RECRUITMENT OF OYSTERS WITHIN THE HUDSON RIVER ESTUARY

A Final Report of the Tibor T. Polgar Fellowship Program

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Carthan, R. and J. S. Levinton. 2013. Recruitment of oysters within the Hudson River Estuary. Section III: 1-28 pp. *In* S.H. Fernald, D. Yozzo and H. Andreyko (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 2012. Hudson River Foundation.

ABSTRACT

The eastern oyster, *Crassostrea virginica*, was once a major ecological element in the Lower Hudson, but was nearly driven to extinction by the early 20th century owing mainly to sewage-related pollution, but also affected by overexploitation and habitat alteration. Today, the eastern oyster is generally rare from the Tappan Zee to New York – New Jersey Harbor, and no longer is a major resource species or a foundation species for marine communities. A healthy larval supply is essential for oyster restoration. To examine variation in oyster recruitment, oyster-shell bags were placed from the Tappan Zee to Governors Island to examine spatial differences in oyster recruitment. Three sites were established within the Tappan Zee at Ossining, Philips Manor and Irvington and three more were established at lower Manhattan: one at Pier 40 and two at Governers Island. Water temperature, salinity, and dissolved oxygen were monitored biweekly. Observations of invertebrate recruitment were made with emphasis on barnacles and bivalves. Only zebra mussels recruited to Ossining, which suggested a salinity limitation to oyster survival at this site. Strong recruitment of the barnacle *Balanus improvisus* occurred in July within the Tappan Zee; this species was present at Pier 40 in lower Manhattan, but absent from two sites at Governors Island. A pattern of larval retention within the lower Hudson estuary explains this. Oyster recruitment was strongest at the southern end of the Tappan Zee at Irvington but also occurred in the mid-Tappan Zee at Philips Manor. No oysters recruited to the Manhattan sites. It seems likely that the Tappan Zee recruitment came from a larval source within the Tappan Zee.

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INTRODUCTION

The eastern oyster *Crassostrea virginica* is a bivalve mollusk that can provide many ecosystem services when abundant in estuarine and coastal environments on the east and Gulf coasts of North America. They filter algae, bacteria, fine sediments and occasionally toxins from the water (Officer et al. 1982, Newell 1988). Oyster reefs provide habitat for marine organisms such as shrimp, crabs, clams, snails and worms, as well as many species of fish such as snook, grouper, redfish, black drum and more (Coen et al. 2007). They also can strongly influence nitrogen cycling in estuaries (Newell et al. 2005). Oysters are also an indicator of regional watershed properties due to their differential sensitivity to changes in water quality and climate (Levinton et al. 2011).

Unfortunately the ecosystem services provided by oysters are not being fully exploited because of destruction of oyster reefs due to pollution, habitat alteration, overexploitation and disease (Coleman and Williams 2002), especially within the Hudson River Estuary (Franz 1982, Kurlansky 2006). The lack of adults in the current lower Hudson results in too few larvae to sustain oyster populations, especially reefs, and there is not enough shell to attract larval settlement and promote sustainability of oyster mounds (Mann and Powell 2007).

The Hudson River was formerly known to contain oysters in high abundance (Franz 1982). This study examined the possible availability of recruiting larvae of these oysters in the Hudson River, as well as the distribution of larval recruitment in the Lower Hudson, and settlement of other species, including predators of oyster larvae as they settle. Larval settlement can be monitored by placing bags of shell that can be used to collect recruits with the assumption that recruitment is an estimate of larval abundance.

The main objectives of this study were to estimate recruitment and measure of oyster recruit growth rates while monitoring important physical variables for oysters including temperature, salinity, and oxygen.

The hypothesis that settlement rates will vary between sites was tested. It was expected that settlement in the Tappan Zee would be observed because a preliminary study showed settlement in 2008 (J. Levinton, unpublished data) and settlement has been observed at a nearby Oyster Restoration Research Program (ORRP) experimental reef at Hastings, New York, (B. Peterson, verbal communication). If oysters settle in New York Harbor, it is expected that growth rate of recruits will be greater in these higher salinity waters (Pier 40, Governors Is.) in comparison to the growth rates in lower salinity environments within the Tappan Zee-Haverstraw Bay area. Finally, two sites have been established on Governors Island, one close to an existing ORRP experimental reef and one approximately 1 km away. It was hypothesized that if oyster recruitment occurs, it will be greater closer to the experimental reef and that this reef will cause higher recruitment than other sites. This would be explained by a source of larvae from the experimental reef.

METHODS

Site Descriptions

Six sites were chosen for study, selected for access to the Hudson River in two general geographic areas (Figure 1). These sites were divided between lower Manhattan-Governors Island and the Tappan Zee. The structure of sampling allowed for overall comparison of the Tappan Zee versus New York Harbor recruitment, and also allowed an

investigation of the salinity gradient within the Tappan Zee (salinity declines toward the north), and the possible effect of the ORRP experimental reef at Governors Island.

Lower Manhattan / Governors Island Sites:

1. Pier 25, north side (P25): Shell bags were suspended from the vessel *Lilac* on the north side of the pier.

2. Yankee Pier, Governors Island (Gov-Y). This pier is ca 200 m from the Hudson River Foundation experimental oyster reef.

