Appendix E-6: Alternative Development
Small-Scale Oyster Restoration Package

Hudson Raritan Estuary Ecosystem Restoration

Draft Integrated Feasibility Report &
Environmental Assessment
February 2017

Prepared by the New York District, North Atlantic Division,
U.S. Army Corps of Engineers

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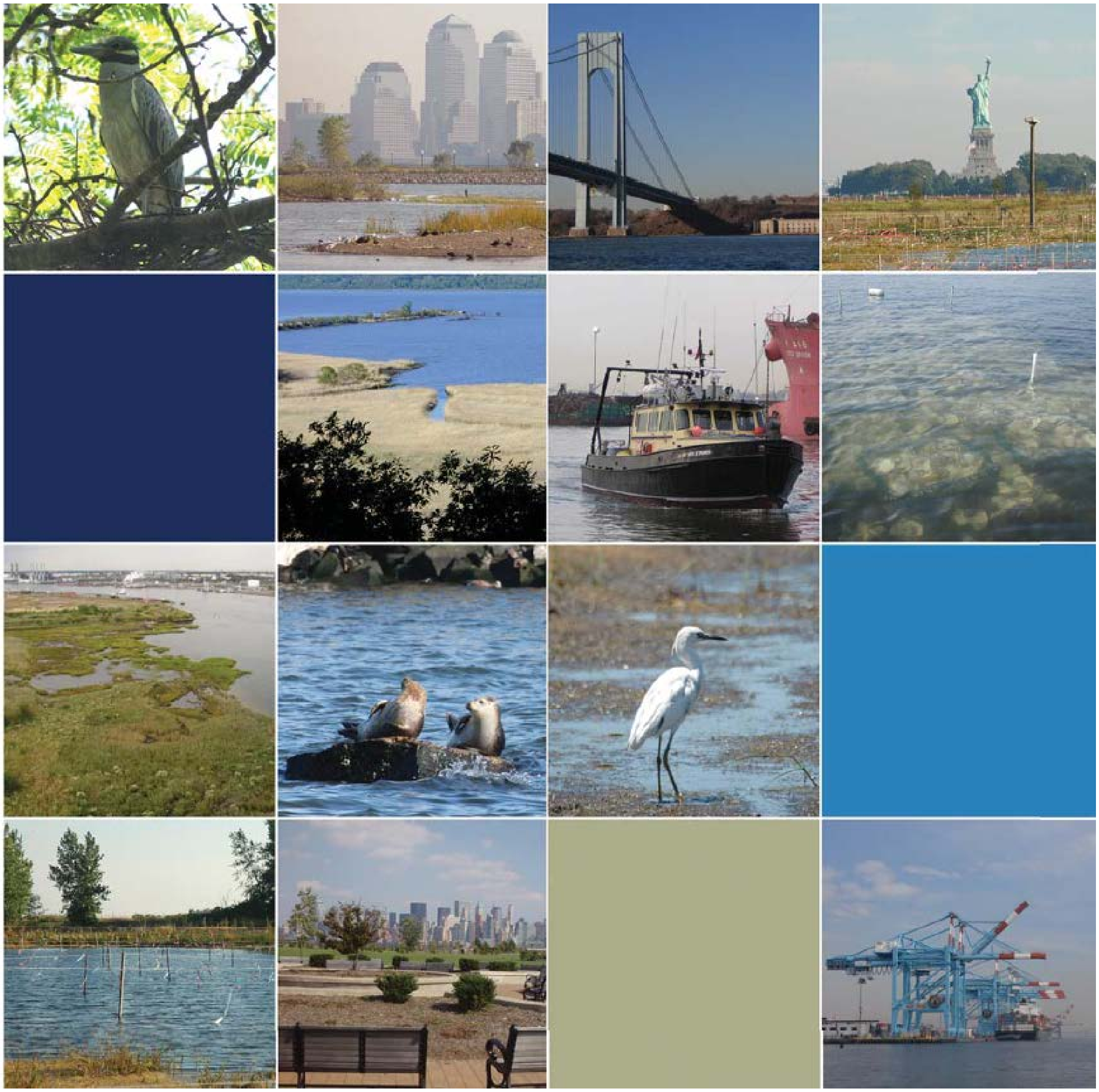
HUDSON RIVER FOUNDATION for Science & Environmental Research, Inc.



Executive Summary

In 2001, the US Army Corps of Engineers (USACE), in partnership with the non-federal Sponsor, the Port Authority of New York and New Jersey (PANYNJ), initiated the Hudson Raritan Estuary (HRE) Ecosystem Restoration Feasibility Study. The goal of the HRE Feasibility Study is to develop a long-term strategy to restore and enhance degraded environments within the estuary in partnership with regional stakeholders.

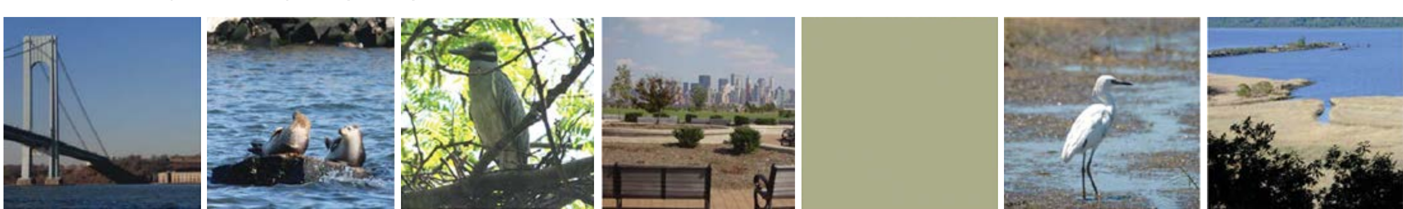
As part of HRE Feasibility Study, the USACE and the PANYNJ, in partnership with the New York-New Jersey Harbor Estuary Program, prepared the Draft Hudson-Raritan Estuary Comprehensive Restoration Plan (CRP) (USACE and PANYNJ, 2009): an interim document that serves as the foundation of the feasibility study and guides ecosystem restoration efforts throughout the estuary. The CRP is intended for use by restoration practitioners as a framework that guides work towards a series of shared restoration goals, providing ecological benefits to the estuary (USACE and PANYNJ, 2014).

To achieve the CRP program goal of “To develop a mosaic of habitats that provides society with renewed and increased benefits from the estuary environment”, the CRP identifies 12 specific restoration targets, termed target ecosystem characteristics (TECs), that are collectively critical to the estuary’s ecological viability (USACE, 2016). The 12 TECs define restoration actions relating to specific habitat types, complexes, contamination issues or societal values. Each TEC was assigned short- and long-term quantitative objectives that collectively contribute to achieving the overall program goal of the CRP.

Oyster reefs and their restoration were identified as a TEC for the HRE with a target statement and overarching goal to “Establish sustainable oyster reefs at several locations” (USACE, 2016 and PANYNJ, 2014). The Oyster Reefs TEC was assigned a short-term objective of establishing 20 acres of reef habitat across several sites by 2020, and a long-term objective of establishing 2,000 acres of oyster reef habitat by 2050. Therefore, the HRE FR/EA includes recommendations for oyster restoration for near-term construction in order to achieve these restoration objectives and associated sub-objectives to incorporate diverse habitat to improve feeding, breeding and nursery grounds for fish and communities. Secondary benefits include incorporating habitat structure to provide secondary coastal storm risk management benefits (e.g., wave attenuation, shoreline stability, and shoreline resiliency) to serve as potential natural and nature-based features and improving water quality through filtration.

This Oyster Package of the Alternatives Development Appendix provides the evaluation for small-scale oyster reef restoration opportunities recommended at select sites throughout this urbanized estuary, and ultimately to provide conceptual plan alternatives for restoration actions. The small scale oyster restoration actions would advance improving shorelines throughout the HRE that currently are lined with bulkheads, piers, or rock revetments, by restoring oysters as living breakwaters where appropriate. In support of this purpose, the appendix summarizes the findings of evaluations of the following, culminating in the identification of recommended restoration techniques and sites, and presentation of conceptual plans for future small-scale oyster restoration efforts:

- Historic significance and decline of oysters in the HRE.
- Recent and ongoing oyster restoration efforts of many organizations, including NY/NJ Baykeeper, New York City Department of Environmental Protection (NYCDEP), the Urban Assembly of the New York Harbor School (Harbor School), the Hudson River Foundation, and the Billion Oyster Project (BOP).



- Ecological benefits from oyster restoration.
- Oyster restoration techniques/methods used throughout the HRE.
- Candidate locations for future oyster restoration to be recommended for near-term construction in the HRE, specifically, Soundview Park, Bush Terminal, Governors Island, Jamaica Bay, and Naval Weapons Station Earle
- Oyster restoration methods and conceptual restoration plans recommended for the candidate oyster restoration locations

It is well documented that oyster restoration would provide significant ecological uplift to the HRE. Oysters are valuable organisms that can provide a multitude of ecological benefits including providing habitat for various aquatic species, filtering the water column, and, in some geographic areas, encouraging the growth of tidal shallows and salt marshes. Additionally, oysters can contribute to the reduction of climate change impacts by attenuating storm surges and sequestering carbon.

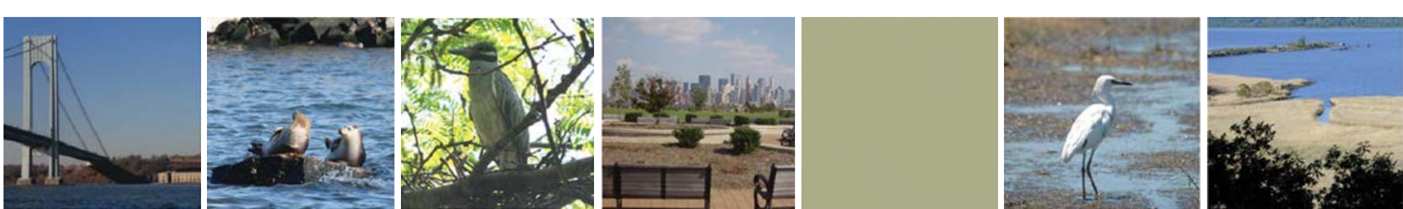
Previous oyster reef restoration activities, including the Oyster Restoration Research Project (ORRP) and other actions by the Harbor School/ BOP, NY/NJ Baykeeper, the Hudson River Foundation and NYCDEP, have already provided encouraging results as oysters have been observed to survive for multiple years after placement on artificial substrate. The HRE Feasibility Study has taken the data provided by these restoration activities and has built upon them, serving as the foundation of recommendations for specific restoration techniques, site considerations, and management of existing reefs.

With respect to the five (5) candidate sites, Governors Island would be an important component in future restoration efforts due to the proximity of the Harbor School. The Harbor School serves as the production hub of the BOP, a long-term, large-scale plan to restore one (1) billion live oysters to New York Harbor over the next twenty years, and, in the process train thousands of young people in New York City to restore the ecology and economy of their local marine environment. A goal of BOP is that by 2030, one (1) billion live oysters will be distributed around 100 acres of reefs, making the HRE once again the most productive waterbody in the North Atlantic and reclaiming its title as the oyster capital of the world (BOP, 2015).

The restoration process begins by collecting wild oysters from New York Harbor. Wild, or more likely, feral, oysters are used when possible to carry forward the genes that have made them successful in this challenging environment. These oysters become the broodstock for the next generation and are conditioned to spawn in the Harbor School Aquaculture classroom also known as, the Harbor School Oyster Hatchery. After a three-week-long conditioning period, the oysters spawn and the resultant larvae are cultivated in the lab for another two (2) weeks. These larvae are introduced to clean shells that have been collected from restaurants. They will attach to the shells and metamorphose through the process of remote setting. The product of remote setting is the clusters of oysters that become the building blocks of our oyster reefs. These clusters are transferred to one of several nursery sites around the harbor where they are cultivated for an additional year. Year-old oysters are then installed at reef sites (USACE, 2016).

Feasibility-level conceptual plans were developed for small-scale restoration at the five (5) sites in the HRE, incorporating restoration techniques that have been tested during pilot programs implemented between 2010 and 2015. The designs include combinations of restoration techniques most suitable for the conditions, such as bathymetry, tidal currents, and substrate, at each site. The proposed small-scale oyster restoration creates over 50 acres of reef structure which, allowing for natural mortality associated with restoration, should meet the year 2020 objective. It is envisioned that, between the

HRE Feasibility Study oyster restoration projects and continuing restoration efforts by the sponsors and other entities in the HRE study area, there will be considerably more functioning oyster reef habitat by 2050.



Hudson-Raritan Estuary Ecosystem Restoration Feasibility Study
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Alternative Development Small-Scale Oyster Restoration Package

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1. Introduction

The work documented in this appendix package focuses on the assessment and alternatives development for the proposed small-scale oyster restoration within the Hudson River Estuary (HRE). Table 1-1 presents the oyster restoration sites to be recommended in this HRE Draft Integrated Feasibility Report and Environmental Assessment (FR/EA).

Table 1-1: Small-Scale Oyster Restoration Sites Recommended for Construction

Planning Region	Site
Jamaica Bay	Head of Bay
Harlem River, East River and Western Long Island Sound	Soundview Park
Upper Bay	Governors Island
	Bush Terminal
Lower Bay	Naval Weapons Station Earle

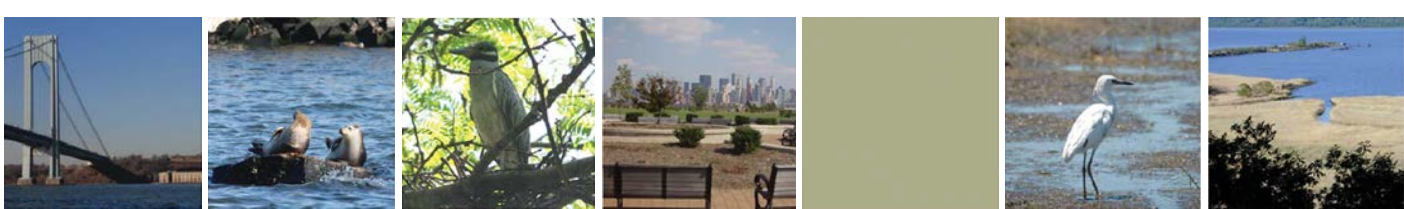
This appendix outlines the history of oysters in the HRE, restoration objectives, prior oyster restoration projects, evaluation of oyster restoration techniques and methods, site baseline conditions and the development of the recommended conceptual plan alternatives for small-scale oyster restoration projects. These restoration actions would provide physical habitat for native fish and aquatic wildlife as well as water quality improvements that will promote a more healthy estuarine system.

2. Project Area Context

Prior to European colonization, oysters and oyster reefs were key components of the estuarine habitat in the HRE. Today, although the vast majority of oyster reefs in the HRE have been degraded or destroyed by human activities, isolated populations do exist in a few areas of the HRE, where water quality, hydrodynamics, and substrate conditions combine to promote opportunities for limited reproduction, spatfall (i.e., settlement of spat), and growth.

The islands, bays, and waterbodies that comprise the HRE were largely shaped and formed during the last ice age. When the ice retreated, a series of shallow estuarine bays were left, which provide ideal habitat for oysters and the formation of oyster reefs.

The confluence of the Hudson River, Raritan River, and Hackensack and Passaic Rivers; coupled with the tidal circulation provided by the Atlantic Ocean, East River and Long Island Sound; and sheltered by Sandy Hook and the Verrazano Narrows; the HRE provided ideal conditions for oysters to live and grow. In fact, it is estimated that during the time of European settlement in the 16th century, half of the oysters on earth could be found in the HRE (Kurlansky, 2007). It is believed that at that time approximately 350 square miles of oyster beds were present in the HRE. Principal concentrations were along the Brooklyn and Queens shorelines in the East River, in Jamaica Bay, and along the Manhattan shoreline of the Hudson and East Rivers. Oyster beds occurred in the Hudson River as far north as Stony Point, New York, and also along the Raritan Bay shoreline in the vicinity of Keyport, New Jersey.



Oysters grew in the Keyport, Raritan and Hackensack Rivers, and on reefs surrounding Staten Island, City Island, Liberty Island, and Ellis Island (Mackenzie, 1996 as cited on HRE CRP OPG, 2012).

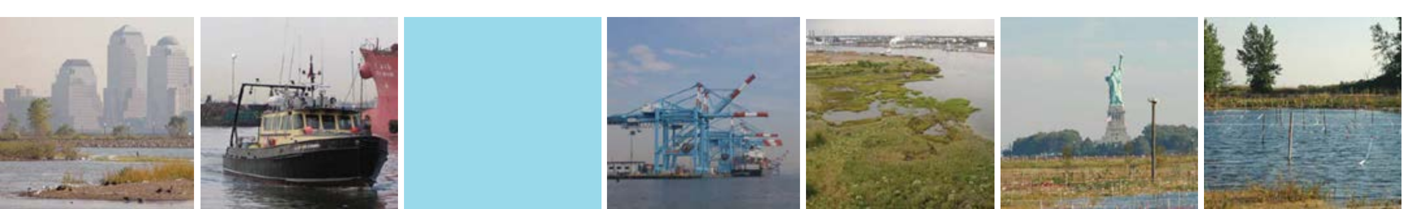
Accounts from early settlers at the time identified that great reefs of oysters were present along the shores of Brooklyn, Queens, Manhattan, and the other coastlines of the HRE. Large banks of oysters occurred in Raritan Bay, along the New Jersey coastline and as far north in the Hudson River as Ossining. In fact, several names of locations in New York Harbor are derived from oysters (e.g., Pearl Street in Manhattan, Oyster Island (now Liberty Island), etc. Early maps of the time reflect the shallow shoals and oyster banks in the HRE (Figures 2-1 and 2-2). Large oyster beds were present in the HRE until the early 20th century (Figure 2-3).

European colonization and the growth of the New York metropolis lead to the removal of a good portion of the oyster reef habitat (e.g., shallow shoals along the coast). Local laws governing the over-exploitation and degradation of oyster beds were enacted in New York City during colonial times. In 1658, the then-Dutch colony of New Netherland enacted legislation regulating the taking of oysters on Manhattan Island and in the East River. In nearby Great South Bay limits on the number of vessels engaging in the harvest of oyster were set forth in 1679 (Kirby and Miller, 2005). By the mid-18th century raw sewage was entering the waters of NY/NJ Harbor adjacent to Manhattan Island. Shoreline modifications represented a direct impact to native oyster beds.

Overharvesting of natural oyster populations was so prevalent that by the early 19th century, the oyster industry of Jamaica Bay was primarily based on stock brought in from other estuaries to the north and south of New York City, including Delaware and Chesapeake Bays (Kirby and Miller, 2005). Nonetheless, by 1880, New York City’s oyster beds, whether farmed or native, were producing 700 million oysters each year (Kurlansky, 2006).

By the early 20th century, the relationship between oyster consumption in New York City and the periodic outbreak of diseases such as cholera and typhoid was apparent. Temporary closures of New York City oyster beds occurred in 1915 and in 1921. By 1925, the Jamaica Bay oyster fishery was closed permanently. Moreover, throughout the 20th century, oysters, pollution and reduced water quality contributed to sharp declines in oyster populations. However, with the passage of the Clean Water Act and improvements in water quality over the last few decades, oysters are now becoming reestablished in the HRE. Oysters and oyster reefs perform an important ecological function by filtering our waterways to providing important habitat for numerous marine species.

Today, the quantity of oysters in the HRE is a fraction of their former numbers. Large, dense beds and reefs are no longer present. Oysters now generally appear as isolated individuals along rocks and other hard substrates in the HRE. Oysters are sessile organisms. When enough oysters survive in a concentrated area for a numbers of years, the shells of former generations remain cemented together through a biogeochemical process. After decades and centuries, these oysters and oyster beds grow vertically and laterally to form what is called an oyster reef. These reefs can provide immense ecological benefits as compared to other habitats.



