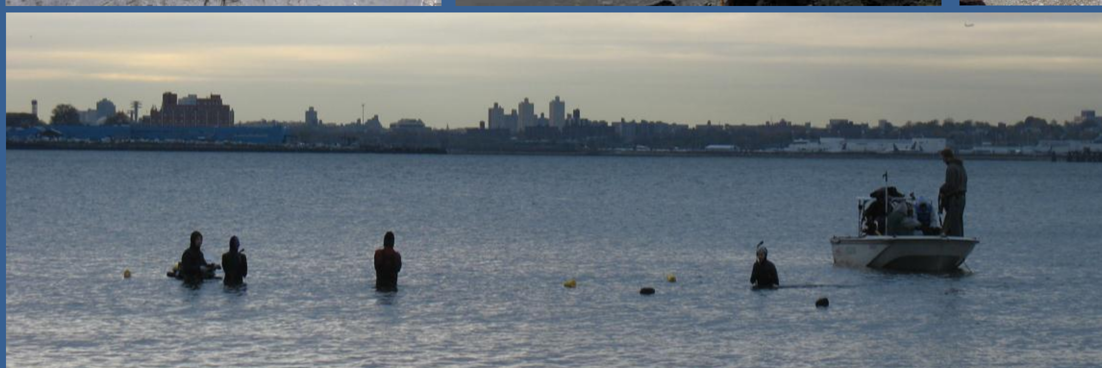
2009-2012

Oyster Restoration Research Project (ORRP) Final Technical Report

ORRP Phase I: Experimental Oyster Reef Development and Performance Results



Raymond Grizzle (ray.grizzle@unh.edu), Krystin Ward (kward@unh.edu)
University of New Hampshire, Jackson Estuarine Laboratory, 85 Adams Point Rd, Durham, NH 03824

Jim Lodge (jim@hudsonriver.org), Dennis Suszkowski, (dennis@hudsonriver.org)
Hudson River Foundation, 17 Battery Place, Suite 915, New York, NY 10004

Katie Mosher-Smith (katie@nynjbaykeeper.org), Kerstin Kalchmayr (kerstin@nynjbaykeeper.org)
New York/New Jersey Baykeeper, 52 West Front Street, Keyport, NJ 07735

Pete Malinowski (pmalinowski@nyharborschool.org)
New York Harbor School, Governors Island 10 South Street, Slip 7 New York, NY 10004

Executive Summary

This report describes the results of the Oyster Restoration Research Proejct (ORRP) Phase I (2010-2012) studies to assess development (oyster retention, growth and survival) and performance (water filtration and habitat provision) at five experimental reef sites (Bay Ridge Flats, Governors Island, Hastings, Soundview and Staten Island). This report also provides an assessment of where additional efforts should be focused and questions that need to be answered. Because the constructed experimental reefs essentially replaced the habitat that existed at the time of construction, there is a need to understand these changes on the broader ecosystem. Thus, another objective of the ORRP Phase 1 studies was to evaluate "habitat substitution" by comparing the faunal benthos before and after reef construction.

Reef construction consisted of placement of rock bases followed by a thin mollusk (mostly surf clams) shell veneer at all five sites in Sep/Oct 2010. In Oct/Nov 2010 oyster spat-on-shell (SOS) produced from remotely set larvae were spread by hand over the surface of each reef. SOS were distributed again at Governors Island, Hastings and Soundview in June 2011; additional SOS were distributed at Governors Island from July-November 2011. Reef development was assessed by replicate quadrat sampling periodically from Nov 2010–Oct 2012. Water filtration was measured using *in situ* fluorometers at Hastings and Soundview in July 2011, and at Soundview in Aug 2012. Habitat provision was assessed by characterizing the organisms other than oysters (=resident taxa) found in experimental trays containing shell placed onto each reef.

During 2011, the reefs at Soundview, Hastings and Governors Island showed development patterns indicating potential for further restoration activities based on four criteria: SOS survival and growth, natural recruitment, and environmental conditions. All three sites had some level of natural recruitment, and the SOS showed good growth. All three, however, also had substantial *apparent* mortality (suggested by observed density differences from initial SOS seeding) but there is evidence that much of this "mortality" was caused by transport (by waves and currents) of SOS off the reef. For Soundview and Governors Island, some of these transported oysters were found alive inshore of the experimental sites. During 2012, the reefs at Soundview and Hastings showed similar trends for SOS growth and survival, and both particularly had exceptional natural recruitment. The reef at Governors Island, however, had poor survival (high apparent mortality) and low observed natural recruitment. Environmental conditions (salinity, temperature, etc.) were well within acceptable ranges for the eastern oyster at all three sites, except Hastings had quite low salinities for much of spring/summer 2011 and 2012. The other two reefs (Staten Island and Bay Ridge Flats) were not adequately assessed due to access and other logistical problems.

Whole-reef water filtration rates were expected to be low on the two reefs assessed (Soundview and Hastings) because they were measured when the reefs were in very early development phases (small oysters at low density). Nonetheless, both reefs showed measureable chlorophyll removal at times in 2011, even though they were also strongly affected by waves which re-suspended bottom sediments. In 2012, the Soundview reef had substantial filtration rates, removing >20% of the chlorophyll for much of the time.

Habitat provision was also expected to be minimal due to the young age of the reefs, but by the final sampling in Oct 2012 they showed high species richness as well as greater total community density compared to the pre-construction infaunal communities. With respect to habitat substitution, these data

confirmed the expected (based on studies in other areas) replacement of the pre-construction soft-sediment infaunal communities by more taxonomically rich and higher density epibenthic communities typical of oyster reefs.

In conclusion, based on the four development criteria (see above) and performance data, the Soundview site had best overall development patterns indicating the best prospects for successful restoration efforts (Phase 2) utilizing similar reef construction techniques which rely on high natural recruitment and lower energy environments. It is emphasized that this does not mean the other sites have no potential for further restoration efforts, but that Soundview showed the most potential. The Phase I assessment studies also revealed several issues that must be, and can be, addressed in designing future efforts. Perhaps the most critical challenge to overcome will be developing techniques for reducing the transport of SOS by waves and tidal energy in the high energy environments typical of NY/NJ Harbor. Another important message of the Phase I project is that future efforts must maintain an adaptive approach, reacting as necessary to findings that may emerge from monitoring.

Introduction

The goal of the overall Oyster Restoration Research Project (ORRP) is to further scientific understanding of oysters reintroduced into the NY/NJ Harbor Estuary. This phase of the project is designed to take the first steps toward determining the feasibility of achieving the oyster restoration targets of the Comprehensive Restoration Plan (USACE, 2009), and to gain local and practical oyster restoration experience. By constructing several experimental reefs in different areas (Fig. 1),

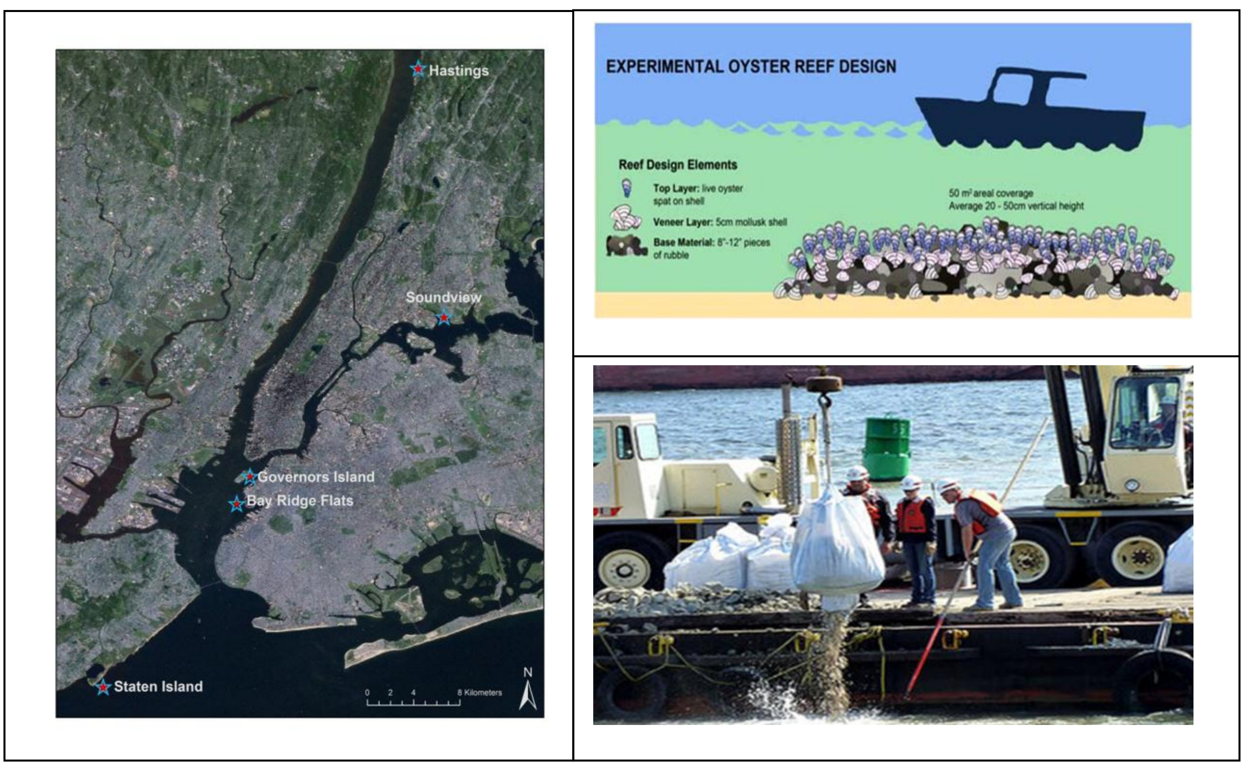


Fig. 1. Location of five experimental ORRP oyster reefs, schematic of individual reef design (upper right), and photo of shell veneer being placed on the Governors Island reef.

monitoring their development, assessing how oysters are affected by natural factors, and how the surrounding environment is affected by oysters, the project will provide important new information from which larger scale restoration decisions can be made.

This final technical report describes the results of ORRP Phase I most relevant to assessing development and performance of the five experimental oyster reefs, including an assessment of habitat substitution. The term “development” is used here to refer to growth and survival of oysters on the reefs. “Performance” refers to what is now more commonly termed “ecosystem services.” For the present study, performance metrics were restricted to water filtration and habitat provision. Because the constructed reefs essentially replaced the benthic habitat that existed at the time of construction, there is a need to understand the impacts of the constructed reefs on the broader ecosystem. The assessment of habitat substitution was essentially a comparison of the benthos before (soft-sediment infaunal benthos) and after (epibenthos on reefs) reef construction.

