowski (Northeastern University). They gave advice and feedback from site selection to monitoring techniques. The scope of this project included the placement of approximately 100 cubic yards of reclaimed, loose cultch in the form of cured oyster and quahog shell. According to Cohen et al. (2009), oyster shells have been placed in coastal waters for oyster culture to serve as cultch, a settling surface for oyster seed, and to create or improve habitat for native oysters and other organisms. The reef was sub-tidal to avoid damage caused by ice scouring and consisted of a little over one-acre area in Shimmo Creek, a sub-embayment of Nantucket Harbor (Figure 7). The project followed The Nature Conservancy's design which was to achieve a somewhat patchy distribution of cultch, with 50% to 75% of the bottom covered with shell and the remainder left available for burrowing invertebrates or aquatic vegetation to grow, enhancing the overall diversity of the site (Pelikan et al. 2015). Additionally, Kraeuter et al. (2003) and Hewitt et al (2005) suggested that areas where high density shell was placed on the sea floor to create a patchy effect resulted in increased hard clam recruitment as well as overall species biodiversity. The goal was to create a shellfish bed that mimics the structure of natural beds and can support a high diversity of estuarine organisms.

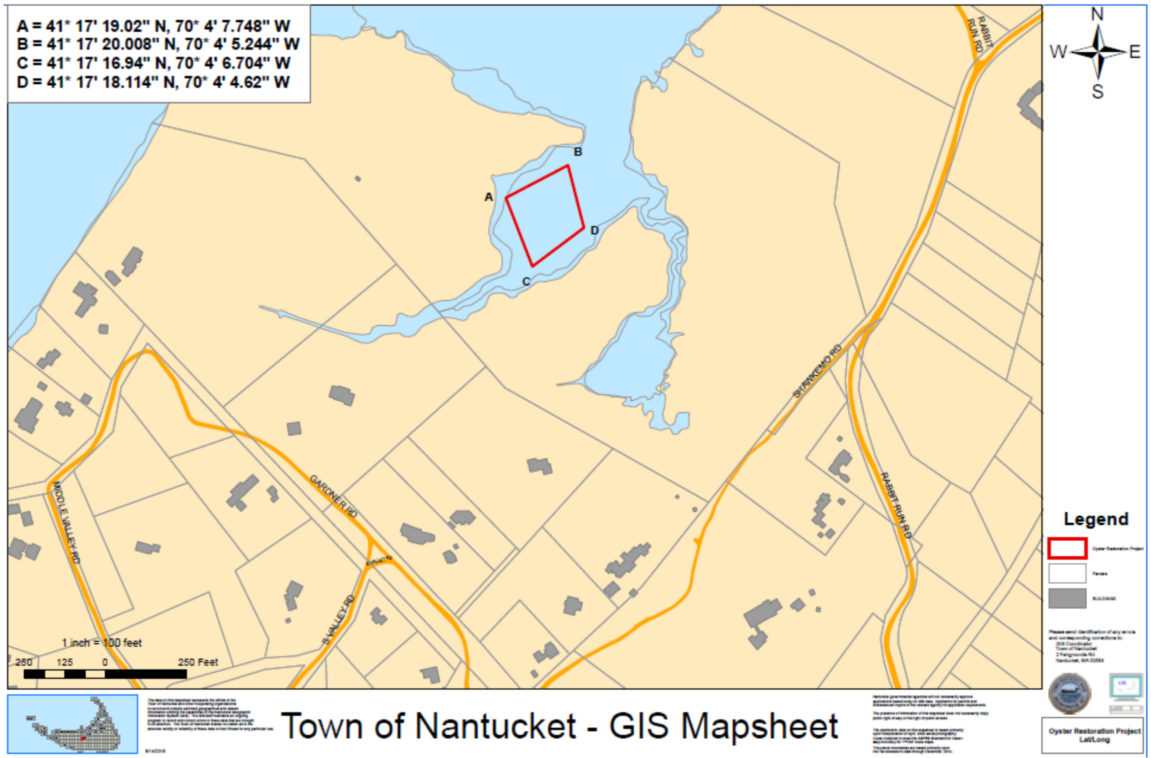



Figure 7. One-acre area in Shimmo Creek for reef establishment.

Initially, the design was to have ten rows comprised of ten cubic yards (7.65m³) of shell to achieve a reef relief height between 10-15cm. In between the shell rows there would be nine bare bottom rows to promote the growth of aquatic vegetation and benthic invertebrates (Figure 8). Schulte et al. (2009) found that reef height was a major influence for oyster reef success because it drove oyster abundance and density. High relief reefs maximize oyster growth and survival and minimize disease and sedimentation due to optimal flow rates. In 2017, half of the shell recycling pile was taken by accident and not returned. This resulted in not enough shell to deploy all ten shell rows, so only five rows were put out. Over the first year, some of the shell was buried due to soft sediment and storm events. Instead of making an additional five rows of shell, only three were made and the amount of shell was increased from 10 cubic yards to 12.5 cubic yards (9.56m³) per row the following year. In total, the site had seven parallel bare bottom rows in between eight parallel shell rows (Figure 9). The project's footprint was 4,611 m² (1.14 acres) and the reef area (available cultch for settlement) was 1,677 m² (0.41 acres).

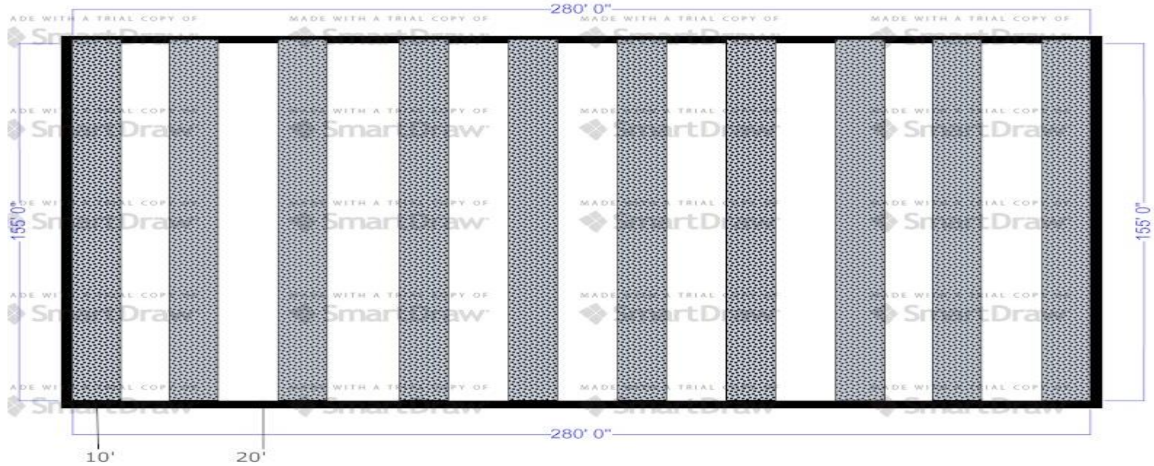



Figure 8. Initial engineered plan for restoration site included 10 shell rows that were 10 feet wide (white columns) and 9 bare bottom rows that were 20 feet wide (grey columns).

