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A Stock Assessment of the Eastern Oyster, *Crassostrea virginica*, in the Maryland waters of Chesapeake Bay

A REPORT TO THE MARYLAND GENERAL ASSEMBLY

DECEMBER 1, 2018

As required by the Sustainable Oyster Population and Fishery Act of 2016 (Senate Bill 937, Natural Resources Article §4–215, revised in 2017, HB 924, Chapter 27).

Maryland Department of Natural Resources Fishing and Boating Services

in consultation with

The University of Maryland Center for Environmental Science

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Executive Summary

Introduction

In 2016, the Maryland General Assembly passed the Sustainable Oyster Population and Fishery Act of 2016 (Senate Bill 937, Natural Resources Article §4–215, revised in 2017, HB 924, Chapter 27). This legislation directed the department to conduct a stock assessment that will provide guidance for the development of biological reference points for the management of the oyster population. The legislation requires that a report be submitted to the Maryland General Assembly and to the Governor on December 1, 2018. This report fulfills that mandate, summarizing the results of the first formal stock assessment of the Maryland oyster population and fishery and presenting estimates of biological reference points for use in management. This report also provides a list of management approaches that will serve as a platform for future discussions regarding oyster management. Finally, the legislation required submission of all analyses to an independent peer review by stock assessment experts. This report contains a summary of the stock assessment analyses that were conducted and a summary of the peer review. The full stock assessment report with detailed descriptions of the analytical and modeling approaches and the full peer review report are available at http://dnr.maryland.gov/fisheries/Pages/oysters/Oyster_Stock_Assess.aspx. As directed by the Act, the stock assessment was conducted by the department in consultation with the University of Maryland Center for Environmental Science.

Spatial Scale and Time Span of Assessment

The available survey and harvest data supported an analysis on the spatial scale of NOAA code, which are regional units of the Maryland portion of Chesapeake Bay to which commercial harvest is attributed (Figure Executive Summary 1). A single stage-structured model was developed but run separately with common rules on 36 individual NOAA codes allowing the assessment results to reflect varying rates of reproduction, growth and mortality within the Maryland Bay. NOAA code-specific results can be combined for Maryland-wide estimates. Available survey and harvest data supported a 19-year assessment period beginning in 1999 and ending in 2017 (years indicate the beginning of the fishing seasons on October 1).

Stock Assessment Model Estimates of Oyster Abundance

Maryland-wide, estimates of the abundance of market-size (≥3 inches) oysters varied between approximately 600 million and 200 million individuals over the assessment period. The estimated abundance of market-size oysters was highest in the initial year of the time series (1999), decreased to approximately 200 million individuals by 2002, and remained close to that level until 2010. After 2010 the estimated abundance of market-size oysters increased through 2014 to more than 450 million and declined to about 300 million thereafter. In 1999, the estimated abundance of market-size oysters was highest in the Choptank River and Eastern Bay regions. After 2006 estimated abundance in the Eastern Bay regions declined and the regions of highest abundance were the Choptank River and Tangier Sound. Overall, the estimated abundance of market-size oysters was higher in 2017 than it was during the period from 2002 through 2007 but lower than in 1999. **This pattern of return towards 1999 levels of abundance differed among regions, with some regions showing little to no increase and others showing substantial increases in the abundance of market-size oysters since 2002.**

Stock Assessment Model Estimates of Harvest Fraction

The harvest fraction for each NOAA code is calculated as the percentage of market-size oysters 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.

Biological Reference Points

NOAA code-specific biological reference points were developed for the Maryland oyster resource including a minimum safe (threshold) level of abundance. If oyster abundance declines below this level, the population in that NOAA code would be classified as 'depleted' or 'overfished'. Both of these terms are convention in fisheries management when a population declines below an identified threshold abundance. For the purposes of this report, the term 'depleted' will be used since the oyster population has declined for many reasons (e.g. disease, habitat loss) that are independent of fishing. NOAA code-specific target harvest fractions and maximum safe (threshold) harvest fractions above which fishing is deemed unsustainable were also calculated.

The Threshold Abundance Reference Point

The proposed threshold abundance reference point proposed is the minimum estimated number of market-size oysters during the assessment period, 1999 through 2017 for each NOAA code, as estimated by the assessment model. The choice of the lowest value of the time-series 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 below those levels. If abundance falls below the threshold, the oyster population within that NOAA code would be considered depleted. Given the current low abundance of oysters relative to historic periods and significant changes in the ecosystem (e.g., habitat loss, disease), it was not possible to generate a suitable method for calculating an abundance target.

Because the threshold abundance level is proposed as the lowest value within the assessment time frame, no areas were found to be depleted, although a few areas were close or equal to the time-series minimum in the final year of the assessment (2017). In these areas, any future declines occurring without an interim increase in abundance, would place them in the depleted category. This was true of NOAA codes in the Chester River (NOAA codes 131, 231, 331) and one in the middle Chesapeake mainstem (NOAA code 127). The southern portion of Tangier Sound and the southeastern part of the Chesapeake mainstem (NOAA codes 192 and 129 respectively) had their lowest abundance values in 2016.

Target and Limit Harvest Fraction Reference Points

The proposed target harvest fraction (fishing level) is an estimate of the harvest fraction (U) which provides maximum sustainable yield (MSY). If U_{MSY} is achieved annually, it is expected to yield a maximum harvest over time, while resulting in a stable or increasing oyster population (given current abundances of oysters in Maryland). As an upper limit (threshold) reference point, the recommendation is to estimate U_{crash} which represents the absolute maximum harvest fraction that would allow sustainable harvest. If U_{crash} is exceeded over time it will result in eventual disappearance the population. The limiting rate for oyster population growth is likely the ability of oysters to produce shell. Therefore, shell production is an important process to include in sustainable harvest reference point calculations for oysters. The target (U_{MSY}) and limit (U_{crash}) reference points were estimated separately for each NOAA code using a reference point model that describes population growth as a logistic function of abundance with carrying capacity determined by the amount of habitat. The amount of habitat depends on habitat production from living oysters, habitat loss and shell and artificial substrate plantings.

Annual estimates of harvest fraction from the assessment model can be compared to the target and limit reference points in order to determine if harvest is at sustainable levels. It should be noted that, for each NOAA code, the correct estimate of harvest fraction for comparison to the reference points depends on the management objective for oysters planted in the area. If oysters were planted with an objective of supplementing the fishery, then the exploitation rate that accounts for planted oysters should be the most appropriate for comparison with the reference points. If, however, the oysters were planted as part of restoration efforts to increase population size, then the exploitation rate that does not include planted oysters should be used. For the purposes of this report, all estimates of harvest fraction are corrected for the number of planted oysters. However, both methods are presented in tables in the body of the report.

Estimates of the proposed limit (threshold) reference point, U_{crash}, vary over NOAA codes and range from zero to 0.45 (45 percent) per year. Estimates of the proposed target, U_{MSY}, ranged from zero to 0.22 (22 percent) per year. Estimated target and limit reference points were highest, on average, in the southernmost NOAA codes, Tangier Sound and the Potomac Tributaries, and were lower for the more northerly regions.

There was substantial variability among NOAA codes and regions in their status relative to the harvest fraction reference points in the most recent year**. In the most recent fishing season (2017-2018), 19 NOAA codes had exploitation rates above the limit reference point (U_{crash}), three were between the target and limit reference points, and 14 were at or below the target reference point.**

The Role of Sanctuaries and Restoration Efforts in Sanctuaries in the Stock Assessment Model

Oysters in sanctuaries were included in the calculation of the threshold abundance reference points. The assessment was not able to address how sanctuaries affect harvest fraction reference points for several reasons which are detailed in the body of this report. However, oysters in sanctuaries are included in the annual model-based estimates of harvest fraction that are compared to the reference points. Because the annual estimates of harvest fraction are calculated as the number of individuals harvested divided by the estimated abundance of oysters in a NOAA code, including sanctuary oysters in the calculation will generally lower estimates of annual harvest fraction because the oysters in the sanctuary that are protected from harvest raise the abundance within the NOAA code.

Overall, substantial improvements in information are needed to quantify the effect of sanctuaries on oysters in areas outside of sanctuaries. The large restoration sanctuaries have been in place for less than 10 years which is minimal time for assessing the impacts of potential larval dispersion to other areas. If it is found that oyster abundance increases in areas outside of sanctuaries because of larval supply from sanctuaries, then the currently proposed reference points would allow for a subsequent increase in sustainable harvest.

Impact of Hatchery Plantings (Aquaculture and Public Fishery) on the Spawning Potential in the Fishery

It is difficult to determine how planted oysters contribute to the spawning potential of the fishery because once oysters are planted on public bottom or in sanctuaries they cannot always be readily distinguished from wild oysters. Also, aquaculture uses diploid and triploid oysters, the latter of which are specifically bred not to spawn. Cultured oysters may also be harvested year-round and sometimes at a smaller size than wild-harvested oysters, which complicates determination of whether they are harvested before or after they spawn.

The number of market-size oysters estimated from the stage-structured model as 'wild origin' was, on average, 18 times greater than the number harvested from commercial shellfish leases during 2012-2017. The estimated number of market-size oysters generated from hatchery and wild plantings in non-lease areas was substantially greater than the number of oysters that were reported as being harvested from commercial shellfish leases.

The magnitude of lease harvest is small relative to the estimated abundance of oysters of wild origin, indicating that the spawning potential of oysters on leases is likely small relative to the population outside of leases at the Maryland-wide scale. In addition, any potential increase in the proportion of triploid oysters planted on leases would further erode the contribution of these animals to the total spawning potential.

Potential Management Strategies

The Sustainable Oyster Population and Fishery Act of 2016 (Senate Bill 937, Natural Resources Article §4–215) directs the Maryland Department of Natural Resources to "…identify management strategies to address the maintenance of a sustainable oyster population and fishery."

This report presents a list of potential tools that could be used in the management of the oyster resource. The list was assembled with input from Oyster Advisory Commission, Tidal Fishery Advisory Commission, Sport Fishery Advisory Commission and the County Oyster Committees and provides the platform for a future public process to determine the course of management.

For each area, some combination of the listed tools would result in effective management. The decision on which tools to apply will depend on the management objectives which should be determined through a public process. Because the stock assessment was conducted on the spatial scale of NOAA code, there is the potential that management tools can be spatially distinct since management actions that could be effective in one area could be less effective in others due to differences in reproduction, growth and mortality rates of oysters.

There are four types of management tools for oysters: 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 habitat, 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 the Bay.

Independent Peer Review

As mandated by the guiding legislation, all analytical approaches involved in the stock assessment model and in the development of biological reference points were submitted to an independent peer review.

The peer review was conducted with the logistical support of the Atlantic States Marine Fisheries Commission and was funded through an EPA Chesapeake Bay Implementation Grant (CBIG). The panelists were selected via an objective process in which the Maryland Department of Natural resources submitted a request to the director (Dr. Larry Jacobsen) of the Northeast Fisheries Science Center (NOAA, National Marine Fisheries Service) Invertebrate Population Dynamics group to provide a list of stock assessment scientists within the continental United States who would be qualified to review the Maryland oyster assessment. Dr. Jacobsen provided contacts for six individuals he deemed qualified. Three panelists were selected from the list based on their experience, availability and willingness to do the work.

