OYSTER RESTORATION RESEARCH PROJECT

Monitoring of and Improvements to the
Oyster Restoration Research Partnership Experimental Reefs

FINAL REPORT
2011 HEP/NEIWPCC FUNDING

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Oyster Restoration Research Project Partners include the Hudson River Foundation, NY/NJ Baykeeper, United States Army Corps of Engineers, The University of New Hampshire, The Urban Assembly New York Harbor School, The New York Harbor Foundation, The Trust for Governors Island, The New York – New Jersey Harbor Estuary Program, Loyola University Chicago, Baruch College, CUYN, Brooklyn College, The New England Interstate Water Pollution Control Commission, New York City Department of Parks and Recreation Natural Resources Group, New York City Department of Environmental Protection, United States Environmental Protection Agency, Region 2, New York State Department of Environmental Conservation - Hudson River Program, NOAA Restoration Center, Bay Ridge Flats Oyster Project, Rocking the Boat, the Bronx River Alliance, and The River Project.

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Introduction

The New York-New Jersey Harbor Estuary Program (HEP) is a National Estuary Program authorized in 1987 by the U.S. Environmental Protection Agency. The program is a multi-year effort to develop and implement a plan to protect, conserve, and restore the estuary. Participants in the program include representatives from local, state, and federal environmental agencies, scientists, citizens, business interests, environmentalists, and others. In 2010, HEP provided funding to the ORRP for the purchase of field equipment, reef material, aquaculture facility equipment, and boat support.

The Oyster Restoration Research Project (ORRP)

Oysters were once a very abundant and cherished resource of the Harbor estuary. By the early 20th century, sediment, water pollution and over harvesting had all but eliminated these once dominant features. While no known reefs and only a handful of individuals remain today, water and sediment quality has improved dramatically and the restoration of the Eastern oyster (*Crassostrea virginica*) to the Harbor Estuary may now be possible. The promise of their restoration has captured the interest of scientists, policy makers, and the general public, all recognizing the importance of the oyster as a symbol of environmental improvements, and as a means of further connecting people to the estuary.

The oyster's contribution to overall estuary water quality and health is special. Oysters are a keystone species that create and maintain complex benthic habitats by building oyster reefs. Oyster reefs are known to promote the presence of a variety of aquatic species; invertebrates, fishes and other filter feeders that are attracted to the reefs in search of food and refuge. Additionally, oysters themselves provide water filtration services, play a part in nutrient cycling and provide shoreline stabilization.

Historically, the primary interest in the oyster was as a food product and little attention was paid to their contribution to the ecosystem. While the historical importance of the oyster fishery to the NY/NJ Harbor is clear, our region's restoration efforts are not aimed at reviving the lost commercial fishery but instead are focused on achieving ecosystem benefits.

Restoring oysters and oyster reefs is one of the eleven restoration targets making up the regionally developed and supported Comprehensive Restoration Plan (CRP) that was developed by HEP partners including the US Army Corps of Engineers (USACE), the Port Authority of New York and New Jersey (PANYNJ), and the Hudson River Foundation. The Comprehensive Restoration Plan sets a goal of restoring 500 acres of oyster reef by 2015 and 5,000 acres by 2050.

Many regional partners have been working to advance the target goal set by the CRP as a way to demonstrate progress in moving from planning to implementation. In August 2009 the Hudson River Foundation convened a panel of expert oyster scientists to gain advice on how to proceed with large scale oyster restoration research in the Hudson Raritan Estuary.

The overall consensus of the expert panel was that in order to advance oyster restoration in the HRE, HRF and its partners should move toward an integrated and coordinated research effort centered on a series of relatively small "experimental" reefs. The initiation of relatively small-scale "on-the-ground" restoration efforts and appropriate monitoring would enable the evaluation of several key and interrelated research questions; how oysters are affected by natural forces and how the surrounding environment is affected by oysters, and subsequently assist in the refinement and articulation of specific goals and criteria for evaluating restoration success. Furthermore consolidating the ongoing efforts of the various entities working with oysters into a cohesive partnership would provide valuable resources and expertise to the overall initiative.

Oyster Restoration Partnership

The HRF panel laid down the frame work for the multi partner Oyster Restoration Research Project (ORRP) that has become a partnership of not-for-profit organizations, federal, state and city agencies. The Partners continue to contribute a combination of funds, equipment, and personnel and have agreed to fulfill specific obligations. The partners have also agreed to meet regularly as part of the NY/NJ Harbor Estuary Program's (HEP) Oyster Workgroup, a sub-group of the HEP Comprehensive Restoration Plan workgroup.

The project began in 2010 with the construction of 6 experimental oyster reefs, which will be monitored over a 2 year period from 2011 till end of 2012.

The ultimate goal of the ORRP is to determine the best sites and methods to use in scaling up to large-scale oyster reef restoration in the New York / New Jersey Harbor Estuary through the scientific monitoring of these constructed reefs, as well as provide new information from which future oyster restoration decisions can be made.

Reef Location:

The HRF panel made further recommendations on reef size, construction materials as well as suitable sites for reef placement.

Six reefs were built for this project. They are located:

1) East coast of Staten Island,
2) Bay Ridge Flats off the coast of Redhook, Brooklyn
3) East coast of Govenors Island
4) Soundview lagoon at the confluence of the Bronx and East Rivers
5) Hastings on Hudson.
6) Dubos Point, Jamaica Bay

The sixth reef in Jamaica Bay is managed exclusively by New York City Department of Environmental Protection (NYCDEP) and their contractors, and will be reported on by NYCDEP in a stand-alone report. The remaining five reefs have been managed by HRF and Baykeeper, and will be discussed in this report.

