

BILLION OYSTER PROJECT

New York Harbor Oyster Monitoring Report

2023 – 2024





ABOUT BILLION OYSTER PROJECT

The mission of Billion Oyster Project is to restore oyster reefs in New York Harbor through public education initiatives. Oyster reefs contribute to several ecosystem services, including providing habitat complexity that enhances species biodiversity and abundance, improving water quality through filtration and sediment stabilization, and enhancing shoreline resilience and adaptation.

We envision a future in which New York Harbor is the center of a rich, diverse, and abundant estuary. The communities surrounding this complex ecosystem have contributed to its construction and, in return, benefit from it with endless opportunities for work, education, and recreation. The Harbor is a world-class public space, well-used and well-cared for—our Commons. By 2035, Billion Oyster Project aims to create self-sustaining oyster populations by introducing 1 billion oysters, creating 100 acres of oyster reef habitat, and engaging 1 million people in their work.

By the end of 2024, Billion Oyster Project has collected 2.8 million pounds of shells from restaurants. These shells provide habitat for oysters in the waters of New York City. Over 150 million live oysters have been reintroduced by the Billion Oyster Project in the waters of New York Harbor, and over 20,000 NYC students have been engaged in the process.

RECOMMENDED CITATION

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Brooklyn Bridge Park Corporation
Brooklyn Navy Yard
Hudson River Park Trust
Inwood Marina
New York Harbor School
New York State Office of Parks, Recreation, and Historic Preservation
One°15 Brooklyn Marina
Richmond County Yacht Club
Sebago Canoe Club
SUNY Maritime College
The Trust for Governors Island
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Executive Summary

This is the sixth edition of Billion Oyster Project's Annual Monitoring Report. The report summarizes the 2023 and 2024 post-installation monitoring results from twelve oyster restoration sites as well as pre-installation activities at several sites in New York Harbor. Data were collected by staff, academic partners, community scientists, and students using protocols developed by Dr. Mike McCann. For more information about past oyster restoration projects, please refer to our annual reports, which are available on our website.

Seven oyster performance and health metrics were applied to twelve sites around New York Harbor. **Table 1** provides a high-level overview of oyster performance and health, with each site assigned a qualitative grade. A summary of our main findings is here:

Oysters continue to show positive growth & recruitment

- Oysters across multiple restoration sites showed strong growth, particularly at Brooklyn Bridge Park, Bush Terminal Park, Paerdegat Basin, and Soundview Park.
- Recruitment was strongest at Brooklyn Bridge Park and Bayswater Point State Park.

But, challenges with mortality & disease persist at some locations

- In Staten Island, long-running pilots at Great Kills Harbor and Lemon Creek Lagoon had annual mortality exceeding 70-80% and without the addition of new oyster cohorts, the pilots were removed after 6+ years of installation.
- Two non-human, oyster-specific diseases occur in New York Harbor. Dermo (*Perkinsus marinus*) intensity increases as oysters age and is likely contributing to mortality at sites like Brooklyn Bridge Park, Great Kills Harbor, Paerdegat Basin, and Bush Terminal Park. Fortunately, MSX (*Haplosporidium nelsoni*) remains low at all sites.

Therefore, reefs need adaptive management & higher seeding density

- Across the Harbor and at individual reef sites, oysters are reaching reproductive age, but the total number of reproductive adult oysters is insufficient. As a result, mortality continues to exceed recruitment at restoration sites.
- Therefore, multiple cohorts of oysters at higher densities should be introduced over several years to compensate for losses.

Successes are leading to expansion

- Brooklyn Bridge Park's Phase 1 of a two-acre reef project is underway.
- Expansions are planned for Bush Terminal Park and Paerdegat Basin.
- Ongoing adaptive management is planned for Soundview Park.
- Pre-installation surveys are underway to inform the design of four new reefs in the Queens and Bronx portions of Western Long Island Sound.
- Multi-acre restoration will increase the odds that recruitment can outpace mortality.

Oyster restoration continues to provide environmental & community benefits

- Restored reefs support biodiversity, with species like skillefish, blackfish, and oyster toadfish observed at multiple sites.
- Over 150,000 NYC students and adults have participated in hands-on restoration activities, helping to advance education and community involvement.

Although oyster restoration and research activities have been ongoing in New York Harbor for nearly two decades, best practices continue to evolve. Restoration design, monitoring, and implementation should remain dynamic, guided by a spirit of adaptive management. As we refine our data collection protocols, it is essential to embrace continuous learning and make data-informed decisions. **Table 2** provides a high-level overview of the recommended restoration actions for each site. These restoration sites continue to offer valuable opportunities for future learning and will help us explore the potential for oyster restoration in other parts of the Hudson-Raritan Estuary.

For more details on the data and trends that informed the assigned qualitative grades and recommended restoration actions for each site, refer to the following sections, organized by waterbody.

Other Sites and Projects

While this report focuses on active restoration sites maintained and monitored, it's important to note that BOP is also involved in other oyster restoration projects throughout the estuary. These include:

- Since 2015, school groups, various community groups, and individuals have participated in BOP's Oyster Research Station program. Data from this program are not included in this report.
- In May 2021, BOP and New York Harbor School introduced 5,000 donated adult oysters to the Governors Island reef site in the Buttermilk Channel between Brooklyn and Manhattan as part of the Supporting Oyster Aquaculture and Restoration (SOAR) effort led by The Nature Conservancy and The Pew Charitable Trusts.
- In 2021 and 2022, BOP served as a sub-consultant to Hudson River Park Trust to set structures with juvenile oysters for their Tribeca (north of Pier 26) and Gansevoort (south of Pier 54) Habitat Enhancement projects. These sites are not discussed in this report. Reports may be found on the Hudson River Park Trust's website.
- BOP is a member of the Living Breakwaters project team and aims to introduce oysters to the completed breakwaters in 2025 and 2026.
- BOP supports Hudson River Foundation in post-installation monitoring of the 2018 restored oyster reef at Governor Mario M. Cuomo/New NY Bridge Project at Tappan Zee.

Table 1. Summary of oyster performance and health metrics at each restoration site. Available oyster health metrics are assessed based on 2024 data. NA indicates data is not available. Grades are categorized as green, yellow, or red.

Site*	Structure/ Cohort	Growth	Mortality	Recruitment	Disease		Reproduction	
					Dermo	MSX	Spawning	Sex Ratio
Brooklyn Bridge Park - One15 Marina	Cabinet Reef	Positive	High	Consistent	NA	NA	NA	NA
	Gabion Reef	Positive	Stable	Consistent	NA	NA	NA	NA
	SEAPA Nursery	Positive	Low	Consistent, but low	Moderate	Low	Moderate	50:50
Bush Terminal Park	Bagged Shell Reef	Stable	High	None	NA	NA	NA	NA
	Cabinet Reef (2016)	Stable	Stable	Fluctuating	Moderate	Low	High	Approaching
	Cabinet Reef (2018)	Positive	High	Fluctuating				
	Deepwater Cabinet	Stable	High	None	NA	NA	NA	NA
Brooklyn Navy Yard	SuperTray Nursery	Positive	Stable	Fluctuating	NA	NA	NA	NA
Coney Island Creek	Cabinet Reef	Positive	Stable	NA	NA	NA	NA	NA
Great Kills Harbor	2016 Cohort	Stable	High	None	NA	NA	NA	NA
	2017 Cohort	Stable	High	None	Moderate	Low	Moderate	Approaching
	2018 Cohort	Positive	High	None				
Lemon Creek Lagoon	Bagged Shell Reef	Negative	High	None	NA	NA	NA	NA
	ECONcrete Disks	Positive	High	None	NA	NA	NA	NA
	Mini Gabions	Negative	High	None	NA	NA	NA	NA
Williamsburg Field Station	Bagged Shell Reef 2021 Cohort	Negative	NA	NA	NA	NA	NA	NA
	Bagged Shell Reef 2022 Cohort	Positive	Stable	NA	NA	NA	NA	NA
Bayswater Point State Park	Bagged Shell Reef	Positive	High	Consistent	NA	NA	NA	NA
Head of Bay	Shell Reef	Positive	High	Consistent, but low	NA	NA	NA	NA
Paerdegat Basin	Cabinet Reef	Positive	Stable	Consistent, but low	High	Low	Moderate	Skewed
Soundview Park	Gabion Reef	Positive	Stable	None	NA	NA	NA	NA
	Shell Reef	Positive	Stable	None	Low	Low	High	Skewed

*Governors Island Ecodock not listed.

Table 2. Summary of recommended restoration action for each site.

Waterbody	Site	Recommended Restoration Action
Upper and Lower Harbor	Brooklyn Bridge Park - One15 Marina	- Continue post-installation monitoring. - Conduct biannual post-installation monitoring of installed reef balls. - Install the rest of phase 1 reef balls.
	Bush Terminal Park	- Continue post-installation monitoring. - Complete pre-installation activities for the expansion area. - Request a multi-phase oyster reef restoration project in a two-acre reef footprint in the southern half of the basin between Bush Terminal Park lagoons and Pier 5.
	Brooklyn Navy Yard	Continue annual post-installation monitoring.
	Coney Island Creek	Install cabinet reef earlier in the year to maximize community engagement events for the field season.
	Governors Island Ecodock	- Continue functioning as a nursery and temporary holding bay. - Continue annual post-installation monitoring.
	Great Kills Harbor	- Continue post-installation monitoring. - Consider removing the site due to high oyster mortality and disease presence.
	Lemon Creek Lagoon	Site was removed in April 2024.
	Williamsburg Field Station	Site was removed in June 2024.
Jamaica Bay	Bayswater Point State Park	- Continue post-installation monitoring. - Request to restock the bagged shell reef and consider adding a layer of blank shell bags to provide vertical relief from sedimentation.
	Head of Bay	- Continue post-installation monitoring. - Request to reseed the donor shell reef every 2-3 years.
	Paerdegat Basin	- Continue post-installation monitoring. - Conduct pre-installation monitoring for the expansion area.
Western Long Island Sound	Soundview Park	- Continue annual post-installation monitoring. - Reseed shell reef and install more reef balls to protect the shell reef.

Introduction

Restoration Objective

BOP seeks to assist in the recovery of functional, self-sustaining oyster populations to New York Harbor. To restore functional and self-sustaining oyster populations BOP will implement multi-acre restoration projects that add oyster spat and reef substrate in four regional waterbodies that make up New York Harbor: the Hudson River, Western Long Island Sound, Upper/Lower New York Harbor, and Jamaica Bay.

A functional oyster reef provides ecosystem benefits: they create habitat complexity and connectivity and enhance fish and invertebrate biodiversity, water filtration, and shoreline protection. Self-sustaining populations persist over time and reproduce without intervention; in other words, a reproductively active adult oyster population exists and suitable reef substrate is available. Annual recruitment is consistent and annual mortality is stable. Unlike the Chesapeake Bay, Southeast, and Gulf Coast, where robust wild oyster populations jumpstart restoration progress, New York Harbor is larvae-limited and substrate-limited, so significant intervention and adaptive management are necessary. While there is evidence of small self-sustaining wild oyster populations, their size, isolation, and the absence of reef substrate inhibit their expansion and function.

Restoration Strategy

To meet its goal of restoring 100 acres and one billion oysters by 2035 and to address the main factors inhibiting the recovery of functional, self-sustaining oyster populations, BOP aims to introduce multiple cohorts of oysters and add hard substrates.

1. Introducing Multiple Cohorts of Oysters

Oyster recruitment data from wild oyster surveys, larval dispersion and recruitment studies, and pilot restoration projects from 2006 to the present indicate the presence of isolated reproducing adult oyster populations in New York Harbor, especially in the Hudson River and western Long Island Sound. However, these populations are small and cannot sufficiently serve as a larval source for all of New York Harbor. To offset low or inconsistent recruitment, restoration projects need to introduce multiple cohorts of oysters over multiple years.

BOP's oyster performance data from sites Harbor-wide show substantial but expected mortality post-installation, especially in the first three years. This reflects restoration trends in other regions, including the Chesapeake Bay; the University of Maryland documented a 70% annual mortality in the first two months following the deployment of spat-on-shell (Webster & Merritt 2022). Annual mortality in the first three to four years of a restoration project results in substantially fewer adult oysters per acre compared to the number of spat initially introduced. The introduction of high numbers of spat during the initial deployment phase is an accepted practice among restoration practitioners and is a necessary strategy to counteract the high mortality rates.

The target stocking density at which successful restoration outcomes are achieved with minimal additional intervention required is not yet well understood in New York Harbor, but as described above, annual recruitment and annual mortality trends indicate a need for higher initial stocking densities at project onset. The literature also stresses that stocking densities vary depending upon several factors: water quality, disease, predation, oyster age, size, and proportion of females in the population (Moore et al. 2017). These factors create high annual variability, which can be further affected by habitat availability

in nearby areas. New York Harbor is characterized as a low recruitment, high mortality environment, so oyster restoration projects in New York Harbor require higher seeding density to reach positive population density and avoid the threshold of population states below which population extinction occurs. This is why BOP introduces tens of millions of spat per installation or phase. Intervention is expected and necessary.

2. Adding Substrate

Oysters require substrate, such as rocks, shells, or other hard structures, to provide a stable surface on which oyster larvae attach and grow, forming dense, interconnected reef structures. The vertical relief facilitates higher rates of oyster survival and growth and larval settlement and recruitment (Theuerkauf et al. 2015; Ziegler et al. 2018) - trends that lead to positive population growth. Hard substrate is absent in the Harbor due to the loss of oyster reef habitat, shoreline filling, and dredging, so much of the estuary bottom is characterized by fine, soft sediment. Unlike soft sediment, which offers limited attachment points and shelter, hard-structured habitats with intricate surfaces provide a diverse array of refugia and microhabitats for oysters, sedentary species, and motile species of invertebrates and fish (Peterson & Kulp 2013; Glenn et al. 2020). The addition of hard substrate and enhancement of habitat structural complexity notably increases biodiversity (species richness and species abundance) of mobile species (Karp et al. 2018), epibenthic and infaunal invertebrates (Rodney & Paynter 2006), increases vertical relief of the bottom to encourage higher rates of oyster larvae settlement and recruitment (Theuerkauf et al. 2015; Ziegler et al. 2018) (as well as the settlement of other epibenthic species, such as mussels), and promotes species interactions (Reeves et al. 2020).

Since 2010, BOP has piloted restoration techniques and applied lessons learned from regional partner projects, using gabions, reef balls, shell, oyster castles, cages, and small concrete structures (McCann 2019). BOP directly seeded or filled these structures with juvenile oysters (spat) to offset low or inconsistent recruitment as site-specific conditions or project designs required. By directly seeding reef structures in a remote setting facility, BOP simultaneously applies both restoration strategies (1: adding multiple cohorts of oysters, and 2: adding substrate) to add large quantities of spat per installation or project phase.

The lessons learned and data from BOP's pilot projects provide valuable insight into larval setting rates, oyster performance, substrate suitability, and ecological uplift in an urbanized estuary.

Our projects aim to achieve the following objectives:

- Complete pre-installation monitoring to understand baseline conditions at the site.
- Install an appropriately sized reef footprint and reef area with a proportionate quantity of spat based on pre-installation monitoring and pilot data.
- Install seeded and unseeded reef substrate to provide suitable surface area for oyster reef development and habitat enhancement.
- Propose a post-construction monitoring plan and adaptive management strategies to evaluate success over time.
- Phase the project over multiple years to introduce multiple age classes of oysters.

Regional Waterbodies

BOP leads ongoing oyster restoration projects and an active pipeline of proposed oyster restoration projects that would advance its goal to restore a self-sustaining oyster population within four regional waterbodies in New York City: 1) Upper and Lower New York Harbor, 2) Hudson River, 3) Jamaica Bay, and 4) Western Long Island Sound (**Figure 1**).

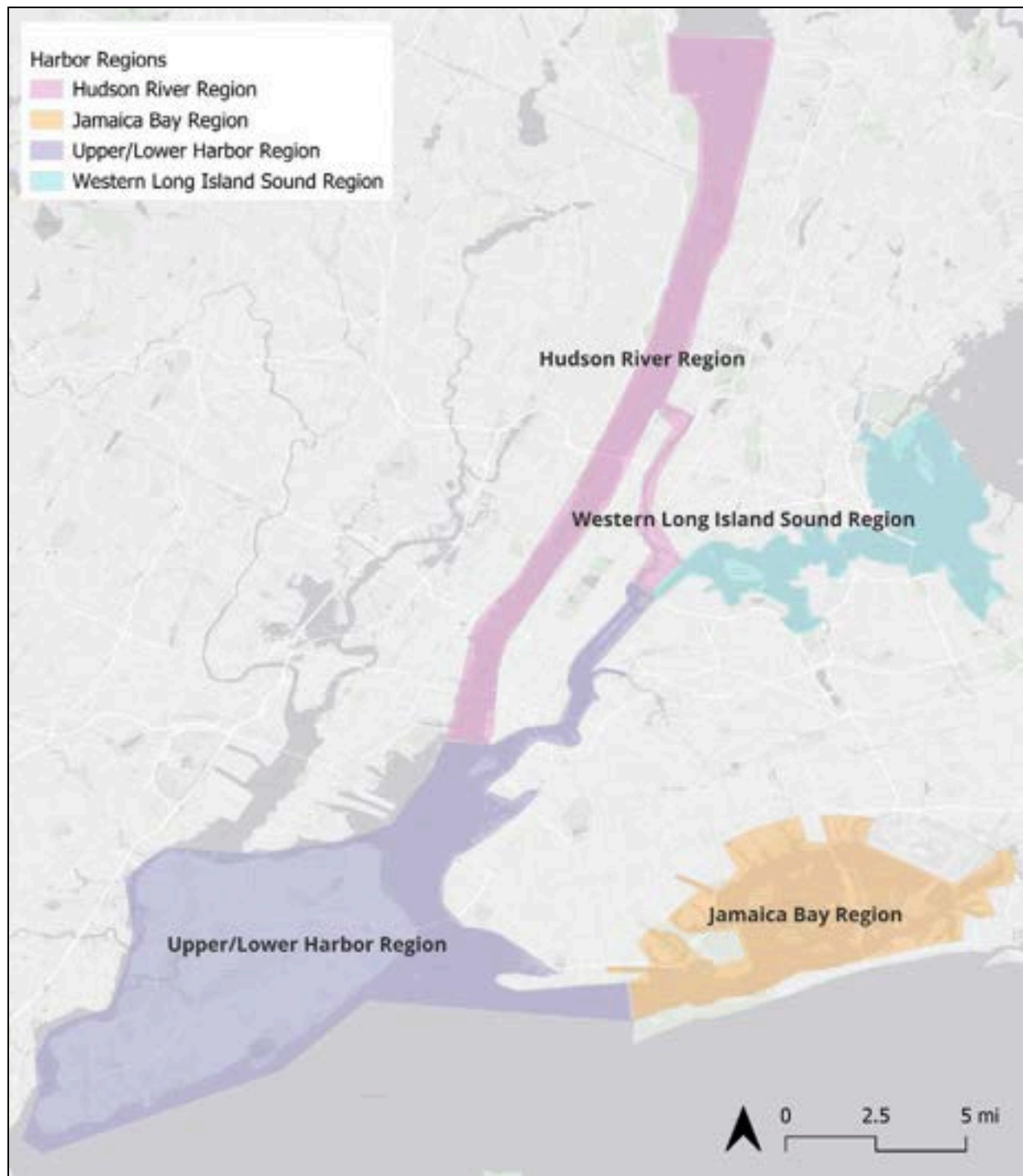


Figure 1. Map of regional waterbodies in the New York Harbor.

Summary of Sites

Table 3 summarizes the restoration sites in New York Harbor that BOP is actively monitoring. While the majority of the post-installation monitoring is occurring in restoration sites located within the Upper and Lower Harbor, BOP is working on expanding the restoration of other regional waterbodies, specifically large-scale restoration in the Western Long Island Sound and Hudson River.

Table 3. Summary of active restoration sites in 2024 by regional waterbodies.

Waterbody	Site	Structure	Structure Placement	Status of Site
Upper and Lower Harbor	Brooklyn Bridge Park - One15 Marina	Cabinet Reef (BBPC)	On-bottom	Post-Installation
		Gabion (BBPG)		
		SEAPA Nursery (BBPN)	Off-bottom	Installation in 2024
		Bay Ball Reef	On-bottom	
	Bush Terminal Park (BTP)	Bagged Shell Reef	On-bottom	Post-Installation
		Cabinet Reef		
		Deepwater Cabinet		
	Brooklyn Navy Yard (BNY)	SuperTray Nursery	Off-bottom	Post-Installation
	Coney Island Creek (CIC)	Cabinet Reef	On-bottom	Post-Installation Annual Structure Removal
	Governors Island Ecodock (GIE)	SuperTray Nursery	Off-bottom	Post-Installation Annual Structure Removal
	Great Kills Harbor (GKH)	SuperTray Nursery	Off-bottom	Post-Installation
	Lemon Creek Lagoon (LCL)	Bagged Shell Reef	On-bottom	Post-Installation Site Removed in 2024
		ECONcrete® Disks		
		Mini Gabion Reef		
	Williamsburg Field Station (WFS)	Bagged Shell Reef	On-bottom	Post-Installation Site Removed in 2024
		Cabinet Reef		
Jamaica Bay	Bayswater Point State Park (BW)	Bagged Shell Reef	On-bottom	Post-Installation
	Head of Bay (HOB)	Shell Reef	On-bottom	Post-Installation
	Paerdegat Basin (PB)	Cabinet Reef	On-bottom	Post-Installation
Western Long Island Sound	Soundview Park (SV)	Gabion Reef	On-bottom	Gabions Removed in 2024
		Shell Reef	On-bottom	Post-Installation
		Bay Ball Reef	On-bottom	Installation in 2024

Restoration Background

This section provides a brief introduction to the oyster sources, structures, and methodology used for monitoring activities at our restoration sites. An explanation of the grading metric is also provided to identify the key metrics used to assess oyster performance and health at each site or structure.

Larval Sources

In past years, BOP sourced larvae from Muscongus Bay Aquaculture (Maine, USA). In 2023, BOP expanded its sourcing to include Oyster Seed Holdings, LLC (Virginia, USA). A list of larvae suppliers are listed in **Table 4**.

Once larvae are obtained from approved hatcheries, larvae are directly set to cured shells (recycled from partner restaurants) or reef substrates in the Remote Setting Facility on Governors Island. After two to four weeks in the setting facility, the seeded structures are then deployed to permitted restoration sites. Wild oyster larvae may also recruit to restoration sites and set to the developing reef. For more information on the oyster life cycle and our shell collection process, please refer to BOP's website.

Table 4. Summary of hatcheries and quantity of larvae procured.

Larvae Supplier	Location	Number of Eyed Larvae Procured	
		2023	2024
Muscongus Bay Aquaculture	Bremen, ME	NA	66,400,000
Oyster Seed Holdings	Hudgins, VA	129,000,000	95,000,000

Oyster Structures

BOP applies oyster restoration techniques to each site based on site-specific conditions, project objectives, and our evolving understanding of best management practices for oyster restoration in a heavily urbanized city. The current techniques are included in **Table 5**.

Table 5. On-bottom and off-bottom structures used for oyster restoration.

Structure Figure and Description	
 SuperTrays UV-resistant aquaculture plastic trays measuring 2' x 2'. SuperTrays are stackable, filled with spat-on-shell, and may be bridled together using a $\frac{3}{8}$ inch polypropylene line to facilitate setting in the remote setting facility or suspension from floating docks or piers.	 SEAPA Cages 20L baskets are typically used in aquaculture to grow oysters, these structures are filled with spat-on-shell and suspended off-bottom in stacks of 2-3 to form nurseries. BOP uses SEAPA cages with the following dimensions: 2.5' x 8" x 6".
 Bagged Shell Individual plastic mesh bags that hold approximately 600 shells and 0.3 cubic yards of material. Individual bags are submerged in the intertidal area, which can be accessed via wading during low tide and secured with PVC pipes that are inserted on the outer edge of the plot.	 EConcrete® Disks EConcrete® disks provide a substrate for biofouling marine organisms, including oysters. Each disk is approximately 10-12 lbs and has a diameter of approximately 10 inches. The disks can interlock when stacked on top of each other, the stack is then stabilized by placing a shaft anchor through the middle of each disk.
 Cabinet Reef Welded rebar frames that contain mesh files filled with oysters. Cabinet reefs facilitate hands-on programming by students and community members. BOP uses two sizes of cabinets, a 4' x 2' x 2' welded rebar frame with 14 mesh files, and a 10' x 2' x 2' with 28 mesh files.	 Gabion Welded steel structures filled with spat-on-shell. Once installed, they act as surrogate reef structures in the absence of natural oyster reefs while the juvenile oysters grow, and create a three-dimensional habitat for benthic species. BOP has used three sizes of gabions (cube: 1' x 1', rectangle: 2' x 1', large: 4' x 2' x 2').
  Reef Ball Reef balls of varying sizes are used to mimic the structure and function of a natural oyster reef. Bay balls are a type of reef ball. Bay ball units weigh up to 500 lbs each. These units may be cast with a footer to minimize subsidence in soft sediment and may be installed unseeded or seeded with juvenile oysters. In some cases, they are deployed with the assistance of a marine contractor.	

Monitoring Methodology

Oyster Performance

Depending on the restoration structure and approach and site conditions, one of two monitoring protocols are utilized to assess oyster performance: clump monitoring or quadrat monitoring. Clump monitoring is used when oysters are loose and unaggregated and is typical for recent spat-on-shell installations. Quadrat monitoring is used when oysters are cemented to each other and is typical for reef balls or older spat-on-shell installations. Clump monitoring involves the evaluation of 30 oyster clumps per structure, defining clumps as shells containing varying quantities of oysters. This method serves as the default protocol unless oysters have grown through existing structures and begun reefing, at which time they cement to each other. Quadrat monitoring, in contrast, entails assessing all oysters within a quadrat sized appropriately for the structure. At many reef sites, BOP begins with clump monitoring and transitions to quadrat monitoring as the reef grows and expands.

At each reef site, both live and dead box oysters (oysters with both valves intact) are assessed. Shell height is measured from the umbo (hinge) to the outermost edge of the oyster using calipers. The shell height measurement to the nearest whole millimeter is recorded. Additionally, the oysters are checked to determine if they are alive or dead. Signs of a dead oyster include visibly gaping open shells, softness or movement in the shell, discharged bubbles when the shell is lightly pressed, or hollow sounds when the shell is tapped lightly. The density of oysters per shell or per structure is also measured.

Wild recruitment is assessed by counting all the oysters with shell heights less than 25 mm at least one-year post-installation or during a wild oyster survey. Oysters introduced by BOP would have grown more than 25 mm after one year, which means any oysters that are smaller than 25 mm are wild recruits at the site. A wild oyster survey is typically conducted in the fall (we recommend October for New York Harbor and Hudson Raritan Estuary) by which time reproduction should have occurred and any recruits grown large enough to be visible during intertidal shoreline surveys. The survey involves counting and measuring all oysters found within one meter left and right of a transect of known length.

BOP estimates the current oyster population for each site by considering the initial population size, annual percent mortality, and annual percent recruitment. Annual percent mortality is calculated as the total number of dead box oysters divided by the total number live and dead box oysters sampled. Annual percent recruitment is calculated as the total number of juveniles (< 25 mm) divided by the total number of live and dead box oysters sampled. The current oyster population is estimated by subtracting the annual percent mortality and adding the annual percent recruitment to the previous population estimate. Because there is only a single estimate of these values without a measure of variance, the current oyster population estimate is not calculated with a standard deviation or other measure of variance. Over time, we expect annual mortality to stabilize as the restored reef matures and consistent recruitment balances out mortality. But if reefs are not re-seeded or recruitment is insufficient, mortality rates may increase 4-7 years post-installation.

Oyster Health

Disease and reproduction are major factors that can impact the health and performance of restored oysters. Monitoring the reproductive status of adult oysters provides us with information about the reproductive timing and capability of a restored oyster population. Dermo (caused by *Perkinsus marinus*) and MSX (caused by *Haplosporidium nelsoni*) are parasitic protozoan diseases that can infect oysters with detrimental effects. Typically, 10 to 30 introduced adult oysters (2-3 years old) from select sites are

sampled and sent to the Stony Brook University Marine Animal Disease Lab (Stony Brook, NY) to complete diagnostics for oyster health metrics.

Benthic Species Characterization

Benthic species characterization is conducted during pre-restoration site investigations. All benthic grab samples are to be used for infaunal analyses and collected along predetermined transect lines. The number of transects and grab samples will be determined based on site size. Grab samples can be conducted via foot in wadable areas or by vessel in non-wadable areas.

Grab samples are collected using either a stainless steel Wildco hand corer or a Ponar/van Veen sediment grab anchored to a davit of a vessel. The use of the different benthic grab samplers will be determined by cost, availability, and vessel resources to support the sampler weight.

The sediment samples are washed on a 0.5 mm sieve in the field and sent to a lab for identification to the lowest practical taxon (species when possible) following standard taxonomic keys and weighed. Benthic grab samples are used to determine the benthic community composition and characteristics (diversity, biomass, and abundance). This data will be used as a baseline for future analysis of the impact of restored oyster reefs on the biodiversity in the area.

Mobile Species Characterization

As biogenic habitat constructors, oyster reefs can support a high level of biodiversity. Epibenthic and mobile biodiversity sampling will be determined by species abundance and species richness across all sites and structures using a combination of methods, including 1) trapping, 2) seining, and 3) passive visual observation during monitoring events. Data will generally be collected by trapping and seining over the field season (spring to fall) while observational data will be gathered at various frequencies with each site visit.

Trapping: Baited and unbaited minnow or sea bass traps are deployed for 48-72 hours at the site. Occasionally, traps are filled with shells to roughly 50% capacity. All traps are attached to a line off a pier or staked along the shoreline to prevent them from being washed away. Staff swiftly remove the traps from the reef, transfer the trapped contents to plastic trays, and rinse with seawater directly from the site to collect any additional dislodged organisms.

Seining: This method is primarily used in intertidal areas that are wadable at low tide. A minimum of two people are required to conduct a seining. At least three seine hauls are typically conducted at each site.

Observation: Mobile species like fish and crabs utilize the restored oyster reef for different purposes, which include but are not limited to foraging, shelter, refuge, etc. (Mercaldo-Allen et al., 2023). Young mobile species can take residence in restored oyster structures and become stuck when they grow too big to escape. Therefore, staff have passively observed and reported mobile species that are found within structures during monitoring activities.

Depending on the number of organisms collected and staff capacity, either all individuals or just a subset of each species are identified and total length (including the caudal fin for fish) is measured. Typically, only the size of fish and crabs is measured, not that of snails and other organisms. Species are identified,

counted, photographed for species identification, and measured using a fish board or calipers before being released back into the water at the site.

Grading Metrics

To assess the performance and health of oyster restoration at each site, seven metrics are used to evaluate oyster growth, mortality, recruitment, reproduction, and disease with assigned qualitative grades. These metrics do not directly indicate whether the restoration activities are providing ecosystem benefits (e.g., biodiversity enhancement, water quality improvements), although growth indicates oysters are feeding, and thus filtering the water, and oysters store some carbon in shells and tissues as they grow. Not all metrics can be applied to every site due to the type of site conditions, date of restoration installation activity, or age of restored oysters. Some metrics are not relevant in the first 1–2 years of restoration (i.e., recruitment, reproduction, disease). The seven metrics are described in **Table 6**.

Table 6. List of oyster performance and health metrics used to assess oysters at restoration sites.

Metric Category	Parameter and unit of measurement	Explanation	What indicates good oyster performance?	Available Grades
Growth	Shell height (unit: mm)	Oyster growth is assessed by measuring the total shell height from the umbo to the outermost edge.	Mean shell height increases within the growing season and between years.	Positive Stable Negative
Mortality	Annual mortality is calculated by the number of dead box oysters sampled divided by the total number of live and dead box oysters sampled (unit: %)	Oysters naturally have a high mortality as spat and after the initial period of high mortality, mortality should eventually stabilize.	Annual mortality stabilizes after the initial mortality.	Low Stable High
Recruitment	Multiple peaks on size frequency histograms	Size frequencies are calculated based on the total number of sampled oysters that are classified into specific size groups.	More than one peak on the size-frequency histogram indicates the recruitment of new oysters.	Consistent Fluctuating or Consistent, but low None NA (not enough data)
	New spat (oysters <25 mm one year post-installation) = new recruitment	Mature oysters produce larvae that are pelagic and swim in the water for 2-3 weeks. After, the larvae transition to the bottom, settling onto hard substrates such as oyster shells or rocks.	The presence of naturally recruited wild oyster spat.	
Reproduction	Stages of gonadal development (unit: % of individuals per stage) to calculate percent spawning per sample (stages S1-S4)	Stages are determined based on expert assessment of gonad condition that describes the development of gonads and gametes within oysters and readiness to spawn.	Oysters mature following their second year of life. Therefore, only these larger/older oysters are sampled. An equal ratio of males and females with developing or fully ripe gonads indicates a well-performing oyster population.	Spawning: Low Moderate High
	Sex ratio	Oysters switch sexes during their adult life. They all begin as males. As oysters mature, their ratio in the population approaches 50:50 (i.e., one female to one male).		Sex Ratio: 50:50 Approaching Skewed
Disease	Disease prevalence (unit: %) and intensity (unit for MSX is qualitative, i.e., low, medium, and high, and for Dermo, the Mackin Scale from 0 to 5)	Dermo and MSX are types of oyster diseases that can lead to lower fitness and mortality. Prevalence describes the proportion of individuals that are infected, while intensity describes the degree of infection.	Older oysters (~2-3 years old) are susceptible to diseases, especially in high-salinity waters. Consistent low prevalence and intensity or gradual increase of prevalence and intensity over a long period of time is considered good oyster health at the site.	Dermo: Low Moderate High MSX: Low Moderate High

Growth and Recruitment

Oysters are expected to survive and grow over time, although smaller oysters may experience higher mortality rates. As differences exist within a site (e.g., crowding, location on the reef) and among individual oysters (e.g., genetic variations), these differences are likely to become more noticeable as the oysters grow. To visually analyze these changes, smoothed density plots or histograms, which account for differences in sample sizes, are employed. These plots allow for easy assessment of oyster growth or the impacts of other factors by comparing graphs for different sampling periods, structures, or cohorts.

In the case of a single cohort of oysters of similar age, their shell heights are expected to follow a normal distribution, forming a bell-shaped curve with a single peak and two nearly symmetrical tails. However, if there are multiple cohorts of oysters present in a single sample, multiple peaks, not necessarily of equal size, may be visible. When comparing data from different sampling dates, it is not uncommon to observe smaller oysters in later samples than in earlier samples. This could be due to slow growth during specific periods or because only a portion of the oyster population is sampled. Additionally, the appearance of smaller oysters in later samplings may also be a result of a new cohort due to natural settlement events.

Mortality

Like growth, oyster mortality is an important metric in understanding the success of oyster restoration, but it can be difficult to track over time as oyster reefs become more spatially complex and as new recruits settle to the reef.

Juvenile oysters, called spat, attach to hard substrate in high densities. At small sizes, spat are especially vulnerable to predation and environmental stressors. The spat grows quickly over the first 1–2 years of life, but as they grow they must also compete for space and food. As a result, only a few oysters which recruit to or are restored to a reef are expected to survive to adulthood. Mortality is thus expected to be greatest in the first several years after installation. As oysters grow, the mortality rate of mature individuals should decline and stabilize over time and may rise again 4–7 years post-installation as oysters die of old age or disease. Mortality can be measured in several ways, depending on the reef structure, pace of oyster growth, and accretion.

Disease

Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) are two parasitic protozoan diseases that can infect oysters with detrimental effects (Mackenzie Jr. 2007). Dermo intensity is reported on the Mackin scale from 0 to 5, with 5 being the highest intensity. Rankings of 3 or higher typically indicate lethal intensities that are presumed to cause mortality. MSX diagnosis was made using histopathology on formalin-fixed sections. For these diseases, “prevalence” refers to the percentage of the population that tests positive for a given disease, and “intensity” refers to the degree to which an individual oyster is infected with a given disease.

Reproduction

It is necessary to monitor the reproductive timing and capability of a restored oyster population. Oysters have separate sexes and can switch sex (male to female and back, Thompson et al. 1996) at the time of sexual maturity (typically ~2 years after settlement). In addition, oysters’ gonads produce gametes (eggs and sperm) only during warmer seasons, when they are preparing to spawn. To determine the stage of

reproductive development, both (1) sexual maturity and (2) readiness to spawn are assessed (**Table 7**). The sex ratio is determined to understand the likelihood of successful fertilization upon spawning.

Table 7. Stages of reproductive development in oysters as assessed by the Stony Brook University Marine Animal Disease Lab.

	Stage	Description
I	Inactive	No gonadal activity, resting
G1	Gametogenic I	Gametogenesis has begun; no ripe gametes visible
G2	Gametogenic II	First ripe gametes appeared; gonad developed to about one-third of its final size
D1	Developing I	Gonad increased in mass to about half the fully ripe condition; each follicle contains about equal proportions of ripe and developing gametes
D2	Developing II	Gametogenesis still progressing; follicles mainly contain ripe gametes
R	Ripe	Gonad fully ripe, early stages of gametogenesis rare; follicles distended with ripe gametes; ova compacted into polygonal configurations; sperm with visible tails
S1	Spawning I	Active emission of gametes has begun; gamete density reduced
S2	Spawning II	Gonad about half empty
S3	Spawning III	Gonadal area reduced; follicles about one-third full of ripe gametes
S4	Spawning IV	Only residual gametes remain; some may be undergoing cytolysis
U	Undetermined	Gonad tissue rudimentary (completely undeveloped, as is the case in very young oysters) or absent

Typically, oysters with gonads that are categorized as gametogenic (G1–G2) or developing (D1–D2) are preparing to spawn, while those that are ripe (R) or spawning (S1–S4) are actively reproducing (**Table 7**). Oysters in inactive (I) or undetermined (U) stages are either not ready to spawn or have recently spawned (**Figure 2**). Since oysters can change sex between male and female, equivalent (50:50) or female-skewed sex ratios indicate that a population has reached sexual maturity and conditions are optimal for successful fertilization (Powell et al. 2013, Harding et al. 2013). Some individuals can have both male and female reproductive organs. The term "hermaphrodite" is used by biologists to refer to non-human organisms that have both male and female reproductive organs, whereas the term "intersex" is used to describe people with both male and female reproductive or sexual anatomy.

