Oyster Management Review: 2016-2020

A Report Prepared by

Maryland Department of Natural Resources

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Oyster Management Review:

2016-2020

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Section 1: Executive Summary

Oyster Management Review

2016-2020

Maryland Department of Natural Resources

Purpose of Report

In 2010, the Maryland Department of Natural Resources (DNR) overhauled its regulations for managing oysters in Maryland's portion of Chesapeake Bay. The regulations expanded the scale of oyster sanctuaries, created new opportunities for oyster aquaculture, and designated areas to be maintained for the public fishery. The preamble of the 2010 proposed oyster regulation states:

> "*The department has committed to reviewing the effectiveness of the locations of sanctuaries, public shellfish fishery areas, and aquaculture areas every 5 years and to propose changes where needed.*"[1]

This report is the second five-year oyster review covering the 2016 to 2020 time period. The first report, published in 2016, reviewed 2010-2015 information.[2] This report uses available information to describe the current status of oyster sanctuaries, Public Shellfish Fishery Areas (PSFAs), and Maryland's aquaculture industry 10 years after the management plan was adopted. Their effectiveness is measured against the 12 objectives of the 2010 proposal with the overall goal to restore the ecological function of oysters and to enhance the commercial fishery for its economic and cultural benefits. The management plan adopted in 2010 sought to resolve the dual goals of ecological and economic restoration by creating distinct management areas each with its own objectives – sanctuaries, PSFAs, and aquaculture areas.

Overview of Management Areas

The total acres of bottom within the three types of distinct management areas are as follows: 7,593 acres of active lease aquaculture area; 253,007 acres of sanctuary, of which 31% (78,961 acres) is historic oyster bottom; and 175,836 acres of PSFA, of which 72% (126,715 acres) is historic oyster bottom. There is an additional 121,761 acres of historic oyster bottom that is

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[1] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010
dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf

[2] Maryland Department of Natural Resources. 2016. Oyster Management Review: 2010-2015.
dnr.maryland.gov/fisheries/Pages/oysters/5-Year-Oyster-Review-Report.aspx

neither in sanctuaries nor in a designated PSFA, but is open to the public oyster fishery. Historic oyster bottom is defined as the area charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments[3], and does not necessarily represent the productive oyster bottom in 2020.

Sanctuaries - Status of 2010 Objectives

Objective #1: Protect half of the Bay's most productive oyster grounds that remain and allow investigation of the reasons why these remain most productive.

This objective is being met. When the current sanctuary boundaries were created in 2010, Jones and Rothschild 2009 'best bars' analysis was used to ensure half of the productive oyster bottom was in sanctuaries. Based on the number of 2009 'best bars' and since sanctuary boundaries have not changed since 2010, 59% of the bars still have all or some portion of their acreage in sanctuaries. The 'best bars' analysis was updated in 2020, and found 50% of productive bars are located either entirely or have a portion of bottom within a sanctuary.

Objective #2: Facilitate development of natural disease resistance.

This objective is underway and remains under evaluation. Over the past 10 years, research has been conducted to understand the evolution or current status of disease resilience in wild oyster populations, but that research has been limited. In addition, disease levels over this time period have been below the long-term averages. Consequently, oysters are less challenged by disease to develop disease resilience. Despite these factors, new information is emerging on variants of diseases (specifically *Perkinsus marinus* (dermo)) and monitoring is underway of age classes derived from the survivors of previous outbreaks. Therefore, this objective will remain under evaluation as we observe over time whether a significant population of oysters has become or will become resistant or tolerant to *Haplosporidium nelsoni* (MSX) and dermo diseases.

Objective #3: Provide essential natural ecological functions that cannot be obtained on a harvest bar.

This objective is being met and will continue to be evaluated. There have been no reductions in sanctuary areas and extensive work is underway to expand restoration work in sanctuaries, therefore the program continues to provide essential ecological functions that exist. Maryland is on track to meet the commitment to restore five large-scale restoration sanctuaries. Work is also underway in other sanctuaries to develop three dimensional habitat that can be evaluated. Ongoing research is beginning to show how a complex, three-dimensional structure created by large-scale restoration sanctuaries impacts the food web and nutrient cycling to benefit the oyster reef and the ecosystem as a whole. Maryland's Oyster Management Plan was updated and includes a goal of promoting "the creation of oyster reefs with higher profiles above the bay bottom to enhance oyster productivity."

[3] Maryland Department of Natural Resources. 1997. Maryland's Historic Oyster Bottom: A Geographic representation of the traditional named oyster bars. dnr.maryland.gov/fisheries/Documents/maryland_historic_oyster_bottom.pdf

Objective #4: Serve as a reservoir of reproductive capacity.

This objective remains under evaluation. The sanctuary program continues as a reservoir of reproductive capacity and in most sanctuaries, the overall reproductive potential has remained stable or increased. While reproductive potential has increased, fertilization, larval development, and successful spat sets are needed to grow the population over time. Even if fertilization is successful, the fate of the larvae is not guaranteed due to a wide and fluctuating range of biological and environmental variables.

Objective #5: Provide a broad geographic distribution across all salinity zones.

This objective is being met. Oyster sanctuaries are distributed proportionately across all salinity zones in Maryland's portion of Chesapeake Bay. Approximately 30% of historic oyster bottom[4] in sanctuaries are located in low-salinity areas, 56% in medium-salinity areas, and 15% in high-salinity areas.

Objective #6: Increase our [the department's] ability to protect these important areas from poaching.

This objective is being met. The ability to protect sanctuaries from poaching has been maintained by the designation of large sanctuary areas, implementation of the Maryland Law Enforcement Information Network (MLEIN) monitoring system, and the department's ability to suspend and revoke licenses administratively. The increase in uniformed Natural Resource Police (NRP) officers and the department's aviation unit have further bolstered the department's ability to protect sanctuaries from poaching.

Public Shellfish Fishery Areas - Status of 2010 Objectives

Objective #1: Retain 168,000 acres of natural oyster bars including 76% (27,000 acres) of the remaining 36,000 acres of remaining productive oyster habitat identified in the Programmatic Environmental Impact Statement (PEIS).

This objective is being met. 175,836 surface acres are classified as PSFAs.

Objective #2: Protect half of the bars identified by Jones and Rothschild (2009)[5] as "consistently most productive" for the benefit of licensed oystermen.

This objective is being met. Based on the number of 2009 'best bars' and since sanctuary boundaries have not changed since 2010, more than half (71%) of the bars are still located outside sanctuary boundaries and are open to harvest. Based on the total acres of historic oyster bottom of 'best bars', 74% of the acres are located outside sanctuary boundaries and are open to harvest.

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[4] As charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments

[5] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf

Objective #3: Implement a more targeted and scientifically managed public oyster fishery.

This objective is being met. A Maryland oyster stock assessment and a science-based modeling tool have been developed, and harvest rules for the oyster season are being set annually based on the fishing levels and abundance relative to the biological reference points.

Aquaculture – Status of 2010 Objectives

Objective #1: Simplify the aquaculture regulatory process.

This objective is met. Legislation passed in 2009[6] removed many impediments to shellfish aquaculture in Maryland and streamlined the regulatory process.The department continues to work internally and with the Aquaculture Coordinating Council to identify and implement legislative and regulatory changes intended to facilitate existing aquaculture industry operations and new business development. In addition, the department actively works with the U.S. Army Corps of Engineers Baltimore District to assist this agency in developing methods needed to streamline the federal permitting process for Maryland shellfish aquaculture.

Objective #2: Open new areas to leasing to promote shellfish aquaculture industry growth.

This objective is met. Legislation passed in 2009[7] opened thousands of acres for shellfish aquaculture leasing.

Objective #3: Provide alternative economic opportunities for watermen.

This objective is met. Maryland commercial oyster harvesters are benefiting from economic opportunities provided by aquaculture. Nearly 50% of leaseholders are commercial licensed oyster harvesters in Maryland's public fishery who are now investing in shellfish aquaculture. Additionally, the department has worked to develop new markets for invasive species and new species such as shrimp, to expand economic opportunities for watermen and reduce harvest pressure.

Classifying Sanctuaries and Public Shellfish Fishery Areas

To evaluate individual sanctuaries and PSFAs, areas were ranked based on population metrics (spat, small and market density, mortality, and cultch) as described in Section 5 of this report. The rank was then assigned to different classification levels: Level A, B, C, and D, respectively corresponding to >80%, 80-50%, 50-20% and <20% percentiles. Level E areas had insufficient data to determine their classification. The levels are based on data that reflect relative oyster productivity of the areas. The 176 PSFAs were grouped into the 39 large harvest areas called

[6] SB 271, Chapter Number 173, 2009 mgaleg.maryland.gov/webmga/frmMain.aspx?tab=subject3&ys=2009rs/billfile/sb0271.htm
[7] IBID

NOAA Code areas. It is important to note that each NOAA Code may contain multiple PSFAs and some PSFAs do not reside entirely within a single NOAA Code.

Six sanctuaries (out of 51 sanctuaries) and six NOAA Code harvest areas (out of 39 NOAA Code harvest areas) ranked as Level A. These are areas with high oyster density, and spat, as well as higher amount of cultch, and low mortality. These are areas that are considered productive and have good habitat. Many of these areas have received investment toward enhancing the population in the form of wild seed plantings, hatchery seed plantings, shell plantings, or substrate addition. All five of the large-scale restoration sanctuaries (Harris Creek, Little Choptank, Tred Avon, St. Marys, and Manokin) along with Nanticoke River Sanctuary ranked in Level A. Four of the six Level A NOAA Code harvest areas had consistent high harvest (Broad Creek region (537), Fishing Bay region (043), Pocomoke Sound region (072), and Tangier Sound North region (292)). The other two Level A NOAA Codes were Tred Avon River region (637) and Honga River region (047), but had less consistent harvest.

Eight sanctuaries and eight NOAA Codes ranked as Level B. These are areas with relatively good oyster density, and spat, as well as higher amount of cultch, and low mortality. These areas may have ranked better in one category than another, but the combined rankings were above average. Many of these areas have received investment toward enhancing the population in the form of wild seed plantings, hatchery seed plantings, or shell plantings. The Level B sanctuaries were Choptank ORA[8] Zone A, Hooper Strait, Lower Mainstem Bay, Neal Addition, Point Lookout, Somerset, Upper Choptank River, and Upper Patuxent River. The Level B NOAA Code harvest areas were Smith Creek region (086), Wicomico River East region (096), Lower Patuxent River region (168), St. Marys River region (078), Upper Patuxent River region (368), Little Choptank River region (053), Harris Creek River region (437), and the Middle Choptank River region (237).

Eight sanctuaries and nine NOAA Codes ranked as Level C. These are areas with relatively variable oyster density, spat and cultch, and low mortality. These areas may have ranked better in one category than another, but the combined rankings were below average. These regions may have received investment toward production in the form of wild seed plantings, hatchery seed plantings, or shell plantings. The Level C sanctuaries were Chester River ORA Zone A, Cook Point, Howell Point, Lower Choptank, Mill Hill, Sandy Hill, Severn River, and Upper Chester River. The Level C NOAA Code harvest areas were Tangier Sound South region (192), South River region (088), Lower Choptank region (137), Big Annemessex region (005), Wicomico River West region (274), Lower West Chesapeake Bay region (229), Eastern Bay region (039), St. Clements and Breton Bay region (174), and Middle Chester River (231).

Six sanctuaries and five NOAA Code harvest areas ranked as Level D. Level D areas are often known to have low densities of oysters or poor habitat, though they may have low mortality. The Level D sanctuaries were Breton Bay, Calvert Shore, Herring Bay, Lower Chester River, Miles River, and Wye River. The Level D NOAA Code harvest areas were Upper Chesapeake Bay

[8] ORA: Oyster Recovery Area

region (025), Upper Middle Chesapeake Bay region (127), Lower Middle Chesapeake Bay region (027), Lower Chester River region (131), and Miles River region (060).

Level E areas had insufficient data to determine their classification. There are 23 Level E sanctuaries. Some of these sanctuaries have small acreage with little historic oyster bottom thus they are not sampled by the Fall Survey. Sanctuaries, such as Fort Carroll Sanctuary, have had restoration efforts and may be productive areas. Some sanctuaries, such as Plum Point, have had artificial substrate placed and the Fall Survey is unable to sample these areas. There are nine Level E NOAA Code harvest areas. Many of these NOAA Codes tend to have little acreage open to the public fishery. For example, 88% of the Nanticoke River NOAA Code (062) is within a sanctuary.

Section 2: Purpose of Report

In 2010, the department overhauled its regulations for the management of oysters in the Maryland portion of Chesapeake Bay. The new regulations expanded oyster sanctuaries, created new opportunities for oyster aquaculture, and designated areas to be maintained for the public fishery. The preamble of the 2010 oyster regulation states:

"*The department has committed to reviewing the effectiveness of the locations of sanctuaries, public shellfish fishery areas, and aquaculture areas every 5 years and to propose changes where needed.*"[9]

The three types of management areas identified in the preamble are defined as follows:

- Sanctuaries – Areas permanently closed to oyster harvest. Some sanctuaries have been targeted for extensive oyster restoration projects to potentially accelerate the recovery of oyster populations within the sanctuary, increase their environmental benefits, and contribute to enhancement of populations outside the sanctuary.
- PSFAs – Areas where shellfish are harvested for commercial purposes. Oyster aquaculture leases are not allowed in these areas unless a petition to declassify is approved, which may occur if a biological survey indicates that the area does not have enough oysters to support commercial harvest by the public fishery[10].
- Aquaculture – Areas where aquaculture leases are issued by the state to individuals or businesses for private aquaculture.

Defining 'Effectiveness'

Effectiveness is defined relative to the original management objectives of the 2010 regulation[11]: to restore the ecological function of oysters and to enhance the commercial fishery for its economic and cultural benefits.

Objectives for sanctuaries, as stated in regulation:

1. Protect half of the Bay's most productive oyster grounds that remain and allow investigation of the reasons why these remain most productive;
2. Facilitate development of natural disease resistance;
3. Provide essential natural ecological functions that cannot be obtained on a harvest bar;
4. Serve as a reservoir of reproductive capacity;
5. Provide a broad geographic distribution across all salinity zones; and
6. Increase our [the department's] ability to protect these important areas from poaching[12].

[9] Maryland Register, Vol 37, Issue 14, p. 943. Friday July 2, 2010
dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf
[10] (COMAR 08.02.23.03) dsd.state.md.us/COMAR/ComarHome.html
[11] IBID
[12] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010
dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf

Objectives for Public Shellfish Fishery Areas:

1. Retain 168,000 acres of natural oyster bars, including 76% (27,000 acres) of the remaining 36,000 acres of remaining productive oyster bottom identified in the Programmatic Environmental Impact Statement (PEIS);
2. Protect half of the 'best bars' identified by Jones and Rothschild (2009)[13] as "consistently most productive" for the benefit of licensed oystermen; and
3. Implement a more targeted and scientifically managed wild oyster fishery[14] [hereafter referred to as public fishery].

Objectives for Aquaculture:

1. Streamline the regulatory process for aquaculture;
2. Open new areas to leasing to promote shellfish aquaculture industry growth; and
3. Provide alternative economic opportunities for watermen[15].

This report provides information on oyster populations within the 51 individual sanctuaries and 176 PSFAs before and after their creation. The status of the aquaculture industry is also examined. Even though future trends may change, a comparison of oyster populations before and after 2010 is a useful first indicator of the effectiveness of the locations of sanctuaries and PSFAs. In particular, ecological benefits, such as a water filtration and creation of habitat for other species, can be linked to oyster survival, abundance, biomass, and size structure[16,17].

Any assessment of effectiveness must be considered in the context of the 10 years since the 2010 oyster management regulations were implemented. Ten years may not be a sufficient time to determine if fundamental and durable changes to the oyster population have occurred, given the relatively long life (15-20 years[18]) of the oyster and the variable nature of the estuarine environment. For example, wet years and dry years have significant impacts on oyster reproduction, growth, disease pressure and mortality, and historically the climate shifts multiple times between these two conditions over periods of several years[19,20].

Additionally, this report evaluates effectiveness separately for the three types of management areas focusing on measurements taken before and after implementation of the 2010 regulations.

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[13] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf

[14] Maryland DNR Oyster Open House 2009. slides 13 and 57. dnr.maryland.gov/fisheries/Pages/oysters/5-Year-Oyster-Review-Report.aspx

[15] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010 dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf

[16] Grabowski, J.H., Peterson, C.H. 2007. Restoring Oyster Reefs to Recover Ecosystem Services in Ecosystem Engineers: Plants to Protists. Academic Press.

[17] Luckenbach, M.W., Coen, L.D., Ross, P.G. Jr., Stephan, J.A. 2005. Oyster reef Habitat Restoration: Relationships Between Oyster Abundance and Community Development based on Two Studies in Virginia and South Carolina. Journal of Coastal Research. SI. 40:64-78.

[18] Buroker NE. 1983. Population genetics of the American oyster *Crassostrea virginica* along the Atlantic coast and Gulf of Mexico. Marine Biology 75:99-112.

[19] Tarnowski, 2010. Maryland Oyster Population Status Report, 2009 Fall Survey. dnr.maryland.gov/fisheries/Documents/2009FSreport.pdf

[20] Tarnowski, 2012. Maryland Oyster Population Status Report, 2011 Fall Survey. dnr.maryland.gov/fisheries/Documents/2011FSreport.pdf

Given available data, direct comparisons are inappropriate due to the spatial variability of the environment which can result in large differences in spatfall, growth, and mortality.

The report does compare the performance of individual sanctuaries and PSFAs (as grouped into NOAA Code harvest areas). Performance is measured by productivity of the area. A productive area has a high density of oysters, good habitat, and high survival. Ranking individual areas based on these productivity metrics allows for the comparison of individual sanctuaries and individual NOAA Codes.

Section 3: Description of the Three Types of Management Areas

In 2010, three types of oyster management areas were created in Maryland's portion of Chesapeake Bay (Figure 3-1): sanctuaries, PSFAs, and aquaculture.

Sanctuaries encompass 253,007[21] surface acres of which 31% (78,961) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments) (Table 3-1)[22,23]. Areas without oysters are included in the sanctuaries and connect the historic oyster bottom. Currently, PSFAs total 175,836 surface acres of which 72% is historic oyster bottom[24]. There is an additional 121,761 acres of historic oyster bottom that is neither in sanctuaries nor a PSFA, but is open to the public oyster fishery. Historic oyster bottom is defined as the area charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments[25], and does not necessarily represent the productive oyster bottom in 2020. At the end of 2020, there are 7,593 acres of active leased aquaculture area.

[21] In the 2010-2015 Oyster Management Review Report published in 2016, the sanctuary acres presented in Table 3-1 were 252,285 (surface area) and 78,520 (historic oyster bottom as it mistakenly did not include the older sanctuary bottom now encompassed by 2010 sanctuaries (e.g., States Bank is now encompassed by Upper Choptank Sanctuary).

[22] Yates, Charles. 1913. Survey of Oyster Bars of Maryland 1906 to 1912. biodiversitylibrary.org/item/96740

[23] Maryland Department of Natural Resources. 1997. Maryland's Historic Oyster Bottom: A Geographic representation of the traditional named oyster bars. dnr.maryland.gov/fisheries/Documents/maryland_historic_oyster_bottom.pdf

[24] In the 2010-2015 Oyster Management Review Report published in 2016, PSFA surface acres were reported as 179,943 and PSFA historic bottom acres were reported as 142,006 acres. These values have changed due primarily to a typo (overstatement of acreage) in the original report, but also because of various housekeeping corrections to certain PSFA boundaries, declassifications and additions. The acreage of PSFAs will continue to change going forward, as there is an ongoing analysis being conducted to update the shoreline GIS layer, along with an expectation of future declassifications and/or additions.

[25] Maryland Department of Natural Resources. 1997. Maryland's Historic Oyster Bottom: A Geographic representation of the traditional named oyster bars. dnr.maryland.gov/fisheries/Documents/maryland_historic_oyster_bottom.pdf

Table 3-1. Three types of management areas in Maryland's portion of Chesapeake Bay as established in 2010.

Management Type	Total Area (acres)	Area of Historic Oyster Bottom (acres)[1]	Productive Oyster Bottom (acres)[2]	Permitted Activities
Sanctuaries[4]	253,007	78,961	9,000	Shellfish restoration, clamming in some sanctuaries[3]
Public Shellfish Fishery Areas (PSFA)[5]	175,836	126,715	27,000	Commercial and recreational harvest of oysters. No aquaculture.
Aquaculture Areas	7,593	2,765	-	Aquaculture (includes both on-bottom and water column leases)

[1] Historic oyster bottom as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments. There is an additional 121,761 acres of historic oyster bottom that is neither in sanctuaries nor in a PSFA, but is open to the public oyster fishery.

[2] Productive oyster bottom as defined in the U.S. Army Corps of Engineers, Norfolk District. 2009. Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster. dnr.maryland.gov/fisheries/Pages/eis.aspx

[3] Clamming is permitted only in sanctuaries established in 2010 but not on legally designated oyster bars.

[4] In the 2010-2015 Oyster Management Review Report published in 2016, the sanctuary acres presented in Table 3-1 were 252,285 (surface area) and 78,520 (historic oyster bottom as it mistakenly did not include the older sanctuary bottom now encompassed by 2010 sanctuaries (e.g., States Bank is now encompassed by Upper Choptank Sanctuary).

[5] In the 2010-2015 Oyster Management Review Report published in 2016, PSFA surface acres were reported as 179,943 and PSFA historic bottom acres were reported as 142,006 acres. These values have changed due primarily to a typo (overstatement of acreage) in the original report, but also because of various housekeeping corrections to certain PSFA boundaries, declassifications and additions. The acreage of PSFAs will continue to change going forward, as there is an ongoing analysis being conducted to update the shoreline GIS layer, along with an expectation of future declassifications and/or additions.

