2022 and 2023 Maryland Oyster Monitoring Report

Analysis of Data from the ‘10 Tributaries’ Sanctuary Oyster Restoration Initiative in Maryland

Data discussed in this report were collected in fall 2022 and fall 2023. This report was produced by the NOAA Fisheries Office of Habitat Conservation's Restoration Center and NOAA Chesapeake Bay Office divisions, in partnership with the [Maryland Oyster Restoration Interagency Workgroup] of the [Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team].

This report, past monitoring reports, tributary-specific oyster restoration plans ('blueprints'), and other oyster restoration technical documents produced by the Maryland Oyster Restoration Interagency Workgroup of the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team are available at https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams.

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Cover photo and above photo, credit Oyster Recovery Partnership.

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Executive Summary

Context for This Report

The 2014 Chesapeake Bay Watershed Agreement[1] includes a goal to restore oyster populations in 10 Chesapeake Bay tributaries by 2025 (hereafter, the '10 Tributaries Initiative').

In Maryland, partners including the National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers' Baltimore District, Oyster Recovery Partnership, and the Maryland Department of Natural Resources are working to achieve this goal through the Maryland Interagency Oyster Restoration Workgroup (hereafter, 'the Workgroup'). The Workgroup is convened under the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program and is chaired by Stephanie Reynolds Westby (NOAA).

A set of oyster restoration success criteria, commonly known as the Chesapeake Bay Oyster Metrics[2], was developed prior to implementing restoration work in the 10 Tributaries. The recommendations therein call for reefs to be monitored 3 years, and again 6 years, post restoration. A subset of reefs in Little Choptank and Tred Avon rivers were due for monitoring in fall 2022 and fall 2023.

This report describes reef health relative to four criteria set forth in the Oyster Metrics document: oyster density, oyster biomass, multiple year classes, and shell budget. See Discussion section for more information.

Data and analyses in this report can be used to inform what adaptive management measures, if any, should be taken on each of the monitored reefs. Results may also guide restoration in other tributaries.

Healthy spat were seen during fall oyster monitoring work. Credit: Oyster Recovery Partnership.

Key Monitoring Results

Key results from 2022 and 2023: 88 6-year-old reefs (comprising 246 acres) were monitored in 2022 and 2023 combined. Of these, 98% met the minimum threshold oyster density success criteria and 83% met the higher, target oyster density (Figure 1). Oyster biomass tracked closely with oyster density. See 2022 and 2023 monitoring summaries in Tables 2 and 3.

Key results from 2015 through 2023: 197 6-year-old reefs (comprising 681 acres) were monitored from 2015 through 2023. Of these, 98% met the threshold density and 83% met the target density. Oyster biomass has tracked closely with oyster density. See summary of monitoring results across all years in Table 4.

Every reef monitored, at both year 3 and year 6, from 2015 to 2023, showed the presence of multiple year classes of oysters. This equates to a 100% success rate for the multiple year class Oyster Metrics success criteria.

Some reefs monitored in 2022 and 2023 did not meet the shell budget metric, as currently measured. See details in the Discussion section.

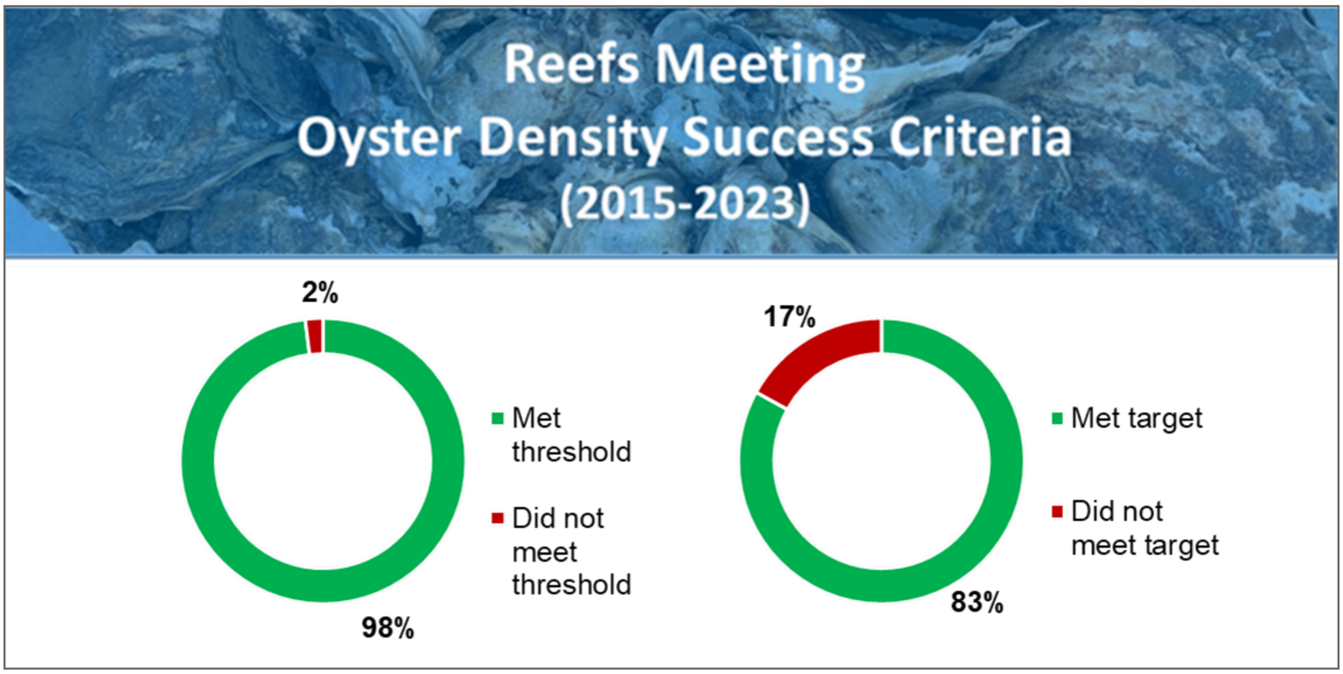

Figure 1: *Across all 6-year-old reefs monitored from 2015 to 2023, 98% met the minimum threshold criteria for oyster density (15 oysters per m^2) and 83% met the higher target for oyster density (50 oysters per m^2).*

Section 1: Background and Overview

1.1: Policy Drivers, Oyster Metrics Success Criteria, and Oyster Restoration Planning

The 2014 Chesapeake Bay Watershed Agreement[1] oyster outcome calls for restoring oyster populations in 10 Chesapeake Bay tributaries by 2025. The Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team (Fisheries GIT) is charged with working to achieve this goal. Driven by Executive Order 13508 (Chesapeake Bay Protection and Restoration) of 2009, some work toward tributary-scale oyster restoration was underway even before the 2014 Chesapeake Bay Watershed Agreement was signed. The Fisheries GIT had convened the Chesapeake Bay Oyster Metrics Workgroup, which, in its 2011 report "Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries,"[2] (hereafter, 'Oyster Metrics') established Bay-wide, science-based, consensus success criteria for oyster restoration to be tracked 3 years, and again 6 years, following initial restoration (Table 1). The 2022 and 2023 Maryland Oyster Monitoring Report describes success relative to four of the six Oyster Metrics criteria (oyster density, oyster biomass, multiple year classes, and shell budget); see Discussion section for more information.

Reef-level success criteria	**Biological Metrics**	**Oyster Density**: Minimum threshold = 15 oysters per m^2 over 30% of the reef area. Target = 50 oysters per m^2 over 30% of the reef area.
		Oyster Biomass: Minimum threshold = 15 grams dry weight per m^2 over 30% of the reef area. Target = 50 grams dry weight per m^2 over 30% of the reef area.
		Multiple Year Classes: Presence of multiple year classes on the reef, as defined by oysters in at least two of the following size classes: market (>76 mm); small (40-75mm); spat (<40mm).
		Shell Budget: Stable or increasing shell volume on the reef
	Structural Metrics	**Reef Footprint**: Stable or increasing reef footprint compared to baseline.
		Reef Height: Stable or increasing reef height compared to baseline
Tributary-level success criteria	A minimum of 50% of currently restorable area within a given tributary, that constitutes at least 8% of historic oyster habitat, meets the reef-level success criteria.	

Table 1: *Oyster Metrics reef-level and tributary-level success criteria.*

Once these success criteria were adopted, the Fisheries GIT convened interagency workgroups in Maryland and Virginia to plan and coordinate restoration work in each state. In Maryland, the Workgroup is chaired by the National Oceanic and Atmospheric Administration (NOAA) and includes members from the Maryland Department of Natural Resources (DNR), Oyster Recovery Partnership (ORP), and the U.S. Army Corps of Engineers' Baltimore District (USACE). The Workgroup developed oyster restoration tributary plans (also known as "blueprints") for Harris Creek[3], Little Choptank River[4], Tred Avon River[5], upper St. Marys River[6], and Manokin River[7] in consultation with a group of consulting scientists and the public.

1.2: Overview of Report Content

Restored reefs are monitored at 3 and 6 years after construction, per recommendations from the Oyster Metrics and each river's tributary plan. In 2022 and 2023, a subset of restored reefs in Little Choptank River and Tred Avon River had matured to 3 or 6 years and were monitored in the fall of the relevant years. Summarized monitoring results for these reefs are included in this report (see Tables 2 and 3). Reference reefs (controls that received no restoration action) were also monitored, and results for these reefs are similarly summarized in Tables 2 and 3. Additionally, sentinel reefs (restored sites that are monitored annually) were monitored in fall 2022 and fall 2023. Data on these reefs are in Appendices A1 and A2.

This report describes success relative to four of the six Oyster Metrics criteria: oyster density, oyster biomass, multiple year classes, and shell budget. In the earlier years of monitoring under the 10 Tributaries Initiative, all six Oyster Metrics success criteria were measured (the previously listed four Metrics, plus reef height and reef footprint). However, over the course of nearly a decade of monitoring, all reefs (100%) passed these two metrics. This information, combined with a requisite halt in sonar work during the pandemic years and the resource-intensive nature of measuring these parameters using sonar equipment, has led NOAA to adapt to measuring these parameters only on reefs that, per other, more sensitive Metrics, are showing signs of potential poor reef health. This revised protocol is consistent with the adaptive management recommended in the original Oyster Metrics document. (See Discussion section for full description.)

