

*Tier 2 Oyster Sampling Report
Tappan Zee Bridge Hudson River Crossing Project
Westchester and Rockland Counties, New York*

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Introduction

Princeton Hydro, LLC (PH) was contracted by AKRF, Inc. (AKRF) to conduct Tier 2 oyster sampling at the Tappan Zee Bridge Hudson River Crossing Project. This is in part a follow-up to oyster sampling similarly conducted in 2013. Nine sites were selected during Tier 1 for subsequent investigation based on sediment quality data and other relevant factors (Figure 1). Two of the sites (8 and 9) were located north of the Tappan Zee along the eastern bank. The remaining sites were south of the bridge; five of these (1, 3, 5, 6, and 7) extended from immediately adjacent to the bridge south to the Piermont pier on the western channel margin while the remaining two sites (2 and 4) were on the eastern channel margin.

The study was conducted in two phases. The first phase included sampling all nine sites, with 10 dredge grabs conducted within each area. After the first phase was completed, the data was summarily analyzed to identify which five areas should be resampled at a higher frequency focusing on oyster frequency, capture density, age-class distribution, and sediment/habitat suitability. Once identified the five selected areas (1, 3, 5, 8, and 9) were resampled; 15 dredge grabs were collected in each area.

In addition to live processing of the oysters (counts and shell dimensions) a number of oysters were retained and transferred to the New York Harbor School faculty to initiate a Tappan Zee oyster propagation study.

This report will summarize all field activities and provide analysis of the findings.

Methods

Aerial maps, NYSDEC GIS digital data, and other map resources were used to generate sampling figures using ArcGIS. For phase I sampling 10 points were selected at random within each of the nine sampling sites, for a total of 90 points. In Phase 2, 15 points were selected at random within the five identified areas to be sampled for a total of 75 points.

For Phase I sampling was conducted over a three-day period from May 4 to May 6, 2015. Similarly, the Phase II sampling was also conducted over three days from May 12 through May 14. A Peterson dredge of 1.00 ft² or 0.093m² was used to collect the samples. Once anchored over the sampling station, the dredge was lowered over the side of the boat and subsequently retrieved. The dredge was emptied into a tote to limit loss of sample. During opening of the dredge, the quantity of material was assessed to determine if there was incomplete sampling or sample wash during retrieval. If so, the collected material was discarded and a second sample collected.

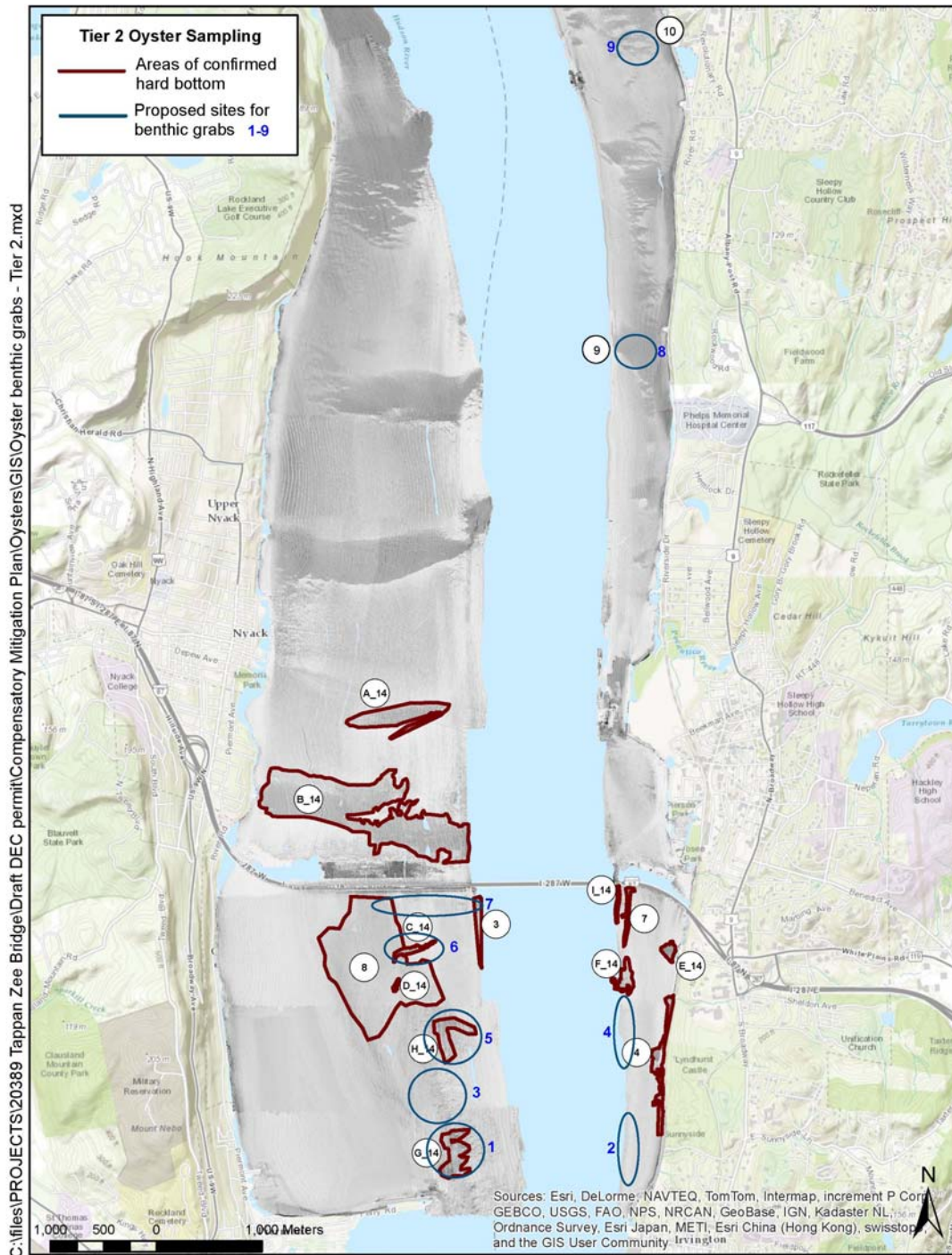


Figure 1: Tier 2 Oyster Sampling Areas

Source: Prudent Engineering in collaboration with AKRF for the NY Thruway Authority developed as part of NYSDEC's mitigation permit for the New NY Bridge. Digital data for the sidescan mosaic is archived by NYSDEC.

The material was sieved in the river in a 500 µm sieve bucket to wash the samples. The sample was then picked through. Any live oysters encountered were enumerated and measured. This included shell length, also known as shell height, from the hinge to the far growth edge, and shell width roughly perpendicular to the first axis and measured along the widest section. All measurements are recorded in mm.

Sediment quality assessments were conducted concurrently with the oyster sampling. Each dredge sample collected for oysters was field inspected for the general consistency, particle class including shell materials, color, odor, and any other pertinent features of the sediments. Other organisms encountered were also noted including other bivalves, crustaceans, isopods, amphipods, and polychaetes.

Prior to initiating field work Princeton Hydro secured a License to Collect or Possess (License # 455) through the NYSDEC Special Licenses Unit. As a condition of the permit Princeton Hydro must submit a report detailing the methods, results, and other pertinent information. A modified version of this report will be submitted.

Phase I

The summary table provided below Table 1 provides data for frequency (proportion of dredge samples where oysters were detected), total abundance, average areal density, and average dimensions.

