New York City Oyster Monitoring Report

2018

BILLION OYSTER PROJECT

The Nature Conservancy

About The Nature Conservancy

The Nature Conservancy (TNC) is a global environmental nonprofit working to create a world where people and nature can thrive. Founded in the United States in 1951, TNC has grown to become one of the most effective and wide-reaching environmental organizations in the world. Thanks to more than a million members and the dedicated efforts of our diverse staff and more than 400 scientists, we impact conservation in 72 countries across six continents. Our mission is to conserve the lands and waters on which all life depends. Our vision is a world where the diversity of life thrives and people act to conserve nature for its own sake and for its ability to fulfill our needs and enrich our lives.

About Billion Oyster Project

The mission of Billion Oyster Project (BOP) is to restore oyster reefs to New York Harbor through public education initiatives. We envision a future in which New York Harbor is the center of a rich, diverse, and abundant estuary. The communities that surround this complex ecosystem have helped construct it, 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. To date, BOP has collected 1.3 million pounds of shells from restaurants and planted more than 28 million oysters in New York Harbor.

Recommended Citation

Burmester, EM, and MJ McCann. 2019. New York City Oyster Monitoring Report: 2018. Billion Oyster Project and The Nature Conservancy. New York, NY.

Acknowledgments

Restoring New York Harbor takes a city! We are grateful to the hundreds of students helping as part of their STEM education, 70+ educators, thousands of volunteers, 70+ New York City restaurants donating shells, and passionate partners and supporters who are making this project a reality, including:

Americal Littoral Society
Brooklyn Community Board 13
Brooklyn Community Board 18
Canarsie Community Development
Canarsie Courier
City Parks Foundation- Coastal Classroom
Community Education Council- District 18
Coney Island Beautification Project Inc.
Coney Island Cub Scouts
Coney Island Girl Scouts
Coney Island History Project
Cultural Academy for Arts and Science
Fresh Creek Nature Association
Friends of Kaiser Park/Coney Island Generation Gap
I.S. 211 John Wilson
I.S. 68 Isaac Bildersee
I.S. 98 Bay Academy
Institute for Collaborative Education
J.H.S. 234 Arthur W. Cunningham
Jamaica Bay- Rockaway Parks Conservancy
Jewish Community Council of Canarsie
John Dewey High School
Kingsborough Community College
Kurt Hahn Expeditionary Learning School
Millennium Development
Mott Haven IV
National Parks Conservation Association
New York Aquarium
New York City Parks
New York Harbor School
New York State Assemblymember Jaime Williams
New York State Department of Environmental Conservation
New York State Marine Education Association
New York State Parks
New York City Parks
NYC Council Member Alan Maisel
P.S./I.S. 288 Shirley Tanyhill School
P.S. 104 The Bays Water
P.S. 188 Michael E. Berdy
P.S. 90 Magnet School for Environmental Studies
PACE University
Partnerships for Parks
Rachel Carson High School
Science and Resilience Institute at Jamaica Bay
Sebago Canoe Club
Senator Roxanne Persaud Office
SWIM Coalition
Waterfront Alliance

We'd like to thank Latifah Abdul-Malik and Chester Zarnoch, PhD, of Baruch College for analysis of nutrient samples and Mohammad Alauddin, PhD; Mary Gad; and Liz Suter, PhD; of Wagner College for analysis of heavy metal samples. This report has been greatly improved thanks to technical input and review from Pete Malinowski and Katie Mosher of BOP and Emily Maxwell of TNC.

Letter from Billion Oyster Project Director of Restoration

Dear Reader,

For many New Yorkers, summer in the city means visits to the ice cream truck and walking on hot asphalt. But for Billion Oyster Project staff and interns, summer means ‘field season’—legs planted firmly in the Harbor, measuring oysters, seining for fish, and monitoring water chemistry. From May through October, Billion Oyster Project and The Nature Conservancy collaborated with students, community scientists, and other partners to collect and analyze information about the city’s growing oyster population and the ecosystem that surrounds it.

The water bodies that surround our city are as different from each other as each New York neighborhood is from the next. From the small and gentle creeks in Raritan Bay and Lower New York Harbor to the mighty Hudson, Bronx, and East Rivers, each water body has qualities that require different structures and field monitoring techniques. Monitoring helps us better understand how restored oysters respond to different growing environments and helps us learn more about the impact that restored oysters are beginning to have on various water bodies.

This is the second Annual Monitoring Report co-written by Billion Oyster Project and The Nature Conservancy. The Nature Conservancy believes that the lessons learned in New York City are important to restoration efforts in other urbanized estuaries in the United States and around the globe and is proud to collaborate with us to collect and analyze data that inform our work. This report helps Billion Oyster Project understand how to build bigger and more successful reefs and gets us closer to our goal of restoring a billion oysters to New York Harbor.

It’s not all about the numbers. New York City’s piers and bulkheads were built to serve as infrastructure. They were not designed to support the aquatic life that we know could and should be here now. Nor were they designed for people to access the water safely. Our neighborhoods need ecologically vibrant shorelines in the same way that people need big, green parks. Each year, more and more parks and marinas, boating clubs, and nonprofits are making space for oyster projects that use innovative research and restoration materials like hanging cages and removable units that can be monitored through our programming. No matter the scale, each small oyster cage and each multi-acre reef brings more baby oysters to the estuary and gets us all closer to the goal of restoring New York Harbor together.

While field season is the busiest time of year for our staff, it’s probably not surprising that it’s also our favorite time of year. There’s nowhere we’d rather be than hip-deep in the harbor as it teems with life, hoping to measure an oyster that’s grown too big for our calipers! We hope you’ll connect with us next field season at one of our community oyster monitoring events and watch as New York Harbor comes alive with sea horses, spider crabs, eels and anemones.

See you in the water!

Katie Mosher

Katie Mosher, Billion Oyster Project Director of Restoration

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Introduction

You are reading the second edition of the *New York City Oyster Monitoring Report.* This report is produced by Billion Oyster Project and The Nature Conservancy. It reports on the 2018 season and is an update of the first report (McCann 2018), which described the 2016 and 2017 seasons. Since 2014, BOP has been restoring oysters to New York Harbor and providing meaningful opportunities for young people and community members to engage in the work. In 2016, BOP and TNC began a partnership to advance the science of oyster restoration. Since then, much has been learned about how, where, and why to restore oysters in the most urbanized waters in the United States. The current efforts reported in this document were shaped by and advance nearly two decades of prior efforts to research and restore oysters to the waters surrounding New York City. The history of these past efforts has been summarized in the report *Restoring Oysters to Urban Waters* (McCann 2019). The document you are reading provides an in-depth view of the science and research that is currently happening at BOP restoration sites.

The primary results of our work are presented succinctly in the **Main Findings** (p. 6). Detailed information about each restoration location is reported in **Site-by-Site Results and Recommendations** (p. 8) and **Assessing Performance at Each Site** (p. 17). The remainder of the document summarizes the results of scientific monitoring in detail and is intended for a technical audience. It is organized around specific topics, including **Reproductive Status** (p. 39), **Food Availability** (p. 56), and **Biodiversity** (p. 62).

Main Findings

New York/New Jersey (NY/NJ) Harbor is ready for oyster restoration. NY/NJ Harbor is suitable habitat for oysters and is ripe for continued restoration effort. Oysters survive, grow, and reach reproductive maturity in these waters, and juvenile oyster recruits are able to locate suitable substrate when it exists.

Reproduction and recruitment are promising, but it's unclear whether this trend will continue and whether it will be enough to achieve self-sustaining reefs. Continued and increased efforts to measure recruitment at locations beyond restoration sites are necessary to understand oyster population dynamics across a broader geography.

Growth and survival are promising at most sites in the Harbor. As seen in previous years, oysters grow rapidly in the first year after restoration and continue to grow in subsequent years. Exceptions to this rule are the two sites in or near the East River (i.e., Brooklyn Navy Yard and Governors Island EcoDock) and sites where bagged shell reefs were used, where growth is slower.

Adaptive management is key for successful oyster restoration. Each new restoration site and every monitoring expedition is an opportunity for learning and improving our practice. For instance, we have found that growth and survival rates in the first year following restoration vary based on how oysters were installed. Because different sites will have different needs, new types of installation should continue to be developed and refined with an adaptive management approach in mind.

All sites experience hypoxia (i.e., low oxygen) that may negatively impact oysters. Some sites have low levels of food. Most other water quality attributes appear to be suitable for oysters. Water quality concerns, particularly with regard to low oxygen, should be closely monitored in conjunction with their impacts on oyster restoration and other marine life. However, water quality may not be the only predictor of restoration success. At sites like Coney Island Creek, where water quality is impaired from combined sewer outflows and illegal discharges, oysters still thrive and recruit naturally.

Disease is likely causing mortality in older oysters at some sites, especially at the Brooklyn Navy Yard and Great Kills Harbor on Staten Island. Continued disease monitoring, particularly of the parasitic protozoan Dermo (*Perkinsus marinus*), is necessary. Additional interventions such as disease-resistant strains may be necessary to help populations that reach sexual maturity but have a high incidence of disease-related mortality.

A diversity of organisms live in and around restored reefs. We still have much to learn about the biodiversity of marine life in the NY/NJ Harbor and how creating suitable and productive habitat will impact marine organisms over the short- and long-term. It is clear, however, that a variety of organisms are using restored oyster reefs as a habitat in which to feed, reproduce, and take shelter.

Figure 1. Students from PS 90 measure oyster growth at the Coney Island Creek Community Reef.

Site-by-Site Results and Recommendations

In addition to the general findings reported above (*Main Findings*, p. 6) and the description of the sites that follows (*Overview of Sites,* p. 10), we also offer these results and recommendations that are specific to each restoration site:

Brooklyn Navy Yard

Growth rates are slower than at other sites, but oysters are reaching reproductive ages (although the population is skewed male). The parasitic disease Dermo is prevalent, and disease intensities are high enough to cause mortality.

Recommendation: Continue monitoring at this site. Increased management may be necessary if disease-based mortality increases.

Canarsie Community Reef

Overall, year 1 results are promising. Rapid growth resulted in a high density of large oysters that cemented to the files (i.e., cages).

Recommendation: Continue monitoring and increase restoration efforts where possible.

Coney Island Community Reef

Despite limitations due to permitting constraints, year 1 results are promising. Rapid growth resulted in a high density of large oysters that cemented to the files (i.e., cages). Recruitment on natural substrates (e.g., intertidal rocks) at this site was promising in 2018.

Recommendation: Continue monitoring and increase restoration efforts where possible.

Governors Island EcoDock

Growth rates are slower than at other sites. Oysters are reaching reproductive ages, but only low levels of natural recruitment have been observed.

Recommendation: Because of its proximity to BOP headquarters, use this site to pilot different strains, structures, and restoration materials.

Great Kills Harbor

Despite encouraging growth and reproduction, the parasitic disease Dermo is prevalent, and disease intensities are high enough to cause mortality. The need to physically break apart oysters that cement to the restoration structures (i.e., Super Tray Nursery) at this site makes it difficult to assess density and survival.

Recommendation: Expand disease testing efforts at this site. Increased management may be necessary if disease-based mortality increases.

Lemon Creek Lagoon

Overall promising growth and survival for year 1, but the results vary depending on the type of installation unit used, with the bagged shell reef showing the slowest growth.

Recommendation: Continue monitoring and increase restoration efforts where possible. Refine the design of bagged shell reefs. Continue using this site for biodiversity monitoring.

Lemon Creek Nursery

Promising growth trends. The need to physically break apart oysters that cement to the restoration structures (i.e., OysterGro® Nursery) at this site makes it difficult to assess density and survival.

Recommendation: Continue monitoring and increase restoration efforts where possible. Test other restoration approaches (e.g., single-set seed) to reduce the need for maintenance.

Sunset Park Community Reef

Promising trends in survival, growth and reproduction, but results vary depending on the type of restoration structure used, with the bagged shell reef showing the slowest growth.

Recommendation: Continue monitoring and increase restoration efforts where possible. Refine the design of bagged shell reefs. Continue using this site for biodiversity monitoring.

Overview of Sites

This report shares the results of monitoring at eight oyster restoration sites in New York Harbor (Table 1, Fig. 3). All sites were permitted and installed by BOP. The Canarsie Community Reef, the Coney Island Community Reef, and the Lemon Creek Lagoon Reef were newly installed in 2018. Several sites include cohorts of oysters installed on multiple years or on multiple types of gear (see *Restoration Structures* below). For example, the Sunset Park site at Bush Terminal Park has community reefs that were installed in 2016 and 2018 and a bagged shell reef installed in 2018. The results of each cohort or structure are typically reported separately for oyster growth, disease, and reproduction, while results for water quality and food availability are reported for the entire site. Both the Brooklyn Navy Yard and Governors Island EcoDock host floating nurseries that hold many oysters. These sites were permitted and installed prior to 2016, and this document reports on a subset of oysters that were installed at each site in 2017 or 2018 specifically for monitoring.

Restoration Structures

A variety of different restoration approaches and structures were used, depending on unique site conditions, project objectives, and our continually developing understanding of best practices for oyster restoration in these waters. Community reefs are welded, steel rebar structures that hold cages of oysters off the bottom (Fig. 1D). These structures allow the cages to be removed for monitoring above the water surface. The term “nursery” describes restoration sites where oysters are held off the bottom in floating or suspended structures, regardless of the size or age of the oysters. Nursery gear types include OysterGros® (Fig. 1C) and Super Trays (Fig. 1F), both of which are used in commercial aquaculture. 2018 was the first year in which several restoration approaches were tested, including bagged shell reefs (Fig. 1A) and ECOncrete® discs (Fig. 1E). Smaller versions of gabions (Fig. 1B) that have been piloted at the Hudson Reefs near the Mario Cuomo Bridge (formerly the Tappan Zee Bridge) were used at Lemon Creek Lagoon.

Oyster Sources

In New York Harbor, oyster populations are not only limited by the lack of suitable hard substrate to colonize but also lack sufficient breeding individuals to seed those substrates. Therefore, restoration in most parts of NY Harbor requires the introduction of live oysters. For these BOP restoration sites, spat on shell oysters were typically used: high densities of juvenile oysters were “set” or attached to oyster shell that was collected from local restaurants or other sources and cured. In some cases, the juvenile oysters were attached to other substrates, such as ECOncrete® discs. Two oyster strains were used: 1) larvae acquired from Muscongus Bay Aquaculture (Maine) and raised and settled onto shell or other structures in the BOP Hatchery on Governors Island, or 2) larvae set onto shell or other structures that came from adult oysters which had been living in Oyster Research Stations (i.e., hanging cages with oysters monitored by students and community groups) or oyster nurseries, and which were conditioned to and spawned in the BOP Hatchery. For the latter method, the adult oysters were retrieved from either the Oyster Research Stations at Richmond County Yacht Club (Great Kills Harbor, Staten Island) or from the BOP EcoDock on Governors Island. In both cases, the adult broodstock was originally from aquaculture sources (either Muscongus Bay, Maine, or Fishers Island, New York), but had acclimated to local conditions.

Sites Not Included in This Report

BOP has other restoration sites that are not included in this report. The community reef at Brooklyn Bridge Park was installed in 2016 and monitored through 2017. In 2018, access to the site was prohibited by safety concerns over falling debris from the Manhattan Bridge. Therefore, no monitoring occurred in 2018. BOP is exploring options to relocate the community reef to another location in Brooklyn Bridge Park. Data analysis is managed by partners at two other sites, the NYC Department of Environmental Protection's Head of Bay project near John F. Kennedy International Airport and the New York State Thruway Authority's Hudson River reefs near the Mario Cuomo Bridge. These partners are the Hudson River Foundation and Dr. Ray Grizzle at University of New Hampshire, and the results will be reported elsewhere. BOP anticipates that restoration will occur at other sites, including Soundview (Bronx), Bayswater Point State Park (Queens), and the Staten Island Living Breakwaters. Oyster research and restoration at Soundview has occurred since 2006 and will be expanded in the future. Results from previous years can be found on the Hudson River Foundation's website[1].

Figure 2. Cabinets were installed at the Sunset Park Community Reef in Bush Terminal Park, Brooklyn.

[1] https://www.hudsonriver.org/article/hudson-river-foundation-publications

Table 1. Restoration structures and installation details

Site	Structure	Install date	Oyster source ±	Size at install (shell height, mm)	Number oysters installed
Brooklyn Navy Yard * **(BNY)**	Super Tray Nursery	4/10/2017	Muscongus Bay, ME	34.9	2,750
Canarsie **(CCR)** (Paerdegat Basin)	Community Reef	7/27/2018	Muscongus Bay, ME	~5	480,000
Coney Island Creek **(CIC)** +	Community Reef	7/16/2018	Muscongus Bay, ME	~5	92,000
Governors Island EcoDock * **(GI)**	Super Tray Nursery	8/21/2018	Muscongus Bay, ME	~5	~20,000
	Super Tray Nursery	4/10/2017	Muscongus Bay, ME	29.5	7500
Great Kills Harbor **(GKH)**	Super Tray Nursery	8/23/2016	Muscongus Bay, ME	27.7	15,836
		6/12/2017	GKH oyster garden broodstock	4.1	141,327
Lemon Creek Nursery **(LCN)**	OysterGro® Nursery	6/12/2017	GKH oyster garden broodstock	4.1	228,780
Lemon Creek Lagoon **(LCL)**	ECOncrete® Discs	8/15/2018	GI nursery broodstock	~5	242,000
	Gabions	8/15/2018	Muscongus Bay, ME	~5	
	Bagged Shell Reef	8/15/2018	Muscongus Bay, ME; GI nursery broodstock	~5	
Sunset Park (Bush Terminal Park) **(SP)**	Community Reef	6/28/2016	Muscongus Bay, ME	~2	969,452
	Community Reef	8/22/2018	Muscongus Bay, ME; GI nursery broodstock	~5	180,000
	Bagged Shell Reef	8/23/2018	Muscongus Bay, ME; GI nursery broodstock	~5	135,000

* Details for the Governors Island EcoDock represent only a small fraction of the oysters at the site.
± See text for a complete explanation of oyster sources.
+ Due to permitting restrictions, all oysters installed at this site in 2018 were removed at the end of the season.

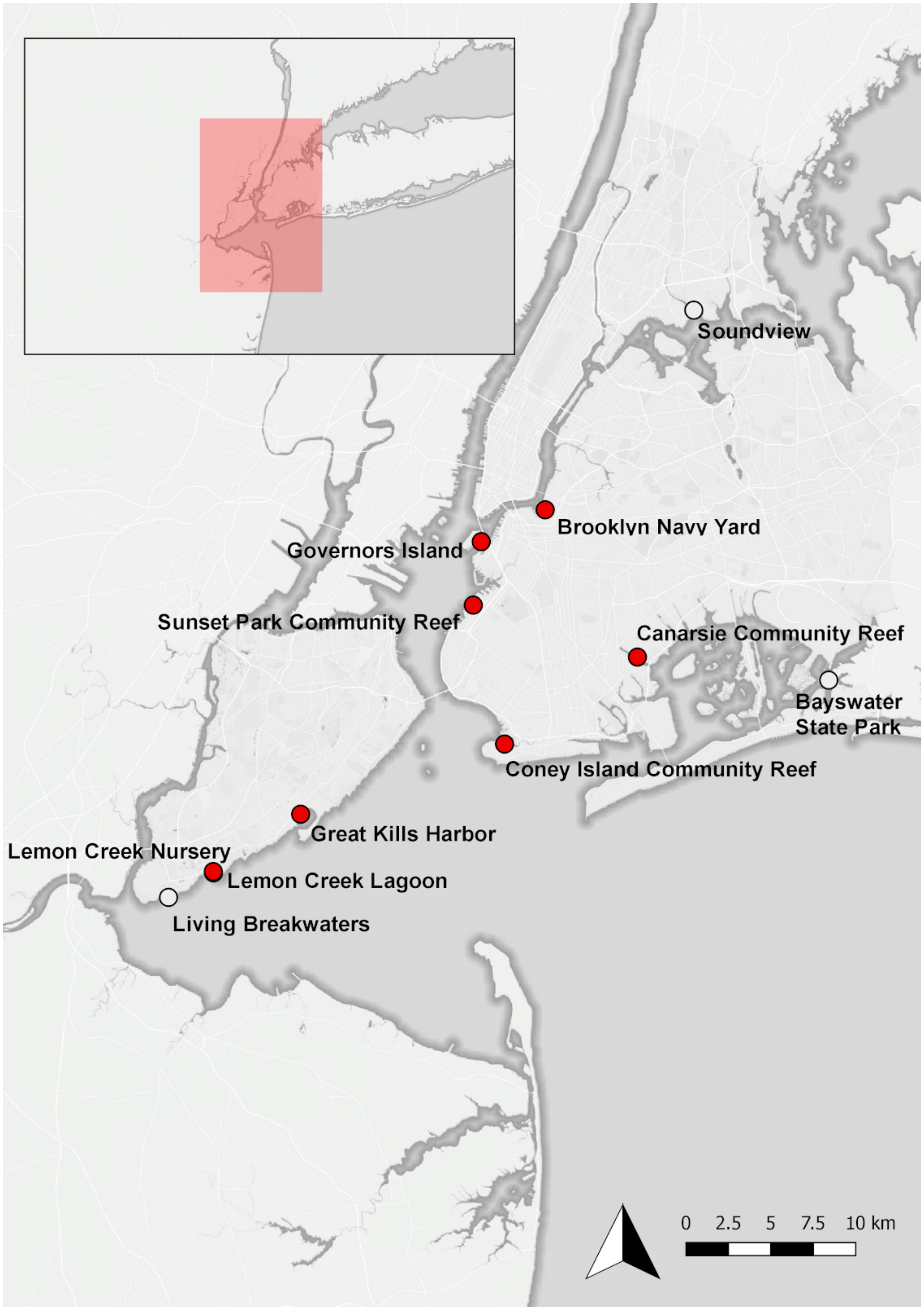


Figure 3. The eight current oyster restoration sites in New York Harbor described in this document are represented by red circles. The three future restoration sites are indicated with white circles.

Figure 4. Examples of structures employed to install oysters: (A) bags, (B) gabions, (C) OysterGros®, (D) community reef files, (E) ECOncrete® discs, and (F) Super Trays.

Performance Metrics

To assess the performance of oyster restoration at each site, several metrics were developed, focusing on oyster survival, growth, disease, and reproduction. These metrics specify qualitative categories that essentially translate to “good,” “moderate,” and “poor” performance. These metrics do not indicate whether the restoration activities are providing ecosystem benefits (e.g., biodiversity enhancement, water quality improvements). Not all metrics can be applied to every site, due to the type of installation, site conditions, age of restoration activity, or other constraints. Some metrics are not relevant in the first 1 to 2 years of restoration. For example, the presence of more than one oyster size class would not be expected immediately at a site where juvenile oysters were installed (unless oyster recruits came from nearby populations). The nine performance metrics are described in Table 2.

Figure 5. This spat-on-shell was set at the BOP hatchery on Governors Island.