Map 1: Indicating location of ORRP oyster reefs

Sites were selected from a wide geographic range within the HRE in order to test the effects of a variety of hydrodynamic and environmental conditions (with specific regard to salinity) on oysters on artificial reefs. ORRP partners were also interested in specific sites where previous restoration research efforts had already been initiated, and that showed promising results. Ultimate site selection however was determined by sediment type that would be conducive for oyster survival and growth. The three harbor reefs (Staten Island, Bay Ridge and Govenors Island) can only be accessed by divers while the two shallow reefs (Hastings and Soundview) can be accessed from the shoreline at low tide.

Reef Design

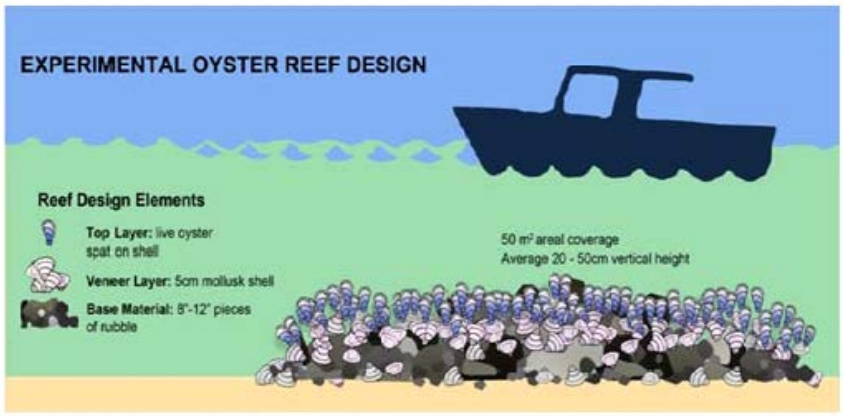

Figure 1: Illustrating ORRP reef design

The reefs were designed to mimic natural oyster reefs as much as possible. The experimental reefs also needed to have characteristics that allowed for sufficient sampling (monitoring) to assess *development* (growth, survival, and reproduction of the oysters) and *performance* (processes typically considered to be ecosystem services).

The HRF panel recommended installing a rock rubble base layer followed by a clam shell veneer on top of which the live oysters would be placed. These reef materials would provide a stable base for reef development (rubble base), and adequate surface features that promote oyster spat survival and larval settlement (clam shell veneer). Each reef footprint measures 10' x 15'.

USACE provided boats, barges, cranes and crew to construct the reefs.
Experimental reef construction consisted of placement of the initial rubble layer followed by a thin mollusk (mostly surf clams) shell veneer at the five sites in Sep/Oct 2010. In Oct/Nov 2010 juvenile oyster spat-on-shell (SOS) produced from remotely set larvae were spread by hand over the surface of each reef.

In support of the ORRP's restoration research goal, HEP/NEIWPCC provided funding to NY/NJ Baykeeper to perform and contribute to the following seven tasks:

Task 1 Management and performance of administrative tasks
Task 2. Provision of data collection training materials and sessions
Task 3. Aquaculture: collaboration with subcontractor(s) hired to breed and raise local oysters
Task 4. Assessment of development of reefs
Task 5. Determine success of restoration project: Results and Discussion
Task 6. Coordinate with partners, regulators, and funders
Task 7. Submit final report

Task 1. Management and performance of administrative tasks:
Quality Assurance Plan, Scheduling and Permitting

Summary
In order to ensure quality data collection for the Oyster Restoration Research Project a Quality Assurance Project Plan (QAPP) was drawn up and completed by Baykeeper. The QAPP describes environmental data collection activities and documents the projects technical planning process. The benefits of the QAPP are to communicate, to all parties, the specifications for implementation of the project design and to ensure that the quality objectives are achieved for the project. To obtain permission to remove wild oysters for disease testing and breeding purposes an amendment to the project's current NYS DEC License to Collect and Posses had to be approved.

Management Activities:

- *QAPP:* Baykeeper submitted the final draft of the QAPP to EPA and HEP/NEIWPCC on April 25th, and it was signed by EPA on 6/22/2011. Baykeeper submitted quarterly progress reports to HEP/NEIWPCC, Dr. Raymond Grizzle, and the Hudson River Foundation (**Attachment 1, Reports).** Data management (each data point and observation was entered into Excel and re-checked against the original data sheet for accuracy) was complete on January 13th, 2012 (**Attachment 2, Data).**

- *Scheduling:* working with all partners and volunteers to schedule monitoring events, providing equipment (waders, gloves, etc.), and arranging access to sites either by land or by boat. Scheduling activities also included coordination of field activities, reef access, and assistance with placement of research materials with research partners from University of New Hampshire, Baruch College, Stony Brook University, and Loyola University Chicago, and facilitation of visits to the reefs by individuals from the press, project partners, and associates.

- *Permits:* NYS Department of Environmental Conservation License to Collect and Possess (**Attachment 3, Baykeeper LCP #1321**): a permit amendment was granted by NY State DEC to cover the collection of local, wild, oyster broodstock for use in 2011 rearing activities.

- *Sub-contracting:* arranging for sub-contracted activities including aquaculture, boat hire, and disease testing.

