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Maryland Chesapeake Bay Oyster Management Plan (May 2019)

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Preface

Fishery Management Plan Background

Fishery Management Plans (FMPs) serve as a framework for conserving and wisely using fishery resources. An FMP provides a format for undertaking management measures throughout Maryland state waters. In addition, FMPs allow the Department of Natural Resources to specifically address issues that are unique to Maryland resources. The goal of an FMP is to protect the resource while allowing sustainable harvest. For example, the Atlantic States Marine Fisheries Commission (ASFMC) states that the main objective of fisheries management is to "allow enough harvest to sustain and build the fishing and seafood industries while protecting the productivity and sustainability of the marine ecosystems." Therefore, ecological, economic and sociological factors affecting the resource are considered in the process. Elements of a plan include: quantifying biologically appropriate levels of harvest; identifying habitat requirements and recommending protection and restoration measures; expanding single-species management to include ecosystem-based approaches; monitoring the status of the resource, including fishery-dependent and independent surveys; and defining and enforcing management recommendations.

Development of an FMP begins with the Maryland Department of Natural Resources Fishing and Boating Services staff preparing a draft document. Guidelines for the contents of a plan have been delineated in Natural Resources Article, §4-215, Annotated Code of Maryland. Staff review previous management measures, current monitoring data and results, stock assessment conclusions, scientific research data, ecosystem and socioeconomic factors, and other relevant data and information. The plan development team defines goals, objectives, strategies and options/actions for addressing problems/issues. The plan is then reviewed by the Department's advisory commissions such as the Sport Fisheries Advisory Commission (SFAC), Tidal Fisheries Advisory Commission (TFAC), Oyster Advisory Commission (OAC) and Aquaculture Coordinating Council (ACC). After review by the advisory bodies, the plan undergoes a 30-day public comment period. Public comment is incorporated in the final version of the plan when practicable and then the final plan is adopted by the appropriate Maryland authorities.

Upon adoption of an FMP, the appropriate management entities will advance the recommended actions. In some cases, regulatory and statutory actions may be necessary to fully implement a management action and must go through the appropriate process, including scoping and public comment. The progress of FMP implementation is tracked and the status of the stock and fishery is annually updated. If the status of a stock changes significantly and management strategies are changed accordingly, amendments and revisions to the plan may be recommended.

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1.0 Introduction

Life History

The Eastern oyster, *Crassostrea virginica*, is native to coastal waters from the Gulf of St. Lawrence in Canada to the Atlantic coast of Argentina (Carriker and Gaffney, 1996). It is common in estuaries and coastal areas of reduced salinity and can occur as extensive reefs or 'bars' on hard to firm bottoms in both the intertidal and subtidal zones (Carriker and Gaffney, 1996). As is typical of animals that have evolved to inhabit an environmentally variable estuarine environment, oysters can tolerate a broad range of both temperatures and salinities (Shumway, 1996). In Maryland, sub-freezing temperatures and ice scouring restrict oyster bars to the subtidal zone (Galtsoff, 1964).

In Maryland's Chesapeake Bay, variable salinity and temperature regimes are the primary environmental determinants of oyster population dynamics given their influence on reproduction, growth and mortality (Shumway, 1996). Mortality rates are interrelated with temperature and salinity because of the presence of two oyster protozoan parasites, *Perkinsus marinus* (Dermo disease) and *Haplosporidium nelsoni* (MSX). Dermo disease was identified in Chesapeake Bay oysters in 1949 but did not become a major problem until the mid-1980s (Ford and Tripp, 1996). MSX appeared in Chesapeake Bay in 1959, and by the 1970s had dramatically reduced oyster densities in Virginia's high salinity oyster habitat (National Research Council, 2004). MSX is active at temperatures above 10°C although it is intolerant of salinities below 10 parts per thousand (ppt) (Ford and Tripp, 1996). The highly lethal Dermo disease proliferates most rapidly at temperatures between 25° and 30°C and salinities greater than 15 ppt, but survives at much lower temperatures and salinities (Ford and Tripp, 1996). During the latter part of the 20th century, these diseases had a devastating impact on oyster populations in Chesapeake Bay, although they acted on a population that was already compromised by poor water quality, fishing pressure and habitat loss (National Research Council, 2004). The presence of these two pathogens adds complexity to oyster population dynamics in Chesapeake Bay because associated mortality rates may vary substantially among years and spatially within the same year depending on where oysters are located within Chesapeake Bay. A recent study by the Virginia Institute of Marine Science demonstrated Chesapeake Bay wild oysters are developing increased resistance to these diseases but it is still unknown how the resistance was developed (Virginia Marine Institute of Science 2019). Future research on this topic could provide important insight for overcoming the negative impact of these diseases on oyster populations.

Gametogenesis and spawning in oysters are directly correlated with water temperature (Shumway, 1996). In Chesapeake Bay, oysters begin gametogenesis in the spring and spawning can occur from late May to late September but generally peaks in late June/early July (Shumway, 1996; Thompson et al., 1996). The larval stage lasts for about 2 to 3 weeks, depending on food availability and temperature. Larval growth rates increase rapidly with increasing temperature; the fastest rates occur near 30°C. Larvae appear to migrate vertically, particularly at later stages and tend to concentrate near the bottom during the outgoing tide and to rise in the water column during the incoming tide, thus increasing their chances of being retained in the estuary (Kennedy, 1996; Shumway, 1996).

Oysters are either male or female (the reported incidence of simultaneous hermaphroditism is less than 0.5 percent) but may change sex over the winter when they are reproductively inactive. Generally, oysters function as males when they first mature which can happen as early as 6 weeks post settlement (Thompson et al., 1996). As individuals grow, the proportion of functional females in each size class increases, with an excess of females occurring among larger (and presumably older) animals (Galtsoff, 1964). As oysters grow larger and heavier, their annual fecundity (number of eggs produced) increases. 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 (Mann and Evans, 1998).

There is no definitive study of the longevity of the oyster. Several ages have been proposed, the most common being 20 years (Sieling, ca. 1972; Buroker, 1983; Mann et al., 2009; NOAA-CBO, 2018), but the statements are either unsupported or make questionable inferences from other sources. Oysters from plantings in Maryland have been reported to survive at least 9 years (assuming no natural reproduction in these areas; Paynter et al., 2010).

Current Status

Maryland's oyster population is currently estimated at a historically low abundance and the decline can be attributed to many factors, including harvest pressure, lack of habitat, disease mortality, reduced water quality and the interactions among these factors. The role of degraded water quality and its impact on the oyster resource has a dual nature: oysters are negatively impacted by sedimentation, turbidity and anoxic conditions, which can inhibit oyster restoration, yet oysters have the potential to improve water clarity by removing algae and suspended solids from the water through their suspension-feeding activities.

Since 1939, the department and its predecessor agencies have been conducting a Fall Oyster Dredge Survey in Maryland to assess the overall health of the oyster population. The data collected by the dredge survey provide critical information for conducting an oyster stock assessment. Five types of indices are calculated from the dredge survey: the Spatfall Intensity

Index, obtained from a subset of 53 oyster bars, is a measure of recruitment success and the potential increase in the population; the Oyster Disease Indices, derived from a subset of 43 oyster bars, document disease infection levels; the Total Observed Mortality Index, calculated from the 43 oyster bar Oyster Disease Indices subset, is an indicator of annual mortality rates of post-spat stage oysters; the Biomass Index measures the number and weight of oysters from the 43 oyster bar Oyster Disease Indices subset relative to the 1993 baseline; and starting in 2005, the Cultch Index is a measure of oyster habitat from the 53 oyster bar Spatfall Intensity Index subset (Tarnowski, 2018).

In 2017, the 33-year median value of the Spatfall Intensity Index was 23.6 (spat per bushel of material) (Figure 1). The index ranged from a minimum of 2.0 in 1996 to 276.7 in 1997. On average, Tangier Sound, St. Mary's River and Broad Creek have the highest spatfall values.

In 2017, the Total Observed Mortality Index, an indicator of annual natural mortality, was 14 percent (Figure 2). The Total Observed Mortality Index over 33 years has ranged from a low of 7 percent in 2012 to a high of 58 percent in 2002. The index correlates closely with disease intensity and prevalence. The mean Dermo disease prevalence was 69 percent in 2017 and mean infection intensity for dermo disease was 2.5. MSX disease mean prevalence was 3 percent in 2017. Since 1990 when disease information is reported in the Annual Fall Survey, the annual mean for Dermo prevalence has ranged from 38% to 93%, dermo intensity has ranged from 1.2 to 3.8, and MSX has ranged from 0.1% to 29%.

The Biomass Index is a relative measure of how the oyster population is doing over time. It accounts for recruitment, individual growth, natural mortality and harvesting in a single metric. In assessing the size of the population, the Biomass Index integrates both the abundance of oysters and their collective body weight. The Biomass Index has ranged from 0.53 in 2002 to 2.09 in 2013 and was 1.4 in 2017 (Figure 3).

The Cultch Index is a relative measure of oyster habitat and was 0.83 bushels per 100 feet in 2017. Cultch is crucial for providing hard substrate for oyster setting as well as habitat for the myriad of other organisms associated with the oyster community.

For the purpose of the Fall Oyster Dredge Survey, cultch is defined as primarily both oysters (live and dead) and shell. Although 13 years is a comparatively short time frame for discerning long-term trends in the Cultch Index, a distinctive pattern emerged over this period (Figure 4). A three-year rolling average was used to smooth out the interannual variability inherent in the index (the average is associated with the terminal or third year). The increase in the Cultch Index during the early 2010s reflects improvements in recruitment and survivorship during this period, especially the strong spatsets in 2010 and 2012. The growth and good survivorship of these year classes contributed substantially to the index. The subsequent decline may be due to the removal of these oysters and lower recruitment, as well as ongoing taphonomic processes such as burial, degradation, etc. (Tarnowski, 2018).

Maryland's Oyster Fishery

The oyster fishery in Maryland has been managed since the early 1800s (Kennedy and Breisch, 1983). Oysters in Maryland's Chesapeake Bay are harvested by private aquaculture (discussed in section 7.0), the recreational fishery (discussed in section 6.6) and the commercial fishery. Peak historical harvest in the 1880s was 15 million bushels, but at that time, the harvest was loosely managed and New England fishermen were rapidly removing oysters from the bay to supply national demand. Oyster populations were dramatically impacted as shown by the great declines in harvest. Harvest was relatively stable from about the 1920s to the mid-1980s as management efforts increased. After the 1980s, oyster populations were greatly impacted by the diseases MSX and dermo which were first noted in oyster populations during the 1950s and 1960s. Given current harvest regulations and the effects of disease, harvest statistics beginning in the 1980s provide a more realistic picture of today's harvest. Since 1980, commercial harvest has ranged from 2.5 million bushels (1980) to 25,843 bushels (2003) (Figure 5). More recent harvest data, such as data during the time period associated with the 2018 stock assessment (1999 to 2017), ranges from 431,013 bushels (2014) to 25,843 bushels (2003).

As required by Natural Resources Article, §4-701, Annotated Code of Maryland, individuals must have a Maryland commercial fishing license to commercially harvest oysters on public bottom. In addition to their annual license renewal fee, these licensees must pay an annual surcharge fee of $300 in order to activate their license to harvest oysters prior to each season. This allows the department to identify a subset of licensees that are active in an oyster season. Maryland regulation limits the number of commercial licenses for the harvest of oysters to 737. Maryland also has a cap of 2,091 commercial fishing licenses that enables the licensee to participate in a wide variety of fisheries, including oysters. Individuals possessing this 'umbrella' license must also pay the annual surcharge to harvest oysters. As such, there are 2,828 individuals who have the potential to harvest oysters in any given year (Code of Maryland Regulations [COMAR] section 08.02.01.05). Since the 1994 oyster season, an average of 804 individuals paid the annual surcharge for oyster harvest (Figure 5). However, this number can fluctuate dramatically with changes in oyster abundance. For example, the number of surcharges rose from 599 in the 2011-2012 season to 1,134 in the 2014-2015 season, likely the result of above average spat sets occurring in 2010 and 2012 that increased the availability of oysters for harvest. Between the 2009-2010 to 2017-2018 harvest seasons, an annual average of 20 percent (ranging from 8 percent to 37 percent) of individuals that purchased an oyster surcharge reported harvesting no oysters.

Unlike many other species, the state and the commercial fishing industry invest in oyster management through replenishment planting activities. The replenishment plantings are currently funded by a grant from the Maryland Department of Transportation, revenue from the oyster bushel tax and revenue from the purchase of an oyster surcharge from the commercially licensed fishers. The average annual revenue generated from the bushel tax since 1991 is $208,740 (excludes export tax). The oyster surcharge is currently set at $300 and produces an average revenue of $241,062. There is currently no data available on revenue generated from the recreational fishery since recreational harvesters are prohibited from selling their oysters. Furthermore, no information is known regarding revenue from participating in recreational harvest (e.g. purchasing recreational harvest gear).

Whereas all revenue generated from the oyster bushel tax, export tax, and oyster surcharge go towards public fishery replenishment plantings of seed and substrate, an annual grant from the Maryland Department of Transportation funds various functions within the department. The grant started in 1997 and the amount has ranged from $1.5 million to $2 million dollars annually. On average about 60% of these funds go towards planting seed and substrate on public fishery bottom. The remainder of the MDOT funds has been used for operational costs, monitoring, and sanctuary plantings. Since 2011, the department also has received other funding towards sanctuary restoration (a federal grant from NOAA and state capital funds).

There are a variety of permissible gears for the commercial harvest of oysters. Gear types are restricted both in terms of when and where they can be used as well as in their dimensions (COMAR section 08.02.04). The primary gears are hand tongs, patent tongs, diver, power dredge and sail dredge. Hand tongs are typically constructed of two wooden shafts ranging from 16 to 30 feet with rakes at the ends to harvest oysters. Patent tongs are similar to hand tongs, except the patent tongs are suspended from a cable, are larger and heavier and are opened and closed with hydraulic power. Divers use a surface-supply air hose or, in some cases, SCUBA to collect oysters, cull them and then send them to the surface. A power dredge is a chain-mesh bag attached to a frame that is lowered to the bottom using a winch. The dredge is pulled along the bottom using a motorized vessel to collect oysters and then retrieved. A sail dredge, operated from a sailboat or skipjack, is typically a chain-mesh bag attached to a frame and pulled across the bottom using a boat under sail power. Sail dredges are allowed to use an auxiliary yawl boat to push the skipjack two days per week, which renders them similar to power dredges. The average harvest per gear type since the 2009-2010 harvest season is 48 percent by power dredging, 21 percent by patent tongs, 15 percent by hand tongs, 9 percent by sail dredge and 7 percent by diving. The average number of individuals harvesting by gear type is 51 percent by power dredging, 22 percent by patent tongs, 21 percent by hand tongs, 5 percent by diving and 1 percent by sail dredge (Note: an average of 33 percent of watermen use multiple gears to harvest throughout the season).

Fishery managers began a more comprehensive and coordinated management of oysters throughout Chesapeake Bay with the adoption of the Chesapeake Bay Oyster Management Plan

(1989), subsequent revisions in 1994 and 2004, and an amendment in 2010. In addition, efforts to rebuild Chesapeake Bay's native oyster resource have been directed by commitments in the Chesapeake 2000 Agreement, 2009 Programmatic Environmental Impact Statement, 2010 Maryland's 10-Point Oyster Restoration Plan and 2014 Chesapeake Bay Watershed Agreement. Since the oyster management plan addresses more than just the public fishery, the plan uses a more comprehensive title, the "Maryland Chesapeake Bay Oyster Management Plan," but is still considered a fishery management plan as described in the preface.

2.0 Oyster Management

The purpose of the 2019 Maryland Chesapeake Bay Oyster Management Plan (OMP) is to provide both a general framework and specific guidance for implementing a strategic, coordinated, multipartner management effort. Representatives from the department developed the plan with stakeholder input from the oyster industry, environmental groups, academia, federal agencies and the general public. The plan defines multiple strategies for protecting, rebuilding and managing the native oyster population. Two source documents provided information for this plan: the Oyster Management Review 2010-2015 (Maryland Department of Natural Resources, 2016); and a stock assessment of the Eastern Oyster, *Crassostrea virginica*, in the Maryland waters of Chesapeake Bay (Maryland Department of Natural Resources, 2018).

2.1 Goal

The goal of the 2019 Maryland Chesapeake Bay Oyster Management Plan is *to conserve, protect and where possible, rebuild oyster populations to fulfill their important ecological role and to support the culturally significant oyster fishery and industry throughout the Maryland portion of Chesapeake Bay*.

Achievement of this goal could:

- Produce more oysters than are removed each year by natural mortality and harvest;
- Accelerate recovery of the Chesapeake Bay and improve water clarity by filtering sediment and phytoplankton from the water, in turn reducing nitrogen and phosphorus levels;
- Provide ecosystems benefits and ecologically valuable reef habitat for crabs, fish, benthos and other organisms;
- Result in fishing levels that are consistently around the target within 8 to 10 years;
- Support Maryland's traditional fishing economy and cultural heritage;
- Enhance opportunities for aquaculture; and
- Generate additional revenue from processing, shipping and secondary sales of Maryland oyster products.

2.2 Objectives

Overarching Oyster Resource Objectives:

1. Develop and implement compatible and equitable management measures for the oyster resource throughout Maryland’s Chesapeake Bay.
2. Utilize the best available data to support science-based management of the oyster resource.
3. Include the benefits of ecological services provided by oysters as part of an ecosystem-based approach to managing the oyster resource.

4. Apply an adaptive management approach to modify or adjust objectives, strategies and/or actions as monitoring results, scientific data and other relevant information become available to improve outcomes.
5. Continue oyster population surveys, fishery monitoring programs, and ecological and ecosystem monitoring, and make improvements as needed.
6. Consider the interactions of different management areas and sector interests (e.g., public fishery, aquaculture, sanctuaries) in the development of equitable management measures.
7. Develop enforcement strategies that are compatible with the spatially defined management areas and their specific objectives.
8. Solicit public input on management of the resource for the benefit of all citizens.
9. Take into account socio-economic considerations during management decisions.
10. Ensure adherence to public health requirements during the deliberation of management decisions.

Sanctuary Objectives:

1. Increase oyster populations to levels that improve important ecological functions and yield adequate broodstock to sustain regional populations.
2. Improve oyster habitat and increase oyster biomass by utilizing appropriate techniques considering the influence of environmental conditions.
3. 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.
4. Conduct and complete large-scale restoration in five tributaries by 2025.
5. Support, enhance, and increase ecological restoration activities in other tributaries throughout the Chesapeake Bay.

Public Fishery Objectives:

1. Achieve a sustainable public oyster fishery.
2. Manage the oyster fishery according to science-based biological reference points through harvest rates that are based on oyster stock assessments.
3. Manage the oyster fishery using a combination of input and output controls, habitat modification and stock enhancement to meet targets and thresholds.

Aquaculture Objectives:

1. Support policies and partnerships that increase private investment in oyster aquaculture.
2. Expand oyster aquaculture production in areas of suitable habitat.

2.3 Adaptive Management

Adaptive management is a structured, iterative process of decision-making. It generally involves a variety of strategies and techniques that can be refined or modified based on input from monitoring results, new scientific research data and/or improved understanding from empirical observations. Since adaptive management is based on a learning process, initial objectives and actions will most likely need to change over time and will ultimately improve long-term management outcomes. Adaptive management requires feedback, flexibility and the ability to adapt and make necessary changes. Implementation of adaptive management could include establishing or modifying certain parameters of the oyster fishery by public notice to allow flexibility in developing a sustainable fishery.

Essential elements of adaptive management for oysters include biological considerations, results from restoration projects, evaluations of fishery management measures and the periodic reassessment of objectives. Oyster restoration efforts (activities to restore oyster populations for ecosystem and ecological benefits), replenishment (activities to improve the public fishery for economic benefits) and fishery management strategies may differ by salinity zone. The extent of disease mortality, natural recruitment and the results of activities in special management areas (sanctuaries and public fishery areas) will factor into the determination of the type of habitat and seed restoration, replenishment efforts and fishery management measures that take place in a particular salinity zone. Restoration activities will be focused in areas that will maximize the possibility of success, while optimizing monitoring and funding resources. Geospatial analysis of relevant data (e.g., salinity, bottom type, environmental conditions, spat settlement history, disease and biomass estimates, etc.) will aid in the decision-making process. Spatially explicit population dynamic models that include the major factors influencing mortality and recruitment rates across multiple salinity regimes, may help to develop appropriate management strategies. The department will also continue to support restoration activities in tributaries throughout Chesapeake Bay.

Adaptive Management Strategy 2.3

The department has practiced and will continue to practice a policy of adaptive management. Before oyster projects are implemented in Maryland's Chesapeake Bay, the results of previous efforts will be considered to formulate the best approach for each project.

Action 2.3.1

Utilize the best available data and knowledge from oyster projects collectively to maximize the success of each project.

Action 2.3.2

Utilize the following essential elements of adaptive management as a guideline to improve the success of oyster projects in consultation with stakeholders and partners:

1. Project Design: The department will provide as much information as possible about the methods and performance metrics for each project.
2. Objectives: Project objectives must relate to one or more of Maryland's oyster objectives.

3. Project Review Process: Project plans and site designations should be evaluated through an ongoing review process.
4. Monitoring: Projects must specify an adequate monitoring protocol and include, if necessary, funding to implement the monitoring. Data will be collected in a standardized format and maintained in compatible databases.
5. Evaluation: Results of projects will be shared among the restoration partners and stakeholders through the ongoing project review process and through the development of information management systems.
6. Application: The lessons learned from all of the previous steps will be incorporated into the next iteration of the adaptive management process starting with the project design, thereby improving the project outcomes over time.

Action 2.3.3
Utilize public notices to modify oyster fishery parameters as an adaptive management measures.

2.4 Salinity Influences on Oyster Populations

Salinity greatly affects oyster reproduction, recruitment and survival as well as the selection and success of restoration and replenishment activities. All oyster bars in Maryland are located in mesohaline salinities (5-18 ppt,) but can be divided into three broad zones: low (Zone 1), moderate (Zone 2) and high (Zone 3). Zone 1 has an average salinity greater than or equal to 5 and less than 1 ppt, Zone 2 has an average salinity greater than or equal to 11 and less than 15 ppt and Zone 3 salinities are greater than or equal to 15 ppt (U.S. Army Corps of Engineers, Norfolk District. 2009). These zones are governed by freshwater input from rivers, but are influenced by annual levels of rainfall, wind and tidal mixing. The boundaries of the low- and high-salinity zones are relatively well-defined, except in extreme climatic events (e.g., drought, freshet), while the boundaries of the moderate zone fluctuate annually. However, even the low and high zones can change dramatically due to either severe droughts or record freshets. The best way to visualize the changing nature of salinity boundaries is to create maps. Two seasons are represented as examples, spring (April-June) and summer (July-September) (Figures 6 and 7). To create the maps, salinity data from the Chesapeake Bay Program was averaged from 2000-2017.

By categorizing the mesohaline area of Chesapeake Bay into three zones, some generalizations about the effects of salinity on oyster life history and different management actions can be considered. These generalizations are based on long-term salinity patterns and are subject to modification as environmental conditions dictate.

Zone 1
Zone 1 generally encompasses the portion of the bay above the Bay Bridge in Maryland and the upper reaches of the Potomac, Choptank, Chester, Patuxent and other tributaries in Maryland.

Relative to the other zones, Zone 1 is characterized by lower levels of disease and better survival, but low reproductive capability. It is subject to intermittent, long-term freshets that can result in substantial mortality, particularly in the upper reaches of the zone. Disease exists in this zone, but low salinity greatly reduces impacts of disease so there is less disease mortality and oysters can live longer. However, because of the decreased salinity, spat settlement is very low, often nonexistent. To increase the oyster population, this area is dependent on planting seed (either hatchery or wild, natural seed). Continual seed plantings may be needed in areas that are not self-sustaining through natural recruitment especially at the current low spat settlement levels. Planting substrate is less cost effective and/or efficient than seed planting as a means to increase oyster population due to low recruitment.

Zone 2

Zone 2 has fluctuating boundaries based on climatic variation between wet and dry years. Although Zone 2 appears to be a rather narrow salinity range, it actually encompasses a broad geographic area. This zone experiences a range of spat settlement from low to moderate to high due to fluctuating environmental parameters, primarily salinity. Disease mortality can also fluctuate, generally increasing during drought years and decreasing during wetter periods. When disease mortality is low, this zone can experience rapid recovery of populations and biomass due to increased survival in combination with successful recruitment. The reverse can also happen just as quickly. Replenishment and restoration activities that occur within this area will have varying results depending on environmental and disease conditions.

Zone 3

Zone 3 is comprised of the lower bay mainstem, including Tangier and Pocomoke sounds. Salinities in this zone generally fall within what is thought to be the optimal salinity range for oysters (Shumway, 1996). Although disease pressure can be persistent and mortality rates high, reproductive capability is maximized so that there is likely to be consistent recruitment of new oysters. It has been theorized that oysters that survive intense disease epizootics in this zone may have a genetic disposition toward being more disease-tolerant. This zone may not experience the dramatic rebounds that are possible in Zone 2 if there are constant, high levels of disease mortality. Since 2003 disease issues have been low compared to the high disease levels in 1999-2002. Planting substrate in this zone may be an effective means to increase oyster populations because there is a higher probability of yearly spat settlement events. Planting seed may be necessary after high mortality events (e.g., disease related mortality).

Salinity Influences on Oyster Populations Strategy 2.4

Consider the influence of salinity on oyster populations when developing management strategies and actions for the oyster resource.

Action 2.4.1

Consider how salinity influences reproduction, growth and mortality (particularly from disease and freshets) when developing oyster project objectives for sanctuaries and harvest areas.