Table 2. Performance metrics for oysters at restoration sites

Metric Type	Metric	Explanation	Caveats
Growth	Increase in shell height in first year as spat on shell	Young spat on shell oysters should increase their shell height rapidly in the first year of planting.	Not all restoration activities use spat on shell. In these cases, this success metric will not apply.
	Continued increase in shell height after year 1	Growth rates typically slow down in year 2+, but oysters should continue to increase their shell height.	
	Oysters “reefing” or cementing to each other or gear	As oysters increase in size, they should “reef” or cement to each other and gear.	In some cases, oysters will not cement because 1) they are handled to prevent cementing, as dictated by the gear type, or 2) the site is a high-energy environment (i.e., lots of wave action or current).
Survival	Oyster density stabilizes after initial mortality	As spat, oysters naturally have a high mortality rate. After an initial period of high mortality, survival increases and density of oysters (i.e., number of oysters per clump or number of oysters per m^2) should stabilize.	At some sites, as loose clumps of oysters cement or “reef” together, density measurements will transition from “oysters to clump” to “oysters per m^2.” This will make density comparisons over this period difficult.
Disease	Disease prevalence and intensity are low	Prevalence and intensity of oyster disease (Dermo, MSX) should be low.	Disease testing is not carried out at all sites because 1) disease testing is costly, 2) disease loads are expected to be low in small/young (<1 year old) oysters, and 3) disease testing requires sacrificing oysters (n = 30) at each sampling point.
Reproduction	Gonads developing or spawning	Qualitative or quantitative assessments of gonad condition should show gonads that are ripe and ready to spawn.*	Assessing gonad condition requires sacrificing oysters (n = 30) at each sampling point; therefore, it may not be done at small restoration sites. Small or young oysters do not have conditioned gonads.
	Sex ratios near 50:50	Oysters switch sexes as they grow, with smaller and younger oysters typically being males. Even sex ratios will increase the odds of successful reproduction.	See caveats for the Disease Performance Metric.
	Multiple size classes of oysters present	After 3 or more years, more than one size class of oysters should be present.	Reproduction and recruitment are not expected in the first 1–2 years of restoration at a site. Reproduction may occur at some sites, but due to their hydrodynamic context they may be “source” sites that export larvae elsewhere.
	Juvenile oysters present on unseeded or off-reef structures	Once oysters become reproductive, they may seed nearby structures. The presence of oysters that seeded themselves on nearby structures may indicate suitable conditions for larval survival and transport at that site.	Wildly occurring oysters on nearby substrates may be the offspring of oysters from beyond the site that were transported there.

* See *Reproductive Status* (p. 39) for more information about quantitative assessments.

Assessing Performance at Each Site

The oyster performance metrics were applied to the eight restoration sites. Of those sites, four (Governors Island, Great Kills Harbor, Lemon Creek Lagoon, and Sunset Park) had multiple cohorts or restoration approaches. In those cases, the performance metrics are reported for each cohort or restoration approach. Tables 3 and 4 provide a high-level overview of oyster performance at each site. The remainder of the document reports in greater detail on the data and analyses used to complete this assessment, as well as potential explanatory factors (e.g., water quality, food availability) and pilot efforts to measure the composition and abundance of non-oyster species at select sites.

Table 3. Oyster growth and survival performance metrics at BOP restoration sites

	Growth			Survival
Site	*Increase in shell height in 1st year as spat on shell*	*Continued increase in shell height after year 1*	*Cementing to each other or gear*	*Density stabilizes after initial mortality*
Brooklyn Navy Yard Nursery (2017)	NA (installed as 1+ yr)	**Yes** 56.2 mm (11/2017) 57.1 mm (6/2018) 68 mm (11/2018)	**Light**	NA (insufficient data)
Canarsie - *Community Reef*	**Rapid** 5 mm (8/2018) 39.1 mm (12/2018) *0.25 mm/day*	NA (oysters are <1 year old)	**Yes**	NA (oysters are <1 year old)
Coney Island Creek - *Community Reef*	**Rapid** 5 mm (7/2018) 47.1 mm (11/2018) *0.36 mm/day*	NA (oysters are <1 year old)	**Yes**	NA (oysters are <1 year old)
Governors Island EcoDock (2017)	NA (installed as 1+ yr)	**No** 34.9 mm (4/2017) 69.8 mm (11/2017) 68.7 mm (10/2018)	**Light** High-energy environment	**Declining** 5.5 oysters/clump (4/2017) 4.8 oysters/clump (7/2017) 1.2 oysters/clump (12/2018)
Governors Island EcoDock (2018)	**Slow** 5 mm (8/2018) 15.1 mm (12/2018) *0.09 mm/day*	NA (oysters are <1 year old)	**Light** High-energy environment	NA (oysters are <1 year old)
Great Kills Harbor Nursery [MBSOS] (2016)	NA (installed as 1+ yr)	**Yes** 84.2 mm (11/2017) 81.7 mm (6/2018) 105.3 mm (11/2018)	**Yes** However, oysters were maintained to prevent them from cementing to gear	**Declining** 200 live/tray (6/2018) 162 live/tray (11/2018)
Great Kills Harbor Nursery [GKSOS] (2017)	**Rapid** 4.1 mm (6/2017) 33.5 mm (9/2017) *0.35 mm/day*	**Yes** 44.3 mm (6/2018) 78.0 mm (11/2018)	**Yes** However, oysters were maintained to prevent them from cementing to gear	**Stable** 299 live/tray (6/2018) 287 live/tray (11/2018)

Table 3 (continued). Oyster growth and survival performance metrics at BOP restoration sites

	Growth			Survival
Site	*Increase in shell height in 1st year as spat on shell*	*Continued increase in shell height after year 1*	*Cementing to each other or gear*	*Density stabilizes after initial mortality*
Lemon Creek Lagoon - *ECOncrete®*	**Rapid** 5 mm (8/2018) 45.9 mm (11/2018) *0.47 mm/day*	NA (oysters are <1 year old)	**Yes**	NA (oysters are <1 year old)
Lemon Creek Lagoon - *Gabions*	**Rapid** 5 mm (8/2018) 36.4 mm (11/2018) *0.34 mm/day*	NA (oysters are <1 year old)	**Yes**	NA (oysters are <1 year old)
Lemon Creek Lagoon - *Bagged Shell Reef*	**Moderate** 5 mm (8/2018) 22.8 mm (11/2018) *0.20 mm/day*	NA (oysters are <1 year old)	**No**	NA (oysters are <1 year old)
Lemon Creek Nursery	**Rapid** 4.1 mm (6/2017) 36.6 mm (9/2017) *0.40 mm/day*	**Yes** 36.6 mm (9/2017) 74.8 mm (9/2018)	**Yes** However, oysters were maintained to prevent them from cementing to gear	NA (insufficient data)
Sunset Park - *Bagged Shell Reef*	**Moderate** 5 mm (7/2018) 20 mm (11/2018) 0.17 mm/day	NA (oysters are <1 year old)	**No**	NA (oysters are <1 year old)
Sunset Park - *Community Reef* (2016)	**Rapid** 2 mm (6/2016) 46.9 mm (11/2016)	**Yes** 68.8 mm (9/2017) 68.9 mm (6/2018) 86.5 mm (10/2018)	**Yes**	**Slight decline** 190 live/m^2 (7/2017) 152 live/m^2 (10/2018)
Sunset Park - *Community Reef* (2018)	**Rapid** 5 mm (8/2018) 23.7 mm (10/2018) *0.30 mm/day*	NA (oysters are <1 year old)	**Yes**	NA (oysters are <1 year old)

Table 4. Oyster disease and reproduction performance metrics at BOP restoration sites

<table>
<tr><th></th><th>Disease</th><th colspan="4">Reproduction</th></tr>
<tr><th>Site</th><th>Disease prevalence and intensity
(October)</th><th>Gonad condition scores G1–S4*
(June)</th><th>Even sex ratios
(June)</th><th>Multiple size classes</th><th>Spat on unseeded or off-reef structures</th></tr>
<tr><td>Brooklyn Navy Yard Nursery (2017)</td><td>High
Dermo prevalence: 67%
Dermo lethal intensity: 23%
MSX prevalence: 0%</td><td>Yes
88% developing or spawning</td><td>Skewed Male
Male: 60%
Female: 23%
Undetermined: 17%
(n = 30)</td><td>No</td><td>No</td></tr>
<tr><td>Canarsie - Community Reef (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>Yes</td></tr>
<tr><td>Coney Island Creek - Community Reef (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>Yes</td></tr>
<tr><td>Governors Island EcoDock (2017)</td><td>Moderate
Dermo prevalence: 23%
Dermo lethal intensity: 0%
MSX prevalence: 3%</td><td>Yes
97% developing or spawning</td><td>Skewed Female
Male: 40%
Female: 60%
Undetermined: 0%
(n = 30)</td><td>Some
Qualitative data show some juveniles present</td><td rowspan="2">Yes</td></tr>
<tr><td>Governors Island EcoDock (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>Great Kills Harbor Nursery [MBSOS] (2016)</td><td>High
Dermo prevalence: 87%
Dermo lethal intensity: 13%
MSX prevalence: 3%</td><td>Yes
100% developing or spawning</td><td>~50:50
Male: 58%
Female: 42%
Undetermined: 0%
(n = 30)</td><td>No</td><td rowspan="2">No</td></tr>
<tr><td>Great Kills Harbor Nursery [GKSOS] (2017)</td><td>NA</td><td>NA</td><td>NA</td><td>No</td></tr>
<tr><td>Lemon Creek Lagoon - ECOncrete® (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td rowspan="3">Yes</td></tr>
<tr><td>Lemon Creek Lagoon - Gabions (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>Lemon Creek Lagoon - Bagged Shell Reef (2018)</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>Lemon Creek Nursery (2017)</td><td>NA</td><td>NA</td><td>NA</td><td>No</td><td>No</td></tr>
</table>

* See Table 6 for explanation of gonad condition scores.

Table 4 (continued). Oyster disease and reproduction performance metrics at BOP restoration sites

	Disease	**Reproduction**			
Site	*Disease prevalence and intensity* (October)	*Gonad condition scores G1—S4** (June)	*Even sex ratios* (June)	*Multiple size classes*	*Spat on unseeded or off-reef structures*
Sunset Park - *Bagged Shell Reef* (2018)	NA	NA	NA	NA	
Sunset Park - *Community Reef* (2016)	**Low** Dermo prevalence: 13% Dermo lethal intensity: 3% MSX prevalence: 0%	**Yes** 74% developing or spawning	**Skewed Male** Male: 59% Female: 26% Undetermined: 15% (n = 27)	**No**	**Yes**
Sunset Park - *Community Reef* (2018)	NA	NA	NA	NA	

* See Table 6 for explanation of gonad condition scores.

Figure 6. BOP Community Reefs Regional Manager Tanasia Swift trains community scientists to conduct oyster monitoring protocols at the Coney Island Community Reef.

Oyster Growth

Oyster growth alone is not sufficient to achieve a self-sustaining population, but it is a necessary component for success that can be assessed rapidly following restoration. Rapid growth rates suggest that the oysters at that location are able to reach reproductive maturity quickly. We expect oysters to rapidly increase shell heights within the first few months following installation, and then continue to increase shell heights for the next one to two years, although at a slower rate (Fig. 7).

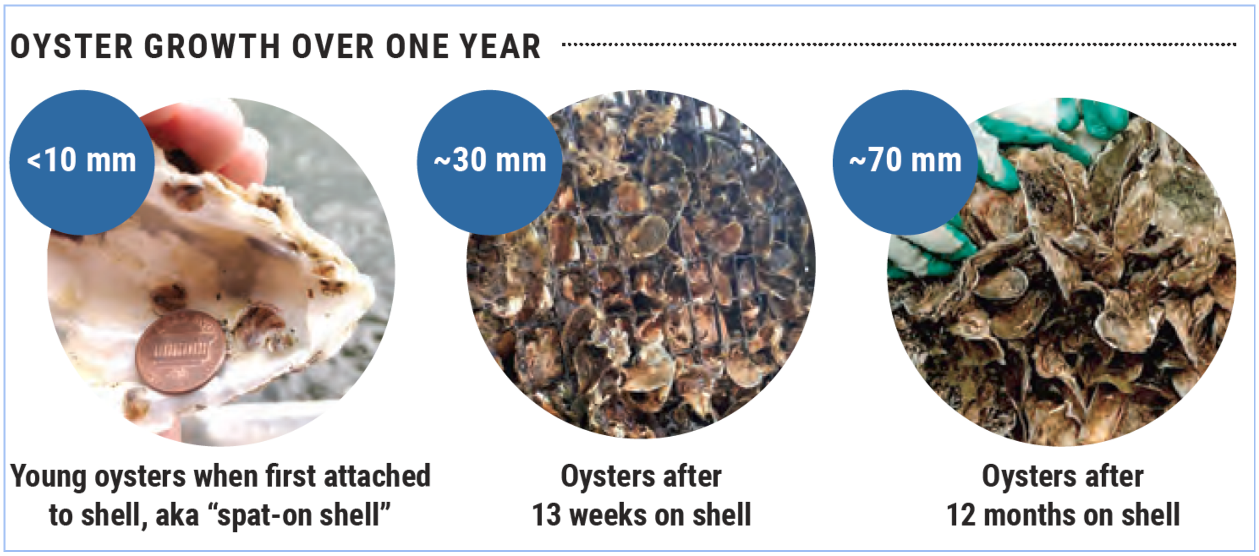


Figure 7. These photos show oyster growth in the first year of restoration at sites with fast growth.

Oyster growth was quantified by measuring change in shell height through time. Shell heights were measured with calipers to the nearest millimeter (Fig. 8). Only the shell heights of live oysters were included in the analysis. The methods for measuring oyster shell height depended on the specifics of the oyster restoration structure and the nature of oyster growth. At some sites, oysters remained in loose clumps and could be separated from each other. At those sites, typically all the individuals in a clump were measured. This method was possible at all sites except for the Canarsie, Coney Island Creek, and Sunset Park Community Reefs and the Lemon Creek Lagoon gabions and ECOncrete® discs.

The oysters often remained in loose clumps because they were grown in aquaculture gear (e.g., Super Trays or OysterGros®) and were handled (i.e., loosely broken up) to maintain the proper function of the gear. In some cases, slow growth rates or a high-energy environment around the oysters may have contributed to their failure to cement to each other.

Figure 8. Field technicians measure oyster growth at Great Kills Harbor.

In other cases, the oysters were cemented to each other or to a substrate, and only the oysters growing at or near the surface were measured. This approach was used for the Canarsie, Coney Island Creek, and Sunset Park Community Reefs and the Lemon Creek Lagoon gabions and ECOncrete® discs.

In the case of ECOncrete® discs, the entire disc surface was surveyed. For gabions, oysters growing out of a single face (i.e., side) were measured. For the community reef files, a 0.1-m^2 quadrat was placed in the center of the broadest side of the file and oysters in that quadrat were measured. For both approaches (i.e., loose clumps of oysters or quadrats), if oyster densities were high, only a subset of 30 randomly selected oysters was measured for each unit (i.e., gabion, shell bag, community reef file), and at least three replicate units were sampled.

Oyster growth was assessed through three performance metrics:

1) Increase in shell height in first year as spat on shell,
2) Continued increase in shell height after year 1, and
3) Oysters "reefing" or cementing to each other or gear.

We opted not to conduct a quantitative comparison of growth rates. Calculating and comparing numerical growth rates (e.g., mm per day) should be done with caution, particularly when the amount of time between sampling dates or the season of sampling dates differed or when the initial size of oysters was unequal. Growth rates are presented in Table 3 to give a general sense of the magnitude of growth in the first year.

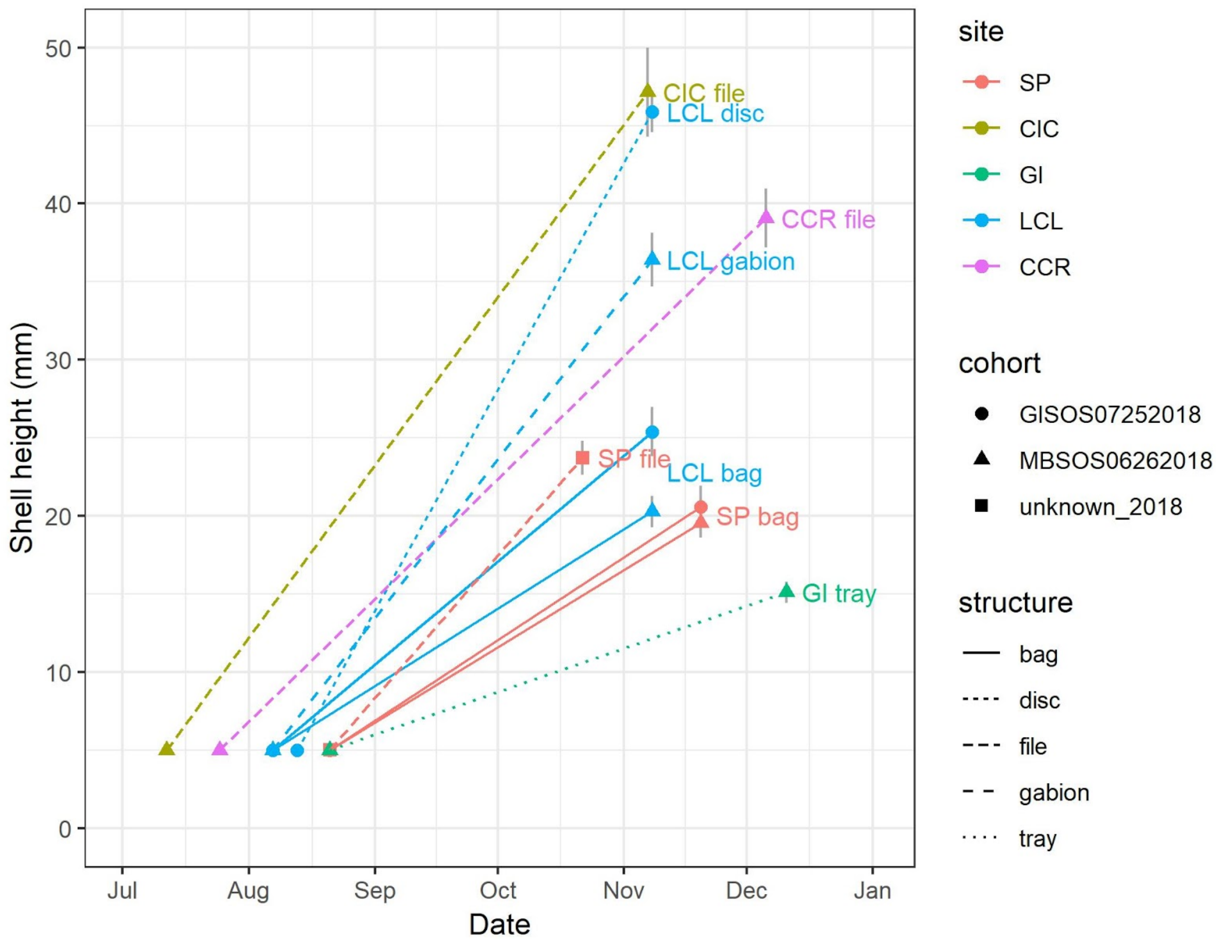


Figure 9. Oyster shell height over time for oysters installed in 2018 at Canarsie Community Reef (CCR), Coney Island Creek (CIC), Governors Island EcoDock (GI), Lemon Creek Lagoon (LCL), and the Sunset Park (SP) Community Reef and bagged shell reef. Error bars indicate 95% confidence intervals. “unknown_2018” cohort is a mix of GISOS07252018 and MBSOS06262018.

Overall, oysters installed in 2018 showed promising growth (Fig. 9). The Canarsie Community Reef (CCR), Coney Island Creek Community Reef (CIC), and Lemon Creek Lagoon (LCL) demonstrated the highest growth rates. At these sites, oyster shell height increased from approximately 5 mm to greater than 35 mm over the course of summer and fall 2018. The Sunset Park bagged shell reef (SP) and Governors Island (GI) grew the slowest.

The methods used to install oysters (Fig. 4) appeared to affect first-year growth rate. At Lemon Creek Lagoon and Sunset Park, oysters installed in bags grew more slowly than those installed in metal cage structures (gabions at LCL or community reef files at SP). In addition, at Lemon Creek Lagoon, oysters set directly on ECOncrete® grew more rapidly than those in other structures.

At all the sites where oysters were installed before 2017, oysters exhibited a continued increase in the average shell height, albeit at a lower rate than during year 1, as expected (Great Kills Harbor, Lemon Creek Nursery, and Sunset Park Community Reef) (Fig. 10).

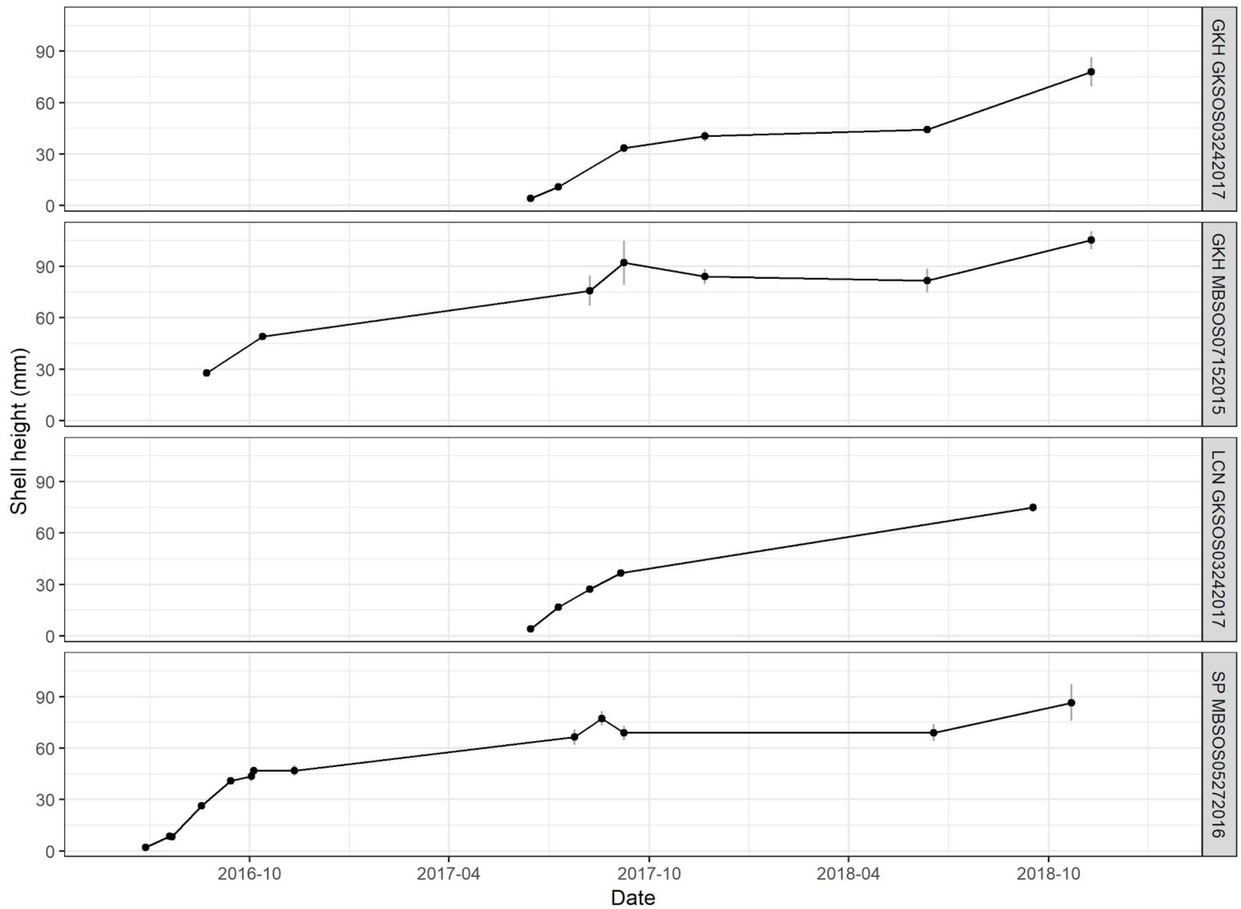


Figure 10. Oyster shell height over time for oysters installed prior to 2018 at Great Kills Harbor (GKH), Lemon Creek Nursery (LCN), and Sunset Park (SP) Community Reef. Error bars indicate 95% confidence intervals.