3. Pier 1, Governors Island (Gov-M). This pier is on the north side of Governors Island, near the oyster study area of the Harbor School.

Up river sites – Tappan Zee and Lower Haverstraw Bay:

4. Ossining (Oss). This is a bulkhead located in back of Westerly Marina, directly on the Hudson River.

5. Phillips Manor, Sleepy Hollow, NY (PM). This is a floating dock located in the Phillips Manor Boat and Beach Club, immediately west of the Phillips Manor train station.

6. Irvington, Irvington Boat Club (Irv). This is a floating dock located in a small bay of the Hudson River.

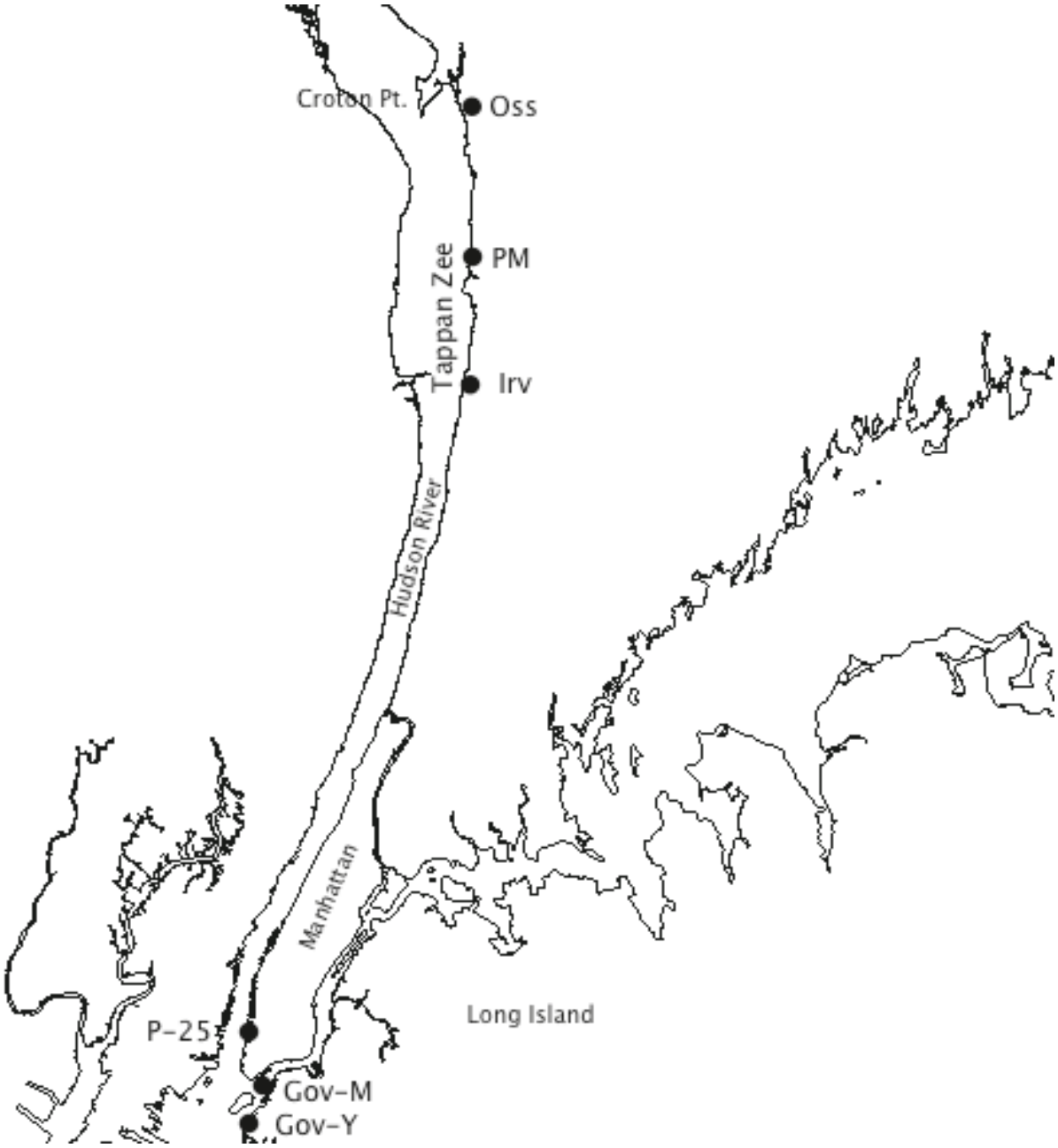

Figure 1. Sampling locations

Figure 2. Shell bag such as those used in recruitment studies

Field Methods

At each site, five bags (Figure 2) of oyster shell in plastic mesh were suspended about 1.0-1.5 m below water level. The shell bags used were constructed of 5 mm mesh with the dimensions 42.3 cm X 29 cm with a 30.5 cm long lead weight along the bottom. The bags were cleaned and filled with two horizontal rows of five shells so in total there were ten shells in each bag. All the shells were in the same orientation from back-side to front so that they could be identified individually within the bags without numbering them. Plastic ties were used to secure the mesh bags, and small pieces of rope were tied to the left and right top corners of the mesh bags. All of the bags were suspended about 1.5 meters below low tide (fixed sites) or below the water (floating docks) at each site by the rope. Bags were put in place on June 20, 2012, checked on July 5 2012 and

approximately every two weeks thereafter until August 31, 2012. One last sampling was done on October 12.