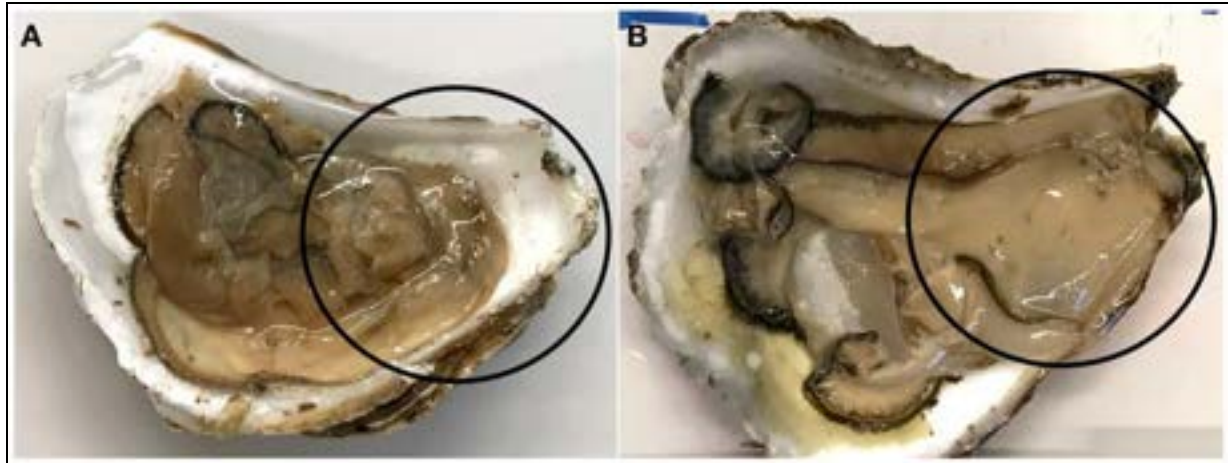


Figure 2. These pictures compare gonad development (circled) in (A) inactive or “unripe” and (B) “ripe” oyster tissue. (Photos courtesy of Dr. Elizabeth Burmester and Dr. Mike McCann)

Upper and Lower New York Harbor

The Upper and Lower New York Harbor region spans from Randalls Island in the north, extending south down the East River, to include Manhattan, Queens, and Brooklyn shorelines, as well as the Verrazano Narrows (**Figure 3**). This very active waterway is the most urbanized of the four regional waterbodies with a shoreline dominated by vertical seawalls, riprap revetments, and piers. Fast currents move through deepened navigational channels. As the Hudson River and East River meet in the Harbor and Narrows, oyster larvae from wild populations in the Hudson near Tappan Zee and Western Long Island Sound region may recruit to substrate in Upper and Lower Harbor. It is therefore critical to add substrate to restoration sites in this region. Smaller bays and coves between piers and waterfront parks are potential protected locations for restoration. As new restoration projects progress and data comes in from projects, and as new opportunities present in 2025, Billion Oyster Project will likely divide the Upper and Lower New York Harbor Region into two distinct waterbodies: the Upper Harbor and the Lower Harbor/Raritan Bay. **Table 8** summarizes the restoration sites and installation details in this regional waterbody.



Figure 3. Map of restoration sites within Upper and Lower New York Harbor.

Table 8. Summary of restoration structures and installation details of each site in the Upper and Lower New York Harbor, organized by installation date.

Site	Structure	Installation date	Larvae source *	Mean shell height at installation (mm)	Number of oysters installed
Great Kills Harbor	SuperTray Nursery	8/23/2016	Muscongus Bay, ME	27.7	15,836
		6/12/2017	Oysters reared in Great Kills Harbor oyster cages	4.1	141,327
		7/10/2019	Muscongus Bay, ME	2-5	200,000
Bush Terminal Park	Deepwater Cabinets	6/28/2016	Muscongus Bay, ME	~2	387,781
	Cabinet Reef	6/28/2016	Muscongus Bay, ME	~2	581,671
		8/22/2018	Muscongus Bay, ME; NYHS Hatchery	~5	180,000
	Bagged Shell Reef	8/23/2018		~5	133,986
Brooklyn Navy Yard	SuperTray Nursery	Fall 2014	NYHS Hatchery	~5	226,000
		Spring 2015	Muscongus Bay, ME	~5	3,500,000
		4/10/2017		29.5	7,500
Lemon Creek Lagoon	ECONcrete® Disks	8/15/2018	NYHS Hatchery	~5	242,000
	Gabions	8/15/2018	Muscongus Bay, ME	~5	
	Bagged Shell Reef	8/15/2018	Muscongus Bay, ME; NYHS Hatchery	~5	
Brooklyn Bridge Park Nursery	SEAPA Cage Nursery	8/28/2020	Muscongus Bay, ME	2-5	215,280
Brooklyn Bridge Park - One15 Marina	Cabinet Reef	9/8/2021	Muscongus Bay, ME	2-5	185,071
	Gabions	8/30/2021		2-5	588,861
	Reef Balls	8/23/2024		2-5	13,400,000
Williamsburg Field Station	Cabinet Reef	9/15/2021	Muscongus Bay, ME	2-5	151,422
	Piling Wrap	10/07/2021		2-5	~7,000
	Bagged Shell Reef	9/17/2021		2-5	270,000
		10/25/2022		2-5	36,735
	SEAPA Cages	07/05/23	Oyster Seed Holdings, VA	2-5	12,000
Coney Island Creek	Cabinet Reef	8/21/2024	Muscongus Bay, ME	2-5	159,152
Governors Island Ecodock	SuperTray Nursery	08/03/2023	Oyster Seed Holdings, VA	2-5	1,200,000
		8/14/2024	Muscongus Bay, ME	2-5	1,432,368

* See Larval Sources on [page x](#) for a complete explanation of oyster sources.

Brooklyn Bridge Park

Project Summary

As of 2024, BOP maintains and monitors several installations in Brooklyn Bridge Park near One°15 Marina and Pier 4 with direct support from New York Harbor School students and interns, local students, and community groups. The project aims to provide insight into oyster health and the performance using on and off-bottom restoration techniques, progressing towards the implementation of larger scale on-bottom restoration at the site. In addition, the project offers public engagement opportunities that reconnect people to the waterbodies surrounding New York Harbor, as well as to the wildlife thriving along the shorelines and in the shallows.

Data trends from 2020-2024 indicate conditions are supportive of larger-scale oyster restoration:

- Oysters are surviving to reproductive age and spawning.
- Annual mortality across all installations averages around 15%, which may be normal or below normal for New York Harbor.
- Average percent recruitment generally declines with recruitment density following a similar trend across all structures.
- Disease prevalence and intensity are low and oysters aged 3+ years are spawning.

Site Overview

In 2020, BOP installed an oyster nursery with thirty SEAPA cages at ONE°15 Marina and Brooklyn Bridge Park as a pilot project (**Figure 4**). In 2021, a field station with three removable oyster cabinets was installed adjacent to Pier 4 Beach and ONE°15 Marina, along with a subtidal reef consisting of five on-bottom gabions at depths ranging from 8-20 feet offshore of Bird Island (**Figure 4**). Additionally, in 2024, 67 bay balls seeded with 13,400,000 spat and eight unseeded bay balls were installed within a one-acre project footprint at Pier 4 in Brooklyn Bridge Park, adjacent to ONE°15 Marina and Pier 3 (**Table 9**).

Table 9. Summary of structures installed and spat introduced at Brooklyn Bridge Park.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
SEAPA Cage Nursery	2020	30	215,280	Biannual
Cabinets Reef	2021	3	185,071	
Gabions	2021	5	588,861	Annual
Reef Balls	2024	75	13,400,000	Biannual



Figure 4. Map of Brooklyn Bridge Park installations as of 2024. The locations of the 2024 reef balls are based on side scan sonar imagery taken in March 2025.

From 2020 to 2024, BOP assessed oyster performance in the SEAPA nursery, community cabinets, and deepwater gabions, with support from New York Harbor School students, interns, local students, and community groups. These structures provide valuable engagement opportunities for students and the community, and offer baseline data that supports the expansion of on-bottom oyster reef habitat to two acres. The SEAPA cages at the Brooklyn Bridge Park Nursery were monitored in the spring and fall to assess oyster performance and conduct regular site maintenance. Monitoring of the community cabinets was conducted biannually and switched to annual monitoring in 2024 due to the increasing number of sites requiring assessment. The gabions were monitored once per year, typically during the summer or early fall.

During monitoring events, BOP staff have observed various fish and invertebrate species inhabiting the oyster shells within the structures and documented the presence of these fauna. In 2024, BOP staff and interns conducted a pilot study to assess fish biodiversity at the Brooklyn Bridge Park Nursery. The study involved deploying three minnow traps for 2–3 days consistently from July to August. Skilletfish, Atlantic silverside, blackfish, flounder, oyster toadfish, cunner, and other fish species were observed during both routine monitoring and trapping efforts, as detailed in **Appendix Figure A1**.

Oyster Performance

Brooklyn Bridge Park/One15 Marina SEAPA Nursery

Growth: Positive

Live oysters in the SEAPA nursery exhibited positive growth from a mean shell height of 11.8 mm in 2020 to 57 mm in 2023 and 70.4 mm in 2024 (**Figure 5**). Oysters typically show increased size by the fall monitoring period, having benefited from warmer summer waters that enhance feeding. In contrast, growth is slower during the spring monitoring period due to reduced metabolic activity over the cold winter months.

Mortality: Low

Annual mortality of the SEAPA nursery is low, compared to the other structures at Brooklyn Bridge Park, fluctuating between 10.4% to 14.4% in 2023 and 2024, respectively. (**Figure 5**). The height of the hanging SEAPA cages could limit predation from oyster drills that were more evident in the cabinet reefs.

Recruitment: Consistent, but low

Despite lower recruitment percentages in 2023 (3.6%) and 2024 (2.0%) compared to previous years (51.7% in 2021), **Table 11** and **Figure 5** show a consistent annual peak of oysters measuring less than 25 mm one year post-installation. This suggests ongoing wild recruitment to the SEAPA nursery.

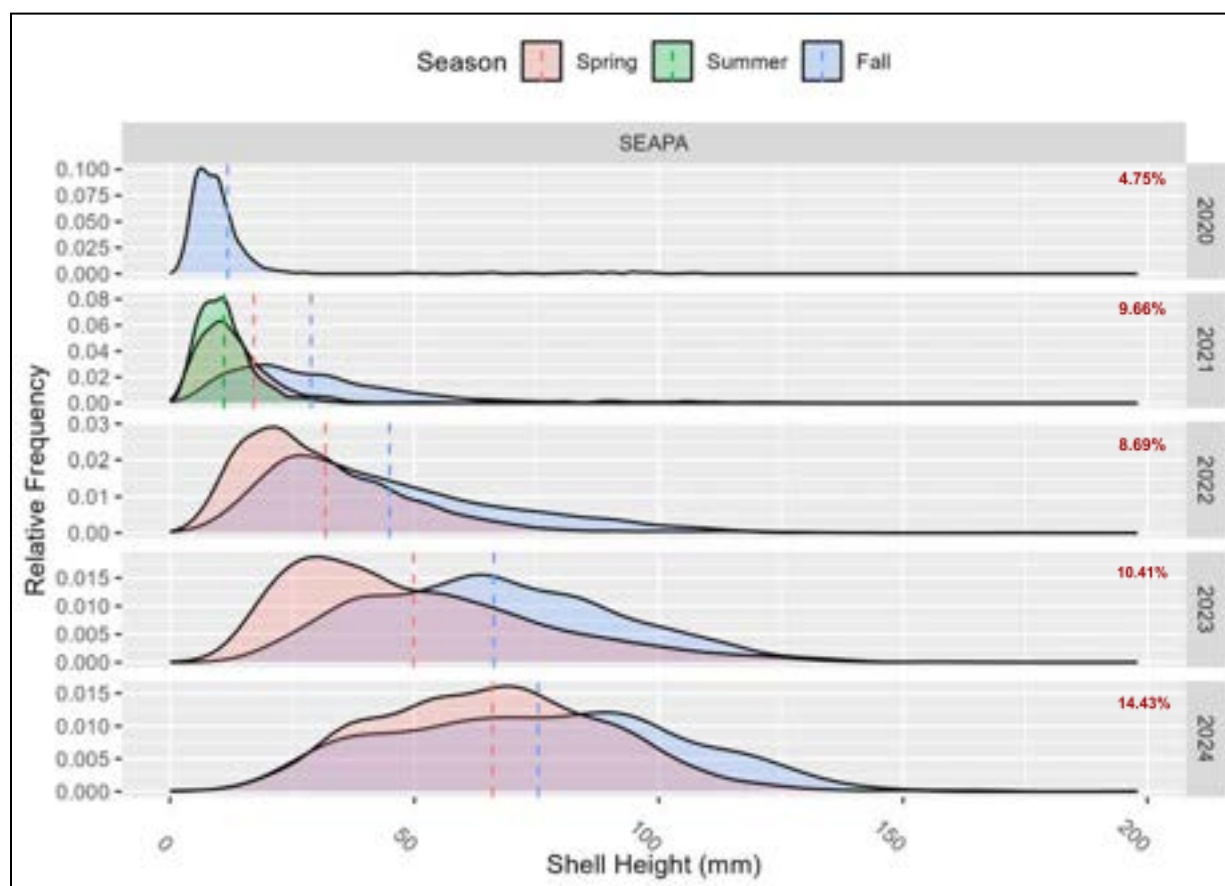


Figure 5. Size-frequency histogram of live oysters in SEAPA nursery, 2020-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Brooklyn Bridge Park/One15 Marina Cabinet Reef

Growth: Positive

Analysis of the cabinet reef data indicates a steady positive growth trend. The mean shell height of live oysters increased from 16.4 mm at the time of installation in 2021 to 26.8 mm in 2023, and continued to grow to 30.3 mm in 2024 (**Figure 6**).

Mortality: High

Because they were deployed in the fall of 2021, this cohort of spat likely experienced significant die-off in the colder conditions over the winter of 2021-2022. Oyster drill predation is also a likely cause of mortality due to their presence and prevalence during monitoring events. These oysters are also frequently handled: BOP staff, community groups, and student groups remove these oysters from files during interactive programming and monitoring events. This stress may contribute to the increasing percent mortality up to 76.9% in 2023 and 78.1% in 2024, compared to other Brooklyn Bridge Park structures (**Figure 6**).

Recruitment: Consistent

There is a consistent occurrence of smaller (<25 mm), and therefore, younger oysters at the site. In 2024, the percent recruitment of sampled oysters was 24.56% (**Table 11**), averaging around 0.07 live recruits per shell (**Table 10**). Young oysters were also observed in 2023 (19.92% of sampled oysters), so annual recruitment is considered consistent (**Table 11**).

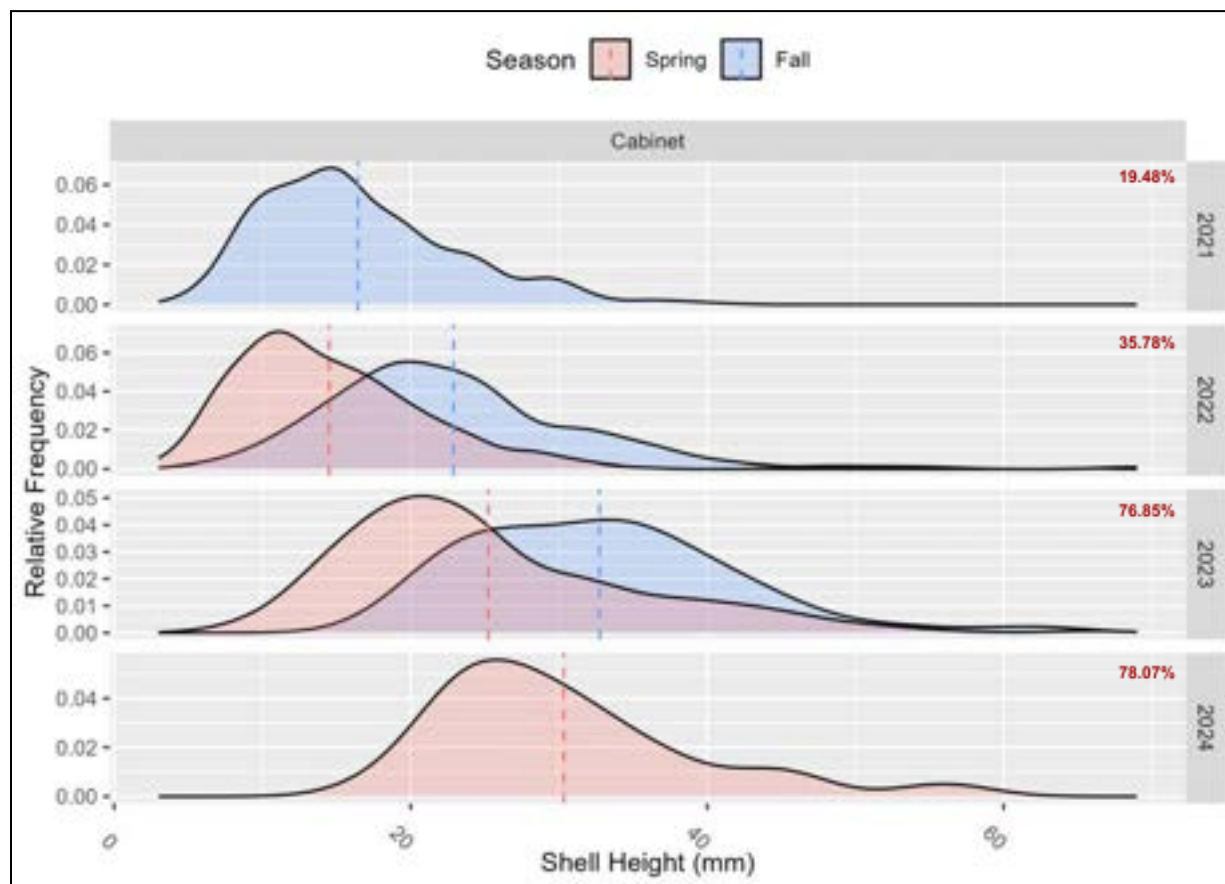


Figure 6. Size-frequency histogram of live oysters in cabinet reef, 2021-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Brooklyn Bridge Park/One15 Marina Gabions

Growth: Positive

Similar to the other structures, the oysters in the subtidal gabions show a positive trend in oyster growth as the overall size frequency expands horizontally, with the mean shell height increasing from 19.3 mm in 2022 up to 33.0 mm in 2023 and 38.4 mm in 2024 (**Figure 7**).

Mortality: Stable

Annual mortality is stable between 25-27% in 2023 and 2024 (**Figure 7**), suggesting that predation by oyster drills is less of a factor in the gabions than the cabinets situated at a shallower depth. In addition, oysters in the subtidal gabions are only handled once per year and accessible only to divers.

Recruitment: Consistent

There is a consistent occurrence of smaller (<25 mm), and therefore, younger oysters at the site. In 2024, 14.8% of the oysters monitored were recorded as recruits, which is a decrease compared to 2023, when the percent recruitment was 29.3% (**Table 11**). Yet, these percentages of recruitment suggest that wild recruitment is occurring to the gabions.

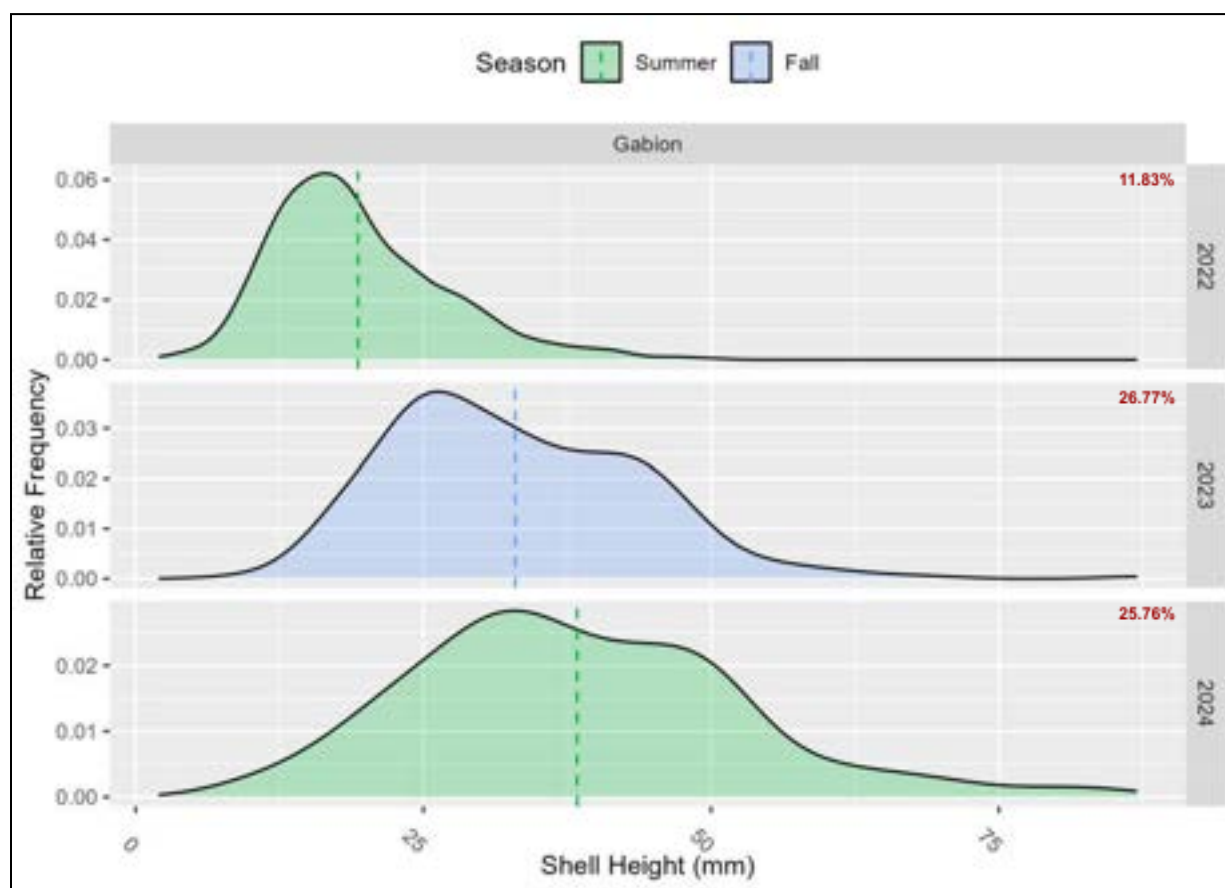


Figure 7. Size-frequency histogram of live oysters in subtidal gabions, 2022-2024. The dashed line represents the annual mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Density

The following oyster density calculations are relevant for sites and structures where juvenile oysters are set on recycled oyster shells (i.e., “spat on shell”). Once deployed at a restoration site, oyster density is calculated as the number of live oysters per shell, and live recruitment is calculated as the number of

oysters under 25 mm per shell, based on clump monitoring conducted across all structures. Overall, oyster density generally decreases over time and sometimes plateaus, which is expected as oysters grow and compete for limited space. The nursery exhibited the highest oyster density, with an average of 2–4 live oysters per shell in both 2023 and 2024 (**Table 10**). Among the two on-bottom structures at this site, the gabion reef showed higher oyster density (1–2 live oysters per shell) compared to the cabinet reef (1 live oyster per 2–4 shells) during the same period (**Table 10**).

Recruitment density followed a similar trend, with live recruits per shell decreasing over time. Between 2023 and 2024, recruitment density in the nursery declined from 0.19 juveniles per shell (or 1 recruit per 5 shells) to 0.10 juveniles per shell (or 1 recruit per 10 shells). In the cabinet reef, recruitment decreased from 0.19 juveniles per shell (or 1 recruit per 5 shells) to 0.07 juveniles per shell (or 1 recruit per 15 shells), and in the gabion reef, from 0.50 juveniles per shell (or 1 recruit per 2 shells) to 0.20 juveniles per shell (or 1 recruit per 4–5 shells) (**Table 10**). This downward trend in recruitment density suggests a potential need for reseeded to bolster the population of reproductively active adults. Continued long-term monitoring will be important to determine whether these recruitment patterns continue to decline or begin to fluctuate.

Table 10. Sample size (live and dead box oysters), oyster density and recruitment density as live oyster per shell and live recruit per shell across all structures at Brooklyn Bridge Park. NA represents no available data and data less than 1 year post-installation cannot be used to calculate oyster density for recruitment.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruits Per Shell
SEAPA Cage Nursery (BBPN)	2020	1770	11.96	<1 year old
	2021	5607	8.40	NA
	2022	4497	3.46	1.18
	2023	4430	2.05	0.19
	2024	1864	3.80	0.10
Cabinet Reef (BBPC)	2021	621	6.49	<1 year old
	2022	1878	2.66	NA
	2023	1093	0.38	0.19
	2024	114	0.24	0.07
Gabion Reef (BBPG)	2021	0	NA	<1 year old
	2022	761	5.08	NA
	2023	437	2.13	0.50
	2024	264	1.37	0.20

Oyster Population Estimates

The annual population estimates across all structures at Brooklyn Bridge Park can be found in **Table 11**. This estimate is calculated using annual percent mortality and percent recruitment data. The population estimate at the SEAPA cage nursery exceeds the initial installation estimate. This is attributed to the combination of low annual mortality and consistent recruitment. Further research or genetic analysis is required to determine whether the recruitment is sourced from the introduced oysters themselves or from wild oyster populations in the harbor. These encouraging trends indicate that the site conditions may be conducive to supporting a self-sustaining oyster population.

Table 11. Estimated population dynamics across all structures at Brooklyn Bridge Park. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and recruitment. NA represents no available data to calculate the annual recruitment.

Structure	Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Post Recruitment Estimate
SEAPA Cage Nursery (BBPN)	2020	215,280	4.75%	205,063	NA	205,063
	2021	205,063	9.66%	185,259	51.68%	281,007
	2022	281,007	8.69%	256,574	22.22%	313,590
	2023	313,590	10.41%	280,957	3.64%	291,184
	2024	313,590	14.43%	268,335	2.03%	273,782
Cabinet Reef (BBPC)	2021	185,071	19.48%	149,010	NA	149,010
	2022	149,010	35.78%	95,690	57.46%	150,670
	2023	150,670	76.85%	34,876	19.92%	41,825
	2024	41,825	78.07%	9,172	24.56%	11,425
Gabion Reef (BBPG)	2021	588,861	NA	588,861	NA	588,861
	2022	588,861	11.83%	519,219	NA	519,219
	2023	519,219	26.77%	380,206	29.29%	491,571
	2024	491,571	25.76%	364,954	14.77%	418,868
Total Estimated Population Size						704,075

Oyster Health

The condition index of a subset of oysters was tested in 2023 and 2024. For the results, please refer to **Appendix Figure B1**.

Disease

Derma: **Moderate**

In 2023, Derma testing revealed that the majority of oysters were classified as stage 0 (no infection), while two individuals were identified as stage 0.5, corresponding to a disease prevalence of 6.9%. No oysters exhibited lethal infection (**Figure 8**). However, laboratory results from 2024 demonstrated an increase in both Derma prevalence and intensity at Brooklyn Bridge Park. Prevalence rose from 6.9% in 2023 to 46.8% in 2024, with the proportion of potentially lethally infected oysters increasing from 0.0% to 23.3%. The reasons for this change are unknown, so testing will continue in upcoming monitoring years.

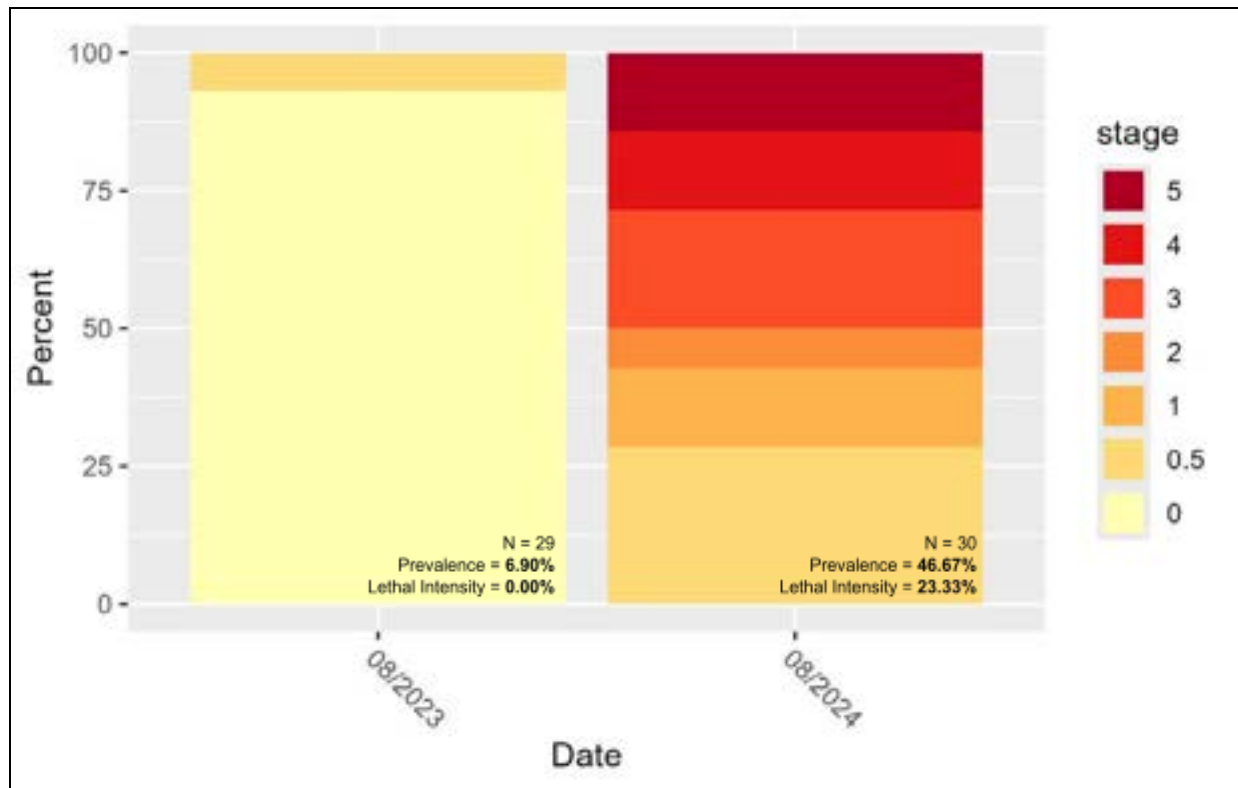


Figure 8. Dermo (*P. marinus*) prevalence and intensity in oysters sampled from the Brooklyn Bridge Park SEAPA Nursery. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be potentially lethally infected.

MSX: **Low**

MSX, which was absent in 2023, was detected in two oysters at Brooklyn Bridge Park in 2024, both exhibiting light infection. This emergence may be attributed to elevated temperatures and salinity levels, environmental factors known to promote the proliferation of pathogens.

Reproduction

Spawning: **Moderate**

Gonad testing in 2023 and 2024 show variability in spawning: 20.7% of sampled oysters spawned in 2023, compared to 43.3% in 2024. In 2024, many oysters were in the final spawning stage, with some initiating another reproductive cycle, suggesting the potential for fall conditioning and spawning (**Figure 9**). In contrast, oysters in 2023 were primarily in advanced gonadal stages, ranging from early development to full ripeness just before spawning (**Figure 9**). The timing of sample collection—early August in 2023 versus mid-to-late August in 2024— or annual differences in environmental conditions likely contributed to the observed differences in reproductive stages between the two years.

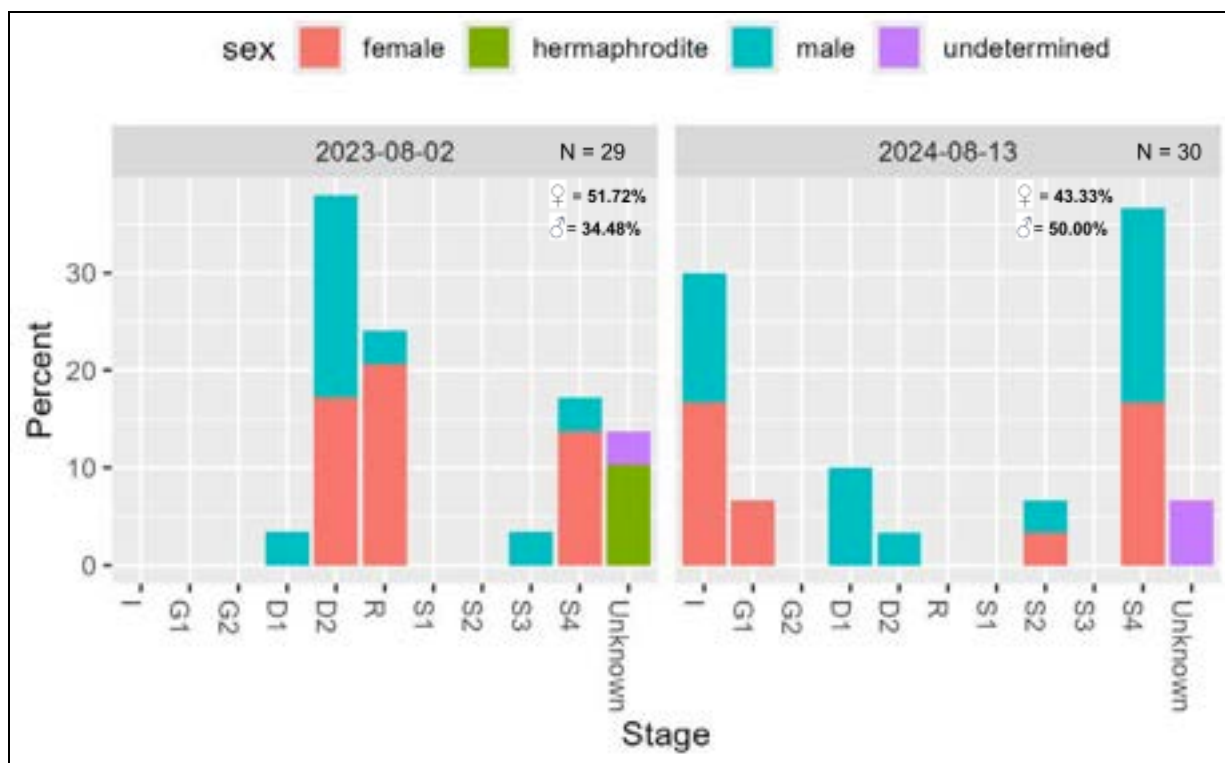


Figure 9. Stage of reproductive development and sex of oysters from Brooklyn Bridge Park Nursery. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Sex Ratio: 50:50

In 2023, the sex ratio was skewed toward females, indicating sexual maturity and favorable conditions for successful fertilization, as the presence of eggs plays a more critical role in reproduction than sperm. By 2024, the sex ratio approached a more balanced 50:50 distribution (**Figure 9**).

Recommended Restoration Action

In response to these positive trends from the pilot installations, and in alignment with the dual restoration strategy to add seeded substrate and multiple cohorts of oysters, **BOP designed and permitted a two-acre restoration project of 240 seeded and unseeded bay balls installed over two phases.** The reef footprint is adjacent to the subtidal gabions between Pier 3 and Pier 4 Beach, with seeded and unseeded bay balls installed in clusters at depths between 10-22 feet below Mean Low Water (MLW). Informed by hydrographic surveys and sediment characterization results, BOP designed the reef as 24 clusters of 10 bay balls with three feet between each bay ball to facilitate both the development of an ecological halo effect and diver access for biannual monitoring. The position of unseeded bay balls were randomly assigned to monitor edge effects and compare performance trends in the interior and exterior of the cluster.

In July and August 2024, 67 bay balls seeded with 13 million spat and eight unseeded bay balls were installed as Phase 1. Larval shortages from hatcheries delayed the installation, so the rest of Phase 1 (38 seeded and 7 unseeded bay balls) will be completed in 2025. The target installation of Phase 2 is 2027, which will include 12 clusters of 10 bay balls (105 seeded and 15 unseeded bay balls). Biannual monitoring of oyster performance and recurring seasonal or annual measuring of changes to biodiversity (benthic, epibenthic, mobile species) will help measure impact over time and adaptively manage the project through future interventions. The results of monitoring of Phase 1 will be submitted to regulatory agencies in a stand alone report in 2025.

Bush Terminal Park

Project Summary

As of 2024, BOP maintains and monitors several installations in Bush Terminal Park Eastern Lagoon (**Figure 10**). The Sunset Park Field Station supports oysters in two structures (community cabinet reefs at two different depths and a bagged shell reef) to provide insight into oyster health and performance using on-bottom restoration techniques, progressing towards the implementation of larger scale on-bottom restoration adjacent to the site. The installations at Bush Terminal Park also provide hands-on education and engagement opportunities with students and community groups that reconnect people to the waterbodies surrounding New York Harbor, as well as to the wildlife thriving along the shorelines and in the shallows.

Trends from 2016-2024 data indicate conditions are supportive of larger-scale oyster restoration:

- Across all structures and cohorts in the shallower depths, the mean shell height consistently increases for the first 2-3 years post-installation, indicating that this site is suitable for oyster growth. Fluctuations of mean shell height across seasons or years may be attributed to recruitment, small sample sizes, and eventual mortality of older oysters.
- Annual mortality across all structures is lowest (<30%) within three years post-installation. Based on this trend, reseeding is recommended three years post-installation.
- Although low, recruitment is occurring across all structures as evidenced by the presence of oysters under 25 mm shell height between 2017 and 2020 and again in 2023.
- Disease prevalence of Dermo is low and lethal intensity ranges from none to low, suggesting that disease is not the leading cause of mortality at this site. MSX was found in two individuals in 2024 out of all the oysters sampled with one showing low infection and the second showing moderate infection.
- Gonad testing shows oysters are reproductively active and spawning in the summer months.
- The sex ratio of tested samples is approaching 50:50 with slight skewness towards males in recent years. Because BOP has not restocked this site with oysters since 2018, it may be inferred from mean shell height and sex ratio that many of these males are recruits.

Site Overview

In 2016, BOP installed five cabinets in the eastern lagoon. Two cabinets (hereafter referred to as the deepwater cabinets) containing approximately 387,781 spat-on-shell are accessible only by divers and are situated near the northern edge of the lagoon. The other three cabinets (hereafter referred to as cabinet reefs) containing approximately 581,671 spat-on-shell were installed at a shallower depth along the southern shoreline of the lagoon and are accessed via wading (**Table 12**).

In 2018, BOP installed five cabinets containing approximately 180,000 spat-in-shell to the existing cabinet reef after the first cohort showed positive growth in their first two years. BOP also added 96 bags of shell (66 bags with 133,986 spat-on-shell, and 30 unseeded bags) adjacent to the cabinet reef (**Table 12**).



Figure 10. Map of Bush Terminal Park Field Station.

Table 12. Summary of structures installed and spat introduced to the eastern lagoon of Bush Terminal Park.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Deepwater Cabinets	2016	2	387,781	Annual
Cabinet Reef	2016	3	581,671	Biannual
	2018	5	180,000	
Bagged Shell Reef	2018	96	133,986	

For the community cabinets and the bagged shell reef, monitoring occurs once in the spring (April-June) to assess winter mortality and in the fall (September-November) to assess growth and recruitment. The data set from 2016-2024 indicates gaps in monitoring, either due to COVID-19 restricted access or weather cancellations. Monitoring of the deepwater cabinets occurs annually during the summer, and activities are conducted by a team of divers.