Size Frequency Distributions

Size frequency distributions (i.e, the number of individuals in a population or sample that fit into different-size bins) allow the viewer to examine the range of sizes of individuals within a population and provide greater detail than a single average size value. Size frequency distributions can also provide information about reproduction and recruitment. We expect a single cohort of oysters of a similar age to have a normal distribution of shell heights (i.e., “a bell curve”) with a single peak and two, nearly symmetrical tails. If there are more than two cohorts (i.e, age groups) of oysters present, then two (not necessarily equal-sized) peaks may be visible.

Although a small number of spat were observed on the adult oysters from the Governors Island EcoDock that were used as broodstock (Fig. 11), no recruitment was observed on restored oysters at any other sites. At all sites, size frequency distributions indicated a single cohort of oysters (i.e., only one “peak”). Figures 13–16 display size frequency distributions at each site. Size distributions can vary according to oyster age, site, and installation type within a site (for instance: bags, gabions, and discs at Lemon Creek Lagoon, Fig. 14).

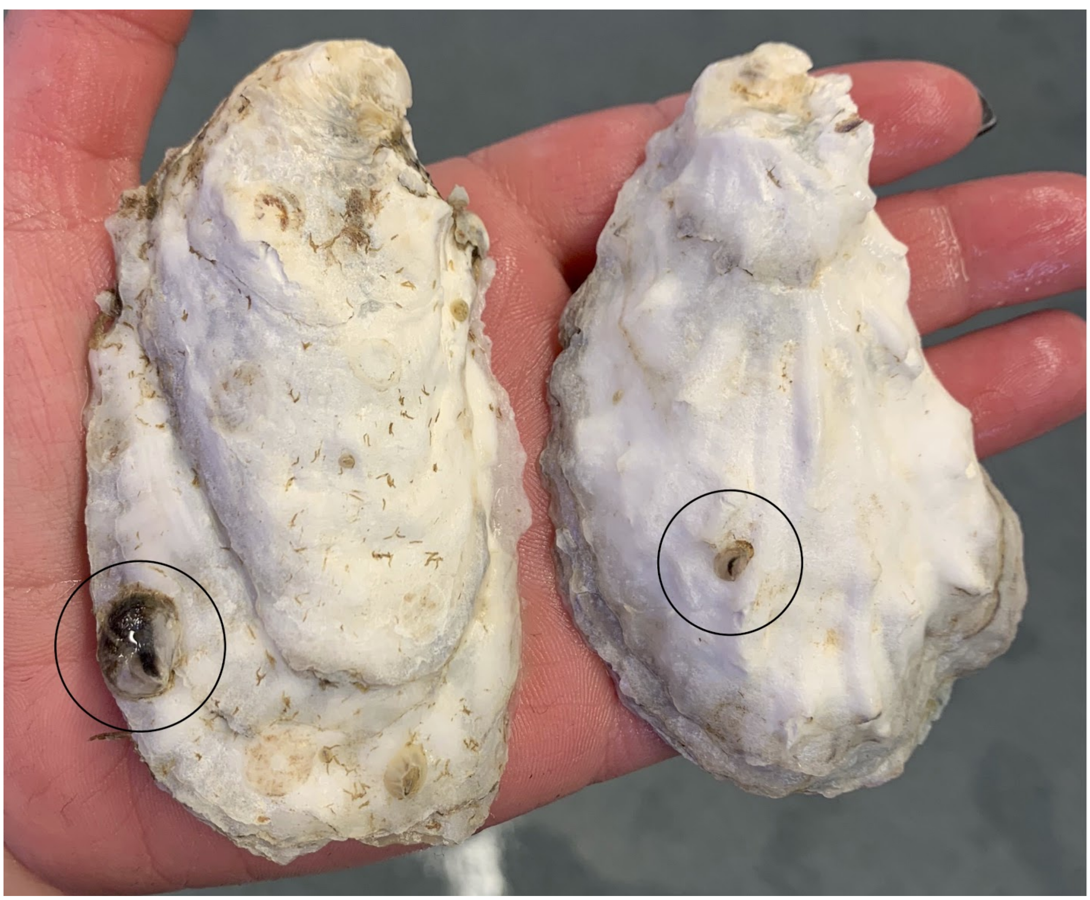


Figure 11. BOP Hatchery Manager, Rebecca Resner, holds adult oysters from the EcoDock that host new oyster recruits (circled).

Figure 12. These oysters grew through the bottom of a community reef file at the Sunset Park Community Reef.

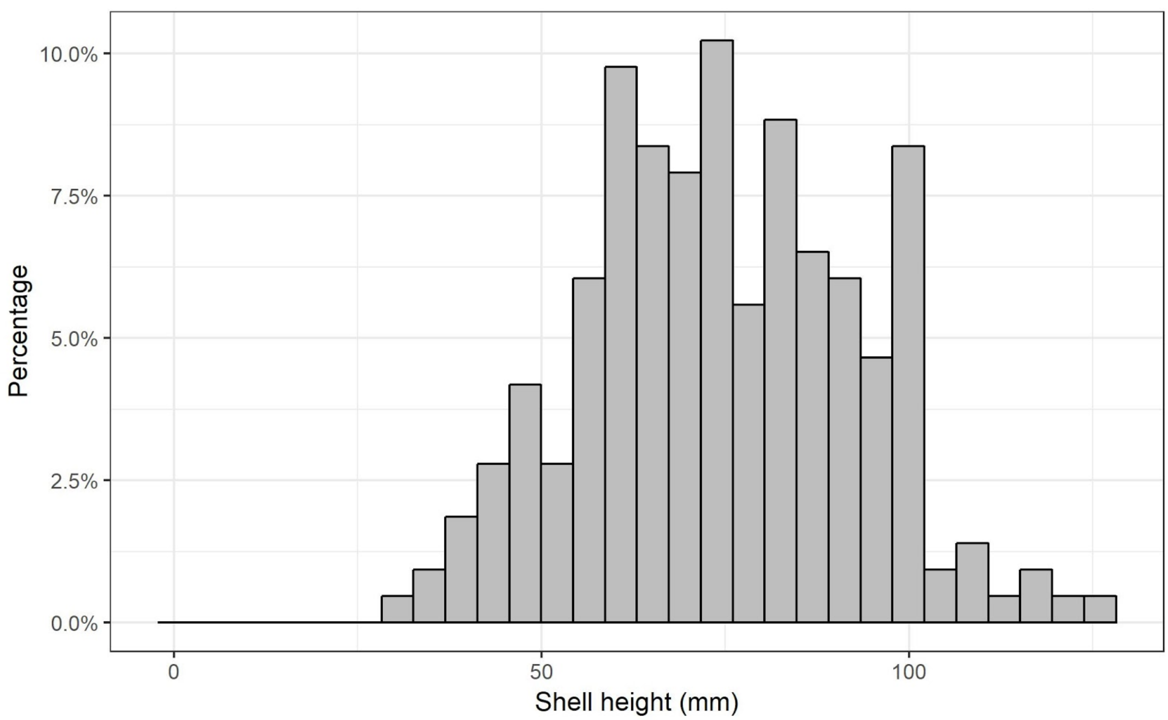


Figure 13. Size frequency distribution of live oyster shell heights at Lemon Creek Nursery in September 2018.

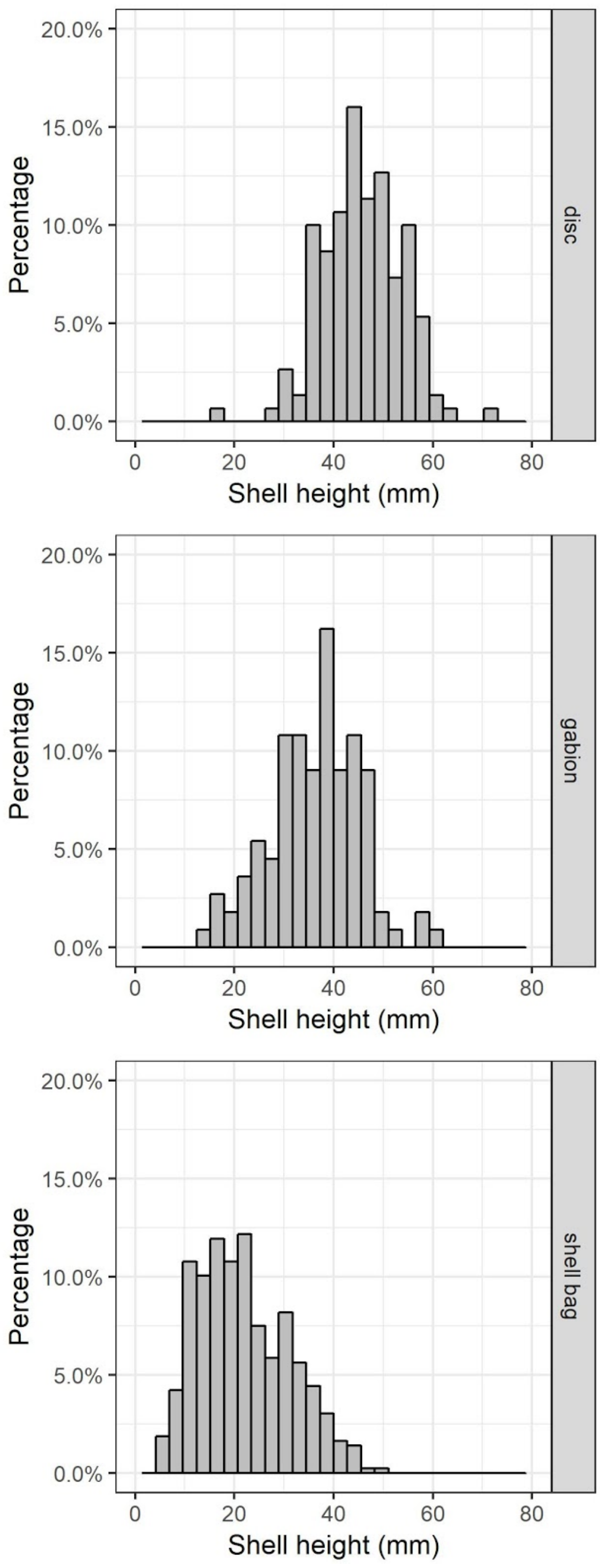


Figure 14. Size frequency distribution of live oyster shell heights on ECOncrete® discs, gabions, and the bagged shell reef at Lemon Creek Lagoon in November 2018.

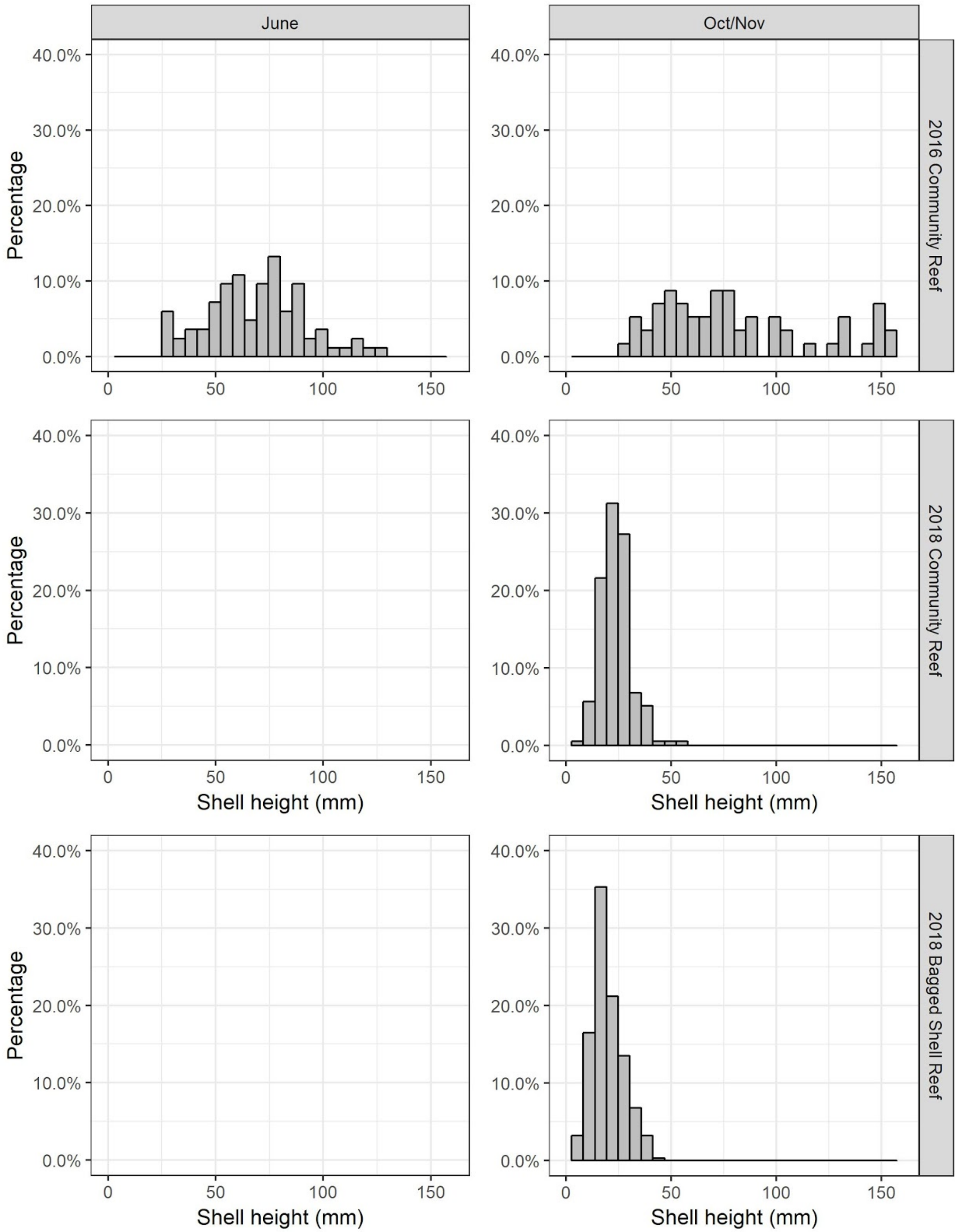


Figure 15. Size frequency distribution of oyster shell heights at Sunset Park in the 2016 community reef (top row), 2018 community reef (middle row), and 2018 bagged shell reef (bottom row) in June and October/November 2018.

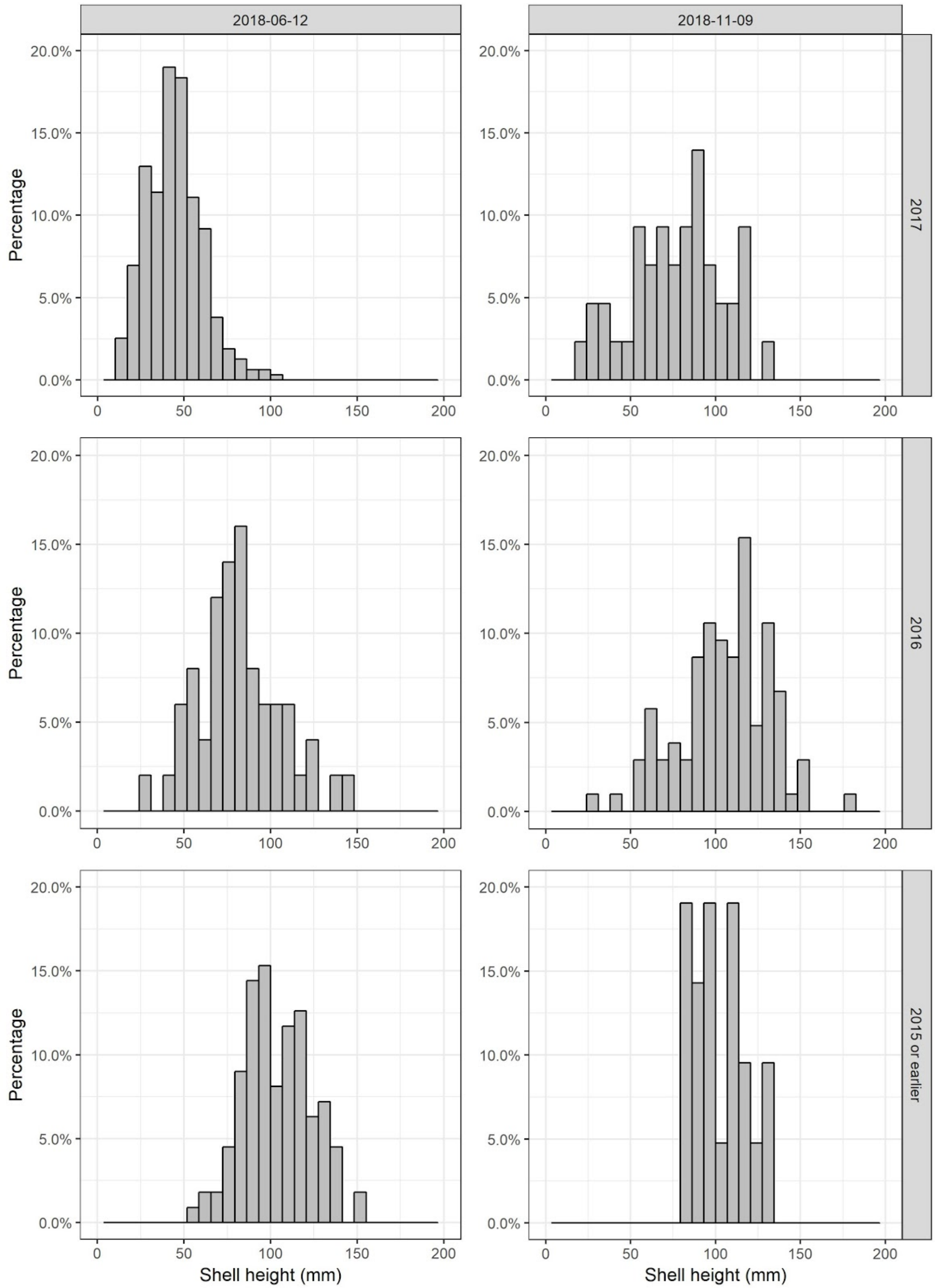


Figure 16. Size frequency distribution of oyster shell heights at Great Kills Harbor in June and November 2018. The top row was installed in 2017, the middle row was installed in 2016, and the bottom row was installed before 2015 in Oyster Research Stations.

Oyster Survival

Like growth, oyster survival is an important metric for understanding the success of oyster restoration, but it can be difficult to track over time. This is particularly true as oyster reefs grow more spatially complex and as new recruits settle to the reef over time.

Oyster survival is determined by measuring changes in oyster density over time. Juvenile oysters must compete for space and resources. As a result, spat grow quickly over the first 1–2 years of life, but they also experience heightened mortality rates during this time. On restored oyster reefs, mortality is expected to be greatest for the first year after installation and to level off over time. Target density for oysters may vary based on the type of installation structure and the type of maintenance that structure may require. Depending on the installation structure (and required level of maintenance), as well as the pace of oyster growth and accretion, density can be measured in one of several ways:

(1) *Live oysters per "clump"*

Typically used for first spat counts prior to installation and for bagged shell reefs in which oysters have not yet grown out through the mesh. This technique was utilized at

- Lemon Creek Nursery
- Lemon Creek Lagoon Bagged Shell Reef
- Sunset Park Bagged Shell Reef

(2) *Live oysters per square meter*

Determined by counting and measuring all live oysters identified within a 0.1-m^2 quadrat. This technique was utilized at

- Canarsie Community Reef
- Coney Island Community Reef
- Lemon Creek Lagoon Gabions
- Sunset Park Community Reef

(3) *Live oysters per tray (or unit volume)*

Used when oysters are stored in installation units of a known volume that are not suitable for overgrowth (such as ECOncrete® discs) and/or are maintained in such a way that breaks oyster "clumps" (such as Super Trays). Because neither live oysters per "clump" nor density (i.e, per square meter) is an accurate indicator in these cases, density is determined using a volumetric approach. This technique was utilized at

- Lemon Creek Lagoon ECOncrete® discs
- Great Kills Harbor Super Trays

Live Oyster Per “Clump”

As anticipated, oysters installed in 2018 experienced heightened mortality over the first few months of deployment, reaching a target density of 1–2 oysters per “clump” in bagged shells at Lemon Creek Lagoon and Sunset Park (Fig. 17). This is consistent with previous findings at the Lemon Creek Nursery (Fig. 18). Results in 2018 for these sites indicate that density has stabilized around 1–2 live oysters per clump.

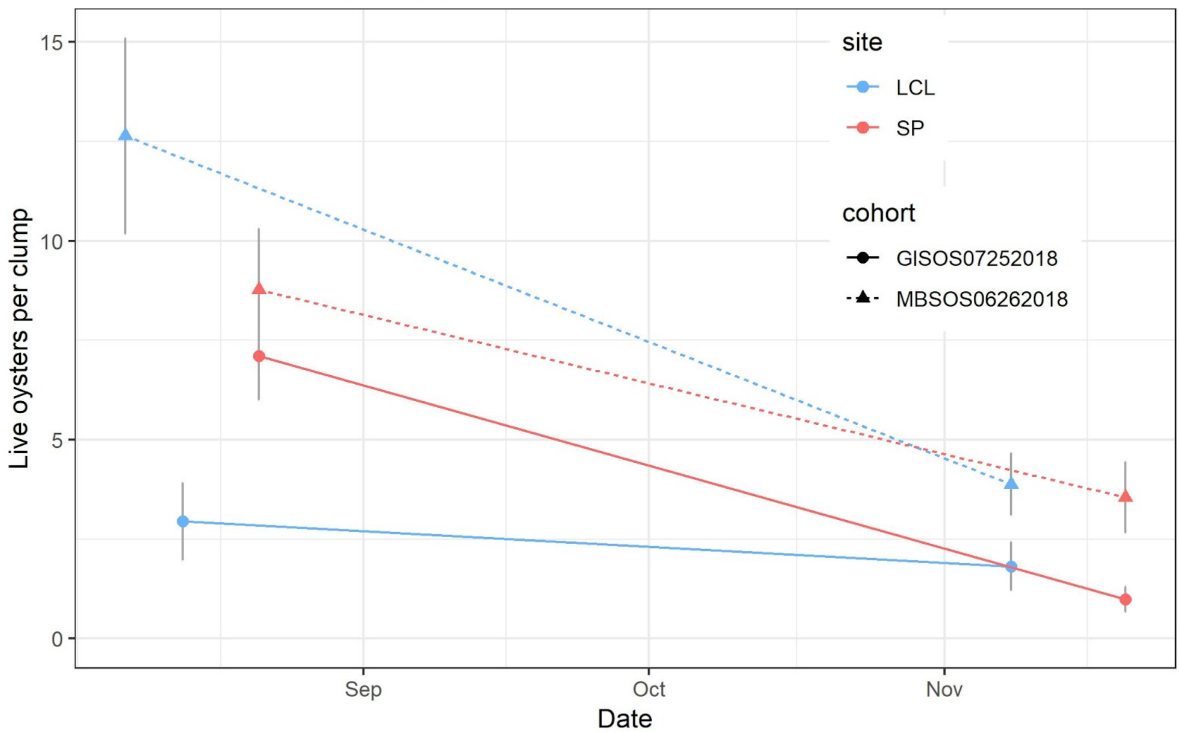


Figure 17. Oyster density (i.e., live oysters per clump) declined over time at bagged shell reefs at Lemon Creek Lagoon (LCL) and Sunset Park (SP) reef at Bush Terminal Park in 2018. Initial densities are measured in the hatchery within one week of deployment. Error bars represent 95% confidence intervals.