Overall, the Review Panel concluded that all Terms of Reference for the stock assessment had been met. The Review Panel supported the conclusions from the stock assessment and agreed that it had fully utilized the available data at an appropriate temporal and spatial resolution. They concluded that the modeling approach is innovative and the results can serve as an adequate basis for management decisions. All stock assessments, however, represent a compromise between the ideal and the realized. Changes in data quality over time, lack of sufficient spatial resolution in the characterization of removals, significant but variable impacts of disease, observation error in monitoring programs, habitat loss, and trends in ecosystem conditions all influence the oyster assessment. It is the opinion of the Review Panel that this assessment deals with these compromises in a rigorous and scientifically credible way.

The panel was comprised of:

Dr. Paul Rago (Panel Chair)

Paul Rago is a member of the Scientific and Statistical Committee of the Mid-Atlantic Fishery Management Council (MAFMC). Prior to his retirement in 2016, he was Chief of the Population Dynamics Branch of the Northeast Fisheries Science Center of the National Marine Fisheries Service (NMFS) in Woods Hole where he led over 40 fishery scientists to assess the status of finfish and shellfish stocks in the Northeast U.S. His stock assessment experience includes nearly all the stocks in the Northeast U.S. and several in other countries. Research interests include quantitative analyses of populations, graphical methods for exploratory data analysis, experimental estimation of gear efficiency, design of bycatch monitoring programs, and cooperative research programs with industry. With the U.S. Fish and Wildlife Service (1978-1992), Dr. Rago served as research coordinator of the Emergency Striped Bass Study and a variety of Atlantic salmon studies. Dr. Rago received his PhD from the University of Michigan.

Dr. Daniel Hennen

Dan Hennen is a Research Operations Analyst for the Population Dynamics Branch of the Northeast Fishery Science Center in Woods Hole, where he has worked since 2009. He serves as lead analyst for stock assessments of Atlantic surfclam, ocean quahog and Atlantic halibut. Dr. Hennen was Research Biometrician for the Alaska Sea Life Center in Seward Alaska from 2004-2009. His research interests include population simulation, automation, parameter estimation, survey analysis, and design. Dr. Hennen received his PhD from Montana State University in 2004.

Dr. Daphne Munroe

Daphne Munroe is an Associate Professor at Rutgers University in the Department of Marine and Coastal Science, Haskin Shellfish Research Laboratory. Dr. Munroe has a PhD from the University of British Columbia where she studied ecological interactions of intertidal clam farming. She has over 15 years of experience doing research in shellfish ecology, focusing on shellfish fisheries and aquaculture and has participated in federal and state assessments for clams and oysters.

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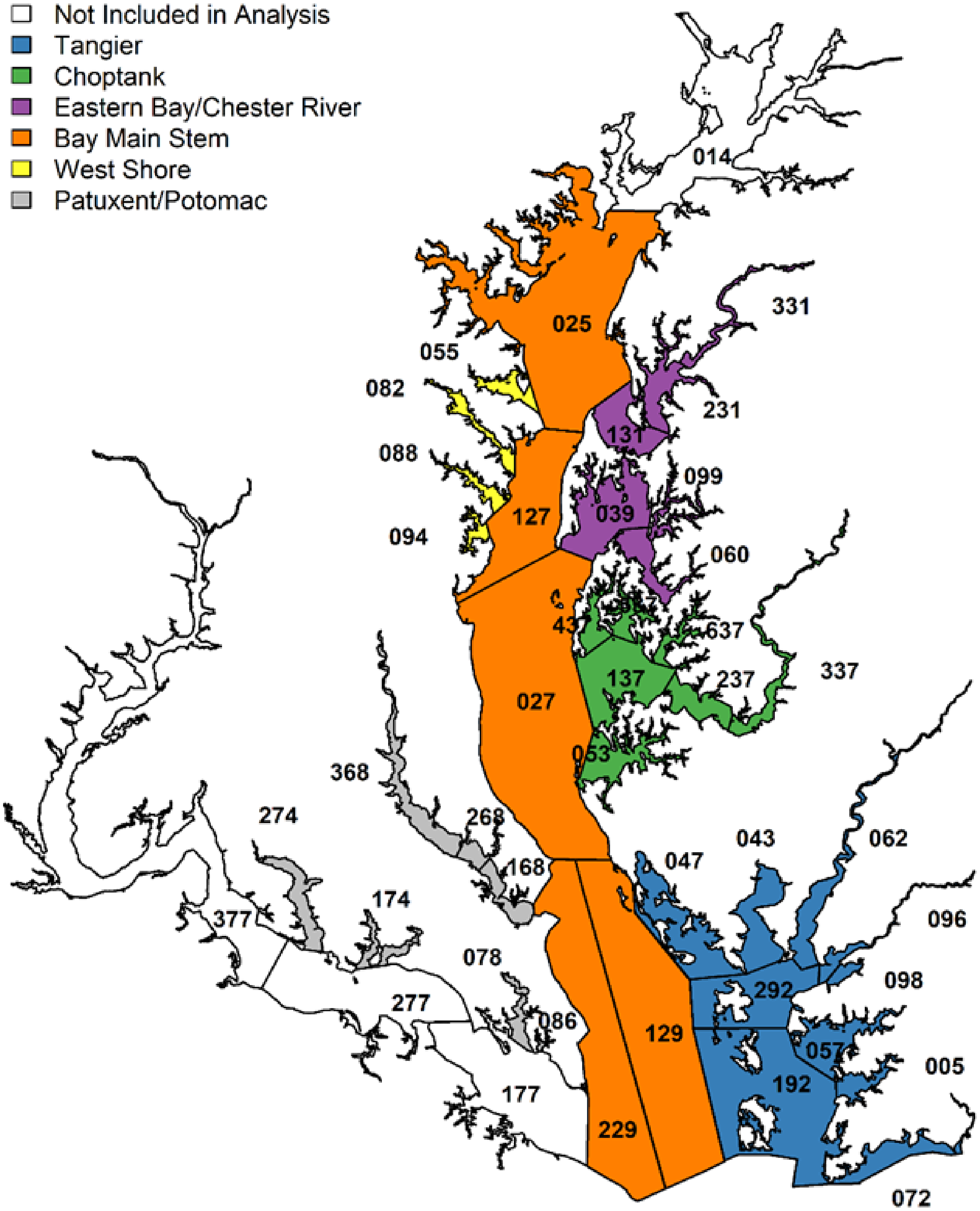

Executive Summary Figure 1. NOAA code harvest reporting areas in the Maryland portion of Chesapeake Bay.

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1 Background and Introduction

1.1 Distribution and Biology

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 the environmentally variable estuarine environment, Eastern 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 the Maryland portion of Chesapeake Bay variable salinity and temperature regimes are 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 the Bay in 1959 and by the 1970s had dramatically reduced oyster densities in Virginia's high salinity oyster grounds (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 and habitat loss (National Research Council, 2004). In any case, the presence of these two pathogens adds complexity to oyster population dynamics in Chesapeake Bay because mortality rates may vary substantially among years and also spatially within the same year depending on where the oysters are located within the Bay.

All oyster bars in Maryland are located in mesohaline salinities (5-18 ppt). Within this salinity range, Maryland oyster bars are further classified into three zones whose boundaries, especially in the mid ranges, shift with varying climatic conditions. Zone one has an average salinity between five and < 12 ppt, Zone two has an average salinity between 12 and 14 ppt and Zone three salinities are greater than 14 ppt (Maryland Department of Natural Resources, 2004). In general, disease pressure intensifies during dry years as a result of the northward intrusion of the salt wedge and the resulting elevated salinities. In these years, Zone one can serve as a refuge from disease so that oysters in these areas may have lower mortality rates relative to the other zones. However, the influx of oyster larvae is intermittent and settlement rates are low in these less saline areas. Oysters in Zone one can also be subject to episodic freshets that result in substantial mortality (Maryland Department of Natural Resources, 2004). Zone two represents a transition area and oysters in these areas may have fluctuating rates of reproduction, growth and mortality based on the salinity variation between wet and dry years (Maryland Department of Natural Resources, 2004). In the Maryland portion of Chesapeake Bay, Zone three salinities are equal to or above 14 ppt and generally fall within what is thought to be the optimal salinity range (14 - 28 ppt) for *C. virginica* (Shumway, 1996). Although disease pressure can be persistent and mortality rates high in Zone three, reproductive capability is maximized so that there is likely to be consistent recruitment of new oysters.

Gametogenesis and spawning in oysters are directly correlated with water temperature (Shumway, 1996). In the Chesapeake, oysters begin gametogenesis in the spring and spawning can occur from late May to late September and 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, tending to concentrate near the bottom during the outgoing tide and rising in the water column during the incoming tide, thus increasing their chance of being retained in the estuary (Kennedy, 1996; Shumway, 1996)

C. virginica are either male or female (the reported incidence of simultaneous hermaphroditism is less than 0.5%) but may change sex over the winter when they are reproductively inactive. Generally, *C. virginica* function as males when they first mature which can happen as early as 6 weeks post settlement (Thompson et al., 1996). As the 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).

No definitive study of the longevity of *C. virginica* could be found for this report. 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. Sieling (ca. 1972) comments “Oysters may live as long as 20 years, at least if undisturbed, as records of oysters kept in laboratories for that long are well known”, but with no supporting references. Powell and Cummins (1985) are cited in two papers for *C. virginica* lifespans of 10 to 15 years and 10 to 20 years, even though this species is never mentioned by them. Likewise, Lavoie and Bryan (1981) are cited for a longevity estimate of at least 15 years, although the only suggestion of longevity in their paper is a von Bertalanffy curve that extends to 14 years but with observed data only up to age eight. The longest estimate, 30 years, was made by Lockwood (1882). He based it on very old-appearing oysters that were supposedly planted 30 years earlier. He supported this assertion by counting 30 bands in the hinge area of both the upper and lower valves of a single oyster, a technique that subsequently has not gained widespread acceptance. *C. virginica* from plantings in Maryland have been reported to survive at least 9 years (assuming no natural reproduction in these areas; Paynter et al., 2010).

1.2 The Importance of Substrate

Larvae of *C. virginica* require a firm, sediment-free surface upon which to settle and metamorphose (Kennedy 1996), and this substrate is typically provided by oyster shell. The larvae's gregarious settlement response produces dense aggregations of oysters coexisting in communities, often called bars, reefs, or rocks (Smith et al., 2005). Oysters are unique in that they create the habitat they require for population growth. In general, the oyster exists because over decades, the rate of shell accretion through recruitment, growth and mortality exceeds by some small amount the rate of shell loss (Mann and Powell, 2007). Fishing not only removes adult animals but also potentially decreases productivity of the population by altering and diminishing necessary habitat (Lenihan and Peterson, 1998). Because the dynamics of shell accumulation and loss are pivotal to the oyster resource (Mann and Powell, 2007), Maryland employs the planting of shell and hatchery reared oyster spat as a key component of oyster resource management. Reefs with higher profiles above the seafloor appear to promote enhanced oyster productivity. Low-profile reefs, are subject to sediment deposition on the reef surface (DeAlteris, 1988; Seliger and Boggs, 1988). Increased sedimentation reduces the nutritional value of material that oysters ingest, leading to reduced growth and reproduction and heightened physiological stress from clogging of the oyster's filtering mechanism (MacKenzie, 1983). Siltation on reefs also impairs habitat quantity and quality for settling larvae and attached juveniles (Bahr, 1976). Smith et al. (2005) concluded that, regardless of the cause, high rates of oyster mortality in the Maryland portion of Chesapeake Bay have reduced the ability of natural oyster bottom to accrete more shell, thereby rendering the remaining shell more susceptible to being covered by sediment.