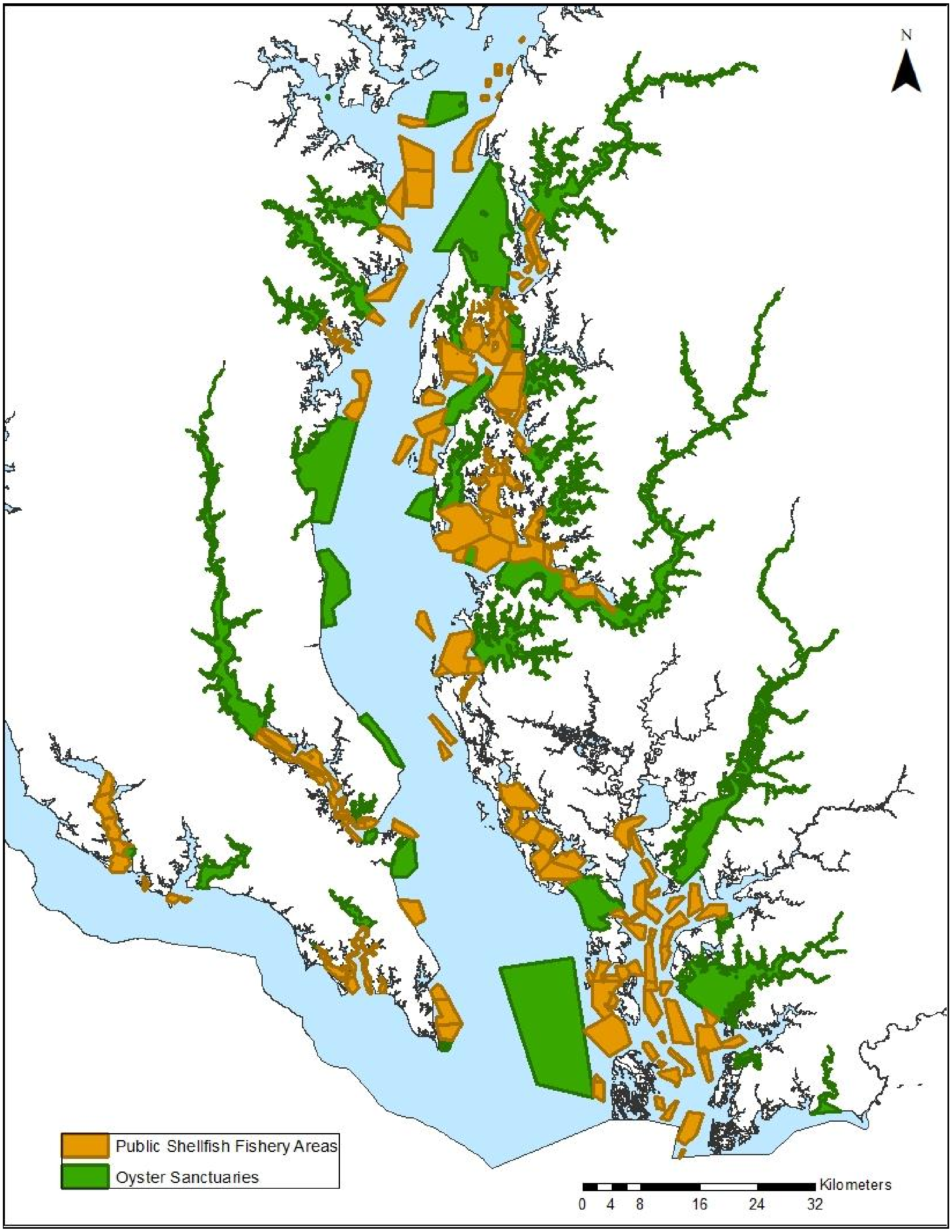

Figure 3-1. Management areas for oysters created in 2010 in Maryland's portion of Chesapeake Bay.

Section 3.1: Sanctuaries

Maryland established 29 sanctuaries between 1961 and 2009. The majority of these sanctuaries were small (less than 500 acres), on the scale of individual oyster bars or within parts of bars, and located in 11 tributaries and the Bay's mainstem. In 2010, 30 new sanctuaries were created. These sanctuaries were created on a much broader scale, incorporating multiple oyster bars and the non-oyster areas between them into single, large sanctuaries. Eight of the original sanctuaries were incorporated into larger 2010 sanctuaries, while 21 remained as established prior to 2010. This resulted in a total of 51 sanctuaries (Table 3-2). The sanctuaries are distributed throughout the range of oysters in Maryland's portion of Chesapeake Bay. The current 2010 sanctuaries are located in 16 tributaries and in the mainstem encompassing 253,007 surface acres (Figure 3-1). Detailed descriptions of each of the sanctuaries are presented in Appendix A.

Post-2010 Changes to Sanctuaries

Since the 2010-2015 Oyster Management Review[26], there have been no changes to the existing sanctuary boundaries. In 2016, based on the 2010-2015 review, proposed changes to sanctuary boundaries were presented for discussion to the Oyster Advisory Commission (OAC). In April 2017, Chapter 27 House Bill 924[27] was enacted, which prohibited the Maryland Department of Natural Resources from altering the boundaries of oyster sanctuaries until a fisheries management plan, that included an oyster stock assessment, was developed. In December 2018, the final legal report for the oyster stock assessment was completed[28]. In January 2020, Chapter 9 Senate Bill 830[29] was enacted. This law prevents the alteration of oyster sanctuary boundaries until a newly convened OAC develops a package of recommendations by consensus based on a 75% majority agreement for management actions to achieve targets identified in the oyster stock assessment. The recommendations are to be submitted by December 2021 and enacted by the department.

In the 2010-2015 Oyster Management Review, three large-scale restoration sanctuaries identified toward Maryland's commitment to the 2014 Chesapeake Bay Watershed Agreement[30]: Harris Creek[31], Little Choptank[32], and Tred Avon[33]. Since then, the final two large-scale restoration tributaries have been chosen: St. Marys River[34] and Manokin River[35] oyster sanctuaries. In July

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[26] Maryland Department of Natural Resources. 2016. Oyster Management Review: 2010-2015. dnr.maryland.gov/fisheries/Documents/FiveYearOysterReport.pdf
[27] Md. Code Ann., Nat. Rec. §4-215 (2017) dnr.maryland.gov/fisheries/Documents/4-215_w2017_changes_April_2021.pdf
[28] Maryland Oyster Stock Assessment: dnr.maryland.gov/fisheries/Pages/oysters/Oyster_Stock_Assess.aspx
[29] Md. Code Ann., Nat. Rec. §4-215 (2020) dnr.maryland.gov/fisheries/Documents/4-215_w2020_changes_Ch_27_hb0924T.pdf
[30] chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf
[31] Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2013. Harris Creek Oyster Restoration Tributary Plan.dnr.maryland.gov/fisheries/Documents/Harris_Creek_tributary_plan_011513.pdf
[32] Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2015. Little Choptank River Oyster Restoration Tributary Plan. dnr.maryland.gov/fisheries/documents/2015_Little_Choptank_Blueprint.pdf
[33] Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2015. Tred Avon River Oyster Restoration Tributary Plan.dnr.maryland.gov/fisheries/documents/2015_Tred_Avon_Blueprint.pdf
[34] Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2020. Upper St. Marys River Oyster Restoration Tributary Plan. dnr.maryland.gov/fisheries/Documents/Reg_Changes/St.%20Mary%27s%20Blueprint%20final.pdf
[35] Maryland Interagency Oyster Restoration Workgroup of the Sustainable Fisheries Goal Implementation Team. 2020. Manokin River Oyster Restoration Tributary Plan. dnr.maryland.gov/fisheries/Documents/ManokinRiver_Oyster_Restoration_Tributary_Plan.pdf

2019, Chapter 17 House Bill 298[36] was enacted codifying the sanctuary boundaries of the five sanctuaries that are receiving large-scale restoration. Initial restoration of 348 acres in Harris Creek was completed in September 2015, and 358 acres in Little Choptank was completed in June 2020, while work is still ongoing in the Tred Avon, St. Marys River, and Manokin River. Appendix A of this report provides more detail on the restoration activities in Harris Creek, Little Choptank, Tred Avon River, St. Marys River, and Manokin River sanctuaries.

Additionally, Governor Hogan and the department committed to conducting restoration in the Anne Arundel rivers, including the Severn, and the Nanticoke sanctuaries. Restoration activities in these areas are underway in various stages and are described in greater detail later in this report.

[36] Md. Code Ann., Nat. Rec. §4–1014 mgaleg.maryland.gov/2021RS/Statute_Web/gnr/4-1014.pdf

Table 3-2. Oyster sanctuaries in Maryland's portion of Chesapeake Bay.

Sanctuary Name	Year Created	Area (acres)	Historic Bottom (acres)	Sanctuary Name	Year Created	Area (acres)	Historic Bottom (acres)
Big Annemessex	2010	749	361	Nanticoke River-Roaring Point	2004	10	0
Breton Bay	2010	3,212	888	Neal Addition	2001	7	7
Calvert Shore	2010	2,214	673	Oxford Laboratory	1961	36	3
Cedar Point	2010	3,473	2,839	Piney Point	1986	13	0
Chester ORA Zone A	1996	6,189	184	Plum Point	1999	6,209	4,405
Choptank ORA Zone A	1996	8,962	236	Point Lookout (original)	1999	104	104
Cook Point	2001, 2010	814	781	Point Lookout[2]	2010	399	396
Cox Creek	2010	2,112	939	Poplar Island	2003	7	7
East Neck Bay[1]	2007	78	66	Possum Point[1]	2007	11	6
Eastern Bay	2010	4,521	939	Prospect Bay	2010	1,478	1,061
Emory's Wharf[1]	2007	65	18	Prospect Bay-Cabin Creek	2005	298	128
Fort Carroll	1995	30	0	Ringgold	2001	120	63
Gales Lump[1]	2002	43	43	Sandy Hill[2]	2009	1,947	1,308
Harris Creek	2010	4,647	1,998	Severn River	1998, 2010	7,804	1,376
Herring Bay	2010	16,792	7,981	Solomons Creeks	2010	617	5
Hooper Strait	2009	7,307	5,317	Somerset	1999	101	6
Howell Point	2001	6	6	South River	2000	2,327	141
Kitts Creek	2001	1,181	95	St. Marys River	2010	1,304	89
La Trappe Creek	2002	377	13	States Bank[1]	2005	82	12
Little Choptank	2010	9,415	1,713	Strong Bay[1]	2003	320	193
Lower Chester River[3]	2010	24,147	6,930	Tilghman Island	2010	2,534	1,345
Lower Choptank	2010	7,172	4,217	Tred Avon River	2010	4,149	1,152
Lower Mainstem Bay	1999, 2010	38,290	8,234	Trent Hall[1]	2003	9	1
Lower Patuxent	2010	335	315	University of Maryland's Horn Point[1]	1986	10	10
Magothy River	2010	5,607	230	Upper Chester River[2]	2010	9,033	2,365
Man O' War/Gales Lump[2]	2010	4,704	2,310	Upper Choptank River[2]	2010	5,898	1,675
Manokin River	2010	16,320	11,040	Upper Patuxent River	2010	14,461	2,228
Miles River	2010	3,449	373	Webster	1997	554	0
Mill Hill	2000	295	188	Wicomico River	2010	450	272
Nanticoke River	2010	16,699	576	Wye River	2010	3,510	1,100

Historic oyster bottom as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments.
1 Lies within a sanctuary established in 2010.
2 Contains one sanctuary established prior to 2010.
3 Contains two sanctuaries established prior to 2010.

Section 3.2: Public Shellfish Fishery Management Areas

The "Public Shellfish Fishery Areas of the Chesapeake Bay and Its Tidal Tributaries (September 2010)"[37] document contains coordinates for all PSFAs in Chesapeake Bay and its tidal tributaries. Detailed descriptions of the PSFAs, which are combined into larger geographically regions called NOAA Code harvest areas, are presented in Appendix B.

Post-2010 Changes to PSFAs

In the previous Five Year Oyster Review Report (2010-2015)[38], PSFA surface acres were reported as 179,943. This value has changed due primarily to a typographical error (overstatement of acreage) in the original report, but also because of various housekeeping corrections to certain PSFA boundaries, declassifications, and additions. The acreage of PSFAs may continue to change going forward, since there is an ongoing analysis being conducted to update the shoreline GIS layer, along with an expectation of future actions.

The current total area of PSFAs is 175,836 acres, which exceeds the 168,000 acre threshold (Figure 3-1). Since 2010, 204 acres have been declassified as a PSFA. These declassifications occurred at the request of lease applicants after a departmental population survey found less than one oyster per square meter.

Section 3.3: Aquaculture Areas

Inconsistent record keeping prevents any discussion on trend assessment prior to 2009. Between 1974 and 2009, the number of acres of leased land in Maryland ranged from 7,519 to 9,470 acres. Through the period 1990 to 2009, very few of these shellfish leases were actively worked.

Post-2010 Changes to Aquaculture

A new shellfish leasing program was launched in 2010 and at that time a strict active use provision in the lease law, requiring leaseholders to actively use their leases or return them to the state, was implemented. The active use provision in the law resulted in a number of old, inactive leases being returned to the state and this lease area was then made available for lease by other prospective oyster growers. Since 2010, the interest in obtaining shellfish leases has increased.

In 2009, two Aquaculture Enterprise Zones (AEZ) were established within the Patuxent River by regulation with the intent of providing individuals/businesses with the opportunity to obtain leases without having to apply for individual permits. However, the 2009 lease law revisions removed the restrictions to obtaining leases in all Maryland counties and provided similar benefits to prospective leaseholders as AEZs. Consequently, the advantages of obtaining a lease within an AEZ were reduced and interest in AEZs never materialized. In 2019, the AEZs were

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[37] Maryland Department of Natural Resources. 2012. Public Shellfish Fishery Areas of the Chesapeake Bay and Its Tidal Tributaries. dnr.maryland.gov/fisheries/Documents/Public_Shellfish_Fishery_Areas_of_the_Chesapeake_Bay_and_Its_Tidal_Tributaries.pdf

[38] dnr.maryland.gov/fisheries/pages/oysters/5-year-oyster-review-report.aspx

removed from regulation as leasing was not occurring in either area and there was strong interest from the public fishery in making these areas part of the PSFA.

Section 4: Effectiveness of Management Areas and Importance of Location

In this chapter, we examine a synthesis of data presented in Appendix A (sanctuaries) and B (PSFAs) to make determinations about the status of the management objectives of the 2010 proposal - to restore the ecological function of oysters and to enhance the commercial fishery for its economic and cultural benefits. The management plan, adopted in 2010, sought to resolve the dual goals of ecological and economic restoration by creating distinct management areas each with its own objectives – Sanctuaries, PSFA, and Aquaculture.

For sanctuaries, objectives as stated in regulation:

1. Protect half of the Bay's most productive oyster grounds that remain and allow investigation of the reasons why these remain most productive;
2. Facilitate development of natural disease resistance;
3. Provide essential natural ecological functions that cannot be obtained on a harvest bar;
4. Serve as a reservoir of reproductive capacity;
5. Provide a broad geographic distribution across all salinity zones; and
6. Increase our [the department's] ability to protect these important areas from poaching[39].

For PSFAs, objectives include:

1. Retain 168,000 acres of natural oyster bars including 76% (27,000 acres) of the remaining 36,000 acres of remaining productive oyster habitat identified in the Programmatic Environmental Impact Statement (PEIS);
2. Protect half of the 'best bars' identified by Jones and Rothschild (2009) as "consistently most productive" for the benefit of licensed oystermen[40]; and
3. Implement a more targeted and scientifically managed wild oyster fishery[41] [hereafter referred to as public fishery].

For aquaculture, objectives include:

1. Streamline the regulatory process for aquaculture;
2. Open new areas to leasing to promote shellfish aquaculture industry growth; and
3. Provide alternative economic opportunities for watermen[42].

Location is a critical factor when considering oyster management areas, due to the wide range of environmental and habitat conditions found on regional and smaller scales down to differences

[39] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010 dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf
[40] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf
[41] Maryland DNR Oyster Open House 2009, slides 13 and 57. dnr.maryland.gov/fisheries/Pages/oysters/5-Year-Oyster-Review-Report.aspx
[42] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010 dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf

within individual bars. Each management area has its own unique history and future potential based on the attributes of its location. The prevailing salinity of a location is a primary environmental determinant of oyster population dynamics, given its influence on reproduction, growth and mortality. Oyster habitat is another key element, providing necessary substrate to which the young oysters can attach. In Maryland, habitat can be extremely patchy, changing greatly within a small distance even on an individual bar. The management areas may have productive oyster bars that are interspersed with patches of sand, mud or other substrate that is unsuitable for oysters. Degradation of oyster habitat is a problem throughout Maryland's portion of Chesapeake Bay, with some remnant bars having little if any remaining substrate on which young oysters can settle[43].

Other factors can be important in accounting for differences in oyster populations among locations, but are less well understood or documented for specific management areas, and so are not included in this evaluation. For example, water currents can carry oyster larvae away from a spawning area ("source area") or can concentrate them in a distant area ("sink area"). Land use may impact management areas in a variety of ways ranging from sedimentation and nutrient enrichment to pesticide use and presence of endocrine disruptors. Likely there are other localized factors affecting oyster populations that are presently unknown.

[43] Smith, G.F., D. G. Bruce,E. B. Roach,A. Hansen,R. I. E. Newell & A. M. McManus. 2005. Assessment of Recent Habitat Conditions of Eastern Oyster *Crassostrea virginica* Bars in Mesohaline Chesapeake Bay. Volume 25: 1569-1590.

Section 4.1: Sanctuaries

There are 51 sanctuaries with a range of available data to assess their effectiveness. Twenty-eight of the current sanctuaries have been regularly monitored by the DNR Fall Oyster Dredge Survey since at least 1990 so that trends in oyster populations can be examined before and after sanctuary creation. Some sanctuaries have had patent tong surveys conducted since 2010, which provide additional information about oyster density, size structure and habitat condition. Appendix A provides detailed information on each sanctuary.

Overall in sanctuary areas, oyster mortality has remained stable and below the long-term baywide average since 2010 when most sanctuaries were established (Figure 4-1). There was a slight increase in observed mortality in more recent years (2016 to 2019).

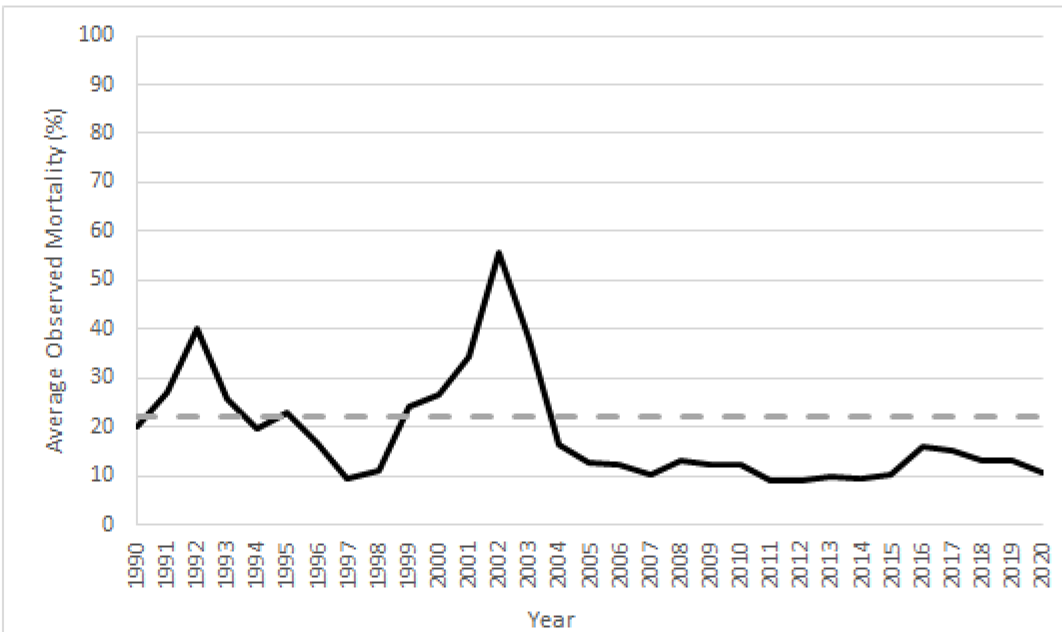

Figure 4-1. Estimated average observed mortality from the Fall Survey oyster bars sampled within current sanctuary areas in Maryland's portion of Chesapeake Bay, 1990-2020. The dotted line represents the long-term baywide average.

Oyster biomass estimates, a measure of oyster abundance and size distribution, are available for 13 sanctuaries since 1990. These bars include: Cason in Little Choptank River, Double Mills in Tred Avon River, Oyster Shell Point in Choptank River, Sandy Hill in Choptank River, Wilson Shoals in Nanticoke River, Old Field in Chester River, Bruffs Island in Wye River, Holland Point in the middle western shore of the bay mainstem, Long Point in Miles River, Cook Point in Choptank River, Flag Pond in the lower western shore of the bay mainstem, Pagan in St Marys River, and Georges in Manokin River.

Average biomass in these sanctuaries began increasing after 2009, peaking in 2015 (Figure 4-2). This was followed by a slight decrease in 2016 and 2017, then increasing again during the last three years. Since 2011, the average biomass in sanctuaries has remained above the long-term baywide average (all oyster bars measured consistently for biomass from 1990-2020).

There can be annual variation in biomass within sanctuaries between different salinity zones. (Figure 4-3). Sanctuaries located in the low-salinity zone initially showed an increase in biomass since 2010, but the increase was not as high as the other salinity zones. More recently, the low-salinity sanctuaries have shown a stable or decreasing biomass. The exception to this trend is the Nanticoke River Sanctuary, which continues increasing in biomass. The three large-scale restoration sanctuaries that have ongoing restoration efforts have an average biomass estimate similar to a high-salinity zone sanctuary despite being located in low/medium salinity zones.