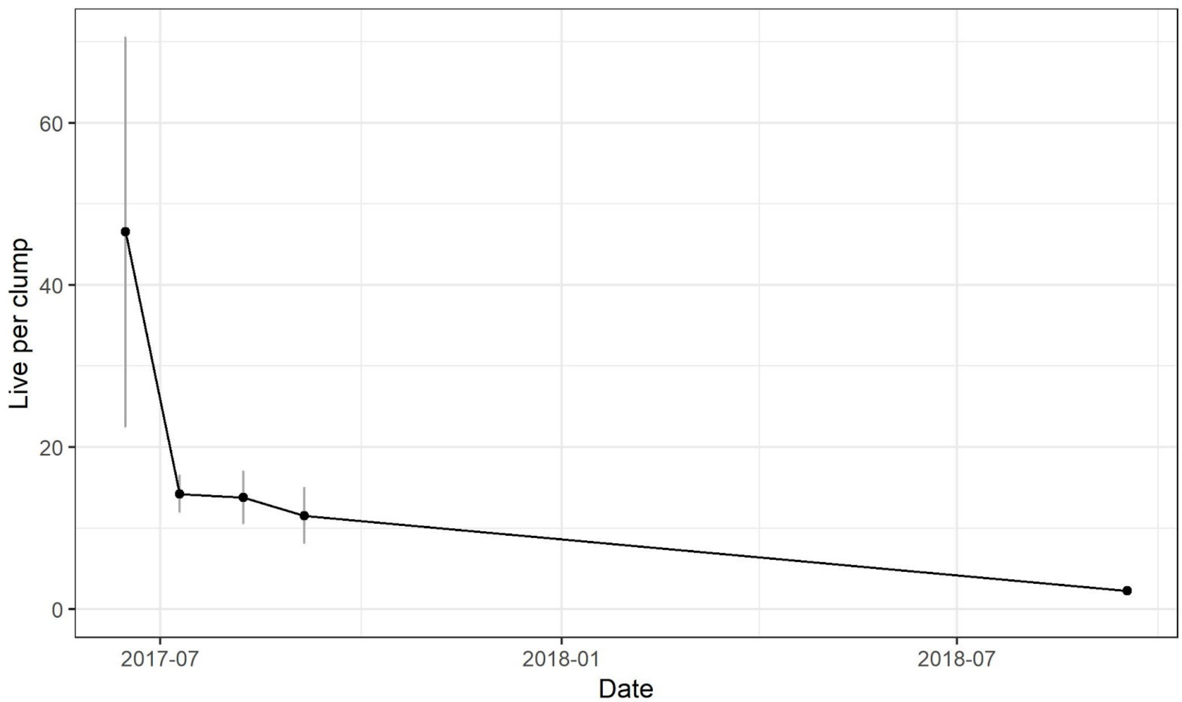


Figure 18. Oyster density (i.e., live oysters per clump) declined over time in Oyster Gros at the Lemon Creek Nursery (LCN) in 2017 and 2018. Error bars represent 95% confidence intervals.

Live Oysters Per Square Meter

Because oysters in community reef files and gabions at the Canarsie Community Reef, Coney Island Community Reef, Lemon Creek Lagoon, and Sunset Park Community Reef grew more quickly and extended through the mesh of their installation structure, mortality rates for these sites cannot be calculated. Densities for these sites (live oysters per square meter) were calculated at the close of the field season (Fig. 19). Density was highest at the Canarsie Community Reef (around 1,200 oysters per square meter) and roughly equivalent in Coney Island, Lemon Creek Lagoon, and Sunset Park (approximately 500 oysters per square meter). The variation in measurements at the Canarsie Community Reef was high, which could contribute to its seemingly higher density value at this site. Oyster density estimates at the Sunset Park Community Reef that was installed in 2016 were variable, with values seemingly lower in June 2018 than October 2018 (Fig. 20). This result is likely due to the fact that oysters are distributed patchily on the community reef file.

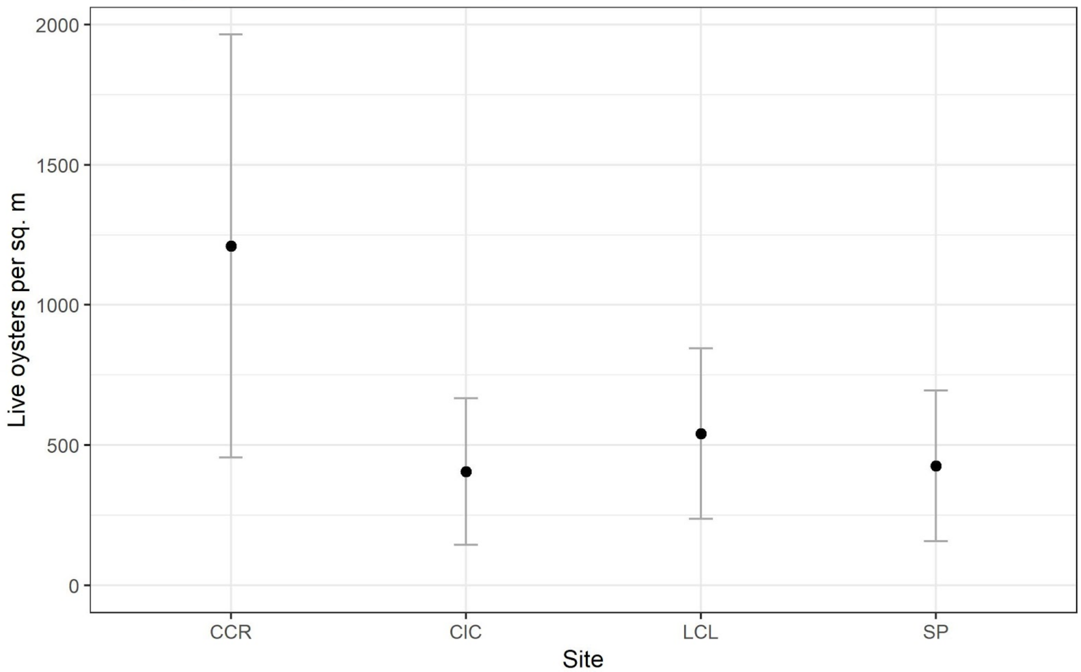


Figure 19. Oyster density (live oysters per square meter) at community reefs and gabions that were newly installed in 2018 (CCR: Canarsie Community Reef, CIC: Coney Island Community Reef, LCL: Lemon Creek Lagoon, SP: Sunset Park Community Reef). Oysters were deployed between July 12 and August 21, 2018, and oyster measurements were taken between October 22 and December 6, 2018. Error bars represent 95% confidence intervals.

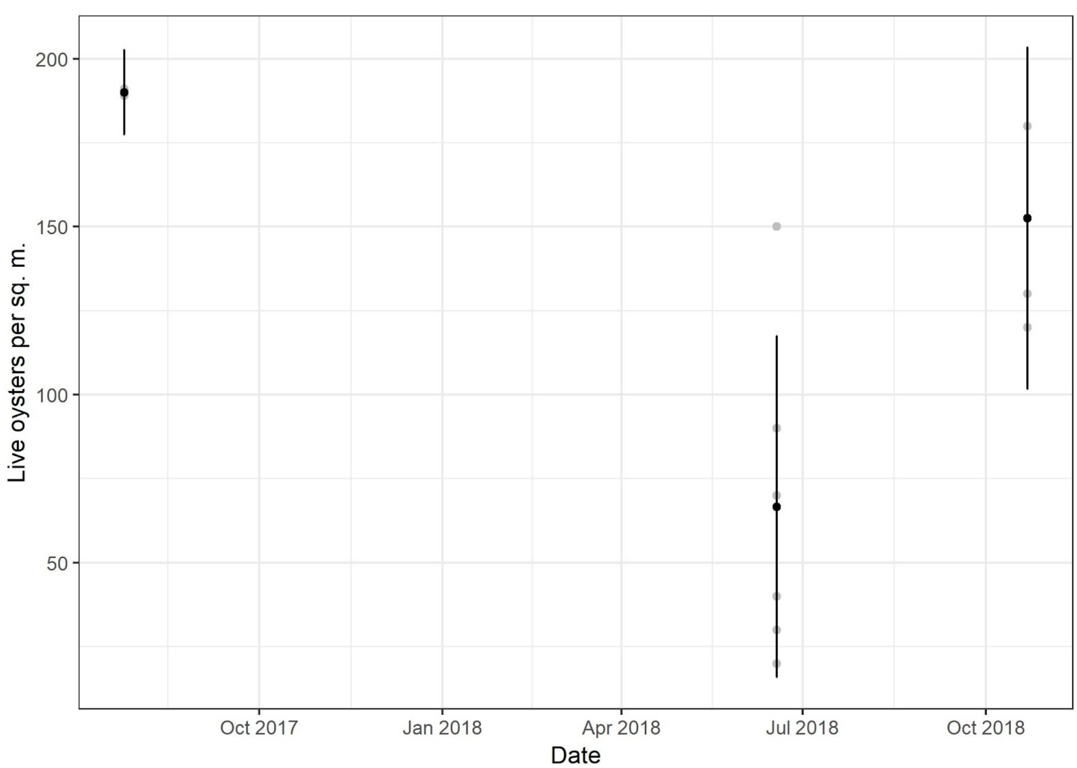


Figure 20. Oyster density (live oysters per square meter) at the Sunset Park Community Reef installed in 2016. Grey points represent individual data points. Black points are average values for each date. Error bars represent 95% confidence intervals.

Live Oysters Per Unit Volume

Seasonal density measurements on the ECOncrete® discs suggest low mortality during their first season (Fig. 21). Discs set with low density (5,000 larvae per disc added to the setting tanks in the Hatchery) hosted approximately 8 oysters, while high-density discs (10,000 larvae per disc) hosted approximately 45 oysters. At Great Kills Harbor, there were no observable changes in density over the course of the season across all three monitored cohorts (Fig. 22). However, this likely reflects management at this site rather than low mortality.

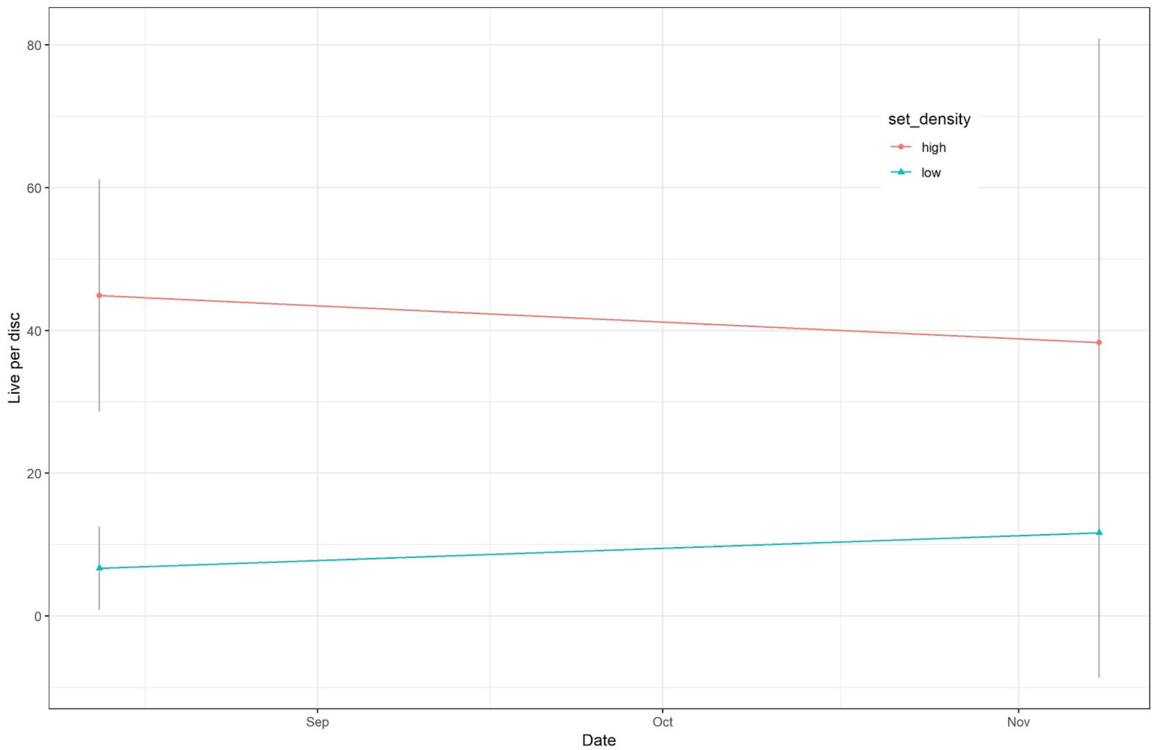


Figure 21. Oyster density (live per disc) on ECOncrete® discs at the Lemon Creek Lagoon changed little in 2018. “set_density” indicates discs that were set with low or high densities of larvae in the Hatchery. Error bars represent 95% confidence intervals.

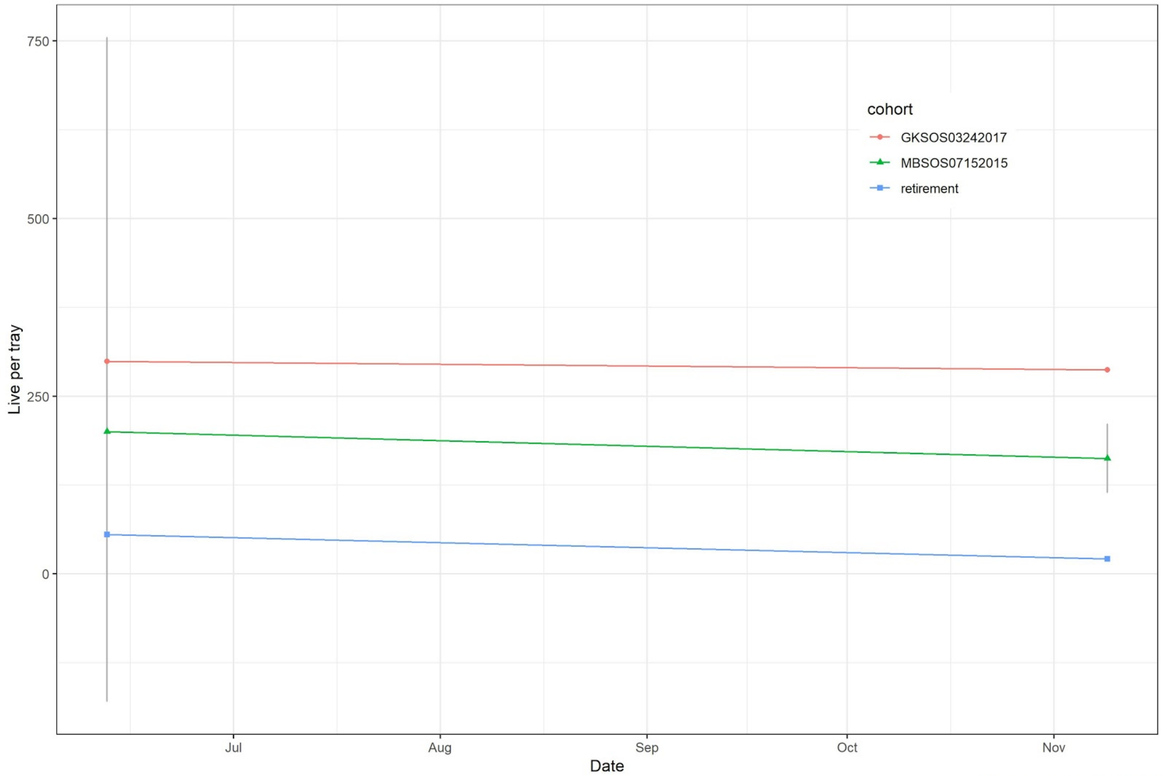


Figure 22. Oyster density (live per tray) in Super Trays at Great Kills Harbor changed little in 2018. Error bars represent 95% confidence intervals.

Disease

Dermo (*P. marinus*) and MSX (*Haplosporidium nelsoni*) are parasitic protozoan diseases that can infect oysters, with detrimental effects. In June and October 2018, oysters (n = 30) were collected from Brooklyn Navy Yard, Governors Island EcoDock, Great Kills Harbor (2016 installation) and Sunset Park Community Reef and sent to Dr. Bassem Allam at the Stony Brook University Marine Animal Disease Laboratory (SBU MADL) for disease diagnostics. Dermo diagnosis was made using FTM (fluid thioglycollate medium) on mantle and rectal tissues. MSX diagnosis was made using histopathology on formalin-fixed sections. SBU MADL also provided data on shell height, condition index, stage of gonad development, and sex ratio (see below). Samples from June were assumed to best represent the reproductive status of oysters, and samples from October represented the maximum disease loads.

“Prevalence” refers to the percentage of the population that tests positive for a given disease. “Intensity” refers to the degree to which an individual oyster is infected with a given disease. 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 intensity is reported as “low,” “medium,” or “high.”

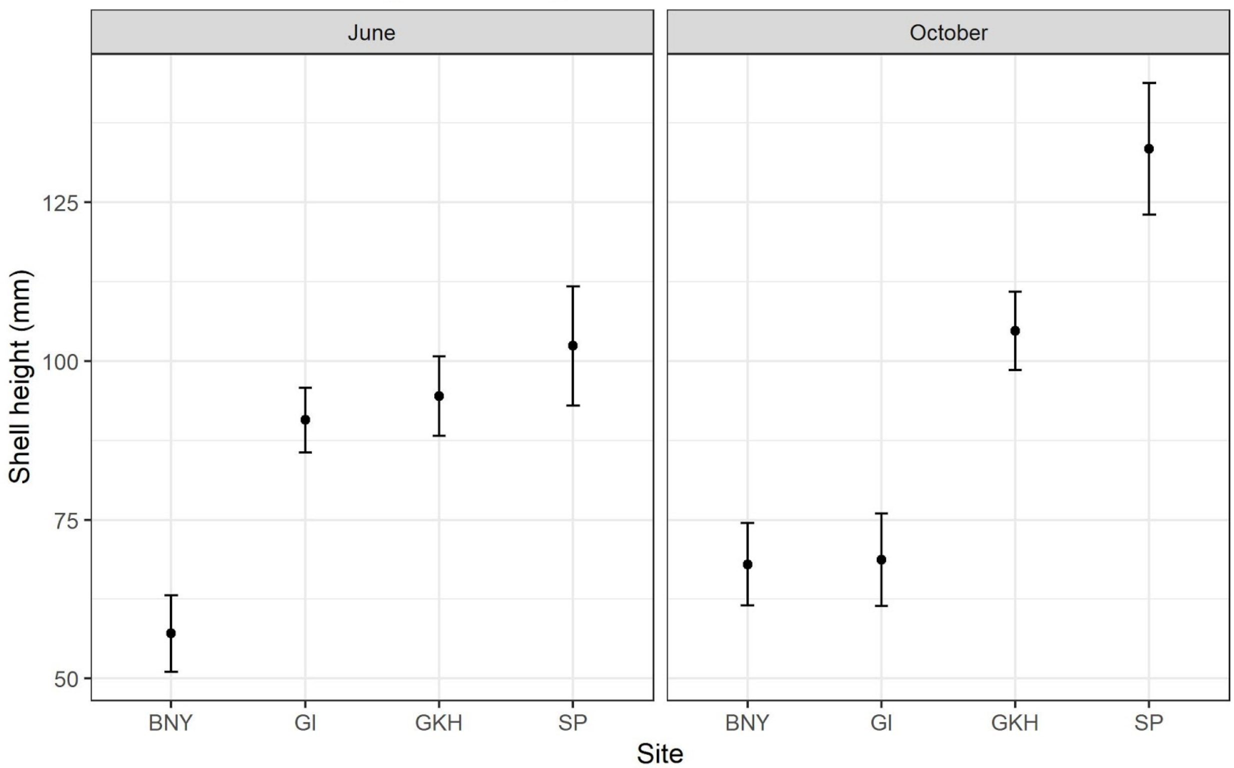


Figure 23. Shell heights of oysters sampled from Brooklyn Navy Yard (BNY), Governors Island EcoDock (GI), Great Kills Harbor (GKH) MBSOS07152015 cohort installed in 2016, and the Sunset Park (SP) Community Reef in June and October (n = 30 oysters from each site, except n = 27 for SP). Error bars represent 95% confidence intervals.

MSX (*H. nelsoni*)

Overall, MSX prevalence was low at all sites. No oyster samples from the Brooklyn Navy Yard (BNY) nor the Sunset Park Community Reef (SP) were found to be infected with MSX in June or October (Table 5). Although prevalence was low at the Governors Island EcoDock (GI: 1 out of 30 oysters in October) and the floating oyster nursery at Great Kills Harbor (GKH: 1 out of 30 oysters in both June and October), infection intensity was potentially lethal at these sites (high at GI and medium at GKH).

Table 5. MSX (*H. nelsoni*) prevalence and intensity at Brooklyn Navy Yard (BNY), Governors Island EcoDock (GI), Great Kills Harbor (GKH) MBSOS07152015 cohort installed in 2016, and the Sunset Park (SP) Community Reef in June and October 2018 (n = 30 oysters per site, except n = 27 for SP in June).

	June		October	
Site	**Prevalence (%)**	**Intensity**	**Prevalence (%)**	**Intensity**
BNY	0%	--	0%	--
GI	0%	--	3.33%	High
GKH	3.33%	Medium	3.33%	Medium
SP	0%	--	0%	--

Dermo (*P. marinus*)

Dermo prevalence and intensity varied greatly by site. In October (when infection is anticipated to be highest), the Brooklyn Navy Yard and Great Kills Harbor demonstrated high infection rates (67% at BNY and 87% at GKH) (Fig. 24). In addition, a large proportion of these oysters (23% at BNY and 13% at GKH) were found to have a lethal infection intensity (scoring 3 or higher on the Mackin scale). Of particular concern, Great Kills Harbor was even found to host lethal infections of Dermo (a maximum Mackin scale ranking of 5) in June. These high infection rates indicate that both restored populations at the Brooklyn Navy Yard and Great Kills Harbor are experiencing disease-related mortality events. Dermo infection intensities were moderate at the Governors Island EcoDock (23%) and low at the Sunset Park Community Reef (13%). Only one (3%) oyster was found to have a potentially lethal Dermo infection (ranking of 3) at the Sunset Park Community Reef.