1.3 Description and History of Fisheries

At the peak of its production in the late 1800s, the Chesapeake Bay was the greatest oyster-producing region of the world, with an oyster harvest twice that of the rest of the (non-US) world (Kennedy and Breisch, 1983). However, commercial landings in Maryland plummeted in the last part of the 19th century, with annual harvests decreasing by more than half between the late 1800s and the 1930s (Table 1, Figure 1). Over the following 50 years, harvests remained fairly stable, fluctuating around 2 million bushels annually until another decline occurred in the late 1980s primarily due to the oyster diseases MSX and Dermo (Maryland Department of Natural Resources, 1987). Since that time, commercial yields have remained at less than 420,000 bushels with a low of 19,028 bushels occurring in the 2003-2004 oyster season due to drought conditions and resulting elevated disease-related mortality (Maryland Department of Natural Resources, 2016). Although the department has harvest records back to the latter part of the 19th century, this stock assessment is conducted on a 19-year time series beginning with the 1999-2000 harvest season. This represents the time period when the most comprehensive and consistent harvest reports are available along with corresponding survey indices.

Maryland's commercial oyster fishery remains an important cultural and economic driver within Bay-side communities. Over the years since the 1999-2000 harvest season, the average annual ex-vessel value of the Maryland oyster fishery is estimated to be $6,888,960.

Oyster bars throughout the Maryland portion of Chesapeake Bay vary widely in their habitat quality and level of productivity. The patchiness of oyster habitat combined with the regional management of the harvest gears and the activities of the County Oyster Committees results in an oyster population and fishery that is spatially complex. During the time series covered by this assessment (1999-2000 through 2016-2017 seasons), the bulk (75 percent) of the harvest was generated by a small percentage of harvest reporting areas, known as NOAA codes and the fishery is generally consolidated in the lower Eastern regions of the Maryland portion of the Chesapeake.

1.4 Management

The Maryland oyster fishery is currently managed using a variety of laws and regulations that are mainly targeted at controlling effort:

Licensing and limited entry: Maryland regulation limits the number of commercial licenses for the harvest of oysters to 737. In addition to their annual license renewal fee, these licensees must pay an annual surcharge of $300(US) in order to activate their license to harvest oysters prior to each season. Maryland also has a cap of 2,091 commercial fishing licenses which enable 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, which allows the department to identify the subset of these licensees are active in an oyster season. As such, there are 2,828 individuals who have the potential to harvest oysters in any given year (Code of Maryland Regulations [COMAR] 08.02.01.05, Natural Resources Article §4-10). Since the 1999-2000 oyster season, an average of 803 individuals paid the annual surcharge for oyster harvest. 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 fueled by above average spat sets occurring in 2010 and 2012 which increased the availability of oysters for harvest.

Gear: There is a variety of permissible gears for the commercial harvest of oysters. Gears are restricted both in terms of when and where they can be used as well as in their dimensions (Code of Maryland Regulations [COMAR] 08.02.04, Natural Resources Article §4-10). 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.

Season and time limits: The harvest of wild oysters in Maryland is restricted to the months of October through March (power dredging is conducted November-March). The department has the authority to extend the season into April in the event of significant weather events such as icing that impede harvest during the normal season. Harvesting is allowed Monday through Friday from sunrise to 3 p.m., and the hours are extended to sunset in November and December. Because oyster harvest seasons straddle the calendar year, this report refers to 'seasons' rather than years. In cases where a year is used, it refers to the beginning year of the season.

Bushel limits: Daily catch limits have remained basically unchanged since the 1980s and depend on gear types. Currently, all gear types except power and sail dredge are allowed 15 bushels/license/day, not to exceed 30 bushels/vessel. Power dredges are allowed 12 bushels/license/day, not to exceed 24 bushels/vessel. Sail dredges are allowed 150 bushels/vessel/day.

Size limits: In 1927 the minimum size limit for oysters harvested from public grounds was increased from 2.5 to 3 inches, and this size limit remains in place to the present day (Kennedy and Breisch, 1983).

In addition to the traditional use of effort and size limit controls described above, the Maryland wild oyster fishery has historically been managed on a fine spatial scale (bar level) in cooperation with the oystermen of the State. In 1947 legislation created county oyster committees whose charge is to interact with management and to advise on closing and opening bars; and on shell and seed planting activities (Kennedy and Breisch, 1983). The county oyster committees remain in place to the present day and are closely involved in the management of harvest bars (Natural Resources Article §4-1106). Funding for county efforts to improve certain bars through the planting of hatchery spat on shell, wild spat on shell, or just cultch (shell) is generated from the $300 license surcharge paid by each oysterman, by a $1 tax levied on each bushel of oysters harvested, an oyster export tax, (Natural Resources Article §4-1020, §4-701) and since 1996, by a grant from the Maryland Department of Transportation, Port Authority.

The active management of the wild oyster fishery has historically focused on bolstering the productivity of individual bars through the placement of shell and oysters in order to maintain some level of harvest, rather than on population level parameters related to overall stock sustainability.

In 2010, the Maryland Department of Natural Resources (MD DNR) amended its management plan for oysters to include a 10-point plan for the restoration of the oyster population and fishery in the Maryland portion of Chesapeake Bay (Maryland Department of Natural Resources, 2010). To implement the amended plan, the Maryland Department of Natural Resources overhauled its regulations for managing oysters; expanding the scale of oyster sanctuaries, creating new opportunities for oyster aquaculture, and designating areas to be maintained for the public fishery. Several objectives were laid out within the preamble to the regulations including to "*Implement a more targeted and scientifically managed wild oyster fishery*" (Maryland Register, 2010).

1.5 Call for Stock Assessment

This represents the first formal stock assessment of the Maryland oyster population and fishery. It is the first attempt to estimate biological reference points for use in management. This assessment was conducted as a means toward achieving the goal of a more scientifically managed fishery and was mandated by the Maryland General Assembly as part of the Sustainable Oyster Population and Fishery Act of 2016 (Senate Bill 937, Natural Resources Article §4–215, revised in 2017, HB 924, Chapter 27). This legislation directs the department to conduct a stock assessment that will provide guidance for the development of biological reference points for the management of the oyster population. A full report of assessment results will be submitted to the Maryland Oyster Advisory Commission and the Maryland General Assembly on or before December 1, 2018.

1.6 Terms of Reference

The terms of reference for this stock assessment were developed based on the Sustainable Oyster Population and Fishery Act of 2016 and were reviewed by Maryland's Oyster Advisory Commission:

1) Complete a thorough data review: survey data, reported harvest and effort data, studies and data related to population rates (growth, mortality and recruitment), available substrate, shell budgets, and sources of mortality.

> a) List, review, and evaluate the strengths and weaknesses of all available data sources for completeness and utility for stock assessment analysis, including current and historical fishery-dependent and fishery-independent data.
>
> b) Identify the relevant spatial and temporal application of data sources.
>
> c) Document changes in data collection protocols and data quality over time.
>
> d) Justify inclusion or elimination of each data source.

2) Develop stock assessment model or index based approach that estimates biological reference points and document status of the stock relative to estimated reference points. To the extent possible, quantify sources of uncertainty within model.

3) Compare estimates of stock status generated by index and model-based approaches. Justify selected approach.

4) Include sanctuaries and restoration efforts in sanctuaries in the development of stock assessment approaches.

5) Examine how hatchery plantings (aquaculture and public fishery) impact spawning potential in the fishery.

2 Description of Data Sources

Available sources of data were evaluated to determine their potential for use in the oyster stock assessment. The available data are described in detail in the stock assessment report and include harvest and effort reported by harvesters and buyers, data to monitor trends in oysters over time and space from the fall dredge survey and patent tong surveys, data on available habitat from the historical Yates bar survey and the Maryland Bay Bottom Survey, data on planting activities of wild seed, spat on shell, and shell, and data on other restoration activities. In addition, a thorough exploration of the peer-reviewed literature was conducted to obtain estimates for parameters that could not be estimated from available date (i.e. rate of habitat loss).

Two sources of commercial harvest and effort data are collected by the Maryland Department of Natural Resources (the department): seafood dealer buy tickets and individual harvester reports (harvest reports). Every dealer registered to buy oysters in Maryland completes a buy ticket report for every purchase made from a licensed commercial harvester. These reports are then submitted to the department. Because oysters are almost always harvested and sold to seafood dealers on the same day, buy tickets represent a record of daily oyster harvest. Harvest reports are required from all commercial license holders who paid the annual surcharge to harvest oysters, even if no oysters were harvested. Harvest reports are submitted to the department monthly and describe daily harvest, effort, and other information for that month. Ultimately, buy tickets were used in the analyses because they represented the longest time series available. The assessment is based on a 19-year time period (1999-2000 through 2017-2018 seasons) for which buy ticket data with gear type and NOAA code and were available. This period also contains years of both high and low mortality as well as the years with the lowest harvest. The buy ticket data were used in “depletion analyses,” which were used to summarize the daily catch and effort data as well as estimate abundance at the start of the fishing season and fraction of the population harvested. These depletion analysis estimates were also used as a data source for the stage-structured assessment model.

Since 1939, the Maryland Department of Natural Resources and its predecessor agencies have conducted surveys to monitor the oyster population in the Maryland portion of Chesapeake Bay. The survey uses a 32-inch-wide (0.81 meter) dredge. For each sample, live oysters are sorted into spat (recently settled oysters), smalls (≥ one year old and <3 inches), and markets (≥ 3 inches). Small and market boxes (dead oysters with hinges articulated) are also counted and the relative age of the boxes is assessed. Samples are collected on natural oyster bars, seed and shell plantings and in sanctuaries from mid-October through late November. This survey was designed to look at long-term trends in aspects of the oyster population (spat density, disease, biomass and mortality) rather than to estimate abundance. In the stock assessment, standardized counts of live oysters and boxes were used as data to which the assessment model was fitted to estimate abundance and natural mortality. Live oysters and oyster box counts were also used in two different methods to estimate natural mortality.

The Maryland Department of Natural Resources regularly conducts patent (hydraulic) tong surveys for a variety of purposes: 1) to evaluate the effects of power dredging, 2) to assess the effects of waterway dredging or construction on oyster populations and 3) to assess potential aquaculture lease sites. When Maryland expanded the oyster sanctuary program in 2010, the department began a study to evaluate oyster populations within sanctuaries. These surveys use a stratified random sampling design, with the strata based on substrate type. The number of sampling points varies based on the estimated amount of potential oyster habitat within the sanctuary but ranges generally from 50 to 300. The patent tongs used in these surveys sample an area of 1 square meter. Any oysters in the sample are sorted into spat (newly settled oysters), smalls (≥ one year old and < 3 inches), markets (≥ 3 inches) and boxes (dead oysters with hinges articulated). Live oysters and boxes are counted and measured. Because patent tongs sample a fixed area of the bottom, oyster density can be calculated.

