FINAL REPORT

Tier 3 Tappan Zee Bridge Oyster Restoration Pilot Study – University of New Hampshire

December 21, 2017

Submitted to: Fred Jacobs, AKRF, Inc.

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Introduction and Background

This report describes the results of a 3-year (2015-2017) pilot study conducted by the Hudson River Foundation (HRF) in partnership with the University of New Hampshire (UNH) and the NY Harbor Foundation under the direction of AKRF, Inc. and the New York State Thruway Authority (NYSTA). The goal of the study was to inform the design of the Tappan Zee Bridge Oyster Restoration Project by providing information on the performance of three potential restoration substrates at three potential restoration sites. The performance metrics included attracting (recruiting) oysters (*Crassostrea virginica*), supporting oyster growth and survival, and the longevity and sustainability of the three different substrates and construction techniques: 1) metal gabion cages containing oyster shells; 2) small Reef Balls (”Lo-Pro”); and 3) larger Reef Balls (“Mini-Bay”).

Methods

Study Design

Three replicates of each of the three test substrates were deployed on June 22, 2015 at three sites in the general vicinity of the Tappan Zee Bridge (Fig. 1). Each replicate consisted of one of each of the test substrates attached by a line so that all three substrates could be retrieved in one effort. This design allowed comparisons to be made among substrates and among sites. The three sites were chosen based on a previous study that characterized the occurrence at all three sites of live oysters at densities comparable to other areas in the northeastern US, and were among the sites recommended for further study (Princeton Hydro 2015). The present study was done in conjunction with other Tier 3 studies aimed at characterizing water quality conditions and oyster recruitment in the same study area (AKRF 2016a, b).

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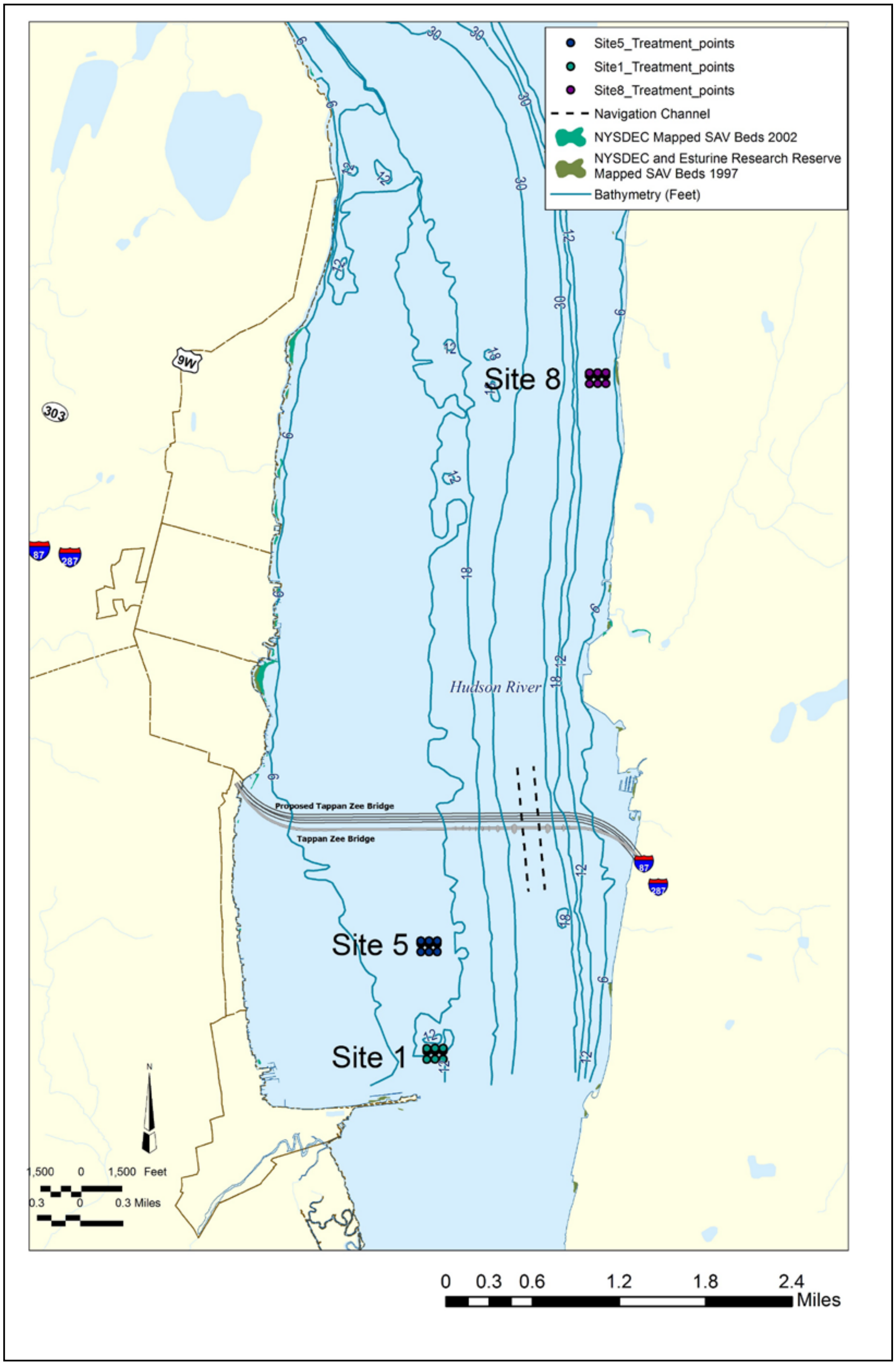

Fig. 1. Sites (1, 5, and 8) where test substrates were deployed.