Management Problems / Solutions: None

Task 2. Training activities: materials and sessions

Summary:
All ORRP partners that would be participating in the data collection process were familiarized with the field monitoring protocols prior to going out into the field. Training activities ensured consistency and quality in data collection.

Training Activities:

- *Training*: development of educational field training materials (**Attachment 4, Manual)** and delivery of classroom training to partners at Rocking the Boat, Bronx River Alliance, NYC Parks, and New York Harbor School (**Attachment 5, Roster).** Classroom training activities were completed by April 15th, 2011.

Training Problems / Solutions:

- The original plan of developing a land-based simulation reef was not realized, as space on Governors Island was no longer available. Instead, we printed out maps to orient field technicians to each site as part of the training session. UANYHS SCUBA divers were trained to pull samples using small amounts of the actual reef material (rock, shell, and oysters).

- Occasionally new participants joined data collection activities in the field. Participants that did not received classroom or land-based training from Baykeeper staff prior to their participation in the field worked side by side with either Baykeeper, UANYHS, or Hudson River Foundation staff during monitoring activities to ensure consistency in method and recording.

Task 3. Aquaculture: collaboration with subcontractors hired to breed and raise local oysters

Developing a 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 oyster diseases, MSX and Dermo. This suggests that development of broodstocks on a regional basis is the most effective way to produce larvae for remote setting and production of SOS used to seed restored reefs. In 2011 a set of wild oysters were specifically collected in the hopes to develop a native broodstock. ORRP's partner the Urban Assembly New York Harbor School (UANYHS) attempted initial broodstock conditioning for spawning purposes

Aquaculture Activities:

Oyster breeding techniques were developed by the Hatchery Manager Pete Malinowski at NY Harbor School based on advice from Steve Malinowski of the Fishers Island Oyster Farm, *Hatchery Culture of Bivalves a Practical Manual* and *Oyster Hatchery Manual. Protocols for North Carolina Oyster Hatchery Operations.*

- *Broodstock collection:* 173 total wild oysters were collected from the proximity of the Hastings on Hudson, Soundview, and upper Harbor reefs in March, 2011. They were held in the Harbor School EcoDock and later conditioned (prepared for spawning) in April 2011 **(Attachment 2, Data).** In order to minimize the possibilities of genetic bottlenecking a large broodstock is required hence 173 oysters were used for breeding purposes.

- *Spawning:* Broodstock were conditioned (prepared for spawning) in two stages: Stage one began following collection, stage two followed natural gametogenesis in ambient harbor water. A total of 8 spawns with 8 different groups were conducted from the end of May through end of June. Groups of 8 were used to maximize the chances of spawning success. Each group contained 15 oysters as this number would produce the maximum number of larvae that the hatchery manager and his students could work with. Each set of broodstock was conditioned separately in UANYHS's indoor aquaculture facility on Governors Island

- All 8 spawning attempts failed. Multiple variables contributed to the failed attempts, as each attempt experienced unique problems.

  Additional Spawning attempts were also made by Cornell University Cooperative Extension of Suffolk County in July 2011.

- *Oyster planting:* Remaining oysters from the 2010 cohort were placed on three reefs in 2011 (**Table 2 in task 5).** Oysters were placed on portions of each reef that previously demonstrated the best retention and survival of spat on shell. These reefs were Govenors Island, Soundview and Hastings on Hudson

Aquaculture Problems / Solutions:

Problems experienced with broodstock groups:

Larval group #1 metamorphosed and settled on the walls of the culture tank over a weekend. Because access to the school facility had been limited to weekdays it was not possible to monitor the animals over the weekend. That has since been remedied. Hatchery manager now has full access to the facility.

Larval group #2 became contaminated with filamentous brown algae. Most likely the algae gained access to the mixing tank and was then introduced to the larval tank. All culture media is first chlorinated, then passed through sand and carbon filters and is subjected to sterilization by ultraviolet light while in the mixing tank. This apparently was insufficient to prevent brown algae growth in the culture tanks. The algae made handling group #2 very labor intensive. Water changes took between 2 and 4 hours, as the screens quickly became fouled with the algae. These extended water changes placed an added stress on the larvae, as did the algae itself. By filtering the culture media down to one micron before adding it to the culture tanks the problem has been avoided in future groups. In retrospect, the group should have been discarded, saving about 25 hours of labor over the course of a week and a half. The group had a small number of larvae retained on the 125 micron screen, however none were retained on the 175 micron screen.

Group #3 had a small percentage of animals develop to the D-stage. The vast majority of fertilized eggs showed signs of abnormal development in the form of partially formed or open valves. This group was taken through to the 125 micron screen over two weeks. Growth continued to slow and eventually stopped at around the 160 micron mark. The average size on the Harbor oysters is significantly less than the other broodstocks, most likely contributed to underdeveloped eggs.

A rapid spike in water temperature killed group #4. The temperature spike was caused by a faulty thermostat, controlling the 800-watt heating element charged with maintaining the culture media at 25°C. Future errors of this kind can be avoided by using more reliable heating elements. During the end of June the algae system began showing signs of crashing.

No animals in group #5 developed to the D-stage. Many partially developed animals were observed 48 to 72 hours following fertilization.

Inconsistent live algae supply was most likely the cause of slow growth in groups #6. Problems in the algae system have been diagnosed as contamination through the air lines. All airlines were replaced and as a temporary measure the T-iso cultures have been physically separated from the *tetraselmis.* , In addition separate air pumps have been purchased for each kalwall, limiting the chance of cross contamination.