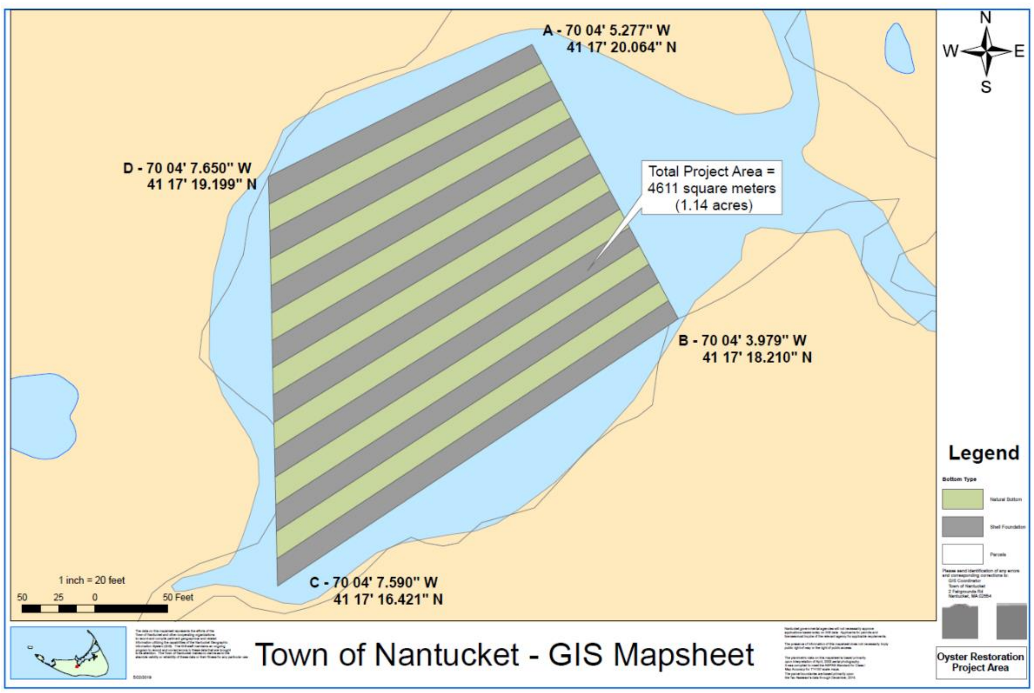



Figure 9. Shimmo's project footprint indicating 8 shell rows in grey and 7 bare bottom rows in green.

Remote set oyster seed (i.e. spat on shell) produced by the Town of Nantucket's Brant Point Shellfish Hatchery were added to the site to aid in overcoming recruitment limitation (SMP High Priority: Goal 1, Objective 1, Recommendation 1). From 2017-2019, a total of 841,837 oyster spat on scallop shell were produced by the hatchery and added to the restoration site. Scallop shell was recommended and chosen to aid in monitoring wild recruitment versus hatchery grown oysters. The supporting rationale was that if there was oyster shell available, oyster larvae will preferentially attach to it rather than scallop shell. The differing shell makes it easier to identify hatchery grown oysters during dive surveys. Further, over 14,500 adult broodstock oysters have been added to the reef to increase spawning events and natural recruitment. Brumbaugh et al. (2006) found that stocking adult shellfish in relatively high densities may be likely to improve the chances of successful spawning and reproductive success. This strategy may be useful for enhancing populations from a range of bivalve species including oysters in areas where natural recruitment is limited.

The DMF allows shellfish closures in approved areas for a period no longer than three years without petitioning for an extension. The petition must be filed with the DMF by the Town of Nantucket stating the proposed regulations that would enact the closure (Hickey et al. 2015). The idea of closing planted shellfish areas for more than three years is new in Massachusetts and the town of Falmouth was the first to do so in the state. Currently, the restoration site is closed to shellfishing due to high bacterial loads. The DMF has deemed it not safe for shellfish consumption so at this time petitioning will be put on hold. If this classification changes then the Town of Nantucket will petition the DMF to keep the restoration site as a sanctuary. Continuing to develop spawning sanctuaries was a high priority in the SMP (Goal 1, Objective 3, Recommendation 1) and will provide other areas in the harbor with oyster larvae which may help re-establish populations. Brumbaugh et al. (2006) suggests that very few bivalve fisheries, if any, have been managed with any evidence of long-term sustainability, both in the U.S. and in many other parts of the world. Oysters have posed a unique challenge to fishery managers since fishing activities for these species, unlike most fish and other mobile organisms, also simultaneously removes their habitat (Brumbaugh et al. 2006). Under the Town of Nantucket's Shellfishing Policy and Regulations Section 2.8 Habitat Sensitive Areas: "No commercial or recreational shellfishing may occur in areas deemed 'habitat sensitive' and have a posted closure by the Board of Selectmen or its designee" (adopted March 2015). This Town regulation may allow the restoration site to be closed to shellfishing for more than three years. Not only will this project restore oysters, but it will provide habitat for many different species including fish, shellfish (scallops, hard and soft-shell clams), crustaceans (crabs, shrimp), and water fowl.

## Pre-Restoration Monitoring

The Town of Nantucket's oyster restoration project's monitoring protocol follows the "Oyster Habitat Restoration Monitoring and Assessment Handbook," which was the result of a working group made up of restoration scientists and practitioners from around the coastal United States (Baggett et al. 2014). The work group found that many oyster reef restoration projects in the past have not been monitored to the extent that allows for comparison. As a result, the group's goal was to develop recommendations for a set of Universal Metrics (i.e. reef areal dimension, reef height, oyster density, oyster size-frequency distribution) that should be monitored for all oyster restoration projects. The working group also developed guidelines for assessing optional Restoration Goal-based Metrics (Baggett et al. 2014). These specific monitoring techniques and performance criteria allow for post-restoration comparisons between restoration projects in different regions.

In order to determine the ecological impacts that an oyster reef provides, a control site was recommended. According to Baggett et al. (2014), control sites were unaltered areas that mimic the pre-restoration conditions (e.g., sand or mud substrate) and should have similar physical characteristics (e.g., flow, wave action, tidal range, salinity, proximity to open water, water temperature, freshwater influence, substrate type, water depth, etc.). Control areas would allow for determining the degree of local enhancement resulted from the project and reference areas determine if the restored reef was performing to the level of a healthy natural reef (Baggett et al. 2014). Since there was not an appropriate control site for the Shimmo Creek restoration project, a before after control impact method was used to compare parameters pre and post construction throughout sampling years.

Several pre-restoration surveys started in the summer of 2015 and continued through 2016. The reef was established in 2017 and anything after that year was considered post-restoration monitoring. The Natural Resources Department performed the monitoring surveys unless outside scientific help was needed.

Pre-restoration water quality sampling started in August 2015 and continued from June-September every year after. Parameters measured were: salinity, dissolved oxygen, temperature, conductivity, phosphate, ammonium, nitrate, nitrite, total dissolved nitrate, particulate organic nitrogen, particulate organic carbon, chlorophyll a, and phaeophytin. Data for total pigments, total nitrogen, dissolved inorganic nitrogen, and dissolved organic nitrogen were calculated from measured parameters. In July and August, HOBO data loggers were deployed and took dissolved oxygen readings every 15 minutes. Two were deployed at the site, one “on the reef” which means cultch was under the logger and one “off the reef” which was deployed on a bare bottom row so only sediment was present under the logger (see Appendix A for protocol). The HOBO also recorded temperature and light penetration. Ideally, light penetration should be greater following reef establishment because oysters filter particulate matter out of the water column. This data provided a way to evaluate objective 2 in the Town’s SMP which was to determine how a small-scale oyster reef in a sub-embayment can affect water quality (Shellfish Management Plan et al. 2010). In addition, water quality monitoring fulfilled two medium priority recommendations in the habitat management section (Goal 1, Objective 1&3, Recommendation 5&3).

Spat settlement was monitored using oyster spat collectors. The Nature Conservancy and Buzzards Bay Coalition customized steel mesh lobster traps that hold 4 ceramic tiles to monitor natural spat settlement (da Silva Quintal et al. 2014; Figure 10). Three to four of these customized lobster traps were used as spat collectors and deployed at the restoration site in late June and retrieved in early fall (SMP High Priority: Habitat Management Goal 1, Objective 3, Recommendation 5; Shellfish Resources Goal 1, Objective 3, Recommendation 2; See Appendix A for protocol).

Figure 10. Spat collector that holds four unglazed tiles used for recruitment studies (daSilva Quintal et al. 2015).

In October 2015, a predator and oyster growth pilot project was deployed in Shimmo Creek. A “mini reef” (1.13m x 0.82m) was built using plastic clam trays filled with 210,000 spat on shell oysters. The project’s objectives were to identify and quantify oyster predators in Shimmo Creek, measure the impacts of these predators during various oyster life stages, implement a predator management protocol if necessary, specifically test for impacts from the mud blister worm (*Polydora*), and determine if 10cm or 15cm reef relief height was appropriate for restoration efforts in Shimmo. Data was collected via dive surveys and time lapse cameras. This pilot project fulfilled three SMP objectives (Habitat Management Goal 1, Objective 3, Recommendation 5; Shellfish Resources Goal 1&2, Objective 1, Recommendation 2&1).