Oyster Sampling

Similar sampling methods were used all 3 years of the study, but there were important variations among the years due to differences in the number of substrates retrieved, differences in substrate characteristics that affected sampling effectiveness, and other issues (Table 1). In brief, gabions were sampled by extracting 1 or 2 of the 8 "mini-gabions" (~32 cm x 32cm x 32 cm cube) that were assembled to form each overall gabion substrate, removing the shell cultch material, and counting and measuring some subset of the live oysters on the cultch. Both types of Reef Balls were sampled by counting and measuring (shell height using calipers or ruler) all live oysters in replicate quadrats, except in 2017 when all live oysters on the outside of each Reef Ball were counted and measured. Details on the methods for 2015 and 2016 are described in the previous progress reports (Lodge et al. 2016, 2017). For 2017, the major change was counting all the live oysters on the outer surfaces of both types of Reef Balls, instead of quadrat sampling. This was done because of the low densities of oysters on the Reef Balls. This change insured that sufficient data were collected to adequately characterize the size and density of oysters, but also resulted in fewer replicates. For all 3 years and all 3 substrates the density data were expressed in per m^2 units.

Table 1. Summary of sampling methods for measuring oyster metrics.

Year	Site	Substrate Type	Sampling Method	# Samples Collected
2015	1	Gabion	mini-gabions extracted; live oysters counted; 50 oysters measured	2
		Mini-Bay	0.1 m^2 quadrats; live oysters counted and measured	4
		Lo-Pro	0.1 m^2 quadrats; live oysters counted and measured	4
	5	Gabion	mini-gabion extracted; live oysters counted; 50 oysters measured	1
		Mini-Bay	(no live oysters in quadrats)	4
		Lo-Pro	(no live oysters in quadrats)	4
	8	Gabion	mini-gabions extracted; live oysters counted; 50 oysters measured	2
		Mini-Bay	0.1 m^2 quadrats; live oysters counted and measured	4
		Lo-Pro	0.1 m^2 quadrats; live oysters counted and measured	4
2016	1	Gabion	mini-gabion extracted; live oysters counted; 50 oysters measured	1
		Mini-Bay	0.025 m^2 quadrats; live oysters counted and measured	4
		Lo-Pro	0.025 m^2 quadrats; live oysters counted and measured	3
	5	Gabion	mini-gabion extracted; live oysters counted; 50 oysters measured	1
		Mini-Bay	0.025 m^2 quadrats; live oysters counted and measured	4
		Lo-Pro	0.025 m^2 quadrats; live oysters counted and measured	7
	8	Gabion	mini-gabions extracted; live oysters counted; 50 oysters measured	4
		Mini-Bay	0.025 m^2 quadrats; live oysters counted and measured	8
		Lo-Pro	0.025 m^2 quadrats; live oysters counted and measured	7
2017	1	Gabion	(no substrate retrieved)	0
		Mini-Bay	all live oysters counted and measured	1
		Lo-Pro	all live oysters counted and measured	1
	5	Gabion	mini-gabions extracted; live oysters counted; 50 oysters measured	2
		Mini-Bay	all live oysters counted and measured	2
		Lo-Pro	all live oysters counted and measured	2
	8	Gabion	mini-gabions extracted; live oysters counted; 50 oysters measured	2
		Mini-Bay	all live oysters counted and measured	2
		Lo-Pro	all live oysters counted and measured	2

Fouling community

Oysters are typically only one of the species making up the overall (fouling) community of invertebrates that naturally develops on hard substrates in estuarine waters (i.e., the "oyster reef community"). The non-oyster component of the fouling community was characterized by taking replicate photographs of 0.025 m^2 quadrats placed randomly on each of the Reef Ball substrates and three of the gabions, and processing the photographs in the laboratory. All invertebrates were identified to the lowest taxonomic level practical (species in most cases; voucher specimens were returned to the laboratory for identification) and counted; data were expressed in per m^2 units.

Results and Discussion

Although there was wide variability in the numbers of replicate samples of the substrates collected each year (Table 1), sufficient data were collected to address the three major performance metrics: attracting (recruiting) oysters, supporting oyster growth and survival, and the longevity and sustainability of the three different substrates and construction techniques. Additionally, the overall fouling community that developed on the substrates was characterized all 3 years, focusing on how other species might affect development of oyster populations on the substrates.

One replicate (with all three substrate types) was retrieved from Site 8 on October 15, 2015 and from Sites 1 and 5 on October 16, 2015 (Table 1; Fig 2). These samples represented 4 months of development of the invertebrate communities on the test substrates. All three substrates from all three sites were in good condition. The major issue was in locating and connecting with the substrate lines, resulting in only one complete set of substrates being retrieved from each site. The gabion at Site 5 was also damaged.

One replicate (with all three substrate types) was retrieved from Site 8 on October 24, 2016 and from Sites 1 and 5 on October 25, 2016 (Table 1; Fig. 2). These samples represented 16 months of development of the invertebrate communities on the test substrates. All of the substrates were in good condition, except two of the mini-gabions had been lost from one of the gabions at Site 5 and the rebar used for framing the gabions showed signs of deterioration (Fig. 2).