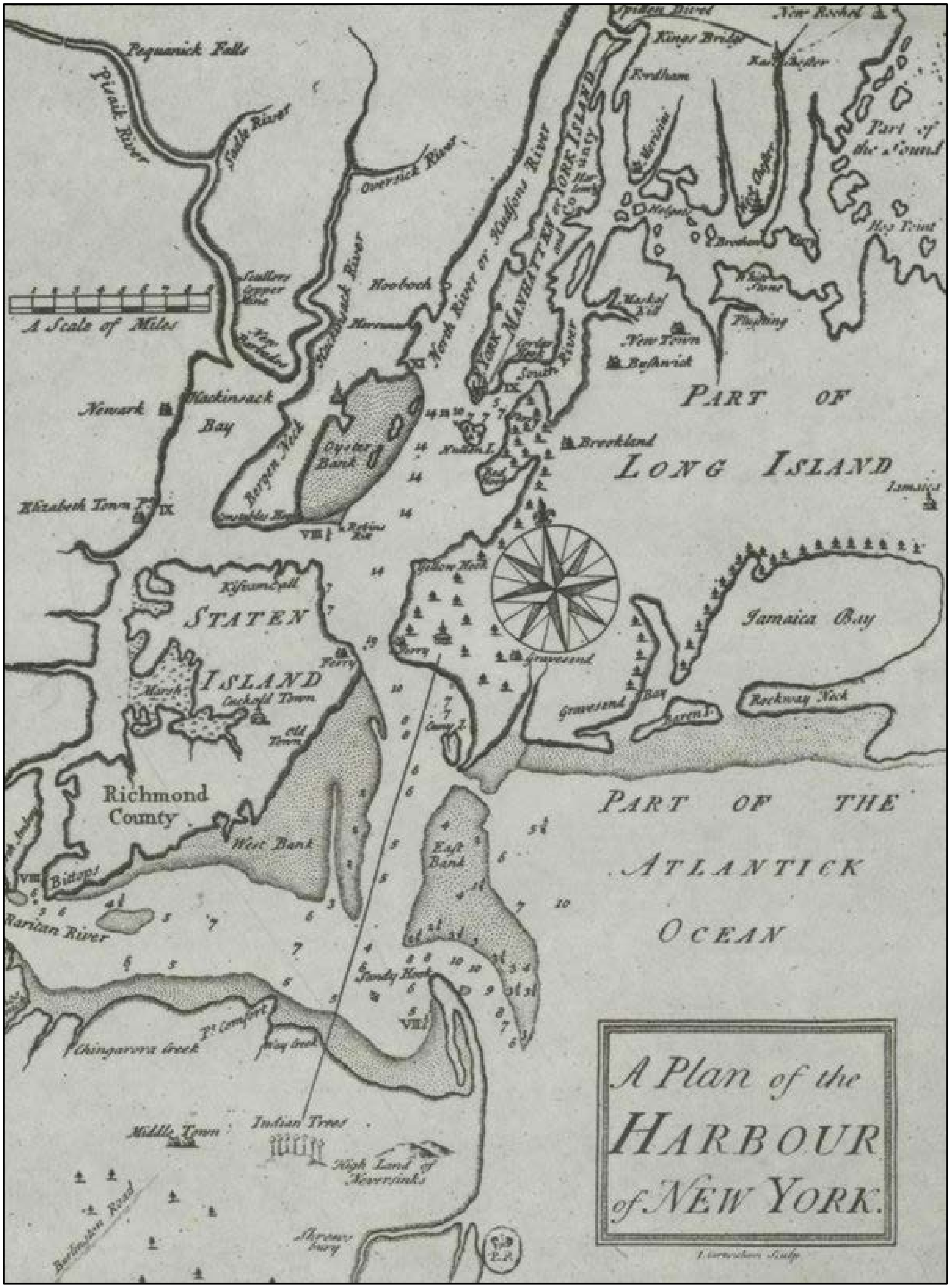


Figure 2-1: The Carwitham Plan New York Harbor – 1735

Source: Cohen and Augustyn, 2014

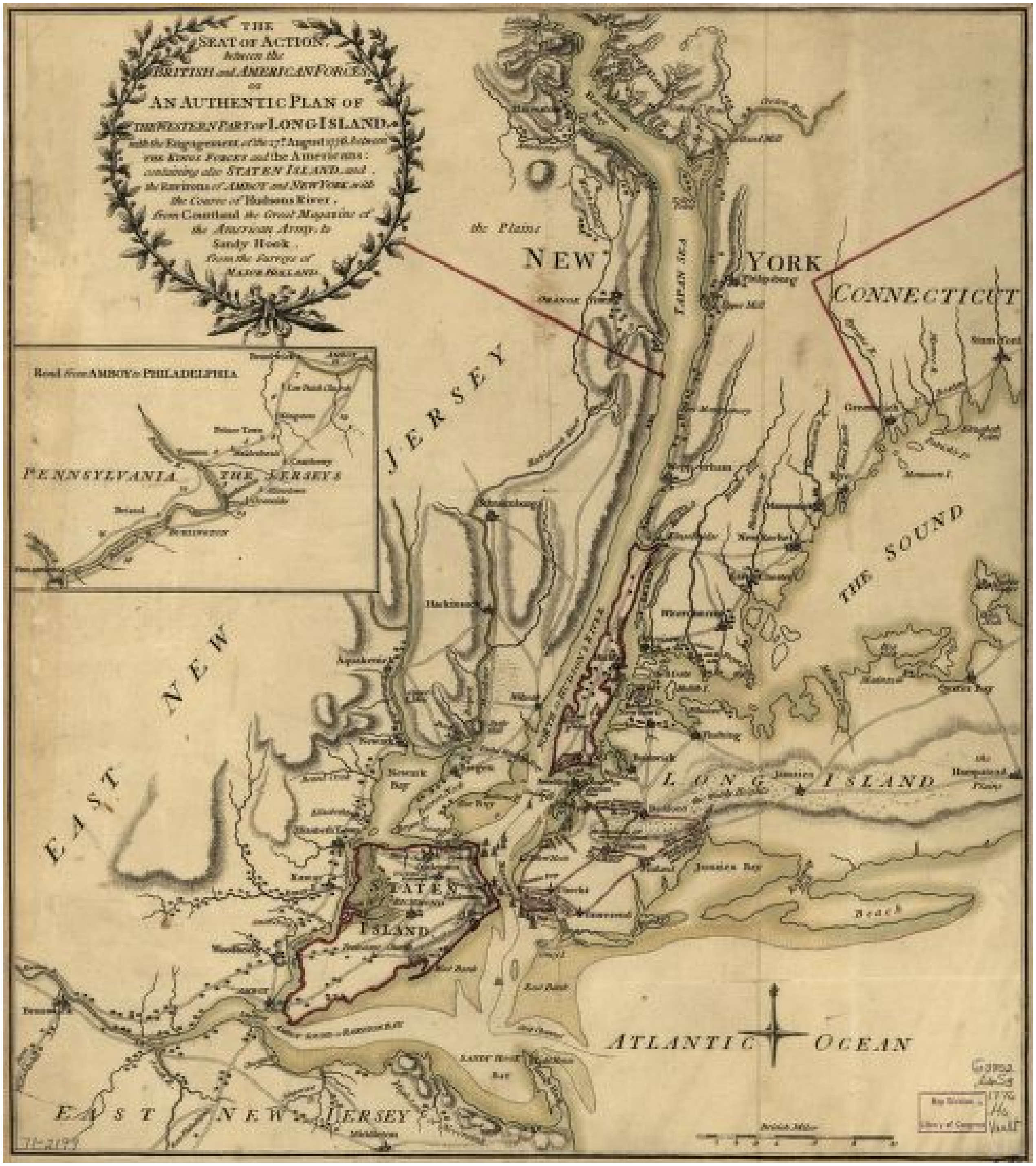


Figure 2-2: New York Harbor 1776 (Adapted from Samuel Holland, *The Seat of Action between British and American Forces*)
Source: Library of Congress, Geography and Map Division

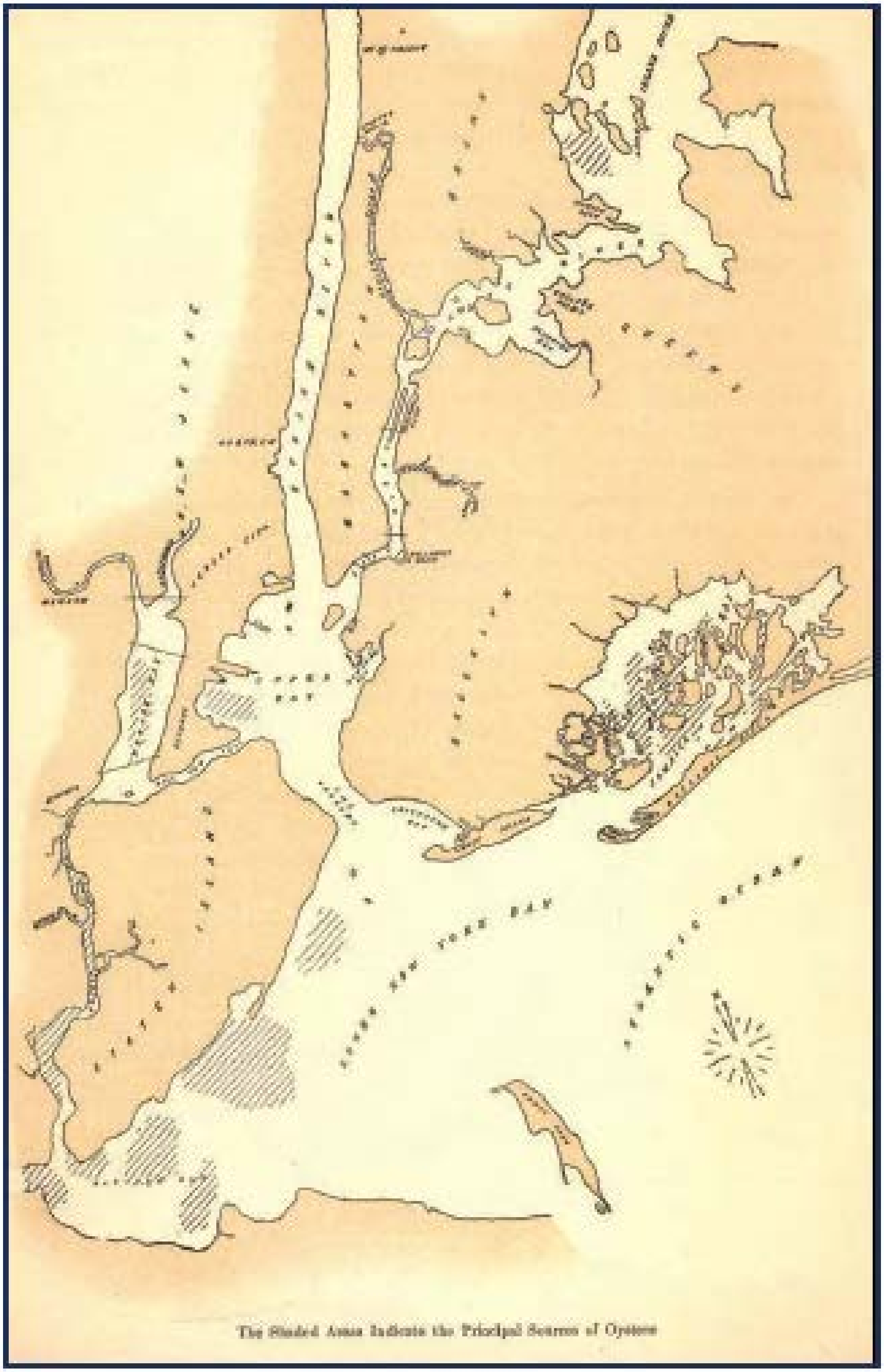


Figure 2-3: Historic Presence of Oysters (dashed lines) in the HRE.

Source: 1911 Metropolitan Sewage Commission

In order to address the historic significance of oysters in the HRE, and the oyster's decline, many organizations including the NY/NJ Baykeeper, the Urban Assembly of the New York Harbor School (Harbor School), the Hudson River Foundation and the New York City Department of Environmental Protection (NYCDEP), and others have advanced oyster restoration in the HRE.

2.1 The Billion Oyster Project

The Harbor School is a public high school located on Governors Island that has technical programs in a variety of marine fields (marine science, diving training, etc.). The Harbor School has been involved at some level in oyster restoration at all locations within the HRE. One program in particular, aquaculture, has played an important role in oyster restoration in New York Harbor. The laboratory and aquaculture facilities at the school can grow more than a million oysters per year and provide facilities, expertise, and dedicated students to support these large-scale oyster restoration efforts (BOP, 2015). The Billion Oyster Project (BOP) and Harbor School are creating new pilot projects at Bush Terminal Park and other sites throughout the Harbor.

The Harbor School serves as the production hub for the BOP, a long-term, large-scale plan to restore one (1) billion live oysters to New York Harbor over the next twenty years and in the process train thousands of young people in New York City to restore the ecology and economy of their local marine environment. A goal of the BOP is that by 2030, one (1) billion live oysters will be distributed around 100 acres of reefs, making the HRE once again the most productive waterbody in the North Atlantic and reclaiming its title as the oyster capital of the world (BOP, 2015).

The restoration process begins by collecting wild oysters from New York Harbor. Wild, or more likely, feral, oysters are used when possible to carry forward the genes that have made them successful in this challenging environment. These oysters become the broodstock for the next generation and are conditioned to spawn in the Harbor School Aquaculture classroom also known as the Harbor School Oyster Hatchery. After a three-week-long conditioning period, the oysters spawn and the resultant larvae are cultivated in the lab for another two (2) weeks. Remote setting begins when lab technicians introduce larvae to clean and cured shells that have been collected from restaurants. Larvae then begin metamorphosis, attaching to the shells; the resulting clusters of spat on shell are the building blocks of our oyster reefs. These clusters are transferred to one of several nursery sites around the harbor where they are cultivated for an additional year. Year-old oysters are then installed at reef sites.

Oyster reef construction is the shared responsibility of BOP staff and Harbor School's six (6) career and technical education (CTE) programs. Faculty and students from each program work together to prepare, install, and monitor oyster reefs and habitat restoration efforts. All of these activities, when conducted in New York Harbor, require a high level of skill. The water quality is compromised, currents are strong, visibility is limited and commercial traffic is constant. These added challenges require a great deal of expertise from Harbor School students.

Reef construction is a partnership effort. The BOP works directly with dozens of non-profit and government partners to advance oyster restoration in the harbor. Through the Oyster Restoration Research Project (ORRP) and Rebuild by Design, BOP has become a leader in the restoration world and the primary supplier of oysters for restoration. The six (6) CTE programs are described below:

- Aquaculture students, with support from BOP schools and volunteers, grow the oysters.

- Vessel operations students operate the boats needed to transport people, supplies, and equipment to reef sites, and provide surface support for diving installation and scientific monitoring.
- Marine Systems Technology students maintain the boats used by the school for oyster restoration, as well as construct metal and cement based artificial reefs infrastructure.
- Professional Diving students conduct underwater mapping once a site has been selected, and because most New York Harbor restoration sites are fully subtidal, they also play the key role in building, maintaining, and monitoring reef sites.
- Ocean Engineering students design and operate remotely operated underwater vehicles that can take video and monitor parameters in locations or conditions that are unsuitable for SCUBA divers.
- Marine Biology Research Program students have a direct role in monitoring, assessing new sites, gathering baseline data, and scientific research. They also operate *in situ* water monitoring instruments and conduct manual tests for nutrients and bacterial content, working closely with aquaculture students to better understand how water chemistry affects oyster growth in the hatchery and the harbor.

Through this work, the BOP currently produces between nine (9) and 11 million set oysters per year. With added hatchery equipment and a more advanced remote setting facility this will increase to 25 million set oysters per year.

2.2 Oyster Restoration Research Project

Oyster restoration has occurred sporadically throughout the HRE, with the most significant effort implemented under the ORRP. The ORRP, a partnership[1] of over 30 not-for-profit organizations, federal, state and city agencies, as well as citizens and scientists, has been restoring oysters and conducting research on oyster reefs in the HRE since the inception of the program in 2010, with the goal of furthering scientific understanding of oysters reintroduced into the estuary (Grizzle et al., 2012, 2013). The ORRP constructed experimental reefs at Bay Ridge Flats, Governors Island, Hastings, Soundview Park, and Staten Island in 2010 and 2011 (Grizzle et al., 2013). A key component of these restoration efforts were the contributions of the Harbor School and the BOP.

Beginning in 2010, the ORRP has been using the reefs to monitor and assess survival and growth of the oysters on the reefs; ecosystem services provided by the experimental reefs; and restoration techniques best suited for future oyster restoration efforts within the HRE (Grizzle et al., 2013). The objective of the ORRP is to determine where oysters will flourish in the HRE and develop methods best

[1] Hudson River Foundation, NY/NJ Baykeeper, the Urban Assembly New York Harbor School, U.S Army Corps of Engineers, The Port Authority of New York & New Jersey, New York Harbor Foundation, The Trust for Governors Island, The New York/New Jersey Harbor Estuary Program, The New England Interstate Water Pollution Control Commission, New York City Department of Parks and Recreation Natural Resources Group, New York City Department of Environmental Protection, U.S. Environmental Protection Agency, Region 2, New York State Department of Environmental Conservation - Hudson River Program, NOAA Restoration Center, Bay Ridge Flats Oyster Project, Rocking the Boat, Bronx River Alliance, University of New Hampshire, SUNY Stony Brook, Baruch College, CUNY, Loyola University Chicago, Brooklyn College, Wildlife Conservation Society, WCS-NOAA Lower Bronx River Partnership.

suited for scaling up to large-scale oyster reef restoration (USACE and PANYNJ, 2009). As such, this data should be consulted when planning for oyster restoration throughout the harbor.

Based in part on its experience restoring oysters in the HRE and on its research findings, the ORRP has provided recommendations for future oyster restoration within the HRE. The HRE Feasibility Study has taken the research provided by these pilot programs and has built upon them, serving as the foundation of recommendations for specific restoration techniques, site considerations, and management of existing reefs.

Some other oyster restoration efforts by other project partners, NY/NJ Baykeeper (Keyport Reef, the Navesink Reef, the Liberty Island Reef and Naval Weapon Station Earle) and NYCDEP, have carried out initial restoration studies in Sandy Hook Bay and Jamaica Bay, respectively. Although, the restored oyster reefs are relatively recent with limited data results, initial monitoring efforts have provided encouraging results as oysters have been observed to survive for four (4) seasons after placement on an artificial substrate. Efforts by the project sponsors in New York Harbor were evaluated at the feasibility level to support future restoration efforts as part of this HRE Feasibility Study.

2.3 Rebuild By Design: Living Breakwaters Project in Tottenville

The south shore of Staten Island is vulnerable to wave action and erosion, particularly on its south shore in Tottenville. Dredging and the diminishment of natural and farmed oyster reefs have left it increasingly exposed over time. Tottenville experienced severe erosion from the Hurricane Sandy, and, given the predicted impacts of sea level rise, it will continue to lose acreage in the future if no action is taken to protect the area. The Living Breakwaters project is being implemented by the New York Governor's Office of Storm Recovery and proposes offshore structures that will provide habitat and protect Staten Island's southeast shoreline (Living Breakwaters/Rebuild by Design, 2017).

As part of the schematic design phase (30 percent design) for the Living Breakwaters project, a baseline survey was conducted to characterize the fouling communities inhabiting artificial structures within the proposed project area (Perkol-Finkel and Sella, 2015). The acquired data was used to maximize the ecological performance and habitat creation opportunities of the Living Breakwaters, and provide science-based input to the design and future planned monitoring program. The report showed that manmade structures with similar materials to oyster restoration materials (e.g., rocks, etc.) are rapidly colonized by marine fauna. Some 43 different species were identified, including oysters at one (1) of the six (6) locations. Moreover, habitat complexity (e.g., variable depths, variable and increased rugosities, etc.) leads to the colonization of different types of organisms.

3. HRE Objectives and Ecosystem Benefits

3.1 HRE Objectives

As part of HRE Feasibility Study, the USACE and the PANYNJ, in partnership with the New York-New Jersey Harbor Estuary Program, prepared the Draft HRE Comprehensive Restoration Plan (CRP) (USACE and PANYNJ, 2009) and Version 1.0 (USACE, 2016) as an interim document that serves as the foundation of the feasibility study and guides ecosystem restoration efforts throughout the estuary. The CRP was intended for use by restoration practitioners as a framework that guides work towards a series of shared restoration goals, providing ecological benefits to the estuary.

To achieve the CRP program goal, “to develop a mosaic of habitats that provides society with renewed and increased benefits from the estuary environment”, the CRP identifies specific restoration targets that are collectively critical to the estuary’s ecological viability, termed target ecosystem characteristics (TECs). Each TEC defines specific goals for an important ecosystem property or feature that is of ecological and/or societal value. Based on the historical significance of oysters within the region, oyster reefs and their restoration were identified as a TEC for the HRE with a target statement and overarching goal to “establish sustainable oyster reefs at several locations.” The Oyster Reefs TEC was assigned a short-term objective of establishing 20 acres of reef habitat across several sites by 2020, and a long-term objective of establishing 2,000 acres of oyster reef habitat by 2050. The small-scale oyster restoration also meets the sub-objectives outlined in Table 3-1 and presented in Chapter 3 of the main report.

Table 3-1: Oyster TEC Target Sub-Objectives and Secondary Benefits

TEC	Target Statement/Sub-Objectives/Secondary Benefits
Oyster Reefs	**Target Statement** Establish sustainable oyster reefs at several locations.
	Sub-Objectives • Incorporate diverse habitat structure to improve feeding, breeding, and nursery grounds for fish and benthic communities.
	Secondary Benefits • Incorporate habitat structure to provide secondary coastal storm risk management benefits (e.g., wave attenuation, shoreline stability, and shoreline resiliency), serving as potential natural and nature-based features. • Improve water quality through filtration.