Biweekly Sampling Methods

Fouling organisms were cleaned off of mesh bag surface along with any mud or debris that could interfere with the settlement of oyster larvae. Water Quality was measured using a YSI Model 85 temperature-salinity-oxygen meter. Temperature (^{o}C), salinity (ppt), percent saturation and absolute oxygen concentration (mg L^{-1}) were recorded at each site. An example of data collection is shown in Table 1.

Table 1. Oyster water quality monitoring data for 6/20/12.

Locality	Temperature (^{o}C)	Salinity (ppt)	% Saturation	Dissolved Oxygen
Gov-Y	21.9	21.2	61.0	5.0 mg L^{-1}
Gov-M	22.4	20.7	65.3	5.17 mg L^{-1}
P25	21.4	19.8	62.0	5.0 mg L^{-1}
Irv	23.7	6.0	78.1	6.19 mg L^{-1}
PM	25.7	4.8	78.3	7.90 mg L^{-1}

RESULTS

Water Quality

Temperature variation was uniform (Figure 3) among the three New York Harbor sites, throughout the two months the study took place with a slight variation of two degrees Celsius. In the Tappan Zee, there was a slightly larger variation of temperature of about four degrees Celsius. On the second sampling date (6/18-20/2012), a slight dip in temperature of three degrees Celsius was recorded in both regions. Water temperature was consistently higher within the Tappan Zee – Haverstraw Bay sites relative to the New York Harbor sites, which were closer to the open ocean. The most southerly Tappan Zee site, Irvington, had the lowest temperature, which might indicate mixing with the cooler southerly part of the Hudson.

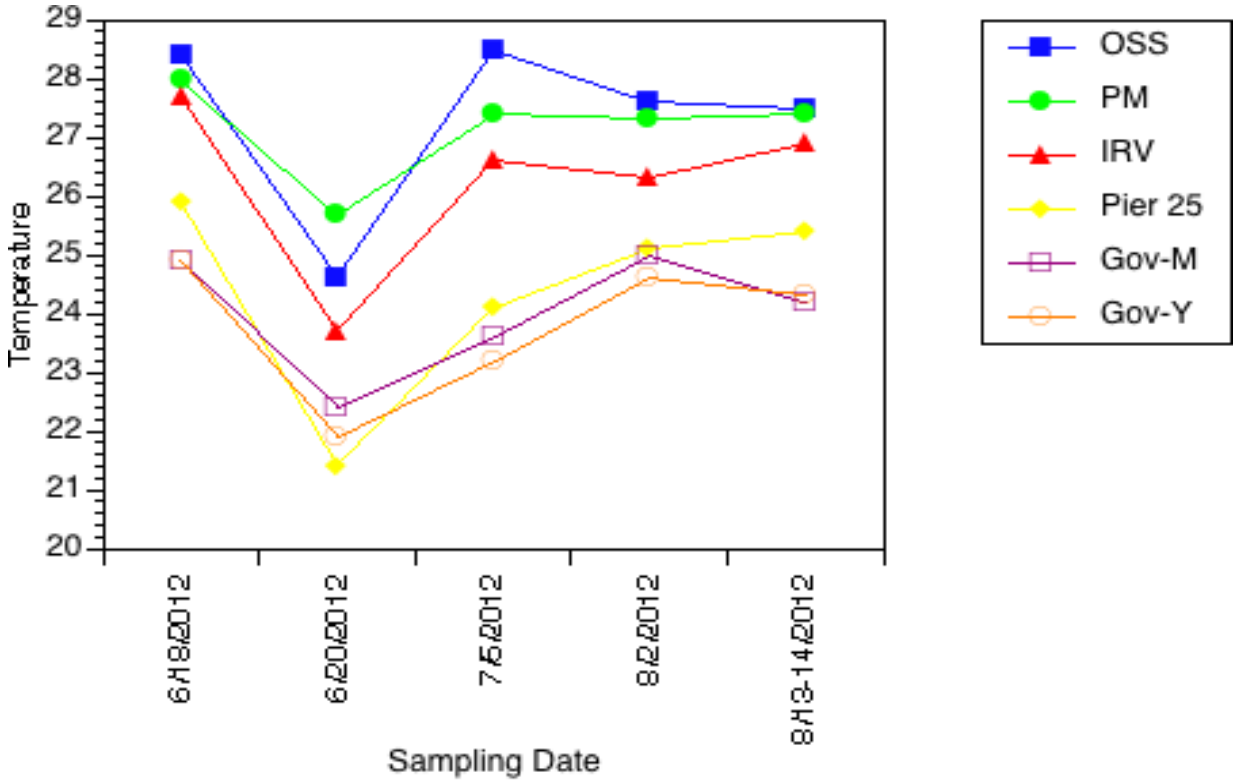

Figure 3. Temperature (°C) variation among the sampling sites.

Salinity (Figure 4) in the New York Harbor sites was distinctly higher than the Tappan Zee-Haverstraw sites. Salinity variation throughout the sites located in the Tappan Zee area was fairly uniform with an average salinity of approximately 4-10 ppt. The lower Hudson also exhibited a fairly uniform salinity of approximately 19-25 ppt. All of the sites exhibited a small decrease of about 2 ppt on the second sampling date (6/20/2012), corresponding to the temperature drop. For most of the sampling period, Ossining had the lowest salinity whereas Irvington had the highest.

