Paynter Lab Annual Monitoring and Research Summary 2013

Submitted to the Oyster Recovery Partnership

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Executive Summary

The Paynter Laboratory at the University of Maryland conducted monitoring activities on many oyster restoration sites in Maryland in 2013, most exclusively in Harris Creek. These activities included pre-planting sonar imagery analysis and ground truthing (GT), post-planting monitoring (PPM), patent tong (PT) surveying, disease diagnostics, and research. GT was used to assess bottom quality prior to the planting of spat-on-shell by the Oyster Recovery Partnership (ORP). GT provides information on bottom type and quality for spat-on-shell plantings. PPM consisted of sampling newly planted spat within four to eight weeks after planting to determine survivorship and growth rates. PPM data are critical in determining the relationship between bottom type and spat survivorship as well as establishing a time zero population estimate. PT surveys were conducted to estimate the population number and density of oysters on various older bars as well as to sample the oysters for size and disease. Disease monitoring involved sampling oysters through both patent tong and diver surveys and diagnosing tissues for *Perkinsus marinus* prevalence. Research conducted this year was in collaboration with scientists from the Oyster Hatchery at the Horn Point Laboratory, University of Maryland Center for Environmental Science (UMCES). With the help of hatchery staff we initiated a second spat survival experiment wherein spat-on-shell were purposefully placed on various bottom types including shell, sand, and mud in order to learn more about survivorship on those bottom types.

Disease monitoring data (Section I) revealed significantly elevated *P. marinus* prevalences and weighted prevalences relative to other years, however some locations were still low overall. In addition, oysters sampled included both ORP-planted oysters as well as native oysters at some locations. This may account for higher disease levels than previous years, particularly when paired with higher average salinity observed throughout 2012 and 2013. If salinities remain elevated, Dermo disease could become a significant source of mortality in the next few years. Careful monitoring should reveal if the native oysters succumb before the hatchery oysters, or vice versa.

As in previous years, side scan sonar data (SSS) were used for guidance when selecting sites to GT (Section II). In 2013, SSS were available for most sites surveyed, greatly improving the efficiency of site selection and GT efforts. Also contributing to effective site selection and GT, the NOAA Chesapeake Bay Office (NCBO) generated Coastal Marine Ecological Classification Standard (CMECS) provided an extra level of detail with regard to expected bottom for all sites surveyed in Harris Creek. The Harris Creek tributary was a focus of 2013 restoration efforts, and CMECS data were available for all of the bars surveyed there. Additionally, the US Army Corps of Engineers (ACOE) deployed alternate substrate at multiple Harris Creek restoration targets. The accuracy of substrate deployment data also enhanced GT efficacy. At least parts of most surveyed bars were recommended for planting.

PPM (Section III) showed that the mean survivorship of spat planted was approximately 37%, which was the same as 2012, but much higher than the average survivorship of spat in previous years. Fourteen sites were sampled and survival ranged from 4 to 88%. As in 2011 and 2012, we believe this success is strongly related to the effort made by our team (Paynter Lab members and Steve Allen of ORP) to direct plantings to areas of more shell-rich bottom targets than in years past. This was accomplished through the use of acoustic data, diver GT, and in the case of several plots in Harris Creek, artificial substrate planted by the ACOE. Higher salinities may have contributed to better survival as well.

Patent tong sampling (Section IV) was conducted on two scheduled bars (States Bank and Strong Bay) and on four long-term monitoring sites (Little Neck, Lodges, Mill Point, and Change). Patent tong data on both scheduled sampled bars and the four long-term bars will be important to estimate oyster numbers, size, biomass, mortality, and Dermo disease as the restored bars age. The data may also indicate significant poaching activity in the future. This was the first year that all age classes on the scheduled bars were sampled together, revealing highly variable oyster quantities at these sites. However, one-year survival on three of the long-term bars was above 60%, with oyster growth between 20 and 35 mm. The third site (Change) was recently added, and so has no prior year to compare to.

The last six years of monitoring data suggest that we are learning to do restoration better and that we are learning to collect the right data to show it. Continued monitoring and adaptive management are critical to the success of the program. In summary, this report describes our findings in detail and presents data and analyses that provide a pathway to adaptive management in oyster restoration by the Oyster Recovery Partnership. Each aspect of our efforts is presented below in sections, as well as a summary of our time in the field and laboratory work related to/funded by the ORP.

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Section I: Annual Summary

Field Summary

- Experimental work
  - Spat survival study
    - The final sampling of the spat survival study in Trappe Creek was conducted on: July 29, 2013.
    - Loss of multiple experimental plots and limited recovery led to inconclusive results.
    - The experiment was redesigned and incorporated into the wild-hatchery comparison study; the protected location and easy shore-access of the new study site should allow for a more reliable sample collection.
  - Wild-hatchery comparison study
    - In May of 2013, sampling sites were scouted as potential experimental sites for a growth and survival study comparing hatchery-reared and wild oyster spat.
    - Bobby Leonard offered use of his oyster lease bottom, and a site was selected near his dock and setting tanks in Edge Creek (a branch of Broad Creek).
    - B. Leonard deployed shell throughout the site to create a consistent shell base.
    - Three treatments of oysters were planted: hatchery spat-on-shell spawned in 2013, hatchery spat-on-shell spawned in 2012 and planted in Harris Creek, and wild spat spawned in Broad Creek in 2012. Both 2012 treatments were collected in 2013.
    - Additionally, the 2013 hatchery treatment was also deployed on mud and sand, to reprise the spat survival study on three distinct substrates.
    - All treatments were sampled in December of 2013 and will be sampled again in May of 2014.

- Student work
  - Evaluation of use of oyster structure and biodeposits by reef community (Karen Kesler, PhD Candidate)
    - K. Kesler continued mesocosm studies investigating trophic transfer within an oyster reef.
    - Stable isotope tracer studies were conducted at Horn Point Laboratory.
    - Fall sampling from a site in the Severn River was conducted to measure seasonal isotope values of reef organisms. Sampling will take place again in the spring and summer of 2014.
  - Aquaculture-focused thesis project (Anna Priester, MS student)
    - A. Priester began MEES program at UMCP.
    - Aquaculture-focused project to be designed in 2014.
  - Effect of hypoxia/anoxia on oyster heart rate (Drew Needham, BS in 2013)
    - Hypoxia/anoxia trials completed.

        - Manuscript to be written and submitted for publication in 2014.
    - Effect of salinity differences on oyster heart rate (Michelle Gray, Eleanor Roosevelt HS Class of 2013, UMCP undergraduate Class of 2018)
        - Salinity trials completed and presented at ERHS student symposium.

- Pre-planting ground truthing
    - See Section II for detailed summary.
    - Twenty-five target sites were surveyed; many of these sites were previously covered with alternate substate (granite or mixed shell) deployed by the United States Army Corps of Engineers.
    - All surveyed sites were located in Harris Creek.
    - Twenty-four target sites were deemed suitable (at least over a portion of the site) for planting and of these, twenty were planted in 2013.

- Post-planting monitoring
    - See Section III for detailed summary.
    - Twenty-five sites planted with spat-on-shell in 2013 were surveyed four to eight weeks post-planting.
    - Most sites were located in Harris Creek; two were in the Severn River.
    - Mean survival for 2013 was 37.4%, which is similar to the 36.8% survival observed in 2012.
    - Relatively high survival may be related to improved site selection and bottom type.

- Patent tong surveys
    - Standard patent tong survey sites:
        - See Section IV for detailed summary.
        - States Bank (Choptank River) and Strong Bay (Chester River) were surveyed as part of the regular patent tong surveys, conducted two and five years post-planting.
        - At States Bank and Strong Bay, all plantings were surveyed in order to make future patent tong surveys more efficient.
        - Surveys included plantings from 2003, 2005, and 2007-2010 at each site.
        - At Strong Bay, mean oyster density and mean biomass density were low across the site, 1.8 oysters/m^2 and 3.7 g/m^2.
        - At States Bank, mean oyster and biomass densities were higher, but only biomass density reached the Oyster Metric Workgroup's minimum criteria for success. (9 oysters/m^2 and 17.5 g/m^2)
        - Survey population estimates were lower than expected at both sites.
    - Long-term monitoring sites:
        - See Section V for detailed summary.

        - Four sites in Harris Creek were surveyed as part of a multiple-year long-term monitoring plan.
        - Sites included: Change, Little Neck, Lodges, and Mill Point.
        - 2013 represents the second survey year for all sites except Change, which was surveyed for the first time in 2013.
        - Overall, population trends at each site were as expected: mean oyster density decreased between 2012 and 2013 while biomass density increased, the oyster population at each site increased in length, and dermo infection intensities increased over time.

- Disease (*Perkinsus marinus*, dermo) monitoring
    - Oysters were sampled to test for dermo disease, caused by *P. marinus* at multiple sites in 2013.
    - In addition, in 2013 aquaculturists sent samples to the lab to be tested (these results are not presented in this report).
    - Table 1 below shows mean infection values for 2008 through 2013; both prevalence and infection intensity have increased although salinities have remained fairly consistent with exception to 2011.
    - Figures 1 and 2 show locations of sites sampled in 2013 with dermo prevalence (Figure 1) and intensity (Figure 2).
    - Table 2 shows site-specific dermo prevalence and intensity for each site and age class sampled in 2013 as well as tributary means. Prevalence and intensity were much lower in the Severn River than eastern shore tributaries.
    - As expected, at sites with multiple age classes of oysters, older oysters were more heavily infected with dermo than younger oysters.

Table 1. Mean dermo infection values for sites sampled between 2008 and 2013. Prevalence refers to the percentage of a population showing some degree of dermo infection. Intensity refers to the overall degree of infection, scored on a scale from zero (no infection) to five (heavy infection). SEM represents standard error of the mean.

Year	**Mean Prevalence (%) ± SEM**	**Prevalence Range**	**Mean Intensity ± SEM**	**Intensity Range**	**Mean Salinity (ppt)**
2008	30.0 ± 5.3	0 - 93	0.28 ± 0.09	0 - 2.07	N/A
2009	26.1 ± 4.2	0 - 90	0.32 ± 0.09	0 - 1.77	12.3
2010	35.9 ± 4.7	0 - 100	0.41 ± 0.09	0 - 2.53	11.3
2011	40.8 ± 6.0	0 - 100	0.43 ± 0.10	0 - 1.67	6.6
2012	52.8 ± 5.7	0 - 100	0.88 ± 0.14	0 - 2.54	12.5
2013	70.6 ± 6.6	33 - 100	1.00 ± 0.18	0.14 - 2.90	12.5

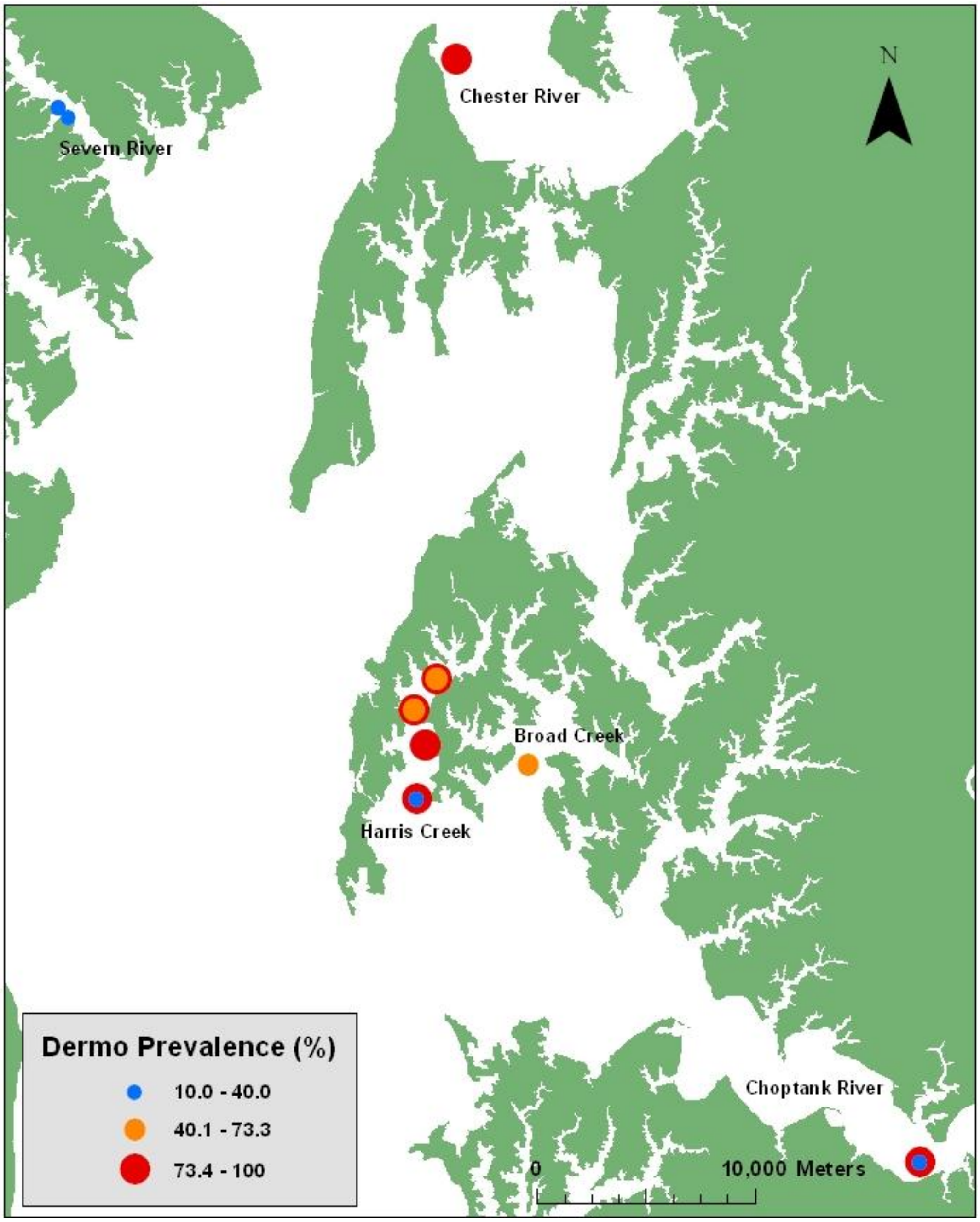


Figure 1. Dermo prevalence at sites sampled in 2013. Dermo prevalence, or the percentage of a sample infected with some degree of dermo, is shown at each site sampled in 2013. More heavily infected sites (73.4-100% infected) are shown in large red circles, while small orange and smaller blue circles indicate lower prevalence values. Multiple values appear at several sites due to the sampling of multiple age classes.

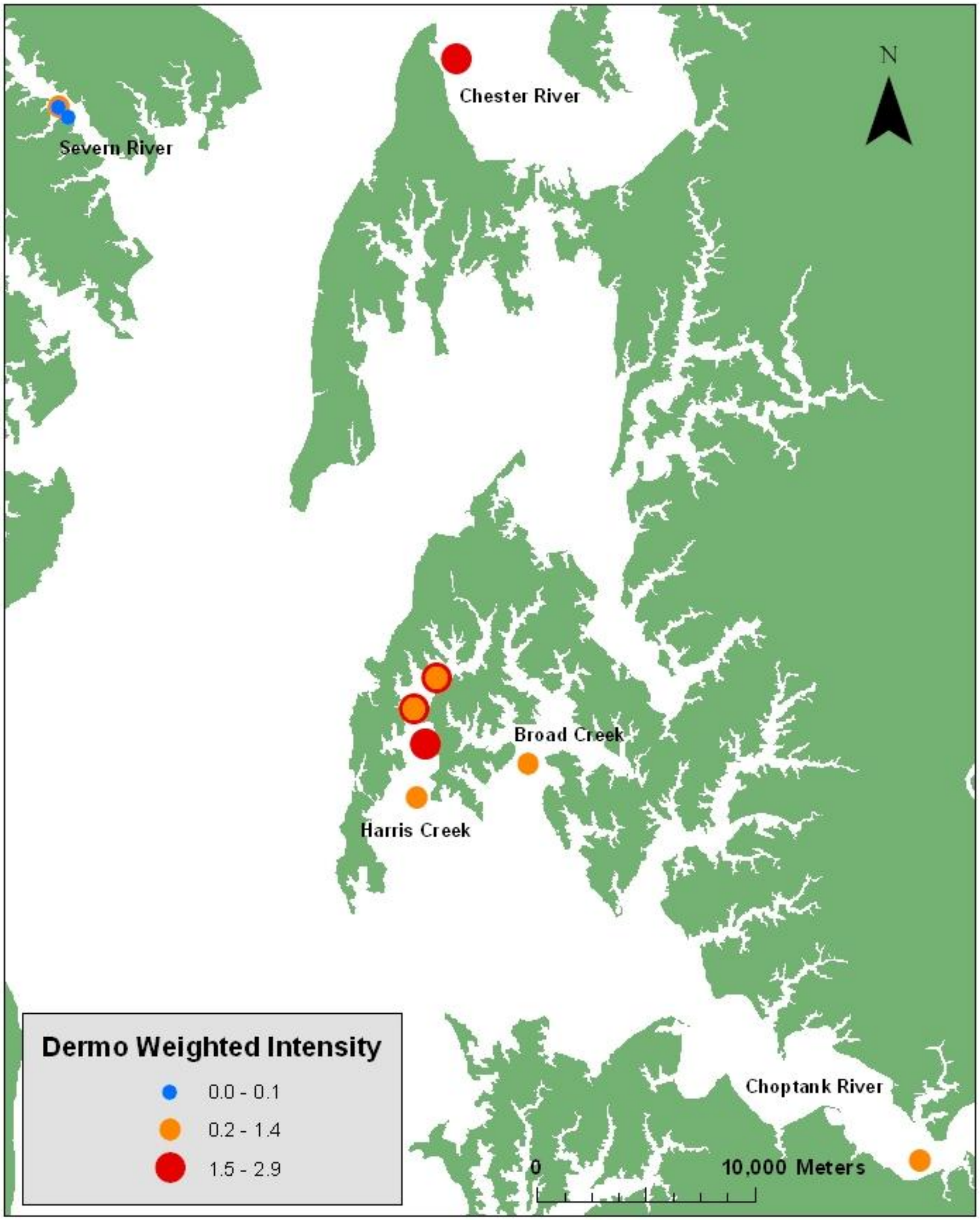


Figure 2. Dermo weighted intensity at sites sampled in 2013. Dermo weighted infection intensity, or the degree of dermo infection in a sample set, is shown at each site sampled in 2013. Higher intensities (1.5-2.9 out of 5) are shown in large red circles, while small orange and smaller blue circles indicated lower infection intensities. Multiple values appear at several sites due to the sampling of multiple age classes.

Table 2. Dermo summary for sites sampled in 2013. All sites and age classes tested for dermo infection are presented by tributary. SEM represents standard error of the mean.

Region	Bar Name	Plant Year	Date Collected	# of Oysters Tested	Average Shell Height (mm)	Average Total Weight (g)	Average Shell Weight (g)	Dermo Prevalence (%) ± SEM	Dermo Weighted Intensity
Broad Creek	NA	Natural Small	30-Aug-13	30	53	25.6	21.1	66.7	0.55
		Natural Medium	30-Aug-13	29	73	66.8	55.1	72.4	1.45
		Natural Large	30-Aug-13	30	102	166.6	139.7	93.3	2.10
		ALL		**89**	**76**	**86.4**	**72.0**	**77.5 ± 8.1**	**1.37 ± 0.4**
Chester River	Strong Bay	Multi-year, Small	14-Oct-13	30	72	83.8	76.1	96.7	1.81
		Multi-year, Large	14-Oct-13	30	130	196.9	155.2	96.7	2.90
		ALL		**60**	**101**	**140**	**116**	**96.7 ± 0.0**	**2.36 ± 0.5**
Choptank River	States Bank	Natural Small	22-Oct-13	30	71	85.0	72.1	40.0	0.64
		Natural Large	22-Oct-13	27	121	204.2	167.9	88.9	1.19
		ALL		**57**	**96**	**145**	**120**	**64.4 ± 24.4**	**0.92 ± 0.3**
Harris Creek	Change	Natural Small	06-Nov-13	30	53	31.7	26.0	96.7	0.90
		2013	06-Nov-13	30	72	40.2	30.3	33.3	0.14
	Mill Point	Natural Small	06-Nov-13	30	56	35.8	29.9	93.3	1.84
		Natural Large	06-Nov-13	30	92	142.7	120.5	100.0	2.13
		2011	06-Nov-13	31	90	53.7	40.8	96.8	1.81
	Lodges	Natural Small	04-Nov-13	30	55	38.2	32.8	80.0	1.24
		Natural Large	05-Nov-13	30	96	176.8	152.9	90.0	2.00
		2012	04-Nov-13	29	74	63.2	50.4	55.2	1.11
	Little Neck	Natural Small	28-Oct-13	30	54	36.6	30.0	73.3	1.44
		Natural Large	30-Oct-13	22	98	183.6	159.4	100.0	2.19
		2012	28-Oct-13	29	74	52.0	40.4	100.0	1.83
	ALL	**ALL**		**321**	**74**	**78**	**65**	**83.5 ± 6.6**	**2**
Severn River	Weems Upper	2010	11-Nov-13	30	102	111.6	85.9	13.3	0.01
	Wade 2-3	2010	11-Nov-13	30	91	76.1	58.1	33.3	0.05
	Wade 2-4	2010	11-Nov-13	30	90	80.0	60.4	10.0	0.01
	Wade 2-5	2010	11-Nov-13	30	85	69.7	52.3	23.3	0.04
	ALL	**ALL**		**120**	**92**	**84**	**64**	**20.0 ± 5.3**	**0.03 ± 0.0**

- Water quality monitoring
    - Water quality was measured at all sites. Variables measured included: temperature (°C), salinity (ppt), and dissolved oxygen (mg/L).
    - Sites sampled for water quality in 2013 are shown in Figure 3 and data for all sampled sites are presented in Table 3.
    - Tributary data are not drastically different from one another, however the Severn River shows lower salinities, which may influence its lower dermo presence.

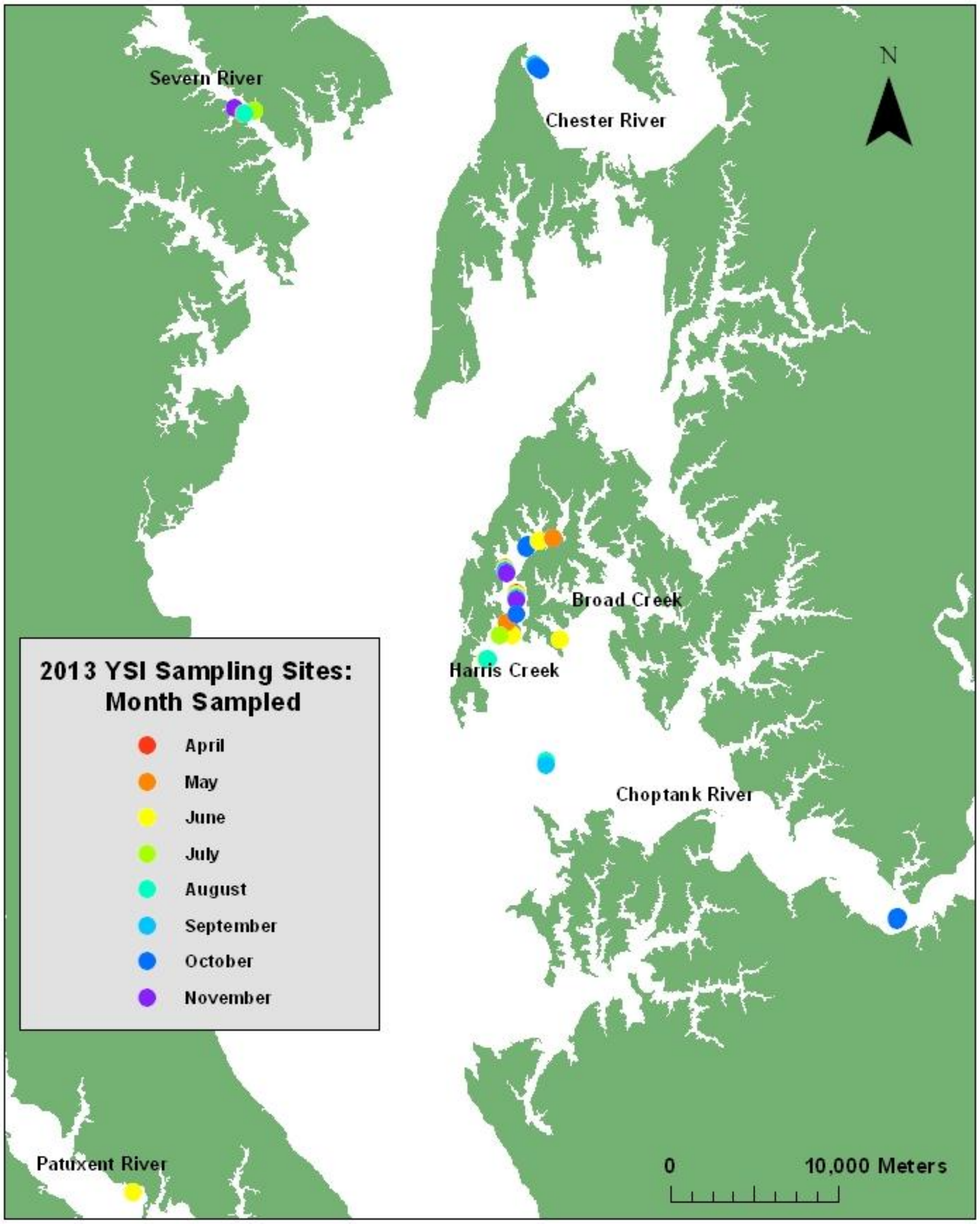


Figure 3. Water quality sampling sites. All sites sampled for water quality in 2013 are shown. Sampling points are differentiated by color for each sampling month.

Table 4. 2013 water quality data. Site and tributary water quality sampling data are presented. Tributary water quality metrics were not dramatically different from one another in 2013. 'Section' indicates lower, middle or upper tributary (L, M, or U), while location refers to the placement of the YSI near the water's surface (S) or bottom (B).

River/Region	Section	Site	Date	Location	Temp (°C)	Salinity (ppt)	DO (mg/L)
Broad Creek	M	Basel Lease	6/18/2013	S	22.2	12.5	7.3
			6/18/2013	B	22.2	12.5	7.0
		ALL			**22.2**	**12.5**	**7.2**
Chester River	L	Strong Bay	9/30/2013	S	17.8	13.7	9.4
			9/30/2013	B	17.8	14.6	5.9
			10/2/2013	S	18.4	12.8	10.3
			10/2/2013	B	18.4	16.0	2.3
			10/3/2013	S	18.2	12.3	10.6
			10/3/2013	B	17.9	13.0	8.7
			10/14/2013	S	15.0	12.9	9.7
			10/14/2013	B	14.9	12.9	9.7
		ALL			**17.3**	**13.5**	**8.3**
Choptank River	L	Cook Point	8/12/2013	S	24.0	11.6	8.5
			8/12/2013	B	22.5	13.2	5.0
			9/11/2013	S	22.1	14.4	8.5
			9/11/2013	B	21.3	15.3	6.2
	U	States Bank	10/21/2013	S	14.2	12.3	9.3
			10/21/2013	B	14.2	12.4	9.1
			10/21/2013	S	14.4	11.4	9.7
			10/21/2013	B	14.2	12.4	8.5
			10/24/2013	S	12.3	12.7	10.2
			10/24/2013	B	12.3	12.5	10.2
	ALL	**ALL**			**17.2**	**12.8**	**8.5**
Harris Creek	L	Change	5/14/2013	S	14.2	11.7	9.8
			5/14/2013	B	14.1	11.7	9.0
			6/4/2013	S	21.9	11.5	8.7
			6/4/2013	B	20.6	11.4	8.1
			6/11/2013	S	21.5	11.3	8.0
			6/11/2013	B	21.1	11.3	8.3
			9/5/2013	S	22.6	12.7	8.3
			9/5/2013	B	22.3	13.0	7.4
			11/6/2013	S	9.3	15.6	10.5
			11/6/2013	B	9.1	15.6	10.6
		Tilghman Wharf	6/28/2013	S	24.6	12.0	8.1
			6/28/2013	B	23.8	12.1	7.0
			8/2/2013	S	22.5	10.9	8.1
			8/2/2013	B	22.0	10.9	7.8
			8/12/2013	S	24.5	11.2	9.2
			8/12/2013	B	23.1	11.4	6.7
	M	Eagle Point	5/14/2013	S	14.2	11.7	9.8
			5/14/2013	B	14.1	11.7	9.0
		ORP Bar	7/16/2013	S	25.9	11.6	8.4
			7/16/2013	B	25.5	11.6	6.6
		Lodges	5/17/2013	S	17.4	11.8	8.9
			5/17/2013	B	16.3	11.8	7.6
			6/28/2013	S	24.6	12.0	8.1
			6/28/2013	B	23.8	12.1	7.0
			9/11/2013	S	22.7	12.4	7.8
			9/11/2013	B	22.1	12.5	7.3

River/Region	Section	Site	Date	Location	Temp (°C)	Salinity (ppt)	DO (mg/L)
	U	Mill Point	9/24/2013	S	17.3	13.1	8.6
			9/24/2013	B	17.2	13.2	7.9
			11/4/2013	S	9.5	15.5	10.7
			11/4/2013	B	9.5	15.5	10.5
			4/26/2013	S	13.2	12.1	9.8
			4/26/2013	B	13.0	12.1	9.7
			6/17/2013	S	22.6	12.6	8.1
			6/17/2013	B	22.1	12.6	8.3
			6/18/2013	S	22.6	12.6	7.8
			6/18/2013	B	22.1	12.6	7.3
			8/2/2013	S	22.7	11.3	7.6
			8/2/2013	B	22.3	11.3	6.7
			9/5/2013	S	22.8	12.2	8.2
			9/5/2013	B	22.7	12.2	7.7
			11/5/2013	S	8.9	15.5	10.5
			11/5/2013	B	8.7	15.5	10.5
		Turkey Neck	10/17/2013	S	15.9	14.9	9.4
			10/17/2013	B	15.5	14.8	9.3
		Little Neck	9/5/2013	S	22.8	11.9	6.8
			9/5/2013	B	22.6	11.9	6.8
			10/25/2013	S	9.2	14.1	10.5
			10/25/2013	B	9.0	14.4	10.1
			10/28/2013	S	9.1	14.5	10.7
			10/28/2013	B	8.8	14.8	10.7
			10/30/2013	S	9.4	14.8	9.9
			10/30/2013	B	9.3	15.1	9.9
		Rabbit Island	6/28/2013	S	25.4	12.3	7.2
			6/28/2013	B	24.8	12.3	7.1
		Upper Harris Creek	5/17/2013	S	18.1	11.7	8.7
			5/17/2013	B	17.7	11.8	7.8
			10/17/2013	S	15.7	13.4	8.7
			10/17/2013	B	15.5	13.8	7.8
	ALL	**ALL**			**18.1**	**12.8**	**8.6**
Patuxent River	M	Buck Lease	6/20/2013	S	21.4	10.9	8.5
			6/20/2013	B	21.0	11.0	7.0
		ALL			**21.2**	**11.0**	**7.8**
Severn River	M	Peach Orchard	7/15/2013	S	24.9	6.5	9.3
			7/15/2013	B	24.4	8.6	2.8
		Wade	11/11/2013	S	12.7	12.8	11.8
			11/11/2013	B	12.5	12.9	10.4
		Weems Upper	4/24/2013	S	11.3	7.9	11.6
			4/24/2013	B	11.2	8.3	12.6
			8/19/2013	S	22.1	9.1	7.0
			8/19/2013	B	22.0	9.1	6.4
		ALL			**17.6**	**9.4**	**9.0**

Publications and presentations (asterisks indicate presenting author)

- National Shellfisheries Association joint meeting with World Aquaculture Society and American Fisheries Society; Nashville, TN (February 2013)
    - Attended by Kennedy Paynter, Hillary Lane, and Adriane Michaelis.
    - Each presented talks at conservation/restoration aquaculture shellfish session.
        - K. Paynter*, A. Michaelis, and H. Lane. The relationship between restoration site quality and eastern oyster *Crassostrea virginica* density and biomass in the northern Chesapeake Bay.
        - H. Lane*, A. MIchaelis, V. Politano, and K. Paynter. The effectiveness of hydraulic patent tong surveys to characterize *Crassostrea virginica* population demographics over time on four bars in the northern Chesapeake Bay.
        - A. Michaelis*, H. Lane, S. Allen, and K. Paynter. A method for effectively identifying potential oyster *Crassostrea virginica* restoration sites in the northern Chesapeake Bay.
    - Posters presented on behalf of Drew Needham and Taylor Davis.
        - D. Needham*, A. Michaelis, H. Lane, and K. Paynter. The effect of temperature on the heart rate of the eastern oyster *Crassostrea virginica* from the northern Chesapeake Bay.
        - T. Davis*, H. Lane, A. Michaelis, and K. Paynter. The influence of spat-on-shell density on flat mud crab *Eurypanopeus depressus* predation of eastern oyster *Crassostrea virginica* spat.
- Benthic Ecology Meeting; Savannah, GA (March 2013)
    - Karen Kesler attended and presented a poster.
        - K. Kesler* and K. Paynter. Evaluating the impact of complex structure on trophic transfer in a *Crassostrea virginica* reef food chain.
- American Fisheries Society Tidewater Chapter Meeting; Solomons, MD (March 2013)
    - Hillary Lane and Adriane Michaelis attended and presented talks.
        - H. Lane*, A. Michaelis, M.J. Wilberg, and K. Paynter. Large-scale *Crassostrea virginica* population and habitat analysis in two rivers in the northern Chesapeake Bay.
        - A. Michaelis*, H. Lane, S. Allen, and K. Paynter. Quantifying eastern oyster (*Crassostrea virginica*) restoration success in the northern Chesapeake Bay.
- International Congress of Conservation Biology; Baltimore, MD (July 2013)
    - A. Michaelis attended and presented as part of restoration ecology session.
        - A. Michaelis*, H. Lane, S. Allen, and K. Paynter. Measuring oyster (*Crassostrea virginica*) restoration success in the northern Chesapeake Bay.
- S. Lombardi, G. Chon, J. Lee, H. Lane, and K. Paynter (2013). Shell hardness and compressive strength of the eastern oyster, *Crassostrea virginica*, and the Asian oyster, *Crassostrea ariakensis.* Biological Bulletin 225: 175-184 (2013).

- S. Lombardi, N. Harlan, and K. Paynter (2013). Survival, acid-base balance, and gaping responses of the Asian oyster *Crassostrea ariakensis* and the eastern oyster *Crassostrea virginica* during clamped emersion and hypoxic immersion. Journal of Shellfish Research 32(2): 409-415.

Conclusions and lessons learned

- See section VI for full details.
- Ground truthing (GT)
    - 25 bars were surveyed, 24 were recommended for planting.
    - Many sites were covered in alternate substrate, and divers confirmed presence of alternate substrate suitable for a spat-on-shell planting.
    - Even with enhanced GT efficiency through available bottom type data, multiple GT targets were amended to create more suitable planting targets, thus indicating that GT surveys are essential to successful restoration.
- Post-planting monitoring (PPM)
    - 25 sites were surveyed; 23 sites in Harris Creek and 2 in the Severn River.
    - Overall survival was 37.4%, consistent with 2012 and showing increased survival relative to earlier years.
    - Sites overplanted throughout the season at intervals greater than four weeks proved challenging to sample as unique plantings.
    - Substrate type and predation continue to be thought of as the most important factors influencing early spat survival.
- Patent tong surveys
    - Two bars (Strong Bay and States Bank) were surveyed as part of the regular monitoring plan; all plantings at each site were sampled.
        - Overall, these sites did not meet minimum Oyster Metrics Workgroup (OMW) criteria for success (15 oysters/m^2 and 15 g biomass/m^2), however data suggest distinctions between older and more recent plantings; densities were greater within more recent plantings.
    - Four sites were surveyed as part of the long-term monitoring of sentinel sites in Harris Creek; individual plantings were surveyed at Change, Little Neck, Lodges, and Mill Point.
        - All sites are young (0-2 years since planting) and exceeded the OMW criteria for success.
        - Trends observed from 2012 to 2013 were as expected, with oyster densities decreasing at each bar (in varying amounts) and biomass densities increasing.
        - Disease presence at these sites was higher than anticipated in such young populations and may prove detrimental to survival as these oysters age.

Section II: Ground Truthing 2013

In the spring of 2013, 25 individual sites were selected by the Oyster Recovery Partnership (ORP) for ground truthing (GT) surveys by the Paynter Lab in order to determine the suitability of sites for new spat-on-shell plantings. Many of these surveys occurred on alternate substrate (granite or mixed shell) deployed in 2012 or 2013. All sites were located in Harris Creek, and in some cases, multiple plots were surveyed within a Yates bar. Yates bars demarcate the extent of historic oyster reefs, and are now used to denote geographic "neighborhoods" within a tributary. Figure 1 shows the sites sampled in the 2013 season.

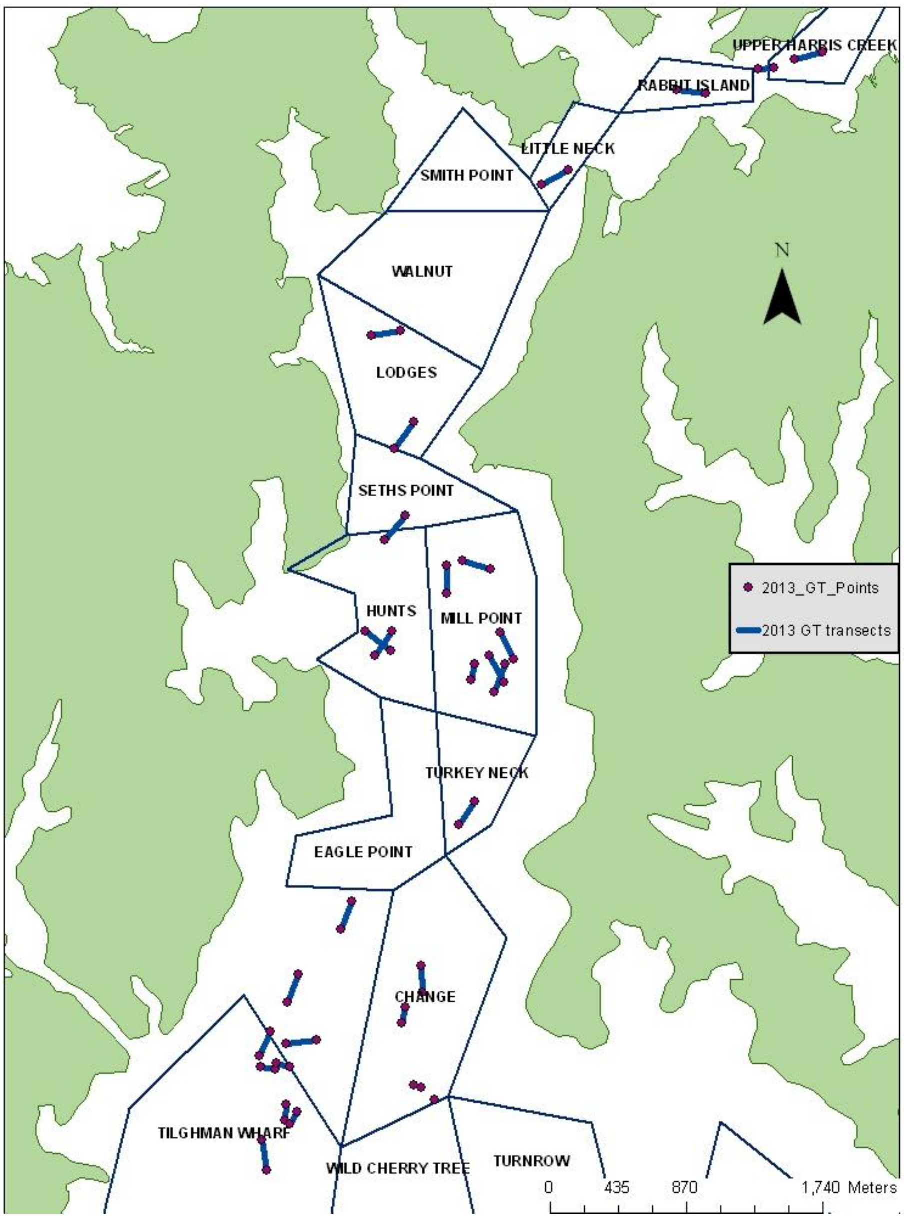


Figure 1. 2013 Pre-planting ground truthing sites. Labeled polygons represent Yates bars. All sites are in Harris Creek. Site summaries are presented below, with specfic maps of each site along with the survey data summary.