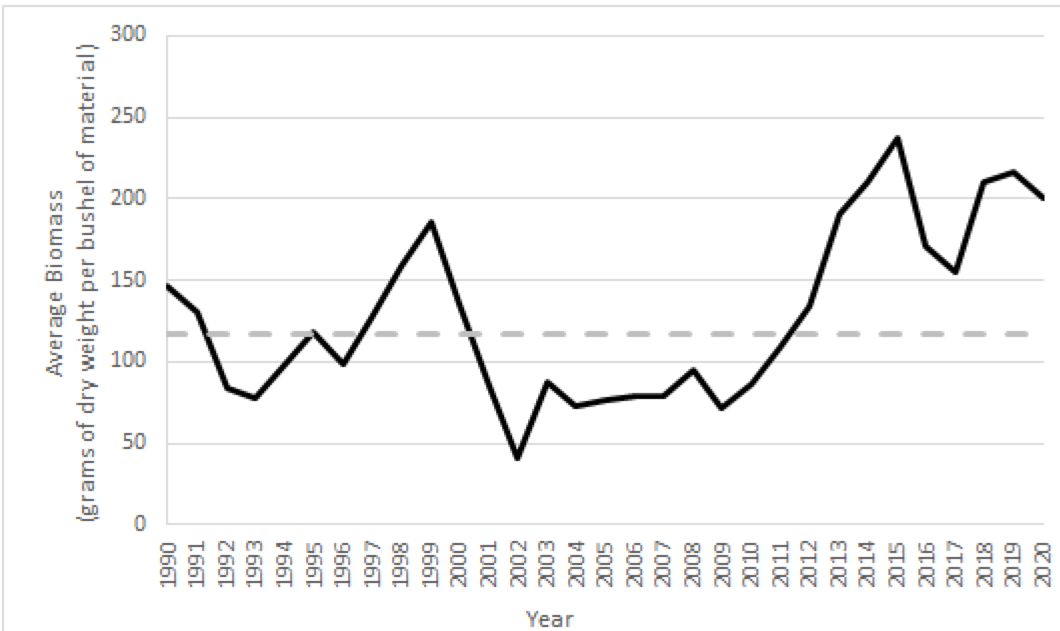

Figure 4-2. Estimated average biomass index from the Fall Survey for 13 oyster bars consistently sampled within current sanctuary areas in Maryland’s portion of Chesapeake Bay, 1990-2020. The dotted line represents the long-term baywide average.

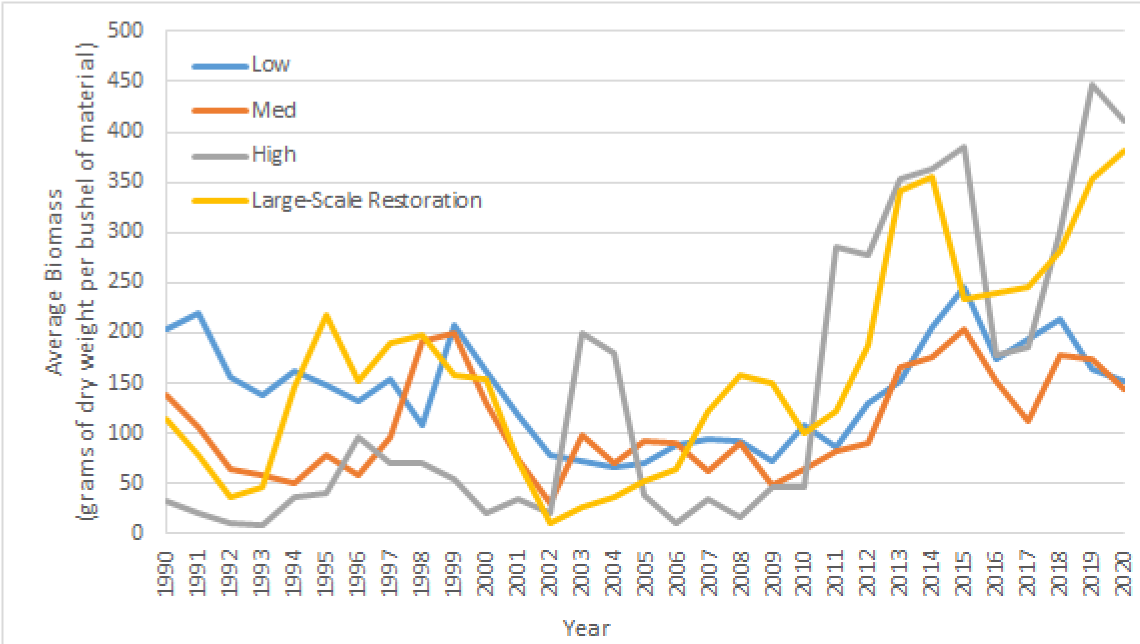

Figure 4-3. Estimated average biomass index for each salinity zone from the Fall Survey for 13 oyster bars consistently sampled located within current sanctuary areas in Maryland's portion of Chesapeake Bay, 1990-2020. Low-, medium- and high-salinity zones are defined as: low salinity = <11 parts per thousand (ppt), medium salinity 11 to 15 ppt, and high salinity > 15 ppt. Large-scale restoration sanctuaries as defined as those with ongoing restoration (three bars in Harris Creek, Little Choptank, and Tred Avon) located in average low-medium-salinity zones.

Although a time series of data is presented for each sanctuary in Appendix A, drawing firm conclusions about the consequences of sanctuary establishment is difficult in the absence of control areas or reference sites, and also given the relatively short time period of 10 years since establishment. When examining differences between sanctuary and harvest areas, true control sites would be harvest bars that are identical to the sanctuary bars in every way except for the experimental change (prohibition of harvest). Since it is not possible to match any individual sanctuary to an identical PSFA, it is highly difficult to screen out effects of salinity, hydrodynamics (water flow), bathymetric (water depth) characteristics, and water quality that would confound comparisons. In complex, time-variant systems where no two study areas are alike, long time-series of data become a critical tool for separating signals from noise within the system and show the impacts of management changes such as harvest prohibition and/or restoration[44].

[44] D.M Karl. 2010. Oceanic Ecosystems Time-Series Programs, Ten Lessons Learned. Oceanography Vol. 23, No. 3.

Section 4.1.1: Sanctuary Objective #1

Protect half of the Bay's most productive oyster grounds that remain and allow investigation of the reasons why these remain most productive

Sanctuary Objective # 1 Status: *This objective is being met. When the current sanctuary boundaries were created in 2010, Jones and Rothschild 2009 'best bars' analysis was used to ensure half of the productive oyster bottom was in sanctuaries. Based on the number of 2009 'best bars' and since sanctuary boundaries have not changed since 2010, 59% of the bars still have all or some portion of their acreage in sanctuaries. The 'best bars' analysis was updated in 2020 and found, 50% of productive bars are located either entirely or have a portion of bottom within a sanctuary.*

In 2010, an analysis of 'best bars' was used to establish sanctuary boundaries as 50% of the 'best bars' were in sanctuaries. Of the 17 'best bars' in Jones and Rothschild 2009 [45], five are located completely within sanctuaries. In addition, five other 'best bars' are located partially within a sanctuary (Appendix C, Table C-4A). Thus, 59% of the 2009 'best bars' have either all or some of their acreage located in PSFA. Due to the fact that some of these bars also have acreage in PSFAs, 71% of the 2009 'best bars' are located in PSFAs.

When considering the total acreage of historic oyster bottom encompassed by 2009 'best bars', 2,064 acres (26%) is located within sanctuaries. Historic oyster bottom refers to oyster bars charted by the Yates Survey (1906 to 1912)[46] and its amendments. It should be noted, however, that the historic oyster bottom does not necessarily represent current viable oyster reefs with oysters and substrate. As estimated in the PEIS (2009), only 36,000 acres of the historic oyster bottom is viable today[47].

The productivity of bars can change over time, thus using current data is more appropriate to determine if this objective is being met. Furthermore, a productive bar should not only consistently contain high numbers of market oysters as Jones and Rothchild stated, but also have good recruitment - consistently high numbers of smalls and spat - and have relatively low mortality to ensure that spat and small oysters survive to become market-sized.

This objective was assessed based on updated analysis to define productive oyster bottom (Appendix C). Based on Appendix C Table C-5 that used the expanded data set from 2009-2018, 13 of the 26 bars have all or some portion of historic oyster bottom[48] outside of sanctuaries (50%). Conversely, 15 of the 26 bars have all or some portion of historic oyster bottom within

[45] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf
[46] Yates, Charles. 1913. Survey of Oyster Bars of Maryland 1906 to 1912. biodiversitylibrary.org/item/96740
[47] U.S. Army Corps of Engineers, Norfolk District. 2009. Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster. dnr.maryland.gov/fisheries/Pages/eis.aspx
[48] Historic oyster bottom as charted in the Yates Oyster Survey of 1906 to 1912 and its amendments.

sanctuaries (58%). Due to the fact that some of these bars have acres in both sanctuaries and PSFAs, some bars can be counted twice. When considering acreage of the updated list of 'best bars' from 2009-2018, 4,472 acres (39%) are within sanctuaries.

To determine if this objective was met using the updated 'best bars' analysis, all bars were used regardless of whether or not they were planted with oysters and shell. Bars can become productive oyster bottom through management actions such as adding oysters. Given that a 'best bar' should have high counts of all size classes of oysters, a bar with a one-time planting of oysters would not be expected to be a 'best bar' especially if it is located in an area with known low to no natural recruitment. However, a bar may become a 'best bar' by boosting an existing oyster population through multiple plantings, planting oysters and/or cultch in areas where there is known recruitment, and/or tributary-scale plantings on multiple bars within the same time period.

Some bars have received significant plantings through restoration efforts throughout 2009-2018. It should be noted that the Fall Survey cannot sample all the bars in these large-scale sanctuaries. Sites that have received stone as a reef base are unable to be sampled by a dredge, thus, these sites are not included in this analysis. Large-scale restoration monitoring reports[49] often show oyster densities on stone substrate similar to (and sometimes higher than) oyster densities on a mixed shell reef base or on seed-only sites. Thus, these bars could possibly be 'best bars' due to the extensive multi-year seed plantings that populate the bars with spat, small, and market oysters.

All of these updated 'best bars' were located in sanctuaries that are either currently receiving large-scale restoration or will be shortly. Harris Creek Sanctuary had six 'best bars'; its initial restoration was completed in 2015, and all of the planned second seedings were completed in 2020. Little Choptank River Sanctuary had one 'best bar'; its initial restoration was completed in 2020, but still has ongoing planned second seedings. The St. Marys River and Manokin River sanctuaries also had 'best bars,' two and four, respectively. These sanctuaries started receiving large-scale restoration in 2021.

Due to the fact that either the amount and/or location of plantings can change over time, the 'best bars' analysis should not remain static. Instead this analysis should be updated frequently to monitor both natural changes and impacts from human manipulation.

[49] Maryland Oyster Restoration Interagency Workgroup under the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team. 2020. 2019 Oyster Reef Monitoring Report: Analysis of Data from Large-Scale Sanctuary Oyster Restoration Projects in Maryland Collected from Fall 2019 through Summer 2020. 76pg.
dnr.maryland.gov/fisheries/Documents/Reg_Changes/2019_Maryland_Oyster_Restoration_Update_FINAL.pdf

Section 4.1.2: Sanctuary Objective #2

Facilitate development of natural disease resistance

***Sanctuary Objective #2 Status*:** *This objective is underway and remains under evaluation. Over the past 10 years, research has been conducted to understand the evolution or current status of disease resilience in wild oyster populations but that research has been limited. In addition, disease levels over this time period have been below the long-term averages. Consequently, oysters are less challenged by disease to develop disease resilience. Despite these factors, new information is emerging on variants of diseases (specifically dermo) and monitoring is underway of age classes derived from the survivors of previous outbreaks. Therefore, this objective will remain under evaluation as we observe over time whether a significant population of oysters has become or will become resistant or tolerant to MSX (Haplosporidium nelsoni) and dermo (Perkinsus marinus) diseases.*

This objective remains under evaluation as we observe over time whether sanctuaries can assist in facilitating the development of a significant population of oysters that is resistant or tolerant to MSX and dermo diseases, which would increase survival, growth, and reproduction of Maryland oysters.

Disease resistance is defined as the ability of the oyster to prevent infection. Disease tolerance is the maintenance of relatively normal function (growth, reproduction, survival) despite the presence of disease in the animal. Both conditions may develop through natural selection with the same outcome - increased survival. For the purpose of this report, we use the term "resilience," recognizing that either or both tolerance or resistance could develop.

MSX and dermo diseases are caused by pathogenic parasites that can result in devastating oyster mortalities. Dermo was first detected in Chesapeake Bay in 1949, and MSX in 1959.

A management tool to foster the development of resistance is to protect older and larger oysters that may have survived exposure to disease. One option is to close an area to harvest. Studies of how these populations respond to disease pressure over time could show if disease resilience develops. Larger oysters also represent important contributors to future generations, because oysters become more fecund (produce more eggs) as they grow larger. Sanctuary protection of these large, surviving oysters is one strategy to conserve genes that may confer disease tolerance or resistance for future generations. Carnegie et al.[50] evaluated archival histological samples from New Jersey, Chesapeake Bay and South Carolina from 1960 to 2018 in an effort to evaluate dermo infections. They found a phenotypic change in the samples that coincided with major dermo disease outbreaks, hypothesizing an ecosystem response of the parasite to the introduction of MSX. During the past 10 years disease pressure has been relatively low, with average disease

[50] Carnegie, R.B., S. E. Ford, R. K. Crockett, P. R. Kingsley-Smith, L. M. Bienlien, L. S. L. Safi, L. A. Whitefleet-Smith & E. M. Burreson. 2021. A rapid phenotype change in the pathogen *Perkinsus marinus* was associated with a historically significant marine disease emergence in the eastern oyster. Scientific Reports volume 11, Article number: 12872. nature.com/articles/s41598-021-92379-6

levels below the long-term averages, thus, oysters likely aren't being sufficiently challenged by disease to develop resilience.

There is an additional benefit to protecting large old oysters. Although one objective of sanctuaries is to observe whether disease resilience can be developed over time, it is clear that oysters in any area (sanctuary or harvest area) can die from predation, adverse environmental conditions such as freshets (freshwater flows), and old age, as well as disease. However, if large oysters are not removed by harvest, the shells of those that die remain in place as substrate for the potential recruitment of future generations of larvae. These shells provide habitat for a diverse assemblage of associated animals and plants and may contribute to reefs growing over time[51,52].

Current State of Knowledge - Oyster Disease Resistance

While no studies to test whether oysters in Maryland sanctuaries have developed tolerance or resistance to MSX and dermo have been carried out since the establishment of the sanctuary program in 2010, it has been demonstrated that oyster resilience to both diseases is heritable, and desirable genetic characteristics can be strengthened by planned, selective breeding[53,54]. Oyster hatcheries are now capable of producing larvae for aquaculture use that exhibit specific disease resilience characteristics, however these oysters are the result of intense selective cross breedings, which does not typically occur in nature where any random oyster can mate with any other oyster. Additionally, it is not economically or biologically viable to use these oysters for restoration purposes.

Following at least 60 years of natural selection through outbreaks of dermo and MSX, there is some evidence of increasing tolerance or resistance to MSX disease for oysters in Chesapeake and Delaware bays[55,56,57]. Data on dermo disease among different size classes of public oysters in Virginia's Chesapeake Bay indicate that the intensities of dermo infections are frequently lower in the largest (oldest) oysters. These results suggest that large, older oysters represent survivors of long standing disease pressures. The survival and lower infection intensities of these larger, older oysters collectively reflect their ability to tolerate or resist dermo disease pressure. Recent

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[51] Kellogg, M.L., Ross, P.G., Luckenbach, M.W., Dreyer, J.C., Pant, M., Birch, A., Fate, S., Smith, E., Paynter, K. 2016. Integrated assessment of oyster reef ecosystem services: Fish and crustacean utilization and trophic linkages. Report to NOAA Chesapeake Bay Office, 19 pp. hdl.handle.net/10288/22190

[52] Kellogg, M.L., Cornwell, J.C., Owens, M.S., Paynter, K.T. 2013. Denitrification and nutrient assimilation on a restored oyster reef. Marine Ecology Progress Series 480: 1-19.

[53] Ford, S.E., Haskin, H.H. 1987. Infection and mortality patterns in strains of oysters *Crassostrea virginica* selected for resistance to the parasite *Haplosporidium nelsoni* (MSX). Journal of Parasitology 73: 368-376.

[54] Ragone Calvo, L.M., Calvo G.W., Burreson, E.M. 2003. Dual disease resistance in a selectively bred eastern oyster, *Crassostrea virginica*, strain tested in Chesapeake Bay. Aquaculture 220: 69-87.

[55] Carnegie, R.B., Burreson, E.M. 2011. Declining impact of an introduced pathogen: *Haplosporidium nelsoni* in the oyster Crassostrea virginica in Chesapeake Bay. Marine Ecology Progress Series 432: 1-15.

[56] Carnegie, R.B., Burreson, E.M. 2009. Status of the major oyster diseases in Virginia 2006-2008: A summary of the annual oyster disease monitoring program. Virginia Institute of Marine Science, Gloucester Point, VA vims.edu/research/departments/eaah/programs/molluscan_health/_documents/monitoring_rpt_2009.pdf

[57] Ford, S.E., Bushek, D. 2012. Development of resistance to an introduced marine pathogen by a native host. Journal of Marine Research 70: 205- 223. hsrl.rutgers.edu/abstracts.articles/JMR%20EID%20volume/FordBushek_2012_Development_of_resistance_to_an_introduced_marine_pathogen_by_a_native_host.pdf

study of known families of oysters, using newly developed scientific tools, has expanded understanding of the mechanisms underlying dermo resistance, and generated a list of genes whose role should be investigated further[58].

The decline in observed mortality in recent years among Maryland oysters may indicate the possibility of increasing disease resilience, although controlled studies that separate the effects of disease pathogens from salinity would be necessary to validate this result. Data collected by the Fall Survey indicate that the infection rates (prevalence) of both dermo and MSX, and dermo intensity have been generally below the time-series average since 2003, but when they have increased there has been no or only slight corresponding increases in mortality (Figure 4-4, Appendices A and B). Other reasons for the lower mortalities besides disease resilience may include favorable and timely freshwater stream flows into the bay that decrease disease pressure, or a decline in the virulence of the pathogens.

[58] Proestou, D.A., Sullivan, M.E. 2020. Variation in global transcriptomic response to *Perkinsus marinus* infection among eastern oyster families highlights potential mechanisms of disease resistance. Fish and Shellfish Immunology 96:141-151

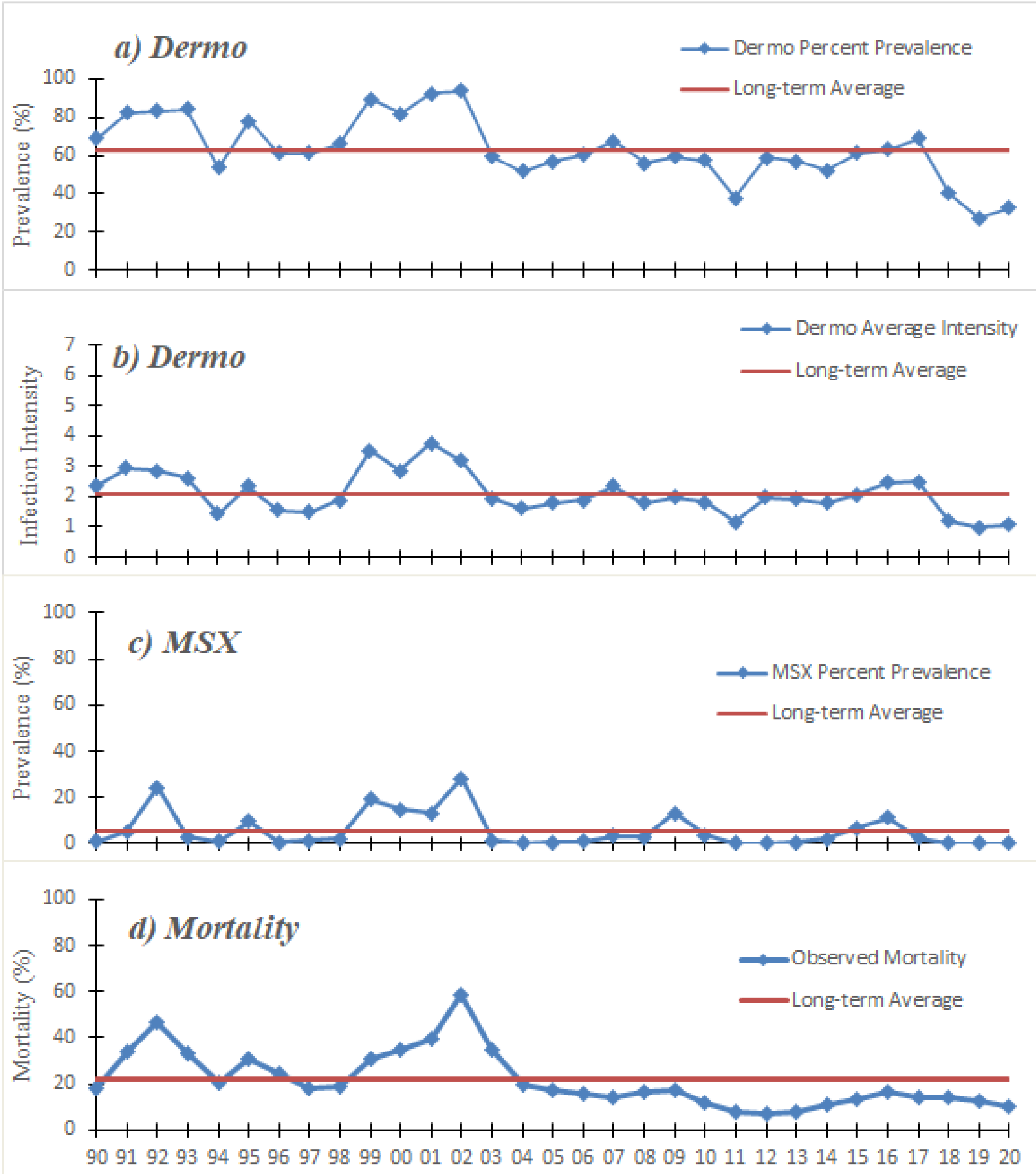

Figure 4-4. Annual measurement and time-series averages for a) dermo disease prevalence, b) dermo disease intensity level, c) MSX disease prevalence, and d) observed percent (%) mortality, 1990-2020.

Measuring Disease Resistance

Until the recent development of modern genetic screening tools, it has been impractical to directly and objectively evaluate whether oysters within sanctuaries develop tolerance or resistance faster than oysters in harvested populations. In addition, more needs to be known about both the functional and genetic basis for resilience in order to develop objective genetic or biochemical markers to identify resilient animals.