To survey transient crustaceans and fish, seine net surveys were conducted once each spring, summer, and fall. In addition, multiple un-baited fish traps were deployed at random locations within the project footprint once a month for 24 hours in July, August, and September to quantify the density (catch per unit effort; individuals/hour) and length (mm) for every species (see Appendix A for protocol). The baseline surveys from 2016, continued post construction to observe and compare if adding habitat in the form of shell attracted multiple species versus a site without oyster shell habitat.

In 2016, submerged aquatic vegetation (SAV) monitoring was initiated at the site. No eelgrass was found during the initial surveys. This survey continued annually (see Appendix A for protocol). At each sampling location, the number of eelgrass shoots within a haphazardly deployed quadrat (0.5 $m^2$) were counted, as well as a visual estimate of percent substrate covered by both eelgrass and macro algae. SAV density (shoots/$m^2$) and percent coverage measurements provided data on secondary effects of oyster reefs. Baggett et al. (2014) suggested that the presence of oyster habitat may increase SAV coverage through water clarity improvements and/or sediment stabilization. The modified Braun-Blanquet scale was used for percent coverage (Fourqurean et al. 2001):

| Braun-Blanquet scale | Number of eelgrass shoots | Percent cover |
|---|---|---|
| 0 | 0 | 0 |
| 0.1 | 1 | <5 |
| 0.5 | <5 | <5 |
| 1 | >5 | <5 |
| 2 | >5 | 5-25 |
| 3 | >5 | 25-50 |
| 4 | >5 | 50-75 |
| 5 | >5 | 75-100 |

**Post-Restoration Monitoring**

Post restoration monitoring surveys were performed annually in September or October to allow spat to grow to a sufficient size, greater than ten mm (see Appendix A for protocol). Four universal metrics: oyster density, oyster size-frequency distribution, reef areal dimensions, and reef height should be sampled for every reef regardless of restoration goals (Baggett et al. 2014). Universal metrics allow for assessment between restoration projects within and across regions.

Live oyster density (individuals/$m^2$) was the number of live oysters with recruits included. This metric was analyzed using either 0.25 $m^2$ or 0.5$m^2$ quadrats every 5m down a transect line. Either all oysters were removed within the quadrat and counted on land or divers counted densities underwater.

Oyster size frequency distribution measured oysters along different size classes and provided information about oyster growth and survivorship/mortality of cohorts (SMP Goal 3, Objective 1, Recommendation 2). At least 250 oysters per reef were measured (length in mm) using calipers and placed into assigned five mm classes (0-5mm, 6mm-10mm, etc.).

Reef areal dimension ($m^2$) consisted of the project's footprint and the reef area. The footprint was the actual extent of the reef project and can be determined in a couple different ways. The first way uses continuous GPS points while walking or kayaking around the project's perimeter. Secondly, transects can be run in a grid pattern through the project footprint using either side-scan or multi-beam sonar while continuous GPS points were taken. Side-scan sonar efficiently created images of large areas of the seafloor. Multi-beam sonar emits sound waves to acquire water depths. An alternative method that was cheaper included the use of aerial footage produced by a drone, which was ground truthed by dive surveys and then a computer program, ArcGIS, was used to determine the project's areal dimension. We used this alternative method.

Reef height (m or cm) measured the mean height in relation to the adjacent substrate; in addition, minimum and maximum reef height were measured. Reef height was measured using a ruler or graduated rod every five meters along the transect line. The ruler was placed vertically on top of the sediment and another ruler was placed horizontally on top of the shell to obtain an accurate reading. The average of all height measurements was determined as the mean reef height. Reef height was measured three months post construction and annually thereafter.

Percent cover of reef substrate (oysters and cultch) estimated available habitat for oyster spat to settle on. This was determined using quadrats every five meters down the transect line. The percentage of quadrat covered in shell was recorded and then an average was calculated for each shell row. Measurements were taken three months post construction and annually thereafter.

The ratio of males to females, also known as sex ratio, was determined annually in late June to early July. Oysters are protandrous hermaphrodites meaning that they change sex from male to female as they grow older (Baggett et al. 2014). According to Mann and Powell et al. (2007), this ratio can provide valuable information concerning generation times and the susceptibility of the population to collapse. Sex ratio was a good indicator of the site's overall capacity for embryo production. At least 25 random oysters (> 25 mm) were sampled across available size ranges and the sex was determined using a microscope (see Appendix A for protocol). To calculate sex ratio, the number of males was divided by the number of females.

## Timeline

July 17, 2015: Nature Conservancy visit to help with site selection
July 24, 2015: Oyster cages deployed for oyster growth study
August 13, 2015: Site selection dive surveys at Shimmo
October 7, 2015: Predator study deployed
March 2016: Restoration draft proposal completed, and reviews sent out
April 2016: Project design finished
April 2016-April 2017: Obtain necessary permits
June-September 2016: Pre-reef monitoring surveys
May 2017: Spat on shell production
June 2017: Half cultch placement
July 2017: Broodstock placement
September 2017: Post-reef monitoring surveys
October 2017: Spat placement
June 2018: Finish cultch placement
July 2018: Broodstock placement
September 2018: Post-reef monitoring surveys

October 2018: Spat on shell placement
July 2019: Broodstock placement
September 2019: Spat placement and post-reef monitoring surveys
June-August 2020: Cultch placement in areas that sunk
September 2020: Spat placement and post-reef monitoring surveys

## Results

Since the project was implemented, initial data suggests that eelgrass shoot density has increased since the restoration project was implemented. Eelgrass was not present at the restoration site until 2018 when six shoots were counted in 154 m² of monitored bottom during the annual dive survey. This equated to an average density of 0.09 shoots/m². The percent of eelgrass coverage per m² was 0.39% or 0.1 on the Braun-Blanquet scale. In 2019, a total of 97 shoots were found during the annual dive survey resulting in an average density of 1.17 shoots/m². The percent of eelgrass coverage per m² was 3.38% or 0.5 on the Braun-Blanquet scale. Since the reef was initiated, eelgrass has begun to appear in areas where it was not before.

Overall, oyster density has increased with restoration efforts; no oysters were found prior to restoration and now they are present. Oyster spat on shell produced by the Town of Nantucket Brant Point Shellfish Hatchery were not added to the restoration site until 2016. That year 210,000 spat attached to oyster shell were placed on four plastic claim trays for the predator and growth study. In 2017, hatchery grown spat on shell were deployed after the annual survey and all 16 oysters found during the survey were adults either from the predator/growth study or broodstock that were previously deployed by NRD. The average oyster density was 0.48 oysters/m² for the first five shell rows (only half the reef was built in 2017). In 2018, the remainder of the shell rows were installed, and 78 oysters were counted in the quadrats during the annual dive survey equating to an average oyster density for the restoration site of 1.39 oysters/m². In one year from 2017 to 2018, oyster density increased by 34.5% at the site. In 2019, a total of 80 oysters were counted in the quadrats and the average oyster density was 1.45 oysters/m². From 2018 to 2019, the average oyster density only increased by 0.06 oysters/m².

Oyster spat recruitment has increased since the project was implemented. Only 1 oyster spat was found when all three spat collectors were retrieved in the fall in 2016 (pre-construction). Post construction in 2017, spat recruitment increased resulting in four spat attached to the tiled collectors and 60 spat were collected in 2018. The data suggests that spat recruitment increased since restoration efforts were initiated. In 2019, the spat collectors were deployed using a different method and not kept out from June to September but rather collected and re-deployed every week. This proof of concept study was done to gain information on larval preference between oyster shell collectors and tile collectors. No spat attached to either of the collectors. The first evidence of natural recruitment on shell at the restoration site was seen in the 2019 dive survey. Two of the oyster clumps that were collected for oyster size frequency had two spat attached that were 26mm and 27mm which was close to the average size of spat, 24.5mm, collected on the tiles in 2018. In addition, oysters have been identified growing along the marsh edge attached to ribbed mussels. This means that either the older oysters on the reef were naturally spawning and the larvae stayed at the restoration site, or larvae from the oyster growers in the eastern part of the harbor (~7,000 meters away) made it into Shimmo Creek to settle.