Past monitoring reports are available from the Chesapeake Bay Program's Maryland and Virginia Oyster Restoration Interagency Teams Publications page.

In addition to Oyster Metrics success criteria monitoring, oyster disease data is also collected by DNR, and is available in DNR's annual Fall Survey Report. Water quality data is available at DNR's Eyes on the Bay website and on the NOAA Chesapeake Bay Interpretive Buoy System website.

1.3: Funding and Acknowledgements

Monitoring data for the biological success metrics (oyster density, oyster biomass, multiple year classes, and shell budget) were collected, managed, and analyzed by ORP, Specialty Underwater Services, Van Clark Underwater Services, and contracted commercial watermen, with assistance from Workgroup partners. This was accomplished with:

- 2022 funding: a $107,625 award from NOAA to ORP, and a $112,770 programmatic agreement from USACE to ORP.

- 2023 funding: a $125,000 award from NOAA to ORP, and a $60,822 programmatic agreement from USACE to ORP.

This report was drafted by NOAA, with guidance from the Workgroup. Results of these analyses will be used to document the success or failure of restoration relative to the Oyster Metrics criteria, to guide adaptive management of these reefs, and to inform future oyster restoration efforts. Technical review of this report was provided by technical experts and Workgroup members, per NOAA research communications guidelines.

Section 2: Overview of Monitoring

2.1: Monitoring Synopsis

In fall 2022, the following were monitored (Figures 2 and 3):

- 3-year-old reefs: 6 in the Little Choptank River and 2 in the Tred Avon River
- 6-year-old reefs: 41 in the Little Choptank River and 7 in the Tred Avon River

In fall 2023, the following were monitored (Figures 4 and 5):

- 3-year-old reefs: 6 in the Little Choptank River and 1 in the Tred Avon River
- 6-year-old reefs: 22 reefs in the Little Choptank River and 18 reefs in the Tred Avon River

Large-scale restoration work under the 10 Tributaries Initiative has also occurred in Harris Creek and the St. Marys and Manokin rivers. All Harris Creek restored reefs are now more than 6 years old, which is the monitoring time frame recommended in Oyster Metrics. Results from restoration work here have been tallied as part of Table 4, where cumulative results are described. Restored reefs in the St. Marys and Manokin rivers are not yet 3 years old, so have not yet been monitored per Oyster Metrics recommendations. Data to determine success relative to the four measured metrics (oyster density, oyster biomass, multiple year classes, and shell volume) were collected at the same time, using a stratified random survey design. Methods used to select sampling sites, analyze samples, and assess success relative to each metric were identical for all reefs. See Appendix B for full monitoring methods.

2.2: Location of Monitored Reefs

All 3-year-old, 6-year old, and reference reefs monitored in 2022 and 2023 are represented on the maps that follow.

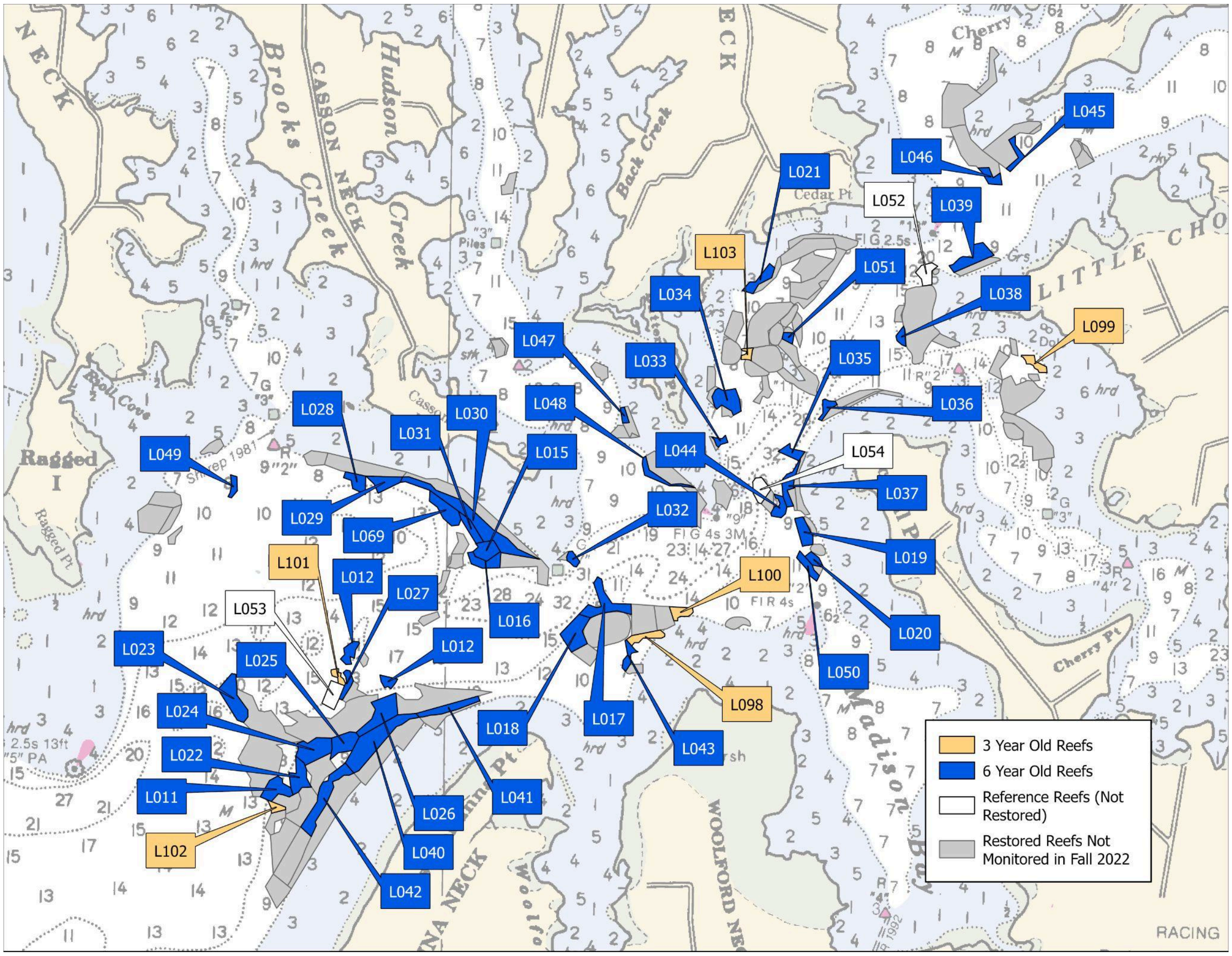

Figure 2: *Locations of Little Choptank River reefs monitored in fall 2022. 6 3-year-old reefs and 41 6-year-old reefs were monitored.*

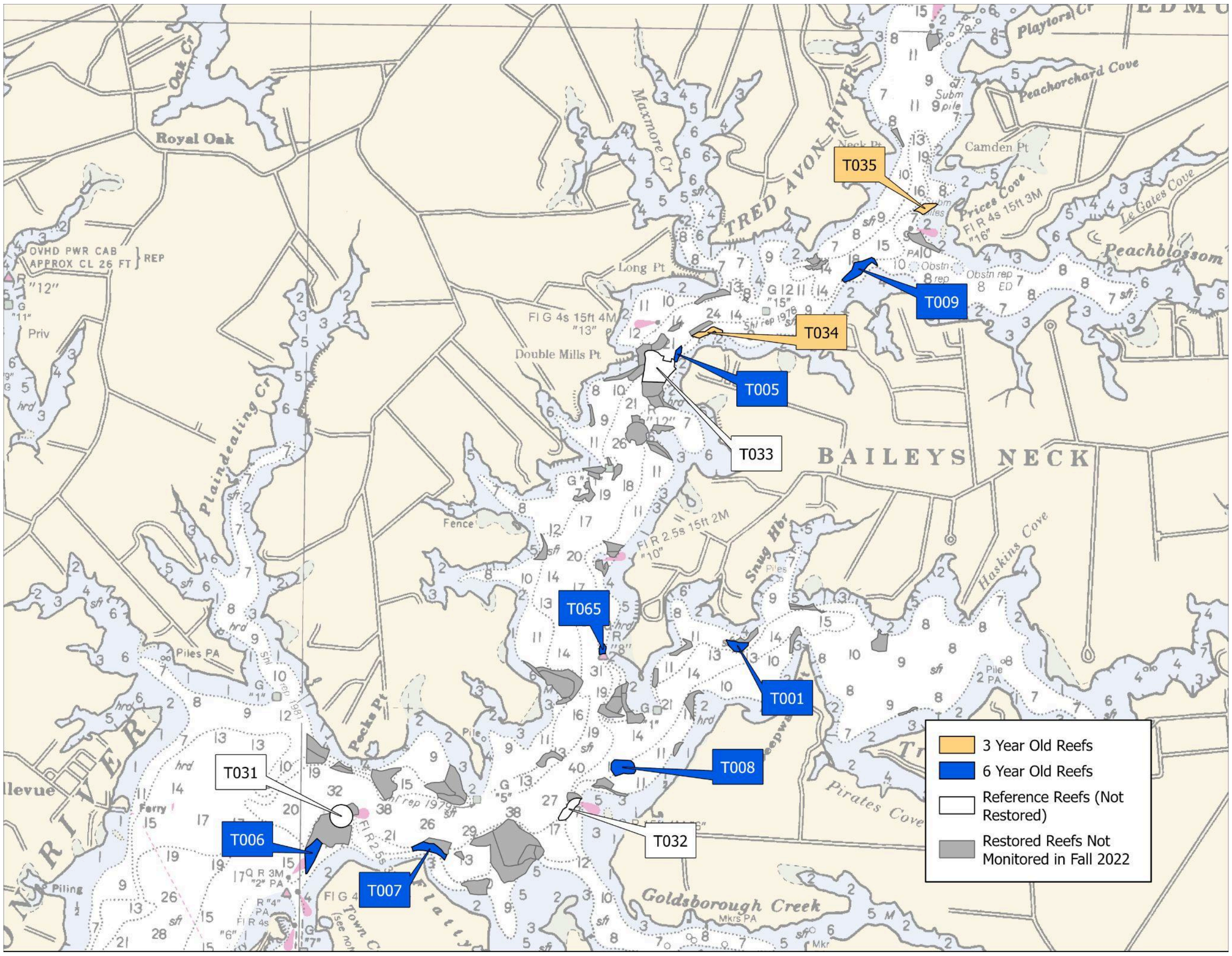

Figure 3: *Locations of Tred Avon River reefs monitored in fall 2022. Two 3-year-old reefs and 7 6-year-old reefs were monitored.*