Phase I Summary Table						
Area	Frequency	Abundance	Average Density (m ⁻²)	Average Dimensions (mm)		
				Length	Width	
1	0.30	18	19.4	65.6	46.6	
2	0.00	0	0.0	NA	NA	
3	0.30	13	14.0	55.7	39.8	
4	0.00	0	0.0	NA	NA	
5	0.20	15	16.1	70.5	49.7	
6	0.20	2	2.2	29.0	23.5	
7	0.10	1	1.1	40.0	35.0	
8	0.60	28	30.1	15.0	12.9	
9	0.30	8	8.6	15.4	13.3	

Detection frequency, a surrogate for distribution, is relatively low for all areas, with the exception of Area 8. This indicates that even where oysters (*Crassostrea virginica*) are found they tend to be found in discrete pockets, which seems strongly correlated to sediment suitability. Areas 2 and 4, located in the southeastern part of the study site, were the only areas where no oysters were found. Not coincidentally, these areas contained no coarse substrates.

Abundance and average density are more useful metrics for prioritizing the areas. Clearly, Areas 1, 3, 5, 8, and 9 had the highest abundance and areal density, but the dredge frequencies were low except for Area 8 at 0.6. Even these values are relatively low to moderate densities.

Shell dimension averages provide an indication of the size-class structure. This data can be used to further split the five preferred areas into two cohorts. The first group consists of Areas 8 and 9 which were dominated by spat as indicated by the small average shell length and width dimensions. There were several larger oysters however in each of these areas. The second cohort consisted of Areas 1, 3, and 5, which are adjoining. These areas were clearly dominated by larger oysters with mean shell length exceeding 55 mm in each of the areas. More interesting is that no spat were present in these areas with the smallest measured shell height at 34 mm, although few oysters were less than 50 mm.

As mentioned above substrate quality is obviously a component of these findings. General sediment quality for each of the areas is given as follows:

- Area 1: Where oysters were found the sediment consisted almost solely of oyster shells and shell hash with little fine sediment. In other portions of the areas the sediment was dominated by dark gray sediments.
- Area 2: The sediment was nearly uniform throughout the area consisting of dark gray fines with a thin stratum of fresh brown silt on top, and organic detritus was relatively common as well. *Mya arenaria* (soft-shell clam) was dominant here. Sample 2-1-9, was an outlier and included very fresh oyster material and angular gravel with sharp edges, which seems to indicate recent placement/deposition.
- Area 3: Gray and black fines predominated in this area, but shell and shell hash was also common. Shell material increased in the matrix where viable oysters were located.
- Area 4: This was nearly identical to Area 2, dark gray fines overlain by fresh brown silts with a minor organic detritus component. The sediment here was more consolidated and clay-like than in Area 2.
- Area 5: While each sample was relatively similar, the sediment matrix included dark gray fines, spent shells, shell hash, and gravels in this area.
- Area 6: Of the southwestern group this continues the pattern of increasingly coarse materials moving north, like cobble and gravel, spent shells, and shell hash interspersed in a matrix of dark gray and brown fines.
- Area 7: This area was primarily black, dark gray, and brownish silts, of varying consistency, with relatively low levels of shell hash and few spent shells.

- Area 8: Substrates were primarily spent shells, a mix of oyster, quahog (*Mercenaria mercenaria*), and ribbed mussel (*Geukensia demissa*), and coarse shell hash. Fresh brown silt was common but relatively minor.
- Area 9: This area had a high proportion of spent shells and coarse shell hash, but also a higher concentration of brown and gray fines.

Based on this data, Princeton Hydro recommended that Areas 1, 3, 5, 8, and 9 be resampled. These recommendations were forwarded to AKRF and were accepted.

Additional data for both project phases can be found in the appendix including sampling maps, coordinates, and shell dimensions, sampling depth, substrate description, and other benthic macroinvertebrates identified for each dredge grab.

Phase II

Results of Phase II sampling are included in the summary table below.

Phase II Summary Table						
Area	Frequency	Abundance	Average Density (m ⁻²)	Average Dimensions (mm)		
				Length	Width	
1	0.33	23	16.5	82.5	49.3	
3	0.07	2	1.4	95.0	55.0	
5	0.20	20	14.3	39.2	23.8	
8	0.93	60	43.0	17.0	14.6	
9	0.13	8	5.7	11.4	11.3	

Results of the resampling in Phase II were relatively similar to the Phase I results for most of the areas. Area 3 seemed to be the major exception. Frequency dropped from 0.30 (3 of 10) to 0.07 (1 of 15). This may be mostly a function of the overall poor sediment quality in this area, and the low distribution in general. A review of the sediment indicates that the samples from Phase II generally had fewer coarse particles than had been encountered previously. Area 5 showed some interesting patterns as well; while frequency, abundance, and average density were almost unchanged, there was a major reduction in shell dimensions. This is the result of capturing spat in the sample, which had not been previously observed in any of the five samples areas in the southwest of the study area. This may indicate higher viability in this area than the initial sampling showed. Finally, Area 8 showed large increase in frequency, driving changes in abundance and density, yet the yet average dimensions were little changed. Area 9 saw a major reduction in frequency but only a modest decrease in average density.

As mentioned above, 25 oysters were retained that were provided to the New York Harbor School. All oysters came from Areas 1 and 3 and were collected on May 13, 2015.

Finally, the datasets from Phase I and Phase II were pooled in order to utilize the entirety of the collected data. Areas 2, 4, 6, and 7 were only sampled in Phase I and each area included 10 dredge grabs; Areas 1, 3, 5, 8, and 9 were sampled in both phases and each area therefore includes 25 dredge grabs. The summary table is provided below.

Phase I and Phase II Combined Summary Table					
Area	Frequency	Abundance	Average Density (m ⁻²)	Average Dimensions (mm)	
				Length	Width
Phase I Only					
2	0.00	0	0.0	NA	NA
4	0.00	0	0.0	NA	NA
6	0.20	2	2.2	29.0	23.5
7	0.10	1	1.1	40.0	35.0
Phase I and II Combined					
1	0.32	41	17.6	75.1	47.7
3	0.16	15	6.5	60.9	41.9
5	0.20	35	15.1	52.6	34.9
8	0.80	88	37.8	16.4	14.1
9	0.20	16	6.9	13.4	12.3

To summarize, the combined Phase I and Phase II table above shows that of the nine areas the five that were resampled were clearly superior in all respects. Sediment quality is a primary controlling factor on oyster utilization in the study site. While the resampled areas are better, distribution remains very patchy with the exception of Area 8, in which oysters were encountered in 80% of the dredge grabs. Finally, among the resampled sites, there are clearly two different cohorts. The cohort north of the bridge is dominated by oyster spat. This would suggest that conditions for veliger settlement are improved in this location, which again may be related to the abundance of shell material. Yet the lack of larger oysters suggests that sustained growth is interrupted, which may point to instability in the substrate. The second cohort, between the bridge and the Piermont pier, is dominated by large oyster. Of the 75 dredge samples taken in those three areas between both phases, only two contained spat. This suggests better conditions for growth, yet poor conditions for settlement. Fine sediments are quite common here and depositional processes may bury younger oysters. Certainly there are a host of other factors including hydraulics, pathology, and water chemistry that are not herein considered.