Action 2.4.2
Continue to closely examine current environmental parameters in each zone since salinity patterns will vary annually and zonal boundaries will shift and adjust actions as necessary to reach oyster project outcomes.

2.5 Partners

There are many state, federal and local agencies, organizations, and stakeholders actively involved in the oyster resource in Maryland and Chesapeake Bay. There are an array of objectives, directives and interests among the groups. The ultimate goal of the department is a thriving oyster resource that benefits the ecology, culture and economy of the Chesapeake Bay. The multi-faceted challenge of managing oysters is bigger than one group can solve alone. It is in the best interest of all partners to utilize a strategic framework that will focus goals and objectives, minimize redundancy and optimize the use of limited resources. Working cooperatively will require a commitment from each group to coordinate with the department for the planning, monitoring, permitting and implementation of management strategies and actions for sanctuaries, the public fishery and associated industries and aquaculture.

A coordination process will integrate group effort and ultimately improve oyster outcomes. It is a continuous process that requires effective leadership and communication to facilitate information and exchange ideas. Effective coordination involves an accepted organizational structure and direct interactions through committees and meetings. Each group must take responsibility for participating in the process.

Partner Strategy 2.5
The department will promote the effective coordination of state, federal and local agencies, organizations, and stakeholders to meet oyster outcomes for the ecology, culture and economy of the Chesapeake Bay.

Action 2.5.1
Engage state, federal and local agencies, organizations, and stakeholders in the development and implementation of effective coordination strategies that maximize cooperation and meet oyster resource planning objectives and policies.

3.0 Substrate

Oyster larvae require a hard, sediment-free substrate to set upon and metamorphose into oyster spat. This substrate is often oyster shell. Oysters are unique in that they create the habitat required for population growth. Shell mass increases when oysters die in place but decreases when oysters are removed by harvest (Soniat et al., 2014). Planting shell may be able to sustain a constant shell mass in specific areas over short time periods, but may not be able to maintain a positive shell budget throughout Maryland's Chesapeake Bay over the long term. In the absence of harvest and other anthropogenic effects, the rate of shell accretion through recruitment, growth and mortality exceeds by some small amount the rate of shell loss (Mann and Powell, 2007). Reefs with higher profiles above the bay bottom appear to promote enhanced oyster productivity due to less sedimentation and hydrodynamic effects. Low-profile reefs are subject to sediment deposition on the reef surface thus making the substrate less suitable for recruitment.

Maryland's Chesapeake Bay is currently shell limited, where shell loss is greater than shell accretion and there is not enough fresh or dredged shell to replenish and restore all oyster habitat (Maryland Department of Natural Resources, 2018). Oyster shell plantings in low recruitment areas may not be the best use of the limited shell available, however, oyster seed (which consist of live oysters and shell) may be a better option for public fishery replenishment and sanctuary restoration. Fresh shell comes from shucking houses and dredged shell comes from old shell deposits buried in the bay bottom. Currently, there are few shucking houses in Maryland and most fresh shell is being purchased from an out-of-state vendor. The cost of shucked shell increased from $0.50 per bushel in 2006 to $2.75 per bushel in 2017. There are few deposits of buried shell left in Maryland's portion of Chesapeake Bay and the department does not have an open permit to dredge shell from those remaining deposits at this time. The U.S. Army Corps of Engineers (USACE), Baltimore District, proffered a provisional permit to the department to dredge some shell from the Man O'War Shoal on May 17, 2018. Upon the approval of a Water Quality Certification and Coastal Zone Management Consistency concurrence by the Maryland Department of the Environment, this permit can be validated by the USACE. The Department is also exploring other potential shell deposits in the Bay to determine their viability as a source. Shell can also be recycled from restaurants, the public, food festivals and other events for hatchery use after they are cleaned and aged, but these supplies are limited.

Due to oyster shell limitations, alternative substrates have been used in restoration projects such as:

- Biogenic: mixed clam and other shellfish shell and fossilized shell.
- Geologic: sandstone, stone including granite and amphibolite and limestone marl.
- Anthropogenic: porcelain, concrete (including crushed rubble, oyster castles and oyster reef balls) and stabilized coal ash.

Many considerations should be examined when selecting substrate for oyster replenishment and restoration activities. Geologic and anthropogenic substrates may not be preferred in public fishery areas due to fishing gear constraints. Geologic and anthropogenic substrates could be the most viable option for oyster sanctuaries but should be used in a manner that does not negatively impact the Chesapeake Bay (e.g. creating navigational issues by altering the water depth, introduction of pollution or contaminants, etc.). Using some geologic and anthropogenic substrates as a foundation in restoration may provide more interstitial space and three-dimensional structure, thus increasing the ecosystem benefit of reefs as habitat for more species and increasing surface area for spat settlement. Geologic and anthropogenic substrates can also be used in combination with natural oyster shell.

Substrate Strategy 3.0
Promote the conservation and protection of natural oyster substrate (oyster shell) and evaluate and utilize alternative substrates as a method to ensure that the rate of habitat accretion exceeds loss.

Action 3.0.1
Develop a decision-making process on how to equitably utilize limited natural shell and alternative substrates for sanctuary restoration, fishery enhancement and aquaculture and make decisions according to the process.

Action 3.0.2
Explore options for the mitigation of shell loss.

Action 3.0.3
Promote the creation of oyster reefs with higher profiles above the bay bottom to enhance oyster productivity.

Action 3.0.4
Develop a shell budget that will lead to practical applications, such as but not limited to, managing shell plantings, enhancing reef restoration, identifying areas of harvest closures/openings and determining total allowable catch.

Action 3.0.5
Evaluate and develop cost-effective strategies to identify sources and quality of shell and alternative substrate to supplement oyster habitat throughout Maryland’s Chesapeake Bay.

Action 3.0.6

Develop comprehensive maps of current oyster habitat within Maryland's Chesapeake Bay that include updated oyster bar boundaries and utilize best available data to locate oyster habitat and ground-truth the best areas for placing available substrate.

Action 3.0.7
Promote and support shell recycling from viable public or private sources.

Action 3.0.8
Evaluate potential strategies including private sector engagement, public-private partnerships (P3s), and economic incentives to retain processed shell in Maryland.

Action 3.0.9
Evaluate the feasibility and effectiveness of utilizing different alternative substrates in public fishery areas for the purpose of improving harvest.

4.0 Stock Status

In 2018, the department, in consultation with the University of Maryland Center for Environmental Science, conducted the first Maryland oyster stock assessment and developed biological reference points based on the biological characteristics of the oyster population and other factors affecting the population. In the final year of the stock assessment which was the 2017-2018 season, overfishing was occurring in 19 of the 36 areas assessed. However, the oyster population was not classified as overfished or depleted (section 4.1). The results of the oyster stock assessment provide a basis for the department to work with stakeholders to determine management approaches (Maryland Department of Natural Resources, 2018).

The oyster stock assessment included data from 1999 through 2017 for each National Oceanic and Atmospheric Administration (NOAA) code harvest reporting region within Maryland's Chesapeake Bay. The time frame of 1999 to 2017 was used in the assessment because of consistent data reporting methods since 1999 and not due to any biological or environmental factors. Maryland-wide, the estimated abundance of market oysters varied between approximately 200 and 600 million individuals over the assessment period (Figure 8). Estimated market abundance was highest in 1999, the initial year of the time series, decreased to about 200 million individuals by 2002 and remained close to that level until 2010. After 2010, estimated market abundance increased through 2014 to more than 450 million and declined to about 300 million thereafter. In 1999, estimated market abundance was highest in the Choptank River and Eastern Bay regions. After 2006, estimated abundance was highest in the Choptank River and Tangier Sound regions. By 2017, estimated market abundance in all Maryland regions was higher than it was during 2002-2007, but lower than in 1999. This pattern of increase toward 1999 levels of abundance differed among regions, with some regions showing little to no increase and others showing substantial increases in market oyster abundance since 2002.

Determining mortality estimates is a critical component of assessing the status of the oyster stock. Natural mortality was generally higher and more variable in the beginning of the time series (1999 to 2002) than in more recent years, which corresponds with greater disease intensity. Despite similar temporal patterns, the year in which natural mortality was lower and less variable varied among the regions of Maryland's Chesapeake Bay. For example, in most of the Tangier Sound region, natural mortality became lower and less variable later than in the Choptank region. In general, average natural mortality was lower in both the northern part of Maryland's Chesapeake Bay and farther upstream in the tributaries.

The harvest fraction for each NOAA code is calculated as a percentage of market-size oysters (greater than or equal to 3 inches) removed from the population by commercial harvest. This varied over time and among NOAA codes, ranging from zero to approximately 80 percent per year. Harvest fraction often tracked abundance in the NOAA codes so that when abundance was increasing over time and there were no large sanctuaries, the percentage of oysters harvested generally increased over the same time period. On average, the harvest fraction was highest in the Tangier Sound region and neighboring NOAA codes. In NOAA codes with no trend or a declining trend in abundance, harvest fraction tended to be low, but showed some variability.

Stock Status Strategy 4.0
The status of the oyster stock will be evaluated through periodic stock assessments using monitoring data, best available scientific methodology, environmental considerations and other relevant information and used to guide oyster management.

Action 4.0.1
Continue to conduct oyster monitoring, including fishery independent and fishery dependent surveys, to provide data for the stock assessment.

Action 4.0.2
Conduct a Maryland Chesapeake Bay stock assessment at least once every two to five years to provide information on the status of oysters, re-examine stock assessment methods and parameters and make any necessary adjustments to the biological reference points.

Action 4.0.3
Continue to refine the oyster stock assessment by improving and incorporating available data.

4.1 Biological Reference Points

Biological reference points are metrics used to assess the status of a stock and for fishery management they are usually associated with levels of biomass or abundance and fishing mortality. Maryland law requires that fishery management plans contain the best available estimates of sustainable harvest rates and minimum abundance levels (Natural Resources Article, §4-215, Annotated Code of Maryland). Specifically, the statute requires the development of a lower limit (threshold) reference point for abundance and target and upper limit (threshold) reference points for harvest fraction (fishing levels). Additionally, there must be objective and measurable means to determine if the oyster fishery is operating within the reference points.

The threshold (or lower limit) abundance reference point is used to identify the level at which a fishery is considered overfished or depleted. It represents an abundance of oysters below which there are likely to be biological, social, ecological and/or economic consequences. An overfished status does not necessarily result from just harvest but could be the result of other factors such as an extended period of low recruitment or an extreme natural mortality event. Harvest pressure is also a consideration. The stock assessment proposed threshold abundance reference point is the minimum estimated number of market oysters during the period 1999-2017 for each NOAA code

(Table 1). The choice of the time-series minimum as an abundance threshold is based on the fact that oysters in most NOAA codes have been able to increase in abundance from their lowest observed levels, but it is unknown whether populations would be able to persist or even rebound, if they go below those levels. Market-size oysters were chosen for the threshold because they are the targeted size group of the fishery and they also produce more eggs per individual than small oysters (oyster shell height less than 3 inches but older than 1 year in age). This reference point (using markets) is proposed as an operational definition for depleted status, similar to the previously used abundance reference points for blue crabs in Chesapeake Bay. Given the current low abundance of oysters relative to historic periods and significant changes in the ecosystem (e.g., habitat loss, salinity, disease), it was not possible to generate a suitable method for calculating an abundance target.

The year with the minimum estimated abundance of market-size oysters varied by NOAA code (Table 2). The minimum value was reached during 2000-2007 for 22 NOAA codes. Minimum estimated abundance occurred during the last year of the assessment, 2017, in four NOAA codes and two NOAA codes had their minimum estimated market abundance in the second to the last year (Figure 9). The majority of NOAA codes had an estimated market abundance well above the lower limit abundance reference point in 2017. However, NOAA codes in the Chester River and one bay mainstem NOAA code had their minimum value in the last year (i.e., at the lower limit). In addition, two other NOAA codes (129 and 192) had their lowest abundance values in the second to the last year.

Table 1: Biological Reference Point from 2018 Oyster Stock Assessment based on data from 1999 to 2017.

NOAA Code	NOAA Code Region	NOAA Code Name	Abundance Threshold (minimum millions of market-size oysters)	Threshold Fishing Mortality	Target Fishing Mortality
25	Mainstem	Bay Mainstem Upper	5.29	0	0
127		Bay Mainstem Upper Middle	12.73	0	0
27		Bay Mainstem Lower Middle	1.3	0.1	0.05
129		Bay Mainstem Lower Eastern Shore	1.19	0.23	0.12
229		Bay Mainstem Lower Western Shore	2.66	0.06	0.03

131	Chester	Chester River Lower	4.6	0	0
231		Chester River Middle	4.81	0	0
331		Chester River Upper	0.57	0	0
82	Upper Bay Western Tributaries	Severn River	1.62	0	0
88		South River	0.89	0	0
39	Eastern Bay	Eastern Bay	4.15	0.02	0.01
60		Miles River	2.79	0	0
99		Wye River	0.37	0	0
137	Choptank	Choptank River Lower	0.51	0.14	0.07
237		Choptank River Middle	2.7	0	0
337		Choptank River Upper	8.5	0	0
437		Harris Creek	2.84	0.02	0.01
537		Broad Creek	5.4	0.16	0.08
637		Tred Avon River	2.78	0	0
53		Little Choptank River	0.85	0.03	0.02
168	Patuxent	Patuxent River Lower	2.07	0.08	0.04
268		Patuxent River Middle	0.27	0.03	0.01
368		Patuxent River Upper	2.4	0	0

5	Tangier	Big Annemessex River	0.28	0.12	0.06
43		Fishing Bay	0.31	0.45	0.22
47		Honga River	1.75	0.32	0.16
57		Manokin River	0.51	0.14	0.07
62		Nanticoke River	2.42	0	0
72		Pocomoke Sound	2.06	0.19	0.09
292		Tangier Sound North	4.14	0.28	0.14
192		Tangier Sound South	5.05	0.26	0.13
96		Wicomico River East	0.3	0.02	0.01
86	Potomac	Smith Creek	0.21	0.13	0.07
174		St. Clements And Breton Bay	0.04	0.01	0
78		St. Mary’s River	0.18	0.26	0.13
274		Wicomico River West	3.46	0	0

In determining appropriate target and threshold harvest fractions to propose for Maryland’s oyster resource, there was consideration of Natural Resources Article, §4-215, Annotated Code of Maryland which states that conservation and management measures adopted under a fishery management plan, to the extent possible “shall prevent overfishing while attempting to achieve the best and most efficient utilization of the State's fishery resources.” Therefore, the recommended target exploitation rate (U) is that which provides maximum sustainable yield (MSY). If U_{MSY} is achieved annually, it is expected to result in a maximum harvest over time, while resulting in a stable or increasing oyster population (given current abundances of oysters in Maryland) (Maryland Department of Natural Resources, 2018).

In order to prevent overfishing, the recommended upper limit for harvest from the 2018 stock assessment is equivalent to the estimate of U_{CRASH} which represents the absolute maximum harvest fraction that would allow sustainable harvest. If U_{CRASH} is exceeded over time, it will eventually result in the disappearance of the population. As noted in Section 3.0, a limiting factor for oyster population growth is likely their ability to produce shell. Therefore, shell production is an important process to include in sustainable harvest reference point calculations for oysters. In the 2018 assessment, the target (U_{MSY}) and limit (U_{CRASH}) reference points were estimated separately for each NOAA code using a harvest fraction reference point model that describes population growth as a function of abundance with carrying capacity determined by the amount of habitat (Table 1, Figure 10 and 11). The amount of habitat depends on habitat production from living oysters, habitat loss, habitat plantings and a maximum amount of potential oyster habitat in the system.

For each NOAA code, the correct harvest fraction to use for comparison to the reference points depends on the management objective for the planted oysters. If oysters were planted with an objective of supplementing the fishery, then the harvest fraction that accounts for planted oysters would be the most appropriate for comparison with the reference points. If the oysters were planted as part of restoration efforts to increase population size, then the harvest fraction that does not include planted oysters should be used. Annual estimates of harvest fraction from the assessment model can be compared to the reference points. The adjusted and unadjusted time series of harvest fraction for each NOAA code relative to the reference points are shown in Tables 3 and 4.

The 2018 stock assessment produced estimates of U_{CRASH}, ranging from zero to 0.45 per year and estimates of U_{MSY}, ranging from zero to 0.22 per year among NOAA codes. Estimates of the target and limit reference point were highest, on average, in the southernmost NOAA codes, Tangier Sound and the Potomac tributaries and were lower for the more northerly regions.

In the terminal year of the 2018 assessment which was the 2017-2018 harvest season, there was substantial variability among NOAA codes and regions in their status relative to the harvest fraction reference points. In the 2017-2018 harvest season, overfishing was occurring in 19 of the 36 areas assessed if harvest fraction is adjusted for spat plantings (Figure 12, Table 4). The number of areas where overfishing is occurring increases to 31 with unadjusted values of harvest fraction (Table 3). In areas with targets and/or thresholds at 0 percent, oyster harvest is not sustainable without planting activities.

Biological Reference Point Strategy 4.1
Utilize biological reference points generated through the most recent stock assessment to determine the status of the oyster stock.

Action 4.1.1

Utilize biological reference points to determine the status of the oysters in Maryland's Chesapeake Bay and update the biological reference points based on the stock assessment.

Action 4.1.2

Develop risk-averse harvest management strategies based on the biological reference points to achieve the target harvest fraction.

1) Determine the appropriate regional scale for managing oysters.
2) Develop triggers for implementing management measures when targets and thresholds are not met or exceeded such as a certain percentage of small oysters that may become market-size in the future within a specific NOAA code.
3) Engage stakeholders in the process of developing harvest management strategies.

Action 4.1.3

Evaluate and develop target levels of abundance including biological limits of abundance.

Table 2. Estimated market abundance in millions (1999 – 2017) in each NOAA code relative to the threshold abundance reference point (Nref). Green indicates estimates above and brown equal to the threshold. Because the threshold is the lowest value in the time series, no areas are depleted.

NOAA code	N_{ref}	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
5	0.28	0.32	0.28	0.49	0.44	0.67	1.38	0.8	0.47	0.56	1.41	1.02	0.78	0.48	0.82	0.67	0.37	1.16	0.43	0.43
25	5.29	28.03	21.81	21.19	16.49	12.91	13.13	30.16	17.72	13.57	19.52	25.58	18.49	5.68	7.03	5.29	8.12	7.28	7.58	8.35
27	1.3	6.43	4.21	2.48	1.3	1.65	2.53	3.41	2.85	1.39	1.65	2.82	2.72	2.46	4.1	3.27	8.73	7.63	4.06	3.08
39	4.15	65.8	60.25	29.97	16.75	20.05	40.01	44.52	27.26	11.32	9.56	4.15	9.02	12.82	19.42	21.99	26.58	25.78	19.22	18.65
43	0.31	8.62	6.45	4.1	2.63	1.28	1.19	0.31	0.33	0.38	4.82	5.6	6.03	7.45	20.22	16.7	10.68	6.51	3.68	2.66
47	1.75	7.54	4.22	5.02	2.49	5.9	4.91	1.75	1.81	2.18	9.76	7.74	5.07	7.78	14.74	10.02	8.58	7.04	3.34	2.78
53	0.85	47.59	40.15	19.57	0.85	1.76	9.01	13.29	14.93	12.59	20.12	17.27	16.14	29.89	46.98	46.59	55.38	52.96	33.36	28.71
57	0.51	1.55	1.05	2.28	1.22	2.1	3.88	0.95	0.57	0.51	1.46	1.5	1.11	1.66	3.56	3.66	4.24	3.7	2.65	2.76
60	2.79	19.64	15.02	8.96	4.06	6.32	7.1	11.68	8.53	5.1	4.08	2.79	3.06	3.54	4.92	5.36	5.31	5.33	4.48	3.67
62	2.42	14.75	12.13	9.08	2.73	2.42	5.99	7.44	5.92	4.84	6.87	8.38	10.23	11.07	14.06	14.51	20.31	20.5	17.87	18.74
72	2.06	6.03	6.8	5.86	5.9	5.18	7.45	2.06	2.12	3.41	3.62	3.55	3.4	5.02	14.79	12.2	8.9	5.04	3.48	3.23
78	0.18	4.89	3.57	3.42	0.18	0.88	1.07	2.83	2.4	1.55	2.67	4.14	2.25	2.39	4.98	5.05	12.21	7.95	2.64	5.03
82	1.62	13.58	24.69	23.86	12.33	7.79	5.09	3.61	2.25	1.63	1.79	2.88	4.49	1.62	3.4	3.37	3.04	4.1	3.58	2.09
86	0.21	0.45	0.33	0.3	0.21	0.26	0.29	0.39	0.45	0.4	0.74	0.46	0.32	0.3	0.91	0.78	1.06	0.93	0.48	0.56
88	0.89	5.38	5.86	2.17	3.13	2.49	2.59	3.75	2.59	0.89	1.69	1.5	1.35	1.11	2.16	1.29	2.87	2.91	2	1.58
96	0.3	2.56	2.08	0.65	0.74	0.6	0.61	0.43	0.3	0.36	0.36	0.39	0.48	1.29	1.85	3.18	4.65	3.81	1.92	1.2
99	0.37	6.8	5.21	1.64	0.74	1.16	1.3	1.22	1.19	0.9	0.6	0.5	0.37	0.37	0.53	0.54	1.43	1.51	1.15	0.77
127	12.73	56.8	57.87	55.61	30.71	20.81	26.2	48.44	27.99	24.82	29.15	17.82	12.76	12.93	16.23	16.12	15.59	16.4	14.42	12.73
129	1.19	5.89	3.73	1.59	1.42	3.55	12.12	15.28	12	2.99	2.08	3.66	3.99	4.37	5.28	3.33	2.27	1.39	1.19	3.09
131	4.6	24.73	17.77	16.41	8.23	7.05	6.67	8.3	7.71	10.72	10.06	6.44	6.57	10.15	10.35	9.87	8.43	6.75	5.14	4.6
137	0.51	13.36	11.31	7.66	0.51	0.7	1.5	1.83	2.45	1.89	2.28	2.34	2.41	4.71	9.77	12.22	14.08	9.34	3.83	2.33
168	2.07	5.04	3.42	3	2.07	4.6	11.61	11.39	6.48	4.73	6.9	7.42	7.61	8.79	12.85	11.22	21.37	17.2	7.35	5.84
174	0.04	0.42	0.34	0.31	0.08	0.05	0.05	0.04	0.04	0.04	0.12	0.1	0.11	0.11	0.08	0.08	0.16	0.16	0.1	0.07
192	5.05	12.11	7.19	15.66	6.28	15.23	16.67	8.63	7.65	7.77	19.49	17.3	15.84	15.66	23.76	19.49	15.09	10.17	5.05	6.13
229	2.66	3.77	3.21	3.03	2.66	5.95	10.31	10.67	8.13	4.46	4.92	4.72	3.26	3.51	5.04	4.87	7.75	7.55	4.88	5.8
231	4.81	76.58	70.41	35.72	22.69	14.84	30.41	16.2	15.33	10.6	8.44	9.3	8.2	7.23	7.37	9.65	7.92	8.01	6.8	4.81
237	2.7	20.67	18.02	15.31	5	2.7	8.64	10.14	9.6	7.84	10.64	12.15	12.39	16.49	18.4	21.02	22.1	20.16	15.94	12.95
268	0.27	3.21	3.75	3.7	0.27	0.33	1.23	1.42	1.21	0.8	0.73	1.71	2.29	2.53	3.19	3.93	3.92	3.26	1.7	1.06
274	3.46	14.96	13.19	15.63	7.21	6.82	10.36	16.05	13.7	4.32	6.01	6.6	5.46	6.53	6.68	4.87	3.46	8.43	6.56	6.58
292	4.14	15.86	10.81	15.24	7.39	6.99	14.42	4.89	4.14	4.87	10.34	9.19	10.7	13.54	32.22	26.63	24.25	17.35	9.2	14.23
331	0.57	4.56	4.45	4.21	3.33	3.07	2.28	2.31	2.26	1.77	1.88	1.29	0.63	0.86	0.83	0.74	0.64	0.79	0.68	0.57
337	8.5	31.07	26.08	33.66	16.02	12.11	8.5	9.78	8.58	9.15	11.71	13.03	15.66	20.09	22.42	21.44	22.47	23.2	20.85	16.94
368	2.4	8.87	6.73	2.93	2.65	2.4	3.64	4.54	4.33	2.44	3.19	3.3	3.27	4.4	4.33	4.38	6.69	6.16	3.62	2.4
437	2.84	37.11	30.27	25.77	3.35	2.84	5.04	7.66	10.7	5.93	7.96	5.13	3.72	5.1	15.99	31.25	48.42	40.1	23.09	27.95
537	5.4	31.66	28.27	23.99	5.85	5.4	13.18	17.65	27.9	16.09	13.68	10.57	18.79	29.6	44.84	33.23	44.61	38.93	25.52	27.37
637	2.78	12.76	11.44	8.48	2.78	3.87	5.02	5.55	6.48	6.02	5.97	4.73	5.16	8.38	10.86	10.59	14.35	13.05	10.28	10.69

Table 3. Estimated harvest fraction (U, unadjusted) for plantings for market oysters during 1999-2017 in each NOAA code relative to the threshold (Ucrash) and target (Umsy) reference points. Green indicates estimates at or below the target, brown indicates estimates above the target but equal to or below the threshold, and red indicates estimates above the threshold reference point. These estimates would be used for areas where the management objective for plantings is restoration.

