Community Based Restoration of Oyster Reef Habitat in the Bronx River:

Assessing Approaches and Results in an Urbanized Setting

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Community Based Restoration of Oyster Reef Habitat in the Bronx River: Assessing Approaches and Results in an Urbanized Setting

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II. Project Summary

This project continued and expanded on a previous smaller-scale multi-site effort by the original and new project partners focusing on the development of general protocols for shallow subtidal oyster reef restoration in the New York Harbor region where natural reefs and recruitment of native eastern oysters (*Crassostrea virginica*) are uncommon. The primary aim of the multi-year effort was: (1) the construction; (2) monitoring; (3) involvement of community partners; and (4) development of novel methods, including adaptive management, ultimately restoring an approximately one acre footprint of productive oyster reef habitat at the confluence of the East and Bronx Rivers, off Soundview Park (Figure 1, near 40°48'42.53"N, 73°52'8.52"W) Bronx, New York.

The primary restoration techniques employed methods found to be effective in previous studies, including those in the Hudson-Raritan Estuary (HRE) and in other areas (e.g., the Northeast U.S.) where the eastern oyster (*Crassostrea virginica*) has declined significantly. These methods include: (1) assessing the best place to deploy hard substrate at the restoration site (mapping); (2) deployment of a quarantined bivalve (clam) mollusc shell base layer subtidally (rarely exposed at low tide) in five reef mounds isolated in space; (3) followed by placement of very young oysters recruited onto an appropriate substrate, shell (spat-on-shell, or SOS) produced through aquaculture using local broodstock (adults) by one of our partners, the Urban Assembly New York Harbor School. We then sampled these distinct (n = 5) reef mounds through time as the planted oysters and potential natural recruitment of oysters occurred, along with other related monitoring of the physical (e.g., salinity, temperature, dissolved oxygen) and biological (e.g., organisms arriving, disease, growth of SOS) environment. Engagement of the community was a major goal of the project and community members and numerous community organizations participated in the pre-construction monitoring, reef construction and monitoring and oyster aquaculture components of the project.

Another added goal was to design and test novel methods of restoration to address the challenge of restoring shallow subtidal oyster reefs at a relatively high energy site with very low natural populations and recruitment. In the later part of the effort we tried a new design consisting of wire mesh (1 ft^3) "blocks" (small gabions), filled with oyster shell, secured together to form a perimeter into which SOS

also from the New York Harbor School was placed. In addition, half of the wire mesh (1 ft^3) blocks filled with oyster shell were also set with juvenile oyster SOS produced by New York Harbor School's Aquaculture group.

Since the project began in 2011, **113** students and community volunteers have contributed an estimated **1,800** hours to the project. **Eighty-three** community volunteers contributed an estimated **258** hours of volunteer hours to the reef construction and monitoring components of the project, and an estimated **1,542** hours of student time were contributed to the oyster aquaculture components of the project. In addition, many additional hours were contributed by partners partially supported under this grant and by other partners involved in the project amongst the **19** cooperating organizations/universities.

The major result of the project was a "constructed shell-dominated 1 acre oyster reef footprint area" that has the potential for longer-term development and sustainability.

III. Background

The eastern oyster, *Crassostrea virginica* forms living shallow to deep subtidal and intertidal three dimensional reefs that are a dominant feature of many Atlantic and Gulf U.S. coastal estuaries (e.g., ASMFC 2007, Beck et al. 2011). However, its populations (and associated reefs) have declined significantly in many U.S. estuaries that once had major fisheries (e.g., Rothschild et al. 1994, Kirby 2004, NRC 2004, zu Ermgassen et al. 2012, Powers and Boyer 2014, Worm and Lenihan 2014). Grabowski and Peterson (2007) and others (Coen et al. 1999, 2007, Baggett et al. 2014) have described a variety of ecological functions of oyster reefs including: (1) oyster production; (2) water filtration; (3) nutrient sequestration; (4) habitat for fish and invertebrates and augmented production; (5) stabilization of adjacent habitats/shorelines; and (6) enhancement of ecosystem complexity. Recent research has attempted to quantify the contribution of oyster habitat to ecosystem functioning in economic terms (e.g., Peterson et al. 2003, Grabowski and Peterson 2007, Grabowski et al. 2012, Hoellein and Zarnoch 2014).

Restoration of the eastern oyster (C*rassostrea virginica*) and its reef habitat to the Hudson-Raritan Estuary (HRE) is important from cultural and historical perspectives, as well as an ecological basis (e.g., Sellers and Stanley 1984, Kurlansky 2006, Levinton and Waldman 2006, ASMFC, 2007, Jacobsen 2008). Oysters have been a prominent part of the HRE for perhaps tens of thousands of years, but have undergone major declines (approaching ecological extinction, Beck et al. 2009, 2011) from poor water quality, disease, habitat degradation and loss, fishing pressure, and likely other stresses in the last 100 years (Steinberg et al. 2004, Kurlansky 2006, Levinton and Waldman 2006). Today, in most areas of the HRE only very small populations of local oysters are known to occur. These native oysters, however, are an encouraging signal to research and restoration practitioners that the water quality may now be able to support the oyster's return (e.g., CRP 2009, Levinton and Doall 2011, Starke et al. 2011, Levinton et al. 2013).

In 2009, a partnership of 19 foundations, university scientists (restoration practitioners), nonprofits, and state and city agencies formed for the purpose of creating a series of oyster reef research sites in the Hudson Raritan Estuary. The Oyster Restoration Research Project's (ORRP) ultimate goal was to determine where oysters in the HRE would flourish, and to develop methods best suited for scaling up to large-scale oyster reef restoration. Partners built five experimental scale (15 ft. x 30 ft. or 0.01 acre, 450 ft^2) oyster reefs throughout the estuary in 2010 (see Figure 1), and assessed reef development and various performance metrics from 2010-2012 (see Grizzle et al. 2013, Peterson and Kulp 2013).

The New York-New Jersey Harbor and Estuary Program (HEP) adopted a Comprehensive Restoration Plan (CRP) that describes the restoration vision for the region (CRP 2009). The CRP, which was developed in collaboration with many partners including the US Army Corps of Engineers (USACE), the Port Authority of New York and New Jersey, and the Hudson River Foundation (HRF), identified oysters as one of eleven unique habitats that need to be restored to improve the ecosystem of the NY Harbor Estuary. The plan set a goal of restoring 20 acres of oyster reef by 2020 and 2,000 acres by 2050.

Figure 1. A., Location of present project at Soundview Park (white arrow) and four other experimental ORRP oyster reefs constructed in 2010; B, schematic of individual reef design (upper right); and C., photo of clam shell foundation being deployed at the Governors Island site.

In brief, the experimental reefs at Soundview Park, Hastings, and Governors Island showed development patterns indicating potential for further restoration activities based on four criteria: (1) aquaculture-produced oyster spat-on-shell (SOS); (2) survival and growth; (3) natural recruitment; and (4) environmental conditions (see Grizzle et al. 2013 and Peterson and Kulp 2013 for details). All three sites had some level of natural recruitment, and the SOS showed good oyster growth and survival. Environmental conditions (salinity, temperature, etc.) were well within acceptable ranges for the eastern oyster at all three sites, except for Hastings which had quite low mean salinities for much of spring/summer 2011 and 2012. It should also be noted that prior to the ORRP work at Soundview Park, the New York City Department of Parks and Recreation's Natural Resource Group (NRG) had conducted oyster studies at the same location since 2004 including studies on the effectiveness of different reef designs, fish and benthic invertebrate population studies, oyster spat settlement, reef subsidence, and oyster recruitment (Mass and Ruzicka 2008, 2009, Leaf 2010). The NRG studies also indicated good potential for the oyster reef development at the Soundview Park restoration site. Based on these prior studies (Grizzle et al. 2013 and Peterson and Kulp 2013), Soundview Park was chosen as the study site for the present project which was a larger scale (~1 acre bottom footprint overall) oyster reef restoration effort.