GT transect paths within a bar were chosen based on side-scan data from the Maryland Geological Survey (MGS). In general, darker return on a side-scan image means harder bottom. The majority of sites surveyed in 2013 had alternate substrate deployed by the US Army Corp of Engineers (ACOE), and in these cases ACOE deployment targets were used as GT target areas. For any sites without ACOE targets, side scan data were used to generate target areas of between one and nine acres for GT. Transect lines of 100 or 200 m were deployed within the target area and the amount of exposed shell, substrate type, penetration, and oyster density were reported by divers every two meters along the transect. Table 1 below outlines the score for each category, with larger values indicating better bottom type.

Table 1. Ground truthing data quantification. Divers evaluated the amount of exposed shell, substrate type, and penetrability on each GT survey. These qualifications were used to determine suitability of a site for planting.

	Exposed Shell	**Substrate Type**	**Penetration (cm)**
Worse	Zero	Silt	70
↓	Very Little / Patch	Mud	40
	Some	Sandy Mud	20
	Exposed	Sand	10
	Oyster Bar	Rock / Bar Fill / Debris	5
		Shell Hash	0
		Loose Shell	
Better		Oyster	

GT transect data were used to create target polygons in ArcGIS at sites deemed suitable for planting of spat-on-shell. Sites were ground truthed not only for planting hatchery seed, but also to evaulate coverage and condition of alternate substrate deployed by the ACOE in 2012 and 2013. Targets were sent to the ORP as recommended sites for spat-on-shell plantings. Of the 25 sites surveyed during the ground truthing effort in 2013, 20 were seeded with spat-on-shell by the ORP during the summer of 2013 and an additional 4 were deemed suitable for planting but not planted in 2013. Much of this success was due to the robust data available on the expected bottom type in Harris Creek as well as 2012 and 2013 restoration work. Specifically, many sites surveyed and subsequently planted contained alternate substrate deployed by the ACOE. GT at these sites involved confirming the status of alternate substrate, to ensure that it was indeed an appropriate site for spat-on-shell plantings.

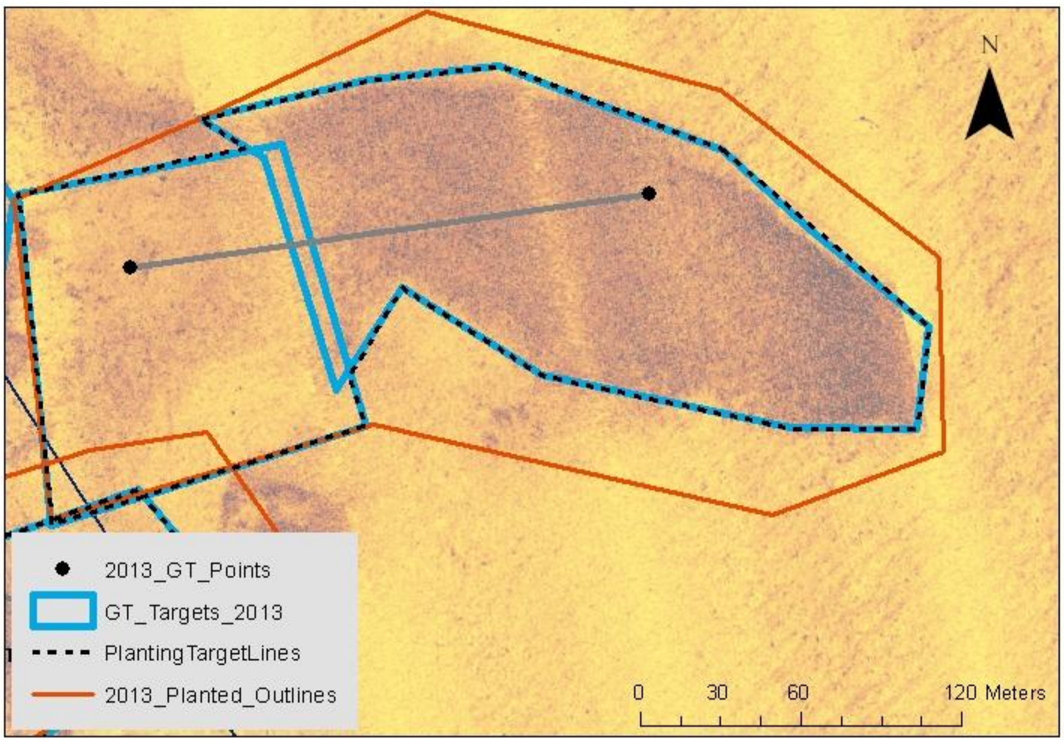
This report contains a detailed map of each site that was surveyed, the associated mode data, as well as a summary of the conclusions deduced from the collected data. On each map GT targets are blue-outlined polygons. The recommended planting targets generated based on GT results are displayed as a dashed black outline, and the resulting actual area of planting is outlined in dark orange.

Site-Specific Data

ACOE 1 (HCORP0c)

GT confirmed the presence of alternate substrate deployed in 2013 on this site, which is not located on a historic Yates bar, and was designated as HCORP. The majority of the transect revealed hard bottom with shell and granite. Based on the side-scan sonar imagery and on-board bottom imagery, the entire site appeared consistent with the surveyed transect and was deemed suitable for planting. This site was planted with spat-on-shell and renamed HCORP0c.

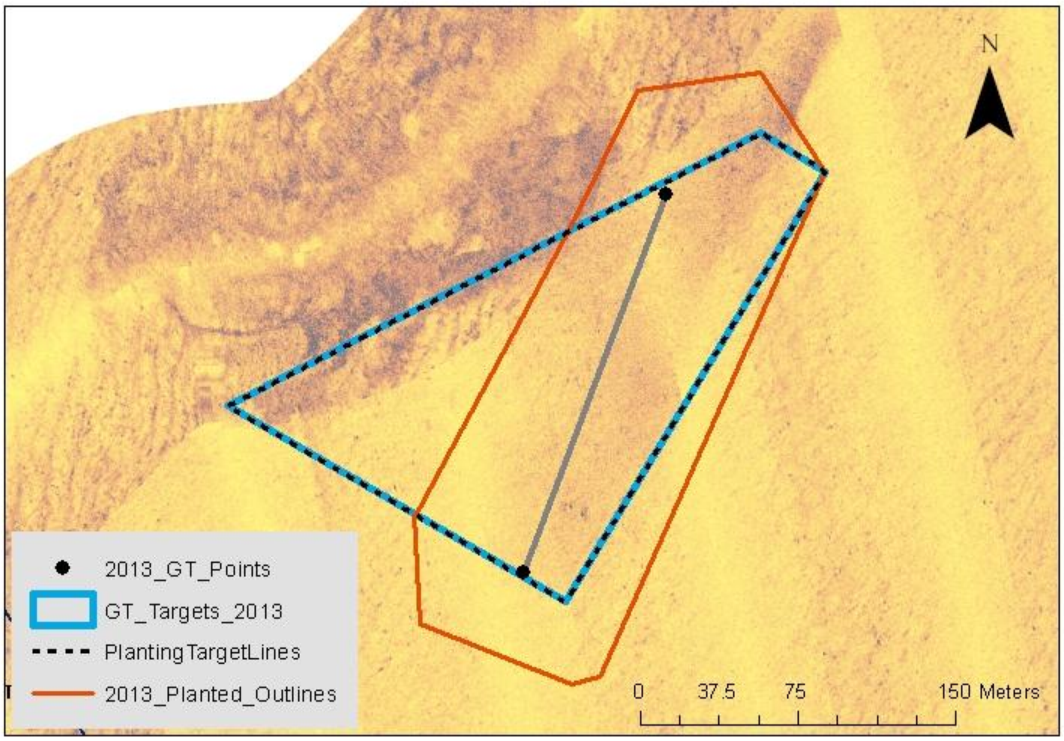
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/04/13	1	Exposed (shell and granite)	0	Artificial (shell and granite)	0.92



ACOE 2 (HCORP0a)

This site was ground truthed to check alternate substrate in both 2012 and 2013; divers found similar bottom composition at each survey. Based on side-scan imagery and on-board bottom imagery, the entire GT target was deemed appropriate for planting and was planted with spat-on-shell. The planting site was renamed HCORP0a.

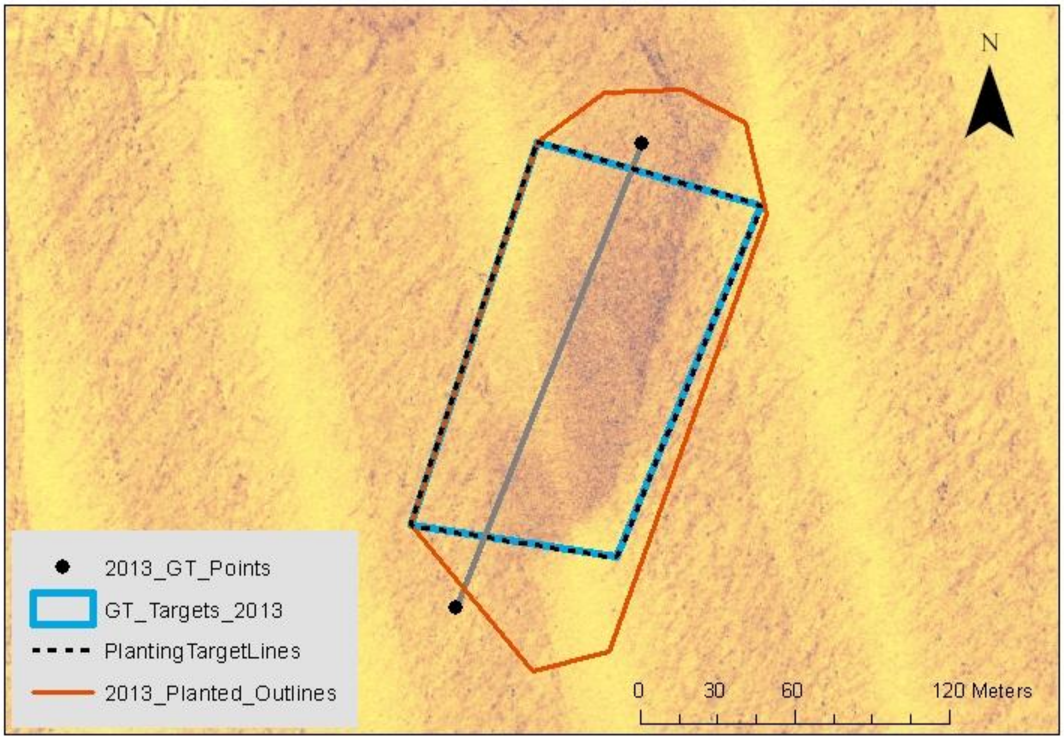
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/14/13	1	Exposed	0	Loose Shell	0.00



ACOE 3 (HCORP0b)

This site was originally surveyed in 2012 when shell hash was the primary substrate, then resurveyed in 2013 with loose shell predominating. On both surveys, the transect covered primarily hard bottom suitable for planting. This site was planted with spat-on-shell and renamed HCORP0b.

Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/14/13	1	Exposed	0	Loose Shell	0.00



ACOE 5 & ACOE 62 (Tilghman Wharf, HACTW0b)

ACOE 5 (Tilghman Wharf)

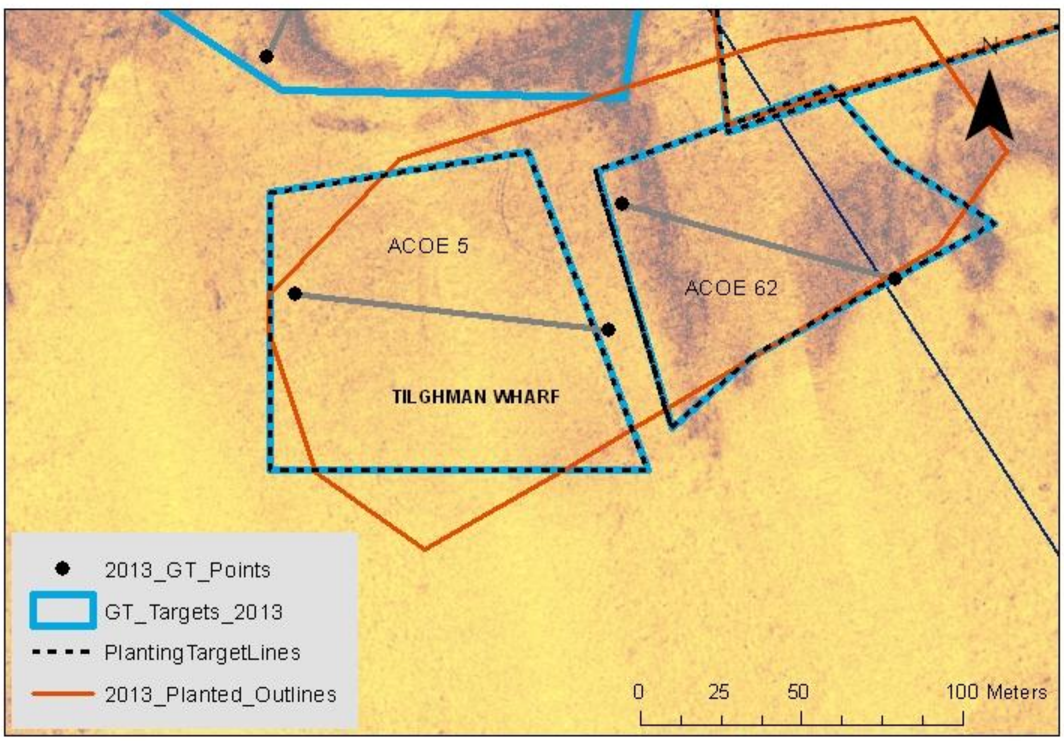
GT confirmed alternate substrate composed of mixed shell. The entire site was recommended for planting, and was planted with spat-on-shell and renamed HACTW0b (combined with Alt Sub 62).

Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/04/13	1	Exposed	0	Artificial (mixed shell)	0.00

ACOE 62 (Tilghman Wharf)

Divers confirmed alternate substrate composed of granite and shell and classified the entire site suitable for planting. This site was planted with spat-on-shell and renamed HACTW0b (overlapping ACOE 5).

Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/04/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 8 & ACOE 79 (Tilghman Wharf, HACTW0d)

ACOE 8 (Tilghman Wharf)

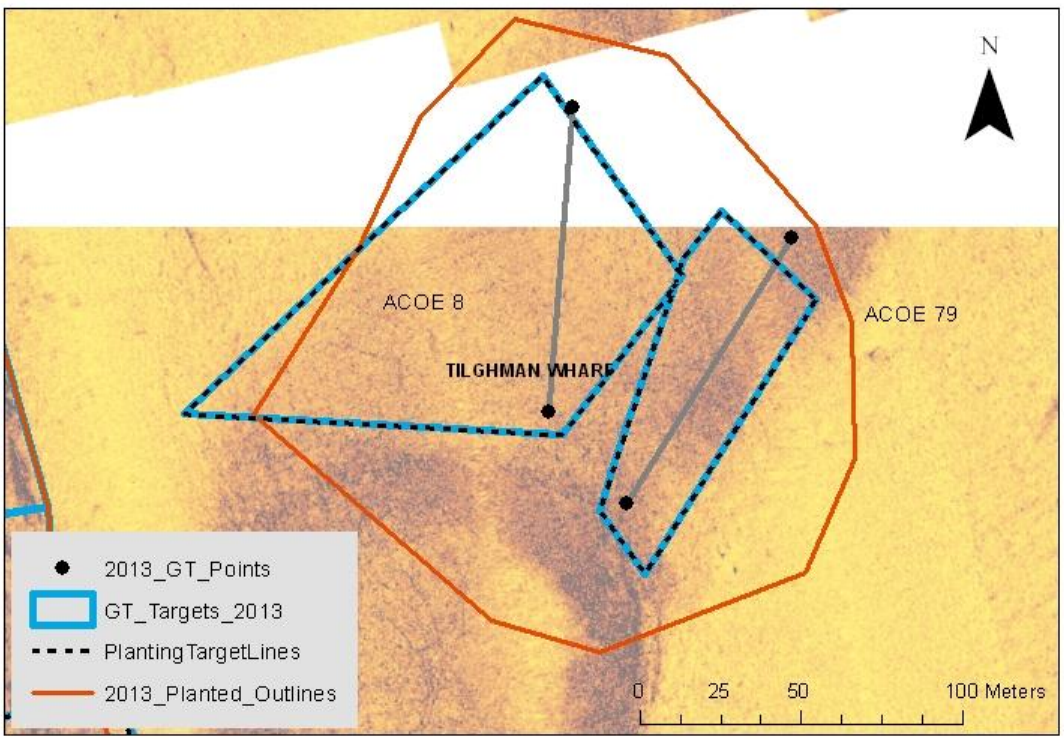
GT confirmed alternate substrate of mixed shell with 0-cm penetration in this area of Tilghman Wharf and the entire site was recommended for planting. This site was planted with spat-on-shell and renamed HACTW0d.

Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/04/13	1	Exposed	0	Artificial (mixed shell)	0.10

ACOE 79 (Tilghman Wharf)

Divers confirmed alternate substrate (granite) with minimal penetration and deemed the site appropriate for planting. This site was planted with spat-on-shell and renamed HACTW0d (combined with ACOE 8).

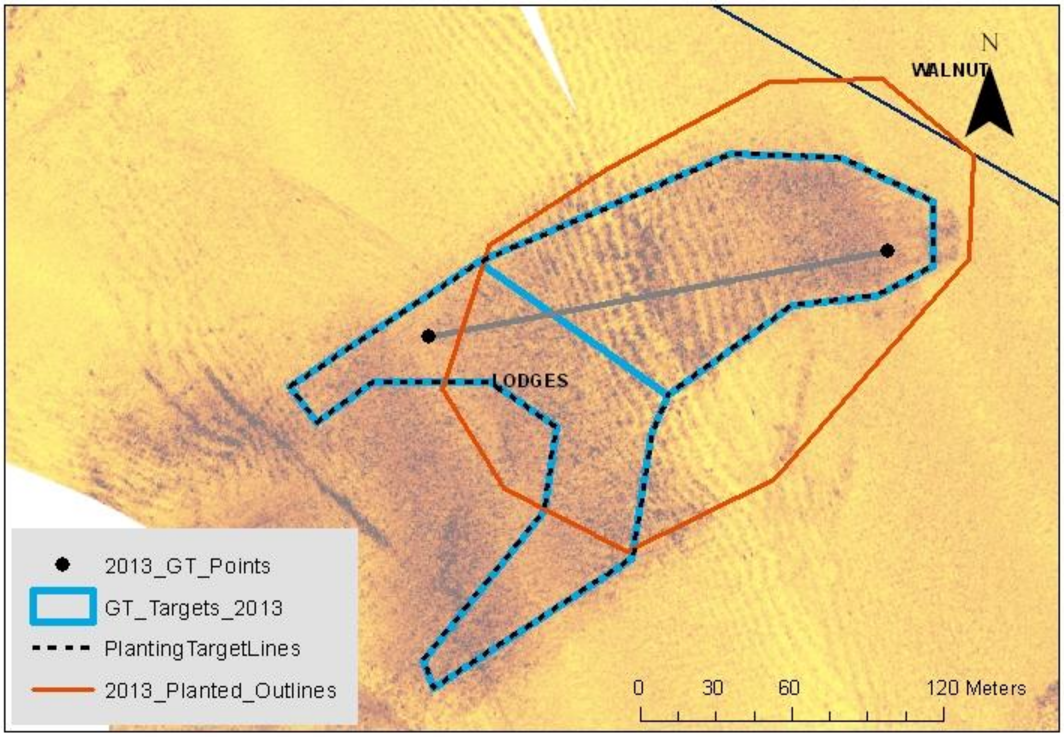
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/11/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 20 (Lodges, HACLO0b)

GT confirmed alternate substrate of granite at this site. Because of the unusual shape of the alternate substrate deployment area, the recommended planting area was rounded. This site was planted with spat-on-shell and renamed HACLO0b.

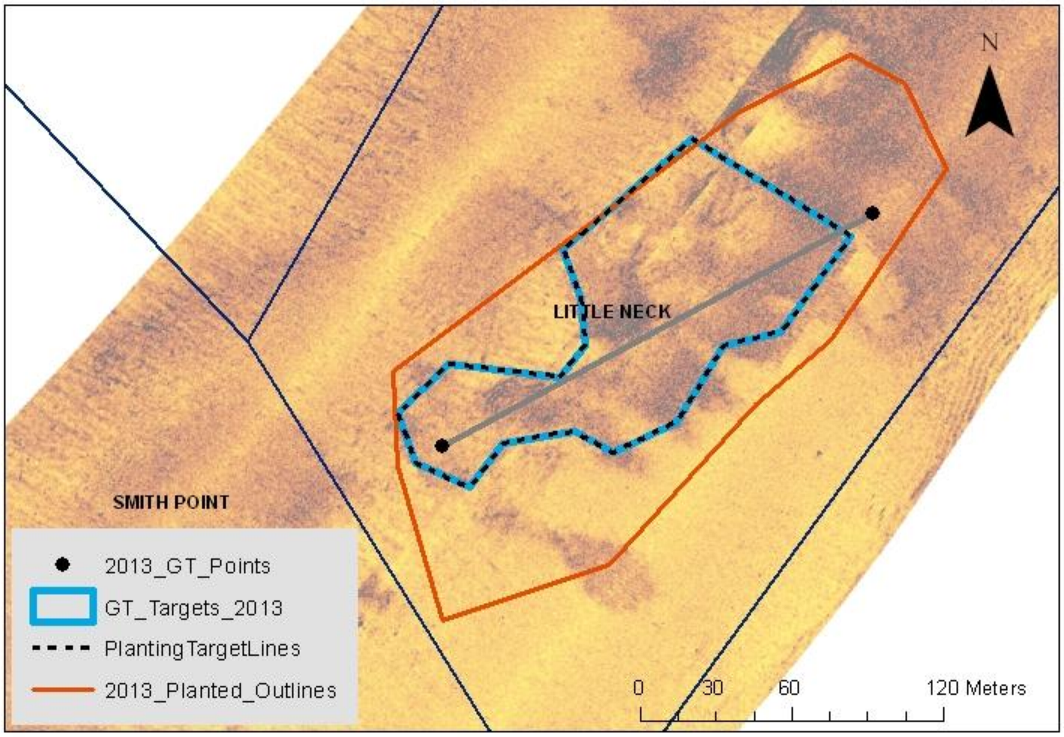
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/17/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 25 (Little Neck, HACLN0b)

Divers confirmed artificial substrate composed of mixed shell with penetration of 10 cm across most of the transect. Side-scan imagery suggested similar bottom throughout the GT target, thus this site was recommended for planting. This site was planted with spat-on-shell and renamed HACLN0b.

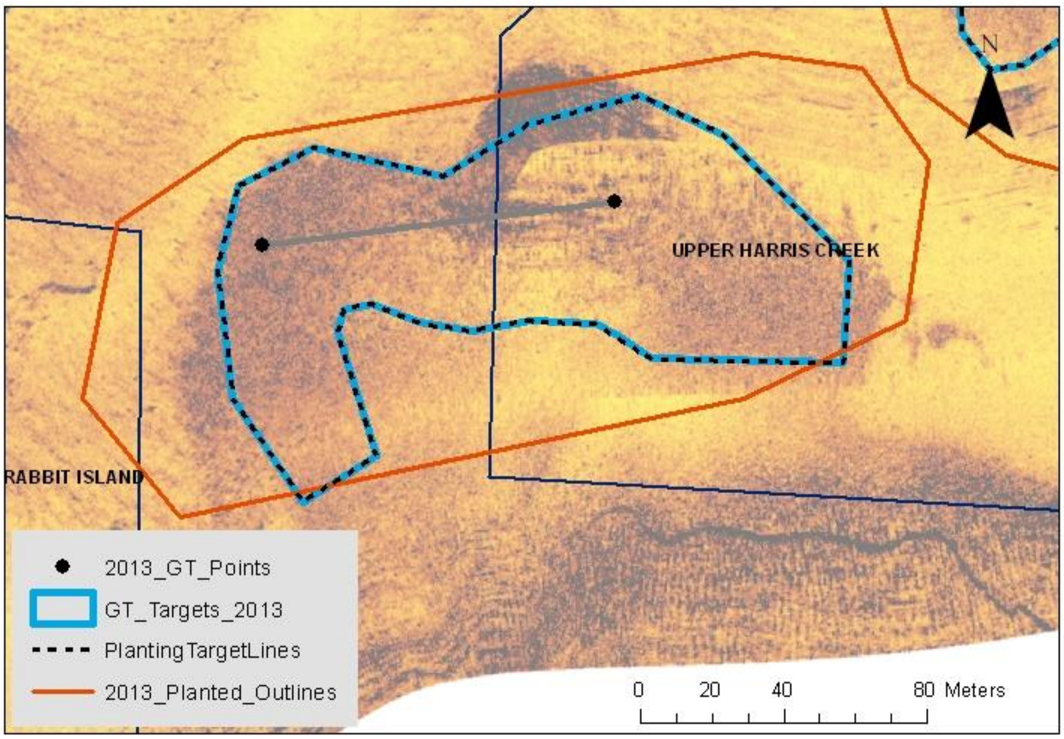
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/17/13	1	Exposed	10	Artificial (mixed shell)	0.00



ACOE 29 (Upper Harris Creek, HACUH0c)

GT confirmed granite at this site, with similar hard bottom across the transect. It was deemed suitable for planting and was seeded with spat-on-shell. This site was renamed HACUH0c.

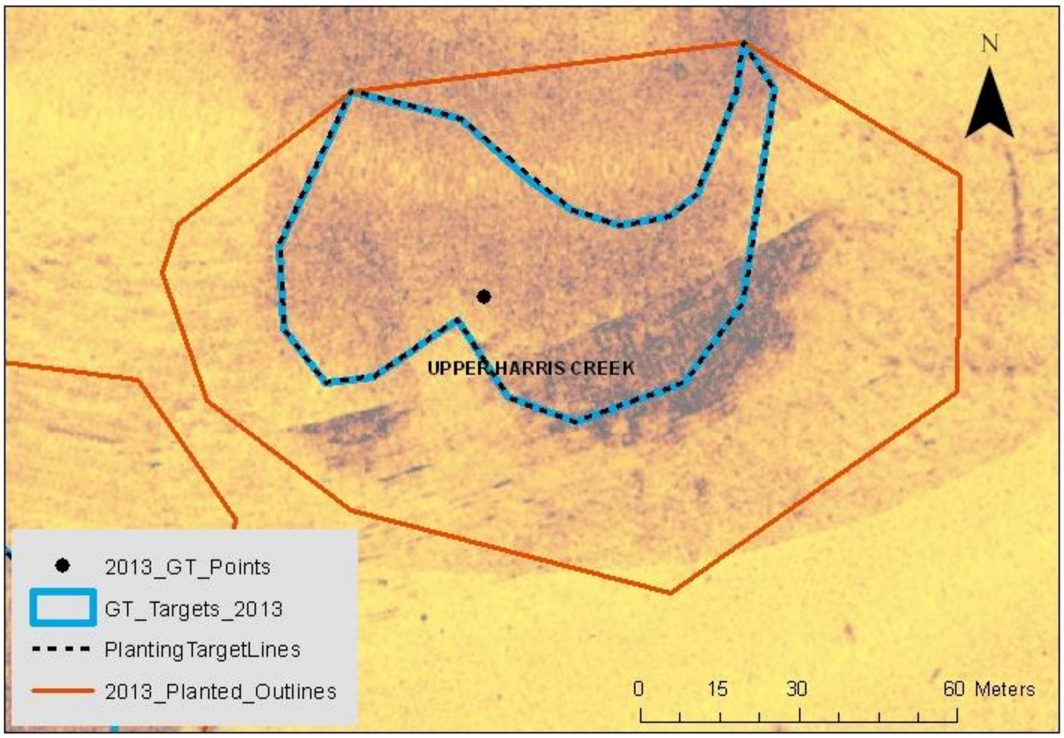
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/17/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 30 (Upper Harris Creek, HACUH0b)

Divers confirmed mixed shell alternate substrate with penetration of 10 cm throughout the site. Because of the small area of this site, no transect was surveyed. Instead a diver dropped in the center of the GT target, and swam to cover a significant portion of the target area. This site was planted with spat-on-shell and renamed HACUH0b.

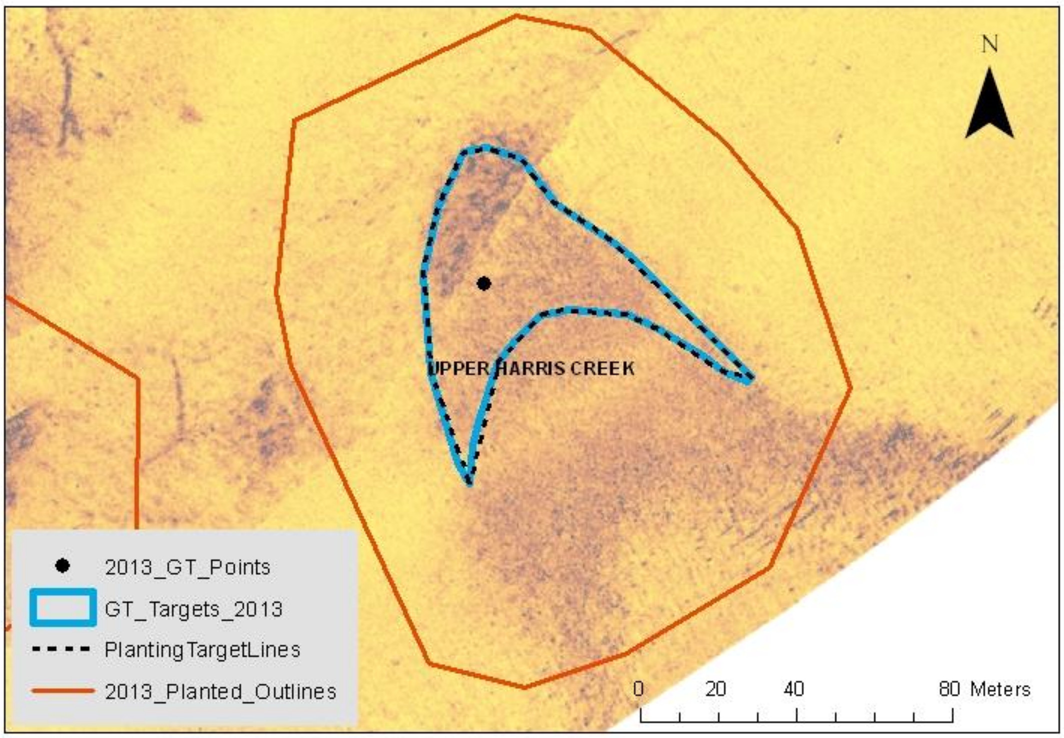
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/17/13	N/A	Exposed	10	Artificial (Clam Shell)	0.00



ACOE 31 (Upper Harris Creek, HACUH0a)

Divers confirmed alternate substrate throughout ACOE 31 to be mixed shell appropriate for planting. As with ACOE 30, no transect was deployed and divers swam the target area. This site was planted with spat-on-shell and renamed HACUH0a.

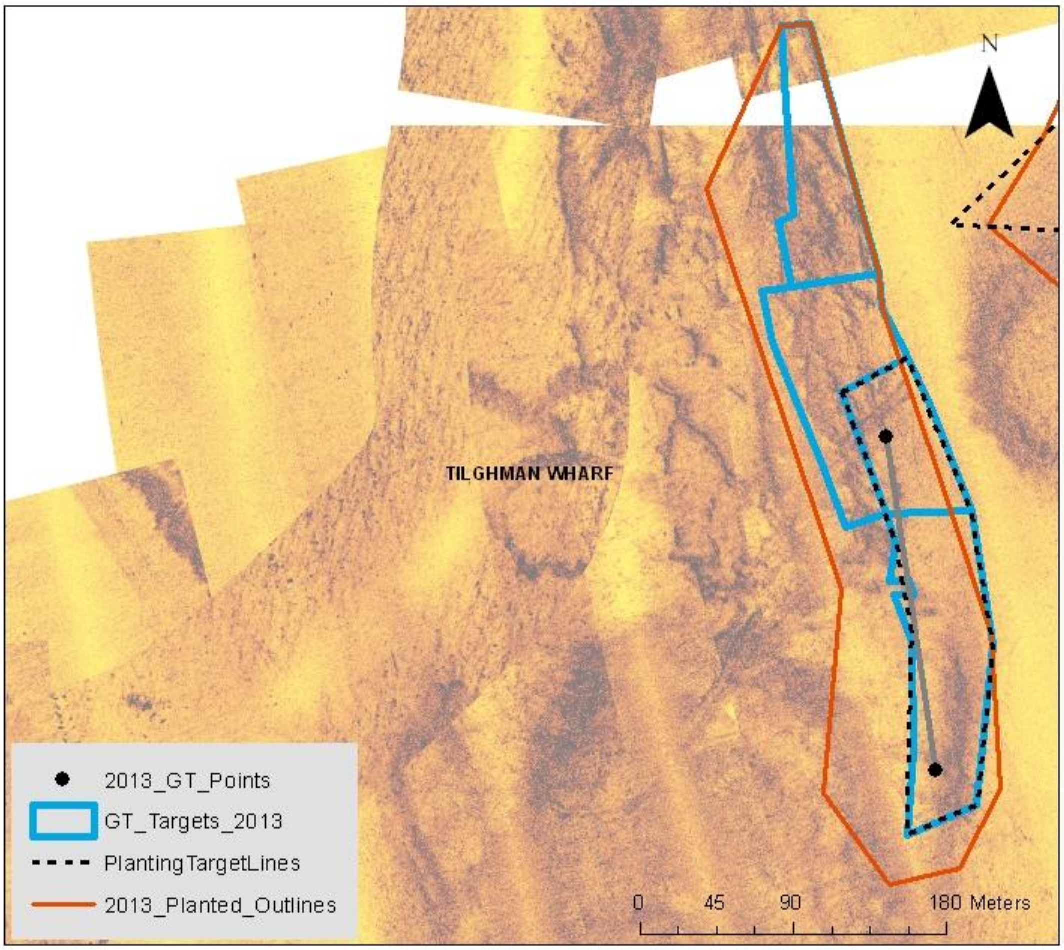
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
5/17/13	N/A	Exposed	10	Artificial (mixed shell)	0.00



ACOE 49 (Tilghman Wharf, HACTW0c)

Alternate substrate was confirmed at ACOE 49; divers identified granite throughout the transect and recommended the surveyed area for planting. This site was planted with spat-on-shell and renamed HACTW0c.

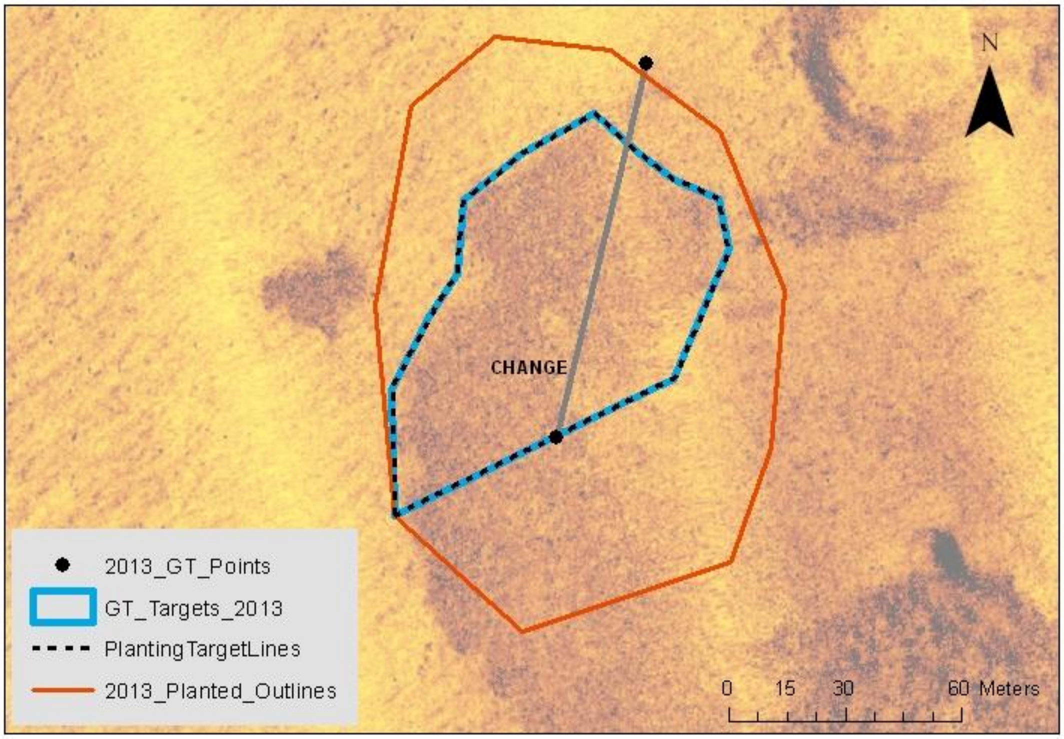
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/17/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 54 (Change, HACCH0i)

Divers confirmed alternate substrate composed of granite. Side-scan sonar imagery and on-board bottom mapping showed that the site was similar throughout the target area and the entire site was recommended for planting. This site was planted with spat-on-shell and renamed HACCH0i.