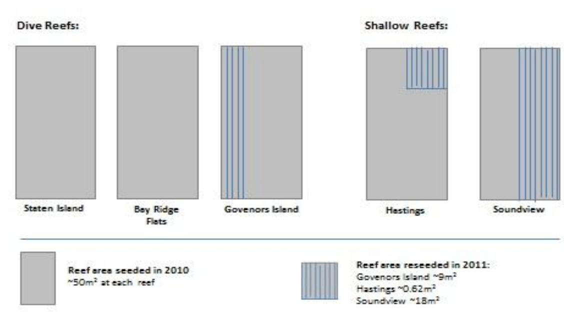
Methods

Reef construction and development

Reef construction consisted of placement of rock bases followed by a thin mollusk (mostly surf clams) shell veneer, with work done by the Army Corps of Engineers in Sep/Oct 2010 (Fig. 1). The areal coverage of each “footprint” varied somewhat, but averaged ~50 m^2 (5 x 10 m). In Oct/Nov 2010 juvenile oyster spat-on-shell (SOS) produced from remotely set (June 2010) larvae at NY Harbor School were spread by hand over the surface of each reef (Table 1). Adhering to an adaptive management approach, additional SOS were distributed on three of the reefs when it was discovered that substantial erosion and transport of SOS had occurred. Additional SOS placement also varied spatially at each of the three reefs (Table 1).

Table 1. Overview of initial SOS distribution (Fall 2010) and re-seeded SOS quantity and distribution over each reef during June 2011. Additional SOS were strategically placed along the shore-side perimeter of the GI reef (42,000 between July-November 2011).

Reef	SOS quantity placed Fall 2010	Coverage area	SOS quantity placed June 2011	Coverage area
SV	~58,500	~50m^2	~55,700	Northern half of reef ~18m^2
HH	~53,000	~50m^2	~10,100	Northeastern corner of reef ~0.62m^2
GI	~61,500	~50m^2	~42,000	Western portion of reef ~9m^2
BR	~55,000	~50m^2	Not re-seeded	NA
SI	~56,000	~50m^2	Not re-seeded	NA



Reef development mainly was assessed by taking replicate 0.1 m^2 quadrat samples. The first monitoring event occurred a few weeks following the first SOS placement in Oct/Nov 2010. Thereafter, commencing in May 2011, when possible, each of the five reefs was monitored periodically until November 2011, ending the first year of the project (see "Monitor" events in Fig. 2).

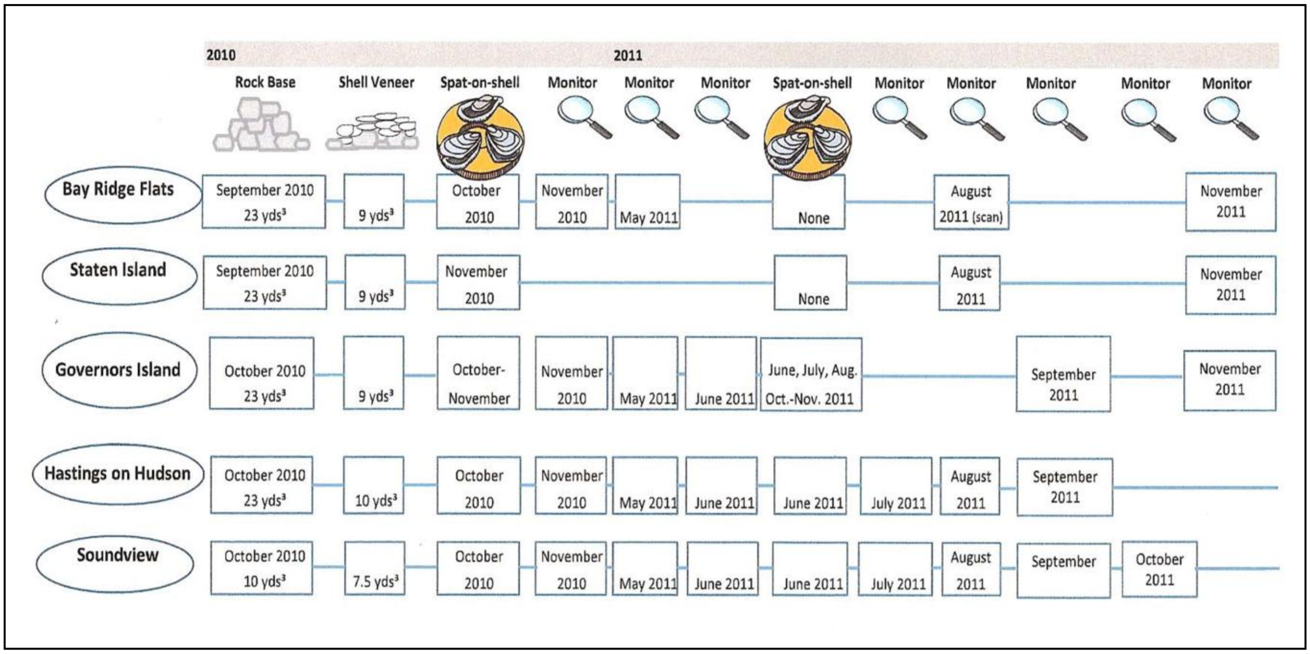


Fig. 2. Timeline of reef construction and monitoring during 2010-2011 (see Fig. 4 below for 2012 monitoring.).

The replicate 0.1 m^2 quadrats were placed haphazardly within one of nine cells ("quadrants" in Fig. 3) distributed systematically across the reef, yielding a total of nine replicate quadrats. All loose shell material on the surface of the reef was removed from each quadrat, the contents placed in a plastic tray and returned to the boat or shoreline for processing. All live and dead bivalves were identified and measured (shell height or length to nearest mm using calipers or a ruler). Only measurements of bivalves with two intact shells were made. After processing, all samples were returned to the reef. Two of the reefs (Hastings and Soundview) were sampled by wading at low tide, and the others were sampled by divers.

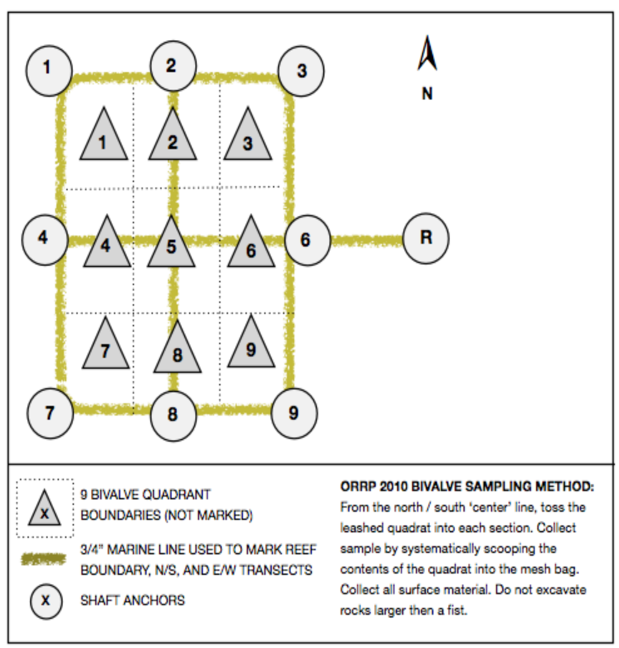


Fig. 3. General design of reef sampling by replicate quadrats; on each sampling occasion, one quadrat was excavated in each of nine cells shown by numbered triangles (see text for details).

It is important to mention that as the reefs began to develop over summer 2011, monitoring protocols were modified at Hastings, Soundview and Governors Island due to the re-seeding of SOS at these three reefs (Figs. 1 and 2; Table 1). The standard 9-quadrat samples were not always taken, and monitoring efforts thereafter in 2011 were focused on the newly seeded areas. During 2012, the same sampling protocol was followed (Fig. 4).

Water quality data were collected during every monitoring event with a handheld YSI meter that measured dissolved oxygen, water temperature, salinity and pH. Additionally, sondes (with sensors for chlorophyll *a*, turbidity, temperature, salinity, dissolved oxygen, and depth) were placed at Governors Island, Soundview and Hastings from May–Nov 2011 and at Hastings and Soundview from May-Oct 2012 (Fig. 4).

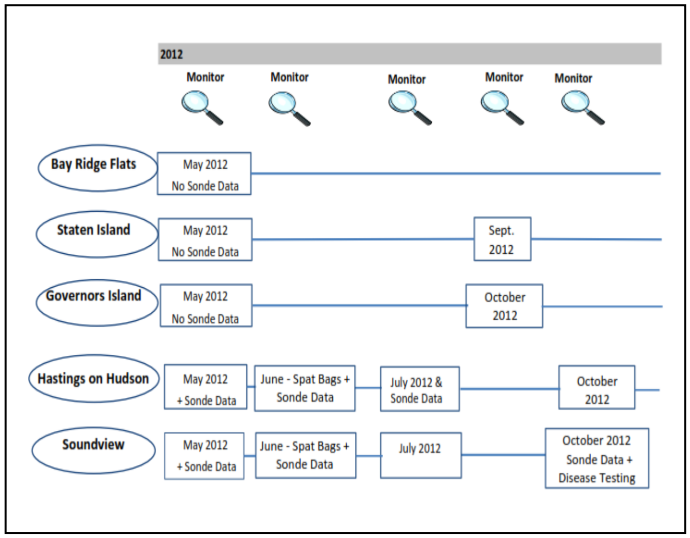


Fig. 4. Timeline for quadrat sampling of reefs and water quality monitoring in 2012.

In conclusion, two facts should be emphasized: (1) Bay Ridge and Staten Island received no additional SOS beyond the initial seeding event; and (2) Governors Island, Hastings and Soundview received additional SOS in 2011. The additional SOS were distributed to supplement the decreased (mainly by transport by waves of SOS off the reefs) density of live oysters on the three most promising reefs.

Reef performance

Assessment of reef performance both years of the study focused on two ecosystem services: water filtration and habitat provision. Whole-reef water filtration was measured on two of the reefs using *in situ* fluorometers and following methods in Grizzle et al. (2006, 2008). This involved placing one fluorometer immediately upstream and another downstream of the reef and recording data at frequent intervals; it is essentially the standard method that has been widely used (see Dame 1996 for review), but involves direct *in situ* measurements instead of taking water samples for subsequent analysis in the laboratory. The fluorometer readings are directly related to the concentration of chlorophyll *a* in the water column, and are sometimes reported as relative fluorescence units, or simply as millivolts (mV) in the present study. If several simplifying assumptions (e.g. well-mixed water column; see Grizzle et al. 2008 for details) are made, a simple calculation of the difference between the two readings provides a direct measure of how much chlorophyll is being removed and how much of the overall water column is being filtered. For the present study, fluorometer data were recorded at 5-second intervals for up 1.5 hours over two of the study reefs (Hastings and Soundview) during 2011, and for ~2 hours over Soundview only during 2012.

The second reef performance metric—habitat provision—was assessed by deployment of experimental trays (as part of another project directed by Bradley Peterson) that were filled with mollusk shell and nestled into the surface of the experimental reefs. This design mimicked the constructed reef (which had a mollusk shell veneer) and allowed consistent quantitative sampling. Replicate trays (0.14 m^2 in opening area) were removed periodically and all shell material was removed and returned to the laboratory for processing. In the lab, all organisms were sorted, identified to lowest taxon practical (species in most cases), and counted.