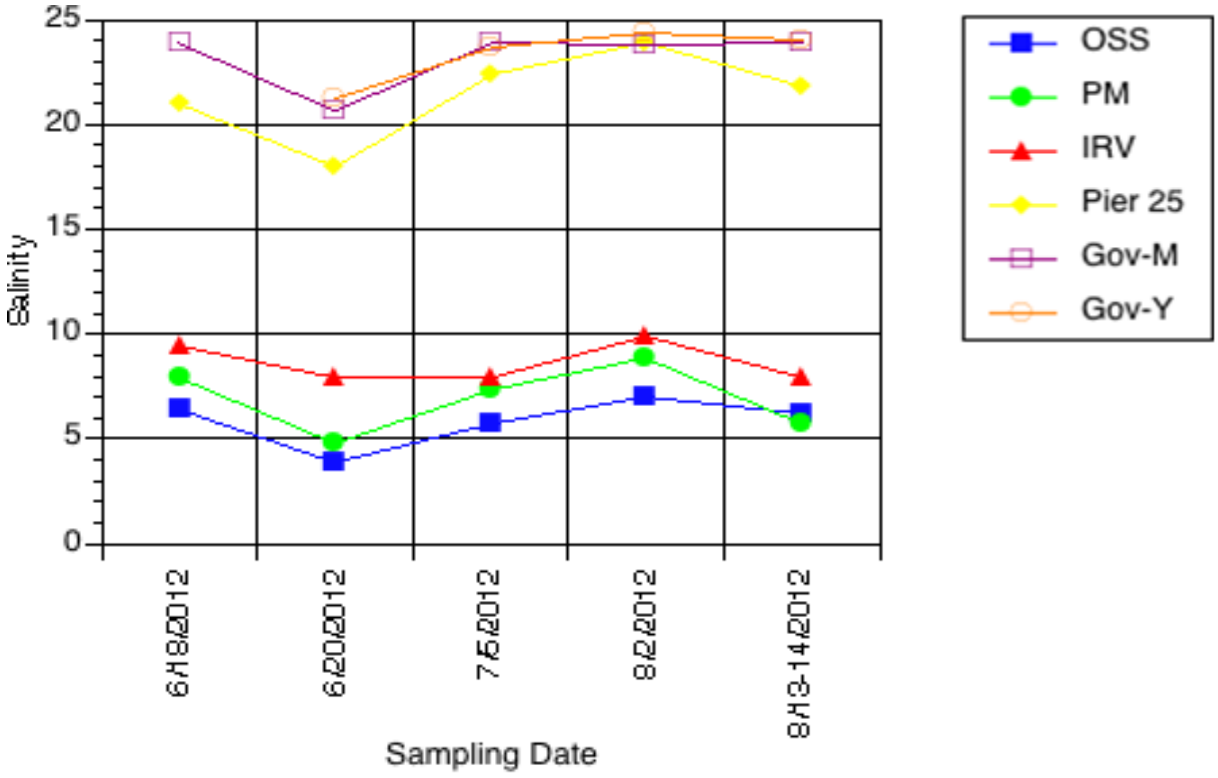

Figure 4. Salinity (ppt) over time at the sampling sites.

Oxygen concentration throughout these sites was fairly scattered but declined generally after June 20 (Figure 5). The variation had a range of about 3 mg/l throughout the sampling period with an average concentration of around 5 mg/l with some outliers noted at Ossining, Philips Manor, and the Governors Island site Gov-M. Oxygen reached a high of about 8 mg/l at Ossining on 7/5/2012 and at Philips Manor on 6/20/2012. Oxygen reached a high of about 8 mg/l and the Governors Island site along with Philips Manor Reached a low of 2 mg/l at Governors Island and Philips Manor on 6/18/2012. All in all, however, dissolved oxygen was usually above 4 mg/l and likely not a source of stress to oysters.