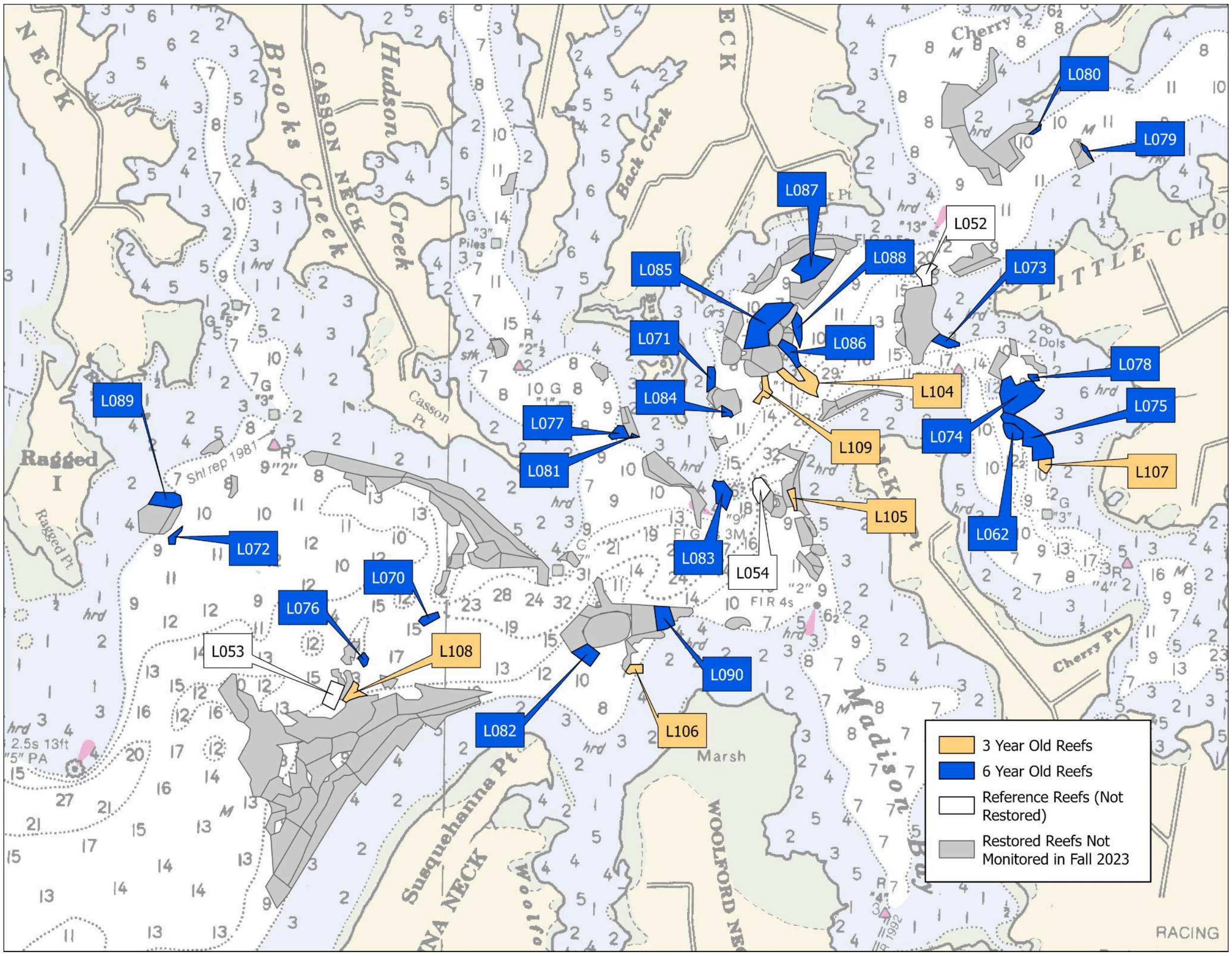

***Figure 4:** Locations of Little Choptank River reefs monitored in fall 2023. 6 3-year-old reefs and 22 6-year-old reefs were monitored.*

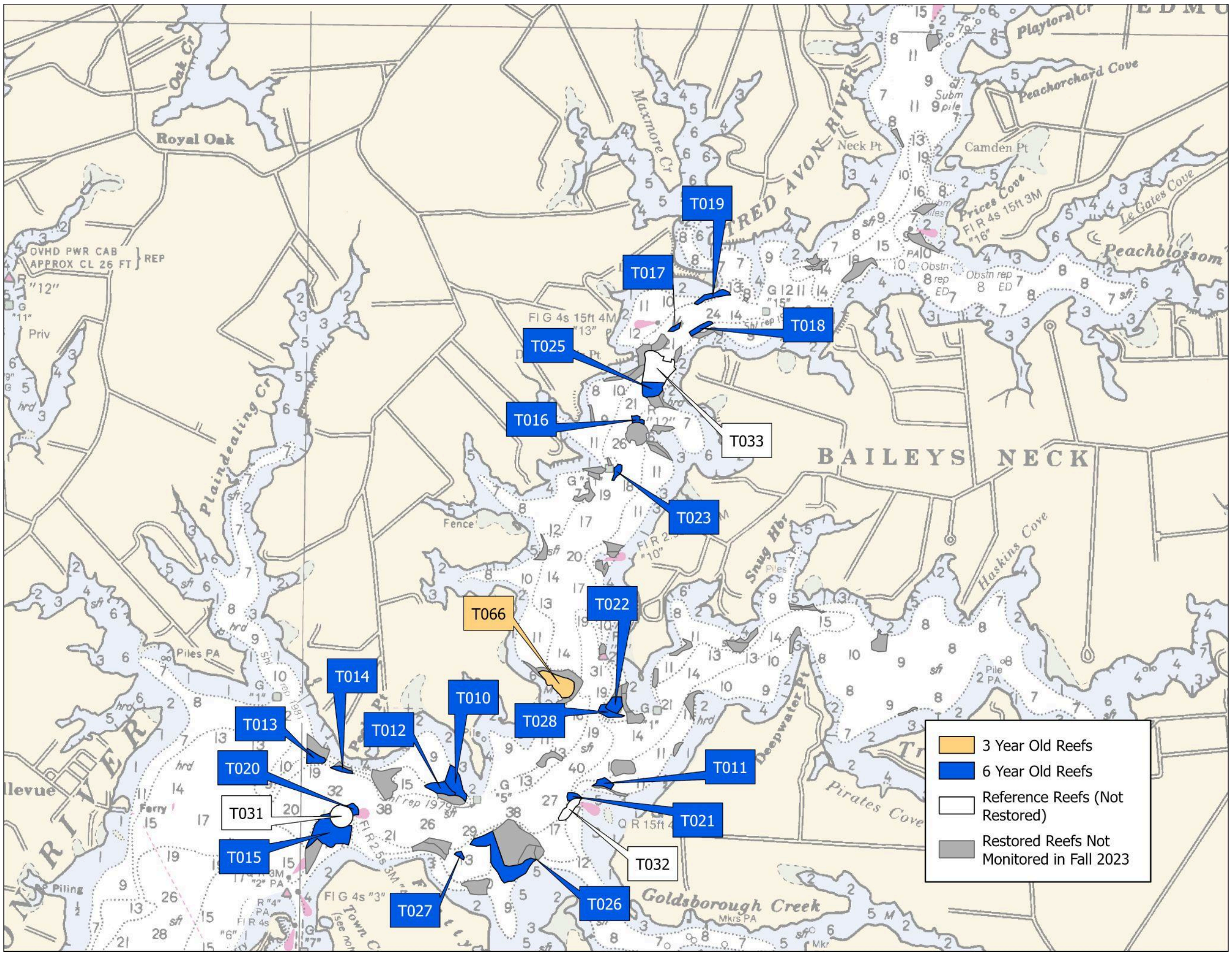

Figure 5: *Locations of Tred Avon River Reefs monitored in fall 2023. 1 3-year-old reef and 18 6-year-old reefs were monitored.*

Section 3: Results Summary

3.1: Summary of Fall 2022 and Fall 2023 Monitoring Results

Summary of results are depicted in Table 2 and Table 3, respectively. The tables show the percent of 3-year-old, 6-year-old, and reference reefs in each tributary that met each Oyster Metrics success criteria. The tables also depict percentages for all tributaries combined for 3-year-old, 6-year-old, and reference reefs.

