Oyster Density Determination
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 an oyster density determination at the Tappan Zee Bridge Hudson River Crossing Project. The New York State Department of Environmental Conservation (NYSDEC) Permit 3-9903-0043/00012 issued for the project included the following Mitigation Condition:

> *In collaboration with the Department, the Permittee will seek to harvest local oysters and historic reef materials from the dredge zone and stockpile these for subsequent habitat re-establishment.*

As such, a restoration plan has been formulated, with two options, to harvest oysters and oyster reef material including oyster shells, shell hash, and other components of current or historical oyster reef for placement at other mapped oyster reefs along the western bank of the river; these reefs are in the vicinity of the project but outside of the dredge footprint. The harvesting is to be performed in the eastern portion of the dredge footprint, adjacent to the eastern shore of the river in two discrete low-density oyster beds totaling approximately 8 acres, first mapped in the fall of 2009. Sampling was performed in the identified harvest area as well as the placement/recovery area to determine the density of live oysters and assess the substrate quality.

Methods

Aerial maps, NYSDEC GIS digital data, and other map resources were used to generate a proposed sampling location figure using ArcGIS. In total, 60 points were established. 30 of the points were located in the oyster fishing area, on the east side of the river within the dredge footprint. This unit consisted of two discrete areas; area A to the west and area B to the east. The 30 points were apportioned by area within areas A and B such that there were 12 points in area A and 18 points in area B. The other 30 stations were established in the placement or recovery area located along the west bank of the river, well north of the bridge and outside of the dredge footprint. This area corresponds to a known historic oyster reef. The sampling locations were selected at random with ArcGIS. The coordinates of the approved sampling locations were then uploaded to a GPS unit which was used by the field scientists in the work vessel to locate the sampling points. A single point, Fb-25, was relocated in the field because work barges had been anchored over the sampling point; the point was moved approximately 14 m west of the original location and subsequently GPS located.

Sampling was conducted over a two-day period from June 26 to June 27, 2013. A Peterson dredge of 1.00 ft^2 or 0.093m^2 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. 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. The measurements were taken along two axes: the primary axis started near the hinge and moved to the tip of the shell; the other axis was located roughly perpendicular to the first and measured along the widest section.

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.

In addition, some basic water quality profiles were collected using a calibrated multi-probe water quality meter.

Results

The three sampled areas (Fishing Area A, Fishing Area B, and Placement/Recovery Area), showed some distinct differences in oyster utilization and sediment quality. A summary table of each of the areas is provided below.

Table 1: Capture Summary

Parameters	Fished Area			Placement /
	A - West Area	B - East Area	Total	Recovery Area
Sampling Stations	12	18	30	30
Frequency of Oysters	9	6	15	12
Maximum per Sample	12	5	12	4
Total Oysters	35	17	52	17
Average Density (m^{-2})	31.40	10.17	18.66	6.10

Overall, oyster density is fairly low throughout the examined areas. The best area for oyster colonization was area A of the fishing zone. This area had the highest detection frequency (9 of 12 points), the highest density at a single sample, the greatest number of oysters in total, and the highest average density. The sampling data is provided below (Table 2).

Table 2: Capture Data Area A of Fishing Zone

Station	Frequency	Dimensions (mm)
Fa-1	12	80x45, 17x15, 85x55, 85x50, 90x50, 11x10, 100x65, 9x9, 17x12, 8x8, 50x40, 70x45
Fa-2	5	65x40,15x15, 75x50, 10x10, 10x10
Fa-3	4	60x50, 75x50, 15x15, 8x10
Fa-4	1	130x50
Fa-5	0	
Fa-6	3	90x45, 55x35, 13x10
Fa-7	2	100x50, 10x10
Fa-8	0	
Fa-9	0	
Fa-10	2	55x42, 12x10
Fa-11	1	70x50
Fa-12	5	55x35, 45x35, 130x50, 70x50, 70x60