Appendix I

Area 1			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
1-1-1	17.0	Little sediment, multiple species shells (none viable), and some shell hash.	None
1-1-2	20.0	Several clusters of attached oysters and oyster shell, no fines. Several mud crabs.	115 x 50 88 x 66 34 x 30 38 x 36 45 x 29 36 x 28
1-1-3	18.0	Mix of oysters and mussel matreial, little sediment and shell hash. Several crabs.	59 x 46 61 x 56 62 x 46
1-1-4	18.4	Gray fine sediment, some shell hash and clam valves. Several mud crabs.	None
1-1-5	15.6	Brown sediments, with a mix of oyster and clam shells and shell hash. Numerous mussels and mud crabs.	98 x 59 54 x 34 68 x 57 100 x 58 54 x 41 35 x 25 98 x 56 71 x 53 65 x 51
1-1-6	20.7	Mix of gray/black sediment, with clam and oyster shells, and shell hash.	None
1-1-7	17.3	Mix of gray/black sediment, with spent clam and oyster shells, some shell hash. 1 bloodworm.	None
1-1-8	20.6	Gray fine sediment, shell hash, several spent oyster and clam shells. Some mud crabs.	None
1-1-9	17.3	Gray/black fine sediments with shell hash and oyster shells.	None
1-1-10	17.4	Heavy gray fine sediment, shell hash, with oyster and clam shells.	None

Area 2			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
2-1-1	17.3	Dark gray clay, brown silt, some detritus. Viable <i>Mya</i> .	None
2-1-2	20.0	Loose brown silt, and a few clams.	None
2-1-3	7.9	Gray fines, brown silt. A strong septic odor. Few spent clam shells and several live <i>Mya</i> .	None
2-1-4	17.5	Gray fines under brown silt, trace of detritus. Some spent clam valves and live soft clams.	None
2-1-5	22.1	Dark gray fines and brown silt. Several spent clam shells.	None
2-1-6	20.5	Dark gray fines with a thick brown silt stratum. Some organic detritus, . 12 soft clams, several isopods, and an amphipod.	None
2-1-7	33.0	Gray fines but mostly brown silt. Some organic detritus and 30 viable soft clams.	None
2-1-8	14.8	Gray fines but mostly brown silt. Some organic detritus and a few isopods.	None
2-1-9	30.3	Brownish-gray fines and some fine sand. Some very fresh oyster shells and very angular gravel with sharp edge, and one large cobble (6"). This looks like placed material.	None
2-1-10	6.2	Grayish fines and organics,. About 15 <i>Mya</i> , 2 crabs, and 5 isopods.	None

Area 3			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
3-1-1	16.7	Gray fines, with broken oyster and clam shells. 1 mud crab.	None
3-1-2	15.3	Gray fines, with oyster, clam, and mussel shells. Several mud crabs and red algae.	80 x 55
			36 x 27
			58 x 37
			75 x 55
3-1-3	15.1	Mix of gray and black thick fines, oyster and clam shells, some gravel, and shell hash.	None
3-1-4	18.3	All gray fines. 1 mud crab.	None
3-1-5	16.8	Gray and black fines, with spent oyster, clam, and ribbed mussel shells, and shell hash. 2 mud crabs and red algae.	40 x 26
			43 x 38
			50 x 28
			58 x 35
3-1-6	14.8	Gray and black fines, oyster, clam and mussel shells and shell hash. Several mud crabs.	None
3-1-7	18.7	Some brown fines, with minor shell hash and broken oyster shells.	None
3-1-8	15.8	Gray and brown fines, with oyster, clam and mussel shells. Multiple mud crabs.	68 x 50
			49 x 47
			62 x 45
3-1-9	17.5	Brown and gray clay, minor shell hash.	None
3-1-10	16.1	Heavy gray and black fines, with oyster, clam and mussel shells, and organic detritus. Multiple mud crabs.	None

Area 4			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
4-1-1	21.6	Gray fines and sand with brown silt. About 25 live <i>Mya</i> and several hard clams.	None
4-1-2	29.3	Gray fines, brown silt from an uneven bottom. Roughly 50 <i>Mya</i> and a bloodworm.	None
4-1-3	28.0	Gray fines, brown silt, with 45 <i>Mya</i> .	None
4-1-4	20.0	Majority gray fines, brown silt, and very fine detritus. About 10 soft clam and 1 isopod.	None
4-1-5	14.7	Black clays with brown silt, and several soft clam shells.	None
4-1-6	14.5	Black clays and brown silt, very consolidated. Trace shell hash, 3 <i>Mya</i> and 6 isopods.	None
4-1-7	18.1	Gray clays covered with brown silt. Trace detritus and 1 oyster valve.	None
4-1-8	19.0	Dark gray fines, consolidated, with brown silt. Very fine detritus. 30 <i>Mya</i> and 1-0 isopods.	None
4-1-9	15.8	Black clay and brown silt, several soft clams.	None
4-1-10	26.8	Gray clays, brown silts, and trace detritus. 40 <i>Mya</i> .	None

Area 5			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
5-1-1	13.8	Gray fines, bloodworms, oyster, mussel and clam shells. Bloodworms and crabs, red algae on oysters.	75 x 55
			67 x 56
			59 x 50
			77 x 58
			78 x 50
5-1-2	14.4	Black and gray fines, oyster, clam and mussel shells, shell hash and gravel.	85 x 54
5-1-3	14.2	Black and gray fines, oyster, clam and mussel shells, shell hash and gravel, with some organic detritus.	None
5-1-4	13.2	Minor amount of gray fines, oyster, clam and mussel shells, with shell hash.	None
5-1-5	14	Black and gray fines, oyster, clam and mussel shells, shell hash and gravel. Several bloodworms.	None
5-1-6	13.5	No fines, mostly oyster with some clam and mussel shells, with shell hash. Ribbed mussels and mud crabs present.	60 x 35
			78 x 50
			58 x 47
			66 x 48
			85 x 48
			55 x 41
			64 x 48
80 x 45			
5-1-7	14.1	Minor amount of gray fines, oyster, clam and mussel shells, with shell hash.	70 x 61
5-1-8	13.1	Brown and gray fines, broken oyster, clam and mussel shells, shell hash and minor gravel. Several mud crabs.	None
5-1-9	13.9	Black and gray fines, broken oyster, clam and mussel shells, shell hash and minor gravel. 3 mud crabs.	None
5-1-10	13.7	Few gray fines, with spent oyster, clam and mussel shells, with shell hash and gravel.	None

Area 6			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
6-1-1	12.8	Largely coarse shell hash, a mix of oyster and mussels. 1 crab.	None
6-1-2	13.0	Brown and gray clay and silts, consolidated. Some shell material, and some small cobble. 4 ribbed mussels.	8 x 7
6-1-3	13.0	Brown and gray thick sediment, some shell hash and fresh valves.	None
6-1-4	13.0	Gray fines and oyster shell hash with rounded gravel. 1 mud crab	None
6-1-5	12.6	Brown and gray fines, minor shell hash, mix of oyster and clam.	None
6-1-6	13.0	Brown and gray silts, mud crabs, modest amount of hash and shell, mostly oyster, some fresh. 2 crabs.	None
6-1-7	12.6	Nearly all shells, mostly oyster. This oyster was extremely thin-shelled, nearly translucent.	50 x 40
6-1-8	13.3	Black fines and brown silt, very little shell material, mostly clam.	None
6-1-9	12.9	Brown fines and gray clays, little shell hash, mostly clam.	None
6-1-10	13.2	Brown and gray fines with little shell hash, and deteriorated oyster shells.	None

Area 7			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
7-1-1	9.2	Black thick sediment and brown silt, trace shell hash	None
7-1-2	11.5	Brown gray silt, and minor oyster, clam, and mussel material.	40 x 35
7-1-3	12.1	Black thick sediment and brown silt, very fine shell hash.	None
7-1-4	12.3	Brownish gray clays, clumpy, no shells.	None
7-1-5	12.0	Brown and gray silt, some sand. Minor shell hash and spent valves, mostly oyster. 1 mud crab.	None
7-1-6	12.4	Loose brown silts, minor shell material, a mix of clam and oyster.	None
7-1-7	12.1	Brown silts and fine sands, minor shell hash and valves, a mix of clam and oyster.	None
7-1-8	13.1	Brown silts and some fine sand. Minimal hash and spent valves from clams and oysters.	None
7-1-9	14.1	Brown gray silts, loose. Some shell hash and broken valves. One crab and an isopod.	None
7-1-10	12.1	Dark gray fines, brown silts, trace hash. One hard clam.	None