			Oyster Density		Oyster Biomass		Multiple Year Classes	Shell Budget
Reef Type	**Tributary**	**# of reefs monitored in fall 2022**	**% of reefs meeting minimum threshold**	**% of reefs meeting target**	**% of reefs meeting minimum threshold**	**% of reefs meeting target**	**% with multiple year classes present**	**% with stable/ increasing shell budget**
3 Year Old	Harris Creek	3 year monitoring is complete in Harris Creek						
	Little Choptank	6	100%	33%	100%	100%	100%	TBD
	Tred Avon	2	50%	0%	100%	50%	100%	TBD
	All Tribs Combined	**8**	**88%**	**25%**	**100%**	**88%**	**100%**	**TBD**
6 Year Old	Harris Creek	6 year monitoring is complete in Harris Creek						
	Little Choptank	41	100%	93%	100%	100%	100%	85%
	Tred Avon	7	71%	43%	86%	71%	100%	86%
	All Tribs Combined	**48**	**96%**	**85%**	**98%**	**96%**	**100%**	**85%**
Reference Reefs	Harris Creek	4	100%	50%	100%	75%	100%	N/A
	Little Choptank	3	100%	100%	100%	100%	100%	N/A
	Tred Avon	3	100%	33%	100%	33%	100%	N/A
	All Tribs Combined	**10**	**100%**	**60%**	**100%**	**70%**	**100%**	**N/A**

Table 2: *Percent of 3-year-old, 6-year-old, and reference reefs monitored in fall 2022 that met each Oyster Metrics success criteria. In 2022, only Little Choptank River and Tred Avon River had 3-year-old and 6-year-old reefs. 3-year-old reefs have the designation 'TBD' for shell budget, as shell volume must be measured at least one more time to determine if there is a stable, increasing, or decreasing shell volume trend (shell budget). Reference reefs show 'N/A' in the shell budget column, as these reefs are not measured annually for shell budget.*

			Oyster Density		Oyster Biomass		Multiple Year Classes	Shell Budget
Reef Type	**Tributary**	**# of reefs monitored in fall 2023**	**% of reefs meeting minimum threshold**	**% of reefs meeting target**	**% of reefs meeting minimum threshold**	**% of reefs meeting target**	**% with multiple year classes present**	**% with stable/ increasing shell budget**
3 Year Old	Harris Creek	3 year monitoring is complete in Harris Creek						
	Little Choptank	6	100%	83%	100%	100%	100%	TBD
	St. Marys	No 3 year old reefs in St. Marys in fall 2023						
	Tred Avon	1	100%	100%	100%	100%	100%	TBD
	All Tribs Combined	**7**	**100%**	**86%**	**100%**	**100%**	**100%**	**TBD**
6 Year Old	Harris Creek	6 year monitoring is complete in Harris Creek						
	Little Choptank	22	100%	82%	100%	100%	100%	68%
	St. Marys	No 6 year old reefs in St. Marys in fall 2023						
	Tred Avon	18	100%	78%	100%	94%	100%	100%
	All Tribs Combined	**40**	**100%**	**80%**	**100%**	**98%**	**100%**	**83%**
Reference Reefs	Harris Creek	4	100%	25%	100%	100%	100%	N/A
	Little Choptank	3	100%	100%	100%	100%	100%	N/A
	St. Marys	2	100%	100%	100%	100%	100%	N/A
	Tred Avon	3	100%	100%	100%	100%	100%	N/A
	All Tribs Combined	**12**	**100%**	**75%**	**100%**	**100%**	**100%**	**N/A**

Table 3: *Percent of 3-year-old, 6-year-old, and reference reefs monitored in fall 2023 that met each Oyster Metrics success criteria. In 2023, only Little Choptank River and Tred Avon River had 3-year-old and 6-year-old reefs. 3-year-old reefs have the designation 'TBD' for shell budget, as shell volume must be measured at least one more time to determine if there is a stable, increasing, or decreasing shell volume trend (shell budget). Reference reefs show 'N/A' in the shell budget column, as these reefs are not measured annually for shell budget.*

3.2: Summary of Cumulative Results, 2015-2023

Reef monitoring under the 10 Tributaries Initiative started in 2015. Summary results from fall 2015 through fall of 2023 are depicted in Table 4. The table shows the percent of 3-year-old and 6-year-old reefs, in each tributary, that met each oyster metric throughout the monitoring years. Figures 6 and 7 are graphic representations of the percent of reefs from 2015 through 2023 that met oyster density and oyster biomass minimum threshold and target metrics.

			Oyster Density		**Oyster Biomass**		**Multiple Year Classes**	**Shell Budget**
Reef Type	**Tributary**	**# of reefs monitored in fall 2015–2023**	**% of reefs meeting minimum threshold**	**% of reefs meeting target**	**% of reefs meeting minimum threshold**	**% of reefs target**	**% with multiple year classes present**	**% with stable/ increasing shell budget**
3-year-old	Harris Creek	90 (348 acres)	98%	80%	98%	81%	100%	TBD
	Little Choptank	104 (358 acres)	98%	87%	98%	81%	100%	TBD
	Tred Avon	34 (93 acres)	85%	15%	91%	21%	100%	TBD
	All Tribs Combined	**228 (799 acres)**	**96%**	**73%**	**97%**	**72%**	**100%**	TBD
6-year-old	Harris Creek	90 (348 acres)	99%	80%	99%	79%	100%	98%
	Little Choptank	82 (272 acres)	100%	90%	100%	96%	100%	84%
	Tred Avon	25 (61 acres)	92%	68%	96%	88%	100%	96%
	All Tribs Combined	**197 (681 acres)**	**98%**	**83%**	**99%**	**87%**	**100%**	**92%**

Table 4: *Percent of 3-year-old and 6-year-old reefs monitored from 2015 through 2023 that met each Oyster Metrics success criteria. 3-year-old reefs have the designation 'TBD' for shell budget, as shell volume must be measured at least one more time to determine if there is a stable, increasing, or decreasing shell volume trend (shell budget).*

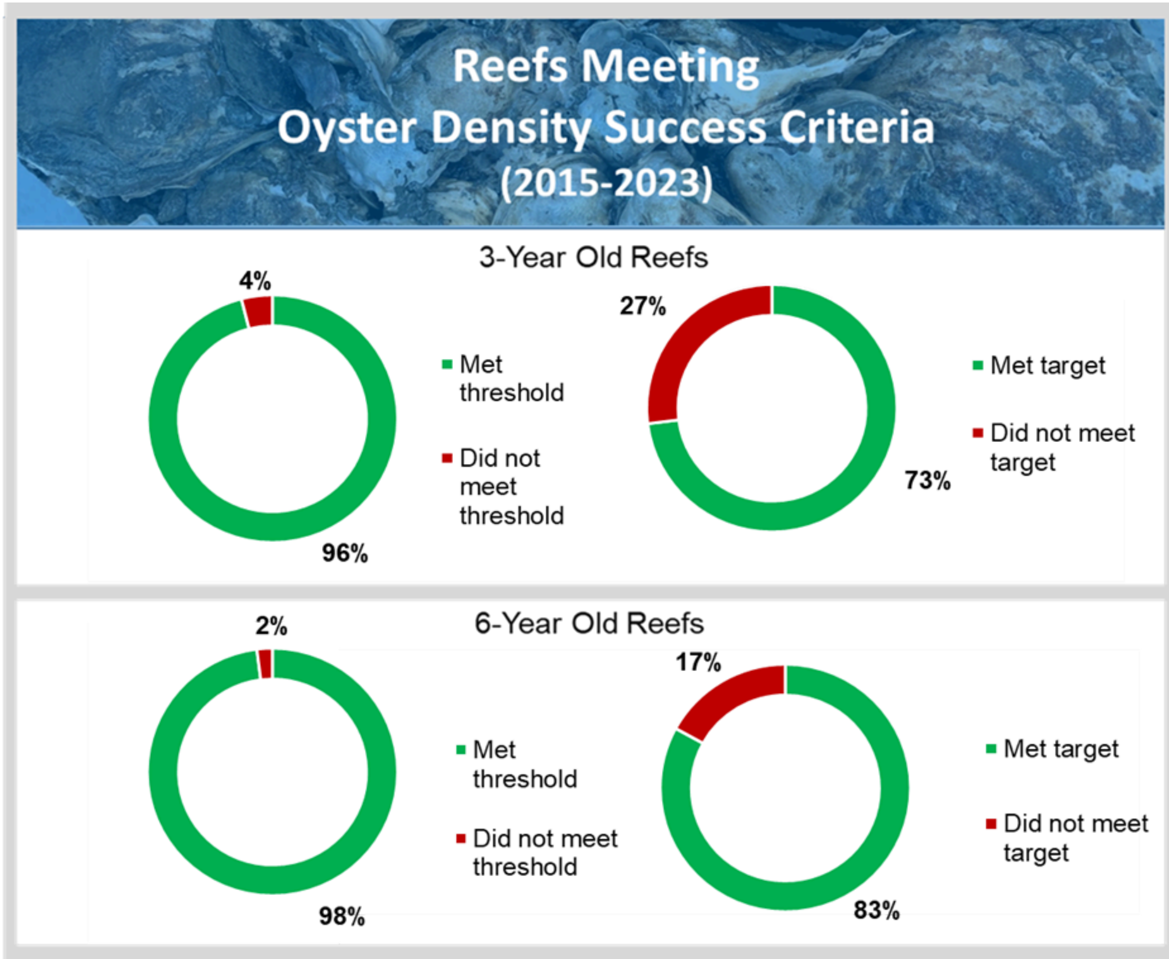

Figure 6: *Cumulative percentage of reefs meeting the oyster density success criteria 2015–2023.*

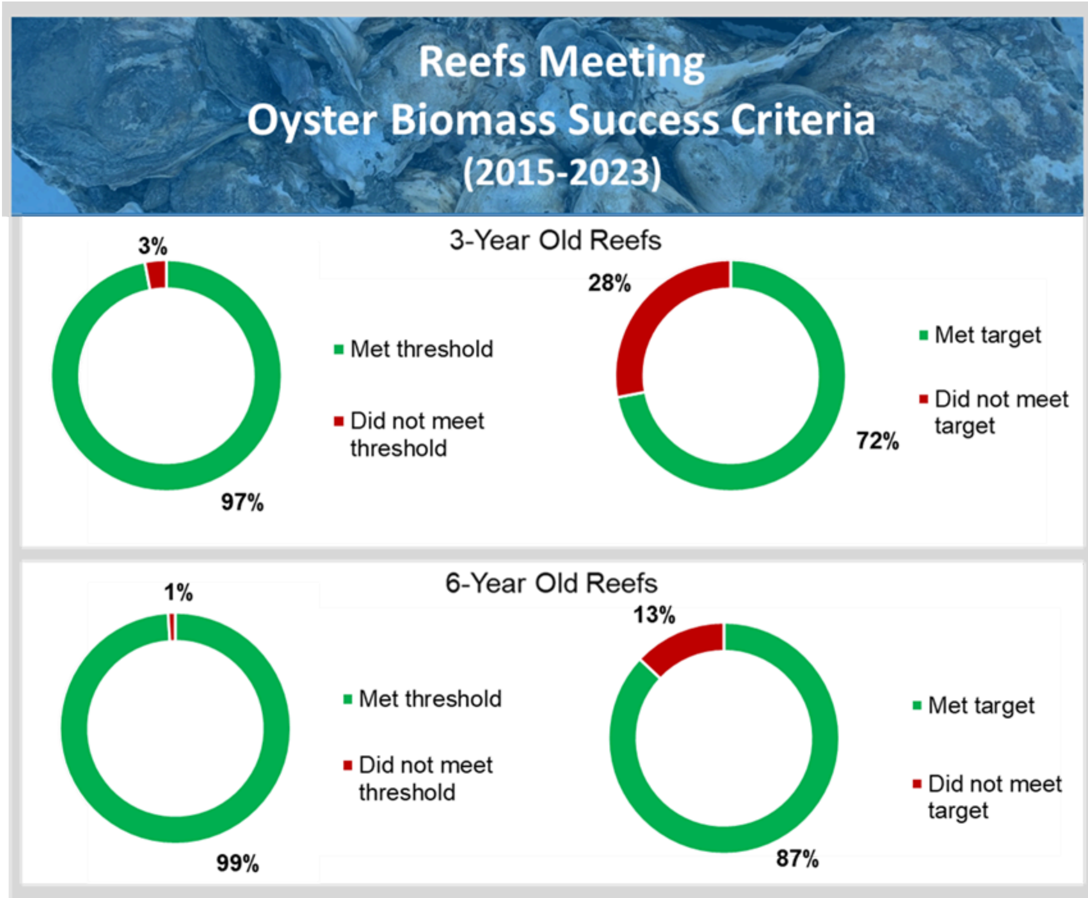

Figure 7: *Cumulative percentage of reefs meeting the oyster biomass success criteria 2015–2023.*

Section 4: Discussion

4.1 Overall Trends

Trends observed in previous monitoring years generally continued in 2022 and 2023, with a large majority of restored reefs meeting the four Oyster Metrics success criteria measured (oyster density, oyster biomass, multiple year classes, and shell budget).