While this area had the best oyster capture, the sediment quality is relatively poor (Table 3). The area is dominated mostly by fine-grained materials, and spent oyster shells and oyster shell hash are a small component of the sediment; in fact, these coarser materials accounted for at most 20% of any of the individual samples and considerably less collectively. The *Target Ecosystem Characteristics for the Hudson River Estuary*: *Technical Guidance for Developing a Comprehensive Ecosystem Restoration Plan* (Bain et al., 2007) state that the substrate TEC for Eastern oyster is "exposed and clean oyster, other shell, or hard surface". This is obviously lacking in this area. However, the sediment stability TEC states that sediment must be "hard enough so that oyster growth rate can overcome any submersion." Interestingly, the sampling points with the greatest oyster recovery in this area, namely points Fa-1, Fa-2, Fa-3, and Fa-12, are all noted for having a consolidated, plastic, or clay-like consistency as well as some hash or spent shells that indicate some degree of sediment stability or hardness that allows colonization of the site. It should also be noted that there is active if low larval recruitment in the area, as shown in the shell dimensions in table 2.

Table 3: Sediment Data Area A of Fishing Zone

Station	Sediment Description	Frequency
Fa-1	Mostly plastic, black clay with some shell hash. The oysters are well colonized by ribbed mussels and barnacles.	12
Fa-2	Black fines and clay, quite consolidated with a plastic texture. Some medium-grained shell hash and some spent shells.	5
Fa-3	Brownish-gray clay with sands. Some fine shell hash and some minor gravel. Ribbed mussels, barnacales, and polychaetes observed in sample.	4
Fa-4	Mostly grayish fines with some overlying brown fines. Very little organic detritus with some fine shell hash.	1
Fa-5	Two distinct strata in this sample; a loose brown silt, approximately 5-10 cm thick, over a drak gray plastic clay. Some fine shell hash, some rounded gravel, and spent oyster shells.	0
Fa-6	Brownish silts and fine sand. Increased shell hash density, up to around 20%, and spent shells. The shells are well colonized by ribbed mussels and barnacles. A small amount of gravel in the matrix including rounded river stone.	3
Fa-7	Mostly gray fines with a thin layer of brown fines. Some sand in the matrix, as well as some organic detritus and fine shell hash with several spent shells. The shells were colonized by ribbed mussels and barnacles.	2
Fa-8	Brown and gray silt with a loose consistentcy. A trace amount of organic detritus and a few shell fragments.	0
Fa-9	Primarily dark gray fines with a thin surface stratum of brown fines. Sample consistency is very loose. Several spent shells and a trace amount of fine shell hash and organic detritus. Several live clams identified.	0
Fa-10	Dark gray to black fines, with some plasticity to the sample. A trace of organic detritus and fine shell hash. Several spent shells with coarse hash. This sample had a distinct petroleum odor.	2
Fa-11	Mostly grayish silt and sand, with some brown fines. A minor amount of gravel in the matrix and organic detritus. Spent shells account for about 10% of the composition. Ribbed mussels, barnacles, and crabs were all oberved in the sample.	1
Fa-12	Fairly consolidated gray fines with some brown silt overlying. Shells account for about 20% of the sample which is interspersed with fine shell hash. Oysters are colonized by ribbed mussels and barnacles. Polychaetes were observed in the sample.	5

The eastern box, area B of the Fishing Zone, had fewer oysters and a much lower density than the area A. The reason for the disparity seems relatively simple; there is greater indication of active deposition exhibited by an increased thickness of loose, brown silt deposits and stratification within the sediment. As with area A, the oysters in area B are most closely associated with coarser substrates. It should be noted that while there is increased deposition in general, the quantity of shell hash and spent oyster shells is actually greater in area B, and this is where the oysters are primarily concentrated. While the oysters are generally found in the coarser substrate types, the colonization of these areas is far from complete and periodic deposition/scour cycles may explain their absence in some cases. For instance, Fb-25 is described as primarily coarse shell hash and spent shells, yet the material is embedded in fines, and no oysters were identified. The capture data and sediment descriptions are provided in tables 4 and 5 below. Fewer larvae were recovered as percentage of total catch in this area.