Area 8			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
8-1-1	8.7	Brown fines but mostly shell hash, mostly oyster and some ribbed mussel.	5 x 5 10 x 7
8-1-2	8.1	Mostly oyster shell, a minor clam component. Also ribbed mussel.	4 x 4 6 x 6 8 x 8 8 x 4 8 x 5 11 x 10
8-1-3	9.8	Oyster material, from hash to large valves, quite weathered, some clam and ribbed mussel components.	None
8-1-4	8.7	Mostly spent oyster shell, minimal fines.	7 x 4 7 x 9 5 x 5 8 x 8 4 x 9 12 x 8 6 x 6 65 x 60
8-1-5	9.8	Mostly coarse shell hash with some clumpy dark fines. Mostly oyster material. One live Blue Crab and other mud crabs.	None
8-1-6	7.7	Dark fines, but mostly shell hash and shells, 85% oyster with the balance ribbed mussel.	35 x 30 20 x 15 15 x 10 6 x 6 6 x 6 8 x 8 15 x 15 7 x 7
8-1-7	6.8	Mostly coarse hash and shells, several crabs	62 x 45
8-1-8	8.2	Mostly shell hash and spent valves with minor brown fines. Mostly oyster material.	10 x 8 8 x 8 55 x 45
8-1-9	8.5	Brown gray fines, shell hash, and clam and oyster shells. Several large <i>Mercenaria</i> and mud crab	None
8-1-10	7.7	Mostly oyster shell hash and some brown fines. Some clam material.	None

Area 9			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
9-1-1	13	Brown and gray fines, some old oyster shell and shell hash. 3 live <i>Mercenaria</i> and an isopod	None
9-1-2	13	Gray fines and brown silts atop. Some cobble up to 4", coarse shell hash, and spent shells, primarily hard clam. Several live hard clams.	None
9-1-3	11.8	Mostly spent shell and shell hash, largely oyster material. Some rounded gravel.	13 x 14 12 x 12 24 x 15 40 x 30
9-1-4	12.1	Mostly oyster shell hash and spent valves, with some fines. Minor coarse gravel.	10 x 10 8 x 10
9-1-5	12.1	Brown fines, shell hash, and a mix of clam and oyster shells.	None
9-1-6	12	Gray fines with brown silt, mostly spent clam shells that are fresh and several live hard clam. Minor shell hash.	None
9-1-7	12.6	Gray fines with brown silt. This had a strong septic odor. Very loose consistency, a number of clams and spent shells, no hash.	None
9-1-8	11.3	Very fine brown sands with spent oyster material, some fresh but most degraded. Several <i>Mercenaria</i> .	10 x 10 6 x 5
9-1-9	11.3	Gray fines and brown silts, spent oyster shells and large quantities of shell hash.	None
9-1-10	10.9	Gray clays, some large spent clam shells.	None

Area 1			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
1-2-1	20.2	Mostly spent oyster shell and coarse shell hash. Numerous ribbed mussels and crabs.	100 x 60
			90 x 60
			60 x 50
			80 x 45
			90 x 50
1-2-2	19.0	Brown silts with minor fine organic detritus and trace fine shell hash. Several <i>Mya</i> and isopods.	None
1-2-3	18.0	Mostly oyster material with clusters. Several crabs, <i>Mya</i> , and ribbed mussels.	100 x 50
			120 x 45
1-2-4	18.5	Clusters of oysters with little shell hash. Ribbed mussels and a crab.	90 x 50
			150 x 50
			60 x 40
			100 x 50
1-2-5	17.6	Brown gray silts some large oyster shell and shell hash with a few <i>Mya</i> shells.	8 x 8
			110 x 55
			90 x 60
			50 x 40
			70 x 50
1-2-6	18.0	Mostly consolidated gray clays, trace shell and one spent hard clam shell.	90 x 75
			80 x 60
			50 x 40
1-2-7	17.2	Mostly brown-gray fines and clumpy clays. Little shell hash or shells, mostly soft clam, some oyster and ribbed mussels. Several live <i>Mya</i> .	None
1-2-8	18.1	Brown-gray fines and clumpy clays. Trace shell hash.	None
1-2-9	17.0	Brown-gray fines with minimal shell hash and some spent clam shells. 5 live <i>Mya</i> .	None
1-2-10	13.0	Mostly oyster clusters with minor shell hash. Numerous ribbed mussels and some bloodworms.	100 x 60
			45 x 30
			80 x 55
1-2-11	15.3	Mostly brown silts and clumpy gray clays. Minor shell hash, mostly clam and ribbed mussel. Several live <i>Mya</i> .	85 x 50
			None
1-2-12	17.5	Mostly brownish-gray silt and some clumpy clay. Trace shell hash. An isopod and around 10 live <i>Mya</i> .	None
1-2-13	14.2	Grayish silt and clumpy gray clays. Trace shell hash and gravel. 1 spent oyster valve.	None
1-2-14	13.1	Mostly dark brown silt, minor shell hash and organic detritus including some coarse pieces. Several <i>Mya</i> .	None
1-2-15	16.2	Brown-gray silts, trace shell hash. About 20 live <i>Mya</i> and 1 isopod.	None

Area 3			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
3-2-1	14.4	Loose brown silt, minor shell hash and shells, mostly hard clam, but also oyster, ribbed mussel, and soft clam. 1 crab	100 x 60 90 x 50
3-2-2	12.0	Gray fines with brown silt on top. Minor shell hash and spent valves, mostly clam. Minor organic detritus. Live isopods and <i>Mya</i> .	None
3-2-3	13.5	Loose brown fines, minor shell hash mostly <i>Mya</i> . Several live <i>Mya</i> and isopods	None
3-2-4	12.2	Dark gray fines and brown silt. Minor shell hash and fine to coarse organics. Some oyster clusters.	None
3-2-5	15.3	Mostly brown silts and sands, very fine shell hash and some spent shells.	None
3-2-6	15.3	Brown and gray silts. Minor shell hash and spent, deteriorated hard and soft clam valves. 1 isopod.	None
3-2-7	15.0	Very consolidated dark gray clay with brown silt. Trace fine shell hash. 2 crabs.	None
3-2-8	14.2	Mostly loose dark silts. Minor shell hash and some broken shell. Some ribbed mussel shell. 1 crab.	None
3-2-9	17.7	Very consolidated hard dark gray clay. Trace shell hash.	None
3-2-10	14.2	Hard gray clay, some brown silt. Trace shell hash and one spent clam valve.	None
3-2-11	14.0	Very consolidated dark gray clays. Minor shell hash and fine organic detritus. 15 viable <i>Mya</i> .	None
3-2-12	12.7	Hard gray clay.	None
3-2-13	13.3	Very hard dark gray clay. Trace shell hash and a few spent hard clam valves. 2 crabs.	None
3-2-14	14.2	Hard clay, dark gray, some brown silt. Trace hash.	None
3-2-15	14.5	Brown silts over dark gray fines, consolidated. Trace shell hash and organics. 30 <i>Mya</i> .	None