NOAA code	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	U_{crash}	U_{msy}
5	0.14	0	0.07	0	0	0	0.03	0.01	0	0	0	0	0.12	0.02	0.26	0.36	0.81	0.25	0	0.12	0.06
25	0.02	0.03	0.03	0.06	0.01	0.02	0	0.02	0.03	0.03	0.02	0.05	0	0	0	0.02	0.12	0.14	0.07	0	0
27	0.32	0.07	0.05	0.05	0.02	0.01	0.02	0.39	0.08	0.11	0.08	0.13	0.03	0.15	0.47	0.18	0.4	0.32	0.19	0.1	0.05
39	0.24	0.42	0.23	0.06	0.06	0.09	0.22	0.3	0.15	0.15	0.12	0.04	0	0.05	0.17	0.07	0.11	0.18	0.11	0.02	0.01
43	0	0	0	0.03	0	0.02	0.01	0	0.05	0.15	0.42	0.24	0.51	0.56	0.85	0.83	0.67	0.84	0.57	0.45	0.22
47	0	0	0	0.05	0.01	0.13	0.03	0.02	0.08	0.42	0.56	0.19	0.27	0.32	0.58	0.57	0.42	0.74	0.16	0.32	0.16
53	0.16	0.15	0.03	0.05	0.13	0	0.06	0.06	0.03	0.01	0	0	0.01	0.01	0.01	0.02	0.01	0.01	0	0.03	0.02
57	0.01	0.04	0.21	0.17	0.16	0.17	0.04	0.05	0.07	0.01	0.06	0.01	0	0.01	0.12	0.17	0.09	0.1	0.16	0.14	0.07
60	0.4	0.3	0.17	0	0	0.01	0.07	0.03	0	0.05	0	0	0	0	0.03	0.08	0.14	0.08	0.03	0	0
62	0.11	0.01	0.05	0.03	0	0.04	0.01	0	0.01	0	0.06	0.01	0.1	0.19	0.15	0.16	0.08	0.1	0.09	0	0
72	0	0	0	0	0	0.01	0	0.03	0.06	0.04	0.04	0	0.15	0.55	0.63	0.46	0.47	0.4	0.37	0.19	0.09
78	0.18	0.4	0.11	0	0	0.02	0.05	0.19	0.18	0.14	0.16	0.08	0.08	0.46	0.34	0.19	0.27	0.63	0.82	0.26	0.13
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0	0	0	0	0
86	0.35	0	0	0	0	0	0	0.02	0.02	0.02	0.01	0.01	0.01	0.17	0.25	0.23	0.26	0.37	0.4	0.13	0.07
88	0.03	0.01	0.03	0.01	0	0.01	0.01	0.07	0.11	0.08	0.14	0.07	0.06	0.17	0.48	0.06	0.19	0.22	0.15	0	0
96	0.03	0	0.01	0	0	0	0	0.01	0.01	0.07	0.04	0.11	0.13	0.28	0.2	0.14	0.59	0.56	0.19	0.02	0.01
99	0.33	0.47	0.25	0.02	0	0.03	0.02	0	0	0	0.1	0	0	0.04	0	0.01	0	0	0.01	0	0
127	0.01	0.01	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0.01	0.06	0.05	0	0
129	0.13	0.1	0	0.01	0.01	0.01	0	0	0.13	0.48	0.35	0.01	0.03	0.28	0.63	0.87	0.29	0.11	0.26	0.23	0.12
131	0.27	0.04	0.04	0.02	0.01	0.07	0.01	0.08	0.05	0.05	0.02	0.02	0	0	0.01	0.05	0.04	0.02	0.12	0	0
137	0.09	0	0.03	0.02	0	0.04	0.01	0.27	0.25	0.24	0.15	0.23	0.07	0.26	0.28	0.45	0.61	0.65	0.64	0.14	0.07
168	0	0	0	0	0	0	0.02	0.03	0	0.01	0.01	0.07	0.17	0.23	0.35	0.38	0.54	0.53	0.27	0.08	0.04
174	0.08	0	0	0	0	0	0.16	0	0	0.23	0.05	0	0.09	0.06	0	0	0	0.12	0.08	0.01	0
192	0.04	0.04	0.06	0.16	0.04	0.21	0	0.11	0.19	0.12	0.38	0.24	0.35	0.38	0.54	0.37	0.65	0.43	0.27	0.26	0.13
229	0.01	0	0.02	0	0	0.02	0	0.01	0	0.02	0.08	0.01	0.07	0.08	0.21	0.12	0.08	0.18	0.21	0.06	0.03
231	0.1	0.05	0.08	0.1	0	0.01	0.04	0.06	0.04	0.05	0.03	0.07	0	0	0	0.04	0.01	0.01	0.13	0	0
237	0.01	0.07	0.05	0.02	0	0	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.05	0.11	0.08	0.11	0	0
268	0.02	0	0	0	0	0	0.02	0.06	0.03	0	0.04	0.13	0.03	0.02	0.1	0.21	0.34	0.29	0.2	0.03	0.01
274	0.13	0.04	0.01	0.01	0	0	0.02	0	0.04	0.03	0.02	0.04	0.01	0.14	0.3	0.25	0.15	0.12	0.03	0	0
292	0.01	0	0.01	0.07	0.1	0.12	0.06	0.09	0.19	0.13	0.17	0.02	0.29	0.26	0.49	0.48	0.85	0.89	0.53	0.28	0.14
331	0.09	0	0	0.09	0	0.01	0	0	0	0	0.01	0.63	0	0	0	0.01	0	0	0.03	0	0
337	0.05	0.01	0.04	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
368	0.03	0	0	0	0	0	0.01	0.02	0.04	0.02	0	0.05	0.01	0.02	0.06	0.15	0.21	0.23	0.15	0	0
437	0.11	0.19	0.01	0	0	0	0.04	0.12	0.11	0.05	0.01	0.06	0.08	0.04	0.03	0.04	0.04	0.03	0.03	0.02	0.01
537	0.13	0.3	0.03	0.03	0.04	0.02	0.13	0.43	0.29	0.1	0.05	0.07	0.09	0.37	0.53	0.31	0.4	0.29	0.28	0.16	0.08
637	0.06	0.18	0.02	0	0	0.01	0.01	0	0	0	0	0	0.01	0.02	0.04	0.04	0.07	0.05	0.02	0	0

Table 4. Estimated harvest fraction (adjusted for plantings) for market oysters during 1999-2017 in each NOAA code relative to the threshold (Ucrash) and target (Umsy) harvest fraction reference points. Green indicates estimates at or below the target, brown indicates estimates above the target but equal to or below the threshold, and red indicates estimates above the threshold reference point. These estimates would be used in areas where the management objective for plantings is to supplement the fishery

NOAA code	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	U_{crash}	U_{msy}
5	0.14	0	0.07	0	0	0	0.03	0.01	0	0	0	0	0.12	0.02	0.26	0.36	0.81	0.25	0	0.12	0.06
25	0.02	0.03	-0.44	-1.42	-3	-8.9	-19.3	-3.11	-6.19	-15.16	-18.9	-7.43	-4.98	-5.28	-0.79	-2.3	-2.03	-1.08	-1.69	0	0
27	0.32	0.07	0.05	0.05	0.02	0.01	0.02	0.39	0.08	-2.01	-6.27	-4.65	-2.26	-0.33	0.34	0.18	0.4	0.32	0.07	0.1	0.05
39	0.24	0.42	0.2	0.04	0.06	0.09	0.22	0.3	0.15	-0.02	-0.2	-2.16	-2.5	-0.96	-0.47	-0.19	-0.03	0.16	0.1	0.02	0.01
43	0	0	0	-0.25	-0.31	-0.16	-0.13	-0.06	0.02	0.15	0.42	0.24	0.51	0.56	0.85	0.83	0.67	0.82	0.54	0.45	0.22
47	0	0	0	0.05	0.01	0.13	-0.19	-0.22	-0.07	0.41	0.56	0.19	0.12	0.29	0.58	0.57	0.42	0.74	0.162	0.32	0.16
53	0.16	0.15	0	0.01	0.06	-0.01	0.05	0.06	0.03	0.01	0	0	0.01	0.01	-0.01	0	0	-0.02	-0.16	0.03	0.02
57	0.01	0.04	0.21	0.17	0.16	0.17	0.04	0.05	0.07	0.01	0.06	0.01	-0.15	-0.06	0.08	0.17	0.09	0.1	0.16	0.14	0.07
60	0.4	0.3	0.1	-0.02	-0.01	0	0.07	0.03	0	0.05	0	-0.15	-0.17	-0.12	-0.07	0.02	0.14	0.08	0.03	0	0
62	0.11	0.01	0.05	-0.34	-1.04	-2.3	-3.41	-3.68	-3.65	-2.73	-2.75	-1.35	-0.77	-0.12	0.08	0.16	0.08	0.05	0.05	0	0
72	0	0	-0.03	-0.02	-0.01	0	0	0.03	0.06	0.04	0.04	0	0.15	0.55	0.63	0.46	0.47	0.4	0.37	0.19	0.09
78	0.18	0.4	0.11	0	0	0.02	0.05	0.19	0.18	0.14	0.16	0.03	0.07	0.46	0.34	0.19	0.27	0.63	0.81	0.26	0.13
82	0	0	-0.01	-0.01	-0.01	-0.02	-0.03	-0.03	-0.02	-0.23	-0.15	-0.87	-1.88	-6.45	-6.31	-6.56	-9.95	-9.22	-6.25	0	0
86	0.35	0	0	0	0	0	0	0.02	0.02	0.02	0.01	0.01	0.01	0.17	0.25	0.23	0.26	0.37	0.4	0.13	0.07
88	0.03	0.01	-0.2	-0.09	-0.11	-0.52	-0.78	-0.54	-0.24	-2.59	-3.19	-4.37	-3.85	-5.99	-2.07	-8.95	-6.86	-5.24	-3.01	0	0
96	0.03	0	0.01	-1.01	-1.15	-0.71	-0.62	-0.52	-0.26	-0.11	-0.03	0.1	-1.64	-0.25	-1.57	-0.35	0.49	0.55	0.18	0.02	0.01
99	0.33	0.47	0.25	0.02	0	0.03	0.02	0	0	0	0.1	0	0	0.04	0	0.01	0	0	0.01	0	0
127	0.01	0.01	-0.34	-0.65	-0.87	-1.28	-3.23	-3.77	-5.73	-9.19	-10.5	-9.32	-4.54	-1.26	-0.96	-0.78	-0.59	-0.48	-0.43	0	0
129	0.13	0.1	0	0	0.01	0.01	0	0	0.13	0.48	0.35	0.01	0.03	0.28	0.63	0.87	0.29	0.11	0.26	0.23	0.12
131	0.27	0.04	-0.1	-0.26	-0.28	-0.32	-0.78	-0.64	-1.57	-1.82	-1.94	-2.88	-5.98	-8.66	-11.24	-9.6	-4.24	-2.39	-1.34	0	0
137	0.09	0	0.03	-0.02	-0.02	0.03	0.01	0.27	0.25	0.24	0.15	0.23	0.07	0.15	-0.02	0.37	0.58	0.64	0.63	0.14	0.07
168	0	0	-0.21	-0.6	-0.47	-0.48	-0.47	-0.4	-0.37	-1.02	-1.71	-1.36	-0.7	0.02	0.34	0.3	0.5	0.51	0.12	0.08	0.04
174	0.08	0	0	0	0	0	0.16	0	0	0.23	0.05	0	0.09	0.06	0	0	0	0.12	0.08	0.01	0
192	0.04	0.04	0.06	0.16	0.04	0.21	0	0.11	0.19	0.12	0.35	-0.17	0.13	0.34	0.52	0.36	0.63	0.36	0.24	0.26	0.13
229	0.01	0	0.02	0	0	0.02	0	0.01	0	0.02	0.08	0.01	0.07	0.08	0.21	-0.49	-0.78	-0.46	0.03	0.06	0.03
231	0.1	0.05	-0.19	-0.66	-1.5	-6.56	-7.12	-2.96	-2.43	-4.01	-2.69	-4.35	-5.06	-2.8	-0.88	-0.65	-0.46	-0.42	-0.31	0	0
237	0.01	0.07	-0.16	-0.13	-0.1	-1.96	-1.73	-1.47	-1.35	-0.6	-0.41	-0.52	-1.19	-1.42	-1.86	-1.12	-0.87	-0.55	-0.33	0	0
268	0.02	0	-0.01	-0.01	-0.07	-0.02	0	0.06	0.03	0	0.04	-0.01	-0.02	0	0.09	0.2	0.34	0.29	0.2	0.03	0.01
274	0.13	0.04	-0.43	-0.54	-1.09	-4.01	-7.54	-8.2	-5.48	-7.82	-9.1	-2.34	-1.29	-0.84	-0.27	-0.13	0.03	0.01	-0.2	0	0
292	0.01	0	0.01	0.07	0.1	0.12	0.06	0.09	0.19	0.08	0.06	-0.55	-0.02	0.24	0.47	0.47	0.85	0.87	0.51	0.28	0.14
331	0.09	0	0	0.09	-0.06	-0.07	-0.07	-0.12	-0.13	-0.63	-0.69	-0.05	-0.1	-0.09	-0.07	-0.06	-0.03	-0.03	0.01	0	0
337	0.05	0.01	-0.15	-0.35	-0.37	-0.48	-0.92	-1.19	-1.69	-2.8	-3.47	-4.99	-6.97	-8.47	-7.49	-3.85	-2.71	-1.86	-1.53	0	0
368	0.03	0	-0.21	-0.25	-0.41	-1.24	-2.22	-2.78	-2.77	-3.69	-3.51	-3.92	-5.19	-3.06	-1.42	-0.31	0.02	0.23	0.15	0	0
437	0.11	0.19	0.01	-0.07	-0.11	-0.05	-0.42	-0.15	0.01	-0.23	-0.29	-0.12	0.03	0.04	-0.05	-0.51	-1.42	-2.72	-5.2	0.02	0.01
537	0.13	0.3	0.03	-0.02	-0.03	0	0.12	0.43	0.29	0.1	-0.1	-0.67	-0.51	0.16	0.51	0.29	0.4	0.28	0.27	0.16	0.08
637	0.06	0.18	0.02	-0.64	-0.98	-0.65	-0.51	-0.37	-0.33	-0.26	-0.23	-0.16	-0.18	-0.11	-0.05	0.01	0.07	0.05	-0.07	0	0

5.0 Sanctuaries

The creation and maintenance of sanctuaries is intended to protect broodstock, enhance natural recruitment, encourage disease tolerance through natural selection and provide ecological services such as water filtration and habitat for other species. Sanctuaries may contribute to a regional increase in oyster abundance and biomass and to the development of disease-resistant broodstocks over the long term (a century or more). Sanctuaries can be used as a management tool in oyster restoration with or without substrate and seed plantings. In areas of high recruitment, low mortality, low sedimentation and adequate substrate, solely using the absence of harvest as a management tool may restore the oyster population. However, in most Maryland sanctuaries, substrate and seed plantings will need to occur to restore the population as this will increase oyster biomass (i.e., broodstock (spawning adults) and larval production). Some sanctuaries have been targeted for large-scale, extensive oyster restoration projects to potentially accelerate the recovery of oyster populations within the sanctuary, increase their environmental benefits and contribute to enhancement of oyster populations outside the sanctuary.

To achieve ecological restoration, the scale of sanctuaries remains important. Emerging global scientific consensus states that having 20 to 30 percent of an ecosystem within a marine protected sanctuary is a reasonable goal to ensure protection of biodiversity (World Conservation Union, 2004). Therefore, in 2010 Maryland expanded its oyster sanctuary program to 51 areas which protected 24% of the oyster bottom habitat. In 2018, there were 252,285 surface acres in oyster sanctuaries, of which 78,520 acres were delineated in the 1906-1912 Yates Oyster Survey and its amendments (Maryland Department of Natural Resources, 2016) (Figure 13). The 78,520 acres of historic chartered oyster bar area within sanctuaries equates to 24% of the total historic charted oyster bar area as of 2018. All public oyster harvest, both commercial and recreational, is prohibited in oyster sanctuaries, while aquaculture operations are allowed with certain restrictions. Aquaculture may be compatible with restoration by adding to localized water quality improvements, providing ecosystem functions through oyster shell habitat creation (plantings) and enhancing natural recruitment when reproductive oysters are used. Areas already under lease at the time lease laws were changed in September 2010 are not considered part of the sanctuaries that were newly established at that time (COMAR section 08.02.04.15). Between August 2011 and December 2018, the department issued 76 new shellfish aquaculture leases on 2,145 acres within sanctuaries.

Amendment 1 to the 2004 Chesapeake Bay Oyster Management Plan allowed clamming in certain sanctuary areas. The intent of an oyster sanctuary network is not to prohibit the commercial and recreational harvest of managed clam species. Clam harvesting within those specific sanctuaries is allowed outside of a buffer around any oyster bar as delineated in the charts of the 1906-1912 Yates Survey and its amendments or any leased area (Natural Resources Article, §4-1037, Annotated Code of Maryland). The clamming buffer restrictions were developed to avoid physical damage to oyster reefs and any damage from sedimentation (Manning 1957, Tarnowski 2006). All other laws governing clamming outside of sanctuaries apply within sanctuaries as well.

Location is a critical factor when considering oyster sanctuaries due to the wide range of environmental and habitat conditions found regionally, and at smaller scales and differences within individual oyster bars. 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 (shell and hard substrate) is another key element because it provides the 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. Management areas may have productive oyster bars that are interspersed with patches of sand, mud or other habitat that is unsuitable for oysters. Degradation of oyster habitat is a problem throughout Maryland's Chesapeake Bay, with some remnant bars having little if any remaining substrate on which young oysters can settle.

Other factors can be important in accounting for differences in oyster populations among locations but are less understood or documented for specific management areas. 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 runoff containing sediment and nutrients and discharges from industrial facilities. Likely, there are other localized factors affecting oyster populations that are presently unknown.

Given the complexity of the Chesapeake Bay ecosystem, it could take many decades to show how oyster populations respond to the absence of harvest. In 2015 (five years after most sanctuaries were created), only 39 percent of the sanctuaries exhibited positive changes since becoming sanctuaries, such as increased biomass and reproductive capacity (Maryland Department of Natural Resources, 2016). This percentage is reasonable because many restoration activities have taken place over a shorter period of time and are still on-going in some sanctuaries. The overall, long-term behavior of sanctuaries will depend on many factors, including changes in weather, water movement patterns, disease and predator/prey abundance.

Although time is important for understanding the biological consequences of sanctuary management, there can be some justification to consider adjustments to the boundaries of the current sanctuary areas. There are sanctuaries (and public fishery bottom) that are known to have little to zero habitat and/or very low densities of oysters. These areas may not be restored either for ecological or fishery purposes without substantial financial investment by the government, individuals, or by private entities. Since the ultimate goal is to have more oysters in the water, sanctuaries that are currently performing poorly could contribute to the economic and cultural benefits of fishing communities, particularly if the areas are managed in a way that balances harvest with continuous investment to maintain oyster populations (Maryland Department of Natural Resources, 2016).

The Chesapeake Bay jurisdictions have committed to implementing the goals and outcomes of the 2014 Chesapeake Bay Watershed Agreement. The oyster restoration outcome is to restore native oyster habitat and populations in ten tributaries of the Chesapeake Bay (five in Maryland and five in Virginia) by 2025. To date, large-scale restoration work has been conducted in Harris Creek, Little Choptank River, and Tred Avon River on 730 acres. Large-scale restoration in the Upper St. Mary's River and the Manokin River will start in 2019. Large scale restoration activities can consist of pre-restoration oyster population surveys, planting substrate and oyster spat-on-shell, and post-restoration oyster population surveys to monitor progress. Federal, state, and non-profit organizations have funded these restoration activities to date (Table 5).

Table 5. Large-scale restoration expenditures by tributary, organization, and activity type since 2012 towards meeting the 2014 Chesapeake Bay Watershed Agreement.

Tributary	Organization	Activity Type	Calendar Year 2012	2013	2014	2015	2016	2017	2018
Harris Creek	USACE	Substrate	$1,500,000	$1,800,000	$1,800,000	$5,184,000	$0	$0	$0
	NOAA	Seeding	$1,200,000	$1,100,000	$715,000	$832,000	$80,000	$312,000	$62,982
	MDNR	Substrate	$0	$3,500,000	$5,570,000	$0	$0	$0	$0
	MDNR	Seeding	$1,000,000		$1,000,000	$1,500,000	$258,000	$395,850	$93,997
	CSX	Transport	$0	$0	$675,000	$0	$0	$0	$0
Little Choptank River	USACE	Substrate	$0	$0	$0	$0	$0	$0	$0
	NOAA	Seeding	$0	$0	$175,000	$322,000	$778,000	$301,270	$1,269,472
	MDNR	Substrate	$0	$0	$13,200,000	$2,900,000	$0	$0	$0
	MDNR	Seeding	$0	$0	$267,800	$581,000	$2,370,000	$345,100	$1,697,631
	CSX	Transport	$0	$0	$1,800,000	$0	$0	$0	$0
	NFWF	Seeding	$0	$0	$0	$370,000	$0	$0	$0
Tred Avon River	USACE	Substrate	$0	$0	$0	$1,370,000	$0	$1,825,564	$447,000
	NOAA	Seeding	$0	$0	$0	$0	$0	$267,200	$79,530
	MDNR	Substrate	$0	$0	$0	$0	$0	$0	$0
	MDNR	Seeding	$0	$0	$0	$39,000	$602,000	$274,050	$118,694
	NFWF	Seeding	$0	$0	$0	$0	$0	$129,850	$0
		TOTAL	$3,700,000	$6,400,000	$25,202,800	$13,098,000	$4,088,000	$3,850,884	$3,769,306

* This table includes only costs for reef construction and seeding funding. Monitoring is not included. Marylanders Grow Oysters and Chesapeake Bay Foundation funding is not included. USACE = U.S. Army Corp of Engineers, Baltimore District. NOAA = National Oceanic and Atmospheric Administration. MDDNR = Maryland Department of Natural Resources. CSX = CSX Train Transportation . NFWF = National Fish and Wildlife Foundation.

Sanctuary Strategy 5.0

Continue to maintain a sanctuary program throughout Maryland's Chesapeake Bay with the purpose of protecting broodstock, enhancing natural recruitment and providing ecological services.

Action 5.0.1

Maintain a network of clearly marked oyster sanctuaries throughout Maryland's Chesapeake Bay and its tributaries.

Action 5.0.2
Ensure sanctuaries are of sufficient size, include at least 20 to 30% of productive oyster bottom and 50% of the 'best bars' are distributed to promote regional oyster production and ecological services, and are managed based on defined and measurable criteria.

Action 5.0.3
Continue to utilize oyster seed (wild seed and/or hatchery-reared spat-on-shell) to increase the existing oyster population in sanctuaries where appropriate.

Action 5.0.4
Continue to monitor sanctuaries to evaluate oyster population status and measure progress toward the commitment to increase oyster biomass and abundance.

Action 5.0.5
Consider the following steps when establishing a new oyster sanctuary or expanding the size of an existing sanctuary in Maryland's Chesapeake Bay:

1. Evaluate the biological and physical parameters of an area and justify how designating the area as a sanctuary will provide regional ecological services and increase oyster abundance and biomass.
2. Develop a restoration and monitoring plan for the area.
3. Ensure new sanctuary boundaries are clearly marked and easily enforceable.
4. Monitor and evaluate the effectiveness of the sanctuary using appropriate standards and timeframe.
5. Ensure that boundaries do not divide existing oyster bars when possible.

Action 5.0.6
Consider the following steps when removing a sanctuary or reducing the size/area of a sanctuary:

1. Justify why the sanctuary should be removed or modified based on scientific information gathered over time (e.g. ten years of data indicates that an area has poor habitat, low oyster densities or is not performing to expected outcomes of increased oyster production and beneficial ecological services).
2. Justify how if the area was not an oyster sanctuary it could:
    a. Contribute to the goal of increasing oyster production; and/or
    b. Provide economic and/or cultural benefits to another community; and/or
    c. Be replaced by creating a new oyster sanctuary area.
3. If removal of a sanctuary designation would likely further the goal of increasing oyster production, develop a plan to manage this area to increase the oyster population,

including the appropriate metrics for tracking population size in the area and identify the costs and funding sources for implementation of the plan and associated monitoring program.
4. Conduct seed and/or substrate planting activities as mitigation, if necessary, in other sanctuary area.

Action 5.0.7
Conduct an updated 'best bar' analysis to determine if there has been a spatial shift in oyster productivity of the 'best bars'.

5.1 Oyster Gardening for Sanctuary Enhancement

Oyster gardening is the practice of growing oysters at private piers for ecological benefits. It is a type of non-commercial aquaculture where oysters cannot be marketed or sold for human consumption. Numerous programs exist that utilize citizen volunteers to grow hatchery-reared spat-on-shell at private waterfront piers to help raise awareness and stewardship of the oyster resource.

Marylanders Grow Oysters is one specific oyster gardening program. The program started in 2008 in the Tred Avon River and currently operates in 30 tributaries across Maryland. Each participating area is coordinated by a volunteer person or group who oversees their growers and the distribution and collection of cages and spat. They also coordinate the plantings with the department. Each grower hosts two or more cages filled with spat-on-shell at their pier or dock. The grower tends to the young oysters for about nine months before they are collected and planted in a sanctuary. Oysters grown in this program cannot be held for more than a year and must be planted on oyster habitat.

Although oysters grown for gardening cannot be eaten or sold, oyster gardeners must register, report and comply with the requirements set forth by the National Shellfish Sanitation Program (NSSP) Model Ordinance and the U.S. Army Corps of Engineers' Maryland State Programmatic General Permit (MDSPGP-5). The NSSP provides oversight to state shellfish activities and the Corps has regulatory jurisdiction over oyster gardening. Gardeners need to annually register with the department and maintain a log of activity related to their oyster garden. Gardeners must report how many oysters they have grown and where they have been planted. Registration and reporting may be completed for participating groups by their coordinators or individual growers may report on their own if not under a group. The annual gardening data can then be used for restoration tracking, mapping, public health compliance and decisions concerning other oyster management activities.

Oyster Gardening Strategy 5.1

Continue to support citizen-based oyster gardening efforts through outreach, technical advice and funding, if available.