Groups #7 and #8 were raised on algae paste, a less desirable feed than cultured algae. Neither group exhibited strong growth from the start. With the new upgrades to the algae system there should be enough food to avoid using paste

- *Larval Culture:* Every attempt was made to determine the cause of slow and abnormal growth of each brood. However it is important to note that due to the number of possible variables and vulnerability of the animals in question, in most cases these causes represent a best guess of the hatchery manager. Slow and abnormal growth was a result of poor gamete condition, overly ambitious stocking densities, compromised culture media, and faulty heating elements." (Additional details regarding the size of collected

broodstock; dates and amount of larvae produced can be found in **Attachment 6, Aquaculture Report,** *-P. Malinowski, UANYHS)*

- *Spawning and larval culture: Supplementation of eyed larvae:* To supplement UANYHS's efforts, Cornell University Cooperative Extension of Suffolk County (CCC) was asked to attempt to produce eyed larvae with ORRP's collected Soundview broodstock. Unfortunately those spawning attempts were not successful. CCE reported that the oysters were in poor condition with compromised health due to boring sponge and/or mud blister worm infections.

- *Remote Setting and Grow-out:* No remote setting activities were performed in 2011. ORRP's remaining 2010 hatchery oysters were distributed throughout the course of the summer, with the exception of ~5,000 being held by UANYHS in the aquaculture center through spring of 2012.

Group #	Broodstock Source	Males/Females (M/F)	Stimulated (Y/N)	Eggs Produced (in millions)	% Fertilization	Stocking Density (animals/mL)
1	Soundview	5F/7M	Y	45.3	82	20
2	Hastings	3F/8M	Y	10.1	35	35
3	Harbor	2F/9M	Y	9.4	15	5
4	Soundview	4F/11M	Y	67.7	74	35
5	Soundview	1F/8M	N	55.6	78	15
6	Soundview	1F/13M	N	5.4	87	35
7	Hastings	3F/5M	Y	14.5	89	20
8	Soundview	4F/10M	N	95.1	91	10

Table 1 shows the spawning and fertilization rate for eight groups of broodstock. Percent fertilization was determined using visual identification of developing embryos. Number of eggs was determined using a counting slide and several random samples.

Task 4. Assessment of development of reefs

Summary:
By placing oysters out on experimental reef beds it is possible to evaluate the fuller range of natural factors that affect oyster reef development. These factors include the influence of predators, and the effects of hydrodynamics of the underwater environment. Similarly this project also provides an opportunity to see how oyster reefs affect their surroundings (eg. changes in aquatic community and new ecosystem services provided). This report will cover reef development as it pertains to oyster growth, recruitment and retention. (See ORRP Phase I technical report by Grizzle et al 2011 for reef performance analysis – **Attachment 9**).

Reef development was primarily assessed by taking nine replicate 0.1 m^2 quadrat samples per reef at every monitoring session (where possible) and measuring the size of the live and dead oysters. Other bivalves present in the sample were also measured and recorded. Data collected under Phase 1 (November 2010 – October 2011) of the ORRP was used to assess reef development (oyster retention, growth and survival) at five ORRP experimental reef sites. Reefs were monitored after the initial SOS placement in fall 2010 and then periodically every 6 weeks from spring 2011 – fall 2011.

Assessment Activities:

- The five reefs were visited a total of 22 times for monitoring between May and November 2011 (see **Figure 2 in Task 5**).
- **The data collected included** bivalve, sediment, and water quality data; site assessments and species observations were recorded, (**Attachment 2**, **Data**).
  Cultured and wild oysters from the reef and reef areas were collected at the end of the field season in 2011 and tested for disease. **(Attachment 7, Disease Testing.)**

Assessment Problems / Solutions:

- **Reduction of monitoring events at Staten Island and Bay Ridge Flats:** Due to the heavy loss (transport and mortality loss) of oysters on the Bay Ridge Flats and Staten Island reefs, ORRP PI DR. Ray Grizzle, in consultation with the other ORRP partners, made the decision to instead focus funding and effort on the three reefs that had the best results over-winter (Governors Island, Hastings on Hudson, and Soundview.) Instead of re-stocking Bay Ridge and Staten Island and monitoring them 5 times over the course of 2011, we did not restock them and instead monitored them 3 times.

Task 5. Determine success of restoration project: Results and Discussion

See Figure 2 for timeline of events of the ORRP phase I. Experimental reefs were constructed in the fall 2010 and initial spat on shell (SOS) seeding occurred shortly thereafter (see Table 2 for SOS amounts). Monitoring events took place every 6 weeks (where possible) beginning in the spring 2011 until fall 2011. An initial monitoring event occurred straight after the first seeding in fall 2010. Attempted broodstock culturing using wild oysters took place in May – June 2011. Reseeding Soundview and Hastings reef took place in June 2011, and Govenors Island reseeding took place from June through to November 2011 (table 2). Disease testing occurred at the end of the field season in November 2011.