Area 5			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
5-2-1	14.3	Mostly dark gray fines, fairly consolidated. Trace shell hash and some spent oyster and hard clam valves. 10 <i>Mya</i> and 5 isopods.	None
5-2-2	14.0	Fairly loose brown silt. Some spent oyster and hard clam shells and minor fine shell hash. Oyster cluster came up on anchor.	None
5-2-3	13.5	Brown silts with good quantity of spent oyster and hard clam shell. Some coarse sand and minor shell hash. Several crabs.	None
5-2-4	14.3	Loose dark gray silt. Some old spent oyster, hard clam, and ribbed mussel material. Trace gravel.	None
5-2-5	12.8	Dark gray fines with some brown silt. Few old oyster shells and ribbed mussel material, minor shell hash and detritus. 1 <i>Mya</i> and 1 isopod.	None
5-2-6	13.5	Dark gray fines and loose brown silt. Few spent valves of hard clam, minor oyster shell hash. 3 live <i>Mya</i> .	None
5-2-7	12.5	Mostly oyster shell and cluster, some loose brown silt. Some shell hash. Many live ribbed mussel and 2 crabs.	70 x 45 70 x 50 50 x 30
5-2-8	12.1	Loose brown silt, many spent oyster shells and moderate shell hash.	None
5-2-9	13.2	Dark gray fine with loose brown silt. Few spent shells, mostly oyster but also hard clam. Minor shell hash and fine organics. Several live <i>Mya</i> and polychaetes.	None
5-2-10	12.6	Loose brown silt. Lots of spent oyster shells and some shell hash. Trace fine gravel.	None
5-2-11	13.2	Some loose brown silt. Oyster cluster and spent oyster shell. Fair amount of coarse organic detritus, some red algae.	85 x 45 70 x 40 70 x 50 8 x 6 80 x 35 5 x 3 8 x 7 8 x 10 6 x 6 6 x 6 8 x 6 6 x 6
5-2-12	12.0	Nearly all oyster clusters, few viable. A number of ribbed mussels. No soft sediments or hash.	100 x 50 7 x 10 6 x 6 35 x 20 85 x 45
5-2-13	12.8	Dark gray fines and brown silts. Some spent valves, a mix of oyster, hard clam, and soft clam. Minor shell hash. 1 live <i>Mya</i> .	None
5-2-14	12.2	Mostly spent oyster shells and minimal shell hash with some fine brown silt.	None
5-2-15	12.2	Mostly dark gray and brown silt. Moderate shell density, mostly aged oyster, but some hard clam. 1 viable <i>Mya</i> .	None

Area 8			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
8-2-1	9.6	All spent oyster shells, some shell hash. 1 crab.	25 x 20
8-2-2	12.0	Mostly coarse shell hash and broken oyster shell, some brown silt. 1 crab.	None
8-2-3	11.3	Primarily oyster shell hash and spent shells. 2 crabs many small ribbed mussels.	40 x 30 12 x 8 10 x 7 40 x 30 12 x 10 6 x 6 10 x 15 10 x 10 15 x 15 60 x 50 7 x 7 7 x 7
8-2-4	12.3	Mostly coarse shell hash and broken shell. Minor coarse gravel. Some ribbed and blue mussel shell.	5 x 5
8-2-5	11.0	Mostly very coarse oyster shell hash. 1 live <i>Mercenaria</i> , some ribbed mussels, and 2 crabs.	8 x 8
8-2-6	9.1	Brown and gray silts. Broken shell, hard clam and oyster. Lots of shell hash and many tiny blue mussel shells. Several live <i>Mercenaria</i> .	7 x 8
8-2-7	6.9	Nearly all spent oyster shells and some fine hash. Ribbed mussels and 1 live <i>Mercenaria</i> .	50 x 40 8 x 8 2 x 2 11 x 10 9 x 9
8-2-8	8.6	Mostly oyster and coarse shell hash. Some ribbed mussels and hard clam material. 1 crab.	7 x 8 7 x 8

Area 8 (continued)			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
8-2-9	8.0	Mostly spent oyster valves and medium shell hash and some brown silt. Some ribbed mussels.	9 x 7
			30 x 25
			12 x 10
			12 x 8
			13 x 12
			8 x 6
			12 x 12
			10 x 10
			10 x 10
			10 x 10
8-2-10	9.0	Brown silt and fine sand. Mostly spent oyster shells and hard clam material and shell hash. Trace gravel, possibly slag. Ribbed and blue mussel shells. Several crabs.	12 x 12
			7 x 7
			14 x 12
			11 x 10
8-2-11	7.1	Almost all spent oyster shells, minor hash. Some hard clam valves. Crabs.	10 x 10
			55 x 45
8-2-12	7.7	Mostly spent oyster shell, trace silt, minor shell hash. Some ribbed mussel material.	5 x 4
8-2-13	8.0	Mostly spent oyster valves, minor silt. Some hard clam and ribbed mussel material. Trace gravel. Several mud crabs.	30 x 20
			6 x 5
			35 x 25
			8 x 8
			8 x 8
			7 x 7
8-2-14	6.2	Some sand and some silt but mostly shell hash. A mix of oyster and hard clam shells. Several crabs, an isopod, and two <i>Mercenaria</i> .	9 x 7
			6 x 6
			25 x 25
			8 x 8
8-2-15	6.9	Mostly spent oyster shells with some hard clam valves. Minor sand and silt, trace gravel. Some ribbed mussel.	7 x 7
			8 x 8
			70 x 40
			45 x 30
			5 x 5
			45 x 40

Area 9			
Sample	Depth (ft)	Sediment Description	Oysters (mm)
9-2-1	10.1	Mostly spent shells, deteriorated, and shell hash. Some grayish fines and gravel. Several live <i>Mercenaria</i> , bloodworms, 1 whelk spat.	None
9-2-2	9.9	Spent oyster shells with some hard clam. Some brown gray silt. Several live hard clam. Minor shell hash and trace gravel.	None
9-2-3	9.1	Mostly spent shells of hard clam and oyster, some gray silt. Minor shell hash and trace gravel. A crab and an isopod.	None
9-2-4	8.7	Almost all spent oyster shells with some clam. Minor brown silts and shell hash.	12 x 12 8 x 8 12 x 8
9-2-5	9.4	Brown gray silt and moderate amount of spent clam shells, little oyster material. Several large <i>Mercenaria</i> and amphipods.	None
9-2-6	8.7	Mostly spent oyster shells with some clam material and coarse shell hash. Several amphipods, mud crabs, and ribbed mussel.	10 x 12 11 x 13 8 x 7 15 x 20 15 x 10
9-2-7	10.0	Dark brown gray silts and sands with spent hard clam shell. Minimal oyster material, trace organic detritus. Several live hard clam.	None
9-2-8	9.8	Brownish-gray fines, moderate amount of spent shells, mostly clam but some oyster. Several viable hard clam. 1 isopod and 1 crab.	None
9-2-9	10.2	Lots of brown silt. Some spent clam shells and viable clams. Trace shell hash and moderate organic detritus. 1 scud.	None
9-2-10	9.7	Brownish-gray fines and spent shells, almost all hard clam. Around 10 viable hard clams. Moderate medium gravel.	None
9-2-11	8.5	Almost all medium sand. Some spent hard clams with several viable. Some ribbed mussel and an isopod. Minor detritus.	None
9-2-12	10.2	Brown-gray silt, moderate amount of spent oyster shell. Some spent and viable hard clam. Fine shell hash. 2 mud crabs.	None
9-2-13	10.5	Mostly brown gray silts, moderate amount of spent clam valves, several viable. 1 live <i>Mya</i> . Some fine shell hash.	None
9-2-14	10.2	Brown-gray silts, lots of coarse shell hash and a mix of oyster and clam valves. 15 viable <i>Mercenaria</i> and 3 crabs.	None
9-2-15	10.4	Some brown-gray silts, broken oyster shell and shell hash. Oyster shell is aged. Some clam shells and 2 live. Minor coarse gravel. 1 crab.	None