Table 4: Capture Data Area B of Fishing Zone

Station	Frequency	Dimensions (mm)
Fb-13	0	
Fb-14	1	80x55
Fb-15	3	55x50, 90x80, 50x40
Fb-16	0	
Fb-17	0	
Fb-18	0	
Fb-19	2	75x50, 75x50
Fb-20	0	
Fb-21	3	90x70, 90x70, 70x50
Fb-22	0	
Fb-23	0	
Fb-24	0	
Fb-25	0	
Fb-26	0	
Fb-27	3	100x55, 80x50, 50x50
Fb-28	0	
Fb-29	0	
Fb-30	5	70x55, 85x65, 80x50, 10x10, 13x13

Table 5: Sediment Data Area B of Fishing Zone

Station	Sediment Description	Frequency
Fb-13	Loose brown silts primarily. Spent shells up to 20% of the sample with a litle shell hash. All the shells look quite aged.	0
Fb-14	Mostly loose, brown silts. A moderate amount of spent shells, up to 10%, and a litte shell hash.	1
Fb-15	The sample is primarily spent shells with some brownish fines.	3
Fb-16	Primarily spent shells with a bit of clumpy gray fines. Very little shell hash. The shells are quite degraded, but there is some ribbed mussel colonization.	0
Fb-17	Brown fines overlaying clumpy gray silts and clay. A decent quantity of shell hash and spent shells, but the shells are quite degraded. Found one large live clam.	0
Fb-18	Two distinct strata. Brownish fines with sand and some shell hash. Underneath, clumpy gray fines with some spent shells. Some gravel in the matrix up to 3 cm.	0
Fb-19	A mix of brown and gray silts with about 10% shell hash. Includes minor amounts of sand and gravel up to 5cm. A number of spent shells found colonized by barnacles and a few ribbed mussels.	2
Fb-20	Brown fines and some shell hash overlying a more consolidated layer with about 20% coarser materials including shell hash, spent shells, gravel, and even some small cobble.	0
Fb-21	Mostly shell hash and spent shells with very few fines.	3
Fb-22	Mostly shell hash, from fine to coarse grained, and large spent shells. Some brown fines in the matrix. Ribbed mussels and barnacles colonized the shells.	0
Fb-23	An upper stratum of loose brown fines, underlain by more consolidated gray fines. Some very fine organic detritus. A few spent shells, quite degraded.	0
Fb-24	Loose brown and black fines. Around 20% of the sample is spent shells and another 10% shell hash.	0
Fb-25	Mostly coarse shell hash and spent shells, quite aged. This is embedded within loose, brown silt.	0
Fb-26	Mostly shell hash, from fine to coarse. Some spent shells, but highly degraded.	0
Fb-27	Sample is primarily shell hash and spent shells, underlain by a plastic, dark gray clay.	3
Fb-28	A mix of brown and gray fines, fine shell hash, and spent shells. The shells are colonized by ribbed mussel.	0
Fb-29	Mostly dark gray silt with some fine shell hash. Spent shells comprise 15% of the matrix. Shells look quite aged and well embedded in the sediment.	0
Fb-30	Fairly dense with spent shells. The remainder is loose brown silt with very little shell hash.	5

The placement/recovery area had the lowest average oyster density, yet the capture frequency was higher than area B indicating a slightly higher distribution although at a lower density. All abundance metrics were inferior to area A. The sediment quality appears quite high and consists largely of either spent oyster shells or shell hash. Fines were generally a minor component, although at several sampling stations the sediment was characterized as fine-grained. While shells and shell material dominate, there is relatively little variation in bathymetry and the bottom seems relatively planar. There seems to be relatively little active reef building although larvae were sampled. Capture data and sediment descriptions are provided in tables 6 and 7.

Table 6: Capture Data Placement/Recovery Area

Station	Frequency	Dimensions (mm)
R-1	0	
R-2	0	
R-3	1	20x12
R-4	0	
R-5	4	80x45, 45x35, 20x15, 20x20
R-6	1	45x40
R-7	0	
R-8	1	10x8
R-9	1	50x40
R-10	0	
R-11	1	15x15
R-12	2	12x12, 17x15
R-13	0	
R-14	0	
R-15	0	
R-16	0	
R-17	1	17x20
R-18	0	
R-19	1	60x50
R-20	0	
R-21	0	
R-22	1	10x15
R-23	0	
R-24	0	
R-25	1	50x45
R-26	0	
R-27	0	
R-28	0	
R-29	0	
R-30	2	12x10, 10x12