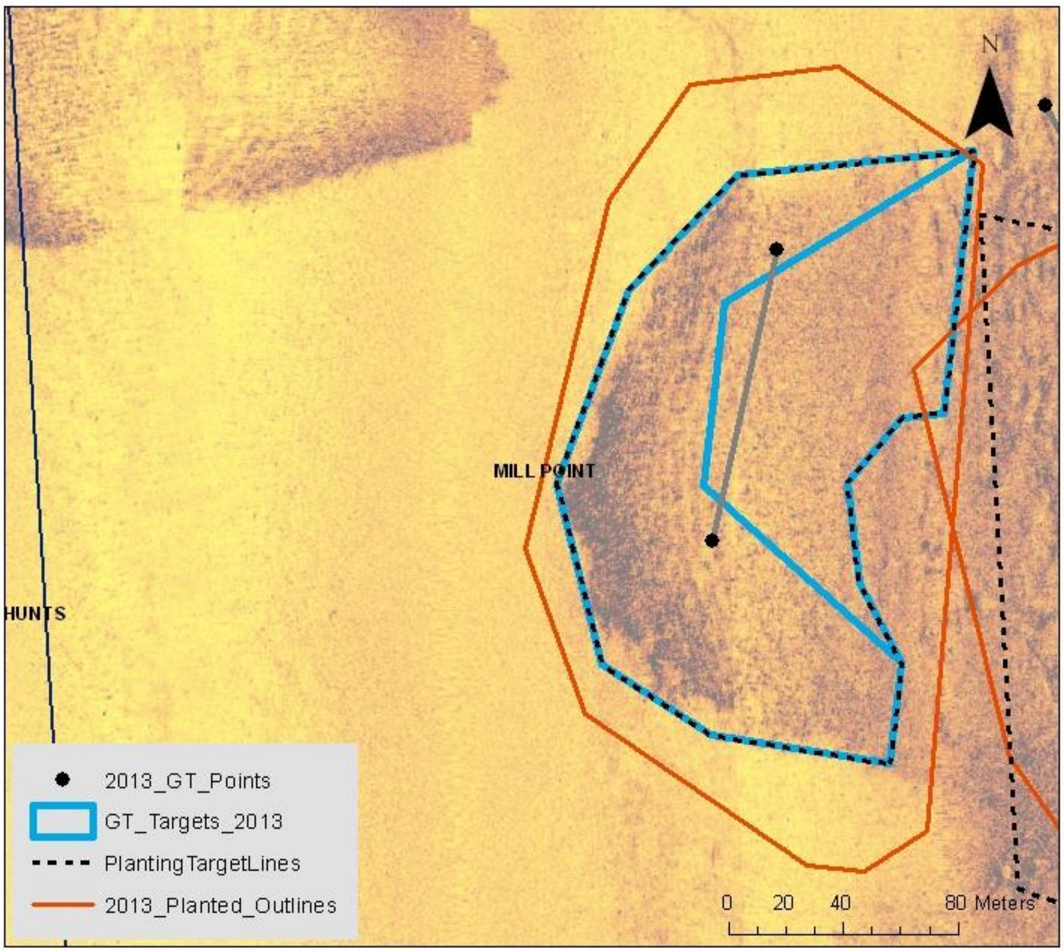
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/11/13	1	NA-Granite	0	Artificial (granite)	0.00



ACOE 57 (Mill Point, HACMP0E3)

ACOE 57 was surveyed to confirm alternate substrate condition and evaluate suitability for planting. Divers swam a single transect across the center of the target area, and observed granite throughout the survey. Side-scan sonar suggested similar bottom throughout, and this site was recommended for planting. This site was planted with spat-on-shell and renamed HACMP0E3.

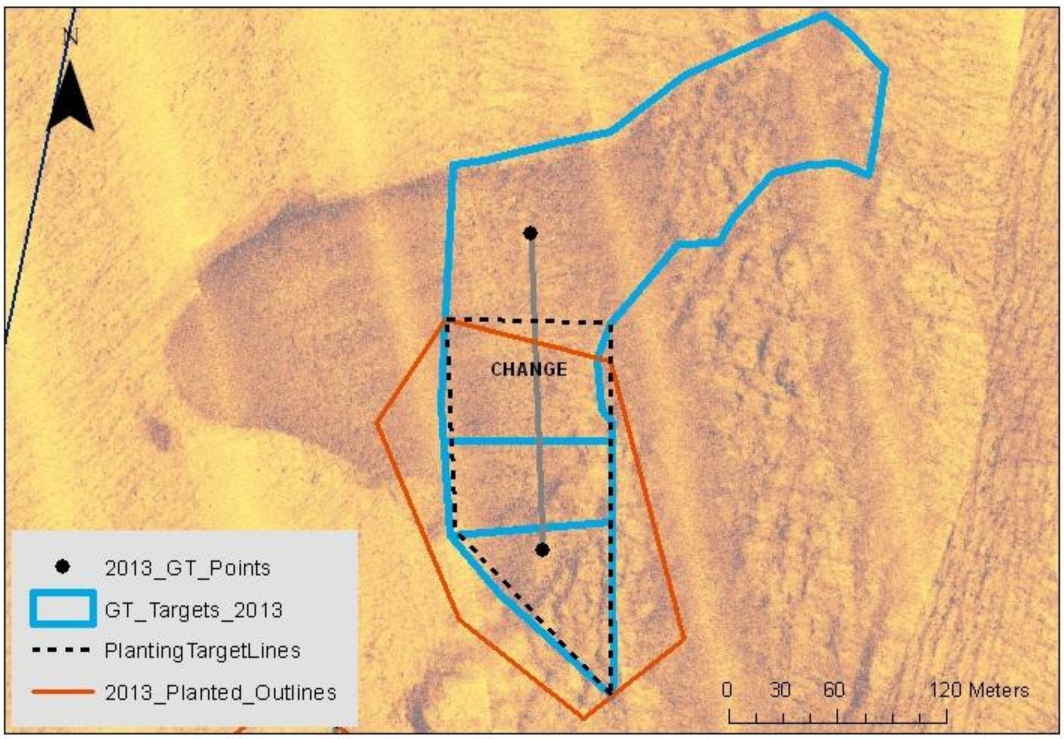
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/17/13	1	NA-Granite	5	Artificial (granite)	0.00



ACOE 71 (Change, HACCH0h)

ACOE 71 was surveyed by divers to confirm presence of alternate substrate and evaluate the site's suitability for spat-on-shell planting. Divers identified granite along the southern portion of the transect, but found sandy bottom at the northern end. The planting target was adjusted and the southern portion of the GT target area was recommended for planting. This site was planted with spat-on-shell and renamed HACCH0h.

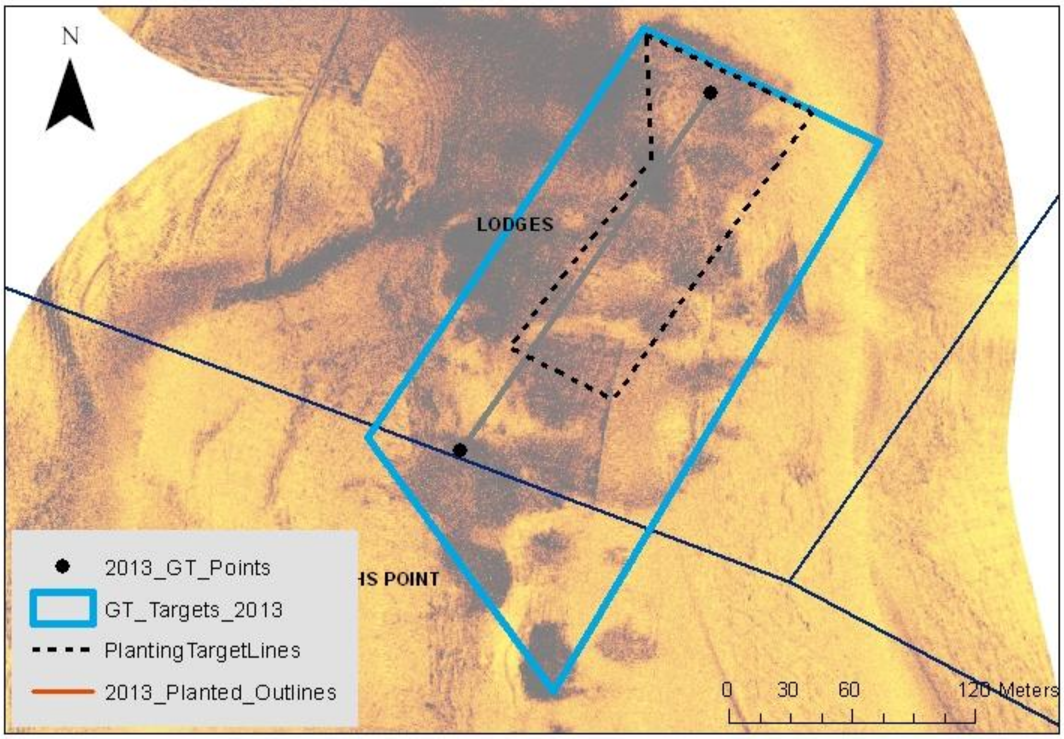
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/04/13	1	NA-Granite	0	Artificial (granite)	0.37



Lodges

Pre-planting GT was conducted at this location with no alternate substrate. The northern portion of the transect had 5-cm penetration within exposed shell. The southern portion of the transect was sandy with 10-cm penetration. The planting target was adjusted to exclude the softer southern bottom and emphasize the northern area, but was not planted in 2013.

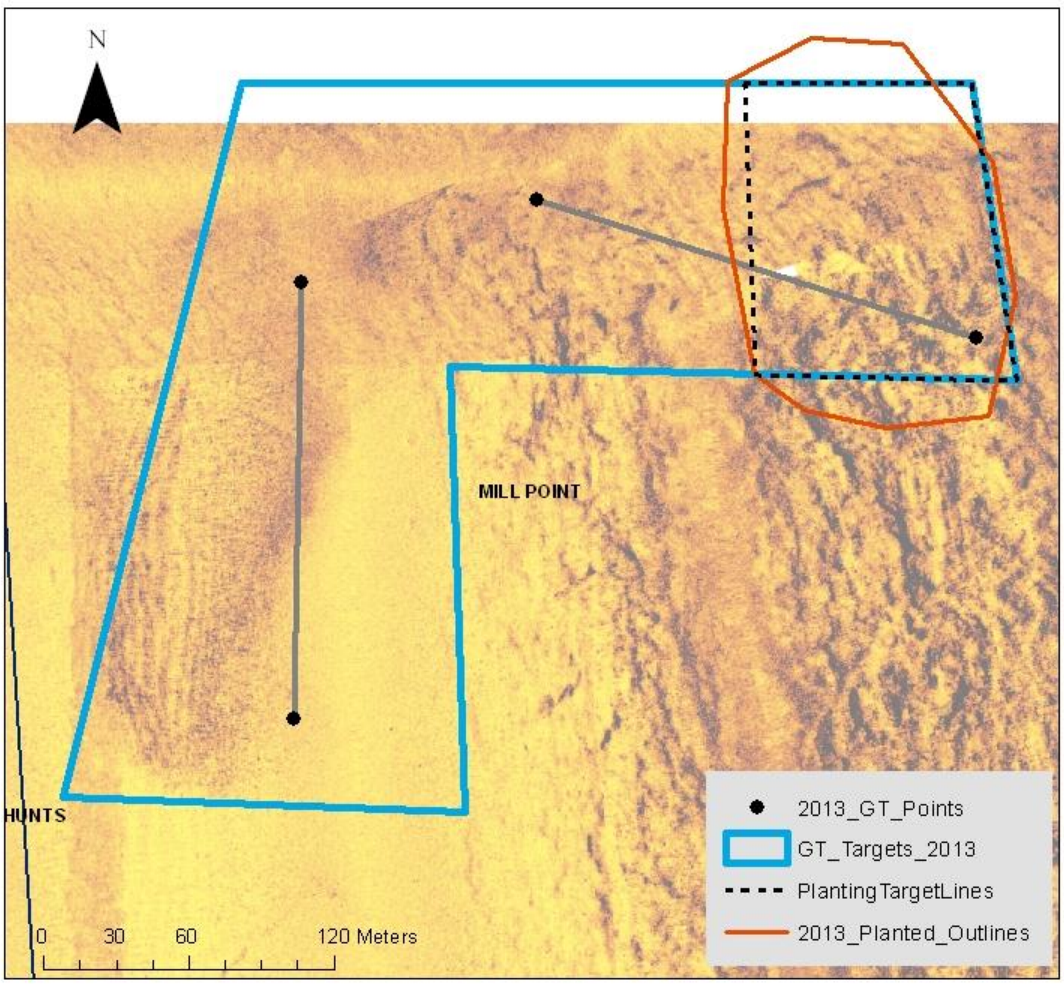
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/28/13	1	Exposed	5	Loose shell	1.67



Mill Point A (HACMP0E2)

Mill Point A was surveyed with two non-overlapping transects over natural bottom. The eastern transect had a higher oyster density and shallower penetration than the western transect. A planting target was created based on GT in the easternmost part of the site, to include the areas with hard bottom. This target was planted with spat-on-shell and renamed HACMP0E2.

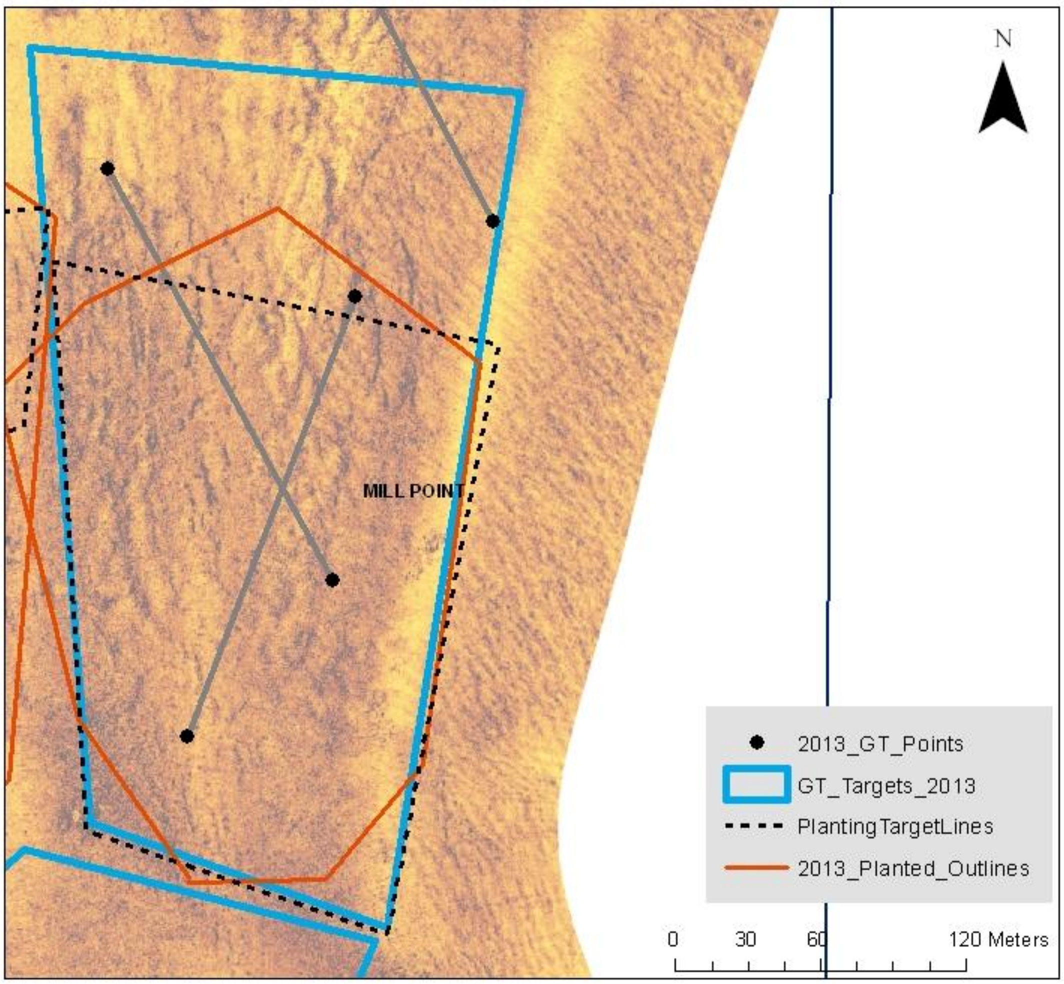
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
4/26/13	1	Some	5	Loose shell	6.66
4/26/13	2	Some	10	Sand	1.08



Mill Point B (HACMP0E1)

Mill Point B was surveyed with two intersecting transects to evaluate planting suitability in the absence of alternate substrate. The first transect had a lower oyster density and a deeper penetration compared to the hard bottom and higher oyster density found on the second transect line. The southern portion of the site was recommended for planting. This site was planted with spat-on-shell and renamed HACMP0E1.

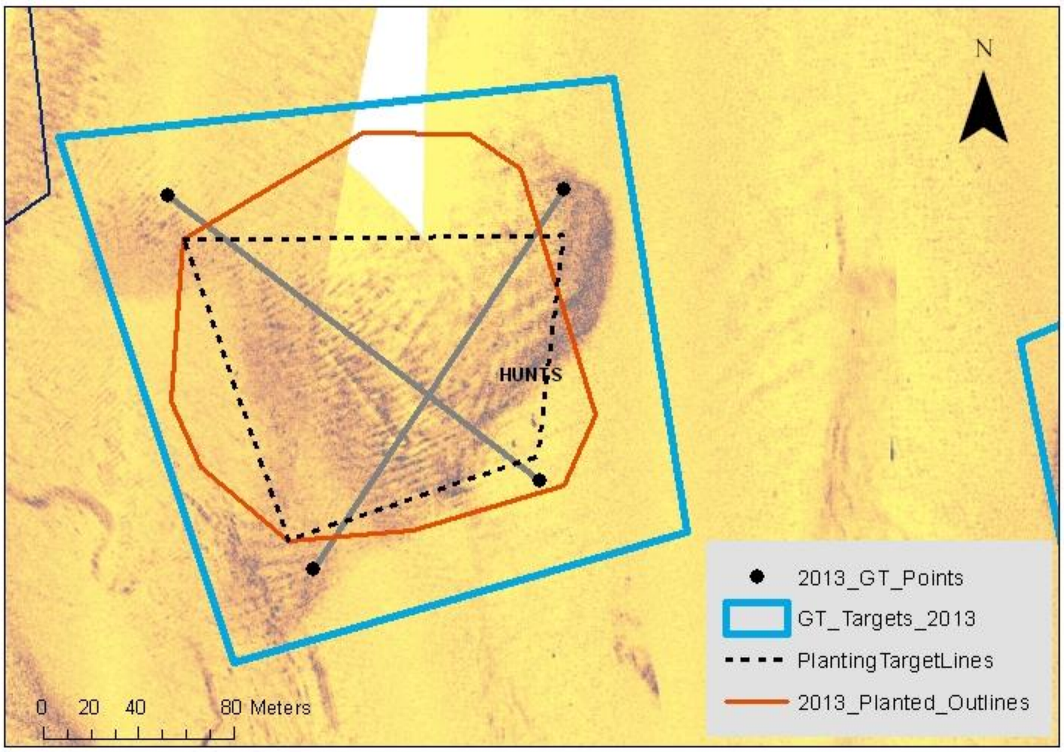
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
4/26/13	1	Very Little	5	Sand/Loose shell	4.06
4/26/13	2	Exposed	0	Loose shell	6.90



Mill Point C (Hunts, HACHU0a)

Pre-planting GT at Hunts took place over natural bottom. Two intersecting diver transects revealed a minimal amount of exposed shell, but a higher oyster density compared to other sites. The intersecting middle span of these lines was deemed suitable for planting, and a planting target was created accordingly. This site was planted with spat-on-shell and renamed HACHU0a.

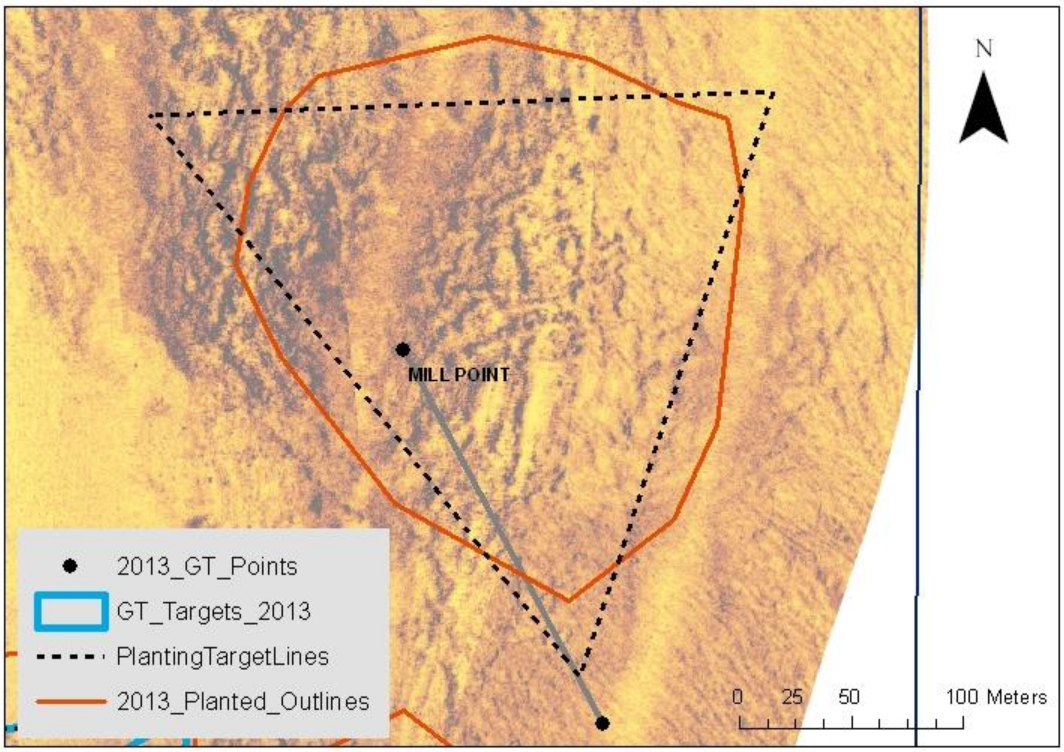
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
4/26/13	1	Some	10	Loose shell	5.68
4/26/13	2	Very Little	10	Sand	2.29



Mill Point D (HACMP0d)

Divers re-surveyed a transect swam in 2012 at Mill Point D. Alternate substrate was not planted at this location, nor were spat-on-shell in 2012. The 2013 transect revealed penetration of 5 cm compared to 10 cm the previous year. The entire site was recommended for planting. It was planted with spat-on-shell and renamed HACMP0d.

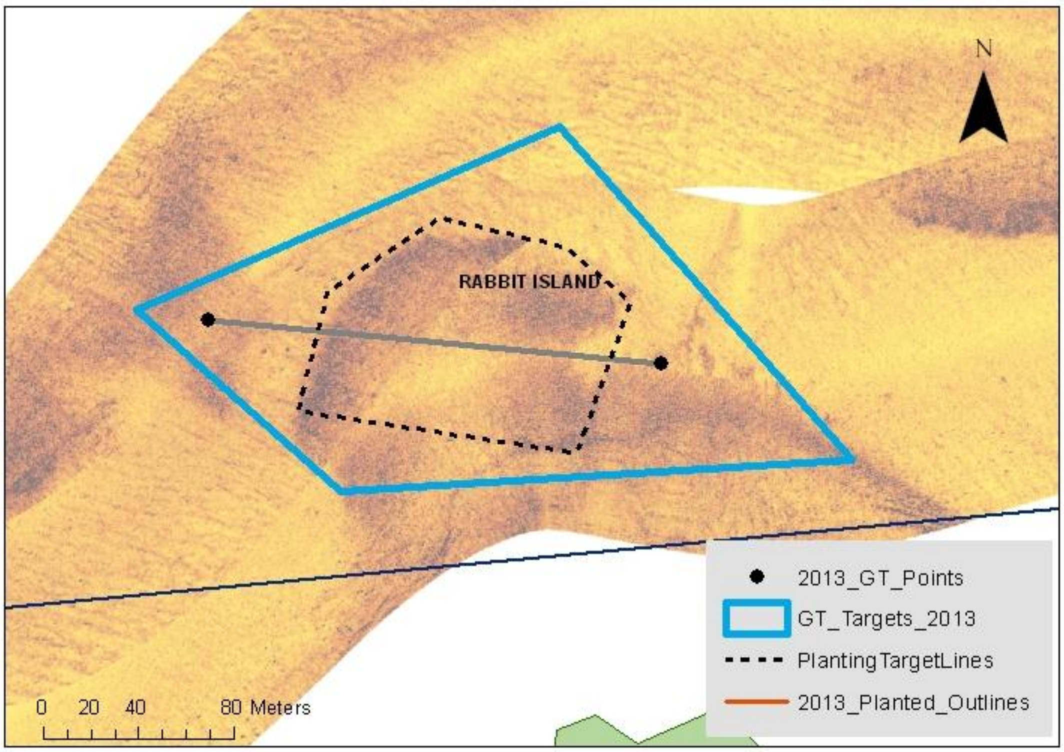
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
4/26/13	1	Exposed	5	Loose shell	3.99



Rabbit Island

Pre-planting GT was conducted at Rabbit Island, in the absence of alternate substrate. The central portion of the transect revealed bottom suitable for planting, but approximately 50 points from the edges were eliminated when creating the planting target. The recommended area had exposed shell, 5 cm penetration and 3 oysters/m^2. This site was not planted in 2013.

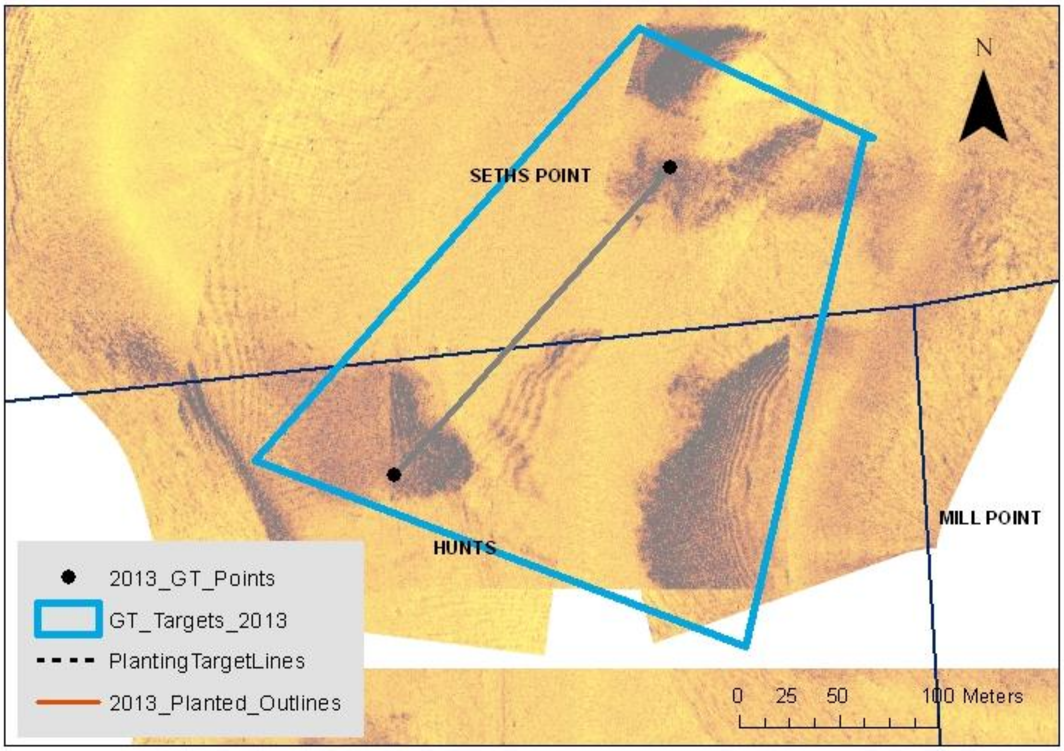
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/28/13	1	Exposed	10	Loose shell	1.35



Seths Point

This site was surveyed to evaluate its potential for a spat-on-shell planting. With zero exposed shell, high penetration levels, and a sandy mud substrate, this site was scored as not ideal for planting. No planting target was generated.

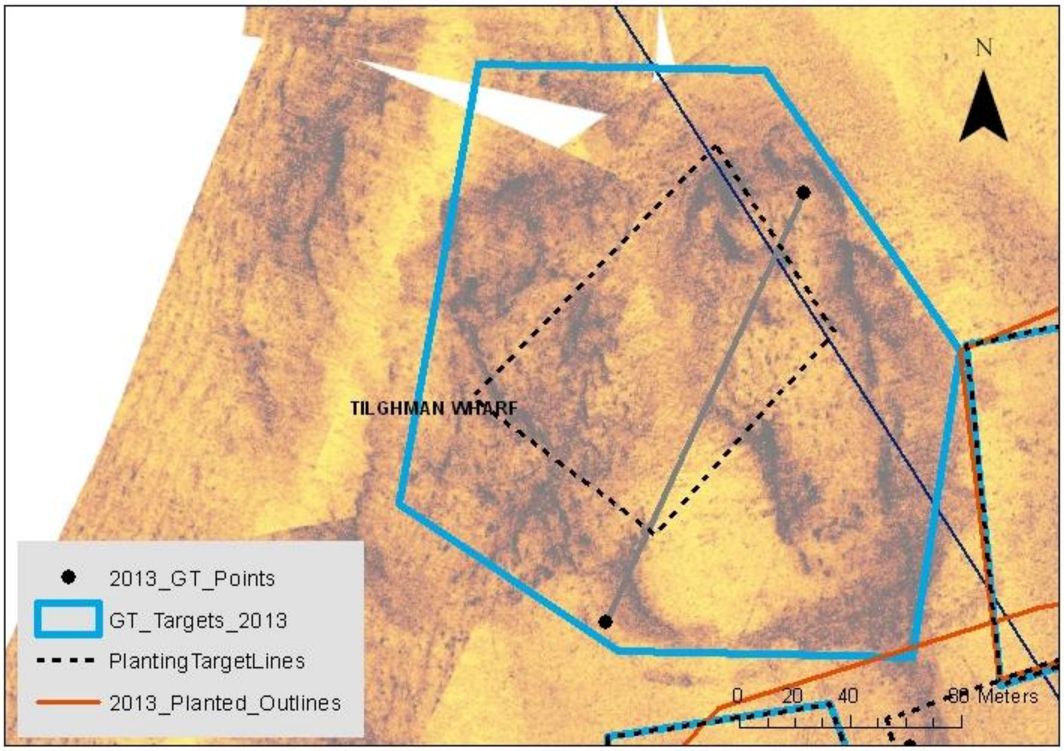
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
7/19/13	1	Zero	20	Mud	2.26



Tilghman Wharf

This site was not a target for alternate substrate deployment, but was surveyed for planting of spat-on-shell potential. Only the central points of the transect revealed appropriate bottom type, and the planting target was adjusted accordingly. This site was not planted in 2013.

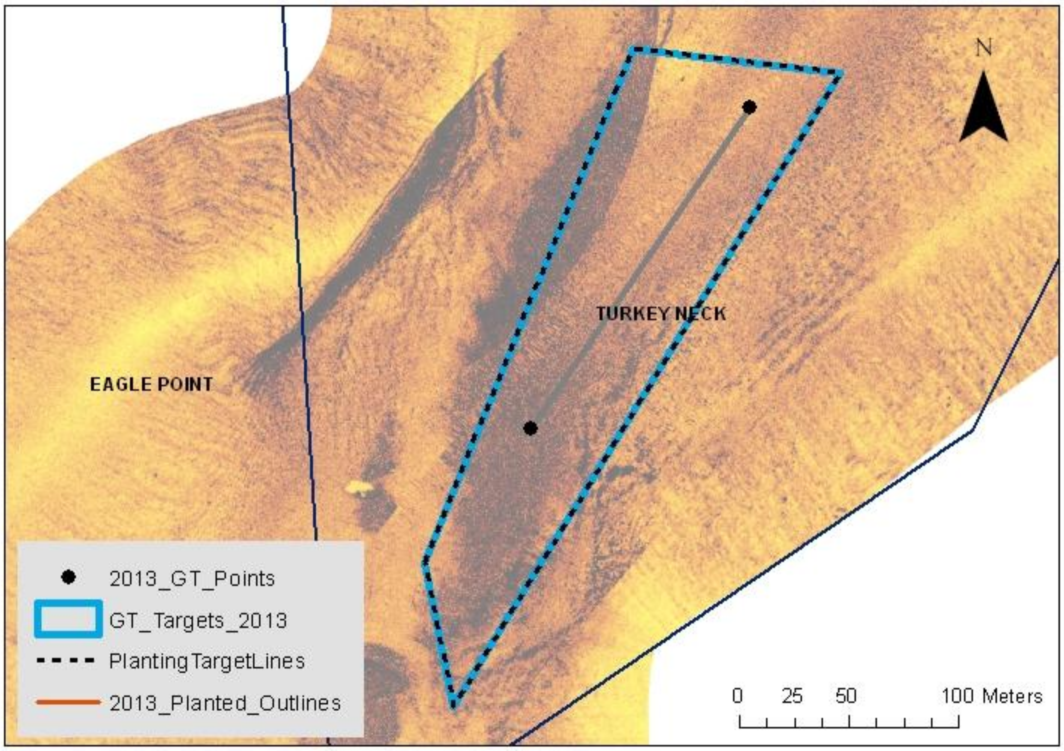
Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
6/28/13	1	Very Little	5	Mud/loose shell	1.83



Turkey Neck

A narrow site at Turkey Neck was surveyed to evaluate its potential to receive a spat-on-shell planting without alternate substrate addition. The transect, which ran lengthwise through the target, revealed a fairly high oyster density and hard bottom. A planting target was generated but was not planted in 2013.

Date	Transect #	Mode Exposed Shell	Mode Penetration (cm)	Mode Substrate Type	Mean Oyster Density (#/m^2)
7/19/13	1	Exposed (shell)	0	Loose shell	8.85



Conclusions

In the spring of 2013, 25 bars were ground truthed by divers from the Paynter Lab to determine 1) bottom suitability for spat-on-shell planting and 2) confirm the presence and distribution of alternate substrate (granite or mixed shell), where deployed. Sites were chosen based on available side scan sonar and known deployment of alternate substrate, therefore the bottom at sites was generally very good. Of the 25 bars surveyed, 24 were identified as having bottom appropriate for planting and 20 were planted in the summer of 2013, indicating that pre-survey site selection was successful at identifying sites that were suitable for planting. Additionally, at most sites alternate substrate provided a consistent hard bottom in the expected target area.

Section III: Post-Planting Monitoring 2013

Data Summary

In 2013, divers surveyed 25 sites planted with spat-on-shell from the Horn Point Laboratory Oyster Hatchery in Cambridge, Maryland 4 to 8 weeks after each planting occurred. The purpose of these surveys was to determine the density and short-term survivorship of spat-on-shell plantings and establish a time zero population estimate. The survey date, number of acres planted, and amount of spat planted at each of the 25 locations are presented in Table 1. All locations were within historic Yates bars, and bar names reflect such designations, with the exception of a new area identified as "ORP bar" throughout this report. For example, the bar ID HACCH0e indicates that the bar is within Harris Creek (HAC), the Yates bar name is Change (CH) and is distinguished from other sites in Change by its letter (0e). As suggested by the planting dates, several of the bars received multiple plantings over the same areas in an attempt to increase the density of spat planted at a single location. For sites where plantings were more than two months apart, the later planting was sampled and analyzed separately, and the bar ID designated "2"; such overplantings are also noted in the table. Figure 1 shows the location of 2013 spat-on-shell post-planting monitoring sites. As part of the 2013 tributary-focused restoration plan, Harris Creek was the primary restoration site where spat-on-shell was planted; two sites in the Severn River were also planted in 2013 (Peach Orchard and Weems Upper).

Table 1. 2013 Post-planting monitoring hatchery summary. Data below includes initial planting metrics.

Region	Bar	Bar ID	Planting Dates (2013)	2013 PPM Sample Date	Acres Planted	Amount of Spat Planted (millions)
Harris Creek	Change	HACCH0e	5/13, 5/14	7/8/2013	6.56	49.59
		HACCH0f	5/22, 5/28	7/8/2013	6.87	42.1
		HACCH0g	5/30	7/16/2013	2.99	20.08
		HACCH0g2 (overplanting)	9/23	11/6/2013	3.16	32.23
		HACCH0h	6/26, 7/1	8/2/2013	5.45	28.06
		HACCH0i	7/30	9/5/2013	3.27	12.65
		HACCH0i2 (overplanting)	5/7	11/21/2013	2.18	4.37
	Hunts	HACHU0a	5/7	6/17/2013	5.19	19.46
	Little Neck	HACLN0b	7/17, 7/22, 7/24	9/5/2013	5.28	23.4
	Lodges	HACLO0b	7/31, 8/7, 8/14	9/11/2013	5.45	30.66
	Mill Point	HACMP0d	5/2, 5/6	6/17/2013	9.43	46
		HACMP0e1	4/30, 5/1	6/17/2013	9.42	40.85
		HACMP0e2	5/8	6/17/2013	3.78	16.42
		HACMP0e3	7/2, 7/8, 7/10	8/2/2013	6.31	36.37
	Turkey Neck	HACTN0a	9/18	10/17/2013	0.75	30.23
	Tilghman Wharf	HACTW0b	6/5	7/16/2013	4.79	19.28
		HACTW0c	6/18, 6/19, 6/24	8/2/2013	8.89	41.8
		HACTW0d	6/25, 7/15	8/12/2013	5.78	28.55
	Upper Harris Creek	HACUH0a	8/28, 9/16	10/17/2013	4.22	32.82
		HACUH0b	9/4	10/17/2013	2.7	15.08
		HACUH0c	9/9, 9/11	10/17/2013	5.05	27.91
	ORP bar	HCORP0a	5/16	7/8/2013	6.18	27.16
		HCORP0b	5/29	7/16/2013	4.69	25.48
		HCORP0c	6/10, 6/11, 6/12, 6/17	7/16/2013	10.14	61.36
		HCORP0c2	9/25	11/6/2013	6.3	18.95
Severn River	Peach Orchard	SVRPE0b	5/21	7/1/2013	5.29	18.5
	Weems Upper	SVRWU0b	5/20	7/15/2013	0.39	25.9

2013 Post-Planting Monitoring Sites

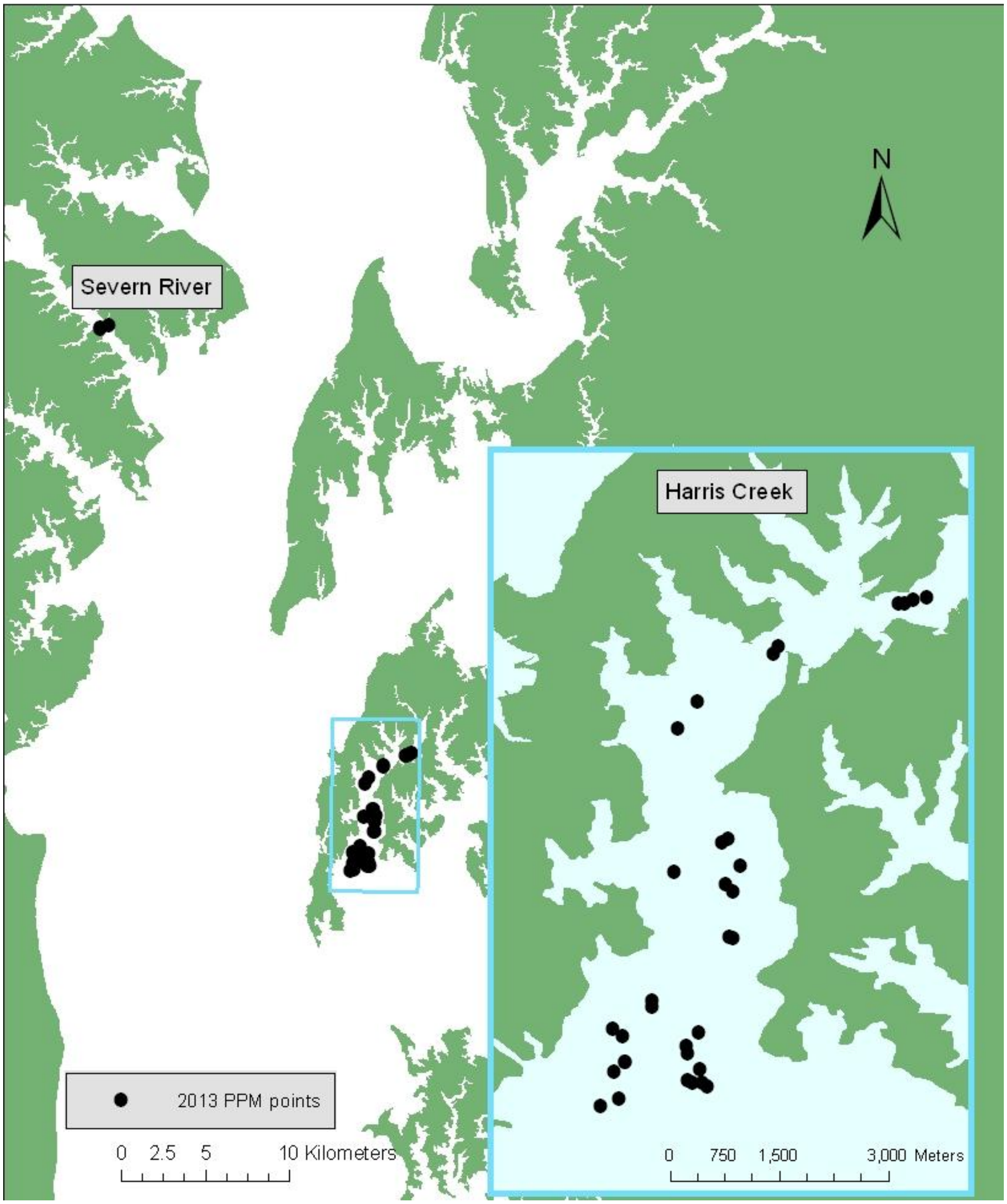


Figure 1. 2013 Post-planting monitoring sites. All sites surveyed post-planting in 2013 are represented by black circles. The majority of spat-on-shell planting efforts were focused in Harris Creek; the inset shows Harris Creek survey locations in closer detail.