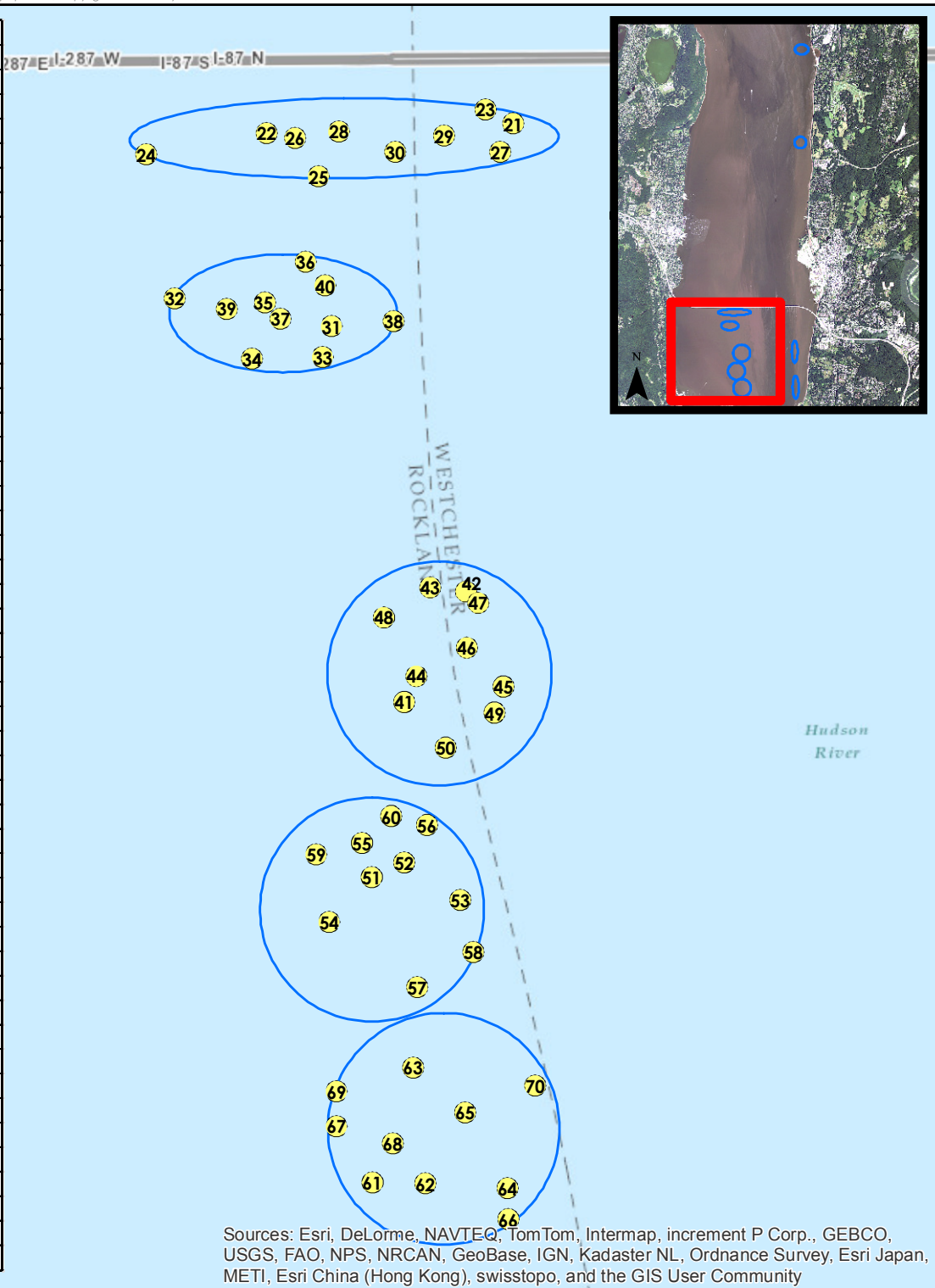
Tier 2 Oyster Sampling Report
 Tappan Zee Bridge Hudson River Crossing Project
 May 2015

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1-1-3	63	41.04886	-73.89478	6-1-3	33	41.06384	-73.89716
1-1-4	64	41.04630	-73.89217	6-1-4	34	41.06382	-73.89914
1-1-5	65	41.04791	-73.89333	6-1-5	35	41.06500	-73.89876
1-1-6	66	41.04565	-73.89216	6-1-6	36	41.06586	-73.89763
1-1-7	67	41.04764	-73.89694	6-1-7	37	41.06467	-73.89833
1-1-8	68	41.04727	-73.89537	6-1-8	38	41.06460	-73.89518
1-1-9	69	41.04837	-73.89692	6-1-9	39	41.06489	-73.89984
1-1-10	70	41.04846	-73.89139	6-1-10	40	41.06536	-73.89707
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2-1-3	83	41.04809	-73.87363	7-1-3	23	41.06905	-73.89259
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2-1-5	85	41.04595	-73.87488	7-1-5	25	41.06766	-73.89724
2-1-6	86	41.04718	-73.87477	7-1-6	26	41.06847	-73.89790
2-1-7	87	41.04846	-73.87545	7-1-7	27	41.06815	-73.89219
2-1-8	88	41.05006	-73.87423	7-1-8	28	41.06860	-73.89666
2-1-9	89	41.04950	-73.87519	7-1-9	29	41.06850	-73.89374
2-1-10	90	41.04634	-73.87374	7-1-10	30	41.06816	-73.89512
3-1-1	51	41.05289	-73.89591	8-1-1	11	41.11508	-73.87233
3-1-2	52	41.05318	-73.89499	8-1-2	12	41.11588	-73.87326
3-1-3	53	41.05240	-73.89343	8-1-3	13	41.11476	-73.87090
3-1-4	54	41.05194	-73.89710	8-1-4	14	41.11414	-73.87188
3-1-5	55	41.05360	-73.89618	8-1-5	15	41.11495	-73.87375
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3-1-8	58	41.05129	-73.89309	8-1-8	18	41.11562	-73.87110
3-1-9	59	41.05337	-73.89744	8-1-9	19	41.11380	-73.87239
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4-1-6	76	41.05624	-73.87375	9-1-6	6	41.13973	-73.87225
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4-1-8	78	41.05969	-73.87460	9-1-8	8	41.14091	-73.87124
4-1-9	79	41.05851	-73.87414	9-1-9	9	41.14186	-73.87112
4-1-10	80	41.05752	-73.87514	9-1-10	10	41.14006	-73.86969
5-1-1	41	41.05657	-73.89497				
5-1-2	42	41.05890	-73.89321				
5-1-3	43	41.05898	-73.89421				
5-1-4	44	41.05711	-73.89461				
5-1-5	45	41.05688	-73.89220				
5-1-6	46	41.05771	-73.89320				
5-1-7	47	41.05865	-73.89288				
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5-1-9	49	41.05632	-73.89245				
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Tier 2 Oyster Sampling Report
Tappan Zee Bridge Hudson River Crossing Project
May 2015

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3-2-8	53	41.05435	-73.89721	9-2-8	8	41.14030	-73.87081
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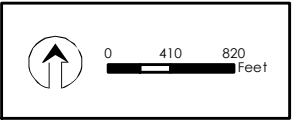
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6-1-6	36	41.06586	-73.89763
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Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community



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NOTES:
 1. Sample locations were randomly selected using ArcGIS.
 2. Topographic basemap obtained from ArcGIS Online Basemaps.
 3. 2011 NAD orthoimagery obtained from USDA GeoSpatial Data Gateway.