IV. Goal and Objectives

The overall goal of the project was to build upon previous research by our partners and others towards development of an effective oyster (*Crassostrea virginica*) restoration protocol for the New York Harbor region and initiate a pilot effort totaling nearly 1 acre overall.

Oyster restoration in the northeastern U.S. is in its early developmental stages as compared to areas further south, in large part because oyster populations in the northeast are typically both "substrate" (mainly the shells of live oysters on the reefs) and "recruitment" (because of very low reproductive output from extant natural reefs) limited (e.g., Levinton and Doall 2011, Levinton et al. 2013), which is often the result of severely depleted oyster populations (e.g., Brumbaugh and Coen 2009, Mann et al. 2009a, Powell et al. 2012). As an added difficulty, strong currents, waves, and boat wakes must be addressed in reef design and construction (e.g., Walters et al. 2002, Coen et al. 2004, Brumbaugh et al. 2006).

In order to meet the overall goal, the following objectives were addressed.

(1) Assess site suitability, map and construct reef footprints using bivalve quarantined ('cured') mollusc shell, including assessing alternative construction methods for medium-scale (~1 acre) reef restoration. This includes monitoring of reef development (density of living and dead filter-feeding organisms, SOS survival and growth, etc.) and changes in reef footprints (Universal Metrics 1 & 2 in Baggett et al. 2014) through time;

(2) Use aquaculture methods to produce oysters (SOS) to 'jumpstart' these relatively shallow, subtidal reef restoration sites through the engagement of community partners in the major components of the project;

(3) Assess in a limited fashion organisms (infaunal primarily) within and adjacent to the restoration area prior to and during restoration efforts and related "habitat complexity" (recruiting organisms), (Universal Metrics 2 & 3 in Baggett et al. 2014); and

(4) Assess the potential for long-term sustainability of the restored oyster reef. For a restoration goal based metric (Ch. 9, metric #1 in Baggett et al. 2014).

The major bottom types at the study site were mapped in order to determine the best locations for reef construction by field inspection as well as low-altitude imagery obtained by a stationary balloon deployed by project partners and the Public Lab team (see Figure 2 and Balloon Mapping, see http://www.oyster-restoration.org/oyster-restoration-research-reports/# and http://publiclab.org/notes/liz/8-21-2012/bronx-river-soundview-park-oyster-reef-mapping). Field inspection consisted of walking multiple transects at low tide back and forth across the area, marking waypoints on a Garmin GPS handheld unit and polygons on a Trimble GPS unit, and representing the positions of each bottom types noted (Figure 3). The major bottom types mapped included: (1) soft sediments (mud/fine sand), firm sand/gravel/rock, and large rocks. We also noted previous oyster restoration footprints (Figures 3 & 4).

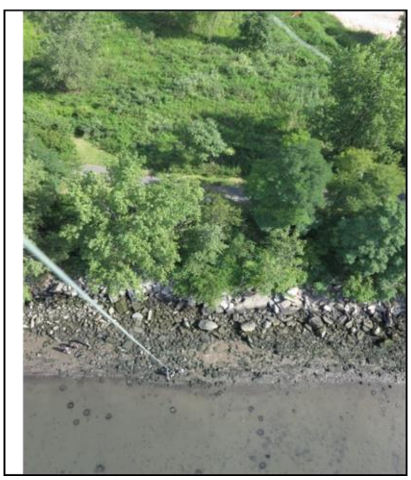


Figure 2. Image from balloon mapping showing some shallow seaward bottom habitat features from Public Lab.

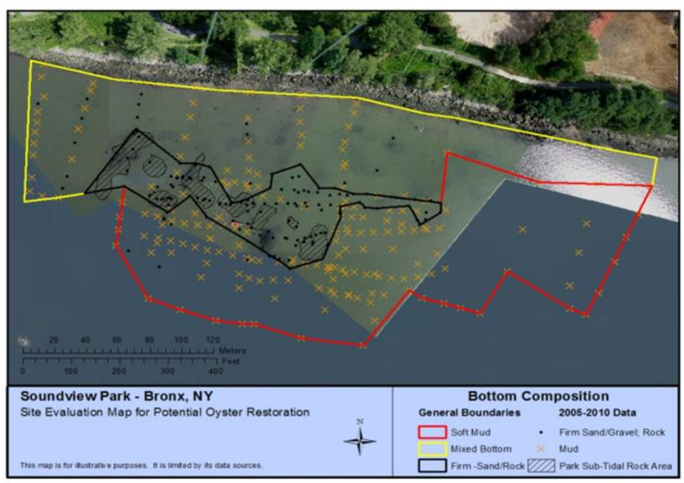


Figure 3. Bottom type characterization prior to reef construction using field assessments and GPS resulting in above ArcGIS map superimposed on the Public Lab balloon imagery by K. Schulte.

V. Methods

Site Survey and Reef Construction

Reef construction consisted of two phases: (1) deposition of seasoned molluscan (surf clams and ocean quahogs) shell from a barge forming five individual mounds within the overall 1-acre restoration footprint to form the reef base (Figure 4; see also Figures 3.1 and 8 in Baggett et al. 2014), and (2) placement of juvenile spat-on-shell (SOS) produced by the Harbor Foundation/Harbor School using standard aquaculture methods (see Aquaculture Section below for details) on October 16, 2013 (Figure 5) at two densities. The effort was highlighted by local and national (Al Jazeera America) news programs. The large "control" reef had no added SOS oysters to act as a control on SOS addition (Coen and Luckenbach 2000, Baggett et al. 2014, 2.5.2, Comparison with Natural or Reference Reef). All bivalve mollusc shell was 'seasoned' (quarantined) for more than six months to remove any soft tissue and minimize the possibility of contamination by invasive organisms or disease (Bushek et al. 2004, NOAA Fisheries Service 2013).

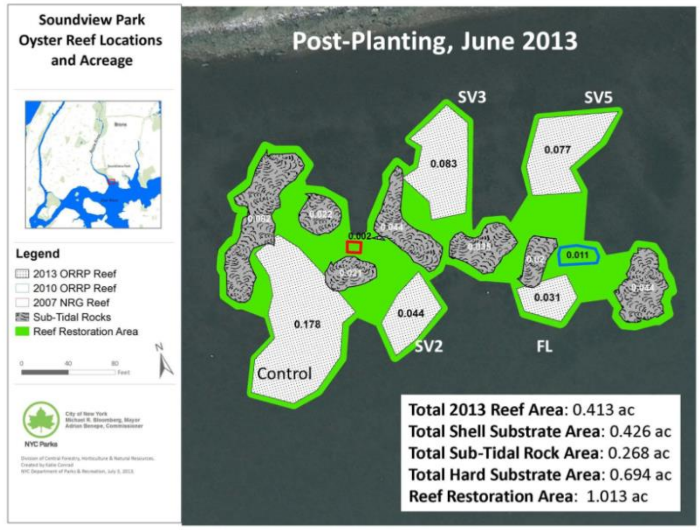


Figure 4. Reef areas/shape in 2013 soon after construction. Overall area in green ~1 acre. Red box indicates the NRG "community reef".

Figure 5. Deploying SOS within each reef footprint at two densities from 'Supertrays' delivered from the Urban Assembly New York Harbor School in 2013.