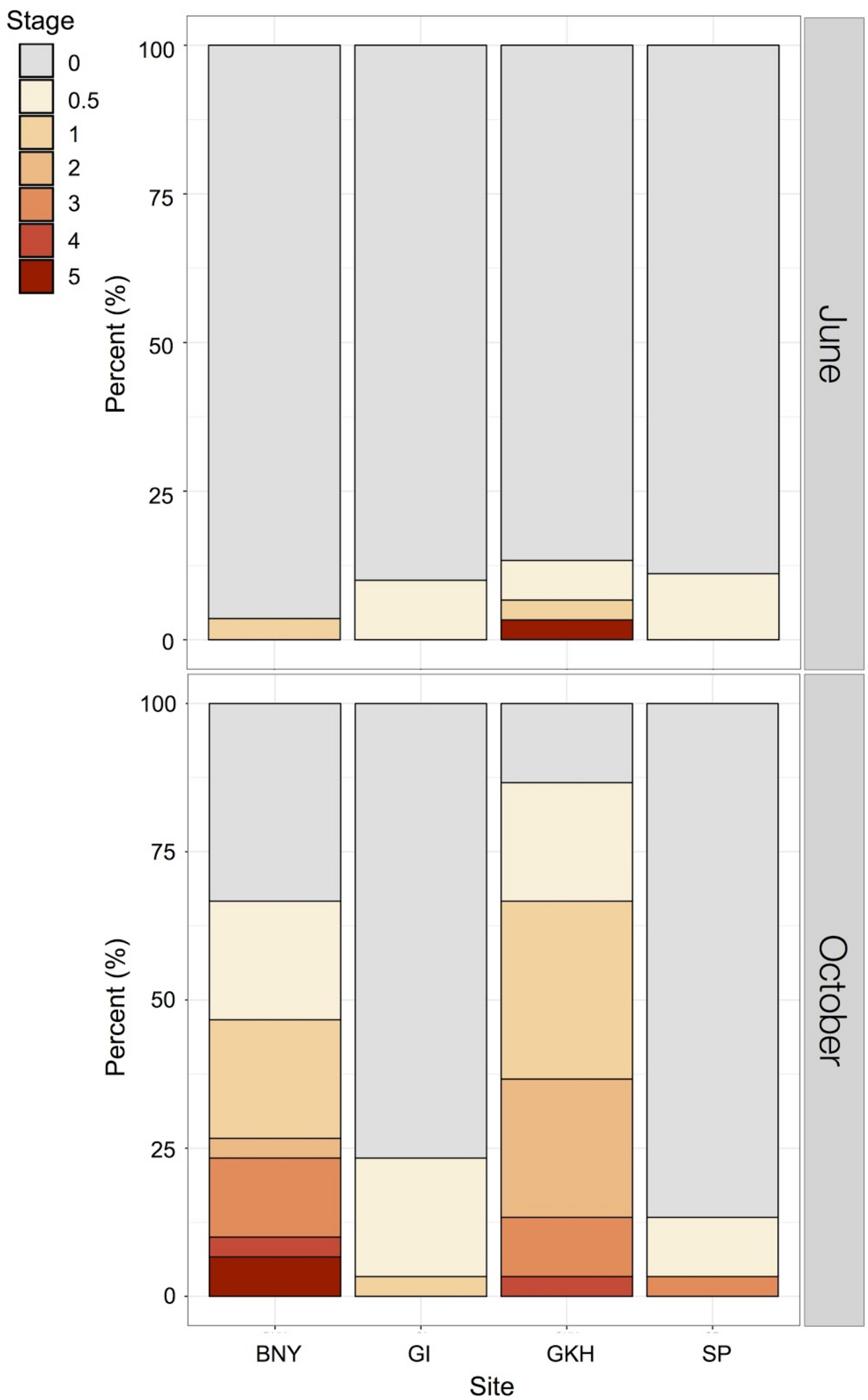


Figure 24. Dermo (*P. marinus*) prevalence and intensity in oysters from Brooklyn Navy Yard (BNY), Governors Island EcoDock (GI), Great Kills Harbor (GKH) MBSOS07152015 cohort installed in 2016, and the Sunset Park (SP) Community Reef in June and October 2018 (n = 30 oysters per site, except n = 27 for SP in June). Oysters with intensities ranking 3 or higher are considered to be lethally infected.

Reproductive Status

Monitoring the reproductive status of adult oysters provides us with information about the reproductive timing and capability of a restored oyster population. Oysters have separate sexes and can switch sex (male to female) at the time of sexual maturity (typically ~2 years after settlement). In addition, oysters maintain gonads to produce gametes (eggs and sperm) only during warmer seasons when they are preparing to spawn. Because of these factors, we were able to assess an oyster's (1) sexual maturity and (2) readiness to spawn by determining their stages of reproductive development (Table 6) and to assess the population's long-term capacity to grow by determining its sex ratio.

The reproductive status and sex ratio of oysters from Brooklyn Navy Yard, Governors Island EcoDock, and Great Kills Harbor (MBSOS07152015 cohort, installed in 2016) were measured in June and October 2018. As stated previously, we expected the June samples to provide the best understanding of reproductive status across sites, whereas samples were analyzed for October primarily for the disease results, with reproductive status at that time as a secondary interest.

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. Oysters in inactive (I) or undetermined (U) stages are either not ready to spawn or have recently spawned (Fig. 25). Since oysters can change sex from male to female, equivalent (50:50) or female-skewed sex ratios indicate that a population has reached sexual maturity and that conditions are optimal for successful fertilization.

The results of the reproductive status assessments at all four sites were promising (Fig. 26). At all four sites, close to 75% or more of the oysters had developing gametes or were actively spawning in June 2018, with Great Kills Harbor and Governors Island having the highest percentage of gonad conditions scores between G1 and S4 (100% and 97% for the two sites, respectively). These two sites also had sex ratios that were near 50:50 or skewed slightly to female. This result is promising because the presence of eggs is more important for successful fertilization than the presence of sperm. Brooklyn Navy Yard and Sunset Park had slightly lower percentages of oysters with gonad condition scores between G1 and S4 (88% and 74% respectively), and sex ratios were skewed slightly to male. As expected, the results from October showed that most oysters had inactive or undetermined gametes or only residual gametes remaining following spawning (S4).

Table 6. 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

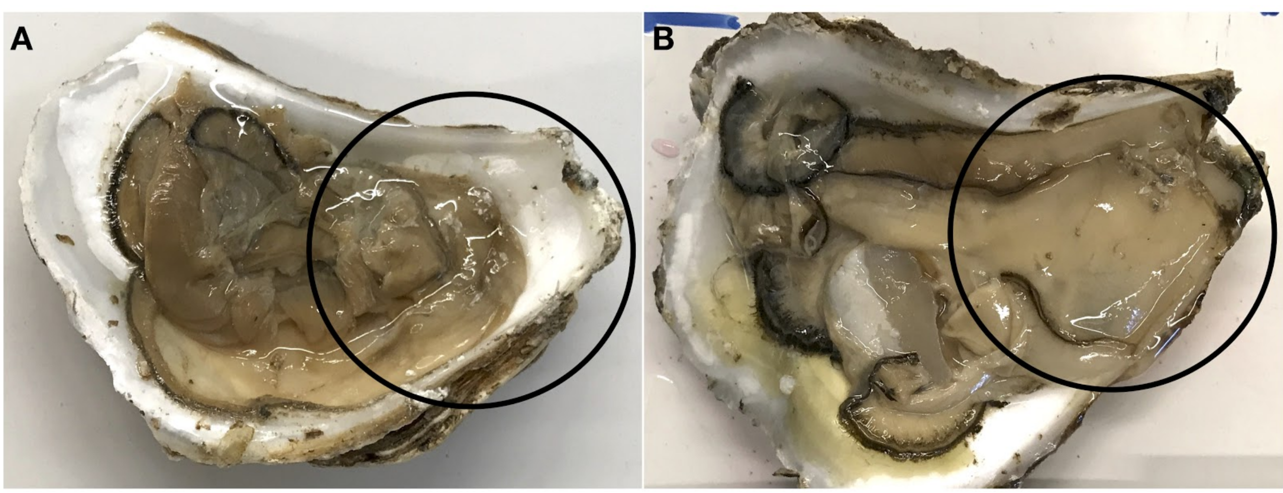


Figure 25. These pictures compare gonad development (circled) in (A) inactive or “unripe” and (B) “ripe” oyster tissue.

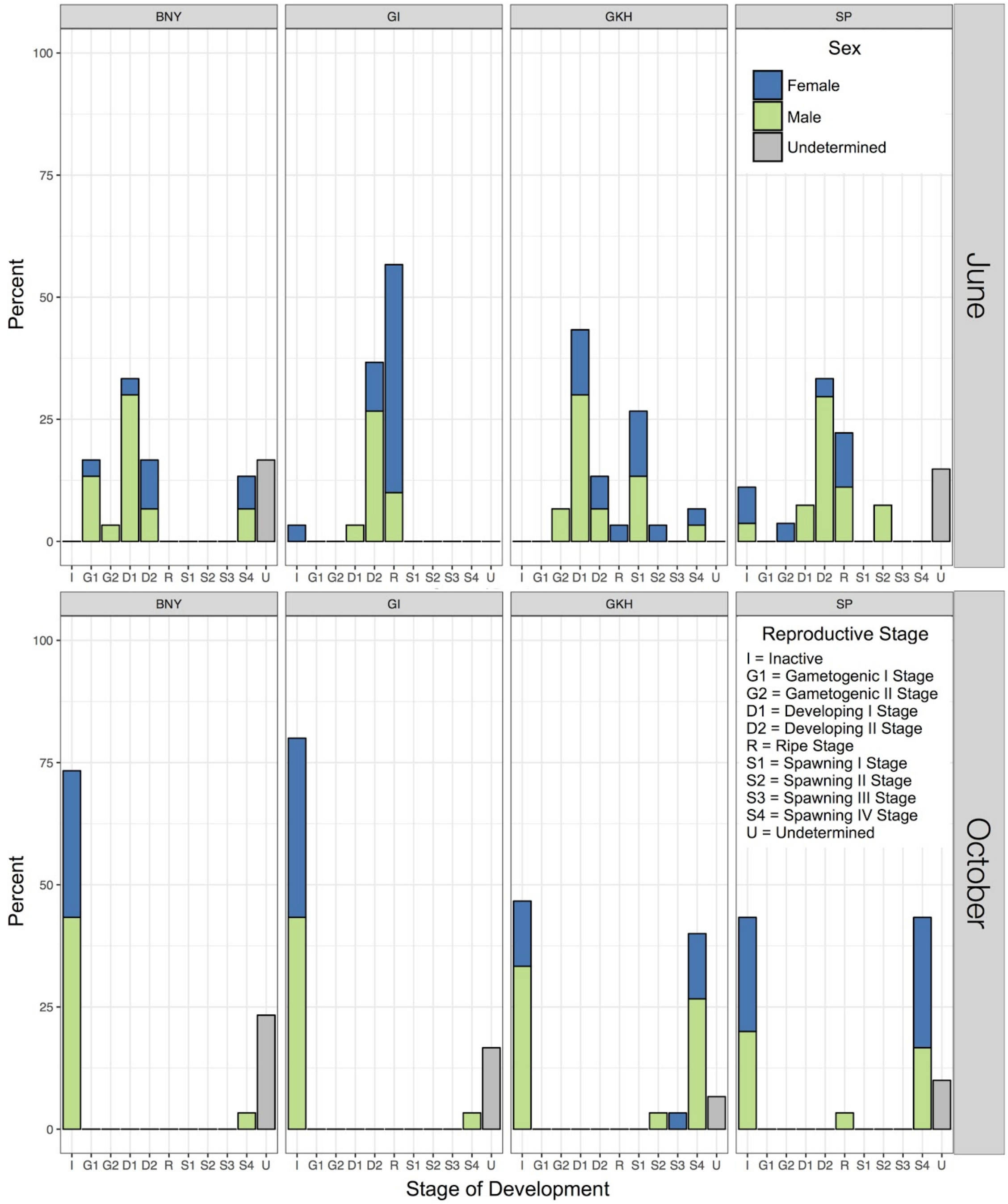


Figure 26. Stage of reproductive development and sex of oysters from Brooklyn Navy Yard (BNY), Governors Island EcoDock (GI), and Great Kills Harbor (GKH) MBSOS07152015 cohort (installed in 2016) in June and October 2018 (n = 30 oysters from each site). Sexual maturity generally increases from left to right, but see Table 6 for a full description of the reproductive stages.

Condition Index

The condition index of oysters from the Brooklyn Navy Yard, Governors Island EcoDock, Great Kills Harbor (2016 installation), and the Sunset Park Community Reef was measured in June and October 2018. Condition index was calculated as (dry mean weight / dry shell weight) x 100. Other condition indices for oysters exist and many are used in commercial production, with higher values indicating higher quality oysters (i.e., 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 condition index can indicate spawning or other events. These results provide a snapshot of condition index across sites.

For the four sites sampled in 2018, Great Kills Harbor had the highest value condition index (5.09, SD = 1.21, n = 30) in October (Fig. 28). For all sites, except for the Governors Island EcoDock, condition index was greater in October than in June. The higher October condition index at Great Kills Harbor and the Sunset Park Community Reef, in addition to the large proportion of oysters still in the S3 and S4 stages, suggest a later season spawn at these sites. It is likely that a younger cohort of oysters was sampled from the Governors Island EcoDock in October. This is supported by the lower shell height for the October oysters (Fig. 23). Although the Sunset Park Community Reef oysters had a greater shell height (133.4, SD = 27.7, n = 30) than the Great Kills Harbor oysters in June 2018 (104.7, SD = 16.5, n = 30), their lower condition index (3.73, SD = 1.12, n = 30) indicated that they were much “thinner” than Great Kills Harbor oysters (Fig. 27). As observed in the previous year’s monitoring report (McCann 2018), the Sunset Park oysters continue to resemble the “long and thin” growth morphology of wild oysters in other regions, such as the Carolinas and Virginia, where oysters grow intertidally and increase their shell height rapidly as a result of intraspecific (i.e., within species) competition for food.

Figure 27. (A) Thinner morphology oysters growing through files at the Sunset Park Community Reef, and (B) thicker morphology oysters collected from an Oyster Research Station at the Canarsie Community Reef.

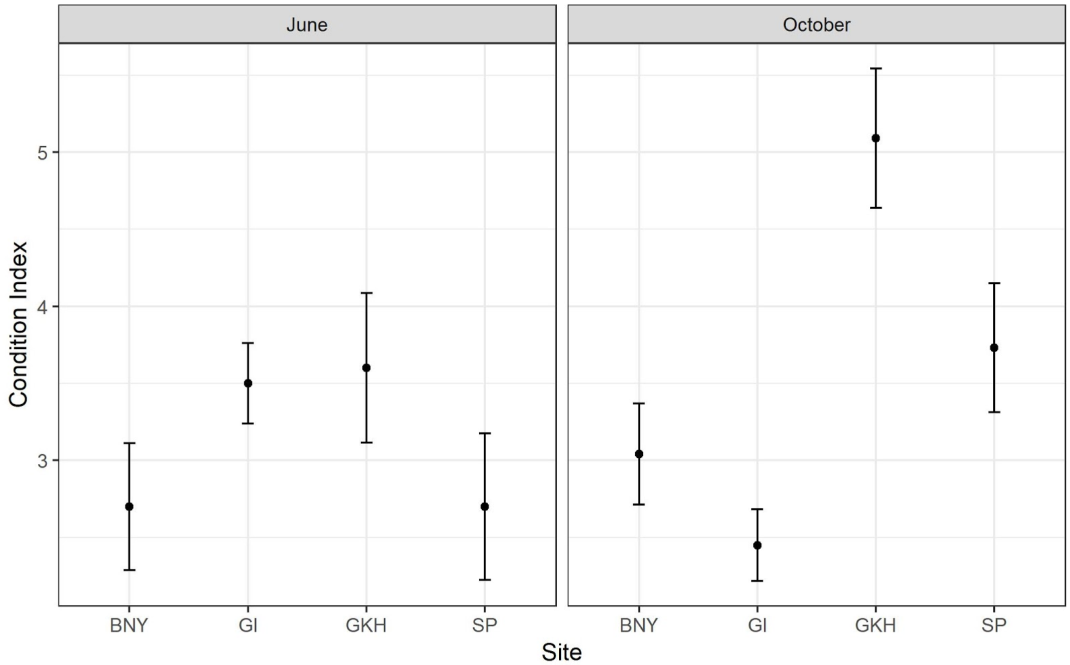


Figure 28. Condition index of oysters from Brooklyn Navy Yard (BNY), Governors Island EcoDock (GI), Great Kills Harbor (GKH) MBSOS07152015 cohort, and Sunset Park (SP) Community Reef in June and October (n = 30 oysters from each site, except n = 27 for SP and n = 28 for BNY in June). Error bars represent 95% confidence intervals.

Figure 29. Adult oysters (installed in 2016) collected for disease and reproduction testing in October 2018 at Great Kills Harbor.

Recruitment

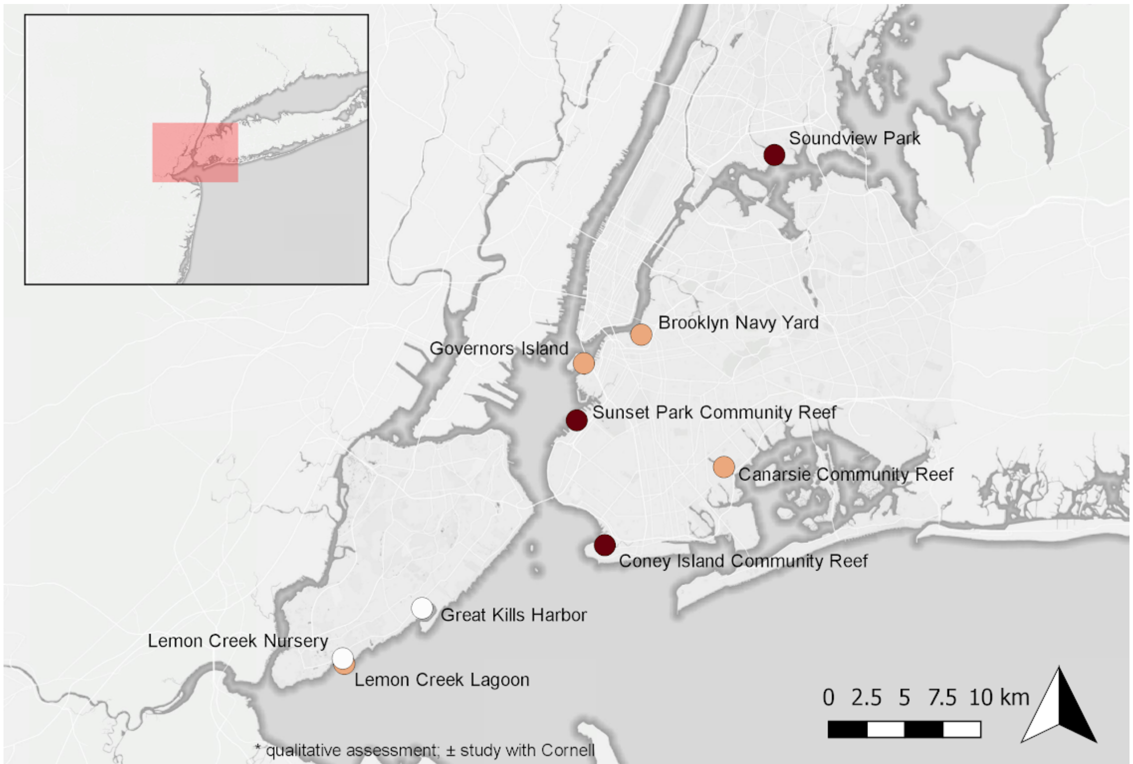
One of the performance metrics listed in Table 4 is "Spat on unseeded or off-reef structures." The presence of juveniles or "recruits" is a positive sign for restoration (Fig. 30). Although there is no guarantee that the young oysters are the offspring of the oysters restored at that site, the presence of recruits is promising because it indicates that conditions are suitable for larval survival and transport at that site. For example, the juvenile oysters observed on intertidal rocks at Coney Island Creek were not the offspring of the oysters restored at that site, which were less than one year old and not reproductively mature. Regardless, their presence indicates that a source population is nearby and that conditions at the site are suitable for larvae.

Figure 31 reports the presence and relative strength of recruitment at the restoration sites. These results come from a variety of sources, including informal surveys of substrates adjacent to the restored reef or nursery (e.g., intertidal rip-rap, bulkheads) or survey of "unseeded" restoration structures (e.g., ECOncrete® discs or bagged shell that were not set with oysters in the hatchery). Some of the blank shell bags were deployed as part of a larger, Harbor-wide study with Dr. Matt Hare of Cornell University. These assessments complement the examination of size frequency distributions that looked for the presence of a second size class of oysters as an indication of recruitment.

Of the sites reported in Figure 31, Coney Island Creek, Sunset Park, and Soundview[2] had the greatest amount of recruitment. Great Kills Harbor and the Lemon Creek Nursery were the only sites where recruitment was not observed in 2018.

Figure 30. (A) Wild oyster recruits, along with barnacles and anemones, on intertidal rocks adjacent to the Coney Island Community Reef in summer 2018 (Swiss Army multitool for size comparison), and (B) wild oyster recruits seen at West Harlem Piers Park at 125th Street in Manhattan.

[2] Soundview is a forthcoming BOP restoration site.



Site	Recruitment	Substrate	Dates Deployed	Recruitment?
BNY	Light	Intertidal bulkhead *	NA	Yes
CCR	Light	Blank shell in cage	Jul - Dec 2018	Yes
		Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal pilings, rocky & soft substrate *	NA	No
CIC	Extensive	Blank shell in cage	Jul - Nov 2018	Yes
		Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal rocky substrate *	NA	Yes
GI	Light	Intertidal pilings*	NA	No
		Oysters growing in Super Trays	NA	Yes
GKH	None	Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal pilings *	NA	No
LCL	Light	ECOncrete disc	Aug - Nov 2018	Yes
		Blank shell in bag	Aug - Nov 2018	No
		Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal rocky substrate *	NA	No
LCN	None	Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal pilings & soft substrate *	NA	No
SP	Extensive	Blank shell in cage	Jun 2016 - Oct 2018	No
		Blank shell in cage	Aug - Oct 2018	No
		Blank shell in bag ±	Aug - Oct 2018	No
		Intertidal rocky substrate *	NA	Yes
SV	Extensive	Intertidal rocky substrate *	NA	Yes

Figure 31. Map and table of sites where recruitment was monitored on various substrates in 2018. Colors indicate qualitative levels of recruitment. This figure does not include other sites that were monitored for recruitment as part of a Harbor-wide study with Dr. Matt Hare of Cornell University.

Water Quality Measurements

Oysters both influence and are influenced by the water quality conditions of their environment. While we know that oysters can improve water quality, we don't expect to detect significant improvements given the relatively small scale of these restoration projects. Instead, we measure a suite of water quality parameters to understand how environmental conditions impact oyster performance.

On several sampling dates, point water quality data were measured using a Horiba U-52 multiparameter instrument (Fig. 32). This instrument measures temperature, dissolved oxygen, salinity, pH, conductivity, turbidity, and total dissolved solids. All samples were taken just below the water surface, adjacent to the restored oysters. Typically, three replicate samples, taken at least two minutes apart, were recorded on each sampling date. These samples only provide a snapshot of the water quality conditions at a site, and were typically taken in conjunction with the regular maintenance of water quality data loggers. (See *Continuous Water Quality Measurements* below.) The Horiba U-52 can also measure parameters not recorded by the water quality data loggers, such as pH and turbidity.