Action 5.1.1
Assist gardening programs to increase the number of stakeholders involved, through outreach, education and attendance of local meetings to provide information and advice.

Action 5.1.2
Identify and authorize appropriate areas within sanctuaries for planting oysters raised by oyster gardeners and maintain these planted areas as sanctuaries. Continue to confirm planting areas with oyster gardening groups in advance of the planting season.

Action 5.1.3
Continue to require Marylanders Grow Oysters program participants and other oyster gardeners to register annually and report the quantity of oysters planted, planting date(s), receiving site location (latitude/longitude) and any other data the department deems appropriate.

Action 5.1.4
Develop a comprehensive and accurate record-keeping system for the Marylanders Grow Oysters program.

Action 5.1.5
Ensure that all oyster gardening activities, both state-run programs as well as private oyster gardening activities, follow the requirements of the National Shellfish Sanitation Program Model Ordinance to protect public health and comply with the U.S. Army Corps of Engineers federal permit requirements.

Action 5.1.6
Identify new sources of funding for gardening efforts such as Marylanders Grow Oysters.

6.0 Fishery Management

Fishery management strategies are often based on biological reference points that indicate maximum levels of safe harvest (thresholds) and target levels of harvest that provide a margin of safety from the threshold, which are designed to prevent overfishing. The distance between the target and threshold harvest levels is a function of the level of risk managers and stakeholders are willing to accept. An ideal situation is to estimate the amount of oysters that can be taken safely from the population while maintaining a sustainable population size and age structure. For the oyster resource, the term ‘population’ depends on spatial scale. It can refer to Maryland’s baywide population of oysters or to the population in discrete regions or bars. The term ‘population’ in this document refers to the Maryland baywide population of oysters. When referring to discrete regions or bars, the term ‘region-specific populations’ will be used.

The target levels of harvest identified in the 2018 stock assessment are estimates of the maximum level of harvest over time that will maintain a stable or increasing oyster population (given current abundances of oysters in Maryland). The upper limit harvest reference point represents the absolute maximum harvest fraction that would allow sustainable harvest. Managing the public oyster fishery by regulating harvest can be accomplished using tools such as bushel limits and season limits (Appendix A). These management tools can be used separately or in conjunction with other tools. Most tools are more effective when implemented with other tools. Management on varying spatial scales is possible since actions effective in one area could be less effective in another area. Using management tools expediently is critical to adaptive management of the oyster fishery. To that end the department may utilize public notices to establish and modify harvest parameters such as seasons, daily catch limits, days of the week, and times for catching oysters for recreational and commercial purposes. The department may also open and close oyster harvest areas by public notice. An example of public notice use under these circumstances would include closing a specific oyster harvest area until a majority of oysters in that area reach marketable size.

There are four types of management tools: output controls, input controls, habitat modification and stock enhancement. Output controls limit the amount of oysters that can be taken out of the water. Input controls limit the amount of effort in the fishery, which indirectly controls the amount of oysters harvested. Habitat modifications are measures to prevent damage to habitats, to restore damage where it has occurred and to increase habitat. Since oysters create their own habitat, many of the input, output and stock enhancement tools may also be considered habitat modification tools. Stock enhancement tools have the potential to increase the population by adding new oysters into Maryland’s Chesapeake Bay. These tools are defined in more detail in Appendix A. Description of Harvest Management Tools.

Methods for regulating harvest are not limited to those listed in Appendix A. Alternate methods for controlling harvest or effort can be considered by the department. Strategies for controlling fishing mortality will require input from the Tidal Fisheries Advisory Commission, Sport Fisheries Advisory Commission, Oyster Advisory Commission, County Oyster Committees and public discussion and may possibly require changes in regulations and/or public notices.

Fishery Management Strategy 6.0
Adopt biological reference points (target and threshold fishing rate) at an appropriate spatial scale that can be used to manage harvest at a sustainable level and develop management measures in conjunction with stakeholders.

Action 6.0.1
Evaluate the potential use of management tools including those referenced in Appendix A, either separately or in conjunction with each other and implement them to manage the oyster resource consistent with the fishery management strategy.

Action 6.0.2
Improve the accuracy and specificity of reported harvest data on buy tickets submitted by seafood dealers in compliance with reporting requirements.

Action 6.0.3
Improve accuracy and specificity of reported harvest data by commercial licensed harvesters in compliance with reporting requirements.

Action 6.0.4
Monitor the oyster fishery and population to determine fishing mortality rates in relation to biological reference points.

Action 6.0.5
Conduct fishery-dependent sampling of oyster size distribution to better quantify the number of oysters per bushel and the number of undersized oysters per bushel.

Action 6.0.6
Continue to monitor latent effort and work with the commercial industry and other stakeholders to identify potential strategies to control or decrease effort if necessary.

6.1 Fishery Management Areas

There are different types of management areas for the public fishery including: Yates Oyster Bars, Non-Yates Oyster Bars, Natural Oyster Bars (NOBs), Public Shellfish Fishery Areas, Harvest Reserves Areas, Open/Close Areas, Rotational Harvest Areas and Seed Areas. Each of these management areas are used in different ways with the intent to increase sustainable public fishery harvest. Since there are a limited number of resources (e.g., hatchery seed, shell and funding) to support the different fishery management areas as well as aquaculture and sanctuaries, it will be necessary to formally decide how to allocate the limited resources among these areas (see Action 3.1)

Four of the areas are categorized by how oyster habitat in Maryland's Chesapeake Bay have been delineated and are currently referenced in statute and regulation (Table 6):

- Yates Oyster Bars
- Non-Yates Oyster Bars
- Natural Oyster Bars (NOB)
- Public Shellfish Fishery Areas (PSFA)

Yates Oyster Bars: Yates Oyster Bars were delineated by the Yates survey, conducted from 1906 to 1912, which was the first comprehensive survey of Maryland's oyster bars. The primary objective of the survey was to delineate the legal boundaries of the oyster bars to facilitate leasing grounds outside of the bars for aquaculture. The survey examined 350,000 acres of bay bottom and mapped 780 bars covering 215,448 acres over a six-year period.

Non-Yates Oyster Bars Additions: Since the Yates survey, additional areas were mapped and oyster bars delineated. These new bars (Non-Yates Bars) were added to the list of Maryland oyster bars. Many of these bars have "Addition 1" in their name. The Non-Yates bars consist of 325 oyster bars covering 115,205 acres.

Currently, there are 1,105 historic oyster bars covering 330,653 acres as mapped in the State of Maryland Shellfish Closure Areas book produced by the department annually. Historic oyster bars or bottom are defined as a combination of the Yates Bar and Non-Yates Bars. It should be noted, however that these historic oyster bars do not necessarily represent current viable oyster habitat with oysters and substrate.

Natural Oyster Bars (NOB): From 1975-1983, the department conducted the Maryland Bay Bottom Survey to map the bottom types found in Maryland's Chesapeake Bay. Bottom type categories included cultch (primarily oyster and clam shells), mud, mud with cultch, sand and sand with cultch. The results of this survey charted 294,205 acres of cultch and mixed cultch that could be potential oyster bottom. 208,536 NOB acres (69.8 percent) overlap the historic oyster bars area (Yates and Non-Yates bars). The primary reason for the charts of these NOB areas was to determine areas where clamming could not occur.

Public Shellfish Fishery Areas (PSFA): In 2010, the department developed Public Shellfish Fishery Areas pursuant to a legislative mandate. The PSFA designation is for areas where oysters have been actively harvested for commercial purposes by the public fishery during the previous three years. The primary reason for the delineation of these PSFAs is to ensure aquaculture leases are not located in these areas (a PSFA may be declassified if a petition for declassification is approved). PSFAs are areas where the public can harvest oysters for commercial and recreational purposes. Oyster aquaculture and clamming are not allowed in PSFAs. In 2010, the PSFA included 179,943 acres and of those, 142,006 acres (78.9 percent) overlap the historic oyster bottom (Yates and Non-Yates bars). There are 109,676 acres of historic oyster bottom that are neither in sanctuaries nor in a PSFA, but are open to public oyster harvest.

Table 6: Current acres, as of 2018, of oyster bottom charted as Yates oysters bars (charted from the 1906-1912 survey), Non-Yates bars (charted and added after the 1906-1912 Yates Survey), Natural Oysters Bars (charted from the 1975-1983 Maryland Bay Bottom Survey) and Public Fishery Shellfish Areas (charted in 2010).

Oyster Bottom Type	**Total Surface Area (acres)**	**Acres of historic oyster bottom (Yates and Non-Yates Bars) in Maryland's Chesapeake Bay as charted in the Yates Oyster Survey from 1906 to 1912 and its amendments**		
		Total Acres	**In Oyster Sanctuaries**	**Not in Oyster Sanctuaries**
Historic Oyster Bottom - Yates Bar	215,448	215,448	57,862	157,586
Historic Oyster Bottom - Non-Yates Bar	115,205	115,205	21,006	94,199
Natural Oyster Bar (NOB)	294,356	208,536	49,916	158,620
Public Shellfish Fishery Area (PSFA)	179,943	142,006	0	142,006
Oyster Sanctuaries	252,285	78,520	78,520	0

Note: NOB, PSFA and sanctuary bottom types include surface area that does not overlap the historic oyster bottom. There is a 69.8 percent overlap between NOB and historic oyster bottom. There is a 78.9 percent overlap between PSFA and historic oyster bottom. There is a 31.1 percent overlap between sanctuaries and historic oyster bottom.

Historic oyster bottom does not necessarily represent the productive oyster bottom in 2018, nor at the time of the Yates Survey. An analysis conducted as part of the 2009 Programmatic Environmental Impact Statement estimated that there are approximately 36,000 acres of productive oyster bottom remaining in Maryland's Chesapeake Bay of which 76% is currently outside of sanctuary areas. The 36,000 acres does not include bottom with poor oyster habitat that could potentially be restored with financial investment in substrate and seed oysters (Maryland Department of Natural Resources, 2016).

Given the change in oyster habitat since 1906 and the discrepancies of the boundaries between these four areas (Yates Bars, Non-Yates Bars, NOBs and PSFAs), oyster habitat should be re-delineated so that charted oyster bars more accurately reflect areas of productive oyster habitat. By re-delineating productive oyster habitat, the department could improve its management of oyster resources and maximize the benefits of bay bottom usage for the public (e.g. oystermen, clammers, aquaculture, crabbers, finfish fisheries). Fishing restrictions around oyster bar boundaries (e.g. no soft clam harvest using hydraulic dredges within 150 feet of an oyster bar) will continue to be maintained.

Fishery Management Areas Strategy 6.1
Identify and maintain the designation of productive oyster habitat.

Action 6.1.1
Conduct a new bay bottom survey in Maryland's Chesapeake Bay and delineate the boundaries of oyster bars. Using the results of the survey and other quantitative data:

1. Redefine boundaries of Maryland's oyster bars and publish new oyster bar charts as necessary.
2. Manage the oyster resource based on the new charted boundaries of Maryland's oyster bars and not the older charted Yates Bars, Non-Yates Bars, NOBs or PSFA.

Action 6.1.2
Allow for the modification of charted boundaries of Maryland's oyster bars based on the results of a biological survey or other quantitative data.

6.2 Harvest Reserve Areas

Harvest Reserve Areas are individual oyster bars that are closed to harvest for a period of time and are opened after certain biological criteria are met (Natural Resources Article, § 4-1009.1.). The purpose of these areas is to enhance harvest by holding the areas "in reserve" while maintaining a sustainable and healthy oyster population. Generally, stock enhancement practices (shell or seed plantings) are applied in these areas with the intent to allow the population to rebound quicker. Harvest management may be based on determining oyster abundance and average shell height and establishing a decision-making protocol for harvesting under different environmental conditions.

To date, Maryland has designated two oyster bars as Harvest Reserve Areas (Bramleigh Reserve in Wicomico River West and Evans Reserve in Tangier Sound). The Harvest Reserve Areas were selected based on having good oyster habitat and low-to-moderate disease mortality. Since the best grow-out sites can change from year to year, designating new Harvest Reserve Areas will be based on the best available information. Allowing or prohibiting harvest in Harvest Reserve Areas may be based on average oyster shell height, disease prevalence and intensity and natural mortality rates. The department may regulate harvest within the allowed open season and set specific bushel limits, day/time limits or other limits using the different management tools listed in Appendix A.

Harvest Reserve Strategy 6.2
Develop guidelines for managing harvest and monitoring oysters in Harvest Reserve Areas.

Action 6.2.1

1. Mark each Harvest Reserve Area with buoys and list the coordinates of each area in the State of Maryland Shellfish Closure Areas book.
2. Apply the statutory criteria for allowing or prohibiting harvest in Harvest Reserve Areas based on the desired biological characteristics of the population.
3. Monitor the oyster population in Harvest Reserve Areas (e.g., population size, age structure and disease prevalence and intensity).
4. Use stock enhancement management tools and/or habitat modification tools as appropriate in Harvest Reserve Areas.
5. Open and close Harvest Reserve Areas based on the monitoring results using all required public notice procedures.

6.3 Rotational Harvest Areas

Rotational Harvest Areas are closed to harvest for a set time period during which stock enhancement and/or habitat modification activities are conducted, then opened to harvest for another set time period and then closed again and the process is repeated. The closure time generally depends on the capability of the oyster population to rebound and grow to market size. The success of rotational harvest depends on growth and abundance increases during the closure period being greater than the levels of depletion during the harvest period. Rotational Harvest Areas are large areas (e.g., multiple oyster bars) occurring throughout a region. In conjunction with closing/opening/closing areas to harvest, habitat and stock enhancement should be used to shorten rebounding time and increase population abundance more quickly. Monitoring of Rotational Harvest Areas is necessary to determine when a high proportion of oysters are market size and to determine appropriate harvest management parameters, e.g., bushels limits, day/time limits or other management controls. Areas could be opened sooner than planned (though only during the oyster season) if disease may cause increased mortality or prolonged rainfall may cause freshet mortality. Accurate and timely harvest data obtained from these areas is crucial in determining the length of the closure period and the amount of stock enhancement needed. This methodology is heavily employed in the Chesapeake Bay by Virginia.

Rotational Harvest Strategy 6.3
Work toward a more sustainable harvest by managing fishing effort and monitoring oysters on specific bars using Rotational Harvest Areas.

Action 6.3.1
Create Rotational Harvest Areas

1. Develop a plan for each Rotational Harvest Area that includes the following information:
    a. Open and closed periods for each portion of the area.
    b. Stock enhancement and substrate planting actions.
    c. Monitoring program establishing the frequency of monitoring, data to be collected and who will conduct the monitoring.
    d. Budget and funding sources for planting activities and monitoring.
    e. Criteria for opening each portion of the area (e.g., a specific percentage of the oysters are market size).
    f. Harvest management parameters for the area (e.g., bushel limits, time/day limits).
    g. Adoption of additional methods for managing the rotational area if needed (e.g., entry limits).
    h. Methods for collecting accurate harvest information.
2. If an area is proposed to be a rotational harvest area and it is already classified as another management area type, it will need to be reclassified as a Rotational Harvest Area.
3. Manage the area in accordance with the plan.
4. Include Rotational Harvest Areas in the State of Maryland Shellfish Closure Areas book.
5. Comply with all public notice procedures for opening and closing an oyster bar established by the department in regulation.

Action 6.3.2
Monitor, assess and modify Rotational Harvest Areas as appropriate to ensure the desired outcomes are being achieved.

6.4 Seed Areas

Seed Areas are locations with high spat sets where young seed oysters (spat and smalls) are produced, collected and transplanted to poorer setting areas for grow-out and harvest (Natural

Resources Article, § 4-1103). Oyster shell or another suitable substrate is planted in areas with high natural spat settlement. Typically Seed Areas have been located in waters of the mid- to lower Eastern Shore and the lower Western Shore of Maryland. Seed Area locations are selected based on spat setting records and coordination between the department and the county oyster committees in order to avoid conflicts due to gear, any other industry activities on the site and other users of the area. After settlement, the seed oysters (usually spat but they could also be small-sized oysters) are transported to oyster bars in grow-out regions where recruitment is lower and survival rates are higher than their original location or to areas with low broodstock with the intent to enhance recruitment. These areas where seed are transported for grow-out and harvest are called ‘planted areas.’

When conducting a Seed Area project, specific data should be recorded such as the exact coordinates where seed is collected, depth, bottom type, salinity and exact coordinates where seed is planted, number of individual seed and bushels of seed planted, acres planted and disease levels. Through a monitoring program, survival rates for each planting or a subset of planted sites should be recorded. Through Seed Area efforts, oyster habitat, recruitment, growth and survival are potentially enhanced. Seed Areas can be opened and closed by complying with all public notice procedures for opening and closing an oyster bar established by the department in regulation.

Seed oysters are a natural product, not hatchery reared, and thus can carry the etiologic agents for MSX and Dermo diseases. To protect against disease transfers and the introduction of other organisms, protocols will be developed based on the department’s 2015 Mollusc Disease Control Policy (Dungan and Marcino, 2015) and implemented for the management of Seed Areas and planting areas. These protocols include, but are not limited to, testing for pathogens at both the Seed Area and planted area, comparing pathogen levels at both sites and approving or denying the planting of seed based on the results. If any pathogen prevalence at the Seed Area is greater than pathogens in or around the desired planting area, the planting will be denied. If any pathogen prevalence at the Seed Area is less than or equal to pathogens in or around the desired planting area, the planting may be approved.

Currently, Seed Area production has been limited by poor natural recruitment (spat settlement) and reduced shell availability making it not cost effective. The cost to conduct a seed program includes paying for shell, transporting and planting shell, monitoring seed counts (the number of spat per bushel of material) and disease levels, collecting seed, and transporting and planting seed. To operate cost effectively, a Seed Area program requires a high "cut-off" number of seed per bushel below which the program ends. Criteria are needed for replanting the area with substrate after seed are moved in order to maintain the habitat. For example, in Maryland's historic seed program a layer of approximately 6 inches of shell was annually maintained on an active Seed Area. In Virginia, two bushels of shell are currently re-planted for every one bushel of seed removed to ensure the bottom remains productive.

Seed Area Strategy 6.4
Increase regional oyster populations by recruiting oysters in Seed Areas and transporting the seed to other bars.

Action 6.4.1
Identify oyster habitat in various regions of the Bay that may be able to function as Seed Areas then delineate and manage these areas.

Action 6.4.2
Develop and utilize the seed transplanting guidelines to control the movement of disease.

Action 6.4.3
Develop minimum seed counts that maximize the cost efficiency of moving/transporting seed to other areas within the Maryland portion of Chesapeake Bay.

6.5 Opening and Closing Oyster Bars

The department may close and then reopen specific oyster bars (or portions of bars) within an oyster harvest area that have:

- Planted wild seed or hatchery-reared spat-on-shell that consist of mostly small-sized oysters (less than 3 inches); and/or
- Large abundance of natural, small-sized oysters (less than 3 inches) and few market-sized oysters; and/or
- Low population abundance or density; and/or
- Undesirable ratio of small to market-sized oysters.

These areas are usually closed after consultation with the appropriate county oyster committee to conserve oyster populations and to reduce harvest pressure. After the area is closed, the department may consult with the appropriate county oyster committee to determine when to open the area and how to best manage harvest. For example, the county oyster committee may request lower bushel limits, fewer harvest days or less time allowed per day than what is otherwise authorized for that bar. The department may open these areas if previously closed and set harvest management parameters. Oyster bars within sanctuary areas cannot be opened to harvest unless the sanctuary designation in that area is removed.

Opening and Closing Oyster Bars Strategy 6.5
Increase survival and abundance of oyster populations by managing fishing effort through the opening and closing of oyster bars.

Action 6.5.1

Consider the following steps when deciding to open or close an oyster bar (or portion of a bar).

1. Mark a closed area with buoys.
2. Determine the criteria for opening a bar. Criteria may vary depending on regional differences or management objectives, such as disease, salinity, size and seasonal time periods.
3. Monitor the closed area to determine when the criteria for opening the area is met (e.g., size structure (oyster shell length) of the oyster population).
4. Set harvest management parameters (e.g., specific bushel limits, time/day limits) for an opened oyster bar while taking into account enforcement concerns.
5. Comply with all public notice procedures for opening and closing an oyster bar established by the department in regulation.

6.6 Replenishment Plantings

Oyster populations can be enhanced and replenished. After harvest and under ideal environmental conditions, a population can be replenished by planting substrate, wild seed and hatchery-reared spat-on-shell.

Due to the lack of dredged shells, most shell used for plantings is currently fresh shell from shucking houses. Also, due to both the low abundance of shells that can be planted and lack of high recruitment, most wild, natural seed is currently imported from Virginia where seed counts are much higher. Since both dredged shell and fresh shell are a limited resource, alternative substrates should be examined to determine suitability for use on public fishery bottom. A suitable alternative substrate on public fishery bottom should not adversely impact navigation, other fisheries, the ecosystem, or harvest gear.

Hatcheries can be used to produce larvae and spat for a variety of purposes, ranging from recreational and commercial oyster aquaculture to broodstock enhancement and support of commercial fisheries. Hatchery spat-on-shell can be free of endemic oyster parasites and may provide some advantage when placed in the natural environment. In areas of low natural spat settlement, the use of hatchery spat-on-shell provides an initial, dense population of oysters that otherwise would not be available. However, the overall number of oysters that hatcheries can generate on an annual basis cannot compare with the numbers of larvae produced baywide by wild stocks in most years. Currently, demands for hatchery spat-on-shell exceed production in Maryland.

Replenishment plantings are currently funded by a grant from the Maryland Department of Transportation, revenue from the oyster bushel tax and revenue from the purchase of an oyster surcharge from commercially licensed harvesters (Table 7). Since 1991, the oyster bushel tax has been set at $1 and the export tax at $0.30. However, the cost to buy and plant a bushel of shells is currently around $5 which results in deficit funding for plantings on a per bushel basis. The average annual revenue generated from the bushel tax since 1991 is $208,740 (excludes export tax). The oyster surcharge is currently set at $300 and the average annual revenue from surcharges is $241,062. Table 7 indicates that these two sources of revenue are not enough to fully fund repletion efforts, or even just the shell planting component. In the future, additional funding or public-private partnership opportunities should be sought.

Table 7: The amount of replenishment plantings for the public fishery and the cost associated with the plantings.

Planting Year	Amount Planted for Public Fishery			Cost
	Virginia Wild Seed (Bushel)	Hatchery Seed (Million)	Fresh Shell (Bushel)	
2013	11,177	106.60	119,800	$1,064,205.89
2014	0	211.94	84,936	$1,033,060.63
2015	0	198.45	200,812	$1,727,752.70
2016	5,099	254.67	269,920	$2,384,880.90
2017	51,362	163.32	100,608	$1,792,936.21
2018	33,141	71.49	113,332	$1,254,748.00

Replenishment Strategy 6.6
Use replenishment plantings to maintain and increase sustainable bar productivity for the public fishery.

Action 6.6.1
Continue to utilize the current hatcheries to produce larvae for setting new spat-on-shell.

Action 6.6.2
Encourage the development of private hatcheries to produce larvae for sale.

Action 6.6.3
Encourage the development of private spat setting facilities to produce spat-on-shell.

Action 6.6.4
Evaluate and consider future funding opportunities or the use of public-private partnerships (P3s) to support replenishment plantings.

6.7 Public Health and Oyster Harvest

Oysters are adapted to filter food from the water column through their gills. As part of their feeding process they also filter and concentrate many pollutants, including bacteria and viruses. Even though pollutants may be at low levels in the environment, oysters can accumulate and concentrate pollutants and disease-causing bacteria. Cooking is an effective way to minimize the risk of disease-causing bacteria but oysters are frequently consumed either raw or partially cooked. For public health concerns, it is mandatory that shellfish be harvested from approved waters and handled according to sanitary guidelines. Waters lying adjacent to wastewater treatment plant outfalls are classified as prohibited by the National Shellfish Sanitation Program (NSSP). Prohibited means that harvest of oysters and clams for any purpose is not permitted.

The NSSP was developed in 1925 when the U.S. Public Health Service (now the Food and Drug Administration) responded to a request for assistance from state and local public health officials in controlling illness associated with the consumption of raw shellfish (oysters, clams and mussels). The public health control procedures established by the Public Health Service were dependent on the cooperative and voluntary efforts of state regulatory agencies and the shellfish industry.

The Interstate Shellfish Sanitation Conference (ISSC) was formed in 1982 to foster and promote shellfish sanitation through the cooperation of state and federal control agencies, the shellfish industry and the academic community. One of the foremost goals of the ISSC has been the adoption of the NSSP Guide for the Control of Molluscan Shellfish Model Ordinance which would embody the principles and requirements of the NSSP. Adoption of the Model Ordinance by each of the ISSC participating states implies commitment by each state to provide the necessary legal authority and resources to implement the regulatory requirements identified in the Model Ordinance. Adoption also ensures uniformity across state boundaries and enhances public confidence in shellfish product. The NSSP Model Ordinance is incorporated by reference in COMAR section 10.15.07.01 and cross referenced in 08.02.23.04(F)(2) for aquaculturists and 08.02.04.03(F) for commercial shellfish harvesters.

Maryland, as a member of ISSC and NSSP, has the ability to participate in interstate shellfish commerce and ensure the safety of shellfish products harvested from the state. Maryland's participation is dependent upon the observance of and compliance with the NSSP. If the State of Maryland is not able to illustrate the ability to comply with the requirements of the NSSP, Maryland's ability to participate in the ISSC and in turn interstate shellfish commerce, would be in jeopardy.

The Model Ordinance includes minimum requirements necessary to ensure that shellfish are harvested and handled appropriately and are safe for human consumption. This includes but is not limited to, bacteriological standards for classifying shellfish growing waters, sanitary surveys, harvester licensing and education requirements, harvesting vessel and gear standards, harvester to dealer transaction requirements, tagging and product identification requirements, safe product handling and time to temperature standards, enforcement patrol standards and guidance for enforceable legal penalties sufficient to encourage compliance.