Standout points include:

- For 6-year-old reefs, on all tributaries combined (the point at which, per Oyster Metrics, a reef can be considered successfully restored):
    - Among those monitored in 2022, 96% met the minimum threshold for oyster density, and 85% met the higher target density.
    - Among those monitored in 2023, 100% met the minimum threshold for oyster density, and 80% met the higher target density.
    - Among those monitored from 2015 through 2023, 98% met the minimum threshold for oyster density, and 83% met the higher target level for oyster density.
- Oyster biomass tracked closely with oyster density for reefs of all ages and across all years.
- 100% of all reefs monitored met the success criteria for multiple year classes.
- Similar to past years, Tred Avon reefs generally show lower oyster densities than restored reefs in other tributaries.

4.2 Shell Budget Success Criteria

The 2022 and 2023 monitoring results differed from previous years in that, for the first time, some 6-year-old reefs did not meet the shell budget success criterion, as currently measured. This was observed for 13 reefs in Little Choptank River, and 1 reef in Tred Avon River (site-specific details in Appendix A1 and A2). These reefs were restored using a variety of treatments, including seed only, stone, mixed shell, and fossil shell (see Section 5 for definitions), and were sampled using a combination of gear types (divers and patent tongs; see 'Use of Multiple Gear Types' subheading below). All reefs that failed shell budget criteria received additional substrate 4 or 5 years post restoration, in the form of spat-on-shell, in the course of the planned second seeding.

All of these reefs, except for site T001 (1.7 acres) in Tred Avon River met both the oyster density and biomass criteria, with average reef densities ranging from 29 to 35 oysters per square meter in the Tred Avon, and from 31 to 328 oysters per square meter in the Little Choptank (see Appendices A1 and A2 for reef-specific average oyster density and biomass). These are well above the threshold density of 15 oysters per square meter, and many are even above the target density of 50 oysters per square meter. Moreover, several of these reefs had higher oyster densities and biomass at 6 years than at their 3-year monitoring. Additional sampling and data analyses were conducted by the Workgroup to investigate mechanisms contributing to the failure of the shell budget metric. NOAA conducted sonar sampling for reef structure, and ORP and NOAA conducted video sampling using the established Rapid Assessment Protocol video sampling (see PDF [for methods]) to visually assess the overall reef condition. These surveys were done on two reefs in Tred Avon River (reefs T001 and T002), and seven reefs in Little Choptank River (reefs L010, L011, L017, L022, L40, and L42). Key points from this work include:

- Tred Avon: Images obtained using the Rapid Assessment Protocol on reef T001 showed heavy sedimentation on the eastern half of the reef with 82% of the samples returning either a score of 0 or 1, suggesting low quality reef habitat. The sonar data also shows signs of reef disturbances on the eastern half, when compared with sonar data taken soon after reef construction. This, along with the above-mentioned fact that this reef also failed the oyster density Metric, suggests that this reef is not thriving, potentially due to reef disturbance during the construction of the adjacent reef. Although Reef T002 was not technically part of the monitoring cohort, it was monitored. Images obtained on this reef using the Rapid Assessment Protocol showed healthy reef habitat, with more than 30% of samples taken scoring 3. Sonar data showed no detectable structural issues compared with when the reef was constructed. This, combined with the higher reef biomass and density observed in this monitoring cycle relative to 3 years prior, suggests a healthy reef.
- Little Choptank River: All seven surveyed reefs exceeded minimum expectations for successfully restored reefs using the Rapid Assessment Protocol. The sonar data revealed no appreciable structural differences from post-construction surveys. (Though on reef L011, sonar data shows an even pattern of disturbance over a very small portion of the reef, consistent with propeller scarring or similar anthropogenic activity.) The video and sonar imaging, together with the fact that all of these reefs pass the oyster density and biomass criteria, and all have more oyster biomass than they did when monitored 3 years prior, suggest these reefs are healthy.

Additionally, in the summer of 2023, DNR resampled the seed-only sites in Tred Avon and Little Choptank that were failing the shell budget metric, per the fall 2022 survey. All sites had two to three times more substrate than was indicated during the 2022 survey. This significant difference in shell volume speaks to the variance between gear on different sampling vessels. A GoPro camera was used to examine the patent tongs' ability to sample the 6-year-old reefs during the 2023 survey. The pictures did show that on some reefs it was hard for the patent tongs to retrieve a full sample based on the three-dimensional reefs and the clumping of oysters.

The preponderance of evidence on the reefs that did not pass the shell budget Metric suggests that most of the reefs in question are, in fact, functioning as healthy oyster habitat. It is likely that the issue lies in how the Metric was written, interpreted, or measured than with the reefs themselves. The shell budget Metric, as written in the Oyster Metrics document, requires a reef to show a 'stable or increasing' shell budget.

Shell volumes on restored oyster reefs are inherently variable. For example, Figure 8 shows shell volume on a restored sanctuary (non-harvest) reef in Virginia over a 20-year time series. The shell volume varies appreciably year to year. Using this example, taking data points from any two years and defining a trend could result in different conclusions. Even with annual monitoring, it is unclear whether a meaningful trend can be discerned in the space of 6 years, as recommended in Oyster Metrics. Examining shell volume data collected annually in Harris Creek, Tred Avon, and Little Choptank reveals similarly variable shell volume trends (Figure 9).

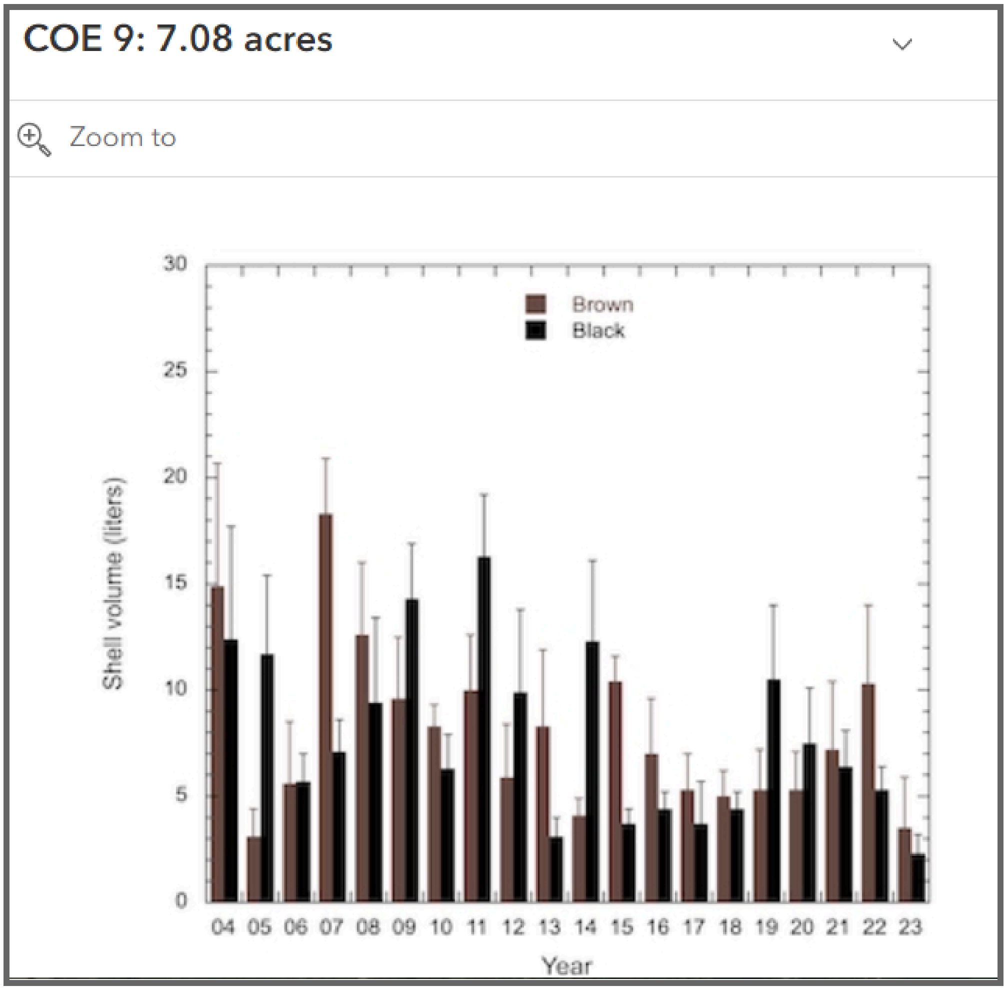

Figure 8: *Shell volume data over time (shell budget) data from reef COE 9, a 7.8-acre restored oyster reef in the Great Wicomico River in Virginia. Graph credit: Oyster Stock Assessment and Replenishment Archive (VOSARA). Brown shell refers to shell with no mud or brown, oxic mud; black shell refers to any shell with black, typically anoxic, mud.*