Table 7a: Sediment Data Placement/Recovery Area

Station	Sediment Description	Frequency
R-1	A mix of spent shells and coarse shell hash. Loose brown fines comprise about 15% of the sample.	0
R-2	Most of the sample is brown-gray fines and fine sand. Around 30% is highly degraded and dark spent shells, and shell hash. Clam shells and live clams were a component of the sediment.	0
R-3	Shell hash and spent shells form the majority of the sediment with about 5% brown silt. The observed oyster was attached to a ribbed mussel shell.	1
R-4	Around 40% brown fines and fine sand. The rest is an even mix between shell hash and spent shells, most of which are clam shells.	0
R-5	Mostly spent shells of fairly high quality and some shell hash. Brownish fines and fine sand are less than 10% of the sample.	4
R-6	Approximately 10% is is loose, brown silt. The remainder is shell hash and spent shells.	1
R-7	The sample is primarily degraded spent shells and fine to coarse shell hash. Shell material is embedded in brown fines and sands. Barnacles on the oyster shells.	0
R-8	A mix of deteriorated spent shells and coarse shell hash. About 15% of the sample is brown and gray fines and fine sand.	1
R-9	Spent shells, well colonized by barnacles are the majority of the sample. Also shell hash and less than 10% brown fines and fine sand. The shells are rather fresh. Several hard clams observed and one ribbed mussel.	1
R-10	The majority is spent shells and shell hash and most of the shells are severely degraded. Nearly 30% of the sample is brown fines and fine sand, but also includes trace gravel. Several crabs and a ribbed mussel were seen.	0
R-11	Mostly spent shells and coarse shell hash with few fines.	1
R-12	Around 30% or the sediment matrix is brown and black fines and sand. The rest is medium shell hash and spent shells. Half the shells were aged and blackened while the other half were relatively fresh.	2
R-13	Spent shells and shell hash form the majority of sediment. About 15% is brown fines.	0
R-14	Mostly degraded spent shells and shell hash. About 30% is brown and gray fines embedding shell material.	0
R-15	Brown fines comprise about 40% of the sample. The rest is spent shells and shell hash.	0
R-16	The entire sediment matrix is shell hash and spent shells without fines. Clam shells were observed in low number. One ribbed mussels and some barnacles.	0
R-17	Nearly 80% of the sediment is spent shells, the remainder is mostly fine shell hash. Minimal fines.	1
R-18	Primarily degraded spent shells and oyster hash. About 1% of the sample is brownish-gray fines and sand.	0

Table 7b: Sediment Data Placement/Recovery Area

Station	Sediment Description	Frequency
R-19	Mostly spent shells and shell hash with about 15% of brown fines and fine sand.	1
R-20	Almost entirely spent shells and shell hash.	0
R-21	Mostly degraded spent shells and shell hash. About 10% is grayish-brown fines. Ribbed mussels are present.	0
R-22	Brown and gray fines and fine sand comprised 70% of the sample. The remainder is coarse shell hash and spent shells.	1
R-23	Over 90% of the sample is coarse shell hash and spent shells. The remainder is loose, brownish fines. A few ribbed mussels and barnacles on the shells.	0
R-24	95% is coarse shell hash and spent shells. The remainder is dark silt.	0
R-25	Spent shells and fine to coarse shell hash are the majority of the sample. Approximately 35% is loose brown fines.	1
R-26	About 80% of the sample is brown and gray silt and fine sand. The rest is mostly shell hash and a few aged spent shells. Hard clam shells make up a large proportion of the shells. One live hard clam.	0
R-27	Mostly fine to coarse shell hash with aged and degraded spent shells. About 20% of the sediment is loose, brown silt.	0
R-28	Mostly spent shells and shell hash. About 20% is brown and gray silt and fine sand. Several live hard clams observed and a ribbed mussel.	0
R-29	This sample was quite heterogeneous. About 70% was gray fine sand and silt. The remainder is shell hash, coarse gravel, and cobble up to 10 cm. The shells were clearly buried and highly degraded.	0
R-30	Mostly coarse shell hash with several spent shells. About 10% of the sample is fine grayish sand and silt.	2