Two complete replicates from Site 8 and one complete replicate from Site 5 were retrieved on October 17, 2017. One replicate was retrieve from Site 1 on October 18 but the gabion was missing (Table 1; Fig. 2). Most of the Reef Balls were in good condition, except some that may have been damaged in the sampling process. In contrast, most of the gabions showed signs of deterioration that in large measure appeared to be the result of failure of the rebar framing from broken welds.

Fig. 2. Retrieval of test substrates by year and site. Note damaged gabions all three years.

<u>Oyster Metrics</u>

Figures 3 – 5 below provide photographic documentation of the overall 3-year development of oyster reef communities (oyster populations and other fouling organisms) on the test substrates at each of the three study sites. Although substantial quantitative differences were evident (as discussed below), there was good oyster reef development on all three substrates and at all three sites.

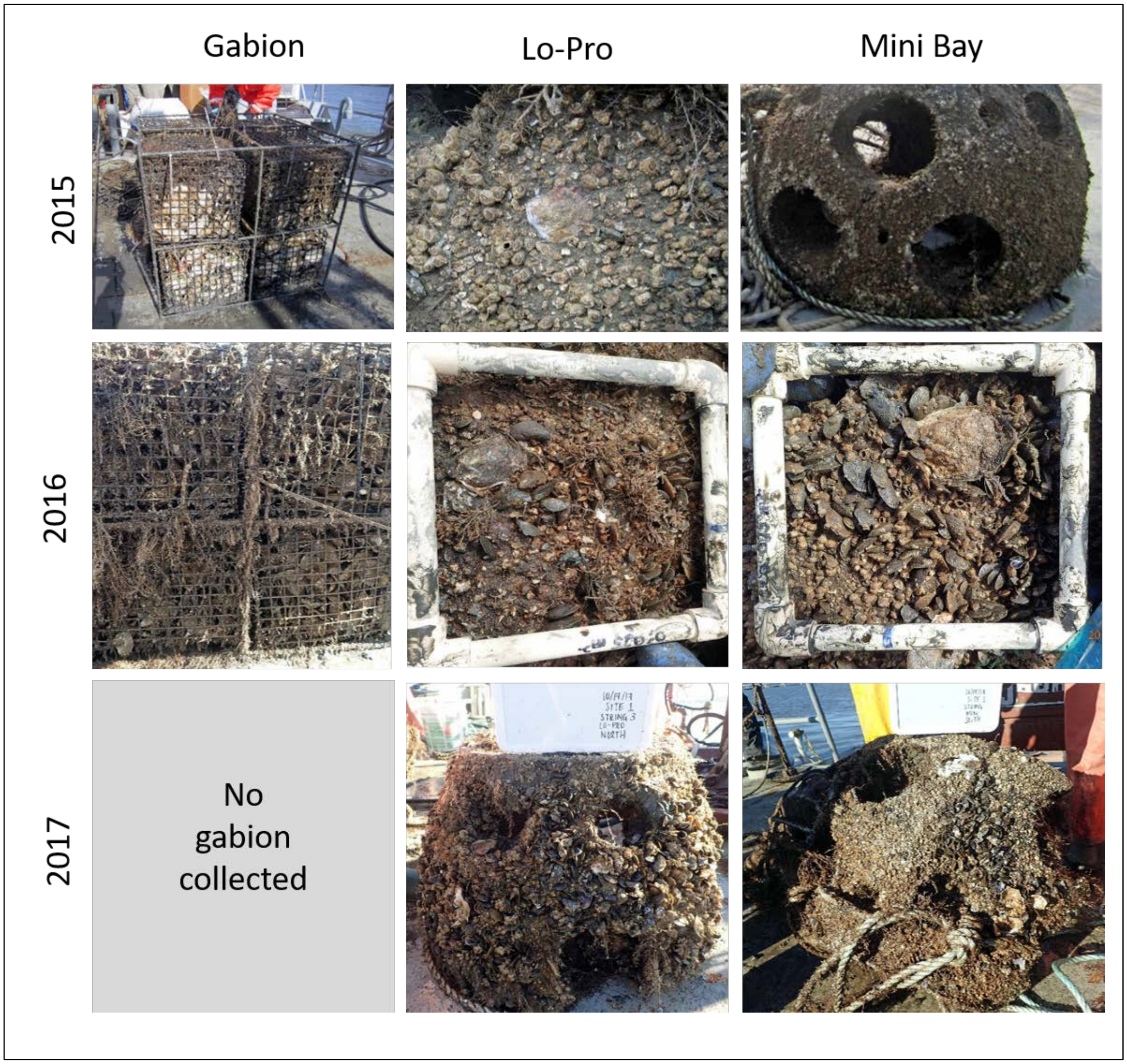

Fig. 3. Example photos of the oyster reef community on three substrate types each of the three years from Site 1.