Habitat substitution

The "before" samples for habitat substitution were obtained during the period May 18-20, 2010 when all five study sites were sampled; the Hastings and Staten Island sites were partially re-sampled in September 2010 due to the need to move the planned location of the experimental reef. The September samples were substituted for the appropriate samples taken in May, and all (May or September) were considered "before" (pre-construction) samples. A total of eight (8) replicate van Veen grab (0.04 m^2 sampling area) samples (with latitude/longitude recorded) were taken at each site. Because the exact location for reef construction was not known at that time, the aim was to take samples within the area with an approximate radius of ~100 m. Each sample was washed on a 1 mm mesh sieve, the residue stored on ice and later frozen until processed. In the laboratory, all organisms were sorted to major taxonomic group (Class level [e.g., Polychaeta, Gastropoda] or lower), counted, and weighed (wet weight to nearest 0.1 g).

The grab data resulting from the above process were compared with the data from experimental trays taken as part of the reef development studies (see methods above) in order to characterize how the new habitat provided by the constructed reefs compared to the previous soft-sediment habitat they replaced.

Results and Discussion

Reef development and water quality monitoring – Year 1

The five reefs had different combinations of construction and monitoring activities due to differences in environmental conditions, accessibility for monitoring, and responses to monitoring data, as discussed above (see Fig. 2 for summary). In particular, it was decided early on to maintain an adaptive management approach based on monitoring data. The major result in this respect was the decision to deploy additional SOS on three of the reefs in 2011 as described above and illustrated in Figure 1. Deployment of additional SOS, however, made interpretation of the routine quadrat data more complicated. Also, it was discovered that SOS had been transported (likely by waves and/or boat wakes) off some of the reefs. Thus, these two complicating factors must be discussed before considering the routine quadrat data for 2010 and 2011.

Quadrat samples taken in early 2011 indicated high *apparent mortality* on all five reefs. The term "apparent mortality" is used because some of the dramatic decreases in live oyster density were probably due to erosion and transport of SOS from the reef rather than mortality. Referring to Figure 5, if actual over-winter mortality had occurred the total live + dead oyster counts should have been similar when comparing Nov 2010 and May 2011, but the May 2011 total counts were substantially lower at Bay Ridge, Governors Island and Hastings, suggesting that oysters had been removed from the sampling area. The Soundview data did not

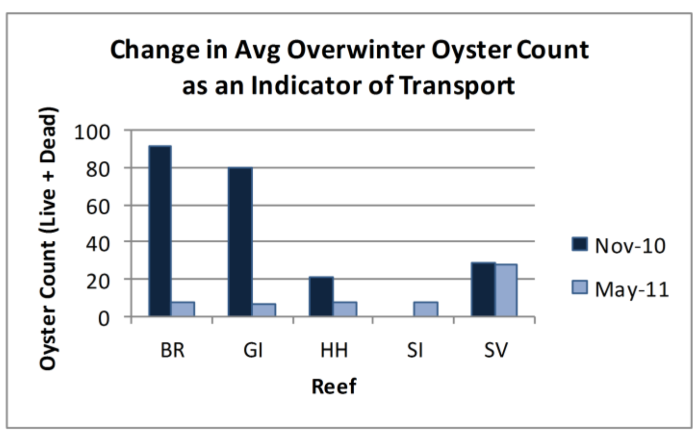


Fig 5. Total (live + dead) spat counts used as indicator of transport off the reef (see text for details).

show this trend, but SOS planted in fall 2010 were discovered at a location just north of the reef in the Summer of 2011 (Fig. 6). These “transported” SOS had grown and had good survival, though no quantitative data were obtained from this area during 2011. The 2011 re-seeded areas at Soundview, however, were sampled and the oysters in these areas showed good growth and survival (determined by comparing size-frequency changes from 2010 to 2011) as well as low numbers of spat <10 mm shell height, indicating that natural recruitment had occurred (see inset in Fig. 6). Thus, the changes in total oyster density during 2011 on the reefs was likely due to different combinations of erosion and transport of the SOS from the reef as well as natural recruitment and mortality. Development of each reef is considered separately below.

Of the five experimental reefs, Soundview had the best overall development patterns indicating good prospects for further restoration activities. The routine quadrat sampling data indicated substantial apparent mortality of the 2010 SOS, but also new recruits from spat settlement resulting from spawning by wild oysters. This natural recruitment was evident in two ways. First, size-frequency plots of the September 2011 quadrat data showed two size classes (at 10 mm shell height and at 35 mm) as well as a possible third at 65 mm (Fig. 6). Individuals <25 mm shell height likely represented oysters settling in 2011 and thus new recruits from wild oysters. Recruits from wild oysters could also be identified based on the substrate upon which the spat were found. Spat on clam shell had to be from wild oysters because only oyster shells were used in the remote setting tanks to produce the SOS placed onto the reefs.

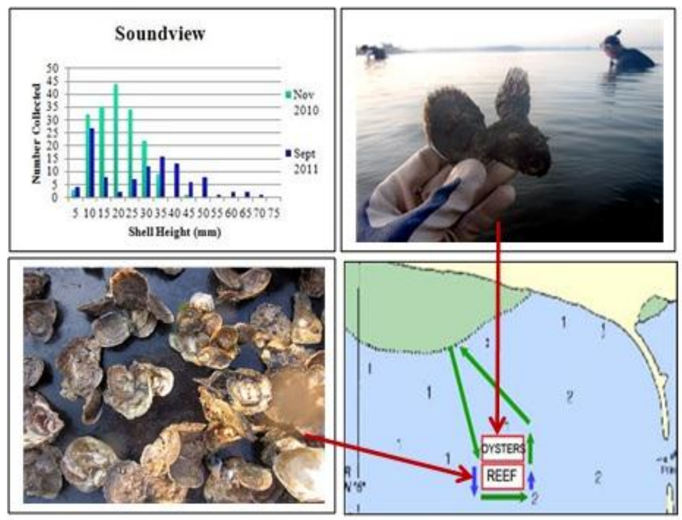


Fig. 6. Upper left: Size-frequency plots of initial (2010) and final in 2011 live oysters collected from the Soundview reef; Lower right: location of original reef and “transported” SOS to north side of original reef (see text for details).

Figure 7 summarizes the data for spat identified from wild oysters for Soundview, Hastings and Governors Island. Thus, new recruitment from wild oysters was strongly indicated for the Soundview reef. Finally, and as discussed above, some of the 2010 SOS had been transported from the reef surface and transported onto the bottom just north of the reef (Fig. 6) where they appeared to be growing and surviving. Although these findings indicate that future restoration efforts need to address the SOS transport problem, they also strongly suggest good growth as well as likely successful natural recruitment and thus the potential for long-term sustainability.

In addition to data from the experimental reef, other information from the general area indicates suitable conditions for long-term sustainability of oysters at the Soundview site. Live juvenile and adult oysters commonly occur in the intertidal zone on the rip rap material along the adjacent shoreline, and on rocks and other hard substrates in the shallow subtidal waters just offshore. The NYC Department of Parks & Recreation’s Natural Resources Group (NRG) has conducted two oyster restoration projects in the general area. The initial project, which was completed in 2008, involved placing surf clam shell in the shallow subtidal zone in 2006 and 2007. This resulted in natural oyster spat recruitment in both monitoring years as well as a diverse fish community using the area (Mass and Ruzicka 2008). Additional monitoring in 2010 by NRG showed similar results (NRG 2010). In sum, there is substantial evidence indicating the Soundview site has excellent potential for long-term sustainability of oysters.

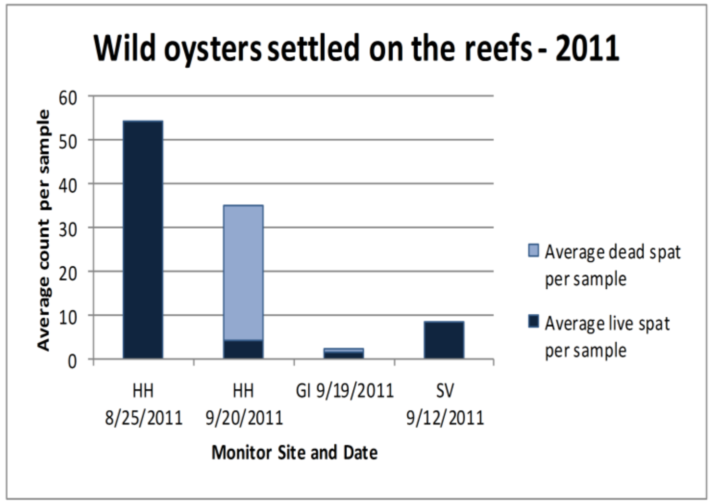


Fig. 7. Spat from wild oysters for Hastings, Governors Island and Soundview reefs (see text for details).

The reef at Governors Island also showed potential for future restoration efforts. Significant transport of SOS off the reef during the winter months was likely a result of swift currents and boat wakes in Buttermilk Channel. As discussed above, transport off the reef was addressed in 2011 by re-seeding with over-wintered SOS on five different occasions. The September addition was made outside the established perimeter of the reef and thus was not sampled during the November monitor. The two fall monitoring events showed good retention and growth. The November 2011 data also showed twenty-one oysters <20 mm in size, suggesting spat from wild oysters (i.e. natural spat set). Additionally, juvenile and adult oysters commonly occur on the seawall on the opposite (Brooklyn) side of Buttermilk channel. As noted above for the Soundview reef, future restoration efforts need to address the SOS transport problem at Governors Island, but available data also indicate good growth as well as likely successful natural recruitment and thus the potential for long-term sustainability.

The Hastings reef also showed potential for further restoration efforts. Although it had substantial mortality of the 2010 SOS (Fig. 8), there was greater recruitment from wild oysters than on any of the other reefs (Fig. 7). The Hastings reef also differed dramatically from the other four reefs in that it was exposed to prolonged (several weeks) low salinities in 2011 (Fig. 9), which likely contributed to SOS mortality. Nonetheless, live juvenile and adult oysters commonly occur in the intertidal zone along the shoreline. These observations suggest that the oyster population in the Hastings area may be adapted to much lower salinities than the other sites.

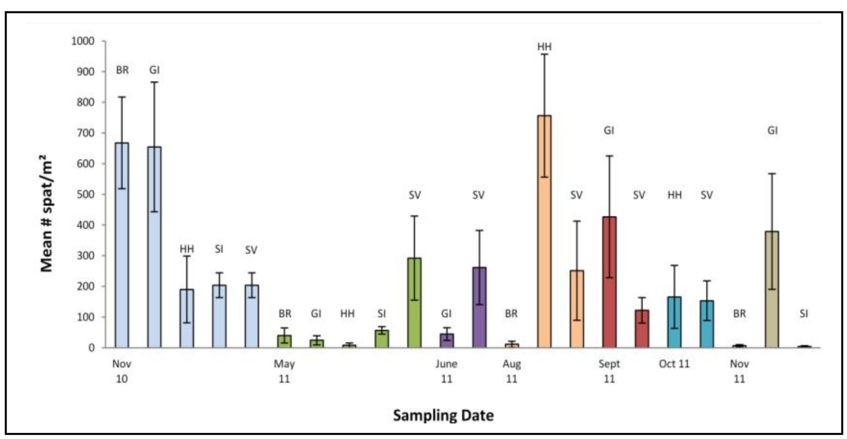


Fig. 8. Summary of live oyster density data by reef and sampling period for 2010 and 2011.