Several attempts have been made to estimate the amount of oyster habitat in Chesapeake Bay. The first was the Yates survey from 1906 to 1912. The purpose of this survey was to identify the boundaries of “Natural Oyster Bars” within Maryland’s portion of the bay, so that areas outside of oyster bars could be used for oyster aquaculture leases. The Bay Bottom Survey was conducted from 1975-1983, generating maps that updated the Yates bars. This survey used a dragged acoustical device, patent tongs and sonar, to produce bottom classifications that included sand, mud, cultch (oyster shells) and hard-bottom.

Almost every oyster bar in Maryland has been manipulated over time through replenishment and restoration efforts to improve oyster bar productivity. Replenishment efforts were intended to enhance the public fishery for economic benefit. Restoration efforts were those activities occurring after the establishment of a sanctuary with the objective to restore oyster populations for ecosystem and ecological benefits. The types of enhancements employed in both replenishment and restoration include planting fresh and dredged shell, transplanting natural, wild seed, and planting hatchery-reared spat in hopes of increasing oyster populations. Records of shell and seed plantings since 1999 were used in the assessment. Since 2010, planting data has been recorded using GPS trackers, and exact track lines are provided to the department. Prior to 2010 there are issues within the data concerning both precision and completeness of records, and care must be used when trying to infer total planting volume within a given area.

3 Assessment Model Description and Results

3.1 Model Description

Stage-structured assessment models were developed for each of 36 NOAA codes to estimate time series of abundance, harvest fraction (fishing levels) and natural mortality rates of oysters (modified from Wilberg et al. 2011 and Damiano 2017). The five stages used in the models are those described in the fall dredge survey: spat (recently settled oysters), small (≥ one year old and <3 inches), market (≥ 3 inches), small box, and market box. The model year began October 1 which is the beginning of the oyster season for all gears except power dredge which begins November 1. The beginning of the model year (October 1) is about the same time as the fall dredge survey. The processes being modeled included recruitment (natural spat set and plantings), growth from small to market sizes, natural mortality (including disease-related mortality) of smalls and markets, the effect of fishing on small and market oysters (fishing levels), changes to habitat over time, effects of planting substrate and oysters, and the disarticulation of small and market boxes.

3.2 Model Results

Maryland-wide, the estimated abundance of market-size oysters varied between approximately 600 million and 200 million individuals over the assessment period (Figure 2). The estimated market abundance was highest in 1999, the initial year of the time series, decreased to approximately 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. These changes in abundance were strongly influenced by recruitment patterns (Figure 3). In 1999, estimated market abundance was highest in the Choptank River and Eastern Bay regions, but estimated abundance was highest in the Choptank River and Tangier Sound regions after 2006. Maryland-wide, estimated market abundance was higher in 2017 than it was during 2002-2007 but lower than in 1999. This pattern of increase towards 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.

A unique feature of oysters is that natural mortality can be estimated empirically from field observations of live oysters and boxes. Additionally, a statistical model was developed that corrects for assumptions of the empirical method (e.g., unequal capture efficiencies between live oysters and boxes and persistence of boxes for longer than one year) and allowed for estimation of uncertainty. This provided beneficial additional information on natural mortality rates to be a valuable tool for examining the 'reasonableness' of assessment model-based estimates.

Across NOAA codes, estimated natural mortality was generally higher and more variable in the beginning of the time series than in more recent years (Figures 4-21). Despite similar temporal patterns, the year in which natural mortality first began to be lower and less variable varied among the regions of the bay. For example, in most of the Tangier Sound region, natural mortality became lower and less variable later than in most NOAA codes in the Choptank region. In general, average natural mortality was lower in both the northern part of the bay and farther upstream in the tributaries.

Harvest fraction is calculated as the percentage of market oysters removed from the population by harvest. These varied over time and among NOAA codes, ranging from zero to about 80 percent per year (Figures 22-40). Harvest fraction often tracked market abundance in the NOAA codes. In NOAA codes where abundance was increasing over time and there were no large sanctuaries, the percentage of oysters harvested generally increased over time during the period from 2008 through 2016. 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.

4 Biological Reference Points

Maryland law requires that fishery management plans contain the best available estimates of sustainable harvest rates and minimum abundance levels (biological reference points, Natural Resources Article §4-215). Specifically, statute requires the development of target and upper limit (threshold) reference points for harvest fraction (fishing levels) and a lower limit (threshold) reference point for abundance. Additionally, there must be objective and measurable means to determine if the oyster fishery is operating within the reference points. To fulfill this requirement, NOAA code-specific production models were developed to estimate target and threshold fishing level reference points (modified from Wilberg et al. 2013).

The proposed threshold abundance reference point is the minimum estimated number of market oysters during the period 1999-2017 for each NOAA code. 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 below those levels. Additionally, minimum abundance during the period from 1999 through 2017 is likely the minimum during the last several hundred years. Market-size oysters were chosen because they are the targeted size group of the fishery and they also produce more eggs per individual than small oysters. This reference point 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, 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. The minimum value was reached during 2000-2007 for 22 NOAA codes (Table 2). 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 41). 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 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.

In determining appropriate target and threshold harvest fractions to propose for Maryland's oyster resource, there was consideration of Natural Resources Article §4-215 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).

In order to prevent overfishing, the recommended upper limit 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 result in eventual disappearance the population. As noted above, the limiting rate 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. 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. 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 should be the most appropriate for comparison with the reference points. If, however, 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. For the purposes of comparisons with the harvest fraction reference points in this report, all estimates of harvest fraction are adjusted for the number of planted oysters. However, annual estimates of harvest fraction estimated using both methods are presented in Tables 3 and 4.

Estimates of the proposed limit reference point, U_{crash}, ranged from zero to 0.45 per year and estimates of the proposed target (Figure 42), U_{MSY}, ranged from zero to 0.22 per year among NOAA codes (Figure 43). 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. There was substantial variability among NOAA codes and regions in their status relative to the harvest fraction reference points in the most recent year. In the most recent fishing season (2017-2018), 19 NOAA codes had harvest fractions above the limit reference point, three were between the target and limit reference points, and 14 were at or below the limit reference point (Figure 44).

5 Comparing Estimates of Stock Status Generated by Index and Model-Based Approaches

Analyses were conducted to determine whether an index approach could be used in lieu of the full stage-structure model to monitor stock status relative to the reference points. An index approach is a simpler analytical method that has fewer data requirements than the full assessment model and can, therefore, be conducted more quickly and with fewer staff resources than a full assessment. The harvest fraction estimates from depletion analyses were considered as an alternative to estimates of harvest fraction from the stage structured model, and indices of density from the fall dredge survey were considered relative to estimated market abundance from the stage-structured model.

Harvest fraction was estimated by the depletion analyses using only the commercial harvest and effort data (i.e., the index-based approach) and also by the stage-structured stock assessment model (i.e., the model-based approach). Estimates of harvest fraction from the stage-structured model were lower than estimates from the depletion analyses in most NOAA codes and years. This lack of agreement was acceptable because of perceived issues with the estimates from the depletion analyses. The main issues include:

1) Depletion analysis can only be used in areas with enough harvest to produce a measurable decline in catch per unit effort (CPUE). A decline in fishery CPUE may not be observed because the harvest is not sufficient to reduce CPUE. In particular, because daily harvest is constrained by the allowable number bushels per vessel per day, catch per license per day may not be a sufficiently responsive metric to changes in oyster abundance. This is especially true since two licensed individuals on the same vessel may each catch their full daily bushel limit, so that a vessel with two licenses on board has, effectively, twice the limit of a vessel with one license. Potential issues with using the depletion method include changes in fishing locations during the course of the season, inaccuracies in reported harvest or effort or insensitivity of the selected metric of CPUE to change in abundance. In addition, in areas with large sanctuaries, the

depletion method likely overestimates harvest fraction because it only reflects the change in abundance in the fished areas.

2) From a practical perspective, in many years it was not possible to obtain estimates of exploitation rates using only the depletion method. This was caused either by a lack of harvest in a NOAA code or by infeasible estimates from the depletion model (a positive relationship between cumulative catch and CPUE). Therefore, relying on this method to monitor the exploitation rates relative to their limit and target would rely on sufficient fishing pressure in all NOAA codes.

Ultimately, the depletion method does not appear to be practical to use alone for monitoring the status of the stock relative to the exploitation rate and abundance reference points, with the possible exception of limiting the analysis to only the NOAA codes with consistently high harvest.

Two methods were compared for monitoring abundance relative to the threshold reference point. The first method was the estimated market abundance from the stage-structured model relative to the minimum abundance reference point (minimum estimated market abundance during 1999-2017). The second approach used only the fall dredge survey standardized indices (average number per half bushel) with the minimum non-zero value from the time series during 1999-2017 selected as the limit reference point. In particular, this analysis focused on a comparison of the year of the time-series minimum from both methods and on the status of the stock in the most recent year (from both methods) relative to the threshold reference point.

The index-based approach for abundance produced very similar results to the stage-structured assessment model for some NOAA codes, but was substantially different for others. There was a close correspondence in the year of minimum abundance or density in the Tangier Sound and Choptank River regions with no NOAA codes having more than a one-year difference in the year of the minimum. Similarly, there was a close correspondence in the trends over time relative to the reference points in these two regions.

The other regions had larger differences in both the year of the minimum and the pattern over time between the stage-structured model and the standardized fall survey estimates. In the Eastern Bay Region, the NOAA codes in the Chester River had similar patterns of model estimates of market abundance and fall survey indices of market density, but the patterns were different for the other NOAA codes in the region. In these latter NOAA codes, the index of density was farther above the minimum value in the most recent years than it was for estimated abundance. This similar pattern of higher levels relative to the minimum in the most recent years for the indices of market density were also present in all NOAA codes in the

Chesapeake Bay Mainstem Region, most of the NOAA codes in the Patuxent and Potomac Rivers Region and both NOAA codes in the Western Shore Region. Many of the NOAA codes had large difference in the year of the minimum value, with ten of 20 NOAA codes (outside the Tangier Sound and Choptank Regions) having differences of at least three years.

These differences arise because the stage-structured model estimates abundance, whereas the fall dredge survey index is a measure of density (number per area). The stage-structured model includes changes in oyster habitat over time, whereas the standardization of fall dredge survey time series does not include any adjustments for changes in habitat. Therefore, it is possible that abundance could decrease, but densities could remain relatively high if habitat has declined substantially. Under conditions of declining habitat, which have been documented in Maryland, an index of density could lead to a different conclusion about stock status relative to an abundance reference point.