Beyond the issue of developing genetic markers, estimating, and comparing disease resistance of oysters in different populations or locations would require considerable resources. Sanctuary populations would need to be surveyed for the presence of those genes that may in future be confirmed as conferring resilience. Although relative resistance of oysters in differing locations could be tested, the impacts of those differences on oyster populations outside of the sanctuaries could be difficult to determine. This is because oyster larvae grow and disperse under influences of variable tidal and wind-driven water currents during two to three weeks of their early lives, before attaching to an available hard substrate. Local oyster populations receive larvae from neighboring populations, and also export their own larvae to join neighboring populations. In consequence, contributions by sanctuary oysters to disease resistance will be difficult to evaluate except over broad geographic areas and over long periods of time. Currently, this remains a conceptual expectation for Maryland oyster sanctuaries.

Section 4.1.3: Sanctuary Objective #3

Provide essential natural ecological functions that cannot be obtained on a harvest bar

Sanctuary Objective #3 Status: *This objective is being met and will continue to be evaluated. There have been no reductions in sanctuary areas and extensive work is underway to expand restoration work in sanctuaries, therefore the program continues to provide essential ecological functions that exist. Maryland is on track to meet the commitment to restore five large-scale restoration sanctuaries. Work is also underway in other sanctuaries to develop three dimensional habitat that can be evaluated. Ongoing research is beginning to show how a complex, three-dimensional structure created by large-scale restoration sanctuaries impacts the food web and nutrient cycling to benefit the oyster reef and the ecosystem as a whole. Maryland's Oyster Management Plan was updated and includes a goal of promoting "the creation of oyster reefs with higher profiles above the bay bottom to enhance oyster productivity."*

It is widely recognized that oysters and the reefs they create are a vital component of a healthy Chesapeake Bay ecosystem. Oyster reefs that are undisturbed by harvest gear can provide complex three-dimensional habitat which provides habitat for many other species[59,60]. Perhaps more importantly, research is beginning to show how three-dimensional structures impact the food web to benefit the oyster reef and the ecosystem as a whole. It has been demonstrated that substituting vertically oriented living oysters for the flat shells of dead oysters increases survival of young oysters[61]. Due to this, one of the department's actions for sanctuaries within the 2019 Oyster Management Plan is to "Promote the creation of oyster reefs with higher profiles above the bay bottom to enhance oyster productivity".

Increasing habitat complexity and oyster abundance also increases the exchange of nutrients and energy between the bottom and the water column, a process called benthic-pelagic coupling. Oysters filter large volumes of water and can reduce the local concentration of suspended particulates (primarily phytoplankton), thereby increasing water clarity. This process plays a major role in the production and biological structure of the system[62,63].

The Interagency Workgroup (convened by the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team consisting of the department, National Oceanic and Atmospheric Administration (NOAA), United States Army Corps of Engineers Baltimore District, and Oyster

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[59] Tolley, S.G., Volety, A.K. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. *Journal of Shellfish Research* 24:1007-1012

[60] Lenihan, H.S., Peterson, C.H., Byers, J.E., Grabowski, J.H., Thayer, G.W., Colby, D.R. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications* 11(3), pp 764-782.

[61] Grabowski, J.H. 2004. Habitat Complexity disrupts predator-prey interactions but not the trophic cascade on oyster reefs. *Ecology* 85(4), pp 995-1004.

[62] Marcus, N.H., Boero, F. 1998. Minireview: The importance of benthic-pelagic coupling and the forgotten role of life cycles in coastal aquatic systems. Limnology and Oceanography 43(5), pp 763-768.

[63] Mann, R., Powell, E.N. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. *Journal of Shellfish Research* 26(4), pp 905-917.

Recovery Partnership) monitors large-scale restoration on reefs three and six years after initial restoration to gauge restoration success toward the 2014 Chesapeake Bay Watershed Agreement. Reef height and reef footprint are evaluated as part of this monitoring. Data from the 2019 monitoring report found that 100% of restored reefs in Harris Creek, Little Choptank and Tred Avon sanctuaries with a calculated reef height and footprint had stable or increasing reef extents [64].

The NOAA Chesapeake Bay Office funded eight projects from 2013-2019, and the National Fish and Wildlife Federation (NFWF) funded one project from 2017-2018 evaluating the oyster reef ecosystem services of restored oyster reefs[65]. The projects occurred in seven tributaries baywide, three of which were in Maryland waters (Harris Creek, Little Choptank and Tred Avon). The funded projects by NOAA focused on the general research themes of nutrient cycling, macrofaunal communities, fish communities, and economic modeling. The studies were short term, so ecosystem function relative to reef maturity was not addressed.[66]

Nutrient Cycling

- University of Maryland Center for Environmental Science (UMCES) and Virginia Institute from Marine Science (VIMS) "Integrated Assessment of Oyster Reef Ecosystem Services: Quantifying Denitrification Rates and Ecosystem Services" (2015-2019)
- UMCES "Natural Engineers in Ecosystem Restoration: Modeling Oyster Reef Impacts on Particle Removal and Nutrient Cycling" (2014-2017)

Nutrient cycling studies found an increase in the rates of nutrient cycling with an increase in oyster density[67]. They found the nutrient cycling was enhanced by the activity of the entire reef community. Nitrogen removal rates were estimated to be 57 pounds of nitrogen per acre per year for low oyster biomass, translating to approximately 20,000 pounds of nitrogen removal for the Harris Creek restoration project. Restored reefs are expected to remove seven times as much nitrogen than an unrestored area.

Macrofaunal Communities

- VIMS "Ecosystem Services of Restored Oyster Reefs in the Lower Chesapeake Bay: Oyster Populations and Benthic Macrofaunal Communities" (2014-2018)
- University of Maryland and VIMS "Oyster Reef Ecosystem Services: Macrofaunal Utilization of Restored Oyster Reefs" (2015-2019)

Macrofaunal community studies saw a strong relationship between oyster reef biomass and macrofauna biomass, which is used as food by fish and crabs, in some species. Densities can exceed 5,000 individuals per square meter. Macrofaunal diversity increased with structural

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[64] Maryland Oyster Restoration Interagency Workgroup under the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team. 2020. 2019 Oyster Reef Monitoring Report: Analysis of Data from Large-Scale Sanctuary Oyster Restoration Projects in Maryland Collected from Fall 2019 through Summer 2020. 2020.
[65] Bruce, D. G., J. C. Cornwell, L. Harris, T. F. Ihde, M. L. Kellogg, S. Knoche, R. N. Lipcius, D. N. McCulloch-Prosser, S. P. McIninch, M. B. Ogburn, R. D. Seitz, J. Testa, S. R. Westby, and B. Vogt. 2021. A Synopsis of Research on the Ecosystem Services Provided by Large-Scale Oyster Restoration in the Chesapeake Bay. NOAA Tech. Memo. NMFS-OHC-8, 52 p.
[66] IBID
[67] IBID

complexity of the restoration site. This increased macrofaunal biomass is important as a food source for the higher trophic level organisms, providing enhanced foraging habitat, thus supporting ecosystem-based fishery management[68].

Fish Communities

- NOAA " Fish Utilization of Subtidal Mesohaline Oyster Restoration Sites in the Chesapeake Bay" (2014-2017), VIMS "Oyster Reef Ecosystem Services: Finfish Utilization and Trophic Linkages" (2015-2019)
- VIMS "Ecosystem Services of Restored Oyster Reefs in the Lower Chesapeake Bay: Importance for Blue Crabs and Finfish" (2014-2017)
- Virginia Commonwealth University (VCU) "Pathways to Production: An Assessment of Fishery Responses to Oyster Reef Restoration and the Trophic Pathways that Link the Resource to the Reef" (2014-2017)
- Smithsonian Environmental Research Center (SERC) "Application of Dual-frequency Imaging Sonar to the Study of Oyster Reef Ecosystem Services" (2015-2018)

Fish community studies found an increase in abundance of small reef-resident fish with increasing oyster density[69]. Survival of juvenile blue crab was found to be three times higher on oyster reefs than on unstructured habitat. Thirty-five species of larger transient fish were collected on oyster reefs, of which eighteen have commercial or recreational value. Diets of two species of perch were found to be dominated by oyster-reef dependent macrofauna, though there was no difference found between those caught on restored reefs versus non-restored sites[70].

Economic Modeling

- Morgan State University "Estimating Ecological Benefits and Socioeconomic Impacts from Oyster Reef Restoration in the Choptank River Complex, Chesapeake Bay" (2017-2018)

The study evaluating the ecology and economic impacts found that there are substantial economic gains to a region from retaining restored oyster reefs and allowing them to mature.[71]. If remain as sanctuaries, this study suggests that the restored reef in the Choptank Complex (Harris Creek, Tred Avon and Little Choptank) could improve fishery landings with an associated economic benefit of $23 million annually, supporting an additional 300 jobs.

In addition, an Oyster (Best Management Practice (BMP) Expert Panel has been established to review scientific research demonstrating removal of nutrients (nitrogen and phosphorus) from the water column by oysters. This panel will also identify oyster practices for BMP

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[68] Bruce, D. G., J. C. Cornwell, L. Harris, T. F. Ihde, M. L. Kellogg, S. Knoche, R. N. Lipcius, D. N. McCulloch-Prosser, S. P. McIninch, M. B. Ogburn, R. D. Seitz, J. Testa, S. R. Westby, and B. Vogt. 2021. A Synopsis of Research on the Ecosystem Services Provided by Large-Scale Oyster Restoration in the Chesapeake Bay. NOAA Tech. Memo. NMFS-OHC-8, 52 p.

[69] IBID

[70] Kellogg, L.M., P.G. Ross, M.W. Luckenbach, J.C. Dreyer, M. Pant, A. Birch, S. Fate, E. Smith, and K. Paynter. 2016. Integrated assessment of oyster reef ecosystem services - Fish utilization and trophic linkages. Virginia Institute of Marine Science, 20 p

[71] Knoche, Scott, Thomas F. Ihde, Giselle Samonte, Howard M. Townsend, Douglas Lipton, KristyA.Lewis, and Scott Steinback. 2020. Estimating Ecological Benefits and Socio-Economic Impacts from Oyster Reef Restoration in the Choptank River Complex, Chesapeake Bay. NOAA Tech. Memo. NMFS-OHC-6, 68 p.

consideration, develop a pollutant removal crediting framework, and determine pollutant removal effectiveness estimates for nutrients where there is sufficient science.

In 2016, the Chesapeake Bay Program's Water Quality Goal Implementation Team (WQGIT) approved panel recommendations for BMPs for oyster aquaculture practices to help meet nitrogen and phosphorus reduction goals toward the Total Maximum Daily Load (TMDL) for the Chesapeake Bay Agreement. In January 2018, the U.S. Environmental Protection Agency (EPA) said that the pollutants sequestered by in-water BMPs could legally be counted toward the TMDL reduction goals. In 2019, the Oyster BMP panel submitted a report suggesting that oyster reef restoration should also be considered toward BMPs for meeting the TMDL. The WQGIT approved the use of these estimates for planning purposes[72]. Conservative estimates used for the estimate of nitrogen removal for restored reefs is 57 pounds of nitrogen per acre per year. This was calculated using a low biomass estimate[73]. Since the biomass is higher on restored reefs than on areas harvested, there is more nitrogen removal in restoration areas. Nitrogen can also be found in the tissue of oysters and removed by harvesting oysters. The Oyster BMP panel estimated 198 pounds of nitrogen would be removed by harvesting 1,000,000 aquaculture oysters (equivalent to about 250 oysters per square meter on one acre)[74].

Summary Sanctuary Objective – Ecological Functions

Efforts to evaluate three dimensional structure on restored oyster reefs exhibited an increase in reef extent. Studies to evaluate the ecosystem services provided by restored oyster reefs support evidence of nutrient cycling with increased nitrogen removal rates, increased macrofaunal communities and a diverse abundance of fish communities. These ecosystem functions are projected to have a positive economic benefit and can be used towards TMDL reductions. Given the time it takes to build a complex, 3-D oyster reefs and increase oyster abundance in tributaries either through restoration or naturally, it may take more than 10 years before ecological benefits could be achieved and fully measured. Oyster reefs present in Chesapeake Bay grew over centuries so that by the late 1880's the Chesapeake Bay was the greatest oyster-producing region in the world[75]. It is unrealistic to expect complex reefs will form within a decade.

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[72] Chesapeake Bay Program Water Quality Goal Implementation Team July 8, 2019 meeting chesapeakebay.net/what/event/water_quality_goal_implementation_team_conference_call_july_8_2019

[73] Chesapeake Bay Program Water Quality Goal Implementation Team July 8, 2019 meeting chesapeakebay.net/channel_files/33998/cornwell_et_al_june2019_enhanced_dnf-oyster_reef_restoration_planning_interim_bmp.pdf

[74] Cornwell, J., J. Reichert-Nguyen, and W. Slacum. 2016. Oyster Best Management Practice Expert Panel—Recommendations on the Oyster BMP Reduction Effectiveness Determination Decision Framework and Nitrogen and Phosphorus Assimilation in Oyster Tissue Reduction Effectiveness for Oyster Aquaculture Practices. Presentation to the Chesapeake Bay Program Water Quality Goal Implementation Team. oysterrecovery.org/wp-content/uploads/2017/01/Presentation_Oyster-BMP-Panel_1st-Report_WQGIT_Approval_12-19-16_Final_1.pdf

[75] National Research Council. 2004. Non native Oysters in the Chesapeake Bay. 344 pages

Section 4.1.4: Sanctuary Objective #4

Serve as a reservoir of reproductive capacity

Sanctuary Objective #4 Status: *This objective remains under evaluation. The sanctuary program continues as a reservoir of reproductive capacity and in most sanctuaries, the overall reproductive potential has remained stable or increased. While reproductive potential has increased, fertilization, larval development and successful spat set are needed to grow the population over time. Even if fertilization is successful, the fate of the larvae is not guaranteed due to a wide and fluctuating range of biological and environmental variables.*

Reproductive capacity is examined by calculating an index of the potential number of eggs that may be produced by the oysters present in the area over time. In doing these we account for the fact that oysters transition from male to female as they age. According to Galtsoff[76], the oyster gonad is bisexual – during the first breeding season the majority of the young oysters are males, but there are still some females. By the second season there may still be more males, but generally the ratio is equal. In subsequent years, the ratio may favor females. As oysters grow larger and heavier, their annual fecundity (number of eggs produced) increases (Figure 4-5)[77]. In addition, oyster fecundity rises very quickly with increasing shell height so that even a small increase in the number of older, larger oysters will cause a large increase in reproductive potential. Generally speaking, the biomass and reproductive potential of a population will show the same trends.

An index of reproductive potential can be calculated for the 43 "disease bars" sampled in the Fall Survey, the same areas for which we calculated indices of biomass, because these samples have size information (shell height (mm)) for each oyster collected a bushel of material[78]. Following the Mann and Evans model to calculate egg production[79], the number of eggs were estimated for each oyster using shell height and a factor was applied to the estimate, which decreases oyster egg viability in lower salinity zones. There is some evidence that oysters that are habituated to low salinity do not experience diminished egg viability[80]. However, including this factor provides a lower-end estimate of egg production. Using the assumption that the sex ratio of oysters is 50% male, 50% female[81], the estimated number of eggs was divided in half to simulate only half of

[76] Galtsoff, P.S. 1964. The American Oyster *Crassostrea virginica* Gmelin. Fishery Bulletin of the Fish and Wildlife Service, Volume 64. Washington, D.C. 480 pp.
[77] Mann, R., 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, Vol. 17. No.1, 239-253.
[78] Tarnowski, M. (ed.) 2020. Maryland Oyster Population Status Report: 2019 Fall Survey. Maryland Department of Natural Resources, Annapolis, MD, # 17-050420-232, 71 pp. dnr.maryland.gov/fisheries/pages/shellfish-monitoring/reports.aspx
[79] Mann, R., 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, Vol. 17. No.1, 239-253.
[80] Davis, H.C. 1958. Survival and growth of clam and oyster larvae at different salinities. Biological Bulletin. 114:296-301.
[81] Galtsoff, P.S. 1964. The American Oyster Crassostrea virginica Gmelin. Fishery Bulletin of the Fish and Wildlife Service, Volume 64. Washington, D.C. 480 pp.

the oysters are female and have eggs. Estimates of reproductive potential are available for 13 of the 51 sanctuaries.

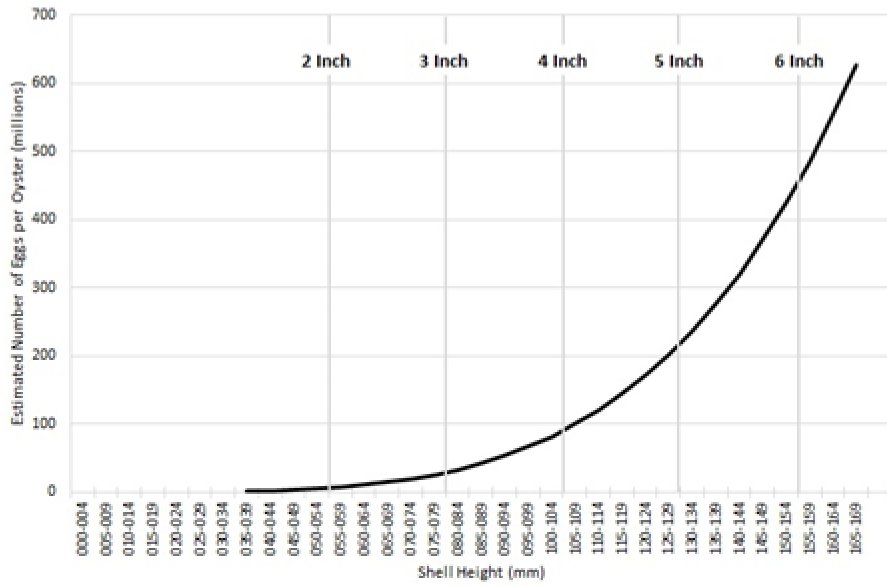

Figure 4-5. The annual estimated number of eggs produced for an individual female oyster of a given shell height[82]. The number of eggs produced increases very quickly with increasing size. Estimated egg production does not account for effects of salinity on egg viability.

The overall reproductive potential in sanctuaries has increased since 2011 with 2015 being the highest value in the 32-year time series (Figure 4-6). While reproductive potential has increased, this alone is not enough to increase the population over time. Even if fertilization is successful, the fate of the larvae is not guaranteed due to a wide and fluctuating range of biological and environmental variables.

Sanctuary location affects reproductive potential largely due to different salinity zones. Medium- and high-salinity zone sanctuaries showed, on average, higher reproductive potential than the low-salinity zone sanctuaries (Figure 4-7). Four sanctuaries with continuous length data from 1990 to 2020 have been identified as being in the low-salinity zone. The reproductive potential in the middle and upper Choptank River, low-salinity zones represented by Sandy Hill oyster bar (Sandy Hill Sanctuary) and Oyster Shell Point oyster bar (Upper Choptank Sanctuary) showed an initial increase since becoming a sanctuary, but more recently has remained stable. Old Field, a low-salinity bar in the Upper Chester River, showed less promising results. These areas are now showing a decline in reproductive potential due to low densities of oysters. The Nanticoke River Sanctuary, a low-salinity region represented by Wilson Shoal oyster bar, has shown a different trend than the other low-salinity bars, whereas it has continued to increase its reproductive potential until 2020.

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[82] Mann, R., 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, Vol. 17. No.1, 239-253.

Medium-salinity regions have a larger variability in reproductive potential between oyster bars in different areas. Wye River Sanctuary, as represented by Bruff Island oyster bar, also showed an increase in reproductive potential. However, Bruff Island oyster bar may not be completely representative of Wye River Sanctuary as it is located at the mouth of the river. The Fall Survey, along with a patent tong survey in 2020, sampled multiple bars within the sanctuary and found low market-sized oyster densities with little to none small-sized oysters and spat. The other medium-salinity zone sanctuaries (Holland Point in Herring Bay Sanctuary and Long Point in Miles River Sanctuary) showed less promising results. These areas are now showing a decline in reproductive potential due to low densities of oysters. Cook Point Sanctuary in the lower Choptank River showed an increase in reproductive potential since becoming a sanctuary, but declined in 2016. There were relatively high natural mortalities in Cook Point Sanctuary in 2016 and 2017, which led to a decline in market-sized oysters. However, with the relatively high spatset in 2016 and 2020, the reproductive potential seems to be increasing. This trend was not observed within the Calvert Shore Sanctuary as represented by Flag Pond bar. Pagan bar in the St Marys River Sanctuary has shown a continued increase in reproductive potential from 2010 to 2020.

The high-salinity sanctuary represented by Georges bar in Manokin River had substantial gains in reproductive potential since becoming a sanctuary in 2010. Of the 13 oyster bars, Georges had the highest reproductive potential.

Three sanctuaries (Harris Creek, Little Choptank, and Tred Avon sanctuaries) have been receiving ongoing large-scale restoration efforts and are located in low- and medium-salinity regions. All three of these sanctuaries showed an increase in reproductive potential (Figure 4-7). From 2016 to 2020, the average annual estimated reproductive potential was higher in the large-scale restoration sanctuaries than most of the low- and medium-salinity zone sanctuaries.

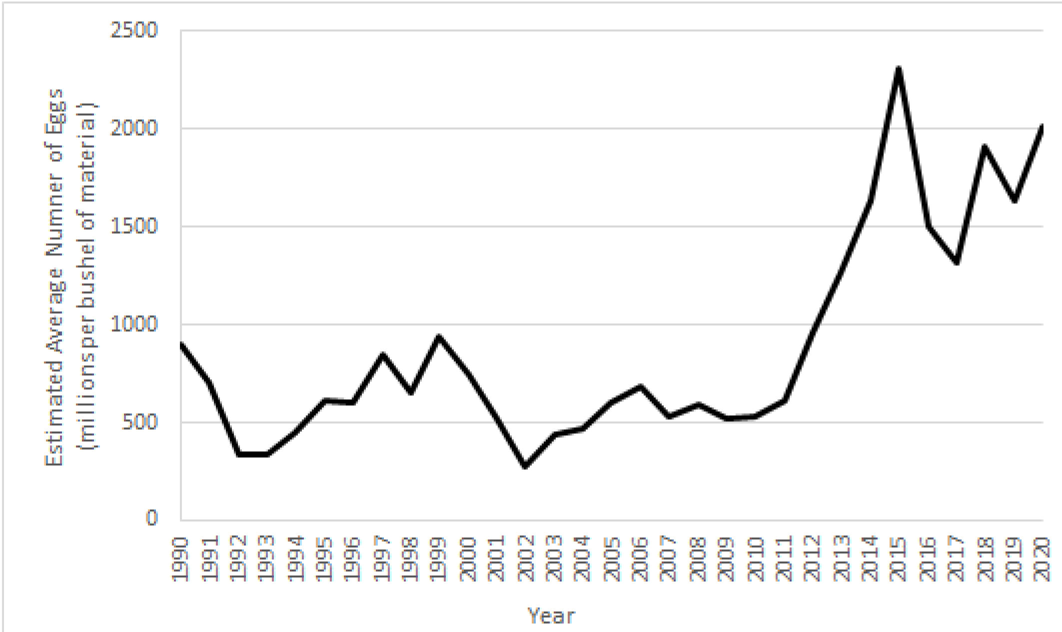

Figure 4-6. The estimated number of eggs per year that could be produced per bushel of material averaged over the 13 sanctuary oyster bars sampled by the Fall Survey in Maryland's portion of Chesapeake Bay.