A final consideration in assessing development of the reefs from the perspective of future restoration efforts is water quality. Data collected during routine reef monitoring generally suggest environmental conditions suitable for growth and reproduction of oysters (Fig. 9). At four of the sites (Soundview, Governors Island, Bay Ridge Flats and Staten Island), salinity, temperature, pH and dissolved oxygen were well within the range of tolerances for eastern oysters (Shumway 1996). Salinity at Hastings, however, dropped far below optimum levels for several weeks during summer 2011. This likely explains the near-100% loss of 2010 SOS at Hastings, and further suggests that the live juvenile and adult oysters commonly found on rocks along the shoreline may be adapted to lower salinities than are typical for the eastern oyster. This finding also suggests that future restoration efforts at Hastings should consider developing a broodstock for larvae production from oysters found in that area.

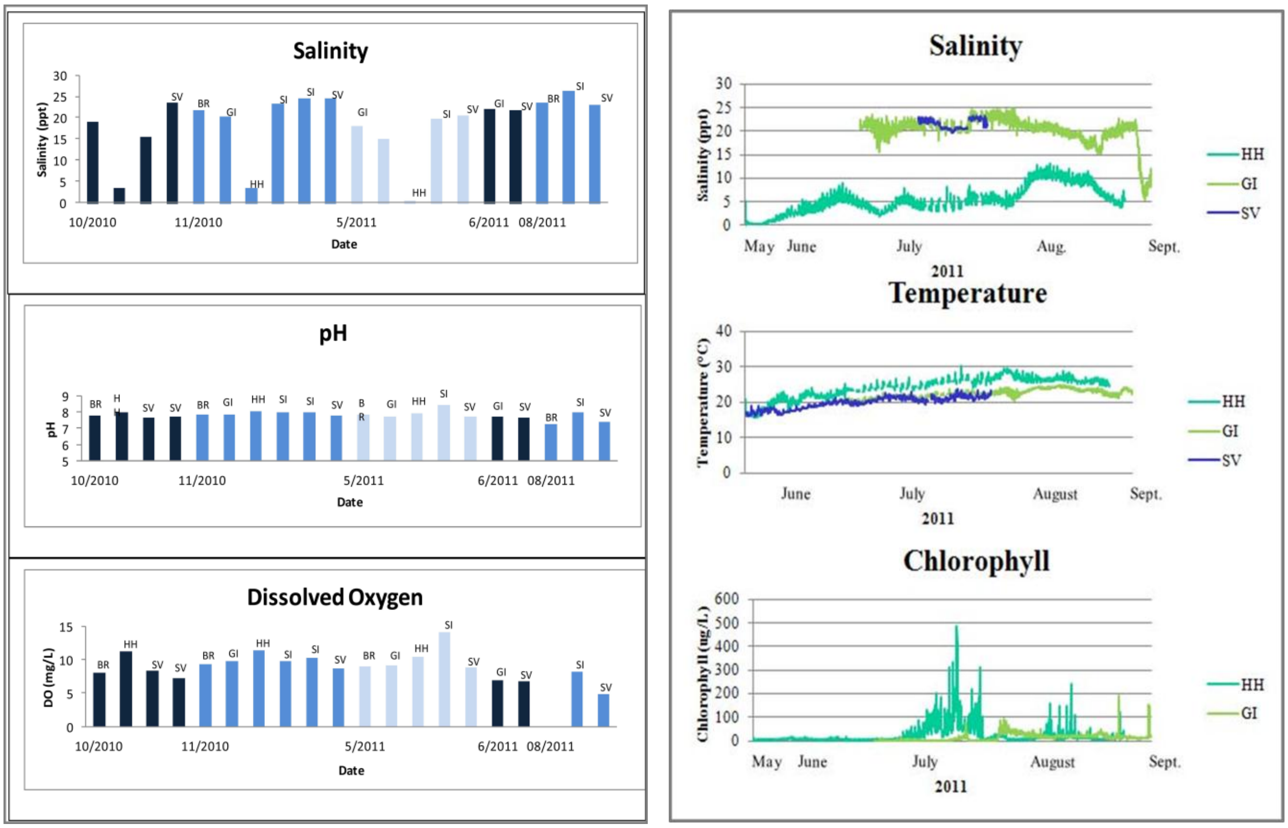


Fig. 9. Left: water quality data collected during routine monitoring visits during 2010-2011; Right: Sonde data collected near three of the reef sites in 2011.

Reef development and water quality monitoring – Year 2

During 2012, sampling was focused on the three sites showing the most promise for further restoration efforts: Soundview, Hastings, and Governors Island. Data assessment was complicated by the addition of SOS to each during 2011, as discussed above (Table 1, Fig. 2). To make among-reef comparisons based on each reef as a whole, the 2012 data are expressed as total oyster abundances on each reef (areal coverage: ~50 m^2 per reef). Each experimental reef is discussed separately below.

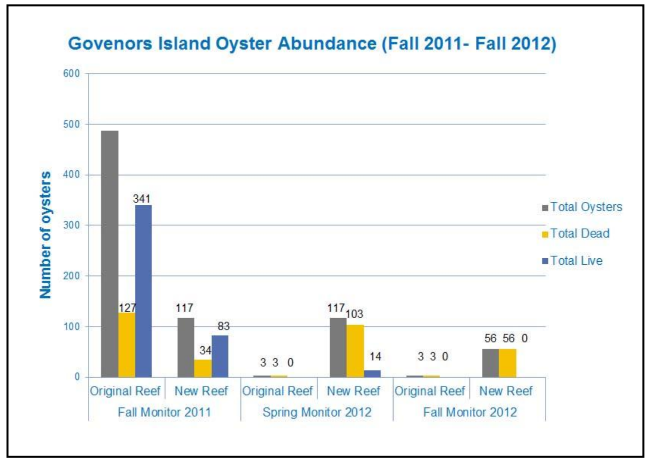


Fig. 10. Live and dead oyster abundances on Governors Island reef in originally seeded areas and areas re-seeded in 2011.

In Nov 2011, the Governors Island reef had substantial numbers of live oysters on the original and re-seeded sections (Figs. 8 and 10). By the final sampling in fall 2012, however, no live oysters were found in either area (Fig. 10). Diver observations made on three occasions in 2012 confirmed the dynamic nature of this site with respect to boat wakes and tidal currents. Clam shells had been transported off the reef, and soft sediments had been deposited among the rocks. Although no live oysters were found, small mussels were abundant in some areas in April and May, but no live mussels were found in October.

The Hastings reef had an estimated total of only 7 live oysters in spring 2012 (Fig. 11), indicating high over-winter mortality or transport off the reef similar to Governors Island reef (Fig. 10). However, there was substantial natural recruitment in summer 2012 (size classes <20 mm in Fig. 11) such that by fall 2012 there were >600 live oysters on the reef, including some >60 mm probably representing oysters recruiting in 2011. These data suggest that natural recruitment might be sufficient for long-term sustainability of constructed reefs in that area, but mortality might also be high for oysters in their second and probably subsequent years (see more discussion in disease testing section below).

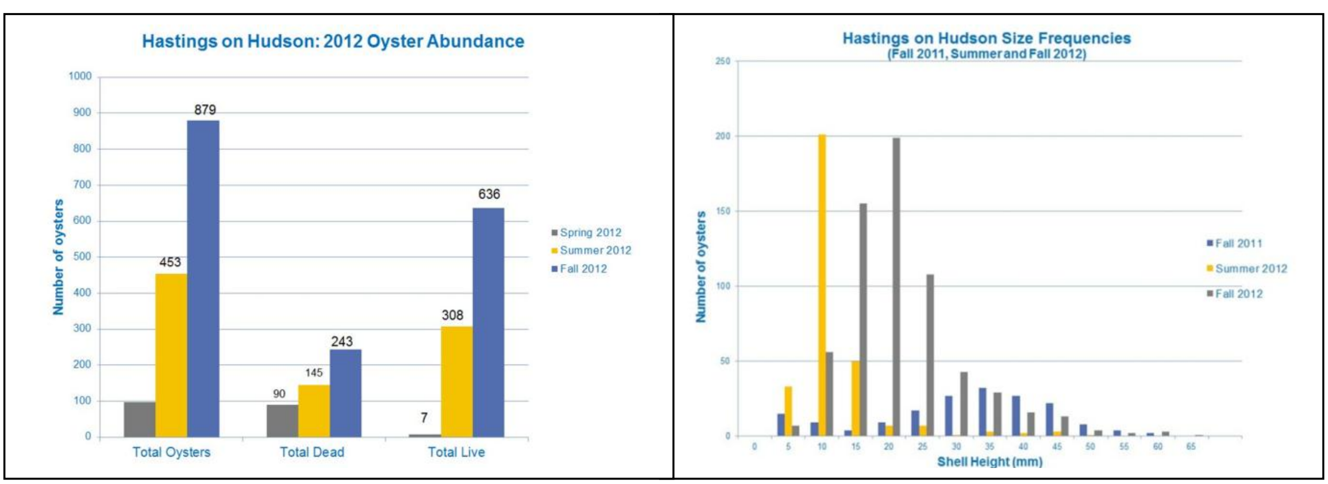


Fig. 11. Left: live and dead oyster abundances on Hastings reef in originally seeded areas and areas re-seeded in 2011. Right: size-frequency plot for all live oysters on Hastings reef for fall 2011 through fall 2012.

Sampling on the original reef footprint showed good over-winter survival (139 total live oysters in spring 2012; Fig. 12) and substantial summer 2012 recruitment. Moreover, live oysters up to ~85 mm shell height were also present in fall 2012, indicating good growth and survival (see more discussion below in disease section). In sum, these data suggest good prospects for natural recruitment as well as at least some potential for oysters to survive into the third year—both requirements for long-term sustainability of constructed reefs.