The stage-structured model is recommended for evaluation of the status of abundance relative to the proposed reference points because it can easily be compared to both the harvest fraction and abundance reference points. Furthermore, it is recommended that the stage-structured model be used for monitoring the status of the harvest fraction relative to its target and limit reference points. The stage-structured assessment model integrates more available data than the other methods, including a trend in habitat over time. If the goal is to maintain abundance above the minimum estimated level during 1999-2017, then including changes in habitat is an important consideration. Because the stage-structured models integrate more data on density of oysters and changes over time than the depletion analyses, the estimates of harvest fraction should be more accurate and reliable. There is potential to use the depletion analysis in limited NOAA codes that have consistently high harvest, particularly if more accurate harvest data become available.

6 The Role of Sanctuaries and Restoration Efforts in Sanctuaries in the Development the Stock Assessment Model

The 4th term of reference explicitly directed that sanctuaries and restoration efforts be included in any modeling approach. This was addressed by 1) including substrate and spat plantings (i.e., restoration efforts) explicitly in the stage-structured assessment model and 2) conducting the assessment at the NOAA code level. Substrate additions (shell and alternative) increase habitat in the stage-structured model. Plantings of spat and wild seed also increase abundance of spat and small oysters, respectively. For the limit abundance reference point, oysters in sanctuaries count towards the limit within a NOAA code.

Fishing mortality on oysters in Maryland varies spatially. Sanctuaries represent one end of the fishing mortality continuum by mandating locations where harvest is prohibited. A few NOAA codes are complete or nearly complete sanctuaries (e.g., Severn, upper Chester, upper

Choptank and Nanticoke Rivers), and conducting the assessment at the NOAA code level explicitly accounts for sanctuary status on the population dynamics. However, for most other NOAA codes, sanctuaries and public harvest areas are both present. It was not possible to conduct modeling efforts a spatial scale smaller than the NOAA code level, because reported harvest at smaller spatial scales is not thought to be accurate.

In the methods employed in this analysis, oysters in sanctuaries count towards the abundance reference point within a NOAA code. However, it was not possible to address how sanctuaries affect exploitation rate reference points for several reasons outlined below.

1) The potential for increased productivity in areas outside of sanctuaries due to larval export from sanctuaries relies on larvae being the limiting factor for oyster abundance in a region. If the limiting factor for productivity outside of sanctuaries is not larvae, but something else such as available habitat, then an increase in larval supply will not result in increased numbers of spat. In most areas, the amount of available habitat is highly uncertain and has not been surveyed since the late 1970s-early 1980s. Without knowing what the limiting factor is for oyster populations in a NOAA code, it is difficult to determine if larval export from a sanctuary would increase productivity in neighboring areas outside of the sanctuary.

2) The connectivity among sanctuary and non-sanctuary areas would have to be known to modify exploitation rate reference points for the effects of sanctuaries. While progress is being made in understanding larval dispersal, larval transport models have yet to be validated for oysters in Maryland. Due to the limited understanding of larval oyster dispersal in Maryland, trying to fine tune reference points for these effects seems premature.

3) If abundance of adult oysters does not increase in a sanctuary, there will not be additional production within the sanctuary available to increase harvest rates outside the sanctuary. For example, oyster abundance in NOAA code 331 (upper Chester River) has not increased despite being a sanctuary, and therefore there is no increased production in this sanctuary to allocate to nearby public fishery areas.

4) If oyster abundance increases because of larval export from sanctuaries to surrounding areas, then the number of bushels allowed for sustainable harvest will increase even if the target fishing mortality reference point remains unchanged. For example, if the target is 0.1 (i.e., 10% of the population can be harvested) and there are 10 million market oysters in a NOAA code, then the target level of harvest would be 1 million oysters. If the number of oysters increased to 15 million because of increased spat sets caused by larval supply from a sanctuary, then the target level of harvest would increase to 1.5 million oysters (10% of 15 million).

Overall, substantial improvements in information are needed to quantify the effect of sanctuaries on oysters in areas outside of sanctuaries. If oyster abundance increases in areas outside of sanctuaries because of larval supply from sanctuaries, then the currently proposed reference points would allow for a subsequent increase in sustainable harvest.

7 The Impact of Hatchery Plantings (aquaculture and public fishery) on the Spawning Potential in the Fishery

It is difficult to determine how planted oysters contribute to the spawning potential of the population because once oysters are planted on public bottom or in sanctuaries they cannot always be readily distinguished from wild oysters. Also, aquaculture uses diploid and triploid oysters, the latter of which are specifically bred not to spawn. Cultured oysters may also be harvested year-round and sometimes at a smaller size than wild-harvested oysters, which complicates determination of whether they are harvested before or after they spawn.

The approach used to address this term of reference was to make a broad comparison among 1) the estimated abundance of market-size oysters from the stage-structured assessment model, 2) the estimated number of market-size oysters generated by hatchery plantings using two different values for the assumed planted spat survival during their first two months (15% - base model, 5% - sensitivity analysis), and 3) the number of market-size oysters harvested from leased grounds. While this simple comparison provides a perspective on the relative importance of planted oysters relative to wild oysters, there are several important caveats to the analysis: 1) the harvest of oysters from lease grounds is used as a proxy value for the number of market-size oysters that may be on lease grounds, 2) a mortality rate is applied to hatchery spat to project the number of market-size oysters present in the population and this rate may vary spatially and temporally, 3) the reproductive output per individual is similar among wild and planted oysters, and 4) aquaculture data are not currently available on a NOAA code scale so this comparison must be done in aggregate for the entire Maryland portion of Chesapeake Bay. This aggregation will mask important spatial variation in the contribution of planted and aquaculture oysters because areas with plantings often receive higher fishing pressure than neighboring areas. Data on aquaculture planting numbers and harvest were summarized from leaseholder reports. The data included the bushels planted on leases, the number of individuals planted on leases by ploidy (diploid or triploid) and the bushels of oysters harvested.

The stage-structured assessment models were used to estimate the number of market-size oysters from plantings outside of leases each year. The number of market oysters from plantings outside of leases were then subtracted from overall market abundance to estimate the number of market oysters from wild production. These calculations assume that planted oysters experience the same mortality rates as wild oysters after October 1 of the year in which they were planted.

The number of oysters planted on leases in the Maryland portion of Chesapeake Bay increased by 30% from 231.7 million in 2012 to 301.3 million in 2016. Additionally, the percentage of planted oysters that are triploid more than doubled to 34% in 2016 from 15% in 2012 as the number of triploid oysters planted increased while diploid oyster plantings remained relatively constant. The number of oysters harvested from commercial shellfish leases in the Maryland portion of Chesapeake Bay increased from approximately 1.0 million in 2012 to 22.2 million in 2017.

The number of market-size oysters estimated from the stage-structured model as 'wild origin' was, on average, 18 times greater than the number harvested from commercial shellfish leases during 2012-2017. The estimated number of market-size oysters generated from hatchery and wild plantings in non-lease areas was substantially greater than the number of oysters that were reported as being harvested from commercial shellfish leases.

The magnitude of lease harvest is small relative to the estimated abundance of oysters of wild origin, indicating that the spawning potential of oysters on leases is likely small relative to the population outside of leases at the Maryland-wide scale. In addition, any potential shift in the proportion of triploid oysters planted on leases would further erode the contribution of these animals to the total spawning potential.

8 Research Recommendations

The following research recommendations were developed in the process of completing this stock assessment. They are arranged by category rather than in order of priority.

Data

- Develop mechanisms to improve accuracy and resolution of reported harvest data including bar level data, the number of licensed individuals on a vessel, and the hours spent harvesting.
- Conduct fishery dependent sampling of oyster size distribution to better quantify the number of oysters per bushel and the number of under-sized oysters per bushel.
- Conduct research to better quantify growth rates that can be incorporated into stock assessment models.
- Conduct research to better quantify natural mortality of wild and hatchery -planted spat.
- Develop a means to mark hatchery-reared planted spat so that the proportion of planted versus wild oysters can be determined in subsequent surveys.

Natural Mortality

- Studies to improve estimates of box decay rate. Because 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 harvest relative to when fall survey is occurring to see if explains some of the difference 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.

Exploitation Rates

- A survey conducted just prior to and directly following the fishery would provide a direct means to estimate exploitation within a given year and could provide a snap shot of conditions relative to selected reference points.

Habitat

- Conduct more ground-truthing surveys on unverified current SONAR data so that existing sonar data can be accurately utilized in determining oyster habitat.
- Develop comprehensive maps of current oyster habitat within the Maryland portion of Chesapeake Bay.
- Studies designed to quantify the rate of habitat decay would better inform the assessment and reference point models; and would contribute to development of a shell budget.
- Develop a mechanism to better understand how shell plantings contribute to habitat and how habitat is quantified.
- Conduct research examining how harvest gears impact oyster habitat.

Sanctuaries and Spatial Scale

- The contribution of sanctuaries to oyster population and fishery dynamics within a NOAA code is an important question for management and will require finer scale spatial survey data within and outside of sanctuaries as well as more accurate bar-level harvest data than is currently available.
- Conduct research to help elucidate 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 stock assessment model that incorporates feedback among areas rather than the current assessment which treats each NOAA code as though it is an isolated population.

Assessment Model

- Incorporate a shell budget into stage structured assessment in order to allow internal estimation of biological reference points.
- Continue to improve the stock assessment model based on lessons learned from this assessment and as new information becomes available.
- Examine alternative spatial structure for stock assessment.

Biological Reference Points

- Harvest fraction reference points for oysters should account for the accretion and loss of shell since oysters produce their own habitat that is required for population growth. Developing a spawner per-recruit type analysis that instead of egg production represents shell per recruit. Research is needed to determine the ratio of shell per recruit that is suitable for target and threshold reference points.
- Research on target levels of abundance including biological limits of abundance (e.g. necessary conditions for successful fertilization).

Aquaculture

- Developing an aquaculture data base that tracks plantings, standing stock and harvest of diploid and triploid oysters at the NOAA code spatial scale would be improve the model's ability to quantify the contribution of aquaculture plantings to the population dynamics within the NOAA code.

9 Objective Means to Monitor Fishery and Population Against Biological Reference Points

Once biological reference points are established, it is important to determine how the population and fishery will be monitored to determine status relative to the reference points. One option is to periodically update the stock assessment models that were implemented in this study. Updating these analyses on a regular basis (e.g. every 2 to 3 years) would provide regular checks of abundance and harvest fraction compared to reference points. In interim years to stock assessment updates, it will be important to monitor trends in fall dredge survey data particularly in NOAA codes where these trends aligned with output from the assessment model – as these could provide warning if abundance is approaching undesirable levels.

In areas of high harvest, depletion approaches may be useful to monitor exploitation rates relative to the target and upper limit reference points.

10 Potential Management Strategies

The Sustainable Oyster Population and Fishery Act of 2016 (Senate Bill 937, Natural Resources Article §4–215, revised in 2017, HB 924, Chapter 27) directs the Maryland Department of

Natural Resources to "…identify management strategies to address the maintenance of a sustainable oyster population and fishery." This section provides a listing (with definitions) of potential management tools that could be used to manage Maryland's public commercial oyster fishery and oyster population based on the results of the stock assessment. No recommendations on which management strategy(s) should be selected and implemented are included. This list of potential tools was assembled with input from Oyster Advisory Commission, Tidal Fishery Advisory Commission, Sport Fishery Advisory Commission and the County Oyster Committees and will provide the platform for a future public process to determine the course of management.