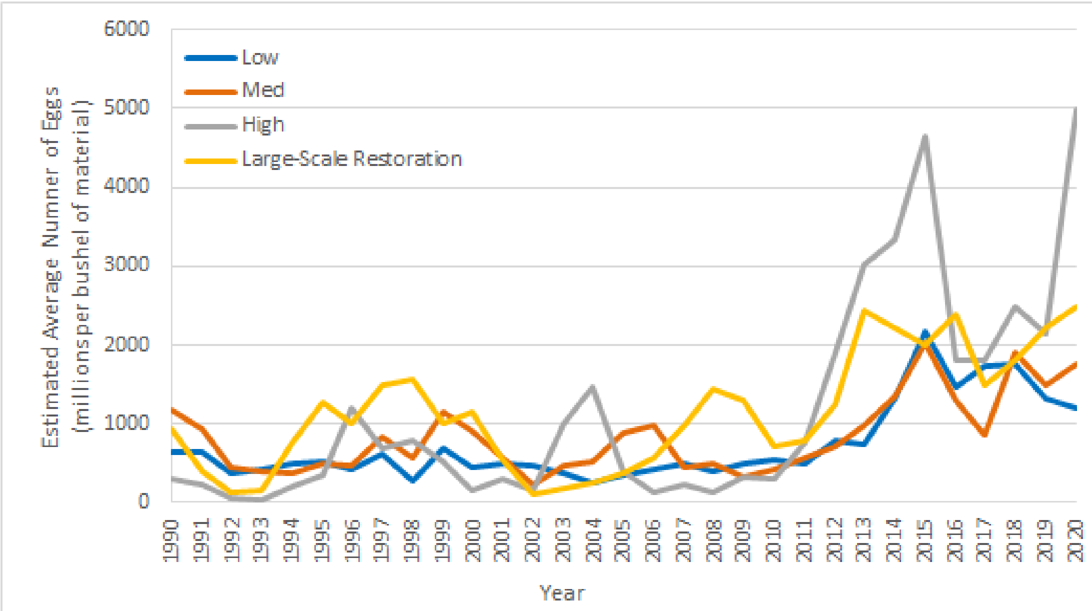

Figure 4-7. Estimated average number of eggs per year that could be produced per bushel of material for each salinity zone from the Fall Survey for 13 oyster bars consistently sampled located within current sanctuary areas in Maryland's portion of Chesapeake Bay, 1990-2020. Low, medium and high salinity zones are defined as: low salinity = <11 ppt, medium salinity 11 to 15 ppt, and high salinity > 15 ppt. Large-scale restoration sanctuaries as defined as those with ongoing restoration (three bars in Harris Creek, Little Choptank, and Tred Avon) located in average low-medium-salinity zones.

Section 4.1.5: Sanctuary Objective #5

Provide a broad geographic distribution across all salinity zones

Sanctuary Objective #5 Status: *This objective is being met. Oyster sanctuaries are distributed across all salinity zones in Maryland's portion of Chesapeake Bay. Approximately 30% of historic oyster bottom*[83] *in sanctuaries is located in low-salinity areas, 56% in medium-salinity areas, and 15% in high-salinity areas.*

Oyster bars in Maryland are located in the mesohaline salinity classification (5-18 ppt). Within this mesohaline zone, Maryland oyster bars are further classified into three zones: Zone 1 has an average salinity less than 11 ppt; Zone 2 has an average salinity between 11 and 15 ppt; and Zone 3 has salinities greater than 15 ppt[84]. Salinity zones were developed to be broad, general categories and some sanctuaries may fluctuate between salinity zones given weather patterns.

Using data collected by the Maryland Department of Environment Shellfish and Fish Monitoring Division, monthly surface salinity data collected at 227 sites (mostly over oyster bars) baywide from 2006 to 2020 was used to classify sanctuaries into different salinity zones. Although bottom salinity would be more appropriate to use to classify salinity zones for oysters, surface salinity datasets had greater spatial and temporal coverage.

Sanctuaries within Zone 1 (22 sanctuaries and 119,186 surface acres) were chosen to increase oyster biomass through stocking and long-term survival. Oysters within Zone 1 are characterized by having lower levels of disease and better survival, but low reproductive capability[85]. Oysters are also subject to intermittent freshets that can result in substantial mortality.

Sanctuaries within Zone 2 (25 sanctuaries and 115,470 surface acres) represent transition areas incorporating the goals of Zones 1 and 3. Oyster located in Zone 2 may have fluctuating characteristics based on the climatic variation between wet and dry years[86]. Annual spat settlement can range from low to moderate to high based on salinity. Mortality related to disease can also fluctuate from year to year. In years with low disease-caused mortality, the oyster populations in this area can recover as long as there is also successful recruitment. However, the reverse can also occur.

Sanctuaries within Zone 3 (4 sanctuaries and 18,351 surface acres) were chosen to attempt to foster disease resistance and enhance reproduction. Oysters in this zone have been subjected to heavy disease pressures, which historically resulted in high mortality[87]. In Zone 3, there are also high recruitment rates that provide a fairly constant influx of new oysters.

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[83] As charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments
[84] Maryland Department of Natural Resources. 2019. Oyster Management Plan. 93 pp. dnr.maryland.gov/fisheries/Documents/MD_Oyster_FMP-2019.pdf
[85] IBID
[86] IBID
[87] IBID

Oyster sanctuaries are distributed across all salinity zones in Maryland's portion of Chesapeake Bay. Based on historic oyster bottom[88], approximately 30% of sanctuary area is located in low salinity (Zone 1), 56% in medium salinity (Zone 2), and 15% in high-salinity areas (Zone 3) (Table 4-1)[89].

Oyster population growth and survival are driven primarily by the amount of spat settlement (reproduction) and by the mortality rate, which in turn are strongly influenced by the prevailing salinity of the area (Figure 4-8). If the rate of spat settlement on a bar is greater than the mortality rate, the population should increase – provided that shell or other hard substrate is not lost or removed.

Presence of shell or hard substrate is a very important component of oyster habitat for spat settlement (Powell et al. 2006)[90]. Along with spatfall and natural mortality, the ability for shell to accumulate on a reef will depend on the interaction of reef height and sedimentation at the location. For reefs to accrete vertically or expand laterally, the addition of shell must exceed shell loss from all sources (e.g., fouling, sedimentation, burial, dissolution, removal through harvesting). Due to the addition and loss of shell depends on many of the same factors as population growth (recruitment, individual growth, boring organisms, mortality) as well as abiotic factors (e.g., dissolution), salinity plays a significant role in reef growth as well. In harvest areas, the ability for shell to accrete will also depend on gear type, effort, and harvest history.

Table 4-1. Sanctuary acres located in each salinity zone.

Salinity Zone With salinity range in parts per thousand (ppt)	Total Surface Acres	% Acres	Total Historic Oyster Bottom Acres*	% Acres
Low (< 11 ppt)	119,186	47%	23,372	29.6%
Medium (11-15 ppt)	115,470	46%	44,087	55.8%
High (> 15 ppt)	18,351	7%	11,502	14.6%

* Historic oyster bottom as charted in the Yates Oyster Survey of 1906 to 1912 and its amendments.

88 As charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments

89 Note: These values differ from the ones reported in the 2010-2015 Oyster Management Review Report published in 2016 by the department. For the previous analyses, only two average rainfall years were used to assess salinity levels in sanctuaries. Using this expanded dataset should be a more accurate representation of the sanctuaries over a longer time period.

90 Powell, E. N., J. N. Kraeuter & K. A. Ashton-Alcox. 2006. How long does oyster shell last on an oyster reef? Estuaries and Coastal. Shelf Science 69:531–542

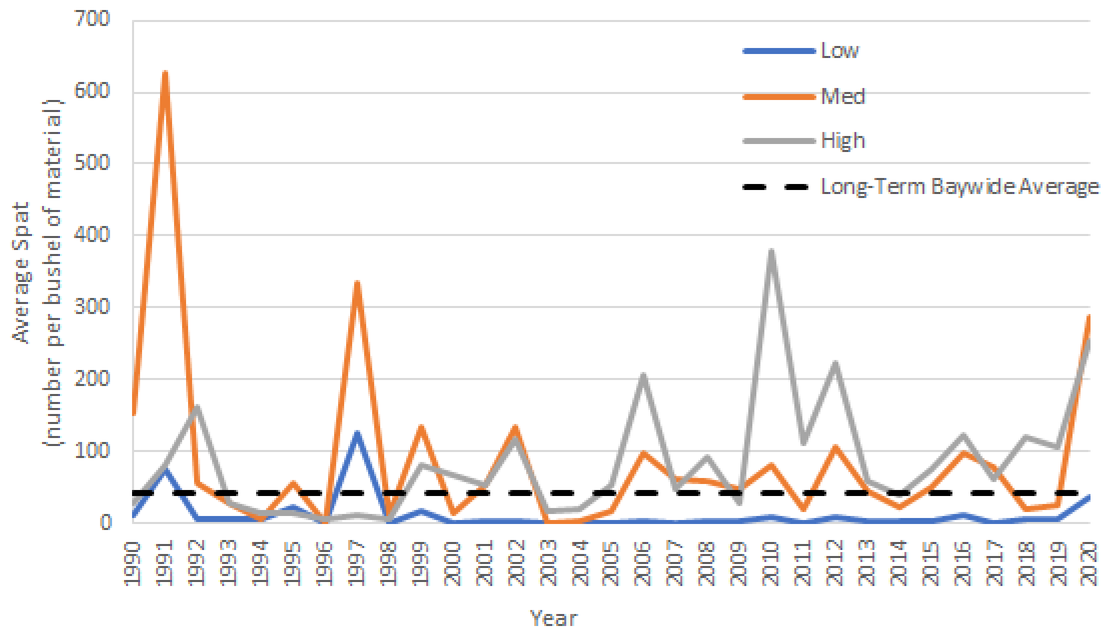

Figure 4-8. Data from sanctuary areas sampled by the Fall Survey showing the average number of spat per bushel over the 30-year time series for low, medium and high-salinity zones where low salinity < 11 ppt, medium salinity 11 to 15 ppt, and high salinity > 15 ppt. Fall Survey samples taken on hatchery spat-on-shell or wild seed plantings were removed.

The oyster sanctuaries are distributed throughout Maryland waters to serve different purposes according to their salinity zone. The sanctuaries provide ecological benefits specific to their particular salinity zones, such as accommodating salinity-restricted organisms (e.g., habitat for redbeard sponge *Microciona prolifera* in high-salinity Tangier Sound, habitat for dark false mussels *Mytilopsis leucophaeata* in the fresher upper reaches of the bay and tributaries). Oysters in lower salinity areas have higher survival rates,which enhances their ecological benefit – more oysters remain alive and for a longer period of time. Medium and high-salinity sanctuaries serve as broodstock reservoirs and disease-resistant populations may naturally develop there.

Locating sanctuaries over the full range of salinity zones may help lessen the effects of catastrophic weather events to the sanctuary network as a whole. For example, should a low-salinity population be devastated by a freshet, the higher salinity areas would still be intact and may aid in the recovery as an ample source of oysters for transplanting or by supplying larvae to eventually repopulate the area. Over time, sanctuaries located in diverse salinity zones will allow us to observe the interplay between changes in salinity and oyster survival and growth.

Section 4.1.6: Sanctuary Objective #6

Increase our [the department's] ability to protect these important areas from poaching

Sanctuary Objective #6 Status: *This objective is being met. The ability to protect sanctuaries from poaching has been maintained by the designation of large sanctuary areas, implementation of the Maryland Law Enforcement Information Network (MLEIN) monitoring system, and the department's ability to suspend and revoke licenses administratively. The increase in uniformed Natural Resource Police officers and the return of the department's aviation unit have further bolstered the department's ability to protect sanctuaries from poaching.*

Building off of the improvements in protecting sanctuaries from poaching realized from 2010 to 2015 through larger sanctuary areas, MLEIN, and increased penalties for poaching in sanctuaries, the department both maintained and improved those gains from 2016 to 2020. Small sanctuaries in isolated areas or located within or in close proximity to a harvest area are more difficult to enforce than larger sanctuaries that include the interconnecting non-oyster habitat bottom between oyster bars. In 2010, many of the new sanctuaries followed this design by encompassing the entire or large parts of tributaries. MLEIN was created in 2010, and consists of radar monitoring, video surveillance, and advanced software that allows NRP to improve enforcement of sanctuaries. Over the last five years, NRP has further increased its use of MLEIN to monitor activity within the sanctuary network. Additionally, NRP's aviation unit was reestablished in November 2016. Having an operational aviation unit has contributed greatly to the department's ability to monitor and enforce conservation laws within the state and a number of cases have been made as a direct result of the presence of the aviation unit.

Another factor that may have decreased poaching was the department's ability to suspend or revoke licenses administratively. In 2010, under the authority of Natural Resources Article, §4-701, Annotated Code of Maryland, the department revised its penalty system to assign points to a licensee's licensing record based on being convicted of certain individual offenses, with more points resulting in more significant suspensions and ultimately permanent revocation from the commercial fishery. Also, in 2011 the department was given the ability to revoke an oyster authorization on issuance of a citation for certain oyster violations, including being inside of an oyster sanctuary by more than 200 feet under Natural Resources Article, §4-1210, Annotated Code of Maryland. This authority allowed the department to take certain egregious offenders off the water more quickly than the points system, which requires a conviction in criminal court and may be delayed by months after the offense. The current suspension and revocation system is designed to act as a deterrent to criminal activities such as poaching in sanctuaries.

Table 4-2 below shows the number of citations issued and administrative penalties levied for sanctuary violations by year. The number of administrative penalties does not always align with the number of citations because administrative penalties generally follow a legal process that may take them into a subsequent year from the violation. Nonetheless, the decline in citations, suspensions and revocations over this time period suggests that fewer individuals are poaching in sanctuaries. Furthermore, while exact patrol numbers are not available, the number of NRP uniformed officers has increased from 221 in 2010 to 231 in 2015 to 270 in 2020, so the decline in violations could correspond to having more officers on the water.

Table 4-2. The number of license revocations and suspensions under Natural Resources Article §4-1210 and NR §4-701, and citations regarding sanctuary violations from 2010 to 2020.

Year	NR §4-1210 Revocation	NR §4-701 (Points) Revocation	NR §4-701 (Points) Suspension	Citations Issued for Sanctuary Violations
2010	N/A	0	1	1
2011	0	0	4	2
2012	0	1	0	0
2013	2	1	0	5
2014	1	0	0	4
2015	0	1	0	10
2016	3	1	0	12
2017	0	0	3	4
2018	2	0	0	0
2019	0	0	1	0
2020	0	0	0	0

Section 4.2: Public Shellfish Fishery Areas

To assess overall trends, PSFAs are grouped into areas called NOAA Code areas because Fall Survey data provide excellent resolution for the 39 NOAA Codes, but not for the 176 individual PSFAs. The NOAA Codes also represent the spatial units used by DNR and the oyster industry to report harvest. Each NOAA Code area may contain multiple PSFAs. Of the 39 NOAA Code areas, 31 encompass PSFAs that have been consistently monitored by the Fall Survey since at least 1990. Fall Survey data used to characterize the productivity of NOAA Codes were collected only in current non-sanctuary areas within the NOAA Code. Data collected in sanctuary areas within the NOAA Codes were not included. Appendix B provides details on each individual NOAA Code.

As in sanctuaries, oyster mortality has remained stable and below the long-term baywide average in NOAA Codes since 2010 when the sanctuaries were created (Figure 4-9).

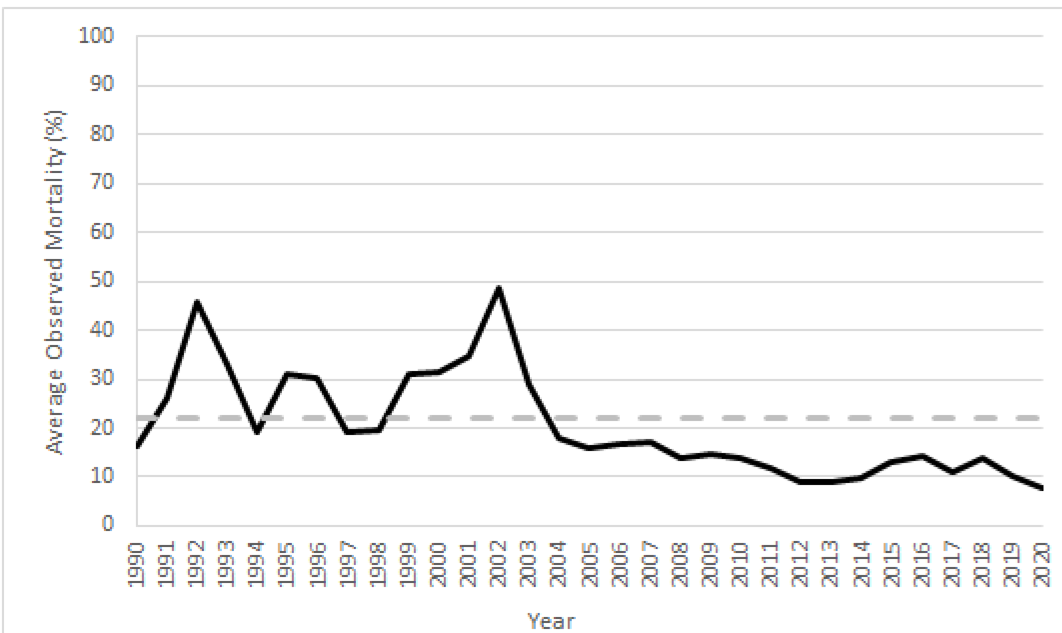

Figure 4-9. Estimated average observed mortality from the Fall Survey for oyster bars located within current non-sanctuary area in Maryland’s portion of Chesapeake Bay, 1990-2020. The dotted line represents the long-term baywide average.

Estimated biomass has been calculated since 1990 for 19 of the 39 in the NOAA Codes on 27 different oyster bars. The bars and their NOAA Code include: Swan Point (025), Stone (027), Bugby (039), Hollicuts Noose (039), Parsons Island (039), Goose Creek (053), Norman Addition 1 (047), Ragged Point (053), Turtleback (060), Marumsco (072), Chicken Cock (078), Hackett

Point (127), Buoy Rock (131), Lighthouse (137), Royston (137), Back Cove (192), Hollands Straits East (192), Old Womans Leg (192), Piney Island East (192), Butler (229), Hog Island (229), Lancaster (274), Mills West (274), Sharkfin Shoal (292), Broome Island (368), Tilghman Wharf (437), and Deep Neck (537).

Some NOAA Codes have multiple bars that were sampled for biomass. Overall biomass increased from 2010 to 2013, then decreased in 2014, and started increasing again in 2017 (Figure 4-10). From 2012 to 2015 and after 2018, the average biomass in fished areas has been above the long-term baywide average (all oyster bars measured consistently for biomass from 1990-2020). Biomass trends in NOAA Code harvest areas is somewhat different than what was observed in sanctuaries where biomass has consistently remained above the long-term average since 2011.

There can be annual variation in biomass within the fished areas between different salinity zones. (Figure 4-11). In recent years, average biomass has been higher in medium-salinity areas than in high-salinity areas. As biomass is a function of both size and abundance, this is likely due to higher harvest in the high-salinity areas, which removes the larger oysters. These results differ from sanctuaries whereas the high-salinity sanctuaries have higher biomass than low and medium sanctuaries.

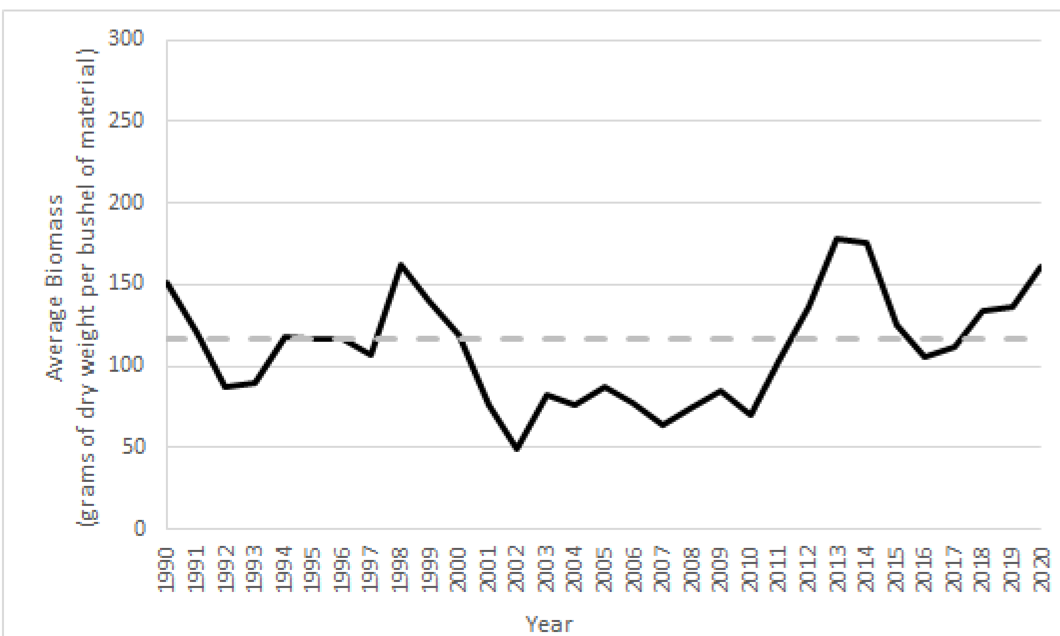

Figure 4-10. Estimated average biomass index from the Fall Survey for 27 oyster bars located within 19 NOAA Code harvest reporting areas in Maryland’s portion of Chesapeake Bay, 1990-2020. The dotted line represents the long-term baywide average.