Using the planting boat's tracklines as a target, divers collected hatchery shells from each survey location. Divers placed a 0.3 m x 0.3 m quadrat on the bottom and collected all shells contained within the quadrat. Attempts were made to collect three to six quadrat samples at each site. When shell densities were too low for quadrat sampling, such that 6 quads contained fewer than 50 shells, divers would haphazardly collect additional shells to bring the total to at least 50. In 2013, quads were used at all sites except HACCH0g2 and HACCH0i2, overplantings where divers selectively collected spat-on-shell from the most recent planting. In all cases, each shell was examined for live spat, boxes, scars, and gapers. The shell heights of the first 50 live spat observed in each quadrat were measured to estimate their size and growth. These shell metrics are summarized in Table 2 for all sample locations in 2013.

In addition to the metrics listed above, each shell was inspected for the presence of the flatworm predator *Stylochus ellipticus*. Values are not included in the table, as *Stylochus* were observed infrequently during the 2013 PPM survey. *Stylochus* were observed in low numbers at the following sites in Harris Creek: HACHU0a, HACTW0b, HACTW0d, HACUH0b, HACUH0c, and HCORP0c. The flatworm was not observed in the Severn River.

As in previous years, spat survival estimates were used to compare planting success across sites. Spat survival was calculated as the measured spat per shell, divided by the initial mean spat per shell, multiplied by 100. Site survival was based on at least 50 shells, unless noted otherwise. The mean spat survival for 2013 plantings was 37.4% (±4.0 SEM). However, survival ranged from 4.2% (Change, HACCH0g2) to 87.9% (Weems Upper, SVRWU0b). The low survival at HACCH0g2 may be an effect of small sample size at that site, as only 15 shells were sampled. Alternatively, since it was an overplanting where the youngest spat were selectively targeted, identification and collection may have been unreliable. The percent survival of spat planted by bar is presented in Table 3.

Table 2. 2013 post-planting monitoring survey summary. Mean number of oysters and shell height for all sites surveyed in 2013 are shown.

Region	Bar	Bar ID	# Shells Sampled	Mean per shell				
				# Live	**# Gapers**	**# Scars**	**# Boxes**	**Shell Height (mm)**
Harris Creek	**Change**	HACCH0e	53	9.43	0.02	0.96	0.6	21.52
		HACCH0f	57	6.33	0	1.47	0.19	20.73
		HACCH0g	83	2.66	0.01	2.67	0.3	24.08
		HACCH0g2	15	1.6	0	0.93	0.4	4.83
		HACCH0h	53	12.26	0	0.42	0.3	21.14
		HACCH0i	52	8.35	0	2.65	0.58	30.48
		HACCH0i2	52	8.79	0.06	4.29	0.13	5.19
	Hunts	HACHU0a	54	8.15	0.07	2.43	0.13	12.74
	Little Neck	HACLN0b	59	3.12	0	13.66	0.39	20.29
	Lodges	HACLO0b	72	5.63	0.03	3.89	0.22	21.04
	Mill Point	HACMP0d	50	6.52	0.02	1.64	0.12	13.23
		HACMP0E1	48	6.46	0.33	0.98	0.5	14.1
		HACMP0E2	91	8.18	0.08	1.86	0.22	10.64
		HACMP0E3	84	6.48	0	3.38	0.19	18.05
	Turkey Neck	HACTN0a	92	15.09	0	2.99	0.04	8.45
	Tilghman Wharf	HACTW0b	50	9.66	0	0.84	0.6	23.96
		HACTW0c	91	5.04	0.01	1.01	0.37	24.43
		HACTW0d	166	8.08	0.01	1.6	0.17	21.24
	Upper Harris Creek	HACUH0a	53	5.42	0.13	4.19	0.28	11.92
		HACUH0b	65	6.2	0.02	1.8	1	15.57
		HACUH0c	79	10.66	0	1.68	1	12.33
	ORP bar	HCORP0a	48	5	0	1.79	0.5	20.82
		HCORP0b	113	14.88	0.01	3.19	0.21	20.63
		HCORP0c	54	6.78	0.02	0.93	0.19	22.76
		HCORP0c2	54	4.15	0	0.83	0.3	30.32
Severn River	**Peach Orchard**	SVRPE0b	78	14.29	0	1.76	0.08	18.06
	Weems Upper	SVRWU0b	62	26.95	0	0.58	0.24	18.98

Table 3. 2013 spat survival by bar. 2013 survival ranged from 4.2% to 87.9%.

Region	Bar	Bar ID	Acres planted	Mean Live Spat per Shell (PPM)	Total Amount of Shell Planted	Amount of Spat Planted (Millions)	Live Spat on Bar (PPM*Shell) (Millions)	2013 % Survival
Harris Creek	Change	HACCH0e	6.56	9.43	1,689,120	49.6	15.9	31.6
		HACCH0f	6.87	6.33	1,689,120	42.1	10.7	25.4
		HACCH0g	2.99	2.66	844,560	20.1	2.3	11.2
		HACCH0g2	3.16	1.6	844,560	32.2	1.4	4.2
		HACCH0h	5.45	12.26	1,689,120	28.1	20.7	73.8
		HACCH0i	3.27	8.35	844,560	12.7	7.1	55.8
		HACCH0i2	2.18	8.79	421,200	4.4	3.7	84.7
	Hunts	HACHU0a	5.19	8.15	844,560	19.5	6.9	35.4
	Little Neck	HACLN0b	5.28	3.12	2,533,680	23.4	7.9	33.8
	Lodges	HACLO0b	5.45	5.63	2,106,000	30.7	11.9	38.7
	Mill Point	HACMP0d	9.43	6.52	1,689,120	46.0	11.0	23.9
		HACMP0E1	9.42	6.46	1,689,120	40.9	10.9	26.7
		HACMP0E2	3.78	8.18	844,560	16.4	6.9	42.1
		HACMP0E3	6.31	6.48	2,533,680	36.4	16.4	45.1
	Turkey Neck	HACTN0a	4.69	15.09	758,160	30.2	11.4	37.8
	Tilghman Wharf	HACTW0b	4.79	9.66	844,560	19.3	8.2	42.3
		HACTW0c	8.89	5.04	2,533,680	41.8	12.8	30.5
		HACTW0d	5.78	8.08	1,689,120	28.6	13.7	47.8
	Upper Harris Creek	HACUH0a	4.22	5.42	1,689,120	32.8	9.2	27.9
		HACUH0b	2.7	6.2	844,560	15.1	5.2	34.7
		HACUH0c	5.05	10.66	1,689,120	27.9	18.0	64.5
	ORP bar	HCORP0a	6.18	5	844,560	27.2	4.2	15.1
		HCORP0b	4.69	14.88	844,560	25.5	12.6	49.3
		HCORP0c	10.14	6.78	3,378,240	61.4	3.1	37.3
		HCORP0c2	6.3	4.15	758,160	19.0	3.0	16.6
Severn River	Peach Orchard	SVRPE0b	5.29	14.29	844,560	18.5	12.1	65.2
	Weems Upper	SVRWU0b	0.39	26.95	844,560	25.9	22.8	87.9
					Total:	756.3	266.7	--
					Mean:	--	--	37.4

Identical metrics were collected in 2008 through 2012 from sites comparable to those sampled in 2013 (see Table 4). In 2010 through 2013, the total acreage planted was less than in 2008 and 2009, due to the fact that an over-planting approach was used where plantings were often deployed over previous plantings of that season. Survival was highest in 2013 of all five years, though 2012's survival was not statistically different from 2013's. Survival in 2013 also had low standard error, indicating consistently good outcomes. As in previous years, data were inspected for possible trends relating spat survival to factors including initial spat per shell density, planted spat per acre, and initial shell height/spat growth rate. Within 2013 data, no trends were observed relating early spat survival to initial spat per shell (Figure 2), initial spat shell height, or spat density per acre (Figure 3). Survival variability was also examined annually, and again no trends were observed connecting spat survival to initial spat per shell or amount of spat planted. Additionally, no trend was observed in survival relative to spat growth rate, indicating that the environmental variation known to impact spat growth (oxygen concentration, food availability) does not seem to be correlated with survival of spat in the northern Chesapeake Bay.

Table 4. Comparison of 2008 – 2013 post-planting monitoring survey summary metrics. 2013 survival was comparable to 2012 survival, and suggests enhanced survival success relative to previous years (2008-2010).

					Means per Year			
Sample Year	**Sample Locations**	**Sites Planted**	**Total Acreage Planted**	**Total Spat Planted (Millions)**	**Initial Spat per Shell**	**Survey Spat per Shell**	**Shell Height (mm)**	**% Survival ± SEM**
2008	20	27	215.64	370	30.2	3.9	14.9	17.0 ±2.8
2009	19	56	408.82	762	17.9	3.4	11.5	12.0 ±1.9
2010	13	16	99.56	374	14.9	2.0	20.1	12.8 ±2.4
2011	12	13	93.53	515	16.5	4.4	20.1	27.0 ±7.7
2012	10	15	124.8	577	16.8	6.7	19.5	36.8 ±12.1
2013	11	25	134.2	756	22.0	6.7	19.6	37.4 ±4.0

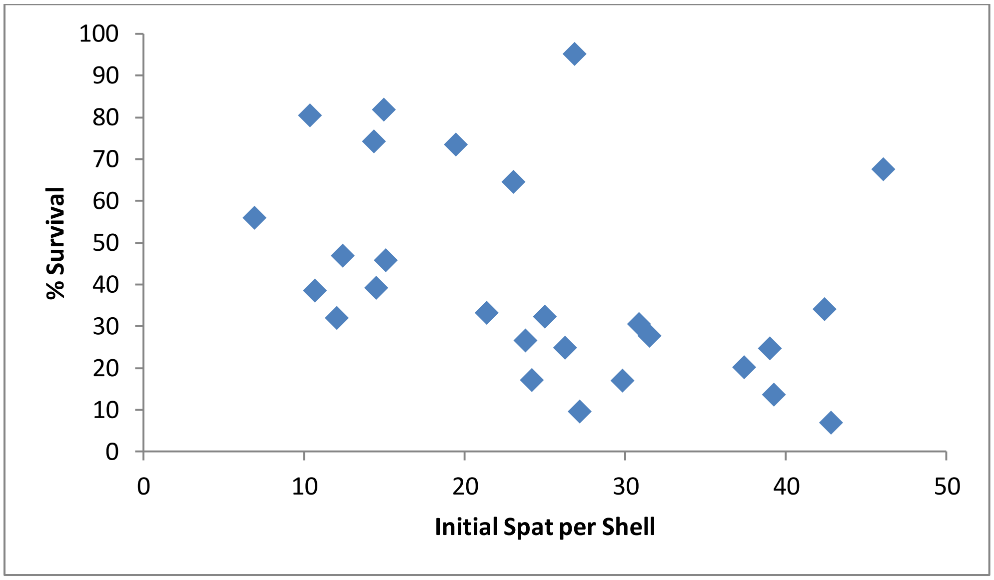


Figure 2. Survival by initial spat per shell for the 2013 post-planting monitoring survey. The data show no trend in survival with initial spat per shell.

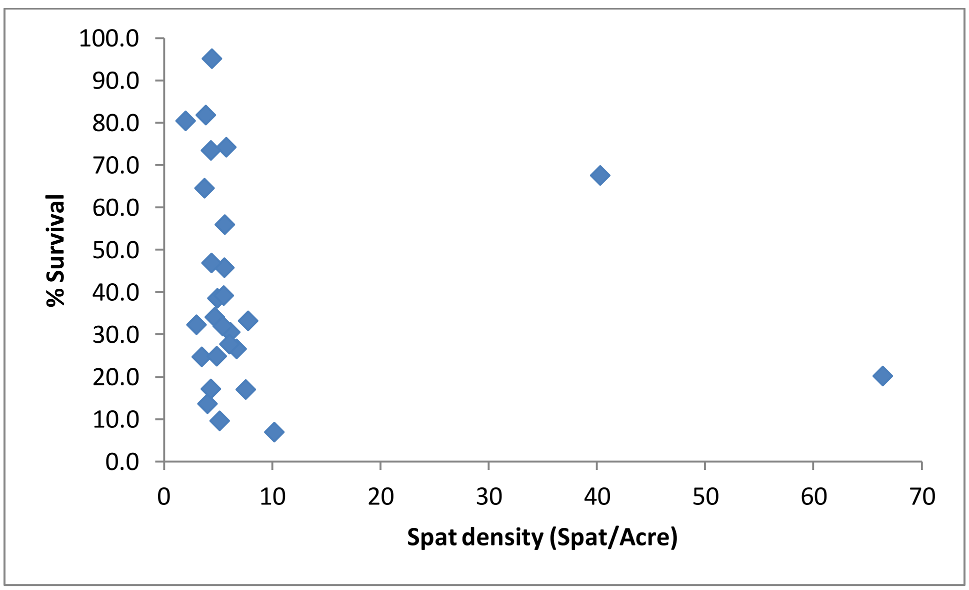


Figure 3. Percent survival by spat per acre (millions of spat/acre) for the 2013 post-planting monitoring survey. The data show no obvious trend in survival based on planning density.

Quadrat-based sampling was employed for the first time during the 2010 survey in order to better understand the relationship of spat and shell density and spat survival; we have continued this method through 2013 although at certain sites the time elapsed between overplanting made quadrat sampling impractical. Using a quadrat to collect shells within a standard area allowed for density comparisons. Table 5 shows the bars sampled using quadrats, as well the metrics per quad. Because only the first 50 spat were measured per site, spat in some quads were only counted, thus no shell height is listed. (Data presented above in Table 2 for 2013 includes sums and averages of these quadrat data for comparison across all bars.)

Table 5. Summary of metrics collected per quad for post planting monitoring sites sampled using the quadrat method in 2013. Each row represents a separate quad.

Bar ID (Bar name, region)	# of Shells Sampled	Mean per shell (per quad)				
		# Live	# Gapers	# Scars	# Boxes	Spat Shell Height (mm)
HACCH0e (Change, Harris Creek)	4	4	0	1	1	27
	0	-	-	-	-	-
	0	-	-	-	-	-
	7	5	0	<1	<1	21
	18	8	0	1	<1	21
	9	9	0	1	<1	18
HACCH0f (Change, Harris Creek)	5	3	0	1	0	26
	20	6	0	2	<1	20
	8	7	0	1	<1	18
	3	9	0	3	0	20
	3	10	0	<1	<1	19
HACCH0g (Change, Harris Creek)	3	2	0	1	0	22
	33	3	0	3	<1	25
	5	2	0	3	<1	24
	18	3	0	2	<1	24
	5	1	0	1	0	24
	19	2	0	3	<1	26
HACCH0h (Change, Harris Creek)	3	11	0	2	<1	22
	8	8	0	1	0	22
	6	13	0	<1	0	20
	9	15	0	<1	<1	22
	4	19	0	0	<1	22
	9	12	0	<1	<1	19
HACCH0i (Change, Harris Creek)	6	9	0	5	<1	43
	6	8	0	3	<1	18
	2	0	0	4	1	35
	22	11	0	2	<1	18
	5	3	0	2	0	38
	5	8	0	1	2	38
HACHU0a (Hunts, Harris Creek)	1	3	0	0	0	12
	9	3	0	1	0	12
	0	-	-	-	-	
	2	9	0	5	1	15
	11	9	0	3	<1	14
	15	11	0	2	0	11
HACLN0b (Little Neck, Harris Creek)	23	2	0	16	<1	17
	13	2	0	11	<1	20
	4	2	0	19	0	23
	2	6	0	26	<1	14
	11	5	0	8	<1	26
	2	6	0	13	0	19
HACLO0b Lodges, Harris Creek)	11	3	0	2	<1	17
	7	3	0	2	<1	20
	0	-	-	-	-	-
	5	6	0	2	<1	15
	6	14	0	5	<1	15

Bar ID (Bar name, region)	# of Shells Sampled	Mean per shell (per quad)				
		# Live	# Gapers	# Scars	# Boxes	Spat Shell Height (mm)
	43	5	0	5	<1	38
HACMP0e1 (Mill Point, Harris Creek)	0	-	-	-	-	-
	1	1	0	1	0	19
	5	10	0	1	<1	12
	15	7	0	<1	<1	13
	2	1	0	0	0	12
	2	7	0	1	0	17
HACMP0e2 (Mill Point, Harris Creek)	10	8	0	3	<1	Counts only
	19	4	0	1	<1	Counts only
	26	7	0	2	<1	Counts only
	36	11	0	2	<1	11
HACMP0e3 (Mill Point, Harris Creek)	21	8	0	5	<1	15
	12	5	0	2	0	20
	6	9	0	3	0	18
	17	9	0	6	0	19
	25	3	0	1	<1	19
	3	9	0	3	1	18
HACTN0a (Turkey Neck, Harris Creek)	4	2	0	0	0	8
	13	14	0	3	<1	8
	60	17	0	3	<1	8
	2	5	0	1	0	9
	13	14	0	3	0	9
HACTW0b (Tilghman Wharf, Harris Creek)	18	11	0	1	<1	24
	6	12	0	2	1	23
	6	5	0	<1	0	26
	4	5	0	1	<1	29
	1	14	0	0	0	21
	12	10	0	1	<1	20
	3	7	0	1	0	25
HACTW0c (Tilghman Wharf, Harris Creek)	21	6	0	1	<1	23
	5	5	0	<1	<1	27
	11	6	0	1	<1	25
	0	-	-	-	-	-
	20	5	0	1	<1	26
	13	5	0	1	<1	23
	21	3	0	1	<1	22
HACTW0d (Tilghman Wharf, Harris Creek)	6	14	0	1	<1	20
	0	-	-	-	-	-
	26	5	0	4	<1	20
	18	5	0	1	<1	27
	2	3	0	2	0	27
	114	9	0	1	<1	13
HACUH0a (Upper Harris Creek, Harris Creek)	7	3	0	1	<1	9
	9	2	0	2	<1	13
	3	2	0	5	0	16
	8	4	0	5	<1	15
	7	12	0	8	<1	12

Bar ID (Bar name, region)	# of Shells Sampled	Mean per shell (per quad)				
		# Live	# Gapers	# Scars	# Boxes	Spat Shell Height (mm)
HACUH0b (Upper Harris Creek, Harris Creek)	2	8	0	1	0	14
	3	4	0	0	0	18
	3	5	0	1	<1	17
	20	6	0	1	<1	15
	20	8	0	3	1	16
	17	5	0	1	1	14
HACUH0c (Upper Harris Creek, Harris Creek)	7	7	0	<1	<1	15
	16	18	0	2	1	12
	12	9	0	1	<1	11
	21	8	0	2	1	12
	23	10	0	2	<1	12
HCORP0a (ORP Bar, Harris Creek)	4	10	0	4	0	18
	0	-	-	-	-	-
	15	5	0	2	<1	21
	12	5	0	1	<1	24
	13	4	0	2	<1	19
	4	5	0	2	<1	23
HCORP0b (ORP Bar, Harris Creek)	13	3	0	3	<1	23
	10	3	0	3	<1	23
	7	2	0	3	<1	19
	1	5	0	2	0	27
	6	4	0	5	<1	21
	9	7	<1	2	<1	24
HCORP0c (ORP Bar, Harris Creek)	12	6	0	1	<1	23
	1	0	0	0	0	Counts only
	4	7	0	1	<1	25
	1	34	0	1	0	22
	6	10	0	1	<1	21
	16	7	0	1	<1	22
HCORP0c2 (ORP Bar, Harris Creek)	9	1	0	<1	<1	19
	2	2	0	0	0	3
	21	5	0	1	<1	34
	0	-	-	-	-	-
	10	5	0	1	<1	49
	12	5	0	1	<1	45
SVRPE0b (Peach Orchard, Severn River)	18	3	0	1	0	18
	5	1	0	3	<1	20
	15	6	0	3	<1	18
	10	<1	0	2	0	20
	25	3	0	1	<1	17
	5	4	0	2	0	16
SVRWU0b (Weems Upper, Severn River)	1	0	0	0	0	Counts only
	7	8	0	<1	0	20
	1	0	0	0	0	Counts only
	1	4	0	3	0	15
	15	5	0	<1	0	22
	5	15	0	<1	<1	19

Spat survival was calculated as the percentage of spat planted (per quad as the initial spat per shell multiplied by the total shells per quad) that was detected by the survey. These data are presented in Table 6 below.

Table 6. Survival data by quad. Survival metrics are presented for sites that were sampled using quadrats in 2013. Percent survival by site is different than in Table 3 because only shells collected in quads are included here, while Table 3 also includes haphazardly collected shells.

Bar ID (Bar name, region)	# of Shells Sampled	Initial Spat/Quad	PPM Mean Live Spat/Shell	Total PPM Live/Quad	Quad % Survival	Site % Survival ± SEM
HACCH0e Change, Harris Creek)	4	119	4	16	13	22.7 ±1.3
	0	-	-	-	Blank quad	
	0	-	-	-	Blank quad	
	7	209	5	38	18	
	18	537	8	147	27	
	9	268	9	85	32	
HACCH0f (Change, Harris Creek)	5	125	3	14	11	28.0 ±0.9
	20	502	6	117	23	
	8	201	7	57	28	
	3	75	9	27	36	
	3	75	10	31	41	
HACCH0g (Change, Harris Creek)	3	71	2	7	10	9.7 ±1.9
	33	785	3	100	13	
	5	119	2	10	8	
	18	428	3	57	13	
	5	119	1	6	5	
	19	452	2	41	9	
HACCH0h (Change, Harris Creek)	3	50	11	32	64	76.8 ±0.7
	8	133	8	61	46	
	6	100	13	76	76	
	9	150	15	134	90	
	4	66	19	74	111	
	9	150	12	110	74	
HACCH0i (Change, Harris Creek)	6	90	9	53	59	43.5 ±0.9
	6	90	8	47	52	
	2	30	0	0	0	
	22	329	11	236	72	
	5	75	3	17	23	
	5	75	8	41	55	
HACHU0a (Hunts, Harris Creek)	1	23	3	3	13	30.5 ±1.1
	9	207	3	27	13	
	0	-	-	-	Blank quad	
	2	46	9	18	39	
	11	253	9	99	39	
	15	346	11	167	48	
HACLN0b (Little Neck, Harris Creek)	23	213	2	50	24	41.9 ±0.9
	13	120	2	27	22	
	4	37	2	8	22	
	2	18	6	12	65	
	11	102	5	60	59	
	2	18	6	11	60	

Bar ID (Bar name, region)	# of Shells Sampled	Initial Spat/Quad	PPM Mean Live Spat/Shell	Total PPM Live/Quad	Quad % Survival	Site % Survival ± SEM
HACLO0b (Lodges, Harris Creek)	11	153	3	37	24	46.4 ±0.9
HACLO0b (Lodges, Harris Creek)	7	98	3	23	24	
HACLO0b (Lodges, Harris Creek)	0	-	-	-	Blank quad	
HACLO0b (Lodges, Harris Creek)	5	70	6	30	43	
HACLO0b (Lodges, Harris Creek)	6	84	14	86	103	
HACLO0b (Lodges, Harris Creek)	43	599	5	229	38	
HACMP0e1 (Mill Point, Harris Creek)	0	-	-	-	Blank quad	21.0 ±1.3
HACMP0e1 (Mill Point, Harris Creek)	1	24	1	1	4	
HACMP0e1 (Mill Point, Harris Creek)	5	121	10	48	40	
HACMP0e1 (Mill Point, Harris Creek)	15	363	7	110	30	
HACMP0e1 (Mill Point, Harris Creek)	2	48	1	1	2	
HACMP0e1 (Mill Point, Harris Creek)	2	48	7	14	29	
HACMP0e2 (Mill Point, Harris Creek)	10	194	8	84	43	39.4 ±0.6
HACMP0e2 (Mill Point, Harris Creek)	19	369	4	74	20	
HACMP0e2 (Mill Point, Harris Creek)	26	506	7	194	38	
HACMP0e2 (Mill Point, Harris Creek)	36	700	11	392	56	
HACMP0e3 (Mill Point, Harris Creek)	21	301	8	172	57	50.3 ±0.8
HACMP0e3 (Mill Point, Harris Creek)	12	172	5	56	33	
HACMP0e3 (Mill Point, Harris Creek)	6	86	9	56	65	
HACMP0e3 (Mill Point, Harris Creek)	17	244	9	150	62	
HACMP0e3 (Mill Point, Harris Creek)	25	359	3	83	23	
HACMP0e3 (Mill Point, Harris Creek)	3	43	9	27	63	
HACTN0a (Turkey Neck, Harris Creek)	4	169	2	8	5	24.5 ±1.0
HACTN0a (Turkey Neck, Harris Creek)	13	548	14	185	34	
HACTN0a (Turkey Neck, Harris Creek)	60	2531	17	1008	40	
HACTN0a (Turkey Neck, Harris Creek)	2	84	5	10	12	
HACTN0a (Turkey Neck, Harris Creek)	13	548	14	177	32	
HACTW0b (Tilghman Wharf, Harris Creek)	18	411	11	195	47	38.8 ±1.0
HACTW0b (Tilghman Wharf, Harris Creek)	6	137	12	73	53	
HACTW0b (Tilghman Wharf, Harris Creek)	6	137	5	30	22	
HACTW0b (Tilghman Wharf, Harris Creek)	4	91	5	19	21	
HACTW0b (Tilghman Wharf, Harris Creek)	1	23	14	14	61	
HACTW0b (Tilghman Wharf, Harris Creek)	12	274	10	123	45	
HACTW0b (Tilghman Wharf, Harris Creek)	3	69	7	21	31	
HACTW0c (Tilghman Wharf, Harris Creek)	21	370	6	129	35	27.9 ±1.1
HACTW0c (Tilghman Wharf, Harris Creek)	5	88	5	25	28	
HACTW0c (Tilghman Wharf, Harris Creek)	11	194	6	68	35	
HACTW0c (Tilghman Wharf, Harris Creek)	0	-	-	-	Blank quad	
HACTW0c (Tilghman Wharf, Harris Creek)	20	352	5	101	29	
HACTW0c (Tilghman Wharf, Harris Creek)	13	229	5	64	28	
HACTW0c (Tilghman Wharf, Harris Creek)	21	370	3	72	19	
HACTW0d (Tilghman Wharf, Harris Creek)	6	101	14	86	85	42.7 ±0.9
HACTW0d (Tilghman Wharf, Harris Creek)	0	0		0	Blank quad	
HACTW0d (Tilghman Wharf, Harris Creek)	26	439	5	121	28	
HACTW0d (Tilghman Wharf, Harris Creek)	18	304	5	90	30	
HACTW0d (Tilghman Wharf, Harris Creek)	2	34	3	6	18	
HACTW0d (Tilghman Wharf, Harris Creek)	114	1926	9	1038	54	
HACUH0a (Upper Harris Creek, Harris Creek)	7	151	3	23	15	21.5 ±1.1
HACUH0a (Upper Harris Creek, Harris Creek)	9	195	2	14	7	
HACUH0a (Upper Harris Creek, Harris Creek)	3	65	2	7	11	
HACUH0a (Upper Harris Creek, Harris Creek)	8	173	4	30	17	
HACUH0a (Upper Harris Creek, Harris Creek)	7	151	12	86	57	

Bar ID (Bar name, region)	# of Shells Sampled	Initial Spat/Quad	PPM Mean Live Spat/Shell	Total PPM Live/Quad	Quad % Survival	Site % Survival ± SEM
HACUH0b (Upper Harris Creek, Harris Creek)	2	40	8	16	40	29.7 ±1.1
	3	60	4	11	18	
	3	60	5	15	25	
	20	398	6	124	31	
	20	398	8	154	39	
	17	338	5	83	25	
HACUH0c (Upper Harris Creek, Harris Creek)	7	129	7	49	38	56.5 ±0.7
	16	295	18	285	97	
	12	221	9	111	50	
	21	387	8	163	42	
	23	424	10	234	55	
HCORP0a (ORP Bar, Harris Creek)	4	133	10	39	29	17.1 ±1.5
	0	-	-	-	Blank quad	
	15	497	5	75	15	
	12	398	5	55	14	
	13	431	4	51	12	
	4	133	5	20	15	
HCORP0b (ORP Bar, Harris Creek)	13	392	3	40	10	13.8 ±1.6
	10	301	3	34	11	
	7	211	2	17	8	
	1	30	5	5	17	
	6	181	4	24	13	
	9	271	7	64	24	
HCORP0c (ORP Bar, Harris Creek)	12	151	6	70	46	84.9 ±0.7
	1	13	0	0	0	
	4	50	7	29	58	
	1	13	34	34	271	
	6	75	10	59	78	
	16	201	7	112	56	
HCORP0c2 (ORP Bar, Harris Creek)	9	225	1	10	4	14.3 ±1.6
	2	50	2	4	8	
	21	525	5	99	19	
	0	-	-	-	Blank quad	
	10	250	5	50	20	
	12	300	5	61	20	
SVRPE0b (Peach Orchard, Severn River)	18	423	3	56	13	13.2 ±1.7
	5	118	1	7	6	
	15	353	6	94	27	
	10	235	0	4	2	
	25	588	3	80	14	
	5	118	4	21	18	
SVRWU0b (Weems Upper, Severn River)	1	32	0	0	0	16.5 ±1.5
	7	223	8	53	24	
	1	32	0	0	0	
	1	32	4	4	13	
	15	478	5	72	15	
	5	159	15	76	48	

In an effort to understand why such a range of survival success was observed, we examined the percent survival variation within Harris Creek, as seen in Figure 4. There were no trends from up to down stream, and in fact adjacent plantings sometimes had very different percent survivals, suggesting that broader geographic variation was not a major factor in survival at this scale.

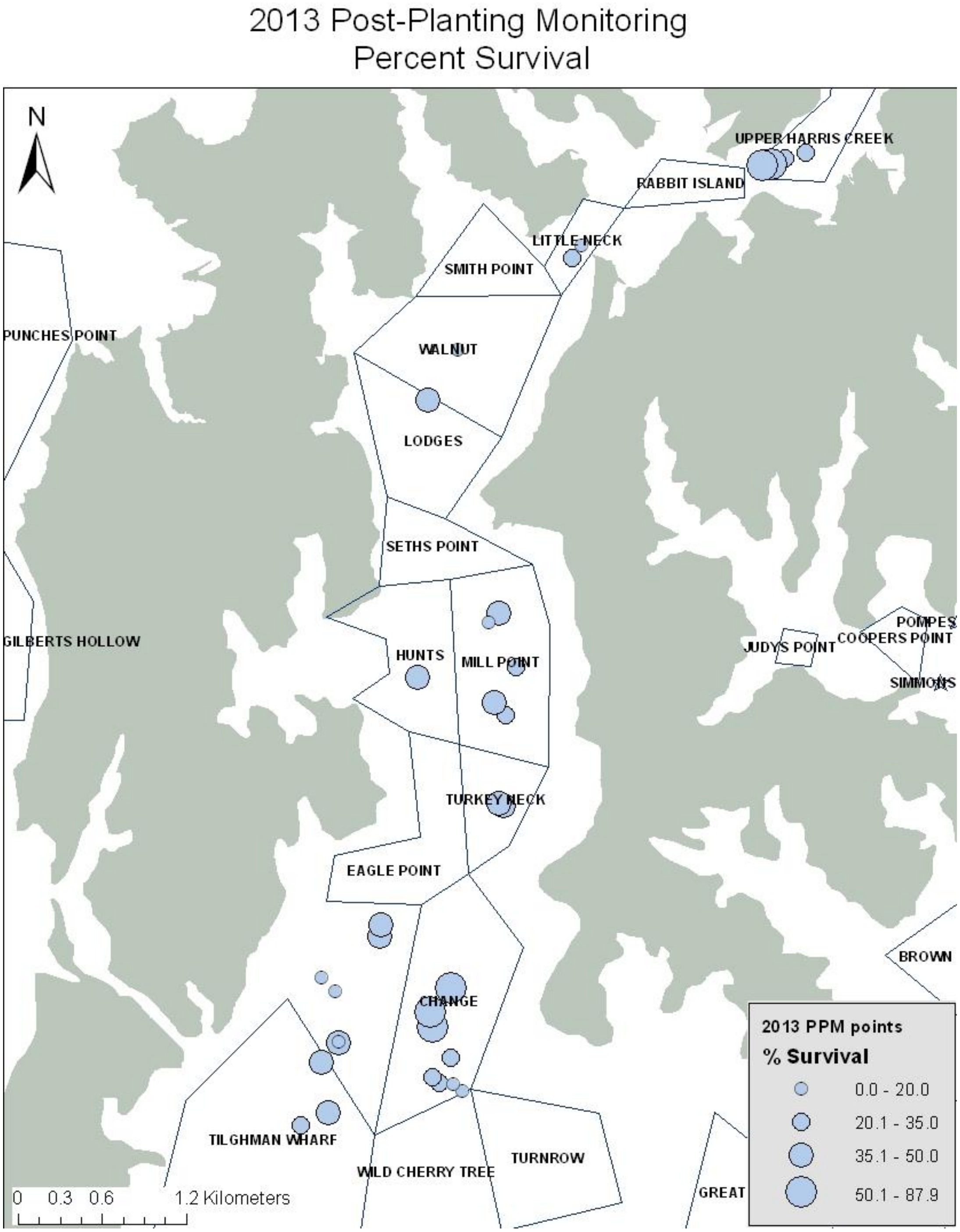


Figure 4. Map of percent survival in Harris Creek. Larger circles indicate better survival. Survival varies dramatically within a tributary, with no geographic trends evident.

Since another potential source of variation in survival is bottom type and quality, we compared natural and artificially restored bottom, as seen in Figure 5. While spat deployed on natural bottom fared slightly better than those on artificial substrate (44% versus 40% survival), the large standard deviations of each indicate that there is no meaningful difference in survival between the two groups. This implies that restoration produces bottom of as good a quality as natural, and that site selection of natural bottom finds sites that perform as well as reconstructed sites. The two bottom types also have similarly sized standard deviations, so it is unlikely that site-to-site differences in survival are related to whether they were planted on alternate or natural substrate.

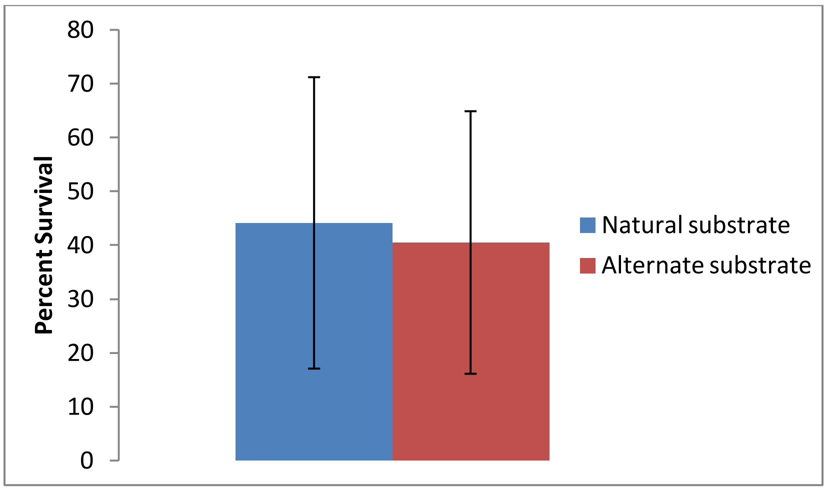


Figure 5. Percent survival in natural vs. alternate substrate. Error bars indicate standard deviation.

In order to examine the source of the variability seen in post-planting spat per shell and percent survival at the quadrat level, 2013 quadrat data were examined for a relationship between spat survival and initial spat density. These data were also compared to quadrat data collected during the 2010 through 2012 post-planting monitoring surveys. No clear trend was observed. Figure 6 shows that there was no discernible relationship between the initial spat per quad and spat survival in 2010 through 2013.

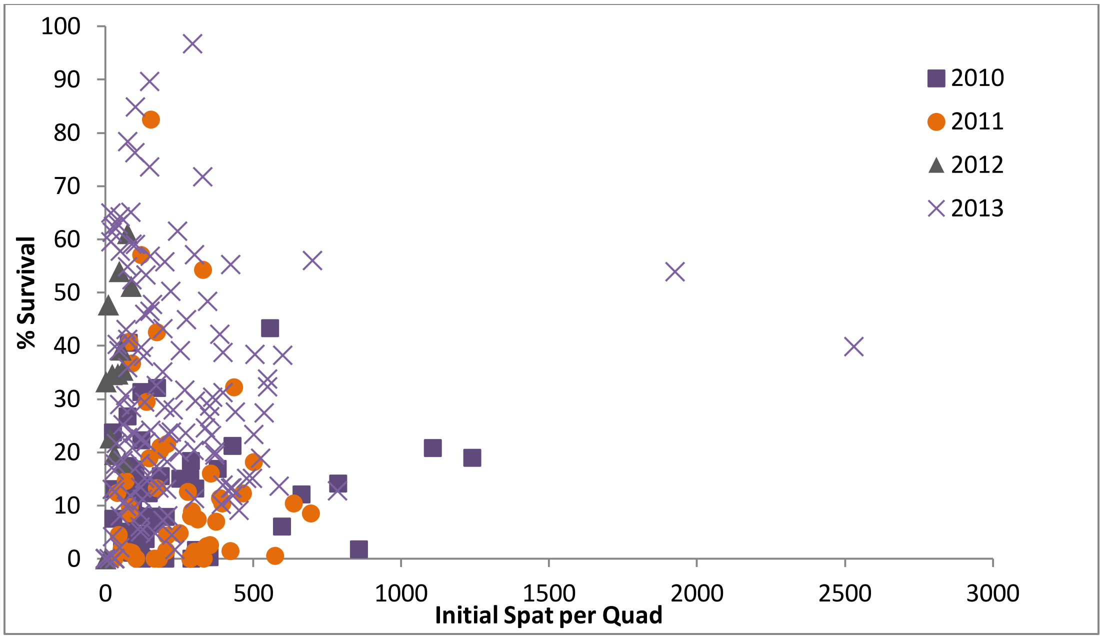


Figure 6. Percent survival relative to initial spat per quad, 2010 through 2013. Data show no obvious relationship between early spat survival and initial spat per quad.