Figure 33 shows the average values for temperature, dissolved oxygen, salinity, and pH, and Figure 34 shows the average values for conductivity, total dissolved solids, and turbidity for all eight sites for June through September 2018. According to the average water quality values shown in Figures 33 and 34, most of the sites have suitable water quality for oyster restoration to occur (Theuerkauf & Lipcius 2016). All sites had average salinity values that were within suitable ranges for oysters and near the optimum level, which is often assumed to be around 20 ppt. Average dissolved oxygen values appeared to be suitable at most sites (> 5 mg/L), but Lemon Creek Lagoon had an average dissolved oxygen of 4.57 mg/L (SD = 1.49, n = 12), which is lower than optimum, and the continuous-time water quality results at most sites were less promising (see *Continuous Water Quality Measurements.*) Some of the sites had average pH values that approached the lower threshold for suitability of 7.5: Brooklyn Navy Yard was measured at 7.38 (SD = 0.05, n = 9), and Lemon Creek Nursery at 7.56 (SD = 0.26, n = 12). If these low pH values persist during other times of the year, they may pose a threat to oysters at these sites (Brown & Hartwick 1988).

Metals Analysis

At the Sunset Park Community Reef, Drs. Mohammad Alauddin and Liz Suter and Mary Gad of Wagner College collected water samples for metal analysis of aluminum, cadmium, copper, zinc, lead, and chromium. Overall, they found that concentrations of most metals were below the levels suggested by the Environmental Protection Agency as harmful to aquatic life. However, the researchers recommended that the concentrations of aluminum and copper and their health implications should be researched further at this site, because the concentrations of these elements were approaching limits for safety, although the results were not conclusive.

Figure 32. TNC Marine Science Technician Tatiana Castro-Gallego and BOP Summer Intern Lisette Mejia monitor water quality with HORIBA water quality meters and maintain HOBO logger equipment.

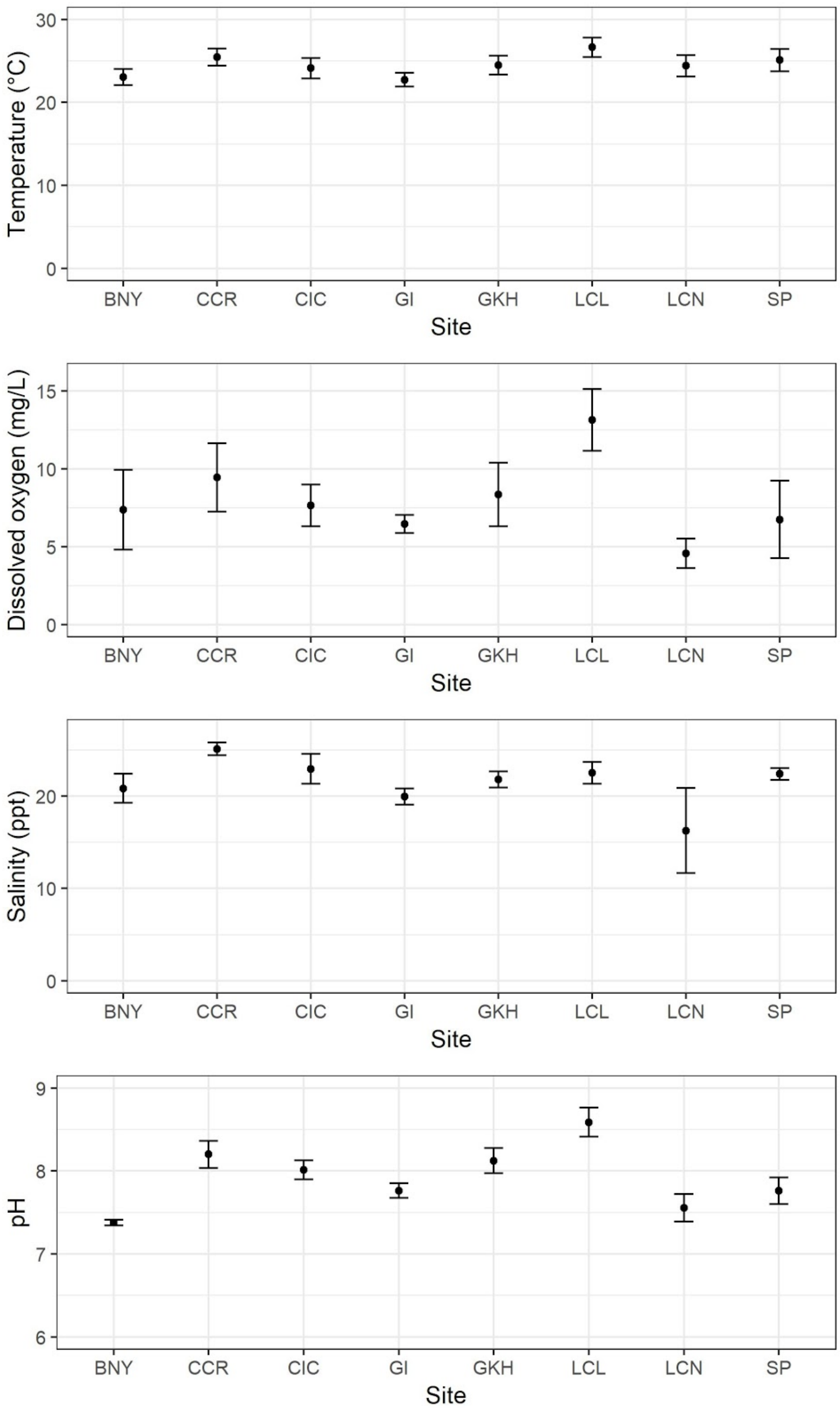


Figure 33. Average values of temperature, dissolved oxygen, salinity, and pH from June through September 2018, based on discrete point sampling for Brooklyn Navy Yard (BNY) (n = 3), Canarsie Community Reef (CCR) (n = 4), Coney Island Community Reef (CIC) (n = 5), Governors Island (GI) EcoDock (n = 6), Great Kills Harbor (GKH) (n = 4), Lemon Creek Lagoon (LCL) (n = 5), Lemon Creek Nursery (LCN) (n = 4), and Sunset Park (SP) Community Reef (n = 4). Error bars represent 95% confidence intervals.

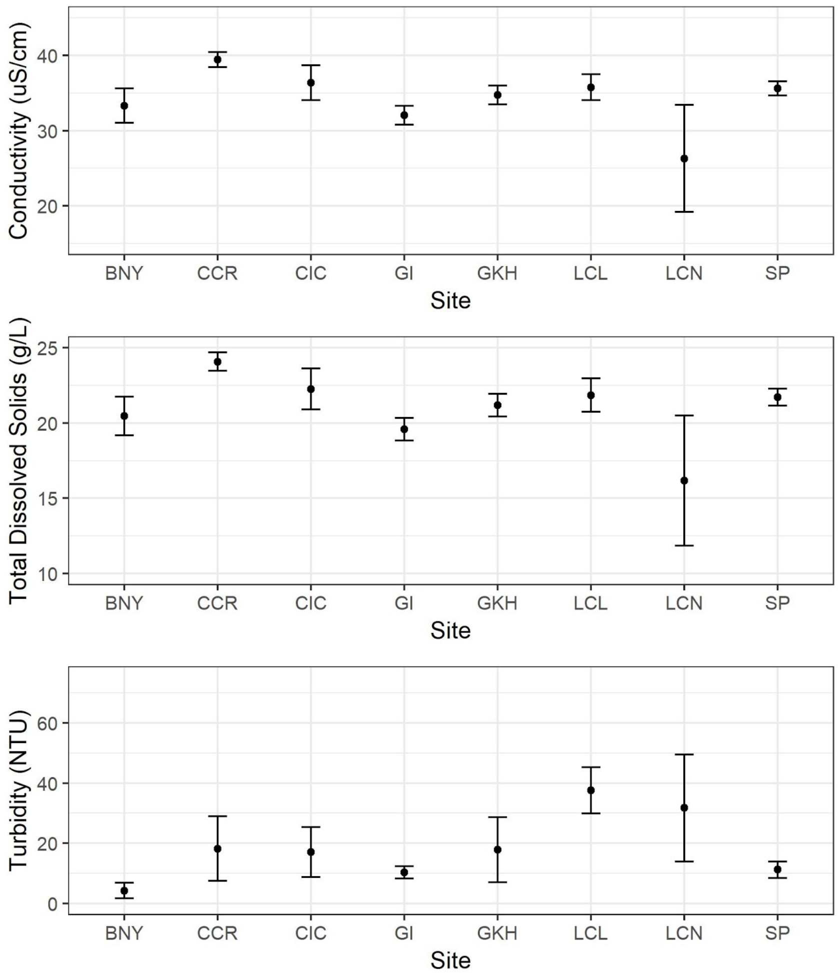


Figure 34. Average values of conductivity, total dissolved solids, and turbidity from June through September 2018, based on discrete point sampling for Brooklyn Navy Yard (BNY) (n = 3), Canarsie Community Reef (CCR) (n = 4), Coney Island Community Reef (CIC) (n = 5), Governors Island (GI) EcoDock (n = 6), Great Kills Harbor (GKH) (n = 4), Lemon Creek Lagoon (LCL) (n = 5), Lemon Creek Nursery (LCN) (n = 4), and Sunset Park (SP) Community Reef (n = 4). Error bars represent 95% confidence intervals.

Continuous Water Quality Measurements

Extreme events in water quality conditions (e.g., hypoxia or low dissolved oxygen) may influence the success of oyster restoration more than the average conditions, and they are harder to detect by traditional approaches that only collect samples during regular site visits. For some extreme conditions, such as low oxygen, occurrence is highest at night or early in the morning, times when researchers are typically not present. Therefore, it is important to collect continuous (i.e., around-the-clock) measurements when possible.

Following a successful deployment in 2017, we used Onset HOBO water quality loggers (models U-24 and U-26) to record high-resolution dissolved oxygen, salinity, and temperature data every 15 minutes on a continuous basis in the 2018 season. We visited the loggers several times in 2018 to remove fouling organisms and sediment build-up, offload data, and recalibrate by taking an independent water quality measurement with a Horiba U-52 multiparameter instrument. Onset HOBOware software was used to adjust the dissolved oxygen values on the basis of the salinity time series and to adjust for fouling. Due to differences in the deployment and maintenance schedule and to adhere with quality assurance protocols, which required some time periods to be excluded, the data from the sites do not span exactly the same time periods.

Figure 35 displays the temperature time series. All sites had their highest average temperatures in July or August (between roughly 25 and 30 degrees Celsius), with sites closer to the Atlantic Ocean, such as sites in Staten Island (i.e., Great Kills Harbor, Lemon Creek Lagoon and Nursery), typically having slightly warmer conditions (Fig. 36a). The two sites in or near the East River (Brooklyn Navy Yard and Governors Island) had the lowest average temperatures in July. By November, average temperatures at all sites had fallen below 15 degrees Celsius.

All sites had an average salinity that was between roughly 20 and 25 ppt (Fig. 36b), which is in the suitable range for oysters. Sites experienced brief decreases in salinity (Fig. 37) that differed from site to site, most likely due to the influence of freshwater inputs during rainfalls. The Canarsie Community Reef, Great Kills Harbor, Lemon Creek Lagoon, and Lemon Creek Nursery had more occurrences of low-salinity events, in some cases approaching <1 ppt.

All sites experienced low dissolved oxygen levels (i.e., hypoxia) that may be harmful to oysters (i.e., <3 mg/L) (Fig. 38). Sites differed in the frequency of low dissolved oxygen events, but for most sites these events were most common in August or September. The Canarsie Community Reef had the fewest hypoxic events (although data were not available after August). Great Kills Harbor, Lemon Creek Nursery, and Brooklyn Navy Yard had levels below 3 mg/L for much of September (88.8, 72.2, and 67.7 percent of samples, respectively). By November, hypoxia was rare at all sites for which data were available (Fig. 39).

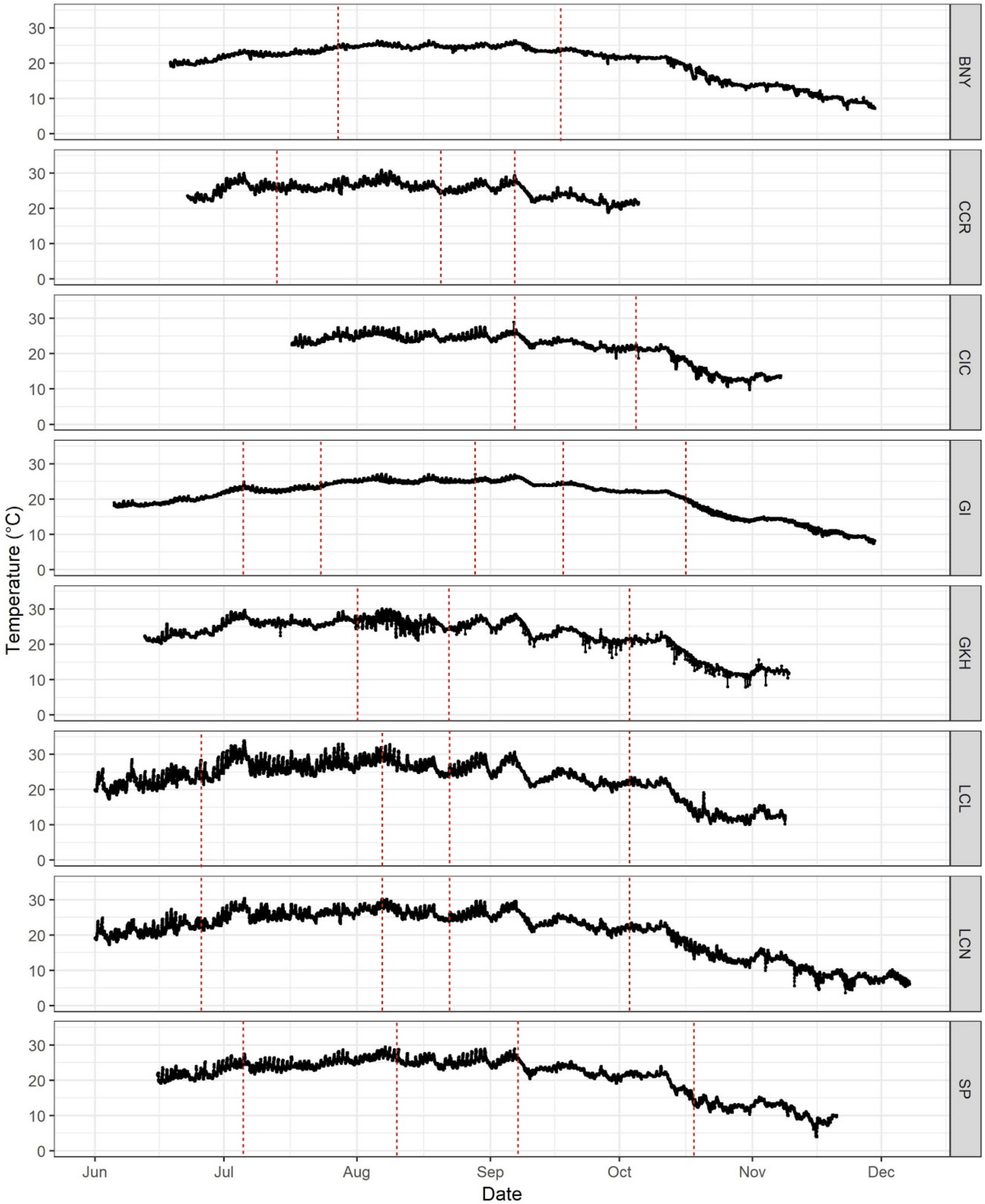


Figure 35. High-resolution (recorded every 15 minutes) temperature data for Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Red lines indicate dates when loggers were cleaned, calibrated, and redeployed.

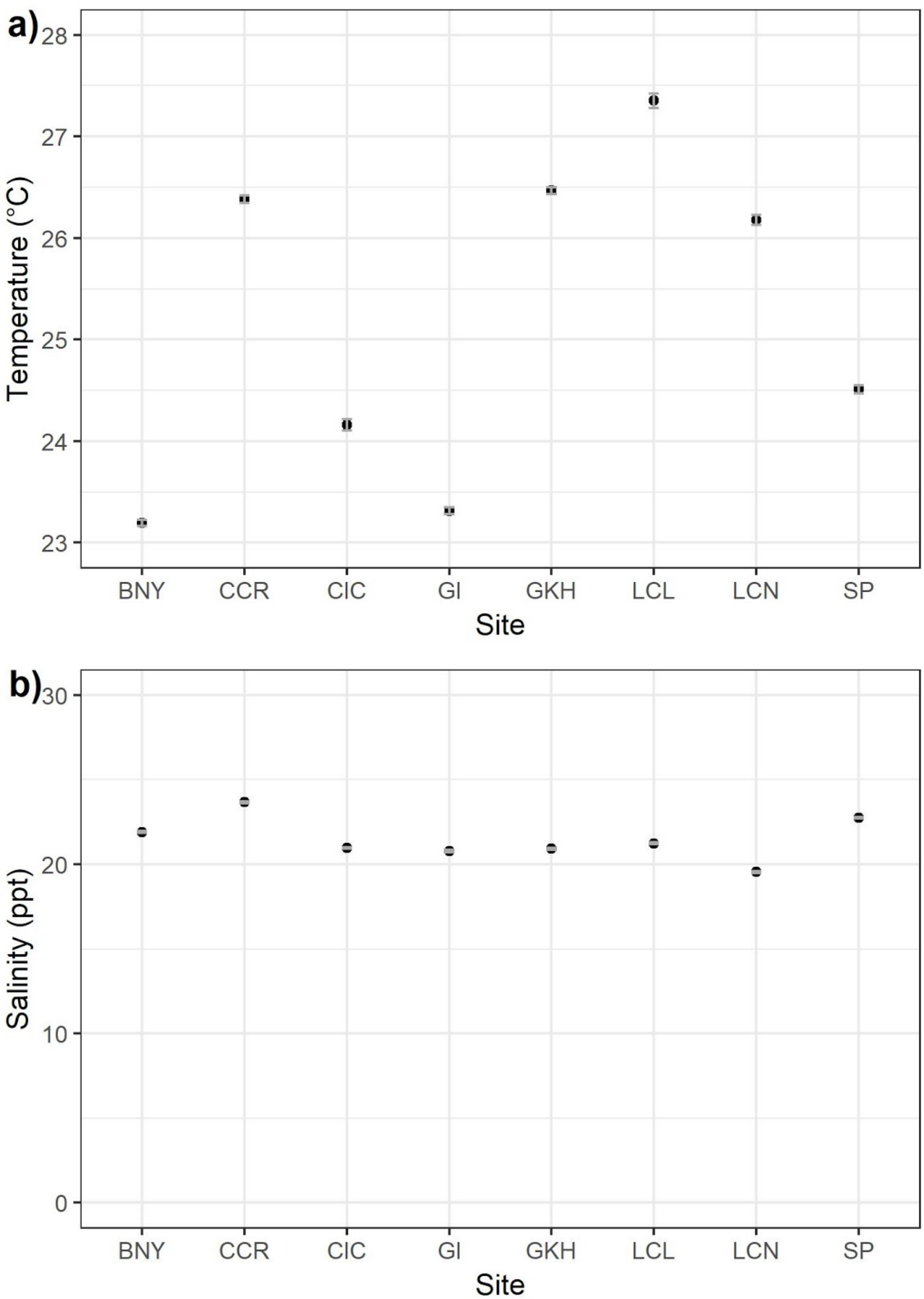


Figure 36. A) Average temperature in July 2018, and **B)** average salinity (ppt) across 2018 from high-resolution (recorded every 15 minutes) data for Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Error bars represent 95% confidence intervals.

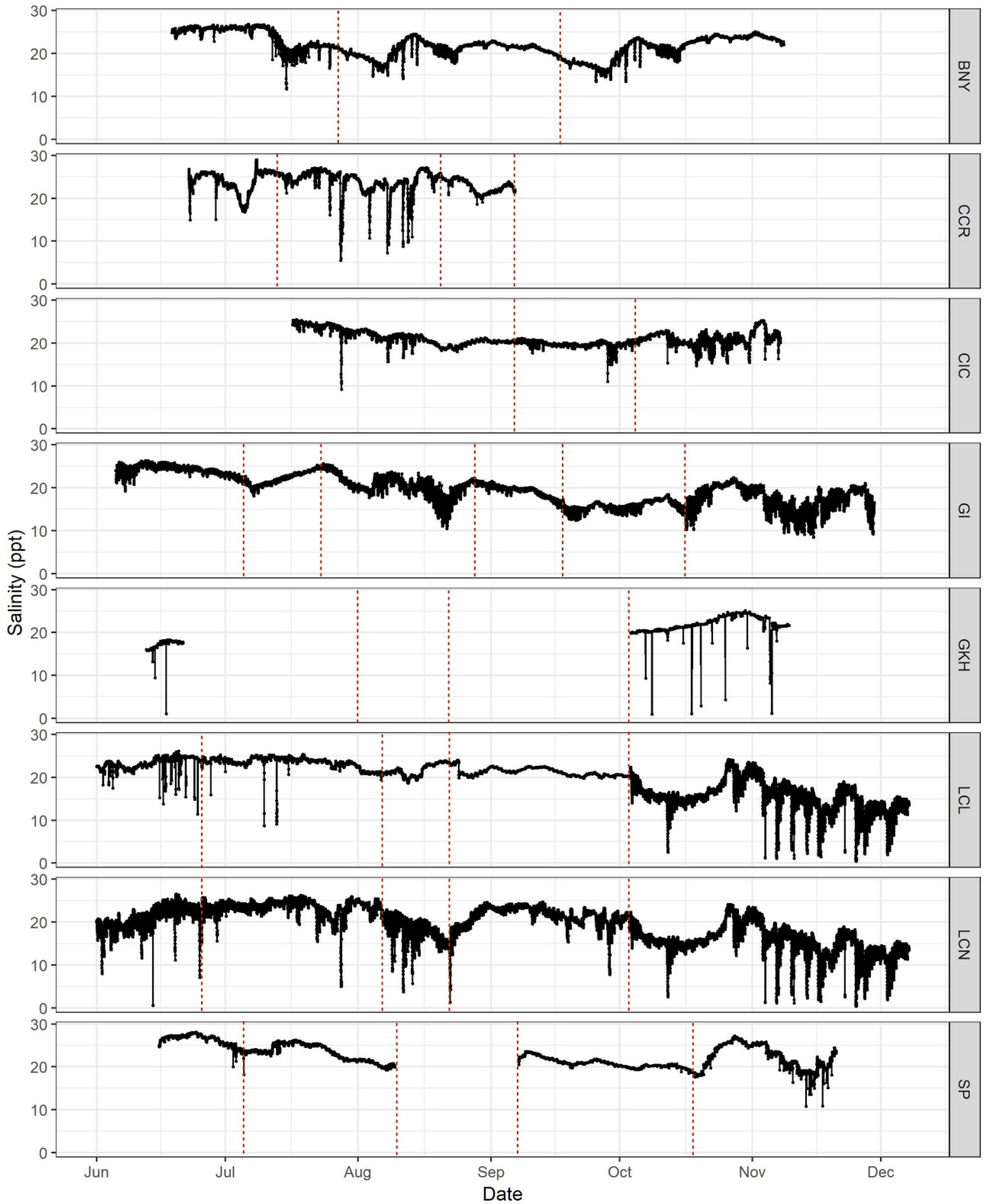


Figure 37. High-resolution (recorded every 15 minutes) salinity data for Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Red lines indicate dates when loggers were cleaned, calibrated, and redeployed.