Since aquaculture harvest can occur during the summer and must comply with the requirements of the NSSP to decrease the risk of illness, Maryland has developed a *Vibrio parahaemolyticus* (*V.p.)* Control Plan. *V. parahaemolyticus* illness is caused by the consumption of raw molluscan shellfish (clams and oysters) infected with this bacterium. Maryland's plan requires leaseholders engaged in the summertime harvest of shellfish to implement certain control measures. These control measures are established in regulation (COMAR section 10.15.07.06).

The Maryland Department of the Environment (MDE) uses the bacteriological standards set forth in NSSP for shellfish harvesting area classifications based on bacteriological water quality and sanitary survey results (Table 8). In addition to shoreline surveys that assess potential and actual pollution sources and risk, the bacteriological fecal coliform standards that must be met for each classification are listed in Table 8.

Table 8: Maryland Department of the Environment (MDE) fecal coliform standards for a three tube decimal solution test set forth in NSSP for shellfish harvesting area classifications.

NSSP Classification	Current Fecal Coliform Standards
Approved/Conditionally Approved (direct harvest permitted)	Median < 14 MPN/ 100 ml 90th Percentile <49
Restricted (relay required)	Median < 88 MPN/ 100 ml 90th Percentile <300
Prohibited (no harvest permitted)	Median > 88 MPN/ 100 ml 90th Percentile > 300

MPN is defined as Most Probable Number

Maryland Department of the Environment Restricted Areas are areas where no direct harvesting of oysters or clams is allowed at any time. Harvest from a private lease or a public oyster bar in a restricted area may be permitted by request for the purpose of natural cleansing (relay). Request for relay of oysters or clams from restricted waters to approved waters must be made in writing to Maryland Department of the Environment in advance of possible relay dates. If approved by the Maryland Department of the Environment, relay can occur only outside of oyster season and when water temperatures are above 50ºF (10ºC).

Maryland Department of the Environment Conditionally Approved Areas are areas where oysters and clams can be directly harvested except for the three days following a rainfall of an inch or greater in 24 hours. Harvesters can learn of conditional closings daily by an announcement broadcast by the Maryland Natural Resources Police, calling the appropriate telephone number or visiting the Maryland Department of the Environment website’s daily advisory on conditionally approved shellfish areas. Conditionally approved means oysters or clams may be harvested when the area is in the open status. Approved means oysters or clams may be harvested any time that is consistent with the department’s harvesting regulations.

Public Health Strategy 6.7

To protect public health, oyster harvesters must follow the sanitation guidelines established by the National Shellfish Sanitation Program and the Interstate Shellfish Sanitation Conference and abide by the areas approved for shellfish harvest by the Maryland Department of the Environment.

Action 6.7.1

Require any person engaged in wild oyster harvest, aquaculture activities or oyster gardening and any person dealing in oysters, to comply with the requirements of the National Shellfish Sanitation Program Model Ordinance. This includes, but is not limited to, requiring compliance with all training, licensing, permitting, oyster handling, reporting and tagging in the Model Ordinance.

Action 6.7.2

Ensure that the National Shellfish Sanitation Program Model Ordinance is properly administered and enforced by the department.

Action 6.7.3

Mark areas designated as Restricted or Conditionally Approved (when in the closed status) by the Maryland Department of the Environment.

Action 6.7.4
Implement and enforce the Maryland Vibrio Control Plan.

6.8 Recreational Harvest

Maryland residents may harvest oysters recreationally without a license or permit. Currently, a Maryland resident may take up to one bushel of oysters per day during the public fishery oyster season but the harvested oysters are only for personal, noncommercial use and cannot be marketed or sold. All of the oysters harvested must meet the minimum size requirement of 3 inches as measured from hinge to bill. The oysters must be culled on the bar where they were caught and all undersized oysters and shell material must be returned to the bar. Oysters can be recreationally harvested only by hand, rake, shaft tong or diving with or without scuba equipment. Also a person may not catch oysters recreationally while on the boat of someone who is catching oysters commercially. Recreational harvest of oysters can only occur in areas that are open to commercial harvest (e.g., not in sanctuaries or restricted areas designated by the Maryland Department of the Environment) and where the harvest gear is allowed.

While recreational harvest of oysters is not as popular as blue crabs, it does occur. The department does not have any data on effort or catch from recreational harvest. Anecdotal information suggests most recreational harvest occurs in the Wicomico and Choptank rivers. The Sport Fisheries Advisory Commission and Tidal Fisheries Advisory Commission have asked the department to explore possible regulatory methods to improve accountability and effort control in the recreational fishery.

Recreational Harvest Strategy 6.8
Improve management of the recreational oyster fishery through increased knowledge and understanding of harvest.

Action 6.8.1
Collect data on recreational oyster harvest including, but not limited to, catch and effort.

Action 6.8.2
Determine appropriate management measures for recreational oyster harvest based on collected data.

Action 6.8.3
Conduct outreach efforts to inform the public of closed harvest areas, and general oyster harvest and public health rules.

7.0 Aquaculture

There are currently[1] 427 shellfish aquaculture leases on 6,963.2 acres in active use within Maryland state waters. These leases are held by 258 distinct individuals or business entities and there are over 500 distinct individuals directly participating in the industry who hold either a Shellfish Aquaculture Harvester Permit or Registration Card issued by the department authorizing them to engage in activity on a lease. Approximately 43 percent of distinct leaseholders who are individuals also report holding a Maryland Tidal Fish License. Oyster production by private growers continues to contribute to the overall increase in oyster biomass, ecological value and economic benefits to Chesapeake Bay. To date, Chesapeake Bay's oyster aquaculture industry utilizes two very distinct culture methods on submerged land and water column leases, respectively.

Leases issued by the state give leaseholders exclusive rights to plant, cultivate, hold and harvest oysters within specified areas. On submerged land leases, leaseholders plant shell and spat-on-shell directly on the bottom. The cultivation of oysters on submerged land leases has a long history in Chesapeake Bay. In Maryland, there are currently 341 submerged land leases on 6,519.5 acres. In 2017, submerged land leaseholders reported harvesting 44,748 bushels of oysters from their leases. This represents 60.4 percent of the 74,044 total bushels of farm-raised oysters harvested from shellfish aquaculture leases in 2017 (Figure 14).

On water column leases, leaseholders plant spat in containers (cages or floats) that rest directly on bottom, float at the surface or are suspended within the water column. There are currently 86 water column leases occupying 443.7 acres. In 2017, water column leaseholders reported harvesting 29,296 bushels of oysters from their leases. This represents 39.6 percent of the total number of bushels of farm-raised oysters harvested from shellfish aquaculture leases in 2017 (Figure 14).

New lease laws that were passed in 2009 have helped to facilitate the growth of shellfish aquaculture by lifting county moratoriums on leasing, removing size limitations on leases, authorizing leases issued to corporations and requiring that leases be actively used for commercial shellfish aquaculture purposes. Since the new lease laws were passed, Maryland has established an infrastructure that supports the responsible development of this industry by:

- Creating shellfish aquaculture loan programs – Funds are used by leaseholders to purchase capital equipment, shell and seed.
- Developing Oyster Aquaculture Education and Training Programs including remote setting training, business planning assistance, lease management.
- Consolidating state permitting authority and industry development efforts at the department.

[1] Acreage totals and statistics reflect Aquaculture and Industry Enhancement Division data through Dec. 31, 2018.

- Establishing an Aquaculture Division at the department (assists applicants with selecting sites and completing their forms).
- Assisting the U.S. Army Corps of Engineers, Baltimore District in establishing a streamlined process for review and issuance of federal permits for shellfish aquaculture activities.
- Expanding law enforcement capabilities.

State efforts to provide opportunities and incentives that will attract private investment in Maryland's commercial shellfish aquaculture industry are having a beneficial impact. Since the new leasing program was implemented in September 2010[2], leaseholders have been planting and harvesting millions of oysters on their leases. This trend is expected to continue as interest in obtaining new leases and expanding existing oyster aquaculture businesses remains strong (Figure 15) and the number of oysters being planted and reaching market size continues to increase. Public-private partnership projects could be used to incentivize aquaculture opportunities, especially within the public fishery.

In order to assure the responsible development of the aquaculture industry, Maryland lawmakers established the Aquaculture Coordinating Council to formulate and make proposals for advancing this industry. The council includes members with a diverse range of experience and expertise (as described in Natural Resources Article, § 4-11A-03.2). The duties of the council include a charge to investigate and, to the extent feasible, enhance the area of state waters that is available to private leases for purposes related to the aquaculture and seafood industries. A report including recommendations which support the continued advancement of the shellfish aquaculture industry is issued annually by the council.

Aquaculture Strategy 7.0

Continue to provide incentives for private investment in shellfish aquaculture production and continue to locate areas for leasing within state waters.

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[2] The department began accepting applications for new commercial shellfish aquaculture submerged land leases on September 7, 2010, after several years of the leasing program being temporarily suspended. The State authority for aquaculture permitting was fully consolidated from the Maryland Department of the Environment (MDE) to the Maryland Department of Natural Resources by additional legislative changes that took effect on July 1, 2011. The department began accepting applications for water column leases and applications within oyster sanctuaries on Aug. 1, 2011. Therefore, the total number of leases issued to date since September 2010 includes six Tidal Wetlands Licenses issued by MDE in conjunction with State water column leases issued by the Board of Public Works.

Action 7.0.1
Partner with other local, state and federal agencies, academics, non-governmental organizations, industry representatives and other stakeholders to further streamline state and federal permitting and to continue to implement and operate financing, education and training programs and support the development of additional industry infrastructure.

Action 7.0.2
Identify areas suitable for submerged land and/or water column leases where the leases would not adversely impact existing living resources.

Action 7.0.3
Manage the oyster aquaculture industry to assure compliance with state and federal regulatory program requirements.

8.0 Monitoring

An essential part of managing the oyster population and fishery is assessing the status of the oyster resource, tracking the restoration and replenishment efforts and evaluating management strategies and actions. Oyster monitoring programs that already exist in Maryland consist of the annual Fall Oyster Dredge Survey, Patent Tong Population Surveys and Large-Scale Oyster Restoration Monitoring.

The Fall Oyster Dredge Survey provides critical data for the stock assessment and is the most comprehensive Maryland database on oysters. Integral to the Fall Oyster Survey are five types of indices intended to assess the status and trends in Maryland’s oyster populations: the Spatfall Intensity Index, a measure of recruitment success and potential increase of the population obtained from a subset of 53 oyster bars; Oyster Disease Indices, which document disease infection levels as derived from a subset of 43 sentinel oyster bars; the Total Observed Mortality Index, an indicator of annual mortality rates of post-spat stage oysters calculated from the 43 oyster bar Disease Index subset; the Biomass Index, which measures the number and weight of oysters from the 43 Disease Bar subset relative to the 1993 baseline; and the Cultch Index, a measure of habitat at the 53 Spat Intensity Index bars. In addition to the Fall Survey collection of oyster information, ecosystem measures also have been part of the monitoring effort. Physical environmental factors are monitored by other groups or agencies and are incorporated into the Fall Oyster Survey reports. Other ecosystem components including habitat (cultch), associated benthic epifaunal, competitors, and predators are recorded during the Fall Survey. An extended time-series of epibenthic organisms associated with the oyster bar community and their ordinal rankings has also been recorded for every bar surveyed.

The Fall Survey has been a source of collaborative research opportunities for scientists and students within and outside of the department. Fall Survey data have been provided to University of Maryland researchers for many different studies. For example, a University of Maryland graduate student is looking into refining mortality estimates from the Fall Survey data. The Survey continues to assist with an innovative pilot fishery program examining triploid oyster plantings on Ragged Point for the Potomac River Fisheries Commission. Data from the Fall Survey continue to be used extensively by researchers for oyster restoration projects (Tarnowski, 2017). Monitoring results (e.g., mortality, disease prevalence and intensity, abundance and biomass, cultch volume and spat settlement) are currently used to guide restoration and replenishment activities. In addition, quantitative area-based surveys using patent tongs or divers in combination with sonar surveys can be utilized to determine when a sanctuary is restored according to predetermined oyster metrics (Oyster Metrics Workgroup, 2011).

With the proposed scope of restoration activities over the next decade, monitoring needs will increase. Monitoring methods should be periodically reviewed and adapted as needed to the changing needs of restoration and stock assessments. Monitoring the oyster stock and oyster restoration projects requires at least two different spatial considerations, a Maryland baywide approach and a site-specific approach (e.g., individual oyster bars or individual NOAA codes). The general framework for monitoring is based on standard scientific methodology. Each oyster project must define its purpose or hypothesis and have a statistically valid monitoring design to address the hypothesis. In addition, each project should identify how it will contribute to the overall objective of increasing oyster abundance and biomass. All oyster projects and sites will be tracked, but at different levels of intensity and for varying lengths of time. As oyster populations in sanctuaries and public fishery areas change over time, the level and type of monitoring may also change over time.

Monitoring Strategy 8.0
Support and enhance monitoring activities to assess the status of the oyster resource, track restoration and replenishment efforts, and evaluate management strategies and actions.

Action 8.0.1
Conduct monitoring programs using scientifically accepted and consistent sampling procedures, timing, data collection and analysis, and provide the results to a central database or databases. Coordinate sampling methodology among federal, state and non-governmental organizations for consistency, taking into account sampling during different times of the year and sampling with different gear types.

Action 8.0.2
Continue the annual Fall Oyster Dredge Survey to monitor population trends and effectiveness of replenishment and restoration plantings, and serve as the basis of the stock assessment.

Action 8.0.3
Continue the Oyster Patent Tong Population Survey to estimate population abundance and biomass.

Action 8.0.4
Continue monitoring efforts of the large-scale restoration projects in sanctuaries to assess the outcome of restoration efforts.

Action 8.0.5
Maintain or increase funding to conduct necessary monitoring activities, if available.

Action 8.0.6
Consider alternatives or improvements to existing monitoring methods to increase accuracy and precision of fishing mortality estimates.

Action 8.0.7
Consider and implement recommendations for changes to the Fall Oyster Dredge Survey, harvest reporting, and other surveys identified or used in the stock assessment and peer review reports.

Action 8.0.8
Utilize scientific data collected by other entities when appropriate to assess the status of the oyster resource, track restoration and replenishment efforts, and evaluate management strategies and actions.

9.0 Socioeconomic Considerations

Oyster harvesting has been an important part of the Chesapeake Bay's culture and economy since colonial times. The most recent dockside value of the commercial oyster harvest in Maryland's portion of Chesapeake Bay was $8.6 million (2017-2018 season) (Figure 16). This figure only includes the value of the commercial harvest; additional economic value is contributed through aquaculture, processors and seafood dealers. There are also a number of secondary industries, fishing communities and a culinary culture associated with oysters. Based on information from the 2013-2017 American Community Survey 5-Year Estimates stated between 0.1 percent and 3.8 percent of the population in the 11 tidal counties of Maryland where oyster bars are located make their living on fishing, farming and forestry. This occupational category comprised a higher percentage of the workforce on the Eastern Shore of Maryland: Kent County (3.8 percent), Somerset County (2.7 percent), Dorchester County (2.0 percent), Queen Anne's County (1.5 percent) and Talbot County (1.2 percent) (U.S. Census Bureau, 2018).

There have been a number of economic analyses of the oyster fishery over the years. The focus of these studies have included the theoretical merits of leased-bottom and public-bottom culture, potential consequences of introducing a non-native species, the cost efficiency of depuration, an evaluation of increased seed prices for the fishery, and a model of investment return and assessments of the economic status of the oyster fishery (1994, 1997 and 2002) (National Research Council, 2004). The National Research Council (2004) summarized the social and economic value of oysters in Chesapeake Bay through 2001. Although there have been significant changes in the overall oyster industry in the past decades, the fishery and more recently, aquaculture, continue to provide economic and cultural value to Maryland. The loss of the oyster fishery for Maryland watermen would have a significant impact on the livelihood and traditions of fishing communities.

More recent economic analyses have focused on the valuation of ecosystem services provided by oyster reefs and the socioeconomic impacts from oyster reef restoration. Grabowski et al. (2012) developed a modeling framework to assess the economic value of oyster reef ecological services. They included water quality improvement, shoreline stabilization, carbon burial, habitat for fish and invertebrates, habitat diversification and oyster production as part of ecological services. They estimated an average annual value of services provided by oyster reefs between $10,000 and $99,000 per hectare, depending on the location of the oyster reef and the suite of ecological services. They concluded that oyster reefs provide value not only as a commercial fishery resource but also as a biogenic habitat. Their analysis suggests that the total potential return on oyster reef restoration investments justifies restoration and protection of oyster reefs. An ecological model developed to represent the restored oyster reef trophic environment in the Choptank River System projects that relatively large increases in blue crab abundance would result from long-term oyster reef restoration in this area. The model projects a 160% increase in blue crab harvest in a future Choptank River system with fully mature, restored and unharvested oyster reefs relative to a non-restored non-sanctuary area. Economic impact modeling projects that the increases in commercial fishing harvest, resulting from the increased food in the system with the protected reefs, could generate additional economic output in excess of $20 million annually in Dorchester and Talbot counties - the two counties adjacent to the restored area (Knoche and Ihde, 2018). In addition, conservative estimates on the economic value of nutrient removal in Harris Creek have been developed (Kellogg et. al., 2018). An annual value of $1,749,078 was associated with nitrogen denitrification and $1,277,155 for phosphorus removal in the Harris Creek sanctuary.

Socioeconomic management decisions to enhance the oyster industry, improve the Chesapeake Bay ecosystem and maintain Maryland's cultural heritage require a process that includes stakeholder input, economic data and scientific knowledge. The Oyster Futures research program successfully utilized the Consensus Solutions process, developed by the Florida State University, to identify oyster management recommendations (Oyster Futures Stakeholder Workgroup, 2018). Key elements of the process included transparency, respect, mutual trust building, equitable representation and multiple iterative facilitated meetings. The advisory groups working with the department (Tidal Fisheries Advisory Commission, the Sport Fisheries Advisory Commission, Oyster Advisory Committee, Aquaculture Coordinating Council and County Oyster Committees) would benefit from using a similar process for developing management strategies for the Maryland oyster fishery.

Socioeconomic Strategy 9.0
Promote and support the socioeconomic benefits from the oyster industry, aquaculture and ecological services including restoration.

Action 9.0.1
Continue to promote and support the analysis of socioeconomic data from the oyster industry, aquaculture, restoration efforts, and ecological services.

Action 9.0.2
Utilize a consensus process to engage stakeholders, advisory groups and scientists on oyster resource policies and management issues that will result in decisions that have broad support among the oyster groups.

Action 9.0.3
Continue working with state agency partners and stakeholders on the development of a nutrient credit trading market to advance Chesapeake Bay restoration goals and provide economic benefits to the oyster industry.

10.0 Enforcement

Sanctuaries and special management areas represent significant investments of money, shell and seed for rebuilding oyster biomass. Effective enforcement of closed areas is crucial for protecting oyster habitat and ecological functions, ongoing scientific investigations in these areas, and resulting increases in oyster biomass. As the number of protected areas increase, the task of protecting these sites will become increasingly difficult. To facilitate enforcement, all special management areas are marked with permanent buoys. In addition, effective enforcement of MDE closed areas is essential for protecting public health and Maryland's public and private oyster industry. Maryland has increased the fines for poaching and continues to improve educational outreach programs. The ability to protect sanctuaries from poaching has improved due to the implementation of the Maritime Law Enforcement Information Network (MLEIN) and the department's ability to administratively suspend and revoke licenses through the points system for multiple harvesting violations or egregious harvesting violations (Maryland Department of Natural Resources, 2016).

Enforcement Strategy 10.0
Continue to strengthen the enforcement of oyster management measures established in statute and regulations, and by public notice.

Action 10.0.1
Evaluate and implement the following enforcement measures.

- Increase enforcement staff to provide for additional marine patrols.
- Utilize fines and administrative sanctions to deter violations.
- Continue efforts to penalize repeat offenders in the fishery by license/entitlement suspension and revocation.
- Buoy all closed and restricted areas as possible.
- Educate the general public, members of the judicial system and stakeholders including commercial fishermen on oyster harvest laws and regulations and changes in those laws and regulations.
- Produce and distribute an annual State of Maryland Shellfish Closure Areas book that has maps and coordinates of closed areas and make the information available online.
- Continue utilizing a citizen hotline for reporting violations.
- Implement harvest management measures that improve enforceability (e.g., prohibit culling while off an oyster bar).
- Develop appropriate enforcement practices to protect oysters in closed areas and consider the use of the MLEIN network, helicopters and other tools for detecting poaching over a broad geographic area.

Action 10.0.2
Strengthen enforcement efforts related to public health violations involving oyster harvest and sale.

11.0 Ecosystem Considerations

Oysters are considered a keystone species of Chesapeake Bay because of the role they play in shaping the ecosystem. They are often referred to as "ecosystem engineers" since individual oysters form reefs that provide a structured habitat for a whole community of organisms. The surface irregularities and infoldings of a reef create a variety of microhabitats that support biodiversity. The three-dimensional structure of oyster reefs provides more surface area and interstitial spaces than a similar-sized flat bottom area. Oyster reefs influence patterns of currents and can act as natural coastline buffers by absorbing wave energy and reducing erosion. Reefs support a diverse suite of resident and transient species including commercially, recreationally and ecologically important fish species (e.g. striped bass, blue crabs, black sea bass) and a diverse array of invertebrate species. As such, oyster reefs provide protection for prey species and supply abundant food for predators. Reefs have been recognized as essential fish habitat for demersal fish and can be thought of as "temperate-zone analogs of tropical coral reefs" (Peterson et al., 2000). The decline in the oyster populations and consequent reduction in ecological benefits may have fundamentally altered the functioning of the Bay ecosystem.

Oyster reefs contribute structure and substrate that sustain the rich community of organisms associated with them. The shell that constitutes the reef adds structure and firm substrate to the estuary, contributing habitat that is in stark contrast to the otherwise soft bottom environment of the bay. Under natural conditions, shell degradation is due to a combination of taphonomic factors, where shell is lost through chemical (e.g., dissolution), physical (e.g., sedimentation, subsidence, breakage, dislodgement from the bar), and biological (e.g., shells riddled by boring sponges, polychaete worms, etc.) processes. For reefs to build, the rate of shell accretion must exceed the rate of shell loss, which under natural conditions occurs by some small amount. The extraordinary outbreaks of disease epizootics in recent decades and two centuries of harvesting have disrupted this balance. The decline of the Chesapeake oyster over the past three decades has resulted in the reduction of a critical functional component of the ecosystem and the gradual disappearance of a significant structural element as well.

Predators, in conjunction with environmental variables such as depth, turbidity, food availability and disease, contribute to the natural mortality of oysters and can affect the abundance and distribution patterns of oyster reefs (Gosling, 2003). Oyster predators affect different phases of the oyster life cycle (Kennedy, 1991). An estimated 99 percent of oyster larvae are lost before settlement mainly due to predation by ctenophores and other planktivores. Newly attached spat are eaten by small crabs (including mud and blue) and carnivorous worms. Small adult oysters are preyed upon by several species of fish, rays, whelks and oyster drills; the latter two more commonly found in higher salinity regions of the mid-bay (Kennedy and Breisch, 2001). As a defense mechanism, oysters are able to produce thicker shells in response to predation (Newell et al., 2007).

Climate change can cause shifts in estuarine and marine communities and is expected to influence ecosystem dynamics especially temperature and salinity, facilitate bioinvasions and cause shifts in the range and distribution of species over the next decades (Lord, 2014). The overall ecological effects of climate change on oysters in Maryland's Chesapeake Bay have not been evaluated. Salinity gradient has been positively correlated with disease-causing pathogens and predation pressures. The range of MSX and Dermo diseases has expanded as salinity and water temperatures have increased (Kennedy and Breisch, 2001). If salinity decreases due to high rainfall years, it could reduce disease but negatively impact reproduction. Precipitation is expected to increase and pH is expected to decrease with climate change. This change could have detrimental effects on oyster shell formation in the form of acidification. Warming temperatures are likely to facilitate an increase in invasive species especially fouling species like tunicates, bryozoans and sponges (Lord, 2014).

One of the major predators of oysters in higher salinity areas is the oyster drill. Although currently not an issue in Maryland, oyster drills have been responsible for impacting oyster populations in Virginia. If salinity increases in Maryland due to climate change, oyster drills may be capable of moving up the bay. Another predator-prey interaction that could be impacted by climate change involves sea nettles (*Chrysaora quinquecirrha*), ctenophores (*Mnemiopsis leidyi*) and oyster larvae. Higher than average rainfall could decrease salinity and decrease the number of sea nettles that prefer brackish to higher salinities. Sea nettles feed on ctenophores, one of their main prey items. When the number of sea nettles decrease, the number of ctenophores are likely to increase. Since ctenophores are a key predator of oyster larvae, more ctenophores would mean fewer oyster larvae (Breitburg and Fulford, 2006). Low numbers of oysters and decreased oyster reef habitat may have altered the oyster – sea nettle – ctenophore dynamics, leading to an increase in ctenophores in the bay. Increasing oyster populations could benefit sea nettles, reduce ctenophores, and subsequently reduce predation on oyster larvae (Breitburg and Fulford, 2006). How well oysters are able to adapt to climate change will depend on a variety of unknown parameters but changes in salinity and temperature will be important.

Oysters, as well as other shellfish organisms, are well-known for their water filtering capabilities. They enhance water quality by removing organic and inorganic particulate matter (reduce sedimentation) and improve clarity. They consume phytoplankton and potentially decrease harmful algal blooms to prevent eutrophication. They assimilate nitrogen and phosphorus into their tissues and shells but also are important in nutrient and energy cycling, transferring nutrients from the water column to the sediment.