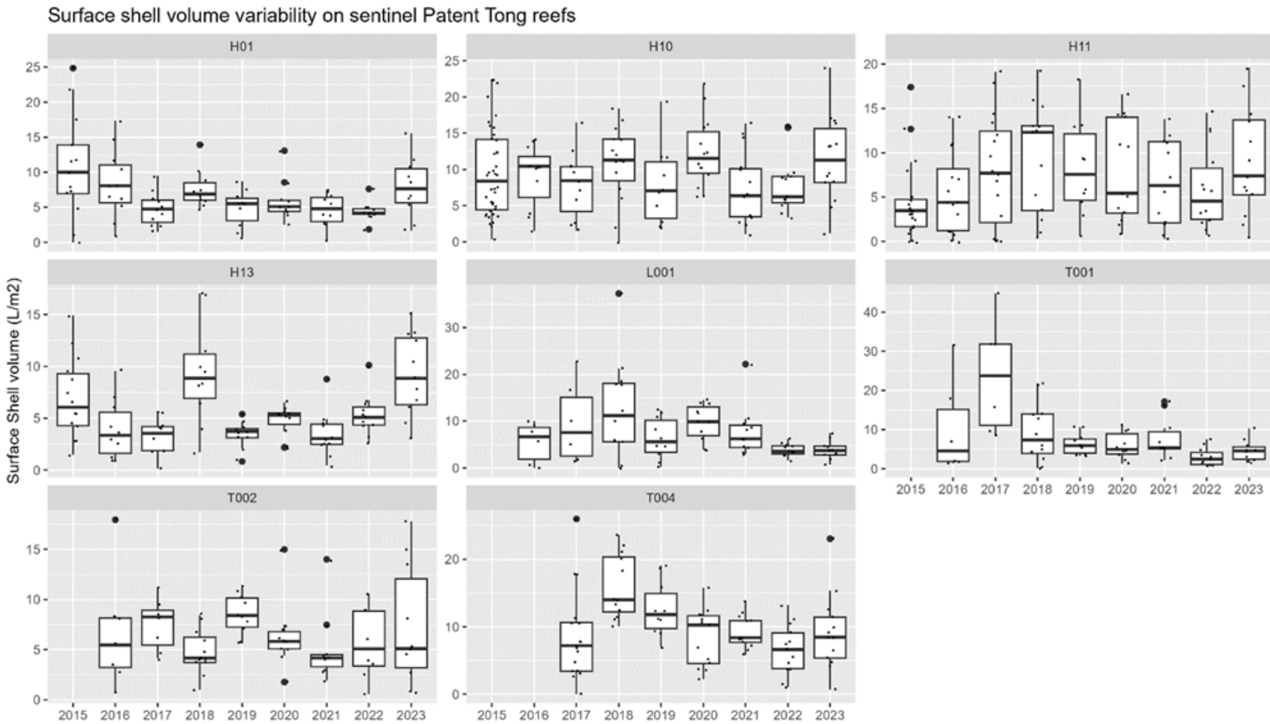

Figure 9: *Shell volume data over time on eight restored reefs in Harris Creek and the Little Choptank and Tred Avon rivers. Graph developed by Oyster Recovery Partnership from data in past Maryland monitoring reports.*

Collectively, the inherent variability in shell volume, differences in gear performance, and additional assessment of the reefs in question cast doubt on the validity of solely using the shell budget metric, as currently interpreted and measured, to determine the ultimate categorization of a reef as a success or failure. The additional data collected on these reefs, and results of the other three metrics, indicate that these reefs are healthy, with the exception of the Tred Avon reef T001. Using the results of the metrics collectively to assess the performance of individual reefs is consistent with the Oyster Metrics document itself.

4.3 Monitoring for Reef Height and Reef Footprint Success Criteria

This report describes success relative to four of the six Oyster Metrics criteria (oyster density, oyster biomass, multiple year classes, and shell budget). In the earlier years of monitoring under the 10 Tributaries Initiative, six Oyster Metrics success criteria were measured (the previously listed four Metrics, plus reef height and reef footprint). However, in more than a decade of measuring the reef height and reef footprint Metrics, not a single reef has failed this criteria. NOAA has been the sole partner undertaking the task of monitoring reefs restored under the 10 Tributaries Initiative to determine if they meet the reef height and reef footprint success criteria. In service to this, NOAA has intensively surveyed 134 reefs, comprising 511 acres, with multibeam sonar, at .25 meter resolution. Each of these reefs has been monitored at least two times to determine whether these metrics have been met, because the success criteria, per Oyster Metrics, is set as 'stable or increasing.' A single survey cannot describe a 'stable or increasing' trend; therefore, multiple surveys over multiple years have been required. Through this work, NOAA has learned that 100% of the reefs monitored, including both restored and untreated reefs (control/ reference reefs), have met these Metrics. This information, combined with a requisite halt in sonar work during the pandemic years and the resource-intensive nature of measuring these parameters using sonar equipment, has led NOAA to adapt to measuring these parameters only on reefs that, per other, more sensitive Metrics, are showing signs of potential poor reef health. (Indeed, this was done in 2022 and 2023, when, as described above, a subset of reefs did not meet the shell budget Metric.) This revised protocol is consistent with the adaptive management recommended in the original Oyster Metrics document. Specifically, the Oyster Metrics document recognizes that "…future research will inform oyster restoration practices, and strongly encourages the use of sound adaptive management practices. We expect that, as the state of knowledge advances, targets and approaches outlined here will evolve."

4.4 Use of Multiple Gear Types

As in previous years, two different types of gear (hydraulic patent tongs, divers) were used to collect oyster density samples, depending on reef substrate type. (See Appendix B, Table 1 for which reef types were monitored with which gear, and Section 5 for definitions of the various reef types.) This was done to maximize the efficiency of restoration monitoring. Earlier field comparisons[8] on harvested natural oyster reefs revealed no difference between oyster densities estimated using divers and those estimated using patent tongs. However, a 2020 field comparison on restored reefs in Harris Creek[9] showed that densities estimated using patent tongs resulted in statistically significantly fewer oysters than those estimated using divers. In that study[9], the densities estimated by divers were 3.35 times higher than those from patent tongs, on average. Because two different gear types were used for sampling, and research [8,9] results varied, it may not be appropriate to use data in this report to compare the efficacy of different reef treatment types. It is worth noting that applying the 3.35 multiplier from the 2020 study[9] to the results from those reefs monitored using patent tongs would appreciably increase the density and biomass on those reefs, and increase the proportion of reefs that met the target vs threshold density. For clarity and consistency, results in this report are given without the 3.35 multiplier on reefs monitored using patent tongs. However, the authors recognize that these results may be quite conservative.

4.5 Abundant Natural Spat Sets in Maryland in Recent Years

In 2020–2023, Maryland saw natural oyster spat sets above the long-term, statewide average. This included particularly abundant spat sets in the St. Marys River in 2022 and a high spat set in Tred Avon River in 2023. The Tred Avon has historically been a lower-natural-recruitment area than any of the other ten tributaries slated for restoration. These trends bode well for the longer-term success of the restored reefs.

4.6 Factors Influencing Future Reef Health

Although the information in this report looks promising for the long-term sustainability of reefs in Harris Creek, Little Choptank River, and Tred Avon River, several factors could affect continued success. These include future water-quality issues (e.g., low salinity, low dissolved oxygen levels), oyster disease, funding for future monitoring and adaptive management, and poaching (illegal oyster harvesting). Data and analyses in this report can be used to understand the success or failure of restored reefs, and to inform future restoration and adaptive management. The monitoring undertaken 3 years post restoration is considered an adaptive management checkpoint. Information from this interval is used by restoration partners to determine whether a reef requires the second-year-class seeding called for in each river's tributary plan, and if unsuccessful reefs should receive other management actions.

Section 5: Definitions

Some words defined here are used only in appendices, not in the report itself.

Fall 2022 monitoring: Monitoring undertaken on restored reefs that turned 3 or 6 years old in fall 2022. Monitoring was also done on reference reefs and sentinel reefs.

Fall 2023 monitoring: Monitoring undertaken on restored reefs that turned 3 or 6 years old in fall 2023. Monitoring was also done on reference reefs and sentinel reefs.

Fossil shell: Consolidated fossil oyster shell material from Florida used as a base to construct reefs. This is oyster shell cemented into a fossilized limestone, and is a true fossil, mined from 30 to 40 feet under dry land, as opposed to the Chesapeake Bay dredged shell.

Mixed shell: A mixture of scallop, conch, and clam shell from seafood processing plants. The shell is double-cracked before being imported into Maryland to ensure a clean product. This process results in the shell being largely fragmented.

Oyster gardening reef: A reef planted with oysters from various community-based oyster gardening programs, where volunteers grow oysters in cages hanging from docks.

Oyster Metrics: Success criteria for restored oyster reefs targeted for restoration under the 2014 Chesapeake Bay Watershed Agreement. These are defined in the report "Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries."[2] See Table 1 for description of the six reef-level criteria.

Premet reefs: Reefs that were assumed to have met the Oyster Metrics density target criteria (50+ oysters per m^2) when surveyed prior to commencement of large-scale restoration efforts, and therefore did not initially receive further restoration treatment. However, the prerestoration data on some reefs was at an insufficient resolution to determine definitively whether or not the reefs met the density target. Thus, it is an assumption that the reefs in fact met the density success metric at that time, but it is not certain. These reefs are monitored every 3 years, as are other reefs, to determine appropriate adaptive management needs.

Reef restoration treatment: The particular method used to restore a reef. See Appendix B, Table 1 for description of reef treatment types.

Reference reefs: Reefs left unrestored (untreated) to serve as comparisons to restored (treated) reefs. Typically, these would be called 'control' reefs, but they are not true controls, as it is not possible to ensure that restoring nearby reefs would not influence these reference reefs. That is, these reefs might receive larvae from nearby restored reefs, so the term 'reference reefs' is used. Per oyster population data collected prior to commencing large-scale restoration work in Harris Creek, the reference reefs did not meet the 50 oysters per m^2 Oyster Metrics target success criterion. See Table 2 for reef treatment type relative to other treatment types.