The intent behind quadrat-based sampling was to collect data across a range of shell densities, in order to identify any patterns related to spat-planting density. However, achieving a wide range of initial spat on shell densities proved difficult in 2010, as most of the quads collected had fewer than 500 spat initially in the area sampled by the quad (see Figure 6). An attempt was made to address this issue in 2011, and some high density quads were selectively collected, but still a majority of the quads contained fewer than 500 spat initially in the area sampled by the quad. In 2012, divers continued sampling with quads, and targeted areas with high numbers of planting tracklines, however initial spat per quad estimates were below 200 spat per quad. In 2013 there were a few quads with higher initial spat numbers, but no evident relationship with survival. Therefore, although it is difficult to make conclusive statements about the effect of initial spat density on spat survival, these data do not suggest that initial spat density (at least in densities below 600 spat/quad) impacts spat survival four to eight weeks post planting.

Conclusions:

The overall spat survival observed during the 2013 post-planting monitoring survey was better than in any previous year on record since conducting post-planting monitoring, though was very similar to 2012 survival. As in 2012 and 2011, we believe that survival success was due in large part to planting site selection as it relates to bottom type. Finer scale identification using bottom type mapping helped to better identify the best locations for spat-on-shell and alternate substrate plantings in Harris Creek and likely contributed to the increased spat survival observed in 2012 and 2013. The majority of plantings surveyed in 2013 were deployed onto ACOE alternate substrate.

To address the relationship between bottom type and spat survival, the Paynter lab partnered with the Horn Point Lab Oyster Hatchery to design and execute a small-scale experiment to examine the effect of spat size and bottom type on spat survival beginning in 2011. Data from the 2011 trial suggested that spat survived better on shell and sand than mud; however questions remained unanswered relating to longer-term survival. This experiment was modified and repeated in 2012 with a final sampling in 2013. A variety of challenges compromised the effectiveness of the 2013 sampling, and as a result the experiment is being repeated with sampling results due in 2014 as part of a larger study investigating hatchery-reared and wild spat growth and survival. Detailed analyses of the data collected in this experiment will be presented to the ORP in a separate 2014 report.

The quadrat method of sample collection remains a valuable tool for understanding survival and population trends at restored oyster bars, but its utility in comparing survival success relative to density is limited due to a generally narrow range of oyster densities. Quadrat sampling provides important density data at year zero for restored oyster bars that can be compared in subsequent surveys, and thus we recommend continued use of the quadrat sampling method whenever possible.

The data collected during the post-planting monitoring survey from 2008 through 2013 speak to the variation present in the survival of hatchery spat-on-shell four to eight weeks post-planting. Spat survival at the bar level consistently ranges from below 10% to over 60% in each year sampled and does not seem to be related to any of the variables that we have measured in our survey (total amount of spat or shell, density of spat and shell, growth rate, region/river, environment). Considering the complex processes involved in executing a successful hatchery spat-on-shell planting, from the spawning of spat at the hatchery, to their transport to the site, to the conditions they grow in, and the sampling method used to estimate survival, it is not surprising that pinpointing factors that consistently influence survival is challenging.

Another factor that may influence short-term spat survival is predation. Experiments to examine the impacts of predation have been attempted in past years but methodological issues prevented the collection of informative data. We believe that the relationship between spat survival and predation is important to explore but should be done on a more comprehensive level in a controlled setting by a student or researcher dedicated to that problem alone.

Overall, the 2013 planting season showed high spat survival, likely due in large part to enhanced planting site selection. Unlike in 2012, large natural spat sets were not observed in Harris Creek in 2013. As the Harris Creek sanctuary restoration blueprint continues to be fulfilled, we will hopefully gain a greater understanding of both early and late spat survival as we monitor spat-on-shell plantings both within and outside of Harris Creek.

Section IV: Patent Tong Survey 2013

Patent tong surveys were conducted in the fall of 2013 on oyster bars in the Chester and Choptank Rivers. According to the ORP monitoring plan, restoration sites are targeted for patent tong surveys two and five years post-planting. Often survey sites have been over-planted, which creates a challenge when attempting to target a single year-class in addition to requiring consecutive surveys at the same site. To alleviate this issue, in 2013 entire bars were surveyed rather than targeting a single year-class. Thus, all plantings at each site were surveyed. Table 1 details the sites surveyed in 2013. Figure 1 indicates the sampling sites for the 2013 patent tong survey. Black circles represent individual bars sampled.

Survey Summary

Table 1. Oyster bars surveyed during the 2013 field season by river and site.

River	Yates Bar Name	Planting Years	Date Surveyed
Chester River	Strong Bay	2003, 2005, 2007-2010	9/30/2013
Choptank River	States Bank	2003, 2005, 2007-2010	10/21/2013

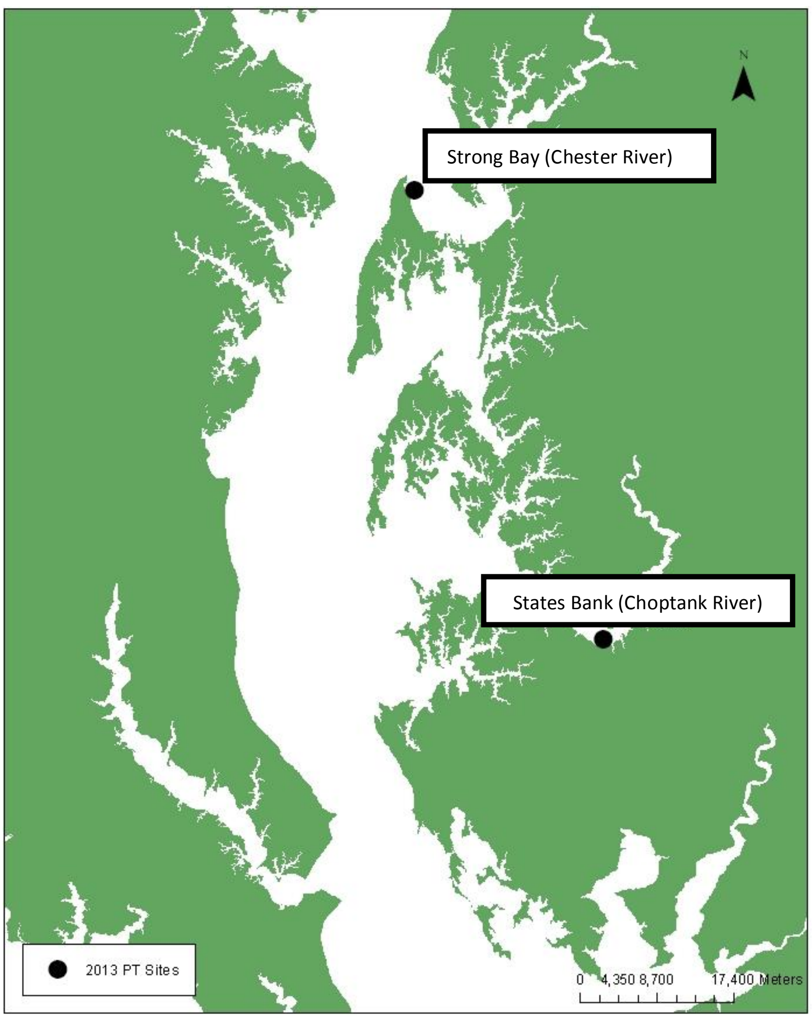


Figure 1. 2013 patent tong survey sampling sites. Black circles represent individual bars sampled.

Methods

Using ArcGIS, a grid of 25 m x 25 m cells was overlaid on the planted area and each grid cell was sampled with hydraulic patent tongs. Statistically, this is defined as a systematic survey and provides not only data on population abundance but also on spatial distribution. Grids for each site, as well as a site data summary, are presented in the "site specific data" section of this report. A series of metrics was collected from each grab, as detailed in Table 2. These metrics were used to generate other averages for each site. The density of oysters at each point was calculated using the area of the tongs and a population estimate was generated using these density data. The total biomass of oysters at each bar was estimated according to Liddel (2007). All data were incorporated into a GIS file in order to allow for spatial presentation of point observations.

Table 2. Patent tong survey metrics. Data collected with each patent tong grab are described.

Data Type	Description
Substrate	Primary, secondary, and tertiary (when present) substrate present in each grab. (Oyster, loose shell, shell hash, sand, mud, rock, or hard bottom)
Shell score	Amount of shell in the patent tong on a scale from 0-5. (0 = no shell in tongs, 5 = tongs full of shell)
Percent black shell	Amount of anoxic versus exposed shell in each grab. (Expressed as a percentage.)
Oyster number	Count of each live or dead (box or gaper) oyster in each grab.
Oyster size	Measurement (to the nearest mm) of each live and dead oyster. At minimum, fifty oysters in each grab were measured and additional oysters were counted.

At each site oysters were collected to sample for dermo disease, caused by the protozoan *Perkinsus marinus*. Because dermo infection levels may increase with age, oysters were sampled according to size at each site. Two size classes of oysters were collected at each site; 30 oysters were collected for each class. Samples were evaluated to determine disease prevalence and weighted intensity within each class. Prevalence refers to the percentage of animals infected at each site and weighted intensity refers to the degree of infection at each site on a scale of zero to five, zero indicating no infection and five indicating very high infection.

Site Specific Data

Survey summaries are presented for both Strong Bay and States Bank. The survey grid for each site is shown below with corresponding planting polygons. Planting polygons represent the perimeter of planting tracklines at each site. Site metrics are presented, detailing the number of oysters surveyed, oyster lengths, oyster and biomass densities, exposed shell presence, and population estimates. The spatial distribution of shell, oysters, and substrate are also presented. Both oyster density and shell score data are presented on a color ramp with red representing high scores/densities and blue representing low scores/densities. Oyster density scales are different for each bar, as the number (and therefore densities) of oysters present at each bar was different. Shell score data are presented on a scale of zero to five, with zero indicating no shell (blue on maps) and five indicating tongs full of shell (red on maps). Substrate distribution is depicted using a similar color scale, however because many more substrate categories exist, their color designations are more complex. On substrate maps, bottom considered to be poor oyster habitat (mud or sand with little or no shell) is shown in colors ranging from black to light blue. More suitable oyster habitat is shown in colors ranging from aqua to pink.

Overall site success is analyzed through factors influencing restoration success that are measured in the patent tong survey: percent of the expected population remaining on the bar, average oyster density, average oyster biomass density, disease prevalence and intensity, amount of area with good shell coverage, and the average percent of buried shell in each grab. These factors are all taken into account when discussing the success of each bar.

Strong Bay

Strong Bay, a sanctuary bar in the lower Chester River, includes planting from six year-classes as seen in Figure 2. All year-classes were surveyed in 2013 to maximize future survey efficiency with the expectation of returning to this site to survey in three years, and potentially eliminating areas that were absent of oysters in 2013. The most recent planting at Strong Bay took place in 2010, however plantings extend back through 2003. In several cases, more recent plantings were placed on top of older plantings.

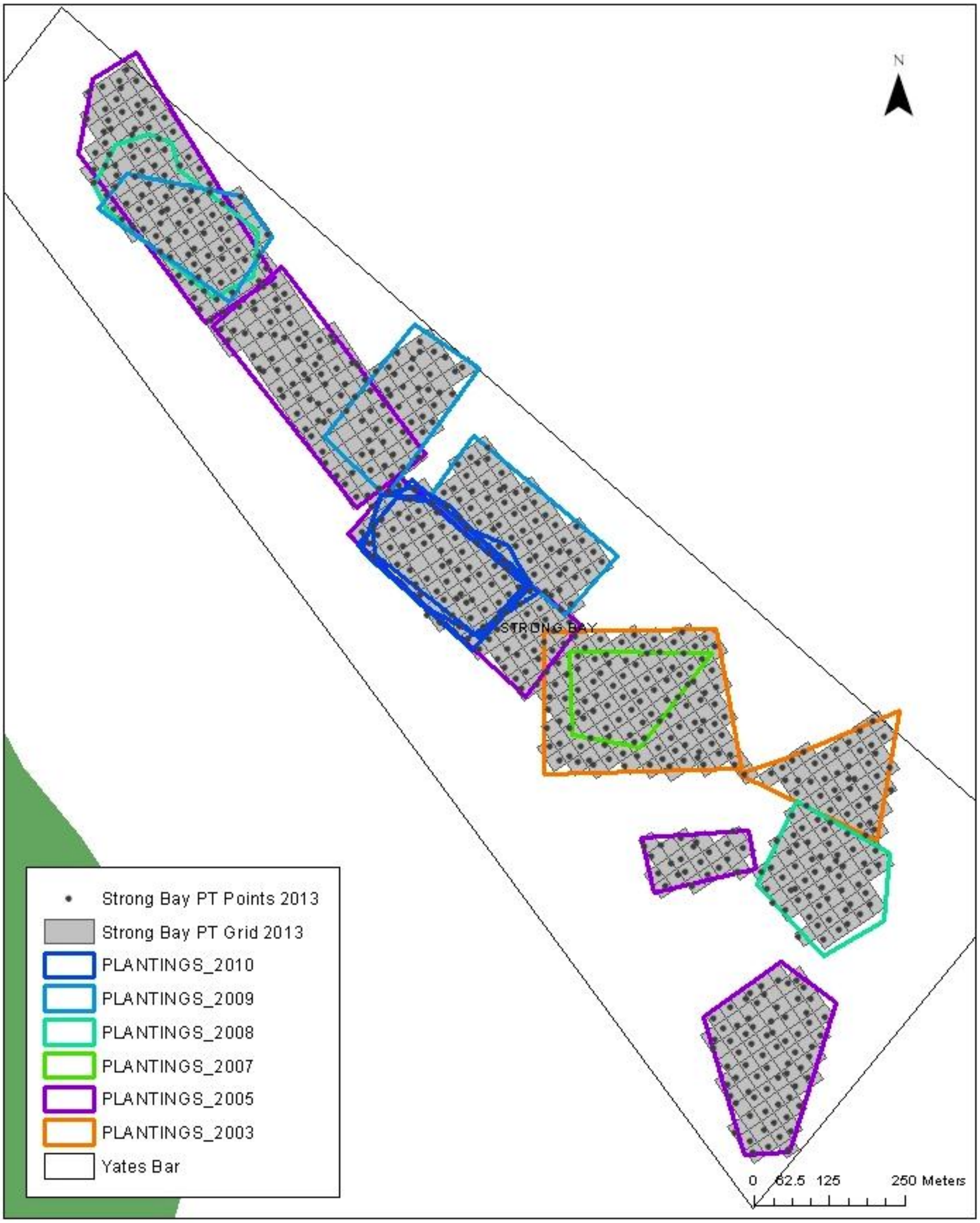


Figure 2. Strong Bay patent tong sampling grid. The survey area at Strong Bay is shown, with gridded cells in light gray. Sampled points are represented by dark gray circles; all cells were sampled excluding a section blocked by an anchored barge north of the 2010 planting. Each year-class planting is shown in a distinctly colored polygon.

Table 3 summarizes the metrics collected for Strong Bay in 2013. Dead oysters (as boxes or gapers) represent a small percentage of the number of oysters surveyed, suggesting that natural mortality is not a major factor influencing the oyster population at Strong Bay presently. The mean oyster length at Strong Bay was 106 mm, but a wide range of error (63 mm) suggests a population comprised of many age classes—this is expected based on the many plantings at this site. Oyster density and biomass density are typically evaluated relative to the Oyster Metrics Workgroup's (OMW) criteria to qualify a restored site as successful. Among these criteria are minimum threshold oyster densities of 15 oysters/m^2 and biomass densities of 15 g dry weight/m^2. Strong Bay does not meet either of these minima based on the 2013 survey. The 2013 survey also revealed overall low shell scores, as suggested by the "% total area with shell coverage". Shell coverage was classified as points with shell scores of three or greater. Only 2% of points sampled at Strong Bay in 2013 qualified as having shell coverage. Additionally, the average percent of buried shell—shell that had been in anoxic conditions based on color—was 25% for the site, suggesting that a portion of the shell at Strong Bay is not available for oyster habitat or settlement.

Table 3. Data collected on 2013 patent tong survey at Strong Bay. "% total area with shell coverage" refers to the percentage of grabs at each bar with shell scores of three or greater. "Mean % buried shell" refers to the relative amount of black or anoxic shell when compared to the total amount of shell observed in each grab. SEM represents standard error of the mean.

# Live Oysters Surveyed	# Dead Oysters Surveyed	Dead Oysters (% of Total)	Mean Live Oyster Length (mm) ± SEM	Mean Live Oyster Density (#/m^2) ± SEM	Mean Biomass Density (g/m^2) ± SEM	% Total Area >5 Oysters/m^2	% Total Area with Shell Coverage	Mean % Buried Shell
2,114	250	12	106 ±63	1.8 ±0.2	3.7 ±0.4	9	2	25

Shell score (3a) and oyster density (3b) are mapped in Figure 3. Observed shell scores were fairly low throughout Strong Bay, as indicated in the figure. Higher shell scores (four or five) are represented by warmer colors (yellow and red) while low shell scores are shown in cooler colors (aqua or blue). Areas with the most shell at this site are found at the northern end of the bar, where 2005, 2008, and 2009 plantings occurred as well as patches near the center (2005 and 2010 overplantings) and southern end (2003, 2005, and 2007 plantings). Oyster density distribution (3b) patterns are somewhat similar, however not all areas of shell contain oysters. Oyster densities at Strong Bay ranged from 0 to 33.4 oysters/m^2, with highest densities near the northern end (2005, 2008, and 2009 plantings).

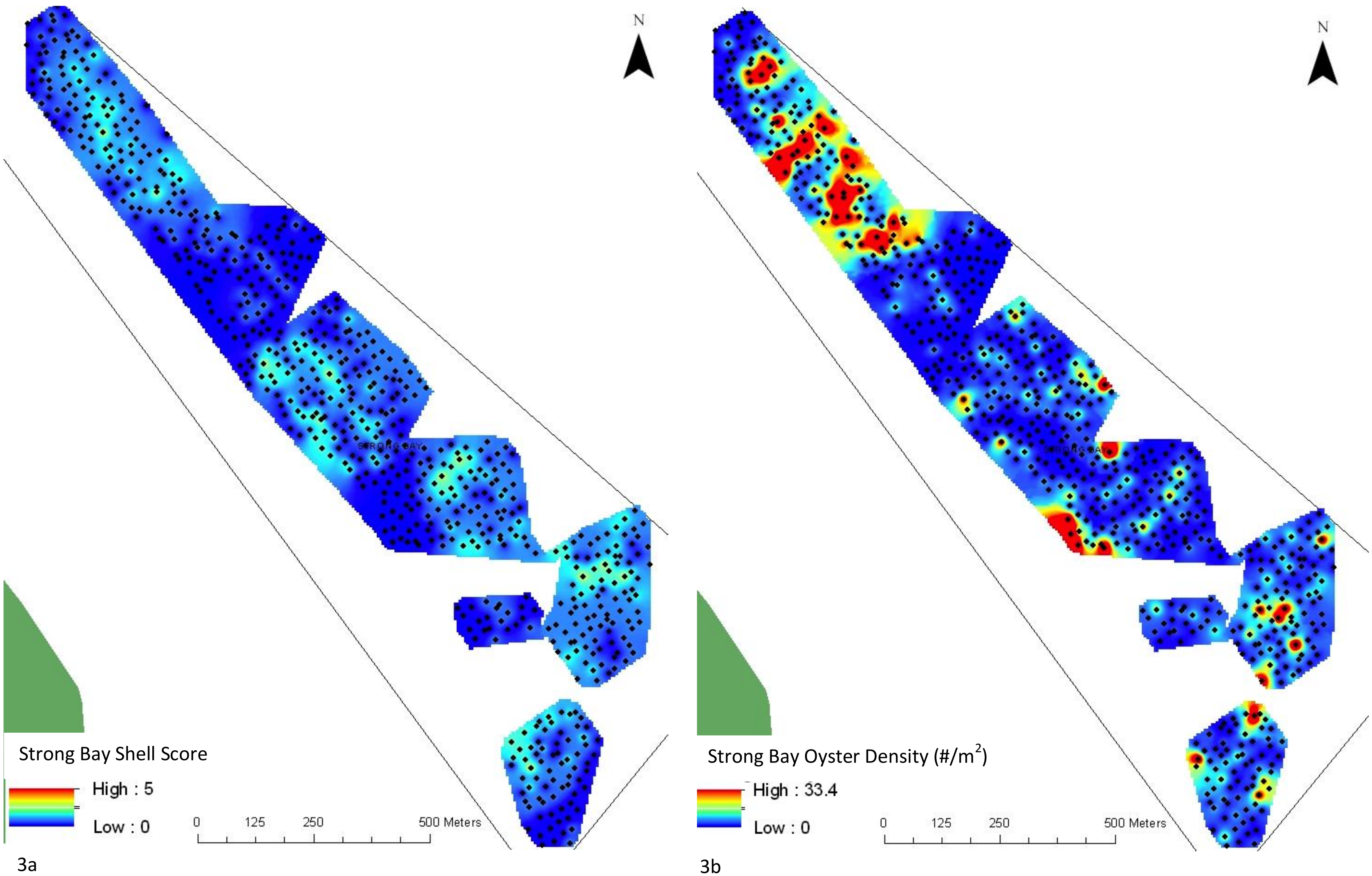


Figure 3. Strong Bay shell score (a) and oyster density (b) distribution. Shell score is ranked on a scale from 0 to 5; oyster density ranged from 0 to 33.4 oysters/m^2 at this site.

Substrate observations show that the majority of bottom at Strong Bay seems suitable for oysters, even with low observed shell scores. As seen in Figure 4, less than 25% of the bottom sampled at Strong Bay would be considered generally poor oyster habitat—unfavorable substrate combinations are shown in shades of black, purple, and blue while aquas through reds indicate better bottom with shell, oyster, or other hard substrate. 71% of grabs at Strong Bay revealed substrate of hard bottom or shell. Substrate data, when paired with shell score and oyster density maps, suggest that oysters were found on areas of good bottom and that although shell scores were low at Strong Bay, much of the site contains hard bottom with substrate suitable for oysters.

Using oyster density per grab, a population estimate was generated for Strong Bay. Table 4 shows an estimated 729,972 oysters based on the 2013 survey, however this is only 7% of the expected population. The expected population was calculated based on the following mortality calculation: it is assumed that approximately 90% of spat are lost within one year after planting and 15% of the remaining population each subsequent year. Expected population estimates were generated for each planting (excluding 2003; five year-classes were used) and combining the sum of each planting's expected 2013 population. Based on this calculation, Strong Bay is well below the expected population of over 9 million oysters.

Table 4. Expected oyster population vs. estimated oyster population at Strong Bay. The population estimate was calculated as the sum of all cell oyster densities multiplied by cell area (625 m^2). Planting data from 2003 were not available, thus planted spat from 2003 are not included in these calculations.

Plant Years	**Spat Planted**	**Expected 2013 Population (Oysters)**	**Population Estimate from Survey (Oysters)**	**% of Expected**
2005, 2007-2010	175,880,00	9,452,719	729,972	7

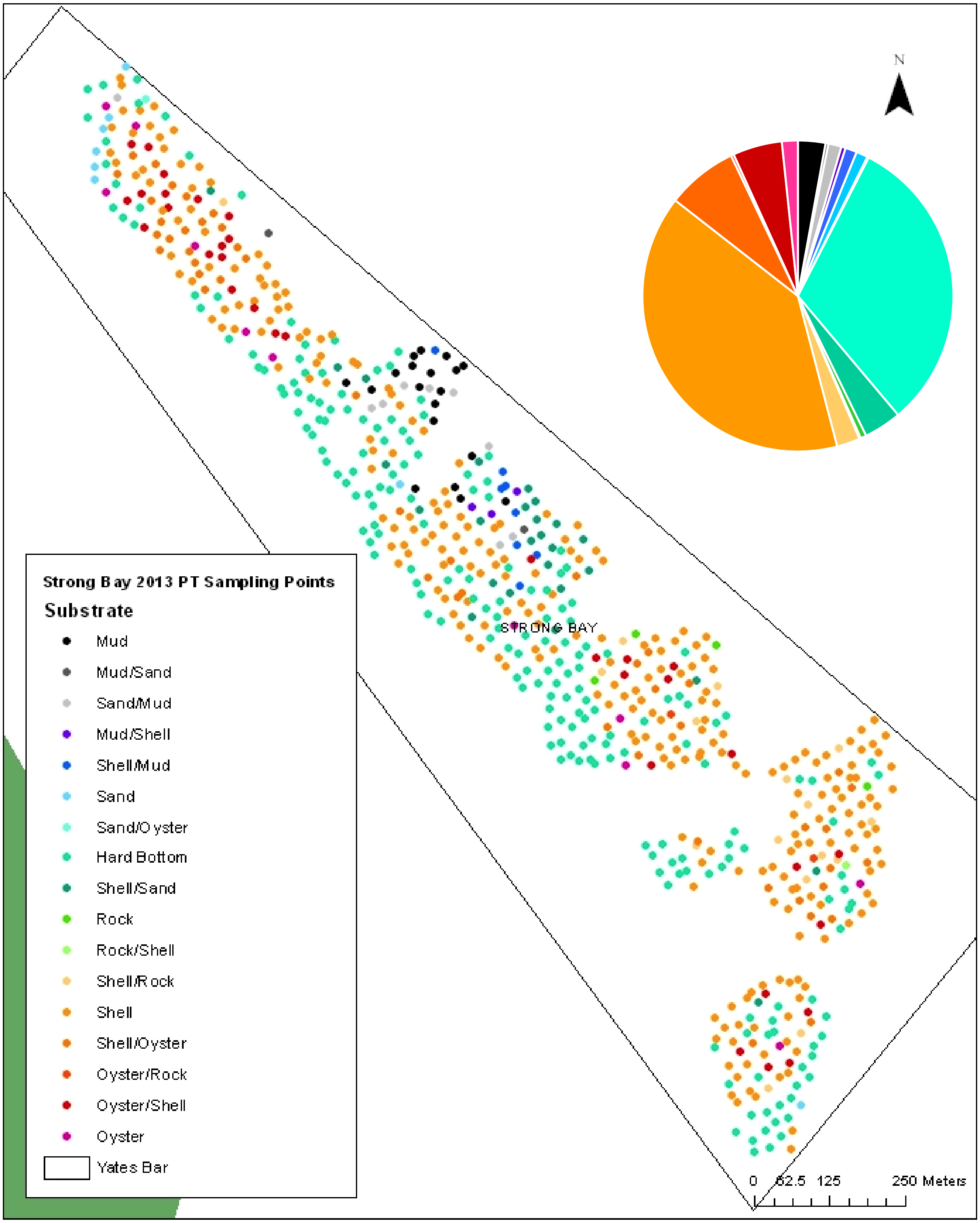


Figure 4. Strong Bay substrate observations. Sampling points are coded on the map such that shades of black, blue, and purple indicate bottom that is not ideal oyster habitat while other colors (aquas, greens, oranges, and reds) represent better bottom with some form of hard substrate (oyster, shell, rock, or hard bottom). The pie chart shows the overall distribution of these substrates. The majority of bottom surveyed at Strong Bay was hard bottom (31%; aqua) and shell (40%, light orange).

Disease was investigated at Strong Bay, as seen in Table 5. Two size classes were sampled with mean lengths of 72 mm and 130 mm. Prevalence was 97% in both groups, but larger oysters possessed a higher infection intensity (2.90 versus 1.81). These values are considered high with the potential to impact a population, particularly if salinities are elevated.

Table 5. Strong Bay disease metrics. Dermo prevalence (percentage of animals infected) and weighted intensity (average infection level on a zero to five scale) by site are shown here. Samples were separated into two size classes.

Date Collected	# Oysters Tested	Mean Shell Height (mm)	Mean Total Weight (g)	Mean Shell Weight (g)	Dermo Prevalence (%)	Dermo Weighted Intensity
14-Oct-13	30	72	83.8	76.1	97	1.81
	30	130	196.9	155.2	97	2.90

Previous surveys at Strong Bay suggested possible evidence of illegal harvest based on lower oyster numbers than expected and a relatively low proportion of dead oysters observed on the survey. The relative number of dead oysters found in 2013 was again low (only 12% of the surveyed oysters), however dermo infection intensity was fairly high at this site. It is possible that future surveys will show greater evidence of natural mortality at Strong Bay.

Only 9% of the area surveyed contained greater than five oysters per m^2, indicating that the majority of plantings at Strong Bay are not approaching OMW metrics of success. Both mean oyster and biomass density values are below the minimum thresholds of 15 oysters/m^2 and 15 g dry weight/m^2. In 2012, however, the northernmost 2009 planting at Strong Bay was at or above these minimum criteria, suggesting that at least some of the plantings at Strong Bay are approaching minimum threshold metrics of success. The oyster density plot (Figure 3b) supports this, as the majority of oysters are found in the northern 2009 planting. Incidentally, the area of the northern 2009 planting is also the area where an anchored barge is maintained throughout most of the year, possibly offering a sanctuary from poaching.

Although the central portion of Strong Bay does not appear to contain many oysters based on the 2013 survey, it is not devoid of oysters. Therefore, it is recommended that the entire bar be surveyed again in three years before eliminating any of the survey area. Considering the relatively low oyster numbers throughout much of this site, however, if any areas were to be targeted, the northern end (containing multiple year-classes) is the best candidate to continue monitoring.

States Bank

States Bank, a sanctuary bar in the upper Choptank River includes planting from six year-classes as seen in Figure 5. As with Strong Bay, all year-classes were surveyed in 2013. The most recent planting at States Bank also took place in 2010, however plantings extend back through 2003. The majority of plantings overlap at the northern end of the grid, with the southern half comprised entirely of 2003 plantings.

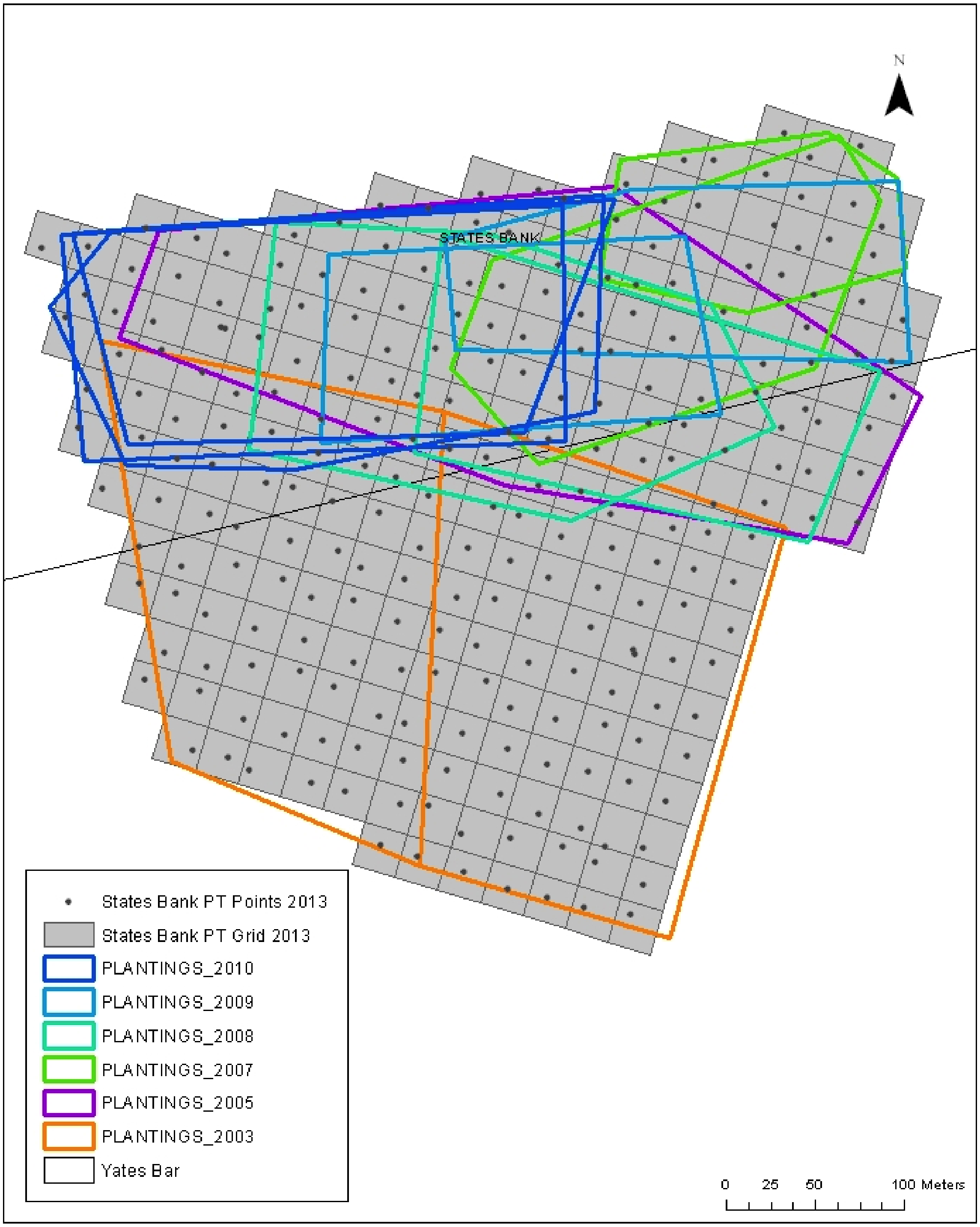


Figure 5. States Bank patent tong sampling grid. The survey area at States Bank is shown, with gridded cells in light gray. Sampled points are represented by dark gray circles. Each year-class planting is shown in a unique-colored polygon.

Table 6 summarizes the metrics collected for States Bank in 2013. Dead oysters (as boxes or gapers) represent a very small percentage of the number of oysters surveyed (4%), suggesting that natural mortality is not a major factor influencing the oyster population at States Bank. Similar to Strong Bay, the mean oyster length at States Bank was 110 mm, but with a fairly large standard error (33 mm) suggesting a population comprised of many age classes. States Bank approaches the OMW minimum oyster density value with a mean density of 9 oysters/m^2, and exceeds the mean biomass density with a mean biomass density of 17.5 g/m^2. Shell coverage (27%) was better at States Bank than Strong Bay, with a lower relative amount of buried shell (11%).

Table 6. Data collected on 2013 patent tong surveys at States Bank. "% total area with shell coverage" refers to the percentage of grabs at each bar with shell scores of 3 or greater. "Mean % buried shell" refers to the relative amount of black or anoxic shell when compared to the total amount of shell observed in each grab. SEM represents standard error of the mean.

# Live Oysters Surveyed	# Dead Oysters Surveyed	Dead Oysters (% of Total)	Mean Live Oyster Length (mm) ± SEM	Mean Live Oyster Density (#/m^2) ± SEM	Mean Biomass Density (g/m^2) ± SEM	% Total Area >5 Oysters/m^2	% Total Area with Shell Coverage	Mean % Buried Shell
3,590	148	4	110 ±33	9.0 ±0.9	17.5 ±1.9	35	27	11

Shell score (6a) and oyster density (6b) are mapped in Figure 6. Both shell score and oyster distribution show that most shell and oysters were located in the northern half of the plot, within 2005-2010 plantings. Oyster density was particularly high in the central part of the northern portion of the grid where multiple plantings overlap. Shell scores ranged from zero to five, with mainly zeroes in the southern portion. Oyster densities ranged from 0 to 76 oysters/m^2. The distribution of oysters and shell at this site supports the idea that shell score and oyster density are positively correlated, as suggested in previous reports submitted to the Oyster Recovery Partnership.

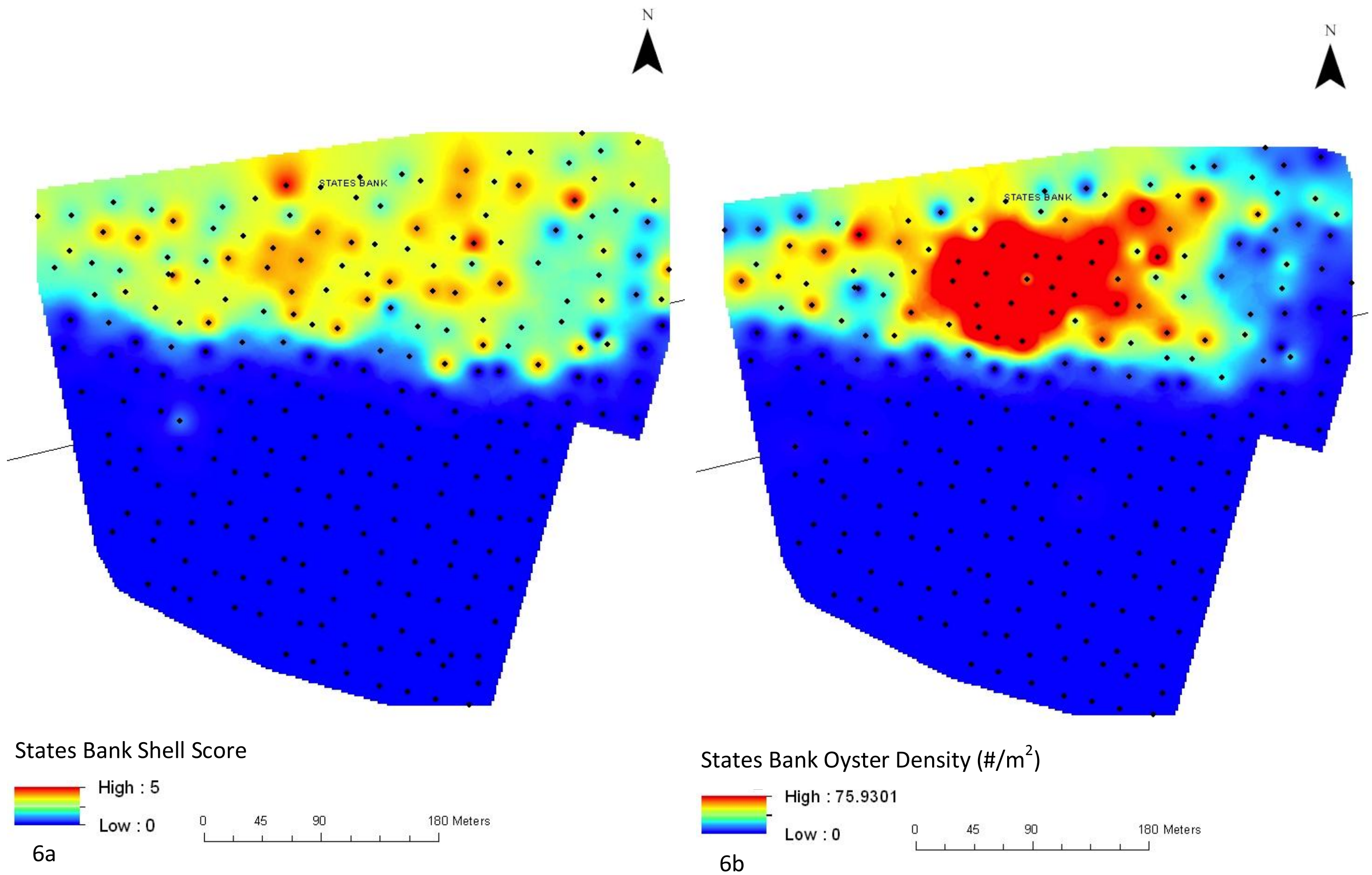


Figure 6. States Bank shell score (a) and oyster density (b) distribution. Shell score is ranked on a scale from 0 to 5; oyster density ranged from 0 to 75.9 oysters/m^2 at this site.