3.2 Ecosystem Benefits

As described in Chapter 2, oysters, oyster beds, and oyster reefs were once common throughout the HRE; however, the loss of oyster habitat due to development and the loss of oysters due to pollution have left the HRE with an abundance of silty and muddy substrates. Although these sediments do have ecological benefits, the restoration of oysters and oyster bed habitats, on the sediment substrates, would have increased ecological value per square meter and result in a marked ecological uplift and functional uplift. Moreover, climate change is predicted to lead to increased storm activity. The presence of oysters, which could ultimately lead to the formation of oyster reefs, would attenuate wave velocities. Also, the oyster shells are carbonate and their establishment and growth would sequester carbon dioxide (CO_2), a greenhouse gas that is contributing to climate change. Finally, the benefits oysters, as filter feeders, provide to water quality is invaluable. One (1) adult oyster can filter up to 50 gallons of water a day.

No model exists to adequately document the diverse benefits and value of oyster restoration to meet USACE cost-benefit analysis requirements. Other USACE districts have been seeking methods to address this. For example, USACE-Norfolk and USACE’s Engineer Research and Development Center in coordination with Virginia Marine Resource Commission are working to develop a model to estimate ecosystem benefits and services from oyster restoration as part of their common ground activities. This effort will include hydrodynamic and ecological modeling to better define the benefits of oyster restoration. However, based on existing literature, in terms of ecological and functional uplift, any successful oyster restoration effort should be expected to:

- Stabilize the shoreline to prevent erosion;
- Improve habitat quality for vegetation, invertebrates, fish;
- Improve water quality through filtration of nutrients, water turbidity, nitrogen, phosphorous, organic carbon; and
- Sequester carbon.

These benefits are explained in detail below.

3.2.1 Oyster Production

Oyster beds and reefs had been a prominent part of the HRE for thousands of years, but have recently undergone major declines, approaching ecological extinction (Beck et al., 2011) due to impacts from disease, declining water quality, and direct physical impacts to habitat. Currently, only small, localized populations of oysters are known to occur in the estuary (Lodge et al., 2015).

Healthy oyster reefs are self-sustaining and self-renewing. Shells of established oysters act as anchor points for establishment of larvae, leading to further recruitment. The mineral base of oyster reefs is a scaffold of dead shells containing void spaces filled with seawater and organic rich biodeposits (Waldbusser et al., 2013). An installed oyster bed can grow larger through recruitment of wild larvae to become a three-dimensional reef if not destroyed by direct impact, disease, or smothering by sediments. By expanding beds and reefs, oyster species are classified as ecosystem engineers, species that modify and define the surrounding environment (Grabowski and Peterson, 2007). As a reef matures, the extended topography increases rugosity of the benthic habitat, increasing benthic surface area (Hargis and Haven, 1999). Under the ideal tidal zone at 20 to 40 percent exposure, Ridge et al. (2015) found accretion rates of approximately 20 millimeters per year in constructed eastern oyster reefs in North Carolina.

3.2.2 Habitat Creation

Oysters are described as a keystone species on the Atlantic coast of the United States (Stanley and Sellers, 1986, Rothschild et al., 1994, USFWS, 2010), as a species whose presence is vital to the structure of the rest of the associated estuarine community. Oyster establishment and growth creates three-dimensional reefs providing habitat for large numbers of species, including vegetation, invertebrates, crustaceans, and fish (Kellogg et al., 2013). Oysters provide hard-bottom habitats that are found to support more productive and higher density invertebrate communities compared to soft-sediment habitats (Grizzle et al., 2013). Oyster reefs also provide complex structures that provide increased attachment points and shelter for marine species (Grabowski and Peterson, 2007). Loss of oyster habitat has been linked to reduced biological production and altered water chemistry (Rothschild et al., 1994), and shifts in estuarine communities from benthic consumer species to phytoplankton and pelagic consumers (Grabowski and Peterson, 2007).

Water filtration by bivalves can reduce phytoplankton, but can also remove diatoms, dinoflagellates, and larva and juvenile stages of other species, shifting the pelagic community (Prins and Escarvage, 2003). Larval, juvenile, and adult oysters also provide a prey resource for invertebrates and fish species, including blue and mud crabs (Stanley and Sellers, 1986).

Increased acreage of oyster reefs would also increase habitat complexity in the HRE (Lodge et al., 2015), as the habitat is rare compared to the more dominant mud flat habitat. Increased habitat complexity is associated with increased landscape diversity and production by supporting an increased number of species. And ad mentioned previously, baseline studies for the Living Breakwaters project found that manmade structures with similar materials to oyster restoration materials may rapidly colonize by marine fauna, and habitat complexity can lead to diversity of organisms (Perkol-Finkel and Sella, 2015).

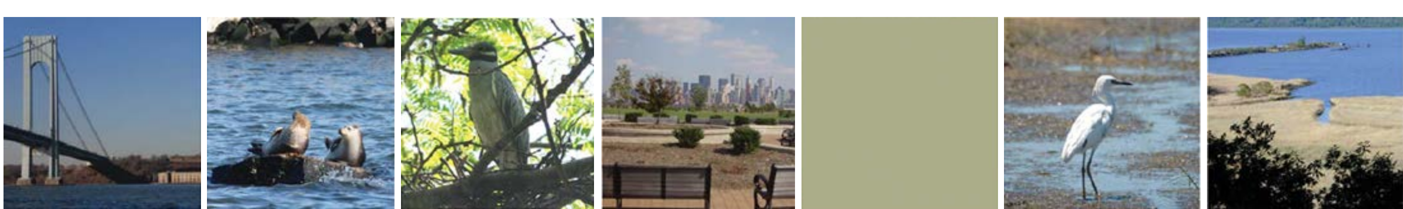
Studies examining the marine community associated with oyster beds have found oysters support a distinct invertebrate and fish community versus mud flat habitat (Zimmerman et al., 1989; Lodge et al., 2015). Changes in taxonomic richness and invertebrate density in established oyster beds versus mud flats are variable. Kellogg et al. (2013) found installed oyster beds in the mid-Atlantic supported 1,085 percent of the density of benthic invertebrates at control mud flat sites (24,585 versus 2,265 organisms per square meter). In oyster reefs on the Gulf of Mexico, Zimmerman et al. (1989) found higher densities of annelids (150 to 370 percent), crustaceans (732 to 2,264 percent), and mollusks (1,120 to 2,275 percent) versus mud flat habitats, over seasonal sampling. On balance, the increased rugosity and biomass of oyster bed/reef restoration efforts leads to a net increase in habitat usage by marine organisms in the HRE. Peterson and Kulp (2013) examined five (5) small-scale, ORRP oyster restoration sites in New York Harbor in 2011and 2012 and found that the reefs were colonized by at least 54 species of fish, crustaceans, annelids, and other organisms.

In studies in the HRE, several epibenthic (e.g., *Balanus, Crepidula*) and infaunal taxa (e.g. *Gemma, Mulinia*) were common to both mud flat and oyster bed habitats, but infauna dominated the mud flat communities while epifauna dominated the constructed oyster bed communities (Grizzle et al., 2013).

The increase in benthic community productivity associated with established oyster bed habitat is believed to improve productivity of economically important fish populations. Striped bass (*Morone saxatilis*) and Atlantic sturgeon (*Acipenser oxyrhynchus*), both high-value fish species of the HRE, utilize oyster reefs as habitat (USFWS, 2010). Zimmerman et al. (1989) found a 20-fold increase in fish density in oyster reef habitats versus mud bottom habitats in the Gulf of Mexico. Analysis of marine habitats of the southeastern United States has shown increases in commercial species due to oyster reefs. Peterson et al. (2003) estimated that 10 square meters of functional restored oyster reef can yield an additional 2.6 kilograms of fish and large mobile crustaceans per year, and Grabowski and Peterson (2007) calculated that an acre of oyster reef could result in an increase of $40,000 of value for finfish fisheries. Scyphers et al. (2011) found constructed reefs enhanced blue crab populations by 297 percent, and approximately doubled populations of other sport fish.

3.2.3 Sediment and Shoreline Stabilization

The hard structure of oyster reefs, in both intertidal areas and further offshore in deeper subtidal waters, may function to moderate wave climate and potentially reduce shoreline erosion from storm events and vessel wakes (USACE, 2016 and PANYNJ, 2009). With increased reef elevation, up thrusting reefs can divert and modify surrounding currents (Hargis and Haven, 1999). Diverted/slowed currents can lead to increased particle settlement. Large reefs (or series of smaller reefs) can act as natural wave attenuators, protecting nearby shorelines and other aquatic, tidal, and terrestrial habitats. Oyster beds/reefs seaward of salt marshes may enhance/supplement the ability of marshes to stabilize shorelines and moderate wave energy (USACE, 2016 and PANYNJ, 2009).



Experiments by Meyer et al. (1997) showed that installing oyster beds at the base of mid-Atlantic tidal wetland sites reversed soil erosion, which preserved the tidal wetland habitat. Sediment loss of 1.3 to 3.2 centimeters/year was reported in sites without oyster beds, compared to sediment gain of 2.9 to 6.3 centimeters/year. The resulting accretion of sediment consistently slowed or reversed loss of marsh vegetation. While sites without oysters showed slow declines in marsh vegetation limits, the addition of oyster clutches (groups of oysters clustered together) was shown to cause a mean net marsh advance of 0.26 meters/year (Meyers et al., 1997). Shoreline retreat has been reduced by as much as 40 percent by constructed oyster reefs (Scypher et al., 2011).

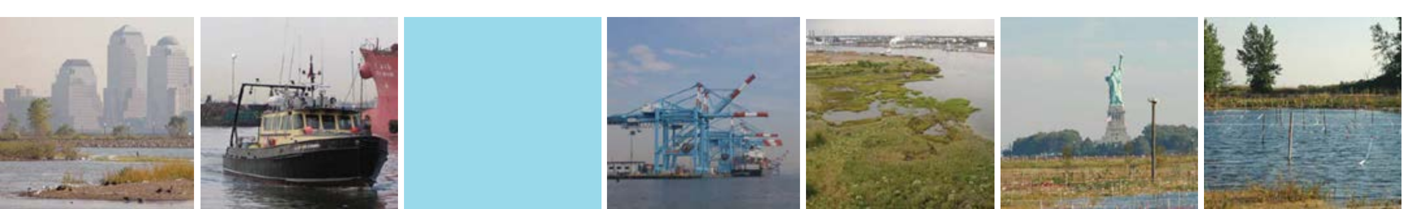
3.2.4 Water Filtration and Nutrient Sequestration

Filtration of water by oysters can improve water quality. As filter feeders, oysters filter large quantities of seston (organic particulates, including phytoplankton) from the water column. At high densities, oysters can filter large volumes of water, which can modify biogeochemical cycles and improve water quality in the surrounding environment. Filtered seston is digested and utilized for growth and maintenance of the organism, or is deposited by the organism on the sediment surface as feces or pseudofeces (undigested but compacted material) with higher nutrient concentrations than the seston (Dame and Patten, 1981; Newell et al., 2013; Hadley et al., 2005; Kellogg et al., 2013). This removal and deposition of organic material can act as a buffer against eutrophication by removing nitrogen, carbon, and phosphorous from the water column, and depositing it in the sediment, where it becomes buried.

Experimental measures of filtration rates for a single oyster vary widely, from 6.8 to 36 liters/hour (Puglisi, 2008), but data shows that more mature beds (with larger oysters at higher density) will filter larger volumes of water than immature beds (Grizzle et al., 2007). Additionally, compared to mudflats, oyster beds and reefs increase the density of benthic invertebrates, many of which are filter- and deposit-feeders, which will further reduce seston concentrations (Kellogg et al., 2013). Removal of seston reduces water turbidity, and reduces water concentrations of nitrogen, phosphorous, and organic carbon. Each of these factors is often elevated in waters adjacent to urban areas, such as the HRE. Removal of seston and nutrients from the water column eases the oxygen debt of the water. The organic molecules are digested and deposited, rather than settling to decay, which can cause an oxygen debt, and anoxia in extreme conditions.

Cressman (2003) recorded reductions of chlorophyll *a,* which is indicative of the concentration of phytoplankton, of 10 to 25 percent in mid-Atlantic intertidal creeks in North Carolina. Kotta et al. (2003), examined filter-feeding mussels in the Baltic Sea, and found that a healthy filter feeding population could clear between three (3) to 26 percent of the phytoplankton stock daily, but that rates of filtration and biodeposition vary strongly with temperature and phytoplankton density. Mesocosm experiments, an experimental tool that brings a small part of the natural environment under controlled conditions, by Prins and Escarvage (2003), showed reduction in phytoplankton of 60 percent in the water column when oysters were present. In established two-year-old oyster beds in the Hudson River Estuary, Grizzle et al. (2013) recorded consistent filtration of 20 percent of chlorophyll *a* from water passing through the oyster beds.

Reduction in phytoplankton can be due to both filtration and changes in water currents caused by the oyster reefs (Cressman, 2003; Kotta et al., 2003). Reduction of chlorophyll *a* indicates improved water clarity, which can increase light penetration, increasing growth of benthic vegetation (Grabowski and Peterson, 2007). Newell and Koch (2004) determined that even modest oyster beds could reduce water turbidity by an order of magnitude, which would benefit establishment of submerged aquatic vegetation. Kellogg et al. (2013) found that establishing oyster reefs increased standing stocks of nitrogen (N) by



95 grams/square meter, and phosphorus (P) by 15 grams/square meter. Denitrification rates (removal of N from the habitat) in established oyster beds were measured at 0.3 to 1.6 millimoles N_2-N /m^2h, and summer rates were among the highest recorded for an aquatic system.

Cressman (2003) found oyster beds may reduce fecal coliform concentrations up to 45 percent, but those results were highly variable and statistically insignificant. Observations by DePaola et al. (1990) in the Pacific Northwest observed fecal coliform concentrations of over 100 times in oysters versus water, suggesting bioaccumulation. Additionally, oyster species can be used as an effective sentinel organism to monitor contaminants. Tissue concentrations of some contaminants (e.g., Polychlorinated biphenyls, Dichloro-diphenyl-trichloroethane) in oysters can be 10 to 100 times higher than in sediment, making oysters a more effective measure of longer-term cumulative contaminant levels in water bodies than direct sampling of water or sediments (Wade et al., 1998).

Direct removal of nitrogen, specifically ammonium and total nitrogen, was reported by Dame et al. (1989) in an experimental study in South Carolina where oysters were removed from tidal creeks. Dense oyster populations in control creeks significantly reduced nitrogen concentrations in comparison to creeks without oysters, indicating a potentially important role for oysters in estuarine material and nutrient cycling. Similarly, Dame et al. (1989) reported that oysters remove particulate phosphorus at a relatively high rate, and postulated that oyster reefs may be an important mechanism in the recycling of phosphorus in estuaries. Grizzle et al. (2006) documented seston removal at natural and constructed oyster reefs in South Carolina, using in situ fluorometry and laboratory analysis of pumped water samples from above the reefs.

3.2.5 Carbon Sequestration

Oyster reefs are recognized as carbon sinks. Calcium carbonate ($CaCO_3$) produced by marine life can become incorporated into the sediment that over time can be transformed into limestone by sedimentary processes. Extensive limestone deposits today are primarily of shelly debris from marine organisms. The reef-forming habitat of many sessile invertebrates that produce $CaCO_3$ shells leads to limestone formation as new organisms settle on top of one another. Dying animals leave behind their shells, which become incorporated into the reef matrix. As more and more live animals settle on the reef, the matrix grows higher in the water column while the base gets pushed below the sediment-water interface. Once there, such shell debris is not vulnerable to dissolution by surface waters the matrix grows higher in the water column while the base gets pushed below the sediment-water interface. Once there, such shell debris is not vulnerable to dissolution by surface waters and may, over time, become marine limestone.

This is a potential benefit of great importance. Fully functioning, biogenic oyster reefs engage in a form of biosequestration, acting to store CO_2 by fixing carbon into their $CaCO_3$ shells. The fixed carbon is effectively removed from the carbon cycle and eventually fixed into limestone. Some CO_2 is released into the water during the production of $CaCO_3$ by oysters. However, the amount of carbon fixed into shell is approximately 12 percent of the shell, by weight. If this shell were to become fixed into a reef such that it is not subject to dissolution by seawater, then this carbon can become sequestered for long periods of time. If transformed into limestone, perhaps for millions of years.

This benefit can be significant. Though oysters, as animal species, are net producers of CO_2 through respiration, oysters remove CO_2 from the water column by sequestering it into the calcium carbonate shells they secrete as protection. The shells are insoluble and, thus, the aqueous carbon concentration is reduced (Grabowski and Peterson 2007, Hall and Dehon 2009, Dehon 2010, Smith 2012, USFWS

2012). Waldbusser et al. (2011) estimated calcification rates of two (2) milligrams $CaCO_3$ per gram of live mass per day under ideal conditions. Dehon (2010) found that installed 45-kilogram concrete rings would facilitate enough oyster recruitment to could absorb 5.7 kilograms of carbon over a 30-month period. The carbon sequestration potential of oyster reef restoration can be projected. Schulte et al. (2009a) determined that high-relief oyster reefs had mean annual accretion rates of 10.7 liters/square meter (L/m^2). To correct for the fact that this measurement is of water displaced by the shells, not the total volume taken up by the shells in a bushel basket, this number is multiplied by three (3), providing an accretion rate of 32 L/m^2 over a 3-year period. This shell could be ultimately dissolved by the water, or alternatively incorporated into the reef matrix. Field observations of intact, dead oyster shells below the living veneer of the reef suggests the bulk of this shell becomes incorporated into the anoxic portion of the reef base over time.

To illustrate the potential of oyster reefs to sequester carbon, it is assumed here that 25 percent of the shell dissolves or is degraded by other erosive forces. As a result, the annual accretion rate of shell is reduced to 8.02 L/m^2/year. For example, restoration of 100 acres of oyster reef could produce 3.24 million liters of reef matrix shell/year. A cubic yard of shell is equivalent to 765 liters, and weighs 460 kilograms, resulting in 5,860 metric tons of reef matrix shell per year. At approximately 12 percent carbon by weight, 703 metric tons carbon per year (C/yr) is sequestered by this reef. For comparison, an average American (2007 data) produces 5.2 metric tons C/yr. The carbon sequestration potential of oyster reefs is comparable other practices being considered to reduce the buildup of greenhouse gases in the atmosphere, such as reforestation.

4. Site and Alternative Selection

Select sites throughout the HRE were evaluated for potential success as small-scale oyster reef restoration opportunities. Building on the past work of the aforementioned organizations, five (5) sites — Soundview Park, Bush Terminal, Governors Island, Jamaica Bay, and Naval Weapons Station (NWS) Earle — were selected as candidates for future small-scale oyster restoration efforts (Figure 4-1). Originally, a site downstream of the Tappan Zee Bridge on the Lower Hudson River was evaluated and was later dropped due to lack of sponsor support.

Site locations and alternatives were evaluated for each site using the information gathered from prior restoration efforts, analyzing site conditions based on readily available data (e.g., water quality, bathymetry, hydrodynamics, etc.), considerations and constraints for oysters and locations, and tested restoration techniques. The conceptual plans identify potential restoration techniques and constraints to oyster reef restoration at each site.

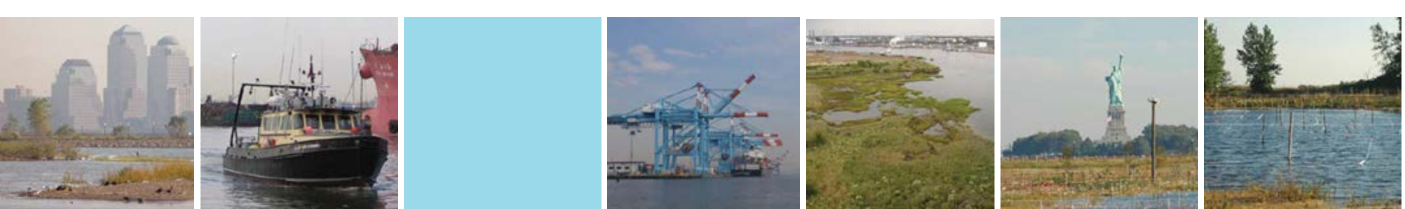


Figure 4-1: Evaluated Proposed Restoration Sites.

4.1 New York Harbor Water Quality

For over 100 years, NYCDEP has conducted a water quality monitoring program throughout New York Harbor. Water quality samples and measurements have been collected annually near Governors Island by NYCDEP. For 2011, the Inner Harbor region (water north of the Verrazano Bridge) was assigned a water classification of “I”. This score indicates that the waters of the Inner Harbor are suitable for fishing and boating, but not bathing. It also indicates that dissolved oxygen readings were never measured below 5.0 milligrams/liter (NYCDEP, 2012).