This list of management tools will provide the basis for future discussions on oyster management. In general, several management tools would likely need to be applied in conjunction with one another in order to result in effective management for an area. Because the assessment was conducted on the spatial scale of NOAA code, different suites of tools could be applied in different areas. This is important because management actions that could be effective in one region could be less effective in others.

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 the Bay.

10.1 List of Management Tools with Constituent Input

Listed below (in no particular order) are potential oyster management tools that can be used to manage for a sustainable oyster population and harvest. This report does not examine where the listed approaches are used in other wild oyster fisheries around the world. As discussions proceed, this sort of research may be helpful to guide decisions. Although it is important to note that the effectiveness of management tools can differ among fisheries due to variations in fishing behavior, enforcement capacity and, particularly, in the socio-economic structure of the fishery.

The following list of potential management strategies was reviewed by members of the Oyster Advisory Commission, Tidal Fishery Advisory Commission, Sport Fishery Advisory Commission and the County Oyster Committees. The members were asked to consult with their various constituencies and to provide the department with any additional ideas for management.

Although the intent of the request was to ensure that the department did not overlook any potential management tools, some feedback went beyond this request by providing opinions whether or not an approach should be applied, crafting holistic proposals or submitting a formal position letter on behalf on an organization. All of this feedback is included. With the exception of formal position letters from organizations, all feedback is anonymous. The feedback received is included under each item in red, italic font. With the exception of removing the identities of the individuals/organizations submitting, the feedback and comments are inserted verbatim. Each individual submission has been assigned a feedback number so that it is possible to tell which comments came from a single submission. A category of management tools entitled 'other' has been added to encompass novel ideas that did not fit into the four main sections: Input controls, output controls, habitat modification and stock enhancement, and also to include comments, management proposals and one formal position statement of an organization. Five submissions stated that they had no additional comment to the original list.

10.1.1 Output Controls

- Definition of 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. This was added in response to one comment, inserted below. Currently the department has regulations that define the container dimensions:

  A metal oyster tub that does not exceed the following inside dimensions: 18 inches top diameter, 16-1/2 inches bottom diameter and 12 inches high.

  A rectangular shaped container that does not exceed the following inside dimensions: 12-5/8 inches width across the top, 12 inches across the bottom, 20 inches length and 11-1/4 inches high.

  A round container that does not exceed the following inside dimensions: 16 -1/2 inches top diameter, 13-1/2 inches bottom diameter and 14-1/4 inches high.

  Feedback:

- *There's no description of what size a bushel is. You know md. Has a different size of oyster bushel than the fed. government has and is different than Virginia's is. I would like to see that in the controls. Also it should be stated in there what containers were allowed (eg. orange fish basket, clam crate, steel oyster tub). (Feedback #13)*

- *Bushel Limits*

  A bushel limit places an upper limit on the number of bushels of oysters 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.

  Maryland currently manages the commercial public oyster fishery using daily bushels limits which vary depending on the gear type. Currently, all gears except power and sail dredge are allowed 15 bushels/license/day, not to exceed 30 bushels/vessel. Power dredges are allowed 12 bushels/license/day, not to exceed 24 bushels/vessel. Sail dredges are allowed 150 bushels/vessel/day. The current daily catch limits have been in place since 1971 for sail dredge, 1983 for power dredging, and 1987 for hand tongs, patent tongs, and diving. The recreational harvest bushel limit is 1 bushel per day per person.

  To change the bushel limits for one season, the department could issue a public notice. If the change was intended to last for more than one season, a regulatory change would be needed.

  Feedback:

- *Bushel limits could be lowered (Feedback #2)*
- *We feel that there is a consensus among our association to have a conversation on possibly lowering the bushel limits from all the gears per person that are in place now. However we feel not to make any recommendation until the sustainability study has been completed and reviewed completely by all the stakeholders to make a sound judgement on new bushel limits if needed. (Feedback #7)*
- *There is a complete description of an idea to use catch history to determine individual, daily bushel limits under the 'other' category. (p. 39 Feedback #14)*

- *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 another 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.

This management tool is not currently used in Maryland public oyster fishery. Implementing a TAC would require a change in the Oyster Management Plan in which such a management system was described and proposed. This would be followed by a regulatory change to both adopt a new Oyster Management Plan as well as create new regulations to implement a TAC program and a public notice provision to open and close the fishery.

Feedback:

- *No total Allowable catch Will not works (Feedback #2)*
- *Total Allowable Catch (TAC): Similar to bushel limits above, the TAC section should also include discussion on how a TAC could be allocated - by sector, by area, etc. (Feedback #4)*

- *Individual Transferable Quotas (ITQs)*

  Individual transferable quotas are one approach for implementing a TAC as described above. ITQ's 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.

  ITQ's are not currently used in the Maryland public oyster fishery. Implementing this would require a change in the Oyster Management Plan in which such a management system was described and proposed. This would be followed by a regulatory change to both adopt a new Oyster Management Plan as well as create new regulations to implement ITQ's.

Feedback:

- *ITQ's will not work we learned our lesson with the Striped Bass (Feedback #2)*
- *A slot or quota system, ITQS or a TAC is **not** recommended. (Feedback #7)*

- *There is additional comment, including and ITQ scenario included with Feedback # 14 (p 39) under the 'other' category.*

- <u>*Minimum Size Limits*</u>
  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% of the population has been allowed to spawn once.

  Since 1927, the oyster size limit has been set at 3 inches. Generally, it takes oysters three years to reach three inches, thus this size limit will allow for some reproduction at age two and three. A two-inch female oyster has the potential to produce an estimated 4.6 million eggs and a three-inch female oyster has the potential to produce an estimated 25 million eggs (Mann and Evans 1998).

  Changing the minimum size limit would require a change in regulation. The department would have to "notwithstand" statutes, but this is legally allowed under statute NR §4-215 and has been done in the past.

  Feedback:
- *Keep minimum size of 3 inches. (feedback #2)*
- *As oysters are protandric hermaphrodites, the proportion of females increase directly with size; removal of only the largest individuals modifies the 'natural sex ratio' disproportionately removing the most fecund females (Rothschild et al. 1994) (Feedback #5)*
- *We feel the size limit of 3 inches is appropriate. (Feedback #7)*

- <u>*Slot Size Limits*</u>
  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% 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.

This management technique is currently not used in Maryland for oysters. Implementation of a slot size limit would require a similar process as changing the minimum size limit. However, if the minimum size of oyster did not change (i.e. the department only added a maximum size), no subsequent legislation would be necessary.

Feedback:

- *No Slot Limit Size!, This has been used before in the Potomac and was not successful.(Feedback #2)*
- *Maximum Size Limits: Although it is implicit in the slot size below, for completeness, it would be good to add maximum size limits in addition to minimum with slot limits as the "combined option." (Feedback #4)*

10.1.2 Input Controls

- <u>*Season Limits*</u>

  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 stages of a population, for example, months when spawning is occurring.

  The harvest of oysters in Maryland's public fishery is restricted to the months of October through March (power dredging is conducted November-March).

  To change the season limits for a single fishing season, the department could issue a public notice. If the change was intended to last for more than one season, a regulatory change would be needed.

  Feedback:

- *No change in season. (Feedback #2)*
- *We feel the season and times are appropriate and should be left alone. (Feedback #7)*
- *The calendar year and time limits appear to be restricted enough and are fine. (Feedback #7)*

- <u>*Time Limits*</u>

  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.

Since 1992, commercial harvesting is allowed Monday through Friday from sunrise to 3 p.m., and the hours are extended to sunset in November and December. Recreational harvest time limits are sunrise to noon Monday through Saturday. Changing the time limits would require a regulatory change.

Feedback:

- *Time limits could be lowered. (Feedback #2)*

- <u>*Gear Limits*</u>

  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 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.

In Maryland, there are a variety of permissible gears for the commercial harvest of oysters that are restricted both in terms of when and where they can be used as well as in their dimensions or configuration. Oysters can be harvested by multiple gear types: hand tongs, patent tongs, diving, power dredging, and sail dredging. Currently, all gears can be used from October to March, with the exception of dredging which can be used from November to March.

All areas open to oystering are open to multiple gear types with the exception of hand tong-only areas and four small Power Dredge Study areas. Some oyster bars are restricted to hand tonging only, but hand tonging is permitted on all oyster bars. Most of the hand tong-only areas are located in shallow waters in more protected creeks and coves.

Patent tongs are prohibited from certain county waters and most tributaries. This gear is primarily employed in the Chesapeake Bay mainstem, the lower Patuxent River, and parts of Somerset County.

Oyster diving was legally established as a gear type in 1973. Diving is allowed on all open bottoms except those reserved for hand tong-only and the few small Power Dredge

Study areas. Divers typically work only on bars where patent-tonging and dredging are prohibited.

In 1993, the power dredging gear type was discontinued, but it was reestablished in 1997 and further expanded in 1999, 2003, and 2010 to include much of the lower Bay and significant parts of the middle Bay below the Chesapeake Bay Bridge. Power dredging is allowed in much of the lower Choptank River and the majority of bottoms in southern Maryland including the mainstem and much of Dorchester, Somerset, and St. Mary's Counties.

Sail dredging is a historical method of oyster dredging with the iconic Chesapeake Bay skipjack sailing vessel. It is similar to power dredging, however, for at least 3 of the 5 days each week the boat must be powered completely under sail. For two days a week, the skipjack can be powered using an auxiliary yawl boat to push the skipjack, effectively making it similar to power dredging. Historically skipjacks operated through the mainstem of the Chesapeake Bay as well as some tributaries such as the Choptank but in recent years, fewer than ten boats are in operation and are generally found in the Tangier Sound region.

Changing the gear limits would potentially require a change in the Oyster Management Plan, regulation, or statute depending on the limits of which gears the department was changing. Certain limits on gears are statutory (i.e. size of dredge, definitions of gears). Certain limits on gears are both statutory and regulatory (i.e. areas where sail dredges are allowed). Certain limits are regulatory only (i.e. hand tong only areas, power dredge areas, power dredge study areas, and patent tong areas). Changing the definitions of gears, size of gears, or areas where gears are allowed may necessitate changing the Oyster Management Plan prior to taking regulatory action, which would require regulation to adopt a new Oyster Management Plan.

Feedback:

- *Gear changes could be possible (Feedback #2)*

- *Entry Limits*

  Entry limits restricts the number of individuals that are granted the opportunity to harvest animals commercially.

  In Maryland, individuals purchase licenses from the State in order to commercially harvest oysters. Maryland regulation limits the number of commercial oyster harvester licenses to 737. Maryland also has a cap of 2,091 commercial tidal fish licenses which enable the licensee to participate in a wide variety of fisheries including oysters. Thus, there are a total of 2,828 individuals who have the potential to harvest oysters in any given year. Along with having a license to harvest oysters, the department also requires individuals to annually purchase a surcharge of $300 if they want to harvest. The revenue from the surcharges is used to conduct seed and substrate plantings for oyster population and fishery enhancement purposes in conjunction with other state funds used for this purpose.