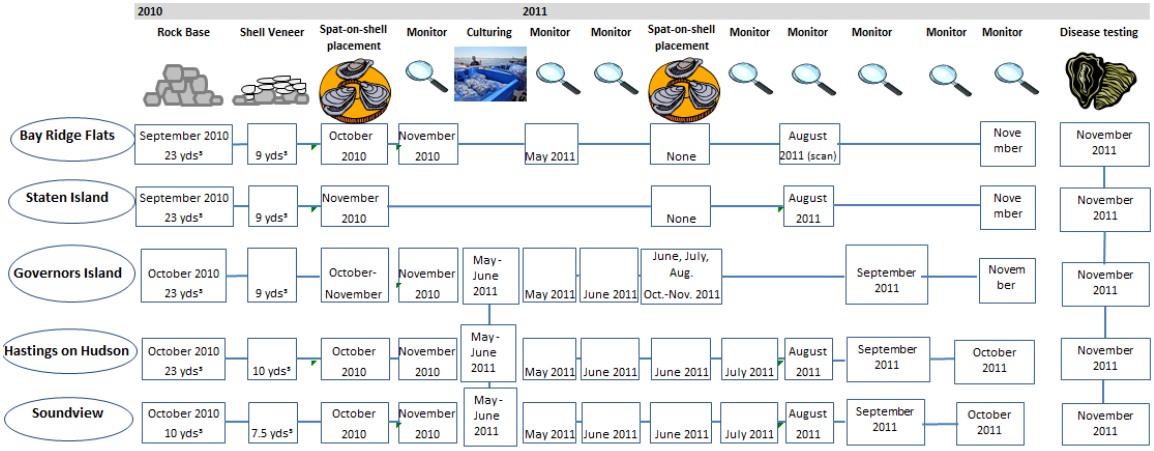

Figure 2: ORRP timeline of events showing reef construction, SOS placement, monitoring events, culturing attempts and disease testing for the ORRP phase 1 - 2011

Table 2: 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	~30m^2	~55,700	Northern half of reef ~18m^2
HH	~53,000	~30m^2	~10,100	Northeastern corner of reef ~0.62m^2
GI	~61,500	~30m^2	~4,200 (46,200 by Nov 2011)	Western portion of reef ~9m^2
BR	~55,000	~30m^2	Not re-seeded	NA
SI	~56,000	~30m^2	Not re-seeded	NA

Reef development as it pertains to oyster growth, mortality and retention will be discussed in this section.

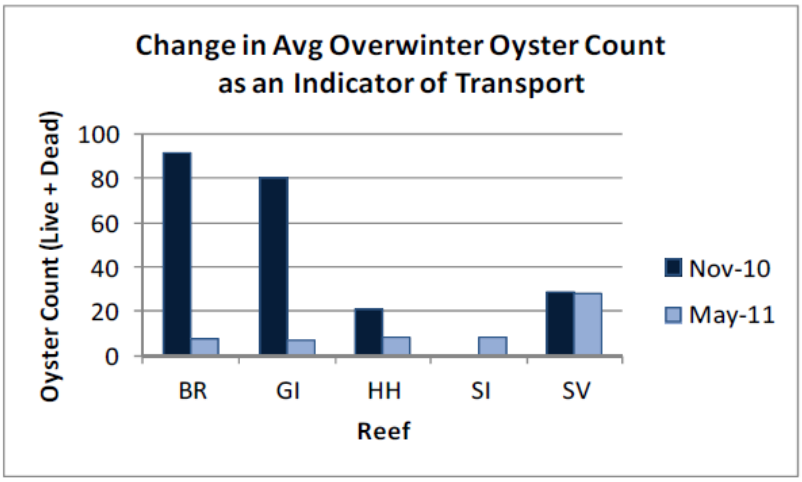

Figure 3: Total (live + dead) spat counts used as indicator of transport off the reef

The quadrat samples taken in early 2011 indicated high *apparent* mortality on all five reefs. We use the term *apparent* mortality because some of the change in live oyster density indicated by the routine quadrat data may be attributable to erosion and transport of the SOS from the reef rather than mortality. Figure 3 shows the total (live + dead) oysters counted from the 9-quadrat samples, the large change in the over winter (Nov 2010 to May of 2011) total oyster count particularly at the Bay Ridge (BR) and the Governors Island (GI) reefs suggest that transport loss and not mortality accounted for the observed differences. Divers did report that they observed oysters outside the boundaries of the reef, which further confirms that the decrease in oysters was due to transport. Although the total oyster count at the Soundview (SV) reef remained similar some of the SOS planted in Nov 2010 oysters were discovered at a location just north of the reef in the Summer of 2011. The Hastings reef however did suffer from high mortality due to prolonged low salinity levels in the spring 2011 caused by winter snowmelt. Water quality data collected around that time confirm this (Figure 5 and 6). Staten Island on the other hand was not monitored post SOS deployment in 2010 due to difficulties in accessing the reef (strong currents have made monitoring very difficult at this site) and it is highly likely that oysters have been transported off the reef as well due to the dynamic underwater environment. Divers at the Staten Island site have also reported seeing oysters outside the boundary of the reef in the spring 2011.

It was decided early on in the project to maintain an adaptive management approach based on the data collected at each reef. As was expected, each reef was affected by different environmental factors, as already postulated in Figure 3, and hence further management decisions were based on individual reef development rather than treating all reefs as equal. Already we began experiencing logistical difficulties in accessing the reefs at Bay Ridge and Staten Island which resulted in a poor data set for these two reefs, and so it was decided to concentrate our resources and efforts at the remaining 3 reefs all which showed favorable environmental conditions for oyster growth and recruitment (Figures 4, 5 and 6). This lead to the decision to deploy additional SOS at these 3 reefs: Govenors Island, Hastings and Soundview. As the reefs began to develop differently from each other it became difficult to draw comparisons between the reefs and thus, development of each reef is discussed separately below. Note that due to limited data sets from Bay Ridge and Staten Island it was not possible to analyze reef development comprehensively.