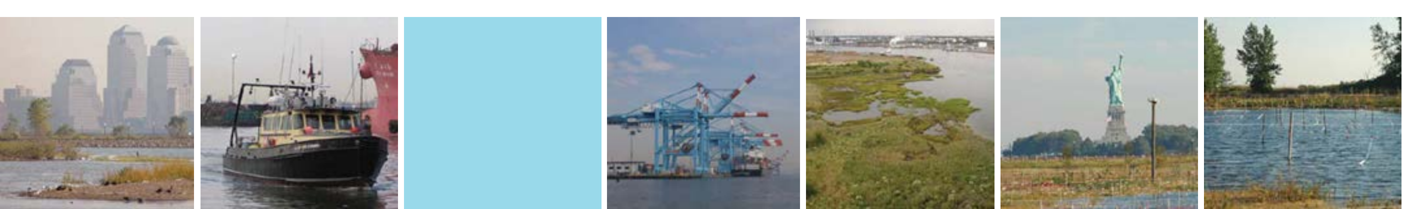
The water quality for the Inner Harbor region is based on the results for individual sampling stations. There are approximately 80 stations around the harbor (Figure 4-2). The 2011 site-specific data for the restoration locations are presented in Table 4-1. The water quality parameters measured at these locations are suitable for oysters.

Broadly speaking, oysters need the following water quality parameter ranges to survive:

- Salinity: Tolerable salinity range varies by life stage. Larvae need 10 to 27.5 parts per thousand (ppt)[2]. Adults can tolerate five (5) to 40 ppt, but optimum range is 14 to 28 ppt[1]. Adults have little growth below five (5) to 10 ppt[1] (NOAA, 2016).
- Temperature: Optimal temperature for larvae is 68 to 90.5 degrees Fahrenheit (°F) and for adults 68 to 86°F. Adults can tolerate 35.6 to 96.8°F and up to 120.2°F for short periods. Larvae can grow in water as cold as 63.5°F (NOAA, 2016).
- pH: Larvae are the most sensitive to pH. The tolerable pH range is 6.75 to 8.75 (NOAA, 2016).
- Dissolved oxygen: Oysters are more tolerant of low dissolved oxygen than are many bay animals. Preferred habitat is at >20 percent saturation, which corresponds to 2.3 milligrams/liter at 50°F and 1.5 milligrams/liter at 86°F (NOAA, 2016).

Oyster physiological requirements are discussed in further detail in Section 4.2.2: General Oyster Restoration Considerations.

[2] ppt originally expressed as practical salinity units (psu). For purposes of consistency throughout the document, all salinities expressed as ppt.



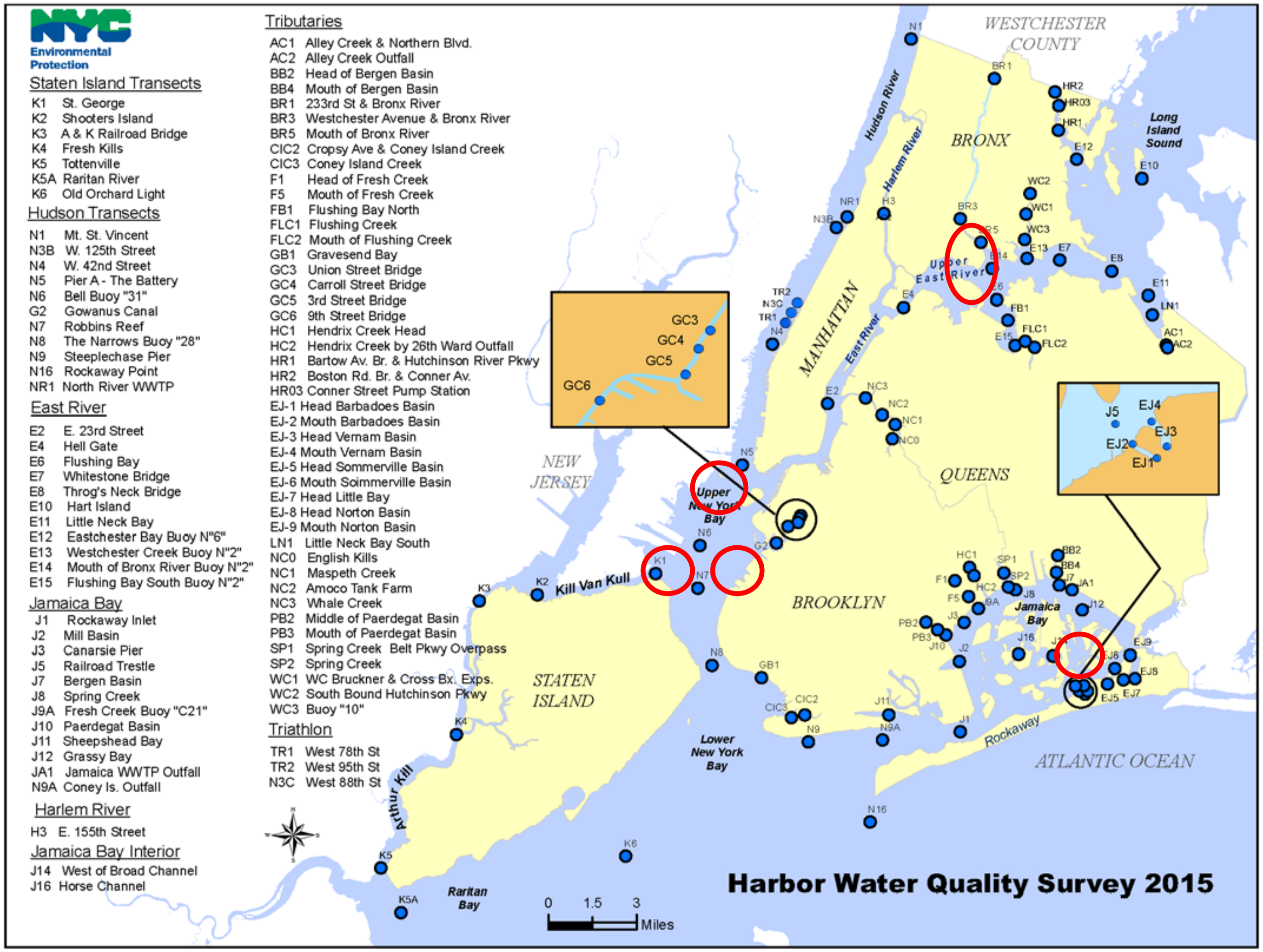


Figure 4-2: NYCDEP Harbor Water Quality Monitoring Stations

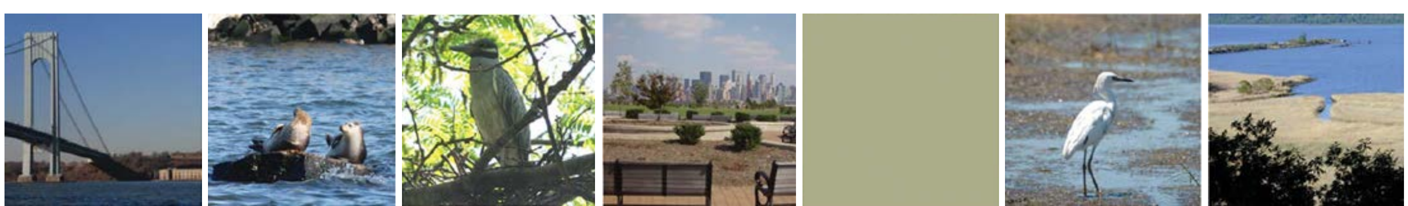
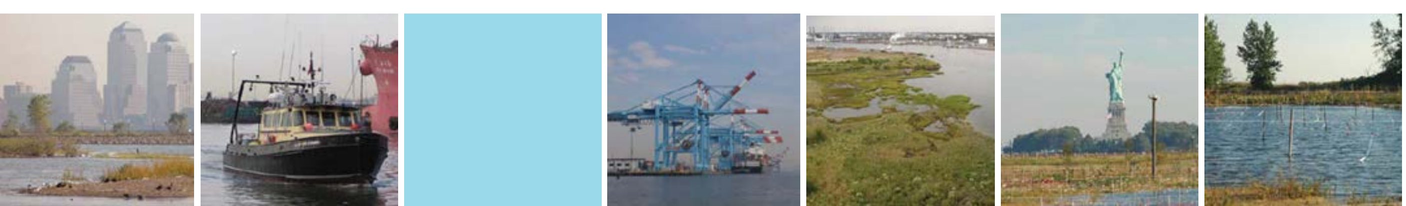


Table 4-1: NYCDEP 2011 Monitoring Results for Locations BR5, E14, G2, J5, J12, N5, and N6

Restoration Site	Related NYSDEP Sampling Location	Date (2011)	Depth (ft)		Salinity (ppt)[3]		O_2 (mg/L)		pH		TSS (mg/L)		Chl a (ug/L)	
			Top	Bot	Top	Bot	Top	Bot	Top	Bot	Top	Bot	Top	Bot
Soundview	BR5	5/16 - 12/13	3.0 - 5.0	8.0 - 24.0	13.2 - 23.5	21.7 - 24.0	3.2 - 11.4	3.0 - 8.2	7.7 - 8.9	7.5 - 8.9	<2.0 - 22.0	4.0 - 16.0	1.1 - 141.0	NS
	E14	1/10 - 12/13	3.0 - 4.0	11.0 - 24.0	18.2 - 24.9	20.3 - 25.1	3.2 - 12.1	3.1 - 12.0	7.4 - 9.5	7.4 - 9.5	4.0 - 26.0	6.0 - 30.0	0.9 - 50.4	NS
Bush Terminal	G2	2/8 - 12/19	3.0 - 4.0	24.0 - 30.0	6.5 - 24.1	16.8 - 26.4	4.0 - 16.0	3.7 - 11.5	7.6 - 9.2	7.6 - 9.1	2.0 - 26.0	2.0 - 26.0	0.9 - 48.9	NS
Jamaica Bay	J5	1/11-10/5	3.0 - 3.0	16.0 - 23.0	21.0-26.7	21.0-27.5	4.5-14.3	2.8-14.92	7.8-9.6	7.8 - 9.7	2.0 - 28.0	4.0 - 30.0	1.7-129.0	NS
	J12	1/11 - 11/26	3.0 - 3.0	31.0 - 37.0	20.1 - 26.4	20.9 - 26.9	3.8 - 15.0	0.1 - 13.8	7.9 - 9.6	7.5 - 9.6	4.0 - 24.0	2.0 - 26.0	5.6 - 135.4	NS
Governors Island	N5	1/10 - 12/13	3.0 - 4.0	41.0 - 51.0	0.6 - 22.7	12.2 - 28.6	4.9 - 12.9	4.6 - 10.9	7.6 - 9.2	7.6 - 9.2	2.0 - 56.0	4.0 - 143.0	0.8 - 16.3	NS
	N6	2/8 - 12/9	3.0 - 4.0	46.0 - 56.0	1.9 - 23.9	21.0 - 29.7	4.8 - 11.3	4.9 - 10.1	7.6 - 9.2	7.8 - 9.2	2.0 - 28.0	2.0 - 34.0	0.6 - 14.8	NS

[3] Data originally identified as psu, converted to ppt for consistency purposes for this report. All other salinities are identified as PPT.



4.2 Oyster Restoration: Constraints and Techniques

4.2.1 Constraints

Conducting restoration projects in densely urbanized areas such as the HRE presents a unique set of challenges, including issues related to contaminated substrates, degraded water quality, land-use conflicts, and habitat trade-offs.

4.2.1.1 Water Quality Issues

Although water quality within the HRE has improved markedly in many areas, seasonal and localized water quality impairments still exist. These impairments may include, but are not limited to, seasonal stratification and episodic anoxia/hypoxia. Shallow, poorly flushed water bodies in densely populated areas may be subjected to eutrophication as a result of nutrient loading from wastewater treatment facilities and combined sewer outfalls. This often leads to seasonal phytoplankton and macroalgae (e.g., *Ulva lactuca*) blooms. As the phytoplankton/algal biomass decays, water column dissolved oxygen concentration is reduced, nitrogen and phosphorus is released, and anoxic, organic sediments accumulate in the affected areas.

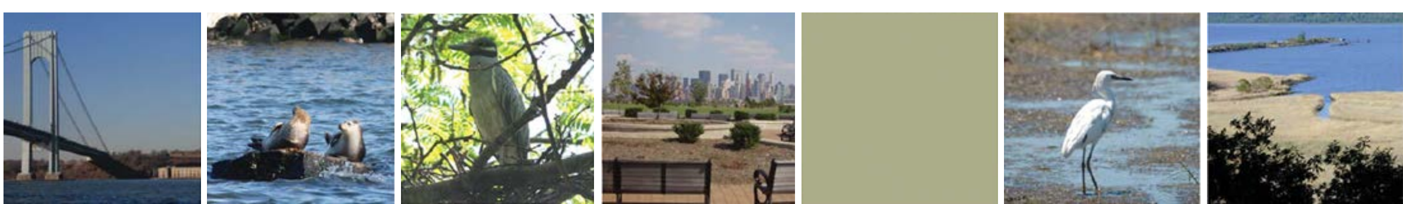
4.2.1.2 Disease and Predation

American oysters are subject to a number of bacterial, viral and protozoan diseases, including the bacteria *Vibrio* and *Pseudomonas*, both of which have been shown to kill oysters under laboratory conditions (Stanley and Sellers, 1986). However, infection by two (2) protozoan parasites, *Perkinsus marinus*, also known as dermo, and *Haplosporidium nelsoni*, also known as multinucleated sphere unknown, (MSX), has caused widespread damage to oyster populations throughout much of the species' range along the Atlantic and Gulf coasts. Dermo was first documented in the 1940s in the Gulf of Mexico. Since 1991, this parasite has been found in oysters from Connecticut, New York, Massachusetts, and Maine (Ford and Tripp, 1996). Dermo is transmitted from dead and dying oysters releasing infective stages of the parasite back into the water column. The initial site of infection is the gill, but the parasite principally attacks the digestive system (Burreson and Calvo, 1996; Chu, 1996). Dermo is most prevalent in conditions of high temperature and high salinity, proliferating rapidly above 20°C and in salinities above 12 to 15 ppt. Dermo-infected oysters exhibit a reduction in growth and reduced reproductive capacity (Paynter, 1996; Paynter and Burreson, 1991).

MSX was first documented in 1957 in Delaware Bay and is now known to infect oysters from Maine to Florida (Ford and Tripp, 1996). At the time of its discovery, the specific disease agent was undescribed, but upon discovery of the spore-forming stage of the parasite in 1966 it was named *Minchinia nelsoni*, and subsequently re-named *Haplosporidium nelsoni* in 1980. The inability of oysters to transmit *H. nelsoni* under laboratory settings strongly suggests the possibility of an intermediate host. MSX first infects the gill, subsequently entering the blood stream to infect other tissues. MSX infection interferes with respiration and feeding, eventually resulting in death. Temperature and salinity play an important role in regulating MSX, with most infections acquired above 20°C and at salinities above 15 ppt (Ford, 1985; Ford and Haskin, 1982, 1987, 1988).

4.2.1.3 Contaminated Substrates

During the Industrial Era, the HRE was subject to the discharge of numerous contaminants that typically include heavy metals, polychlorinated biphenyls, polyaromatic hydrocarbons (PAHs), and



dioxin. These contaminants can degrade an ecosystem by reducing available habitat, lowering biomass, and other factors. Contamination can also greatly reduce the biological and recreational value of the HRE study area through fish consumption advisories, human health risks, and economic impacts through restrictions of commercially harvested species.

The states of New York and New Jersey believe that oyster restoration in prohibited or specially restricted waters creates an attractive nuisance. Both states generally believe that the ecological benefits of having sustainable populations in these waters are outweighed by the potential health risks of consuming poached oysters. There are potential economic repercussions that the consumption of tainted oysters may affect the rest of the shellfish industry. In the case of both oysters and lobsters, concerns exist that fishing could lead to consumption of shellfish that are not safe to eat. This could result in the need to restrict harvesting or fishing in these areas, which would lead to greater enforcement needs and increased costs to the regulatory agencies. Other potential policy issues stemming from creation of reefs would be considered under both the habitat exchange and placement of fill sections. The New York State Department of Environmental Conservation (NYSDEC), NJDEP, NYSDOS, and USACE have jurisdiction in regulating these types of activities.

The NJDEP does not recommend restoration projects for commercially harvested shellfish in prohibited or restricted waters (i.e. closed to shellfishing). In 2010, the NJDEP banned research-related gardening of commercial shellfish species in waters classified as contaminated in order to minimize the risks of illegally harvested or poached shellfish (NY/NJ Baykeeper, 2016). Because they are concerned with illegal harvest of oysters and associated health risks, the NJDEP and NYSDEC recommend considering the restoration of shellfish species that have no commercial value in these waters. Presently efforts are being made to coordinate oyster reef restoration activities within the existing states' permitting framework. While the goals of the regulations are quite defensible (i.e., avoiding public harm with respect to navigation or the environment, protecting public health, etc.), alternative mechanisms for achieving them are being considered.

Contaminant concentrations measured at the specific sites were identified and outlined in the Engineering Appendix (Appendix D).

4.2.2 General Oyster Restoration Considerations

As part of the CRP, key points were identified in the selection for restoration measures proposed at future the candidate sites. These key points are used to evaluate the candidate sites in terms of whether oyster restoration at each of the sites is expected to be successful and, in concert with anticipated relative cost of the restoration techniques to be employed at each of the sites.

4.2.2.1 Site Selection

An important consideration of site selection was to choose sites that:

- Are compatible with local geography, land-use patterns, and navigation features within the study area.
- Avoid or minimize negative impacts to existing aquatic/terrestrial habitats in the vicinity of the restoration area, including plants and animals, and historic/cultural resources.
- Address the concerns and desires of the local community, including educational institutions, private advocacy groups, municipalities and local community boards. Cooperation with these and other stakeholder groups will be essential for the development of a positive public perception of oyster reef restoration in the HRE.

- Are consistent with federal, state and local regulatory agency requirements and policies.

After consideration of the information presented in the previous four (4) bullets, site selection should be a rigorous process. Key items to address in site selection are the following:

- Bathymetry: Existing bathymetric datasets can be used to identify areas that fall within the range suitable for oyster reef formation. Bathymetric design features for oyster reefs that have been constructed within the HRE recently place the height of constructed reefs at least one (1) foot below mean low water; within ranges to provide adequate tidal flow and sufficient water column dissolved oxygen, and at elevations that help to prevent poaching (i.e., as deep as possible but well within range of oyster life requirements).
- Salinity: Oysters are tolerant of a range of salinities; however growth is stunted at sustained salinities below 7.5 ppt. Oysters will not feed or grow in waters of less than five (5) ppt or above 32 ppt. Normal growth requires at least 10 ppt. An optimal salinity range of 12 to 27 ppt will ensure adequate production of gametes and promote rapid larval growth and settlement, while maintaining protection from oyster predators that are common in higher salinity waters, and disease. Autumn salinity measurements can be used to determine maximum values within a proposed reef construction area and spring measurements can be used to determine minimum values.

In addition, other criteria identified in the guide to consider for site selection are the following:

- Existing shellfish beds: Datasets of existing shellfish resources (e.g., clam beds, etc.) could be used to identify areas within the HRE that would benefit the most from oyster restoration.
- Existing navigation channels: Oyster reef restoration projects should not occur in the immediate proximity of navigation channels due to the disturbance from wake effects and sediment re-suspension.
- Tidal hydrodynamics: Tidal circulation patterns determine whether the area may act as a source or sink for larvae, help reduce or eliminate episodic hypoxia, and gently scour fine silt may foul an oyster reef in quiescent waters. Areas with higher current flows promote food delivery and waste removal. Hydrodynamic and/or particle transport models may be used to identify appropriate locations for constructed oyster reefs, particularly with regard to the potential movements and settlement patterns of oyster larvae.
- Attractive nuisance potential: Ideally, areas where illegal harvesting of oysters from constructed reefs can be deterred or prevented should be considered.
- Maintenance and monitoring: Constructed oyster reefs should be readily accessible to perform maintenance and monitoring activities, or to setup staging areas during initial reef construction activities or subsequent maintenance.
- Height: Optimal reef height will vary among geographic locations, as a function of tidal range and climate factors. It is generally believed that natural oyster reefs in the HRE did not achieve the considerable degree of vertical relief seen in estuaries to the south, such as Delaware Bay or Chesapeake Bay (K. Tammi, Roger Williams Univ., personal communication as cited in the 2009 CRP); rather, they formed beds of low to moderate relief. Thus, constructed reef designs in the HRE should take regional variability in height and growth form into consideration. Lenihan et al. (1999) found that oysters restricted to low-flow environment (e.g., at the base of reefs or in sheltered environments) were more susceptible to infection due to generally poor physiological conditions and recommended that restoration practitioners take flow speed and height into

consideration in reef designs so as to elevate oysters above the low-flow benthic boundary layer. An added benefit of locating oysters above the benthic boundary layer is reduced sedimentation and greater food availability/quality.