In 2016 pre-restoration, 18 species were identified in both the fish traps and seine surveys. In 2017 post-restoration, 13 species were captured and identified. In 2018, species richness increased to 18 and in 2019 it increased even more to 24 species captured and identified. The data suggests that richness has increased in the last three years but not prior to restoration efforts. A total of 29 species have been collected and identified from 2016-2019. Fourteen fish species were identified including: four spined stickleback (*Apeltes quadracus*), three spined stickleback (*Gasterosteus aculeatus),* cunner (*Tautogolabrus adspersus*), winter flounder (*Pseudopleuronectes americanus*), summer flounder (*Paralichthys denatus),* Atlantic silverside (*Menidia menidia*), shorthorn sculpin (*Myoxocephalus Scorpius*), tautog (*Tautoga onitis*), black seabass (*Centropristis striata),* mummichug (*Fundulus heteroclitus),* striped killifish (*Fundulus majalis),* sheepshead minnow (*Cyprinodon variegatus),* American eel *(Anguilla rostrate),* and northern pipefish *(Tautoga onitis).* Two types of shrimp where identified, the common shore shrimp (*Palaemonetes vulgaris)* and sand shrimp *(Crangon septemspinosa).* Seven crabs were identified, the green crab (*Carcinus maenas*), long clawed hermit crab (*Pagurus longicarpus*), common spider crab (*Libinia emarginata*), blue crab (*Callinectes sapidus),* pea crab (*Pinnotheres ostreum),* black-fingered mud crab (*Eurypanopeus depressus),* and the flat clawed hermit crab (Pagurus pollicaris). One gastropod was found, the common periwinkle (*Littorina littorea)* and one amphipod *(Carella sp.).* Three isopods were collected, and one was not able to be identified: isopod *(Idotea baltica),* and Baltic isopod (*Idotea baltica).* Two types of shellfish were collected including the hard clam *(Mercinaria mercinaria)* and the ribbed mussel (*Modiolus demissus*).

In 2015 before construction, the average total nitrogen was 0.488 mg/L (n=2; standard error = 0.034). In 2016, again pre-construction, 210,000 oyster spat on shell were added to a small section of the site. That year average total nitrogen decreased to 0.416 mg/L (n=6; standard error = 0.043). In 2017, post construction, average total nitrogen slightly increased to 0.424 mg/L (n=5; standard error = 0.036). In 2018, average total nitrogen decreased even more to 0.290 mg/L (n=4; standard error = 0.027). In 2019, the average total nitrogen increased to 0.419mg/L (n=4; standard error = 0.042). Overall the data suggests that the average total nitrogen at the restoration site fluctuates yearly. This could be for two reasons, either there are not enough oysters at the site to impact total nitrogen or there hasn't been enough sampling years.

Due to the soft bottom sediment in Shimmo, large sections of cultch appeared to have been buried causing a decline in reef height following installation. The rate of shell accretion must be greater than shell loss for an oyster reef to persist (Baggett et al. 2014). According to Baggett et al. (2014), shell accretion occurred through recruitment, growth, and natural mortality; whereas shell loss can be caused by bio-erosion, dissolution, and displacement, as well as, habitat destruction, and shell burial. Multiple years of dive surveys have provided data using reef height measurements and divers' observations to indicate that the reef's rate of shell loss was greater than accretion. In 2017, the average height for the first five shell rows deployed was 2.35cm which was much shorter than the 10-15cm suggested by The Nature Conservancy. In some areas, like the middle of the site, where shell was deployed became completely buried and only sediment can be found (Figure 11).

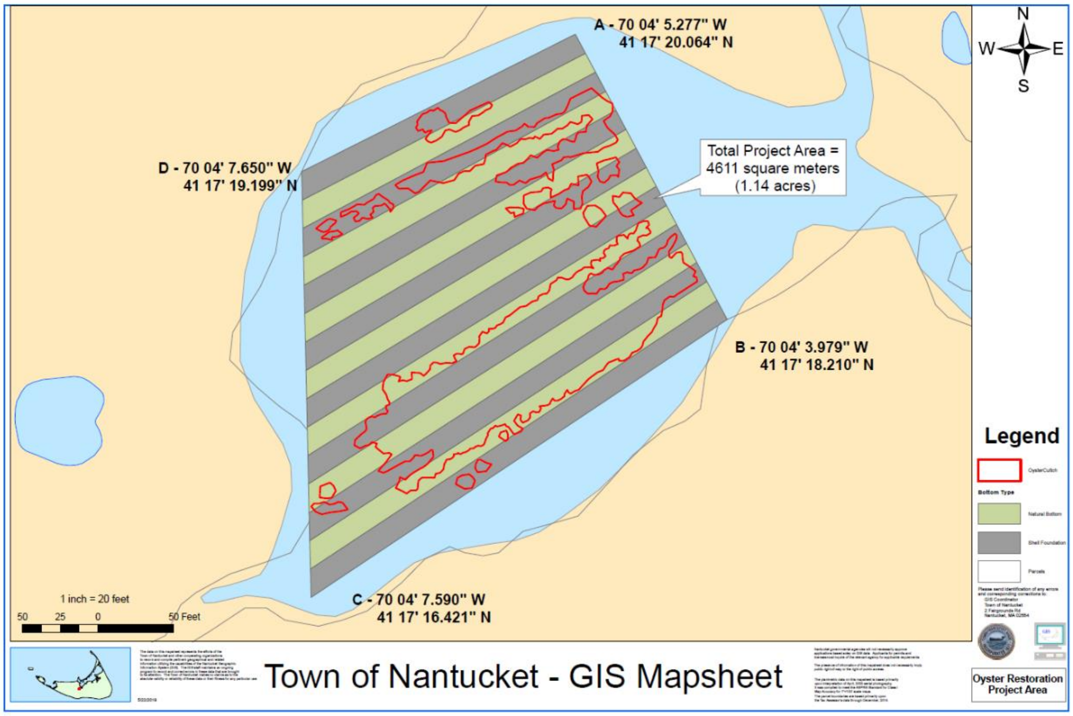



Figure 11. Proposed shell rows shown in grey and the actual shell rows highlighted as the red polygons.

## Observations, Maintenance, and Recommendations

The reef area was the actual area of patches of living and nonliving shell or other construction material used within the project footprint. The plan was to have 50-75% of the bottom covered with shell and the remainder available for benthic invertebrates or submerged aquatic vegetation. Currently, the reef area is 1,677 m² (0.41 acres) which makes up only 36% of the total project footprint (Figure 12). This information suggests that more cultch should be added in the summer of 2020 to increase reef height and determine if other structures such as reef balls or bagged shell would work better at the site. Before shell is added to the site, oysters should be moved to a specific location to reduce burial of live oysters. This will be determined once reef height data is gleaned from the benthic survey conducted in 2018. After oysters are moved, shell can be brought to the site using the same method as building the reef. Every week or so a certain number of fish totes can be deployed to achieve the desired relief of 10-15cm and increase the reef area by at least 50%. This will give time for the shell to settle before the annual dive survey in September when the reef height will be measured every five meters. If the height still isn't achieved in certain areas, more shell should be added during the fall.

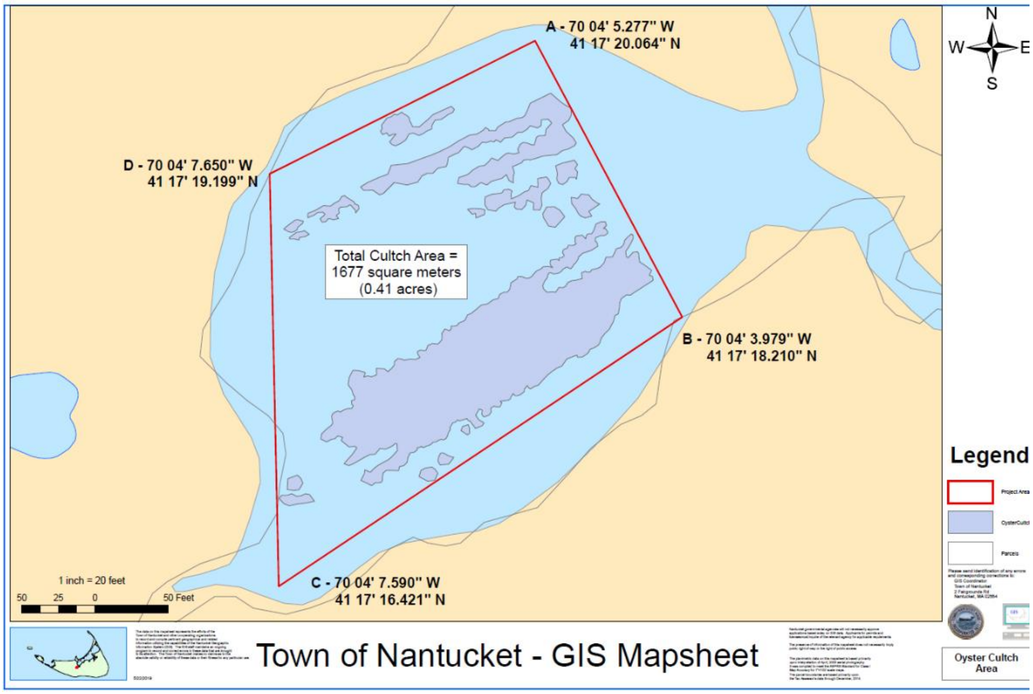



Figure 12. Reef area showing the total cultch area equating to 1677m².