Changing entry limits (number of participants in the oyster fishery) would require a change in regulation, the Oyster Management Plan, and would potentially require a change in statute.

Feedback:

- *No limited entry (it already has a cap). (Feedback #2)*
- *Entry Limits: This section does not specify if the Department is referring to limiting new entrants to the fishery over and above the 2,828 available licenses (or even above the number of recent surcharges) or reducing the total cap on existing licenses. I think these are 2 distinct approaches and some clarification would be helpful.*
    - *License Buy-backs*
    - *A description of license cap and buy-back programs should also be included (Feedback #4)*
- *Buyout program to reduce the latent effort and perhaps to size the entrants to the capacity of the fishery. (Feedback #5)*
- *Sunset the permit so that they become non-transferrable and close out when permit holder stops fishing. (Feedback #5)*
- *There should be a move to have better controls in place for a limited entry fisheries or a restrictive fishery when the Oysters are more plentiful. (Feedback #7)*
- *Reduction in number of licenses. (Feedback #8)*
- *Allow current licenses but set a goal of 500 license. (Feedback #8)*
- *As licenses do not renew eliminate them. (Feedback #8)*
- *Allow licenses to be transferred to sons and daughter of current license holders only. (Feedback #8)*

- <u>Sanctuaries</u>

  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.

In Maryland, oyster sanctuaries were first established in 1961 (Oxford Sanctuary). Sanctuary areas have been added over time and were last changed in 2010. Objectives of the 2010 sanctuary expansion included: 1) facilitate natural disease resistance, 2) provide essential natural ecological functions that cannot be obtained on a harvest bar, and 3) serve as a reservoir of reproductive capacity (Maryland Department of Natural Resources, 2016). Some of Maryland's sanctuaries are just closed to fishing, others receive restoration, and others receive large scale restoration aimed specifically at meeting outcomes of the 2014 Chesapeake Bay Watershed Agreement: Continually increase finfish and shellfish habitat and water quality benefits from restored oyster populations. Restore native oyster habitat and populations in 10 tributaries by 2025 and ensure their protection.

Changing sanctuary boundaries would require a change in regulation (after the requirements have been met from the legislation that prohibited changing the boundaries).

- *Sanctuaries need to be revised as the largest portion are not being worked or planted. (Feedback #2)*

- _Harvest Reserve Areas_

  Harvest reserve areas are areas that are closed to harvest for a period of time and may be opened after certain criteria are considered. The criteria are often based on desired characteristics of a population. The purpose of these areas is maximize harvest while maintaining a sustainable and healthy population. Generally, stock enhancement practices are applied in these areas.

  In the past, Maryland had 19 Harvest Reserve Areas. Currently there are two remaining. Biological criteria required to open an area consisted of: growth rates, disease prevalence and intensity levels, mortality threshold, and biomass threshold.

  Harvest Reserve Areas can be opened and closed using the departments public notice authority and would not need a regulatory change. Adding or removing Harvest Reserve Areas requires a regulatory change.

  Feedback:

- *Harvest Reserve Areas good. (Feedback #2)*

- *Harvest Reserve, Open and Close Areas, Rotational Harvest Areas: Expand these tools by including opening/closing individual reefs or river portions, based on the ecological/biological characteristics of that particular area such as reef structure, reef recruitment, oyster density, age class composition, average oyster size, etc.*
    - *In addition, this strategy/tool should include a biologically-determined sustainable level of harvest. This limit should be set by considering recruitment to the targeted reefs, their contribution to fish habitat, nutrient and sediment reduction, as well as their reproductive capacity. Harvest limits should not be set that jeopardize these characteristics. This approach avoids a specific time-based criterion and ensures a limit to the amount of harvest based on a desire to maintain ecologically functional reefs that can sustain harvest. Prior to implementation of such as "tool", a stock assessment would need to be completed for the bar or region along with some level of regular monitoring. (Feedback #5)*
- *DNR should reclassify the Reserve Areas and use the term Rotational Area. We have one and feel restrained from planting or investing into it due to the restrictions imposed in a reserve area versus a rotational area (Feedback #7)*

- *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 of the industry for the purpose to decreasing the chance of gear mortality of planted seed or spat.

  Areas within Public Shellfish Fishery Areas can be opened and closed using the departments public notice authority and would not need a regulatory change.

  Feedback:

- *Opening and Closing bottom as commercial industry needs. (Feedback #2)*

- *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 in the hopes of rebounding the population quicker.

Implementing rotational harvest areas would potentially require a change in regulation and the Oyster Management Plan depending on where the rotational harvest areas were located. If these areas were currently within a sanctuary and not in a Public Shellfish Fishery Area, a regulatory change would be needed. If the areas were completely located within a Public Shellfish Fishery Area, areas could be opened and closed using the departments public notice authority and would not need a regulatory change.

Feedback:

- *Rotational Harvest is good for the industry as well as environment.*
- *Rotational Harvest: Unlike harvest reserve areas, the opening or closure of rotational harvest areas is dependent only on the time period and does not consider biological criteria. (Feedback #4)*
- *Rotational Harvest appears to be the new sustainable management tool, a separate escrow of moneys should be set aside as an incentive for County Oyster Committees to commit to this new concept. Counties should submit plans as they do know to be awarded portions of this escrowed money. (Feedback #7)*
- *Suggest adding content to the "Harvest Reserve" and "Rotational Harvest" discussion to clarify how much or what size oysters would be removed; or just to recognize that other management tools would be combined with these two to maintain populations at a certain level such as size or bushel limits. If that is not the case, and DNR would permit uncontrolled harvests, then that should be stated also. Basically, what is the difference between Harvest Reserve and Rotational Harvest in practice? You could operate a number of harvest reserves as rotational harvest areas. (Feedback #12)*

<u>*Enforcement and harvest monitoring*</u>

This approach was added into the input control section based on numerous comments received (below).

Feedback:

- *Electronic reporting system (Feedback #5)*
- *Vessel monitoring system for all active permit holders (Feedback #5)*
- *Enforcement – none of these are effective without proper enforcement; the document should include a discussion of enforcement as a fisheries management tool. (Feedback #4)*
- *It would be helpful to include how each of these is enforced. This provides important information on the capacity required to effectively implement these strategies, which should be an important consideration. Additionally, enforcement should be included as*

an additional management measure as each of these is to varying extent, dependent upon enforcement to be an effective tool. (Feedback #4)

- *Input Controls: Surveillance would be a good addition here. This involves the regulation and supervision of oyster fishing activity to ensure that legislation and terms, condition of access and management measure are observed. Violation would, of course, have to be enforced. (Feedback #6).*

10.1.3 Habitat Modification

- <u>*Planting Substrate*</u>

  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.

  In recent years, Maryland has been planting both shell and alternative materials as substrate. Shell has consisted of oyster shell from shucking houses, mixed shell (mixture of scallop, conch, and clam from processing plants), and fossilized shell. Alternative substrate has consisted of stone, concrete rubble, slag, and reef balls. Permits from both Maryland Department of the Environment and the U.S. Army Corps of Engineers are needed to conduct this type of habitat modification.

  Feedback:

- *Planting substrate shell is the best substrate and we don't want stone, rubble, or reef balls on public bottom. Dredge Shell is the best. (Feedback #2)*

- <u>*Planting Dredged or Reclaimed Shell*</u>

  Planting dredged and reclaimed shell are forms of habitat modification that dredges oyster shell in one area and plants the shell on other oyster bars for the purpose of establish, enhance, and protect a population on the bar that the shell was planted. For oysters, the practice is primarily used to provide more substrate for natural spat settlement and to improve the bottom for stock enhancement practices. This practice will also modify the habitat of where shells are dredged from.

  Dredged shells were planted in Maryland from 1960 to 2006 using a hydraulic dredge with a rotating head that cut into the bay bottom and brought buried shell to the surface. This was generally conducted on relict oyster bars that did not have living oysters. The shells were then planted on other oyster bars baywide. Permits from both Maryland Department of the Environment and the U.S. Army Corps of Engineers are needed to conduct this type of habitat modification. The program ended in 2006 primarily due to opposition to the program based on environmental and stakeholder concerns.

Reclaimed shells are silted and degraded shells that are collected and replanted using watermen's oyster dredges (same gear as is used to harvest oysters). In 2012, Maryland contracted waterman to reclaim surface and slightly buried shell. This occurred in areas where shell was previously planted, but they became silted and unavailable for spat set. The shells were then planted on other oyster bars. Permits from both Maryland Department of the Environment and the U.S. Army Corps of Engineers are needed to conduct this type of habitat modification.

Feedback:

- *Reclaimed shell could be successful if deployed properly. (Feedback #2)*

- <u>*Seed Areas*</u>

  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 those 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.

Maryland had a seed area program from 1960 to 2006. There were approximately 20 areas used during that timeframe located mostly in high recruitment areas with moderate to high salinity, typically in the southern counties of Dorchester, Somerset, and St. Mary's counties. The program ended primarily due to the loss of the dredged shell program that supplied the shells needed to create the seed areas. Also, recruitment declined after the late 1990's.

To create a seed area, statute NR4-1103 requires the department to notify the Joint Committee on Administrative, Executive, and Legislative Review (AELR), publish notice at least 30 days before closing an area in one newspaper of general circulation in the State and one newspaper of general circulation in each county in which the affected waters are located, and on the website of the department. A public hearing at least 15 days prior to the closing must also be held in the county seat of the county in which the affected waters are located. If the area is in multiple counties, the hearing must be held in the county seat closest to the waters. If the area is in totally in State waters (i.e. not county waters), the hearing must be in Annapolis. If a proposed seed area was currently within a sanctuary, a regulatory change would be needed to change the boundary of the sanctuary only after the requirements have been met from the legislation that prohibited changing the boundaries.

Feedback:

- *Seed areas are needed on both sides of the Bay. (Feedback #2)*
- *Seed Areas: Moving oysters up Bay from southern MD waters will ensure that their gametes will in fact settle in MD waters. Oysters spawning in Tangier Sound and the Potomac River may in fact be enhancing oyster populations in VA due to larval transport. (Feedback #5)*
- *We feel there should be an emphasis on DNR to designate locations to have a seed areas within the Bay in a Tier 1 river complex. These areas will be small in nature and heavily monitored for compliance. This concept and program was successful in the past and there is no reason it won't be again. (Feedback #7)*

- *<u>Reclaiming Silted Shell</u> – We have witnessed another historic fresh water flow in the Chesapeake Bay again this year. Reclaiming of the silted shell is a priority for us. We feel dredging operations on selected Oysters bars that have been silted in is critical to reclaiming some of our oyster grounds back. NO harvest is being requested and we are proposing no cost to DNR. This has been an issue getting approved in the past and we would like to see it resolved. (Feedback #7)*

- *<u>Mix-managed areas</u> - Would it be appropriate to add in a category under habitat modification for a 'mixed-managed' area where source bars are protected as sanctuaries and sink bars are harvested in some fashion? (Feedback #12).*

10.1.4 Stock Enhancement

- *<u>Planting wild, natural seed</u>*

  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).