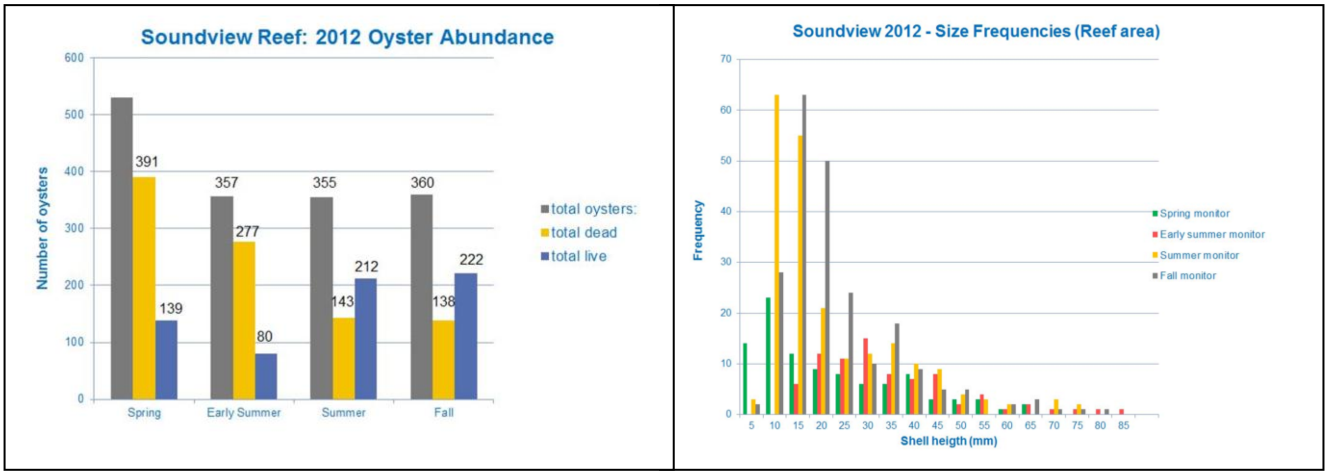


Fig. 12. Left: 2012 live and dead oyster abundances on Soundview reef in areas of original construction and SOS seeding events (original and June 2011). Right: size-frequency plot for all live oysters on Soundview reef in all areas of original footprint for four sampling occasions in 2012.

The "off reef" area at Soundview where the original SOS had been transported by waves (Fig. 6) was quantitatively sampled twice during 2012. Comparison of the size-frequency plots for live oysters in summer and fall 2012 indicated two important characteristics for sustainability of the oyster population in this area of the reef (Fig. 13). There were three peaks in the overall plots for both sampling periods, suggesting multiple year classes for both sampling periods. During summer, one peak was at 10 mm, a second at 35-40 mm, and a third at 70 mm; during fall the first peak had shifted to 15-20 mm, the second remained at 35-40 mm and the third had increased to 90 mm. Age/growth relationships cannot be quantified from these data, but they do suggest two characteristics important for long-term reef development—good growth from summer to fall, and the possibility of survival into the third year—as observed on the adjacent originally constructed and SOS seeded area of the reef (Fig. 12).

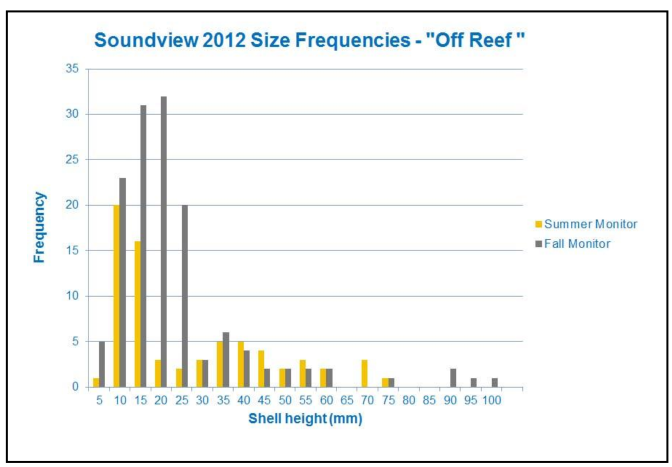


Fig. 13. Size-frequency plot for all live oysters in "off reef" area at Soundview during summer and fall 2012.

Wild oysters in two size classes collected near the Hastings and Soundview experimental reefs (small and large; see Fig. 14 for size data), and large oysters collected off the experimental reef at Soundview, were analyzed in 2012 for MSX and Dermo. Wild oysters at Hastings had both MSX and Dermo infections, with the highest infection levels in the larger (presumably older) size class as expected. Very few of the oysters, however, had advanced level infections. The wild oysters at Soundview were

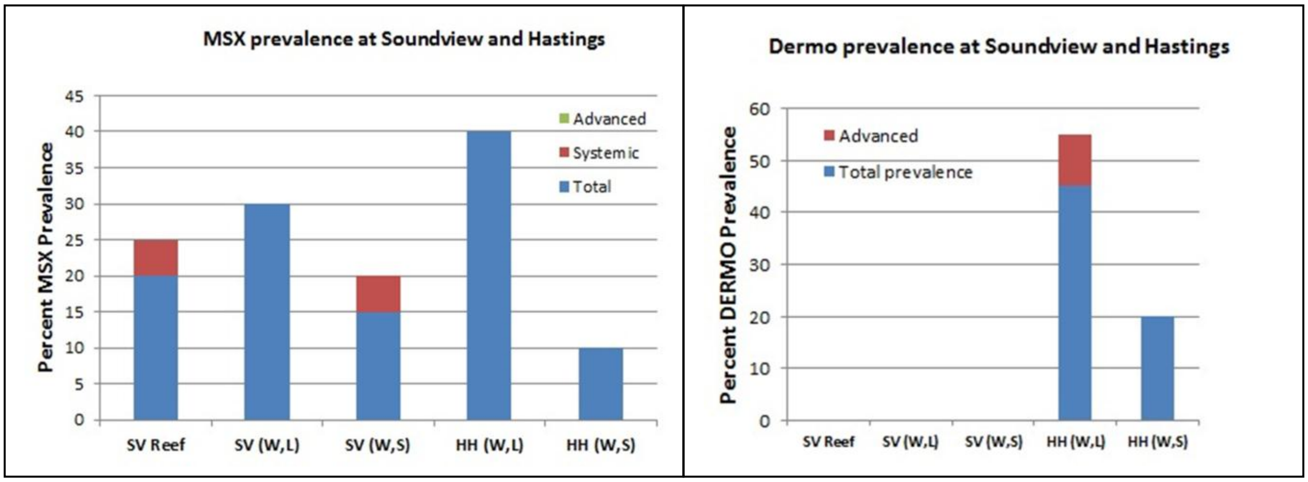


Fig. 14. Disease (MSX and Dermo) prevalence from two size classes of wild oysters collected near the Soundview (SV) and Hastings (HH) experimental reefs, and large oysters from the experimental reef at Soundview ("SV Reef"). Mean shell heights: SV Reef = 69.0 mm; SV (W,L)=71.5 mm; SV (W,S)=31.7 mm; HH (W,L)=74.7 mm; HH (W,S)=28.0 mm.

only infected by MSX, with no advanced stages observed. These data cannot be directly related to oyster mortalities at either site, but they definitely suggest that disease will likely be a factor at both sites. Although it is not possible at this time to know how susceptible the oyster populations in these areas are to the pathogens, in highly susceptible stocks the 2012 MSX prevalences would be considered to be at relatively low levels at both sites. In highly resistant stocks, however, these would be high levels. In any case, it should be noted that even disease resistant stocks will eventually succumb to MSX, generally after reaching ~80 mm in shell height (D. Bushek, pers. comm.). These data suggest that oyster mortality due to disease, particularly MSX, can be expected to generally limit the longevity of oysters in both areas to <5 years, which is probably typical now for the eastern oyster, particularly in the mid-Atlantic and northeastern US estuaries (e.g., Mann et al. 2009).

The experimental reef at Bay Ridge Flats was only sampled in spring 2012; no live oysters were found and the reef was partially covered by sand (diver inspection). The Staten Island reef was only sampled twice in 2012, spring and fall, and no live oysters were found on either occasion. Diver observations indicated that it also was being covered by sand and some shell material had been transported off the reef. Both these reefs appear to be in high-energy areas affected strongly by waves and tidal currents. This does not necessarily mean that oysters cannot survive in these areas. It does suggest, however, that restoration methods as used in the present study—which are similar to those now used in other areas of the northeast and are effective for large spatial scale (acres) efforts—are probably not appropriate for either area.

The final consideration for assessing reef development in 2012 is water quality. As during 2011, water temperature at Soundview and Hastings was very similar from April-October, but salinity was much lower at Hastings (Fig. 15). Again, these data point to the unusual salinity regime that exists at Hastings, but otherwise water quality data at both sites are well within typical ranges for the eastern oyster (see discussion above).

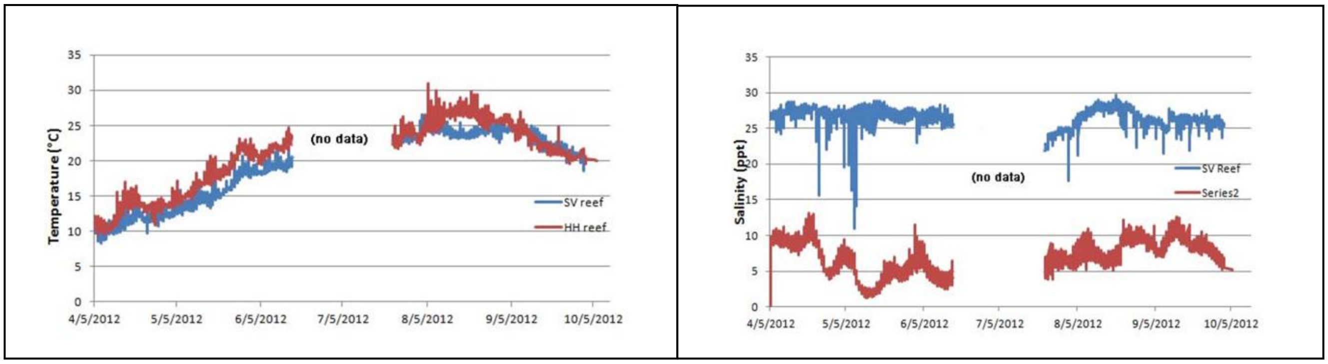


Fig. 15. Temperature and salinity sonde data for 2012 from Hastings and Soundview reefs.

In summary, the Soundview reef showed the best prospects for further restoration efforts because of good growth and survival as well as substantial natural recruitment. Natural recruitment in 2012 onto rocks and other hard substrates along the shoreline was particularly good. Much of the settlement in these areas occurred early in the summer, and abundant spat <30 mm shell height were observed at the last monitoring visit in November. Water quality conditions at Soundview also were well within the typical range for the eastern oyster during 2011 and 2012. MSX prevalence levels were moderate at Soundview in 2012 for both size classes of oysters tested, and no Dermo infections were detected.

The reef at Hastings also showed good prospects for further restoration efforts based on oyster growth and natural recruitment. Although there was poor over-winter survival during 2011/12, there was substantial natural recruitment in summer 2012 such that by fall 2012 there were >600 live oysters on the reef. Water quality conditions at Hastings indicated unusually low salinities during both years of the study, well below optimum conditions for the eastern oyster based on studies in other areas. Thus, if SOS from remote setting are used in future restoration work at Hastings, broodstock from the area or otherwise adapted to low salinities should be used to produce the larvae. Infection prevalence levels for both MSX and Dermo were moderate at Hastings in 2012.

The reef at Governors Island showed promise for further restoration efforts during 2011, but less so during 2012 due to high mortality (or transport?) and no observed natural recruitment. The structure of the reef remained intact and stayed above the sand, at least better than the reefs at Staten Island and Bay Ridge Flats (see below). The proximity of the Governors Island site to the New York Harbor School is also a positive factor. This makes it easily accessible for monitoring and other activities associated with the aquaculture program at the School, which includes maintaining a large population of adult oysters in the Harbor.