- Sedimentation: Excess deposition of sediment, either gradually or in pulses due to stochastic natural or anthropogenic effects, is detrimental to the growth and survival of oyster reefs. The siting and design process for constructed oyster reefs should account for identification of local sediment sources, the probability of periodic sediment re-suspension events (e.g., deep draft vessel passage or maintenance dredging) in the vicinity of the proposed reef. Pre-construction analyses of the rate and magnitude of sediment deposition may be necessary to assure that the rate of sedimentation in the vicinity of a proposed oyster reef will be less than the anticipated rate of vertical accretion.

4.2.2.2 Stock and Substrate Selection

When selecting a broodstock for placement, it is important that the stock matches salinities and diseases present at specific geographical locations. Thus, having a local aquaculture and laboratory facilities that develop larval oysters for spat, and subsequent placement at local sites, would be an important component of future restoration efforts.

In order to reach maturity, spat need to attach to a solid surface. While rocks and other underwater debris are suitable for oyster growth, spat have higher success rates when attached to other oyster shells. Using carefully engineered aquaculture procedures, spat are cultured in specialized tanks and allowed to set onto oyster shells, or cultch. In a few months the spat, numbering about a dozen per shell, will have grown into tiny oysters no larger than a fingernail.

4.2.3 Restoration Techniques

Oyster restoration can be accomplished by a variety of different methods, which could vary from suspending live oysters in a mesh net from a pier to creating an oyster bed where tons of crushed shell and rock are placed on the sea bed and then planted with live oysters. The primary restoration techniques employed methods found to be effective in previous studies, including those conducted by the ORRP, the Harbor School, and BOP. This chapter identifies the various restoration techniques that will be considered for the development of alternatives at each site.

4.2.3.1 Spat on Shell

Spat on shell (SoS) (Figure 4-3) is produced through aquaculture using local broodstock (adult oysters) by the Harbor School. SoS is constructed by placing a base of eight (8)- to 12-inch sized rock/rubble on the bottom, followed by a veneer layer of approximately two (2) inches of mollusk shell on top of the base material. The top layer consists of the oyster spat settled on shell. SoS oyster beds constructed in deeper waters would require the use of a barge and crane. This type of construction can be

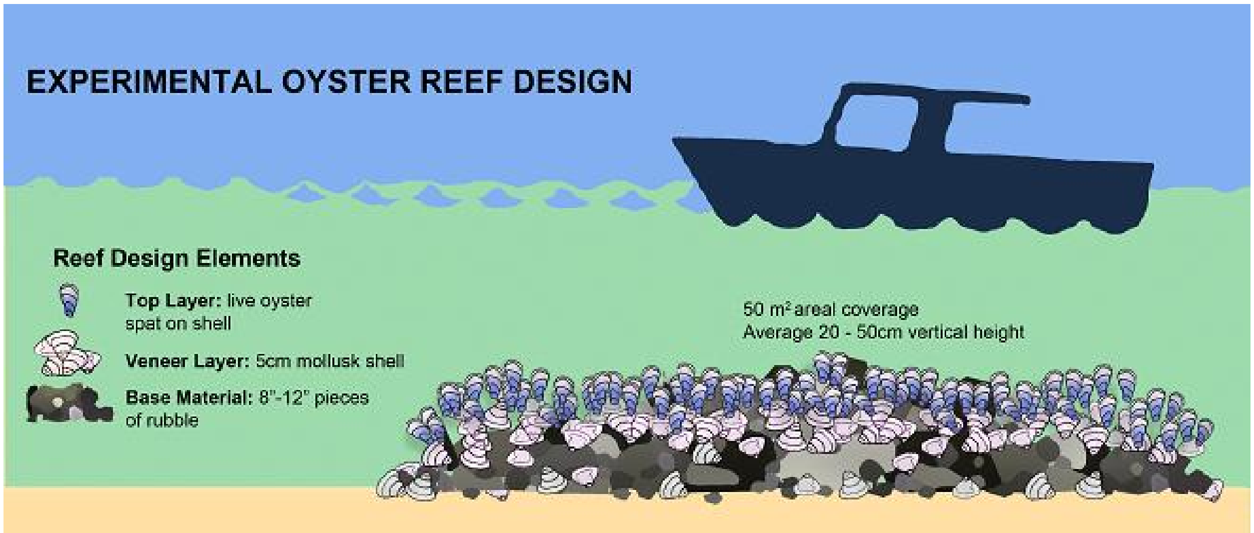


Figure 4-3 : Schematic Experimental Oyster Design - Spat on Shell

accomplished from land; however, it requires an intensive amount of manpower. SoS is suitable for use in lower energy environments with firm substrate, or in combination with other restoration techniques that adequately shelter the SoS from strong currents and smothering by sediments, and prevent its sinking into loose substrate.

4.2.3.2 Reef Balls

A reef ball (Photo 1) is a half dome concrete structure. Within the top and surface of the structure, holes are placed allowing the water to flow through the structure and allows for fish and other aquatic creatures to inhabit the structures interior. Although used successfully to construct subtidal and intertidal reefs (USACE and PANYNJ, 2016), reef balls are better used in subtidal areas where the water depth is at least 10 feet above them to avoid damage from waves and currents (Hardy, 2011).

Photo 1: Reef Ball

NYCDEP, in collaboration with Cornell University's Cooperative Extension Service, established a demonstration oyster reef comprising an array of 12 pre-fabricated concrete reef balls that were remote-set with oysters and placed in Gerritsen Creek, Jamaica Bay (USACE and PANYNJ, 2016).

4.2.3.3 Oyster Condos

The Harbor School at Governors Island, New York, have designed an oyster condo (Photo 2) which are triangular structures constructed with welded rebar designed to hold gabion bags of oysters upright in the water column. Because oyster condos are stable structures, they are ideally suited for marine environments with strong currents. The triangular structure mimics the rugosity, or three dimensionality, of an oyster reef, providing additional habitat opportunities for marine fauna.

Photo 2: Oyster Condo

4.2.3.4 Oyster Castles

Oyster castles (Photo 3) are constructed with interlocking concrete blocks usually about 30 pounds each. The blocks, which are partially hollow are interlocking and stacked like a brick wall. An oyster castle is designed to be instant habitat for oyster spat and growth. Oyster castle blocks are made of shell, limestone and concrete. The 12-inch by 8-inch square blocks are shaped in a tiered-structure that can interlock with each other to resist constant wave motion. It has been determined from previous studies that, in addition to providing immediate habitat for oyster growth, the placement of the castles fosters sedimentation behind them and encourages the regrowth of natural vegetation. This provides a shoreline erosion prevention benefit that is a mix of engineering and nature.

Photo 3: Oyster Castle

Faherty (2011) restored an oyster reef on tidal flats off Lieutenant Island, in Wellfleet, Massachusetts. The study monitored the growth and survival of natural-set oysters to determine which of three (3) treatments — oyster castles, reef balls, and shell cultch (comprising surf clam and oyster shells) — worked best for catching and growing wild oysters. Oyster castles were the only substrate to maintain their structural integrity and to show a net increase in their oyster population each year (Faherty, 2011). Oyster castles also surpassed the other two (2) experimental treatments in terms of oyster abundance, density, and average size.

4.2.3.5 Wire Cages / Gabions

Photo 4: Wire Cages/Gabions

Wire cages (Photo 4) are filled with oyster shells pre-seeded with spat. The cages are then left on the bottom. In 2014, a gabion block restoration pilot effort was designed to address the erosion of SoS observed during the ORRP Phase 1 study and the first year data from the ORRP one-acre oyster reef restoration effort at the confluence of the East River and Bronx River, off Soundview Park (Lodge et al., 2015). In the later part of the Soundview effort, a new design was tested consisting of one (1) cubic-foot wire mesh blocks (small gabions), filled with oyster shell and secured together to form two (2) perimeter reefs, into which two-month age class SoS from the New York Harbor School was placed. In addition, half of the wire mesh blocks filled with oyster shell was also set with juvenile (two-year age class) oyster SoS, also produced by the Harbor School. Both studies were conducted in shallow waters, typically less than four (4) feet in depth.

4.2.3.6 Super Trays

Photo 5: Tray for Hanging Super Tray

Super trays (Photo 5) are square or rectangular, high-density polyethylene crates that allow for the placement of oysters vertically in the water column. To restore oysters, as opposed to constructing oyster reefs, sets of interlocking super trays can be suspended from a structure or a float, allowing water to circulate and flow through the trays and disperse veliger (larvae) to the water column and, ultimately, to nearby constructed reefs or beds, or other areas of hard substrate.

4.2.3.7 Anchored Bags

Anchored bags (Photo 6) are mesh bag filled with oysters placed on the bottom historically used in aquaculture and shoreline stabilization efforts. In intertidal or shallow areas, the reef materials are deployed into patches and mounds in the estuarine waters and along shorelines. Reef materials are bagged and stacked to form a protective reef along the shoreline. In addition, the shell and marl can be deployed with shallow draft barges into mounds and interconnected patch reefs. NYCDEP, in collaboration with Cornell University's Cooperative Extension Service, constructed a 150-square-foot demonstration oyster reef from SoS over shell bags at Dubos Point, Jamaica Bay (USACE,PANYNJ 2016).

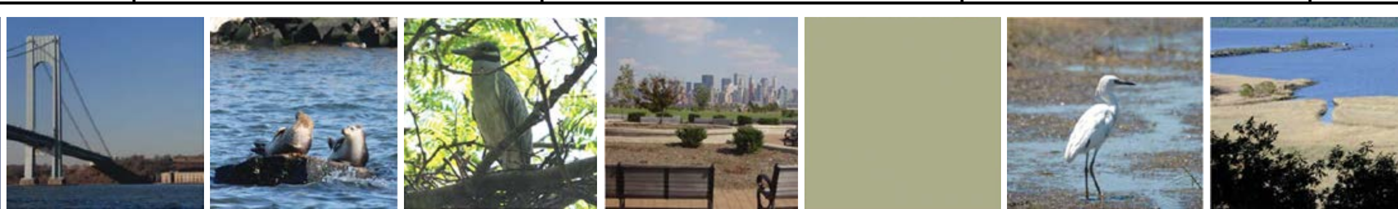
Photo 6: Anchored Bags

4.2.3.8 Summary of Oyster Restoration Techniques

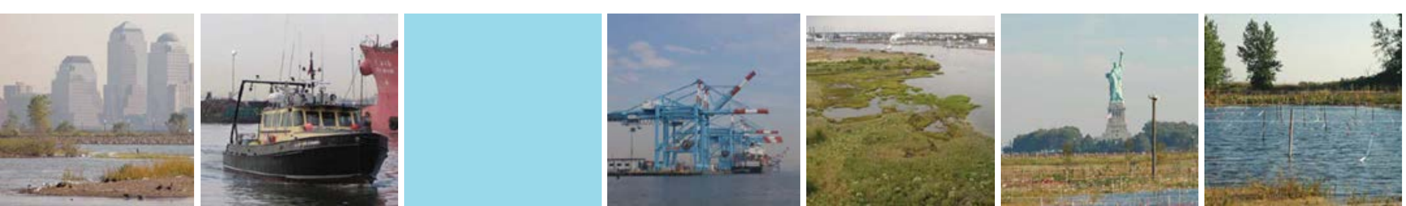
Based on the information presented above, Table 4-2 identifies the best location, pros and cons, and installation effort of each restoration technique.

Table 4-2: Summary of Oyster Restoration Techniques

Restoration Technique	Best Location for Installation	Pro	Con	Installation Effort
Spat on Shell Oyster Beds	• Lower energy environments with firm substrate. • Recommended for: ✓ Bush Terminal ✓ Soundview Park ✓ NWS Earle	• Oysters prefer to attach to other oyster shells. • Best replicates normal settlement and growth most naturally.	• Reef bases can be washed away or smothered in sediments or algae.	• Placement off shore in large areas would require barges and cranes.
Reef Balls	• Firm substrate that can support the 40-pound ball without sinking. • Best used in water depths where wave action is less likely to damage structures. • Recommended for: ✓ NWS Earle	• Can be easily constructed with concrete or a mix of concrete and oyster shells. • Less likely to be adversely affected by sedimentation and anoxic/hypoxic conditions.	• Due to the hollow design with holes in the structure's surface, if poorly constructed could break apart.	• Would likely require boats and divers as they should be placed well below the surf zone.
Oyster Condos	• Firm substrate that can support the 100- to 300-pound condos, without sinking. • Recommended for: ✓ Governors Island ✓ Bush Terminal	• Stable. • Interlocking system that provides good vertical habitat.	• Potential hazard to watercraft.	• Requires boats and divers in waters over four (4) feet at low tide. • Shallower areas could be accessed from land and wading to desired site.
Oyster Castles	• Firm substrate that can support the approximately 30-pound blocks without sinking.	• Stable. • Interlocking system that provides good vertical habitat. • Less likely to be adversely affected by sedimentation and anoxic/hypoxic conditions.	• Potential hazard to watercraft.	• Requires boats and divers in waters over four (4) feet at low tide. • Shallower areas could be accessed from land and wading to desired site.



Restoration Technique	Best Location for Installation	Pro	Con	Installation Effort
Wire Cages / Gabions	• Anywhere except on anoxic mud and/or environments with substantial deposition. • Recommended for: ✓ Governors Island ✓ Bush Terminal ✓ Soundview Park ✓ NWS Earle	• Lightweight. • Easy to make. • Has good record of success so far in the limited installations in the HRE.		• Would likely require boats and divers in waters over four (4) feet at low tide. • Shallower areas could be accessed from land and wading to desired site.
Super Trays	• Hanging from a fixed structure or float. • Recommended for: ✓ Governors Island ✓ Bush Terminal ✓ Jamaica Bay	• Allows oysters to live over a muddy bottom habitat without the need for expensive substrate alteration.	• Requires suitable structure or float to be in place for tray installation.	• Minimal.
Anchored Bags	• Anywhere except on anoxic mud and/or environments with substantial deposition.	• Lightweight. • Easy to manipulate.	• Durability. Bags made with non-toxic materials (e.g., hemp, etc.) have shown to be less durable than plastic or other synthetic materials.	• Would require boats and divers in waters over four (4) feet at low tide. • Shallower areas could be accessed from land and wading to desired site.



4.2.4 Lessons Learned from Prior Oyster Restoration Efforts

The following recommendations for future oyster restoration efforts in the HRE are based on the investigations of the ORRP experimental reefs at Bay Ridge Flats, Governors Island, Hastings, Soundview Park, and Staten Island (Mosher-Smith,2012); Grizzle et al., 2013); Lodge,undated;; and Peterson and Kulp, 2013):

- Increase reef size: Larger reef footprints would aid in the assessment of reef development and performance, provide information more relevant to full-scale restoration, and increase the odds of recruitment from wild oysters.
- Develop mechanisms to limit erosion and transport of SoS off the reef: A large percentage of the planted SOS were hydraulically transported off the rip-rap and clam shell reef bases. Therefore, developing reef construction or reef maintenance techniques for retaining the planted SOS on the reefs is a critical obstacle to overcome when attempting to restore oyster reefs in the high energy areas typical of NY/NJ Harbor.
- Develop native broodstock: As oysters in the HRE may have developed a natural resistance tempered by adaptation to local environmental conditions (temperature, salinity, etc.) to the two (2) critical diseases, MSX and Dermo, development of broodstocks on a regional basis may be the most effective way to produce larvae for remote setting and production of SoS used to seed restored reefs. The long-term success of SoS used to seed restored reefs will likely be dependent on their disease resistance. At the Hastings site, where the oysters may be adapted to a wider range of salinities, restoration projects might be more successful if local broodstocks for larvae and SoS production were developed.
- Adopt monitoring protocols to new reef design: Quadrat-based monitoring methods are well suited for reefs that are accessible from shore, but proved difficult to consistently implement at sites in deeper water that required boats and the use of divers. The overall result was limited data from the deep-water reefs. For future projects that involve shallow and deep-water sites, monitoring methods should be developed that allow direct comparisons of the resulting data. The sampling devices do not have to be identical, but sample size and effectiveness should be similar.
- Adaptive approach: Future oyster restoration efforts must maintain an adaptive approach, reacting as necessary to findings that may emerge from monitoring.

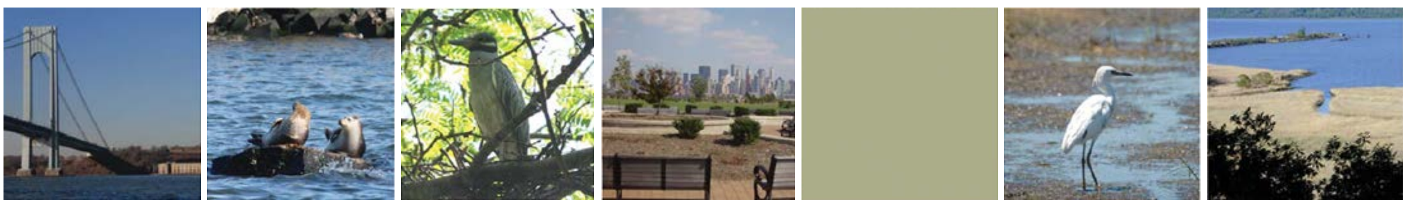
5. Candidate Restoration Sites

5.1 Existing Conditions

The information for each site provided below summarizes readily available regulatory agency resource mapping, prior oyster restoration efforts, published reports and journal articles, and site observations.

5.1.1 Governors Island

Water depths on the Buttermilk Channel (eastern) side of Governors Island vary from less than one (1) foot of water to a maximum depth of 50 feet. Bathymetric contours indicate that the bottom is steeply sloped along much of the shoreline, with depths over 25 feet being reached relatively close (within 300 feet) to the existing shoreline. Relatively shallow flats exist off the southern end of the island. Several areas of pilings, submerged pilings, ruins, moorings and obstructions exist near the shoreline. The substrate existing in and around Buttermilk Channel is described as rock (NOAA Office of Coast



Survey, Chart 12335). The NYSDEC sampled the bottom substrate around the island and classified it as a combination of gravelly sand and silty sand (NYSDEC Benthic Mapper). Figure 5-1 depicts the location of the Governors Island proposed oyster restoration site.

In order to better elucidate the water quality near Governors Island, the available individual sampling data from the closest monitoring stations (N5 and N6) were reviewed. NYCDEP monitoring stations N5 and N6 are relatively close to the island and are considered part of the Inner Harbor region. The results of the monitoring are presented in Table 4-1. Water quality at both N5 and N6 are suitable for oyster growth. Further, water quality data collected at the ORRP Governors Island reef generally suggest environmental conditions suitable for growth and reproduction of oysters (Grizzle et al., 2013).

Tidal current charts indicate that maximum current speeds can reach as high as 3.1 knots at five (5) hours after high tide (Tidal Current Charts, New York Harbor; US Coast and Geodetic Survey).

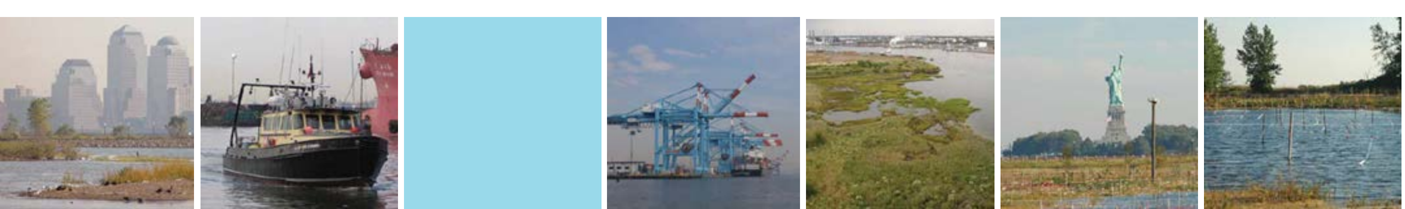
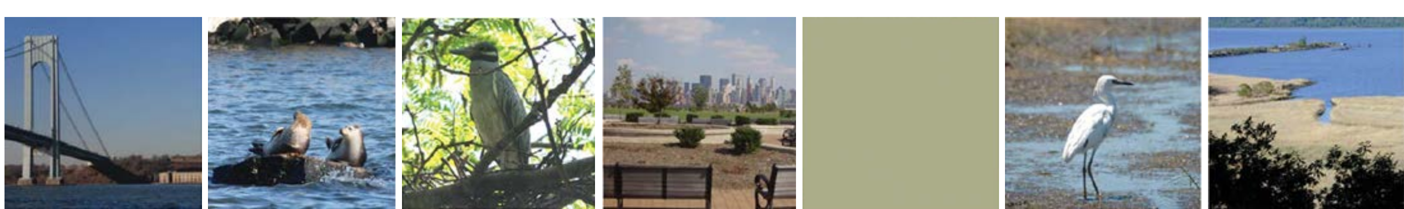


Figure 5-1: Governors Island Proposed Restoration Site Location

Additionally, Governors Island is the site of a 2010 pilot oyster reef from the ORRP. In 2010, as part of the ORRP, a 50-square-meter SoS bed was installed at Governors Island. Although there was some documented survival of oysters, boat wakes and tidal currents in the area dismantled the SoS bed and



prohibited substantial settlement or recruitment (Grizzle et al., 2013). Significant transport of SoS off the reef occurred during the winter months, which was addressed by re-seeding SoS in 2011. The fall 2011 monitoring events showed good retention and growth, as well as evidence of possible natural recruitment from wild oysters (Grizzle et al., 2013). Oyster condos were installed around most of the perimeter of the reef in 2014-2015 to address the issues with transport of spat on shell off of the reef. Conversations with BOP personnel indicate that this engineered solution, used as part of Harbor School curriculum, has increased documented oyster survival. Spat on shell oysters placed in 2016 grew an average of 0.1millimeter per day between June and November of 2016 with a 7.3 percent survival rate. The low survival rate is likely due to predation by oyster drills. Continuing experiments planned for 2017 include placement of larger oysters and experimentation with copper tubing on the cage structures as a predator deterrent.