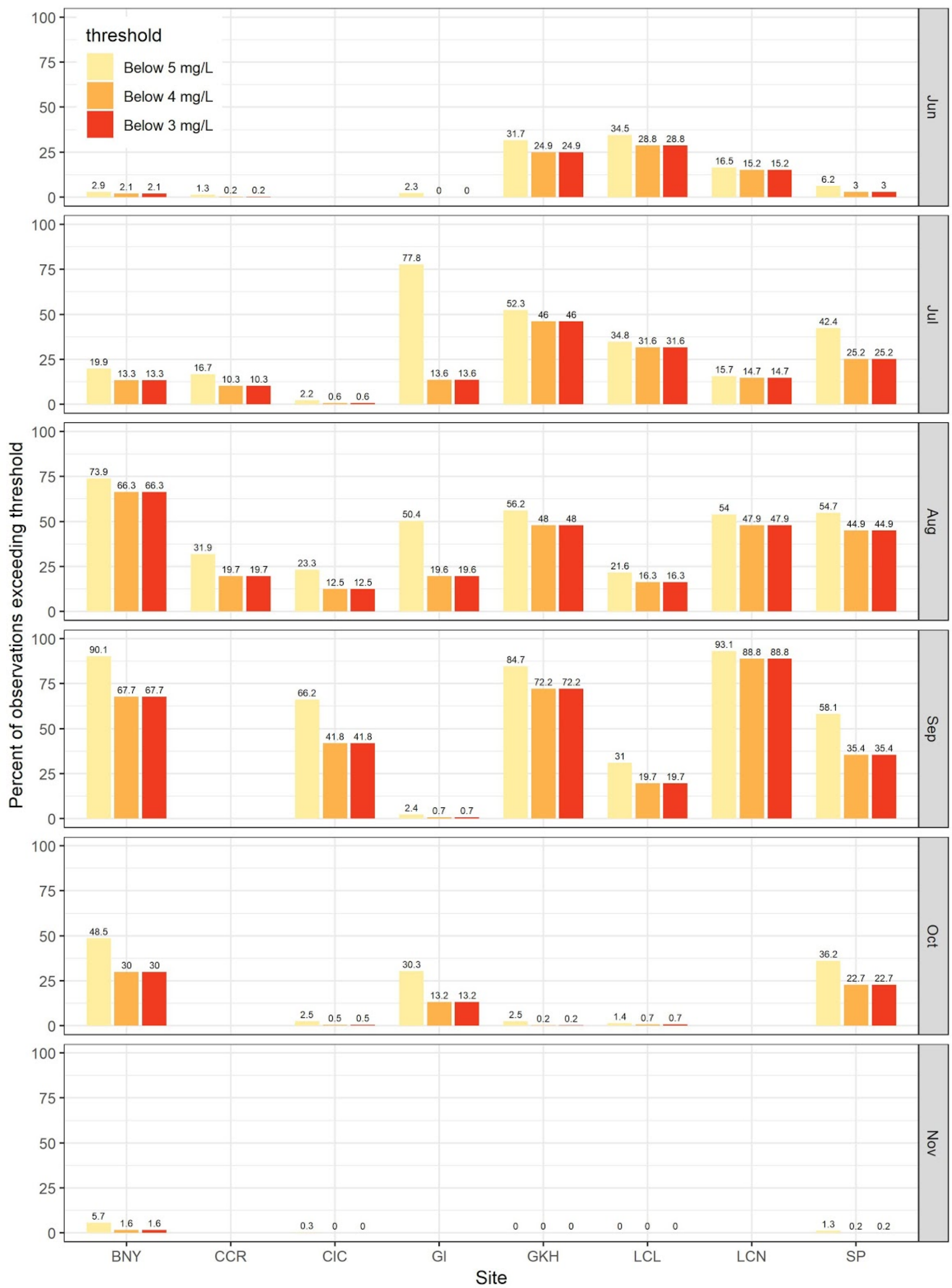


Figure 38. Percent of high-resolution (recorded every 15 minutes) dissolved oxygen measurements below 3, 4, and 5 mg/L in each month in 2018 for Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP).

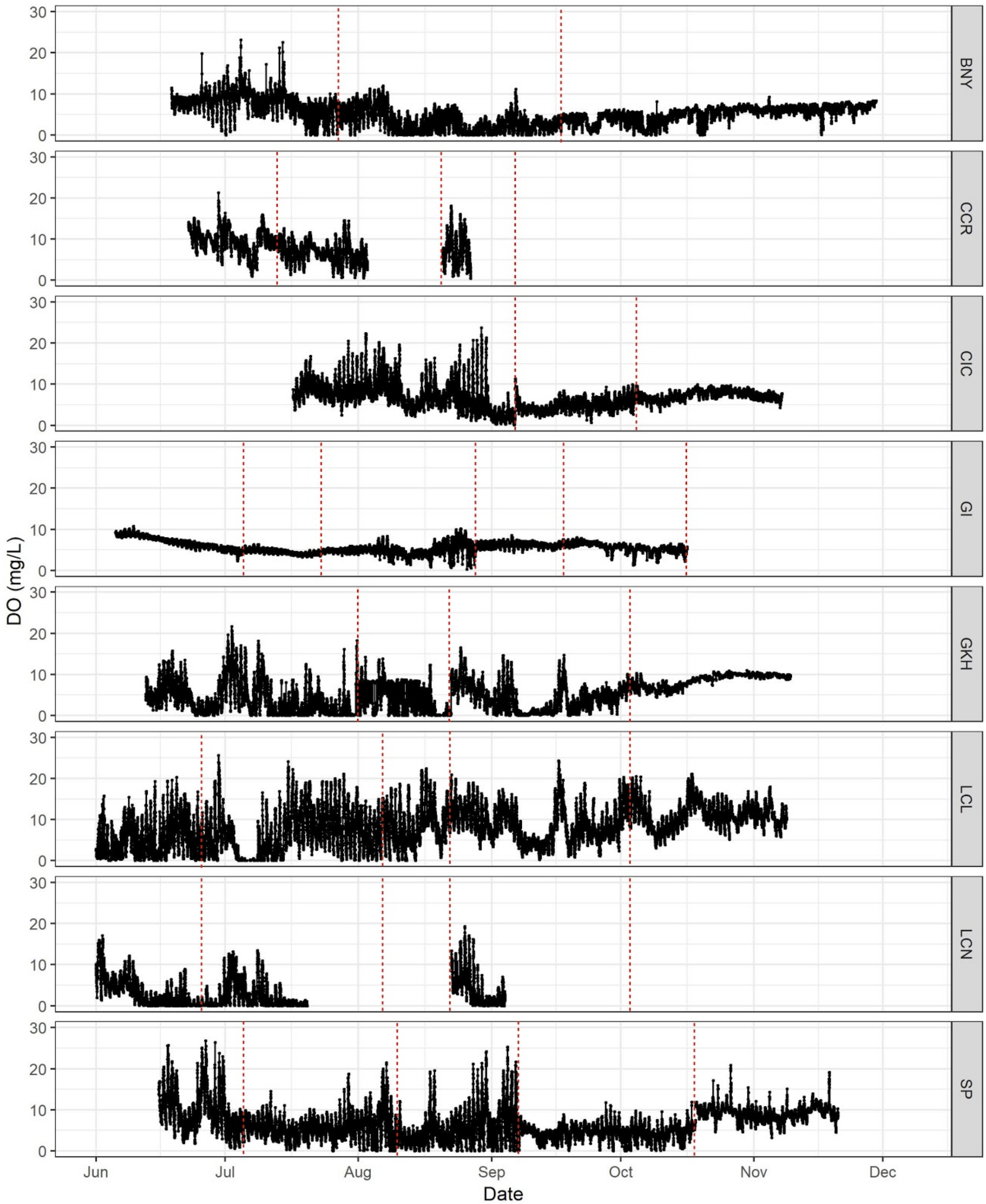


Figure 39. High-resolution (recorded every 15 minutes) dissolved oxygen data for Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Red lines indicate dates when loggers were cleaned, calibrated, and redeployed.

Food Availability

As filter feeders, oysters are influenced by the quantity and quality of phytoplankton. In order to assess food quantity at sites, we quantified the concentration of chlorophyll *a* (the main photosynthetic pigment in phytoplankton) in 2018.

At all sites, a known volume of water was filtered on a 0.7-micron glass fiber filter to measure all available chlorophyll *a*. Additional samples were fractionated between 5 and 20 microns to measure the chlorophyll *a* that is likely available to oysters (Newell & Langdon 1996; Fig. 40). Chlorophyll was extracted from the filters with 90% acetone and quantified via fluorometry with a Turner Designs AquaFluor handheld fluorometer in the BOP Hatchery on Governors Island. The chlorophyll *a* values were corrected via acidification to exclude phaeopigments. On each sampling date, three water samples for each filter size were analyzed to quantify variation. This sampling and analysis protocol was identical to the methods used in 2017. Each site was sampled on three to five dates between June and October 2018. These chlorophyll *a* results should be viewed as only part of the picture; phytoplankton quality, such as species identity and biochemical composition, as well as quantity, may affect oysters.

Lemon Creek Lagoon in Staten Island had the highest average chlorophyll *a* concentration across all sampling dates, with an average concentration of 40.3 µg/L (SD = 22.1, n = 15) for the 5 to 20 µm size range (Fig. 41). Governors Island and Brooklyn Navy Yard consistently had the lowest concentrations, with annual averages of 0.47 µg/L (SD = 0.32, n = 15) and 0.35 µg/L (SD = 0.94, n = 9) for the 5 to 20 µm size range, respectively. Other sites, including Great Kills Harbor, Canarsie Community Reef, Coney Island Community Reef, Lemon Creek Nursery, and the Sunset Park Community Reef had moderate average chlorophyll *a* concentrations for the 5 to 20 µm size range, from approximately 5 to 16 µg/L (Fig. 42). There was no consistent pattern across sites regarding the timing of the highest chlorophyll *a* concentrations; peaks occurred in July, August, or September.

Figure 40. BOP Summer Research Intern Lisette Mejia sets up the vacuum filtration system to filter water samples for chlorophyll analysis.

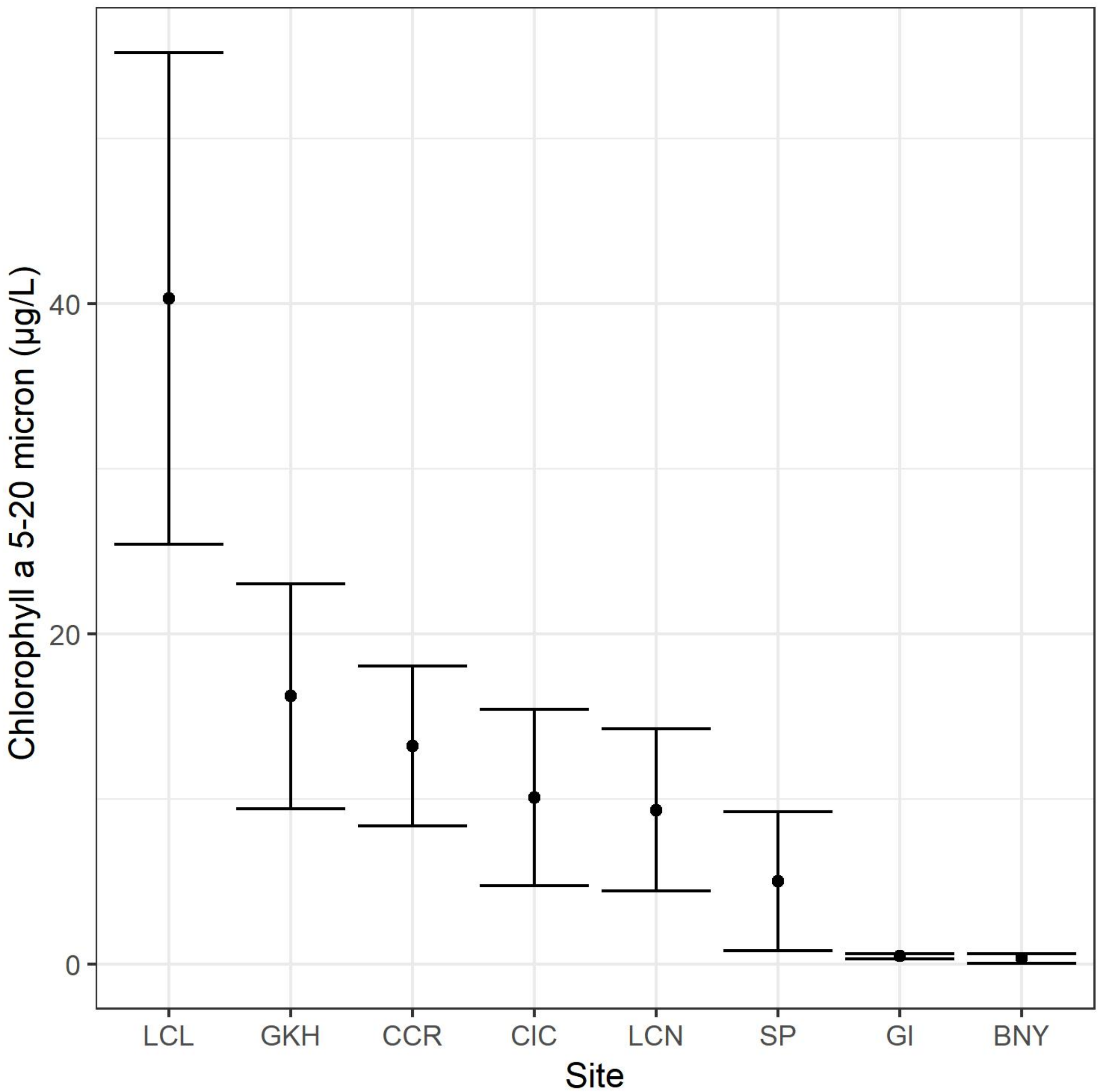


Figure 41. Average chlorophyll *a* concentration for particles between 5 and 20 µm in 2018 at Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Error bars represent 95% confidence intervals.

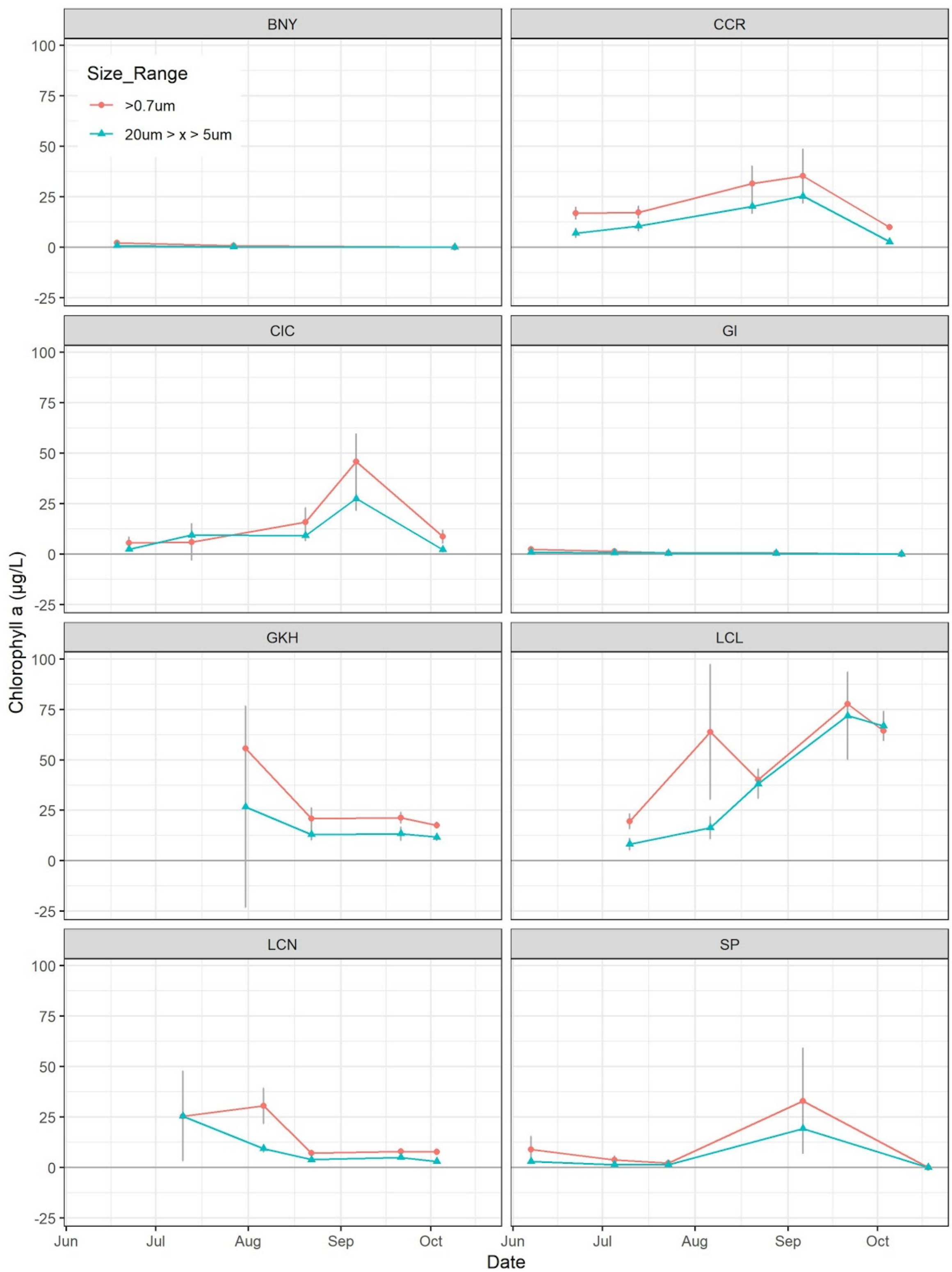


Figure 42. Chlorophyll *a* concentration for all particles >0.7 µm and particles between 5 and 20 µm at Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Community Reef (CIC), Governors Island EcoDock (GI), Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park Community Reef (SP). Error bars represent 95% confidence intervals.

Dissolved Inorganic Nutrients

In order to understand the baseline nutrient conditions at the restoration sites, dissolved inorganic nutrients were quantified from water samples collected in 2018. Although oysters are known to modify nutrient cycling and remove excess nutrients from the water column, we don't expect to detect changes in nutrient concentrations due to the relatively small scale of these restoration projects. Our measurements help us understand the nutrient conditions across sites and the link between nutrient levels and other water quality parameters (e.g., dissolved oxygen, food availability).

At least three replicate water samples on each sampling date were passed through 0.2-µm syringe filters and analyzed by the lab of Dr. Chester Zarnoch (Baruch College) to quantify phosphate (soluble reactive phosphorus) and three forms of nitrogen: nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+). Samples were taken on at least four dates from all sites except for Great Kills Harbor. Readings below detection limits were normalized to zero [ammonium: 0.4 **µ**M, nitrate: 0.2 **µ**m, nitrite: 0.04 **µ**M, SRP: 0.1 **µ**M).

Results for soluble reactive phosphorus and all forms of dissolved inorganic nitrogen (the sum of nitrate, nitrite, and ammonium values) are shown in Figures 43–45. Differences in average soluble reactive phosphate were not substantial among sites. Differences in dissolved inorganic nitrogen were more noticeable, with the highest concentrations at the Brooklyn Navy Yard (>1 mg/L) and the lowest at Lemon Creek Lagoon (close to 0 mg/L). The other six sites had intermediate dissolved inorganic nitrogen values around 0.5 mg/L. None of the sites appeared to exhibit temporal trends in either soluble reactive phosphate or dissolved inorganic nitrogen between April and October.

These samples were not collected to measure the effects of oyster restoration on nutrient cycling, but rather to provide a baseline understanding of differences in nutrient availability at the restoration sites. A study to quantify the ecosystem benefits of oyster restoration with regard to nutrient cycling would require a more targeted sampling effort, and previous efforts to quantify the effects of oyster restoration on nutrient cycling in NY/NJ Harbor have proven difficult (Hoellein & Zarnoch 2014). Further efforts to understand sediment nutrient levels should be undertaken to understand the potential of oysters to enhance nitrogen removal via denitrification. At sites where oysters add either carbon or nitrogen to sediments where those elements are limited, the oysters may enhance denitrification rates. Dr. Zarnoch is continuing to pursue this important research area in NY/NJ Harbor.

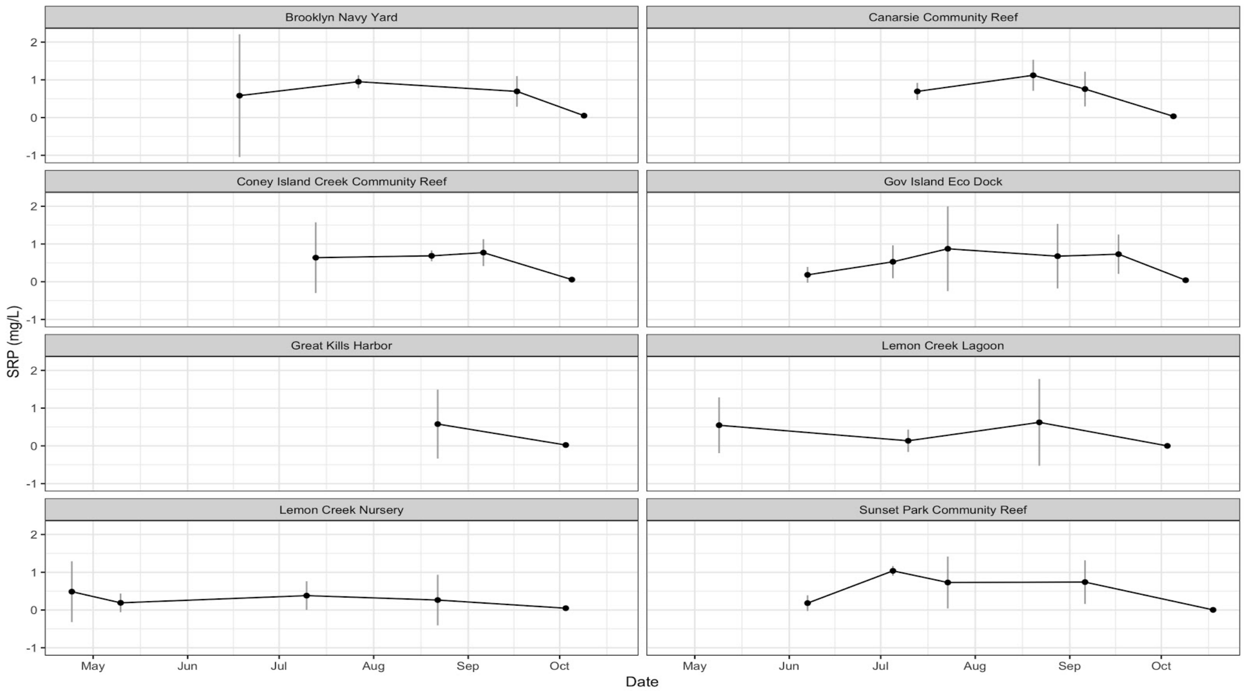


Figure 43. Soluble reactive phosphorus concentrations at Brooklyn Navy Yard, Canarsie Community Reef, Coney Island Creek Community Reef, Governors Island EcoDock, Great Kills Harbor, Lemon Creek Lagoon, Lemon Creek Nursery, and Sunset Park Community Reef in 2018. Error bars represent 95% confidence intervals.