During monitoring events, BOP staff have observed various fish and invertebrate species inhabiting the oyster shells within the structures. Fish biodiversity monitoring indicated a rich diversity and abundance of fish at Bush Terminal Park (**Appendix Figure A2**), emphasizing the reef's role in providing habitat and essential resources for marine biodiversity to thrive.

Oyster Performance

Data from 2016 are excluded (**Figure 11**) because the field team did not distinguish oyster status (live or dead). Only video monitoring was conducted in 2017 for the deepwater cabinets, with no shell height measured and recorded. No data collection occurred in 2020 and 2021 due to the COVID-19 pandemic and related site access restrictions.

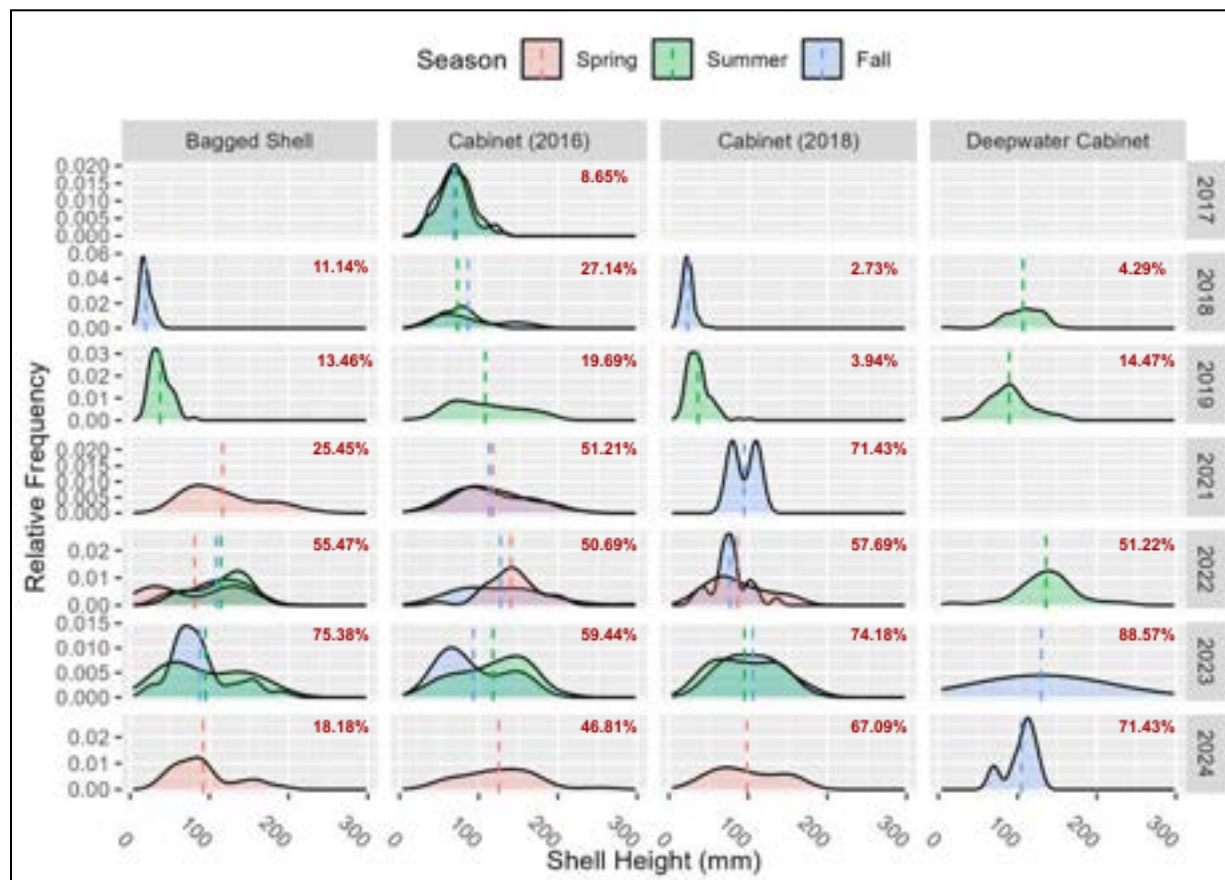


Figure 11. Size frequency histogram of live oysters in bagged shell reef, cabinet reefs (2016 and 2018 cohorts), and deepwater cabinets, 2017-2024. No 2020 data and 2021 deepwater cabinet data were collected due to the COVID-19 pandemic. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Bush Terminal Park Deepwater Cabinets - 2016 Cohort

Growth: Stable

Overall, oyster growth trends positively in the deepwater cabinet oysters (**Figure 11**). The decrease in mean shell height between 2018 and 2019 may have occurred because the 2019 sample (N = 76) had a smaller sample size than the 2018 sample (N = 140). By 2022, live oysters averaged approximately 136 mm in size. By 2023 and 2024, the oysters had grown beyond the length of calipers (160 mm). Measuring oyster shell height underwater has proven difficult especially when visibility is low in such an urban environment. Removing the oysters from the deepwater cabinet to monitor is also difficult as many of the oysters have grown through the files in high density ("reefing"), which would kill many oysters if forcefully removed.

Mortality: High

Mortality of deepwater cabinet oysters has increased since 2022 with mortality greater than 50% of the

sample increasing to 88.6% in 2023 and decreasing slightly in 2024 to 71.4% (**Figure 11**). This could be attributed to growing oysters competing for space, natural aging and mortality of oysters, and increasing Dermo prevalence and intensity in 2023 and 2024.

Recruitment: None

Recruitment was observed in 2018, 2019, and 2021 in 1.4%, 1.3%, and 1.2% of the sampled deepwater cabinet oysters, respectively (**Table 14**). No recruitment was observed in 2023 and 2024, which could be attributed to the low sample sizes (N = 35 and N = 21, respectively).

Bush Terminal Park Community Cabinets - 2016 Cohort

Growth: Stable

Overall, oyster growth trends positively over time among the 2016 community cabinet oysters (**Figure 11**). The decrease in mean shell height between 2022 (132.7 mm) and 2023 (109.1 mm) is likely due to the presence of recruitment observed in 2023 (**Figure 11**). The 2024 monitoring recorded a mean shell height of 125.4 mm, which did not reach the mean shell height recorded in 2022, this may be attributed to the low sample size (N = 47) and the natural loss of older, larger oysters. Another likely contributing factor is the frequent handling of these oysters: BOP staff, students, and community groups regularly remove them for education events, and this may increase annual mortality.

Mortality: Stable

Annual mortality in the 2016 cohort community cabinets has stabilized around 50% over the past four years, with the highest recorded percentage since installation at 59.4% in 2023, followed by a slight decrease to 46.8% in 2024. (**Figure 11**). This trend aligns with expectations, as mortality typically increases and then stabilizes over time due to frequent handling during engagement activities and the increasing intensity of Dermo with age, which ultimately contributes to oyster mortality.

Recruitment: Fluctuating

The presence of recruits in the 2016 community cabinet oysters since their installation, fluctuated between 0.6% (recruitment recorded in 2021) and 2.9% (recorded in 2017) with 1.7% recruitment of the sampled oysters in 2023 (**Table 14**); however, no recruits were observed in 2022 or 2024.

Bush Terminal Park Community Cabinets - 2018 Cohort

Growth: Positive

Overall, oyster growth trends positively for the 2018 community cabinet oysters, increasing up to a mean shell height of 98.3 mm and 98.5 mm in 2023 and 2024 respectively (**Figure 11**). Data from 2021 is excluded due to the low sample size of live oysters (N = 2), as the 2021 monitoring did not provide a representative sample of the 2018 community cabinet oysters.

Mortality: High

Annual mortality in the 2018 cohort community cabinets stabilized around 68% in the last four years, with 74.2% and 67.1% mortality of the sampled oysters recorded in 2023 and 2024 respectively (**Figure 11**). This trend aligns with expectations, as mortality typically increases and then stabilizes over time due to frequent handling during engagement activities and the increasing intensity of Dermo with age, which ultimately contributes to oyster mortality.

Recruitment: Fluctuating

Recruitment was observed in 2019, with 20.8% of the sampled oysters likely within their first year of life. No recruitment was recorded in the subsequent years until 2024, when annual recruitment was measured at 1.3% (**Table 14**).

Bush Terminal Park Bagged Shell Reef - 2018 Cohort

Growth: Stable

There are fluctuations in the overall growth trend of bagged shell oysters (**Figure 11**). Mean shell height initially increased during the first two years post-installation but declined slightly in 2022, reaching 110.7 mm. Growth rebounded in 2023 with a mean shell height of 111.9 mm, followed by another decline to 92.4 mm in 2024. The decrease observed between 2023 and 2024 may be attributed to randomized sampling that excluded oysters from the 2018 cohort and instead captured newer recruits, thereby lowering the overall mean shell height.

Mortality: High

Annual mortality in the bagged shell reef has shown a consistent increase, peaking at 75% in 2023 (**Figure 11**). The sharp decline in 2024 to 18.2% mortality may be attributed to the low sample size ($N = 33$), which likely did not capture the high oyster mortality observed by staff and volunteers. Oysters on the side of each bag resting on the bottom were likely buried in the anoxic sediment, as indicated by shell discoloration, whereas those on the opposite side grew through the bags.

Recruitment: None

Recruitment in the bagged shell reef fluctuated, with annual recruitment of 12.5% in 2019, 2.9% in 2022, and 12.3% in 2023, however, no recruitment was recorded in 2024 (**Table 14**).

Oyster Density

Two monitoring methods—clump and quadrat—were used to assess oyster performance across all structures at this site. Deepwater cabinets were monitored exclusively using the quadrat method, as oysters exhibited “reefing” or cementing between files, making it difficult to remove them for clump assessment. Quadrat monitoring is preferred when oysters have grown through the structure, limiting the ability to assess individuals. As a result, staff transitioned from clump to quadrat monitoring for some structures over time. However, as oyster mortality increased in the bagged shell and cabinet reefs three to five years post-installation, clump monitoring was reintroduced to more accurately assess the remaining oysters.

Using clump monitoring, oyster density in the bagged shell reef had been declining but showed a recent increase—from 0.28 live oysters per shell (1 oyster per 3.6 shells) in 2023 to 0.96 in 2024 (**Table 13**). In the cabinet reefs, oyster density fluctuated over time but began to stabilize, averaging around 0.54 live oysters per shell (1 oyster per 1.8 shells) in the 2016 cohort and 0.34 live oysters per shell (1 oyster per 3 shells) in the 2018 cohort (**Table 13**).

Using quadrat monitoring, oyster density declined over time in all cabinet reefs, leading staff to revert to clump monitoring after 2020 for both cabinet and bagged shell reefs. In the deepwater cabinets, oyster density fluctuated, with a recent increase from 10.8 live oysters per square meter in 2023 to 32.3 in 2024 (**Table 13**).

Recruitment density remained low to nonexistent across all structures, with some recruitment observed one year post-installation in the bagged shell reef and sparse recruitment in the deepwater cabinets in subsequent years (**Table 13**). No recruitment was recorded between 2023 and 2024 in any structure, except in the 2016 cohort cabinet reef, which had a recruitment density of 1 recruit per 138 shells in 2023 but none in 2024 (**Table 13**).

Table 13. Sample size (live and dead box oysters), live oyster and recruitment density (per shell and per square meter) across all structures at Bush Terminal Park. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
Bagged Shell Reef	2018	389	3.43	<1 year old	NA	<1 year old
	2019	104	0.00	0.00	1320	100
	2020	NA	NA	NA	NA	NA
	2021	54	0.91	0.00	NA	NA
	2022	134	0.47	0.00	NA	NA
	2023	65	0.28	0.00	NA	NA
	2024	33	0.96	0.00	NA	NA
Cabinet Reef 2016 Cohort	2016	1783	0.00	<1 year old	NA	<1 year old
	2017	312	NA	NA	1989.61	3.61
	2018	347	NA	NA	1739.84	0.00
	2019	127	NA	NA	113.33	1.11
	2020	NA	NA	NA	NA	NA
	2021	372	0.52	0.01	NA	NA
	2022	141	0.55	0.00	NA	NA
	2023	143	0.42	0.01	NA	NA
	2024	47	0.54	0.00	NA	NA
Cabinet Reef 2018 Cohort	2018	181	NA	<1 year old	294.20	<1 year old
	2019	127	NA	NA	203.33	21.67
	2020	NA	NA	NA	NA	NA
	2021	7	0.29	0.00	NA	NA
	2022	104	0.49	0.00	NA	NA
	2023	213	0.29	0.00	NA	NA
	2024	79	0.34	0.00	NA	NA
Deepwater Cabinets	2016	975	NA	<1 year old	NA	<1 year old
	2017	NA	NA	NA	NA	NA
	2018	140	NA	NA	10.30	0.15
	2019	76	NA	NA	9.21	0.14
	2020	NA	NA	NA	NA	NA
	2021	NA	NA	NA	NA	NA
	2022	78	NA	NA	4.97	0.14
	2023	35	NA	NA	10.76	0.00
	2024	21	NA	NA	32.29	0.00

Oyster Population Estimates

The annual population across all structure types at Bush Terminal Park is presented in **Table 14**. This estimate is calculated using annual percent mortality and recruitment data. The variability in annual

mortality and percent recruitment is likely influenced by frequent handling and sedimentation in the cabinet reefs and bagged shell reef. The actual population estimate is not fully represented due to small sample sizes and gaps in data from certain years.

Table 14. Estimated population dynamics across all structures at Bush Terminal Park. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and recruitment. NA indicates no available data.

Structure	Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
Deepwater Cabinets	2016	387,781	NA	387,781	NA	387,781
	2017	387,781	NA	387,781	NA	387,781
	2018	387,781	4.29%	371,162	1.43%	376,464
	2019	376,464	14.47%	321,976	1.32%	326,212
	2020	326,212	NA	326,212	NA	326,212
	2021	326,212	NA	326,212	NA	326,212
	2022	326,212	53.85%	150,560	1.28%	152,490
	2023	152,490	88.57%	17,427	0.00%	17,427
	2024	17,427	71.43%	4,979	0.00%	4,979
Cabinet Reef 2016 Cohort	2016	581,671	NA	581,671	NA	581,671
	2017	581,671	8.65%	531,334	2.88%	546,661
	2018	546,661	26.80%	400,150	1.32%	405,415
	2019	405,415	19.69%	405,415	NA	405,415
	2020	405,415	NA	405,415	NA	405,415
	2021	405,415	51.34%	197,258	0.56%	198,366
	2022	198,366	51.77%	95,666	0.00%	95,666
	2023	95,666	59.44%	38,802	1.72%	39,471
	2024	39,471	46.81%	20,995	0.00%	20,995
Cabinet Reef 2018 Cohort	2018	180,000	2.73%	175,082	NA	175,082
	2019	175,082	3.94%	168,189	20.75%	203,096
	2020	203,096	NA	203,096	NA	203,096
	2021	203,096	71.43%	58,027	0.00%	58,027
	2022	58,027	57.69%	24,550	0.00%	24,550
	2023	24,550	74.18%	6,339	0.00%	6,339
	2024	6,339	67.09%	2,086	1.27%	2,113
Bagged Shell Reef	2018	133,986	11.14%	119,065	NA	119,065
	2019	119,065	13.46%	103,037	6.00%	109,219
	2020	109,219	NA	109,219	NA	109,219
	2021	109,219	25.45%	81,418	0.00%	81,418
	2022	81,418	55.47%	36,252	1.79%	36,899
	2023	36,899	75.38%	9,083	0.00%	9,083
	2024	9,083	18.18%	7,431	0.00%	7,431
Total Estimated Population						35,151

Oyster Health

Bush Terminal Park oysters were tested for condition index from 2018 to 2020 and again from 2023 to 2024. For the results, please refer to **Appendix Figure B2**.

Disease

Dermo: **Moderate**

Across all sampling years, Dermo prevalence was lowest in young oysters but increased over time, rising from 11.1% in 2018 to 53.3% in 2024 (**Figure 12**). Potentially lethal infection intensity also rose from 0% in 2018 and 2020 to 16.7% in 2024. While lethal intensity increased, overall Dermo prevalence slightly declined between 2023 and 2024. These trends meet our expectations of Dermo prevalence and lethality as disease accumulation typically intensifies with age.

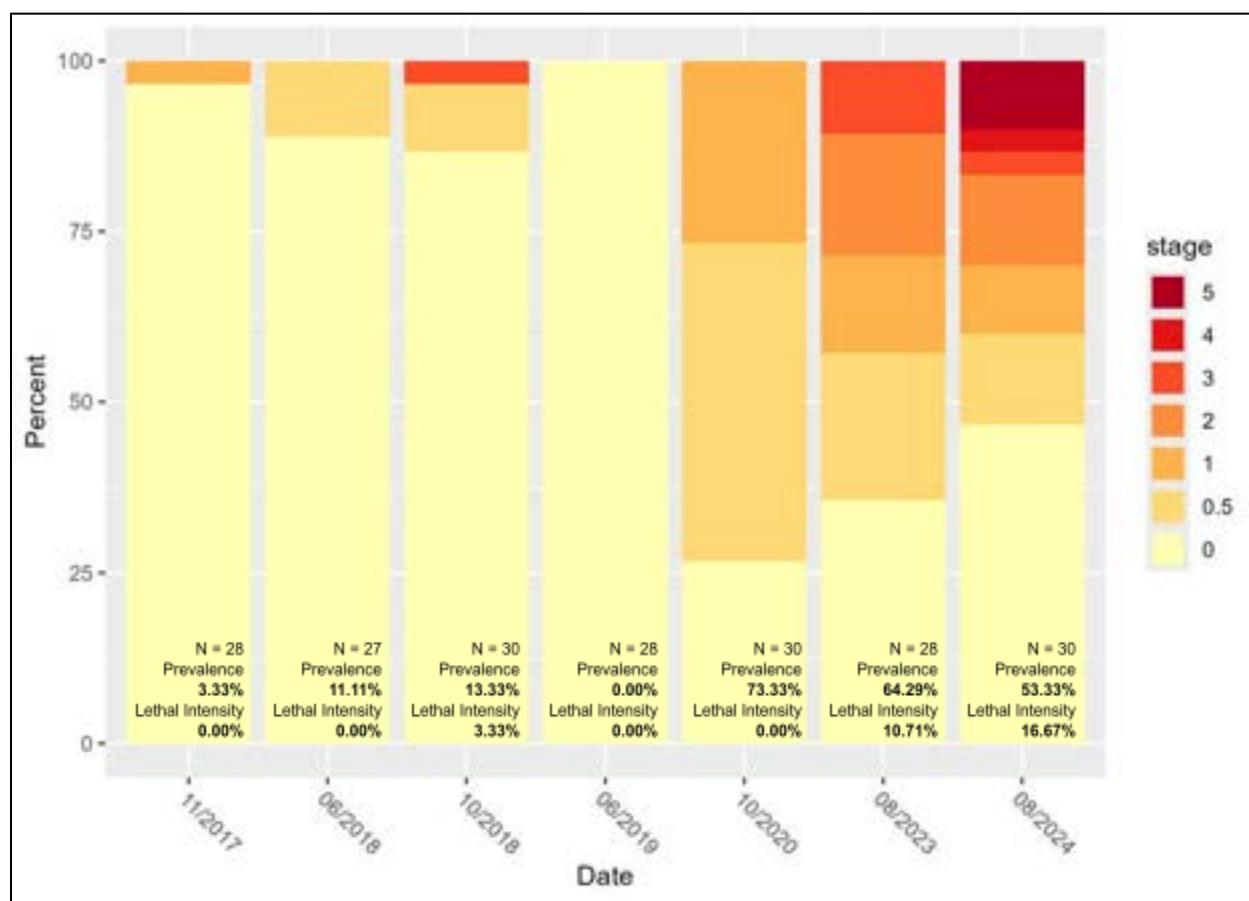


Figure 12. Dermo (*P. marinus*) prevalence and intensity in oysters sampled from the Bush Terminal Park Community Cabinets. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be lethally infected.

MSX: **Low**

MSX was detected in one oyster in 2020 and two oysters (one exhibiting light infection and the other moderate infection) in 2024. Despite this, the overall MSX prevalence remains low. This recent emergence may be linked to rising temperatures and elevated salinity levels, environmental conditions favorable for pathogen proliferation.

Reproduction

Spawning: High

Results showed that 82.1% of sampled oysters at Bush Terminal Park were spawning in August 2023, compared to 76.7% in August 2024. In 2024, many oysters were in the final spawning stage, with some in the inactive stage, indicating that spawning was actively occurring or had recently concluded (**Figure 13**). In contrast, in 2023, most oysters were actively spawning, while some were in stages ranging from late development to full ripeness just before spawning (**Figure 13**). Variations in reproductive stages across years are likely influenced by differences in sampling timing and annual environmental conditions.

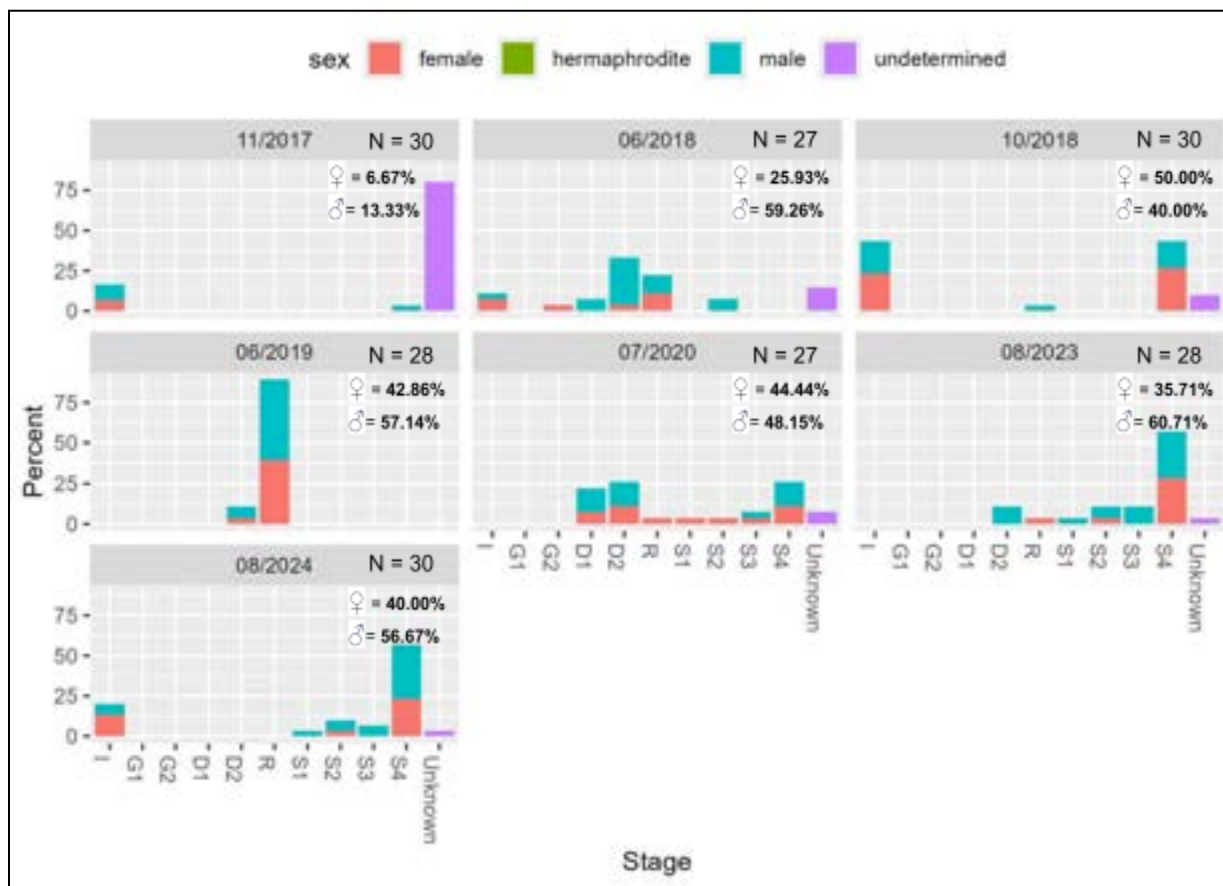


Figure 13. Stage of reproductive development and sex of oysters from Bush Terminal Park Cabinet Reefs. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Sex Ratio: Approaching

In both years, the sex ratio was skewed toward males (**Figure 13**), contrasting with the more balanced 50:50 sex ratio observed in the year prior to 2023.

Recommended Restoration Actions

In response to oyster performance trends from the 2016-2018 cohorts and in alignment with the restoration strategy to add seeded substrate and multiple cohorts of oysters, **BOP designed and will submit for NYSDEC review, a multi-phase oyster reef restoration project in a two-acre reef footprint in the southern half of the basin between Bush Terminal Park lagoons and Pier 5.** The design includes 270 cubic yards (CY) of unseeded shell to create three shell reefs, 360 bay balls set with 72 million juvenile oysters, and 30 unseeded bay balls installed over three phases. Informed by comprehensive pre-installation surveys, including hydrographic and sediment characterization surveys, the project aims to create oyster reef habitat and complement nearshore wild eelgrass beds documented along the northern perimeter of the basin. The project is fully subtidal at depths between 17-22 feet with no waterfront construction or waterfront access for construction required. Phase 1 installation is planned for 2026, followed by Phase 2 installation in 2029, and Phase 3 planned for 2032. In each phase, BOP proposes to install 130 bay balls: 120 seeded with spat (juvenile oysters) and 10 unseeded, and one 90 cubic yard shell reef.

The first phase of this project, proposed for installation in Summer 2026, includes one 90 cubic yard shell reef and 130 bay balls set with 24 million spat. Some of the bay balls will be unseeded to serve as control units to compare wild recruitment and non-oyster epibenthic recruitment to the seeded units. This phase is comparable in size and monitoring scope to the nearby Brooklyn Bridge Park project. Scaling to this size allows BOP to better understand and collect data on oyster performance, especially recruitment, using a substrate with more vertical relief and in a more open location with greater tidal exchange than the lagoons.

Brooklyn Navy Yard (Wallabout Basin)

Project Summary

As of 2024, BOP maintains and monitors a floating nursery in Brooklyn Navy Yard (Wallabout Basin) with support from New York Harbor School students and interns.

Trends from 2023-2024 data show:

- Oyster growth is trending positive.
- Annual mortality is relatively stable.
- Consistent monitoring is needed to verify current trends.

Site Overview

The oyster nursery at the Brooklyn Navy Yard (Wallabout Basin) utilizes a floating longline system designed to accommodate adult oysters. The oysters are contained in supertrays, with each stack suspended from a single float (**Figure 14**). However, due to a dissolved oxygen gradient in the water column, oyster growth slows with increasing distance from the surface.



Figure 14. Map of Brooklyn Navy Yard nursery.

In 2015, approximately 3.5 million young spat were introduced to this nursery (**Table 15**). In 2017, an additional 2,750 oysters were added (**Table 15**). Monitoring was conducted with New York Harbor School students via vessel in the fall of both 2023 and 2024 to assess oyster performance.

Table 15. Summary of structures installed and oyster introduced at Brooklyn Navy Yard (Wallabout Basin).

Structure Name	Year Installed	Quantity of Structure	Oyster Introduced	Monitoring Frequency
SuperTray Nursery	2015	NA*	3,500,000 (Spat)	Annual
	2017		7,500 (Adult)	

*The quantity of structures cannot be determined as oysters transferred to the nursery from other sites were consolidated with the existing cohort to maximize space.

Oyster Performance

Growth: Positive

The mean shell height of oysters at the Brooklyn Navy Yard Nursery increased from 45.5 mm in 2023 to 79.2 mm in 2024 across all cohorts (**Figure 15**). Continued monitoring is necessary to confirm and support these positive growth trends over time.

Recruitment: Fluctuating

Annual recruitment in the nursery fluctuates, with 16.0% of sampled oysters observed as recruits in 2023, but 0.0% in 2024 (**Figure 15**). BOP has occasionally observed wild oysters on the bulkheads surrounding Wallabout Basin, but further monitoring is needed to assess long-term recruitment trends. Additionally, reproductive development results from 2018 indicate that some oysters at this site were actively spawning (**Figure 17**).

Mortality: Stable

Annual mortality in 2023 and 2024 is similar, ranging from 28% to 33% (**Figure 15**). Dermo results in 2018 showed higher prevalence and intensity in the fall than the spring (**Figure 16**), which could explain the higher mortality in 2024 when monitoring oysters later in the year.

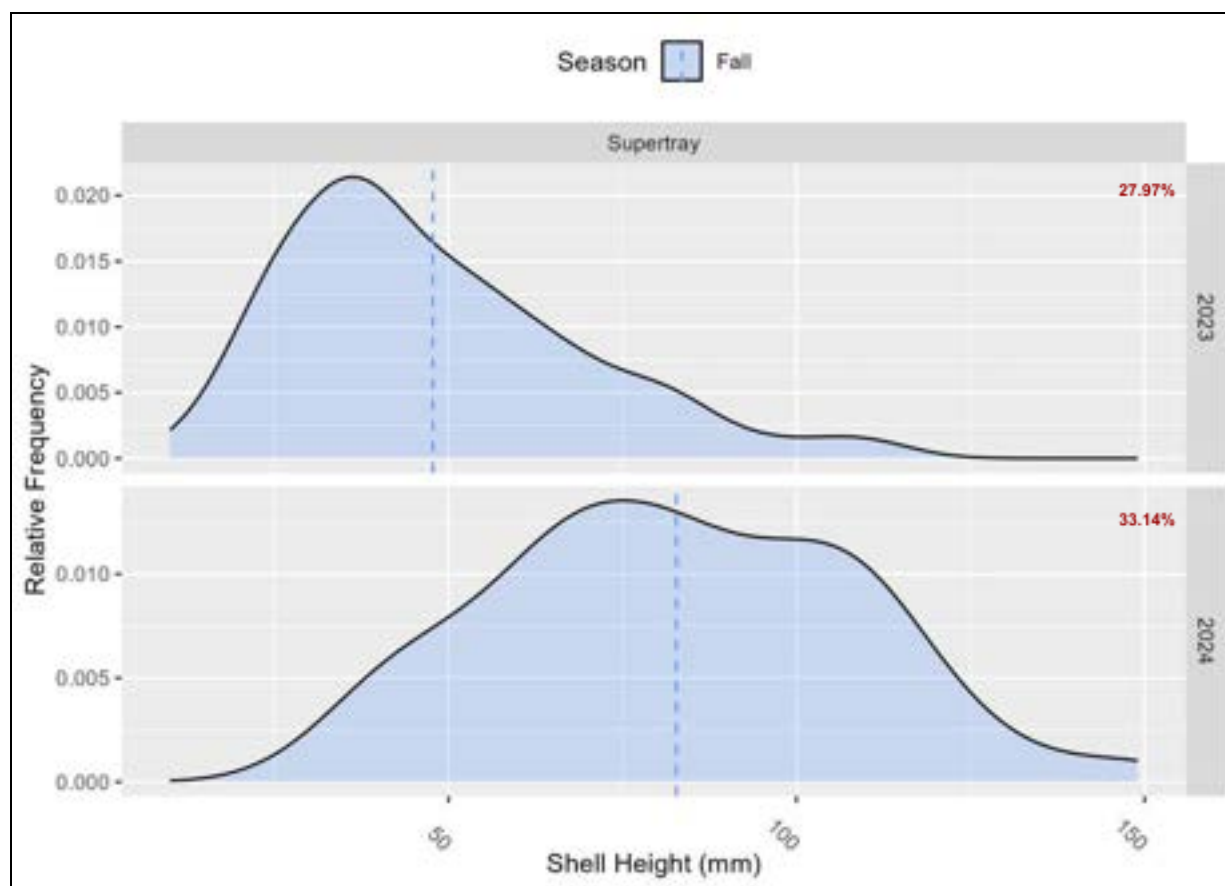


Figure 15. Size-frequency histogram of live oysters in Brooklyn Navy Yard, 2023-2024. The dashed line represents the mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Population Estimates

The current population estimate for Brooklyn Navy Yard cannot be determined. Unfortunately, oysters at this site were not monitored regularly, and oysters from other sites were occasionally transferred to the nursery and consolidated with the existing cohort.

Oyster Health

BOP did not collect any oysters for lab testing in 2023 or 2024. However, the disease and reproduction data for 2018 and 2019 are presented in **Figures 16** and **17**, respectively. Brooklyn Navy Yard oysters were tested for condition index from 2017 to 2019. For the results, please refer to **Appendix Figure B3**.

Disease

Across all sampling years from 2017 to 2019, Dermo prevalence and lethal intensity peaked in October 2018, with a prevalence of 66.7% and a lethal intensity of 23.3% (**Figure 16**). Despite this spike, Dermo presence remained low throughout those years, with lethal intensity recorded at 0.0% outside of the peak. Disease has not been tested since 2019, so these results only reflect the condition of the oysters during the sampling period.

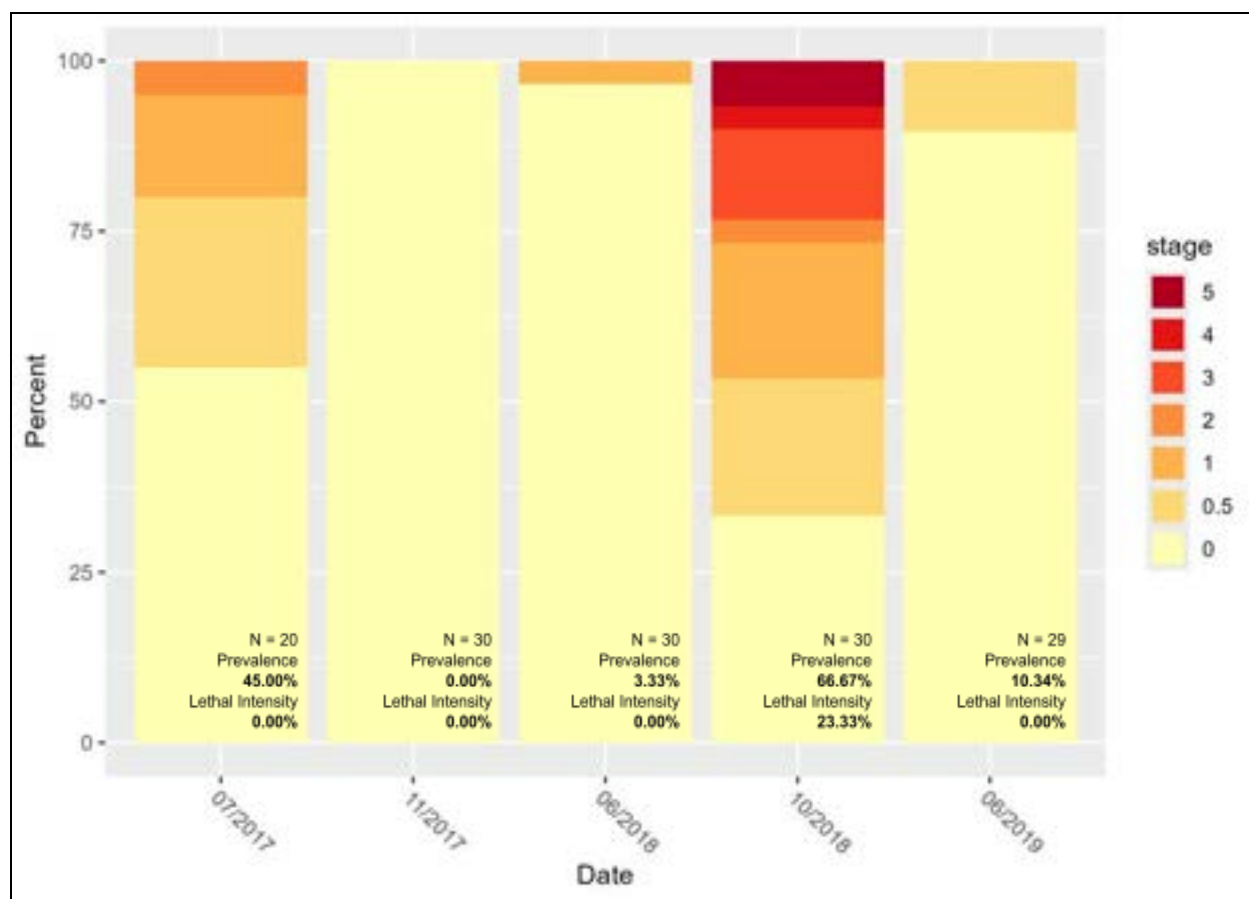


Figure 16. Dermo (*P. marinus*) prevalence and intensity in oysters sampled from Brooklyn Navy Yard. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be potentially lethally infected.

MSX was detected in three oysters in 2017 but has not been detected in subsequent years. While MSX levels at this site are considered low, continued testing is necessary to monitor current trends.

Reproduction

Oyster development stages varied depending on the sampling month. In fall 2017 and 2018, no gonadal activity was observed, whereas in early summer 2018 and 2019, most oysters were in advanced gonadal stages, ranging from early development to full ripeness just before spawning (**Figure 17**). The timing of sample collection—fall in 2017 and 2018 versus early summer in 2018 and 2019—likely contributed to these differences in reproductive stages.

Oysters tested across all sampling years from 2017 to 2019 revealed a sex ratio skewed toward males. More testing is needed to confirm previous trends reflect current conditions.