Literature suggests that a self-sustaining reef has at least 50 oysters/m². To achieve this density with the current reef area there should be 83,850 oysters added to the reef each year, considering mortality rates. When more shell is added to the site and the reef area increases by 50% then at least 167,700 oysters should be stocked to achieve 50 oysters/m² and continue annually until accretion rates increase.

It is recommended that all data currently being collected should continue yearly until the restoration project is ten years old. This extended timeframe is important to assess the ecological performance of the restoration project. At that time, the Town can determine if the project was successful and if monitoring should continue. If any experiments or proof of concept projects are done at the site during the field season, they should not alter the current data being collected in anyway. For example, in the summer of 2019, a different spat collector method was implemented resulting in no data to assess natural recruitment at the reef during that year. This leaves data gaps which are undesirable.

**Recommendations for Future Restoration**

It is recommended that before an oyster restoration project is implemented a sediment budget should be conducted. This will give information on sediment sources and sinks at the site. If a sink is identified during this survey than it is not recommended that loose shell be placed there because the likelihood of burial is high. In addition, if sedimentation is likely at a site, then alternative restoration techniques, other than loose shell, should be used to account for the type and amount of sediment being deposited. For example, if the sediment is very soft then something with a larger surface area and higher relief, like a reef ball, should be used to reduce burial but still provide vertical relief and substrate for oyster attachment. If the sediment at the proposed site is too soft, then alternative sites where the sediment is harder and/or sedimentation rates are lower should be identified.

Another survey that should be done pre-restoration is evaluating the site's bathymetry using side scan sonar. This will give information on the bottom contour before shell or alternative substrate is added. By having this baseline data, it will be easier to find the actual reef height rather than the relative height. This type of survey will save time during the annual dive survey because reef height won't have to be measured every 5m. Instead, every few years side scan sonar can be used to calculate the reef's height.

The final recommendation is to add more loose shell than 100 cubic yards per acre which is recommended by the Nature Conservancy. When restoring an oyster reef there is no such thing as having too much shell substrate unless it is a navigational hazard. Like mentioned above, reef height influences oyster reef success, so increased height can result in faster oyster growth, better survival, and increased density (Schulte et al. 2009). In addition, high relief reefs minimize disease and sedimentation due to optimal flow rates. If logistically feasible, it is recommended to increase shell volume by two ($200y^3$) or three times ($300y^3$) the recommendation.

## Conclusion

This project laid a foundation for future oyster restoration efforts and provided information of effort and scales needed for substantial impact in the form of ecosystem services. Data suggest that improvements have occurred at the site regarding oyster density, eelgrass density, and natural spat recruitment (see results section). Currently, the restoration site is closed for shellfish harvests by the Massachusetts Division of Marine Fisheries due to high bacterial loads. This is unfortunate but could aid in evaluating the effects of a small-scale oyster restoration project can have regarding eco-system services. Additionally, ongoing data collection will not be impacted by oyster harvest at the site. Long term monitoring at the site will continue indefinitely and data will be used to determine if the project is successful in achieve the goal and objectives. The restoration project serves as an educational platform for the local community and visiting scientists to study, collaborate with others, and share data. This document can serve as a resource for restoration scientists or organizations to use during the planning, permitting, implementation, and monitoring process for oyster restoration projects world-wide.

## References


Baggett, L.P., S.P., Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, S. Morlock. 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.

Beck, M.W., R.D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G. Edgar, B. Hancock, M. Kay, H. Lenihan, M. Luckenbach, C. Toropova, and G. Zhang. 2011. Oyster reefs at risk and recommendations for conservation, restoration and management. Bioscience 61: 107-116.

Beck, M.W., R.D., Brumbaugh, L., Airoldi, A., Carranza, L.D., Coen, C., Crawford, D., Defeo, G.J., Edgar, B., Hancock, M.C., Kay, H.S., Lenihan, M.W., Luckenbach, C.L., Toropova, G., Zhang. 2009. Shellfish reefs at risk: a global analysis of problems and solutions. The Nature Conservancy, Arlington, VA.

Brumbaugh, R.D., M.W. Beck, L.D. Coen, L.Craig and P. Hicks. 2006. A Practitioners' Guide to the Design and Monitoring of Shellfish Restoration Projects: An ecosystem Services Approach. The Nature Conservancy, Arlington, VA

Brumbaugh, R., L. Coen. 2009. Contemporary approaches for small-scale oyster reef restoration to address substrate versus recruitment limitation: a review and comments relevant for the Olympia oyster, *Ostrea lurida* carpenter 1864. *Journal of Shellfish Research*. 28:147-161

Chesapeake Bay Program. 2012. "Atlantic Oyster Drill." Accessed January 6, 2016. https://www.chesapeakebay.net/S=0/fieldguide/critter/atlantic_oyster_drill

Churchill, Neil. "Division of Marine Fisheries Dive Survey Protocol for Aquaculture Areas." Telephone interview. 14 July 2015

Cohen, A., C. Zabin. 2009. Oyster shells as vectors for exotic organisms. *Journal of Shellfish Research*. 28:163-167

daSilva Quintal, S. 2015. Buzzards Bay oyster spat monitoring study - 2014. Buzzards Bay Coalition, New Bedford, MA

Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. NOAA Tech. Memo. NMFS F/SPO-88, 105 p.

Flimlin, G., B. Beal. 1993. Major predators of cultured shellfish. Northeastern Regional Aquaculture Center Bulletin No. 180

Fourqurean, J.W., A. Willsie, C.D. Rose, and L.M. Rutten. 2001. Spatial and temporal patterns in sea grass community composition and productivity in south Florida. Marine Biology 138:341-354

Gedan, K., M. Kirwan, E. Wolanski, E. Barbier, B. Silliman. 2010. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. Climate Change

George, L.M., K. DeSantiago, T. Palmer, J. Pollack. 2014. Oyster reef restoration: effect of alternative substrates on oyster recruitment and nekton habitat use. J Coast Conservation

Gosselin LA, Qian PY. 1997. Juvenile mortality in benthic marine invertebrates. Marine Ecology Program Series 146: 265-282

Grabowski, J., C. Baillie. 2013. Tisbury Great Pond oyster habitat restoration project. The Nature Conservancy

Grabowski, J., R. Brumbaugh, R. Conrad, A. Keeler, J. Opaluch, C. Peterson, M. Piehler, S. Powers, A. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. BioScience 62: 900-909

Green, M.A., G.G. Waldbusser, S.L Reilly, K. Emerson, S. O'Donnell. 2009. Death by dissolution: Sediment saturation state as a mortality factor for juvenile bivalves. Limnol. Oceanogr. 54: 1037

Hewitt, J.E., S.F. Thrush, J. Halliday, C. Duffy. 2005. The importance of small-scale habitat structure for maintaining Beta diversity. Ecology 86(8): 1619-1626

Hickey, J.M., T. Shields, J. Kennedy, K. Ford. 2015. Shellfish Planting Guidelines. Massachusetts Division of Marine Fisheries.

Jordan, S., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resources. United States Environmental Protection Agency, Chesapeake Bay Program, Annapolis, Maryland.