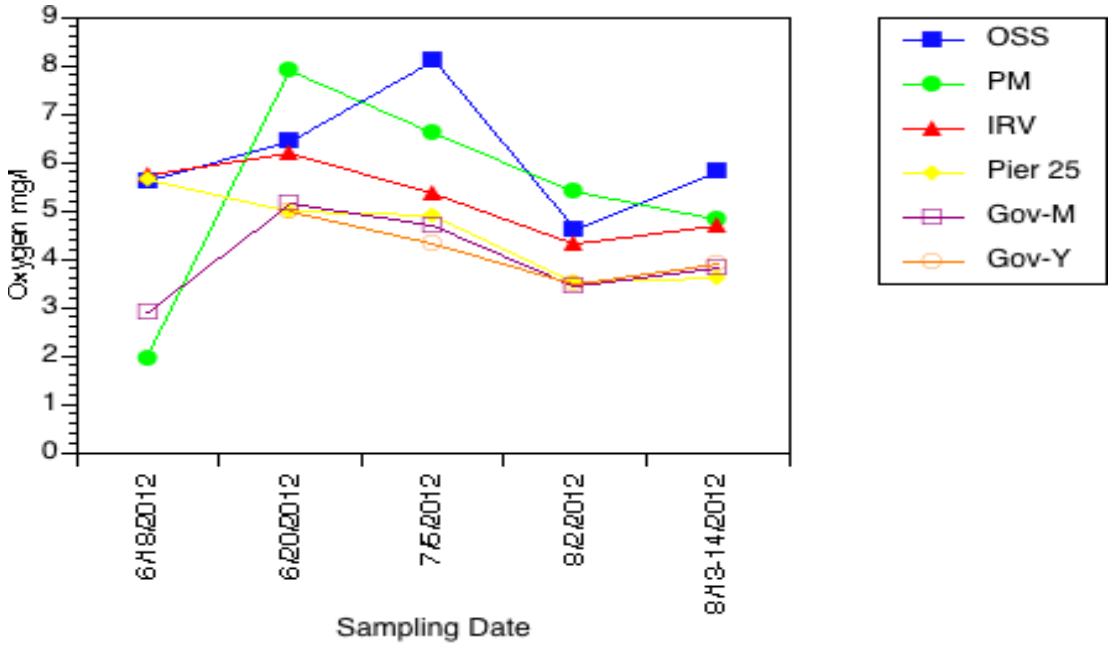

Figure 5. Dissolved oxygen concentration (mg L^{-1}) **at the sampling sites.**

Water quality data collected for this study were compared to data from the Piermont Pier Hudson River Environmental Conditions Observing System (HRECOS) station (www.hrecos.org). This continuously operating station is located between the Philips Manor and Irvington study sites, but on the opposite (western) shore. Average Daily values from the Piermont Pier HRECOS station were in the same range as the data collected at the Philips Manor and Irvington study sites (Table 2).

Table 2. Water quality data from the Piermont Pier HRECOS station.

Date	Average Daily Salinity (ppt)	Dissolved Oxygen (mg/L)	Water Temp (C)
6/18/12	4.9	8.1	22.6
6/20/12	5.5	8.0	23.5
7/5/12	8.2	6.2	27.0
8/2/12	ND	ND	ND
8/14/12	7.8	5.7	27.3

Recruitment

Oyster recruitment

The only sites where oyster settlement was observed throughout the study were Irvington (Figure 6) and Philips Manor, both within the Tappan Zee; these were last sampled on 10/12/2012. Oyster recruitment density declined from Irvington (mean = 36.8) to Philips Manor (mean = 6), with no recruitment observed at Ossining (Figure 7). Recruitment was significantly greater at Irvington than Phillips Manor (ANOVA, $F = 127.5$, $p < 0.0001$). Mean shell length was greater at Phillips Manor (18.3 mm) than Irvington (13.3, ANOVA, $F = 36.4$, $p < 0.0001$). A few zebra mussels were found at Ossining, even when the salinity was 4-6 ppt. No oyster recruitment was found in any of the New York Harbor sites.

Figure 6. Oyster shell taken from shell bag at Irvington on October 12, 2012, showing settled oyster recruits and barnacles.

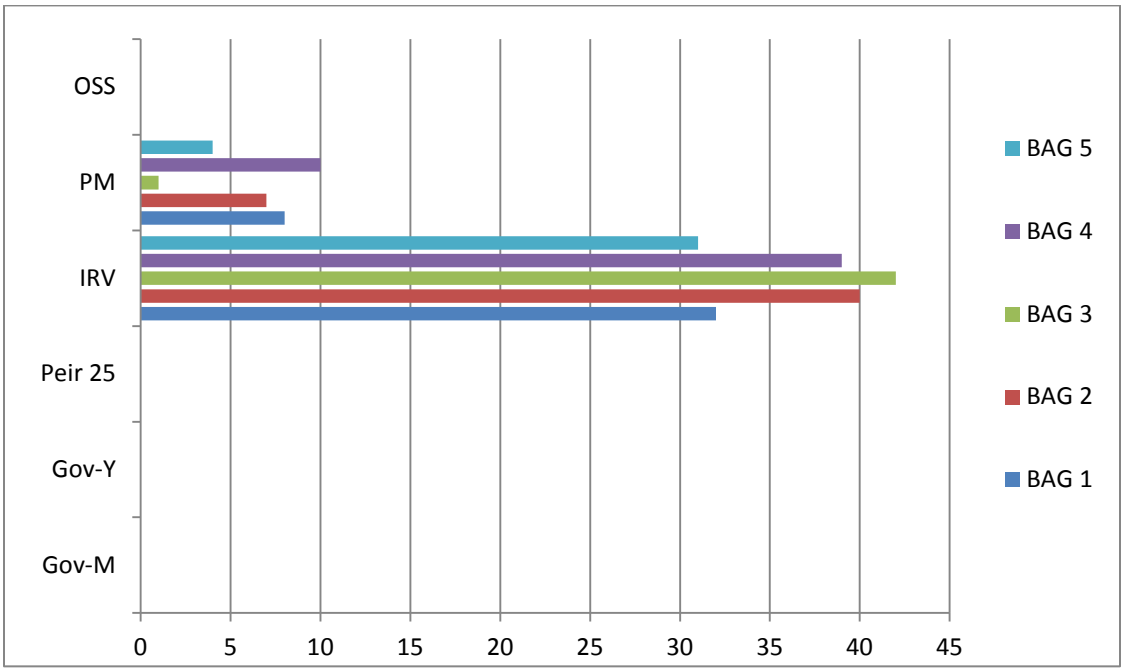

Figure 7. Oyster recruitment numbers, by bag, at the six sites.