Map Projection:
 NAD 1983 StatePlane New York East FIPS 3101 Feet

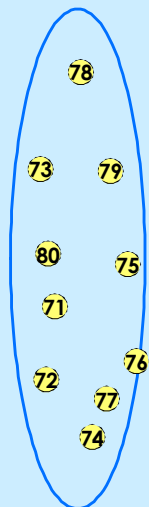
SAMPLING LOCATIONS -MAY 2015- ROUND 1

OYSTER RELOCATION MONITORING STUDY
 TAPPAN ZEE BRIDGE HUDSON RIVER CROSSING PROJECT
 NEW YORK

Legend

● Sample Location
 ○ Sample Area

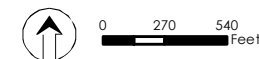
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2-1-3	83	41.04809	-73.87363
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2-1-9	89	41.04950	-73.87519
2-1-10	90	41.04634	-73.87374



LOCATION MAP



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Map Projection:
 NAD 1983 StatePlane New York East FIPS 3101 Feet

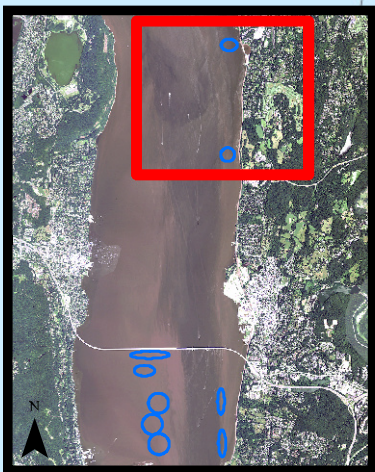
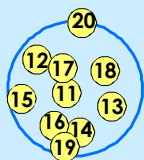
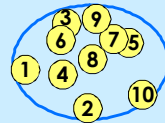
SAMPLING LOCATIONS -MAY 2015- ROUND 1

OYSTER RELOCATION MONITORING STUDY
 TAPPAN ZEE BRIDGE HUDSON RIVER CROSSING PROJECT
 NEW YORK

Legend
 Sample Location
 Sample Area

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Lab ID	Map ID	Lat	Long
9-1-1	1	41.14068	-73.87338
9-1-2	2	41.13975	-73.87141
9-1-3	3	41.14176	-73.87205
9-1-4	4	41.14056	-73.87220
9-1-5	5	41.14130	-73.87009
9-1-6	6	41.13973	-73.87225
9-1-7	7	41.14137	-73.87060
9-1-8	8	41.14091	-73.87124
9-1-9	9	41.14186	-73.87112
9-1-10	10	41.14006	-73.86969
8-1-1	11	41.11508	-73.87233
8-1-2	12	41.11588	-73.87326
8-1-3	13	41.11476	-73.87090
8-1-4	14	41.11414	-73.87188
8-1-5	15	41.11495	-73.87375
8-1-6	16	41.11432	-73.87273
8-1-7	17	41.11568	-73.87242
8-1-8	18	41.11562	-73.87110
8-1-9	19	41.11380	-73.87239
8-1-10	20	41.11676	-73.87182

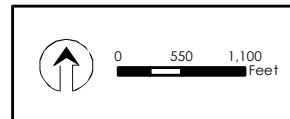


Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

LOCATION MAP



pH PRINCETON HYDRO, LLC.
 1108 OLD YORK ROAD
 P.O. BOX 720
 RINGOES, NJ 08551
 *with offices in NJ, PA and CT



NOTES:
 1. Sample locations were randomly selected using ArcGIS.
 2. Topographic basemap obtained from ArcGIS Online Basemaps.
 3. 2011 NAD orthorectification obtained from USDA GeoSpatial Data Gateway.