Starting in 2014, the Chesapeake Bay Program assembled an expert panel to review all relevant available data and then evaluate the effectiveness of oyster practices on reducing nutrients and suspended sediments. To date, the panel has recommended an Oyster Best Management Practice decision framework for determining the nitrogen, phosphorus and suspended sediment reduction effectiveness of oyster practices. The panel completed a report that includes guidelines on how reductions could be applied and verified for application in the Chesapeake Bay Total Maximum Daily Load. Once approved, the oyster practices and any corresponding nutrient and suspended sediment reduction effectiveness crediting protocols can be selected as a best management practice by jurisdictions (state and/or local governments) to help meet the water quality goals established by the Chesapeake Bay Total Maximum Daily Load.

Ecological Strategy 11.0
Develop policies that protect the ecological functioning of oyster reefs and promote the importance of oysters for their ecological services.

Action 11.0.1
Support the ecological role of oysters for their structural and habitat importance, their ability to enhance water quality and their role in nutrient and energy cycling.

Action 11.0.2
Consider conducting an oyster vulnerability assessment to evaluate potential climate change effects and incorporate the results into the management process.

Action 11.0.3
Utilize decision-support models to design restoration efforts that maximize ecosystem benefits including but not limited to credits for water filtration and denitrification.

Action 11.0.4
Utilize oysters as a Best Management Practice to reduce nitrogen and phosphorus toward meeting the Total Maximum Daily Load goals.

Action 11.0.5
Work with the Maryland Department of the Environment to develop a nutrient crediting system for oysters produced by aquaculture and removed by the public fishery.

Action 11.0.6
Work with the Maryland Department of the Environment to develop a nutrient crediting system for oysters in areas closed to harvest that are part of the denitrification process.

12.0 Research Needs

The following research recommendations were developed in the process of completing the 2019 Oyster Stock Assessment and Five Year Oyster Review Report in 2016. These are important data gaps that, if known, could increase the department's ability to manage the oyster resource. The department should continue to conduct projects with industry partners, government partners, academics, non-profit organizations, and other interested entities to improve its ability to manage the oyster resources.

Data

- Conduct fishery-dependent sampling of oyster size distribution to better quantify the number of oysters per bushel and the number of undersized oysters per bushel.
- Conduct research to better quantify growth rates that can be incorporated into oyster stock assessment models.
- Develop a means to mark hatchery-reared planted spat so that the proportion of planted versus wild oysters can be determined in subsequent surveys.
- Develop a means to determine if naturally recruited spat came from hatchery-reared planted broodstock in sanctuaries (e.g., the far-field effect of sanctuary oysters seeding areas outside of the sanctuary)
- Examine and compare oyster population abundance estimates determined by different survey gear types and methodologies.

Natural Mortality

- Conduct studies to improve estimates of box decay rate. Box abundance is a critical element in the estimation of annual mortality, understanding how long boxes persist under varying conditions will improve estimates of natural mortality.
- Explore the effects of timing of the oyster harvest relative to when the Fall Oyster Dredge Survey occurs to see if it explains some differences between model-based and box count estimates of natural mortality.
- Research to better define longevity and identify primary sources of natural mortality of oysters.
- Examine resiliency of oyster populations to high natural mortality events.
- Expand research and current monitoring programs to provide robust answers to emerging disease questions. This may include determination of a genetic marker from disease resistance and monitoring for this marker.
- Continue to address and find solutions to reduce the effects of oyster diseases.
- Examine and compare natural mortality estimates determined by different survey gear types and methodologies.

Habitat

- Conduct research examining how different harvest gears and their harvest efficiency impact the oyster resource, habitat quality and shell.
- Conduct oyster bar analysis to determine if there has been a spatial shift in oyster productivity.
- Conduct research on the performance of shell plantings over time.
- Conduct research on alternative ways to maximize the use of shell resources in plantings and restoration (e.g., cultchless seed setting).
- Develop a shell budget that will lead to practical applications, such as but not limited to, managing shell plantings, enhancing reef restoration, identifying areas of harvest closures/openings and determining total allowable catch.
- Quantify the rate of habitat decay to inform the stock assessment and reference point models and contribute to the development of a shell budget.
- Conduct research to better understand how shell plantings contribute to habitat and how habitat is quantified to inform the stock assessment model.

Sanctuaries and Spatial Scale

- Conduct research to help explain how individual NOAA codes (as well as sanctuaries and fished areas) contribute to one another's oyster populations. This would allow for a more complete oyster stock assessment model that incorporates feedback among areas rather than the current assessment which treats each NOAA code area as though it is an isolated population.
- Conduct research on ecological services including fish and crab production, nutrient cycling and water quality parameters in targeted restoration areas and other sanctuaries.

Stock Assessment Model

- Incorporate a shell budget into stage structured assessment in order to allow internal estimation of biological reference points.
- Examine alternative spatial structure for the oyster stock assessment.
- Develop a predictive model to forecast the effects of different management strategies.

Biological Reference Points

- Develop a spawner per-recruit type analysis that represents shell per recruit instead of egg production.
- Determine the ratio of shell per recruit that is suitable for target and threshold reference points.

Aquaculture

- Develop an aquaculture database that tracks plantings, standing stock and harvest of diploid and triploid oysters at the NOAA code spatial scale to improve the oyster stock assessment model's ability to quantify the contribution of aquaculture plantings.

- Conduct targeted research on the interactions between shellfish aquaculture and Submerged Aquatic Vegetation (SAV) to assess the effects of activities and gear/equipment used by Maryland shellfish growers on SAV and identify scientific metrics to inform growers on equipment placement, spatial distribution and responsible harvesting and maintenance activities on leases where SAV has encroached.

Other

- Research the economic benefits and impacts of the oyster fishery, aquaculture, and replenishment activities.
- Review best management practices and outcomes for oyster resources and adapt successful techniques and applications from other places and regions.
- Research the economic value of recreational uses of the bay to the abundance of oysters and water quality, and determine whether Maryland's economy might benefit from a reduction in the harvest of wild oysters.

Glossary

Development of a common language is fundamental to any collaborative undertaking. Terms such as oyster reef, bar and habitat or restoration, rehabilitation, repletion and replenishment have been used interchangeably in the past. The purpose of this section is to clarify common terms used in order to avoid confusion in the future.

Aquaculture. The propagation and rearing of aquatic organisms in controlled or selected aquatic environments for any commercial, recreational or public purpose. Specifically, oyster aquaculture is the cultivation of oysters and can be classified according to where it occurs.

> *On-bottom*. Cultivation that involves planting directly on the submerged land without the use of structures (e.g., floats, cages or racks).
>
> *Water Column*. Cultivation that involves the use of structures (e.g., floats, cages or racks).

Commercial oyster aquaculture activities require authorization through a state permit or lease and may also require issuance of a federal permit.

Biomass. The total weight or volume of a species.

Bottom rehabilitation (also referred to as oyster habitat rehabilitation). Repairing damage to bottom habitats within oyster habitat caused by disturbances such as harvest, increased sedimentation rates and shell erosion and loss due to biofouling. In the Chesapeake Bay, this type of rehabilitation is focused on increasing the amount and quality of substrate suitable for oyster settlement, survival and/or growth.

Broodstock. The group of adult (reproductively mature) oysters. Oysters in the Chesapeake Bay typically become reproductive at 1.5 inches (this varies with location), which is below the current minimum market size of 3 inches. Larger oysters (3 to 5 inches) are typically more fecund than smaller oysters.

Bushel. The container used to hold oysters harvested. The size of a Maryland bushel is defined in the Code of Maryland Regulations (COMAR 08.02.04.04) and is different from a U.S. bushel or Virginia bushel.

Cultch. Any material, but primarily oyster and clam shells, that serves as a settlement substrate for oyster larvae.

Department. Within this document, the department refers to Maryland Department of Natural Resources.

Fecundity. Reproductive potential; specifically, the quantity of gametes, especially eggs, produced per individual over some time period. In oysters there is a strong positive relationship between oyster size and fecundity, with larger individuals producing more gametes than smaller individuals.

Harvest. To take, kill, trap, gather, catch or in any manner reduce any oyster to personal possession or attempt to engage in this conduct.

Harvest area/bottom (also referred to as public fishery area, oyster harvest area, or bottom). A general term, not a formal designation, referring to an area where public harvest is allowed.

Hatchery production. The production of spat-on-shell by private, state or nonprofit hatcheries.

Historic oyster bar/habitat. Legal boundaries of oyster bars charted by historic surveys and information including the 1906-1912 Yates Survey and the 1974-1983 Maryland Bay Bottom Survey.

Historically productive oyster bar/habitat. The fraction of historic oyster habitat that was determined to have been occupied by oysters.

Market oyster. An oyster 3 inches or more in length available for legal harvest by the public commercial and recreational fishery. Aquaculture market-sized oysters may be 2 inches or greater year-round when harvested from a water column lease and also when harvested from a submerged land lease outside of the public fishery harvest season.

Oyster bar. General areas where oysters once lived (see historic oyster bar/habitat) or currently live. These areas are represented on charts maintained by the state of Maryland for the purposes of management and enforcement of fishery regulations; they may or may not be a true delineation of current oyster habitat.

Oyster planting (also referred to as oyster stocking or oyster seeding). Placing live oysters (usually seed, but sometimes adults) on a suitable substrate.

Oyster reef. A biogenic structure created and stabilized by an aggregation of living oysters and other sessile (permanently attached) organisms, which provides habitat for a variety of other organisms. A biologically important aspect of oyster reef architecture is the amount and nature of interstitial space. Formation and continued existence of an oyster reef requires conditions favorable for oyster recruitment, survival and growth, and the absence of physical disturbances to the integrity of the reef structure. Oyster reefs are not defined by any particular shape or size, but can be classified by certain gross morphological features such as vertical relief (height or elevation) relative to the sea bottom and the water surface.

Recruitment. Addition of new individuals to some group. In the context of oysters, two interpretations are relevant:

> *Population.* Spat set that has the potential to grow and contribute to harvest and spawning stock.
>
> *Ecological*. Survival beyond the larval and spat stages, at which point individuals become ecologically functional (e.g., water-filtering, reef-building) members of the oyster population.
>
> *Spawning Stock*. Survival to reproduction (i.e., typically at 1.5 inches in size), at which point individuals become genetically functional members of the oyster population.

Reef base. A foundation of material (e.g., shell or alternative materials) placed in such a manner and location and typically accompanied by other management activities (e.g., oyster planting), to encourage the formation of an oyster reef.

Replenishment. Oyster planting in specific areas for public fishery harvest.

Resistance. The relative ability of an organism to avoid infection or to withstand the effects of disease (Ford and Tripp 1996).

Restoration. Returning to a former, normal or unimpaired condition (adapted from Luckenbach et al., in press; Webster's New World Dictionary 1982). In its literal sense, restoration would imply bringing something back to its original state. In the context of oyster reef habitats and oyster populations in the Chesapeake Bay, a return to the original or historical state is probably not feasible. As a general term, restoration does not refer to any specific management activity (see definitions under protection, rehabilitation and enhancement for terms related to specific management activities).

Sanctuary. A formally designated and marked area that is protected by a prohibition on the harvest of oysters except from an approved lease located within a sanctuary.

Seed. Oysters usually less than 1 year of age (spat) used in oyster planting. Size at planting is typically less than 1 inch, but if older year classes are used as seed, then they may be up to 1 inch. Seed may be classified according to its source of production.

Hatchery seed (also referred to as hatchery spat-on-shell). Seed oysters produced by a hatchery. Hatchery seed can be produced from a variety of broodstock sources. Hatchery seed are very young when planted, usually less than four weeks and they are usually less than 0.1 inch in size.

Wild seed (also referred to as natural seed). Seed oysters produced by natural reproduction of wild populations. Natural spat settle upon planted shells for the purpose of enhancing wild harvest areas. Spat comprise the majority of the wild seed and are between 0.5 inches to 1 inch, although some may be smaller or larger.

Shellfish Lease. A lease of the water column within the waters of the state, or land lying beneath the waters of the state, issued by the state for shellfish cultivation.

Shell planting. Placing clean oyster shell on the bottom.

Spat. Juvenile (not yet reproductive) oysters, less than 1 year old, typically ranging in size up to 1.5 inches. Oysters typically become reproductive in their second year of life, at which time they are usually 1.5 inches in size and are predominantly males.

Spat settlement (also referred to as spatfall, spat set). Metamorphosis of planktonic oyster larvae into juvenile oysters (spat), during which the larvae permanently attach to the settlement substrate (cultch).

Stock. The natural genetic unit of a population determined by its isolation from other populations. Stocks are an evolutionarily determined entity. For example, oyster (*Crassostrea virginica*) stocks from northern New England, the mid-Atlantic region and the Gulf Coast vary genetically from one another. For the purpose of this document, we consider all Chesapeake Bay oysters to be one stock.

Subtidal oyster reef. An oyster reef that extends some height above the surrounding bottom, but does not reach the intertidal zone. Subtidal oyster reefs can be further categorized as:

Low relief. From >0 to 1.4 foot in height.

Medium relief. From 1.5 to 6 feet in height.

High relief. Over 6 feet in height.

Transplantation. Moving live oysters from one location to another.

Yates oyster bar. Any submerged oyster bar, reef, rock or area represented as an oyster bar on the charts of the oyster survey of 1906 to 1912. Amendments of additional oyster bars were added to this original list after 1912, however, these bars are referred to as Non-Yates Bars.

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Figures

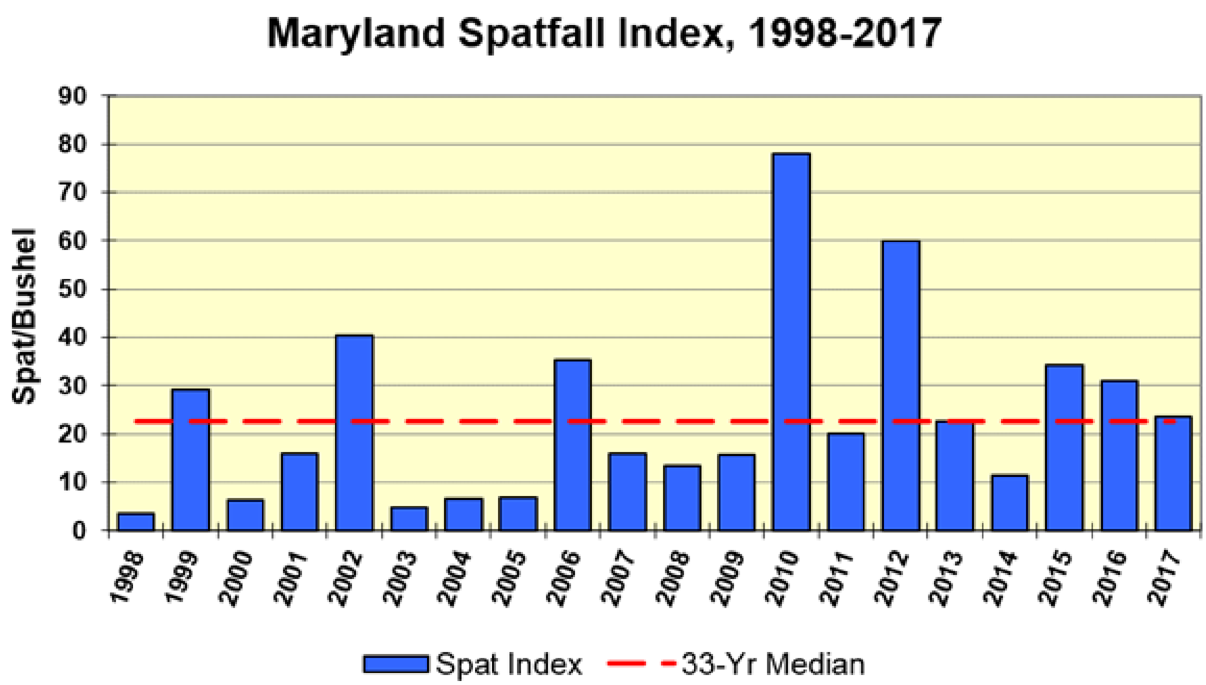

Figure 1. Maryland Fall Oyster Dredge Survey annual results of the Spatfall Index since 1998 and the 33-year median.

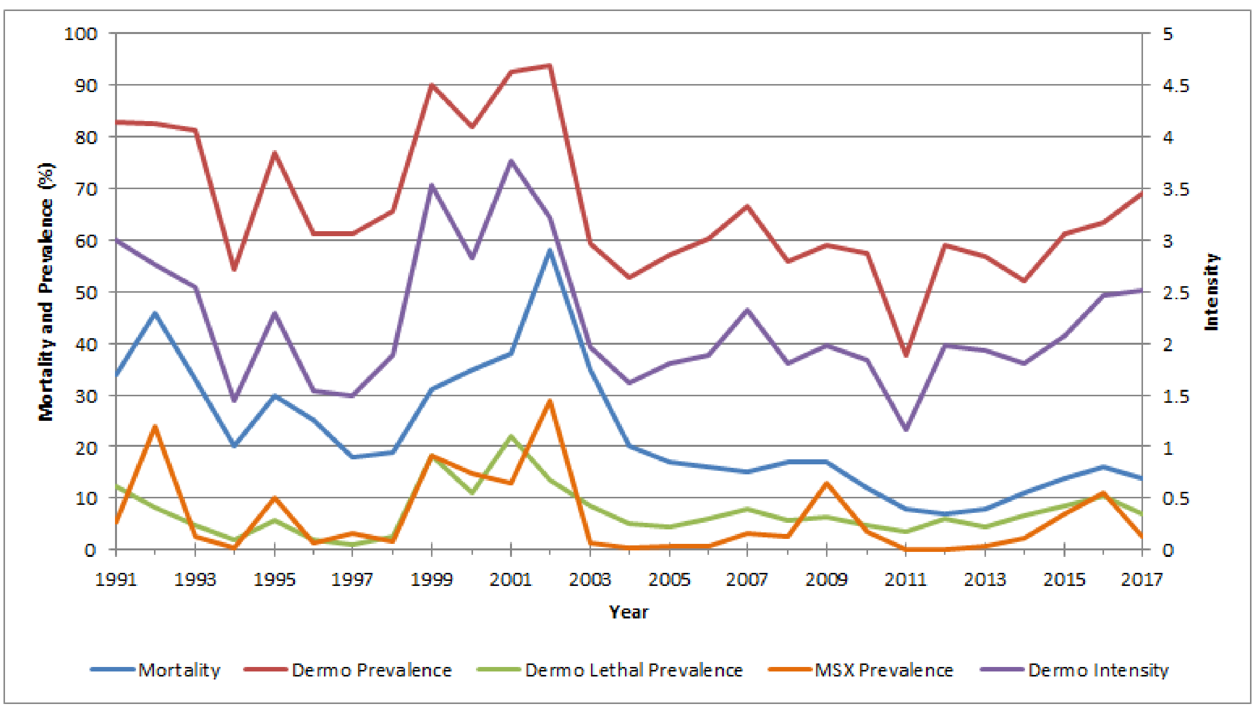

Figure 2. Maryland Fall Oyster Dredge Survey annual results of total observed natural mortality (%), Total Dermo disease prevalence (%), Lethal Dermo disease prevalence (%), MSX disease prevalence (%) and Dermo disease Intensity.

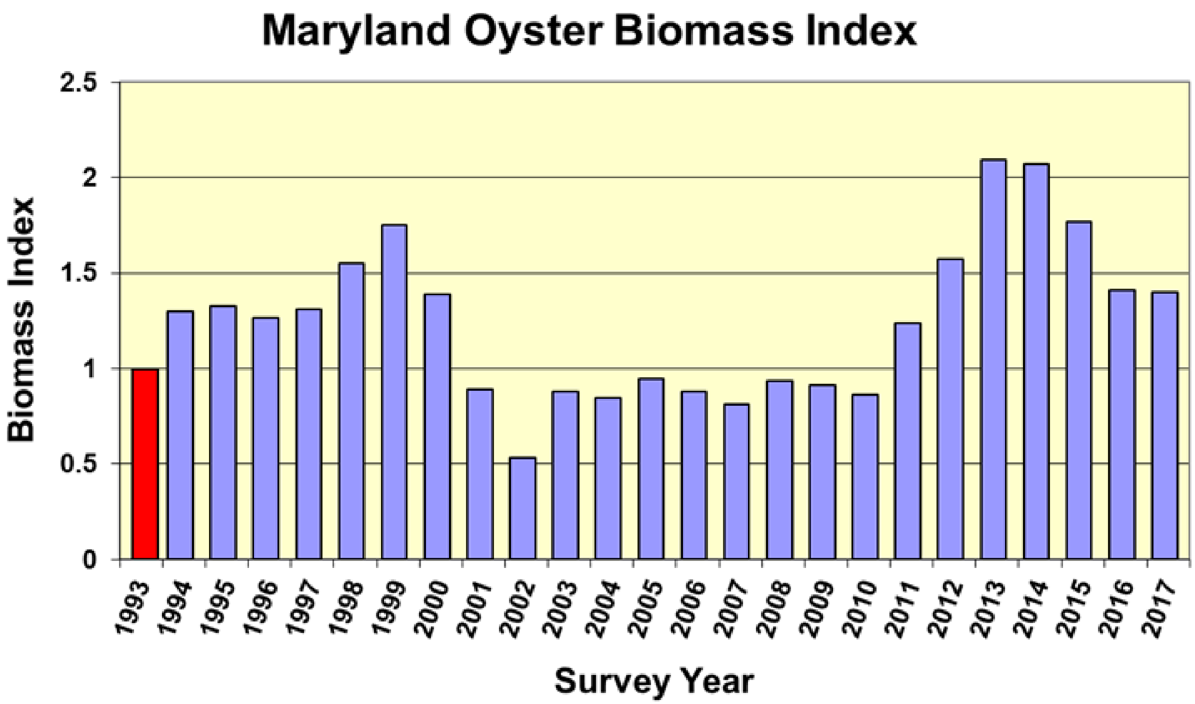

Figure 3. Maryland Fall Oyster Dredge Survey annual results of the Biomass Index as compared to the 1993 baseline biomass index value. The red bar represents the baseline year of the index.

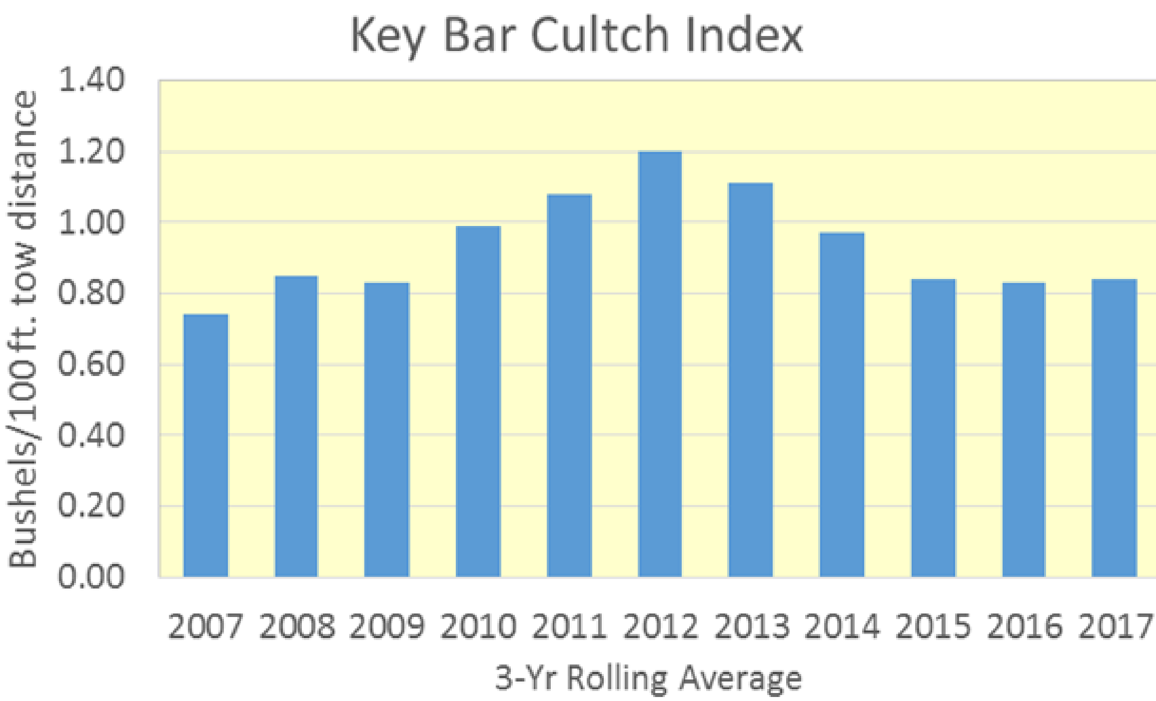

Figure 4. Maryland Fall Oyster Dredge Survey annual results of the Cultch Index.