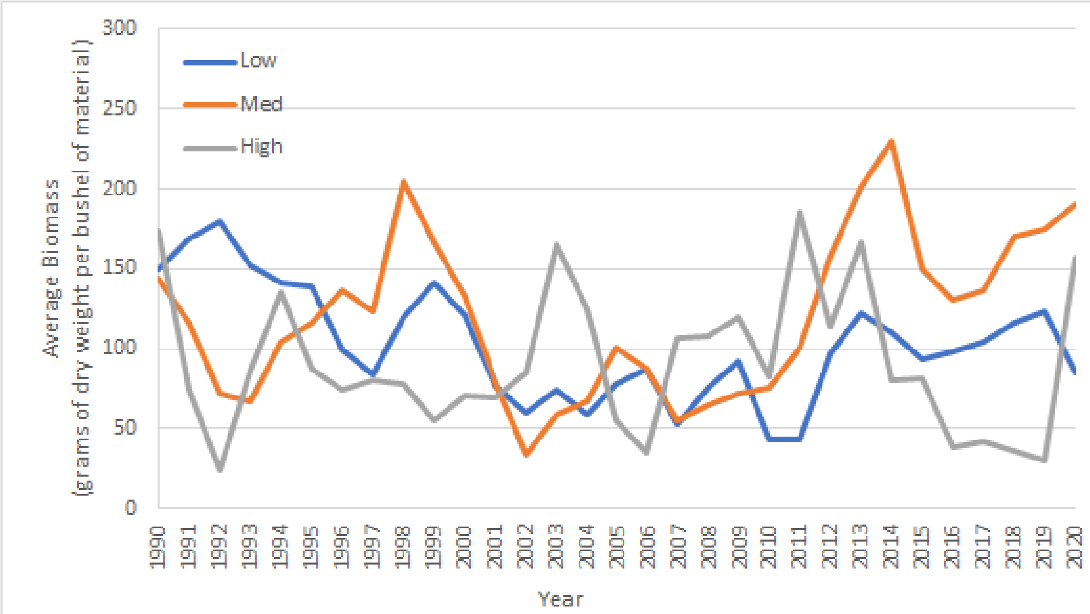

Figure 4-11. Estimated average biomass index for each salinity zone from the Fall Survey for 27 oyster bars located within 19 NOAA Code harvest reporting areas in Maryland's portion of Chesapeake Bay, 1990-2020. Low-, medium-, and high-salinity zones are defined as: low salinity < 11 ppt, medium salinity 11 to 15 ppt, and high salinity > 15 ppt.

Oyster harvest has varied over the years since 1990 (see Appendix B). Droughts increased disease-related mortality, but higher salinity has also increased spatsets. Freshets have caused decreased spatsets, but also lower disease-related mortality overall, however some localized mortality has occurred due to the freshets. Since the current management areas have been in place since 2010, harvest increased during the 2012-13 to 2015-16 seasons due to above average spatsets in 2010 and 2012 coupled with good survival (Figure 4-12). Harvest declined after then until the 2019-20 harvest season.

Approximately 80% of the harvest from the 2010-11 to 2019-20 harvest season came from 10 of the 39 NOAA Codes (Figure 4-13). Broad Creek (537) and northern Tangier Sound (292) had the highest harvest reports. Other NOAA Codes in the lower eastern shore region, including Fishing Bay (043), southern Tangier Sound (192), Pocomoke Sound (072) and Honga River (047) also had high harvest. Lower Choptank River (139) and Eastern Bay (039) on the Eastern Shore also had higher harvest. On the western shore, the lower Patuxent River (168) and St. Marys River (078) were high harvest areas.

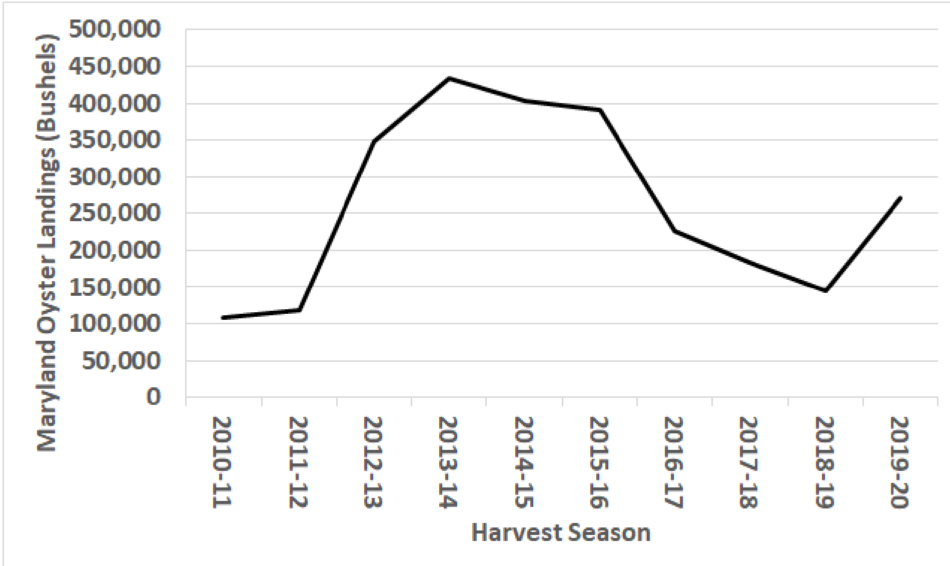

Figure 4-12. Commercial fishery oyster landings in Maryland from the 2010-11 season to the 2019-20 season as reported on seafood dealer buy tickets.

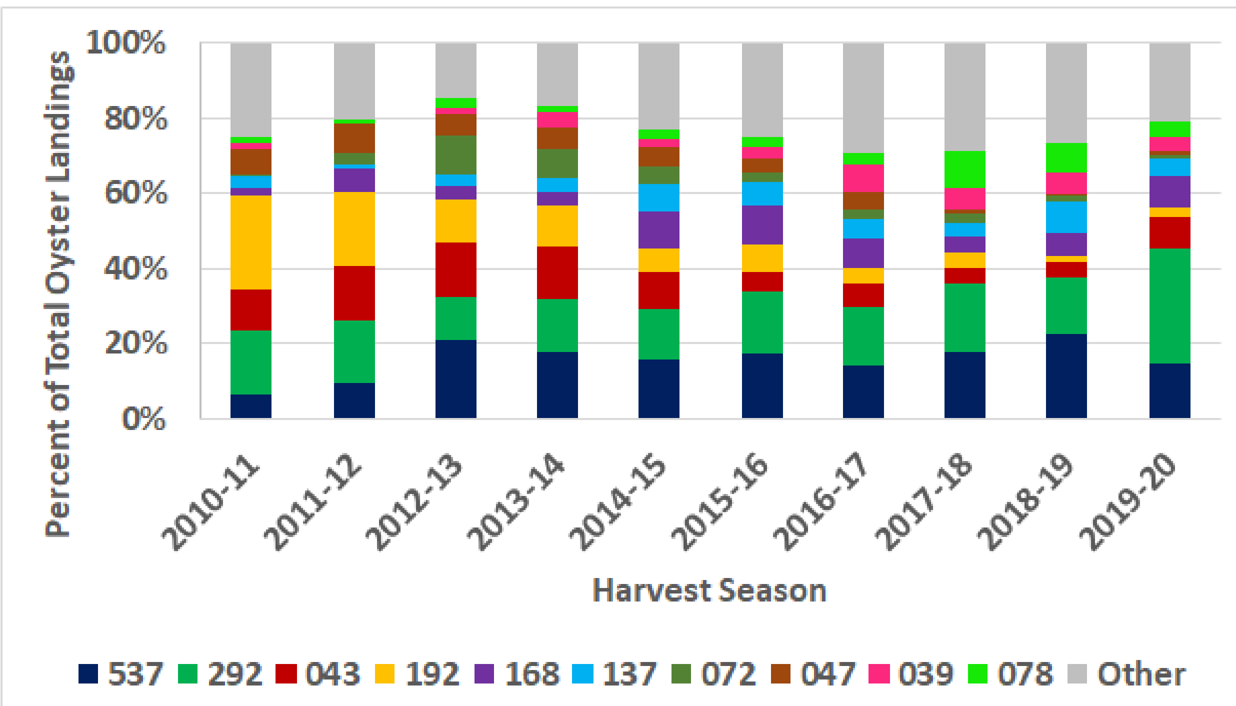

Figure 4-13. Percent of commercial fishery oyster landings by reporting area (NOAA Code) in Maryland from the 2010-11 season to the 2019-20 season as reported on seafood dealer buy tickets.

Section 4.2.1: Public Shellfish Fishery Area Objective #1
Retain 168,000 acres of natural oyster bars including 76% (27,000 acres) of the remaining 36,000 acres of remaining productive oyster habitat identified in the Programmatic Environmental Impact Statement (PEIS)

Public Shellfish Fishery Area Objective #1 Status: *This objective is met. 175,836 surface acres were classified as Public Shellfish Fishery Areas (PSFAs) where aquaculture is prohibited.*

This objective is met. In 2020, 175,836[91] surface acres were classified as PSFAs where aquaculture is prohibited, exceeding the mandated 168,000 acre target. Additionally, 27,477 acres or 76% of the remaining productive oyster bottom is currently located in areas where commercial harvest of oysters is allowed. PSFAs were identified based on feedback from the oyster industry representatives, seafood dealer buy tickets, and bar-specific harvest reports submitted for the 2009-2010 oyster season. A PSFA or portion of PSFA can be declassified in order to allow leasing only when oyster density on the proposed lease area is less than one oyster per square meter. Between 2010 and 2020, 204 acres have been declassified as a PSFA at the request through lease applications whereas a departmental population survey found less than one oyster per square meter.

[91] In the previous Five Year Oyster Review Report (2010-2015), PSFA surface acres were reported as 179,943. This value has changed due primarily to a typo (overstatement of acreage) in the original report, but also because of various housekeeping corrections to certain PSFA boundaries, declassifications and additions. The acreage of PSFAs will continue to change going forward, as there is an ongoing analysis being conducted to update the shoreline GIS layer, along with an expectation of future declassifications and/or additions.

Section 4.2.2: Public Shellfish Fishery Area Objective #2
Include half of Maryland's consistently most productive oyster grounds (Jones and Rothschild 2009) for the benefit of licensed oystermen

Public Shellfish Fishery Area Objective #2 Status: *This objective is being met. Based on the number of 2009 'best bars' and since sanctuary boundaries have not changed since 2010, more than half (71%) of the bars are still located outside sanctuary boundaries and are open to harvest. Based on the total acres of historic oyster bottom of 'best bars', 74% of the acres are located outside sanctuary boundaries and are open to harvest.*

This objective is met. In 2010, an analysis of 'best bars' was used to establish sanctuary boundaries and 50% of the 'best bars' were within PSFAs. Of the 17 'best bars' in Jones and Rothschild 2009[92], seven are located completely within PSFAs. Five other 'best bars' are located partially within PSFAs (Appendix C, Table C-4A). Thus, 71% of the 2009 'best bars' have either all or some of their acreage located in PSFAs. Due to this some of these bars also have acreage in sanctuaries, 59% of the 2009 'best bars' are located in sanctuaries.

When considering the total acreage of historic oyster bottom encompassed by 'best bars', 74% is located outside sanctuary boundaries and is open to harvest. Historic oyster bottom refers to oyster bars charted by the Yates Survey (1906 to 1912)[93] and its amendments. It should be noted, however, that the historic oyster bottom does not necessarily represent current viable oyster reefs with oysters and substrate. As estimated in the PEIS (2009), only 36,000 acres of the historic oyster bottom is viable today[94].

The productivity of bars can change over time, thus using current data is more appropriate to determine if this objective is still being met relative to the 2009 results. Furthermore, a productive bar should not only consistently contain high numbers of market oysters as Jones and Rothschild stated, but also have good recruitment - consistently high numbers of smalls and spat - and have relatively low mortality to ensure that spat and small oysters survive to become market-sized.

If this objective was rewritten to remove citing the Jones and Rothschild 2009 analysis to define productive oyster bottom, the analysis presented in Appendix C could be used to determine if this objective is being met now. Based on Appendix C Table C-5 that uses an expanded data set from 2009-2018, 15 of the 26 bars have all or some portion of historic oyster bottom[95] outside of sanctuaries (58%). Conversely, 13 of the 26 bars have all or some portion of historic oyster bottom within sanctuaries (50%). Due to this, some of these bars have acres in both sanctuaries

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[92] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf

[93] Yates, Charles. 1913. Survey of Oyster Bars of Maryland 1906 to 1912. biodiversitylibrary.org/item/96740

[94] U.S. Army Corps of Engineers, Norfolk District. 2009. Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster. dnr.maryland.gov/fisheries/Pages/eis.aspx

[95] Historic oyster bottom as charted in the Yates Oyster Survey of 1906 to 1912 and its amendments.

and PSFAs, some bars can be counted twice. When considering acreage of the updated list of ‘best bars’ from 2009-2018, 6,976 acres (61%) are within PSFAs.

To determine if this objective was met using the updated, more recent, ‘best bars’ analysis, all bars were used regardless of whether or not they were planted with oysters and shell. Bars can become productive oyster bottom through management actions such as adding oysters through replenishment plantings in PSFAs. Given that a ‘best bar’ should have high counts of all size classes of oysters, a bar with a one-time planting of oysters would not be expected to be a ‘best bar,’ especially if it is located in an area with known low to no natural recruitment. However, a bar may become a ‘best bar’ by boosting an existing oyster population through multiple plantings, planting oysters and/or cultch in areas where there is known recruitment, and/or tributary-scale plantings on multiple bars within the same time period. Some bars have received significant plantings through replenishment efforts throughout 2009-2018 in PSFAs.

Broad Creek, a tributary of Choptank River, had seven ‘best bars’ based on the recent analysis. This region tends to have a relatively high spatset and survival. Other regions within PSFAs that had ‘best bars’ included lower Choptank River (one bar), Fishing Bay (one bar), Harris Creek (two bars), Manokin River (two bars), Pocomoke Sound (two bars), and Tangier Sound (one bar). The two bars in the Manokin River have the majority of their acreage in Manokin Sanctuary (Drum Point, 92% of acreage. Mine Creek, 80% of acreage) and the Fall Survey samples are located within the sanctuary. Based on the methodology of the more recent ‘best bars’ analysis, a rank is given to a bar as a whole and it is assumed to be a consistent rank across the bar acreage. However, if it was determined that the portion of these bars outside of the sanctuary boundary would have ranked lower than the portion inside the sanctuary, the number of ‘best bars’ would decrease to 13 out of 26 (50%).

Due to the fact that either the amount and/or location of plantings can change over time, the ‘best bars’ analysis should not remain static. Instead this analysis should be updated frequently to monitor both natural changes and impacts from human manipulation. This would require amending the preamble of the existing regulation.

Section 4.2.3: Public Shellfish Fishery Area Objective #3

Maintain a more targeted and scientifically managed public oyster fishery

Public Shellfish Fishery Area Objective #3 Status: *This objective is being met. A Maryland oyster stock assessment has been developed and harvest rules for the oyster season are being developed annually based on the fishing levels and abundance relative to the biological reference points.*

The first Maryland oyster stock assessment was completed in December 2018 by the department and UMCES[96]. The assessment developed an oyster population model and biological reference points based on the biological characteristics of the oyster population and other appropriate factors affecting the population such as harvest.

The stock assessment used a stage-structured model to estimate abundance and fishing rates as well as a model with linked shell and population dynamics to develop sustainable fishing reference points to guide fishery management. The stage-structured model integrated several data sources, including oyster buy ticket data, the Fall Dredge Oyster Survey, oyster and shell planting data, bottom mapping data, and the patent tong survey. The results of the stage-structured model were used to estimate sustainable fishing mortality and abundance reference points. An independent peer review panel concluded that the results from the assessment can serve as an adequate basis for management decisions.

In 2020, an update stock assessment was conducted. The results concluded:

- Market abundance - 453 million in 2019, the fifth highest in the time series (1999-2019). Highest in the Choptank River and Tangier regions. Market-sized oysters are greater than three inches in size which could be legally harvested.
- Small abundance - 433 million in 2019, which is slightly below the long-term mean of 480 million. Highest in the Choptank River and Tangier regions. Small-sized oysters one year old or older and less than three inches in size and are not legally harvestable.
- Spat abundance - 284 million in 2019, the sixth lowest in the time series (1999-2019). Highest in the Choptank River and Tangier regions. Spat are oysters less than one year old.
- Harvest fraction - 75% of areas decreased the harvest fraction (amount of oyster harvested compared to the total amount of oysters) between terminal years in the two assessments (2017, and 2019).
- Overfishing status - Showing progress from the prior assessment, the number of NOAA Codes above the upper limit fishing mortality reference point declined from 18 in the terminal year in the last assessment (2017) to five (lower Choptank, Broad Creek, north and sound Tangier Sound, and Wicomico River east) in 2019, while the number of NOAA Codes at or below the target fishing mortality reference point increased from 15 to 25.

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[96] Maryland Oyster Stock Assessment dnr.maryland.gov/fisheries/Pages/oysters/Oyster_Stock_Assess.aspx

- Depleted status - Three NOAA Codes (Severn, lower Chester, and upper Chester) were below the lower limit abundance reference point (depleted abundance) most likely due to environmental causes since these areas include sanctuaries (69%, 98% and 100% of lower Chester, Severn and upper Chester, respectively, are sanctuary areas) and these codes were not estimated to be experiencing overfishing in the last two years.

An update to the stock assessment will be conducted at least every two years and a benchmark stock assessment every six years. This is consistent with both the 2019 Oyster Management Plan [97] and Chapter 9 Senate Bill 830[98] enacted in 2020. The Oyster Management Plan[99] states its objective is to manage the oyster fishery according to science-based biological reference points through harvest rates that are based on oyster stock assessments. The goal is to maintain fishing levels that are consistently around the target within eight to 10 years.

In addition to the stock assessment, an oyster consensus process was initiated through the OAC [100]. The final product of the consensus process in December 2021 will be a package of recommendations for enhancing and implementing the fishery management plan for oysters. The recommendations will be informed by a collaboratively developed, science-based modeling tool to quantify the long-term impacts of identified management actions and possible combinations of management actions on oyster abundance, habitat, harvest, harvest revenue and nitrogen removal.

[97] Maryland Department of Natural Resources. 2019. Maryland Chesapeake Bay Oyster Management Plan. 93 pages. dnr.maryland.gov/fisheries/Documents/MD_Oyster_FMP-2019.pdf
[98] Md. Code Ann., Nat. Rec. §4-215 (2017) dnr.maryland.gov/fisheries/Documents/4-215_w2017_changes_April_2021.pdf
[99] Maryland Department of Natural Resources. 2019. Maryland Chesapeake Bay Oyster Management Plan. 93 pages. dnr.maryland.gov/fisheries/Documents/MD_Oyster_FMP-2019.pdf
[100] OAC. dnr.maryland.gov/fisheries/Pages/mgmt-committees/oac-index.aspx

Section 4.3: Aquaculture Areas

As of the end of 2020 there were a total of 468 leases on 7,593 acres in Maryland. Since 2010, the number of annual lease applications has varied from year-to-year, ranging from 16 to 74 with a total of 575 applications received by the department since the new leasing program was implemented in 2010. (Table 4-3).

The majority of the current leases are in St. Mary's, Dorchester, Talbot, and Wicomico counties (Table 4-4). Throughout all the counties, bottom leases account for 78% of all leases and 92% of the leased acreage. A submerged land lease (also called a bottom lease) is issued when the grower proposes to plant shell and spat-on-shell directly on the bottom. A water column lease is issued to a grower that proposes to raise shellfish in some type of container (floats and/or cages) within the water column. Water column leases account for 22% of all leases and 8% of the leased acreage.

As of 2020, 127 leases (2,851 acres) are located within oyster sanctuary areas where no public fishery for commercial oysters is allowed (Table 4-5). This accounts for 27% of all leases (37% of all leased acreage). The acreage of leases within sanctuaries occupies 1% of the total sanctuary surface area.

Table 4-3. Number of new oyster leases issued from 2010 to 2020 in Maryland.					
Year	**All Lease Applications Submitted**	**Submerged Land Leases Executed**	**Water Column Leases Executed**	**Applications Processed as Lease Amendments**	**All New Leases Issued**
2010	47	0	0	0	0
2011	67	10	14	0	24
2012	71	8	19	0	27
2013	27	28	12	0	40
2014	64	7	15	0	22
2015	62	13	43	0	56
2016	53	28	10	1	38
2017	74	18	13	2	31
2018	51	21	13	2	34
2019	43	21	18	3	39
2020	16	13	3	5	16
Total	575	167	160	13	327

Table 4-4. Number of oyster leases and acreage as of the end of 2020 for each Maryland county.

County	Number of Leases			Leased Acreage		
	Bottom Leases	Water Column Leases	Total	Bottom Leases	Water Column Leases	Total
Anne Arundel	24	3	24	370.05	9.2	379.25
Calvert	13	6	19	142.2	35.8	178
Charles	5	1	6	88.6	7.9	96.5
Dorchester	89	28	117	2,672	199.45	2,871.45
Kent	1	1	2	44.8	4.9	49.7
Queen Anne's	2	4	6	20.4	3.71	24.11
St. Marys	80	31	111	766.33	200.54	966.87
Somerset	38	5	43	1,072	19.7	1,091.7
Talbot	65	10	75	699.89	40.3	740.19
Wicomico	47	0	47	1,127.4	0	1,127.4
Worcester	2	13	15	15.2	52.9	68.1
Total	366	102	468	7,018.87	574.40	7,593.27

Table 4-5. Number of aquaculture leases and leased acreage located in Maryland oyster sanctuaries from 2010 to 2020.		
Year	**Number of Leases**	**Leased Acreage**
2010	118	1,409
2011	100	1,213
2012	71	868
2013	62	797
2014	67	836
2015	70	1,016
2016	90	2,271
2017	103	2,595
2018	110	2,654
2019	120	2,737
2020	127	2,851

Section 4.3.1: Aquaculture Objective #1

Streamline the regulatory process for aquaculture

Aquaculture Objective #1 Status: *This objective is met. Legislation passed in 2009 removed many impediments to shellfish aquaculture in Maryland and streamlined the regulatory process. The department continues to work internally and with the Aquaculture Coordinating Council and Maryland General Assembly to identify and implement legislative and regulatory changes intended to facilitate existing aquaculture industry operations and new business development. In addition, the department actively works with the U.S. Army Corps of Engineers, Baltimore District to assist this agency in developing methods needed to streamline the federal permitting process for Maryland shellfish aquaculture.*

This objective is met. In 2009, the Maryland General Assembly unanimously passed a new lease law[101]. This law removed many of the impediments to shellfish aquaculture development, lifted county moratoria on leasing bottom for growing oysters, removed lease size limitations, provided that leases could be issued to corporations, and established a requirement for leases to be actively used for commercial shellfish aquaculture purposes. It set the stage for creating an infrastructure to support shellfish aquaculture development.