The distribution of oysters at the study site is difficult to explain, but certainly density is low throughout the project area. The Hudson estuary historically has experienced a large scale decline in oyster populations related to the filling of wetlands, overharvest, water pollution, and pathogens. For the project area, salinity also needs to be examined. The salinity TEC for Eastern oyster is: Larvae: 10 -27.5 ‰; Adults: 5 to 10 ‰. The limited in-situ data collected shows that the site was considerably lower than these values (Table 8). The maximum measured salinity was just 1.204 ‰ well below criteria for both larvae and adults. The period prior to sampling had received higher than average precipitation. This also explains a decline in salinity relative to an event conducted in early May when the maximum measured salinity was 2.43‰ or over 200% of the value measured during this event. These low salinity events have been shown to increase mortality in oysters in this area. In 2008 during an oyster study in the estuary, salinity was measured below 2‰ at Ossining which corresponded with a mortality increase of 30% (Levinton et al., 2011). The in-situ data and literature are suggestive

that the salinity regime of the area may be marginal for supporting oyster or at minimum lead to significant mortality events during low salinity events.

Table 8: In-Situ Data

Station	Depth	Temperature	Specific Conductance	Salinity	Dissolved Oxygen		pH
	m	℃	mS/cm	‰	mg/L	% Saturation	S.U.
Fb-24	0.0	23.98	1.820	0.920	7.19	86.5	7.44
	1.0	23.48	1.780	0.899	7.14	85.0	7.56
	2.0	23.12	2.150	1.097	6.94	82.2	7.57
	3.0	23.06	2.350	1.204	6.82	80.8	7.59
R-30	0.0	23.46	1.241	0.617	7.57	90.0	7.56
	1.0	23.37	1.239	0.616	7.12	84.5	7.68
	2.0	23.33	1.239	0.616	7.07	84.0	7.70
	2.9	23.33	1.238	0.615	7.01	83.1	7.71

Fb-24 : Collected on 6/26/13 @ 14:40, high tide was at 13:20

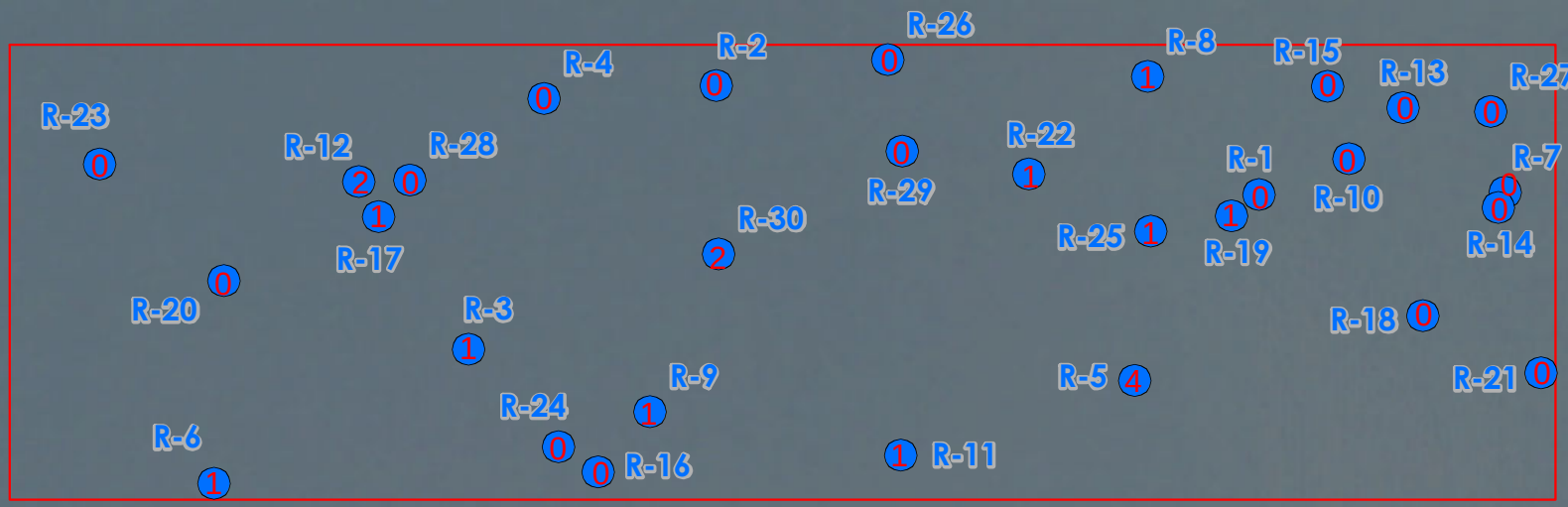
R-30 : Collected on 6/27/13 @ 9:35, low tide was 8:10