BOP has been continuing to expand installations of oyster nursery systems, and now have nurseries at Governors Island, Wallabout Basin, Great Kills Harbor, and Head of Bay. A fifth nursery is slated for installation in Lemon Creek in 2017. These nurseries reflect years of aquaculture experience by BOP staff and Harbor School technicians, and consistently show high growth rates and survival. A hanging nursery on Yankee Pier as called for in the TSP, would be exposed to high water flow rates which increases oyster feeding and growth. Elevation off the bottom will provide excellent protection from predation.

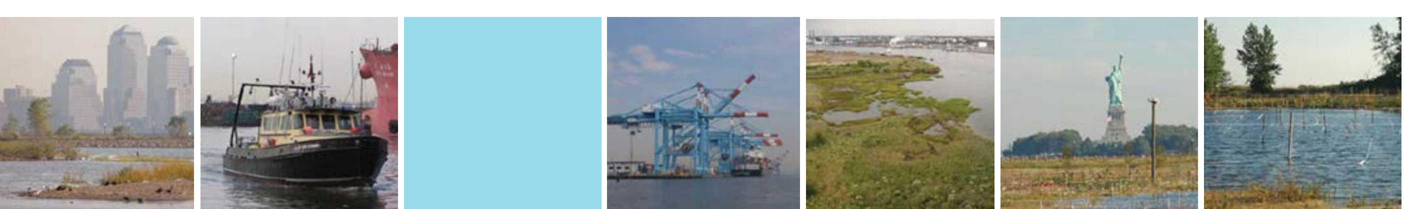
5.1.2 Bush Terminal

The Bush Terminal site is defined by old eroding piers just south of the Gowanus Canal on the western shoreline of Brooklyn. Water depths near Bush Terminal Park are generally shallow, ranging from intertidal along the shoreline to approximately 16 feet, out to the ends of the remains of the old piers. Beyond the piers, the water depth rapidly plummets to over 30 feet (NOAA Office of Coast Survey, Chart 12334). Substrates identified by the NYSDEC include silt and silty sand (NYSDEC Benthic Mapper, 2015). Figure 5-2 depicts the location of the Bush Terminal proposed restoration site.

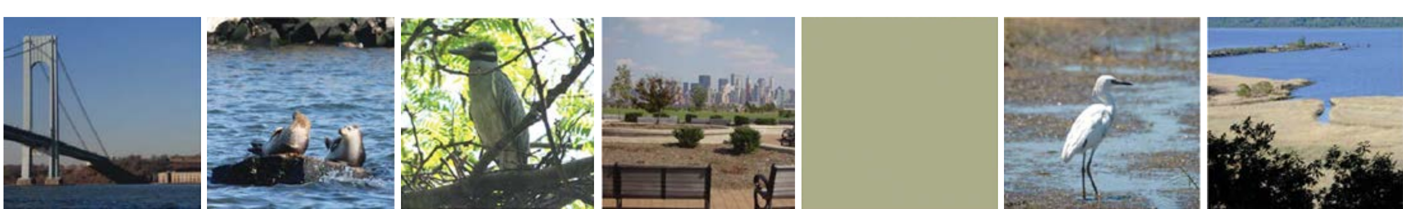
Tidal currents in the area of Bush Terminal range daily from a slack water condition to speeds up to 1.9 knots. The maximum current speeds in the area occur four (4) hours after high tide (Tidal Current Charts, New York Harbor; US Coast and Geodetic Survey). The water quality of this potential project area is likely similar to that of Governors Island. The nearest NYCDEP monitoring stations to the site are N6 and G2. The results of the monitoring are presented in Table 4-1. Based on the review of available current and tide data, it is anticipated that due to the strong tidal flushing action that the waters of the project area are similar to location N6. Water quality at both N6 and G2 are suitable for oyster growth.

The area is a former pier area used for shipping throughout the industrial era. Coupled with its close location to Gowanus Canal, there may be some level of contaminants in the sediments (See Appendix H [HTRW]). Prior to 1974, the Bush Terminal site was an active port. As of 2006, the car floats and Bush Terminal Rail Yard are operated by New York New Jersey Rail, LLC, and used occasionally to deliver New York City Subway cars via the South Brooklyn Railway. Soil, groundwater, and sediment at and underneath the site became contaminated in the 1970s due to the unauthorized disposal of construction and demolition debris and liquid waste including oils, oil sledges, and wastewater (USACE, 2014).

Multiple oyster studies have taken place at and near this location. The first was the Bay Ridge Flats Oyster Pilot Project (2009-2011) which showed extremely high growth rates but low success due to the



dispersal of materials caused by fast currents across the barren flats. A larger, higher-relief reef was installed in 2010 as part of the ORRP, which suffered from high sand deposition on the reef and transport of oysters off the reef. While the high-energy environment is problematic, the strong growth rate was promising, so in 2016 efforts were shifted to the adjacent Bush Terminal Park where proximity to shore and to structures that provide some protection from strong currents would decrease the chances for loss due to transport. Within the protected lagoons, oysters have thrived, growing at a strong and steady rate and persisting in both wild and cultivated forms in multiple year classes. Further addition of engineered structures to the areas around the outer edges of the park would provide excellent shielding from wave energy.



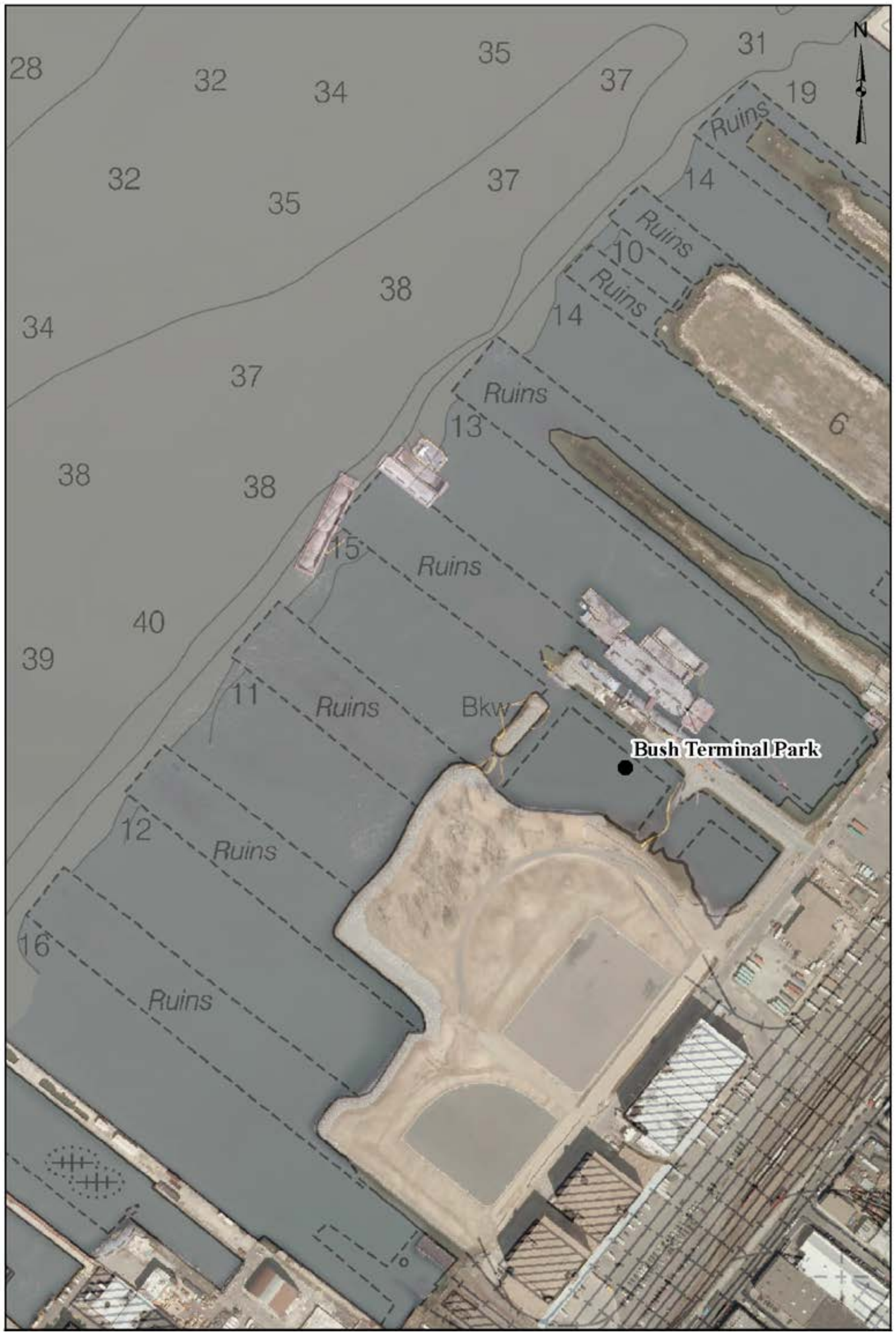


Figure 5-2: Bush Terminal Proposed Restoration Site Location

5.1.3 Soundview Park

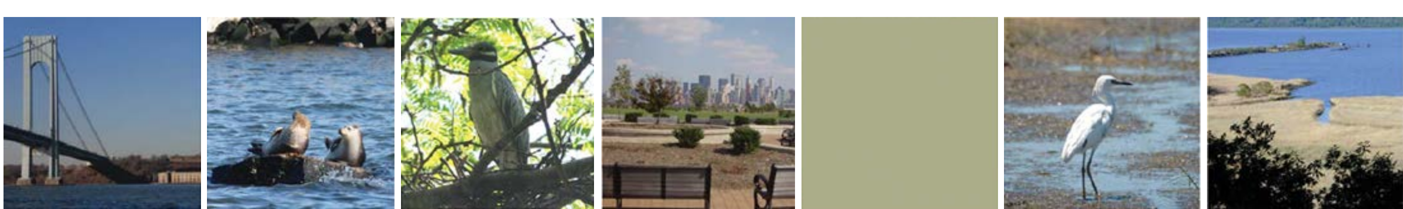
Water depths in the Bronx River near Soundview Park are relatively shallow, between one (1) and three (3) feet outside of the main channel. The main channel has depths ranging from 0.3 feet to 5.9 feet. The substrate in the area is described as soft mud. A sewer outfall pipe is shown located within the park's boundaries (NOAA Office of Coast Survey, Chart 12339). Currents in the area are generally from 0 to one (1) knots. Figure 5-3 depicts the location of the Soundview Park proposed restoration site.

Water quality samples and measurements have been collected annually in the Bronx River near Soundview Park by NYCDEP. The collection point BR5, Bronx River Mouth, is adjacent to Soundview Park and is considered part of the Upper East River and Western Long Island Sound region. The Upper East River and Western Long Island Sound region was assigned a water classification of "I" in 2012 based upon sampling results. That classification indicates that the waters of the Upper East River and Western Long Island Sound are suitable for fishing and boating, but not bathing. It also indicates that dissolved oxygen readings were never measured below 5.0 milligrams/liter (*2012 State of the Harbor Report*, NYCDEP). Sample location BR5 is part of the Harbor Monitoring. Review of the water quality data collected at this location was within the tolerable ranges for oysters. Water quality data collected at the ORRP Soundview Park experimental reef in 2011 and 2012 were well within typical ranges for the eastern oyster and generally suggest environmental conditions suitable for growth and reproduction of oysters (Grizzle et al., 2013).

Although none of the oysters had advanced level infections, large wild oysters collected off the experimental reef in 2012 were infected with MSX, suggesting to Grizzle et al. (2013) that oyster mortality due to disease, particularly MSX, can be expected to generally limit the longevity of oysters in the area to less than five (5) years. No Dermo infections were detected (Grizzle et al., 2013).

In 2010, as part of the ORRP, Soundview Park along with four (4) other sites (Hastings on Hudson, Bay Ridge Flats, Governors Island, and Staten Island) were the test sites for experimental 50-square-meter SoS beds. After two (2) years of monitoring, the Soundview Park reef showed the best prospects for further restoration efforts because of good growth and survival, as well as natural recruitment from wild oysters (Grizzle et al., 2013). Notably, some SoS placed in the fall of 2010 were discovered at a location just north of the Soundview Park reef in the summer of 2011, although the transported SoS had grown and had good survival.

Oyster restoration efforts were further progressed in 2012, through the placement of a one- (1)-acre SoS oyster bed and subsequent placement of wire cage gabions. The study did identify that oysters survived for one (1) full year after being placed in the location. Also, identified was erosion of the SoS bed (Lodge et al., 2015). While no proximal cause for this action can be identified, storm surges, boat wakes and wind driven waves are all likely the reason coupled with the fact the restoration area was very limited in size.



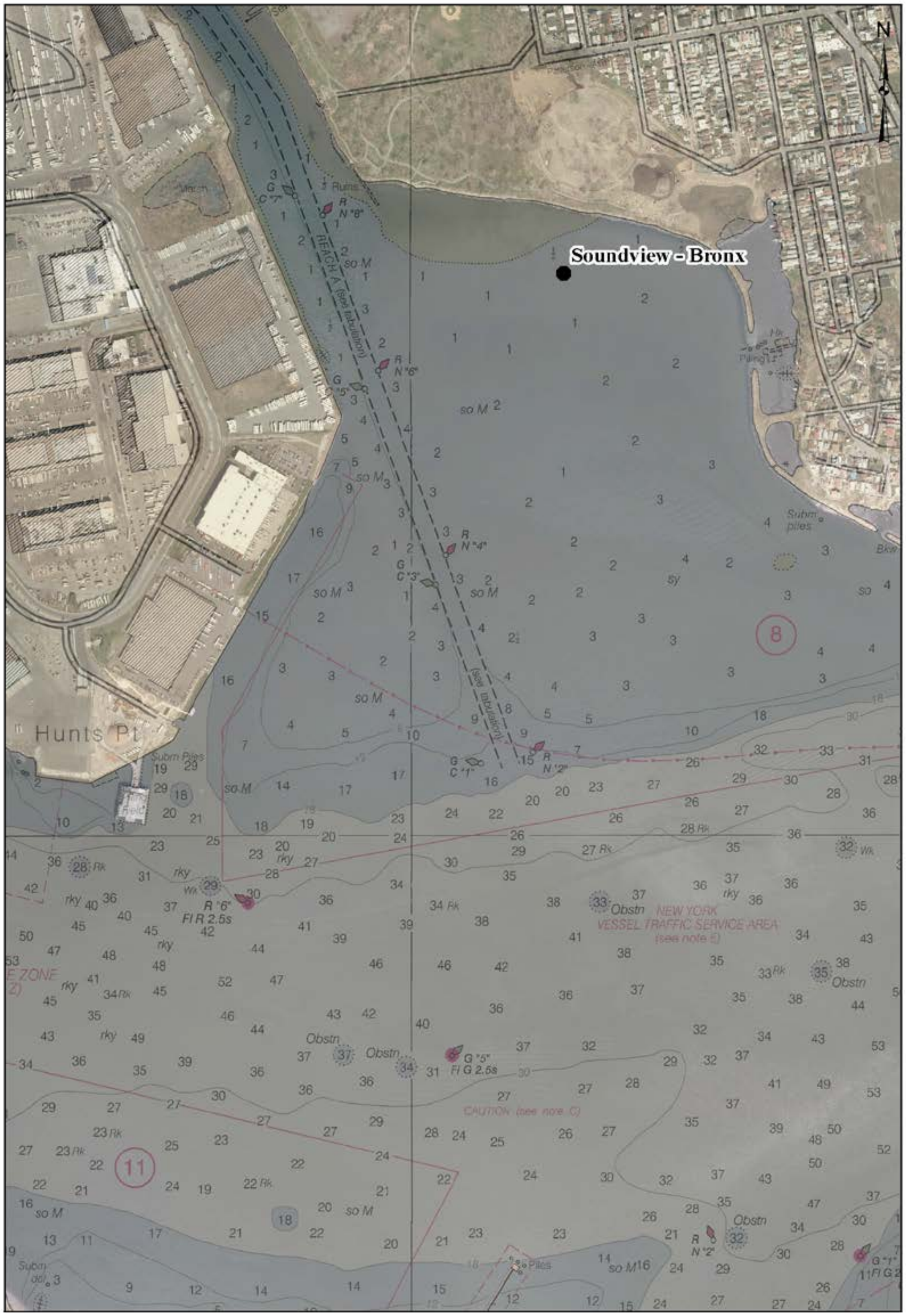


Figure 5-3: Soundview Park Proposed Restoration Site Location

5.1.4 Jamaica Bay

Water depths in the head of Jamaica Bay are fairly deep, up to 33 feet deep. Salt marsh habitat fringes much of the shoreline area. The bottom is steeply sloped close to the shoreline, as depths of over 25 feet are located within 100 feet of the shoreline in many areas. Substrate in the area is noted to be mud (NOAA Office of Coast Survey, Chart 12350). Based on the nearest tidal current station in Jamaica Bay (Grass Hassock Channel), the current speeds in the eastern portion of the bay rarely exceed one (1) knot. Figure 5-4 depicts the location of the Head of Bay proposed restoration site in Jamaica Bay.

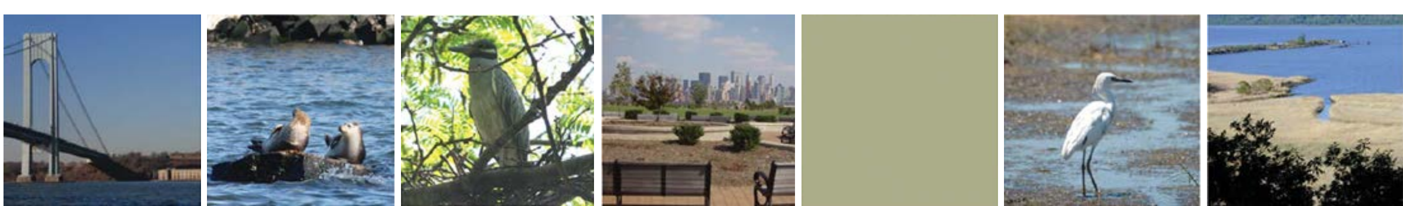
Water quality samples and measurements have been collected annually in Jamaica Bay by NYCDEP. The collection points J5 and J12 are relatively close to the head of the bay area and are considered part of the Jamaica Bay region. The open waters of the Jamaica Bay region were assigned a water classification of “SB” in 2012 based upon sampling results. The score indicates that the waters of the Inner Harbor are suitable for bathing and other recreational uses. It also indicates that dissolved oxygen readings were never measured below 5.0 mg/l (NYCDEP, 2012). The closest water quality monitoring station is J12 (Table 4-1). Review of the data collected at this location was within the tolerable ranges of oysters. Based on oyster modeling results, it is suggested the head of Jamaica Bay provides a greater potential degree of larva retention.

In 2011, NYCDEP conducted small-scale oyster demonstration projects at Dubos Point using a SoS method and at Gerritsen Creek using reef balls. The goals of the project were to demonstrate the effectiveness of water quality and ecological benefits and the effectiveness of safeguards to avoid “attractive nuisance” issues, and to develop information on how to restore a significant habitat type that once thrived in the region. Monitoring parameters included measuring growth, survival, reproduction and recruitment under natural conditions, and measuring exposure to predators. These demonstration projects revealed:

- Adequate conditions for survivability and function;
- Extensive predation;
- Low incidence of disease;
- Growth comparable to other east coast estuaries; and
- Gonadal development, but reproduction and recruitment of oyster larvae not directly observed.

Percent survival was greater on reef balls than on the SoS reef bed. The reef bed was found not to be stable, possibly due to boat activity and strong tidal currents. However, the number of macrobenthic species frequently observed near the oyster bed increased steadily over the life of the project.