Water quality data:
Data collected during routine reef monitoring generally suggest environmental conditions suitable for growth and reproduction of oysters (Fig. 5 and 6). 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. Salinity at Hastings, however, dropped

well below optimum levels for several weeks during summer 2011. This likely explains the near-100% loss of 2010 SOS at Hastings (Fig 3), 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.

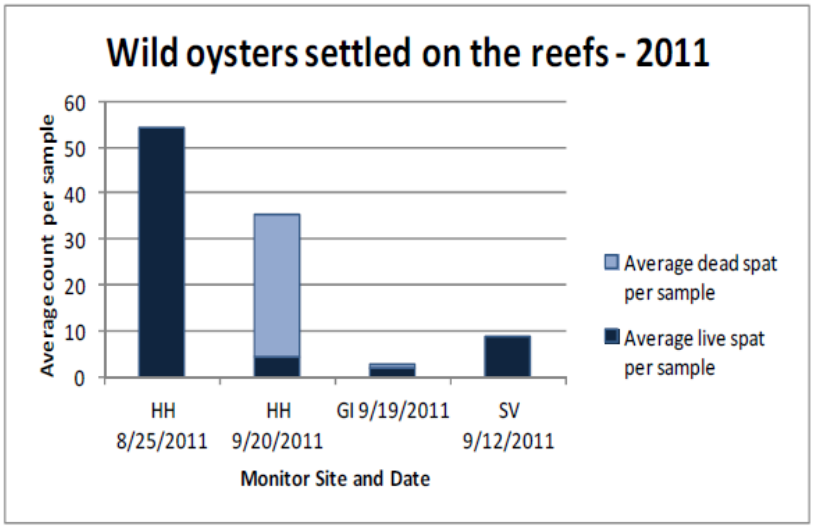

Figure 4: Spat from wild oysters for Hastings (HH), Governors Island (GI) and Soundview reefs (SV).

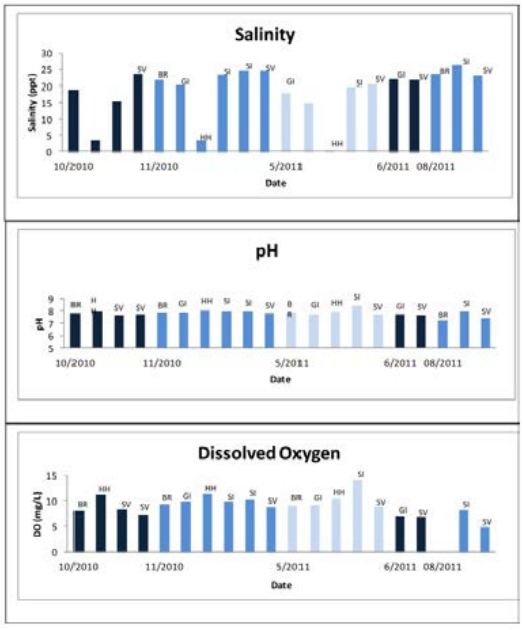

Figure 5: Water quality data collected during routine monitoring visits

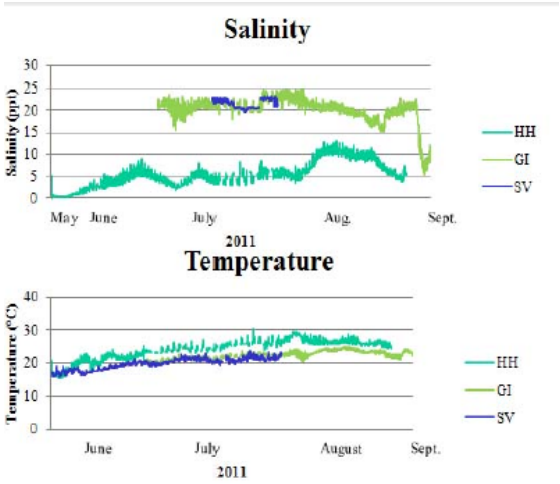

Figure 6: Salinty and Temperature data collected by sonde at Hastings (HH), Govenors Island (GI) and Soundview (SV).