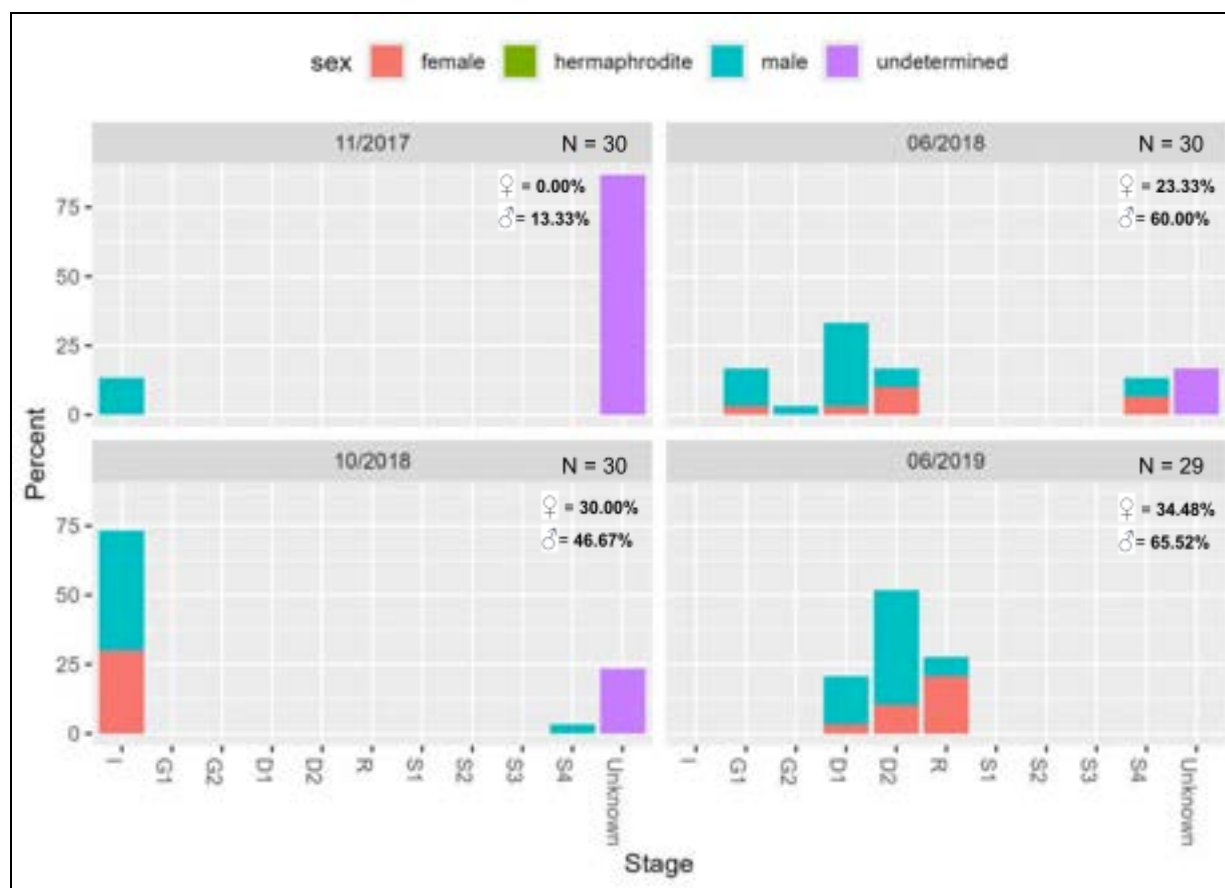


Figure 17. Stage of reproductive development and sex of oysters from Brooklyn Navy Yard nursery. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Recommended Restoration Actions

The Brooklyn Navy Yard nursery will continue to serve as a floating nursery, with ongoing annual monitoring of oyster performance and data analysis of trends. We anticipate stable mortality levels and fluctuating annual recruitment. The Brooklyn Navy Yard nursery benefits from its off-bottom configuration because it experiences little or no sedimentation and predation; water flow is also favorable for oyster growth and reproduction. However, water quality in Wallabout Basin poses challenges to future restoration efforts.

Coney Island Creek

Project Summary

The project area is located in a cove on the southern shore of Coney Island Creek, adjacent to Kaiser Park and near an old fishing pier along the shoreline (**Figure 18**). The project aims to provide insight into oyster performance in a degraded waterbody. Two cabinets filled with spat-on-shell are installed, monitored, and removed within the same calendar year before November 30th in compliance with NYSDEC permit conditions. Data from this project will inform future oyster restoration projects in Coney Island Creek as long-term clean-up efforts advance.

Trends from 2024 data and observations of the site from past years show:

- Positive growth between installation and removal dates.
- Consistent mortality among years.

Site Overview

Coney Island Creek experienced significant degradation due to historical filling, dredging, and industrial activity. A combined sewer outfall is located to the east of the project site, near Shore Parkway and W. 15th Street. Despite these challenges, a small population of wild oysters has been observed on rocks in the intertidal zone beneath the fishing pier. Notably, Coney Island Creek is under evaluation by the EPA for Superfund designation due to its history of pollution. Consequently, BOP is restricted to the application of temporary on-bottom structures at this site, with all oysters and structures required to be removed upon permit expiration.



Figure 18. Map of cabinet reef location at Coney Island Creek.

In 2018, one cabinet was placed on the bottom near the fishing pier in Kaiser Park. The cabinet, which is submerged at all times, was equipped with a locking mechanism to prevent poaching. Oyster monitoring at the site allowed determination of when oysters reached market size, at which point the larger oysters were removed.

In 2021, BOP observed significant degradation of the 2018 cabinet's mesh inserts. The cabinet was replaced with two, 10' x 2' x 2' welded 1/2" rebar oyster cabinets, each equipped with new files and oysters. At the end of 2021, BOP requested a permit renewal; but the pending Superfund designation and regulatory reviews resulted in an adjusted permit condition that requires annual removal of introduced oysters. On December 20, 2022, BOP staff removed two cabinets and all files from the site and relocated the oysters to the Governors Island Reef.

In coordination with NYSDEC in 2024, BOP reinstalled two cabinets which consisted of two cabinets, one with 10 and the other 11 files, and approximately 159,152 spat-on-shell (**Table 16**). The reef was removed on November 13, 2024, in compliance with permit conditions.

Table 16. Summary of structures installed and spat introduced at Coney Island Creek.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Cabinet Reef	2018	2	92,000	Annual
	2020	2	14,223	
	2021	2	117,772	
	2024	2	159,152	

Oyster Performance

Since BOP removes each cohort at the end of each calendar year, it's difficult to infer meaningful trends on oyster oyster performance at this site. Oyster growth is evaluated by comparing the size of oysters at installation with their size at removal. Oyster mortality is assessed by calculating the average annual percent mortality across years.

Growth: Positive

The 2024 cohort exhibited a positive growth trend, increasing from a mean shell height of 3 mm at installation on August 21st to 19.8 mm at removal on November 13th (**Figure 19**). Between the October 29th monitoring and the removal date, a growth rate of 0.2 mm/day was observed, highlighting continued growth during the two-week period.

Mortality: Stable

Annual mortality of the 2024 cohort was stable, averaging around 30%, with a slight decrease at the end of the monitoring period (**Figure 19**).

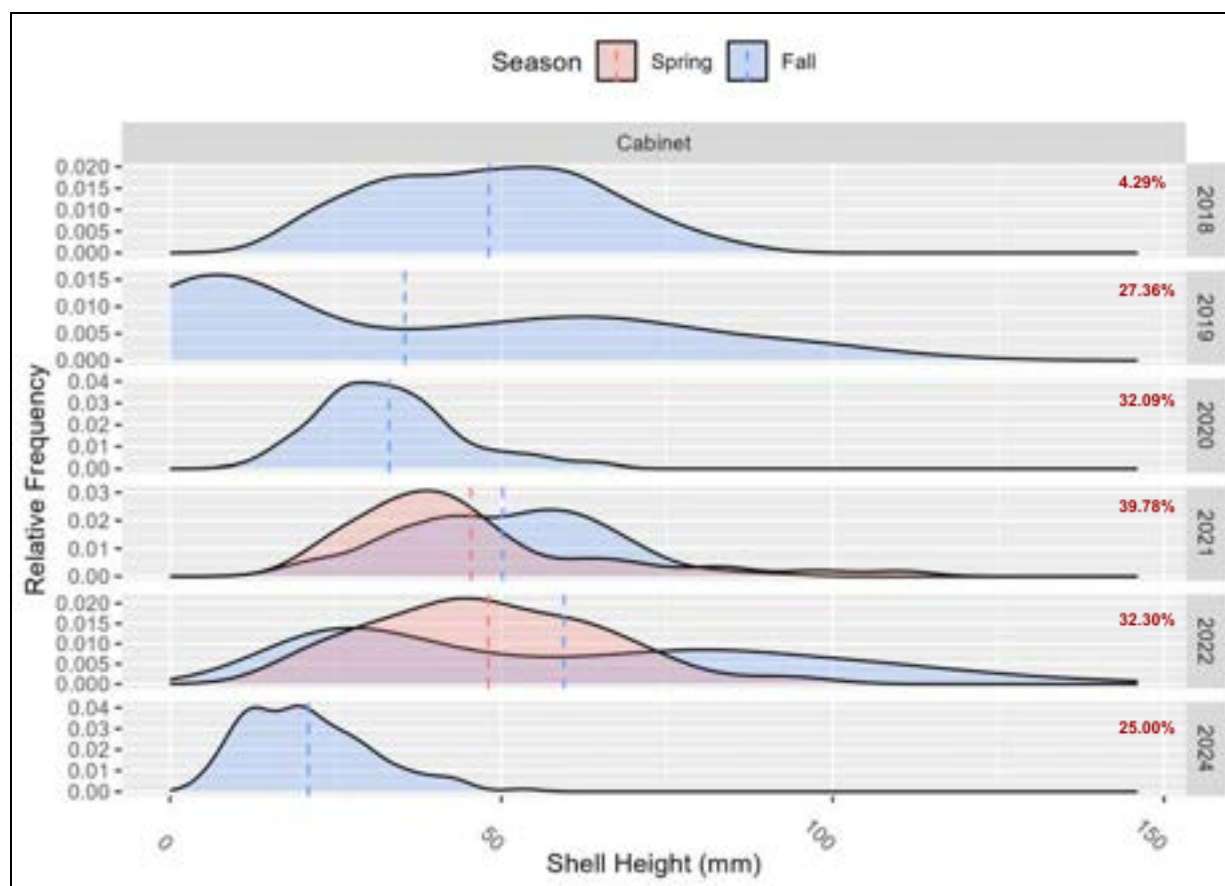


Figure 19. Size-frequency histogram of live oysters in Coney Island Creek cabinet reefs, 2018-2024. Each year represents a different cohort. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Population Estimates

The current population estimate for Coney Island Creek is zero, as all cohorts were removed before the end of the year.

Oyster Health

BOP did not collect any oysters from Coney Island Creek for oyster health assessment.

Recommended Restoration Actions

Similarly to previous years, future installations at Coney Island Creek will depend on the availability of oyster larvae from suppliers during the field season. If sufficient quantities are available, BOP will install a small reef, and the removal of oysters and restoration structures will be scheduled to occur within the same year of installation. At this site, oysters and restoration structures will primarily be used for public engagement activities during the field season. Future restoration efforts at this site will be contingent upon the site's Superfund designation status.

Governors Island Ecodock

Project Summary

As of 2024, BOP continues to maintain and monitor the Supertray nursery in Governors Island Ecodock with support from New York Harbor School students and interns and local students.

Site Overview

The Governors Island nursery is located within the Ecodock, a floating dock at Pier 101 on Governors Island, serving as a temporary nursery for oysters reared at the MAST Hatchery (**Figure 20**). Oysters grow in stacks of super trays suspended from the dock until they are ready for deployment to other restoration sites. The nursery supports the cultivation of approximately 1 million oysters, from newly set spat to individuals up to two years old.

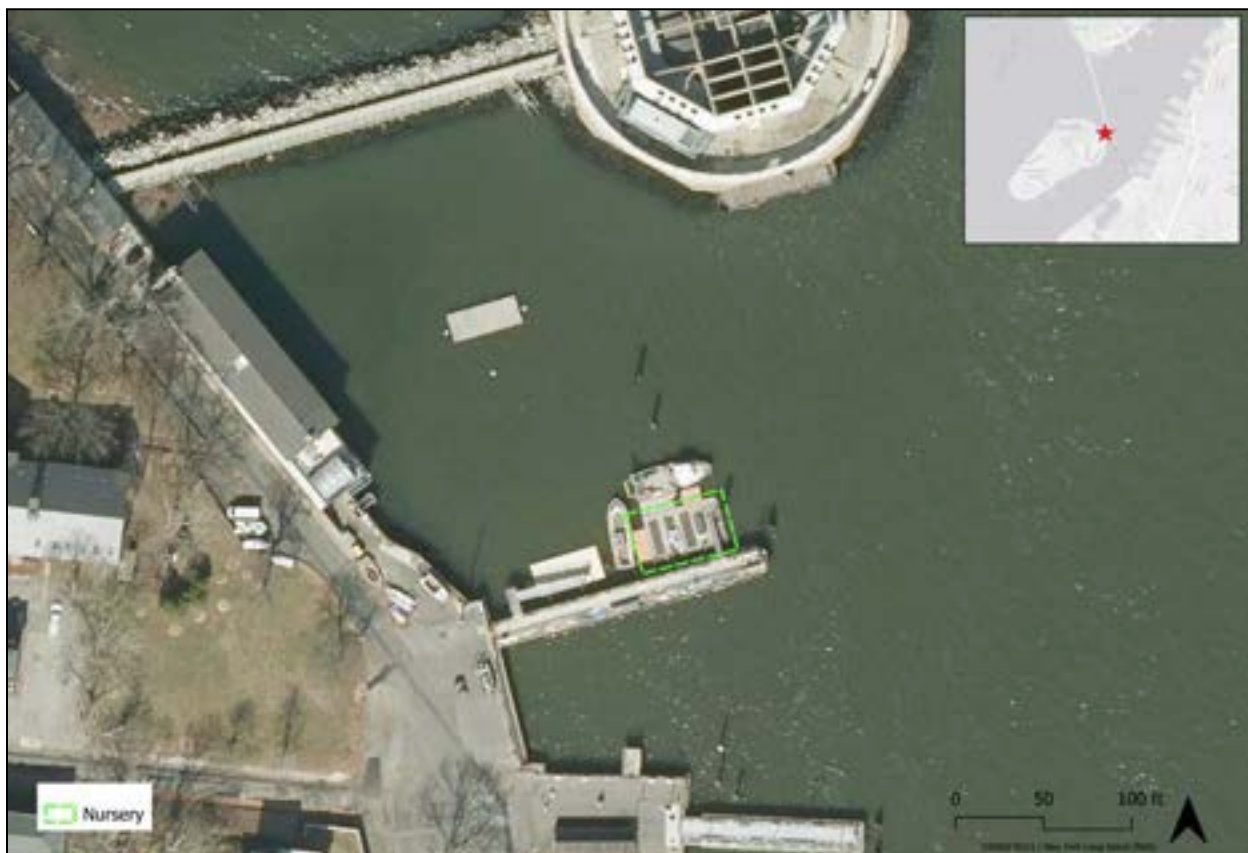


Figure 20. Map of the Governors Island Ecodock nursery site.

The frequent movement of oysters within the nursery and their eventual transfer to other restoration sites pose challenges for conducting regular monitoring activities and maintenance. However, annual monitoring is conducted each fall to assess their growth. Approximately 1,200,000 spat-on-shell were transplanted to the nursery in 2023 and an additional 1,432,368 spat-on-shell were introduced in 2024 (**Table 17**).

Table 17. Summary of structures installed and spat introduced to the Governor Island Ecodock Nursery.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
SuperTray Nursery	2023	60	1,200,000	Annual
	2024	7	1,432,368	

Oyster Performance

Because a new cohort is installed and monitored each year, BOP is unable to draw conclusions on trends for oyster growth, mortality, and recruitment. The yearly cycle of cohort installation and deployment for other restoration activities does not allow for the long-term data needed to identify clear performance trends.

Oyster Population Estimates

The current population estimate for Governors Island Ecodock cannot be determined as remaining cohorts are consolidated together to maximize space on the Ecodock.

Oyster Health

BOP did not collect any oysters from Governors Island Ecodock for oyster health assessment.

Recommended Restoration Actions

Governors Island Ecodock will continue to serve as a short-term holding bay for juvenile oysters before they are transferred to restoration sites or used in the Oyster Research Station and Oyster Research Tank programs. Due to this function and the frequent addition of new cohorts each year, it can be challenging to track oyster performance at the Governors Island Ecodock.

Great Kills Harbor

Project Summary

As of 2024, BOP maintains and monitors the SuperTray nursery in Great Kills Harbor Richmond County Yacht Club, with support from local students, and community members.

Trends from 2018-2024 data indicate the need for intervention based on

- The lack of recruitment and high mortality.
- Recurring presence of Dermo that is likely contributing to high mortality.
- Observed increasing presence of boring sponge that is also likely contributing to high mortality.

Site Overview

BOP established the Great Kills Harbor nursery beneath a pier, accessible via the floating docks of the Richmond County Yacht Club (**Figure 21**). Three cohorts of oysters were introduced in 2016, 2017, and 2019. All cohorts were placed in stacks of three SuperTrays, which were accessible during low tide or using a block and tackle for monitoring and maintenance.

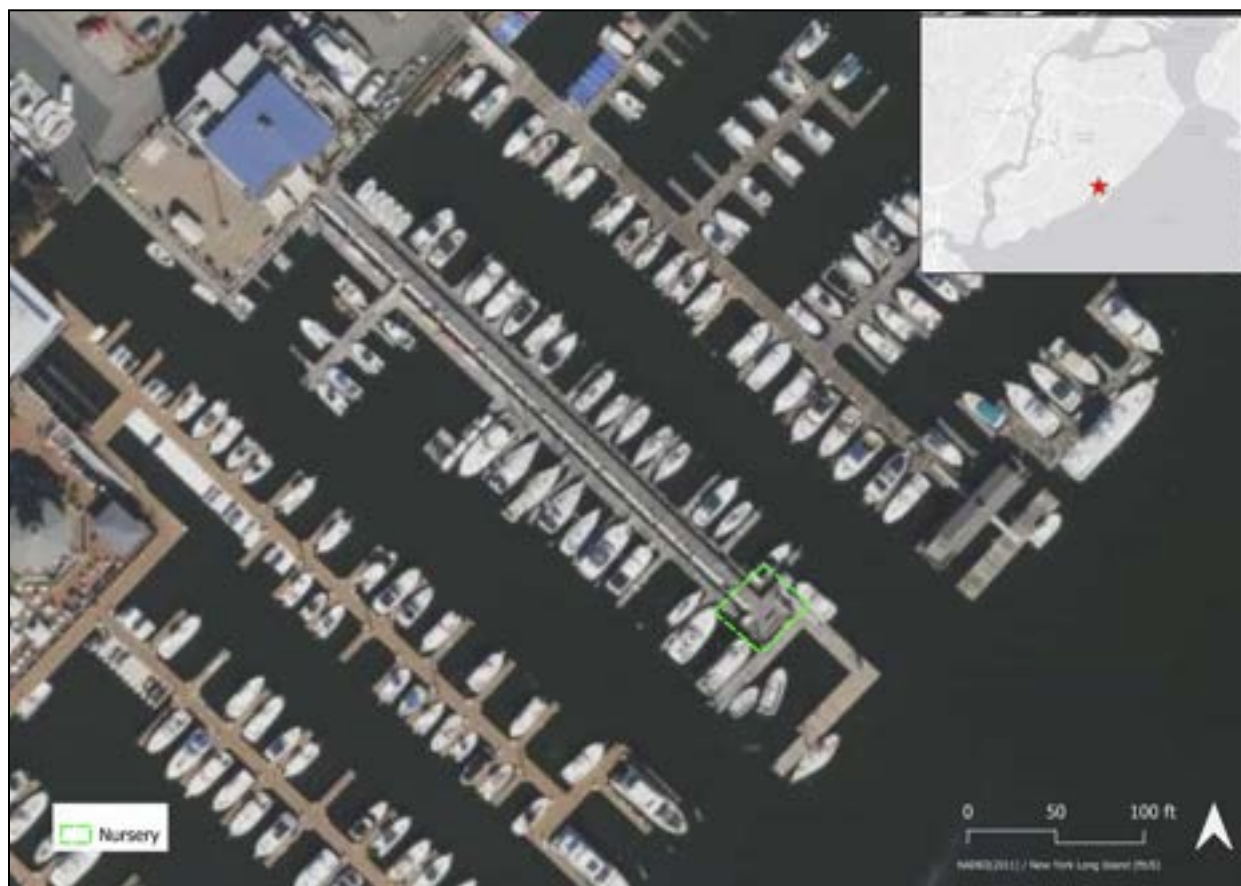


Figure 21. Map of Great Kills Harbor Nursery at Richmond County Yacht Club pier.

Table 18 summarizes the quantity of structures and oysters installed at Great Kills Harbor. In 2016, BOP introduced approximately 15,836 one-year old oysters across two stacks (6 trays) to the nursery. In 2017, twelve more stacks (36 trays) were added, containing approximately 141,327 spat-on-shell. In 2019, six

additional stacks (18 trays) were introduced with approximately 200,000 spat-on-shell.

Table 18. Summary of structures installed and oyster introduced to the Great Kills Harbor Nursery.

Structure Name	Year Installed	Quantity of Structures	Oyster Introduced	Monitoring Frequency
SuperTray Nursery	2016	6	15,836 (Adults)	Annual
	2017	36	141,327 (Spat)	
	2019	18	200,000 (Spat)	

In both 2023 and 2024, monitoring for all cohorts was conducted in the spring. During these monitoring events, BOP staff occasionally observed various fish and invertebrate species inhabiting the oyster shells within the structures, including blackfish, naked goby, and oyster toadfish. A detailed list of fish species observed during routine monitoring can be found in **Appendix Figure A3**.

Oyster Performance

Data from 2016-2017 are excluded from the size frequency graph because shell height and oyster status were not collected in tandem (**Figure 22**). Without this synchronized data, trends in oyster growth or status during these years could not be reliably analyzed or included in the graph. Additionally, no data was collected in 2020 due to the COVID-19 pandemic and related restrictions.

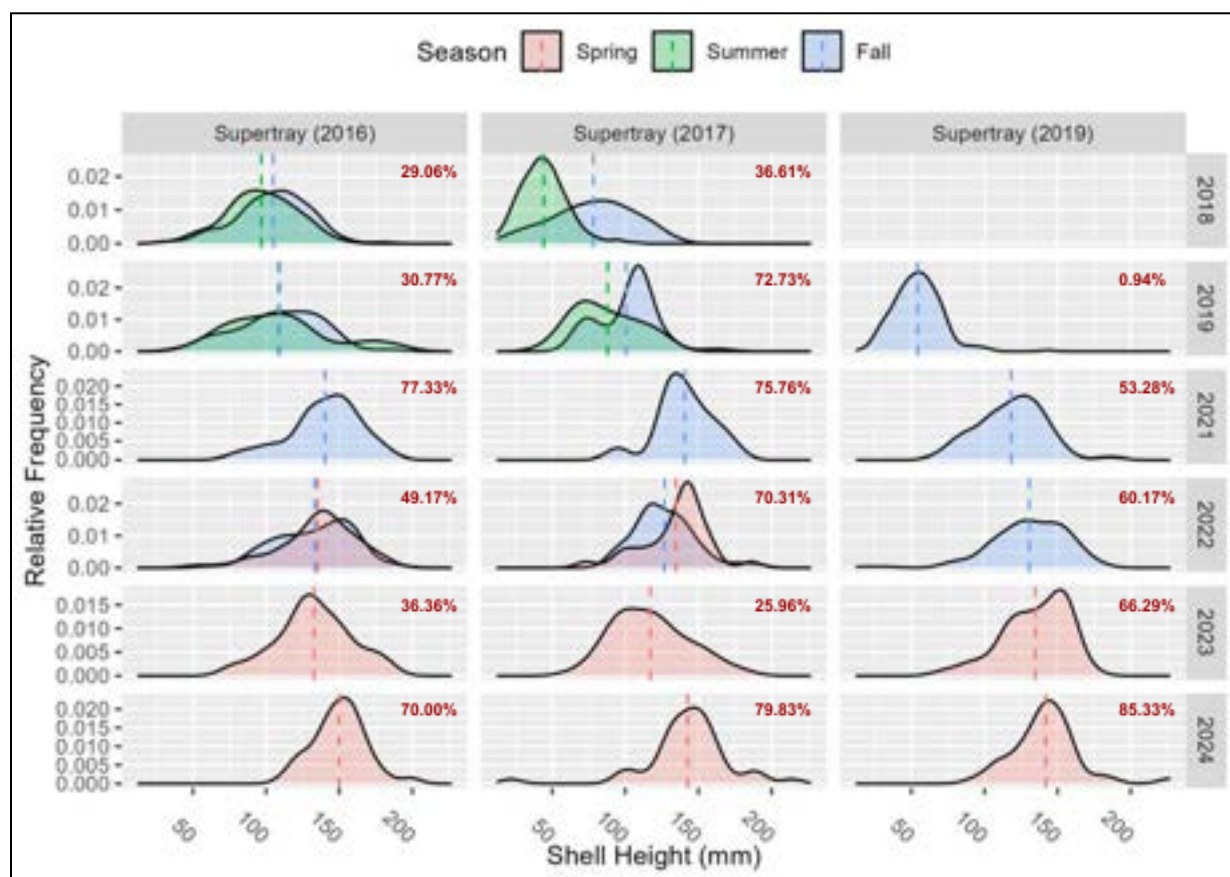


Figure 22. Size-frequency histogram of live oysters by cohort in Great Kills Harbor Nursery, 2018-2024. No data was collected in 2020 due to the COVID-19 pandemic. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Great Kills Harbor - 2016 Cohort

Growth: Stable

Oysters from the 2016 cohort have shown stable growth since their installation, with a slight decline in mean shell height from 140.3 mm in 2021 to 132.9 mm in 2023 (**Figure 22**). This decline in mean shell height during those years may be due to the natural mortality of larger oysters over time, leaving a higher proportion of smaller individuals. However, since 2023, mean shell height has increased again, reaching 150.0 mm in 2024.

Mortality: High

Annual mortality was not calculated for 2016-2017 but the mortality in the subsequent years increased to 36.4% in 2023, and 70.0% in 2024 (**Figure 22**).

Recruitment: None

Recruitment was observed one year after installation; however, no recruitment was detected between 2018-2024 (**Table 20**).

Great Kills Harbor - 2017 Cohort

Growth: Stable

Similar to the 2016 cohort, the mean shell height of the 2017 cohort generally increased over time, except in 2022 and 2023, when it declined from 129.9 mm to 117.1 mm (**Figure 22**). In 2024, mean shell height increased again, reaching 122.4 mm. This decline may be due to the natural mortality of larger oysters, leaving a higher proportion of smaller individuals. Despite sufficient sample sizes (N = 256 in 2022 and N = 104 in 2023), it is also possible that these samples were not fully representative, potentially excluding larger oysters and skewing the observed trends.

Mortality: High

Annual mortality was consistently high between 2019 and 2022, stabilizing at an average of 73%. In 2023, mortality dropped significantly to 26.0% before rising sharply to 80.0% in 2024 (**Figure 22**).

Recruitment: None

Recruitment was observed in 2018, one year post-installation at 3.4%. No recruitment has been recorded until 2024, with the detection of a single recruit representing 0.4% of the oysters sampled (**Table 20**).

Great Kills Harbor - 2019 Cohort

Growth: Positive

The 2019 cohort exhibited a consistent positive growth trend, unlike the other two cohorts at the site, reaching 134.8 mm in 2023 and 141.9 mm in 2024 (**Figure 22**). This steady growth may be attributed to the relatively younger cohort.

Mortality: High

Annual mortality has shown a consistent increase since installation, reaching 66.3% in 2023 and rising further to 85.0% in 2024 (**Figure 22**). This trend may be linked to increases in Dermo prevalence and intensity, which remained high at the site in both years.

Recruitment: None

Recruitment to the 2019 cohort was minimal, with only a single recruit observed in both 2022 (0.3%) and 2023 (0.6%) (**Table 20**). No new recruits have been recorded in 2024.

Oyster Density

Overall, oyster density remains consistently low and fluctuates annually across cohorts. Between 2023 and 2024, oyster density declined across all cohorts: the 2016 cohort decreased from 1 live oyster per 1.5 shells to 1 per 3.2 shells, the 2017 cohort from 1 per 1.3 shells to 1 per 4.9 shells, and the 2019 cohort from 1 per 2.5 shells to 1 per 6.1 shells (**Table 19**).

Recruitment density has generally remained low to nonexistent across all cohorts. The highest recruitment was observed in 2018 for the 2017 cohort—one year post-installation—with 1 live recruit per 13.3 shells. By 2024, this had declined to 1 recruit per 230 shells (**Table 19**).

Table 19. Sample size (live and dead box oysters), live oyster density and recruitment density per shell across all cohorts at Great Kills Harbor. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Cohort	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell
2016	2016	1360	NA	NA
	2017	144	NA	NA
	2018	407	0.85	0.00
	2019	273	0.76	0.00
	2020	0	NA	NA
	2021	150	0.38	0.00
	2022	300	0.54	0.00
	2023	77	0.65	0.00
	2024	130	0.31	0.00
2017	2017	424	NA	<1 year old
	2018	620	0.87	0.08
	2019	242	0.37	0.00
	2020	0	NA	NA
	2021	66	0.53	0.00
	2022	256	0.31	0.00
	2023	104	0.75	0.00
	2024	233	0.20	0.004
2019	2019	212	1.56	<1 year old
	2020	0	NA	NA
	2021	137	1.07	0.00
	2022	344	0.51	0.004
	2023	178	0.40	0.00
	2024	259	0.16	0.00

Oyster Population Estimates

The current oyster population estimates in **Table 20** may not accurately reflect the true population size due to a lack of data collection in 2020, which was impacted by the COVID-19 pandemic. As a result, percent mortality and recruitment for that year were not considered, potentially affecting the accuracy of the estimates.

The low population estimate observed can be attributed to high annual percent mortality, likely exacerbated by the presence of disease at the site, as well as low recruitment levels. Despite this, BOP staff noted a high biodiversity of fish and invertebrates at the site (**Appendix Figure A3**). However, the presence of boring sponge on oyster shells further underscores the challenges in fostering a sustainable and thriving oyster population at this location.

Table 20. Estimated population dynamics across all cohorts at Great Kills Harbor Nursery. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and recruitment. NA indicates missing data.

Cohort	Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
2016	2016	15,836	NA	15,836	NA	15,836
	2017	15,836	NA	15,836	1.85%	16,129
	2018	16,129	29.06%	11,443	0.00%	11,443
	2019	11,443	30.77%	7,922	0.00%	7,922
	2020	7,922	NA	7,922	NA	7,922
	2021	7,922	77.33%	1,796	0.00%	1,796
	2022	1,796	49.17%	913	0.00%	913
	2023	913	36.36%	581	0.00%	581
	2024	581	70.00%	174	0.00%	174
2017	2017	141,327	NA	141,327	NA	141,327
	2018	141,327	36.61%	89,593	3.37%	92,613
	2019	92,613	72.73%	25,258	0.00%	25,258
	2020	25,258	NA	25,258	NA	25,258
	2021	25,258	75.76%	6,123	0.00%	6,123
	2022	6,123	70.31%	1,818	0.00%	1,818
	2023	1,818	25.96%	1,346	0.00%	1,346
	2024	1,346	79.83%	271	0.43%	273
2019	2019	200,000	0.94%	198,113	1.42%	200,917
	2020	200,917	NA	200,917	NA	200,917
	2021	200,917	53.28%	93,859	0.00%	93,859
	2022	93,859	60.17%	37,380	0.29%	37,489
	2023	37,489	66.29%	12,637	0.56%	12,708
	2024	12,708	85.33%	1,864	0.00%	1,864
Total Estimated Population						2,311

Oyster Health

Great Kills Harbor oysters were tested for condition index from 2018 to 2019 and again from 2023 to 2024. For the results, please refer to **Appendix Figure B4**.

Disease

Dermo: **Moderate**

Overall, Dermo prevalence at Great Kills Harbor is notably higher compared to disease levels in oysters from similar restoration sites in Upper and Lower New York Bay. Dermo prevalence tends to rise in the fall compared to spring testing as the infection spreads over time. The potentially lethal infection gradually increased, peaking at 20.0% in 2023 before declining to 16.7% in 2024 (**Figure 23**). This decline could partly be attributed to differences in sample sizes, with a smaller sample in 2023 (N = 15) due to transport-related mortality, compared to a larger sample size in 2024 (N = 30). These results suggest that disease may significantly contribute to oyster mortality at this site. However, both Dermo prevalence and intensity decreased from 2023 to 2024.

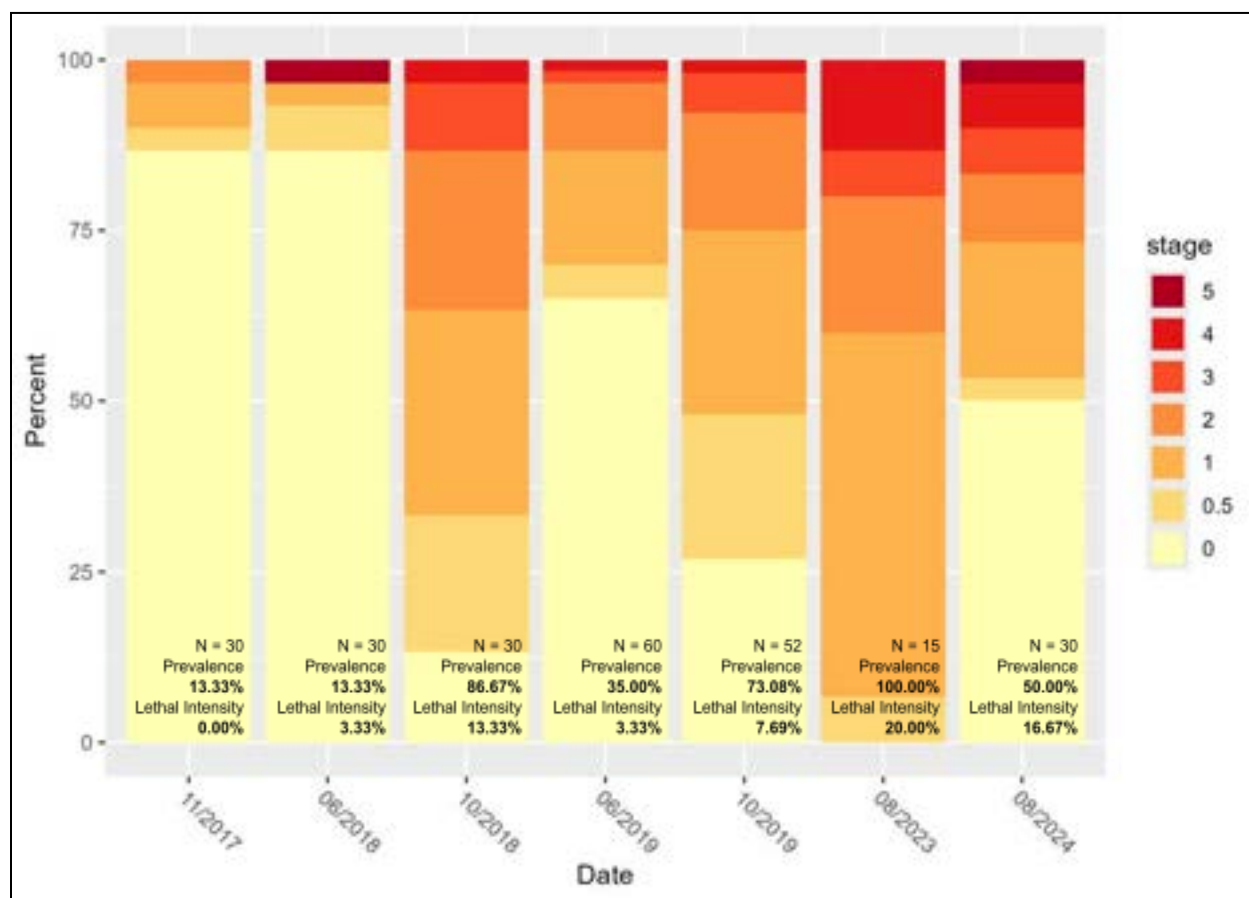


Figure 23. Dermo (*P. marinus*) prevalence and intensity in oysters from Great Kills Harbor. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be lethally infected.

MSX: **Low**

MSX was detected in one oyster in June 2018 and another in October 2018, but its overall prevalence remains low and has not been observed at this site since 2018.

Reproduction

Spawning: Moderate

Results showed that 86.7% of the sampled oysters were spawning in 2023, compared to 46.7% in 2024 (Figure 24). In 2024, many oysters were in the final spawning stage, with some beginning another reproductive cycle, suggesting the potential for fall maturation and spawning. In contrast, oysters in 2023 were predominantly in advanced gonadal stages, ranging from early development to full ripeness just before spawning. Variations in reproductive stages across years are likely influenced by differences in sample collection timing and annual environmental conditions.

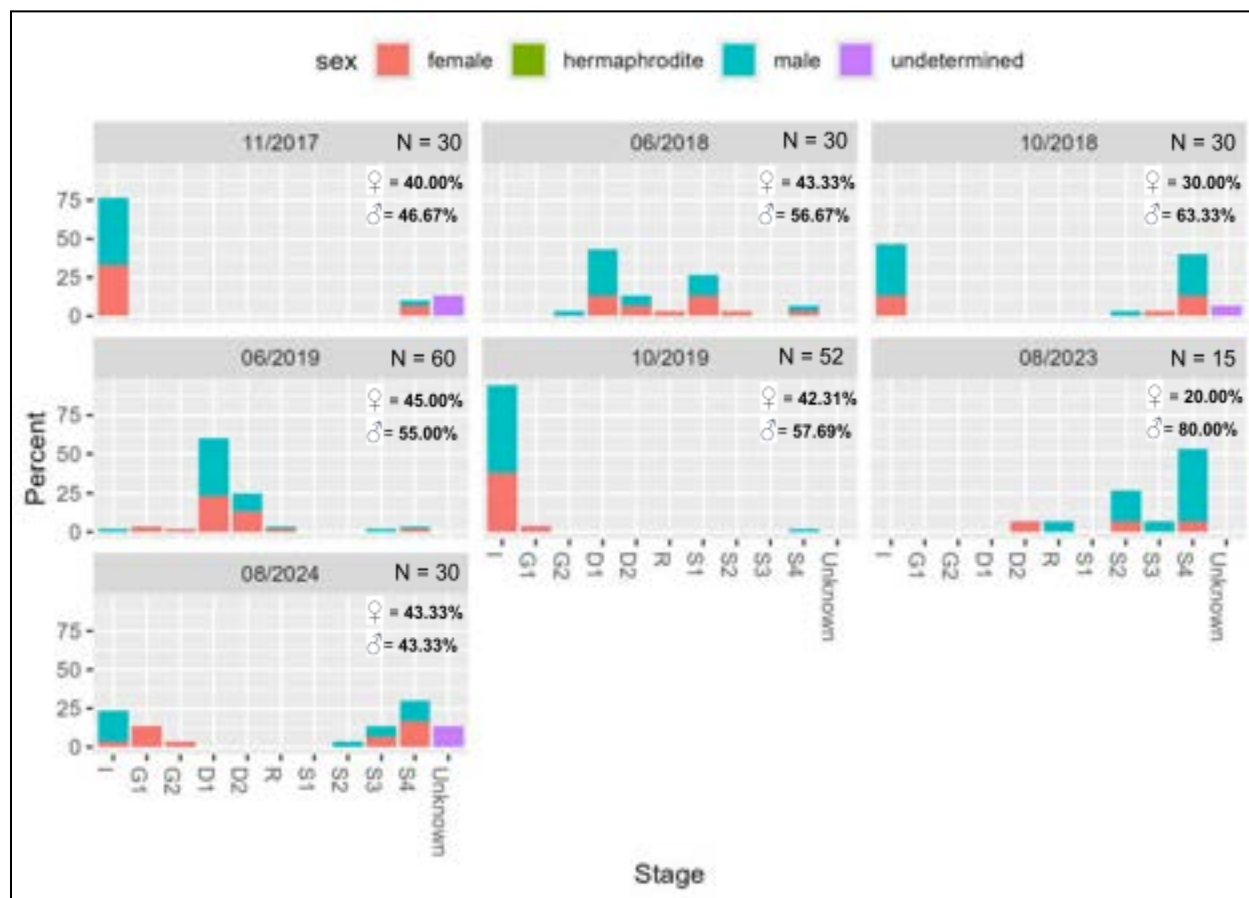


Figure 24. Stage of reproductive development and sex of oysters from Great Kills Harbor nursery. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Sex Ratio: Approaching

In 2023, the sex ratio was skewed toward males, consistent with findings from 2017, 2018 and 2019, whereas the sex ratio in 2024 was 50:50 (Figure 24).