As a companion to this effort, to test for the presence of oyster larvae within other areas of Jamaica Bay, NYCDEP also deployed 96 spat collectors at six (6) sites within Jamaica Bay from mid-June through the end of August 2016. As with the demonstration projects, no recruitment was observed in the spat collectors. However, the small scale of this and many other projects in the region may be contributing to the lack of observed recruitment. To date, many projects were only several hundred square feet in size and had limited buffering capacity.



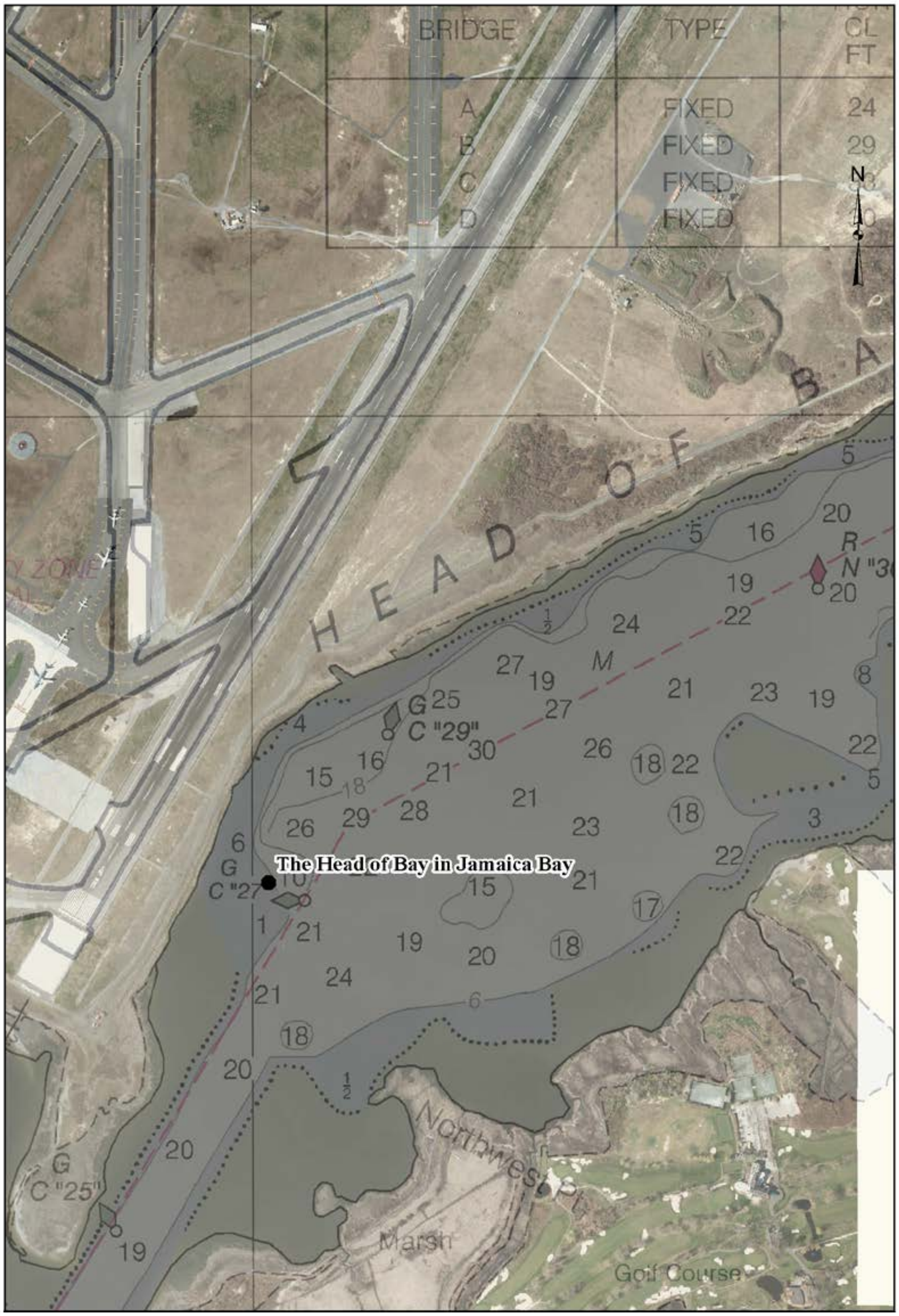


Figure 5-4: Jamaica Bay Head of Bay Proposed Restoration Site Location

Building upon the research already done at the Dubos Point and Gerritsen Creek sites, in 2016, the NYCDEP will be implementing an expanded oyster demonstration project at Head of Bay, Jamaica Bay to help address the scale question and determine if recruitment is a factor of the size of the project. A hydrodynamic model determined that the Head of Bay site was among the highest sites for larvae retention of the 26 release points modeled. It is believed that the Idlewild salt marsh complex plays a substantial role in retaining oyster larvae prior to settlement (NYCDEP, 2015). The proximity of this site to John F. Kennedy Internatinal Airport and the mandatory exclusion zone within the waters of Head of Bay provide excellent attractive nuisance controls.

The plan will consist of a spat donor bed and four (4) receiving beds to determine recruitment. Head of Bay's relatively small width and proximity to the Idlewild salt marsh complex may increase the chance of recruitment on the test beds. In addition, the larger oyster beds would provide a greater degree of buffering capacity and greater resilience to disease and predation. NYCDEP is working with the New York Harbor Foundation, Cornell University and the Hudson River Foundation on the current ongoing oyster restoration effort at the head of Jamaica Bay.

5.1.5 Naval Weapons Station (NWS) Earle

Water depths at the NWS Earle vary from shallow waters of just one (1) to 12 feet out to approximately the midpoint of the pier located there. Beyond the midpoint of the pier to the end of the pier, the water depth goes from 12 to 16 feet. Out past the pier in the Terminal Channel area, water depths reach over 40 feet. Bottom substrates are noted near the pier and indicate substrates including mud and shell (NOAA Office of Coast Survey, Chart 12327). The United States Fish and Wildlife Service (USFWS) notes that the sediments of Raritan Bay and Sandy Hook Bay are predominantly sand, with some areas of gravelly sand overlaid with coarse to fine silt and fine to very fine sand, respectively (USFWS, 1997). Current speeds in the project area, based on NOAA current mapping, are usually less than one (1) knot. Figure 5-5 depicts the specific proposed location at NWS Earle.

Based on available NJDEP data collected near NWS Earle (Table 5-1), the water quality in the project area appears to be able to support the growth of oysters. Based on the 2016 New Jersey Shellfish Growing Water Classification Chart, the potential project area is identified as "restricted", due to potential issues with pollution. As per the NJDEP webpage, shellfish captured in this area must undergo further processing before sale or consumption. Depuration is used for 100 percent of hard clams harvested from the restricted waters of this growing area (NJDEP, 2016).

Oyster restoration in New Jersey waters is currently prohibited by the state; however, the naval facility is exempt from these regulations due to extensive security at the site. Over the last few years, a small scale oyster restoration has occurred along the naval ammunition piers under the auspices of the NY/NJ Baykeeper. An initial pilot study using lantern bags from the piers found very good rates of survival; although, the durability of the bags has become an issue, as a number of the bags were damaged or lost during Superstorm Sandy (NY/NJ Baykeeper, 2014). A new test using metal cages is currently being implemented; no data from these efforts is currently available.

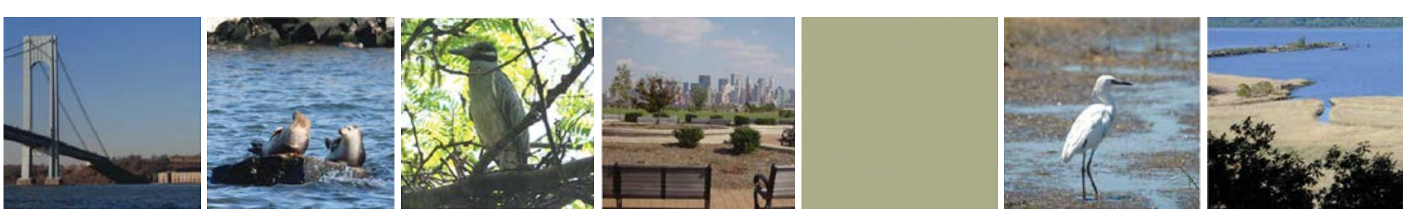


Figure 5-5: NWS Earle Proposed Restoration Site Location

In July 2010 (NY/NJ Baykeeper 2016), NY/NJ Baykeeper's scientific work to test the viability of restoring oysters in the Raritan Bay was halted. With hope for restoring water quality and habitat in the Raritan Bay, NY/NJ Baykeeper approached the Navy about continuing oyster restoration research at NWS Earle, which is under 24/7 security, and therefore eliminates any poaching risk. Commanding Officer Captain Harrison and NWS Earle staff were excited about the idea and helped NY/NJ Baykeeper execute the project.

At NWS Earle, NY/NJ Baykeeper produces juvenile oysters for restoration projects at the Aquaculture Facility. There hatchery-raised oyster larvae attach, set, and grow on shell substrate, as well as reef balls and oyster castles. The larvae attach themselves to the shell and grow in this protected environment. Once the oysters have "set" on the shell, and grown for about two (2) months, they are ready for release onto newly established oyster beds, or reefs. During 2014 and 2015 three different structures-reef balls set with oysters, metal cages filled with spat on shell, and Reef Blocks filled with spat on shell- were tested over a ¼ acre at the NWSE site. Data showed that survivorship was best within the cages since these structures allow the oysters to be off the bottom alleviating pressure from oyster drills. The structures were placed in two (2) to three (3) feet of subtidal water, reducing the possibility of illegal poaching.

In 2015, monitoring of test structures at NWS Earle yielded the following results:

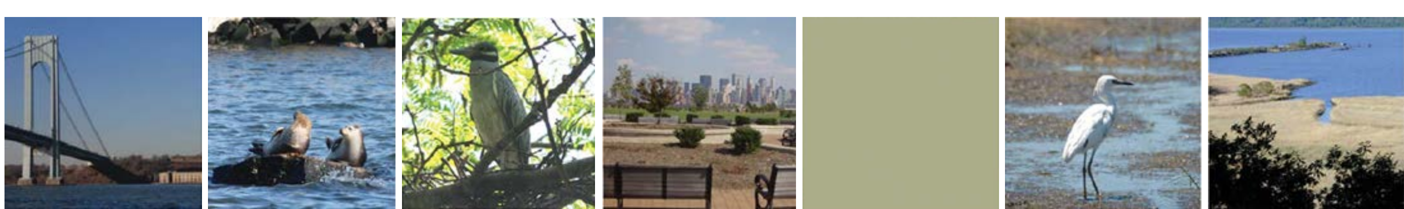
- Three (3) stages of Dermo (or perkinsosis) observed in tissue materials after addition of formalin preservative. Samples sent to Haskin Shellfish Research Lab in November 2015, to test for MSX and Dermo.
- High salinity around the bay in August led to a Dermo outbreak, which caused unusually high mortality.
- Oyster drill predation is a problem, which can be expected as water temperatures rise and salinity increases.
- During an October site visit oysters that had survived were hearty and had grown well. Juvenile oysters were 30 to 40 millimeters in November 2015, just four (4) months after they were set in the tanks at NWS Earle.

During summer 2016, Baykeeper installed the first phase of a living shoreline project at NWS Earle in summer. Oyster castles were set with juvenile oysters at the NY/NJ Baykeeper aquaculture facility and were placed parallel to the mouth of Ware Creek, on NWS Earle property. This project is part of a larger 200-acre plan involving the Navy and Middletown Township to protect infrastructure at the naval base. NY/NJ Baykeeper will be expanding the living shoreline during the summer of 2017.

Table 5-1: Water Quality Data - Raritan Bay Sampling Station 914

STATION	Type	Temperature (C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	Chlorophyll a (µg/L)
914	# Samples	40.0	39.0	40.0	24.00
914	Maximum	25.0	14.9	29.3	88.99
914	Average	13.6	8.7	24.1	13.86
914	Minimum	3.0	3.8	13.3	0.42

NJDEP 2015



5.2 The Tentatively Selected Plan

Five (5) sites were selected for oyster restoration within the HRE. The tentatively selected plan (TSP) for small-scale oyster restoration creates approximately 55 acres of oyster bed habitat in NY/NJ Harbor. The proposed actions at each site would provide immediate positive benefits to improve habitat and water quality and would provide functional uplift to the marine environment.

5.2.1 Governors Island

Due to the challenging physical conditions at Governors Island, which includes strong tidal currents and constant boat wakes, restoration efforts would be limited to small scale reef restoration efforts on the east side of the island. Potential activity on the shallow shoal south of the island would likely require the placement of substantial breakwaters. The TSP at Governors Island includes the creation of a 3.35-acre gabion block and oyster condo bed located on the southeast portion of the island near Yankee Pier. In addition, hanging oyster nursery trays will be placed within under piers in a semi-protected harbor (Figure 5-6).

This restoration was designed to place reproductive stock in hanging trays in close proximity to suitable hard substrate consisting of condos and gabion blocks for settlement. The use of Governors Island, in concert with BOP and the Harbor School, provides facilities, technical experts and a cost-effective means for construction and maintenance, as well as excellent teaching/research opportunities for future generations of scientists. It is strongly recommended that the Harbor School's laboratory facility be considered part of any future restoration effort. The hatchery can provide the needed localized broodstock for placement in future restoration efforts.

5.2.2 Bush Terminal

Bush Terminal would serve as a large anchor project for oyster restoration in New York Harbor as it demonstrates an innovative solution to reutilizing derelict shorelines and piers and it would restore over 40 acres of habitat. The TSP for Bush Terminal includes the creation of 31.65 acres of SoS, 8.48 acres of gabion blocks, 3.49 acres of oyster condos and placement of hanging trays in quiescent bays (Figure 5-7). The derelict piers and lagoons provide wave attenuation and the depths vary from shallow to deep allowing for good habitat diversity.

This project would be partially located within NYC Parks's Bush Terminal Park. The site is close to the Harbor School, which would result in reduced transport costs for future placement of additional oysters. There is a positive synergistic effect with park visitors, staff, local community groups, and schools.

Use of this site provides excellent public access, awareness, and opportunities for future scientific study. In the summer of 2016, BOP and the Harbor School constructed a pilot reef stocked with one million juvenile oysters within the protected lagoons of Bush Terminal Park. Between June and November, repeated monitoring from shore and by divers showed high oyster survivorship of 30 percent, and an average growth of 0.33 millimeter per day. Large wild oysters are present along the shoreline and during the first season of study, some wild oyster recruitment to the pilot reef was evident (BOP personal communication, 2017).

5.2.3 Soundview Park

Previous small-scale oyster restoration attempts at Soundview Park have determined that oysters could survive throughout the year (Grizzle et al., 2013). Building on the success of prior restoration activities,

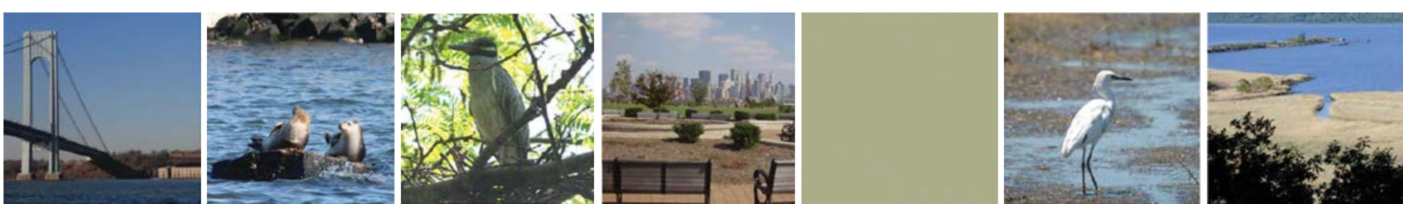
the TSP would continue to expand the existing reef area through the placement of a 0.14-acre gabion block wall to serve as a wave break and a the placement of an additional 0.83 acres of SoS. This restoration will occur in an area with subtidal rock out crops to form an approximately 2.75-acre reef/bed complex (Figure 5-8). The design would continue to provide excellent research opportunities.

5.2.4 Jamaica Bay

Hydrodynamic modeling showed that the water currents at this site are very conducive to oyster larvae transport and settlement. The proposed restoration method is designed to act in concert with an identical effort occurring in 2016. The TSP will include the placement of approximately 0.4 acres of receiving beds mage of suitable hard substrate and 200 one (1) foot by five (5) feet floating oyster bags. The proposed restoration site is located within the Head of Bay, in somewhat quiescent waters of Jamaica Bay. As such, there is a high likelihood of larval resettlement and beginning of an oyster reef. Hanging trays and various recruitment beds will be placed in the Head of Bay as part of the oyster restoration methods (Figure 5-9).

5.2.5 Naval Weapons Station (NWS) Earle

The NY/NJ Baykeeper has conducted oyster restoration at NWS Earle since 2010 on a small 0.25-acre plot in which oyster survival was documented. Building on this success, approximately 7.6 acres of new restoration will be constructed adjacent to the existing restoration site. The TSP includes 3.1 acres of SoS, 3.2 acres of gabion blocks, and 1.3 acres of reef balls/oyster castles. A schematic design of the restoration is identified in Figure 5-10. Being a naval facility with robust security, placement of oyster restoration in naval base water would eliminate the potential threat of poaching of oysters. Results (biodiversity, fouling studies, growth and mortality) from ongoing restoration efforts are currently being processed and appears encouraging.