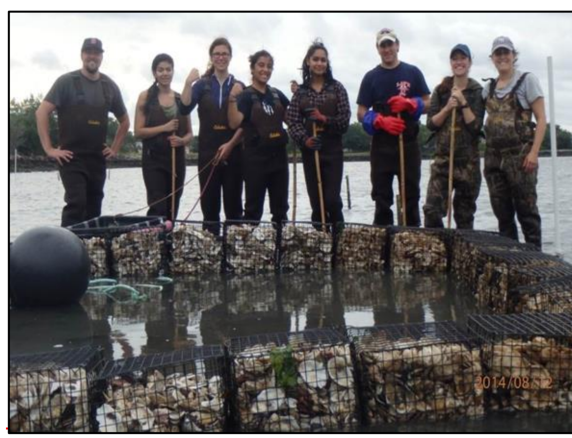


Figure 6. Gabion Blocks secured together forming a 10 ft^2 perimeter 'reef'.

In addition to the loose spat-on-shell reef creation method deployed in 2013and described above, in 2014 we deployed 1ft^3 gabion blocks filled with shells (half set with SOS) and secured together to create two 10 ft^2 perimeter of Gabion block reefs (Figure 6). Within the 10 ft^2 perimeters additional remotely set spat-on-shell were planted in the interior of the gabion blocks. Two age classes (2 month and 2 year) of spat-on-shell were planted. The Gabion block restoration pilot effort was designed to address the erosion of spat-on-shell observed during the ORRP phase 1 study and the first year data from this study. Table 1 above summarizes the date and objectives of the major field activities associated with the project.

Table 1. Major field activities for the duration of the project. Site designations: "SV"=spat from Soundview broodstock; "FI"=spat from Fishermans Island; "LD" = SOS low density (100/m^2); and "HD" = SOS high density (300/m^2).

Date	Objectives	Sites Sampled
8/20/2012	Site survey, mapping, balloon, GIS	Overall study site assessment
8/21/2012	Pre-construction benthic sampling	Overall study site assessment
6/24/2013	Reef base construction	SV5-HD, SV3-HD, SV-2 LD, FI-HD, Control
6/25/2013	Spread shells and map reef areas	SV5-HD, SV3-HD, SV-2 LD, FI-HD, Control
10/15/2013 - 10/16/2013	Deployment of spat-on-shell	SV5-HD, SV3-HD, SV-2 LD, FI-HD
10/17/2013	Quadrats, oyster density, size	SV5-HD, SV3-HD, SV-2 LD, FI-HD, Control
6/16/2014	Quadrats, oyster density, size	SV5-HD, SV3-HD, SV-2 LD, FI-HD
7/14/2014	Quadrats, oyster density, size	SV5-HD, SV3-HD, SV-2 LD, FI-HD
7/14/2014	Site re-survey, mapping	Overall study site assessment
8/12/2014	Gabion reef block installation	Reef A and Reef B
8/13/2014	SOS deployment within Gabion block perimeter	Reef A and Reef B
9/7/12014	Main reef and Gabion reef, oyster density, size	Overall study site assessment
10/6/2014	Gabion reef quadrats	Gabion Reef A and B

Reef Footprint Through Time

Using a Trimble GPS, we mapped the footprint of each of the five shell bases ("reefs") by walking the shell outline at spring low tides soon after planting on June 13, 2013 and again on July 14, 2014. Our intent was to assess whether the shell was spreading out, sinking or piling up given the physical energy at the site from a large fetch allowing waves from winds and boats wakes to disturb the site. We also measured reef height to assess the relative shapes of the reefs. Reefs were not flat over their surface but rather they consisted of many peaks and valleys as one would expect from planting off a barge as well as wave repositioning of the shell. Reef area/shape was determined just after the shell base was constructed and approximately 1 year post-construction by walking the perimeter of each of the five shell mounds (see below Figure 8 A, B) and recording position at multiple points; the resulting datasets were plotted and polygons manually drawn using ArcGIS software to show the shape and size of each mound (Figure 4). The height above ambient bottom of the shell bases was measured (to nearest cm) at multiple points with a marked rod.

Reef Development and Sustainability

Reef development was assessed by quantifying all four of the "Universal Reef Metrics" recommended in Baggett et al. (2014): reef area/shape and reef height (see above), oyster density, and oyster size-frequency. Oyster density and size were determined by excavating 1-2 (replicates) 0.1 m^2 quadrats, counting all live and dead oysters and following Baggett et al. (2014) measuring a minimum of 50 or more live oysters (shell heights with calipers to nearest mm) and then returning the samples to the appropriate reef. For the reef quadrats we measured all live oysters and collected info on dead ones also.

Habitat Complexity

Assessment of habitat complexity was aimed at determining how the restored area compared to habitat that existed in the general area as well as before reef construction; i.e., it provided a quantification of "habitat substitution." This assessment consisted of comparison of the pre-construction benthic community data from the general area of the constructed reef with data from experimental 'Supertrays' deployed adjacent to the "community" reef (see red square in Figure 4). The "before" samples for habitat substitution were obtained at four sites within the general restoration area on August 21, 2012. Two (2) vanVeen grab (0.04 m^2 sampling area) samples were taken at each site and combined to yield a total sample area of 0.08 m^2 of sediment surface area per site. Four experimental 'Supertrays' (at right, each 2' x'2', 0.61 cm x 0.61 cm, or 0.36 m^2) containing the original oyster spat-on-shell (to mimic the constructed reef surface) were not used in the SOS deployments but were left within the reef footprint near the "community reef" and then retrieved in July 2014. All samples (grabs and trays) were washed on a ~1 mm mesh sieve, the residue processed immediately, or stored on ice and in some cases frozen until processed. In the laboratory, all organisms were identified (taxonomy based on Williams 1984, Weis 1995, Pollack 1998) to the lowest taxonomic level practical, counted, and weighed (wet weight to nearest 0.1 g).

VI. Results and Discussion

The project was delayed for nearly a year from Superstorm Sandy which caused a loss of the seasoned shell being stored at Sandy Hook, NJ. This required securing additional seasoned shell from Massachusetts for construction of the reef base. The delayed start allowed us to use larger (older) spat on shell that had been initially produced in 2012 and then over-wintered at the School's aquaculture site before deployment onto the reef base. Additionally, we developed and deployed a pilot to test the use of gabion blocks to form a perimeter reef to reduce the transport and loss of SOS.

Site Survey and Reef Base Construction

The study site consisted of a complicated mix of bottom types including natural soft sediments, rock, fill material, and two previous restoration projects (Figures 2 - 4). The New York City Parks and Recreation, Natural Resources Group constructed an experimental oyster reef in 2007 ("community reef" in Figure 4), and the Oyster Reef Restoration Partnership constructed a reef in 2010 ("ORRP" in Figures 1 & 4); see NRG (2010) and Grizzle et al. (2013) for details. For this effort, the overall plan was to construct the present restoration project mainly in soft-sediment areas, avoiding rocky areas and the two previous reef restoration areas.

Fig. 7. A., Shell barge approaching restoration site with various partners in boats observing. B., barge deploying with pressure hose seasoned mollusc shell to construct shell base.

Construction of the reef bases was completed on June 24, 2013 by deploying 125 yd^3 (or >2,700 U.S. bushels) of seasoned shell from a barge onto the restoration site. Precise shell mound locations and shell heights were obtained by using multiple anchoring points and repositioning of the barge continuously during the placement. Deployment of the shells was carefully controlled using a high pressure hose and "washing" the shells off the barge (Figure 7A, B). More than eight hours were needed to complete the shell deployment. The as-built configuration of the reef base consisted of five separate shell mounds of variable heights (Figures 8B, 9C). Proceeding from left (west) to right (east) in Figures 4 and 9, each of the five shell mounds covered, respectively, 0.178 acres, 0.044 acres, 0.083 acres, 0.031 acres and 0.077 acres, yielding 0.413 acres (within the overall 1 acre restoration site) covered in large part by clam shell.