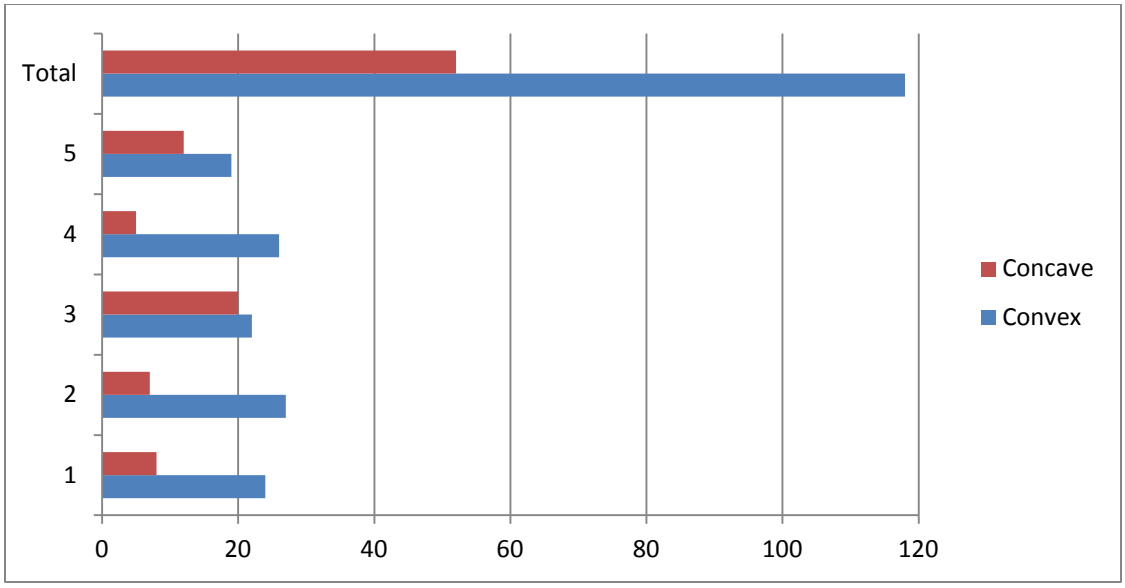

Figure 8. Number of oysters settled on interior and outside of valves.

The numbers of settled oysters were counted on the exterior (convex side) and interior (concave side) of the oyster valves. The numbers are substantial only for the Irvington site, which are reported in Figure 8. As can be seen, oysters settled more frequently on the exterior of the oyster valves, although there was variation among bags. The total numbers were tested for departure from a random distribution, using a Wilcoxon Signed Rank test, which tested the null hypothesis that settlement on the inside and outside of shells was the same frequency. This test suggests that there was a non-random concentration of oyster settlement on the exterior of the oyster shells, since the test was statistically significant (X^2 approximation = 5.8, $p \sim 0.02$).

Barnacle recruitment

In the first sampling period, a strong settlement of the barnacle *Balanus improvisus* was observed (Figure 7*)*. Because one shell bag had to be replaced at Phillips Manor, it was apparent that settlement ended in July. There was an abundance of barnacles that settled on the oyster shells that were placed in the Tappan Zee area. The Ossining, Philips Manor and Irvington sites contained barnacles on all 10 shells in each bag. There were also barnacles that settled on almost all the shells at Pier 25, but the density was conspicuously lower than within the Tappan Zee. No settlement was found at the other two sites at Governors Island (Figure 9).