Kellogg, L., J. Cornwell, M. Owens., K. Paytner. 2013. Denitrification and nutrient assimilation on a restored oyster reef. Marine Ecology Program Series 480: 1-19

Kelly, R., Foley, M., Fisher, W., Feely, R., Halpern, B., Waldbusser, G., Caldwell, M. 2011. Mitigating local causes of ocean acidification with existing laws. Science 332: 1036-1037

Kennedy, V.S. 1996. Biology of larvae and spat. *In* V.S. Kennedy, R.I.E. Newell and A.F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland. pp. 371-421.

Kingsley-Smith, P.R. 2015. Eastern Oyster. Species of Conservation Concern

Kingsley-Smith, P.R., Joyce, R.E., Arnott, S.A., Roumillat, W.A., McDonough, C.J. & Reichert, M.J.M. 2013. Habitat use of intertidal Eastern oyster (*Crassostrea virginica*) reefs by nekton in South Carolina estuaries. *J. Shellfish Res*. 31(4):1009-1021

Kraeuter, J.N., M.J. Kennish, J. Dobarro, S.R. Fegley, G.E. Flimlin. 2003. Rehabilitation of the Northern quahog (Hard Clam) (*Mercenaria mercenaria*) habitats by shelling- 11 years in Barnegat Bay, New Jersey. Journal of Shellfish Research 22(1):61-67

Kragt, M. 2012. Bioeconomic modelling: Integrating economic and environmental systems? International Environmental Modelling and Software Society

Lenihan, H.S. 1999. Physical- biological coupling on oyster reefs: how habitat structure influences individual performance. Ecol. Monographs 69: 251-275

Lenihan, H.S., Peterson, C.H., Byers, J.E., Grabowski, J.H., Thayer, G.W. & Colby, D.R. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecol. Appl*. 11:764-782

MaKenzie, C.L. 1996. History of oystering in the United States and Canada, featuring North America's greatest oyster estuaries. Marine Fisheries Review. 58(4): 1-78

Mann, R., Harding, J.M. 1998. Continue trophic studies on constructed "restored" oyster reefs. Annual research report to the U.S. Environmental Protection Agency, Chesapeake Bay Program, Living Resources Committee, Virginia Institute of Marine Science, Gloucester Point, VA. 71 pp.

Mann, R., Powell, E.N. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. Journal of Shellfish Research 26:905-917.

Massachusetts Municipal Association. 2014. 3 Cape Cod Towns use oysters to improve water quality. Boston, MA. Accessed Feb. 22, 2016. http://www.mma.org/more-community-corner/14120-3-cape-cod-towns-use-oysters-to-improve-water-quality

Meritt, D., D. Webster. Remote Setting Systems. University of Maryland Extension Oyster Aquaculture Technology Series

Meyer D.L., Townsend E.C., Thayer G.W. 1997. Stabilization and Erosion Control Value of Oyster Cultch for Intertidal Marsh. Restoration Ecology 5:93-99

Natural Heritage Endangered Species Program. 2016. Massachusetts List of Endangered, Threatened and Special Concern Species. Westborough, MA. Accessed Feb. 22, 2016. http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html

Newell, R.I.E., C.J. Langdon. 1996. Mechanisms and physiology of larval and adult feeding. *In:* V.S. Kennedy, R.I.E. Newell and A.F. Eble, (eds). The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College

Park, Maryland. pp. 185-229

Newell, R.I.E., G.S. Alspach, Jr., V.S. Kennedy, D. Jacobs. 2000. Mortality of newly metamorphosed eastern oysters (*Crassostrea virginica*) in mesohaline Chesapeake Bay. Marine Biology 136: 665-67

Newell, R.I.E., E.W. Koch. 2004. Modeling sea grass density and distribution in response to changes in turbidity stemming from bivalve filtration of substrate type and tidal height. J. Shellfish Res. 19: 387-395

Newell R, Fisher T.R., Holyoke R, Cornwell J. 2005. Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. In: Dame R, Olenin S (eds) The comparative roles of suspension-feeders in eco-systems. Kluwer, Dordrecht, p 93–120

NOAA. 2019. Technical Aspects of Oyster Restoration. Retrieved from https://chesapeakebay.noaa.gov/oysters/technical-aspects-of-oyster-restoration

Norton, J. 2010. Oyster farming. *Chesapeake Quarterly*, December 2015 issue. Retrieved from http://www.chesapeakequarterly.net/V14N4/side1/

Peabody, B., Griffin, K. 2008. Restoring the Olympia Oyster, Ostrea conchaphila. Habitat Connections 6 (2):1-6

Pelikan, M., J. Kachmar, K. Lombard, R. Konisky. 2015. Nasketucket Bay (Fairhaven) oyster restoration. The Nature Conservancy.

Piazza B.P., Banks P.D., Peyre, M.K. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. Restor. Ecol. 13:499–506

Posey, M.H., Alphin, T.D., Powell, C.M., Townsend, E. 1999. Oyster reefs as habitat for fish and decapods. *In*: M. W. Luckenbach, R. Mann & J. A. Wesson, (eds), *Oyster reef habitat restoration: a synopsis and synthesis of approaches*. Virginia Institute of Marine Science Press, Gloucester Point, VA, pp. 229-237

Powell, E.N., Kraeuter, J.N., Ashton-Alcox, K.A. 2006. How long does oyster shell last on an oyster reef? Estuarine Coastal and Shelf Science 69:531-542

Powers, S.P., C.H. Peterson, J.H. Grabowski, H.S. Lenihan. 2009. Evaluating the success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. Marine Ecology Progress Series 389: 159-170

Reef Innovations. 2013. Retrieved from https://reefinnovations.com/archives/category/projects/breakwaterprojects/page/2

Ries, J., Cohen, A., McCorkle, D. 2009. Marine calcifiers exhibit mixed responses to CO2-induced ocean acidification. Geology 37(12):1131-1134.

Rose, J., S. Bricker., M. Tedesco., G. Wikfors. 2014. A role for shellfish aquaculture in coastal nitrogen management. Environmental Science and Technology 48: 2519- 2525

Schulte DM, Burke RP, Lipcius RN. 2009. Unprecedented restoration of a native oyster metapopulation. Science 325:1124–1128

Sellars, M.A., and J.G. Stanley. 1984. Species profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic) - American oyster. U.S. Fish Wildl. Serv. U.S. Army Corps of Engineers, TR EL-82-4. 15pp.

Shellfish Management Plan. 2010. Nantucket, MA. Accessed Feb. 1, 2016. http://www.nantucket-ma.gov/DocumentCenter/Home/View/88

Shumway, S.E. 1996. Natural environmental factors. In: V.V. Kennedy, R.I.E. Newell and A.F. Eble, editors. The Eastern Oyster *Crassostrea virginica.* Maryland Sea Grant College, University of Maryland. Pp.467-513

Schulte D.M., Burke R.P., Lipcius R.N. 2009. Unprecedented restoration of a native oyster metapopulation. Science 325:1124–1128.

Swann, L. 2008. The use of living shorelines to mitigate the effects of storm events on Dauphin Island, Alabama, USA. Am Fish Soc Symp 64:47–57

Thayer, Gordon W., Teresa A. McTigue, Ronald J. Salz, David H. Merkey, Felicity M. Burrows, and Perry F. Gayaldo, (eds.). 2005. Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 628 pp. plus appendices

Town of Nantucket. 2015. Shellfishing Policy and Regulations. Nantucket, MA. Accessed Feb.1, 2016. http://www.nantucket-ma.gov/DocumentCenter/Home/View/8778

Waldbusser, G., Voigt, E., Bergschneider, H., Green, M., Newell, R. 2011. Biocalcification in the Eastern Oyster in Relation to Long-term Trends in Chesapeake Bay pH. Estuaries Coasts. 34: 221

Wilberg, M.J., M.E. Livings, J.S. Barkman, B.T. Morris, and J.M. Robinson. 2011. Overfishing, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay. Marine Ecology Progress Series 436:131-144

Zu Ermgassen, P.S.E., M.D. Spalding, B. Blake, L.D. Coen, B. Dumbauld, S. Geiger, J.H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw, W. Rodney, J.L. Ruesink, S.P. Powers, and R.D. Brumbaugh. 2012. Historical ecology with real numbers: past and present extent and biomass of an imperiled estuarine habitat. Proceedings of the Royal Society B: Biological Sciences 279:3393-340

## Appendix A

**Seine Survey Protocol**

Seining will happen once in late spring (end of May), summer (end of July/August), and early fall (end of September/early October).