<u>Reef Footprint Through Time</u>

The control reef was the largest followed by SV3, SV5 which were similar in size, followed by SV2 and FI which was the smallest footprint (Figures 4 & 9). Upon reassessment of reef footprints at low spring tide (Figure 8A,B), we again walked the reefs and collectively noted an overall area of four of the five reefs (we could not re-assess the control reef given the rapidly rising tide) at 0.217 acre, versus 0.235 acre, a small negative loss of 0.018 acre (or a change of -7.66%). Reefs mostly lost 4.5-9.7% (SV2, FI) of their areal footprint, whereas reef SV3 lost ~35% of its footprint. However, SV5 gained nearly 21% in area. Part of the potential error of assessing reef footprints can be differences in the person walking the footprint, depth and clarity of the water, even at low tide, to allow for accurate reef visualization.

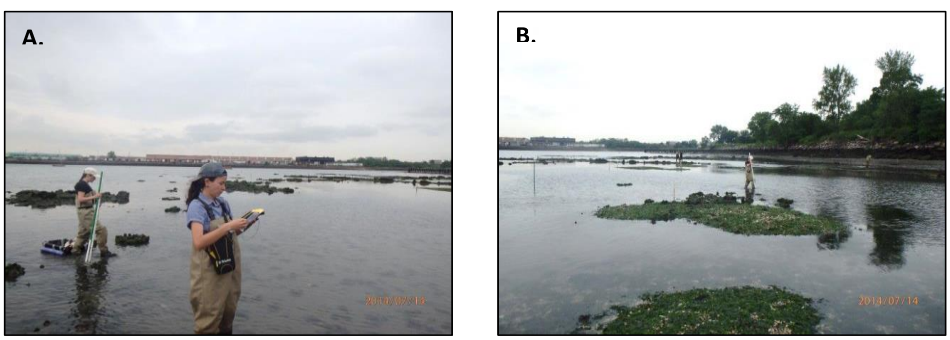


Figure 8. A: Walking the reef footprints with Trimble GPS (S. Tobing, NY Parks Dept.), July 2014; B: Algal covered reefs exposed at extreme spring tide for ease of assessment. Note *Ulva* covering reefs.

In October 2013, approximately three months after the shell base was completed, remotely set spat-on-shell were manually spread onto the surface of four of the five shell mounds, leaving one of the mounds as a "control" site to monitor natural spat set on the reef bases (Figures 9 & 10). Three of the mounds (SV2, SV3 and SV5) received spat produced from wild oyster broodstock from the Soundview area, and one (FI) received spat produced using broodstock from Fishers Island Oyster Farm. Density of the spat-on-shell was also varied, with SV3, SV5 and Fischer Island (FI) receiving an estimated initial planting density of 300 oysters/m^2 and SV2 receiving an estimated density of 100 oysters/m^2.

In addition to the loose spat-on-shell method described above, we developed and deployed 1ft^3 Gabion blocks filled with shells and secured together to create two 10 ft^2 Gabion block reefs. Half of these blocks were set with spat-on-shell in the aquaculture facility at the NY Harbor School (Figure 10A) the remainder contained only seasoned oyster shells. Within the 10 ft^2 perimeters additional remotely set spat-on-shell were planted in the interior of the Gabion block perimeter. Two age classes of spat-on-shell were planted: (1) 2-month old; and (2) ~2-year old oysters. Monitoring data to access this new restoration technique will be collected throughout the 2015 season and is not part of the reef development assessment below.

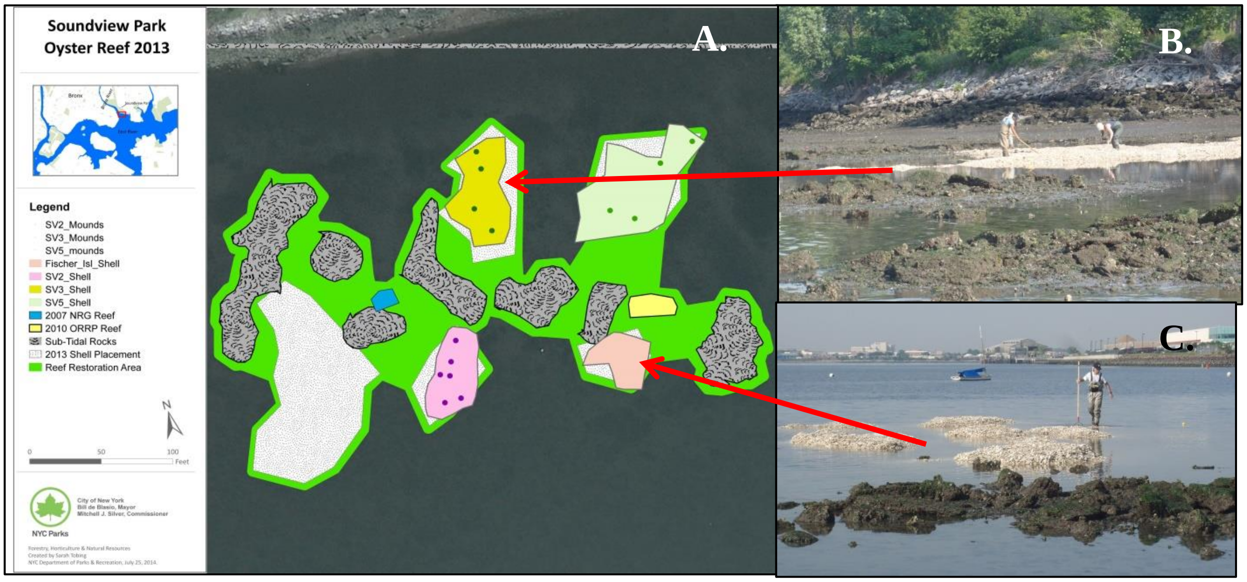


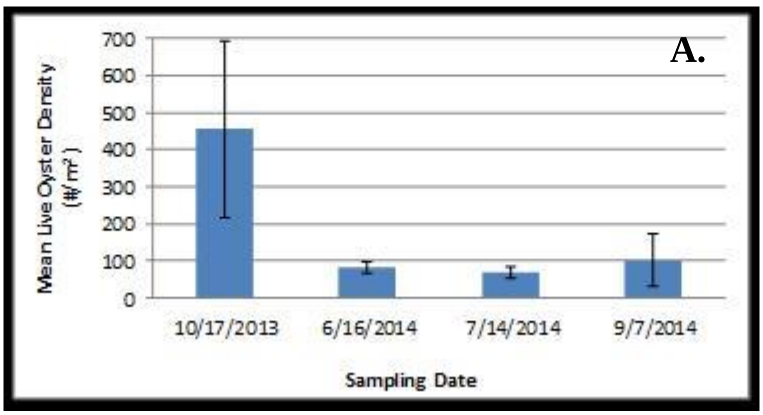
Figure 9. A: As-built reef base configuration and spat-on-shell deployments showing major components and spatial relationship to previously constructed Park reef (small blue polygon “2007 NRG Reef”), ORRP reef (small light yellow polygon “2010 ORRP Reef”), and rock bottom areas present before reef base construction (gray mottled polygons “Subtidal Rocks”). The overall approximately 1 acre restoration area is depicted by the green polygon. Photos B and C (June 2013) are of two shell mounds the day after construction. Manual spreading of shell in B. was used in order to get more even distribution of shell (see text for details). Red arrows denote the locations of photos on the polygon map.

Figure 10. Experimental shell-filled gabions deployed to the restoration site in 2014. A., putting Gabion blocks into remote setting tanks; B., live (SOS) oysters on shell in one of the Gabions; C., inspecting Gabion blocks perimeter restoration site (see text for details).