Second-year-class seeding: A second planting of spat-on-shell some reefs receive approximately 4 years after initial restoration. This is intended to ensure that each reef has at least two year classes, which is an Oyster

Metrics criteria. It can also help ensure that reefs meet the oyster density and biomass criteria. Second-year-class seedings are called for in each river's oyster restoration tributary plan. If a reef shows higher-than-expected oyster density when monitored 3 years post restoration, and a second year class is present, a second-year-class seeding may not be required.

Seed-only reefs: Reefs treated only with hatchery-produced oyster seed (spat-on-shell). No base reef-building substrate was added prior to seeding. This treatment was generally used on reefs where the prerestoration population was 5 oysters per m^2 or greater, but fewer than 50 oysters per m^2 (see Harris Creek Tributary Plan[2], Little Choptank Tributary Plan[3], and Tred Avon Tributary Plan[4] for detailed description of how the Workgroup determined treatment type for each reef). See Appendix B, Table 1 for reef treatment type relative to other treatment types.

Sentinel reefs: A subset of the restored reefs that are monitored annually (rather than only 3 years and 6 years after restoration, which is the standard for other restored reefs). See Appendix B, Table 1 for reef treatment type relative to other treatment types.

6-year-old reef: Reef that received restoration treatment 6 years previously, and—per Oyster Metrics and tributary plans—was monitored 3 years post restoration and again 6 years post restoration.

Spat-on-shell: Hatchery-produced juvenile oysters attached to the shells of dead oysters. Shell typically comes from shucking houses.

Stone substrate reefs: Reefs constructed using a type of stone that is geologically classified as amphibolite. The stone was graded to fit through a 6-inch mesh screen. These reefs were then seeded with spat-on-shell. See Appendix B, Table 1 for reef treatment type relative to other treatment types.

Stone reefs topped with mixed shell: Reefs constructed from a stone base, then capped with mixed shell and seeded with spat-on-shell. See Appendix B, Table 1 for reef treatment type relative to other treatment types.

Stone reefs topped with fossil shell: Reefs constructed from a stone base, then capped with fossil shell and seeded with spat-on-shell. See Appendix B, Table 1 for reef treatment type relative to other treatment types.

Substrate + seed reefs: Reefs treated with reef-building substrate, generally to a height of 6 inches to 1 foot above the surrounding soft bottom. Substrate was either mixed shell, fossil shell, stone, or a combination. Substrate placement was followed by planting with hatchery-produced spat-on-shell. Substrate + seed treatment type was typically used where pre restoration oyster populations were below 5 oysters per m^2, or where sonar surveys found no evidence of shell. See Appendix B, Table 1 for reef treatment type relative to other treatment types.

3-year-old reef: Reef that received restoration treatment 3 years previously, and—per Oyster Metrics and tributary plans—were monitored 3 years post restoration.

References

1. Chesapeake Executive Council, 2014. Chesapeake Bay Watershed Agreement. https://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf

2. Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries. Report to the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program. Oyster Metrics Workgroup. 2011. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

3. Harris Creek Oyster Restoration Tributary Plan: A blueprint to restore the oyster population in Harris Creek, a tributary of the Choptank River on Maryland's Eastern Shore. Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2013. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

4. Little Choptank River Oyster Restoration Tributary Plan: A blueprint for sanctuary restoration. Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2015. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

5. Tred Avon River Oyster Restoration Tributary Plan: A blueprint for sanctuary restoration. Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2015. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

6. St Marys River Oyster Restoration Tributary Plan: A blueprint for sanctuary restoration. Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2020. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

7. Manokin River Oyster Restoration Tributary Plan: A blueprint for sanctuary restoration. Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2020. https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

8. Chai A., Homer M., Tsai C., Goulletquer P. (1992). Evaluation of oyster sampling efficiency of patent tongs and an oyster dredge. North American Journal of Fisheries Management, 12, 825-832.

9. Oyster Recovery Partnership. 2020. Evaluating Hydraulic Patent Tong Efficiency to Estimate Oyster Density on Restored Oyster Reefs. https://www.chesapeakebay.net/documents/ORP_CBL_Project_Award_15794_Final_Report_with_SFGIT_context_statement.pdf

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11. Mann, R. L., & Evans, D. A. (1998). Estimation of oyster, Crassostrea virginica, standing stock, larval production and advective loss in relation to observed recruitment in the James River, Virginia. Journal of Shellfish Research, 17(1), 239.

Appendices A1 and A2: Table of Summary Data by Reef and Length-Frequency Histogram for Each Reef

Comprehensive data for 2022 and 2023 data is available as downloadable files.

Appendix A1: 2022 Data

2022 data is broken into three tables:

- A1: Summary data by reef in 2022
- A1-2: Length-frequency histograms for reefs monitored using divers in 2022
- A1-3: Length-frequency histograms for reefs monitored using patent tongs in 2022

To access Appendix A1, click on this link to download an Excel file: ADD URL/LINK HERE

Appendix A1 is here, for technical review:
https://docs.google.com/spreadsheets/d/1IceOZ2HHSe-rR5b5U0q87qrUxdEl--NF/edit?gid=1532259490#gid=1532259490

Appendix A2: 2023 Data

2023 data is broken into three tables:

- A2: Summary data by reef in 2023
- A2-2: Length-frequency histograms for reefs monitored using divers in 2023
- A2-3: Length-frequency histograms for reefs monitored using patent tongs in 2023

To access Appendix A2, please click on this link to download an Excel file: ADD URL/LINK HERE

Appendix A2 is here, for technical review:
https://docs.google.com/spreadsheets/d/1TjZBLCHBIHYmh8yiRwTmmrrC3jaKLssa/edit?gid=1340580368#gid=1340580368

Appendix B: Monitoring Methods

B1: Methods Summary

See Appendix B3 for full methods description.

Data to determine success relative to the four biological metrics (oyster density, oyster biomass, multiple year classes, and shell volume) were collected at the same time using a stratified random survey design. Methods used to select sampling sites, analyze samples, and assess success relative to each biological were identical for all reefs. Data collection occurred from October through December 2022 and September 2023 through February 2024.

As in previous years, two different types of gear were used to collect samples, depending on reef substrate type:

- Divers were used to collect samples from reefs with substrate materials that were not amenable to patent tong sampling (stone and fossil shell substrate reefs; see definitions in Section 5 of the report).
- Patent tongs were used to collect samples from all other reef types (seed only, mixed-shell base, reference, and pre-met reefs; see definitions in Section 5 of the report).
- See Table 1 for description of the various treatment types and the gear used to monitor the biological metrics on each.

Because two different gear types were used for sampling, and the relative sampling efficiencies of those gears can vary [1,2], oyster density and biomass data may not be directly comparable between reef treatment types. For example, in Harris Creek, oyster densities estimated by divers were ~3 times higher than those from hydraulic patent tongs[2].

Once samples were collected, oyster density and biomass data were standardized based on the area sampled. Data was then analyzed to determine success relative to each oyster metric success criteria (see the full protocol in Appendix C).

Treatment Type	Reef-building substrate added?	Substrate Material	Cap Material	Seed oysters planted onto reef?	Gear type used to collect biological metrics data
Seed Only	No	None	None	Yes (spat-on-shell)	Patent tongs
Mixed shell	Yes	Mixed shell (clam, conch, and whelk)	None	Yes (spat-on-shell)	Patent tongs
Fossil shell	Yes	Fossil shell	None	Yes (spat-on-shell)	Divers
Oyster gardening reef	No	None	None	Yes (adult oysters)	Patent tongs
Stone	Yes	Amphibolite (stone)	None	Yes (spat-on-shell)	Divers
Stone topped with mixed shell	Yes	Amphibolite (stone)	Mixed shell (clam, conch, and whelk)	Yes (spat-on-shell)	Divers
Stone topped with fossil shell	Yes	Amphibolite (stone)	Fossil shell	Yes (spat-on-shell)	Divers
Reference	No	None	None	No	Patent tongs
Premet	No	None	None	No	Patent tongs

Table 1: *Description of treatments used to restore reefs in Harris Creek, Little Choptank River, and Tred Avon River. Also listed is the gear type used to monitor each reef treatment type for the biological metrics (oyster density, oyster biomass, multiple year classes, and shell volume). See Section 5 in the report for full definitions.*

Appendix B1 References

1. Chai A., Homer M., Tsai C., Goulletquer P. (1992). Evaluation of oyster sampling efficiency of patent tongs and an oyster dredge. North American Journal of Fisheries Management, 12, 825-832.

2. Oyster Recovery Partnership. 2020. Evaluating Hydraulic Patent Tong Efficiency to Estimate Oyster Density on Restored Oyster Reefs. https://www.chesapeakebay.net/documents/ORP_CBL_Project_Award_15794_Final_Report_with_SFGIT_c ontext_statement.pdf

B2: Revised Monitoring Protocols for 2022-2023

Overall protocols have remained largely consistent since this monitoring effort started in 2015. However, some adaptation has been required as the effort progressed. Changes from previous protocols are highlighted below. Full methods are described in Appendix B3.

- Oyster biomass metric: Since 2020, the shell height-to-biomass regression developed by Jordan et al.[1] was used to calculate oyster biomass (Appendix B3). This regression was developed using Maryland oysters and, therefore, more accurately represents oyster growth in the restoration tributaries compared to the regression developed by Mann and Evans[2] for oysters in the James River, Virginia. Prior to 2020 the regression developed by Mann and Evans[2] was used to calculate biomass.

- Shell budget metric: Shell budget is assessed by comparing the 6-year surface shell volume with shell volume from 3 years prior (3-year monitoring). However, upon examining previous data sets, the Workgroup discovered that divers had not excavated the entire dive quadrat on stone reefs, leading to potential errors in total shell volume data. Therefore, instead of comparing surface shell volume between 3-year and 6-year monitoring, oyster volume was compared for stone and fossil shell reefs, as it was likely a truer representation of shell budget. A two-way t-test ($P<0.05$) was used on each reef to determine if changes between years were significant. Sites without significant decreases in oyster volume were deemed to have a stable shell budget. This was only applied to diver-surveyed reefs (those constructed from stone or fossil shell), as the patent tong reefs did not experience this data issue. This approach has been in use since 2020. Prior to 2020, total shell volume was used for patent tong and diver sampled reefs. See Appendix A for details on the reef-base material and the monitoring gear used for each reef.