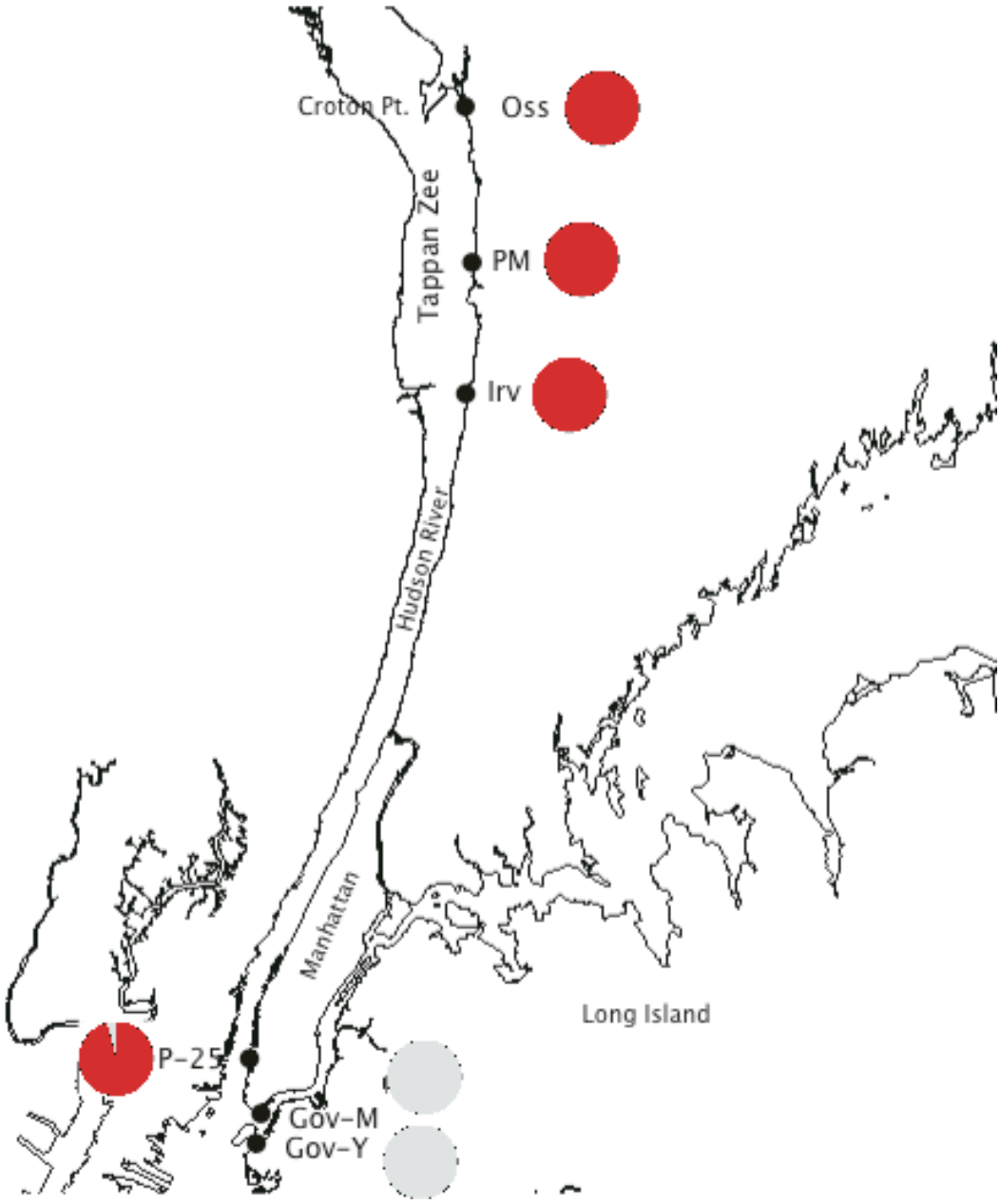

Figure 9. Proportion of shells from all five sample bags per locality, colonized by the barnacle *Balanus improvisus* (red, gray indicates absence).

Other species

A number of other species recruited to the oyster shell bags. The most conspicuous was the sea squirt *Molgula* sp., which nearly covered shell bags at the two Governors Island sites (Figure 10, 11). Also common was the orange colonial sea squirt *Botrylloides violaceus*. The mud crab *Rhithropanopeus harrisii* was common in shell bags within the Tappan Zee. A number of polychaete annelids, amphipods and other species were found within the Tappan Zee shell bags. The snails *Crepidula fornicata* and *C. plana* recruited to shells in the bags at Pier 25 (Figure 12), as did large numbers of the isopod *Idotea sp* (Figure 13).

Figure 10. Colonization of a shell bag at Pier 1, Governors Island by the sea squirt *Molgula sp*.