Substrate observations mirror shell score spatial data in that the most suitable oyster habitat is found in the northern portion of the site. Figure 7 shows that points with some combination of oyster and shell (shades of orange and red) were observed in the northern portion. The southern portion of the site, where only 2003 plantings of spat-on-shell were deployed, contained a mixture of rock and mud. The dominant substrates at States Bank were mud (25% of grabs), rock (23%), and oyster/shell (14%).

As seen in Table 7, the survey-based population estimate at States Bank was close to 1.4 million oysters, however this is only 19% of the expected population based on the formula described above. As with Strong Bay, all plantings with the exception of the 2003 planting were incorporated into the expected population estimate.

Table 7. Expected oyster population vs. estimated oyster population at States Bank. The population estimate was calculated as the sum of all cell oyster densities multiplied by cell area (625 m^2). Planting data from 2003 were not available, thus planted spat from 2003 are not included in these calculations.

Plant Years	Spat Planted	Expected 2013 Population (Oysters)	Population Estimate from Survey (Oysters)	% of Expected
2005, 2007-2010	123,060,000	7,391,164	1,393,634	19

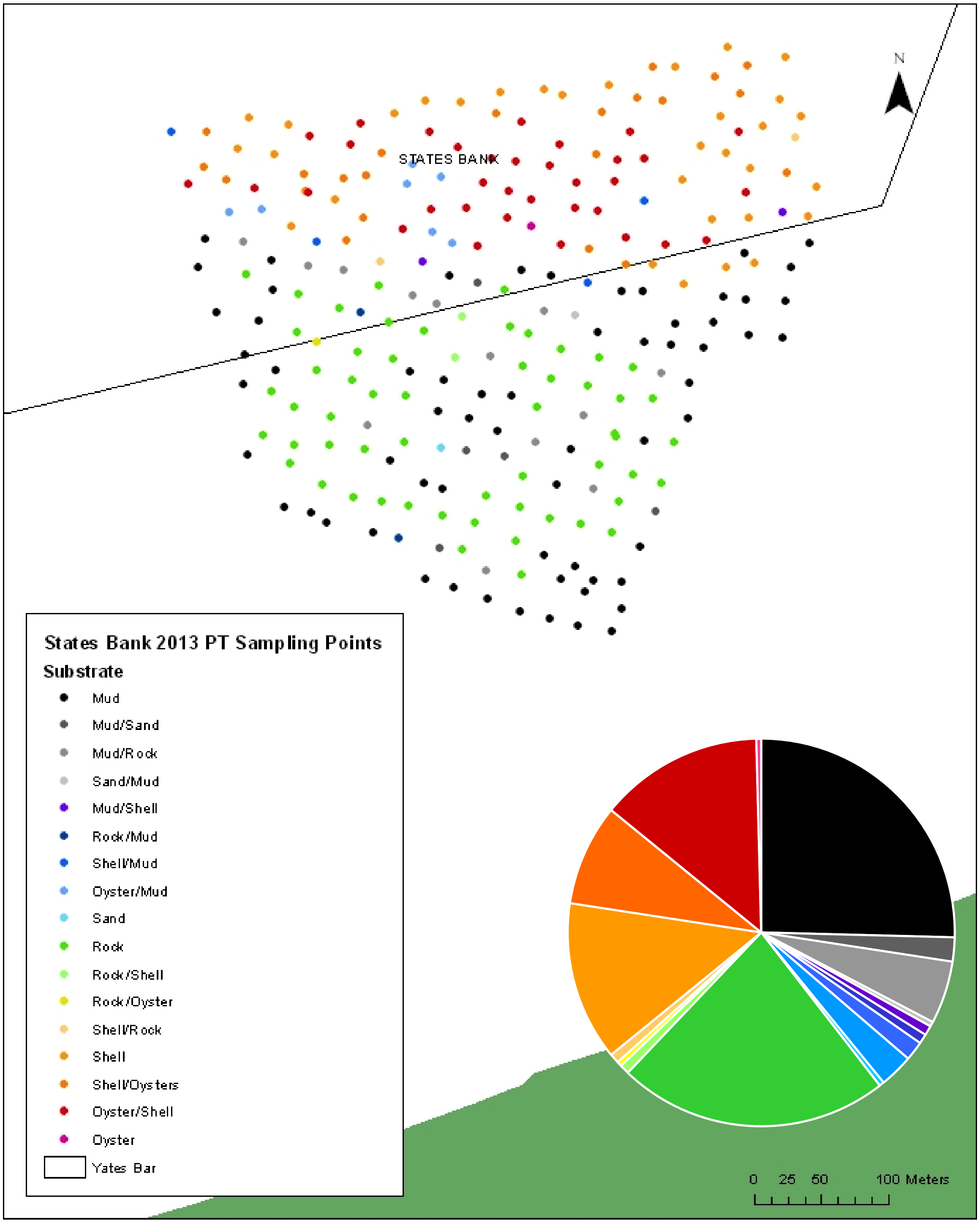


Figure 7. States Bank substrate observations. Sampling points are coded on the map such that shades of black, blue, and purple indicate bottom that is not ideal oyster habitat while warmer colors (aqua, greens, oranges, and reds) represent better bottom with some form of hard substrate (oyster, shell, rock, or hard bottom). The pie chart shows the overall distribution of these substrates. Roughly 40% of grabs had substrate considered to be poor oyster bottom; dominant substrates were mud (25%, black), rock (23%, green), and oyster/shell (14%, red).

Disease data from States Bank are presented in Table 8. As at Strong Bay, two size classes were sampled. The mean lengths of each group at States Bank were similar to Strong Bay samples, at 71 mm and 121 mm. Prevalence was 40% in the smaller group, with a weighted intensity of 0.64. Larger oysters had a prevalence of 89% with a weighted intensity of 1.19. Though infection intensity at States Bank is lower than at Strong Bay, these values could also prove detrimental given the appropriate conditions (high salinity).

Table 8. States Bank dermo metrics. Dermo prevalence (percentage of animals infected) and weighted intensity (average infection level on a zero to five scale) by site are shown here. Samples were separated into two size classes for each site.

Date Collected	# Oysters Tested	Mean Shell Height (mm)	Mean Total Weight (g)	Mean Shell Weight (g)	Dermo Prevalence (%)	Dermo Weighted Intensity
22-Oct-13	30	71	85.0	72.1	40	0.64
	27	121	204.2	167.9	89	1.19

The relative proportion of dead oysters observed at States Bank was low (4%) suggesting that natural mortality is not playing a large role in determining population trends. Dermo prevalence and intensity are moderate within the population, but may prove more detrimental following one or several seasons of high salinity. The surveyed population was only 19% of the expected population based on planting numbers, but mean oyster density (9 oysters/m^2) at States Bank approaches the OMW metric of 15 oysters/m^2 and the biomass density exceeds the minimum criteria. More than 5 oysters/m^2 were observed in only 35% of grabs; none of these grabs occurred in the 2003 planting area. Future surveys would likely eliminate the 2003 plantings, as minimal oysters were found in that area, and density metrics may both exceed the minimum OMW criteria. Based on survey data presented here, it is recommended that States Bank be surveyed again in three years, excluding the 2003 plantings

Conclusions

The 2013 patent tong survey involved a different approach from previous years. While maintaining a two and five year post-planting sampling plan, entire sites were surveyed rather than a single target class within a site. This helped to alleviate challenges that arose from oysters of multiple year-classes on a site and the need to return to such sites year after year. In 2013, all plantings at Strong Bay in the Chester River and States Bank in the Choptank River were surveyed. It is recommended that both sites be surveyed again in three years, possibly eliminating the 2003 planting from the States Bank target area.

The surveys revealed a heterogenous and small population of oysters at Strong Bay and a very distinct area with many oysters at States Bank. While at States Bank the presence of shell was coupled with the presence of high densities of oysters, Strong Bay did not strongly follow this general pattern. While shell is ideal for oyster growth and survival, the patent tong survey this year (and in 2012) indicated that high shell scores are not necessary for the presence of oysters.

The metrics collected in the 2013 patent tong survey provide valuable information about the health, growth, and density of oysters at each site surveyed, especially regarding the inherent variation present in the populations at these restoration sites. Average oyster densities were below the OMW minimum metric of success at both bars, however more recent plantings (2009) are more likely to approach or exceed density values of 15 oyster/m^2. Strong Bay also possessed an average biomass density below the OMW minimum criteria, while States Bank surpassed the minimum 15 g/m^2. The survey population estimates of both bars were much lower than the expected population estimate, suggesting increased mortality due to natural or other causes. Disease intensity was noteworthy at each site, particularly in the larger size classes, however a small proportion of dead oysters were observed in the survey. This suggests that natural mortality may not be the dominant factor influencing population trends at these sites.

The variation in data at these two sites highlights the natural variability present in the restored oyster network in the Chesapeake Bay. While many metrics are monitored, it is difficult to highlight a single factor that influences the success of a restored bar. To better understand factors influencing long-term restoration success, four sites in Harris Creek were also surveyed with patent tongs as part of a multiple-year survey. The 2013 surveys represent year two for three sites in Harris Creek, and year one for the fourth site. The results from this segment of long-term surveys are presented in Section V below.

Section V: Long-Term Patent Tong Monitoring 2013

Survey Summary

In order to develop an understanding of oyster population dynamics over time following a spat-on-shell planting, in 2012 we began monitoring of four individual oyster bars, with surveying to continue for five consecutive years. Previous long-term monitoring of other locations proved valuable in understanding how population levels and substrate at restored bars changes through time, however, these bars were small in area and not all bars were in sanctuary areas. Therefore, three new bars were chosen in 2012 to be the target of a second round of long-term monitoring and were surveyed in 2012. In 2013, an additional bar was added (Table 1). All bars are in Harris Creek, the first tributary-level restoration site targeted by NOAA, DNR, and ACOE. Figure 1 shows the locations of the long-term monitoring sites surveyed in 2013, with bars marked in black and labeled adjacently.

Table 1. Oyster bars targeted for long-term monitoring in 2013.

Tributary	Bar Name	Plant Year	Previous survey	Initial Spat Planted (Millions)
Harris Creek	Little Neck	2012	2012	52
	Lodges	2012	2012	28
	Mill Point	2011	2012	52
	Change	2012	--	10

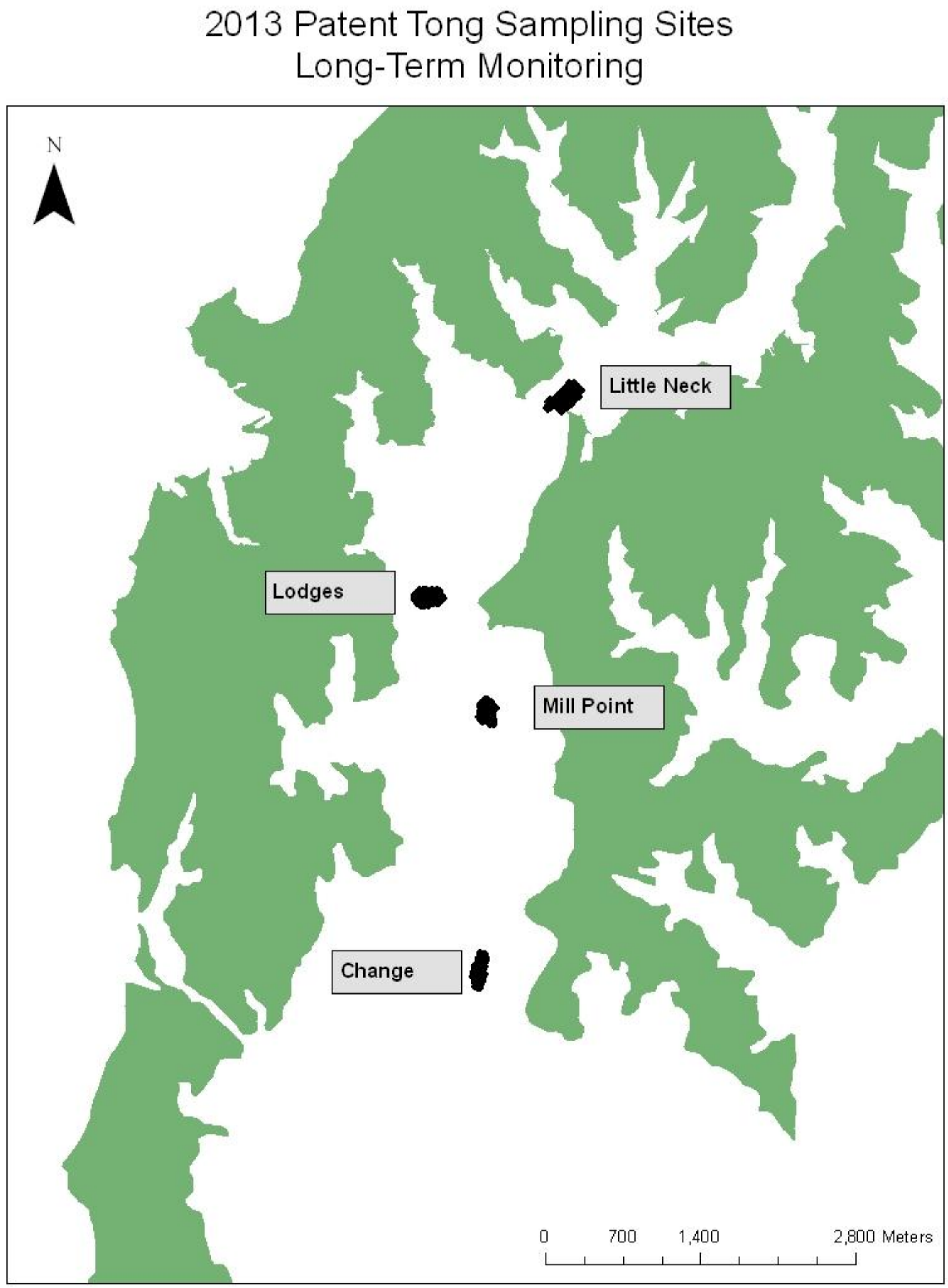


Figure 1. Map of long-term monitoring oyster bars. Sampled bars are black, with bar names in labeled. All bars are in Harris Creek.

Methods

As with the regular patent tong survey sites detailed in Section IV, a grid of 25 m x 25 m cells was overlaid on the planted area and each grid cell was sampled with hydraulic patent tongs. A series of metrics was collected from each grab, as detailed in Table 2. These metrics were used to generate other averages for each site. The density of oysters at each point was calculated using the area of the tongs and a population estimate was generated using these density data. The total biomass of oysters at each bar was estimated according to Liddel (2007). This equation was used to calculate the total biomass in each surveyed cell; cell data were then totaled to determine each bar's biomass. The location of each patent tong survey point was recorded using GPS-enabled ArcPad. This position information allowed for spatial analysis of the data collected at each patent tong survey point.

Table 2. Patent tong survey metrics. Data collected with each patent tong grab are described.

Data Type	Description
Substrate	Primary, secondary, and tertiary (when present) substrate present in each grab. (Oyster, loose shell, shell hash, sand, mud, rock, or hard bottom)
Shell score	Amount of shell in the patent tong on a scale from 0-5. (0 = no shell in tongs, 5 = tongs full of shell)
Percent black shell	Amount of anoxic versus exposed shell in each grab. (Expressed as a percentage.)
Oyster number	Count of each live or dead (box or gaper) oyster in each grab.
Oyster size	Measurement (to the nearest mm) of each live and dead oyster. At minimum, 50 oysters in each grab were measured and additional oysters were counted.

At each site oysters were collected to sample for dermo disease, caused by the protozoan *Perkinsus marinus*. Because dermo infection levels may increase with age, oysters were sampled according to size at each site when appropriate. Samples were evaluated to determine disease prevalence and weighted intensity within each class. Prevalence refers to the percentage of animals infected at each site and weighted intensity refers to the degree of infection at each site on a scale of zero to five, zero indicating no infection and five indicating very high infection.

This was the second year of surveying for three of the bars, and the first survey year for the fourth bar (Change). For previously surveyed bars, results include comparison to 2012 survey results. Results for individual sites are presented below.

Little Neck

Little Neck is an oyster bar located upriver in the Harris Creek sanctuary. It was planted during the summer of 2012 and surveyed with hydraulic patent tongs in the falls of 2012 and 2013. In addition, both native and hatchery oysters were collected and tested for disease (*Perkinsus marinus*, dermo) each year.

During the 2013 planting season, spat-on-shell were planted over the southernmost points of Little Neck. To make comparable analyses between 2012 and 2013, the points with overplanting were removed from the dataset and the 2012 data reworked with only the northern bar area included. Thus, the same cells were analyzed for both years in this report, but fewer points within each survey were analyzed in this report than were contained in the 2012 report.

As seen in Figure 2, the average size of oysters on this site increased between 2012 and 2013. The 2012 survey revealed oyster lengths reflective of the 2012 planting, with the majority of oysters measured at Little Neck between 30 mm and 70 mm in length, while a group of oysters were centered around 90 mm in length. In 2013, oysters were between 50 mm and 100 mm, with no separate larger contingent due to the large size of the bulk of the population. Still, some oysters were larger than would be expected from the 2012 planting, suggesting the presence of natural spat sets on this bar in the past. These larger oysters (>70 mm in 2012, >95 mm in 2013) were categorized as native, and were used to sample the natural population for dermo.

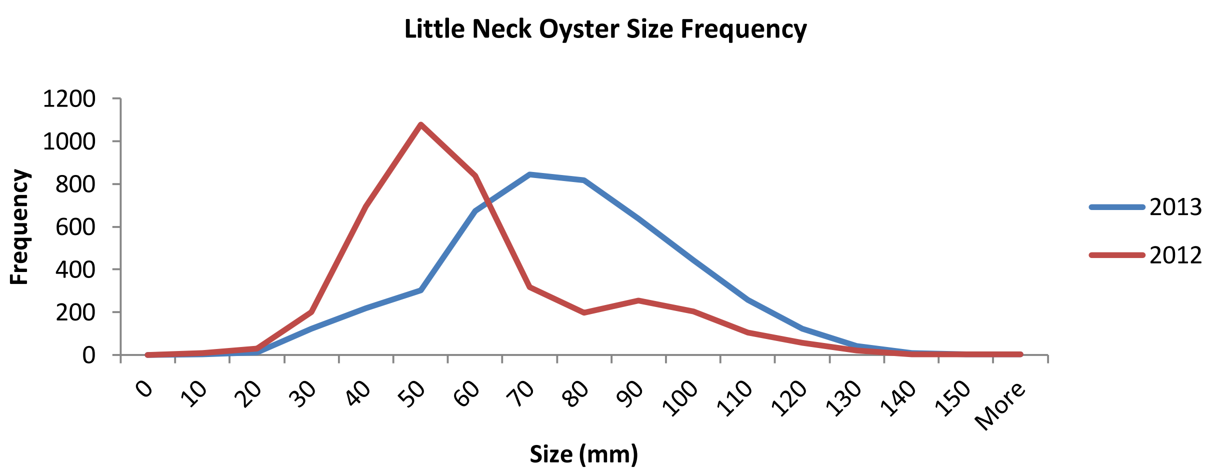


Figure 2. Little Neck oyster size frequency (2012 & 2013). Size frequency data reflect the 2012 planting in both survey years, though larger naturally occurring oysters were also observed. Note that this figure is not indicative of relative numbers of oysters, merely size composition.

Table 3 below summarizes oyster population metrics observed at Little Neck in 2012 and 2013. In both years, live oysters far outnumbered dead; specifically, 2.8% and 5.3% of sampled oysters were dead in 2012 and 2013 respectively. This is reiterated with the high percent of expected population values shown (expected population is calculated based on the equation described in Section IV, where the oyster population is expected to experience 90% mortality within the first year of planting, followed by 15% each subsequent year). Between 2012 and 2013 the mean oyster density diminished from 118 to 72 oysters/m^2. Similarly, the estimated total population of the bar decreased proportionally, as would be expected from natural oyster mortality over time. However, the overall biomass on the bar increased from 1,889 kg to 2,667 kg, which can be attributed to the growth of oysters as seen in Figure 2. Oyster density across the bar can be seen in Figure 3, which illustrates the heterogeneous distribution of oysters on Little Neck in both years, and the variability between years. The majority of oysters in 2012 were found in the southern central portion of the bar, while in 2013 oysters were more evenly distributed. Figure 4 shows mean biomass density at Little Neck for 2012 and 2013 and illustrates the increase in biomass between surveys.

Table 3. Little Neck oyster metrics (2012 & 2013). Oyster population and sampling metrics are shown for Little Neck. SEM represents standard error of the mean.

Sampling Year	Mean Oyster Length (mm)	Live Oyster Count	Box/Gaper Count	% Dead	Mean Oyster Density (#/m^2) ±SEM	Expected 2013 Population (Oysters)	Population Estimate from Survey (Oysters)	% of Expected	Biomass Density (g/m^2) ±SEM
2012	60	14,409	407	2.8	118 ± 14	5,211,000	5,591,615	107	39.8 ± 4.2
2013	75	8,899	501	5.3	71.8 ± 6.5	4,429,350	3,454,581	78	55.4 ± 5.1

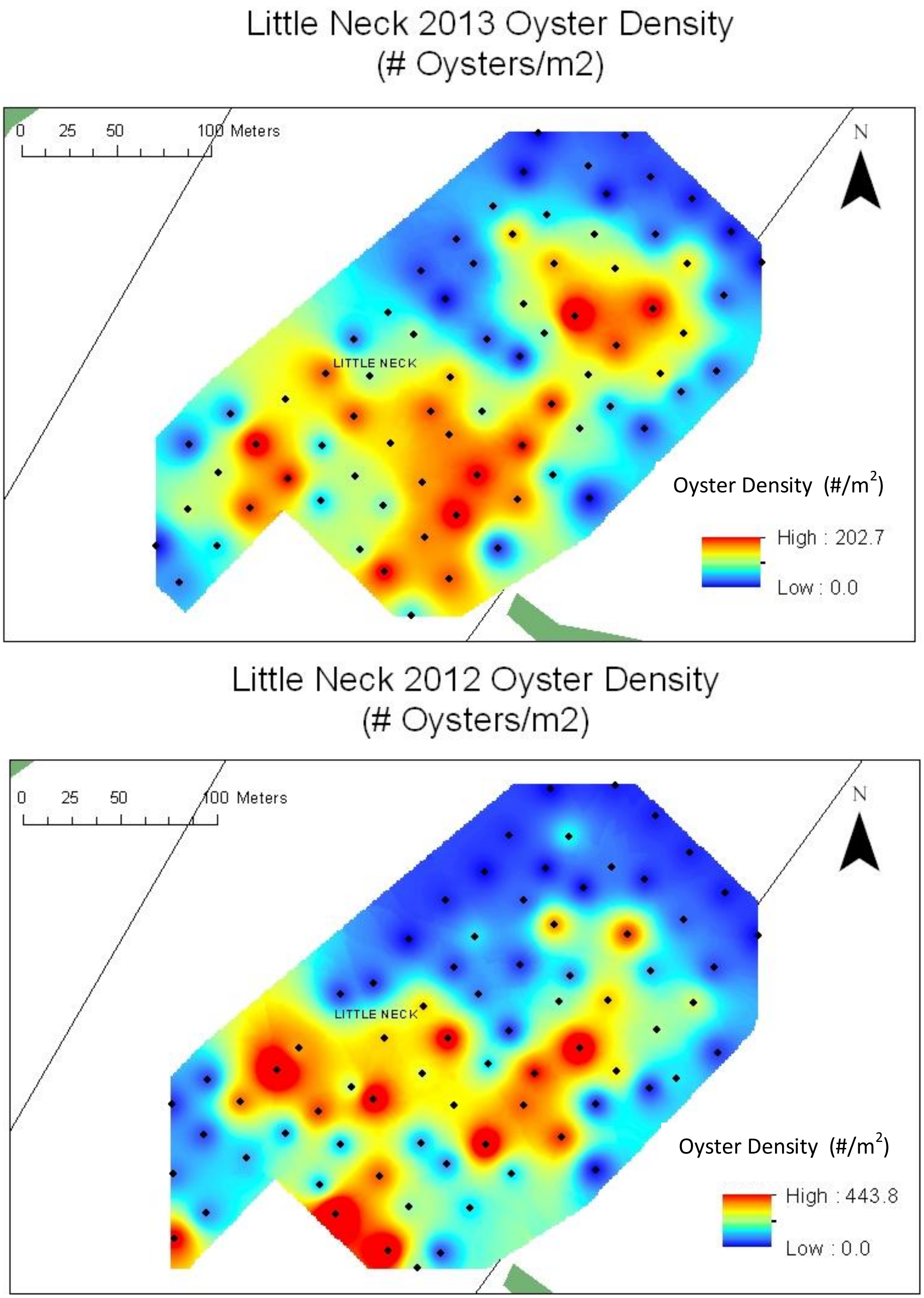


Figure 3. Little Neck oyster density distribution (2012 & 2013). Oyster density (oyster/m^2) is displayed across the bar. Areas shown in red represent highest oyster densities, while cooler colors show lower oyster densities, with zero oysters represented by dark blue. Note that the maximum oyster density is different in the two years.

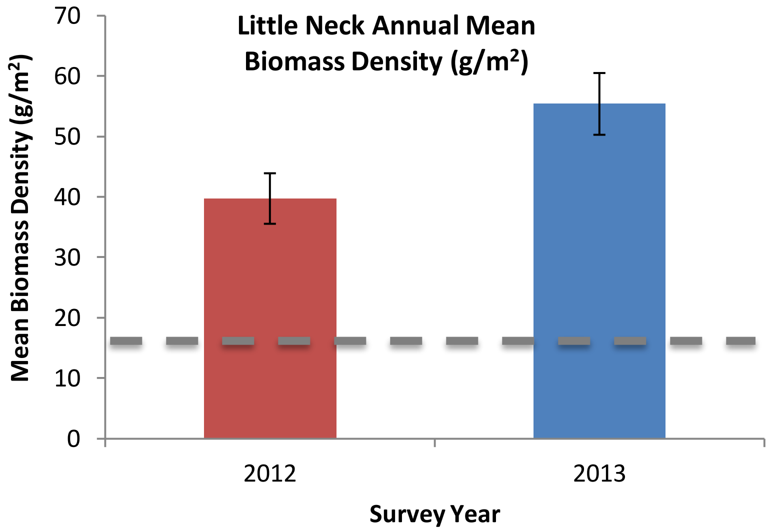


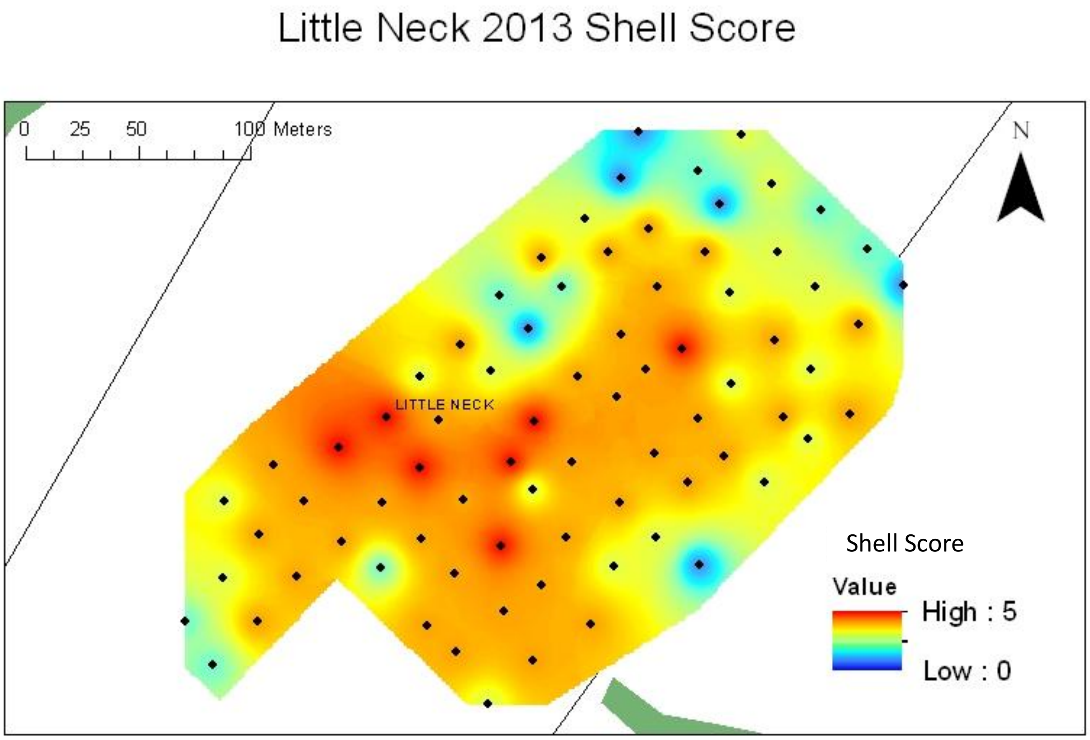
Figure 4. Little Neck annual mean biomass density (2012 & 2013). The mean bar biomass density is shown for 2012 and 2013; error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success. Biomass density was relatively high in 2012, corresponding to the high oyster density due to recently planted spat. Density increased in 2013 as oysters grew.

Oysters were sampled for dermo disease and were classified as either the 2012 planting or native oysters, as described above. In 2012, two classes were sampled: 2012 planting and native oysters. In 2013, an additional class of small natives was observed, thought to be from the 2012 natural spat set. In 2012, dermo prevalence was much greater in the larger, native oysters, as seen in Table 4. In 2013, dermo prevalence similarly increased with oyster size, and was much higher than in 2012. Dermo weighted intensity also was higher overall in 2013, and greater in older oysters. As expected, dermo prevalence and intensity were low in recently planted spat in 2012 (close to zero), but those same oysters were as infected as their native counterparts by 2013. Native oysters showed rather high prevalence with low weighted intensity in 2012, but weighted intensity was high in all classes by 2013. At these levels of infection, dermo could be impacting the population through reduced growth or fecundity.

Table 4. Little Neck disease data (2012 & 2013). Data are presented for both recently planted spat as well as native oysters surveyed from the natural population.

Sampling Year	Oyster Class	Mean Oyster Length (mm)	Dermo Prevalence (%)	Dermo Weighted Intensity
2012	Hatchery 2012	50.07	6.67	0
	Native Large	91.67	73.33	1.07
2013	Hatchery 2012	73.76	100.00	1.83
	Native Small	54.17	73.33	1.44
	Native Large	98.17	100.00	2.19

Not only were oyster metrics evaluated in the survey, but bottom type was detailed at each sampling point. Shell score was documented and is presented in Figure 5. Areas with high amounts of shell (scores of four and five) a shown in red and orange; areas with no or very little shell are shown in cooler colors of blue and aqua. The shell distribtion at Little Neck in 2013 was very similar to 2012, but data suggest a more homogenous distribution of shell. In 2012, several more shell hotspots are seen, but in 2013 more of the bar seems to be covered in with scores of three or greater. One possible cause of this shift may included currents spreading shell piles to decrease relief while increasing shell coverage. Shell score maps correspond to oyster density distribution, as areas of higher shell values are also areas of higher oyster densities for both survey years.



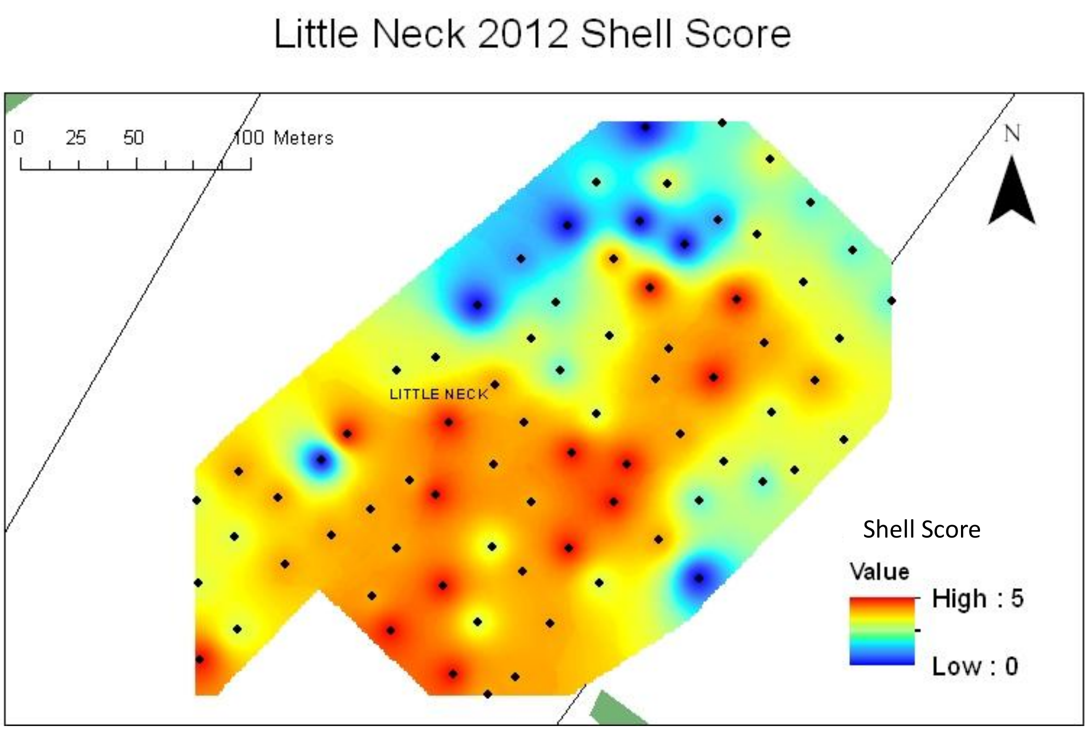
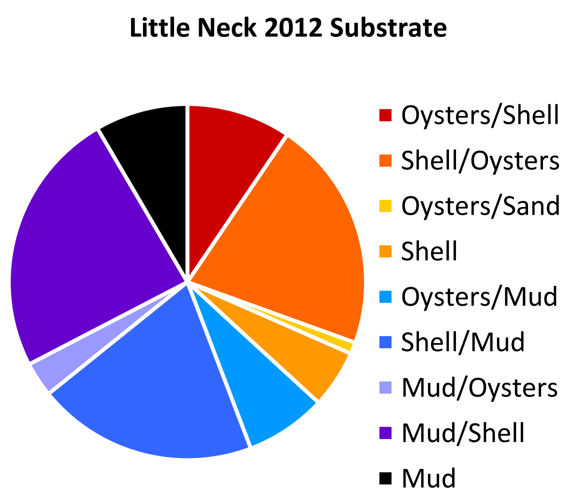


Figure 5. Little Neck shell score distribution (2012 & 2013). Shell score, ranging from zero to five, is displayed across the bar. A score of zero represents a grab without shell and is depicted by dark blue, while a score of five represents tongs full of shell and is shown in red.

Bottom type was also characterized by the primary and secondary substrates observed in each grab. In addition to shell, all other substrates were documented including mud, sand, and oyster. Figure 6 shows the relative number of grabs with each primary and secondary substrate combination observed at Little Neck. Warm shades of red through orange represent what may be considered "good" bottom for oysters, in that each combination contains some form of shell or oyster and mud is not the primary substrate. Shades of blue and purple represent less than ideal bottom, with mud and/or no form of shell or oyster. Nearly 35% of grabs at Little Neck in 2012 suggest good bottom with shell and/or oysters, while in 2013 more than 52% of grabs were substrate associated with good bottom. The largest shift in observed substrate between the 2012 and 2013 survey was an increase in the number of grabs with oysters and shell. As suggested regarding changes in shell score distribution, this shift may be an effect of shell spreading out within the reef, resulting in more grabs with shell. Additionally, as oysters surveyed in 2012 continued to grow, they would take up more space in the patent tong in 2013 than in 2012, which also may have contributed to the shift in observed substrate.



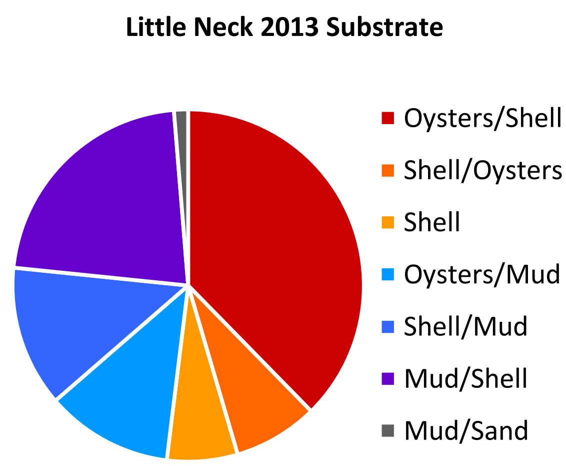


Figure 6. Little Neck substrate composition (2012 & 2013). Shades of red and orange represent what may be considered "good" bottom for oysters, with some form of shell or oyster, and mud not the primary substrate. Bottom type worsens as the color changes to shades of blue, purple, and/or black. These represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. The 2013 survey revealed more grabs with bottom deemed suitable for oysters, possibly due to oyster growth or shell movement.

In addition to quantifying the amount of shell in each grab, the percentage of buried shell within each grab was estimated. Buried shell was identified as black or gray shell, which had obviously been covered in mud prior to being brought to the surface. Alternatively, shell could be brown, or shell that had not been covered in mud before being sampled. Figure 7 shows the relative number of grabs with differing amounts of buried shell. Buried shell percentages were grouped as follows: 0%, 1-25%, 26-50%, 51-75%, and 76-100%. They are shown in Figure 7 as the fraction of grabs at Little Neck possessing that percentage of buried shell. Very few grabs contained greater than 76% buried shell in both years. In 2012, 56% of grabs contained 25% or less buried shell. In 2013, however, only 26% of grabs contained 25% or less buried shell. In the figure, cooler colors such as purple and blue represented larger percentages of buried shell while warm colors (orange or yellow) indicated minimal buried shell.

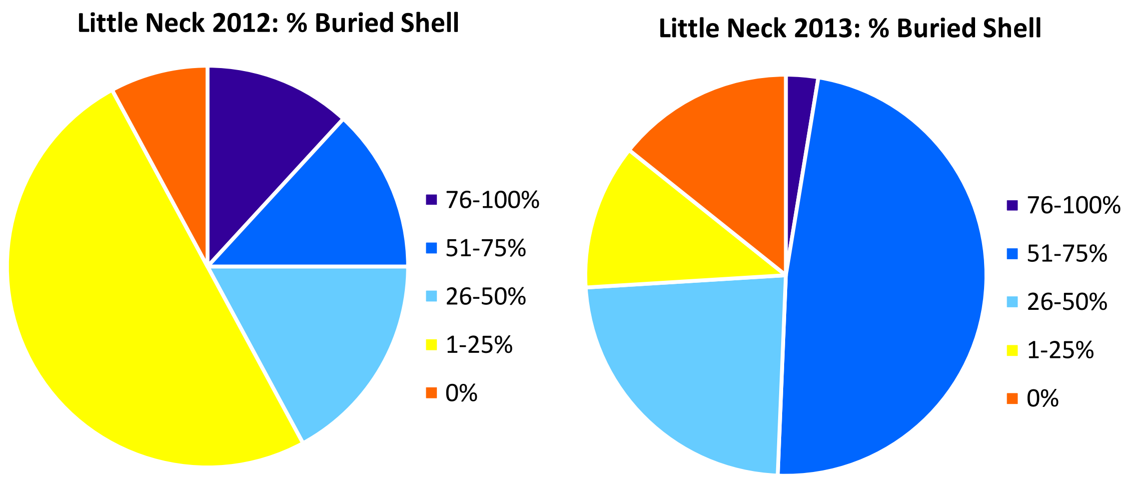


Figure 7. Little Neck percent buried shell (2012 & 2013). Field estimates of percent buried shell were placed into one of five categories as seen in the figure legends. Cooler colors (blue and purple) represent high percentages of buried shell while warmer colors (yellow and orange) indicated low buried shell percentages. In 2012, the majority of grabs (56%) had showed 1-25% buried shell. In 2013, more buried shell was observed in grabs, with 48% of grabs possessing 51-75% buried shell.