- Density and biomass metrics over 30% of the reef: Prior to 2018, monitoring was conducted using a sampling grid superimposed over a GIS layer of constructed oyster reefs. To meet the Oyster Metrics threshold or target, the area of the sampled grid cells meeting the target or threshold must have been equal to or greater than 30% of the reef area. In 2018, the Workgroup, supported by the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team, decided to switch from this systematic sampling design to the current random sampling design. To meet the metrics, at least 30% of the samples collected must meet the specified densities and biomass. Past years of monitoring data were analyzed using this method to ensure that the methods are comparable.

- 6-year monitoring year: In typical years, 6-year monitoring occurs 6 years after the initial seeding year. However, due to Covid-19 and the 2019 freshet, reseedings (which normally take place the year after 3-year monitoring) were delayed for many reefs. Since monitoring immediately after a reseeding can affect the density and biomass results of a reef, the Workgroup decided that, starting in 2024, reefs that received a late reseeding will undergo 6-year monitoring 2 years after reseeding, rather than 6 years after the initial seeding year. To accurately assess the health of reefs at the 6-year mark, reefs from 2022 and 2023 that did not meet a metric and received a late reseeding will be reassessed in 2024 for their official 6-year monitoring results.

Appendix B2 References

1. Jordan, S. J., Greenhawk, K. N., McCollough, C. B., Vanisko, J., & Homer, M. L. (2002). Oyster biomass, abundance, and harvest in northern Chesapeake Bay: trends and forecasts. Journal of Shellfish Research, 21(2), 733-742.

2. Mann, R. L., & Evans, D. A. (1998). Estimation of oyster, Crassostrea virginica, standing stock, larval production and advective loss in relation to observed recruitment in the James River, Virginia. Journal of Shellfish Research, 17(1), 239.

B3: Full Methods for Data Collection and Analysis

This section describes methods for determining success relative to biological Oyster Metrics criteria (oyster density, oyster biomass, multiple year classes, shell budget).

Survey Design

A stratified random survey is used to collect biological data on restored reefs. Each reef is its own stratum, and a random number of sample points are assigned based on reef size, reducing relative error among samples. The number of samples collected at each reef is optimized for data precision and accuracy for each gear type used (Slacum et al. 2018).

- For reefs sampled using patent tongs: the number of samples increased with reef size and averaged 2.5 samples per acre.
- For reefs sampled using divers: 5 samples were collected per reef, averaging 1.5 samples per acre.

ArcGIS is used to generate sampling points for each reef. All reefs that are due for monitoring are compiled into a shapefile, and sampling locations are generated within the area of the reef that was planted with spat on shell. This ensures that sample points are created within the area that received oysters.

Field Collection

Data are typically collected in the fall. Sampling is conducted during daylight hours. Navigation to sampling locations and sample coordinate documentation is done using a differential global positioning system (DGPS) attached to a laptop with ArcGIS 10.8.2 used as the navigational program. The vessel navigates as closely as possible to the designated random points, and a waypoint (virtual GPS marker) is created at the location of each sample.

The gear used depends on the reef material. Hydraulic patent tongs are used to sample on seed-only reefs, mixed-shell-base reefs, reference reefs, and premet reefs. Divers are used to sample on fossil-shell-base reefs, stone-base reefs topped with mixed shell, and stone-based reefs topped with fossil shell. Because two different gear types are employed, it is not appropriate to directly compare oyster density and biomass on reefs sampled with patent tongs versus divers (see Appendix B: Methods summary). For both diver and patent tong data, oyster density and oyster biomass information are standardized based on area sampled.

Patent Tongs

Hydraulic patent tongs are a specialized commercial fishing gear used to harvest oysters in the Chesapeake Bay. The patent tong design functions much like a benthic grab, collecting oysters and underlying substrate from a known fixed area of the bottom. The tongs used in 2022 and 2023 sampled an area equal to 1.928 m^2 of the seafloor. The patent tongs are suspended from a boom over one side of the vessel and deployed to the bottom at each sampling location. A DGPS antenna is positioned adjacent to the location where the patent tongs are deployed, and a waypoint with the geographic coordinates of each sample location is documented.

Diver Surveys

Dive sampling is conducted by navigating the vessel to each sampling location and deploying buoys with anchors to mark each sample location. Divers descend to the bottom at each buoy with a 0.71 m x 0.71 m (0.5041 m^2) quadrat and sample collection crates. The quadrat is placed up current of the buoy anchor. Before disturbing the reef surface, the diver makes observations on the number of oysters visible and the percent of reef substrate within the quadrat. Any material contained within the quadrat, including loose oysters, loose shell, and any reef substrate, are excavated to ~6 inch depth and transported to the vessel for processing. The diver reports the depth of the excavation if bare sediment is reached shallower than 6 inches.

Sample Processing

In each sample, all oysters are counted and identified as live or dead, and a minimum of 30 live oysters are measured for each sample. Oyster clumps, the number of oysters associated with a clump, and the substrate type that oysters are attached to are documented. The shell height and total count of dead (old box) and recently dead (gapers) oysters are documented from each sample. The percent of the sample covered by tunicates or mussels and the percent of the sample that is black (anoxic shell) is documented for each sample. Additionally, field crews measure oyster and shell volume to the nearest half liter using graduated buckets.

Surface and bottom water temperature, dissolved oxygen, pH, and salinity are collected during each sampling event using a YSI Pro-Plus water quality sonde (YSI Corporation, Yellow Springs, Ohio). Other environmental and station-specific variables collected at each site include sample number, date and time, weather information, depth of water, Yates Bar name, vessel name, and staff conducting the monitoring.

Data Entry and Analysis

All data are entered into a Microsoft Access database. QA/QC protocols are used to review data for nonsensical values and typos. Oyster lengths and counts are used to derive density and biomass estimates for each reef. Graphs are made to visually display size class information and proportion of live to dead oysters at the reef level. Additionally, all sample locations are plotted in ArcGIS to ensure that samples are collected on the reef footprint. Methods for analyzing data per each Oyster Metrics success criterion follow.

Oyster Density

- Oyster Metrics success criteria: Minimum threshold = 15 oysters per m^2 over 30% of the reef area; Target = 50 oysters per m^2 over 30% of the reef area.
- Method: Oyster density was calculated as the number of individual live oysters collected in the area of a patent-tong grab or diver quadrat standardized to a square meter. Total counts of live oysters or other variables (e.g., oyster size class, shell volume) were averaged over all samples collected at the individual reef. To meet the Oyster Metrics threshold or target, at least 30% of the samples collected must meet the specified densities.

Oyster Biomass

- Oyster Metrics success criteria: Minimum threshold = 15 grams dry weight per m^2 over 30% of the reef area; Target = 50 grams dry weight per m^2 over 30% of the reef area.

- Method: Oyster biomass per m^2 was calculated from the size of individual live oysters within each sample, using the regression developed by Jordan et al. (2002): W=((10^((log10(L)*2.06)-3.76))), where W = dry tissue weight in g and L = shell height in mm.

  Biomass was then summed for the entire sample and standardized to a square meter. The biomass value is scaled based on the number of oysters measured out of the total number of oysters counted. The same approach as oyster density (above) was employed, in which at least 30% of samples collected had to meet the threshold or target to demonstrate restoration success.

Multiple Year Classes

- Oyster Metrics success criterion: Presence of two or more year classes of live oysters.
- Method: Year-class presence was approximated by examining length frequency data of all oyster heights measured at each reef. Sampling teams are trained to measure and record all oysters, regardless of size. For simplicity, a reef was determined to have multiple year classes when oysters from at least two standard size class categories (market: >76 mm; small: 40–75 mm; spat: <40mm) were present.
- There is no differentiation between hatchery-produced oysters and natural oysters.

Shell Budget

- Oyster Metrics success criterion: Neutral or positive shell budget on the reef.
- Method: The volumes of sampled shell and oysters are measured with graduated buckets and standardized to square meter based on the area sampled by patent tong or diver quadrat. Field measurements of shell resources included total shell volume, total live oyster volume, and the percent of black (buried) shell estimated in a sample. Surface shell estimates were calculated as the percent of the total sampled shell volume that was not considered black shell, as shown below:

  Surface shell volume=Total shell volume-(Total shell volume*Percent Black Shell)

  For patent tong sampled reefs, changes to the shell budget at individual reefs were analyzed by comparing surface shell volume data from 3-year monitoring to surface shell volume from 6-year monitoring (2019 to 2022 and 2020 to 2023).

  For diver sampled reefs, calculating shell volume was conducted similarly but using oyster volume instead of surface shell volume. The Workgroup found that previous volume estimates for stone sites did not involve excavating the entire dive quadrat. Therefore, members of the Workgroup concluded that oyster volume would be a truer representation of volume. To determine if the shell budget was increasing or stable, two-way t-tests were conducted for each reef (3-year vs 6-year volume, significance $P<0.05$). Sites that did not have significant differences between measurements at 3-year monitoring and measurements at 6-yr monitoring were concluded to have a stable shell budget. Sites with significant increases in shell budget were also concluded to have met the metric.

Appendix B3 References

1. Slacum H. W., Liang D., Wilberg M., Paynter K., and Zaveta D. "Implementing Oyster Restoration Monitoring Recommendations". Sustainable Fisheries Goal Implementation Team Biannual Meeting, 17 December 2018, The Mariner's Museum, Newport News, VA.

2. Jordan, S. J., Greenhawk, K. N., McCollough, C. B., Vanisko, J., & Homer, M. L. (2002). Oyster biomass, abundance, and harvest in northern Chesapeake Bay: trends and forecasts. Journal of Shellfish Research, 21(2), 733-742.

Appendix C: 2021 Maryland Monitoring Report Correction

The 2021 monitoring report had an error in one of the tables. Red cells represent changes. The column "6-yr Monitoring cohort year" was updated to reflect the cohort of oysters that were monitored.

Tributary	Reef #	Reef acres	6-yr Monitoring cohort year	Metric failed	Likely cause of failure
Harris Creek	H03	6.5	2018	Shell budget	No clear cause
Harris Creek	H06	4.6	2018	Shell budget	No clear cause
Harris Creek	H45	3	2019	Density, biomass	Poor site location*

*From 2019 Maryland Oyster Monitoring Report