In addition to the loose spat-on-shell method described above, we developed and deployed 1 ft^3 gabion blocks filled with shells and secured together to create two 10 ft^2 gabion block reefs. Half of these blocks were set with spat-on-shell in the aquaculture facility at the NY Harbor School (Figure 10A) the remainder contained only seasoned oyster shells. Within the 10 ft^2 perimeters additional remotely set spat-on-shell were planted in the interior of the gabion block perimeter. Two age classes of spat-on-shell were planted: (1) 2-month old; and (2) ~2-year old oysters. Monitoring data to access this new restoration technique will be collected throughout the 2015 season and is not part of the reef development assessment

Reef Development and Sustainability

Reef development was assessed by taking replicate quadrat samples on four separate occasions (with months post-construction in parentheses): October 17, 2013 (4 months); June 16, 2014 (12 months); July 14, 2014 (13 months); and September 7, 2014 (15 months). Only subsets of the entire study area were sampled on each occasion, and there was wide variability in live oyster density among replicate quadrats. Nonetheless, two major trends were clearly discernable over time for combined datasets for the spat-on-shell put onto the reefs (Figure 11): (1) live oyster density dramatically declined through time; and (2) mean live oyster size increased through growth as the reef oysters developed.



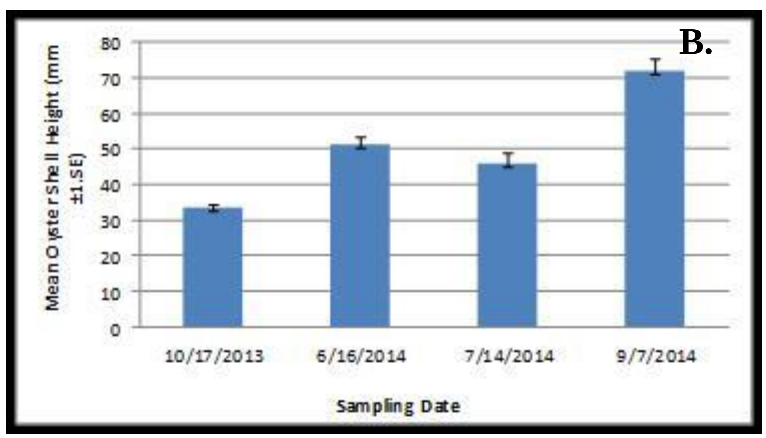


Figure 11. A., Mean (±1 SE) oyster density for combined datasets involving “high density” spat-on-shell treatments (see Table 1); B., mean (±1 SE) oyster shell height for combined dataset for all spat-on-shell treatments.

Most of the decline in density occurred over-winter in 2013, the initial months of the project. Although the cause(s) cannot be identified, it seems likely that predation by other invertebrates or fish would have been minimal during the winter. In contrast, there was no measureable mortality during spring-fall 2014, with mean densities remaining at ~50 to $100/m^2$ (Figure 11A). We are aware of only limited data quantifying oyster densities on natural reefs in the region (e.g., Medley 2010). However oysters have been observed at numerous locations in the HRE and the Long Island Sound (35 miles to the east of the study site) has an active oyster industry with periodic natural recruitment. In addition, extensive "oyster bottom" with some live oysters have been found in several areas in the Hudson River during the EIS work for replacement of the Tappan Zee bridge (also see earlier studies by Bell et al. 2006). Interestingly, the densities observed on our restored reef are similar to what has been typically observed for the past 10 or so years on natural subtidal reefs in New Hampshire; reefs there have typically remained at 50 individual oysters/m^2 or less most years since the late 1990s (New Hampshire Fish and Game Department unpublished data). This may suggest a limit in live oyster densities that can be expected on northeastern subtidal reefs due to the present combination of disease, predation, and other limiting factors.

The growth rates indicated by changes in mean shell height (Figure 11B) were typical of that reported in earlier studies in the region (cf. Cerrato 2006, Medley 2010, Levinton and Doall 2011, Levinton et al. 2013), including our previous work on the ORRP reef (Grizzle et al. 2013). Oysters in the region typically grow at the rate of 30 to 40 mm/yr. in shell height during the first two years.

The project was of limited duration relative to assessing long-term sustainability of the restored reef, and the gabion block restoration method has not yet been assessed. Nonetheless, important information related to "potential' long-term sustainability was obtained. Perhaps most importantly, the changes observed in configuration of the constructed shell bases showed some changes, but there was no consistent trend (Figure 9). Positional accuracy of the GPS units and the difficulty of determining the exact transition of hard shell substrate to soft bottom habitat may explain some of the variations. Nonetheless, it seems reasonable to conclude that there had been at most only minimal changes in overall shape and size of the shell bases used to construct the restored reef. This finding is important for assessing long-term sustainability of the reefs because the earlier smaller ORRP reef had shown substantial wave effects, with live oysters and shell material significantly eroded and transported landward during its 2-year duration (Grizzle et al. 2013). Monitoring reviews have recently highlighted how critical it is to follow through time the reef footprints of restoration projects for longer term periods (Baggett et al. 2014, Powers and Boyer 2014).

Based on our field sampling, we (Grizzle et al. 2013) hypothesized that the transport of shell off the original ORRP reef probably was a result of some combination of boat wakes and wind-generated waves. Similar erosional effects of wave energies on natural reefs have been reported in other areas, especially for intertidal reefs (e.g., Grizzle et al. 2002, Wall et al. 2005, Seavey et al. 2011, Houser 2012). Although the ability of oyster reef material to mitigate shoreline loss is now being documented for intertidal reefs primarily (Piazza et al. 2005, Gregalis et al. 2008, Scyphers et al. 2011, 2014, Manis et al. 2014), there is no quantitative understanding of the wave energies planted shells reefs can tolerate. It will be important to continue to monitor changes in shape and size of the shell mounds constructed in the present study. Ideally these future assessments should include a quantitative characterization of the wave energies associated with any observed changes in reef shape and size because a quantitative understanding will be needed for designing future restoration projects.

A second factor relative to assessing reef sustainability is natural ("larval supply") recruitment. There were no spat observed on the clam shell used to construct the reef base, suggesting no natural recruitment in 2013. Inspection of the size-frequency plots for spat-on-shell spread onto the reef also indicates no recruitment during 2014 because the smallest oysters observed in the Sept. 2014 sampling was ~30 mm shell height (see Figure 12).

The finding of no natural recruitment to the newly restored reef should not. However, lead to the conclusion that no natural recruitment is likely to occur in the future. In fact, available evidence suggests the opposite. Although no quantitative samples were taken, observations made in 2013 on both the ORRP and the older Parks Dept. Natural Resource Group (NRG) reefs and other hard substrates in the general area showed live oysters that had probably recruited in 2012 (Figure 13). Natural "spat" (=recruiting oysters onto amended substrate) sets in the region have shown substantial year-to-year variability (e.g., Mass and Ruzicka 2008, Levinton and Doall 2011, Grizzle 2013, Levinton et al. 2013), probably due to the low numbers of live oysters in the region. Thus, consistent annual recruitment should not be expected.