Recommended Restoration Actions

Due to high disease loads and elevated annual mortality, BOP will remove this nursery in 2025. BOP acknowledges the valuable opportunities this nursery has provided for community engagement in restoration and research initiatives.

The Oyster Research Stations at the Great Kills Harbor site will remain, as these cages are actively used by local teachers and school groups and can be restocked annually for programmatic use if needed. BOP will continue its Oyster Research Stations programming at Great Kills Harbor, engaging Staten Island teachers and students in oyster-related activities and curricula that promote waterfront access and environmental stewardship.

Lemon Creek Lagoon

Project Summary

Lemon Creek Lagoon is located in Lemon Creek Park on the southeastern shoreline of Staten Island. The tidal lagoon is fringed by a salt marsh, with a sediment composition of sandy mud and a maximum depth of nine feet. The lagoon is under the jurisdiction of the New York City Department of Parks and Recreation, is publicly accessible, and is patrolled by NYC Parks' Urban Park Rangers. Installation activities commenced in August 2018, and the permit was extended to December 31, 2024, to accommodate removal activities and prepare a close-out report for the site.

Site Overview

In 2017, BOP designed and permitted a pilot project within the lagoon to evaluate the effectiveness of various oyster reef substrates for potential use in the Living Breakwaters project (**Figure 25**). The installation included seeded and unseeded mini gabions, EConcrete® disks, and a bagged shell reef, covering a total area of approximately 540 square feet (**Table 21**). These substrates served as a pilot study to assess oyster performance and recruitment to EConcrete® materials in preparation for the Living Breakwaters initiative.



Figure 25. Map of installations at Lemon Creek Lagoon, 2023-2024.

Since the reef's installation in 2018, BOP staff have collected data on oyster performance, water quality, and epibenthic biodiversity at the site. Monitoring was conducted biannually to evaluate oyster

performance and maintain the site until 2023, when it shifted to annual monitoring. Data collection was disrupted in 2020, and only one monitoring event occurred in 2021 due to the COVID-19 pandemic. Past water quality and epibenthic biodiversity of the lagoon can be found in past reports on BOP's website and a detailed list of fish species observed during routine monitoring can be found in **Appendix Figure A4**.

Table 21. Summary of structures installed and spat introduced at Lemon Creek Lagoon.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Gabions	2018	12	31,226	Annual
ECONcrete® Disks		18 seeded 18 unseeded	23,419	
Bagged Shell		66 seeded 30 unseeded	187,355	

Oyster Performance

Figure 26 shows oyster performance (growth, mortality, and recruitment) across all structures installed in Lemon Creek Lagoon from their 2018 installation to their final monitoring and removal in 2024.

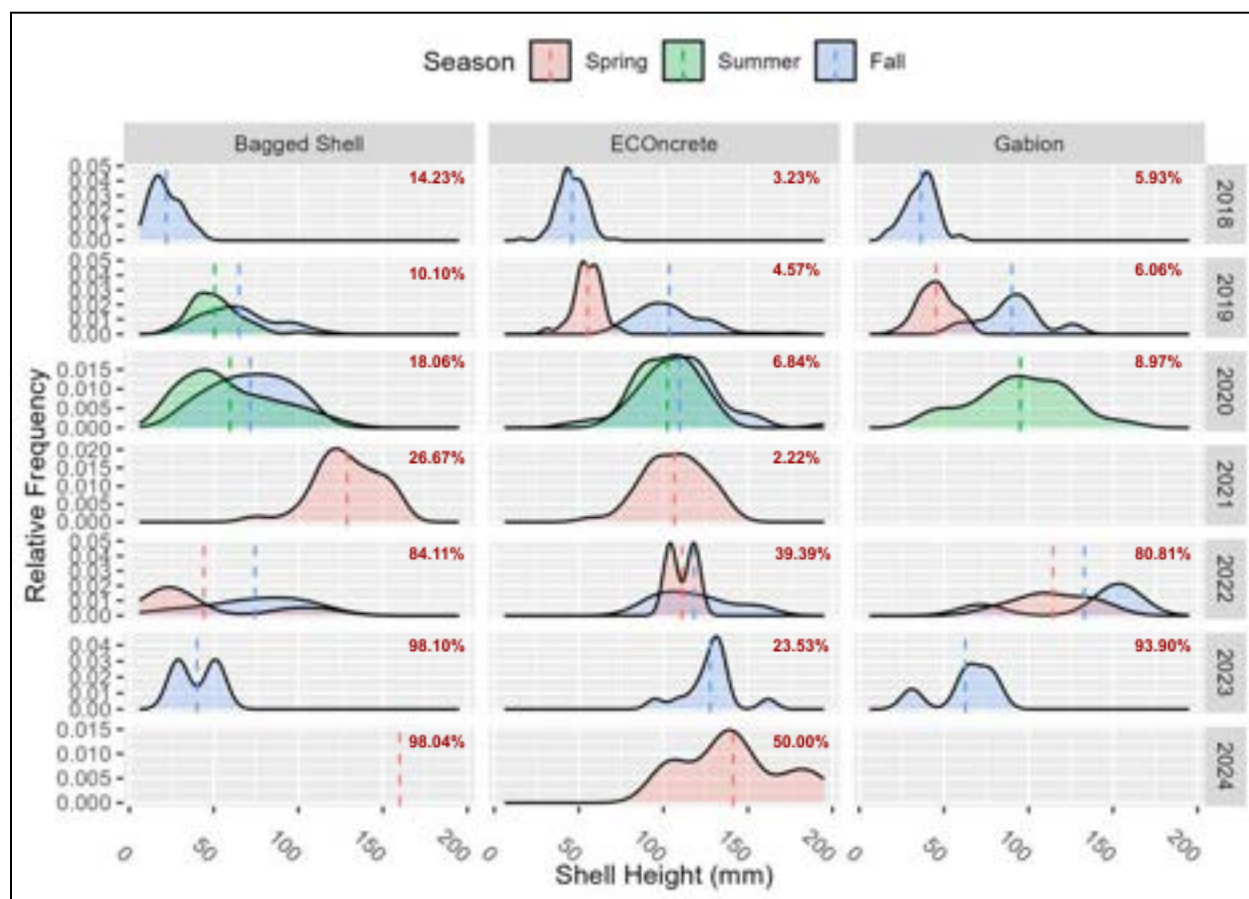


Figure 26. Size-frequency histogram of live oysters by structure in Lemon Creek Lagoon, 2018-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality. Sample size was low for Bagged Shell Reef in 2023 (N = 2) and 2024 (N = 1).

Bagged Shell Reef

Growth: Negative

From 2018 to 2021, oyster performance exhibited a positive growth trend. However, from 2022 to 2024, fluctuations in mean shell height were observed, with a notable increase from 40 mm in 2023 to 160 mm in 2024 (**Figure 26**). These variations in mean shell height are likely due to inconsistent sample sizes, as the number of live oysters monitored declined (15 recorded in 2022, 2 in 2023, and only 1 in 2024).

Mortality: High

Figure 26 illustrates the annual mortality of bagged shell oysters, which remained relatively low from 2018 to 2021, ranging from 10.1% to 26.8%. However, annual mortality increased from 84.1% in 2022 to 98.1% in 2023 and 2024, with only a few live oysters observed (N = 2 in 2023 and N = 1 in 2024). In 2022, BOP staff noted discoloration on oyster shells in the bagged shell reef, indicating potential exposure to anoxic sediment conditions.

Recruitment: None

Despite recruitment being observed in 2022 at 1.4%, no recruitment was recorded in the past two years (**Table 23**).

ECONcrete® Disks

Growth: Positive

Since installation, oysters on the ECONcrete® disks have shown positive growth (**Figure 26**). From 2023 to 2024 (5 and 6 years post-installation), mean shell height increased from 127.6 mm to 141.3 mm on the disks. This increase in mean shell height reflects a consistent trend observed since the installation in 2018, when the average shell height was 45.9 mm, growing to 117.4 mm by 2022.

Mortality: High

Annual mortality was below 10% from 2018 to 2021, the first three years post-installation (**Figure 26**). By 2022, annual mortality increased to 39.4%, slightly decreased to 23.5% in 2023 and peaked to 50% in 2024 (**Figure 26**). This overall increase in annual mortality may be attributable to several environmental stressors, from sedimentation and anoxia or disease to water quality changes in the lagoons. BOP cannot confirm which stressors specifically caused or contributed to the shift in annual mortality.

Recruitment: None

ECONcrete disks show no signs of recruitment since installation (**Table 23**).

Mini Gabions

Growth: Negative

From 2018 to 2022, oyster performance showed a positive trend as the initial cohort matured into adulthood (**Figure 26**). The decline in mean shell height to 62.6 mm in 2023 may be attributed to the mortality of older oysters. No data was collected in 2024, as there were no live or dead box oysters available for assessment.

Mortality: High

Prior to 2021, annual mortality in the gabions was relatively low averaging 7% (**Figure 26**). However, as the oysters reached five years of age in 2023, annual mortality reached 93.9%. This change may be attributable to several factors, including the smaller sample size measured, disease, or other environmental stressors, such as high sedimentation.

Recruitment: None

There was no annual recruitment in the gabions except one recruit recorded in 2023, representing 1.2% of the sampled oysters (**Table 23**). Low recruitment is expected, as the lagoon is connected to Princes Bay via a small inlet/outlet and is often disconnected from the bay at low tide.

Oyster Density

The bagged shell reef was initially assessed using clump monitoring, then transitioned to quadrat monitoring when oysters grew through the bags, and later returned to clump monitoring after the older oysters died. Oyster density in the bagged shell reef has generally declined over time, with some year-to-year fluctuations, but has recently stabilized at approximately 0.02 live oysters per shell (1 live oyster per 41–46 shells) in both 2023 and 2024 (**Table 22**). Recruitment density followed a similar pattern of decline, with no recruitment observed in either year (**Table 22**).

For the EConcrete® disks, oyster density is defined as the total number of live oysters counted across the disk surface area (excluding vertical grooves), converted to a per-square-meter value. Overall, oyster density exhibited a general decline, with a brief increase in 2022 to 41.7 live oysters per square meter before dropping to 21.4 in 2023 and further to 9.9 in 2024 (**Table 22**). Recruitment has not been observed on the disks since installation (**Table 22**).

Oyster density in the mini gabions showed a consistent decline over time. Density data from 2022 to 2023 could not be accurately calculated due to deterioration of the gabion mesh, which made area-based assessments unreliable. In 2024, no live or dead box oysters were observed in the monitored mini gabions, and no recruitment has been recorded since installation (**Table 22**).

Table 22. Sample size (live and dead box oysters), live oyster and recruitment density (per shell and per square meter) across all structures at Lemon Creek Lagoon. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
Bagged Shell Reef	2018	504	3.78	<1 year old	NA	<1 year old
	2019	95	NA	<1 year old	50.00	<1 year old
	2020	155	19.00	0.00	337.50	18.75
	2021	45	0.73	0.00	NA	NA
	2022	105	0.15	0.04	NA	NA
	2023	105	0.02	0.00	NA	NA
	2024	51	0.02	0.00	NA	NA
EConcrete® Disks	2018	310	NA	<1 year old	986.78	<1 year old
	2019	194	NA	<1 year old	730.22	<1 year old
	2020	109	NA	NA	498.32	0.00
	2021	43	NA	NA	21.25	0.00
	2022	32	NA	NA	41.66	0.00
	2023	17	NA	NA	21.38	0.00
	2024	16	NA	NA	9.87	0.00
Mini Gabions	2018	236	222.00	<1 year old	NA	<1 year old
	2019	66	NA	<1 year old	222.46	<1 year old

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
	2020	78	18.50	0.00	212.50	0.00
	2021	0	NA	NA	NA	NA
	2022	99	3.17	0.00	NA	NA
	2023	82	0.06	0.00	NA	NA
	2024	0	NA	NA	NA	NA

Oyster Population Estimates

The estimated oyster population across all structures is presented in **Table 23**, based on annual mortality and recruitment data calculated from each monitoring event. However, the actual population may be smaller than this estimate due to the small sample sizes in recent monitoring years and missing data for mini gabions in certain years. Without the introduction of new cohorts through intervention or consistent natural recruitment to the lagoon, the oyster population continued to decline.

Table 23. Estimated population dynamics across all structures at Lemon Creek Lagoon. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and recruitment. NA indicates missing data.

Structure	Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
Bagged Shell Reef	2018	187,355	14.23%	160,689	NA	160,689
	2019	160,689	10.10%	144,458	0.00%	144,458
	2020	144,458	18.06%	118,362	0.00%	118,362
	2021	118,362	26.67%	86,799	0.00%	86,799
	2022	86,799	84.11%	13,790	1.35%	13,977
	2023	13,977	98.10%	266	0.00%	266
	2024	266	98.04%	5	0.00%	5
ECONcrete® Disks	2018	23,419	3.23%	22,664	NA	22,664
	2019	22,664	4.57%	21,628	0.00%	21,628
	2020	21,628	6.84%	20,149	0.00%	20,149
	2021	20,149	2.22%	19,702	0.00%	19,702
	2022	19,702	39.39%	11,940	0.00%	11,940
	2023	11,940	23.53%	9,131	0.00%	9,131
	2024	9,131	50.00%	4,565	0.00%	4,565
Mini Gabions	2018	31,226	5.93%	29,374	NA	29,374
	2019	29,374	6.06%	27,593	0.00%	27,593
	2020	27,593	8.97%	25,117	0.00%	25,117
	2021	25,117	NA	25,117	NA	25,117
	2022	25,117	80.81%	4,820	0.00%	4,820
	2023	4,820	93.90%	294	1.22%	298
	2024	298	NA	298	NA	298
Total Estimated Population						4,868

Oyster Health

BOP did not collect any Lemon Creek Lagoon oysters for lab testing in 2023 and 2024.

Recommended Restoration Action

During Fall 2023 monitoring, BOP observed substantial structural deterioration of the steel mesh inserts of two gabions, which were removed and disposed of in an upland facility. In Spring 2024, BOP field staff, divers, and NYC Parks Urban Park Rangers met onsite to retrieve, monitor, and remove 16 disks and their rebar supports, five mini-gabions, and six of the bagged shell. Upon conclusion of the monitoring and coordinated permission from NYSDEC and NYC Parks to leave the remaining onsite structures that could not be retrieved without significant intervention and a small population of live oysters.

The Lemon Creek Lagoon Project provided valuable insight into the performance of three different substrates in a waterbody with low natural recruitment and minimal post-installation intervention. Oyster population dynamics (especially mortality) appear primarily driven by site conditions, specifically sedimentation. Future oyster restoration in this area should consider reef substrates with higher profiles to minimize subsidence, especially if sediment dynamics in the lagoon or nearby marina aren't mitigated. Higher profile substrate (such as reef balls, oyster castles, or similar) may promote higher rates of oyster survival, and subsequently higher rates of reproduction and recruitment. Any future oyster restoration projects in this area should include assessing the restored population's reproductive potential and frequency and sex ratios. Reproduction data would inform the need for interventions like reseeding or expansion.

BOP would consider future oyster restoration projects in or adjacent to Lemon Creek Lagoon if opportunities arose to apply different seeded substrates, especially if potential efforts or construction projects sought to mitigate sediment erosion and accretion issues through nature-based design.

Williamsburg Field Station

Project Summary

From 2020-2024, BOP installed and monitored several habitat enhancements at two sites owned by Two Trees Management along the Williamsburg waterfront on the East River: the North 1st Street Pier and Domino Park Seawall Ledge (**Figure 27**). The project sought to 1) provide hands-on interactive opportunities for community and school groups to engage in oyster ecology at North 1st Street, and 2) understand habitat conditions and oyster performance along the seawall ledge, a hardened shoreline along the East River. Secondly, the Seawall Ledge allowed BOP to interact with new designs and alternative materials to understand if introduced oysters survive in an environment with heavy wave action and if specific enhancements performed better than others.



Figure 27. Site map of the Williamsburg Field Station.

Throughout the project, BOP was unable to access some of the installed structures due to material performance, improved understanding of site conditions or design applicability, or general safety concerns. However, the general site accessibility challenges were the main drivers behind BOP's decision to end the pilot project at North 1st Street and the Seawall Ledge. In December 2023, BOP and NYSDEC mutually agreed not to renew the permit for this site but extend it by six months to allow the safe removal of all accessible and identifiable structures. BOP removed structures from the site before June 30, 2024.

Site Overview

The installation at North 1st Street Reef was located in the East River at the end of a 200-foot steel pier within privately owned Domino Park, with public access restricted, and a water depth averaging 16 feet, where 300,000 spat-on-shell were permitted by NYSDEC. In 2020, BOP installed one 2' x 2' cabinet, suspended from the North 1st Street Pier off-bottom. In 2021, BOP installed four more 2' x 2' cabinets on-bottom at the end of the pier; each cabinet was fitted with seven mesh files filled with spat-on-shell, totaling approximately 151,000 oysters in all five cabinets (**Table 24**). The cabinets were intended for hands-on education and engagement with Williamsburg students and community groups; while the cabinets were retrieved bimonthly, oyster growth data was collected only to facilitate teaching and engagement. In late 2022, the pier's owner suspended our access to the cabinets for programmatic use due to structural concerns and ongoing construction on the adjacent property.

The Seawall Ledge is an old concrete retaining wall on timber piles beneath the Domino Park Esplanade, south of the North 1st Street Pier, with water depths averaging 5 to 8 feet, restricted public access, and 700,000 spat-on-shell permitted by NYSDEC. Over two years, on the seawall ledge, BOP installed plastic mesh bags of unseeded cured shell, biodegradable mesh bags of spat-on-shell, one piling wrap with spat-on-shell, six unseeded EConcrete disks, and one flat-paneled mesh fence structure filled with unseeded cured shell (**Table 24**). These installations totaled approximately 377,000 spat-on-shell. Adjustments to the installed oysters are shown in **Table 24** based on updated spat count information. By 2023, recurrent site access challenges led BOP to conclude this pilot study on the East River. Removal activities concluded in June 2024.

Table 24. Summary of structures installed and spat introduced at Williamsburg Field Station.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Cabinet Reef	2021	5	151,422	Annual
Piling Wrap	2021	1	~7,000	
Bagged Shell Reef (Biodegradable)	2021	30	270,000	
Bagged Shell Reef (Plastic)	2022	14	36,735	
EConcrete® Disks (unseeded disks)	2022	6	0	
SEAPA Cages	2023	5	12,000	

Oyster Performance

No oyster performance data were collected for the piling wrap and EConcrete disks due to unsuccessful retrieval of the structures for monitoring. In Spring 2022, BOP discovered that the piling wrap had slipped down to the piling's base, likely due to high wave energy at the site and the insufficient strength of the clamping system. Attempts were made to retrieve the unit, but it could not be recovered. EConcrete discs were installed as unseeded structures and held up by rebar drilled against the wall of the ledge in Fall 2022. However, during the 2023 visit to the seawall ledge, BOP was surprised to find only the rebar and no disks.

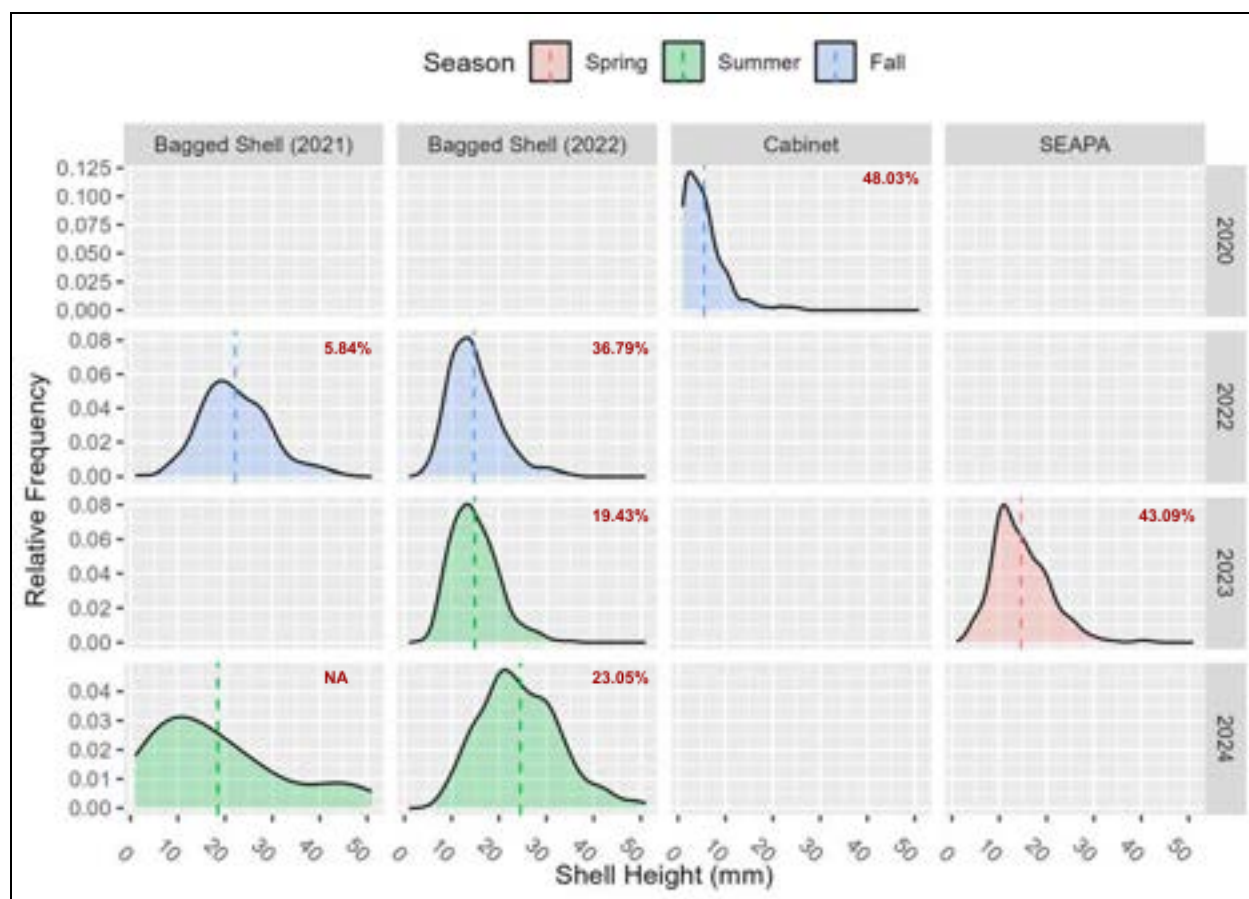


Figure 28. Size-frequency histogram of live oysters by structure in Williamsburg Field Station, 2020-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality. NA in the 2024 histogram of the Bagged Shell Reef (2021) indicates that annual mortality could not be calculated, as only one biodegradable bag containing only live oysters was monitored.

Bagged Shell Reef (Biodegradable) - 2021 Cohort

Given the small sample size of 7 live oysters observed in 2024 for the bagged shell reef 2021 cohort, BOP is unable to identify mortality and recruitment trends based on data from a single time point.

Growth: Negative

Mean shell height in the 2021 cohort in the bagged shell decreased from 22.1 mm in 2022 to 18.4 mm in 2024 (**Figure 28**). This decline may be attributed to the low sample sizes in 2024, where only 7 live oysters were recorded, as most of the biodegradable bags had deteriorated. No data was collected on the 2021 cohort in 2023 due to staff safety concerns related to accessing the ledge and the limited low tide dates.

Bagged Shell Reef (Plastic) - 2022 Cohort

Given that the 2022 cohort was installed in October 2022 and the subsequent monitoring visit took place in June 2023, less than one year after installation, annual recruitment could not be calculated by differentiating size classes and using less than 25 mm as the threshold. Therefore, BOP is unable to identify recruitment trends based on data from a single time point. Based on staff observations during monitoring events, the trench where the bags were placed appears to offer a protected environment, which may have contributed to the presence of wild recruitment in the ledge.

Growth: Positive

Since installation, oyster growth of the bagged shell reef 2022 cohort showed steady growth, with the

mean shell height increasing from 14.7 mm in 2022 and 14.9 mm in 2023, to 24.5 mm in 2024 (**Figure 28**).

Mortality: Stable

The annual mortality of the 2022 cohort remained stable, oscillating from 36.8% in 2022 to a decrease at 19.4% in 2023, before rising again to 23.1% in 2024 among the sampled oysters (**Figure 28**). Despite the high wave energy from vessel traffic, this site seems to have favorable conditions for oysters to survive. BOP has occasionally observed mud crabs in the trench, which could have preyed on the oysters.

Cabinet Reef

The cabinet reefs were primarily designed and installed as community engagement and education tools, not to inform future restoration decisions or recommendations based on their structural performance or the oysters' performance. As a result, BOP did not collect oyster performance data at the same annual frequency as at the Seawall Ledge. However, qualitative observations about the structural condition of the cabinets and the survival of oysters were documented.

A fall monitoring event was conducted in 2020 to assess post-installation oyster growth (**Figure 28**). Without additional data from another time point for comparison, it is challenging to identify any trends in oyster performance. The decision to remove the cabinets from North 1st Street was made in late 2023 because the landowner restricted access to the site.

SEAPA Cages

Similar to the community cabinets, the SEAPA cages were primarily designed and installed as community engagement and education tools, not to inform future restoration decisions or recommendations based on their structural performance or the oysters' performance. As a result, BOP did not collect oyster performance data at the same annual frequency as the bagged shell reefs at the Seawall Ledge. However, qualitative observations about the structural condition of the cabinets and the survival of oysters were documented.

A spring monitoring event in 2023 was conducted to assess post-installation oyster growth (**Figure 28**). Without additional data from another time point for comparison, it is challenging to identify any trends in oyster performance. A fall 2023 visit to the site revealed an absence of cages that were supposed to be hanging on the pier. BOP speculates that the wave energy at this site was strong enough to detach the hanging cages, as it has caused warping in the cages during past incidents.

Oyster Population Estimates

The population estimate for Williamsburg Field Station cannot be determined, as annual mortality and annual recruitment could not be calculated due to missing data for certain years across structures.

Oyster Health

BOP did not collect any Williamsburg Field Station oysters for lab testing in 2023 and 2024.

Recommended Restoration Actions

Generally, oysters in the bagged shell reefs could and did survive at the Seawall Ledge. The Seawall Ledge pilot sought to provide insight into oysters' ability to survive in such a high wave energy environment with hardened shoreline infrastructure. The trench's protection from direct wave impact likely contributed to the low mortality. The ledge is exposed at low tide, but constantly wet due to boat wake and waves. It is also 100% shaded by the Domino Park Esplanade, so oysters do not experience direct sunlight. These two factors reduce desiccation risk. As noted above, however, it is difficult to make conclusions about oyster performance in the East River based on this pilot. Because of site access challenges, the monitoring frequency was too inconsistent to draw meaningful, data-based conclusions about oyster restoration in the East River beyond the qualitative statement of "oysters survived, grew, and appeared to recruit to this location."

A significant outcome of this project is the improved understanding of an enhancement technique versus a restoration technique, and how enhancement more appropriately describes BOP's work at the Seawall Ledge than restoration. Interventions like piling wraps can be effective in introducing oysters to a hardened shoreline where the availability of on-bottom reef habitat is limited or absent; they can be used to enhance existing infrastructure. Unlike larger-scale oyster restoration, which seeks to add millions of oysters and quantities of substrate over multiple years to create an on-bottom multi-dimensional habitat, enhancements like those piloted at the Seawall Ledge can only introduce a few thousand oysters and do not create the same habitat as an on-bottom reef. However, there is still value in increasing the number of spawning adult oysters in the water to add larvae to the estuary, and practitioners (including BOP) should continue to explore habitat enhancement structures.

The dynamic site conditions of the Seawall Ledge required the development of custom designs or specific materials. The project required significant time and funding to develop, prototype, and install such custom structures and restoration practitioners need to consider the overall applicability of designs. Questions like *"Can this design be applied elsewhere in the Harbor? Can this design achieve similar results? Can this design be customized or changed in a cost-effective way?"* should be considered during the Research & Development phases.

Jamaica Bay

The Jamaica Bay Region encompasses 16,000 acres of surface waters and 3,000 acres of islands and marshes ([NYC DEP](#)). The tidal inlet to Jamaica Bay is in the west between Manhattan Beach (Brooklyn) and Breezy Point on the Rockaway Peninsula (Queens). The Bay extends eastward to JFK Airport and Bayswater Point and to Brooklyn and Queens shorelines in the north. Given the single inlet to the Bay, this region is somewhat disconnected from other regional waterbodies. Except for the navigational channels, the Bay is relatively shallow with an average depth of 13 feet. A significant portion of the shoreline is public parkland (New York City Parklands, New York State Parklands, or National Park Service-owned parklands) and remains undeveloped. Future oyster restoration in this regional waterbody will require collaboration with these governmental landowners. Current oyster restoration sites within the Jamaica Bay waterbody include Head of Bay, Paerdegat Basin, and Bayswater Point State Park (**Figure 29, Table 25**). Based on data from these sites, there is strong potential for the successful recovery of oyster populations but the addition of substrate and recurrent reseeding with cohorts of oysters are necessary interventions in this waterbody.

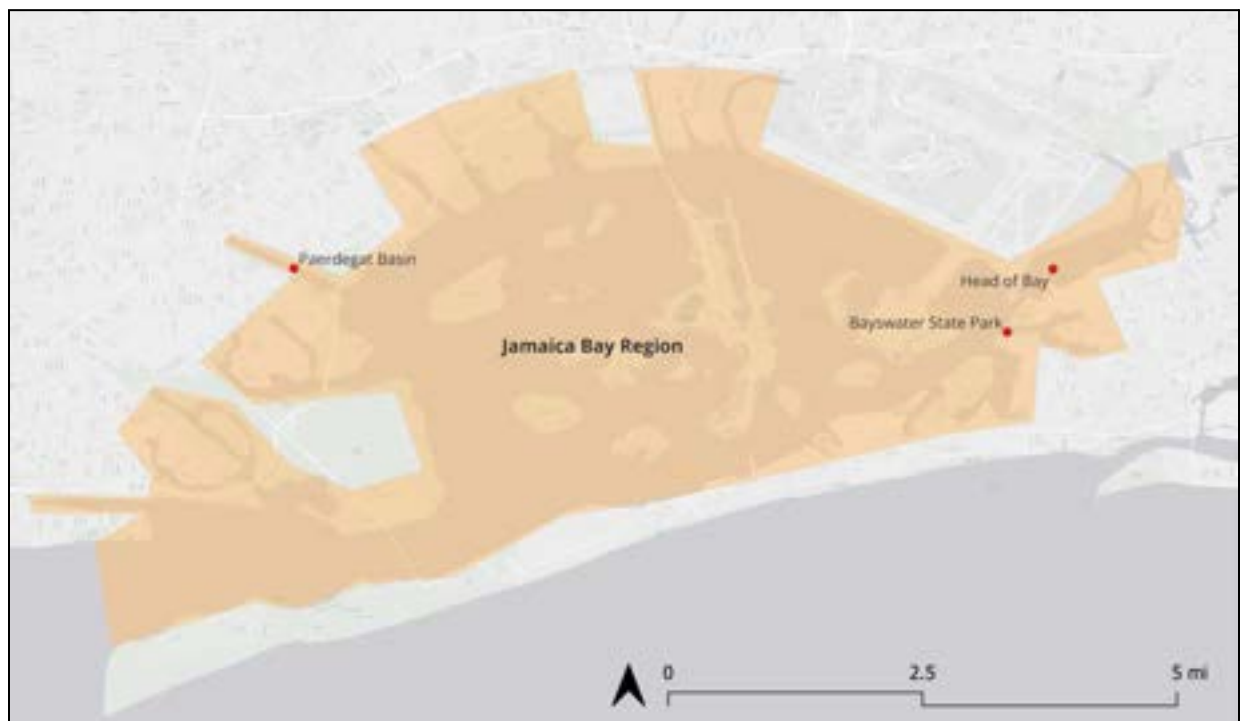


Figure 29. Map of restoration sites within Jamaica Bay.

Table 25. Summary of restoration structures and installation details of each site within Jamaica Bay, organized by installation date.

Site	Structure	Installation date	Oyster source	Size at installation (shell height, mm)	Number of oysters installed
Head of Bay (HOB)	OysterGro	09/01/2016	Merry Oysters, MA Island Creek Oysters, MA	~120	35,200
		11/08/2017 12/08/2017			9,300
		2018	Merry Oysters, MA Island Creek Oysters, MA	~130	40,000*
	Shell Reef	06/16/2023	Oyster Seed Holdings, VA	~10	15,353,000
		07/31/2024		~45	50,000
Paerdegat Basin (PB)	Cabinet Reef	7/27/2018	Muscongus Bay, ME	~5	480,000
Bayswater Point State Park (BW)	Bagged Shell Reef	7/20/2020	Muscongus Bay, ME	~5	30,514
		9/14/2020		2-5	414,749

* Adult oysters were transferred from the floating "donor reef" to the on-bottom "receiver reef" in 2018.

Bayswater Point State Park

Project Summary

As of 2024, BOP maintains and monitors the bagged shell reef installation in Bayswater Point State Park with support from local students and community groups. This project provides insight into oyster health and performance using the shallow nearshore environment of Jamaica Bay, Queens, NY. A secondary objective of the project compares the performance of bags constructed from natural fibers, such as coir or coconut, with those made from plastic mesh. The experimental bags contain either unseeded shell or seeded shell material.

Trends from 2020-2024 data indicate

- Gradual increase of oyster size and consistent recruitment annually.
- High annual mortality relative to the mortality elsewhere in Jamaica Bay.
- The need to reconsider the structure design at this site to minimize mortality.

Site Overview

The Bayswater Point State Park project is located at Motts Point in Joseph Sanford Jr. Channel, eastern Jamaica Bay (**Figure 34**). This site features a sandy beach shoreline bordered by salt marsh and forest.



Figure 34. Map of Bayswater State Park Bagged Shell Reef.

In summer 2020, BOP staff, project partners, and volunteers constructed an on-bottom reef consisting of 96 coir and plastic mesh bags filled with seeded or unseeded shells (**Table 26**). Each bag measures approximately 24" x 6". The bags were secured to the reef perimeter by threading a wire through them and anchoring it to the substrate with steel stakes. The reef remains permanently submerged and can only be accessed during low tide.

Table 26. Summary of structures installed and spat introduced at Bayswater Point State Park.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Bagged Shell Reef	2020	96	445,263	Biannual

Monitoring was conducted during the spring and fall of 2023 and the spring of 2024 to assess oyster performance with local school groups and community members. During monitoring events, BOP staff have observed various fish and invertebrate species inhabiting the oyster shells within the bagged shells and documented the presence of these fauna. The fish species observed during routine monitoring at Bayswater Point State Park in 2023, including numerous Atlantic silverside, are detailed in **Appendix Figure A6**.

Oyster Performance

Growth: Positive

Figure 35 illustrates the overall mean shell height of live oysters, revealing a consistent increase from spring to fall during biannual monitoring and across years. However, a slight decrease in mean shell height was observed between 2021 (46.0 mm) and 2022 (44.9 mm). This reduction may be attributed to the smaller sample size in 2022 (N = 102 live oysters) compared to 2021 (N = 340) and death of larger individuals as they age. After 2022, the mean shell height increases to 56.3 mm in 2023 and further to 62.8 mm in 2024, highlighting the positive and consistent growth of the oysters at this site.

Mortality: High

Annual mortality at this site increased within the first three years post-installation. This elevated mortality is likely attributable to the frequent handling of oysters for programmatic activities and moderate sedimentation at the site, which caused oysters to become partially buried. During monitoring, BOP staff and volunteers observed the darkened coloration of oyster shells, indicating prolonged exposure to anoxic sediment. Annual mortality started to stabilize around 77.5% in 2023 and 2024 (**Figure 35**).

Recruitment: Consistent

Recruitment - as indicated by the occurrence of oysters less than 25 mm shell height - has remained consistent annually since 2021, with 11.9% recruitment observed in the 2023 sampled oysters and 11.9% in 2024, following a peak of 12.4% observed in 2022 (**Table 28**). BOP needs to continue monitoring recruitment at Bayswater to better understand annual trends and the influence of frequent handling and sedimentation. As additional oyster restoration projects in Jamaica Bay are permitted and implemented, these trends may change as larval availability increases.