The reefs at Bay Ridge Flats and Staten Island were not adequately sampled during 2012, but divers observed substantial deposition of sand onto both constructed reefs. All three reefs showed high levels of erosion and transport of shell and SOS. Thus, these two reefs were considered to show less potential than the others for further restoration work. However, it may be that different construction methods (e.g. oyster ‘condos’ or wave breaks) would have resulted in better growth and survival. In any case, additional research at these sites seems warranted.

Reef performance: Water filtration – Year 1

Two of the experimental reefs, Hastings and Soundview, were sampled using *in situ* fluorometry in July 2011. An attempt was made to sample the reef at Governors Island but no useful data were collected due to high waves, mainly from boat wakes. Both Hastings and Soundview datasets showed chlorophyll uptake at times, but overall were very complicated and variable datasets. Both reefs also were strongly influenced by wind waves and sporadic boat wakes that resulted in substantial export of chlorophyll from the reefs. The Hastings reef is fully exposed to northwesterly winds, and boat wakes or wind-generated waves resulted in re-suspension of sediments from the reef and surrounding areas for much of the sampling period (Fig. 16). This resulted in a negative overall chlorophyll "removal" rate. In other words, the reef was a source of chlorophyll during the overall monitoring period instead of a sink. There were, however, two brief periods when some amount of water filtration (chlorophyll removal) was recorded (Fig. 17). The uptake measured was, as expected, small because there were only small oysters at low densities ($<20/m^2$) present on the reef at that time. The overall chlorophyll removal by oyster reefs is typically related to the size and density of oysters (and other filter feeders) on the reef in relation to water depth and flow rate (Cressman et al. 2003; Grizzle et al. 2006, 2008).

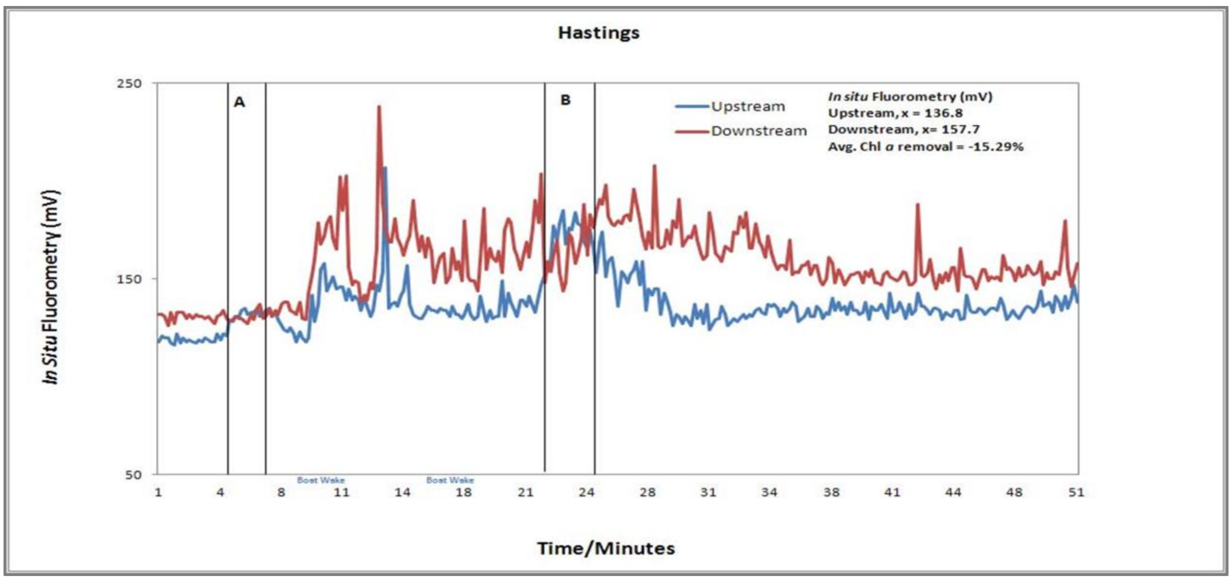


Fig. 16. *In situ* fluorometry data (mV) from one sensor placed upstream (blue line) and one downstream (red line) of the experimental oyster reef at Hastings on Hudson; see Fig. 8 for expanded plot of the time intervals marked by "A" and "B." Also note times when boat wakes and/or wind waves were present.

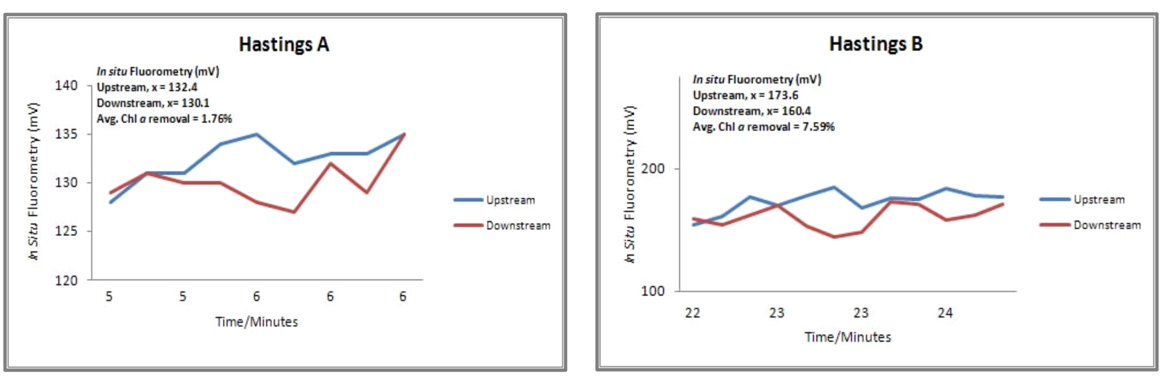


Fig. 17. Selected portions from Figure 7 of overall Hastings dataset showing chlorophyll removal by the reef: 1.76% in A, and 7.59% in B.

The Soundview reef was not as persistently affected by waves during the *in situ* fluorometry monitoring during 2011 compared to the Hastings reef, and a longer time interval was recorded (Fig. 18). Nonetheless, a similar overall pattern was found: brief periods of chlorophyll removal but overall a slightly negative removal percent. When reef filtration (chlorophyll removal) was measureable, it was substantial (Fig. 19): 17.6% over a 6-minute interval ('A') and 40.0% over a 4-minute interval ('C'). These removal rates are likely high relative to an entire tidal cycle because they were made near low tide when water depth was only about ~0.5 m and water flow ~2 cm/s. Even so, they indicate the Soundview reef was providing a measureable amount of water filtration early in its development.

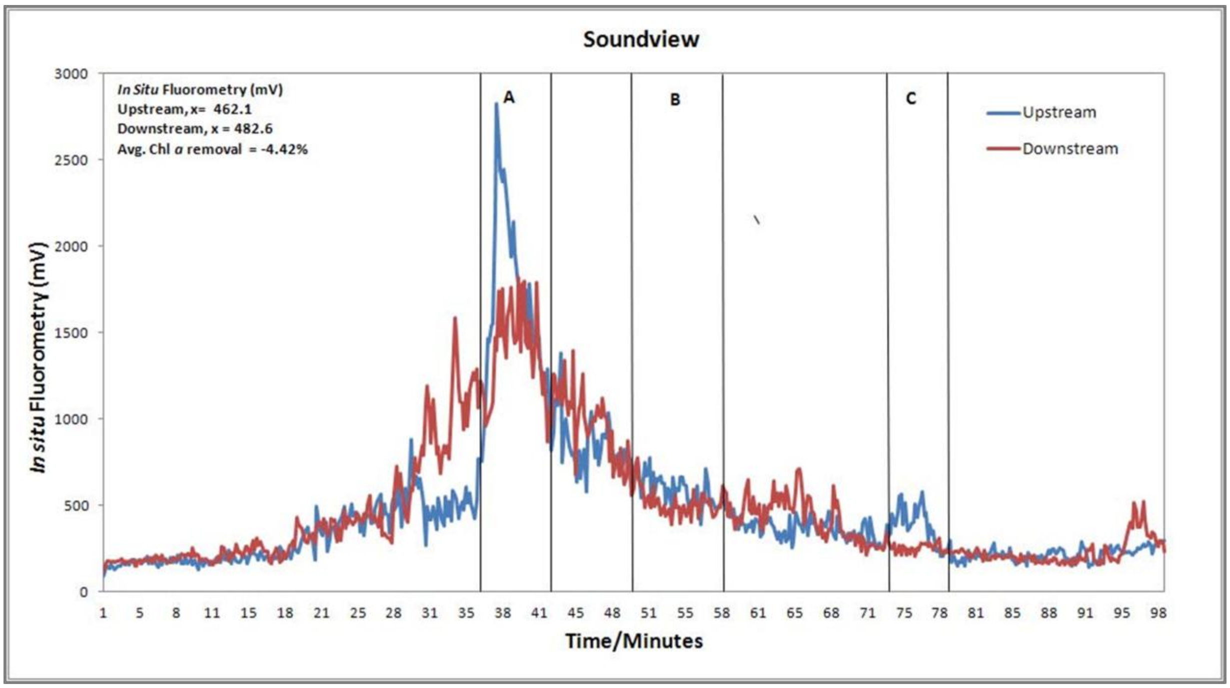


Fig. 18. *In situ* fluorometry data (mV) from one sensor placed upstream (blue line) and one downstream (red line) of the experimental oyster reef at Soundview. Time intervals "A," "B," and "C" denote intervals when the reef had measureable chlorophyll removal; see Fig. 10 for expanded plots of "A" and "C."

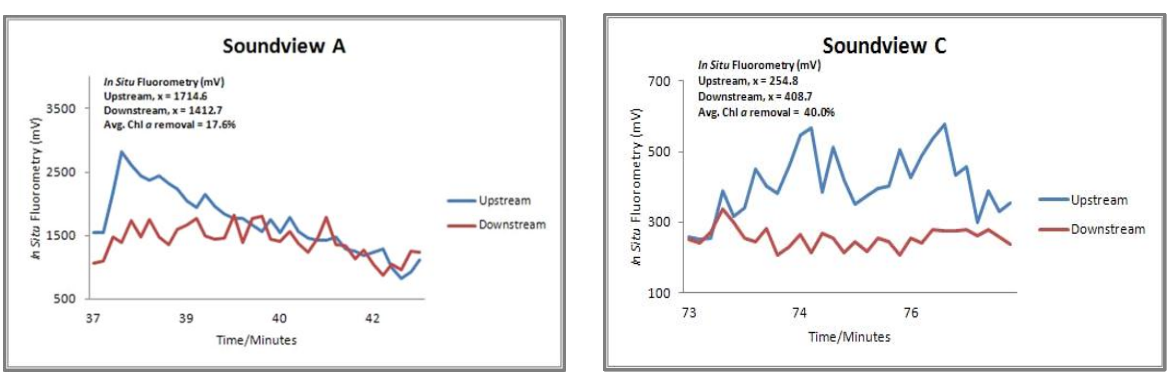


Fig. 19. Selected portions from Figure 18 of overall Soundview dataset showing chlorophyll removal by the reef: 17.6% in "A" and 40.0% in 'C.'