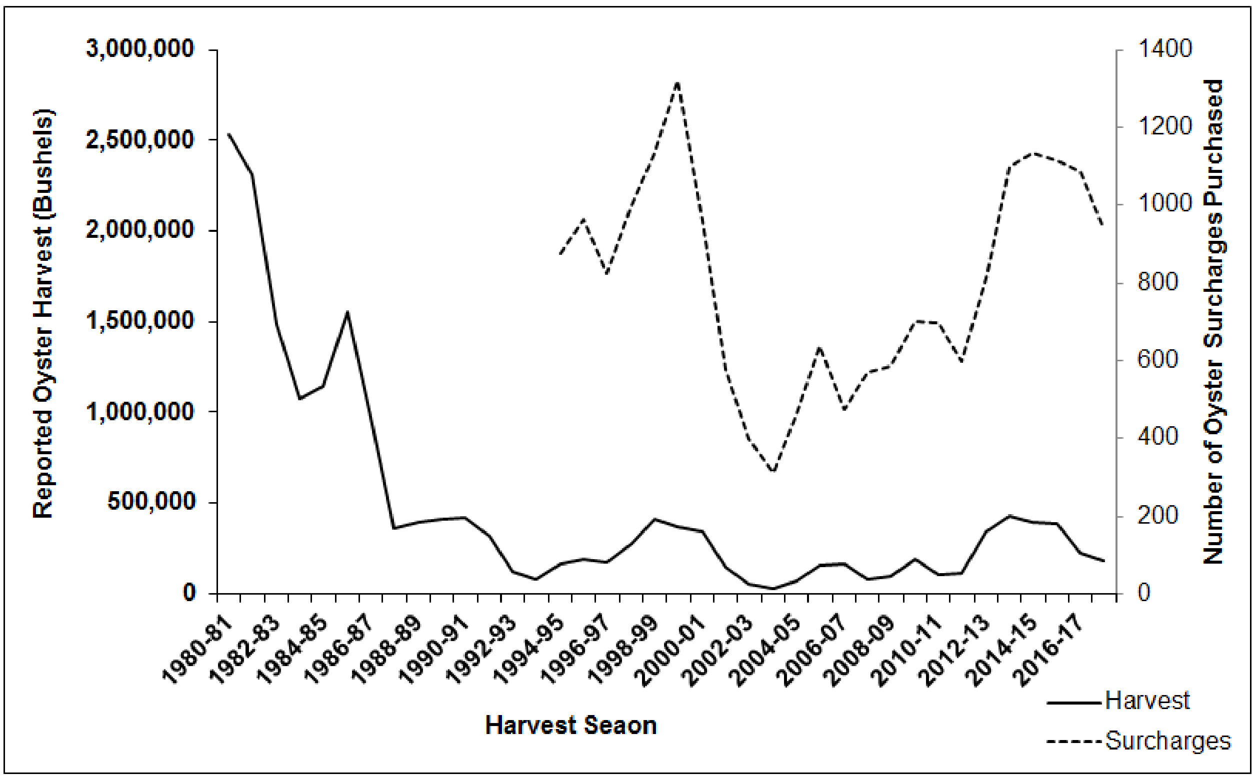

Figure 5. Maryland oyster harvest (bushels) since 1980 for each harvest season as reported by dealer buy tickets. The number of oyster surcharges purchased by oyster harvesters annually since 1994.

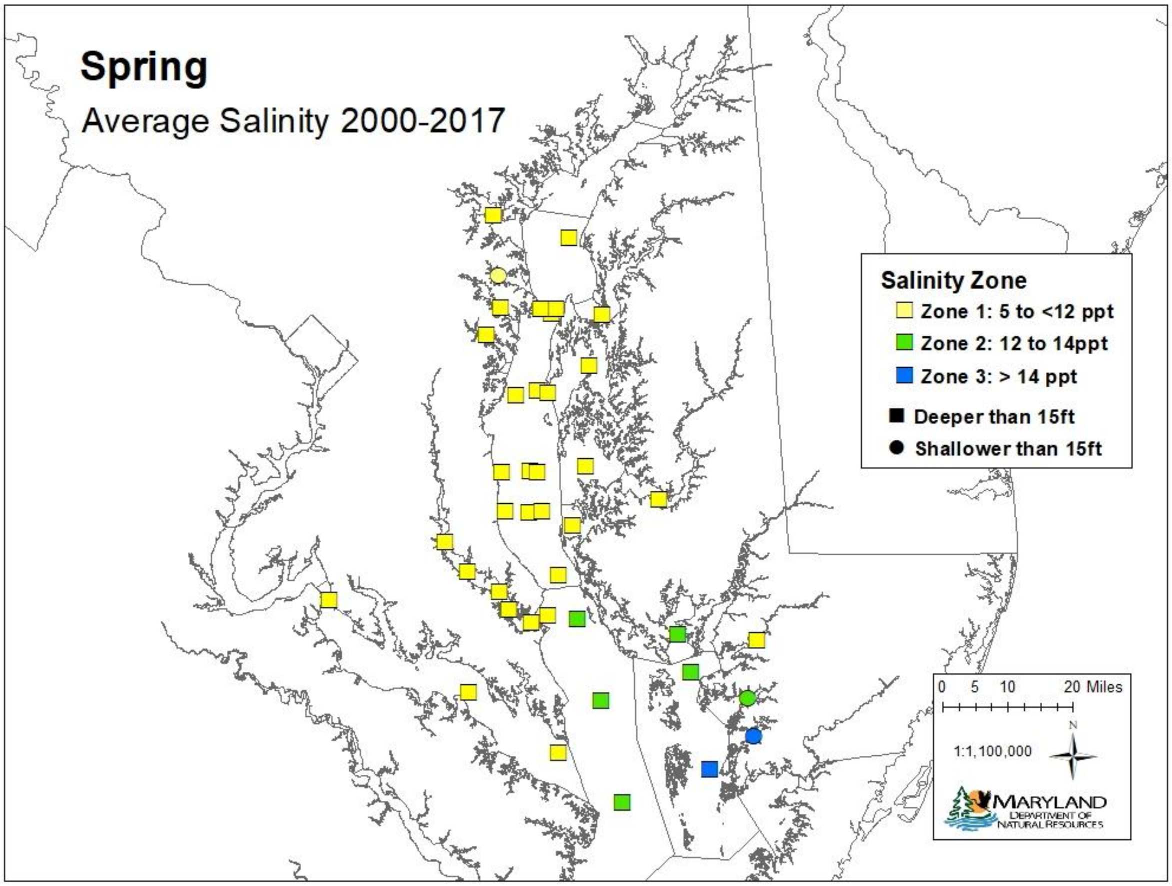

Figure 6: Average spring (April-June) salinity from 2000 to 2017 in Maryland's portion of Chesapeake Bay.

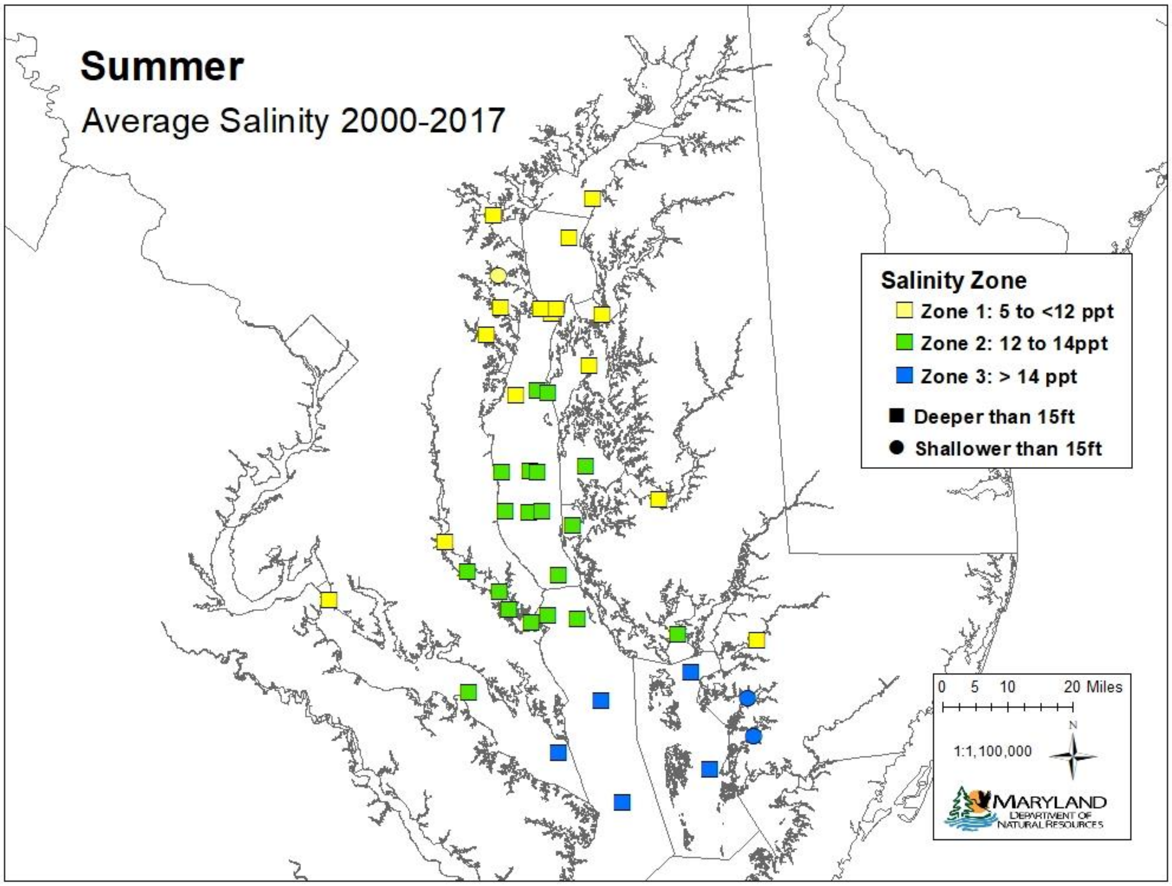

Figure 7: Average summer (July-September) salinity from 2000 to 2017 in Maryland's portion of Chesapeake Bay.

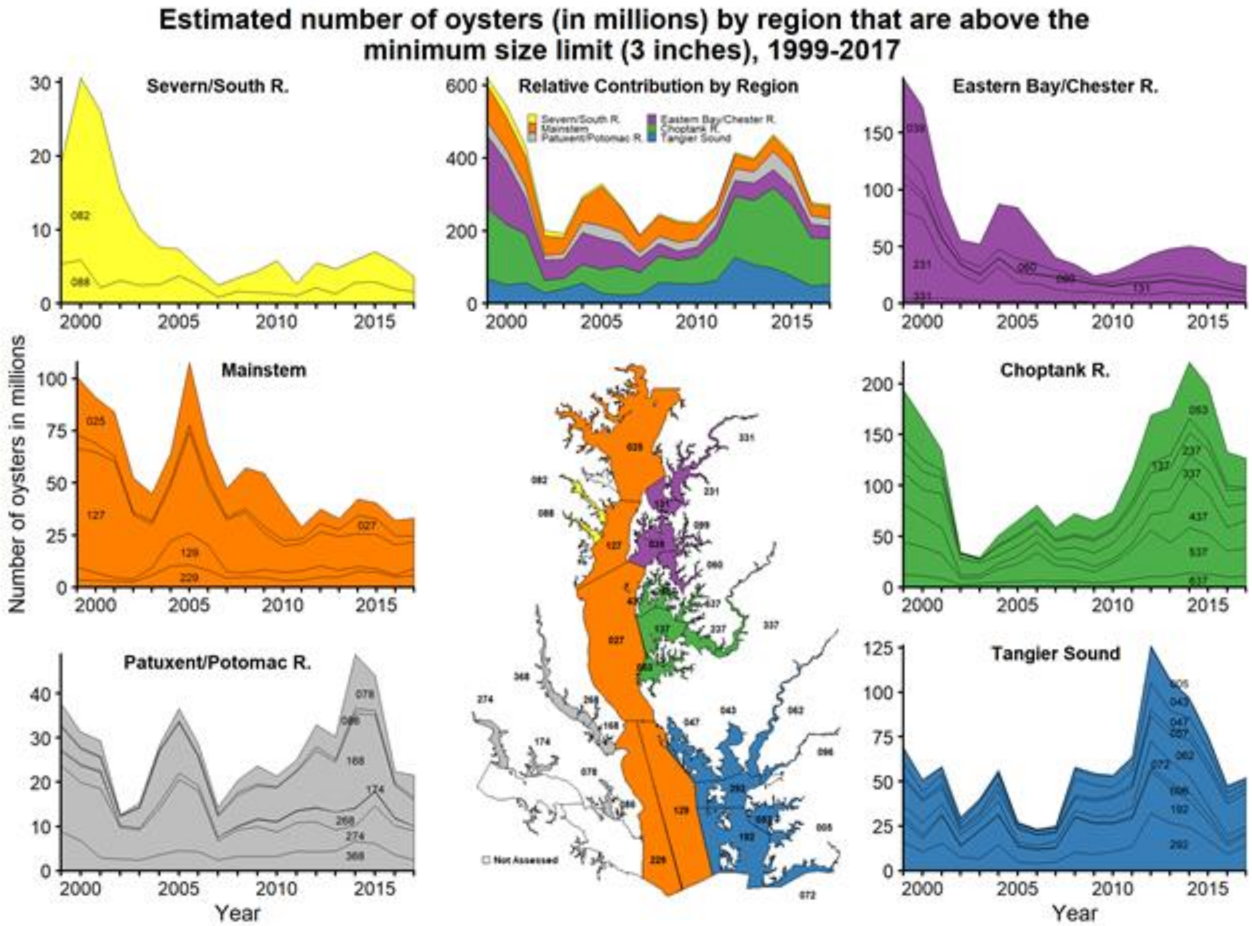

Figure 8. Estimated number of oysters (in millions) by region that are above the minimum size limit (3 inches; i.e., markets), during 1999-2017. Trends in abundance are presented by NOAA code within six regions. The regions are displayed on the map as well as the NOAA code locations.

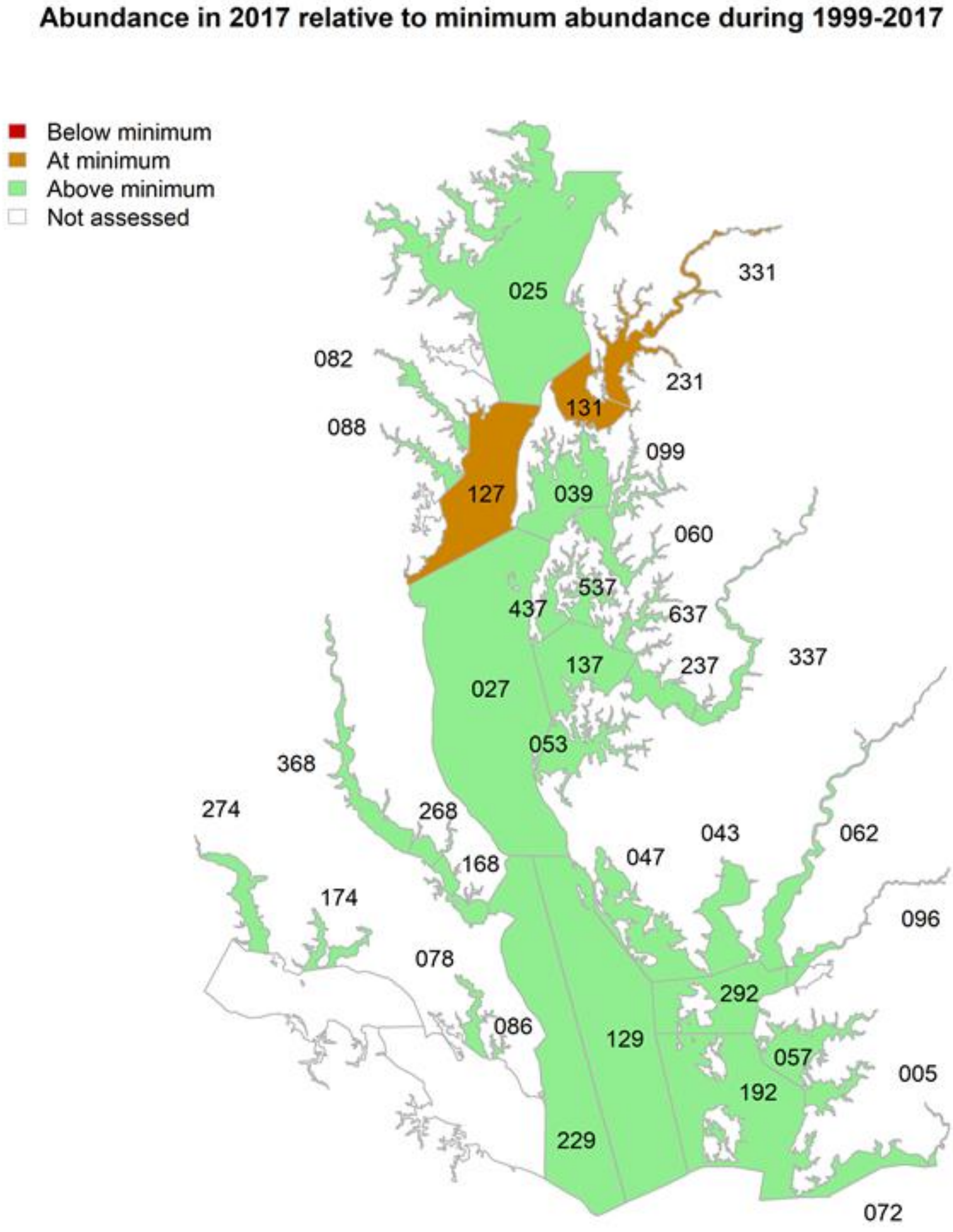

Figure 9. Status of market oyster abundance in 2017 relative to the minimum abundance during 1999-2017.

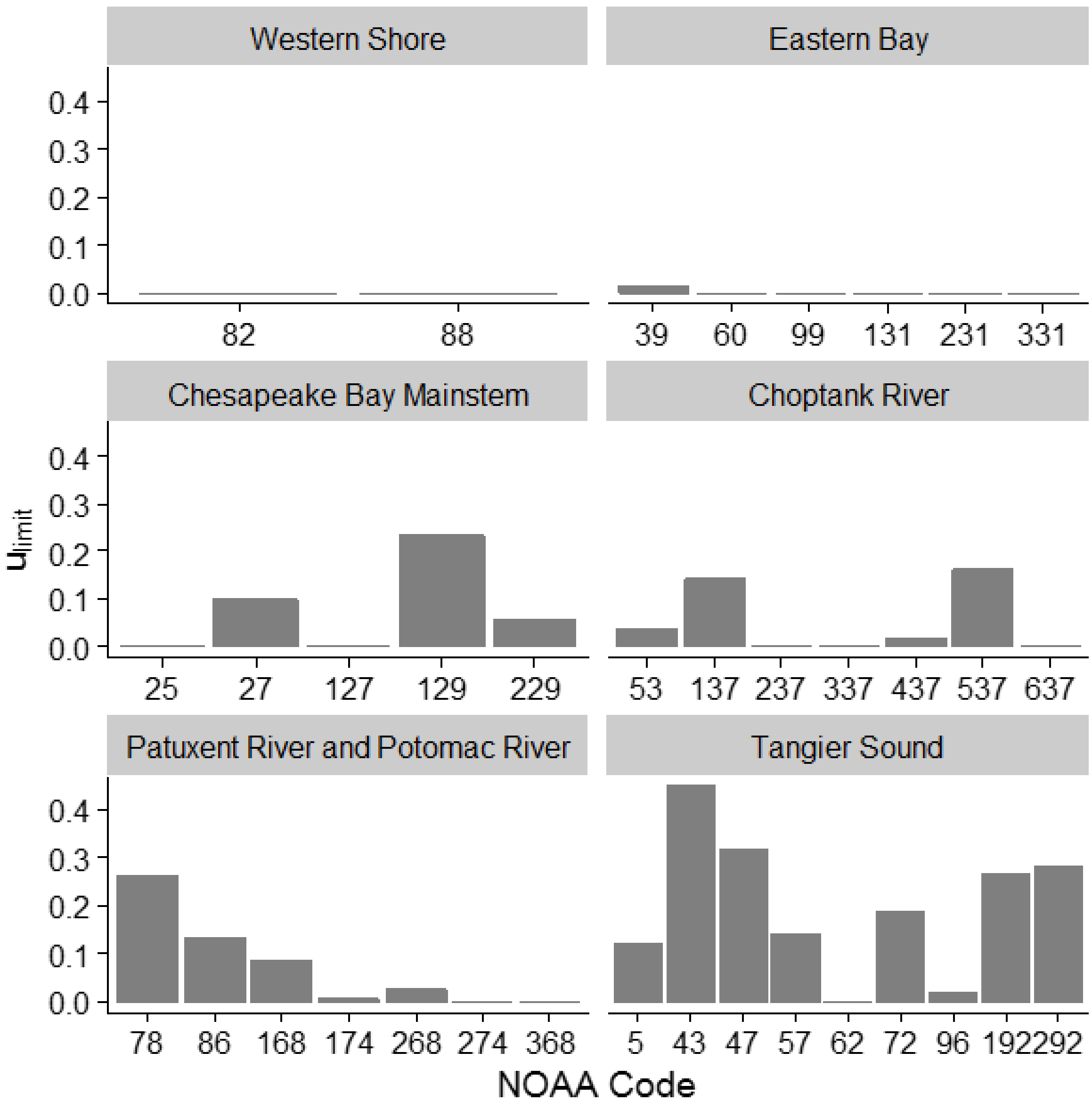

Figure 10. Upper limit exploitation rate reference point (bars) from the linked population-shell dynamics model by NOAA code. Estimates are grouped by region (panels) and panels are arranged geographically with upper panels representing the northern NOAA codes and the right-most panels representing the eastern most NOAA codes.

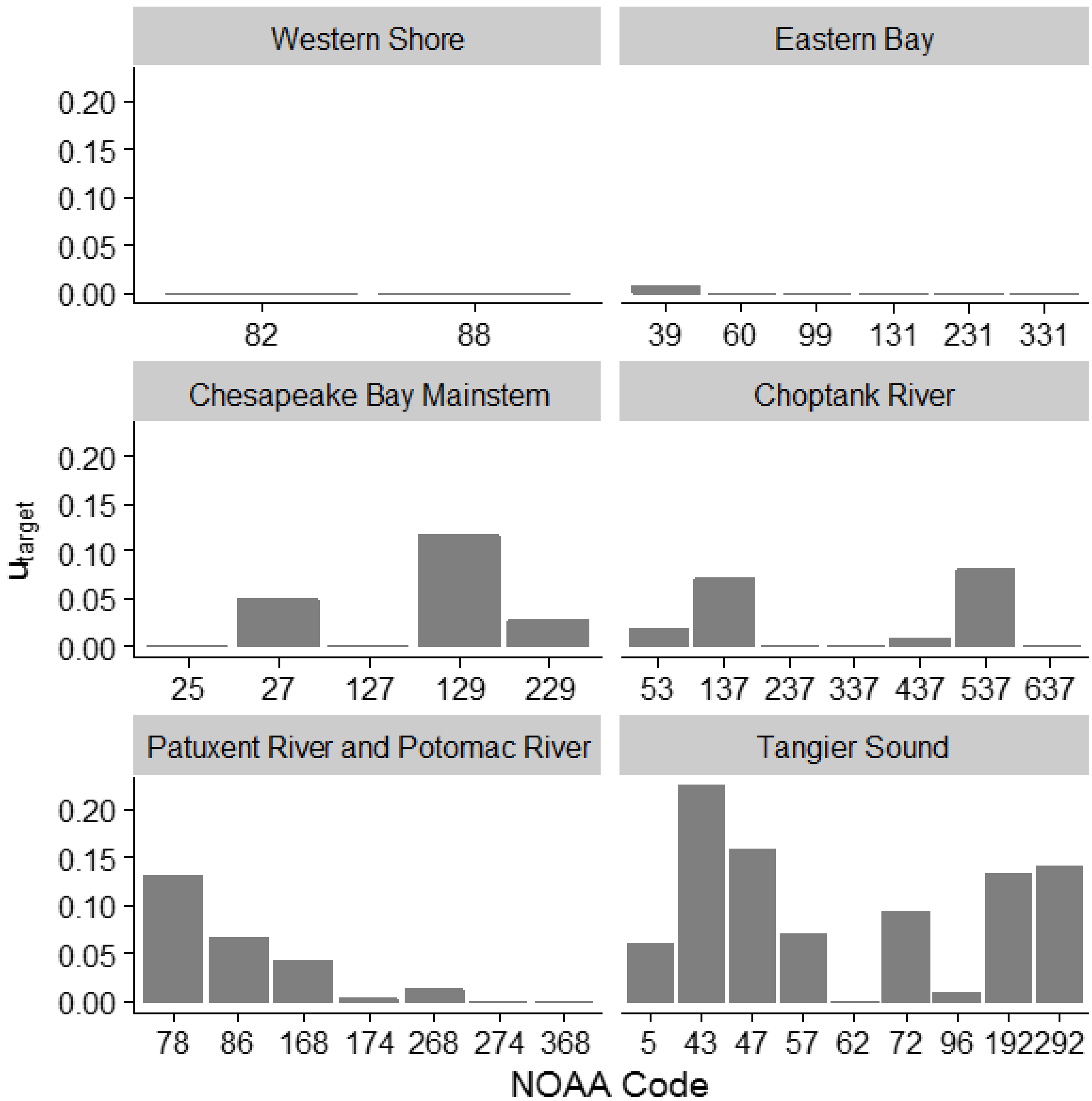

Figure 11. Target exploitation rate reference point (bars) from the linked population-shell dynamics model by NOAA code. Estimates are grouped by region (panels) and panels are arranged geographically with upper panels representing the northern NOAA codes and the right-most panels representing the easternmost NOAA codes.