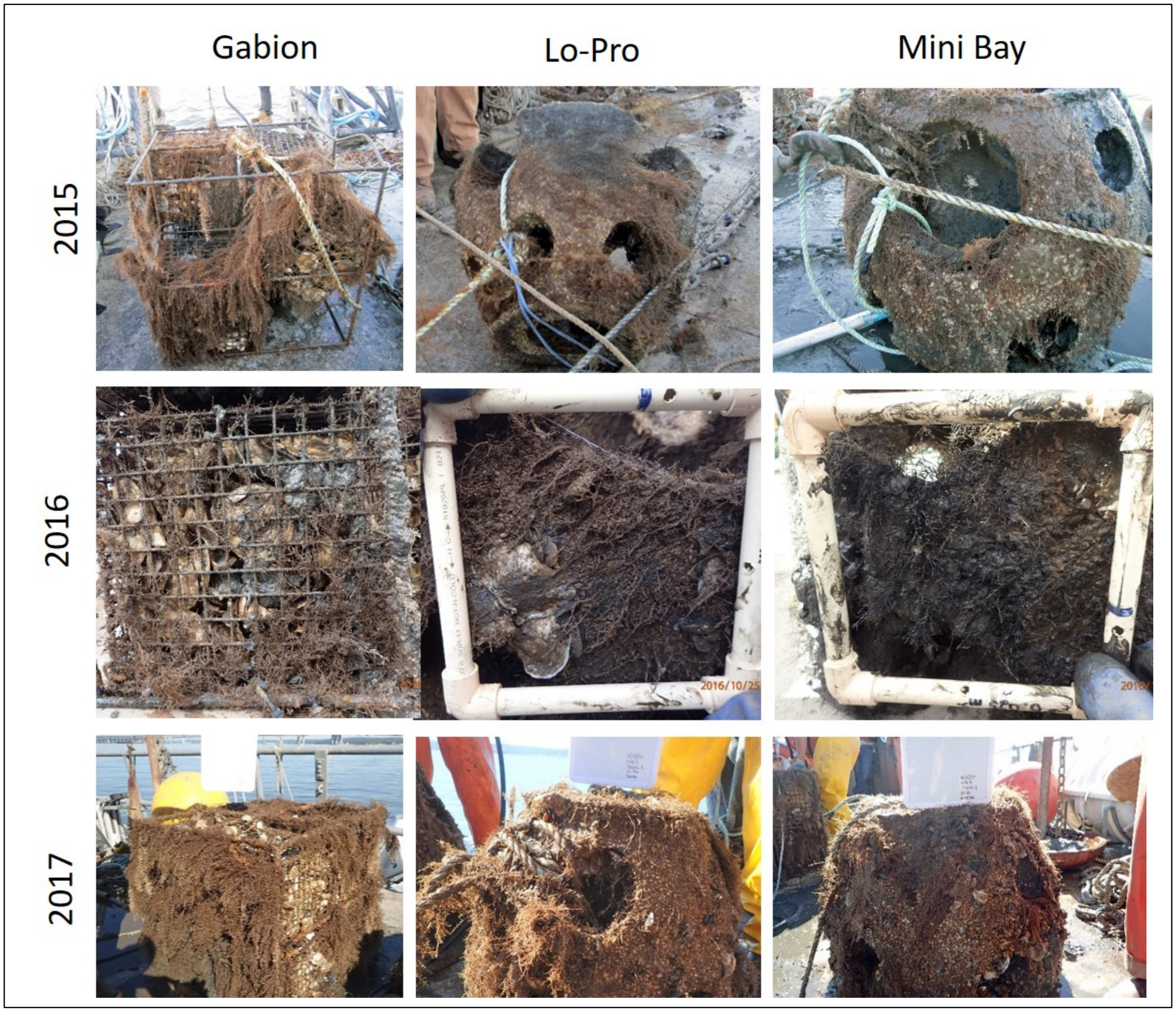

Fig. 4. Example photos of the oyster reef community on three substrate types each of the three years from Site 5.