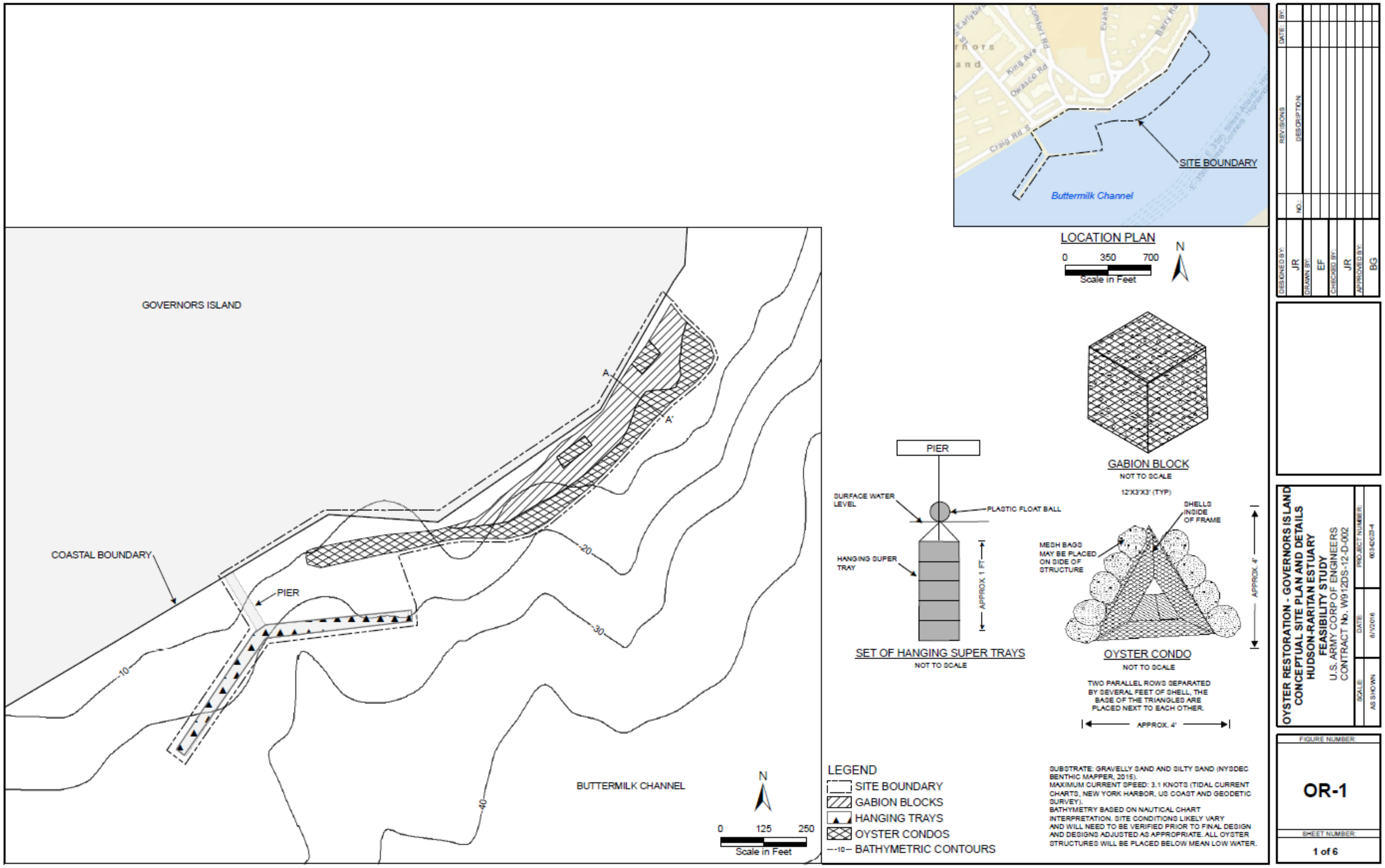


Figure 5-6: Proposed Restoration Governors Island

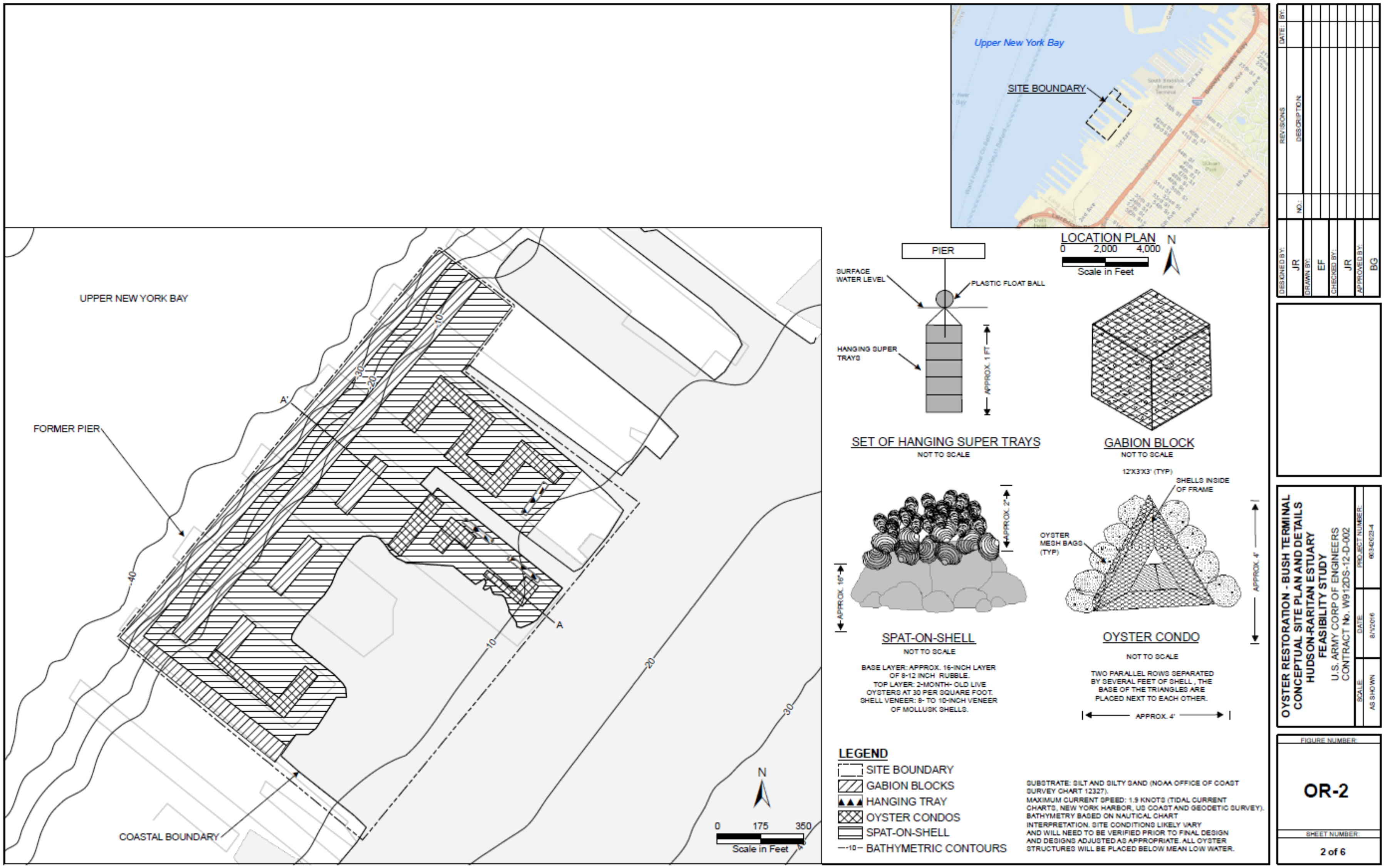
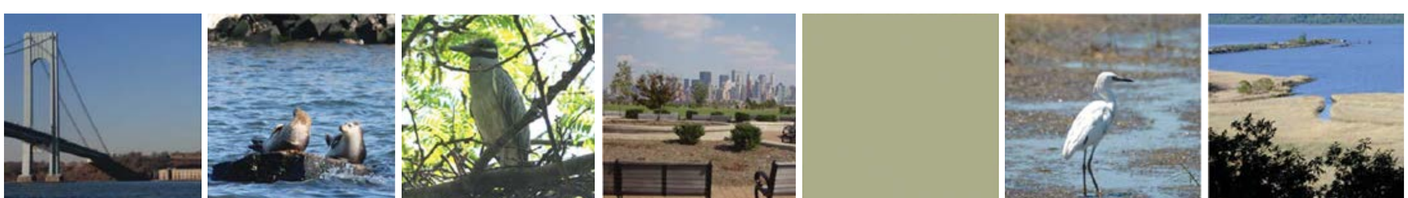


Figure 5-7: Proposed Restoration Bush Terminal



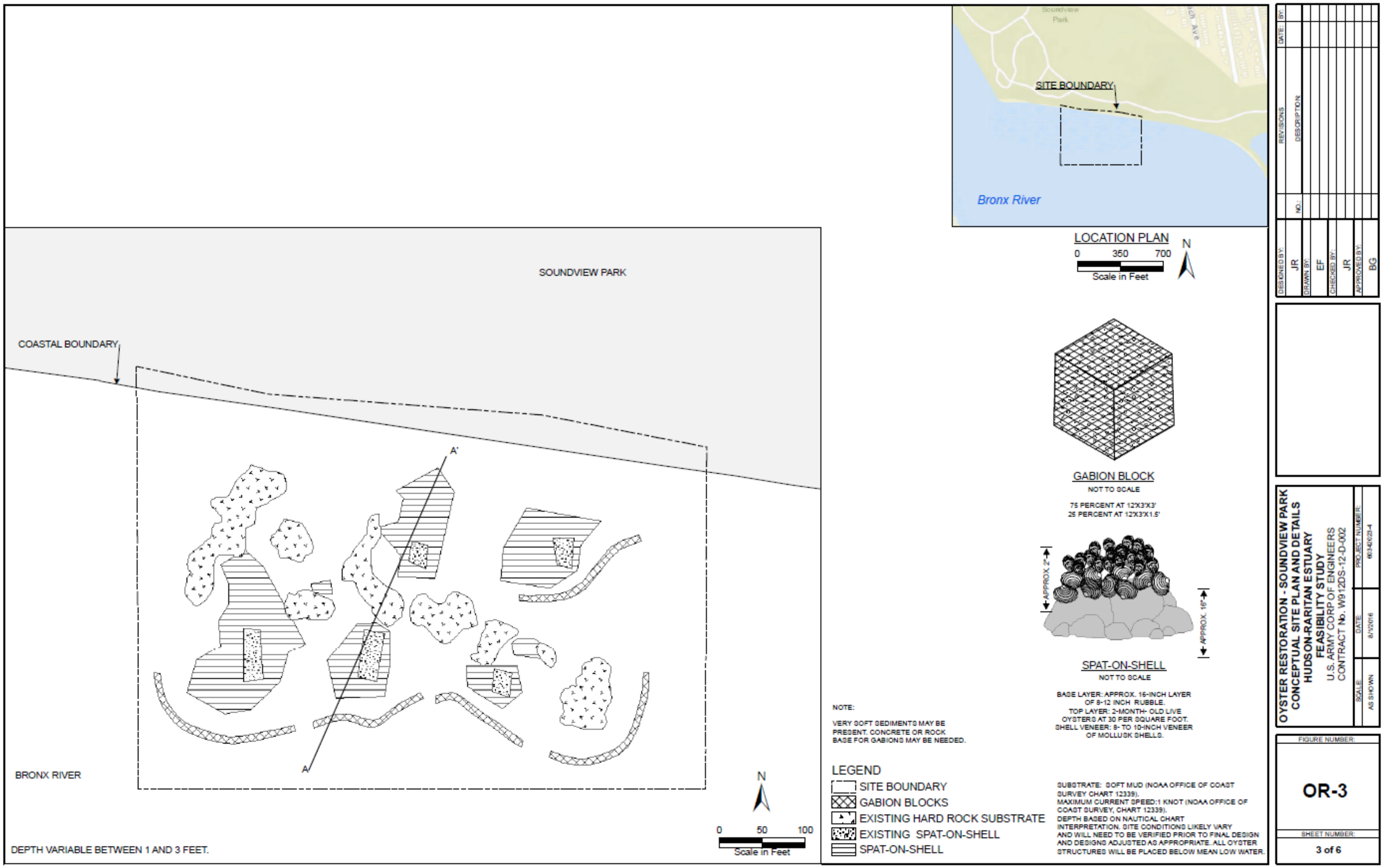
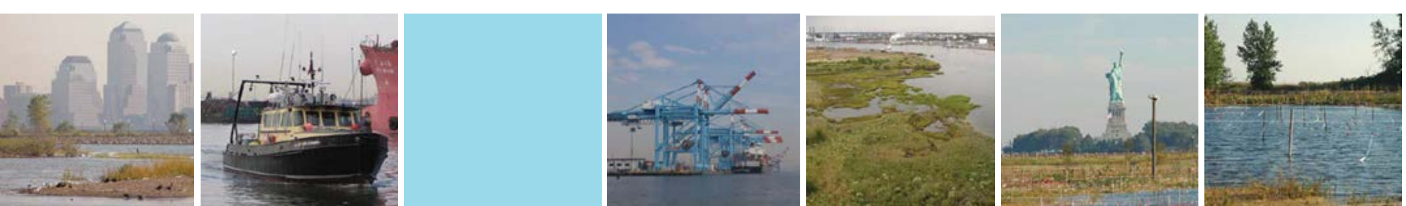


Figure 5-8: Proposed Restoration Soundview Park



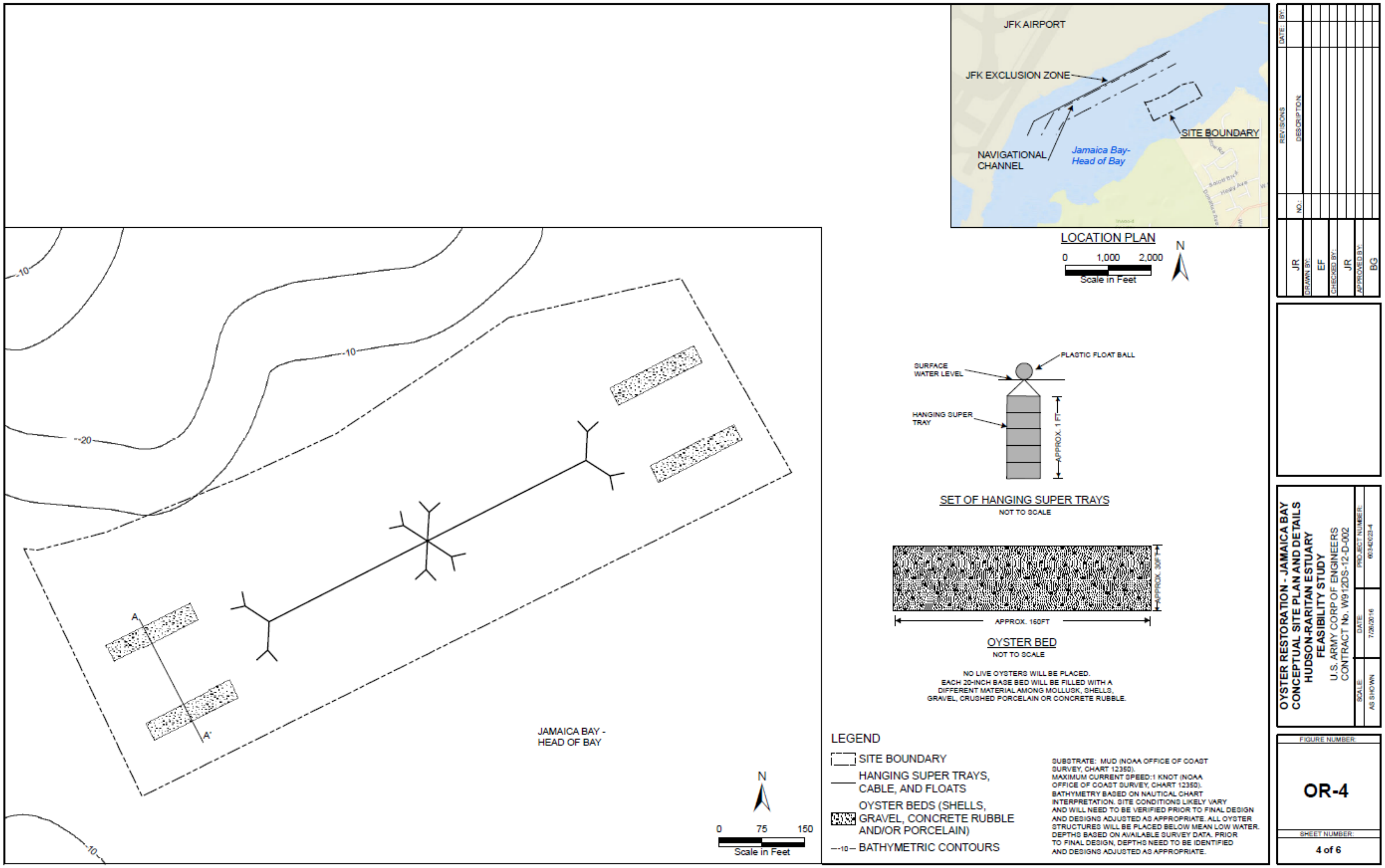
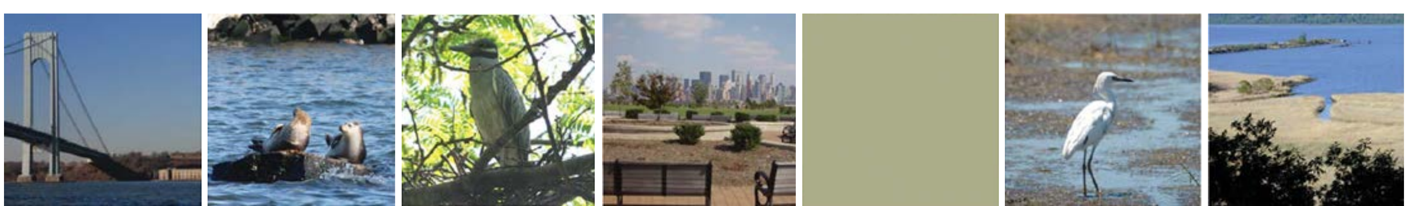


Figure 5-9: Proposed Restoration Jamaica Bay Head of Bay



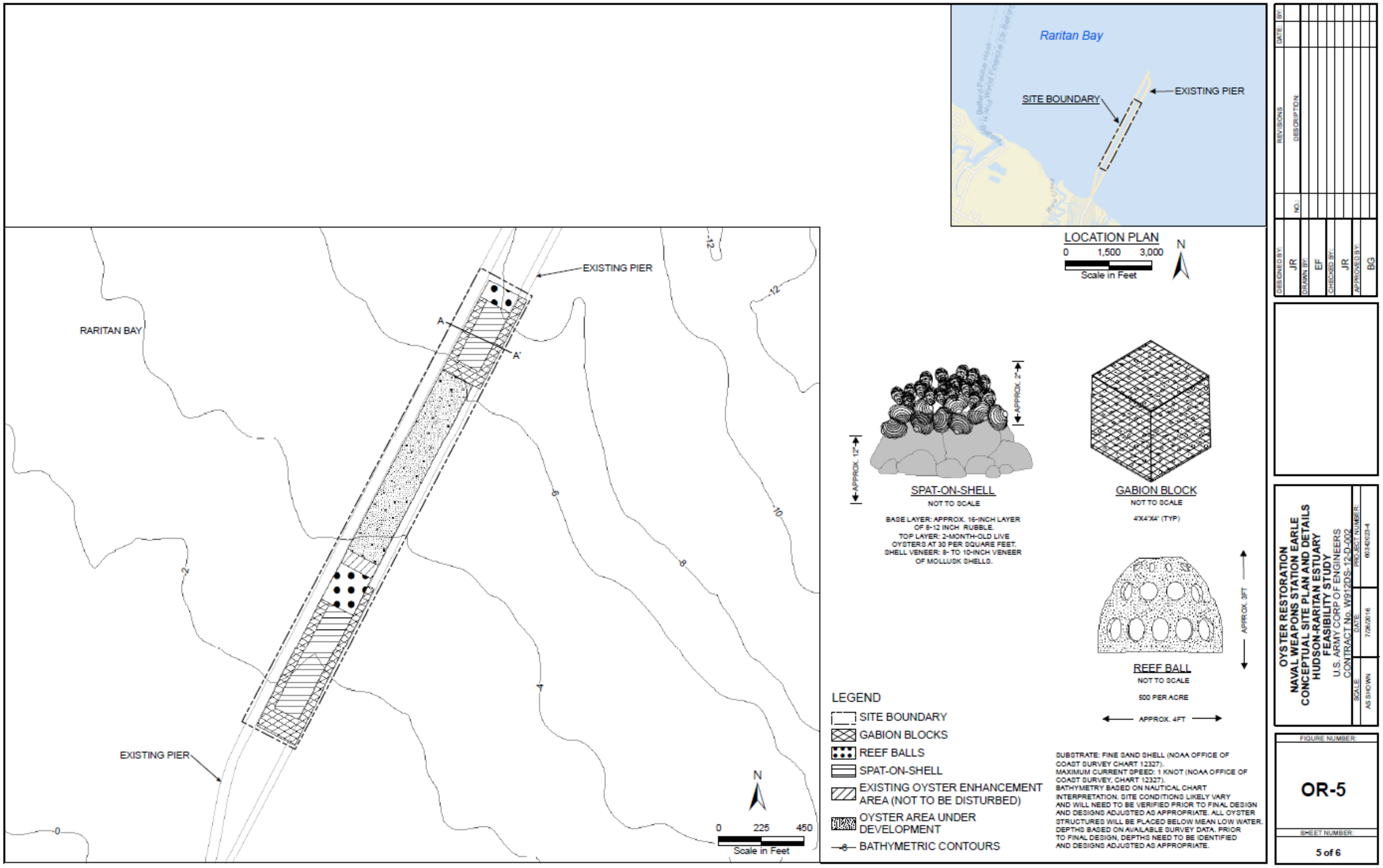
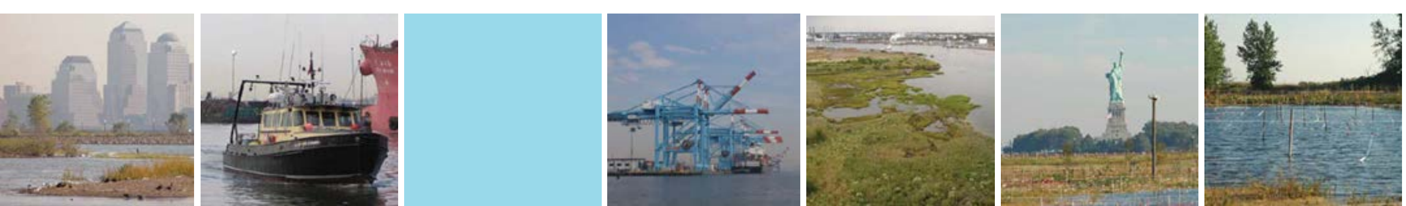


Figure 5-10: Proposed Restoration NWS Earle



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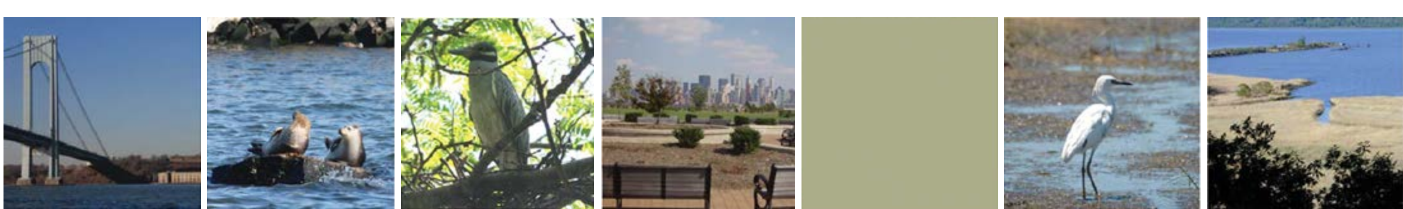

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