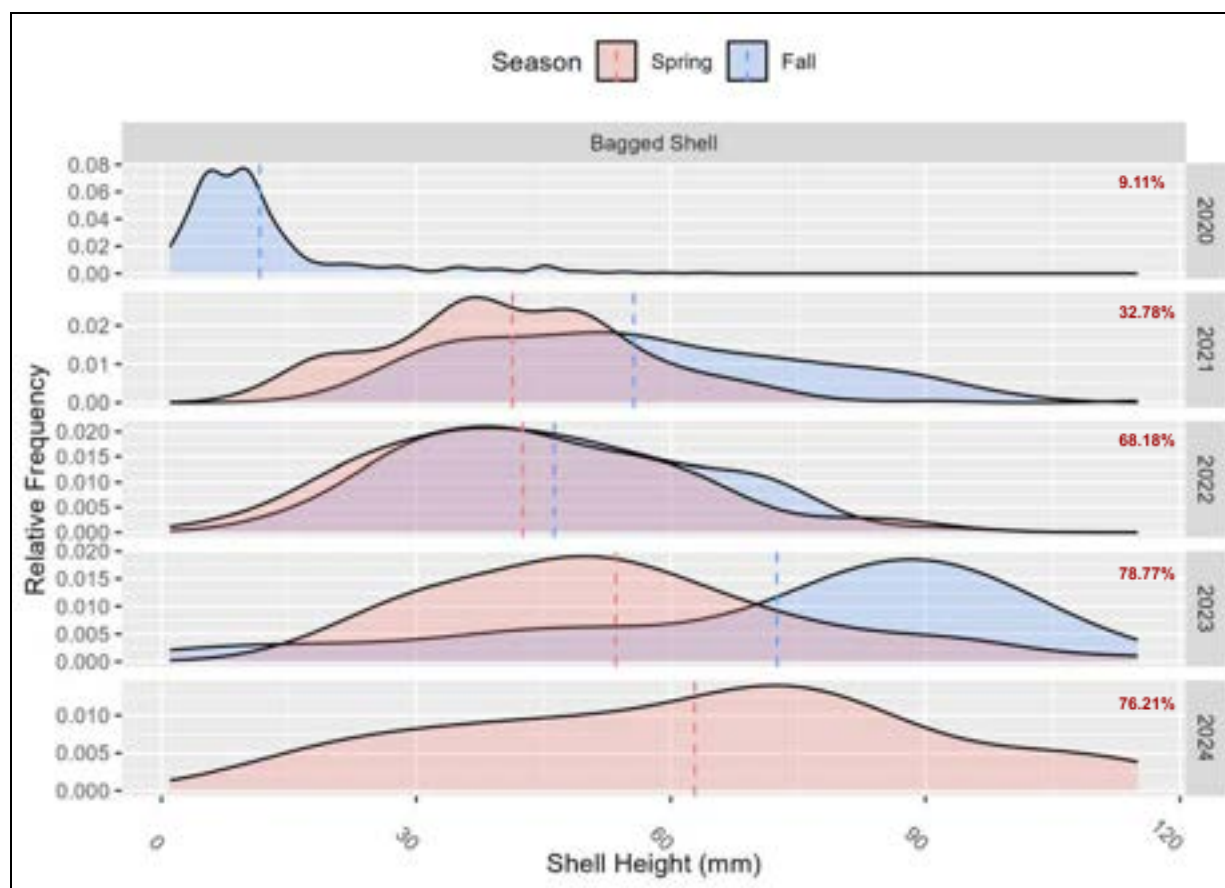


Figure 35. Size-frequency histogram of live oysters in Bayswater Point State Park bagged shell reef, 2020-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Density

Oyster density declined over time but began to stabilize in the last two years, with 1 live oyster per 3.9 shells recorded in both 2023 and 2024 (**Table 27**). Recruitment density also declined overall, with some fluctuation—from 1 live recruit per 66.5 shells in 2023 to 1 per 34.8 shells in 2024 (**Table 27**). Continued monitoring is needed to determine whether these recent trends will persist.

Table 27. Sample size (live and dead box oysters), oyster density and recruitment density as live oyster per shell and live recruit per shell across at Bayswater Point State Park. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell
Bagged Shell	2020	559	6.10	<1 year old
	2021	511	1.04	0.11
	2022	327	0.40	0.04
	2023	325	0.26	0.02
	2024	227	0.26	0.03

Oyster Population Estimates

The annual population estimates for the Bayswater State Park bagged shell reef can be found in **Table 28**. This estimate is calculated using annual mortality and recruitment data. BOP has not added new cohorts of oysters to the site since 2020. Mortality is expected to decrease and stabilize as oysters age. However, the persistently high yet stable mortality at Bayswater is likely due to sedimentation, which has further reduced the estimated population to 5,579 oysters. Despite this, recruitment continues to occur annually.

Table 28. Estimated population dynamics of Bayswater Point State Park Bagged Shell Reef. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and annual recruitment. NA indicates annual recruitment could be calculated.

Year	Start Estimate	Annual Mortality	Post Mortality Estimate	Annual Recruitment	Post Recruitment Estimate
2020	445,263	9.11%	404,712	NA	404,712
2021	404,712	32.76%	272,134	3.13%	280,638
2022	280,638	68.18%	89,294	12.44%	100,404
2023	100,404	78.77%	21,317	11.94%	23,862
2024	23,862	76.21%	5,676	11.89%	6,352

Oyster Health

No oyster health data is available for Bayswater Point State Park, as oysters from this site were not tested.

Recommended Restoration Actions

Oyster performance trends (growth and recruitment) at Bayswater are positive and merit further monitoring and consideration of additional, expanded restoration at this site. Mortality is likely attributable to at least two environmental stressors: frequent handling and sedimentation. **BOP can mitigate these stressors by implementing minor strategies allowed under the current permit.** In coordination with NYSDEC, BOP may seek to restock the reef at Bayswater Point State Park through the introduction of a new cohort of spat-on-shell in 2026 or 2027. A base layer of unseeded bagged shell to create a foundation may be proposed as part of the restocking effort, as higher vertical relief may encourage settlement by wild recruits and offset sedimentation. The installation would remain subtidal. A subset of bags will be tagged and only removed once per year for annual monitoring activities, not for routine programmatic activities, to reduce the stress of frequent handling and provide more comprehensive insight into mortality and growth.

To more effectively address erosion and sedimentation at Bayswater, wave attenuation or addition of strategically selected and placed substrate should be considered. In coordination with NYSDEC and NYS Parks, BOP may recommend the placement of unseeded substrate, such as reef balls, to address the sedimentation issues at the site. North of the project site, near Bayswater Point, shoreline erosion from wave energy, vessel activity, or other sources transports sediment south along the shoreline and deposits it near and atop the BOP project site. BOP will discuss this opportunity and its feasibility with regulatory agencies and partners in 2026 or 2027.

Head of Bay

Project Summary

As of 2024, BOP maintains and monitors four shell reefs installed in Head of Bay, with support from New York Harbor School diving students and interns.

Trends from 2023-2024 data indicate

- Gradual increase of oyster shell height and recurring recruitment annually.
- Higher annual mortality in 2024 relative to the mortality in 2023 but more data is needed to assess the direction of the trend.
- Continue monitoring oyster performance and consider implementing closer surveillance of oyster health at this site.

Site Overview

In 2016, the New York City Department of Environmental Protection (DEP), in partnership with BOP and the Hudson River Foundation, began the “Developing a Self-Sustaining Oyster Population in Jamaica Bay, New York City” project on a one-acre site in Head of Bay (**Figure 36**). This project consisted of a 650-foot long line “donor reef” of 105 OysterGro units stocked with 35,000 adult oysters as well as the construction of four “receiver reefs” composed of cured oyster shells and crushed porcelain. In 2017, an additional 9,300 adult oysters were added to the OysterGro units. The long-term goal of the pilot project was to establish a self-sustaining oyster population that could create a larvae source for Jamaica Bay. In December 2018 and March 2019, the donor reef long line was removed and BOP deployed the ~40,000 adult oysters atop two of the receiver reefs to increase the presence of breeding individuals; little to no wild oyster recruitment has been recorded.

In 2023, BOP received approval from NYSDEC and USACE to install 20 million spat-on-shell on receiver reefs 2 and 3 in a seeding effort designed to compliment the Town of Hempstead’s (TOH) proposed “Head of Bay Oyster Restoration Project” (NYS Consolidated Funding Application #109340) in which 20 million spat-on-shell would be installed on receiver reefs 1 and 4 over four years (5 million per year) with the objective of enhancing approximately 0.33 acres of oyster reef habitat. The addition of 20 million spat-on-shell before TOH’s seeding project was intended to quickly increase larvae supply and create areas of lower sediment deposition thus creating favourable conditions for larval settlement. BOP installed 15.3 million spat-on-shell in 2023.

In 2024, BOP installed another 50,000 adult oysters on the receiver reefs. Due to budget constraints, TOH transferred their approved permits for their “Head of Bay Oyster Restoration Project” to BOP to implement the project. In future years, BOP plans to install the remaining 5 million spat-on-shell from the 2023 seeding efforts, along with the maximum amount permitted under the TOH project approval. These projects will assist in establishing and maintaining a self-sustaining oyster population in Head of Bay with both projects utilizing different broodstock to increase genetic diversity, resulting in multiple cohorts of oysters thus increasing the probability of the successful establishment of a self-sustaining oyster population in Head of Bay.

Table 29 provides a summary of installations at the Head of Bay site since 2016. Monitoring at the site was switched from biannual to annual to evaluate oyster performance in 2022.



Figure 36. Map of Head of Bay site showing the centerline of the receiver reefs constructed in 2016.

Table 29. Summary of structures installed and oysters introduced to Head of Bay.

Structure Name	Year Installed	Quantity of Structures	Oysters Introduced	Monitoring Frequency
OysterGro	2016	105	35,200 (Adult)	Biannual
	2017	105	9,300 (Adult)	
Shell Reef	2018	NA	40,000* (Adult)	
	2023	NA	15,353,336 (Spat)	Annual
	2024	NA	50,000 (Adult)	

* Adult oysters were transferred from the floating "donor reef" in OysterGros to the on-bottom "receiver reef" in 2018.

Oyster Performance

Growth: Positive

Mean shell height increased from 57.9 mm in 2023 to 141.6 mm in 2024 for the cohort installed in 2016-2017 (**Figure 37**). The mean shell height for the cohort installed in 2023 was recorded as 49.3 mm in 2024.

Mortality: High

Annual oyster mortality in the shell reef has increased for the 2016-2017 cohort, rising from 4.6% in 2023 to 25.0% in 2024 (**Figure 37**). Additionally, the 2023 cohort recorded a high percent mortality of 68.0% in

2024. This spike may be attributed to the shell reef's exposure to benthic predators and sedimentation, which likely contributed to increased mortality over time. Additionally, high concentrations of boring sponge were observed in sampled oysters and are suspected to have further contributed to elevated mortality.

Recruitment: Consistent, but low

Annual recruitment is recurring, ranging from 4.1% in 2023 to 2.2% in 2024 across both cohorts (**Table 31**). This trend is illustrated in **Figure 37**, where recruitment is indicated by the curve peaking before the 25 mm mark.

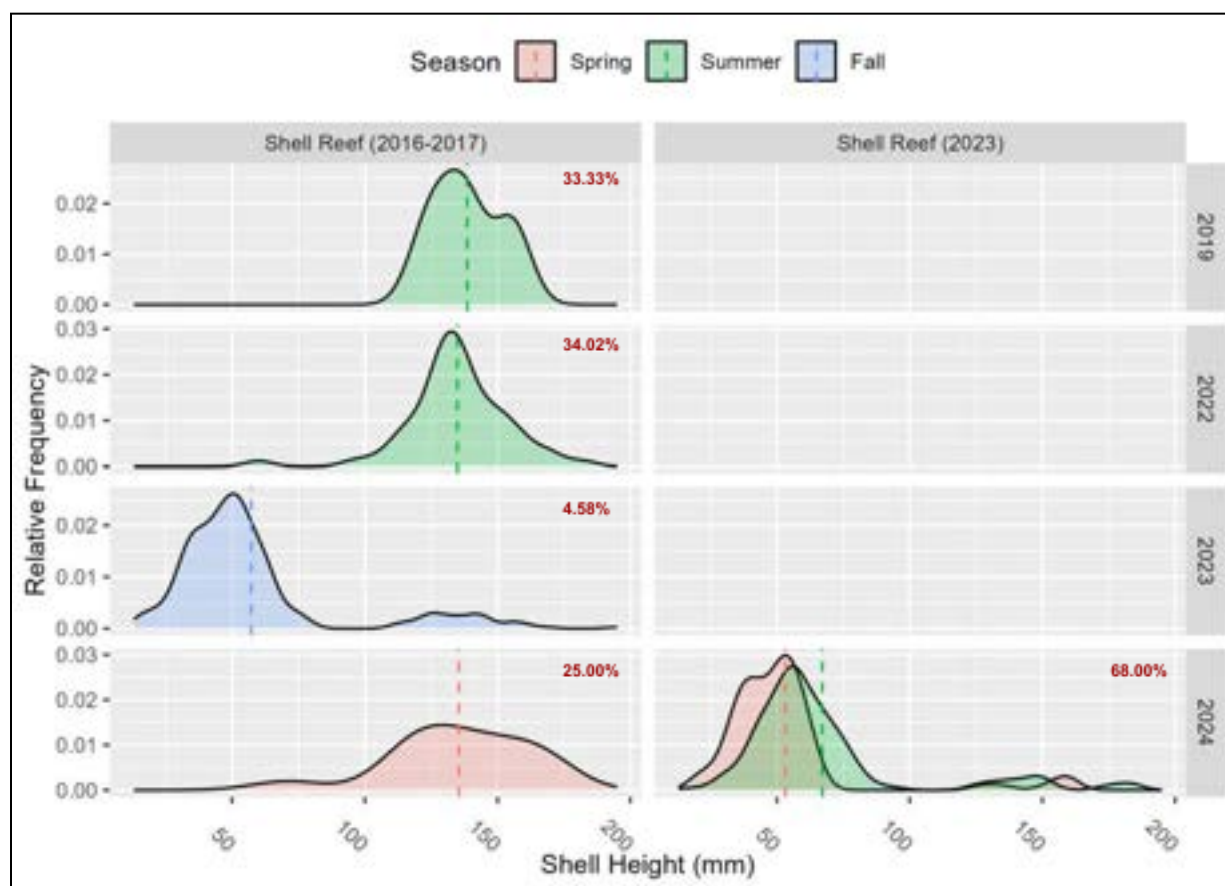


Figure 37. Size-frequency histogram of live oysters in Head of Bay Shell Reef (2016-2017) and Shell Reef (2023). The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Density

Two methods—clump and quadrat monitoring—were used to assess oyster performance at the Head of Bay shell reefs. The quadrat method allows for quantifying the percent cover of live oysters within a defined area, while the clump method provides a sufficient sample size to evaluate growth trends.

Oyster density fluctuated across years for the 2016–2017 cohort: density was 1 live oyster per 1.4 shells in 2022, increased to 3.6 live oysters per shell in 2023, and then declined to 1 live oyster per 1.3 shells in 2024 (**Table 30**). More data is needed for the 2023 cohort to determine overall trends.

Recruitment density for the 2016–2017 cohort was low to nonexistent, with 1 live recruit found in every 7 shells in 2023 and none observed in 2024 (**Table 30**). For the 2023 cohort, 1 live recruit was found in every 34 shells in 2024 (**Table 30**); however, additional data is needed to better understand recruitment density trends.

Table 30. Sample size (live and dead box oysters), oyster density and recruitment density using clump monitoring (live oysters per shell and live recruits per shell) and quadrat monitoring (live oysters per square meter and live recruits per square meter) at Head of Bay shell reefs. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Cohort	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
Shell Reef (2016-2017)	2017	NA	NA	NA	NA	NA
	2018	NA	NA	NA	NA	NA
	2019	21	2.00	0.00	NA	NA
	2020	NA	NA	NA	NA	NA
	2021	NA	NA	NA	NA	NA
	2022	97	0.70	0.00	18.45	0.00
	2023	393	3.57	0.14	NA	NA
	2024	52	0.80	0.00	NA	NA
Shell Reef (2023)	2023	NA	NA	NA	NA	NA
	2024	897	1.78	0.03	7.12	0.17

Oyster Population Estimates

As of 2024, the estimated oyster population of the 2023 cohort at Head of Bay is approximately 5 million, based on annual mortality and recruitment data collected from the time of installation through the most recent monitoring period (**Table 31**). The observed reduction in population size is largely attributed to increased annual mortality and consistent recruitment—an expected pattern in restored reefs. This estimate does not include the population from the 2016–2017 cohort, nor does it account for the 50,000 adult oysters added in 2024, as monitoring was conducted prior to their introduction.

Table 31. Estimated population dynamics of the 2023 cohort at Head of Bay Shell Reefs. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and annual recruitment.

Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
2023	15,353,336	4.58%	14,650,130	4.07%	15,246,57
2024	15,246,573	68.00%	4,878,223	2.22%	4,986,628

Oyster Health

Although oysters from Head of Bay were not tested in 2023-2024, past oyster health data are shown below. The condition index of a subset of oysters was tested in 2017 and 2019. For the results, please refer to **Appendix Figure B6**.

Disease

Across all sampling years, Dermo prevalence was lowest in young oysters but increased over time, rising from 20.0% in November 2017 to 53.3% in July 2019. Lethal infection intensity also increased, climbing from 3.3% to 10.0% (**Figure 38**). A decrease in prevalence and intensity observed in December 2017 was likely due to lower water temperatures entering winter, which slowed Dermo growth and transmission. Additionally, heavily infected oysters may have died since the previous sampling earlier in the season, resulting in a lower prevalence among the surviving population by December. Since disease monitoring has not been conducted since 2019, these results only reflect the condition of the oysters during the sampling period.

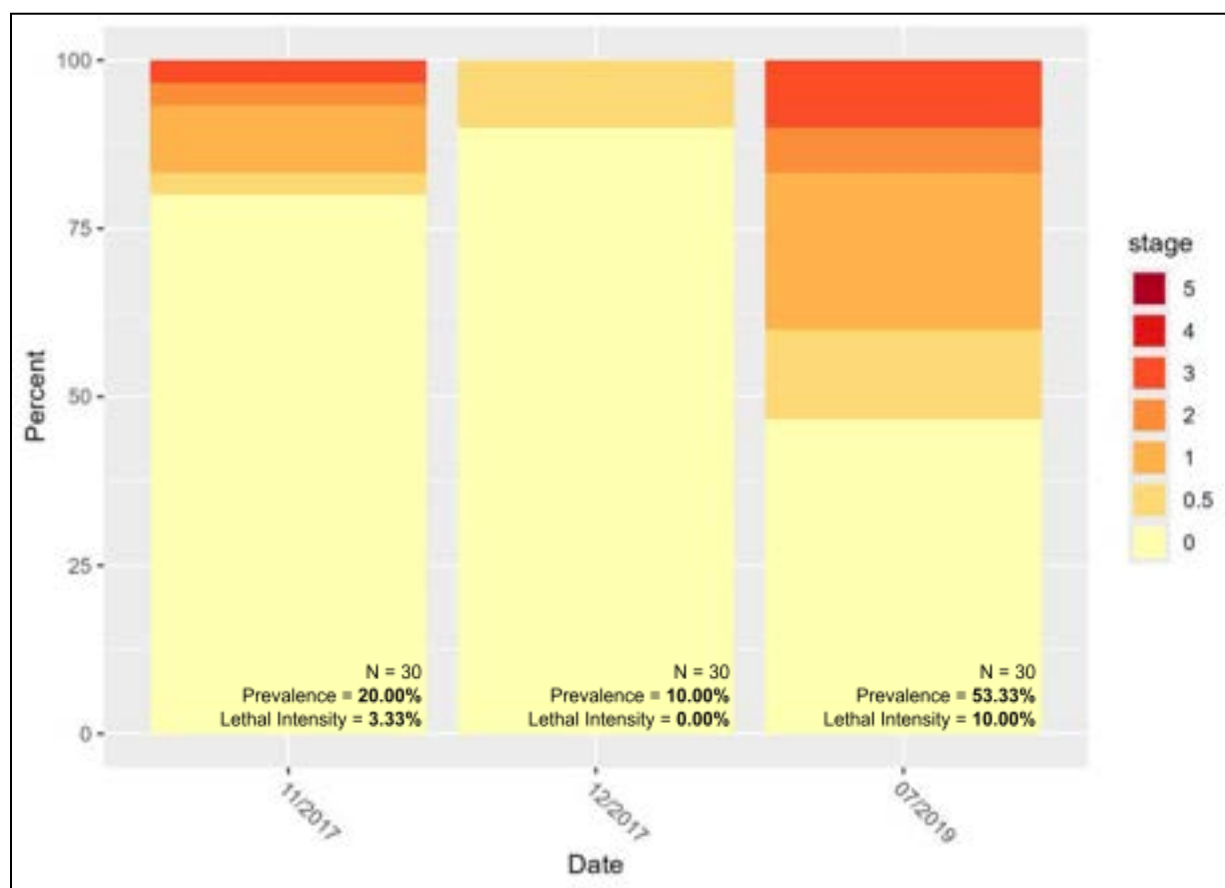


Figure 38. Dermo (*P. marinus*) prevalence and intensity in oysters sampled from Head of Bay. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be lethally infected.

MSX has not been detected in oysters in 2017 and 2019. While MSX levels at this site are considered low, continued testing is necessary to monitor current trends.

Reproduction

Oyster development stages varied depending on the sampling month. In fall 2017, no gonadal activity was observed, whereas in summer 2019, most oysters exhibited advanced gonadal stages, ranging from early development to various spawning phases (**Figure 39**). The timing of sample collection—fall in 2017 versus summer in 2019—likely influenced these differences in reproductive stages. Since reproduction

monitoring has not been conducted since 2019, these findings only represent the oysters' condition during the sampling period.

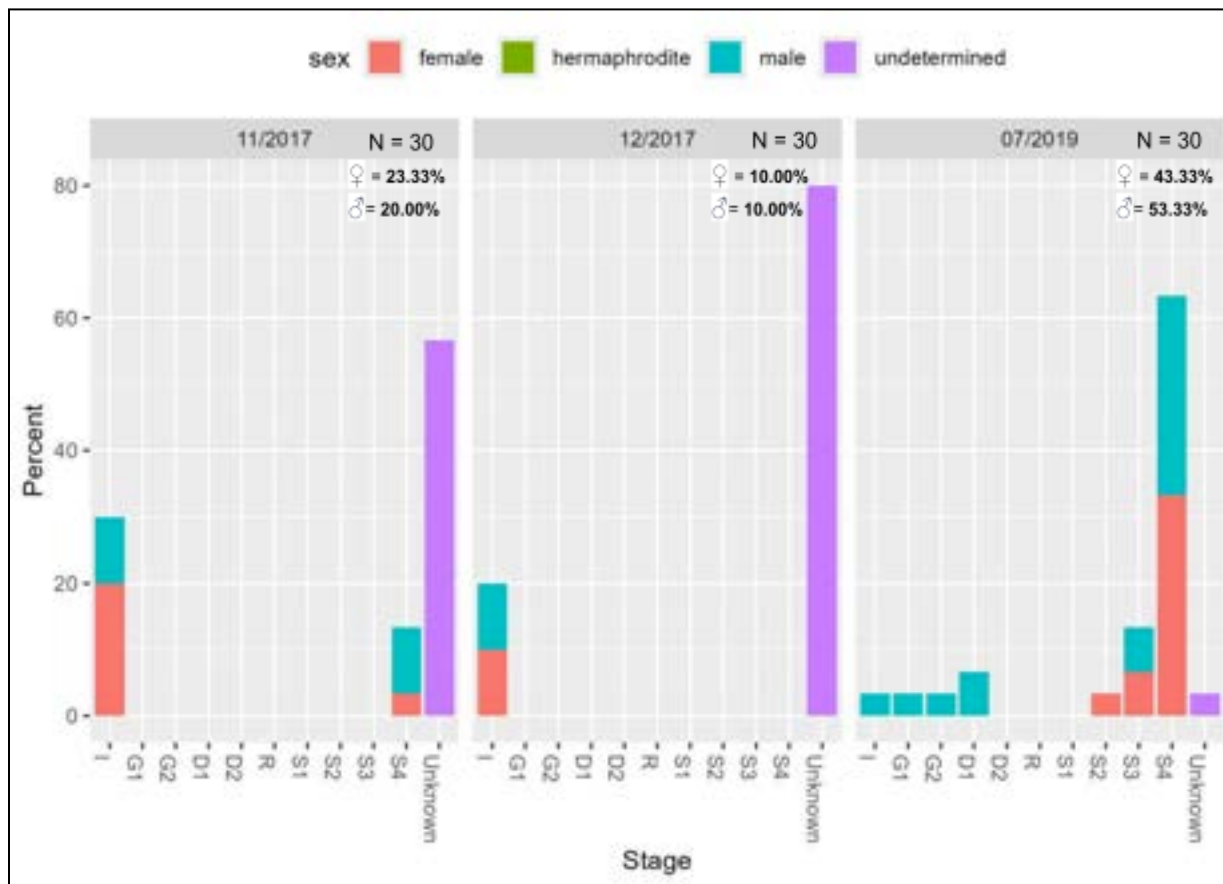


Figure 39. Stage of reproductive development and sex of oysters from Head of Bay. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Oysters tested across all sampling years from 2017 to 2019 initially showed a nearly balanced sex ratio in 2017. However, in 2019, the ratio was slightly skewed toward males, though still approaching the ideal 50:50 balance. Further testing is needed to determine whether this trend has persisted in recent years.

Recommended Restoration Actions

To enhance restoration efforts and understand recruitment in Jamaica Bay at Head of Bay, BOP recommends adding a new layer of cured shell to the receiver reefs before reseeding with spat-on-shell, especially to the two receiver reefs that have not recently received a new cohort of spat-on-shell. Adding shell to these two reefs would address reef patchiness and sediment accumulation, both of which have been observed by BOP divers during annual monitoring. Patchiness and sediment accumulation on low relief reefs in the project site could hinder larval settlement and impact oyster growth and development if not addressed.

If high mortality rates persist at the site, adding a new layer of crushed shell to all of the receiver reefs to improve vertical relief to two of the reefs, and reseeding all receiver reefs in upcoming years will clarify emerging trends in oyster performance. Reseeding oyster restoration sites at recurring intervals within the first 6-10 years post-installation is an accepted and expected management measure utilized by oyster restoration practitioners in waterbodies where wild oyster recruitment is limited like Jamaica Bay. Reseeding, or adding an age class or cohort of juvenile oysters to the Head of Bay site will advance the goal of developing a self-sustaining oyster population at the site by:

- 1) Creating genetic diversity and increasing the reproductive potential of the site, regardless of recruitment (requires the addition of younger year classes containing more males as the original cohort ages and contains more females)
- 2) Increasing the density of oysters within the reef footprint
- 3) Responding to anticipated annual fluctuations in recruitment, annual mortality, and survival
- 4) Responding to low larval availability or inconsistent spawning by adult oysters in Jamaica Bay
- 5) Responding to unanticipated significant annual mortality events or changing environmental conditions in Jamaica Bay.

Paerdegat Basin

Project Summary

As of 2024, BOP maintains and monitors the cabinet reef at Paerdegat Basin Sebago Canoe Club installed in 2018 (**Figure 30**). This project provides insight into oyster health and performance using on-bottom restoration techniques. The installations also provide hands-on education and engagement opportunities with students and community groups that reconnect people to the waterbodies surrounding New York Harbor, as well as to the wildlife thriving along the shorelines and in the shallows.

Trends from 2018-2024 data indicate conditions are supportive of larger-scale oyster restoration:

- Oysters survive to reproductive age and spawn.
- Oyster growth trends positively and annual mortality is stable around 30%.
- Annual recruitment is consistent, ranging from 0.59% to 2.56%.
- Dermo prevalence and intensity is slowly increasing, which is not unexpected, and no MSX was detected across three sampling seasons.

Site Overview

The project site is located on the northeast shoreline of the Paerdegat Basin, adjacent to the Sebago Canoe Club (**Figure 30**). The installation is situated below mean low water on the southeastern side of the club's gangway. The total area of the project site is approximately 0.1 acres, with a combined total footprint of installed material of less than 100 square feet.



Figure 30. Map of Paerdegat Basin installation.

In July 2018, BOP staff installed a total of five 10' x 2' x 2' oyster cabinets made of welded 1/2" rebar and containing approximately 480,000 spat-in-shell (**Table 32**). One cabinet was placed closer to shore to facilitate monitoring events, while access to the four remaining subtidal cabinets from the shore is possible only during the lowest of low tides (**Figure 30**). Monitoring was conducted biannually between 2020 to 2023, but annually in spring of 2024, to evaluate the oyster performance.

Table 32. Summary of structures installed and spat introduced at Paerdegat Basin.

Structure Name	Year Installed	Quantity of Structures	Spat Introduced	Monitoring Frequency
Cabinet Reef	2018	5	480,000	Biannual

During monitoring events, BOP staff have observed various fish and invertebrate species inhabiting the oyster shells within the cabinet reefs and documented the presence of these fauna. Fish biodiversity monitoring indicated a rich diversity and abundance of fish at Paerdegat Basin, particularly in 2023 (**Appendix Figure A5**), emphasizing the reef's role in providing habitat and essential resources for marine biodiversity to thrive.

Oyster Performance

Growth: Positive

Live oysters in the cabinets exhibit positive growth from their installation in 2018 through 2024, with an overall increase of 52.3 mm in mean shell height since 2018. Starting in 2021, the mean shell height stabilized above 80 mm, reaching 86.3 mm in 2023 and 91.4 mm in 2024 (**Figure 31**). Notably, oyster growth is typically more pronounced during fall monitoring at this site, following the warmer summer months when oysters benefit from increased feeding.

Mortality: Stable

Annual mortality is low and stable (**Figure 31**). Despite the oysters' susceptibility to predation by oyster drills, sedimentation, and increases in Dermo prevalence and intensity since 2018, oyster performance trends do not appear to be negatively affected. Annual mortality peaked at 45.8% in 2023 and decreased to 30.1% in 2024, which is similar to the annual mortality (~30%) from 2020-2022.

Recruitment: Consistent, but low

Since the 2018 installation, recruitment consistently occurs each year and peaked at 1.4% in 2020. Between 2023 and 2024, recruitment increased from 0.4% to 0.8%, indicating a growing presence of younger oysters and a positive trend in recruitment (**Table 34**). These low rates are likely attributable to the small population size of the 2018 cohort.

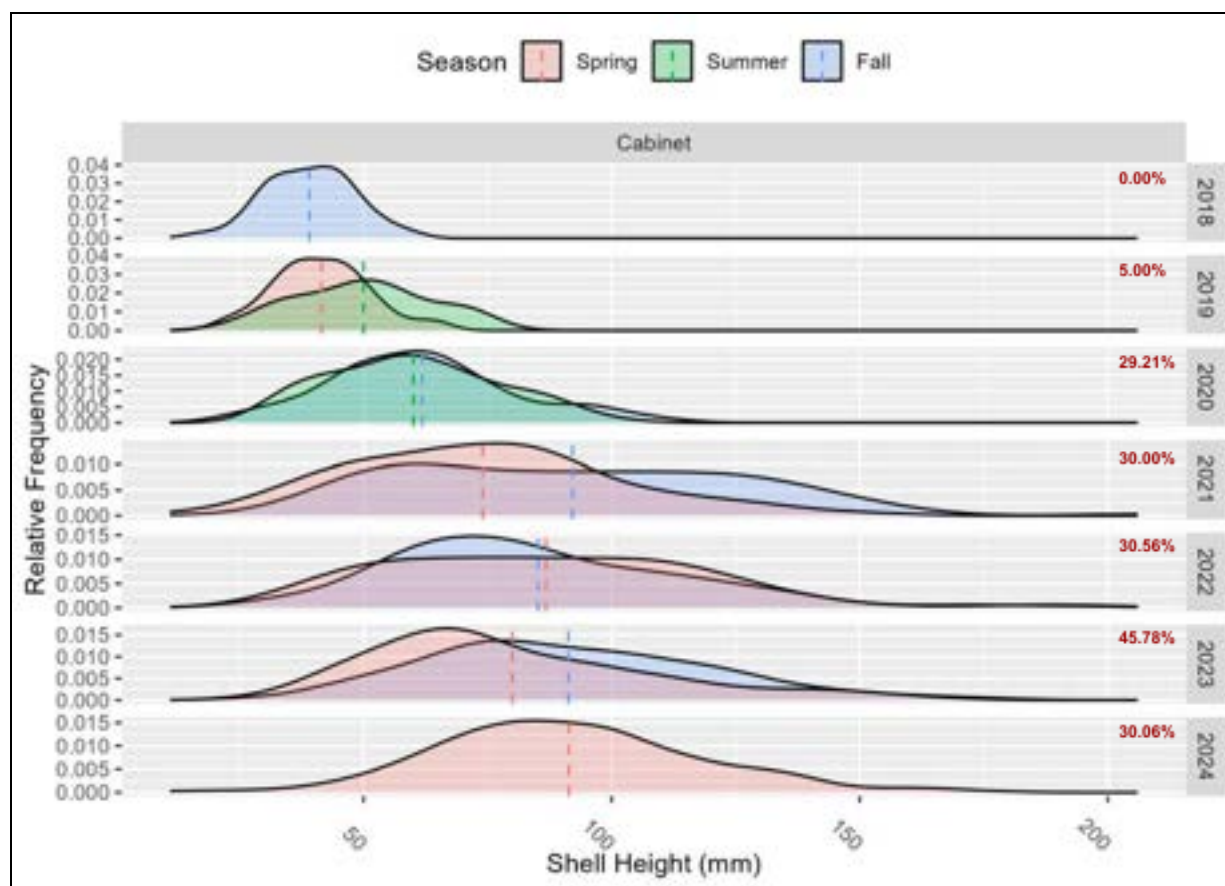


Figure 31. Size-frequency histogram of live oysters in Paerdegat Basin cabinet reefs, 2018-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality.

Oyster Density

Two methods—clump and quadrat monitoring—were used to assess oyster performance at the cabinet reef. Quadrat monitoring is preferred when oysters have grown through the files and can no longer be assessed individually, making clump monitoring less effective. As a result, both methods were used in 2020 and 2023, while other years relied on only one method (**Table 33**).

Using clump monitoring, oyster density generally declined over time despite some fluctuations. Between 2023 and 2024, density decreased from 1 live oysters for every 1.7 shells to every 1.3 shells (**Table 33**). Recruitment density remained low to nonexistent, with only 1 live recruit per 161.5 shells recorded in 2024 (**Table 33**).

Quadrat monitoring similarly showed a fluctuating but overall declining trend in oyster density since installation. Oyster density decreased from 900 live oysters per square meter in 2018 to 133.6 live oysters per square meter in 2020, and to 217.9 live oysters per square meter in 2023 (**Table 33**). No recruitment was detected using this method; however, additional monitoring is needed to determine whether this pattern persists.

Table 33. Sample size (live and dead box oysters), live oyster and recruitment density (per shell and per square meter) at Paerdegat Basin. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
Cabinet Reef	2018	90	NA	<1 year old	900.00	<1 year old
	2019	160	18.17	<1 year old	NA	<1 year old
	2020	267	1.22	0.02	133.59	0.00
	2021	390	0.82	0.01	NA	NA
	2022	324	0.73	0.00	NA	NA
	2023	509	0.60	0.00	217.86	0.00
	2024	356	0.77	0.01	NA	NA

Oyster Population Estimates

The annual population estimates of the Paerdegat Basin cabinet reef can be found in **Table 34**. This estimate is calculated using annual mortality and recruitment data. The initial oyster population introduced to Paerdegat Basin in 2018 was small and BOP has not added new cohorts to the site since installation, so the 2024 estimated population is correspondingly small. Additionally, increased mortality, likely attributable to the frequent handling of these oysters for programmatic activities, and a rise in disease prevalence and lethal intensity, contribute to the low post-recruitment population estimate of 65,400 oysters in 2024 (**Table 34**). This represents an 86.4% decline in the oyster population since their installation in 2018, which highlights the need to add a new cohort to the site for ongoing community engagement, monitoring, and data collection.

Table 34. Estimated population dynamics of Paerdegat Basin Cabinet Reef. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and annual recruitment. NA indicates annual recruitment could not be calculated.

Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
2018	480,000	0.00%	480,000	NA	480,000
2019	480,000	5.00%	456,000	0.00%	456,000
2020	456,000	29.21%	322,787	1.43%	327,398
2021	327,398	30.00%	229,178	0.00%	229,178
2022	229,178	30.56%	159,152	0.49%	159,932
2023	159,932	45.78%	86,721	0.39%	87,056
2024	87,056	30.06%	60,890	0.84%	61,404

Oyster Health

Paerdegat Basin oysters were tested for condition index in 2020 and again from 2023 to 2024. For the results, please refer to **Appendix Figure B5**.

Disease

Dermo: High

Dermo prevalence increased slightly from 83.3% in 2023 to 86.7% in 2024, accompanied by a 10% rise in potentially lethal infection intensity. These values represent an increase compared to 2020 results, when prevalence was 67.7% and no oysters exhibited potentially lethal infections (**Figure 32**). Dermo prevalence tends to be lowest in younger oysters and is expected to increase with age, which explains the higher percentages observed in recent years. This trend suggests that disease is a key factor contributing to oyster mortality at this site.

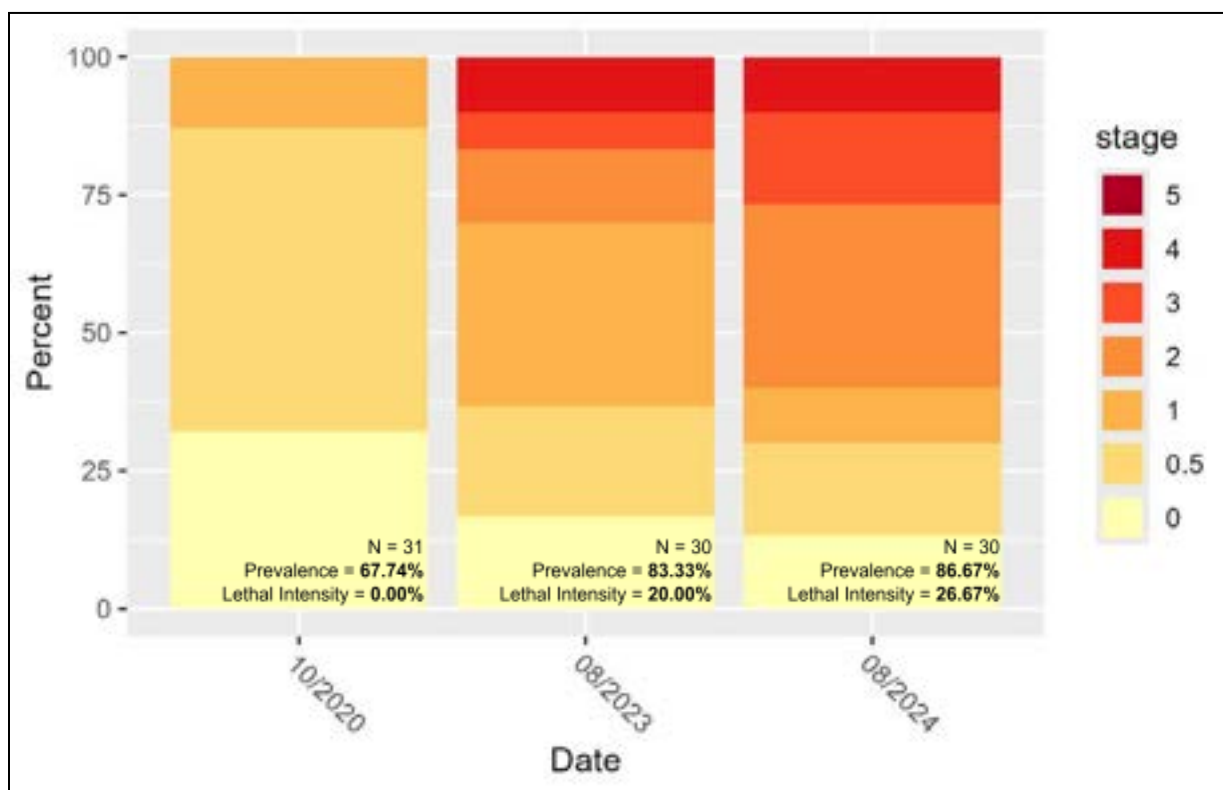


Figure 32. Dermo (*P. marinus*) prevalence and intensity in oysters sampled from Paerdegat Basin. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be lethally infected.