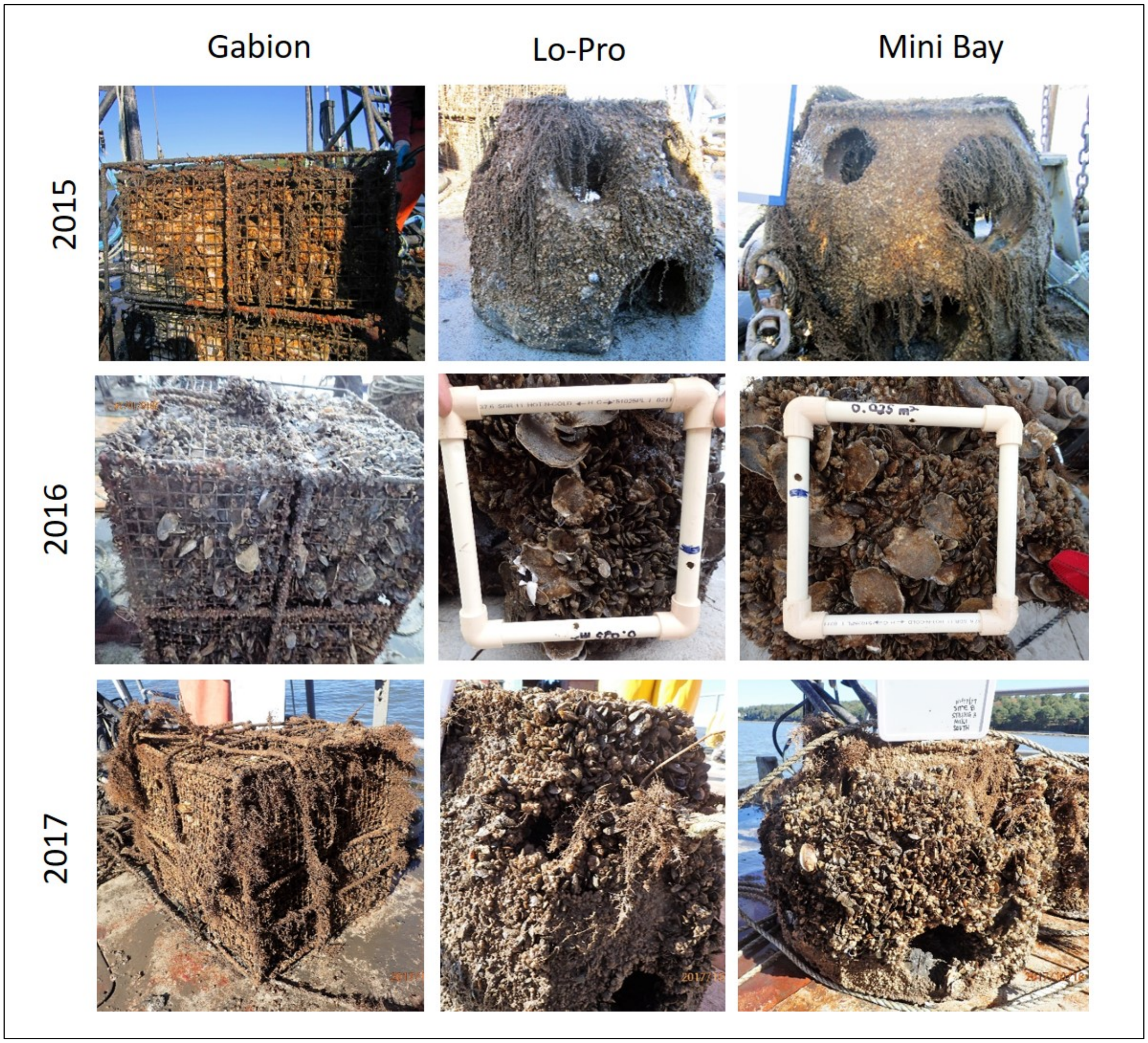

Fig. 5. Example photos of the oyster reef community on three substrate types each of the three years from Site 8.

The combined oyster size dataset (all substrates and sites) clearly showed one year class in 2015, two year classes in 2016, and three in 2017 (Fig. 6). Overall, this indicates successful recruitment all 3 years in the general study area, and suggests reasonable growth and survival. The data from all 3 years indicate oysters <40 - 45 mm can be considered spat when sampling occurs in the fall of the year. Although oyster size frequency data by site are not shown herein, spat (annual recruits) occurred at all three sites all three years. The spat collectors deployed in 2015 and 2016 in the concurrent study by AKRF also showed recruitment at all three sites (AKRF 2016a, b).

The 2016 and 2017 data indicate that year 2 oysters ranged from ~40 to 75 mm, with a mean of ~55 mm. These data compare well with published oyster sizes and growth rates in the northeastern US, including the New York Harbor region (Levinton and Doall 2011, Levinton et al. 2013; Grizzle et al. 2013, 2016; Lodge et al. 2016).

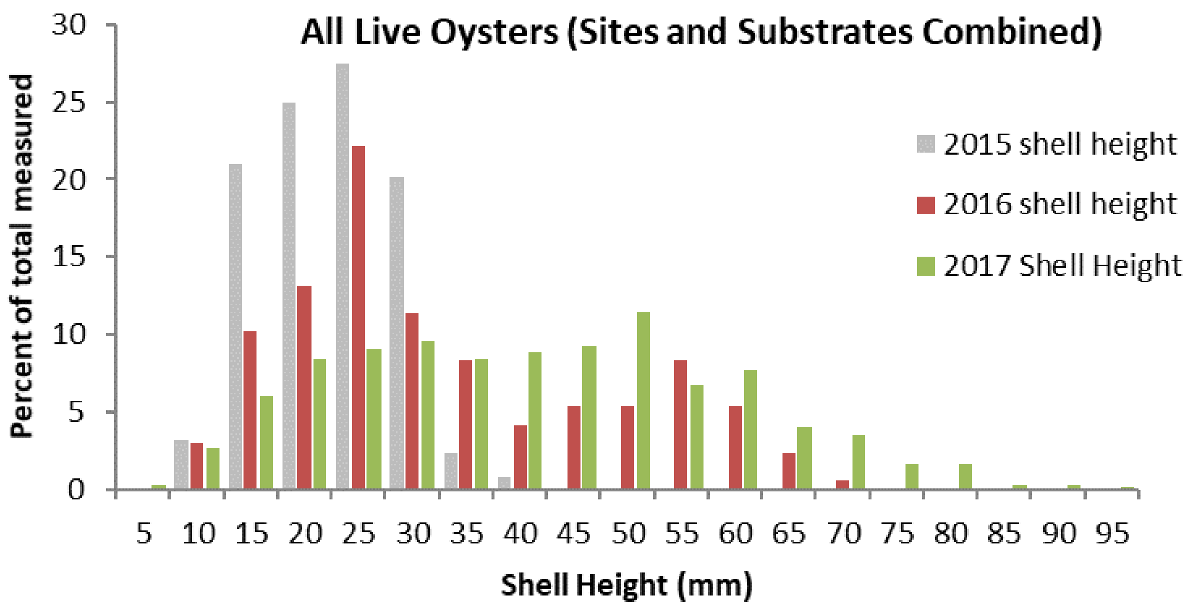

Fig. 6. Size-frequency histogram for all oysters measured on all three substrates and from all three sites.

Assessment of the oyster size data by site and year (combining all three substrates) indicates similar mean shell heights were at all three sites, suggesting similar environmental characteristics among the three sites that affect oyster growth (Fig. 7). Focusing on the 2017 data, ANOVA test indicated no significant differences in mean shell heights (P = 0.314) among the three sites. Mean oyster density differences were also non-significant (P = 0.637) among the three sites, though small sample sizes at some sites (Table 1) resulted in very high variances around each mean.