Reef performance: Water filtration – Year 2

During 2012, *in situ* fluorometry measurements were made only over the Soundview reef but on two separate days with a total of ~2 hr of data recorded (Fig. 20). Chlorophyll removal was strong and consistent on the first day (21 Aug), averaging 21.8% removal for the entire ~1 hr period which was early in a flooding tide. Measurements were made the second day (22 Aug) late in an ebbing tide, and removal was substantial for the first half of the recording period, averaging ~20%. The reef was affected by boat wakes and increased wind waves during the last half of this recording period, and no removal was measured during that time interval.

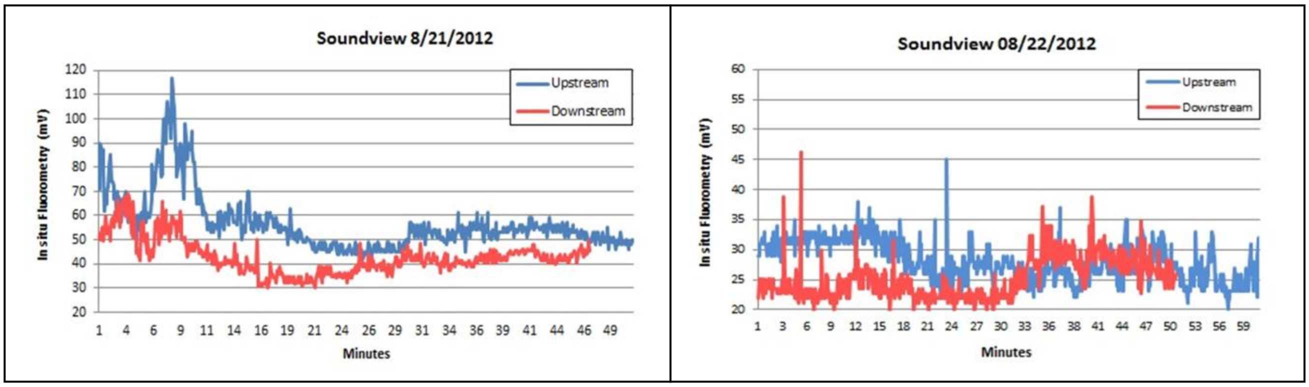


Fig. 20. *In situ* fluorometry measurements recorded on two separate days in summer 2012 over the Soundview reef.

The measurements made during 2012 over the Soundview reef showed much more filtration compared to 2011, as would be expected because oyster size and density had increased. Additionally, the fluorometers were positioned in 2012 so that feeding by oysters (and other filter feeders on the reef) on the "off reef" area (Figs. 6 and 13) was also measured. Few studies have been done on water filtration by restored oyster reefs, but the general trend is not surprising: filtration rates increase as the size and density of oysters (and other filter feeders) increase (Grizzle et al. 2008; Grizzle unpublished data). Thus, it can be expected that this important ecosystem service will increase in magnitude as the reefs develop.

Reef performance: Habitat provision – Year 1

A second important ecosystem service provided by the experimental reefs was habitat provision. Data to assess this performance metric mainly were provided by a separate study conducted by Bradley Peterson and colleagues that used experimental shell-filled trays to sample the resident fauna, and only a preliminary assessment is provided here. For the present report, the data from 2011 (year 1) and 2012 (year 2) are presented separately. A full assessment of habitat provision based on the Peterson data will be presented in a separate report.

The experimental trays showed the expected general trend of increasing taxonomic richness on the reefs over time (Fig. 21). Although most of the sampling was focused on the reefs at Hastings and Soundview, all five reefs were visited at least once. Mean # taxa/tray ranged from <5 at all three reefs sampled in June, but had risen to well over 10 at Soundview, Governors Island and Staten Island. The most taxonomically diverse reefs, Staten Island, had a mean of 23 taxa/tray in August. Total resident faunal community densities (# of individuals/tray) also showed an increasing trend over time, though not as dramatic as taxonomic richness (Fig. 22). The Staten Island reef had the highest densities, averaging nearly 5,000 individuals/tray in August, compared to the other reefs which averaged <1,000 individuals/tray at the final sampling in September or October.

These values (taxonomic richness and total density) are similar to previous studies on oyster reefs in the northeastern US (e.g., Grizzle and Ward 2009), but relatively low (except Staten Island) compared to data from reefs further south along the Atlantic coast (Bahr and Lanier 1981; Coen et al. 1999; Luckenbach et al. 2005; Rodney et al. 2006; Coen and Grizzle 2007; Hadley et al. 2010). However, the overall pattern of increasing taxonomic richness over time and summer maxima in both taxonomic richness and community density reflect typical seasonality for estuarine benthos in the region.

In sum, the data for 2011 show that even at very early (~1 yr) developmental stages the experimental reefs provided hard-bottom habitat of substantial quality from the perspective of taxonomic richness and community density.

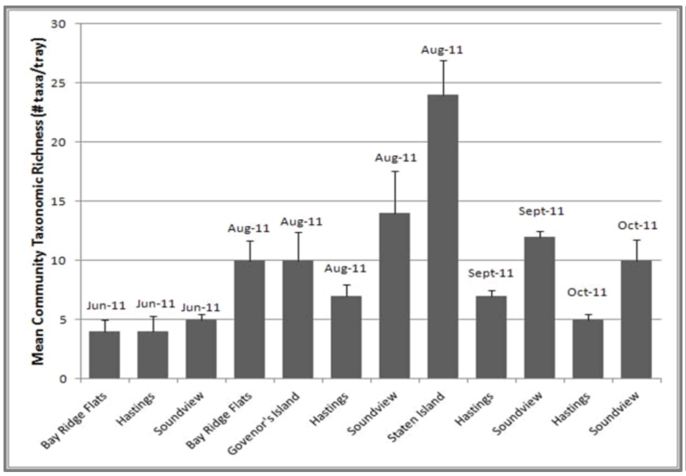


Fig. 21. 2011 mean taxonomic richness (# taxa/tray; 1 SE shown) from experimental trays deployed on the reefs.

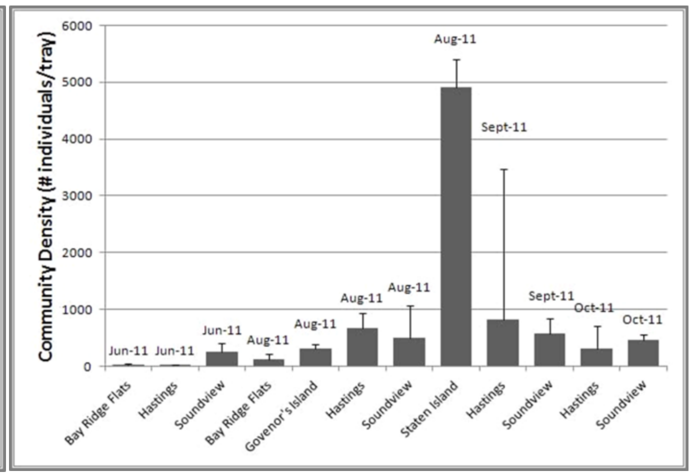


Fig. 22. 2011 mean total community densities (# ind/tray; 1 SE) from experimental trays deployed on the reefs.

Reef performance: Habitat provision – Year 2

During 2012 (year 2), experimental trays were only successfully retrieved from the experimental reefs at Hastings and Soundview, and for the period June-October. Mean taxonomic richness and total community densities followed the same trends (e.g., summer peaks) as in 2011 (Figs. 23 and 24). However, means for density and taxonomic richness were generally lower than in 2011. A more extensive analysis of the Peterson data is in preparation.

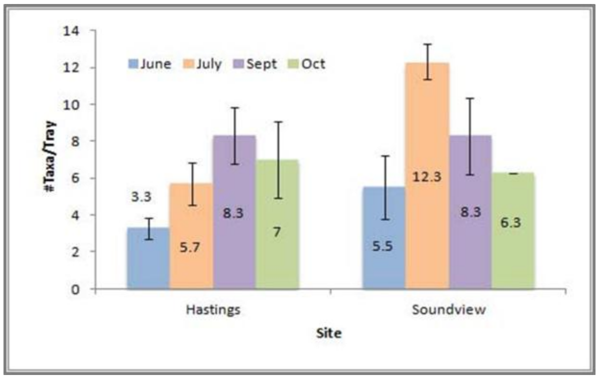


Fig. 23. 2012 mean taxonomic richness (# taxa/tray; 1 SE) from experimental trays deployed on the reefs.

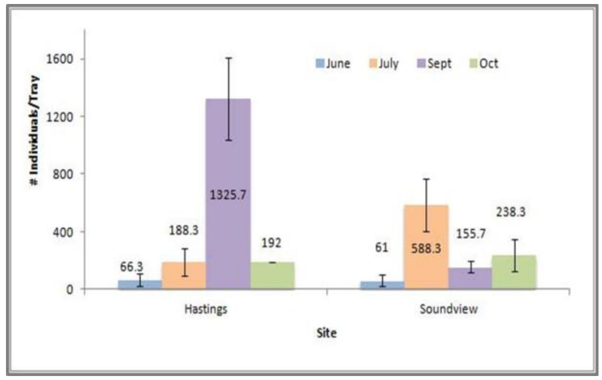


Fig. 24. 2012 mean community density (# ind/tray; 1 SE) from experimental trays deployed on the reefs.

Habitat substitution – 2011 and 2012 data

Assessment of habitat substitution consisted of comparison of the pre-construction van Veen grab data with the 2011/2012 combined experimental tray data. All five reefs were sampled pre-construction but only two of the reefs, Hastings and Soundview, were sampled in fall 2011 and 2012. Therefore, although the assessment of habitat substitution necessarily focuses on a comparison of data from these two reefs, there were similar trends in pre- and post-construction benthic data for all five reefs.

Pre-construction data. Table 2 below summarizes benthic data from pre-construction van Veen grab samples. There was wide variability among the samples as is typical of estuarine infauna, but overall trends were similar to previous studies in the region (Cerrato 2006). Mean community (all invertebrate taxa combined) densities at four of the five sites ranged from 10.6 to 210.9 organisms/0.04 m^2 (Table 2). Such a range is not unusual for estuarine benthos, largely due to wide variability in recruitment and mortality events. One site (Staten Island), however, had extremely high densities (1,387.1 organisms/0.04 m^2). Most of the high densities in individual grab samples were from large numbers of mytilid mussels, the mud snail *Ilyanassa obsoleta*, and the small clam *Gemma gemma*. Previous studies in the region list these taxa as density dominants at times, and also reported similar total densities of macroinfauna (see Cerrato 2006 for review). One of the sites (Staten Island), however, had extremely high densities of the gem clam in one grab (9,189/0.04 m^2). Densities of this magnitude have been reported in other areas (e.g. Sanders 1958), and this species is well-known for wide variations spatially and temporally in population densities.

Mean community biomass from the present study also fell within previously reported ranges, but with wide variability due to the occasional presence of large individuals in a few samples (e.g., mud snails [*Ilyanassa obsoleta*] at Soundview, and one adult surf clam [*Spisula solidissima*] and one large spider crab [*Libinia emarginata*] at Staten Island).