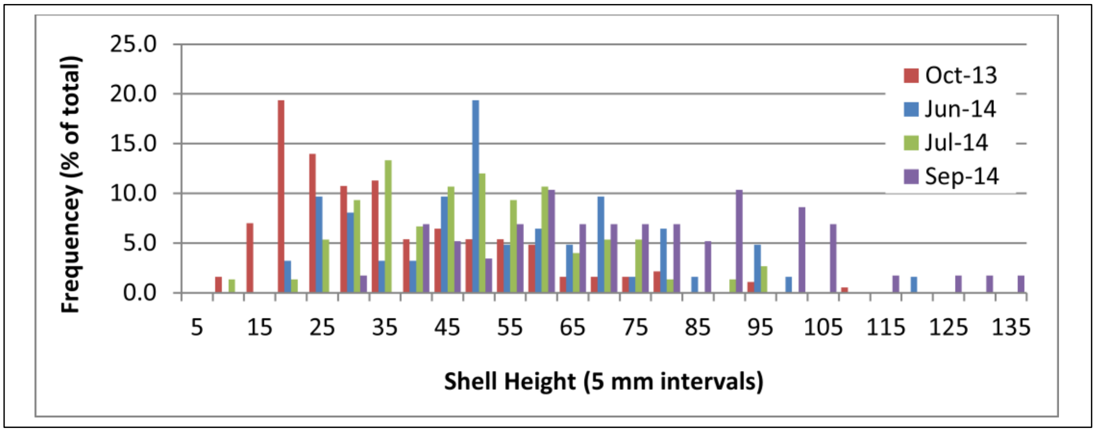


Figure 12. Size-frequency distribution for all four sampling events and including all live oysters retrieved.

Longer-term sampling is needed to assess whether these relatively small reefs are sustainable (Baggett et al. 2014). However, the present study provides a solid database for such efforts, and it includes data from all four universal metrics recommended in recent reviews (Coen et al. 2004, Baggett et al. 2014).

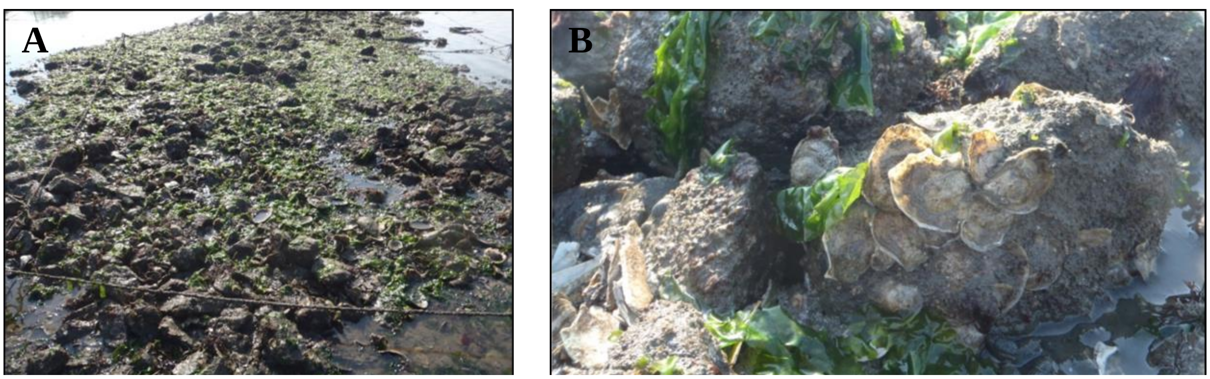


Figure 13. Photos taken in 2013 showing scattered live oysters that had probably settled in 2012. A., "community reef" constructed in 2007; B., close-up of ORRP reef constructed in 2010.

Habitat Complexity

The project resulted in a substantial enhancement in overall habitat complexity in the 1-acre restoration area. Previous work had resulted in construction of two small oyster reefs, one in 2007 and one in 2010 (Figure 4). Although the present project did not involve quantitative assessments of these previous reefs, our field observations indicated both have persisted and still contain small numbers of live oysters (Figure 13). Previous sampling also characterized the benthic communities on the constructed reefs (see Mass and Ruzicka 2008, Grizzle et al. 2013, Peterson and Kulp 2013) and quantified the differences between the restored reefs and adjacent soft-bottom invertebrate and fish communities from the perspective of "habitat substitution."

Habitat substitution was addressed in the present study by comparing the pre-construction soft-sediment benthic community to the benthic community that developed on the constructed reef. Total community densities were similar in the pre-construction soft-sediment benthos compared to the experimental trays placed onto the restored reef areas, but taxonomic richness was much greater in the trays (Table 2). It should be noted that only the density data are directly comparable due to different sample sizes, and there is no straightforward way to adjust for this difference in assessing taxonomic richness. Even so, there were nearly twice as many taxa collected on the constructed reefs compared to the pre-construction, soft-sediment benthic community. Taxonomic composition also differed dramatically, with only two species (highlighted in yellow in Table 2) occurring in both datasets. These findings are similar to data from this site in our previous ORRP phase 1 project (see Grizzle et al. 2013). Essentially all the comparative studies we are aware of involving oyster reefs and unvegetated soft-sediment areas has demonstrated substantial enhancement in habitat complexity, community density, and taxonomic richness in the oyster habitat (e.g., Luckenbach et al. 2005, Hadley et al. 2010, Shervette et al. 2011, Wong et al. 2011).

Table 2. Taxa lists with density data comparing pre-construction van Veen grab data with experimental trays from constructed shell mounds. Taxa occurring in both datasets highlighted in yellow and red.

Pre-construction (four 0.08 m^2 samples)	**Mean density (# Indiv./m^2)**	**Experimental trays (four 0.36 m^2 samples)**	**Mean density (# Indiv./m^2)**
Crepidula fornicata	31.3	*Callinectes sapidus*	0.7
Crepidula plana	25.0	*Crassostrea virginica*	108.4
Illyanassa obsoleta	56.3	*Crepidula fornicata*	1.4
Mya arenaria	12.5	*Dyspanopeus sayi*	54.9
Yoldia sp.	25.0	*Geukensia demissa*	1.4
Unident. Bivalvia	12.5	*Hemigrapsus sanguineus*	39.6
Unident. Gammaridae	12.5	*Littorina littorea*	56.3
Unident. Mactridae	12.5	*Mya arenaria*	0.7
Unident. Nereidae	37.5	*Mytilus edulis*	22.2
		Pagurus longicarpus	1.4
		Palaemonetes pugio	4.6
		Palaemonetes vulgaris	17.4
		Urosalpinx cinerea	36.1
		Unident. Ascidiacea	-
		Unident. Bivalvia	-
		Unident. Polychaeta	-
Community Density (#/m^2 +1SE):	**125.0 (+10.8)**	**Community Density (#/m^2+1SE):**	**123.5 (+29.6)**

Although faunal sampling was relatively limited, we did collect some replicate trays with deployed SOS at the study site in July 2014 (Table 3, Figure 15). A total of four trays were collected and processed. Live oyster totals in trays ranged from **6 to 220** individuals (6, 33, 213, 220 overall), and **6 to 67** oysters were measured from each tray (Table 3). Adjusted to densities per m^2, numbers ranged from **16-573** live oysters/m^2. Mean sizes ranged from **38.2 to 52.5** mm SH (all data, 38.2, 38.5, 47.4 and 52.5 mm). The size freq. combined of these trays is shown in Figure 14.

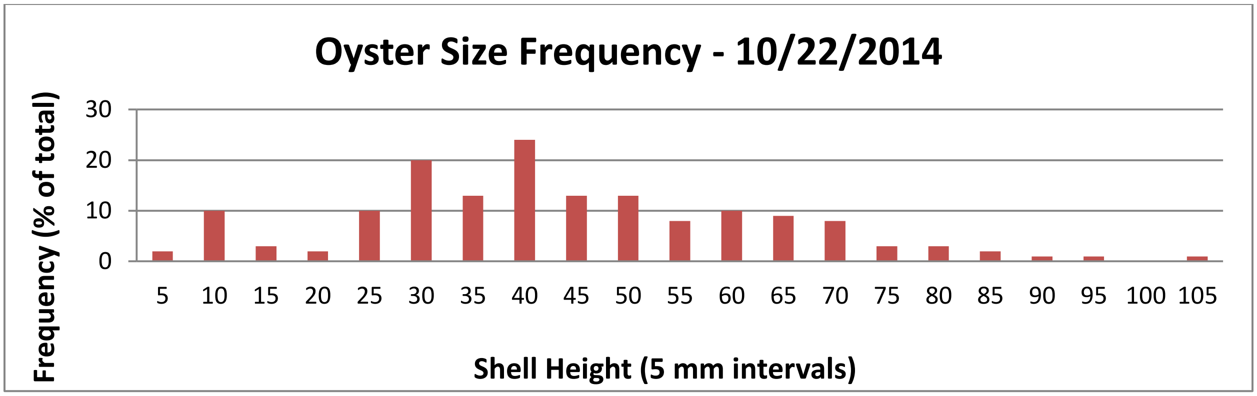


Figure 14. Combined size-frequency distribution for four sampled Supertray contents left at site on reef. Includes only live oysters.