In July 2011, the Maryland General Assembly passed additional legislation to streamline the permitting process for aquaculture by consolidating the state authority for shellfish aquaculture permitting within the department. This legislation granted the department the authority for issuing leases and permits for all types of shellfish aquaculture, including bottom and water column leases. In response to this legislation, the department dedicated resources to implementing the new leasing program and streamlining the permitting process by establishing the Aquaculture and Industry Enhancement Division.

The department continues to work with the Aquaculture Coordinating Council and the U.S. Army Corps of Engineers Baltimore District to streamline the permitting process for shellfish aquaculture. In 2018, the department was provided with statutory authority to issue permits for Shellfish Nursery facilities on land and in tidal waters. In 2019, these facilities, as permitted by the department, were exempted in law from also having to obtain a Tidal Wetlands License or Board of Public Works approval for equipment being used on piers/docks. Also in 2019, the department worked with the Corps of Engineers to plan for and implement changes to the lease application process, which provides completed lease applications to the Corps early in the review process and has resulted in faster turnaround in the review and approval of federal permits.

[101] SB 271, Chapter Number 173, 2009 mgaleg.maryland.gov/webmga/frmMain.aspx?tab=subject3&ys=2009rs/billfile/sb0271.htm

Section 4.3.2: Aquaculture Objective #2

Open new areas to leasing to promote shellfish aquaculture industry growth

Aquaculture Objective #2 Status: *This objective is met. The 2009 Lease Law[102] opened thousands of acres for shellfish aquaculture leasing.*

This objective is met. One of the provisions established in the new lease law removed moratoria on leasing within specific counties. Lifting the county moratoriums opened thousands of acres to leasing that previously could not be leased.

The 2009 lease law[103] also requires leaseholders to actively plant and use a portion of their leases on an annual basis or return the lease to the state. In response to this requirement, many inactive leases reverted back to the state and this acreage has been made available to others interested in leasing. Through the period 2015-2020, the annual total acreage of active leases increased from 3,998 to 7,593 acres. This represents nearly a 53% increase in total lease acreage.

[102] SB 271, Chapter Number 173, 2009 mgaleg.maryland.gov/webmga/frmMain.aspx?tab=subject3&ys=2009rs/billfile/sb0271.htm
[103] IBID

Section 4.3.3: Aquaculture Objective #3

Provide alternative economic opportunities for watermen

Aquaculture Objective #3 Status: *This objective is met. Maryland commercial oyster harvesters are benefiting from economic opportunities provided by aquaculture. Nearly 50% of leaseholders are commercial licensed oyster harvesters in Maryland's public fishery who are now investing in shellfish aquaculture.*

This objective is met. Maryland oyster harvesters are benefiting from economic opportunities provided by aquaculture. In 2020, there were 178 distinct individuals or companies holding leases and DNR had permitted 509 distinct individuals to work on 468 leases. Approximately 45% of leaseholders are commercially licensed oyster harvesters in Maryland's public fisheries who are also investing in shellfish aquaculture (Table 4-6).

Table 4-6. Percent of lease holders that are commercial licensed oyster harvesters in Maryland's public commercial fisheries.

Year	Percent	Year	Percent
2011	No Data	2016	52.7
2012	54.0	2017	51.2
2013	53.4	2018	48.5
2014	54.0	2019	45.5
2015	49.1	2020	45.1

Starting in 2012, the department began requiring lease holders to report their harvest from leases. Prior to this, harvest from aquaculture leases was estimated to be 1.75% of the total harvest (ranging from 0% to 3.78% annually). Harvests from leases increased steadily through the period 2012-2017. Harvest has declined over the period 2018-2020 due to poor environmental conditions (excess rainfall) in 2018 and 2019, and the unfortunate loss of oyster markets in 2020 brought on by the COVID-19 pandemic (Figure 4-14).

During the 2019 calendar year, aquaculture production accounted for 20% of the total oyster harvest. Harvest from submerged land leases accounted for 54% of the total aquaculture harvest in 2019 (29,850 bushels) even though 80% of the active leases were bottom leases. Harvest is highest in the months of April and May as this time period falls just outside of the public oyster fishery, which is open from October 1 to March 31. In 2019, the average wholesale/dockside price per bushel was $55 and the average wholesale/dockside price per individual oyster sold was $0.50. During the 2018-2019 public oyster season, the average price paid per bushel caught by the public fishery was $44.

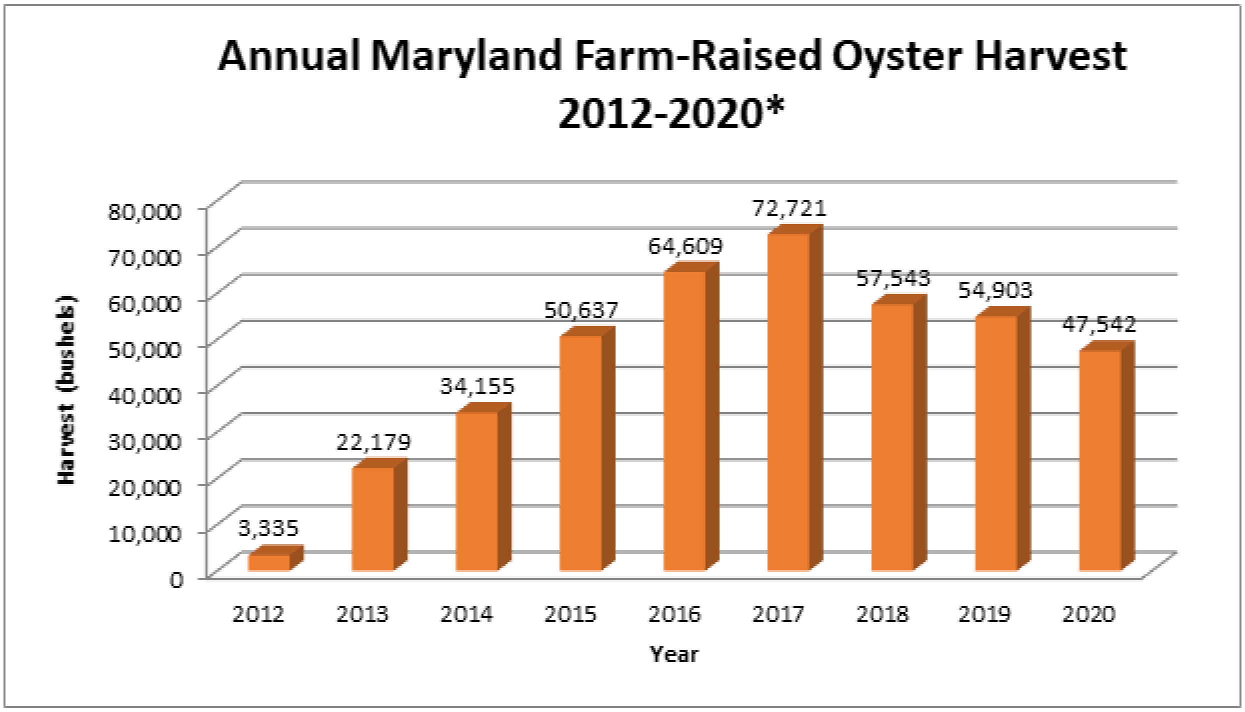

Figure 4-14. Total annual oyster harvest (bushels) by Maryland aquaculture leases. The 2020 bushels harvested is still a preliminary value as the data still needs to have quality assurance - quality control analysis performed.

Section 5: Conclusions and Recommendations

In recent years, oyster populations throughout Maryland, whether in fished or sanctuary areas, have benefited from low disease mortality and three good years of reproduction (spatfall) in 2010, 2012, and 2020. However, the 2018-2019 freshet did hinder reproduction, and in some areas, caused increased mortality. Yet, the strong spat set in 2020 was the 3rd highest since 1985, and has the potential to enhance both fishery and sanctuary areas if the spat survive and grow. Oyster biomass has generally increased in Maryland over the last decade (Figure 5-1).

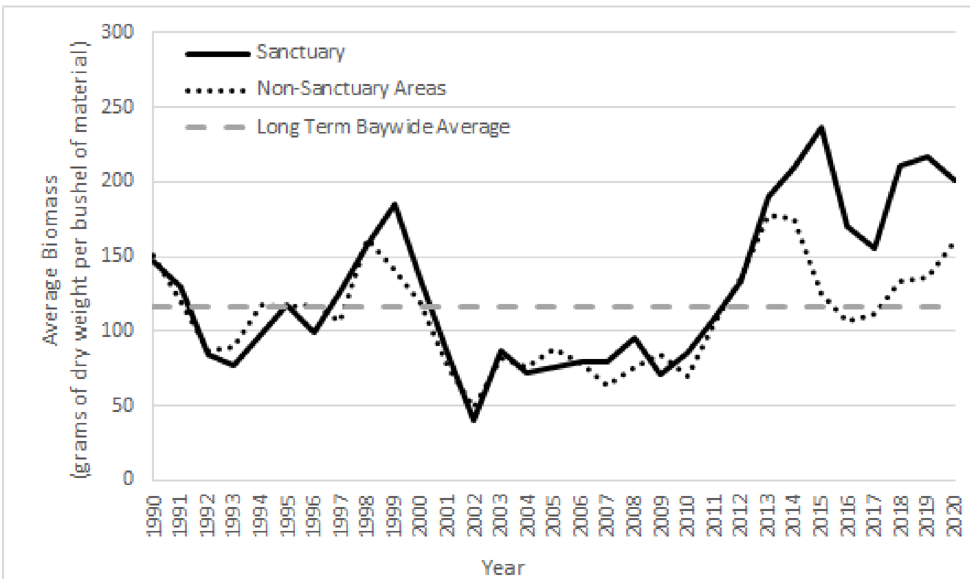

Figure 5-1. Average oyster biomass in grams of dry weight per bushel of material for bars inside and outside the 2010 sanctuary boundary in Maryland's portion of Chesapeake Bay.

Given the complexity and interannual variability of the Chesapeake Bay ecosystem, 10 years may not be long enough to demonstrate how oyster populations respond to the absence of harvest. Furthermore, the 100-year freshet in 2018-2019 lowered salinity, impacted oyster recruitment and, in some areas, caused high oyster mortality. The overall, long-term behavior of sanctuaries will depend on many factors, including changes in weather, water movement patterns, disease, and predator/prey abundance.

To achieve ecological restoration, the scale of sanctuaries remains important. The 2010 regulation placed 24% of Maryland's remaining productive oyster bottom into sanctuary, with the additional objective of including half of the productive bars within the sanctuaries. This is consistent with the 2019 Oyster Management Plan sanctuary objective "Conserve and protect oyster habitat and biomass through maintenance of sanctuaries so that a minimum of 20-30% of oyster habitat, and 50% of the 'best bars' are within sanctuaries."[104] Additionally, new management techniques should be employed in sanctuaries.

There are sanctuaries and PSFAs that are known to have poor habitat and/or very low densities of oysters. These underperforming areas may not be restored either for ecological or fishery purposes without substantial investment either by government or private entities. To date, no such investment has occurred. If the ultimate goal is to have more oysters in the water, then adjusting the boundaries of the current management areas and employing new management techniques would need to be considered. In the near future, the OAC will be making recommendations on management actions to increase oyster abundance and harvest that may address this.

Determining how each sanctuary and PSFAs is performing will provide the OAC with additional information to factor in when making its recommendations. Sanctuaries and PSFAs (grouped into NOAA Code harvest areas) were classified into different levels of productivity as a measure of performance. A productive area is defined as having 1) high density of spat, small-sized oysters, and market-sized oysters, 2) good habitat and 3) high survival. This includes areas planted with shell and oysters. Classifying areas based on productivity allows for comparison between different sanctuary areas and comparison between different NOAA Code harvest areas.

[104] Maryland Department of Natural Resources. 2019. Maryland Chesapeake Bay Oyster Management Plan. 93 pp. dnr.maryland.gov/fisheries/Documents/MD_Oyster_FMP-2019.pdf

Section 5.1: Defining Productive Areas

Though a 'best bars' analysis can provide information about specific bars in areas, another analysis is needed to determine the performance of individual sanctuaries and PSFAs as a whole. Furthermore, determining performance of individual areas allows for the relative comparison of which areas are performing better than others. To determine performance, each sanctuary and PSFA was ranked according to their productivity. A productive area is one that has high density of oysters, good habitat, and good survival.

The relative oyster productivity of sanctuaries and PSFAs were examined based on data from the department's Fall Survey. Natural 'breaks' in available data were used to identify differing levels of productivity using the following characteristics: 1) density of spat, small and market oysters, 2) the amount of cultch (substrate) and 3) total observed mortality. Where data existed, each sanctuary was evaluated. The 176 PSFAs were grouped into the 39 large NOAA Code harvest areas and evaluated. It is important to note that each NOAA Code harvest area may contain multiple PSFAs and some PSFAs do not reside entirely within a single NOAA Code harvest area.

Data from the Fall Survey collected within the last 10 years (2011 to 2020) was used to classify oyster sanctuaries and NOAA Codes according to several metrics: density of market oysters, small oysters, and spat:, the amount of cultch; and total estimated mortality. Biomass was not used as a metric because not all NOAA Codes and sanctuaries have biomass data. The goal was to develop criteria to evaluate the performance of sanctuaries and NOAA Codes and develop a classification system based on those criteria. Each sanctuary and NOAA Code was assigned a letter grade, with 'A' being the best and 'D' being the worst, with 'E' reserved for insufficient data. The 10-year time period was chosen because neither NOAA Code nor sanctuary boundaries have changed since the 2010 expansion of oyster sanctuaries.

The NOAA Code samples were collected outside the current oyster sanctuaries. Some NOAA Codes have no samples taken outside of sanctuaries (Upper Chester River, Upper Choptank River, Manokin River, Severn River, and Wye River). NOAA Codes 055 (Magothy River), 094 (West and Rhode rivers), and 098 (Monie Bay) are not sampled by the Fall Survey. Nearly half of all sanctuaries either have no samples taken in them, or have too few samples to be included in this study. It is important to be cognizant of this as these sanctuaries are classified as Level E due to lack of data.

The methodology for both sanctuaries and NOAA Codes was the same. Fall Survey data from 2011 to 2020 was used. Counts of market oysters, small oysters and spat were standardized to density (number per square meter). Cultch was defined as the amount of material collected (in bushels) per 100 meters of tow distance. Estimated total mortality was calculated as the proportion of dead oysters in the sample to the total live and dead oysters collected. Full dredge samples and samples with missing tow distances, total sample volumes or dredge volumes were not used in the analysis.

For each year in the data series, the raw data (densities, mortality, and cultch) were converted to ranks for each of the five categories. For oyster densities and cultch, the highest number was given a rank of ‘1’, while for mortality the lowest (typically ‘0’) was given a rank of ‘1’. Any ties were given an average of the ranks. Ranks for each sanctuary or NOAA Code were then averaged across years, giving one mean value for each category of data. For each sanctuary or NOAA Code, a score was derived for each category with the following formula:

Category Score = (MaxRankCategory-MeanRankLocation)/MaxRankCategory*100

The MaxRankCategory was the maximum rank for the entire category (market density, small density, etc.). The MeanRankLocation was the mean rank for the NOAA Code or sanctuary in that category. The Total Score is the mean of the category scores. Due to the fact that the NOAA Code dataset was approximately twice the size of the sanctuary dataset, this enabled easier comparisons between the two. The classification was then assigned based on 20%, 50% and 80% percentiles of the Total Score.(Table 5-1).

Table 5-1. Percentiles used in establishing classifications.

Classification	Percentile
A	≥80
B	50-80
C	20-50
D	<20
E	Insufficient data

Section 5.2: Classifying Sanctuaries and NOAA Code Harvest Areas

Results for the classification of sanctuaries and NOAA Codes are shown in Figure 5-2, Table 5-2 and Figure 5-3.

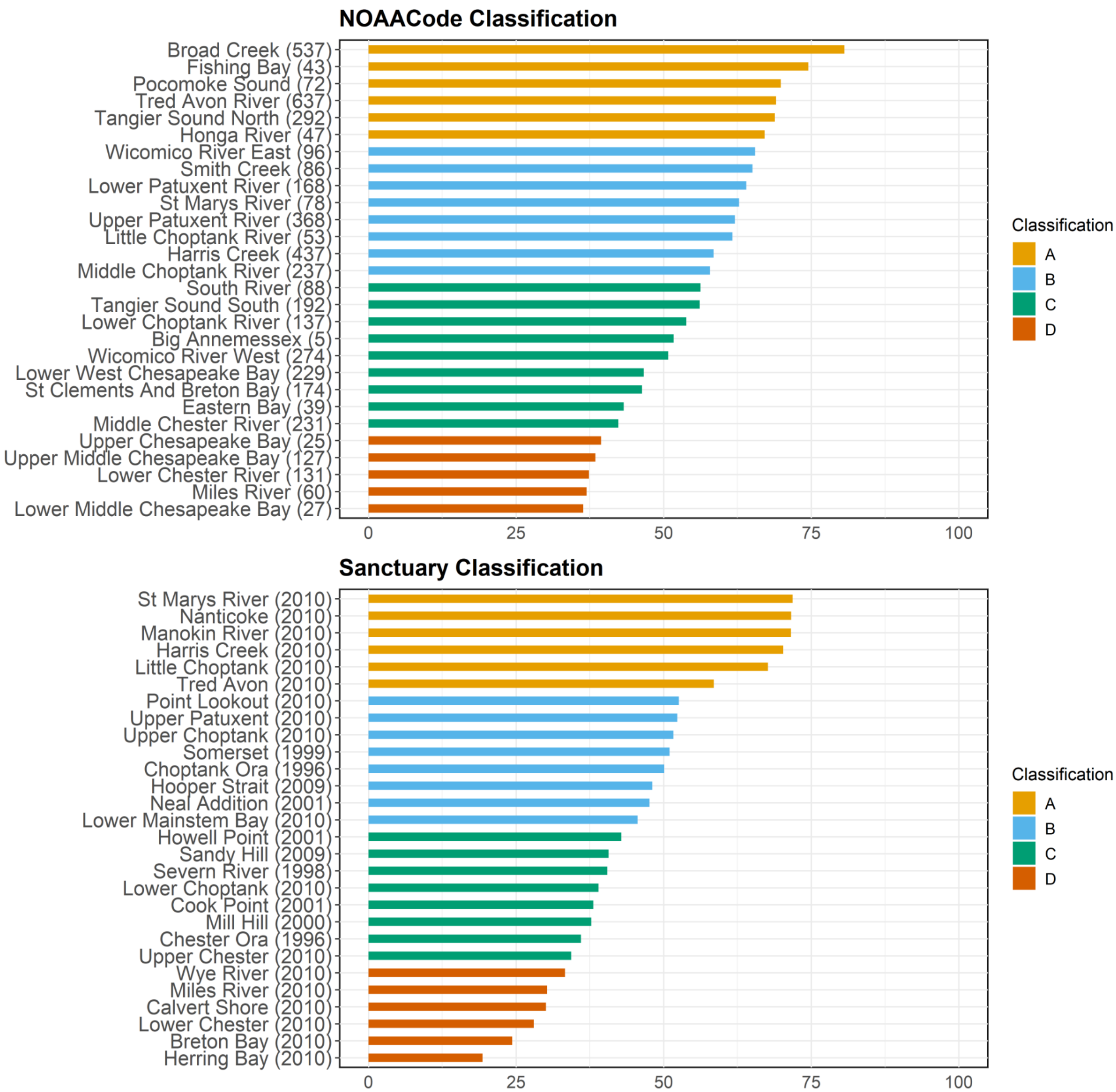

Figure 5-2. Classification (A-D) for NOAA Codes and Sanctuaries.

Table 5-2. Classification (E) - Insufficient Data for NOAA Codes and Sanctuaries.		
Sanctuaries		
Big Annemessex	Magothy River	Ringgold
Cedar Point	Man O'War/ Gales Lump	Roaring Point
Cox Creek	Oxford Laboratory	Solomons Creek
Eastern Bay	Piney Point	South River
Fort Carroll	Plum Point	Tilghman Island
Kitts Creek	Poplar Island	Webster
La Trappe	Prospect Bay	Wicomico River
Lower Patuxent River	Prospect Bay- Cabin Creek	
NOAA Code Harvest Areas		
Magothy River (055)	Severn River (082)	Lower East Chesapeake Bay (129)
Manokin River (057)	West and Rhode Rivers (094)	Patuxent River Middle (268)
Nanticoke River (062)	Monie Bay (098)	
Note: Some of these NOAA Codes tend to have little acreage open to the public fishery and instead the majority of acreage is within a sanctuary.		