Map Projection:
 NAD 1983 StatePlane New York East FIPS 3101 Feet

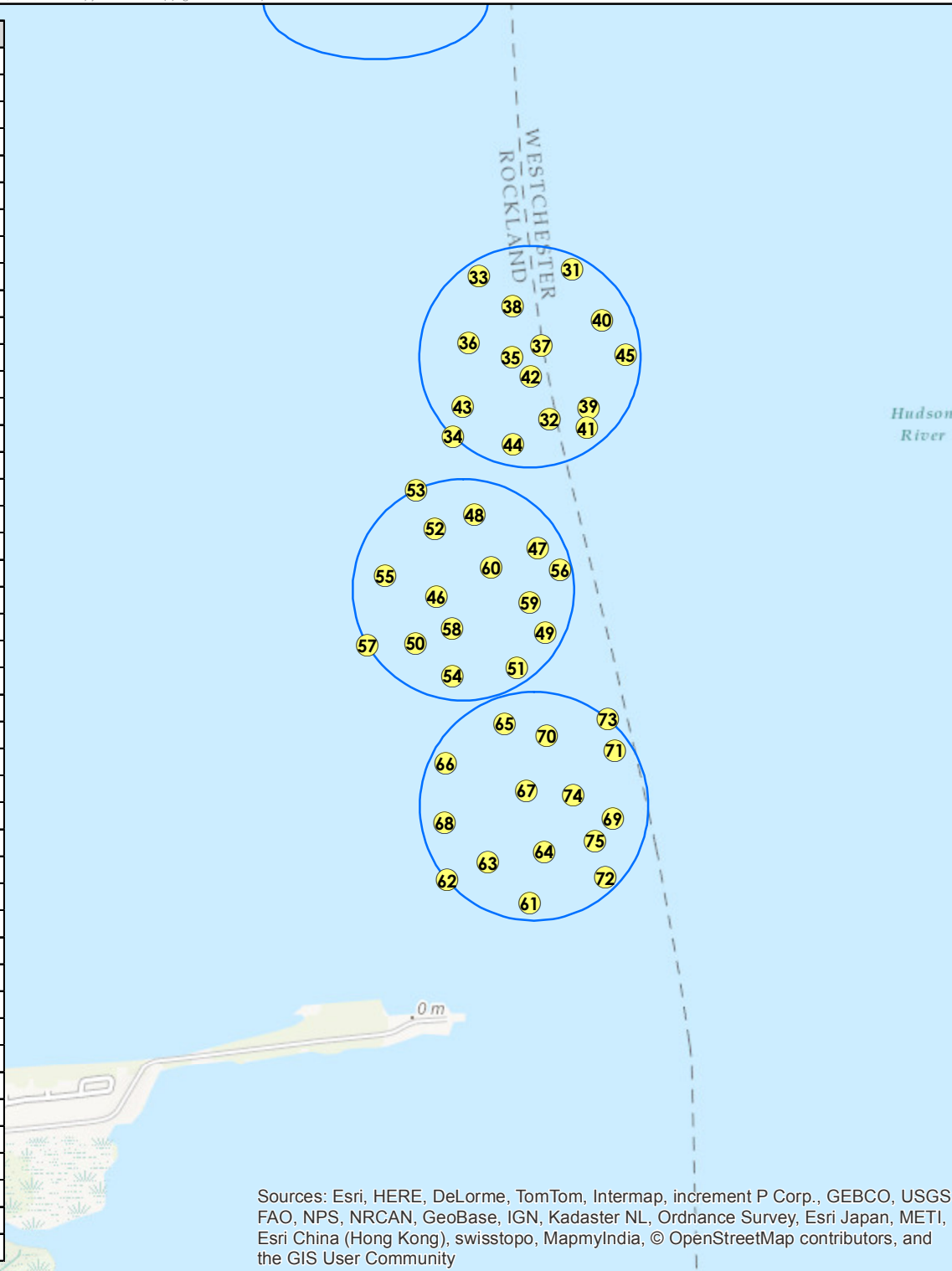
SAMPLING LOCATIONS -MAY 2015- ROUND 1

OYSTER RELOCATION MONITORING STUDY
 TAPPAN ZEE BRIDGE HUDSON RIVER CROSSING PROJECT
 NEW YORK

Legend

- Sample Location
- Sample Area

Sample ID	Map ID	Lat	Long
5-2-1	31	41.05904	-73.89277
5-2-2	32	41.05583	-73.89343
5-2-3	33	41.05889	-73.89540
5-2-4	34	41.05549	-73.89616
5-2-5	35	41.05716	-73.89448
5-2-6	36	41.05748	-73.89569
5-2-7	37	41.05740	-73.89365
5-2-8	38	41.05825	-73.89445
5-2-9	39	41.05607	-73.89233
5-2-10	40	41.05794	-73.89193
5-2-11	41	41.05564	-73.89237
5-2-12	42	41.05676	-73.89395
5-2-13	43	41.05612	-73.89588
5-2-14	44	41.05530	-73.89446
5-2-15	45	41.05719	-73.89127
3-2-1	46	41.05206	-73.89666
3-2-2	47	41.05308	-73.89379
3-2-3	48	41.05381	-73.89557
3-2-4	49	41.05128	-73.89359
3-2-5	50	41.05107	-73.89725
3-2-6	51	41.05053	-73.89441
3-2-7	52	41.05352	-73.89669
3-2-8	53	41.05435	-73.89721
3-2-9	54	41.05037	-73.89621
3-2-10	55	41.05252	-73.89809
3-2-11	56	41.05262	-73.89316
3-2-12	57	41.05104	-73.89861
3-2-13	58	41.05138	-73.89622
3-2-14	59	41.05193	-73.89402
3-2-15	60	41.05267	-73.89511
1-2-1	61	41.04551	-73.89409
1-2-2	62	41.04601	-73.89641
1-2-3	63	41.04638	-73.89525
1-2-4	64	41.04660	-73.89366
1-2-5	65	41.04935	-73.89476
1-2-6	66	41.04850	-73.89642
1-2-7	67	41.04791	-73.89416
1-2-8	68	41.04723	-73.89647
1-2-9	69	41.04730	-73.89173
1-2-10	70	41.04907	-73.89357
1-2-11	71	41.04876	-73.89166
1-2-12	72	41.04604	-73.89196
1-2-13	73	41.04942	-73.89184
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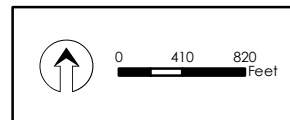


Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Map Projection:
 NAD 1983 StatePlane New York East FIPS 3101 Feet

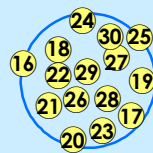
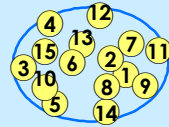
SAMPLING LOCATIONS -MAY 2015- ROUND 2

OYSTER RELOCATION MONITORING STUDY
 TAPPAN ZEE BRIDGE HUDSON RIVER CROSSING PROJECT
 NEW YORK

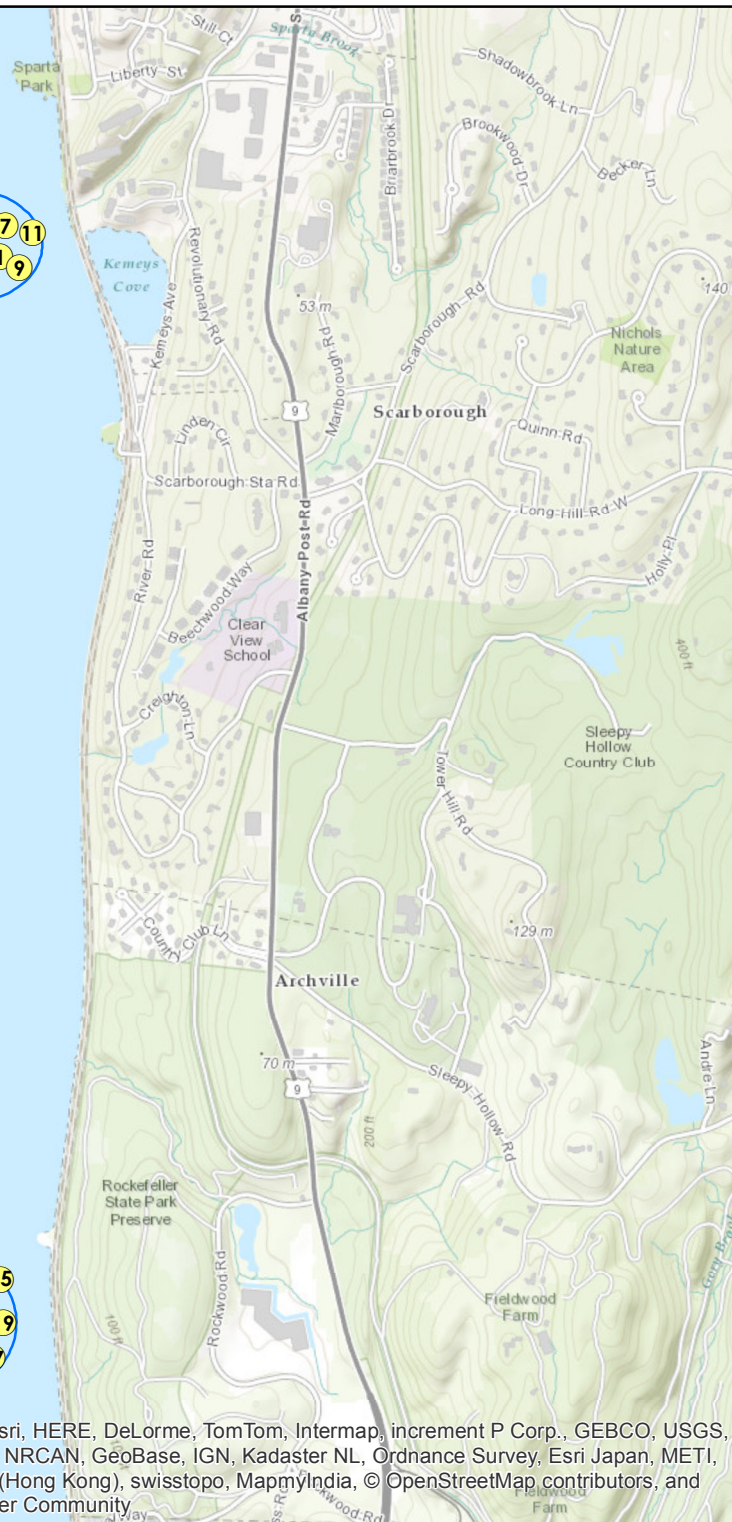
Legend

- Sample Location
- Sample Area

Sample ID	Map ID	Lat	Long
9-2-1	1	41.14056	-73.87020
9-2-2	2	41.14096	-73.87067
9-2-3	3	41.14075	-73.87342
9-2-4	4	41.14180	-73.87258
9-2-5	5	41.13989	-73.87244
9-2-6	6	41.14086	-73.87190
9-2-7	7	41.14131	-73.87003
9-2-8	8	41.14030	-73.87081
9-2-9	9	41.14031	-73.86958
9-2-10	10	41.14028	-73.87276
9-2-11	11	41.14114	-73.86916
9-2-12	12	41.14198	-73.87100
9-2-13	13	41.14129	-73.87158
9-2-14	14	41.13968	-73.87084
9-2-15	15	41.14114	-73.87274
8-2-1	16	41.11561	-73.87408
8-2-2	17	41.11435	-73.87068
8-2-3	18	41.11593	-73.87297
8-2-4	19	41.11517	-73.87033
8-2-5	20	41.11378	-73.87252
8-2-6	21	41.11460	-73.87329
8-2-7	22	41.11530	-73.87299
8-2-8	23	41.11400	-73.87159
8-2-9	24	41.11662	-73.87220
8-2-10	25	41.11620	-73.87041
8-2-11	26	41.11474	-73.87242
8-2-12	27	41.11572	-73.87113
8-2-13	28	41.11475	-73.87143
8-2-14	29	41.11540	-73.87208
8-2-15	30	41.11623	-73.87133



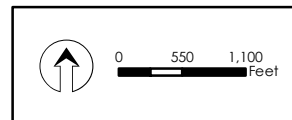
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



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SAMPLING LOCATIONS -MAY 2015- ROUND 2

OYSTER RELOCATION MONITORING STUDY
 TAPPAN ZEE BRIDGE HUDSON RIVER CROSSING PROJECT
 NEW YORK

- Legend**
- Sample Location
 - Sample Area