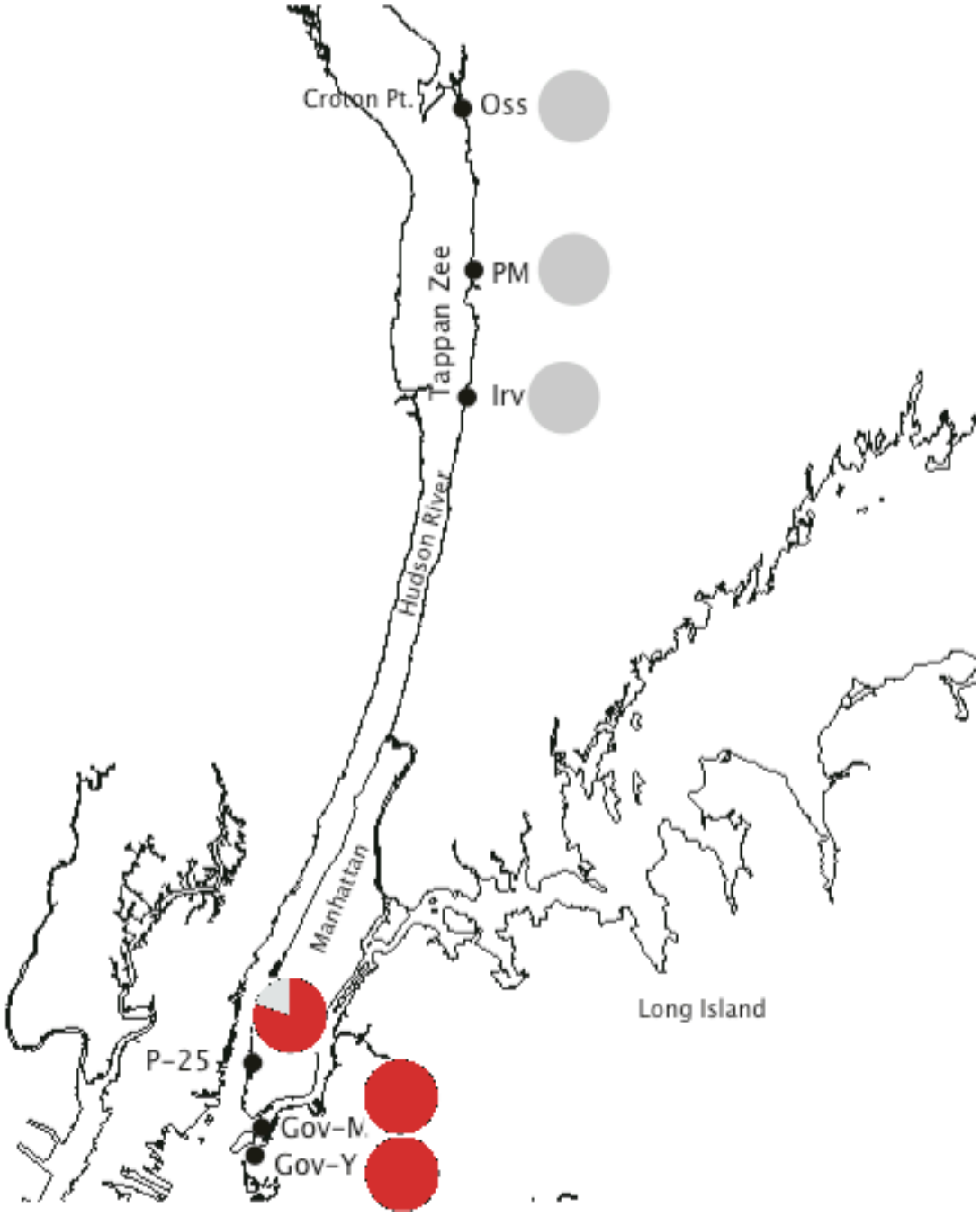

Figure 11. Proportion of shell bags with *Molgula sp*. at the sites (red, light gray indicates absence).

Figure 12. Settlement by the slipper shell (*Crepidula fornicata*) at Pier 25.

Figure 13. Settlement by the isopod *Idotea sp*. at Pier 25.

Diversity

Table 3 shows the total number of identified taxa in the Tappan Zee and New York Harbor samples. As can be seen, a greater number of taxa were found in the New York Harbor set. Much of the difference was explained by colonial ascidians found in New York Harbor.

Table 3. Taxa identified from the two major regions.

New York Harbor sites	Tappan Zee sites
Balanus improvisus, bay barnacle	*Balanus improvisus*, bay barnacle
Molgula sp.	polychaete
Botrylloides violaceus, orange sheath tunicate	*Rhithropanopeus harrisii*, mud crab
Idotea metallica	polychaete
Crepidula fornicata	amphipod
Crepidula plana	*Mytilus edulis*, blue mussel
polychaete	*Dreissena polymorpha*, zebra mussel
Rhithropanopeus harrisii, mud crab	*Idotea metallica*
hydroid	
amphipod	
Mytilus edulis, blue mussel	
Botryllus schlosseri, star tunicate	
Tube worm	
encrusting bryozoan	

DISCUSSION

In this study, the hypothesis that oyster recruitment would be greater closer to the experimental reef was shown to be false. Oyster settlement was not greater in the higher salinity waters of New York Harbor, as represented by the Governors Island and Pier 25 sites. Possible reasons for this are: 1) settlement of other species (e.g., ascidians) may have taken up too much surface area for the larvae to attach to the oyster shells, or 2) they may have been consumed by other organisms that settled before the oyster larvae. Some species that could have prevented and/or disrupted oyster larvae settlement include *Botrylloides*, *Molgula sp.*, and *Balanus improvisus*. The barnacles likely had no effect since the Tappan Zee oyster shells were covered with living barnacles when the oysters recruited in September. A 3rd possibility is that the currents in the vicinity of the constructed reefs are not successfully transporting larvae to the sampling sites. Finally it is possible that there were no larvae at all in the water column of the lower Hudson River/New York – New Jersey Harbor Estuary.

Strong settlement of the barnacle *Balanus improvisus* was observed within the Hudson Estuary, but low settlement was observed in waters off lower Manhattan, and no settlement was observed at Governors Island. This may be due to larval behavior, which promoted retention within the lower Hudson River. Many crustacea in the Hudson River estuary have rhythmic behavior, coincident with rising and falling tides (Morgan 2006).

In conclusion, oyster settlement failed in New York Harbor, at least at the sites established in this study. However, oyster settlement was successful in the lower portion of the Tappan Zee. It is suspected that the larvae in the Tappan Zee originated from within this water body. Settled oysters have been preserved, and they will be analyzed

using neutral genetic markers (microsatellite loci) in the laboratory of Matthew Hare, Cornell University. The markers may demonstrate that Tappan Zee includes an isolated and perhaps locally adapted population of oysters. The data on barnacle settlement suggest that larval behavior may also contribute to localized settlement within the Hudson River estuary, perhaps isolating many species from the oceanic coastal environment.

ACKNOWLEDGEMENTS

I thank the staff of the Irvington Boat Club, the Phillips Manor Beach Club, and the Westerly Marina at Ossining for assistance. Special thanks go to Pete Malinowski of The Harbor School for arranging for localities on Governors Island and to Cathy Drew and especially Nina Zain of The River Project for help on the Lilac at Pier 25. Thanks also to Helena Andreyko, David Yozzo and Sarah Fernald for numerous recommendations for revisions of this manuscript.

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