The sampling map for the site, including the number of oysters enumerated at each station, as well the latitude and longitude coordinates are included in the appendix.

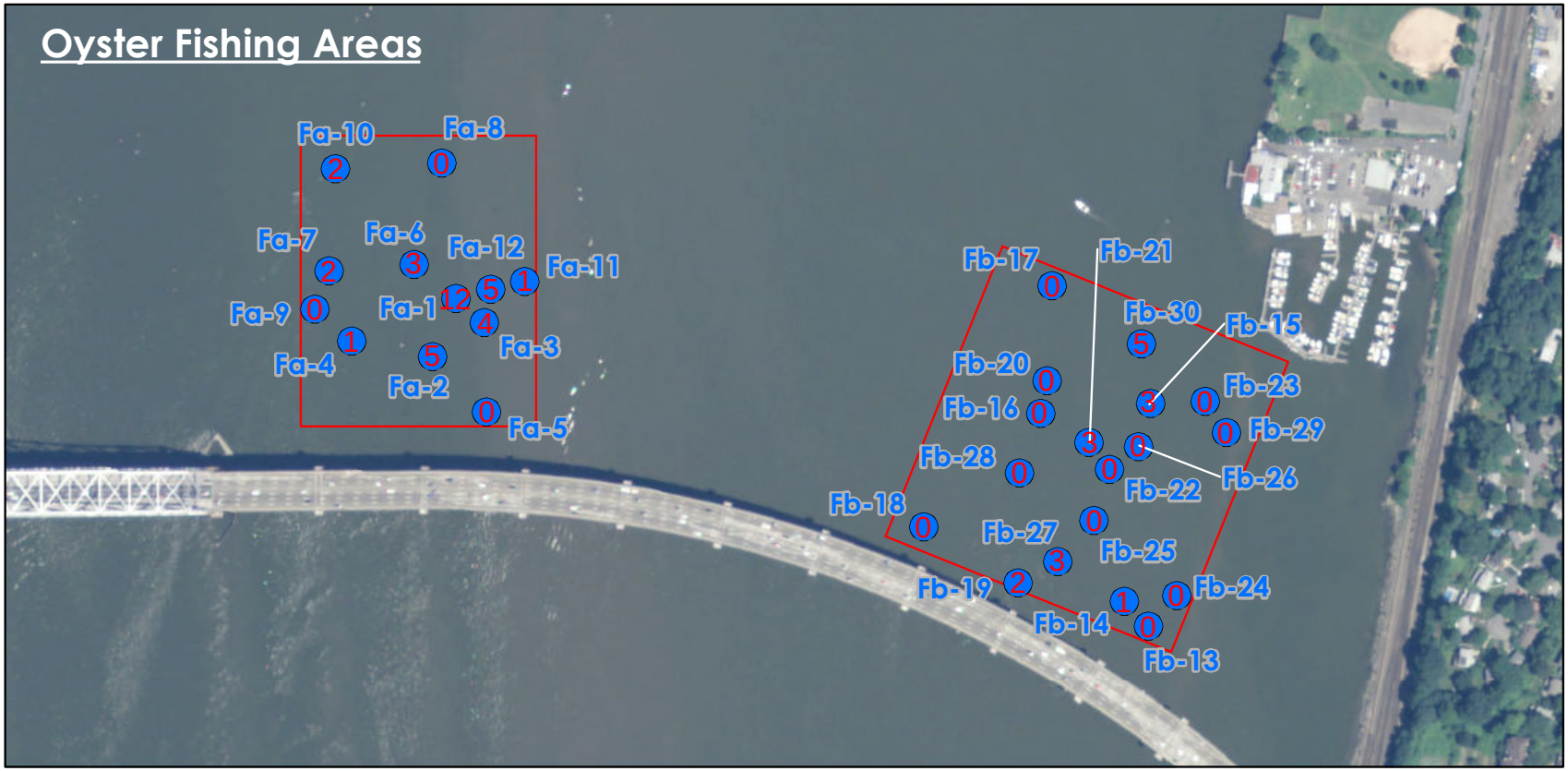
Appendix I

Name	Latitude	Longitude	Name	Latitude	Longitude
Fa-1	41.0713318	-73.8746684	R-1	41.0780793	-73.9044380
Fa-2	41.0709552	-73.8748698	R-2	41.0787319	-73.9085639
Fa-3	41.0711754	-73.8744269	R-3	41.0772217	-73.9104661
Fa-4	41.0710629	-73.8755584	R-4	41.0786608	-73.9098760
Fa-5	41.0705980	-73.8744126	R-5	41.0770137	-73.9053947
Fa-6	41.0715531	-73.8750206	R-6	41.0764595	-73.9124074
Fa-7	41.0715135	-73.8757475	R-7	41.0780859	-73.9025632
Fa-8	41.0722060	-73.8747771	R-8	41.0787682	-73.9052806
Fa-9	41.0712708	-73.8758720	R-9	41.0768524	-73.9090854
Fa-10	41.0721738	-73.8756852	R-10	41.0782860	-73.9037504
Fa-11	41.0714395	-73.8740770	R-11	41.0765936	-73.9071781
Fa-12	41.0713875	-73.8743686	R-12	41.0781896	-73.9112902
Fb-13	41.0691846	-73.8687790	R-13	41.0785783	-73.9033365
Fb-14	41.0693474	-73.8689837	R-14	41.0779983	-73.9026168
Fb-15	41.0706221	-73.8687513	R-15	41.0787018	-73.9039095
Fb-16	41.0705624	-73.8696834	R-16	41.0765077	-73.9094809
Fb-17	41.0713865	-73.8695838	R-17	41.0779906	-73.9111423
Fb-18	41.0698342	-73.8706908	R-18	41.0773774	-73.9031981