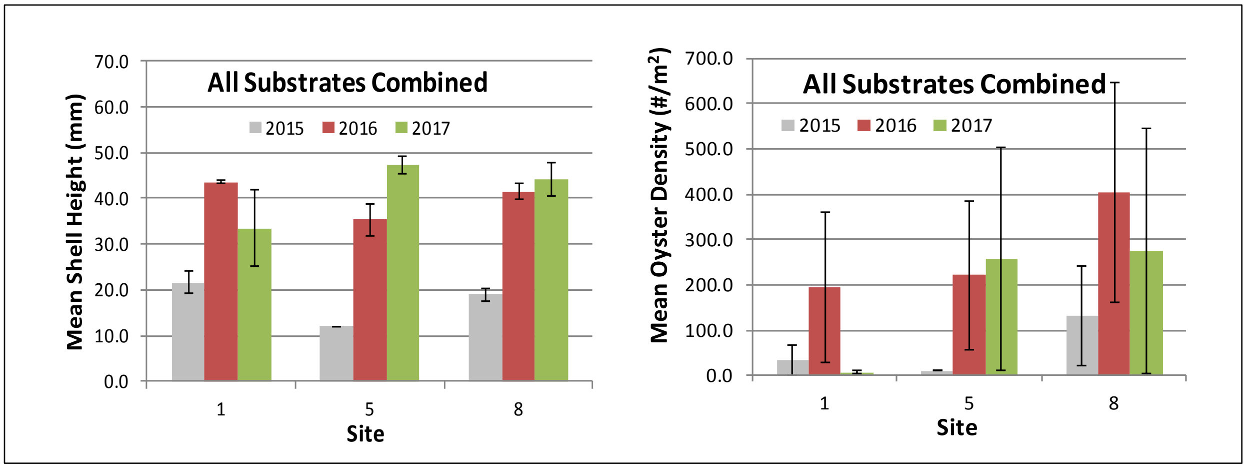

Fig. 7. Oyster mean size and mean density by site and year (all substrates combined).

Assessment of oyster size by substrate (all sites combined) and year showed very similar mean sizes all three years on all three substrates, indicating the three substrates provide similar conditions for oyster recruitment and growth (Fig. 8). Focusing on the 2017 data, ANOVA tests indicated no significant differences (P=0.832) in mean shell height among the three sites. In contrast, there were highly significant (P <0.001) and substantial differences among the three substrates with oysters occurring at much higher densities on the gabions. We emphasize, however, that the two substrate types (Reef Balls and gabions) differ substantially with respect to surface area potentially available for larval recruitment and subsequent reef development. Live oysters of a wide range of sizes were found on shell cultch material deep within each gabion, whereas only the surfaces of the Reef Balls were available as potential substrate. Thus, gabions provide a third dimension for reef development although the long-term survival of oysters deep within the gabions is unknown.

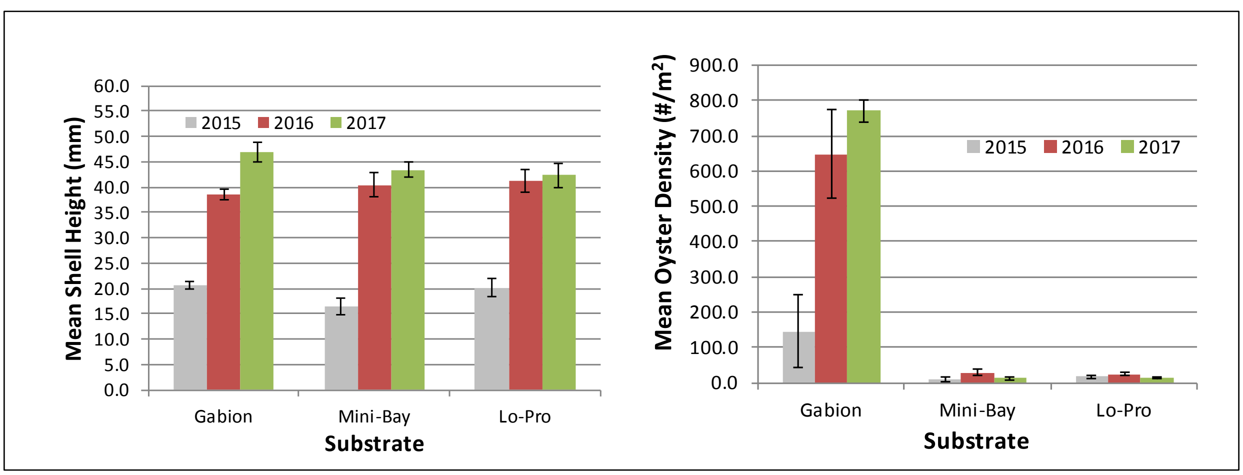

Fig. 8. Oyster size and density by substrate and year, combining the data from all three sites.

Oyster size and density data were also assessed by site, substrate type, and year in order to visually inspect for interaction effects among the variables (Fig. 9). Shell height consistently showed similar mean values by year for all three substrates and all three sites; the only exception being the Lo-Pros at Site 1 in 2017, and this was perhaps due to small sample size (Table 1). Although oyster densities varied widely by both substrate and site, there were consistent trends such as the gabions consistently showing highest values across all three sites.