MSX: Low

MSX was not detected in oysters at Paerdegat Basin in 2023 and 2024.

Reproduction

Spawning: Moderate

Results from tested oysters at Paerdegat Basin showed that 50.0% of the sampled oysters were spawning in 2023, compared to 36.7% in 2024 (**Figure 33**). In October 2020 and August 2023, oysters were observed at various reproductive stages, ranging from early development to spawning. In August 2024, tested oysters were in the final spawning stage, with some initiating another reproductive cycle, suggesting the potential for fall maturation and spawning. Variations in stages across sampling years are likely influenced by differences in the timing of sample collection and variation in environment conditions.

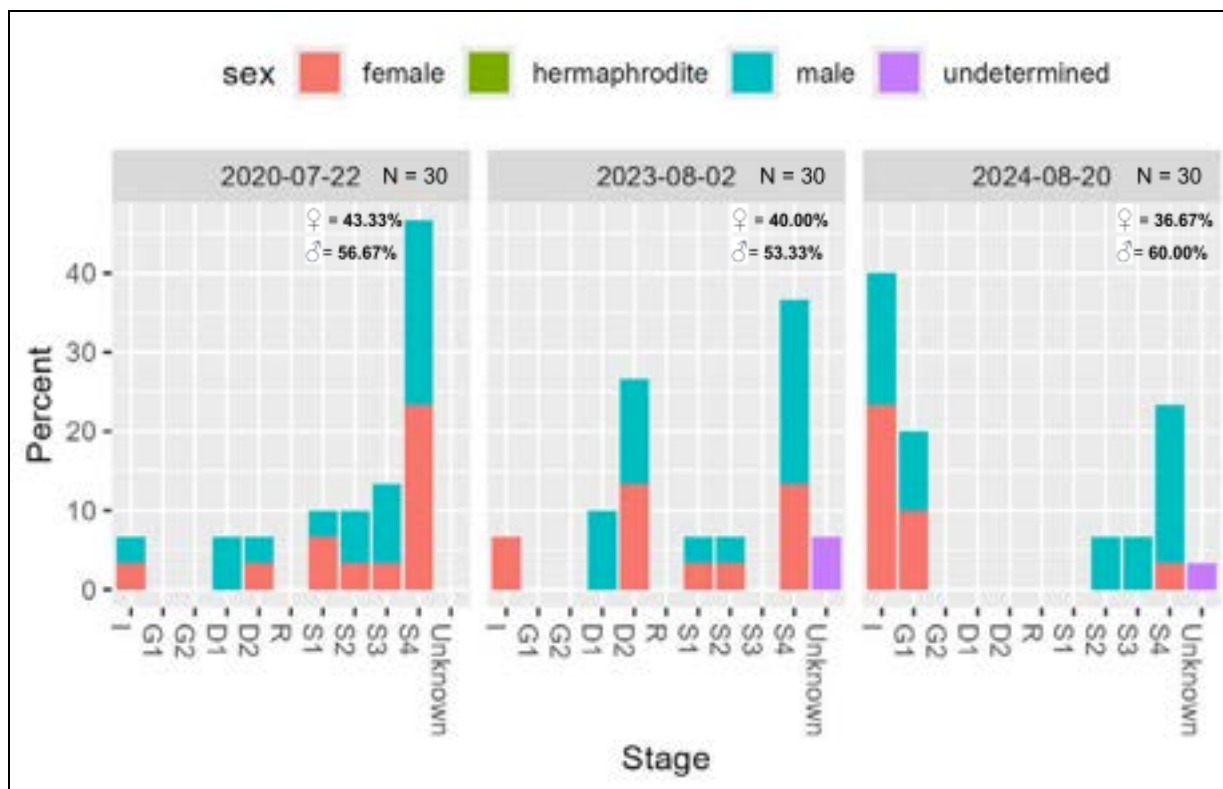


Figure 33. Stage of reproductive development and sex of oysters from Paerdegat Basin. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Sex Ratio: Skewed

The sex ratio of the tested oysters was skewed toward males across all years, increasing from 53.3% in 2023 to 60.0% in 2024, which correlated with a decrease in the percentage of females (**Figure 33**).

Recommended Restoration Actions

With the ongoing community engagement at the site and need to better understand oyster performance trends over time, **BOP may seek to restock the cabinet reef at Paerdegat Basin** through the introduction of a new cohort of spat-on-shell sometime between 2025 and 2027.

In response to positive or stable trends in growth and recruitment from the pilot installations and in alignment with the dual restoration strategy to add seeded substrate and multiple cohorts of oysters, **BOP plans to propose a multi-acre restoration project in the basin, with a total of 5.24 acres of oyster reef habitat in four areas of interest within the Basin.** The project will be phased and include seeded and unseeded substrate. The project's design will also strategically address shoreline erosion on the north and south shorelines of the basin. In coordination with NYC Parks, BOP conducted comprehensive hydrology and sediment studies to understand where oyster restoration should occur to best protect the shoreline from future sediment loss. This planned restoration in Paerdegat Basin will expand BOP's ongoing restoration activities in Jamaica Bay and the Basin, further our understanding of recruitment trends in Jamaica Bay and better define the minimum target stocking density required to maintain positive population density, and how nature-based features such as oyster reefs can stabilize soft shorelines and wetlands.

Western Long Island Sound

The Western Long Island Sound region extends from City Island and Pelham Bay in the Bronx in the northeast, to Little Neck Bay and Flushing Bay, Queens in the south, to the head of the East River near Randall's Island in the west (**Figure 40**). Soft shorelines and salt marshes are more prevalent in the eastern portion of this region, transitioning to industrial and hardened shorelines west of the Whitestone Bridge. Consistent wild recruitment at planned and active restoration sites throughout this region indicates the presence of a larval source, likely commercial and private oyster farms further east along the Long Island Sound shoreline, with the highest densities of wild oysters documented in areas with hard substrate and low wind and wave energy. The shallow gradient and soft shorelines present opportunities to incorporate shoreline protection into designs to reduce erosion and restore or protect wetlands. Together, these conditions enhance the potential for successful restoration outcomes in the region, where BOP has installed various types of restoration structures and spat-on-shell (**Table 35**).



Figure 40. Map of restoration site within Western Long Island Sound.

Table 35. Summary of restoration structures and installation details of each site within Western Long Island Sound.

Site	Structure	Install date	Larvae source	Size at installation (shell height, mm)	Number of oysters installed
Soundview Park (SV)	Shell Reef	2020	Muscongus Bay, ME	~5	9,000,000
		2020		Adult	200,000
		2021		~5	7,300,000
		2022		~5	1,500,000
	Cabinet Reef	2020		~5	200,000
		2020		~5	2,793,101
	Gabion	2020		~5	1,500,000
		2022		~5	1,500,000
	Reef Balls	2024	Oyster Seed Holdings, VA Muscongus Bay, ME	>10	8,900,000

Soundview Park

Project Summary

As of the end 2024, BOP maintains and monitors shell reefs and reef balls installed in the eastern portion of the Soundview project area after removing the gabion reef in the central and western project area in June 2024. The Soundview Oyster Habitat Restoration Project expanded upon the success of previous research projects at the site, which identified Soundview as an optimal location for large-scale reef restoration in New York Harbor. This project provides insight into oyster health and performance using on-bottom restoration techniques. The installations also provide hands-on education and engagement opportunities with students and community groups that reconnect people to the waterbodies surrounding New York Harbor, as well as to the wildlife thriving along the shorelines and in the shallows.

Trends from 2023-2024 data indicate conditions are supportive of larger-scale oyster restoration:

- Oysters survive to reproductive age and spawn.
- Oyster growth trends positively and annual mortality is stable between 39-49% of the sample size.
- The lack of annual recruitment supports the need to reseed the site.
- Dermo prevalence and intensity is slowly increasing, which is not unexpected, with MSX following a similar trend.

Site Overview

The Soundview Oyster Habitat Restoration Project, led by BOP with funding from NYSDEC, restored five acres of oyster reef habitat near Soundview Park at the mouth of the Bronx River (**Figure 41**). This large-scale restoration effort built upon earlier research that identified Soundview as an optimal site for oyster reef restoration in New York Harbor.

Construction began in the summer of 2020. The initial reef installation included approximately 600 cubic yards (CY) of unseeded shell, 200,000 adult oysters deployed atop the shell reefs, and 12.6 million spat-on-shell (**Table 36**). The spat-on-shell was deployed in several formats: 15 cubic yards of loose shell, 169 gabions, and four community cabinets. The gabions were constructed using welded 1/2" flat bar frames (4' x 2' x 2') with 1" galvanized mesh inserts, each capable of holding up to 100,000 spat-on-shell and weighing approximately 350 pounds. The community cabinets, also 4' x 2' x 2', contained 14 mesh files hung from rebar hangers, each cabinet supporting about 100,000 spat-on-shell and weighing approximately 200 pounds.

In 2021, BOP supplemented the initial installation with an additional 7.3 million spat-on-shell added to the shell reefs (**Table 36**). In 2022, a further 3.4 million spat-on-shell were deployed, including 12 gabions and additional loose spat-on-shell (**Table 36**).

During a monitoring event in October 2023, BOP staff discovered significant degradation in the steel mesh inserts of the gabions. Although the welded outer frames remained intact, the failure of the internal mesh compromised the gabions' ability to retain oysters and shells. BOP notified the NYC Parks Natural Resource Group and developed a reconnaissance plan to assess the damage in November and December 2023. Follow-up visits in winter 2023 and early 2024 confirmed widespread degradation.

In response, BOP received permission in spring 2024 to remove the damaged gabions from the western and central reef areas. By June 2024, all compromised gabions had been removed. Sonar surveys confirmed that no gabions remained on-site aside from the four community cabinets.

In late June 2024, BOP installed 240 bay balls—both seeded and unseeded—in the eastern reef area to protect two shell reefs. Additionally, 75 cubic yards of unseeded shells was added to create a tenth shell reef. In total, 8.9 million oysters were introduced to 80 of the bay balls as part of this latest phase of restoration (**Table 36**).

The total project area spans five acres, with 0.96 acres designated for the reef footprint. All loose shells were placed below mean low water, while gabions and reef balls were installed below mean lower low water. Annual monitoring has been conducted to assess oyster performance and overall reef health.

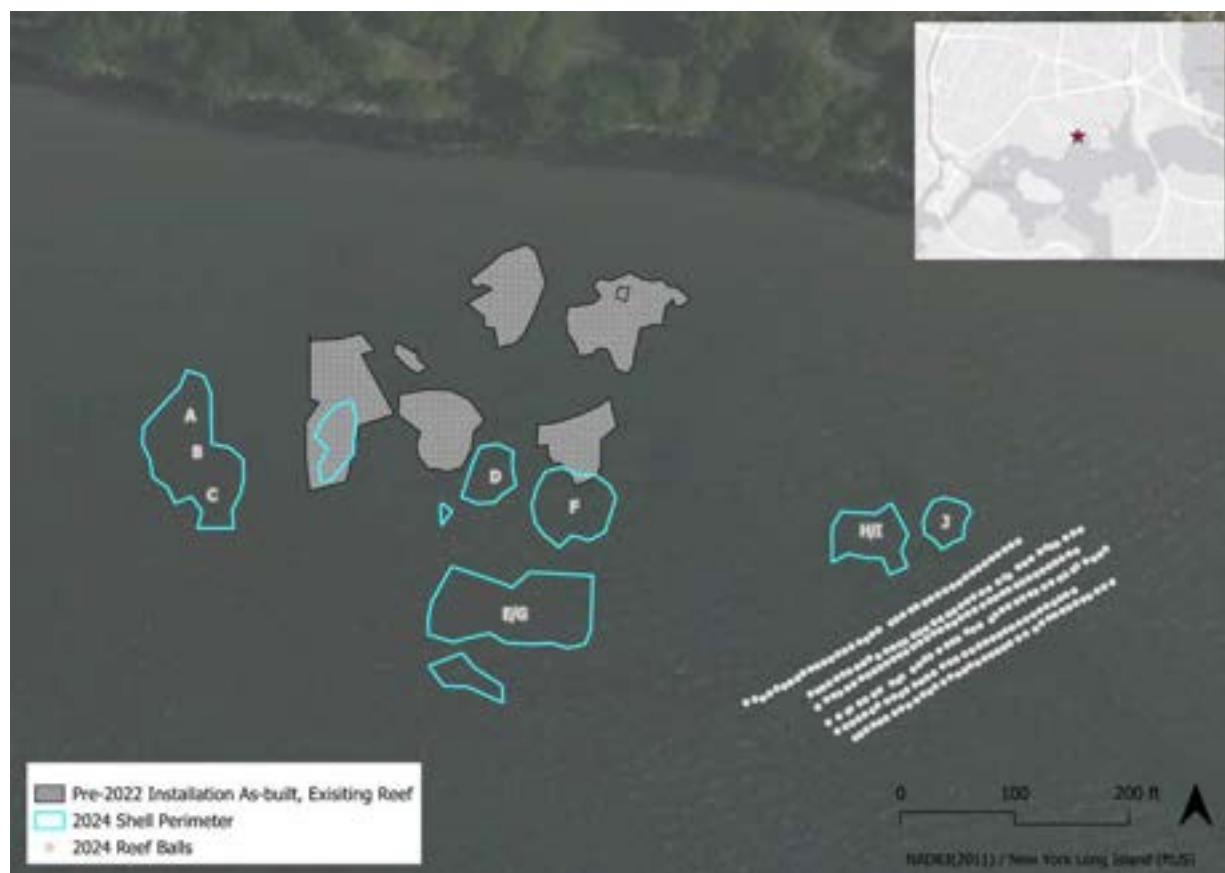


Figure 41. Site of map of the Soundview Park oyster installations as of 2024 following gabion unit removal.

Table 36. Summary of structures installed and oyster introduced at Soundview Park.

Structure Name	Year Installed	Quantity of Structures	Oysters Introduced	Monitoring Frequency
Shell Reef	2020	NA	9,000,000	
	2020	NA	200,000 (Adults)	
	2021	NA	7,300,000	
	2022	NA	1,500,000	

Structure Name	Year Installed	Quantity of Structures	Oysters Introduced	Monitoring Frequency
Gabion*	2020	181	2,793,101	Annual
	2022		1,500,000	
Cabinet Reef	2020	4	200,000	
Reef Balls	2024	80 seeded 160 unseeded	8,900,000	

*All gabion structures were removed in June 2024 but the oysters and shell materials from the gabions were placed on the shell reef.

Oyster Performance

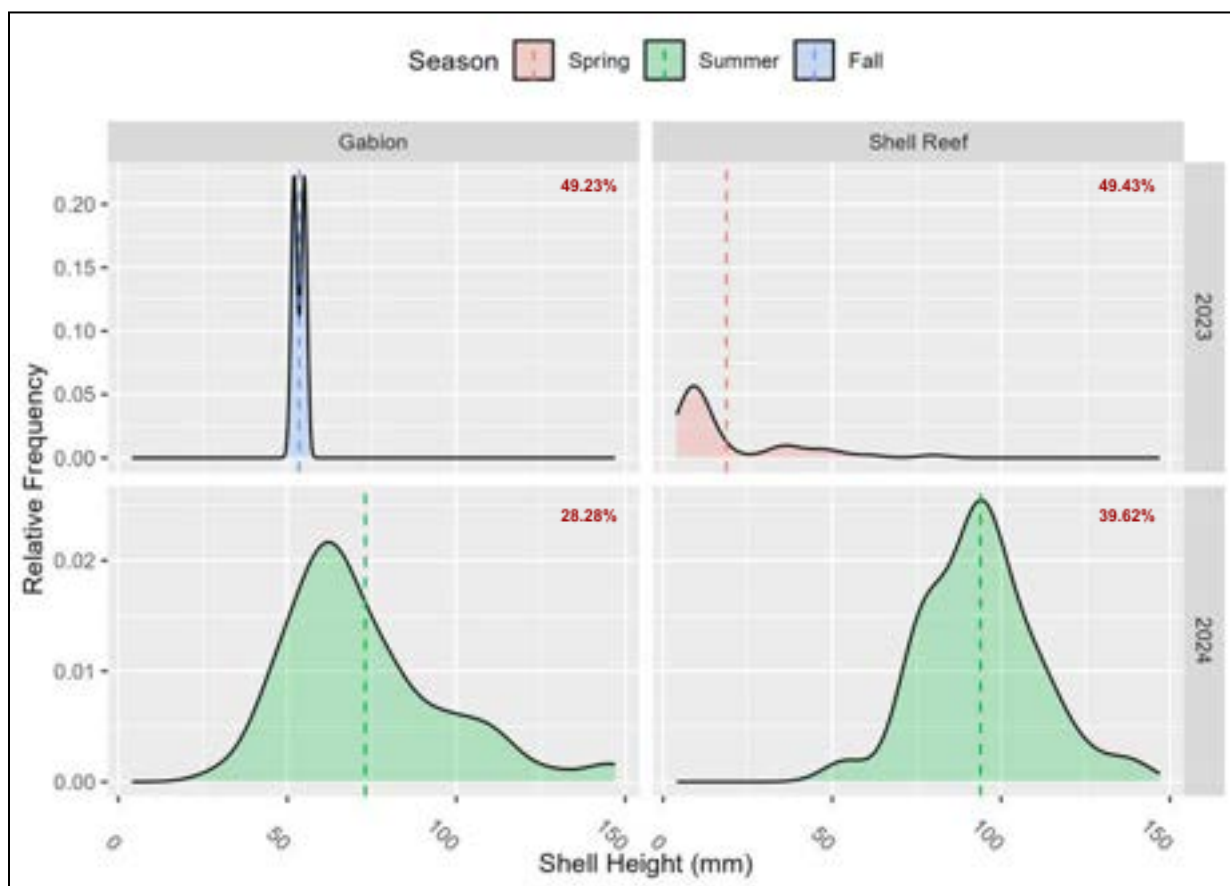


Figure 42. Size-frequency histogram of live oysters in Soundview Park gabion and shell reef, 2023-2024. The dashed line represents the seasonal mean shell height and the red text in the top right corner represents the annual mortality. Only two live oysters were monitored in the gabion reef in 2023.

Soundview Park Gabion Reef

Growth: Positive

Overall, oyster growth shows a positive trend from 2023 to 2024 among the gabions. While mean shell height in 2023 concentrated around 53.5 mm with mean shell height ranging from 52 mm to 55 mm, greater variation was observed in shell heights in 2024, with a mean of 73.1 mm and a range from 30 mm to 147 mm (**Figure 42**). This increased variation in 2024 could be attributed to oyster growth, differential

mortality, or random sampling effects.

Mortality: Stable

Mortality in the gabions decreased from 49.2% in 2023 to 28.3% in 2024, reflecting a 43% reduction (**Figure 42**). This decrease is highly encouraging; however, additional monitoring is necessary to determine whether this trend continues.

Recruitment: None

There is no evidence of oyster recruitment among the Soundview gabions during 2023 or 2024 (**Table 38**). As illustrated in **Figure 42**, no oysters with shell heights below 25 mm were recorded in 2024.

Soundview Park Shell Reef

Growth: Positive

Mean shell height showed a significant increase, rising from an average of 18.7 mm in 2023 to 93.9 mm in 2024, representing substantial growth of 75.2 mm (**Figure 42**). This increase aligns with growth trends observed in the shell reef, indicating that this site provides favorable conditions for oyster growth.

Mortality: Stable

Following the same trend as the gabions, mortality in the shell reef decreased from 49.4% in 2023 to 39.6% in 2024, reflecting a 20% reduction in mortality (**Figure 42**). This decrease is highly encouraging; however, additional monitoring is necessary to determine whether this trend continues.

Recruitment: None

There is no evidence of oyster recruitment observed in the shell reef during 2023 or 2024 (**Table 38**). As shown in **Figure 42**, no oysters with shell heights below 25 mm were recorded in 2024.

Oyster Density

Two monitoring methods—clump and quadrat—were used to assess oyster performance in the gabion reef and shell reef at this site. Quadrat monitoring was preferred when oysters had grown through the mesh of the gabion structures, and it was also used to quantify percent cover of live oysters in shell reefs.

In the gabion reef, oyster density showed an increasing trend from 6.25 live oysters per m² in 2023 (N = 34) to 125 live oysters per m² in 2024 (N = 99) (**Table 37**). However, due to the lack of data from previous years and the removal of the gabions in June 2024 due to structural integrity concerns, long-term trends cannot be accurately assessed. Recruitment density remained nonexistent in the gabion reef (**Table 37**).

In the shell reef, quadrat monitoring was conducted in 2023 when low tides allowed staff to wade in, but due to limited low-tide access in 2024, staff switched to clump monitoring. The use of different methods between years makes it difficult to determine consistent trends in oyster density, highlighting the need for additional monitoring data. Recruitment density was only observed in 2023, where 34.4 live recruits per m² were observed (**Table 37**).

Table 37. Sample size (live and dead box oysters), live oyster and recruitment density (per shell and per square meter) across all structures at Soundview Park. NA indicates no available data. Recruitment density is not calculated for data collected less than one year post-installation.

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
Gabion	2020	NA	NA	<1 year old	NA	<1 year old
	2021	NA	NA	NA	NA	NA
	2022	NA	NA	NA	NA	NA

Structure	Year	Sample Size	Live Oyster Per Shell	Live Recruit Per Shell	Live Oyster Per Square Meter	Live Recruit Per Square Meter
	2023	34	NA	NA	6.25	0.00
	2024	99	1.00	0.00	125.00	0.00
Shell Reef	2020	60	0.00	0.00	NA	NA
	2021	NA	NA	NA	NA	NA
	2022	NA	NA	NA	NA	NA
	2023	87	NA	NA	45.83	34.38
	2024	53	0.76	0.00	NA	NA

Oyster Population Estimates

Table 38 presents the annual population estimates across all structures at Soundview, calculated using annual mortality and recruitment data. The current population estimate for oysters in gabions represents 4.2% of the initial population in 2023, while oysters in shell reefs represent % of the starting population. These estimates are not representative indicators of population estimates due to data collection biases, including degraded gabion structures, patchy distribution and reseeded of shell reefs, and limited tidal access for safe monitoring.

Table 38. Estimated population dynamics across all structures at Soundview Park. Rows highlighted in blue show the population estimate as of 2024 based on annual mortality and annual recruitment. NA indicates no data.

Structure	Year	Start Estimate	Annual % Mortality	Post Mortality Estimate	Annual % Recruitment	Population Estimate
Gabion	2023	4,293,101	49.23%	2,179,574	0.00%	2,179,574
	2024	2,179,574	28.28%	1,563,129	0.00%	1,563,129
Shell Reef	2023	18,000,000	49.43%	9,103,448	NA	9,103,448
	2024	9,103,448	39.62%	5,496,422	0.00%	5,496,422
Bay Balls	2024	8,900,000	NA	NA	NA	8,900,000
Total Estimated Population						15,959,551

Oyster Health

In 2023 and 2024, oysters were collected from the community cabinets via wading at low tide and sent to Stony Brook University Marine Animal Disease Lab for testing. Due to the limited low tide dates in 2024 and a reduced number of oysters in the community cabinets, BOP collected oysters from the shell reef via diving at high tide and sent them for lab testing. Although the oysters collected in different years are from the same cohort, they have been residing in different restoration structures. Therefore, additional lab testing is needed to identify any discrepancies between the two years for the following oyster health metrics.

The condition index of a subset of oysters was tested in 2023 and 2024. For the results, please refer to **Appendix Figure B7**.

Disease

Dermo: Low

Cabinet reef oysters exhibited a higher Dermo prevalence (90.9%) and intensity (36.4%) compared to the shell reef oysters (24.1% and 3.5%, respectively) in 2024 (**Figure 43**). Further testing is needed to determine whether the variation in Dermo prevalence and intensity is due to the type of restoration structure, oyster cohort or age, the duration of exposure, or other environmental factors.

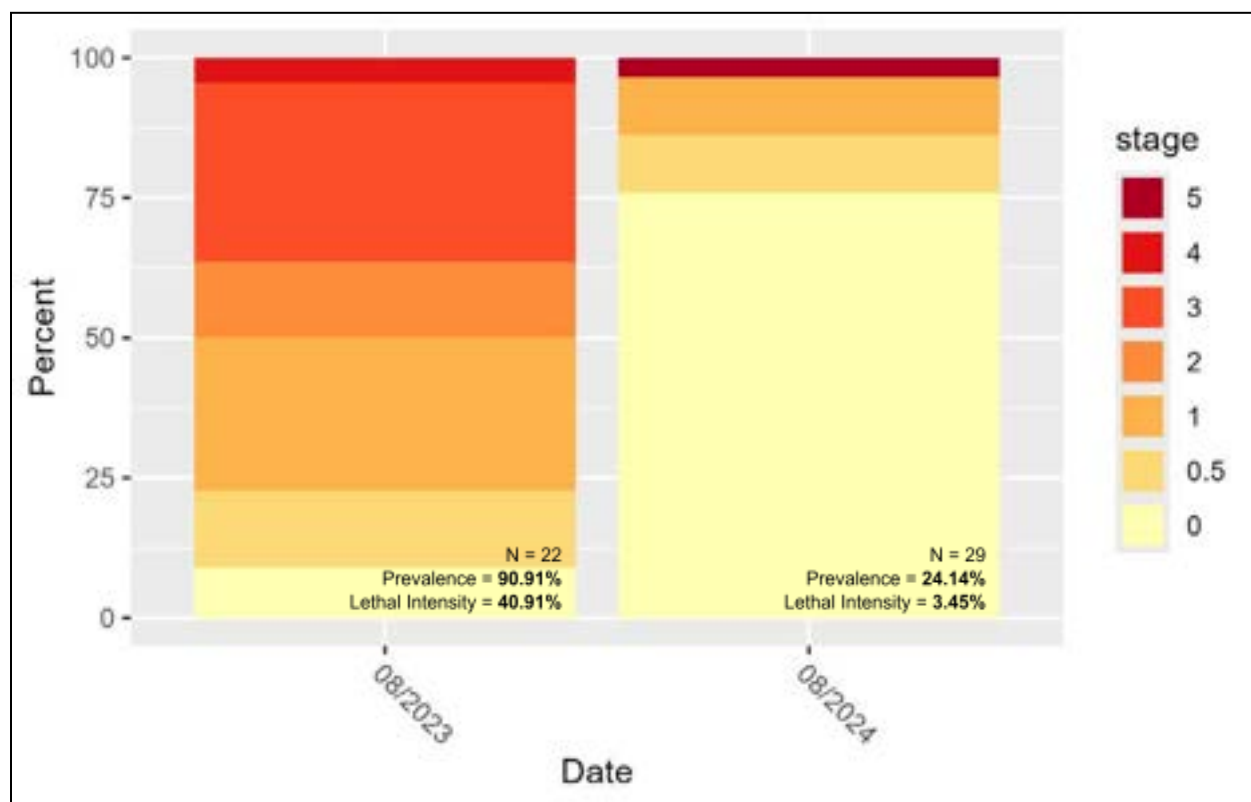


Figure 43. Dermo (*P. marinus*) prevalence and intensity in oysters sampled in August 2023 (N = 22) and August 2024 (N = 29) from Soundview. Oysters with intensities ranking stage 3 or higher on the Mackin scale are considered to be potentially lethally infected.

MSX: Low

MSX was absent in community cabinet oysters in 2023 but was detected in two shell reef oysters in 2024, both exhibiting moderate infections. The emergence of MSX could be influenced by changing site-specific environmental conditions, which may have created favorable conditions for pathogen proliferation.

Reproduction

Spawning: High

Results from tested oysters at Soundview Park showed that 50.0% of the community cabinet oysters were spawning in 2023, while 82.8% of the shell reef oysters were spawning in 2024 (**Figure 44**). In 2024, many oysters were in the final spawning stage, with some initiating another reproductive cycle, suggesting the potential for fall maturation and spawning. In 2023, oysters were similarly in the final spawning stages, but a greater proportion were identified in advanced gonadal stages. The difference in

sample timing—early August in 2023 versus mid-to-late August in 2024—likely influenced the observed variations in reproductive stages between the two years.

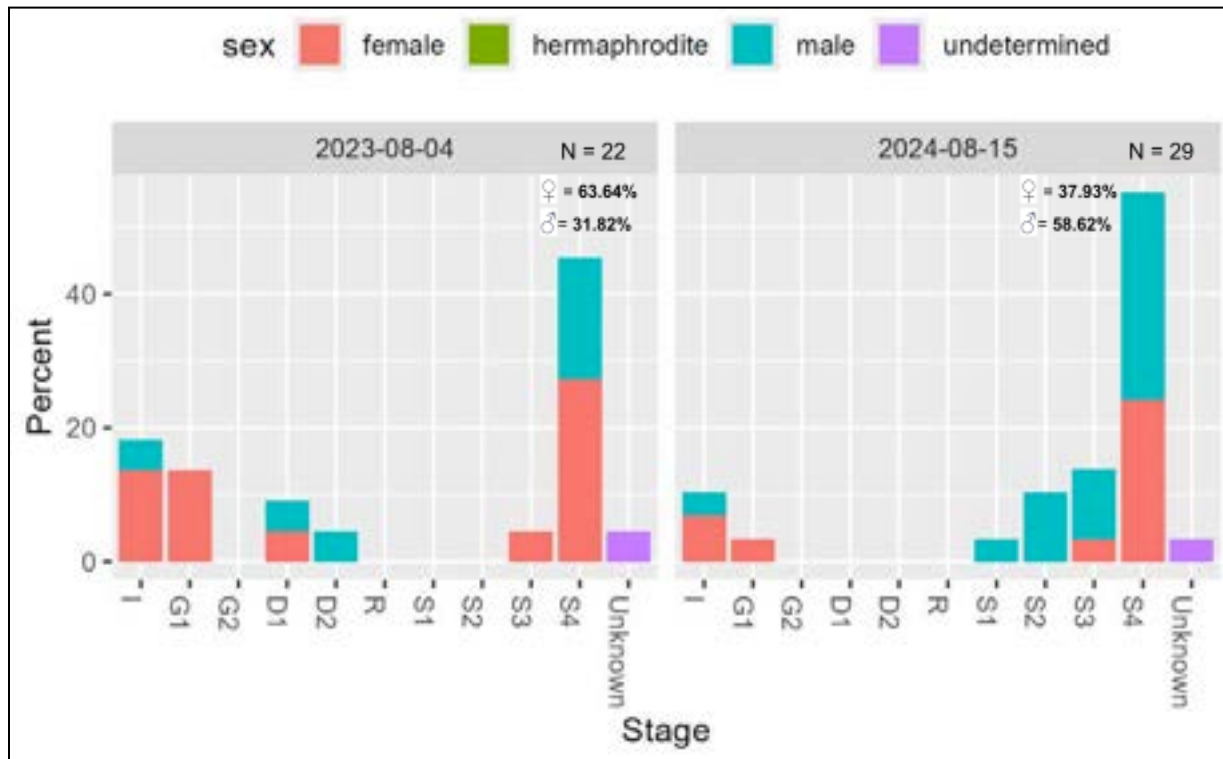


Figure 44. Stage of reproductive development and sex of oysters from community reef in 2023 and shell reef in 2024 at Soundview Park. Sexual maturity generally increases from left to right, but see **Table 7** for a full description of the reproductive stages. Sample size (N), percent female (♀) and male (♂) are also indicated at the top right corner of each graph.

Sex Ratio: Skewed

The sex ratio of the community cabinet oysters was skewed toward males, whereas the sex ratio of the shell reef oysters had the opposite trend (**Figure 44**).

Recommended Restoration Actions

A trend of positive growth, stable mortality, and low recruitment 3-4 years post-construction at Soundview suggest a need to reseed the reef to jumpstart population development. Reseeding oyster restoration sites within the first 6 years post-installation is an accepted and expected management measure utilized by oyster restoration practitioners along the Atlantic Coast in areas where wild oyster recruitment is limited. Reseeding, or adding an age class or cohort of juvenile oysters to the site will advance the goal of developing a self-sustaining oyster population at the site by:

- 1) Creating genetic diversity and increasing the reproductive potential of the site, regardless of recruitment (requires the addition of younger year classes containing more males as the original cohort ages and contains more females)
- 2) Increasing the density of oysters within the reef footprint
- 3) Responding to anticipated annual fluctuations in recruitment, annual mortality, and survival
- 4) Responding to low larval availability in the area
- 5) Responding to unanticipated significant annual mortality events or changing environmental conditions

Reseeding should occur through the addition of seeded bay balls (to replace the removed gabions), and reseeded of the shell reefs, every other year. BOP received a permit amendment to reseed the new shell reef J with spat-on-shell in 2024 but did not do so due to hatchery larvae shortages.

BOP plans to replace the 181 gabions with 130 bay balls seeded with 15 million oysters (100 seeded/30 unseeded) in an upcoming season. This action reestablishes vertical relief within the reef footprint and ensures long-term stabilization of the shell reefs. The replacement of the gabions with reef balls in the western and central reef footprint is considered a critical component of the original project design both for habitat purposes and the retention of the existing shell reefs at the site.

Pre-Installation

This section provides an overview of the site performance criteria that BOP conducts as part of the pre-restoration site investigation for an intertidal/subtidal oyster reef proposal. The purpose of all new projects is to (1) create a permanent oyster reef habitat informed by the research conducted in the pre-installation phase, (2) collect data on oyster performance and health and the success of restoration techniques of large-scale projects post-installation, and (3) continue to provide public engagement opportunities that reconnect people to the New York Harbor waterfront. Each project will also guide future oyster restoration practices at other sites in New York Harbor.

Pre-installation activities are organized into three major research areas: (1) oyster health & performance, and (2) estuarine community utilization, and 3) bottom type mapping and habitat conditions (**Table 39**). BOP, partner experts, and community scientists will work together to characterize the changes in oysters and benthic communities. Data collected for estuarine community utilization, bottom type mapping, and habitat conditions will be used to inform design and permitting of the site.

Table 39. Pre-installation activities for new sites.

Research Area	Protocol	Parameters	Frequency	Method
Wild Oyster Health and Performance	Recruitment	Spat Count	Annually, once in Fall	Lodge et al. 2017
	Disease (optional)	Disease Intensity & Prevalence	Once, late Summer or Fall	Levinton et al. 2013 (Tissue Inspection)
	Reproduction (optional)	Gonad Condition Sex Ratio	Once in Summer	Levinton et al. 2013 (Tissue Inspection)
Estuarine Community Utilization	Benthic Characterization	Biodiversity Abundance	Once, late Summer or Fall	Taghon et al. 2018 (Van Veen or Petite Ponar Grab Samples & Sieving)
	Epibenthic Characterization	Biodiversity Abundance	Once, late Summer or Fall	Fitzgerald et al. 2020 (Diver w/ Clearwater Box)
	Mobile Characterization	Biodiversity Abundance	Traps Annually, thrice per year Spring, Summer, & Fall Seining Annually eDNA Annually (optional)	Able et al. 2005, Baggett et al. 2024 (draft conceptual fish monitoring plan), Kumar et al. 2022 (eDNA for turbid waters), McCann et. al, 2018 (<i>Exploring eDNA</i>)
Bottom Type Mapping and Habitat Conditions	Mapping	Hydrographic Surveys	Once	Side-scan Sonar Multibeam Sonar
	Bottom Type Characterization	Sediment Characterization	Once	Van Veen or Petite Ponar Grab Samples & Sieving

2024 Pre-Installation Activities

Table 40 summarizes the pre-installation activities completed in 2024 at four Western Long Island Sound sites: Powell's Cove, Pugsley Creek, Turtle Cove, and Flushing Bay (**Figure 45**). Data collected from these pre-installation activities can be requested through BOP's website.

Table 40. Pre-installation activities completed in 2024.

Pre-Construction Activity	Powell's Cove	Pugsley Creek	Turtle Cove	Flushing Bay	Paerdegat Basin
Wild Oyster Survey	October 2024	September 2024	September 2024	October 2024	August 2023
Benthic Characterization	September 2024	September 2024	September 2024	October 2024	Planned
Hydrographic Surveys (Side-scan and Multi-beam)	October 2024	October 2024	October 2024	October 2024	October 2023
Hydrologic Study	Planned	Planned	Planned	Planned	April 2024
Wave/Fetch Analysis	September 2024	September 2024	September 2024	Planned	April 2024
Bottom Type Characterization	September 2024	September 2024	September 2024	October 2024	April 2023



Figure 45. Map of sites within Western Long Island Sound where pre-installation activities were completed in 2024.

2025 Pre-Installation Activities

Table 41 provides an overview of the pre-installation activities projected for 2025 at Flushing Bay, Paerdegat Basin, Hudson Reef, and starting site investigation at Four Sparrow Marsh. Data collected during these pre-construction activities will be available for request on BOP's website at the conclusion of the 2025 field season.

Following the abundant wild oysters observed during the 2024 wild oyster surveys at the Western Long Island Sound sites, BOP plans to collect wild oysters from Flushing Bay for laboratory testing to assess disease load and reproductive maturity.

Table 41. Pre-installation activities confirmed for 2025. NA indicates the pre-installation activity is not needed.