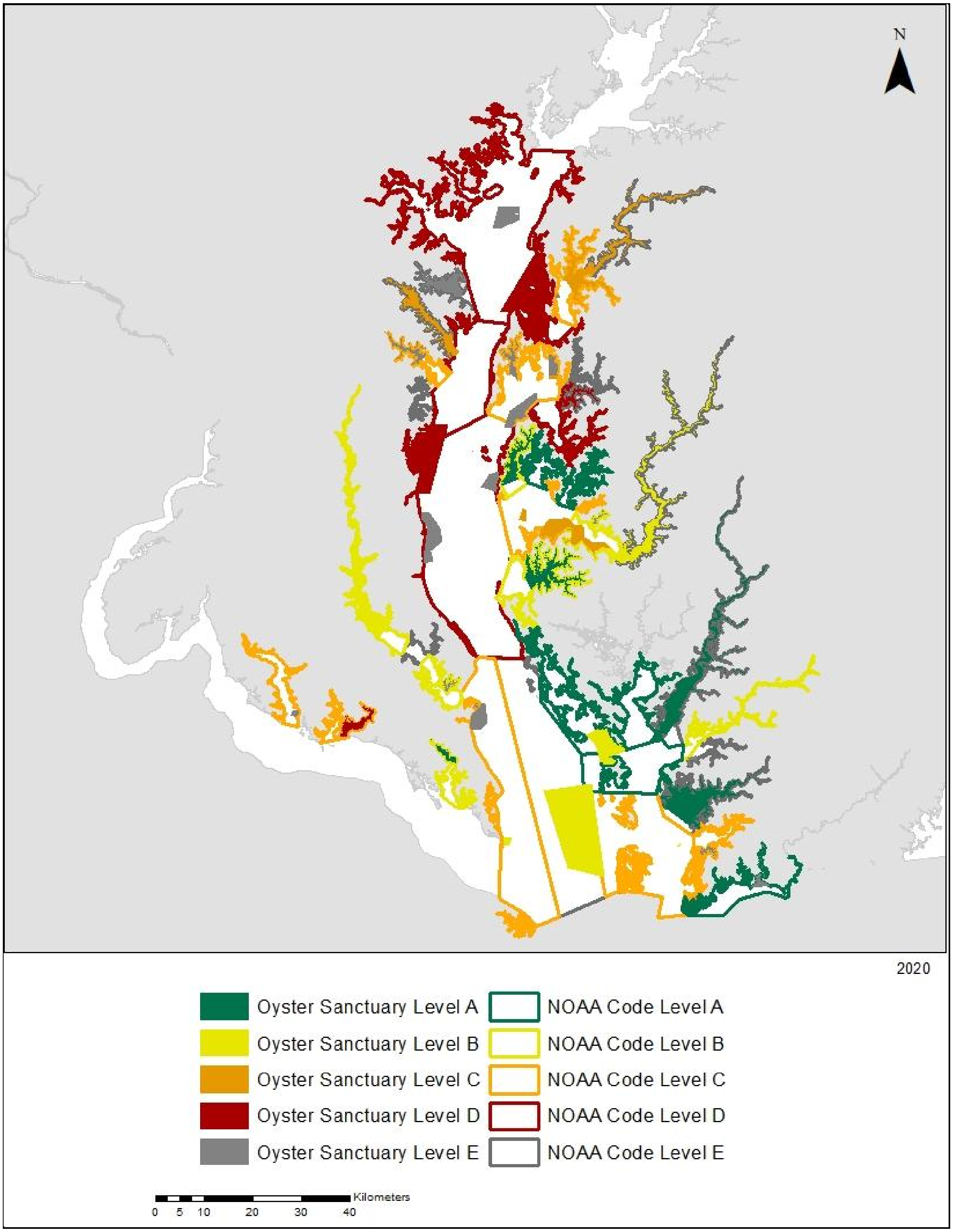

Figure 5-4. Classification (A-E) for NOAA Codes and Sanctuaries.

Section 5.2.1: Level A Sanctuaries and NOAA Code Harvest Areas

Level A areas have a high combined ranking for oyster densities of market-sized oysters, small-sized oysters, and spat, as well as higher amount of cultch, and low mortality. These areas ranked within the upper 80% of the rankings. Many of these areas have received investment toward production in the form of wild seed plantings, hatchery seed plantings, shell plantings, or substrate addition. These are areas that are considered productive and have good habitat.

Level A Sanctuaries

There are six Level A sanctuaries: Harris Creek, Little Choptank River, Tred Avon River, St. Marys River, Nanticoke River and Manokin River. Three of the six areas - Harris Creek, Little Choptank River, and Tred Avon River sanctuaries - have each received significant financial investment in targeted restoration projects to date. These three sanctuaries along with St. Marys River and Manokin River sanctuaries will contribute to the achievement of Maryland's commitment to the Chesapeake Bay Watershed Agreement "*to restore oyster habitat and populations in five tributaries by 2025 and to ensure their protection.*"[105] St Marys River and Manokin sanctuaries ranked high prior to large-scale restoration activities commencing. The Nanticoke River Sanctuary also ranked high for oyster densities, cultch and mortality.

DNR announced in 2017 the intent to develop an oyster management plan for the Nanticoke River sanctuary to determine how to invest state resources. As part of this effort, the Nanticoke River sanctuary is slated to receive spat on shell restoration on approximately 17 acres in 2021.

There is extensive, ongoing research occurring in these five large-scale restoration sanctuaries by academic and federal partners that includes such objectives as: tracking each area's progress toward restoration goals, which were developed by a multi-agency workgroup in 2011, quantifying ecological services of oyster reefs, and better understanding vital components of oyster biology such as larval dispersal[106,107].

Level A NOAA Code Harvest Areas

There are six Level A NOAA Codes: Broad Creek region (537), Fishing Bay region (043), Pocomoke Sound region (072), Tangier Sound North region (292), Tred Avon River region (637) and Honga River region (047). All of these NOAA Codes received significant plantings in the form of wild seed, hatchery seed or shell plantings to enhance the wild fishery. Most of these NOAA Codes tend to be high harvest regions, with the exception of Tred Avon River. While Tred Avon River did rank lower in the density of small-sized oysters and spat, the area ranked high in market density and cultch.

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[105] chesapeakebay.net/chesapeakebaywatershedagreement/goal/sustainable_fisheries

[106] National Oceanographic and Atmospheric Administration, US Army Corps of Engineers, Maryland Department of Natural Resources, Oyster Recovery Partnership. 2016. 2015 Oyster Restoration Implementation Update. Progress in the Choptank Complex (Harris Creek, Little Choptank River, and Tred Avon River Oyster Sanctuaries).
dnr.maryland.gov/fisheries/Documents/2015_Choptank_Oyster_Implementation_Update_FINAL.pdf

[107] chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

Section 5.2.2: Level B Sanctuaries and NOAA Code Harvest Areas

Level B areas have a combined ranking for oyster densities of market-sized oysters, small-sized oysters, and spat, as well as amount of cultch, and mortality within the 50% to 80% range. These areas may have ranked better in one category than another, but the combined rankings were overall above average. Many of these areas have received investment toward production in the form of wild seed plantings, hatchery seed plantings, or shell plantings.

Level B Sanctuaries

There are eight Level B sanctuaries: Choptank ORA Zone A, Hooper Strait, Lower Mainstem Bay, Neal Addition, Point Lookout, Somerset, Upper Choptank River, and Upper Patuxent River. Of these sanctuaries, only two have received restoration efforts since 2010. Neal Addition has received plantings of oysters as part of an oyster gardening effort and the Upper Choptank sanctuary has received multiple seed plantings. Some of these sanctuaries ranked low in terms of the densities of spat, but had a higher ranking for cultch or mortality, while others may have ranked higher for spat densities, but had lower rankings for mortality or cultch. In general, medium- to high-salinity areas have a higher spatfall ranking that lend to the B classification despite a lower ranking for mortality, while the lower salinity areas have a lower ranking for spatfall but a higher ranking for mortality and cultch.

Level B NOAA Code Harvest Areas

There are eight Level B NOAA Codes: Smith Creek region (086), Wicomico River East region (096), Lower Patuxent River region (168), St. Marys River region (078), Upper Patuxent River region (368), Little Choptank River region (053), Harris Creek region (437) and the Middle Choptank River region (237). All of these NOAA Codes received plantings in the form of wild seed, hatchery seed or shell plantings to enhance the wild fishery. Many of these NOAA Codes tend to be in medium-salinity areas which could contribute to higher recruitment if there is suitable cultch for settlement.

Section 5.2.3: Level C Sanctuaries and NOAA Code Harvest Areas

Level C areas have a combined ranking for oyster densities within the three size classes, as well as amount of cultch, and mortality within the 20% to 50% range. These areas may have ranked better in one category than another, but the combined rankings were below average. These regions may have received investment toward production in the form of wild seed plantings, hatchery seed plantings, or shell plantings.

Level C Sanctuaries

There are eight Level C sanctuaries: Chester River ORA Zone A, Cook Point, Howell Point, Lower Choptank, Mill Hill, Sandy Hill, Severn River, and Upper Chester River. Of these sanctuaries, five have received some restoration effort since 2010, including Cook Point, Howell Point, Lower Choptank, Sandy Hill and the Severn River.

Level C NOAA Code Harvest Areas

There are nine Level C NOAA Codes: Tangier Sound South region (192), South River region (088), Lower Choptank region (137), Big Annemessex region (005), Wicomico River West region (274), Lower West Chesapeake Bay region (229), Eastern Bay region (039), St. Clements and Breton Bay region (174), and Middle Chester River (231). Of these regions, seven have received significant plantings in the form of wild seed, hatchery seed or shell plantings to enhance the wild fishery. The only two that did not receive enhancement were the Big Annemessex region (005) and the St. Clements and Breton Bay region (174).

Section 5.2.4: Level D Sanctuaries and NOAA Code Harvest Areas

Level D areas have a combined ranking for oyster densities within the three size classes, as well as amount of cultch, and mortality below the 20% range. These areas may have ranked better in one category than another, but the combined rankings were well below average. Level D areas are often known to have low densities of oysters or poor habitat, though may have low mortality.

Level D Sanctuaries

There are six Level D sanctuaries: Breton Bay, Calvert Shore, Herring Bay, Lower Chester River, Miles River, and Wye River. Of these sanctuaries, four have received some restoration effort since 2010, including Calvert Shore, Herring Bay, Lower Chester River and Miles River sanctuaries.

Level D NOAA Code Harvest Areas

There are five Level D NOAA Codes: Upper Chesapeake Bay region (025), Upper Middle Chesapeake Bay region (127), Lower Middle Chesapeake Bay region (027), Lower Chester River region (131), and Miles River region (060). Of these regions, three have received plantings in the form of wild seed, hatchery seed or shell plantings to enhance the wild fishery, including Upper Chesapeake Bay Region (025), Lower Middle Chesapeake Bay region (027), and Miles River region (060).

Section 5.2.5: Level E Sanctuaries and NOAA Code Harvest Areas

Level E areas had insufficient data to determine their classification.

Level E Sanctuaries

There are 23 Level E sanctuaries: Big Annemesssex, Cedar Point, Cox Creek, Eastern Bay, Fort Carroll, Kitts Creek, La Trappe, Lower Patuxent River, Magothy River, Man O'War/ Gales Lump, Oxford Laboratory, Piney Point, Plum Point, Poplar Island, Prospect Bay, Prospect Bay-

Cabin Creek, Ringgold, Roaring Point, Solomons Creek, South River, Tilghman Island, Webster, and Wicomico River. Of these sanctuaries, eight have received some restoration effort since 2010, including Eastern Bay, Fort Carroll, Magothy River, Oxford Laboratory, Plum Point, Prospect Bay, South River, and Wicomico River sanctuaries. Several of these sanctuaries have small acreage with little historic oyster bottom thus they are not sampled by the Fall Survey. Some sanctuaries, such as Fort Carroll Sanctuary, have had restoration efforts and may be productive areas. Other sanctuaries, such as Plum Point, have had artificial substrate placed. While the Fall Survey is unable to sample these areas, DNR is exploring alternative methods of gathering this data.

Level E NOAA Code Harvest Areas

There are eight Level E NOAA Codes: Magothy River region (055), Manokin River region (057), Nanticoke River region (062), Severn River region (082), West and Rhode Rivers region (094), Monie Bay region (098), Lower East Chesapeake Bay region (129), and Patuxent River Middle region (268). Of these regions, three have received plantings in the form of wild seed, hatchery seed or shell plantings to enhance the wild fishery, including Manokin River region (057), Nanticoke River region (062), and Patuxent River Middle region (268). Many of these NOAA Codes tend to have little acreage open to the public fishery. For example, 88% of the Nanticoke River NOAA Code (062) is within a sanctuary. Three NOAA Codes are entirely within a sanctuary, including Wye River (099), Choptank River Upper (337), and Chester River Upper region (331) and thus were not ranked.

Section 5.3: Recommendations

As mandated by Maryland statute, the OAC[108] is currently conducting a consensus process to develop a recommendation package for enhancing and implementing the fishery management plan for oysters. This plan will be informed by a collaboratively developed, science-based modeling tool to quantify the long-term impacts of identified management actions and possible combinations of management actions on oyster abundance, habitat, harvest, harvest revenue and nitrogen removal. Therefore, this report provides information only and does not include recommendations on management actions.

However the department does recommend some improvements to this report and assessment methodologies. For example, the second PSFA objective states "*Protect half of the bars identified by Jones and Rothschild (2009) as "consistently most productive" for the benefit of licensed oystermen.*". Due to the fact that the objective in the preamble of the 2010 regulation[109] specifically calls out the Jones and Rothschild 2009[110] "best bars" report, the objective is assessed based on this analysis and the objective has been met. However, as oyster populations evolve over time, the "best bars" will as well. Thus, the 'best bars' analysis could be updated with new criteria and results, as in Appendix C.

The classification of sanctuaries and NOAA Code harvest areas determined areas where there was insufficient data to assess some areas (Level E). The ongoing sanctuary patent tong population surveys will assist in assessing some of these sanctuaries in the future. The Fall Survey sites could be examined to determine if additional samples should be taken annually to increase information on these areas. This may not be possible in some areas, in which case alternative methods should be considered for deployment. For example, Plum Point sanctuary has a large artificial substrate in it to improve fish habitat, thus the Fall Survey sampling gear cannot be used in this sanctuary. Other areas may not have any historic oyster bottom in them to survey. In future reports, additional analytical methods should be examined to determine if there is a way to assess these Level E areas.

As 10 years may not be enough time to fully understand the ecological impacts of sanctuaries, research should continue to be conducted to gain knowledge on this. The 51 sanctuaries in Maryland vary in that some just have the absence of harvest, some have small-scale restoration, and some have large-scale tributary level restoration. Depending on the level of investment, the salinity in the sanctuary, the biology of the oyster population residing in the sanctuary, and existing habitat, there could be differing degrees of ecological impacts. Research should strive to understand the potential varying degrees of ecologicals impacts given these differences.

The second objective for aquaculture areas stated "Open new areas to leasing to promote shellfish aquaculture industry growth." In order to continue meeting this objective, areas within existing PSFAs should be periodically evaluated and investigated. PSFAs that are found to be

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[108] More information on the OAC can be found at dnr.maryland.gov/fisheries/Pages/mgmt-committees/oac-index.aspx

[109] Maryland Register, Vol 37, Issue 14, Friday July 2, 2010 dnr.maryland.gov/fisheries/Documents/Oyster%20Packages%20September%202010.pdf

[110] Jones, P.W. and Rothschild, B.J. 2009. Maryland's Oyster Redevelopment Program – Sanctuaries and Harvest Reserves. Final Report to the Maryland Department of Natural Resources. dnr.maryland.gov/fisheries/Documents/Best_Bar_Report_summary.pdf

unproductive and not being used by the public fishery could be reclassified for leasing by prospective shellfish aquaculture individuals and/or businesses. The OAC and Aquaculture Coordinating Council in conjunction with the department could determine a definition for unproductive oyster bottom.

Section 6: Glossary

Aquaculture - the farming of aquatic organisms for human consumption.

Biomass - the dry weight of living matter comprising the population of a particular species and expressed in terms of a given area or volume of the habitat. In assessing the size of the oyster population, biomass integrates both their abundance and their collective body weight (another way of looking at how large they are).

Bottom Groundtruthing – a method for verifying the bottom type classified by sidescan sonar using either patent tong sampling or diving and visually verifying the bottom.

Box Oyster - pairs of empty shells joined together by their hinge ligaments. These remain articulated for months after the death of an oyster, providing a durable estimator of recent oyster mortality.

Bushel - unit of volume used to measure oyster catches. The official Maryland bushel is equal to 2,800.9 cu. in., or 1.0194 times the U.S. standard bushel (heaped) and 1.3025 times the U.S. standard bushel (level).

Conditional Shellfish Harvest Area – an area designated by Maryland Department of the Environment that may be conditionally closed to shellfish harvest based on rainfall and impacts of bacteria and fecal coliform in shellfish that may be potentially harmful for human consumption. The area will be closed to shellfish harvest for three days after a rainfall event of one inch or greater over 24 hours.

Cultch - material that larval oysters can use as substrate for settlement.

Dermo Disease - the oyster disease caused by the protozoan pathogen, *Perkinsus marinus*.

Depleted Status - Market-sized oyster abundance is below the threshold abundance biological reference point (minimum number of oysters from 1999 to 2017) as estimated in the Maryland Oyster Stock Assessment.

Dredging - a method of collecting oysters by dragging a toothed scraping bar fitted with a chain/mesh type bag (the dredge) over an oyster bar.

Dredged Shell - oyster shell dredged from buried ancient (3000+ years old) shell deposits.

Ecology - the scientific study of the distribution and abundance of life and the interactions between organisms and their environment.

Ecosystem - a functional system that includes the organisms of a natural community together with their environment.

Fresh Shell - shells from shucked oysters, usually stored on land for less than a few years before planting as oyster habitat or used in a hatchery as substrate for setting oyster larvae.

Freshet - a deluge of fresh water flooding into Chesapeake Bay, causing salinity to decrease suddenly.

Hatchery - a facility that spawns and fertilizes oysters to produce oyster larvae and spat.

Hatchery Spat-on-Shell – spat settled on shell within a hatchery laboratory using larvae spawned by a hatchery operation.

Haplosporidium nelsoni - The protozoan oyster parasite that causes MSX disease.

Harvest Reserve – area that is closed to commercial oyster harvest until biological criteria are met and the area is opened to harvest.

Historic Oyster Bottom – an oyster bar as charted by the Yates Oyster Survey of 1906 to 1912 and its amendments.

Intensity (of disease) - a measure of the concentration of disease-causing parasites within an oyster; high disease intensity generally results in mortality.

Key Bar (Spat) – a subset of 53 fixed sampling locations in the Annual Fall Oyster Dredge Survey. The annual Spat Index is derived from average spat counts from these Key Bars.

Key Bar (Disease and Biomass) - a subset of 43 fixed sampling locations in the Annual Fall Oyster Dredge Survey. The annual Biomass Index is derived from average counts and size distributions from these Key Bars. Oyster disease information is also collected from these Key Bars.

Larvae (plural form of larva) - a free-swimming (planktonic) and sometimes feeding stage in the early development of certain animals. Oysters have several larval stages including: trochophore, veliger, and pediveliger. Their larvae remain in the water column for two to three weeks before attaching to hard substrate when they become spat.

Market (sized oyster) – oysters that are 76 millimeters (3 inches) or greater and can be harvested legally.

Mesohaline - moderately brackish, estuarine water with salinity ranging from 5 to 18 ppt.

Overfishing Status - Harvest fraction (number of oysters removed from the population from harvest) is above the threshold harvest fraction biological reference points as estimated in the Maryland Stock Assessment.

Oyster Reef Habitat – in reference to bay bottom type mapping surveys, bottom types suitable for larvae settlement.

Patent Tong – a mechanical method of collecting oysters by using two hinged rake heads that are opened and closed by a hydraulic piston and tethered by a cable.

Prevalence (of disease) - a measure of the frequency of occurrence of infection (i.e., the percent of examined oysters that contain at least one disease causing parasite).

Public Shellfish Fishery Area (PSFA) - an area in State waters determined to be economically viable to the commercial oyster fishery. A PSFA is reserved for commercial harvest of wild oysters and cannot be leased for aquaculture.

Recruitment - additions to a population, either through birth or immigration. When oyster larvae settle and attach in the vicinity of other oysters, they are 'recruits' into that population.

Reef Ball – a rounded, hollow, and vented form made of concrete placed on the bottom of the bay with the purpose of oyster restoration and ecological benefits. Reef balls can be seeded with hatchery-produced spat prior to planting or may attract a natural oyster set afterwards, depending on its location.

Replenishment (of habitat) - any of a range of approaches for attempting to increase the amount of suitable habitat for oyster settlement to benefit the public oyster fishery; “standard” habitat method involves placing relatively thin layers of clean shell on existing hard bottom.

Replenishment (of population) - any of a range of approaches for attempting to increase the amount of oyster for harvest by the public oyster fishery; “standard” method involves placing hatchery oyster spat or transferring wild, natural oyster spat.

Restricted Shellfish Harvest Area - an area designated by Maryland Department of the Environment that is permanently closed to shellfish harvest based on rainfall and problems of fecal coliform and other bacteria in shellfish that may be potentially harmful for human consumption.

Restoration (of population) - any of a range of approaches for attempting to increase the population of oysters in Chesapeake Bay to a level at which it provides desired ecosystem services (e.g.,, habitat rehabilitation, planting seed oysters).

Small (sized oyster) – oysters normally ranging between about 40 to 75 millimeters and are at least one year old and generally up to two to three years old. These oysters are not harvested legally.

Secchi Disk - a device for measuring water clarity. A Secchi disk (named after its inventor) is a white circle (usually eight inches in diameter) with a black pattern and attached to a calibrated line. The Secchi disk is lowered into water until the pattern is no longer visible. The depth at which this occurs is called the Secchi depth and is a measure of water clarity. Water clarity decreases as turbidity increases.

Setting; Settlement - the metamorphosis from the planktonic (free-swimming) larval form to the benthic adult form. When oysters set or settle, they permanently attach to a hard substrate.

Shell Height – the distance from the hinge to the ventral margin of an oyster shell; usually the longest dimension.

Spat (seed) – early juvenile oysters that have settled by attaching to a hard substrate. These oysters are less than one year old and usually smaller than 40 millimeters.

Spawning - producing and releasing gametes (eggs or sperm). Gametes are released into the water column where fertilization occurs. Oysters normally spawn from May to September. Males often spawn first and the presence of sperm in the water is a stimulant to the females.

Spatfall - the settling and attachment of larvae to substrate.

Substrate - hard surface to which a fixed organism is attached. Oysters can attach to a wide variety of hard substrates, but prefer oyster shell.

Turbidity – a measure of suspended matter or particles in water that block light penetration; cloudy or muddy in physical appearance. Turbidity reduces water clarity.

Water Quality Sondes – a device used to collect water quality information (i.e., salinity, water temperature, etc.) underwater and sometimes continuously through the water column or over time.

Wild Seed – oysters collected from a natural recruitment area within the bay and transported to an oyster bar in another usually low-recruitment area of the bay. These oysters tend to be spat and small-sized oysters.

Yates Bar Survey – a survey conducted from 1906 to 1912 to designate the boundaries of all oyster bars within Maryland's portion of Chesapeake Bay.