Overall, oyster population trends at Little Neck were as expected when comparing the 2012 and 2013 surveys. Oyster density decreased as expected mortality within the first year reduced spat numbers. Oyster biomass increased as surviving oysters continued to grow. General bottom observed at Little Neck suggests a site suitable for oysters, typical of restored sites.

Lodges

Lodges is an oyster bar located midriver in the Harris Creek sanctuary. It was planted during the summer of 2012, and surveyed with hydraulic patent tongs in the falls of 2012 and 2013. In addition, oysters were collected to sample for disease (*Perkinsus marinus*, dermo) in both native oysters and those planted in 2012.

As seen in Figure 8, the 2012 survey revealed oyster lengths reflective of the 2012 planting. The majority of oysters measured at Lodges were between 30 and 70 mm in length, while a minority were centered around 90 mm in length. In 2013, the majority of oysters were between 60 mm and 120 mm, and the larger class was distinguishable but mostly within the range of the rest of the population. Size frequency at Lodges is very similar to that at Little Neck, showing that both surveys likely accurately reflect the oyster population after 2012 plantings.

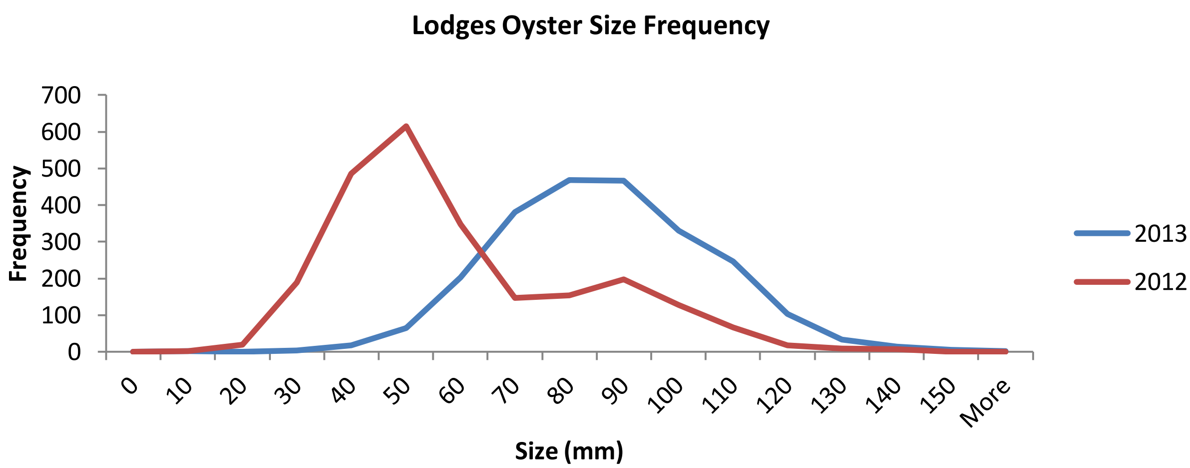


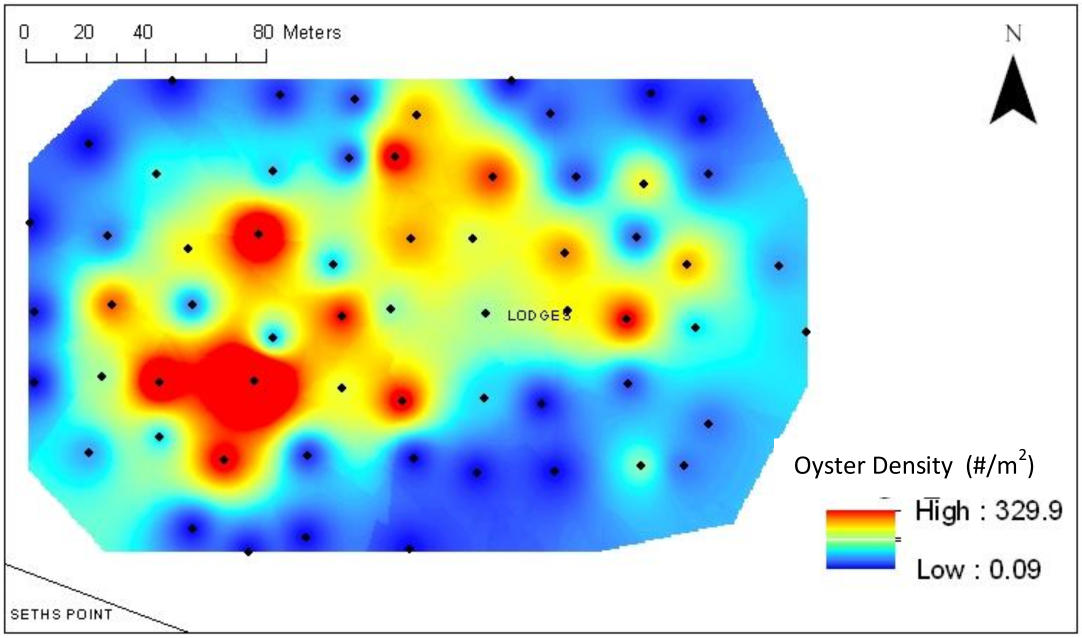
Figure 8. Lodges oyster size frequency (2012 & 2013). Size frequency data reflect the 2012 planting though larger, naturally occurring oysters were also observed. Note that this figure is not indicative of relative numbers of oysters, merely size composition.

Table 5 below summarizes oyster population metrics observed at Lodges in 2012 and 2013. A high number of live oysters were counted relative to dead oysters in both years, indicating low recent death across the bar (less than 4%). As at Little Neck, the percent of expected population surveyed reflects this through high values. The mean oyster density was high, approximately 86 oysters per m^2 in 2012, reflective of the many small spat planted in 2012. Oyster density decreased to 54 per m^2 in 2013, as expected from oyster mortality estimates. Overall bar biomass was high (1,055 kg in 2012), and increased in 2013 (to 1,941 kg). Oyster density throughout the bar can be seen in Figure 9, which illustrates the heterogeneous distribution of oysters on Lodges. The majority of oysters in 2012 and 2013 were found in the central portion of the bar. Density was more heterogeneous in 2013, as well as lower. Biomass density in 2012 and 2013 are shown in Figure 10. Even though total oyster numbers decreased from 2012 to 2013, surviving oysters grew, contributing to an increased biomass density in 2013.

Table 5. Lodges oyster metrics (2012 & 2013). Oyster population and sampling metrics are shown for Lodges. SEM represents standard error of the mean.

Sampling Year	Mean Oyster Length (mm)	Live Oyster Count	Box/Gaper Count	% Dead	Mean Oyster Density (#/m^2) ± SEM	Expected 2013 Population (Oysters)	Population Estimate from Survey (Oysters)	% of Expected	Biomass Density (g/m^2) ± SEM
2012	60	8,522	238	2.79	86 ± 15	2,822,000	3,307,842	117	27.2 ± 4.1
2013	81	5,388	183	3.40	54 ± 8.1	2,398,700	2,091,615	87	50.1 ± 7.3

Lodges 2013 Oyster Density
(# Oysters/m2)



Lodges 2012 Oyster Density
(# Oysters/m2)

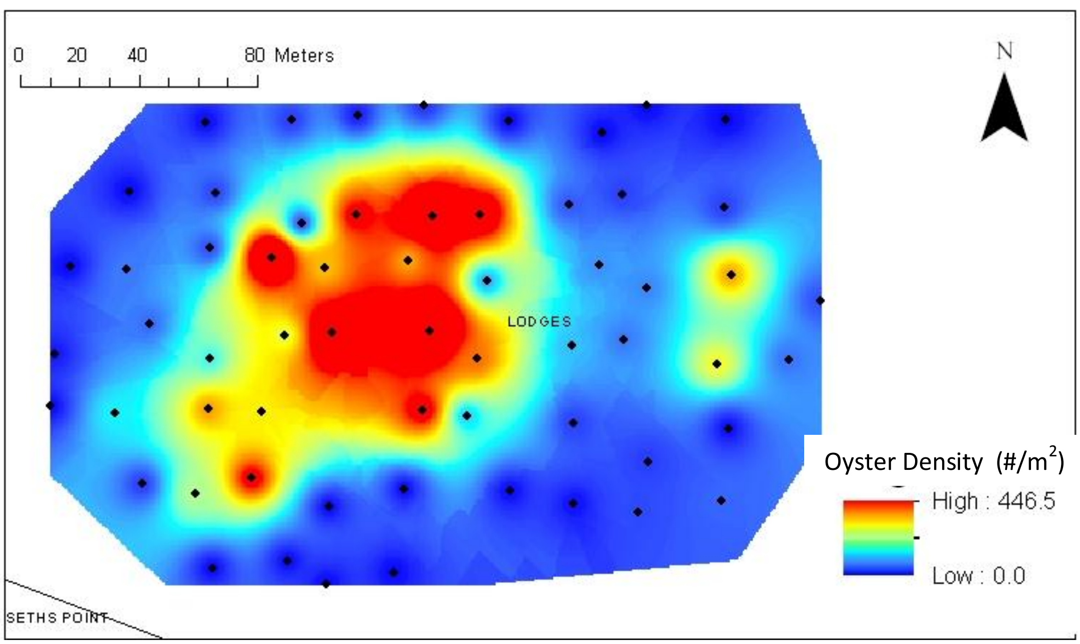


Figure 9. Lodges oyster density distribution (2012 & 2013). Oyster density (oysters/m^2) is displayed across the bar. Areas shown in red represent highest oyster densities while cooler colors show lower oyster densities, with zero oysters represented by dark blue.

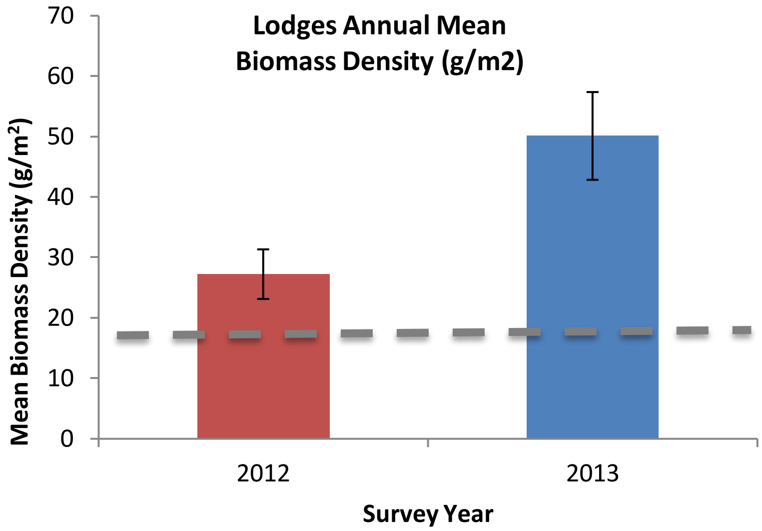


Figure 10. Lodges annual mean biomass density (2012 & 2013). The mean bar biomass density is shown for 2012 and 2013. Error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success. Mean biomass density was relatively high in each year, corresponding to high oyster density reflective of a recent spat-on-shell planting.

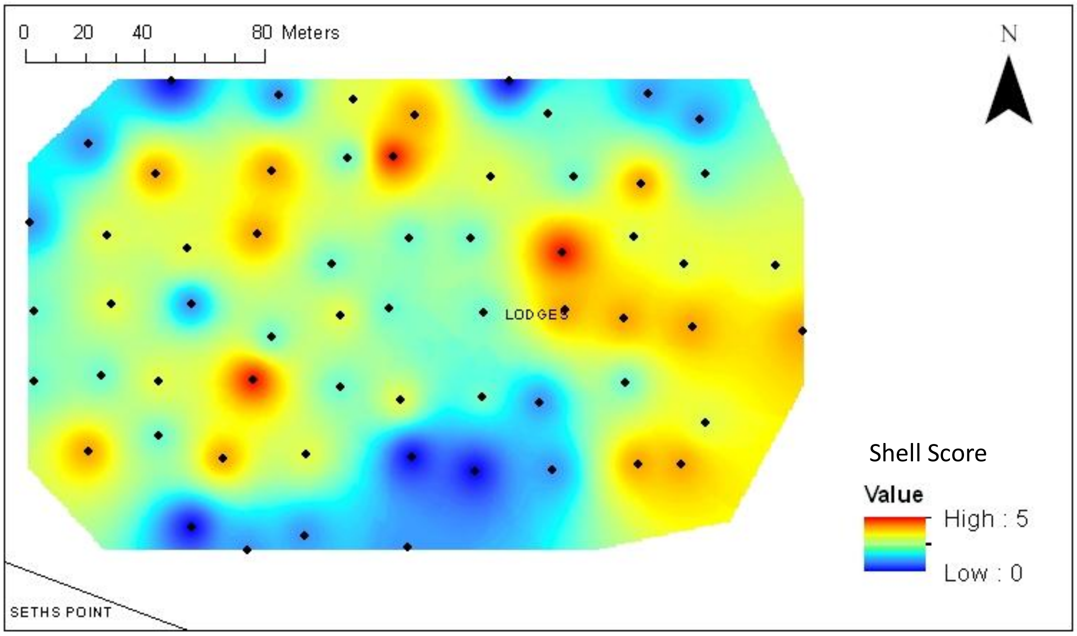
Oysters at Lodges were sampled for dermo disease in 2012 and 2013. In 2012, only hatchery-reared oysters were sampled, but in 2013 two size classes of native oysters were also sampled. Overall dermo prevalence and weighted intensity were low, as seen in Table 6. As expected, there was an increase in dermo prevalence and intensity in the planted oysters. Additionally, in 2013 planted oysters exhibited dermo infection at lower rates than in either class of native oysters. Future surveys will track the possible change in disease presence at Lodges over time.

Table 6. Lodges disease data (2012 & 2013).

Sampling Year	Oyster Class	Mean Oyster Length (mm)	Dermo Prevalence (%)	Dermo Weighted Intensity
2012	Hatchery 2012	41.17	6.9	0.04
2013	Hatchery 2012	73.79	55.17	1.11
	Native Small	55.33	80.00	1.24
	Native Large	96.40	90.00	2.00

As described for Little Neck, changes in bottom type and shell availability were also compared. Figure 11 shows the presence of shell across the bar, as observed in the 2012 and 2013 surveys. Shell scores were low to moderate at Lodges in 2012, but several areas in 2013 showed higher levels of shell. Generally, oyster densities were higher in areas of high shell score in both 2012 and 2013.

Lodges 2013 Shell Score



Lodges 2012 Shell Score

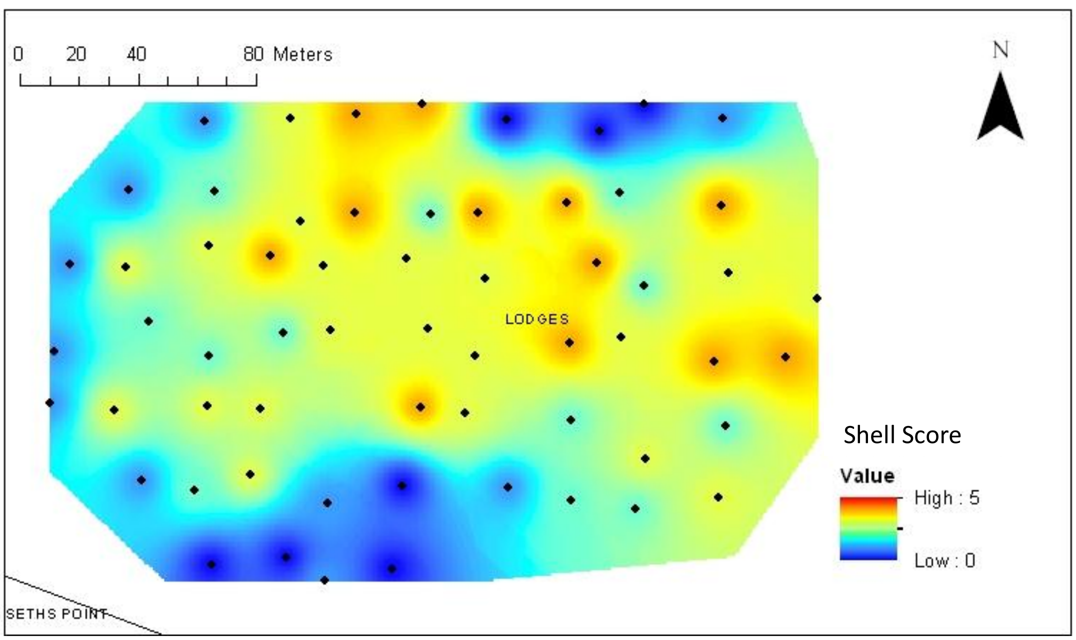


Figure 11. Lodges shell score distribution (2012 & 2013). Shell score, ranging from zero to five, is displayed across the bar. A score of zero represents a grab without shell and is depicted by dark blue, while a score of five represents tongs full of shell and is shown in red. Shell score distribution in 2013 was more heterogeneous in 2012.

Bottom type was also characterized by the primary and secondary substrates observed in each grab. In addition to shell, all other substrates were documented, including mud, sand, and oyster. Figure 12 shows the relative number of grabs with each primary and secondary substrate combination observed at Lodges in 2012 and 2013. Warm shades of pink, red, orange, and yellow represent what may be considered "good" bottom for oysters, in that each combination contains some form of shell or oyster and mud is not the primary substrate. Shades of blue, purple, and black represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. Just over half of grabs at Lodges in 2012 suggested subpar bottom with mud as the primary substrate (56%), and fewer than 25% of grabs revealed no mud. 2013 sampling revealed an increase in oysters/shell, with more than half of grabs suggesting good bottom. As substrate observations in tandem with shell score and percent black shell are monitored annually, changes in bottom quality at Lodges can be inferred.

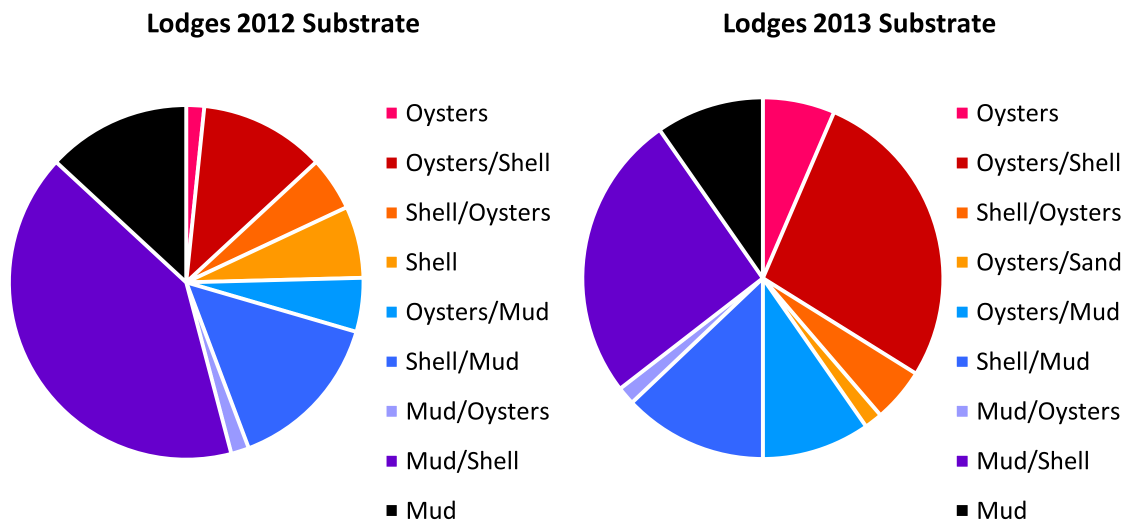


Figure 12. Lodges substrate composition (2012 & 2013). Shades of red and orange represent what may be considered "good" bottom for oysters, with some form of shell or oyster, and mud not the primary substrate. Bottom type worsens as the color changes to shades of blue, purple, and/or black. These represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. In 2012, 25% of the grabs had suitable substrate, while in 2013 closer to 40% were suitable, with most of the change occurring in an increase in oysters/shell grabs and a decrease in mud/shell grabs.

In addition to quantifying the amount of shell in each grab, the percentage of buried shell within each grab was estimated. Buried shell was identified as black or gray shell, which had obviously been covered in mud prior to being brought to the surface. The other shell type was classified as brown shell, or shell that had not been covered in mud before being sampled. Figure 13 below shows the relative number of grabs with differing amounts of black shell. Black shell percentages were grouped as follows: 0%, 1-25%, 26-50%, 51-75%, and 76-100%. They are shown as the fraction of grabs at Lodges possessing that percentage of black shell. In 2012, 69% of grabs had less that 50% buried shell. In 2013, this number shifted to only 32% of grabs contained less than 50% buried shell.

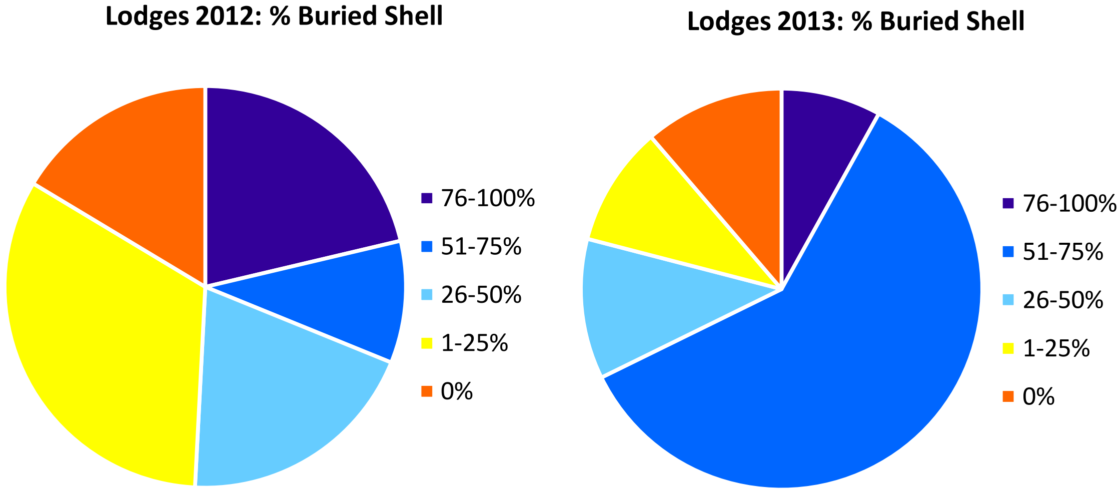


Figure 13. Lodges percent buried shell (2012 & 2013). Field estimates of % black shell were placed into one of five categories as seen in the figure legends. Cooler colors (blue and purple) represent high percentages of buried shell while warmer colors (yellow and orange) indicated low buried shell percentages. 2013 saw a shift to a greater number of grabs with 51-75% buried shell relative to the 2012 survey.

As at Little Neck, oyster population trends at Lodges were as expected in 2013. Early spat mortality within the first year of planting led to lower oyster density and thus a smaller oyster population across the bar. Surviving oyster continued to grow and contributed to an increase in biomass in 2013. Generally, the site at Lodges possessed a good degree of shell coverage in each survey year, as suggested by shell score distribution plots. The abundance of substrate classified as good bottom was less at Lodges than Little Neck, and future surveys may show how this could impact population dynamics.

Mill Point

Mill Point is an oyster bar located midriver in the Harris Creek sanctuary. It was planted during the summer of 2011, and surveyed with hydraulic patent tongs in the falls of 2012 and 2013. In addition, each year surveyors collected oysters to sample for disease (*Perkinsus marinus*, Dermo) for both native oysters and those planted in 2012.

As at Little Neck, during the 2013 planting season spat-on-shell were planted over portions of Mill Point. To make comparable analysis between 2012 and 2013, the points with overplanting were removed from the data, and the 2012 data reworked excluding these overlapping cells. Thus, the same points were analyzed for both years in this report, but fewer points were analyzed in this report than were contained in the 2012 report.

As seen in Figure 14, the surveys revealed oyster lengths reflective of the 2011 planting. The majority of oysters measured at Mill Point in 2012 were between 40 and 90 mm in length, and between 60 mm and 110 mm in 2013. In both years larger oysters were observed, suggesting the presence of natural spat sets on this bar in the past. These larger oysters were categorized as native, and were used to sample the natural population for dermo.

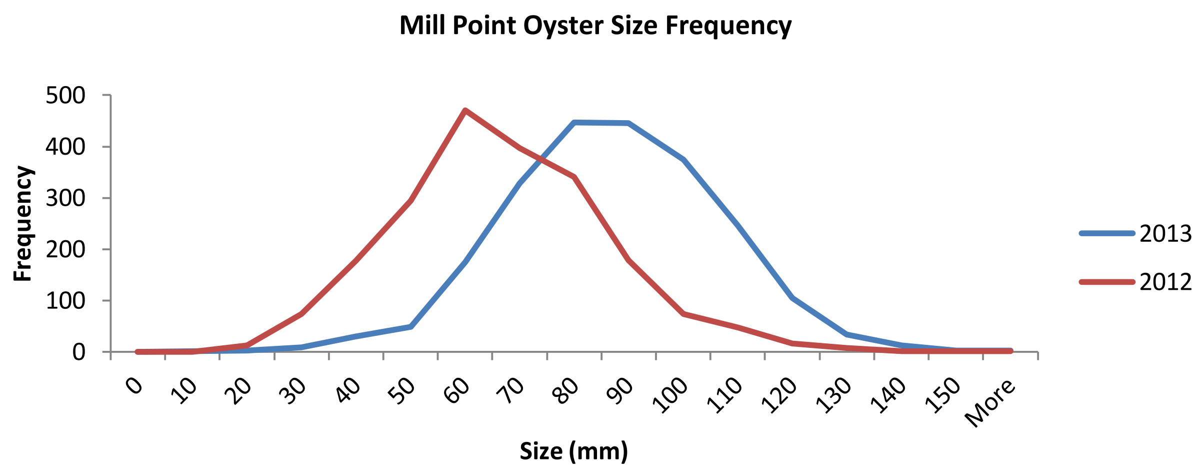
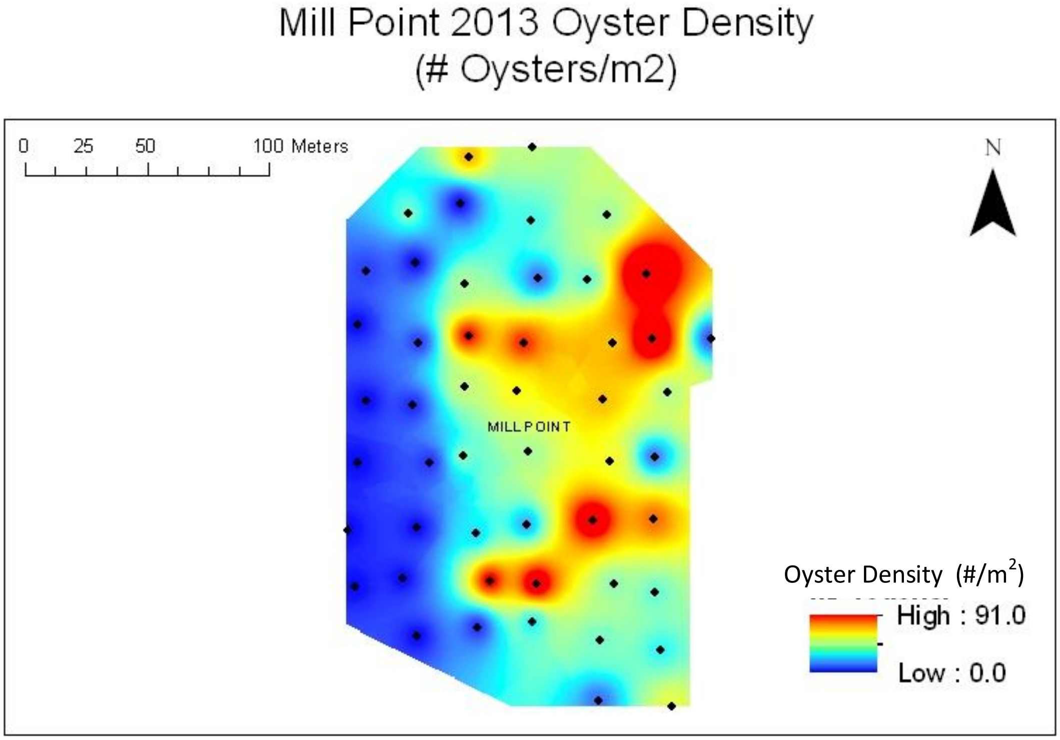


Figure 14. Mill Point oyster size frequency (2012 & 2013). Size frequency data reflect the 2011 planting in both years, with growth between surveys. Note that this figure is not indicative of relative numbers of oysters, merely size composition.

Table 7 below summarizes oyster population metrics observed at Mill Point in 2012 and 2013. A higher proportion of dead oysters were observed at this bar than at others long-term monitoring sites (8% in 2012 and 5% in 2013). This is not reflected through the percent of expected population values at Mill Point. Although the planting at Mill Point is one year older than the other long-term sites, its percent of expected population values (near 20% each year) are lower than other sites. This suggests that more significant mortality within the first year of planting occurred between 2011 and 2012 at Mill Point than did within the first year at other sites. The mean oyster density in 2012 was fairly high, approximately 28 oysters per m^2, reflective of the many small spat planted in 2011. Though this density is lower than some other long-term survey bars in Harris Creek, a density decline is expected one-year post-planting. Two years post-planting it had declined only slightly to 26 oysters per m^2. Similarly, overall bar biomass was lower than other sites, but still high (476 kg), and increased in 2013 to 827 kg. Oyster density across the bar can be seen in Figure 15, which illustrates the heterogeneous distribution of oysters on Mill Point. The majority of oysters in both years were found in the northern central portion of the bar, though the maximum density decreased across years.

Table 7. Mill Point oyster metrics (2012). Oyster population and sampling metrics are shown for Mill Point.

Sampling Year	Mean Oyster Length (mm)	Live Oyster Count	Box/Gaper Count	% Dead	Mean Oyster Density (#/m2) ± SEM	Expected 2013 Population (Oysters)	Population Estimate from Survey (Oysters)	% of Expected	Biomass Density (g/m^2) ± SEM
2012	63.35	3,257	266	8.1	28.6 ± 5.1	4,394,500	910,326	21	14.9 ± 2.6
2013	84.11	2,106	112	5.3	26.2 ± 3.5	3,735,325	817,546	22	26.4 ± 3.5



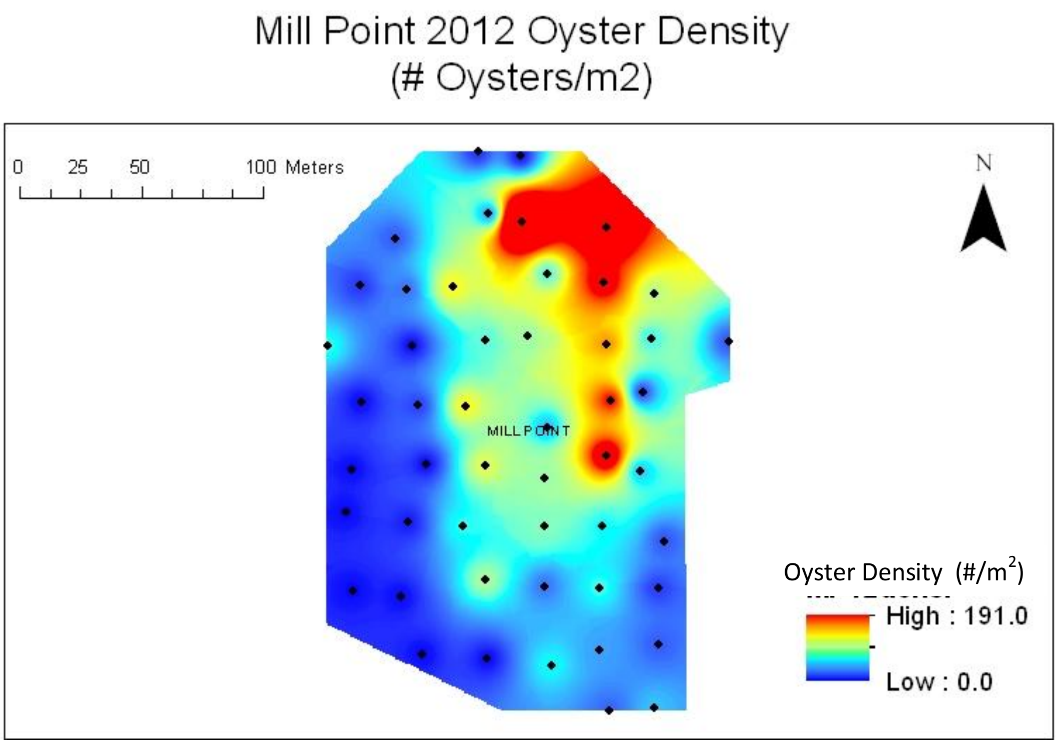


Figure 15. Mill Point oyster density distribution (2012 & 2013). Oyster density (oysters/m^2) is displayed across the bar. Areas shown in red represent highest oyster densities, while cooler colors show lower oyster densities, with zero oysters represented by dark blue. Note that the maximum oyster density is higher in 2012 than 2013.

In addition to oyster density, biomass density was also compared between years. Figure 16 shows mean biomass density at Mill Point for 2012 and 2013. As expected (and seen at other sites), the growth of surviving oysters at Mill Point contributed to a higher mean biomass density in 2013.

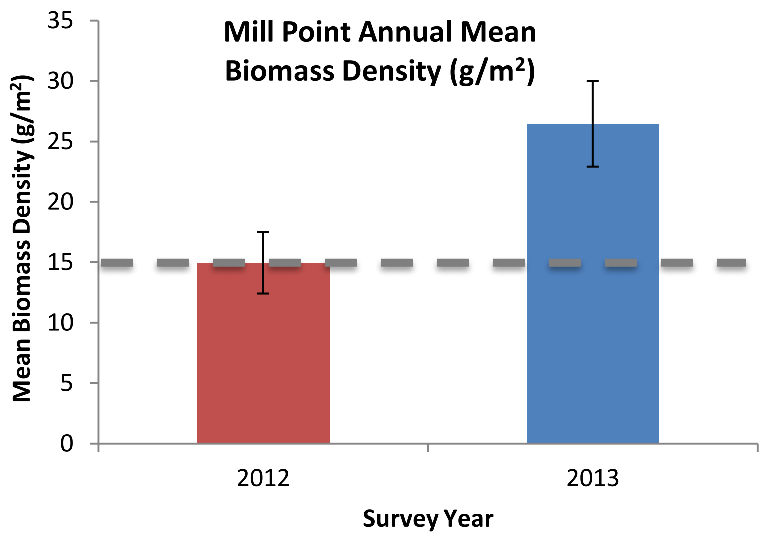


Figure 16. Mill Point annual mean biomass density (2012 & 2013). The mean bar biomass density is shown for 2012 and 2013. Error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success. Biomass density was lower than at Little Neck and Lodges, however this is as expected as sites were planted with differing initial amounts of spat. Bar biomass increased between 2012 and 2013.

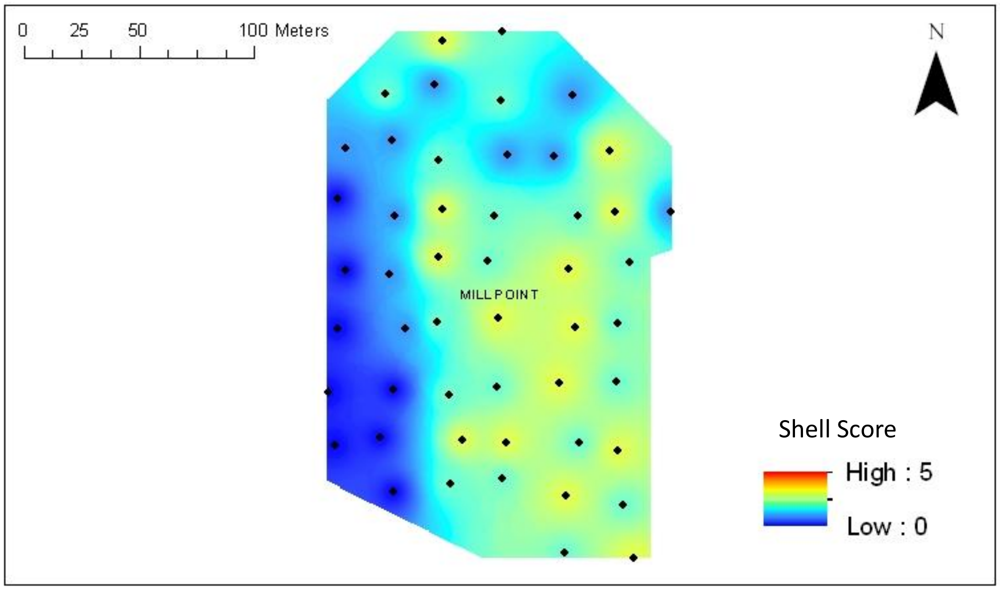
Oysters were sampled for dermo disease and were classified as either the 2011 planting or native oysters, as described above. In 2012, dermo prevalence and intensity were higher in the larger, native oysters, as seen in Table 8. In 2013 an additional class of small native oysters, likely from the 2012 spat set, were observed. Planted oysters had almost all acquired some degree of dermo, and intensity in all classes was much higher than in 2012. Though dermo is not currently present at lethal levels in the adult population, it is likely impacting the population through reduced growth or fecundity. The impact of dermo may become more pronounced in future surveys at Mill Point.

Table 8. Mill Point disease data (2012 & 2013). Data are presented for recently planted spat as well as native oysters surveyed from the natural population.

Sampling Year	Oyster Class	Mean Oyster Length (mm)	Dermo Prevalence (%)	Dermo Weighted Intensity
2012	Hatchery 2011	66.6	26.67	0.31
	Native Large	92.25	62.5	1.01
2013	Hatchery 2011	90.16	96.77	1.81
	Native Small	55.57	93.33	1.84
	Native Large	92.47	100.00	2.13

As described for Little Neck and Lodges, changes in bottom type and shell availability were compared between 2012 and 2013. Figure 17 shows the presence of shell across the bar, as observed in the 2012 and 2013 surveys. Shell presence was quantified as shell score, a metric based off of the amount of shell in each grab. Shell scores range from zero to five, with zero representing tongs with no shell and five indicating tongs completely full of shell. Shell scores were low to moderate at Mill Point in both years, with the majority of grabs possessing scores of three or less, shown on Figure 17 as areas of yellow, aqua, and blue. Areas of highest shell scores were also areas with the greatest oyster densities, seen in Figure 15.