Fb-19	41.0694698	-73.8698909	R-19	41.0779616	-73.9046471
Fb-20	41.0707719	-73.8696310	R-20	41.0776263	-73.9123252
Fb-21	41.0703725	-73.8692782	R-21	41.0770442	-73.9022998
Fb-22	41.0701991	-73.8691045	R-22	41.0782080	-73.9061918
Fb-23	41.0706315	-73.8682823	R-23	41.0783017	-73.9132623
Fb-24	41.0693796	-73.8685372	R-24	41.0766534	-73.9097844
Fb-25	41.0698600	-73.8692400	R-25	41.0778731	-73.9052626
Fb-26	41.0703452	-73.8688519	R-26	41.0788732	-73.9072557
Fb-27	41.0696056	-73.8695525	R-27	41.0785499	-73.9026683
Fb-28	41.0701788	-73.8698696	R-28	41.0781992	-73.9109014
Fb-29	41.0704292	-73.8681022	R-29	41.0783440	-73.9071496
Fb-30	41.0710072	-73.8688246	R-30	41.0777607	-73.9085537

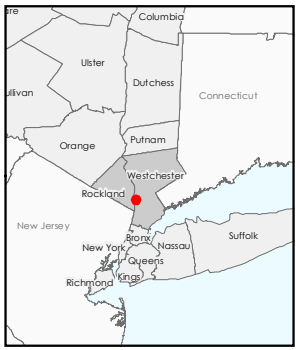
Oyster Material Placement Area



Oyster Fishing Areas



LOCATION MAP



PRINCETON HYDRO, LLC.
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*with offices in NJ, PA and CT

1 inch = 400 feet

0 200 400 Feet

NOTES:
1. Sampling locations were randomly selected using ET GeoWizards, a third-party ArcGIS extension.

2. 2011 NAIP orthoimagery obtained from USDA GeoSpatial Data Gateway.

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

SAMPLING LOCATIONS

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

Legend

- Sample Location
- Oyster Material Replacement / Fishing Area