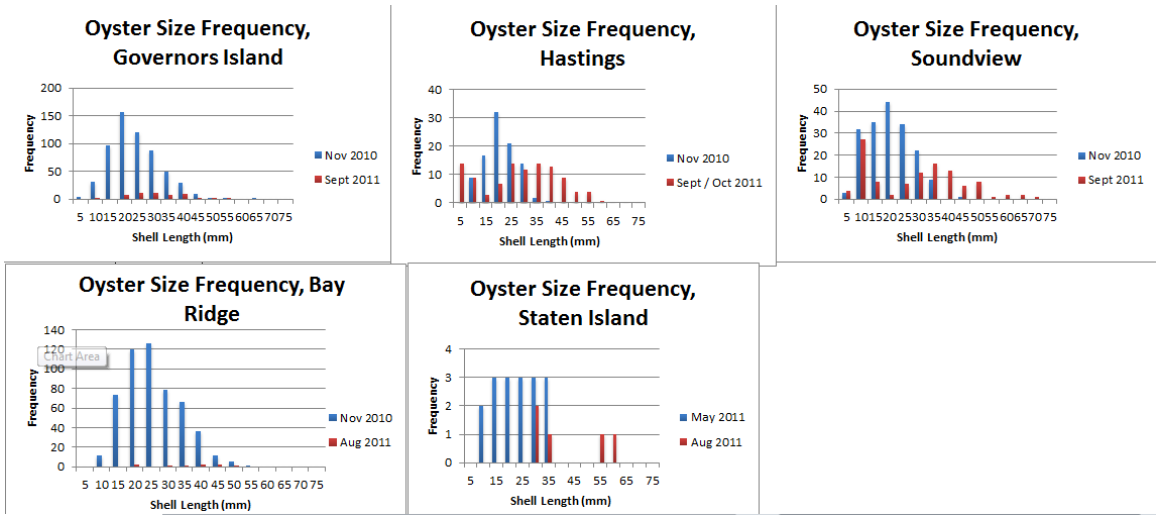

Figure 7: Size frequencies showing frequencies of oysters per size group in the oyster reefs first year of developmental

Reef development: Soundview

The Soundview reef had development patterns indicating good prospects for future restoration activities. The routine quadrat data indicated substantial apparent mortality of the 2010 SOS, but also new recruits from natural spat settlement (Fig 4 and 7). New recruitment was evident in two ways. First, the September 2011 sampling clearly showed two size classes (10 mm [likely recently settled spat] and 35 mm) as well as a possible third at 65 mm (Fig. 3). Secondly, identification of the substrate upon which the spat were found allowed separation of the spat into recruits from wild oysters (settled onto clam shell) as well as remotely set spat (on oyster shell). Figure 4 summarizes the data for spat identified from wild oysters for the Soundview, Hastings and Governors Island reefs. Thus, new recruitment from wild oysters was strongly indicated for the Soundview reef. In addition to data from the experimental reef, other information from the general area indicate 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. Thus, there is substantial evidence indicating the Soundview site has excellent potential for long-term sustainability of oysters.

Reef development: Governors Island
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 (Fig 3 and Fig 7). As discussed above, transport off the reef was addressed in 2011 by re-seeding with over-wintered SOS on five different occasions (Fig. 2). The September addition was made outside the established perimeter of the reef and thus was not monitored during the November monitor. The two fall monitoring events showed good retention and growth (Fig. 7). The November 2011 sampling event also found twenty-one oysters <20 mm in size, suggesting spat from wild oysters (i.e. natural spat set) (Fig 4). 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

Reef development: Hastings
The Hastings reef also showed potential for future restoration efforts. Although it had substantial mortality of the 2010 SOS (Fig. 3), there was greater recruitment from wild oysters than on any of the other reefs (Fig. 4). 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. 5 and 6), 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 is adapted to much lower salinities than the other sites. If so, the larvae used for the 2010 SOS may not have been able to tolerate the low salinities in 2011. This finding also suggests that future restoration efforts at Hastings should consider developing a broodstock for larvae production from oysters found in that area.

Reef development: Bay Ridge and Staten Island Reefs
The few oysters that were found at monitoring events in the summer 2011 showed growth (Fig 7) however numbers were far too few for appropriate analysis and discussion. Further efforts have been concentrated at the other 3 reefs that were easier to access and provided adequate data for analysis.

Disease testing results
A total of 20 oysters were collected from each reef site. Another 20 oysters were collected from the Ecodock where the project's SOS were kept until deployment on the reefs, and another 20 wild oysters found at SV and HH respectively were removed for disease testing. At the Bay Ridge and Staten Island reefs where not enough oysters could be collected from the reef, the closest proxies were taken from nearby Baykeeper oyster gardens (Great Kills Harbor, SI and ShowBoat Barge in Redhook, Brooklyn). Oysters were sent to Haskin Shellfish Research Laboratory for processing.

Table 2: Documenting prevalence of MXS infection at ORRP reef sites. Note GKH and ShBoat are the proxies site for Staten Island and Bay Ridge reefs respectively.

Tissue-section examination results:

Sample ID	Inf. intensity range[1]	MSX infection rating[2]					Prevalence			
		0	1	2	3	4	Total	Systemic	Advanced	Weighted[3]
HH40	none	20	0	0	0	0	0.0%	0.0%	0.0%	0.0
HH60	none	20	0	0	0	0	0.0%	0.0%	0.0%	0.0
HHreef	none	20	0	0	0	0	0.0%	0.0%	0.0%	0.0
SV40	none - moderate	18	0	0	0	2	10.0%	10.0%	10.0%	0.4
SV60	none - heavy	15	2	1	1	1	25.0%	10.0%	5.0%	0.6
SVreef	none - heavy	16	1	1	0	2	20.0%	10.0%	10.0%	0.6
GKH	none - heavy	18	1	0	0	1	10.0%	5.0%	5.0%	0.3
EcoD	none - moderate	8	4	1	3	4	60.0%	35.0%	20.0%	1.6
GIreef	none - heavy	11	2	0	1	6	45.0%	35.0%	30.0%	1.5
ShBoat	none - heavy	16	1	1	0	1	15.8%	5.3%	5.3%	0.4

Disease testing results reported MSX detected at all sites except at Hastings. Advanced, systemic infections were observed at all sites containing MSX infection.