Mill Point 2013 Shell Score



Mill Point 2012 Shell Score

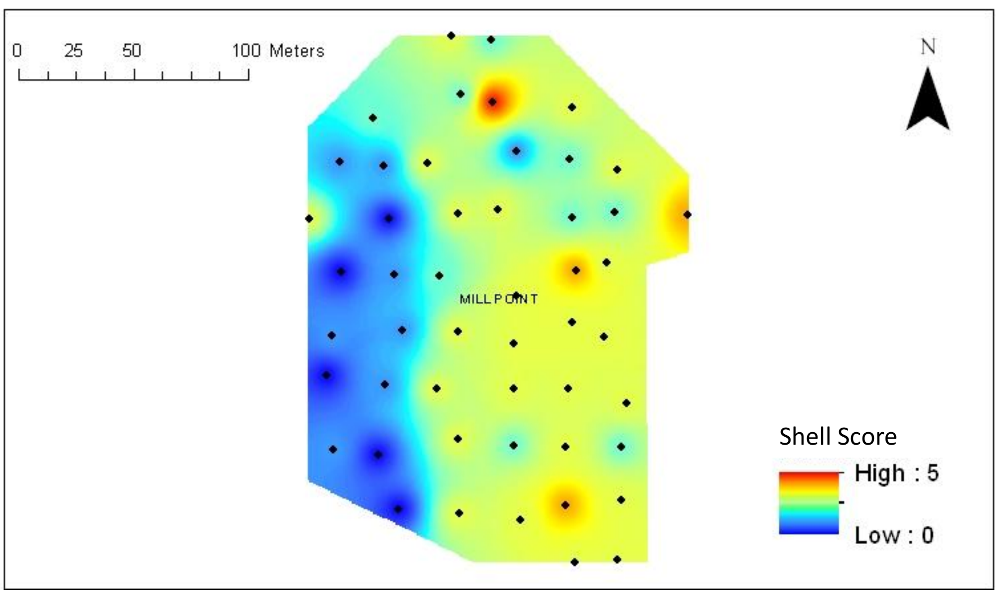
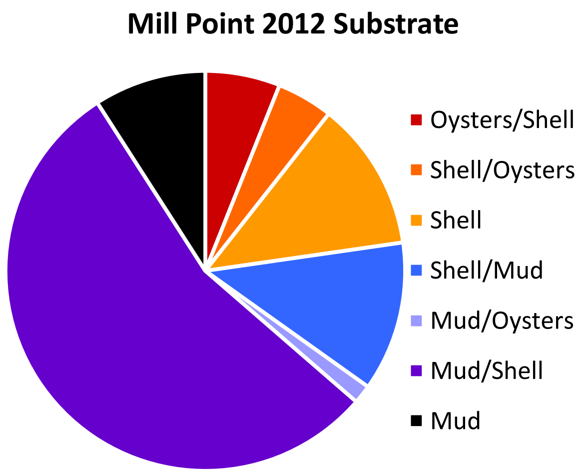


Figure 17. Mill Point shell score distribution (2012 & 2013). Shell score, ranging from zero to five, is displayed across the bar. A score of zero represents a grab without shell and is depicted by dark blue, while a score of five represents tongs full of shell and is shown in red.

Bottom type was also characterized by the primary and secondary substrates observed in each grab. In addition to shell, all other substrates were documented, including mud, sand, and oyster. Figure 18 shows the relative number of grabs with each primary and secondary substrate combination observed at Mill Point in 2012 and 2013. Warm shades of red and orange represent what may be considered "good" bottom for oysters, in that each combination contains some form of shell or oyster and mud is not the primary substrate. Cool shades of blue, purple, and black represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. The majority of grabs at Mill Point in 2012 suggested subpar bottom; mud was the primary substrate and fewer than 25% of grabs revealed no mud. However, 2013 saw a slight shift toward better substrate with the largest changes occurring in the Mud/Shell and Shell/Mud categories, which may indicate differences in surveyor assessment rather than actual changes in substrate.



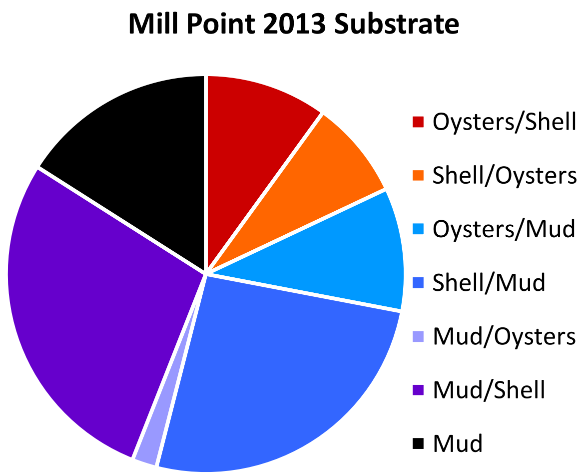


Figure 18. Mill Point substrate composition (2012 & 2013). Shades of red and orange represent what may be considered "good" bottom for oysters, with some form of shell or oyster, and mud not the primary substrate. Bottom type worsens as the color changes to shades of blue, purple, and/or black. These represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. In 2012 approximately 23% of the grabs had substrate deemed good for oysters while in 2013 only 18% were identified as good.

In addition to quantifying the amount of shell in each grab, the percentage of buried shell within each grab was estimated. Buried shell was identified as black or gray shell, which had obviously been covered in mud prior to being brought to the surface. The other shell type was classified as brown shell, or shell that had not been covered in mud before being sampled. Figure 19 shows the relative number of grabs with differing amounts of black shell. Black shell percentages were grouped as follows: 0%, 1-25%, 26-50%, 51-75%, and 76-100%. They are shown in Figure 19 as the number of grabs at Mill Point possessing that percentage of black shell. Surveys show a shift to a lower amount of buried shell in 2013 when compared to 2012.

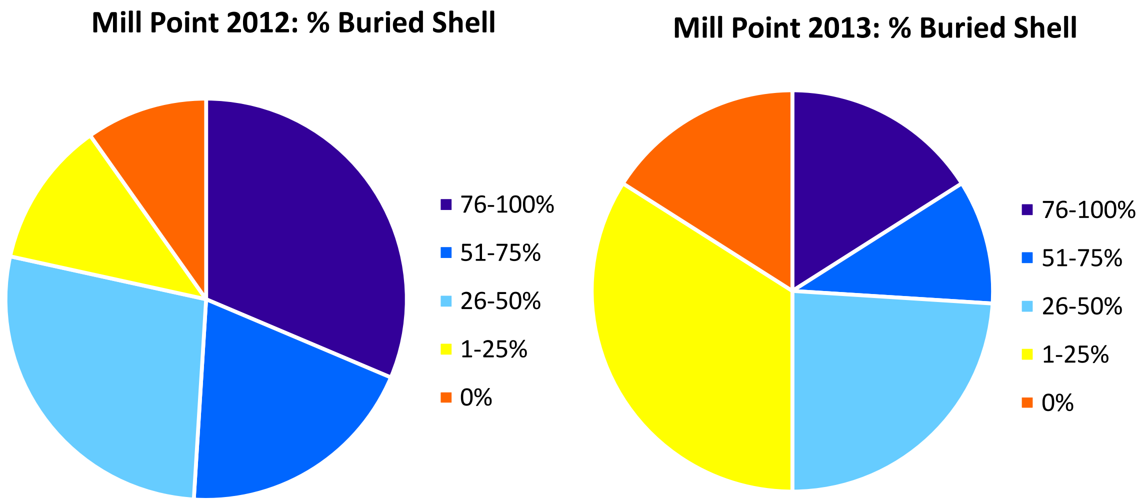


Figure 19. Mill Point percent buried shell (2012 & 2013). Field estimates of percent black shell were placed into one of five categories as seen in the figure legends. Warmer colors (orange and yellow) represent lower percentages of buried shell while cooler colors (blue, and purple) show higher percentages. A greater number of grabs had less than 25% buried shell in 2013 when compared to 2012.

Oyster population trends were as expected at Mill Point in 2013. Oyster density remained fairly similar to 2012; this is as predicted since the Mill Point planting is one year older than other surveyed plantings. Biomass density increased as at other bars. Most oysters were observed on areas of higher shell scores, as illustrated in the shell score and oyster density plots. Observed substrate was not as good at Mill Point as that seen at other sites in either year, however Mill Point possessed a lower overall percentage of buried shell.

Change

Change is an oyster bar located downriver in the Harris Creek sanctuary. It was planted during the summer of 2012, and surveyed with hydraulic patent tongs during the fall of 2013. Oysters were collected to sample for disease (*Perkinsus marinus*, dermo) in both native oysters and those planted in 2012.

As seen in Figure 20, the 2013 survey revealed oyster lengths reflective of the 2012 planting as well as a possible earlier natural spat set. The majority of oysters measured at Change were between 50 mm and 90 mm in length. A few oysters were larger (over 100 mm), suggesting the presence of older native oysters, though in limited quantities.

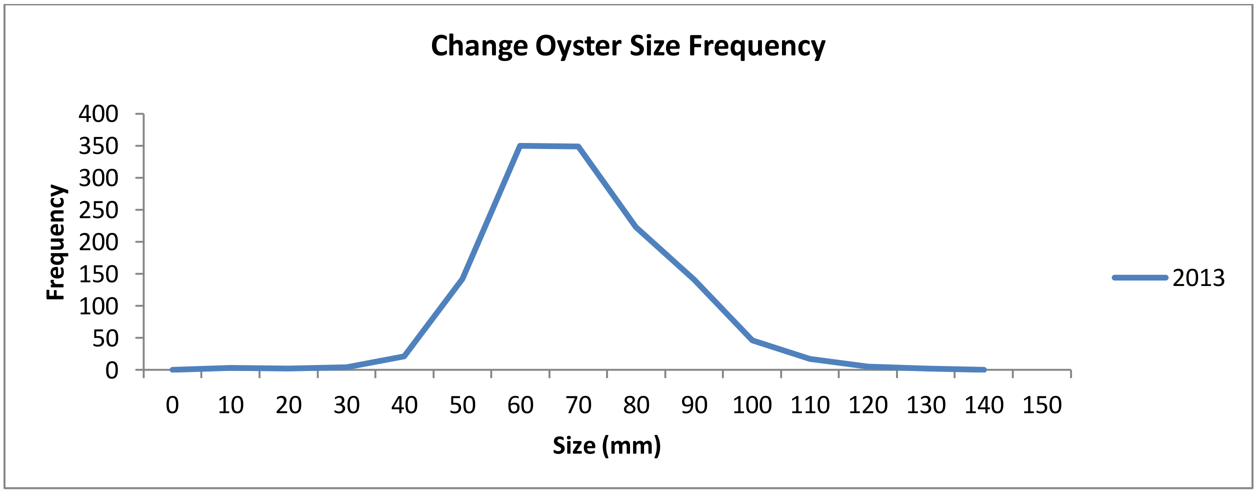


Figure 20. Change oyster size frequency (2013). Size frequency data reflects the 2012 planting as well as older native oysters. Note that this figure is not indicative of relative numbers of oysters, merely size composition.

Table 9 below summarizes oyster population metrics observed at Change in 2013. A high number of live oysters were counted relative to dead oysters, resulting in very low relative death across the bar (less than 3%). The percent of expected population observed was fairly high (87%), though lower than at Little Neck and Lodges, possibly an effect of smaller initial planting numbers. The mean oyster density was lower than on other bars, approximately 27 oysters per m^2. Similarly, overall bar biomass was lower (532 kg). This is likely due to Change receiving a single planting, while other bars were overplanted, sometimes several times, yielding higher initial densities. Oyster density across the bar can be seen in Figure 21, which illustrates the heterogeneous distribution of oysters on Change. The majority of oysters in 2013 were found in the northern central portion of the bar, and at some points reached densities of 171 oysters/m^2.

Table 9. Change oyster metrics (2013). Oyster population and sampling metrics are shown for Change.

Sampling Year	Mean Oyster Length (mm)	Live Oyster Count	Box/Gaper Count	% Dead	Mean Oyster Density (#/m2) ± SEM	Expected 2013 Population (Oysters)	Population Estimate from Survey (Oysters)	% of Expected	Biomass Density (g/m^2) ± SEM
2013	67.73	2,236	66	2.95	26.7±5.4	1,000,000	868,012	87	16.4 ± 3.9

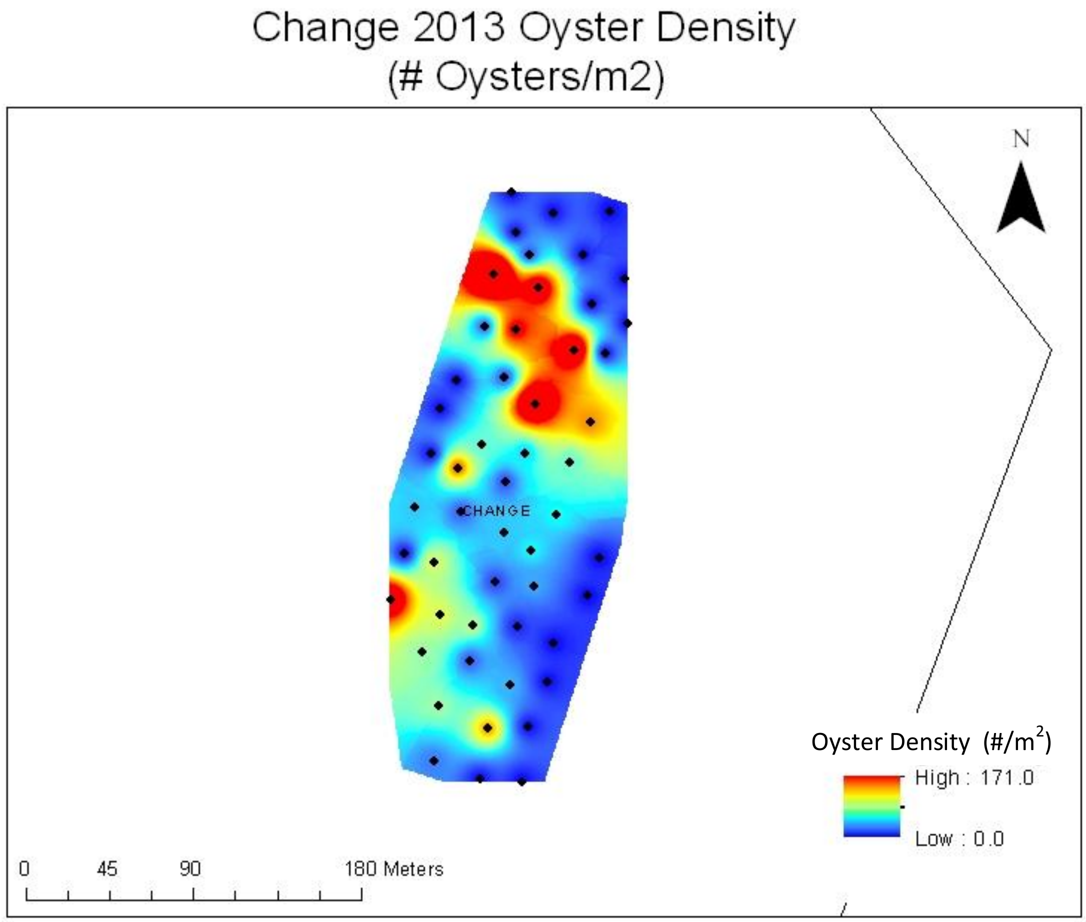


Figure 21. Change oyster density distribution (2013). Oyster density (oyster/m^2) is displayed across the bar. Areas shown in red represent highest oyster densities (171 oysters/m^2), while cooler colors show lower oyster densities, with zero oysters represented by dark blue.

Figure 22 shows mean biomass density at Change for 2013. Although it is lower than biomass densities of other sites, the more important comparison will be to track its change in biomass over time after subsequent surveys.

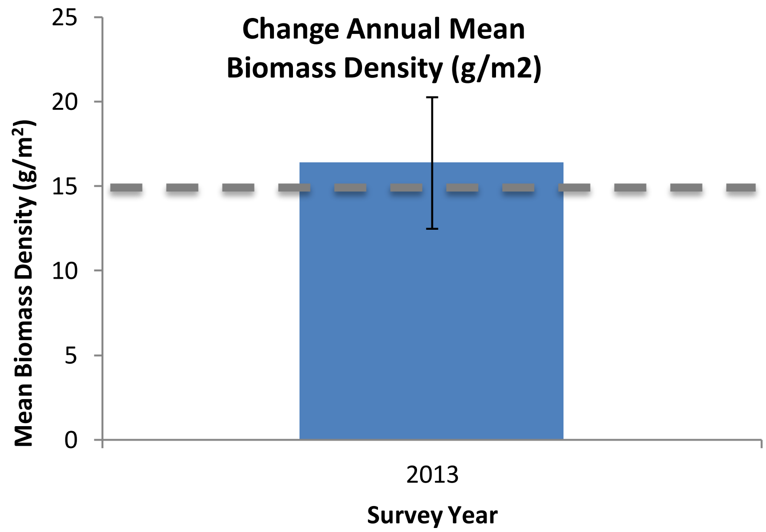


Figure 22. Change annual mean biomass density (2013). The mean bar biomass is shown for 2013. Error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success.

Oysters were sampled for dermo disease and were classified as either the 2012 planting or native oysters, as described above. No large native oysters were observed, but there were smaller oysters likely from a 2012 natural spat set (Table 10). In 2013, dermo prevalence was greater in the smaller native oysters, and both prevalence and intensity were low in planted oysters. Prevalence and intensity values suggest that dermo in the population may worsen as the smallest class of oysters age.

Table 10. Change disease data (2013). Data are presented for both recently planted spat as well as native oysters surveyed from the natural population.

Sampling Year	Oyster Class	Mean Oyster Length (mm)	Dermo Prevalence (%)	Dermo Weighted Intensity
2013	Native Small	53.23	96.67	0.90
	Hatchery 2012	72.37	33.33	0.14

Figure 23 shows the presence of shell across the bar, as observed in the 2013 survey. Shell presence was quantified using shell score, a metric based on the amount of shell in each grab. Shell scores range from zero to five, with zero representing tongs with no shell and five indicating tongs completely full of shell. Shell scores were low to moderate at Change in 2013, with the majority of grabs possessing scores of three or less, shown on Figure 23 as areas of yellow, aqua, and blue. Areas of highest shell scores were also areas with the greatest oyster densities, seen in Figure 21.

Change 2013 Shell Score

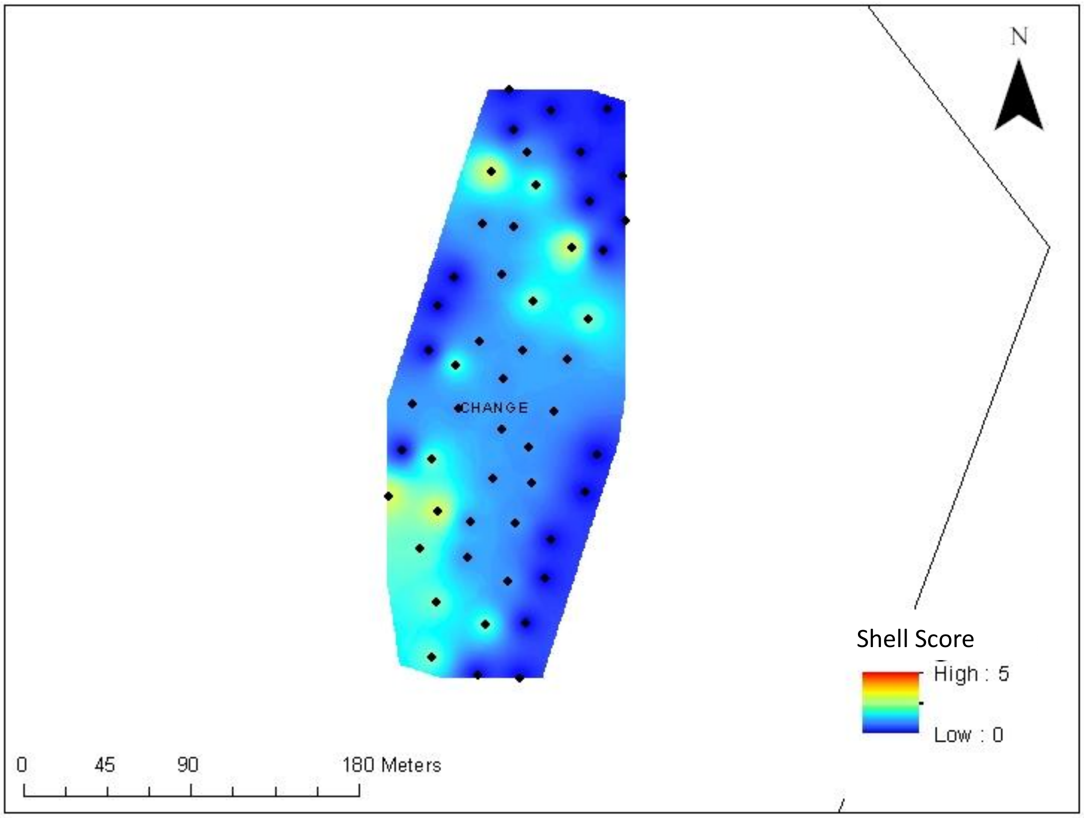


Figure 23. Change shell score distribution (2013). Shell score, ranging from zero to five, is displayed across the bar. A score of zero represents a grab without shell and is depicted by dark blue, while a score of five represents tongs full of shell and would be shown in red.

Bottom type was characterized by the primary and secondary substrates observed in each grab. In addition to shell, all other substrates were documented, including mud, sand, and oyster. Figure 24 shows the relative number of grabs with each primary and secondary substrate combination observed at Change in 2013. Shades of red and orange represent what may be considered “good” bottom for oysters, in that each combination contains some form of shell or oyster and mud is not the primary substrate. Shades of blue, purple, and black represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. Thirty-five percent of grabs at Change in 2013 suggest acceptable bottom, however, mud was the most common substrate.

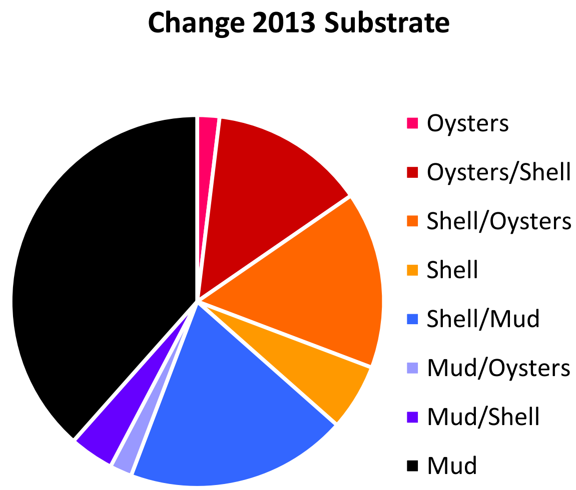


Figure 24. Change substrate composition (2013). Shades of red and orange represent what may be considered “good” bottom for oysters, with some form of shell or oyster, and mud not the primary substrate. Bottom type worsens as the color changes to shades of blue, purple, and/or black. These represent less than ideal bottom, with mud as the primary substrate and/or no form of shell or oyster. In 2013, 35% of grabs had substrate deemed to be good oyster habitat.

In addition to quantifying the amount of shell in each grab, the percentage of buried shell within each grab was estimated. Buried shell was identified as black or gray shell, which had obviously been covered in mud prior to being brought to the surface. The other shell type was classified as brown shell, or shell that had not been covered in mud before being sampled. Figure 25 shows the relative number of grabs with differing amounts of black shell. Black shell percentages were grouped as follows: 0%, 1-25%, 26-50%, 51-75%, and 76-100%. They are shown in Figure 25 as the relative number of grabs at Change possessing that percentage of black shell. A large portion of shell observed in the survey was buried, with 77% of grabs containing over 50% buried shell.

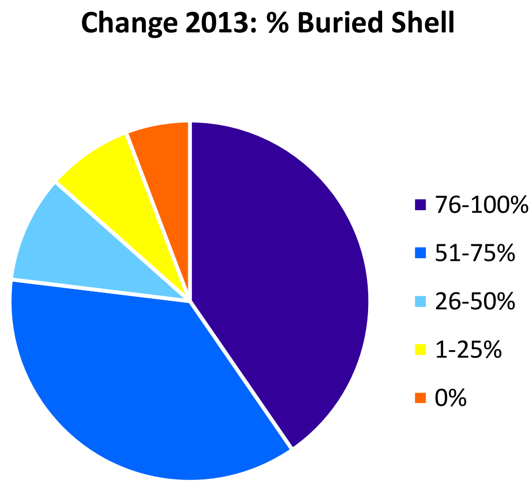


Figure 25. Change percent buried shell (2013). Field estimates of % black shell were placed into one of five categories as seen in the figure legends. Orange and yellow sections represent low amounts of buried shell, while blue and purple sections are high buried shell percentages. Only a small number (14%) of grabs in 2013 possessed less than 25% buried shell.

As Change was surveyed for the first time in 2013 as part of its long-term monitoring plan, the critical component of this project will take place after subsequent surveys at this site. Additional surveys will allow for the tracking of population and disease dynamics over time. The 2013 survey revealed lower oyster densities than other long-term sites, and a smaller amount of suitable oyster bottom. Additionally, disease levels were lower in both hatchery-reared and native oysters at this site.

Conclusions

The 2013 sampling season was the second year of surveying at Little Neck, Lodges, and Mill Point and the first year at Change. For Change, the data included provide baseline information to compare oyster population, growth, and survival over time. For the bars that were previously surveyed in 2012, we can begin to observe trends and changes in both oyster population and bottom quality. Though initial results are revealing, the importance of this study lies in continued annual surveys.

For the three sites surveyed in 2012 and 2013, early differences in population and biomass estimates are apparent. This year's surveys indicate several broad trends common to these bars, as well as differences between them. In all three bars, mean oyster density decreased between years (Figure 26), as would be expected in a non-reproducing population. However, rates of decline were not the same across bars: Mill Point, with an initial density lower than either Little Neck or Lodges, saw a smaller oyster density loss than either of the others. Similarly, percent survival between years was higher for Mill Point (89.8%) than for Little Neck (61.8%) or Lodges (63.2%) (Table 10). This is likely because Mill Point was planted in 2011, while the other bars were planted in 2012, evidence that bars may lose a larger fraction of their oysters in the first year than in subsequent years. Although the mean oyster density decreased over time at the three sites surveyed in 2012 and 2013, the mean density at all four sites exceeds the Oyster Metrics Workgroup's (OMW) minimum criteria to be considered successful (15 oysters/m^2).

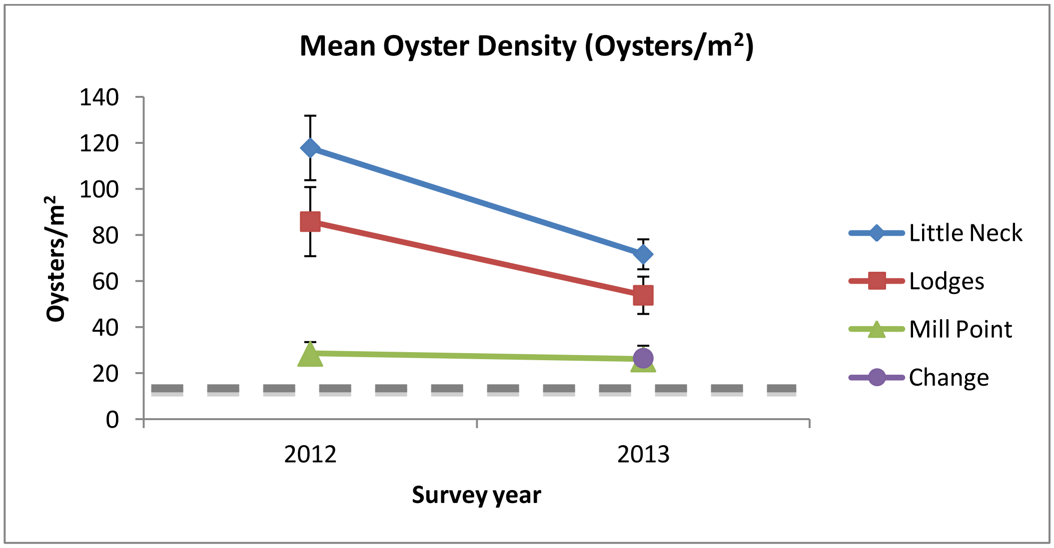


Figure 26. Mean oyster density over time. The mean oyster density at all sites is presented for all survey years. Error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success. Oyster density decreased for all three sites surveyed in 2012 and 2013, but mean oyster density at all four sites exceeds the OMW's minimum threshold for success (15 oysters/m^2).

In contrast, biomass density across each bar increased between years (Figure 27), indicating that the mortality of oysters is more than compensated for in the growth of the survivors. Little Neck, the most densely populated bar in both years, experienced the smallest change in biomass (141.2%). Paired with its low-ranked survival rate, it is possible that very dense plantings may approach a point of diminishing returns, where growth rates are slowed by crowding. This hypothesis is borne out by the differences in growth rate between sites, where oysters on Little Neck grew approximately 20 mm, as compared to 25 mm at Mill Point and 35 mm at Lodges (Table 10). Further, Lodges and Mill Point had comparable percent changes in biomass (184.0% and 173.6%), indicating that biomass accumulation is potentially similar across years, and not merely driven by age differences. Such observations require support through future surveys.

In addition to biomass increasing over time, the success of restoration at these sites is further emphasized by the actual value of the mean biomass density at each site. As with oyster density, each bar exceeds the OMW 's minimum metric of success (15 g/m^2). The 2012 and 2013 surveys suggest that these plantings may serve as evidence of successful restoration, though additional surveys are needed to follow the population beyond two years. All four sites are located in the Harris Creek sanctuary, thus harvest should not impact populations, however disease dynamics may prove problematic. The 2013 surveys revealed fairly high levels of dermo infection at three of the four sites. Large natural mortality has not been observed yet, but has the potential to impact restoration success at these sites.

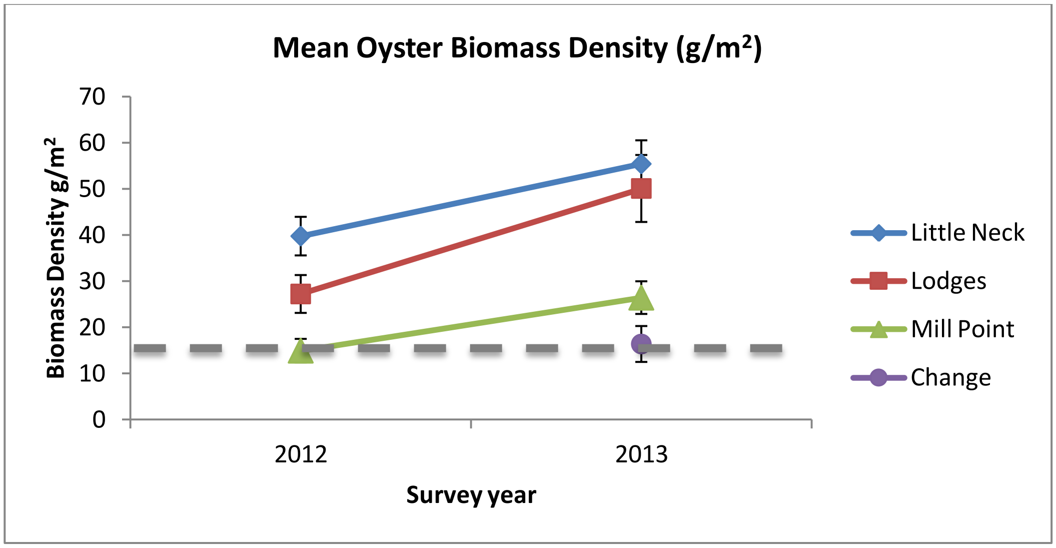


Figure 27. Estimated oyster biomass density at all bars. The 2012 and 2013 estimated oyster density is shown for all four bars that are part of the long-term patent tong survey. Error bars represent standard error of the mean. The dashed gray line represents the OMW minimum biomass density metric of success. Biomass density increased for all sites surveyed in 2012 and 2013. Biomass densities also exceed the OMW's minimum threshold metric of success (15 g/m^2) at all sites.

Bottom type characterization is also possible in these surveys and can provide a means to track changes in bottom composition over time. Table 11 shows the percent "good" bottom on each bar, calculated as the fraction of 2013 grabs that had some form of shell or oyster, and no mud. Bottom quality seems to roughly correlate to oyster and biomass density, indicating that to achieve desirable oyster quantities, the bar must have a hospitable substrate throughout. Also relevant to the bar density is the number of times within the planting season that spat-on-shell was planted on the bar, where more plantings should produce higher initial densities. As expected, bars with the densest oyster populations at the time of survey were also the most heavily planted initially (Table 10, Figure 26).

Change, which was surveyed for the first time this year, does not have data for trends or changes. However, it fits in with the patterns observed in the other bars. It has relatively low oyster and biomass densities, corresponding to its relatively low fraction of "good" bottom and light initial planting. Over future surveys we will assess the long-term influences and trends on this bar.

Table 11. Percent survival and biomass change on Little Neck, Lodges and Mill Point between 2012 and 2013. Percent survival is based on total bar population estimates and percent biomass change is based on total bar biomass. Oyster growth is the estimated difference in peak oyster size (see Figures 2, 8, 14 and 20) and percent good bottom in 2013 is based on the fraction of "warm-colored" substrate categories (see Figures 6, 12, 18 and 24).

Bar name	% Survival	% Biomass change	Oyster growth (mm)	"Good" bottom in 2013 (%)
Little Neck	61.8	141.2	20	52
Lodges	63.2	184.0	35	40
Mill Point	89.8	173.6	25	18
Change	--	--	--	36

Though all four bars surveyed in 2013 are located in the Harris Creek sanctuary, the data show that they are not identical. Substrate and shell data demonstrated that each bar has a unique bottom type composition and shell budget. Similarly, although each bar was planted in 2011 or 2012, differences in oyster and biomass density, and changes within oyster survival and total biomass are becoming apparent. Though the factors driving these changes are likely complex, with continued surveying we hope to elucidate the most important. These observations may be valuable in guiding future restoration projects.

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Liddel, M.K. "A von Bertalanffy Model for the Estimation of Oyster (*Crassostrea virginica*) Growth on Restored Oyster Reefs in the Chesapeake Bay". Ph.D. dissertation, University of Maryland, College Park, 2007.

Section VI: Lessons Learned

Ground Truthing

In the 2013 season 25 bars were surveyed, all in Harris Creek. Twenty-four of those were recommended for planting, of which 20 were actually planted, and the remaining 4 will likely be planted in 2014. Most of the surveyed sites had restoration efforts started with alternate substrate, and GT results indicated that coverage with substrate was for the most part good at those sites. Unaltered sites were selected based on side scan images, which were largely successful at identifying suitable sites for spat-on-shell deployment. However, it was occasionally necessary to restrict the recommended spat-on-shell planting areas, as well as eliminating any unsuitable sites, which together indicate that ground truthing remains a crucial step in the restoration process.

Post-Planting Monitoring

Twenty-five sites were monitored post-planting, all in Harris Creek with the exception of two in the Severn River. Overall survival was 37.4%, which is similar to the 36.8% measured in 2012 and higher than 2008-2011. Various factors were examined for their potential impact on spat survival including spat density per shell, spat density per acre, growth rate, region, and environment. No factors examined trended significantly with spat survival. Considering the complex process involved in executing a successful hatchery spat-on-shell planting, from the spawning of spat at the hatchery, to their transport to the site, to the conditions they grow in, and the sampling method used to estimate survival, it is not surprising that pinpointing factors that consistently influence survival is extremely difficult.

Survival was highly variable between sites, ranging from 8.4% to 84.8%. However, both the highest and lowest survival values came from repeat samplings of overplantings, where a site was replanted more than a month after the previous planting and so had to be monitored separately. This made quad sampling impossible, and spat-on-shell were differentiated from older spat on the same site by size alone. Given how different the survival values from overplanted sites are from normally sampled sites, it seems probably that selective sampling misrepresents the spat quantity of a single planting. For example, spat from earlier plantings that had not grown as expected would be included in the selective sample, resulting in more spat being recorded than actually belonged to the planting. This error source will be difficult to avoid in the future if plantings on a single site continue to be separated by more than four weeks. That said, we believe the sampling is still the best way to estimate survivorship at any given site, which is critical to understanding the relationship between bottom quality, location, substrate type, and planted spat survival.

Among factors influencing post-planting spat survival, substrate type and predation are still thought to be the largest. The experiment in Trappe Creek examining substrate type was sampled for the last time in 2013, but methodological challenges made the experiment unsuccessful. A similar experiment was deployed in 2013 in Edge Creek alongside the wild-hatchery comparison experiment, with initial sampling occurring late in 2013, and is expected to continue through 2014. No research was done on predation this year, however a predation-focused project is still recommended.

Overall, the 2013 planting season had similar survival as in 2012 – they were not statistically different, and substantially higher than in previous years using similar techniques. Additionally, the standard error of survival in 2013 was much narrower than in previous years, suggesting that sites are more consistently reaching higher survival values. This success was likely due in part to enhanced planting site selection through use of bottom type data and ground truthing.

Patent Tong Survey

Specific benchmarks for restoration success were identified by the Oyster Metrics Workgroup (OMW) in 2011. Among these criteria are that the bar should have both an oyster density of 15 or more oysters/m^2 and a biomass density of 15 or more g/m^2. A total of six sites were surveyed with patent tongs in the 2013 season, two regular sites and four long-term monitoring sites. On the regular bars, which were between 3 and 11 years of age, average oyster density ranged from 1.8 to 9.0 oysters/m^2. Average biomass density ranged from 3.7 to 17.5 g/m^2. Taken as wholes, these bars did not meet the OMW's criteria for restoration success. However, if only the areas of more recent plantings are included, States Bank meets or exceeds the threshold. Among long-term monitoring bars, which were one to two years old, average oyster density ranged from 26.2 to 71.8 oysters/m^2, biomass density ranged from 26.4 to 55.4 g/m^2. These sites easily passed the OMW's minimum standards, though they are very young and it remains to be seen how they will survive and grow over time.

Another approach in examining bar success is survival. For the regular bars, expected population size was calculated and compared to measured population. On both bars, the population was less than 20% of expected. On the long-term bars, survival percent between annual surveys was calculated, and in all cases was greater than 60%. This discrepancy may indicate that the tributary-wide restoration of Harris Creek is creating a more favorable environment for oyster bars. It could also point to reduced poaching resulting from the youth and smallness of the Harris Creek oysters. Finally, it could be due to inaccuracy in population estimating methods, especially when extended over several years. Finally, given the substantial increase in initial survivorship shown by PPM data, it is likely that older restoration efforts suffered significantly higher initial mortality rates than suspected, which is why post planting monitoring (PPM) was implemented and remains so important to the overall effort.

As with PPM data, there is evidence to suggest that bottom quality is a leading factor in restoration success. To that end, both substrate type and percent of buried shell were recorded in 2013 patent tong surveys. While not a perfect correlation, higher oyster densities are almost exclusively associated with higher shell scores. Nevertheless, there is variability in oyster survival and density that cannot be explained through bottom quality alone.

This was the first year that comparisons across years could be made for bars slated for long-term monitoring. As expected, while oyster numbers declined, biomass increased as oysters grew. These early growth statistics already look valuable for understanding the behavior of restored bars and the factors influencing those trends. While further years of sampling will be necessary to observe the bars as they age, restored bars in Harris Creek currently meet the OMW's standards of success.

Summary

As in 2012, spat survival post-planting was higher than in previous years, likely due to good site selection confirmed by ground truthing. Restoration efforts continued to be focused in Harris Creek, an area well characterized by side-scan imaging and information regarding the presence of alternate substrate. Additionally, several years of patent tong data have been collected in Harris Creek, and should continue to be surveyed annually for several years.

Identifying the factors that impact restoration success is a continued challenge. The interactions between bottom composition, location, shell exposure, salinity, temperature, water dynamics, predation, natural spat sets, and a host of other potential factors are far too complicated to be fully elucidated. However, we plan to experimentally explore the role of bottom type more fully in 2014, which should generate data that can be applied to more complex scenarios of spat survival in the field. Also, as our dataset grows, we will gain more statistical power to analyze the data in a variety of ways, looking for trends with environmental parameters.