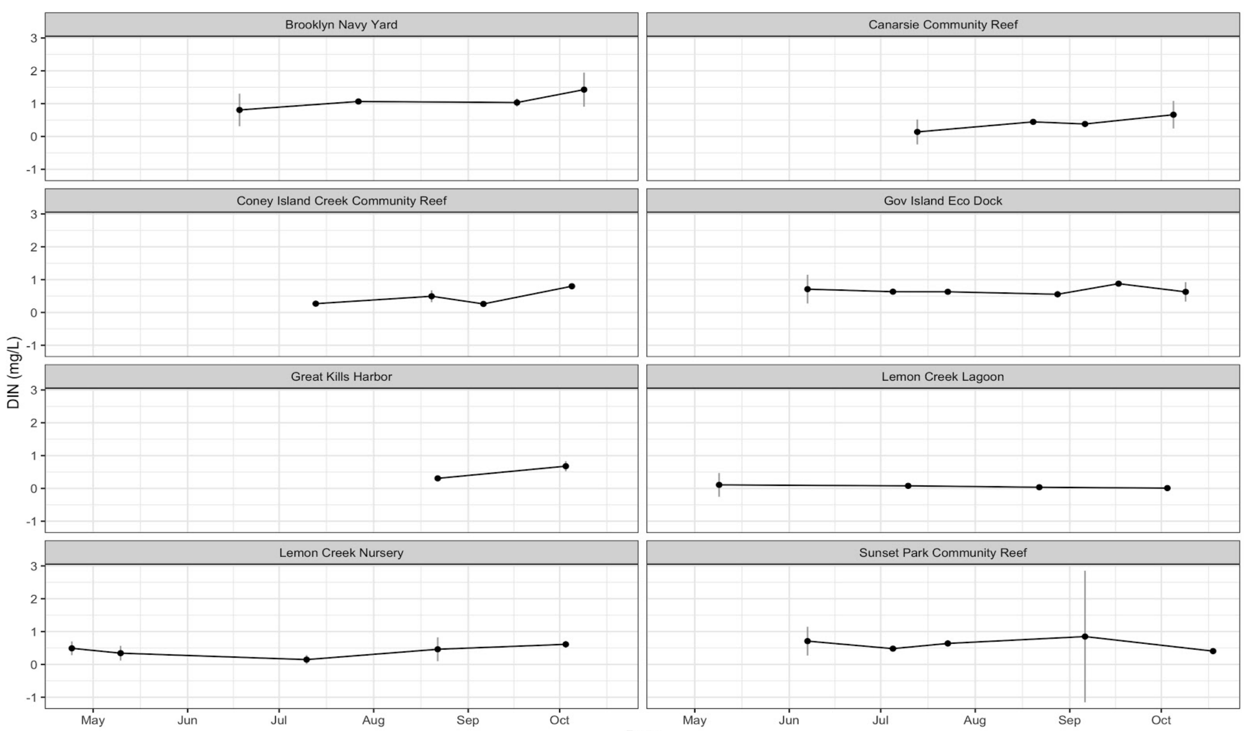


Figure 44. Dissolved inorganic nitrogen (the sum of nitrite, nitrate, and ammonium) concentrations at Brooklyn Navy Yard, Canarsie Community Reef, Coney Island Creek Community Reef, Governors Island EcoDock, Great Kills Harbor, Lemon Creek Lagoon, Lemon Creek Nursery, and Sunset Park Community Reef in 2018. Error bars represent 95% confidence intervals.

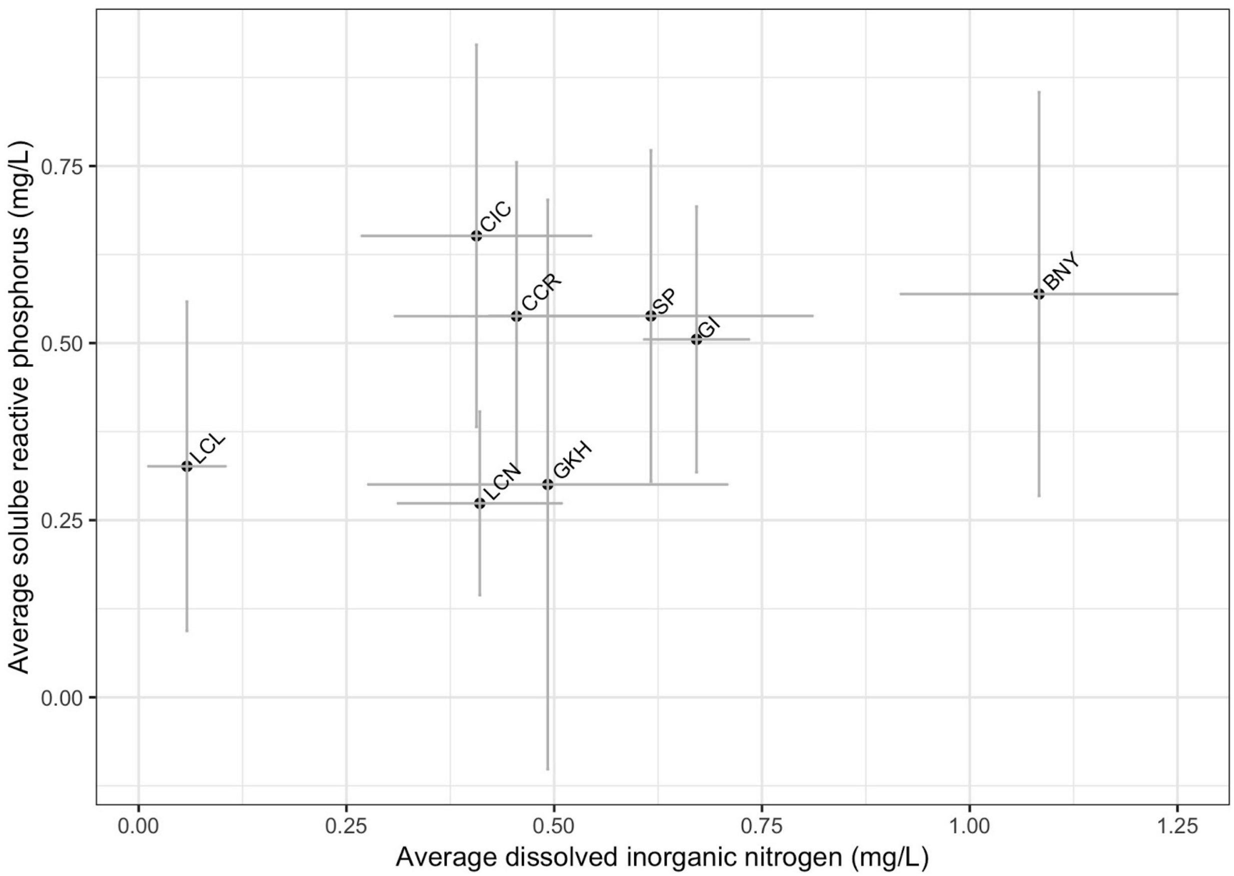


Figure 45. Average soluble reactive phosphorus concentration and dissolved inorganic nitrogen (nitrite, nitrate, and ammonium) in 2018 at Brooklyn Navy Yard (BNY), Canarsie Community Reef (CCR), Coney Island Creek Community Reef (CIC), Governors Island (GI) EcoDock, Great Kills Harbor (GKH), Lemon Creek Lagoon (LCL), Lemon Creek Nursery (LCN), and Sunset Park (SP) Community Reef in 2018. Error bars represent 95% confidence intervals.

Biodiversity

Oyster beds and reefs increase the three-dimensional complexity of the bottom environment and typically support greater biodiversity than adjacent, non-structured habitat, such as muddy or sandy bottoms. Most of the research on biodiversity enhancement by oyster beds comes from other estuaries, such as Chesapeake Bay, bodies of water in the southeastern United States, and the Gulf of Mexico (Peterson et al. 2003, zu Ermgassen et al. 2016). The degree to which restored oysters enhance populations of fish, crabs, and shrimp depends on biogeographic context, as different estuaries are home to different species. Therefore, in 2017, we initiated a study to understand the role of oyster restoration activities on species abundance and composition at the Sunset Park Community Reef at Bush Terminal Park in Brooklyn and Lemon Creek Lagoon in Staten Island. In 2018, we continued the study at these sites with some modifications to our sampling methodologies. As in 2017, we primarily relied on minnow traps to capture organisms at on- and off-reef sites (Fig. 46). Off-reef sites were at least 10 m away from reefs and had a similar depth as reef sites. In 2018, we continued to use minnow traps, but also deployed traps with and without oyster shell inside (those with shell were roughly 50% full) and deployed traps for 48 hours. This approach is also used by Meredith Comi and Dr. Allison Fitzgerald of NY/NJ Baykeeper at the reefs at Naval Weapons Station Earle in New Jersey and Soundview in the Bronx.

At the Sunset Park Community Reef, in addition to placing minnow traps, we also assessed the organisms residing in and around the community reef files (i.e., cages). To do this, we quickly removed the cages from the reef and transferred them to plastic trays to collect all of the contents, including organisms that fell off the outside of the file. We then rinsed the cage with 25–30 gallons of seawater from the site and collected all the organisms that fell off. This approach allowed us to document organisms residing in and around the reef that may not enter the minnow traps.

Sampling occurred at both sites in May, August, and October. At Lemon Creek Lagoon, the May sampling data were taken before oysters were restored. At Sunset Park, the 2018 Community Reef and Bagged Shell Reef were installed after the August biodiversity sampling date.

Table 7 reports the taxa encountered at both sites. A total of 25 taxa were captured at the Sunset Park Community Reef through minnow traps and files, including 10 taxa of vertebrates and 15 invertebrates. Lemon Creek Lagoon had only 15 total taxa, including 6 vertebrates and 9 invertebrates (Fig. 47), but oyster restoration occurred more recently there and at a smaller scale than at Sunset Park. Also, cages were examined at Sunset Park, but not at Lemon Creek Lagoon.

Tables 8 and 9 report the abundance of different organisms caught in minnow traps placed on- and off-reef and with and without oyster shells in the trap. The results did not clearly show greater abundance or taxonomic richness on-reef and in traps with shell, as we originally expected. Lemon Creek Lagoon had higher richness on the reef than off-reef (7 species vs. 5) (Table 8), but Sunset Park had higher richness off-reef than on-reef (11 species vs. 7) (Table 9). Both sites had the unexpected result that on the reef, abundance was higher in traps with shell, and off the reef, abundance was higher in traps without shell. This is likely due to the higher prevalence of adult free-swimming species (e.g., *Fundulus* spp.) that do not exhibit a preference for rugose habitat for cover in off-reef habitat. More study is necessary to understand the complexities of biodiversity and species dynamics at restored reefs and in adjacent habitat.

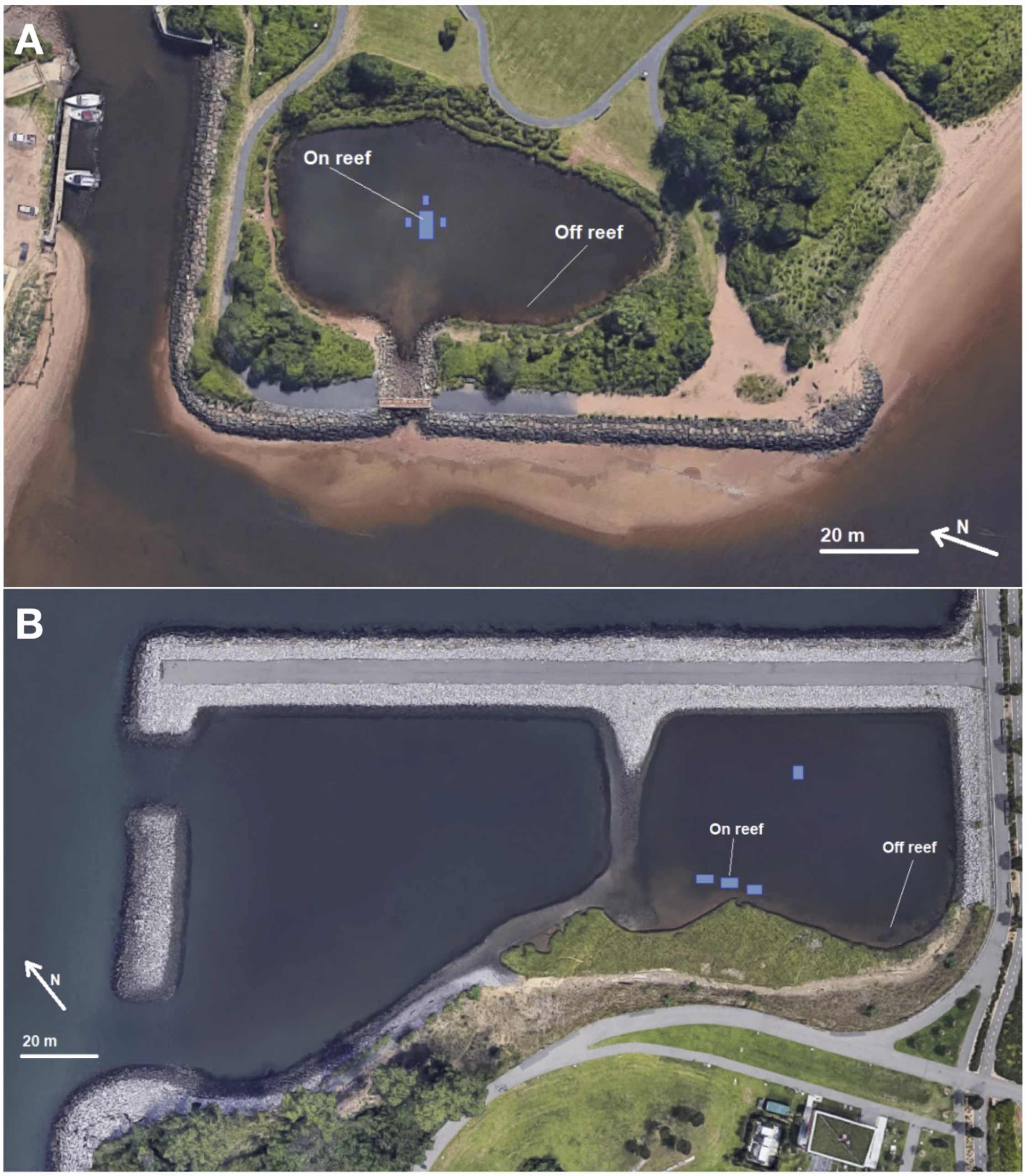


Figure 46. Aerial view of biodiversity study sites at (A) Lemon Creek Lagoon and (B) Sunset Park Community Reef at Bush Terminal Park. Blue polygons indicate approximate size and location of oyster restoration projects.

Table 7. Taxonomic richness at the Lemon Creek Lagoon in Staten Island and the Sunset Park Community Reef at Bush Terminal Park across all sampling events (May, August, and October 2018).

Vertebrates			
Scientific Name	**Common Name**	**Lemon Creek Lagoon**	**Sunset Park**
Anguilla rostrata	American eel		x
Apeltes quadracus	Fourspine stickleback	x	x
Cyprinodon variegatus variegatus	Sheepshead minnow	x	
Fundulus heteroclitus	Mummichog	x	x
Fundulus majalis	Striped killifish		x
Gobiosoma bosc	Naked goby	x	x*
Menidia menidia	Atlantic silverside		x
Morone saxatilis	Striped bass	x	x
Opsanus tau	Oyster toadfish	x	x*
Pseudopleuronectes americanus	Winter flounder		x
Syngnathus fuscus	Northern pipefish		x
Invertebrates			
Scientific Name	**Common Name**	**Lemon Creek Lagoon**	**Sunset Park**
Order Amphipoda	Amphipod	x	x*
Callinectes sapidus	Blue crab	x	x*
Carcinus maenas	Green crab		x↾
Crangon septemspinosa	Sand shrimp	x	x↾
Geukensia demissa	Atlantic ribbed mussel		x
Hemigrapsus sanguineus	Asian shore crab		x
Mercenaria mercenaria	Hard clam (quahog)		x↾
Mnemiopsis leidyi	Sea walnut	x	x
Mytilus edulis	Blue mussel		x↾
Nephtys sp.	Red-lined worm	x	
Nereis spp.	Clam worm		x
Palaemonetes spp.	Grass shrimp	x	x*
Panopeus spp.	Mud crab	x	x*
Class Polychaeta	Polychaete worm(s)		x↾
Tritia obsoleta	Eastern mud snail	x	x*
Urosalpinx cinerea	Atlantic oyster drill	x	x↾

* indicates organisms present in both traps and cages (i.e., Community Reef files).
↾ indicates organisms present in cages (i.e., Community Reef files) only.

Table 8. Total abundance of organisms collected in minnow traps with and without oyster shell and on and off the restored bagged shell reef at Lemon Creek Lagoon in 2018. Pre-install samples were collected in May. Other samples were collected in August and October. n = 288 trap hours for each value reported.

	Pre-install		Off Reef		On Reef	
Species	**Shell Absent**	**Shell Present**	**Shell Absent**	**Shell Present**	**Shell Absent**	**Shell Present**
Apeltes quadracus	4	3				
Callinectes sapidus		2	1			
Carcinus maenas		1				
Crangon septemspinosa	2					
Cyprinodon variegatus variegatus					2	
Fundulus heteroclitus	1		61	47	38	90
Gobiosoma bosc					4	
Morone saxatilis					1	
Opsanus tau				1	1	1
Palaemonetes spp.	13	9	42	7	70	82
Panopeus spp.		14		7	3	
Anguilla rostrata						
Fundulus majalis						
Hemigrapsus sanguineus						
Menidia menidia						
Pseudopleuronectes americanus						
Syngnathus fuscus						
Total Abundance	**20**	**29**	**104**	**62**	**119**	**173**
Taxonomic Richness	**4**	**5**	**3**	**4**	**7**	**3**

Table 9. Total abundance of organisms collected in minnow traps with and without oyster shell and on and off the restored bagged shell reef at the Sunset Park Community Reef in 2018. Samples were collected in May, August, and October. n = 432 trap hours for each value reported.

	Off Reef		On Reef	
Species	**Shell Absent**	**Shell Present**	**Shell Absent**	**Shell Present**
Apeltes quadracus				1
Callinectes sapidus	1	6		
Carcinus maenas				
Crangon septemspinosa				
Cyprinodon variegatus variegatus				
Fundulus heteroclitus	207	101		1
Gobiosoma bosc		11		1
Morone saxatilis	1			
Opsanus tau	1	5	1	2
Palaemonetes spp.	5	44	30	60
Panopeus spp.	4			4
Anguilla rostrata			1	
Fundulus majalis	1	1		
Hemigrapsus sanguineus				
Menidia menidia	1			
Pseudopleuronectes americanus	2			
Syngnathus fuscus		1		
Total Abundance	**223**	**169**	**32**	**69**
Taxonomic Richness	**9**	**7**	**3**	**6**

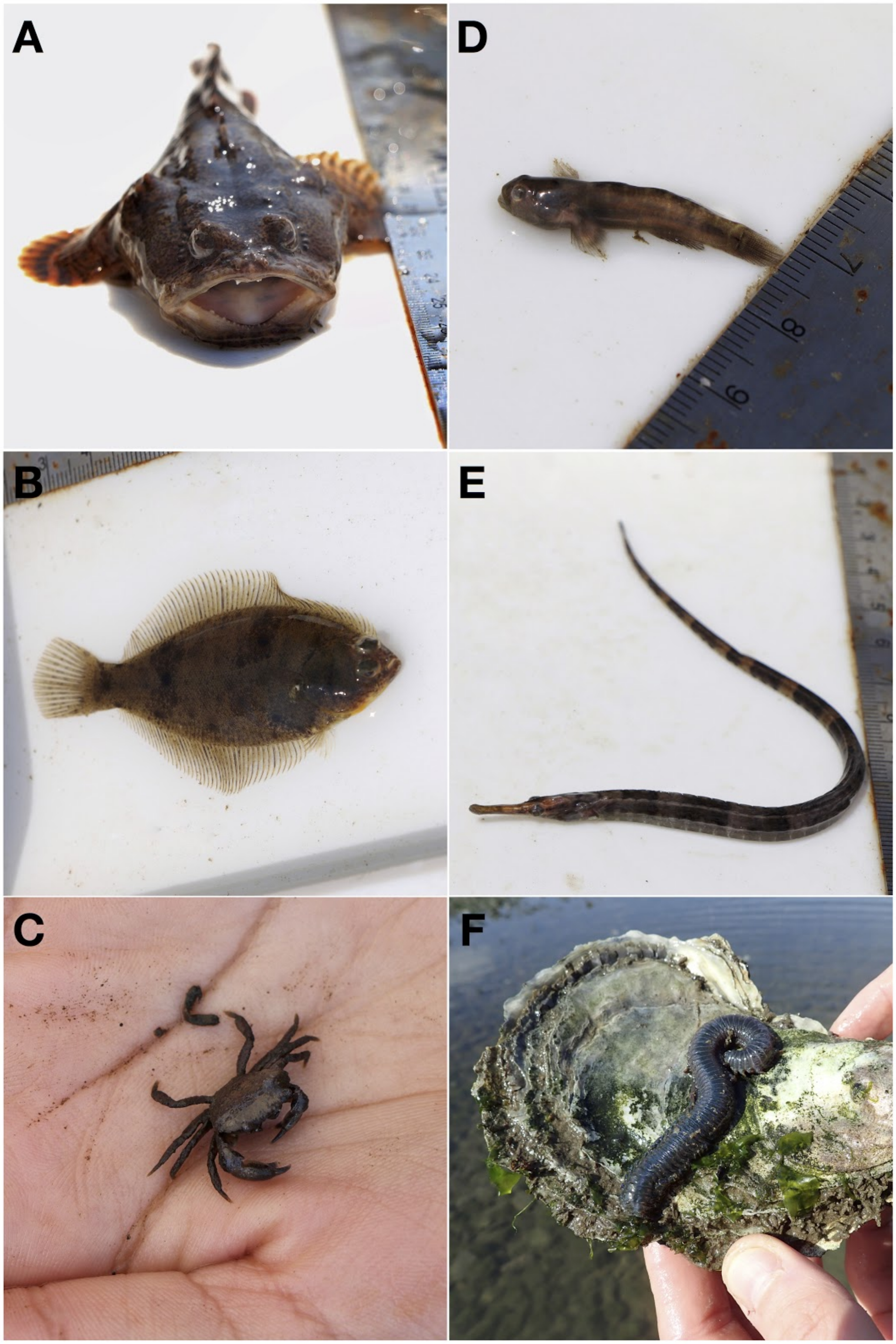


Figure 47. Examples of organisms inhabiting restored reefs: (A) Oyster toadfish (*Opsanus tau*), (B) Winter flounder (*Pseudopleuronectes americanus*), (C) Mud crab (*Panopeus sp.*), (D) Naked goby (*Gobiosoma bosc*), (E) Northern pipefish (*Sygnathus fuscus)*, and (F) Clam worm (*Nereis* sp.).

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Figure 4D: Robina Taliaferrow

Figure 4E: Mike McCann/TNC

Figure 5: Rebecca Resner

Figure 6: Robina Taliaferrow

Figure 7: Billion Oyster Project

Figure 8: Liz Burmester

Figure 11: Rebecca Resner

Figure 12: Robina Taliaferrow

Figure 25: Liz Burmester & Mike McCann/TNC

Figure 27A: Mike McCann/TNC

Figure 27B: Finola Fung-Khee

Figure 29: Mike McCann/TNC

Figure 30A: Mike McCann/TNC

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