Table 3: Documenting the prevalence of DERMO at ORRP reef sites

RFTM examination results:

Sample ID	*Perkinsus* infection levels[4]							Prevalence			Avg intensity of infected indiv.[5]
	0	0.5	1	2	3	4	5	Total	Advanced	Weighted[3]	
HH40	19	1	0	0	0	0	0	5.0%	0.0%	0.0	0.50
HH60	17	3	0	0	0	0	0	15.0%	0.0%	0.1	0.50
HHreef	20	0	0	0	0	0	0	0.0%	0.0%	0.0	0.00
SV40	20	0	0	0	0	0	0	0.0%	0.0%	0.0	0.00
SV60	20	0	0	0	0	0	0	0.0%	0.0%	0.0	0.00
SVreef	19	1	0	0	0	0	0	5.0%	0.0%	0.0	0.50
GKH	7	4	5	2	1	1	0	65.0%	10.0%	0.9	1.38
EcoD	14	1	1	1	1	1	1	30.0%	15.0%	0.8	2.58
GIreef	20	0	0	0	0	0	0	0.0%	0.0%	0.0	0.00
ShBoat	12	2	2	2	1	0	0	36.8%	5.3%	0.5	1.43

Dermo infections were detected in 6 of the 10 samples. Most samples contained a low prevalence of infection, with the exception of Great Kills Harbor the Staten Island reef proxy, and few samples contained advanced infections

(See **attachment 7** for Haskins Lab Disease report).

- ORRP Phase I technical report compiled by Dr. Raymond Grizzle et al 2011is available as a separate report to the Hudson River Foundation. This report will be distributed to all partners by the Hudson River Foundation and see **Attachment 9**.

Task 6. Coordinate with partners, regulators, and funders to discuss the results and analysis of collected data, and it's implications on future projects.

Coordination Activities:

- *HEP Oyster Sub-group meetings* (4/7/11, 9/21/11, and 1/28/12). Baykeeper participated in delivery of results and discussion of progress of activities throughout the year.

Coordination Problems / Solutions:

- *Monitoring of and Improvements to the Oyster Restoration Research Partnership Experimental Reefs* is one of several studies funded in 2011 to assess the development and performance of ORRP reefs. Three additional studies, funded by the Hudson River Foundation, are underway:
    - Dr. Raymond Grizzle: Characterization of water filtration rates of the restored reefs on a seasonal basis using the "upstream/downstream" approach and *in situ* fluorometry.
    - Dr. Chester B. Zarnoch – Baruch College, CUNY; Timothy J. Hoellein – Loyola University Chicago; Brett F. Branco – Brooklyn College, CUNY; Denise A. Bruesewitz – University of Texas**:** *Oyster filtration capacity and nutrient sequestration, and oyster enhancement of nitrogen (N) removal.*
    - Dr. Bradley Peterson, Stony Brook University: Investigating ecological restoration: Enhancement of fisheries due to the presence of oyster reefs in the Hudson River

  Each of these studies is an integral component of the analysis of the collected data and will impact the consequent discussion of implications on future projects. Results of the first year of study for each of these projects are expected in February. Partners will continue to meet regularly with each other, with funders, and with regulators to discuss these studies and to discuss this and other future oyster restoration research projects in the Hudson Raritan Estuary.

Task 7. Submit final report

Activities:

- This final report and attachments describe the methods used **(Attachment 8, Methods)** and results **(Attachment 2, Data)**

Problems / Solutions:

- Analysis of variance of data collected by Baykeeper is discussed in Dr. Raymond Grizzle's 2011 Report to the Hudson River Foundation.

Statement of percentage of project completed
All project tasks are completed.

Conclusion
The regionally developed and supported Comprehensive Restoration Plan (CRP) sets a goal of restoring 500 acres of oyster reef by 2015 and 5,000 acres by 2050. Our initial efforts have resulted in the addition of unique three-dimensional habitats for fish and invertebrates in five locations throughout the Hudson Raritan Estuary. Oyster placed and recruited on these reefs may also contribute other ecological benefits such as water filtration, nutrient cycling, and shoreline stabilization.

By constructing several experimental reefs, monitoring their development, and researching how oysters are affected by natural forces and how the surrounding environment is affected by oysters, this project is providing important new information from which larger scale restoration decisions can be made. This project also serves as a new platform for numerous education and

outreach opportunities. Local history, marine biology, environmental conservation, and policy studies are just a few of the topics that have captured the community's interest. Partners will now have ready access to the data collected and are already developing their own related programming, further engaging the public in the oyster restoration effort and the overall ecosystem restoration agenda.

NY/NJ Baykeeper and all Oyster Restoration Research Project partners are extremely grateful to The Harbor Estuary Program and the New England Interstate Water Pollution Control Commission for the funding support provided for this project.

Recommendations for Future Efforts

Increase reef size

Three of the current sites (Govenors Island, Sounview and Hastings) show potential for future reef expansion. A larger reef footprint will aid in assessment of reef development and performance, as well as provide information more relevant to full-scale restoration. 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 construction effort. The observation of natural spat set at several of the sites suggests that natural recruitment could be a key component to future restoration efforts. In any case, understanding the potential contribution from natural recruitment and exploring methods to enhance settlement rates 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 was hydraulically transported off the riprap 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 testing methods. 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 reef bases. 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.

Aquaculture:

As wild oysters in the HRE have most likely developed a natural resistance to disease tempered by adaptation to local environmental conditions it makes sense to attempt to develop SOS from wild oysters for reef restocking purposes. Another attempt at deriving eyed larvae from local broodstock will be made in 2012. Cornell Cooperative Extension aquaculturists will accompany collection efforts in search for healthy wild oysters in February 2012.