Mean taxonomic richness (Family level or lower) collected per site ranged from 4.5 to 8.3/0.04 m^2, indicating a reasonably diverse macrofauna. Most previous work in the region reported species-level richness and used a wide range of sample sizes, so direct comparisons are not possible. Nonetheless and as noted above, the dominant species and genera found in the present study (e.g., *Gemma gemma*, *Ilyanassa obsoleta*) were common in previous studies in the region (e.g. Dean 1975), and are typical species in soft-bottom areas in the northeast and mid-Atlantic estuaries.

Table 2. Macrofaunal benthic community-level summary statistics (mean and 1 SE) for van Veen grab samples (0.04 m^2 sampling area) taken in 2010 before reef construction. BRF=Bay Ridge Flats, GI=Governors Island, H=Hastings, So=Soundview, SI=Staten Island. Taxonomic Richness=number of Family level and lower taxa per grab sample.

Site	Density (#/0.04 m^2)	Mean	SE	Biomass (g/0.04 m^2)	Mean	SE	Taxonomic Richness	Mean	SE
BRF	4			0.2			2		
BRF	9			0.3			8		
BRF	6			0.1			3		
BRF	16			0.3			5		
BRF	10			2.1			4		
BRF	21			0.5			5		
BRF	1			0.3			1		
BRF	18	**10.6**	**2.51**	0.6	**0.6**	**0.23**	9	**4.6**	**0.98**
GI	450			0.5			8		
GI	69			37.6			6		
GI	14			1.8			6		
GI	101			0.8			4		
GI	352			8.0			9		
GI	647			2.0			8		
GI	29			20.7			9		
GI	25	**210.9**	**85.09**	3.1	**9.3**	**4.68**	7	**8.3**	**0.48**
H	156			6.5			6		
H	17			0.2			3		
H	23			0.4			4		
H	34			0.6			5		
H	25			0.5			6		
H	56			1.1			7		
H	28			1.4			7		
H	41	**47.5**	**16.07**	1.0	**1.5**	**0.73**	5	**5.4**	**0.50**
So	106			38.6			3		
So	47			110.7			5		
So	64			109.2			7		
So	16			3.6			4		
So	43			56.2			6		
So	6			14.9			3		
So	97			14.4			4		
So	20	**49.9**	**13.08**	0.2	**43.5**	**15.89**	6	**4.8**	**0.53**
SI	15			161.0			4		
SI	57			0.4			3		
SI	132			1.1			6		
SI	96			1.0			5		
SI	606			41.2			7		
SI	284			68.9			10		
SI	9200			52.8			8		
SI	707	**1387.1**	**1119.21**	33.3	**45.0**	**18.93**	7	**6.3**	**0.80**

Post-construction data. As noted above, for assessment of habitat substitution, the focus was on data from the Hastings and Soundview reefs. At the end of the project (fall for both years), total community density and taxonomic richness were both higher than the pre-construction benthos at both reefs (Table 3). To our knowledge, there have been no studies in the northeastern US explicitly comparing the benthos from soft-sediment infauna with nearby oyster reef communities. However, mean community densities on both the Hastings and Soundview reefs (Table 3) were substantially greater than those reported by Grizzle and Ward (2009) for 2-yr old restored oyster reefs in New England.

Table 3. Summary statistics for pre-construction (van Veen grab; 0.04 m^2) and post-construction (Oct 2011) experimental tray (0.14 m^2) samples from Hastings and Soundview reef. Note density and wet weight data expressed on a per m^2 basis.

Sample Type	Site	Replicate #	Density (#/m^2)	Wet Wt. (g/m^2)	Taxa/Sample
van Veen grab 2011	Hastings	1	3900	163	6
		2	425	5	3
		3	575	10	4
		4	850	15	5
		5	625	13	6
		6	1400	28	7
		7	700	35	7
		8	1025	25	5
	Soundview	1	2650	965	3
		2	1175	2768	5
		3	1600	2730	7
		4	400	90	4
		5	1075	1405	6
		6	150	373	3
		7	2425	360	4
		8	500	5	6
		MEAN:	**1046**	**1104**	**5**
		Std Error:	**251**	**235**	**0.4**
Peterson Tray 2011	Hastings	1	2226		5
		2	1400		5
		3	1869		5
		4	3073		4
	Soundview	1	756		8
		2	5075		11
		3	3780		11
		MEAN:	**2597**		**7.0**
		Std Error:	**372**		**0.8**
Peterson Tray 2012	Hastings	1	1443		8
		2	899		7
	Soundview	1	200		10
		2	143		9
		3	124		6
		MEAN:	**562**		**8.0**
		Std Error:	**263**		**0.7**

Two recent studies from the southeastern US found greater abundances or production of several invertebrate taxa on oyster reefs compared to adjacent unvegetated soft bottom areas (Shervette et al. 2011; Wong et al. 2011). This research essentially confirms for invertebrates on oyster reefs the trend that hard-bottom habitats in general provide enhanced densities, biomass and production of associated invertebrates compared to bare soft-sediment habitats (Bell et al. 1991; Shervette et al. 2011; Wong et al. 2011).

Table 4. Taxonomic lists for pre-construction (van Veen grabs) and post-construction (Peterson experimental trays for 2011 and 2012) monitoring of experimental reefs. Taxa are listed alphabetically by genus, then higher level taxa.

Pre-construction (van Veen grabs)	**Experimental Trays, 2011 and 2012**
Balanus sp.	*Anomia simplex*
Cancer sp.	*Balanus sp.*
Crepidula sp.	*Bittium alternatum*
Cyathura polita	*Crassostrea virginica*
Dyspanopeus sp.	*Crepidula convexa*
Ensis directus	*Crepidula fornicate*
Gemma gemma	*Crepidula plana*
Illyanassa obsoleta	*Dreissena polymorpha*
Illyanassa trivitata	*Dyspanopeus sayi*
Mulinia lateralis	*Eupleura caudate*
Mya arenaria	*Eurypanopeus depressus*
Pagurus sp.	*Gemma gemma*
Spisula solidissima	*Geukensia demissa*
Unident. Anthuridae	*Gobiosoma bosc*
Unident. Caprellidae	*Hemigrapsus sanguineas*
Unident. Cirratulidae	*Ilyanassa obsolete*
Unident. Gamaridae	*Ilyanassa trivittata*
Unident. Glyceridae	*Libinia emarginata*
Unident. Lumbrineridae	*Lyonsia hyaline*
Unident. Mactridae	*Macoma tenta*
Unident. Mytilidae	*Mercenaria mercenaria*
Unident. Nereidae	*Mulina lateralis*
Unident. Orbiniidae	*Mya arenaria*
Unident. Pectinariidae	*Mytilopsis leucophaeata*
Unident. Phyllodocidae	*Mytilus edulis*
Unident. Polynoidae	*Pagurus longicarpus*
Unident. Spionidae	*Palaemonetes vulgaris*
Unident. Tellinidae	*Petricola pholadiformis*
Unident. Veneridae	*Rangia cuneata*
	Rhithropanopeus harrisii
	Spisula solidissima
	Tellina agilis
	Urosalpinx cinerea
	Unident. Amphipoda
	Unident. Anthozoa
	Unident. Ascidiacea
	Unident. Bivalvia
	Unident. Polychaeta

Taxonomic composition also differed between soft-sediment pre-construction communities and those found on the 1-yr old experimental reefs (Table 4). Several epibenthic taxa (e.g. *Balanus, Crepidula*) typical of hard substrates as well as infaunal taxa (e.g. *Gemma, Mulinia*) typical soft sediments were common to both lists, but for the most part infauna dominated the pre-construction communities and epifauna dominated post-construction. In sum, these data confirm the expected result that soft-sediment benthic communities in the five reef areas were replaced by communities typical of hard bottom oyster reefs.

Conclusions and Recommendations for Future Efforts

Increase reef size

A larger reef footprint will aid in the assessment of reef development and performance, as well as provide information more relevant to full-scale restoration. The relatively small reef footprint in the present project particularly limited our ability to measure habitat provisioning directly attributable to the reefs. The small footprint also meant that SOS that were eroded and transported even a few meters were lost from routine monitoring. Finally, a small footprint makes the monitoring activities themselves more likely to adversely impact oyster survival.

A larger footprint would also increase the odds of recruitment from wild oysters. Adding remotely set SOS (as in the present project) substantially increases construction cost and complexity of the overall restoration effort. The unexpected high level of natural recruitment observed at Soundview and Hastings strongly suggests that natural recruitment could be a key component to future restoration efforts. Understanding the potential contribution from wild oyster populations in different areas of the region and exploring methods to encourage and enhance natural recruitment is an important next step.

Develop mechanisms to limit erosion and transport of SOS off the reef

As discussed herein, a large percentage of the planted SOS were hydraulically transported off the rip-rap and clam shell reef bases. Therefore, developing reef construction or reef maintenance techniques for retaining the planted SOS on the reefs is a critical obstacle to overcome when attempting to restore oyster reefs in the high energy areas typical of NY/NJ Harbor. Oyster reefs naturally occur in areas exposed to wind waves and boat wakes, but the limiting hydrodynamic conditions have not been quantified. Thus, this component of future projects will require some amount of experimentation.

Several potentially useful methods may be appropriate. One involves taking advantage of the oyster's natural clumping tendency during the nursery phase to create three-dimensional “SOS blocks” which are more likely to withstand high energy environments and reduce the loss of oysters from transport off the reefs. Another approach could be covering the newly distributed SOS with biodegradable mesh material. This would stabilize the SOS until their natural clumping tendencies made them less erodible.

Develop native broodstock

Based on recent studies in other areas, it seems reasonable to postulate that oysters in the NY/NJ Harbor Estuary may have developed a natural resistance tempered by adaptation to local environmental conditions (temperature, salinity, etc.) to the two critical diseases, MSX and Dermo (Ford and Bushek 2012). This suggests that development of broodstocks on a regional basis may be the most effective way to produce larvae for remote setting and production of SOS used to seed restored reefs. As expected, prevalence of disease was low to moderate in our oysters but this will likely change as they mature. Thus, the long-term success of SOS used to seed restored reefs will likely be dependent on their disease resistance.

In the case of the Hastings site, ambient salinity levels were extremely low during the entire summer of 2011 and 2012, yet wild oysters ranging from spat to adults commonly occur in the area. This suggests that oysters there are adapted to a wider range of salinities, and restoration projects might be more successful if local broodstocks for larvae and SOS production were developed.

Adopt monitoring protocols to new reef design

Quadrat-based monitoring methods are well suited for reefs that are accessible from shore. However, these methods proved to be difficult to consistently implement at the sites in deeper water which required boats and the use of SCUBA divers. The overall result was limited data from the deep-water reefs. For future projects that involve shallow and deep-water sites, monitoring methods should be developed that allow direct comparisons of the resulting data. The sampling devices do not have to be identical but sample size and effectiveness should be similar. For example, patent tongs deployed from a boat and quadrats excavated by wading could yield comparable data if both had the same areal coverage. Other methods such as underwater video quadrats might also be useful in some cases.

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