Pre-Installation Activity	Bush Terminal Park	Flushing Bay	Paerdegat Basin	Hudson Reef	Four Sparrow
Wild Oyster Survey	Completed	Fall 2025	Fall 2025	Fall 2025	Fall 2025
Disease (Wild Oyster)	NA	August 2025	NA	NA	NA
Reproduction (Wild Oyster)	NA	August 2025	NA	NA	NA
Mobile Characterization	Spring - Fall 2025	Spring - Fall 2025	Spring - Fall 2025	Spring - Fall 2025	NA
Benthic Characterization	Completed	Completed	Fall 2025	Fall 2025	NA
Hydrographic Surveys (Side-scan and Multi-beam)	Completed	Completed	Completed	Spring 2025	NA
Hydrologic Study	Completed	April 2025	Completed	NA	NA
Wave/Fetch Analysis	Completed	April 2025	Completed	NA	NA
Bottom Type Characterization	Completed	Completed	Completed	Summer 2025	NA

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Appendix

Appendix A. 2023-2024 Fish Biodiversity Data

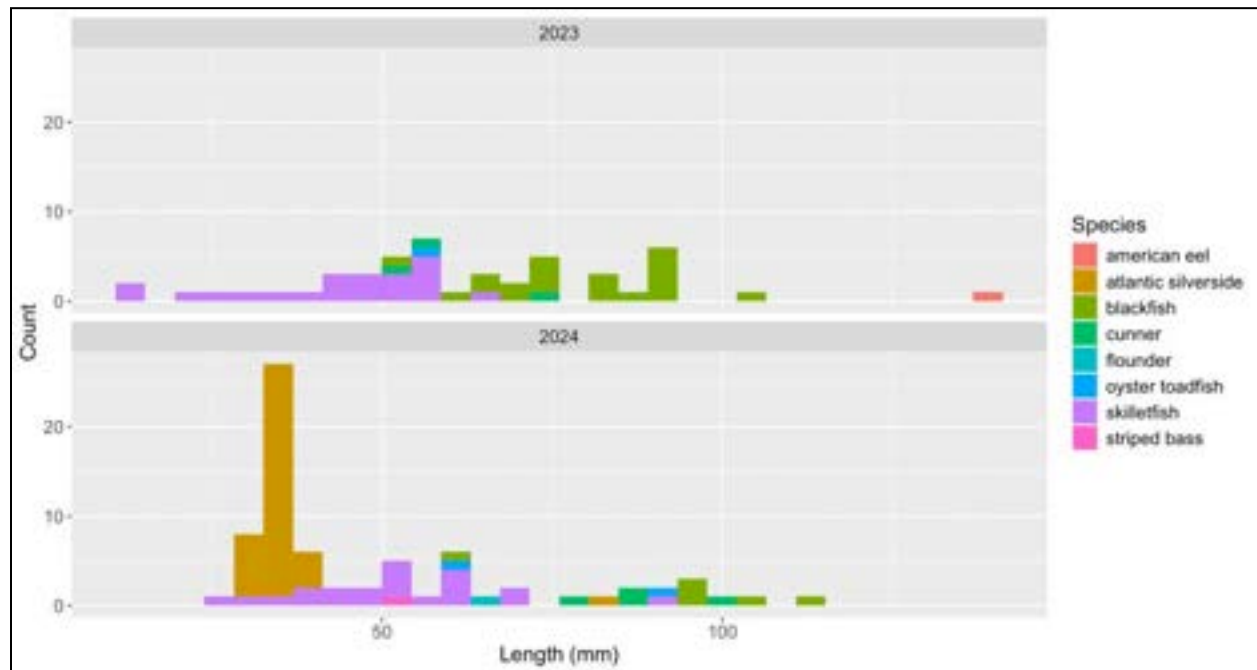


Figure A1. Total fish length measured during observations in May and November 2023 (top) and during observations and seining in May and July 2024 (bottom) at Brooklyn Bridge Park Cabinet and Nursery.

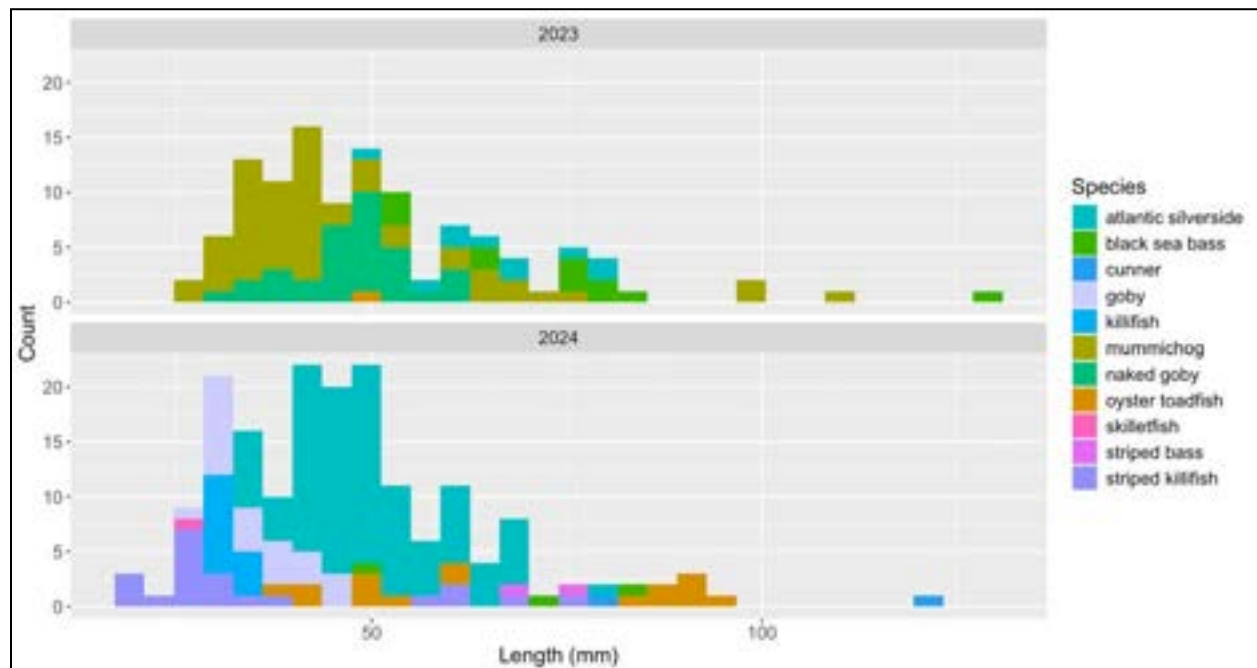


Figure A2. Total fish length measured during observations and seining in June and October 2023 (top) and during observations, seining and minnow trapping in May, July, September and October 2024 (bottom) at Bush Terminal Park.

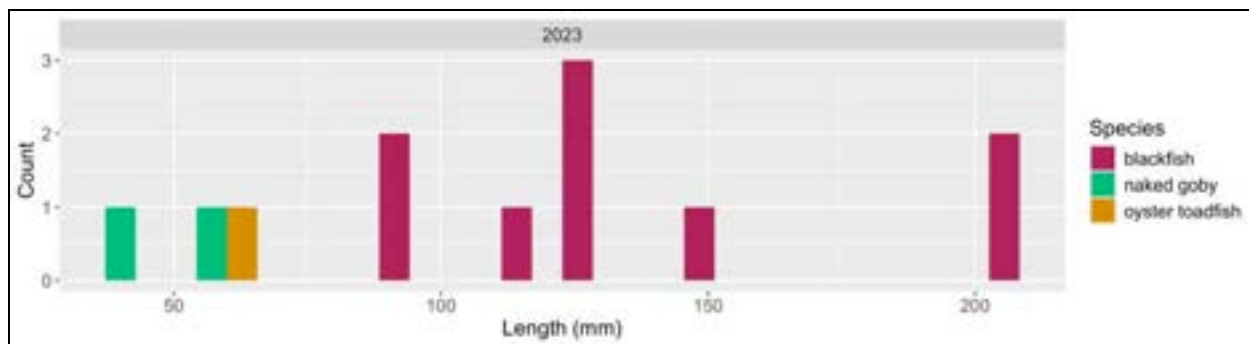


Figure A3. Total fish length measured during observations in May 2023 at Great Kills Harbor.

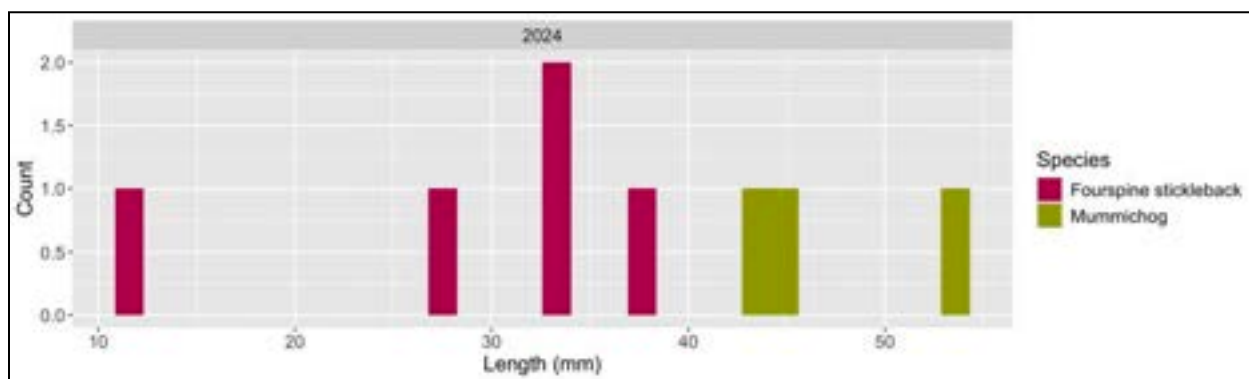


Figure A4. Total fish length measured during seining in May 2024 at Lemon Creek Lagoon.

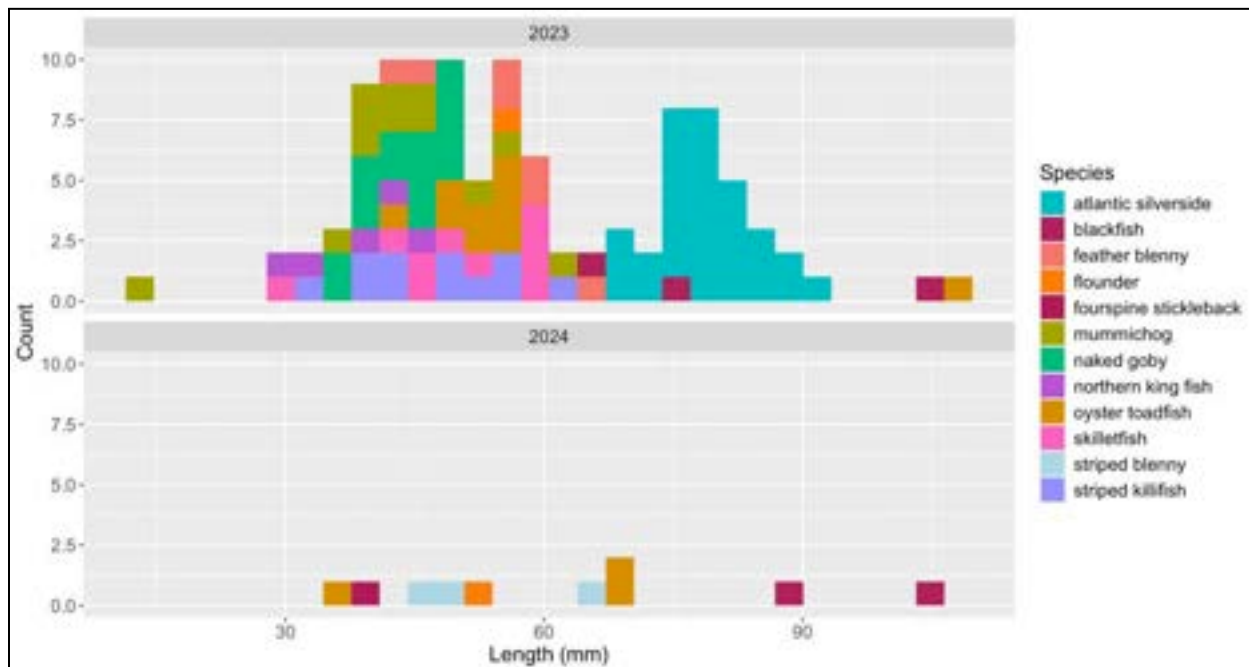


Figure A5. Total fish length measured during observations and seining in May and November 2023 (top) and during observations and seining in May 2024 (bottom) at Paedergat Basin.

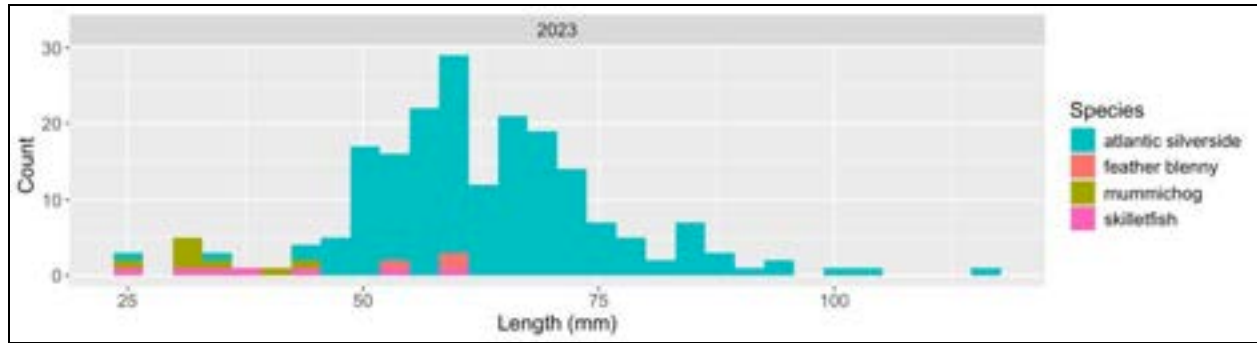


Figure A6. Total fish length measured during observations and seining in September 2023 at Bayswater Point State Park.

Appendix B. 2023-2024 Condition Index Data

Condition index (CI) is calculated as (dry mean weight / dry shell weight) x 100. Other condition indices for oysters are used in commercial production, with higher values indicating more internal body meat relative to shell). If the condition index of the same stock is measured repeatedly over the course of a season, a sudden drop in the condition index may indicate spawning or another event. However, because BOP sampled oysters only once during the reproductive season, it is not possible to link the CI data to the status of reproduction. These results thus provide a snapshot of the condition index of oyster at a reef site.

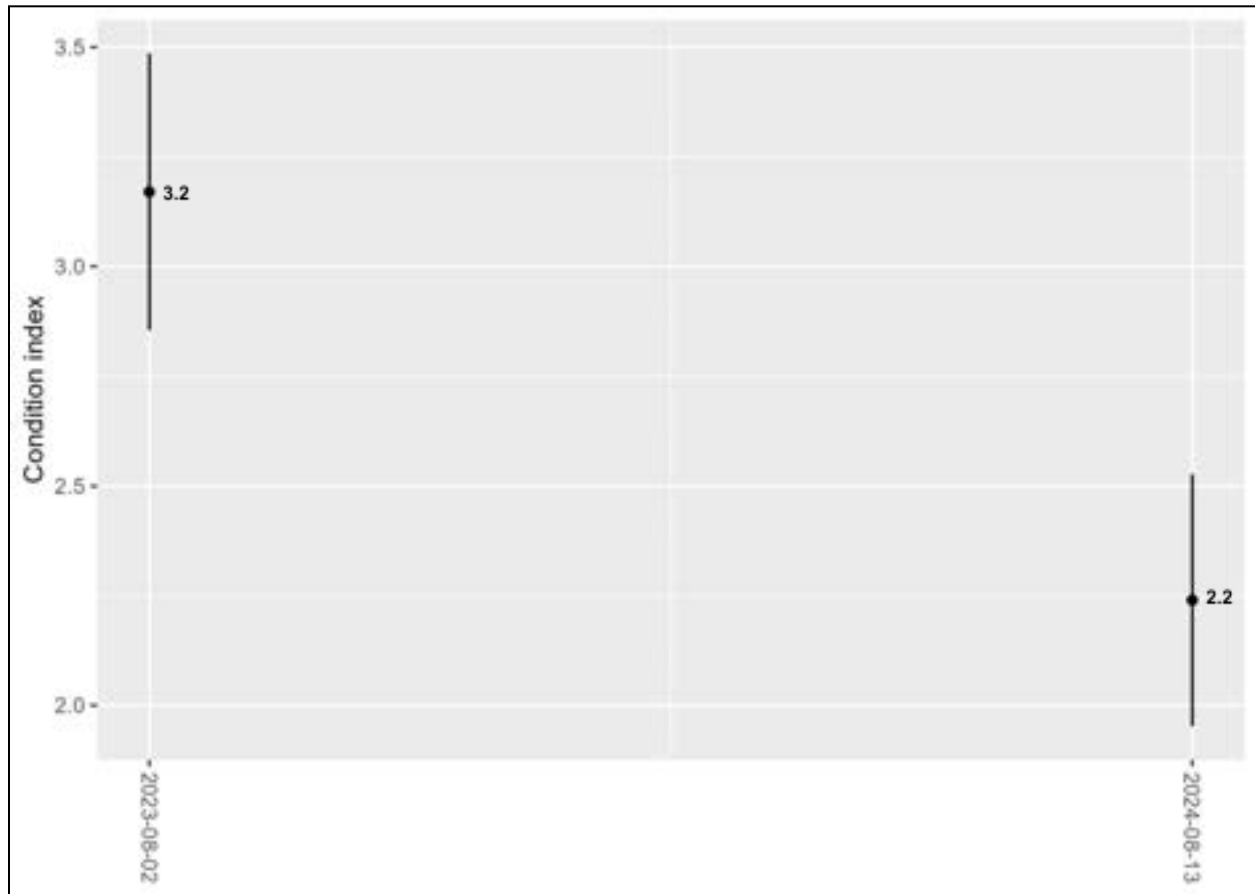


Figure B1. Average condition index of oysters from Brooklyn Bridge Park Nursery in August 2023 (N = 29 oysters) and 2024 (N = 30). Error bars represent 95% confidence intervals.

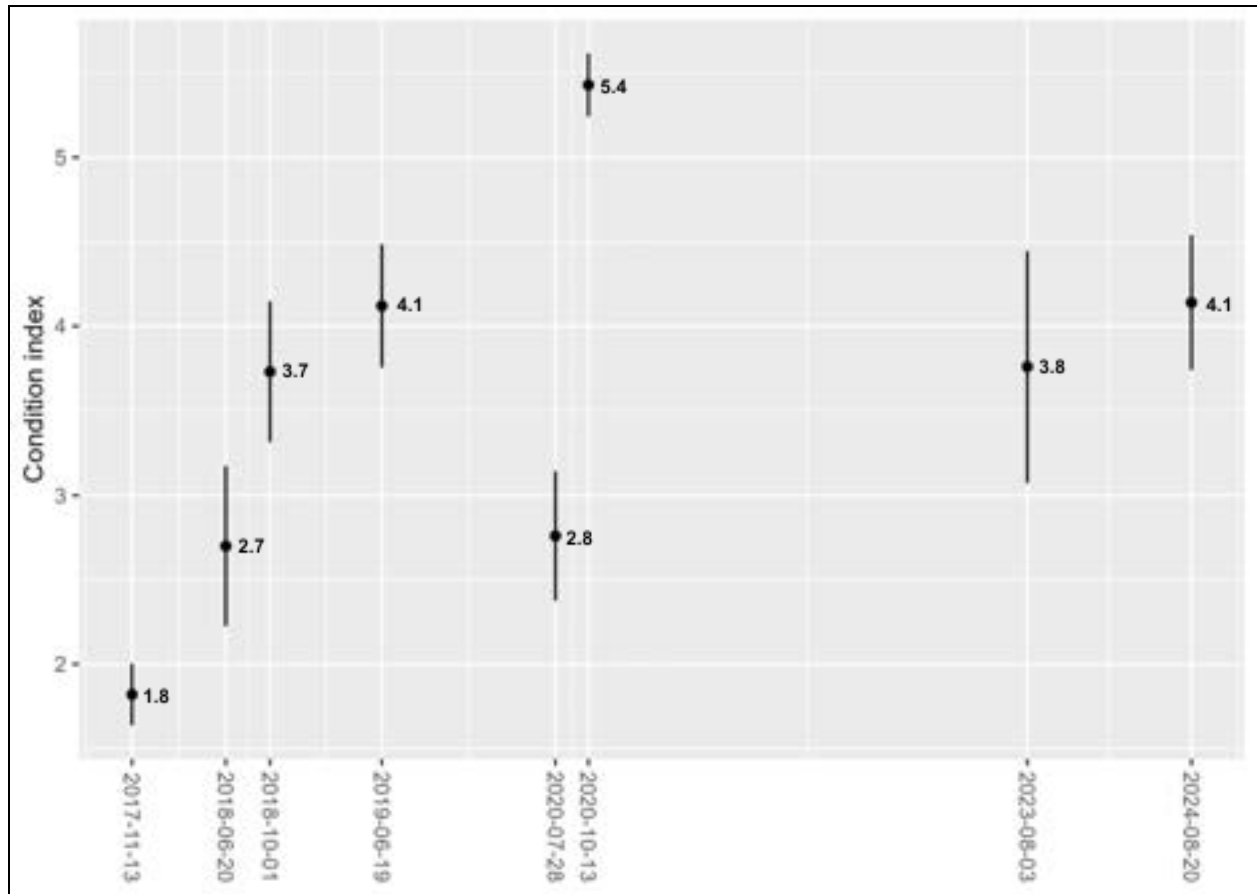


Figure B2. Average condition index of oysters from Bush Terminal Park cabinet reefs in November 2017 (N = 30 oysters), June 2018 (N = 27), October 2018 (N = 30), June 2019 (N = 28), July 2020 (N = 27), October 2020 (N = 30), August 2023 (N = 28) and August 2024 (N = 30). Error bars represent 95% confidence intervals.

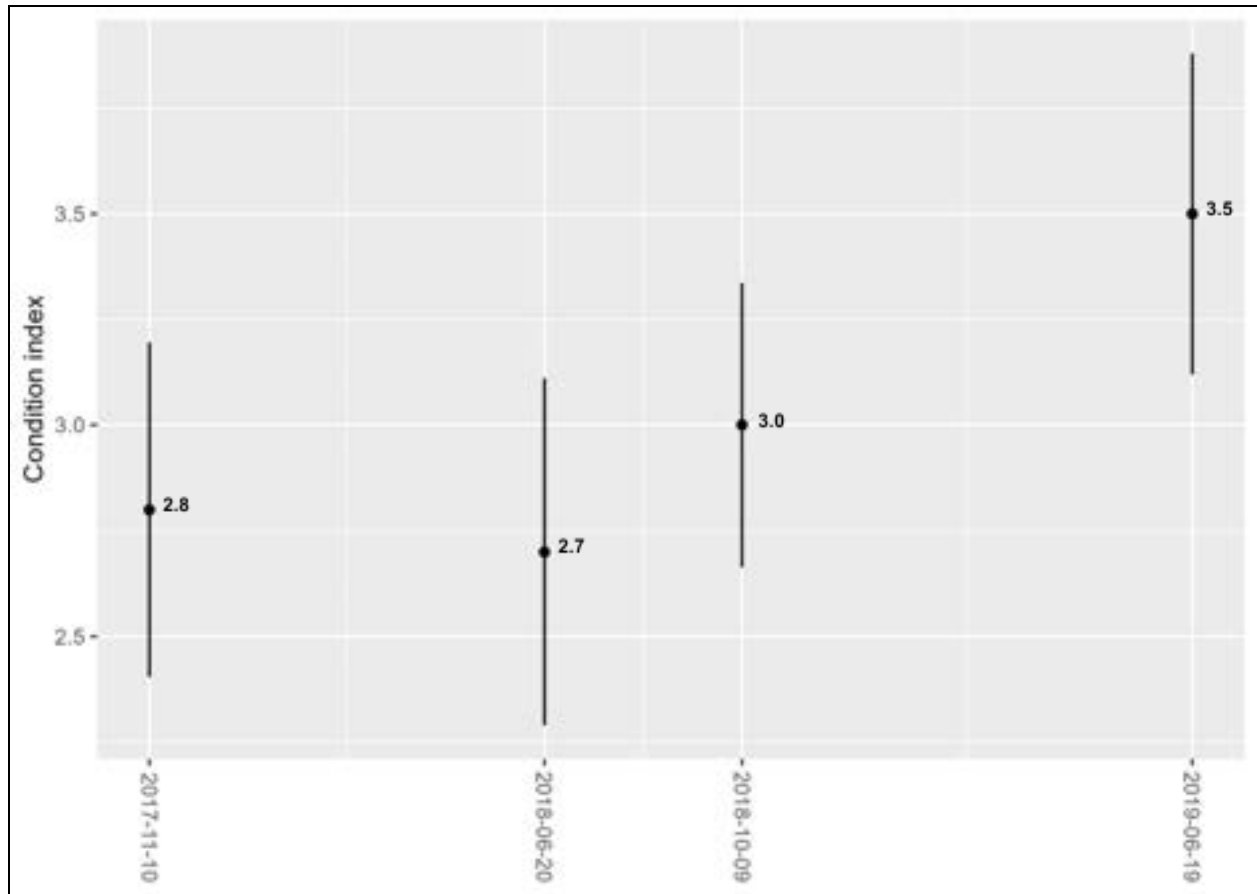


Figure B3. Average condition index of oysters from Brooklyn Navy Yard in November 2017 (N = 30 oysters), June 2018 (N = 30), October 2018 (N = 30), June 2019 (N = 29). Error bars represent 95% confidence intervals.

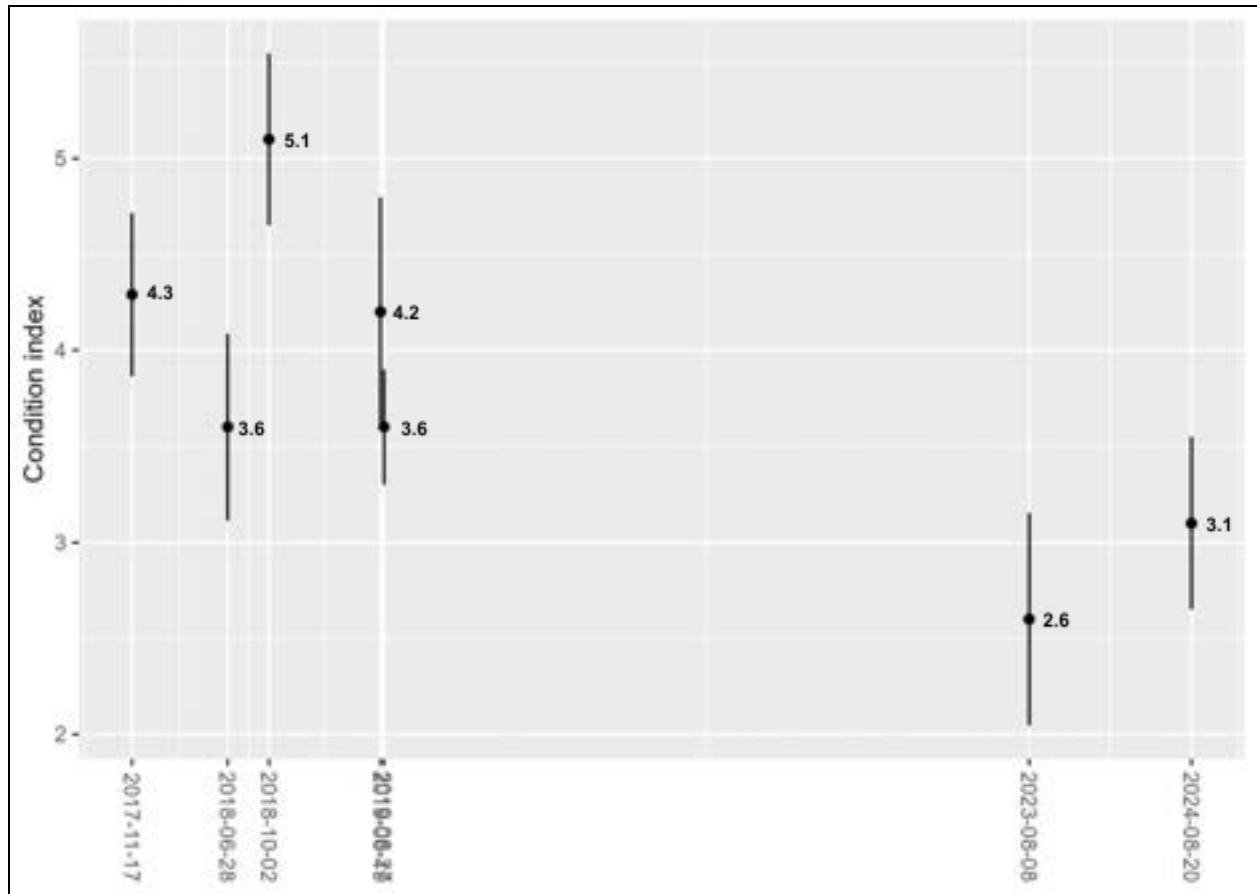


Figure B4. Average condition index of oysters from Great Kills Harbor in November 2017 (N = 30 oysters), June 2018 (N = 30), October 2018 (N = 30), June 2019 (N = 60), October 2019 (N = 52), August 2023 (N = 15) and August 2024 (N = 30). Error bars represent 95% confidence intervals.

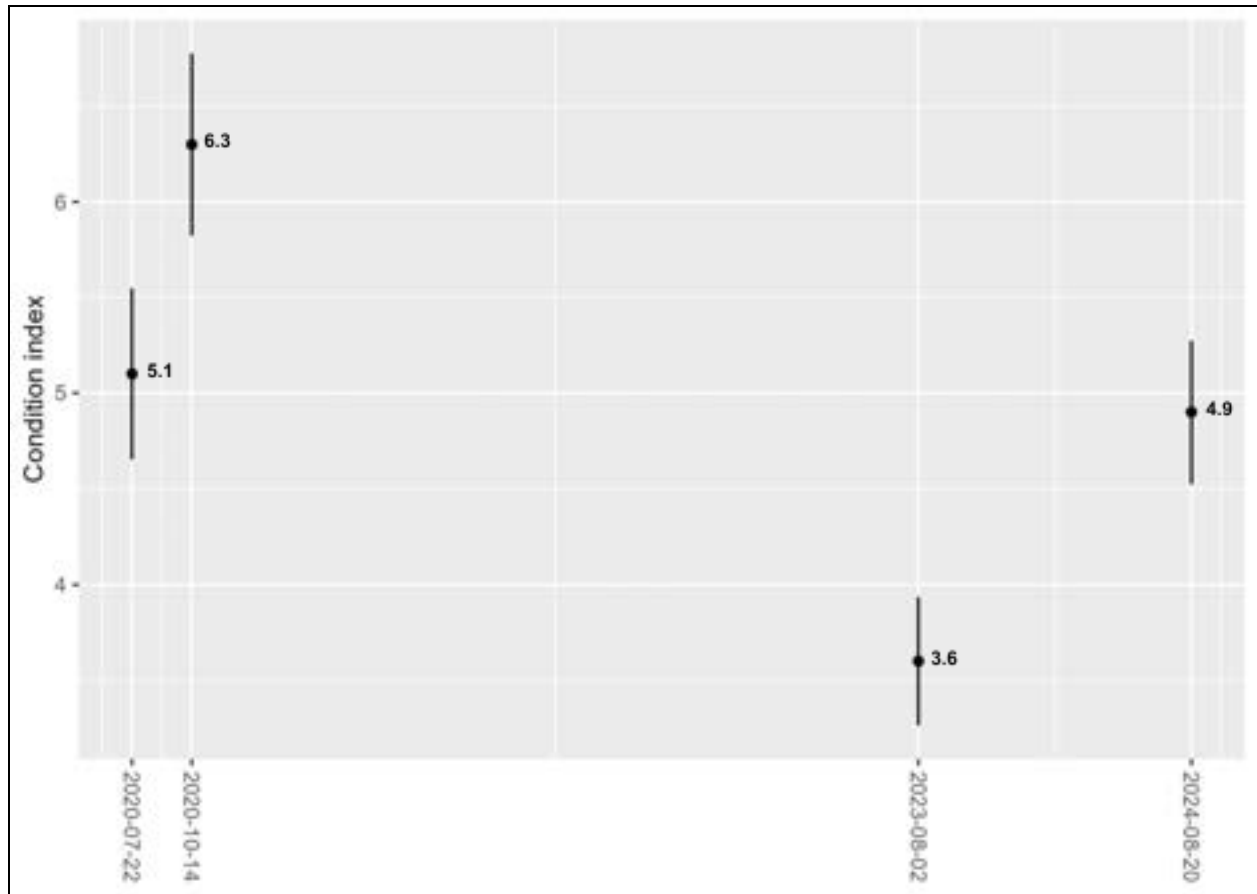


Figure B5. Average condition index of oysters from Paerdegat Basin in July 2020 (N = 30 oysters), October 2020 (N = 31), August 2023 (N = 30) and August 2024 (N = 30). Error bars represent 95% confidence intervals.

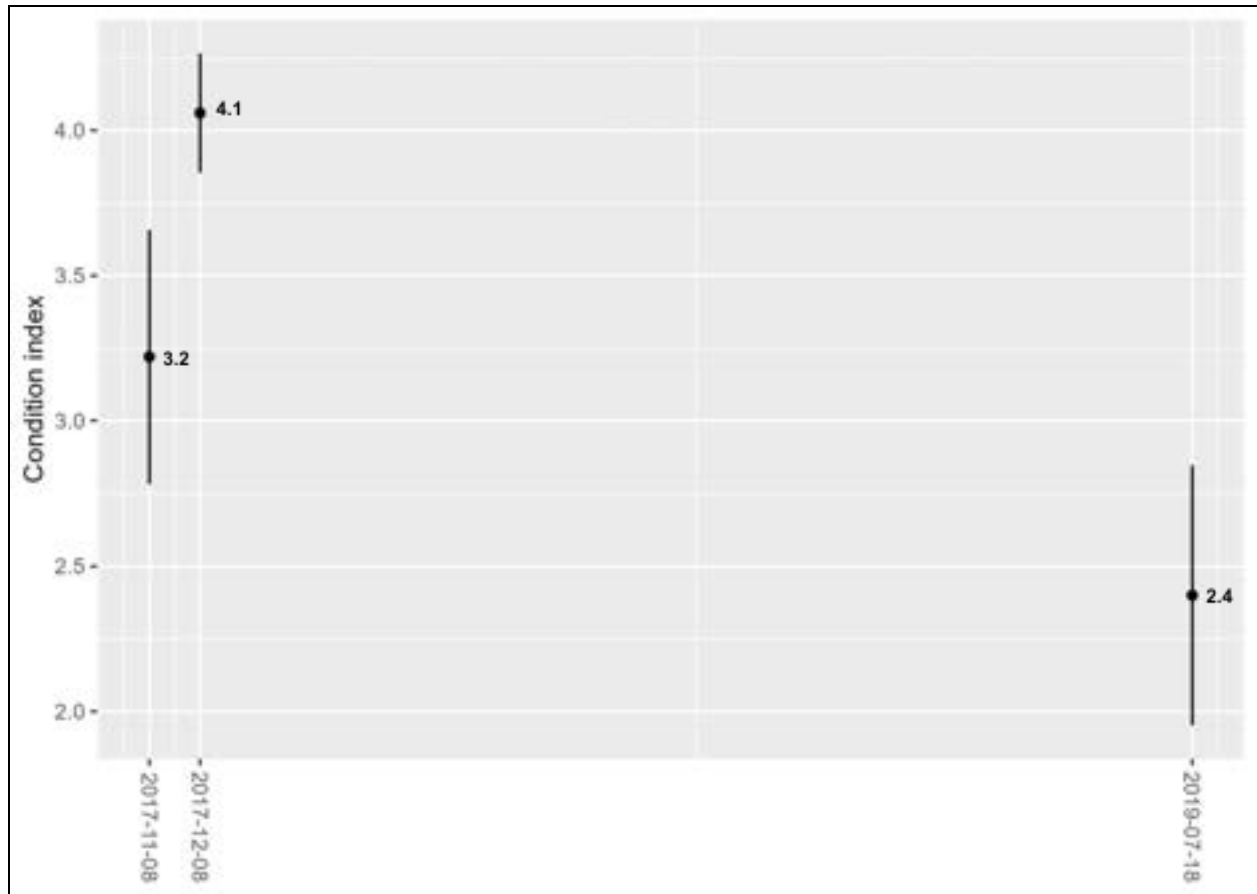


Figure B6. Average condition index of oysters from Head of Bay in November 2017 (N = 30 oysters), December 2017 (N = 30) and July 2019 (N = 30). Error bars represent 95% confidence intervals.

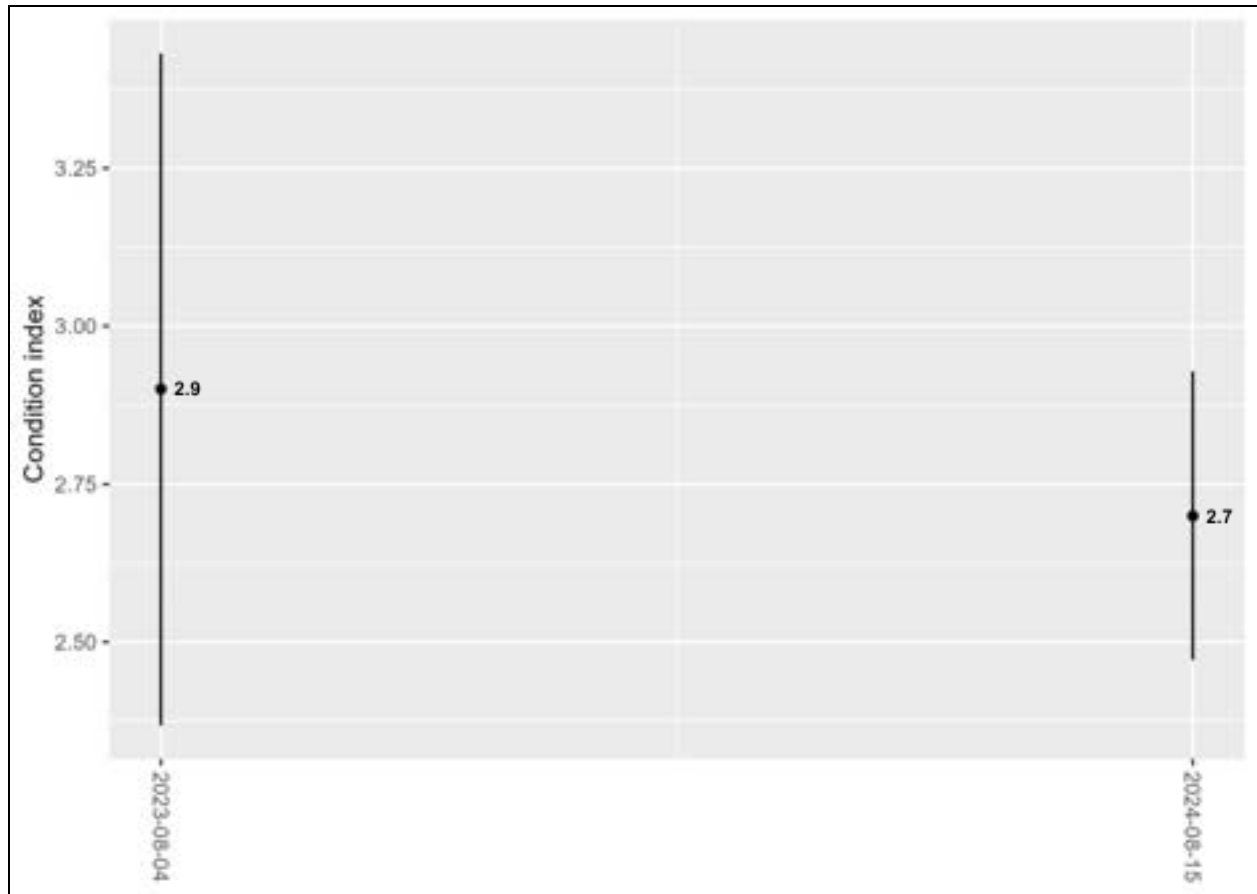


Figure B7. Average condition index of oysters from Soundview Park in August 2023 (N = 22 oysters) and August 2024 (N = 29). Error bars represent 95% confidence intervals.