Table 3. Replicate Supertrays (2' x 2') collected and worked up July 14-15, 2014 (see Figure 14 for data for live oysters). A minimum of 50 oysters were measured though all live oysters were counted.

Total N measured:	50	67	33	6
Mean Size mm:	47.44	38.2835821	38.515152	52.5
1SD	16.2921792	24.1703587	10.015991	12.53395389
Variance:	265.435102	584.206242	100.32008	157.1
Total Live in tray:	213	220	33	6
Date trays collected:	7/15/2014	7/15/2014	7/15/2014	7/15/2014

Figure 15. Typical sample of crabs, shrimp, mussels and gastropods from one of the Supertrays collected in July 2014 submerged.

Molluscs (bivalves, gastropods) and decapods (grass shrimp, blue crabs, hermit crabs, native and introduced crabs) were the numerically dominant taxa in the Supertrays. Overall, the four trays had total numbers of macrofauna ranging from 44 to 132 individuals (Table 3 and Figure 15). Adjusted to per m^2 (assuming trays are 4 ft^2 or 0.372 m^2), the crabs and molluscs ranged from 118 to 355 individuals/m^2 (see Table 3 and Figure 15). The non-native crabs included *Hemigrapsus sanguineus*, and many were ovigerous). The dominant mud crab was *Dyspanopeus sayi* (11 to 26/Supertray, with most ovigerous and quite worn). One small blue crab *(C. sapidus)* was collected. Two species of grass shrimp were collected, *Palaemonetes pugio* (0 to 3 individuals/Supertray) and *P. vulgaris* (3 to 11 individuals, with most ovigerous). Bivalves included mussels *(Geukensis* and *Mytilus*, 2 to 18/Supertray), and softshell clams (*Mya arenaria*). Large numbers of *Littorina littorea* (5 to 54/Supertray), though alive many were quite worn, along with many live *Urosalpinx cinerea* (2 to 27/Supertray).

Interestingly the number of individuals collected correlated with the total number of live oysters in the Supertrays, with the lowest number of oysters (and thereby shell) having the lowest number of associated mobile macrofauna. So as reef complexity increases we would expect the number of associated molluscs and decapod crabs, two important and commonly dominant mobile invertebrates collected, to increase as both prey and predators on restored reefs (e.g., Luckenbach et al. 2005, Hadley et al. 2010, Baggett et al. 2014).

We compared the size and density of oysters in Supertrays (undeployed oysters) vs. loose SOS from Supertrays deployed on reefs (cf. Figures 11 and 12 vs. Table 3 and Figure 14). Supertrays (n =4) sampled contained adjusted to densities per m^2, a total of **16-573** live oysters. In contrast, mean densities from the two densities of deployed SOS on reefs declined to **~50 to 100**/m^2 (Figure 11A). Mean size in the Supertrays ranged from **38-52** mm SH versus means **>70** mm SH for those deployed onto reefs. The Supertrays loose on the community reef (n=4) potentially had moved and lost some of their original oysters without mesh covers, but the significantly larger mean sizes of oysters on constructed reefs suggests that they are growing better probably given that they were loose on shell (SOS) not in these tall sized trays on the bottom.

Community Engagement and Outreach

This project was a collaborative partnership that included federal, state and local government groups, research institutions, and regional and community-based environmental organizations. A central component of the project was the engagement of local community members in the restoration planning, restoration, and monitoring activities. Many of the project team members have long-standing relationships including past project collaborations with the Bronx River Alliance and Rocking the Boat.

A total of **83** community volunteers contributed an estimated **258** hours of volunteer hours to the reef construction and monitoring components of the project. This project successfully built off these established partnerships to engage additional local community members and provided a unique opportunity for community members to work with and learn from the project partners including the academic research community. This project successfully built off these established partnerships to engage additional local community members and provided a unique opportunity for community members to work with and learn from the project partners including the academic research community. This interaction also provided an opportunity for project partners to educate and inform local residents of the importance of protecting and restoring the Bronx River. In return, the Bronx-based community groups and volunteers brought valuable in-kind services to the project in the form of direct labor, boat support and other services.

The NY/NJ Baykeeper actively solicited volunteers from the local community and coordinated and facilitated their involvement throughout the project. Construction of the reef was aided by volunteers who helped delineate the shell placement areas, rake the shell mound, and add SOS to the shell piles in 2013. In 2013-2014, volunteers were used to monitor the “community reef” Supertrays (baskets, see Figure 5 and http://atlanticaquaculture.com/product/super-trays/, 2’ x 2’), assess oyster growth and mortality, and measure the abundance of associated fauna. In 2014, community partners also helped to construct the gabion blocks and the two experimental gabion cage perimeter ‘reefs’.

Community members aided in not only the construction of the reefs, but also the monitoring of the reefs. NY/NJ Baykeeper organized each monitoring day (August and October 2013, and one per month, May-October 2014), and oversaw the volunteers at the site. Volunteers ranged from members of the scientific community (at other organizations and universities) to students and the general public looking to get involved with oyster restoration. In 2013, there were **13** volunteers who came out to help sample the reef. This number increased in 2014 due to active volunteer engagement by NY/NJ Baykeeper. In 2014, there were a total of **73** volunteers who came out to help sample the reef.

Each monitoring session lasted a minimum of three hours, for an estimated total of **258** volunteer hours contributed during the project. The community engagement and volunteer participation in the oyster restoration and research program was highly successful. Project partners are seeking additional funds to continue the reef monitoring program and ensure that the community remains engaged in the restoration of the Bronx River.

In addition, one of our project partners, the *New York Harbor School (NYHS)*, whose public high-school campus and Aquaculture Center are located on Governors Island, facilitated the involvement of high school students in the aquaculture production, restoration methods development and reef construction components including SOS stocking during 2013 and 2014. A class of **30** students participated in the aquaculture development components contributing and estimated **1,440 hours** of student time and an additional **17** students participated in the gabion block development and SOS placement activities contributing an estimated **102** additional volunteer hours for a total of total of **1,542** hours from the NYHS.

Outreach and Publications

Related Workshops/Meetings

Comi, M., 2014. “Making your Mark on the World.” Montclair High School STEM Career Panel. Montclair, NJ. (presentation).

Comi, M., 2014. "Oyster Restoration In the Hudson-Raritan Estuary." Monmouth Conservation Foundation Climate Change Forum. Asbury Park, NJ. (presentation)

Fitzgerald, A.M., M. Comi, S. Tobin, P. Malinowski, and J. Lodge, 2014. Community based restoration in an urban setting: using EcoVolunteers to restore oysters in New York City. 16th ICSR Conference. Charleston, S.C. (poster).

Fitzgerald, A.M., M. Comi, S. Tobin, and J. Lodge, 2014. Community based restoration in an urban setting: using EcoVolunteers to restore oysters in New York City. Restore America’s Estuaries, 7th National Summit. Washington, D.C. (poster).

Lodge, J., 2014. It Takes a Community: Oyster Restoration and Research at Soundview Park, Bronx NY. Reclaiming a River Conference, October 23, 2014. Bronx, NY (presentation).