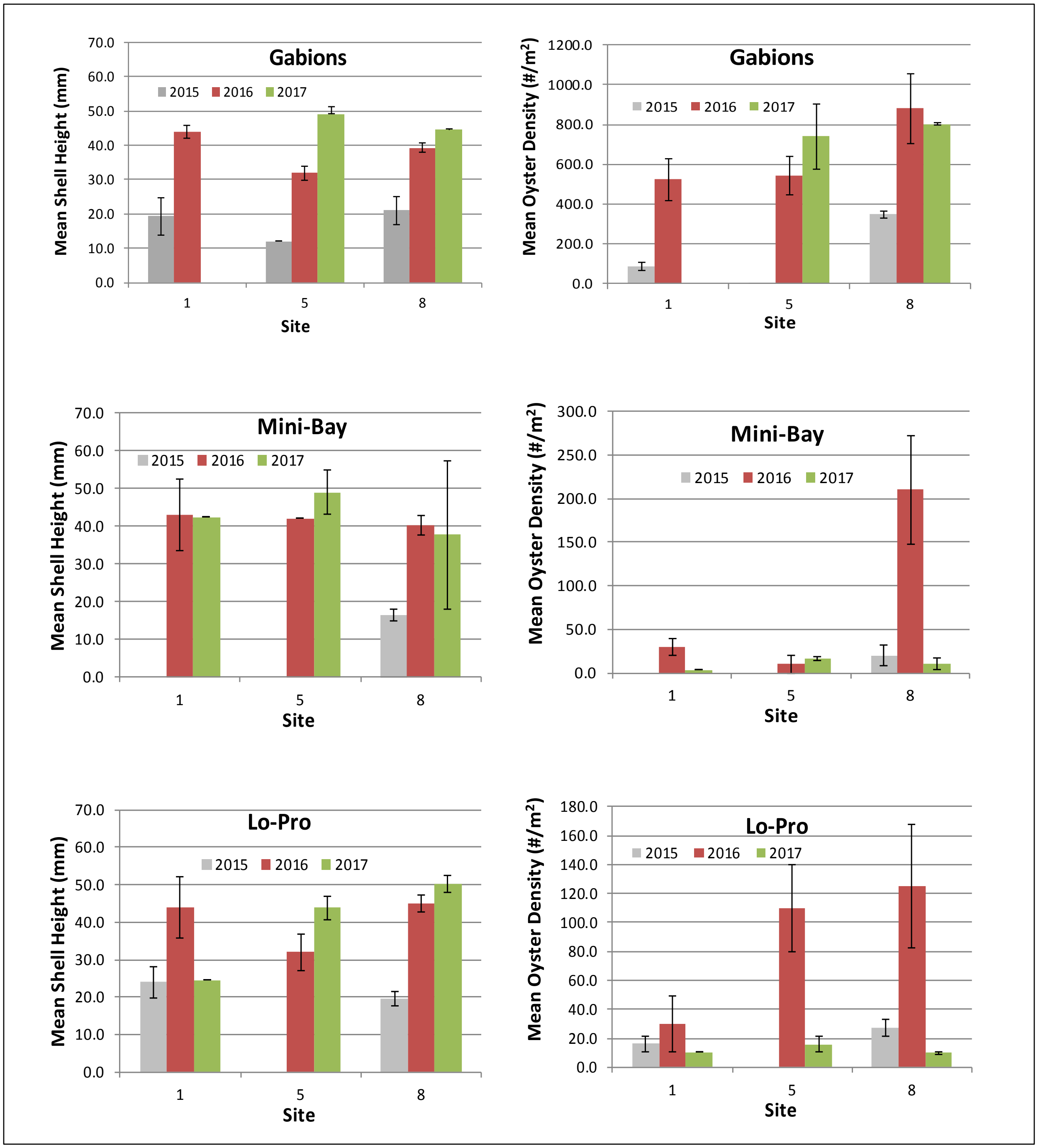

Fig. 9. Oyster mean size and mean density by substrate type and site. Note different scales on oyster density charts.

A final topic to consider for oyster size and density is how our data compare to the ongoing studies by AKRF on water quality and oyster recruitment (AKRF 2016a, b). Perhaps the most important finding in 2015 and 2016 was that recruitment data from both efforts indicated higher spat densities at Site 8, suggesting that there is good potential for natural recruitment and thus sustainability of constructed reefs if located in that area. However, water quality data from Site 8 suggest caution in this respect because both salinity and dissolved oxygen have been well below levels considered stressful to the eastern oyster much of the monitoring period in 2015 and 2016 (see discussion in AKRF 2016b). The 2017 data, however, again showed substantial spat densities as well as growth and survival at Site 8 similar to the other two sites.

Fouling community development. In addition to oysters, four species of epifauna have made up the overall fouling community on the test substrates. Two species that occur as individuals were present all three years in sufficient abundances to determine density: the hooked mussel (*Ischadium recurvum*) and the bay barnacle (*Balanus improvisus*).

Mussels occurred at low to moderate densities at all sites and on all three substrate types in 2015, but greatly increased densities at Sites 1 and 8 in 2016, particularly on the two types of Reef Balls (Fig. 10). Their densities had decreased substantially on all three substrate types and at all three sites in 2017.

Barnacles showed the opposite pattern: moderate to high densities at all three sites and on all three substrate types in 2015, but dramatic declines in 2016 and 2017.

Two colonial taxa present in high abundances in 2015 (an unidentified hydroid and the encrusting bryozoan *Membranipora* sp.) were present in 2016 and 2017 but not in high abundances. No potential causes (e.g., known predators) for their declines were evident, but wide variations in seasonal and year-to-year abundances of both taxa are typical (e.g., Gosner 1978; Saunders and Metaxas 2009).