- At least 3 people are needed.

- Time taken roundtrip is about 3 hours

-Seining will occur either on incoming or outgoing tide but the tide needs to be higher because it's so shallow at the site.

**Materials needed**:

- GPS
- 1/8" seine net
- Waders
- Scale
- Wooden box
- Plastic totes
- Plastic graduated cylinders (50mL, 1L)
- 5-gallon buckets
- ID book
- Calipers
- Notebook

**Protocol**:

1. Seining will take place at two locations (see map below). The blue X is the central location.

2. Two people will walk to the left until they reach the marsh (west) from the central location and walk into waist deep water
3. The seine will be walked parallel to the shore until the central location is reached (~10 minutes)
4. Fill buckets and tubs with water and species will be sorted into individual groups

5. Abundant species (i.e. skeleton shrimp and bittium) are estimated before the second seine survey
6. Staff/volunteers perform water exchanges for the buckets and try to keep everything alive if it is very hot out
7. The second seine survey will be performed to the right (east) from the central location in waist deep water. Surveyors will walk to the end of the "sand spit" and work their way to the central location.
8. The seine will be walked parallel to the shore until the central location is reached (~10 minutes)
9. Follow steps 3-6
10. **ALL species are identified, counted, and the wet weight** will be identified (g)
    a. If the individual species are too light to register on the scale, then weigh all individuals of the same species together and note it on the data sheet.
    b. If there are many small species (i.e. skeleton shrimp) then count a specific number and weigh in a known volume. For example, count how many individuals fit in a 10mL volume. Then collect all individuals in the graduated cylinder and record volume. Multiply volume by known weight to get number of specimens.
11. A **subsample (~25) of each specie's length will be measured (mm)**
12. Enter all data into the data sheet

**Fish Traps Protocol**

**Materials Needed:**

- 6 fish traps with buoys attached
- Pencil
- Maria Mitchell ID book
- Data notebook

**Protocol**

1. 6 fish traps are deployed once in July, August, and September for 24 hours.
   a. They are not baited
   b. Traps should be deployed at high tide in this orientation:


2. The next day at high tide pull up the traps. It doesn't matter in which order.

**Data Collection:**

- Set up the notebook like this:

| | | |
|---|---|---|
| Date Deployed | | |
| Date Retrieved | | |
| | | |
| Fish Trap # | Species | Abundance |
| | | |
| | | |
| | | |
| | | |

- For every trap identify each species and their abundance (# of individuals). Record in notebook. Return species to the water.

**Spat Collector Protocol**

**Materials Needed**:

- 4 spat collectors which are located under the hatchery
- 4 porcelain tiles to put in each collector
- Caliper
- Notebook

**Protocol:**

1. The collectors are deployed in early June to catch the spawn.
2. Deploy the collectors in this orientation:


3. Retrieve collectors in the middle of September

**Data collection:**

Set the notebook up like this:

| Collector # | # spat | Length (mm) |
|---|---|---|
| Tile 1 (outside) | | |
| Tile 2 (inside) | | |
| Tile 3 (inside) | | |
| Tile 4 (outside) | | |

- Record collector #, # of spat for each of the 4 tiles, and the length of each spat in mm

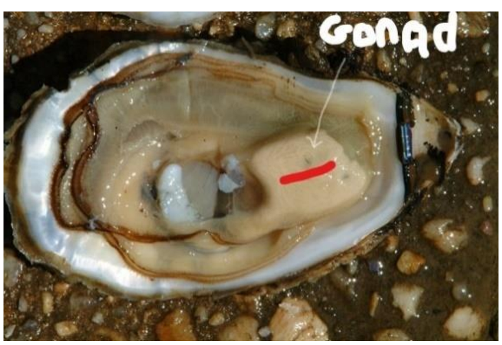
**Sex Ratio Protocol**

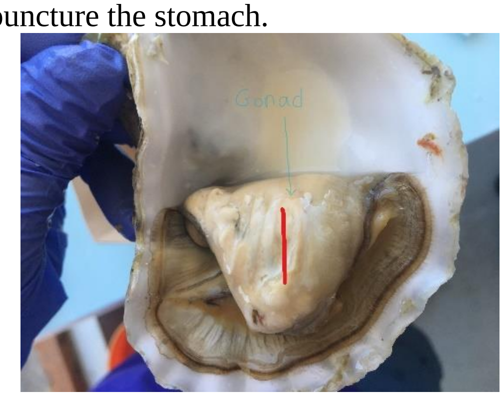
**Materials Needed:**

- Snorkel gear
- Mesh bags (1 for each person)
- Caliper
- Oyster knife
- Gloves
- Razorblade
- Pipette
- Beaker
- Saltwater
- Microscope
- Counting slide

**Protocol:**

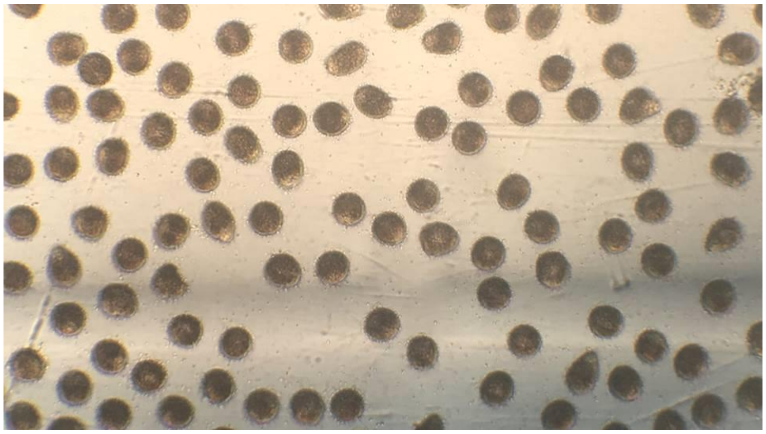
1. Swim along the reef and collect oysters- store in mesh bag
2. A total of **25 oysters** that are **25mm or greater in length** need to be collected
    a. It doesn't matter if they are single oysters or spat on shell
3. Bring the oysters back to the hatchery and measure their length.
    a. Record in the notebook (see data collection section)
4. and open them using the shucking knife (wear gloves)
5. With the razor blade gently slice down the gonad (labeled below). Make sure the cut is shallow or else you will puncture the stomach.






6. Using the pipette, extract the gonad material and place in the beaker. Do this a few times so the sample is a milky color
7. Place a few drops on the counting slide and look under the microscope on the lowest power setting.
8. Look and see if there are eggs and if not eggs present then a male

Eggs



9. Continue this process for all oysters

**Data Collection:**

- Set the notebook up like this and check box if male or female

| Oyster # | Length (mm) | Male | Female |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |

**Dive Survey Protocol**

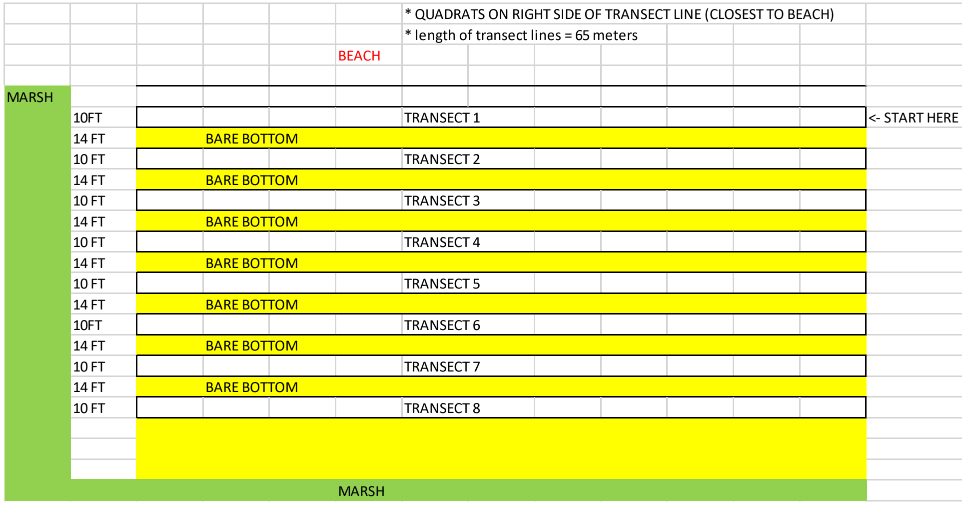
**Materials Needed:**

- Snorkel, mask, fins
- Dive gear if needed (tank, BC, weights, weight belt, regulator)
- Dive slates or clipboards
- Waterproof data sheets
- Transect lines (100m or 2-50 m)
- Rebar stakes (~20)
- 8 buoy lines
- 0.5 $m^2$ quadrats (~5)
- Pvc rulers in cm (~5)
- Spat bags (100)
- Calipers (4)
- Pencils (10)