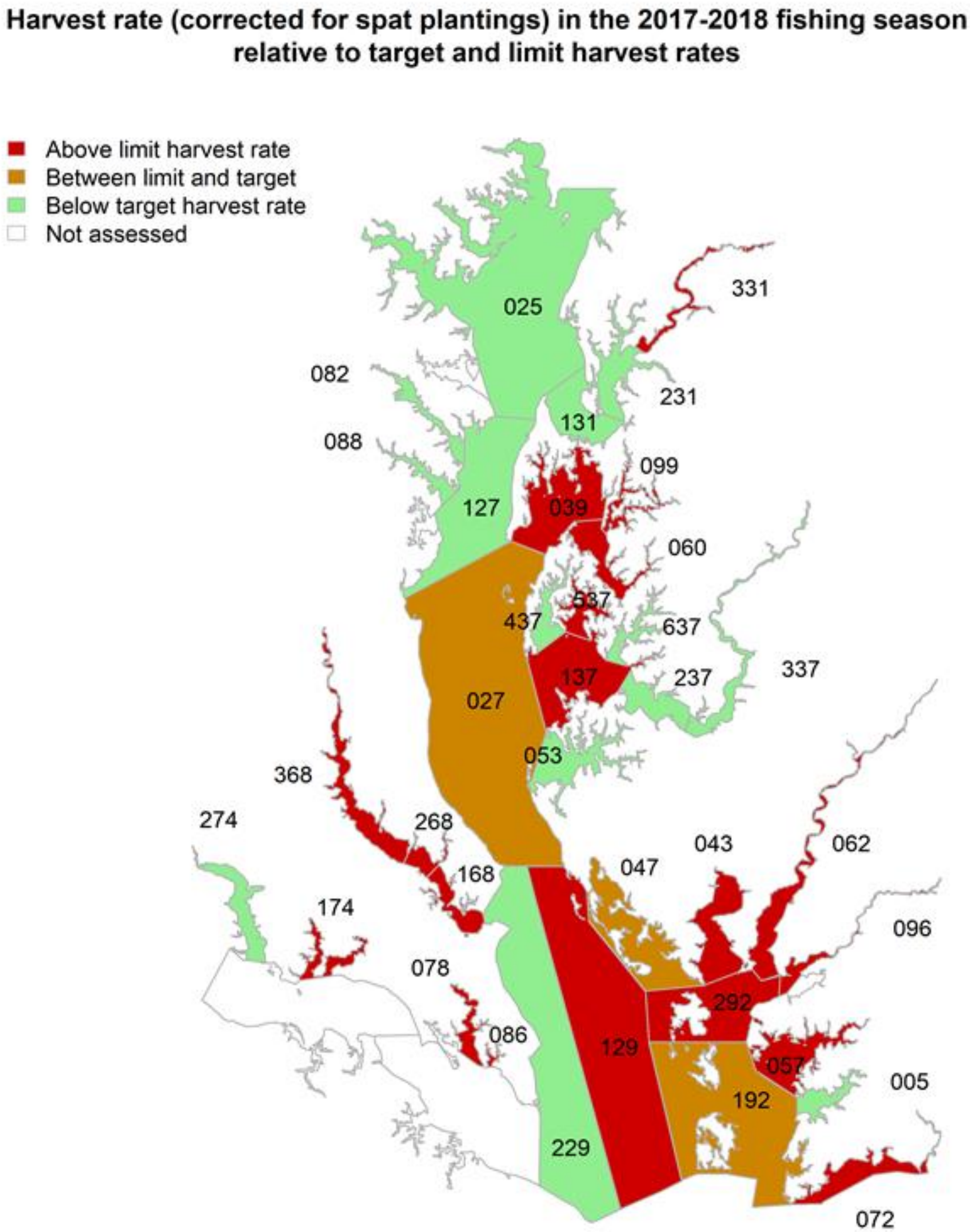

Figure 12. Estimated exploitation rates compared to target and upper limit reference points for the 2017-2018 season (adjusted for seed plantings).

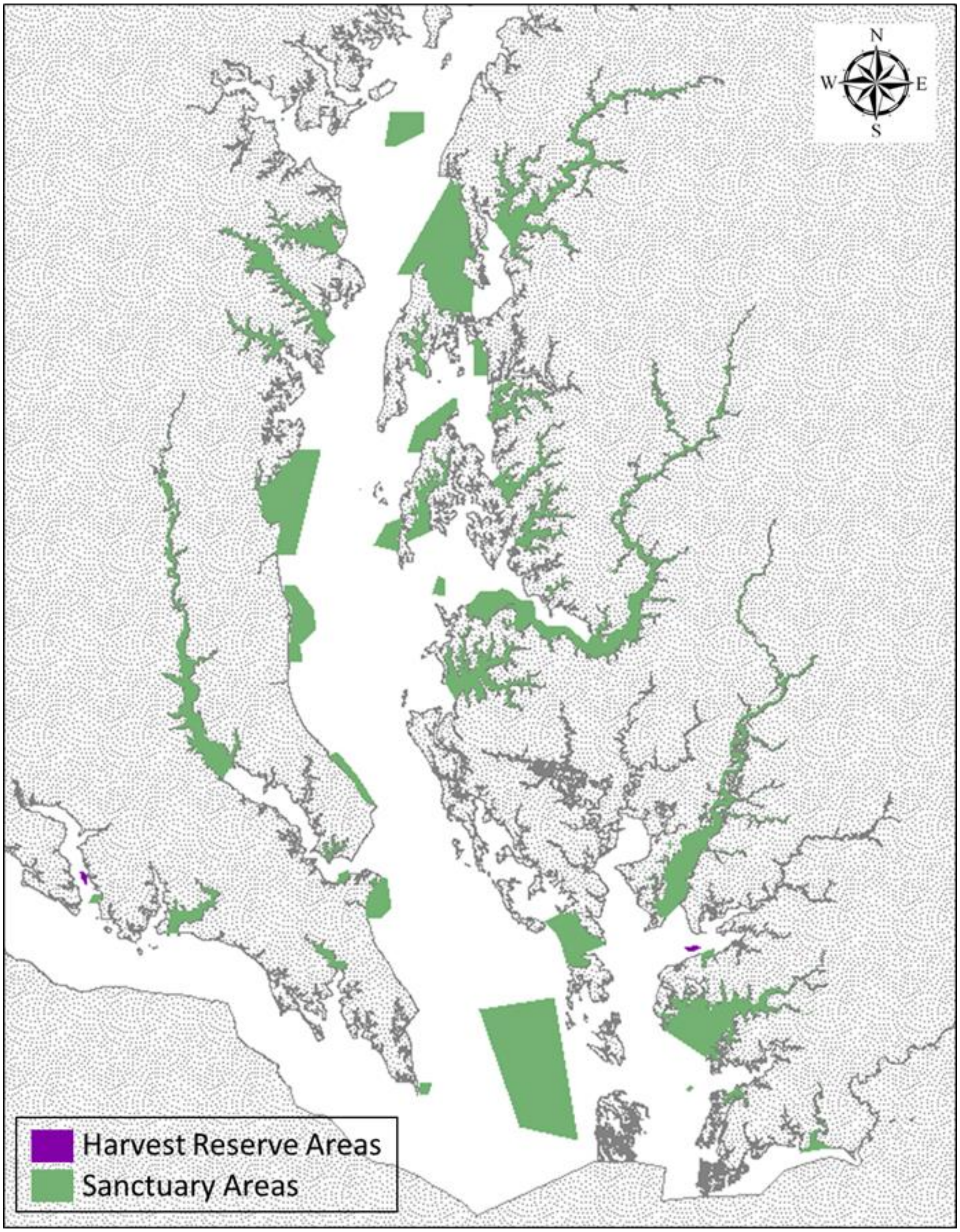

Figure 13. Maryland's 51 oyster sanctuaries and two harvest reserve areas in regulation as of 2018.

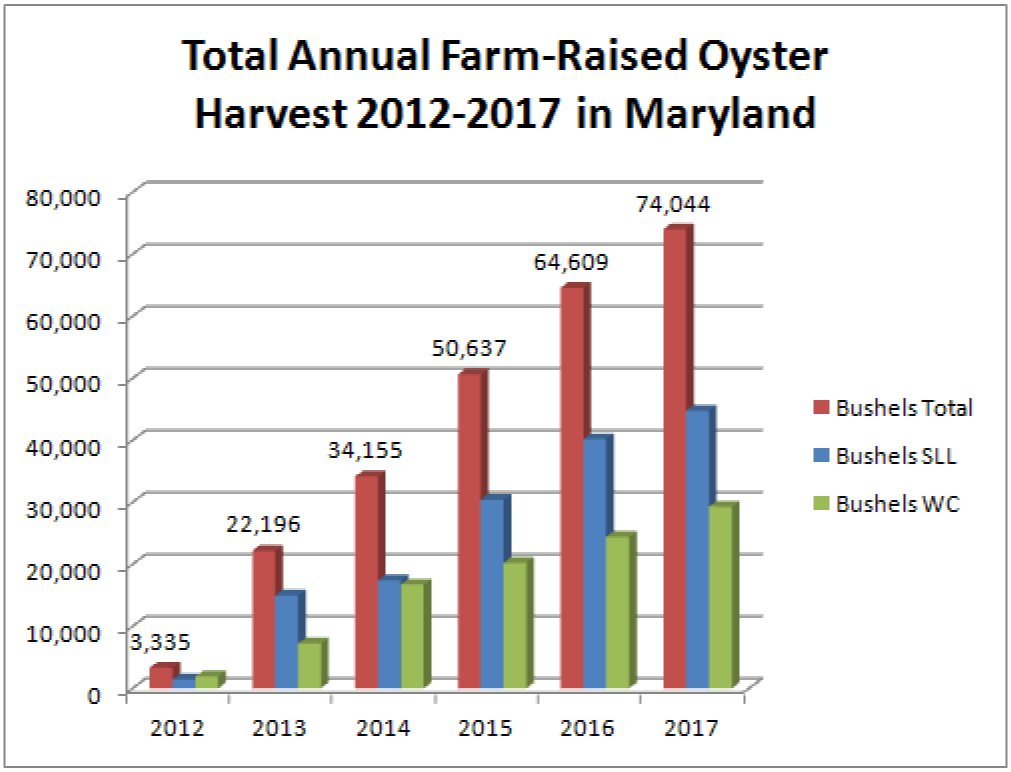

Figure 14: Number of bushels of farm-raised oysters harvested in Maryland's portion of Chesapeake Bay by year from commercial shellfish submerged land leases (SLL) and water column (WC) leases. Final 2018 data was not available at the time of this report.

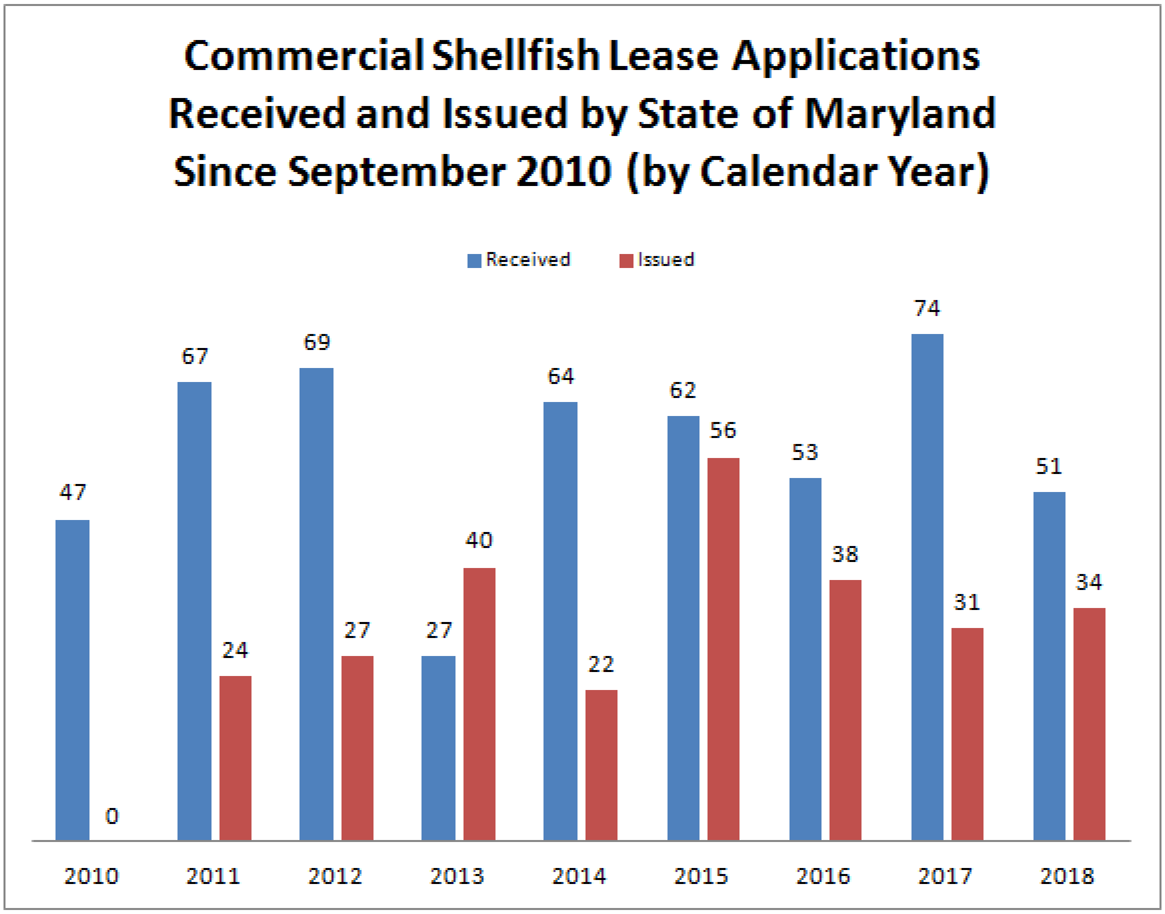

Figure 15: Number of new commercial shellfish aquaculture lease applications received by the Maryland Department of Natural Resources annually since Sept. 7, 2010 and the number of new leases that have been issued as a result of those applications through Dec. 31, 2018.

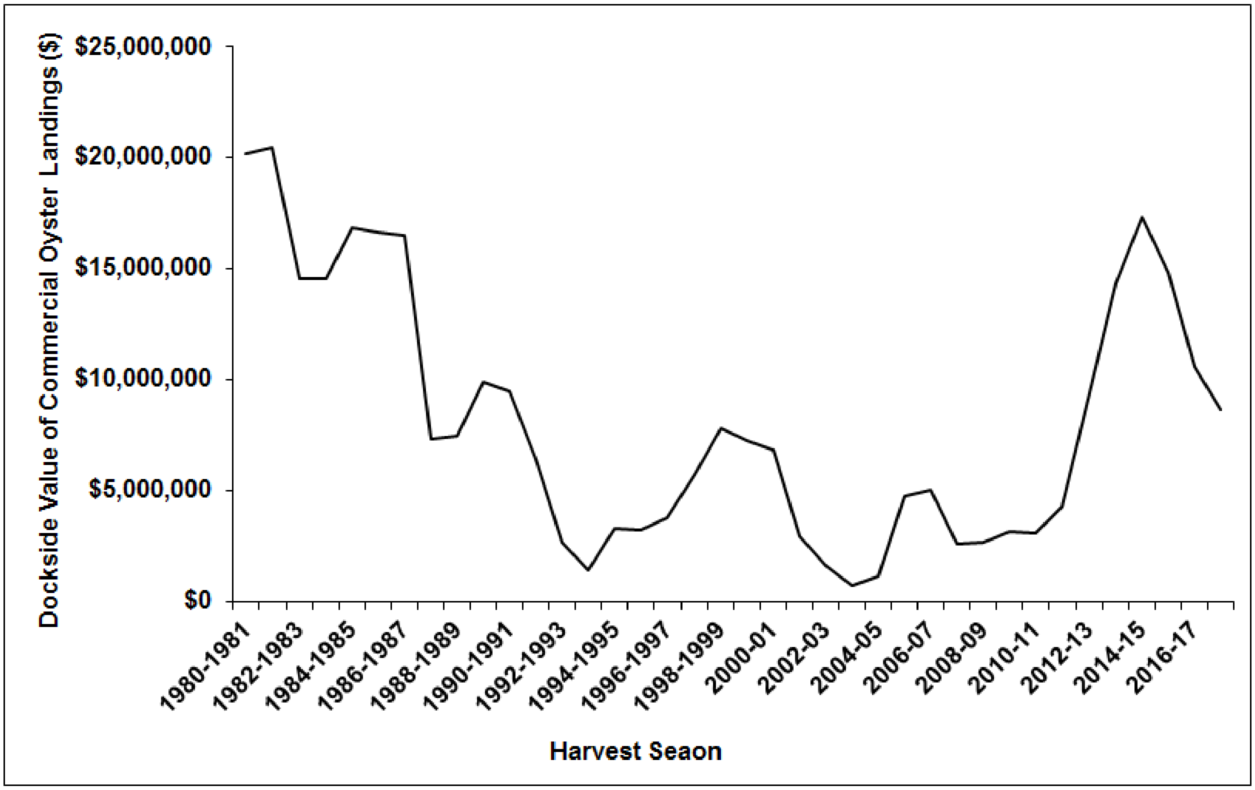

Figure 16. Dockside value of the commercial harvest of oysters in Maryland's portion of Chesapeake Bay.

Appendix A. Description of Oyster Management Tools

There are four types of management tools: output controls, input controls, habitat modification and stock enhancement. Output controls limit the amount of oysters that can be taken out of the water. Input controls limit the amount of effort in the fishery, which indirectly controls the amount of oysters harvested. Habitat modifications are measures to prevent damage to habitats, to restore damage where it has occurred and to increase habitat where required. Since oysters create their own habitat, many of the input, output and stock enhancement tools may also be considered habitat modification tools. Stock enhancement tools have the potential to increase the population through adding new oysters into Maryland's portion of Chesapeake Bay.

<u>Output Controls</u>

- Minimum Size Limits.
  Minimum size limits regulate how large an animal needs to be in order to be harvested. This tool is one of the primary means in a fishery for achieving an established target harvest rate and for avoiding exceeding an established maximum threshold harvest rate. Size limits can also be used in cases where there is no established target or threshold harvest rate to protect younger animals that have not reached spawning age. Generally, minimum sizes are set at or above a level where at least 50 percent of the population has been allowed to spawn once.
- Slot Size Limits.
  A slot size limit regulates a size range that an animal can be harvested. Slot limits allow the harvest of animals between a minimum and maximum size. The intent is to protect smaller-sized animals so that they can reach a reproductive age and allow at least 50 percent of the population to spawn once, as well as protect larger-sized animals that tend to be more fecund (produce more eggs). It can also be used to control harvest to achieve a target harvest rate or to avoid surpassing a threshold.
- Container Dimensions and Fill Limit.
  Although defining the dimensions of a container is not a stand-alone output control, it is included in the list because it is a critical component of any management measure that relies on limiting the number of bushels harvested.
- Bushel Limits or Catch Limits.
  A bushel limit places an upper limit on the number of bushels a harvester or vessel can take per day for commercial harvest on public bottom. Daily bushel limits can be used to achieve a target harvest rate, avoid surpassing a threshold harvest rate or constrain harvest to a desired total harvest amount. Bushel limits can be ineffective when fishing effort (number of participants) is highly variable or unknown because it only restricts an individual's harvest and may not impact the total industry's harvest.
- Total Allowable Catch (TAC).
  A total allowable catch is the total harvest allowed for all harvesters combined during one

harvest season. A TAC can also be referred to as a quota and should not be confused with individual quotas. Applying a TAC is a tool that can be used to achieve a target harvest rate or to avoid surpassing a threshold. In the case of oysters, a TAC could be set by converting the target exploitation fraction into a number of individuals or bushels to be harvested. Managing a TAC can be ineffective if harvest reports are late, incomplete and inaccurate, thus making real-time total harvest unknown. A TAC is only effective if the fishery is closed when the TAC is achieved. The use of TAC's can also lead to derby fishing and incentivize fishing in dangerous conditions, as harvesters strive to catch all they can before the TAC is reached and the fishery is closed. A TAC would likely need to be implemented in concert with a minimum size limit to maintain protection for some level of recruitment.

- Individual Transferable Quotas (ITQs).
  Individual transferable quotas are one approach for implementing a TAC as described above. ITQs assign shares (percentage of a TAC) to individual harvesters. If the TAC rises or falls, the share stays the same so that an individual's quota may be smaller or larger as conditions change, but the percentage 'owned' by an individual is constant. This type of management eliminates the derby effect. One of the most challenging aspects of ITQ management is determining which harvesters are eligible to participate in the ITQ and then how to allocate quota among the participants.

Input Controls

- Season Limits.
  Season limits establish when a fishery is open and closed to harvest. They are one of the primary tools for achieving an established target harvest rate and for avoiding exceeding an established maximum threshold harvest rate. In some circumstances, it is possible to determine a season length necessary to achieve an expected harvest. Season limits may also be used to protect a particular life history stage of a population, for example, months when spawning is occurring.
- Time Limits.
  Time limits are used to restrict harvest to specific days of the week and/or hours in a day. Time limits can work alone or in concert with other management measures to control harvest, but it is difficult to estimate time limits that would achieve a target harvest rate, a total annual catch or avoid surpassing a threshold harvest rate.
- Gear Limits.
  Gear limits restrict the type, characteristics and operation of a fishing gear. Regulating the configuration of gear as well as when and where they are used can be an effective tool for protecting certain size classes of an animal, protecting habitat and controlling the efficiency of harvest. Gear limits may also be used to avoid the conflict of one type of gear interfering with another type of gear. Gear limits can be ineffective if used to

achieve a target harvest rate, total annual catch or avoid surpassing a threshold harvest rate.

- Entry Limits.
  Entry limits restrict the number of individuals that are granted the opportunity to harvest animals commercially.
- Sanctuaries.
  Sanctuaries are areas closed to harvest for the purpose of maintaining or increasing abundance and productivity of an animal, biological diversity and protecting habitats. In addition to being closed to harvesting, sanctuaries may sometimes receive habitat and stock enhancements.
- Harvest Reserve Areas.
  Harvest Reserve Areas are areas that are closed to harvest for a period of time and may be opened after certain biological criteria are considered. The criteria are often based on desired characteristics of the population. The purpose of these areas is to maximize harvest while maintaining a sustainable and healthy population. Generally, stock enhancement practices are applied in these areas. One of the most difficult aspects of managing a Harvest Reserve Area is predicting environmental impacts including salinity and disease on stock enhancement investments.
- Opening and Closing Areas.
  Maryland occasionally opens and closes areas periodically that are normally open to the public fishery for harvest. This is generally done through recommendation from the industry for the purpose of decreasing the chance of gear mortality of planted seed or spat or to protect undersized oysters from illegal harvest or gear mortality.
- Rotational Harvest.
  Rotational Harvest involves closing an area to harvest for a set time period, then opening it to harvest for another set time period and then closing the area again for a set time period. The closure time generally depends on the capability of a species to rebound as the success of rotational harvest depends on growth and abundance increases during the closure period being greater than the levels of depletion during the harvest period. In conjunction with opening and closing areas to harvest, habitat and stock enhancement can be used with the goal of rebounding the population quicker. One of the most challenging aspects of rotational harvest is mitigating the impacts of latent effort on active harvesters and the resource.

Habitat Modification

- Planting Substrate.
  Planting substrate is a form of habitat modification that adds new habitat to establish, enhance and protect a population. For oysters, the practice is primarily used to provide more substrate for natural spat settlement and to improve the bottom for stock enhancement practices.

- Planting Dredged or Reclaimed Shell.
  Planting dredged or reclaimed shell are forms of habitat modification in which buried oyster shell is dredged from one area and planted on other areas to establish new or enhance existing habitat on the planted bar. The practice is used to provide more substrate for natural spat settlement or to improve the bottom for stock enhancement practices, such as planting seed oysters. This practice will also modify the habitat on the site where buried shells are dredged from because the dredging gear used to excavate the shells is invasive and digs a foot or more into the bottom.
- Bar Cleaning.
  Bars with surface shell degraded by silt or sand can be “bar cleaned” during a process in which oyster dredges are dragged across the bottom to loosen and clean the shells when the harvest area is closed. The dredges typically have bags on them to collect the shells and live oysters, which are then pushed back overboard once the dredge is full. Alternatively, the dredges can have the bag removed (“bagless dredging”).
- Seed Areas.
  Seed areas are areas that are planted with shell for the sole purpose of obtaining a significant spat set that can later be relocated to areas of low recruitment as “seed.” The seed oysters grow and then are used to enhance harvest in the low recruitment areas. Seed areas can either be closed to prevent gear mortality from harvest as the spat grow or they can remain open, if there are no harvestable sized oysters naturally occurring on the area.

<u>Stock Enhancement</u>

- Planting Wild, Natural Seed.
  Planting wild, natural oyster seed is a form of stock enhancement that can be used to manipulate population levels. It involves planting young oysters on an oyster bar that were naturally recruited on another oyster bar. This practice can be used to overcome a short-term recruitment limitation and add individuals for the purpose of future harvest. Since oysters also create their own habitat, planting seed can also be a form of habitat modification (substrate addition). Planting wild, natural seed may also cause the transportation of oyster diseases and other organisms. Actions should be taken to decrease this chance.
- Planting Hatchery-Reared Spat-On-Shell.
  Planting hatchery reared spat-on-shell is a form of stock enhancement that can be used to manipulate population levels. It involves producing larvae in a hatchery facility usually using local broodstock oysters collected from Maryland’s portion of Chesapeake Bay. The larvae are then placed in large setting tanks with shell. The larvae sets on shell creating spat-on-shell which is then planted on oyster bars. This practice can be used to overcome a short-term recruitment limitation and add individuals for the purpose of future harvest or to boost oyster populations. Since oysters also create their own habitat, planting hatchery spat can be a form of habitat modification (substrate addition).

Adoption Statement

We, the undersigned, adopt the Maryland Chesapeake Bay Oyster Fishery Management Plan (May 2019) as a guide to managing oysters in the Maryland portion of the Chesapeake Bay and its tributaries. The Maryland Chesapeake Bay Oyster Fishery Management Plan (May 2019) provides a framework for restoring and wisely using the oyster resource. It adopts management strategies based on the best available science.

The Maryland Department of Natural Resources will update the plan as needed and report on progress made in achieving the management plan's goals and objectives.

Date: 5/16/19

Jeannie Haddaway-Riccio Secretary, Maryland Department of Natural Resources

Date: 5/16/19

William C. Anderson Assistant Secretary, Maryland Department of Natural Resources