The timing of larval settlement among the fouling community species could not be determined, but based on the ~100% cover of the barnacles and mussels in some areas it seems possible they could have inhibited oyster settlement. Moreover, and as noted in previous reports (Lodge et al. 2016, 2017), the relationships among potentially competing species in fouling communities is complex (Kochman et al. 2008; Barnes et al. 2010), and barnacles have been shown to inhibit oyster settlement and growth (Boudreaux et al. 2009). Although the present study was not designed to unravel the effects of various species interactions, monitoring of the major species that makeup the overall fouling community in future studies might yield relevant information for interpreting oyster reef development patterns.

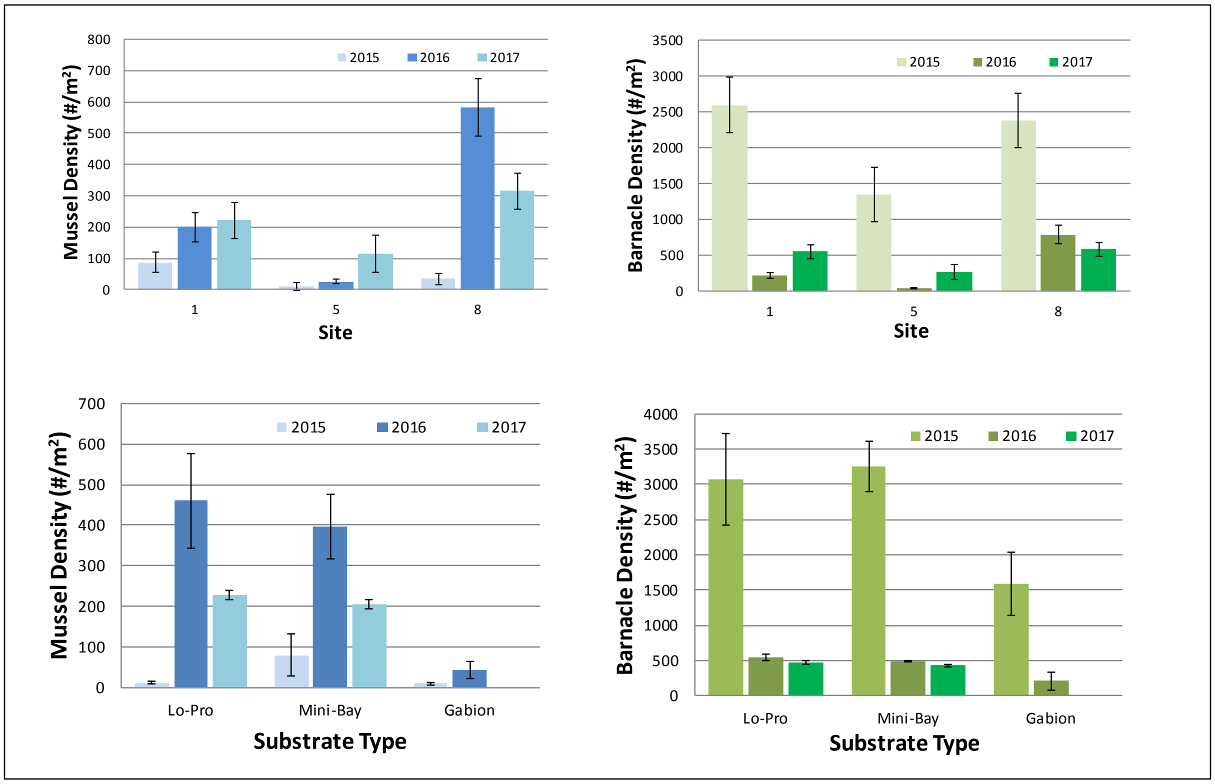

Fig. 10. Top row: mean (±1 SE) mussel density by site with all three substrates combined. Lower row: barnacle density by substrate type with all three sites combined.

Conclusions

The goal of the study was to inform the design of the Tappan Zee Bridge Oyster Restoration Project by providing information on the performance of three potential restoration substrates at three potential restoration sites. Although there were considerable variations in oyster performance metrics among the sites and test substrates, the monitoring data overall suggest that acceptable oyster recruitment, growth and survival can be expected at all three sites and on all three substrates.

One particularly surprising finding was the consistent recruitment and survival of oysters at Site 8, where salinity and dissolved oxygen were well below levels considered stressful to the eastern oyster for much of the monitoring period in 2015 and 2016 (Shumway 1996; also see discussion in AKRF 2016b). It may be that the oysters in this portion of the Hudson River are adapted to such conditions. In any case, data from the present study overall indicate Site 8 has good potential for full-scale restoration efforts.

Oyster growth (as inferred from changes over time in mean shell height) were very similar among the sites and substrates. In contrast, oyster density was consistently highest on the gabions compared to both types of Reef Balls. In large part, this probably was due to differences in structure, with the gabions providing a vertical dimension available for oyster recruitment. Live oysters of a wide range of sizes were found on shell cultch material deep within each gabion, whereas only the surfaces of the Reef Balls were available as potential substrate. Thus, although gabions provide a third dimension for reef development, the long-term survival of oysters deep within the gabions is unknown. Additionally, some of the gabions showed substantial damage in the second and third years of the study, mainly due to broken welds on the rebar frames. The gabions used in full-scale reef restoration should be constructed in a different manner than those used in the pilot study.

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