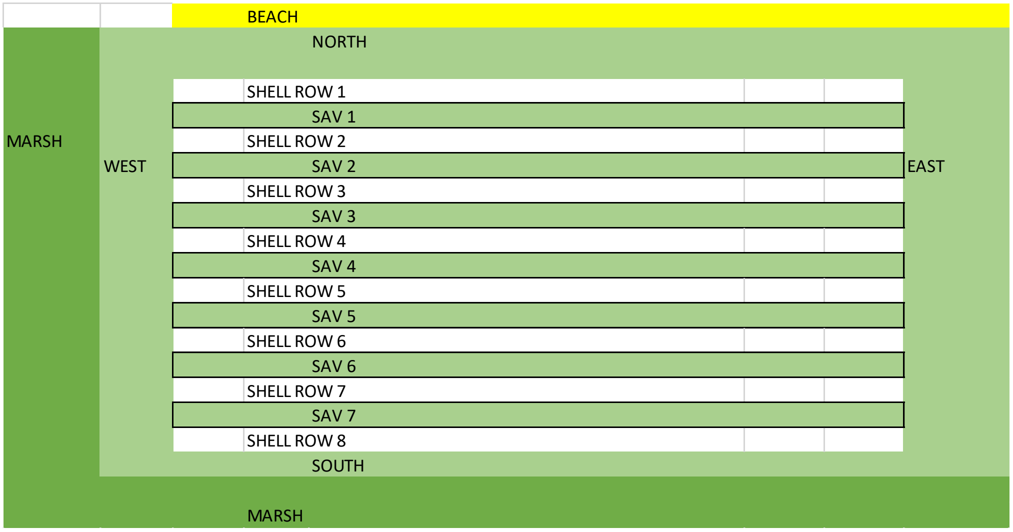
**Protocol:**

- Dive mid to late September
- Can be snorkeled at mid-low tide
- Number of people needed:
    - 4-8 snorkelers: 2 per line; the first person starts at 0m and the second person starts at 65m working towards each other
    - 2-4 people on shore going through the bags to do spat counts and measurements
- Parameters measured: reef height, SAV density, oyster density, size frequency

1. Place a buoy line at the East end of the shell row to mark the beginning (0m) of the transect line.
2. Run a 100m transect line down the middle of each shell row and stake each end. The line starts on the east side and runs west. Line can be moved if no shell is under it.
    a. In 2017 we used 0.5 $m^2$ transects because reef patchy and no spat on shell.
    b. Quadrat placed to the right of line (closest to beach) every 5 m along line (ex. 0m, 5m,10m lines ended at 65m) = 14 quadrats per line
    c. See diagram below:




3. **Reef height**- Place a ruler or piece of PVC that is graduated (by cm) on top of the sediment and measure the distance between top of sediment to bottom of quadrat
    a. Reef height taken every meter and take average to get mean reef height (we did every 5m in 2017)
4. **Oyster density**- Count how many spat on shell and adult oysters per quadrat and record. This can be hard because of the silt which causes visibility issues.
    a. Note in the data sheet if the spat is attached to bay scallop, clam, or oyster shell
    b. Collect the oysters from each quadrat and place in separate labeled bags. Labels are at quadrat intervals (0m,5m,10m,15m, etc.)
5. **Observations**- Note on data sheet if shell is buried or covered by algae, fish/ creatures, algae type
6. **Size frequency**- Use oysters that were collected for oyster density. Measure at least 40 oysters from each sample (i.e. transect line) or a total of 250 for the entire reef. Record on data sheet.
    a. Length data is then grouped in 5mm intervals (ex. 0- 5mm, then 6-10mm, 11-15mm, etc.)
    b. Once finished put oysters back on reef
7. **SAV Density**- Run 100 m transect lines E to W down the bare rows to the left of each shell row and stake each end. See diagram:




a. Every 5m place a quadrat down along the transect line and record in the data sheet:
   i. Eelgrass density = # of shoots
   ii. Percent of eelgrass cover within the quadrat= 0%, 25% etc.
      1. Record percent coverage as follows
      2. 0 = no seagrass present in quadrat
      3. 0.1 = a solitary shoot, <5% cover
      4. 0.5 = less than 5 shoots, <5% cover
      5. 1 = greater than 5 shoots, <5% cover
      6. 2 = greater than 5 shoots, 5 – 25% coverage
      7. 3 = greater than 5 shoots, 25 – 50% coverage
      8. 4 = greater than 5 shoots, 50 – 75% coverage
      9. 5 = greater than 5 shoots, 75 – 100% coverage
   iii. Percent of submerged aquatic vegetation (other than eelgrass) within the quadrat = 0%, 20%, 100%, etc.
   iv. Observations: bottom type, ID macro algae species if available, and other any species seen (crabs, shrimp, etc.)

b. Run a transect line around the perimeter of the site which will result in 4 SAV transect lines
   i. Repeat above steps i.-iv. and record on the data sheet

**Dissolved Oxygen, Light, Temperature Logger Protocol**

**Materials Needed:**

- Buoy lines (2)
- Rebar stakes (2)
- PVC stands (5)
- Zip ties
- Colored rope that sinks
- Hobo dissolved oxygen meters (2)
- Light/temperature meters (3)
- Snorkel gear
- Shuttle
- Shuttle housing for light (1) and DO loggers (1)
- Green scrubby or cleaning brush
- Wire cutters or scissors

**Deployment Protocol:**

- Deploy the second week in July until the end of August

1. Prior to deployment make sure the meter/logger software is updated and the meters are calibrated.
    a. The light and temperature loggers collect data every 15 minutes
    b. The HOBO meters collect data every hour on the hour.
2. One **HOBO meter** is deployed “on the reef” which is located on top of cultch and the other one is “off the reef” which is located still in Shimmo embayment but on the bare bottom (no cultch present)
    a. Take the cap off the Hobo meter probe and sting a large zip tie through the top hole of the meter and the two holes in the PVC so the meter is hanging within the PVC stand
    b. In the designated spots place a buoy line and secure with rebar stake
    c. Push PVC stand into the sediment up to the marked line and make sure the stand will not fall
3. **Light/temperature logger** stands have 2 different sized stands. The taller stand is for “off the reef” and is a few inches below the surface of the water. One of the smaller stands (~10”) is for “on the reef” which will be placed within the cultch. The other smaller stand is for “off the reef” which will be placed on top of the bare sediment.
    a. Using a zip tie secure the logger to the PVC stand. Make sure not to cover the sensor! For extra security, tie a string from the stand through the logger’s hole.
        i. Repeat this step for all light loggers
    b. On reef logger (short PVC stand): Using one of the colored ropes- tie it onto the rebar buoy line used for the “on reef” HOBO meter and swim west until the end of the rope. Tie the rope through the PVC stand. Push stand into the sediment up to the marked line. MAKE SURE THE LOGGER IS FACING SOUTH
    c. Off reef logger (1 short PVC stand, 1 tall PVC stand): Using one of the colored ropes- tie it onto the rebar buoy line used for the “off reef” HOBO meter and swim west until the end of the rope. Tie the rope through the PVC stand. Push

stand into the sediment up to the marked line. MAKE SURE THE LOGGER IS FACING SOUTH

i. Place the other logger stand next to the logger you just deployed.

4. Make sure the buoy line is short enough, so it will not float over the light loggers.