Malinowski, P., 2014. RAE 2014, Learning Through Research and Restoration: New York City Working in Hudson and Bronx River Habitats (While Building Boats, Careers, and Life Skills)

Malinowski, P., 2014. ICSR 2014 (16th), Panelist (Interpreting the NSSP: Where Restorers and Regulators Intersect),

Malinowski, P., 2014. ICSR 2014 (16th), Poster/Paper, Engaging High School Students in Oyster Restoration through Hands –On Authentic Learning Opportunities.

Malinoswski, P., 2014. ICSR 2014 (16th), Plenary Speaker, Engaging Our Youth Through Ecosystem Restoration.

Websites

The report and related efforts will be served up on several websites including the HRF Website http://www.hudsonriver.org/?x=orrp), and the Oyster Restoration Workgroup (see http://www.oyster-restoration.org).

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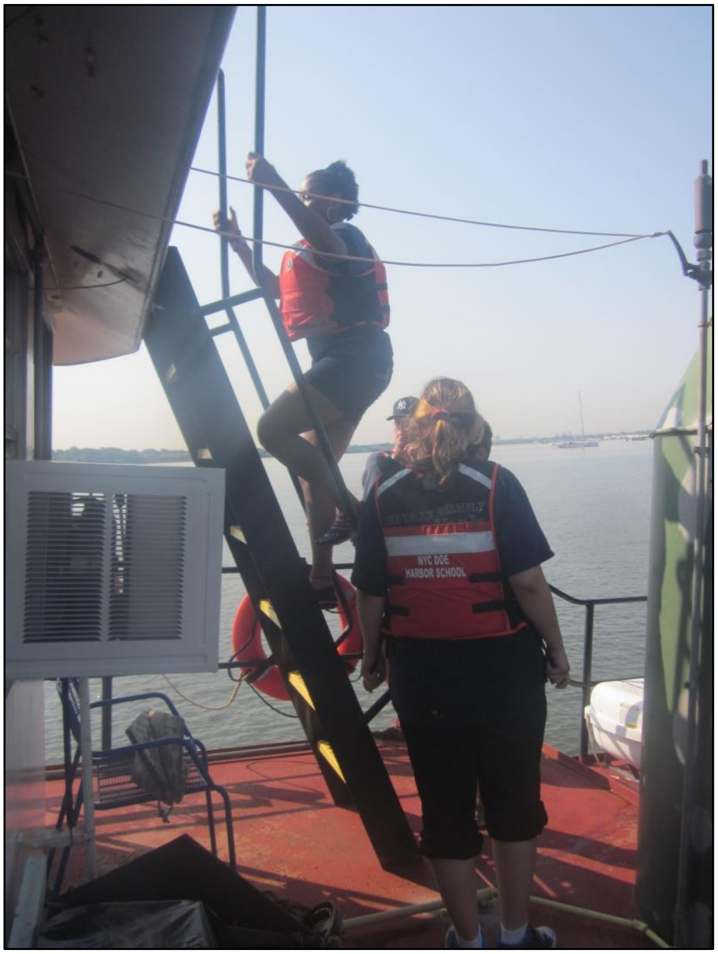
VIII. Appendix

Images from Community Restoration Efforts Through Time

Volunteers and project scientists work on monitoring area. Significant new hard substrates were added (clam shell) to enhance the recruitment of new oysters (spat), in addition to spat already on shell from the High School's hatchery and nursery since recruitment is often quite sparse. Here natural recruitment on tires, bottles, etc.

Construction day, June 24, 2013

Construction day, positioning the barge, June 24, 2013



Construction day, students from Harbor School on barge, June 24, 2013

Students from Harbor School with Oyster Shell

Shell being offloaded with water, bags and crane (see above and below), 6/20/13.

Dr. Ray Grizzle (UNH) and others including NY/NJ Baykeepers and volunteers from project being interviewed at site along shore (http://news.yahoo.com/yorks-environmental-hero-oyster-163717660.html).

Film crew from working with restoration sampling team (Dr. Allison Fitzgerald) from shore.

Sampling from shore at lower tide (see tidal range on rocks on shore) at site in Soundview Park.

Dr. Ray Grizzle (UNH) and Kerstin Kalchmayr (NY/NJ Baykeepers) from project at site sampling quadrats on reefs with AP (Aug. 22, 2012, http://news.yahoo.com/yorks-environmental-hero-oyster-163717660.html).

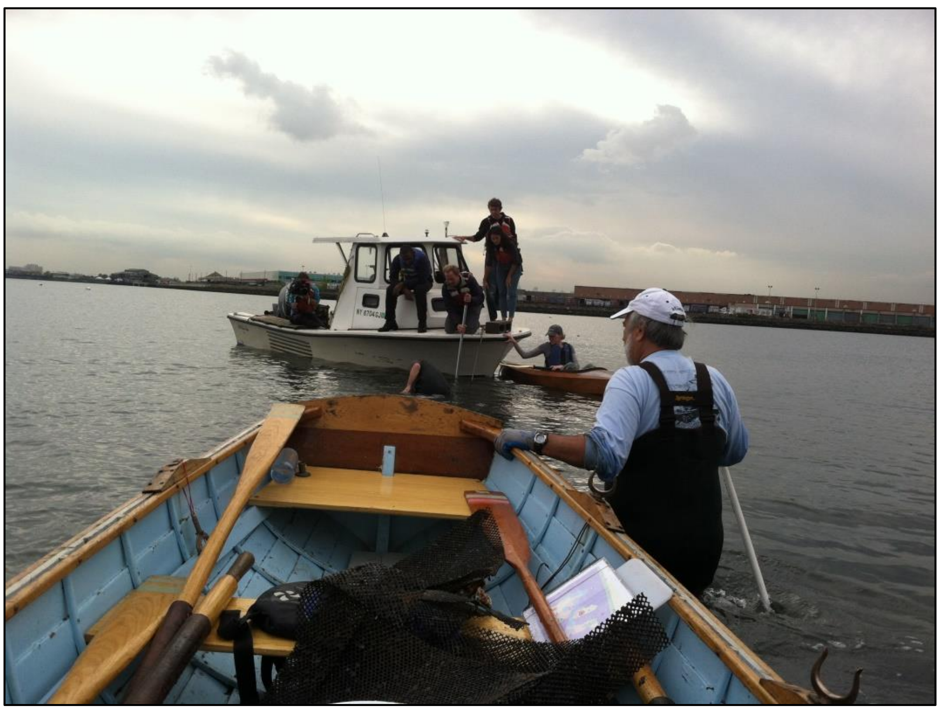
Aug. 22, 2012 photo, Dr. Allison Fitzgerald measuring oysters from a bed at Soundview (Photo: Mary Altaffer/AP).

Dr. Ray Grizzle (UNH) and Dr. Allison Fitzgerald (NY/NJ Baykeepers) from project at site working up oysters from quadrats on reefs.

Preparing to use Helium balloon for mapping reef area (with Public Lab folks) August 21, 2012.

See the proximity of the site to LaGuardia Airport (Aug. 22, 2012) and industrial development. Collecting data at planted oyster reef at Soundview Park in the Bronx (AP Photo/Mary Altaffer). Boat from Rocking the Boat.

Working with Jim Lodge (HRF), Dr. Loren Coen (FAU), volunteers from NY/NJ Baykeepers, Bronx River Alliance and Harbor School deploying oysters on shell (SOS) from Supertrays onto reefs delivered from H.S. October 2013.



Dr. Loren Coen (FAU) and volunteers from Bronx River Alliance, Rocking the Boat and Harbor School vessel deploying oysters on shell (SOS) from Supertrays onto reefs delivered October 16, 2013. School returning emptied Supertrays to School loaded onto School's vessel and Rocking the Boat boat.