  In recent years, Maryland has been purchasing seed from Virginia and planting it in multiple locations. This practice may enhance local populations as well as the Maryland-wide population since oysters are being transported from outside the state. Planting wild, natural seed may also cause the transportation of oyster diseases and other organisms as well.

When planting oyster seed from out of state, only *Crassostrea virginica* may be used and an import permit must be issued by the department. Import may be limited to certain bars, based primarily on salinity and a comparison of Dermo intensity and prevalence and MSX prevalence at the source and destination bars determined by each states' annual fall survey.

In the past, Maryland transported seed produced in Maryland's Seed Areas to areas that had lower recruitment. This practice may enhance localized populations of oysters, but will not enhance the baywide population since these are not new oysters to Maryland's portion of the Bay. Furthermore, it reduces the population of oysters at the source location.

Feedback:

- *Stock enhancement wild seed and Spat on Shell needed to enhance oysters in the bay. (Feedback #2)*

- *<u>Planting hatchery reared spat-on-shell</u>*

  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 the 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 also be a form of habitat modification (substrate addition).

  Since the late 1990's, Maryland has been planting hatchery spat on public fishery bottom, sanctuary areas, and in aquaculture leases. This practice may enhance local populations as well as the baywide population of Maryland since these oysters are considered "new" oysters to the bay.

Feedback:

- *Planting Hatchery Raised Oyster Seed: Clarify that spat-on-shell could be used, or spat-on-alternative substrate. For example, small stone in used in VA for harvest reefs. (Feedback #5).*

10.1.5 Other

This section includes feedback that could not be categorized under one of the four management tool categories: output controls, input controls, habitat modification and stock enhancement. Feedback is inserted verbatim. Because this section is comprised **only** of feedback and there is no departmental text, the font is black.

Feedback:

- *Partial or full moratorium. (Feedback #5)*
- *Moratorium of partial moratorium (e.g. full closure on some stocks but limited fishing on others) is missing from this document and should not be excluded from a complete list of possible management strategies. (Feedback #6)*
- *Suggest adding Harvest Moratorium as a management option. (Feedback #12)*

<u>Territorial Use Rights for Fishers (Feedback #3)</u>

- *"Property rights give fishers ownership over marine resources, thereby providing an incentive to manage for long-term sustainability. Territorial Use Rights for Fisheries (TURFs) are a spatial form of property rights in which individuals or a collective group of fishers are granted exclusive access to harvest resources within a geographically defined area (Christy, 1982). Harvest rights in TURFs can range from privileges to fish in areas that are leased from the government to complete ownership over the delineated TURF area" Marine Policy Volume 75, January 2017, Pages 41-52*
- *Similar to harvest reserves however the private sector acts as reserve manager. Reserves are managed by industry organizations such as waterman's associations or county oyster committees. In Maryland at least two county waterman's associations have leases that they manage. Bottom leases could be considered a type of TURF; though TURFs are typically controlled by a group of fishers. (Feedback #3)*

<u>Shell budgets</u> *– shell budgets that explicitly account for oyster habitat are an important tool to ensure that management practices do not lead to further degradation of the shell resource that supports oyster populations; a description of this tool should be included and its interactions with other tools (gear types, season limits, etc.) should be described. (Feedback #4)*

<u>Ecosystem-based management approaches</u> *– In addition to the approaches described, more managers are moving toward ecosystem-based approaches to management, which are especially important when considering habitat-building species like oysters;*

harvest reserve areas/area closures/gear type restrictions/season limits should all include ecosystem considerations as part of their management to ensure that oyster populations are able to serve their multiple functions for the fishery and the environment (ex: rotational harvest/harvest reserve areas that take the timetable of disturbance to the entire reef community into consideration; considers the evolution of the reef community following disturbance and the timeline of development of ecosystem services). (Feedback #4)

Management of the Recreational Fishery

- *Require a recreational license - report harvest and location*
- *Limited days of harvesting – Thursday, Friday, Saturday only with a 12 o'clock time restraint*
- *Implement a bushel tax, just like the commercial fisheries (Feedback #7)*

- *Should the MDE Shellfish Harvesting Area Designations be included someplace? (Feedback #12)*
- *Please add text to recognize the concern of spreading disease from high to low salinity areas using seed areas. (Feedback #12) Done –please see page 31.*

Increase the Surcharge *for each permit to be commensurate with whatever that permit holder removed the previous year (a few hundred dollars per head does not buy a lot of spat on shell on the bottom. (feedback #5)*

Status quo

- *I would like to add status quo to the tool box. In the late 90's we were at an all time low; the industry and oysters rebounded from that. Individuals left the fishery when it was not productive. They returned when the fishery rebounded in 2012. Over-harvesting is not the issue. Water quality continues to be an issue and climate change is altering the Bay as we know it. A downward trend in a cyclical population is a natural part of the fishery cycle and ecosystem. (Feedback #15)*
- *A status quo option and justification were presented as part of 'Feedback #14' on page 39.*

Feedback #14

The Sustainable Oyster Population and Fishery Act of 2016 directs the Maryland Department of Natural Resources to, "…identify management strategies to address the maintenance of a sustainable oyster population and fishery." The following paper provides justification for certain options that could be used to manage Maryland's public oyster fishery and oyster population.

Background

In the 2010-2011 oyster season, the State of Maryland implemented a reliable system for tracking the number of oyster bushels harvested by licensee through monthly harvest reports, buy tickets, and bushel taxes. Since 2010 the number of oystermen who:

1. *activated an oyster license by paying yearly surcharge ranged from 593 to 1,167;*
2. *reported oyster harvest ranged from 498 to 958; and*
3. *harvested more than 100 bushels per year ranged from 343 to 823.*

Harvesting greater than 100 bushels per year signifies a significant portion of a harvester's income is derived from Maryland's wild oyster fishery.

Approximate Oyster Harvest Income[1]

0 to 100 bushels	*101 to 500 bushels*	*501 to 1001 bushels*	*Over 1001 bushels*
$0 – $5,000	*$5,050 - $25,000*	*$25,000 - $50,050*	*$50,050 - $97,500*

[1] *Income estimates are based on a $50-bushel value.*

If an oysterman currently harvests greater than 100 bushels, a fishery-wide reduction of daily bushel limits, as the result of the implementation of

1. *an established Total Allowable Catch (TAC);*
2. *rotational harvesting; and/or*
3. *a combination of other methods*

would result in a significant reduction in that oysterman's yearly income and stands in sharp contrast to an oysterman who harvested less than 100 bushels. In fact, the resulting management action may increase the yearly harvest of those who reported harvesting less than 100 bushels and decrease those who reported harvesting greater than 100 bushels. To ensure oyster management decisions do not unfairly affect oystermen who genuinely rely on the wild oyster fishery, an oysterman's catch history must be considered when determining future harvest, regardless of the management tool(s) implemented.

If the State of Maryland establishes a new management plan for the wild oyster fishery, it is crucial that oysterman who are economically reliant on the oyster fishery are affected fairly and equitably.

Management Options

Option A: Status Quo- Output Controls, Input Controls, Habitat Modification, and Stock Enhancement

Maryland currently manages the public oyster fishery using output controls, input controls, habitat modification, and stock enhancement. These management tools include:

- *Establish minimum size limits to allow 50% of the oyster population to spawn;*
- *Restrict daily bushel limits to achieve desired target harvest rate;*
- *Restrict time limits to achieve desired target harvest rate;*
- *Restrict gear limits to restrict the type, characteristics, and operation of fishing gear;*
- *Restrict season limits to achieve a desired target harvest rate;*
- *Maintain entry limits to restrict the number of individuals that are granted the opportunity to harvest oysters commercially;*
- *Plant substrate, dredged, or reclaimed shell to enhance habitat,*
- *Plant wild and hatchery seed to replenish population levels;*
- *Designate harvest reserve areas to maximize harvest while maintaining a stable and healthy population;*
- *Open and close Public Shellfish Areas (PSFA) to restrict certain gear types and restrict access during the fall of Maryland's blue crab fishery;*
- *Establish rotational harvest to allow for oyster growth and abundance; and/or*
- *Designate 253,441 acres of Maryland's most productive oyster bottom as sanctuary to protect a spawning network.*

Justification for Status Quo

Commercial landings since 2012 have fluctuated from 350,000 to 425,000 bushel per year, withstanding the 2010 expansion of sanctuaries to protect half of the most productive oyster bars in the State of Maryland. This is a stark contrast to the 2002-2011 time series that produced approximately 25,000 to 190,000 bushel per year after the four-year epizootic, a period from which the public fishery rebounded. With an apparent increase in harvest levels, the establishment of a bay-wide sanctuary system, and conditions which generate low risk for disease, status quo is a viable option for Maryland's oyster management.

Option B: Individual Transferable Quota based on a Total Allowable Catch

Individual transferable quotas based on catch history and determined by a TAC are a fair and equitable management tool for Maryland's commercial oystermen. The precedent of using catch history to determine individual allocation in the State of Maryland was set through the Maryland striped bass fishery. In 2014, the Maryland striped bass fishery transitioned to an Individual Transferable Quota fishery. The striped bass fishery TAC in the state of Maryland was divided amongst current license holders using the following actions:

1. *Determine a historical timeframe[1] to establish individual catch history;*
2. *Divide 25%[2] of the Total Allowable Catch evenly amongst license holders;*
3. *Divide 75% of the Total Allowable Catch based on a fisherman's catch history[3] for a designated time series;*
4. *Average no reported harvest during any year in the time series as a zero[4] i.e. it negatively affects an individual's average; and*

5. *Exclude the averaging of a zero when the harvester did not own a license during any year in the time series, i.e. it does not negatively affect an individual's average.*

   [1] Recommend the 2010-2017 time series for which the State of Maryland implemented a reliable system for tracking the number of oyster bushels harvested by licensee through monthly harvest reports, buy tickets, and bushel taxes.
   [2] A 10% even divide in the oyster fishery may be more realistic as it was later established through the consolidation of the striped bass fishery that allocation was distributed to individuals who were not economically reliant on the striped bass fishery.
   [3] Catch history in the oyster fishery is determined through State mandated, monthly harvest reports and bushel taxes paid during the established time series.
   [4] In the oyster ITQ fishery, a year in which an individual did not pay an oyster surcharge would be averaged as a zero and would negatively affect an individual's average over the time series.

Justification for Individual Transferable Quotas Based on TAC
Benefits of using catch history to determine an individual's allocation of a TAC in Maryland's wild oyster fishery would include:

- *Avoiding unfair reductions on harvesters who sincerely depend on the wild fishery as a source of income, therefore, affecting all harvesters equitably;*
- *Allowing a harvester the flexibility to make sound business decisions through the ability to choose when to (1) market, (2) harvest, and (3) sell his product rather than (1) harvest, (2) market, and (3) sell his product;*
- *Reducing administrative responsibility through the distribution of a specific number of harvest tags that correlate to the individual's transferable quota; and*
- *Increasing harvesters' stewardship of the fishery through a shared sense of responsibility and fishery sustainability.*
- *Flexibility to work collaboratively through transferability with other ITQ fisherman.*

Option C: Catch History to Determine Bushel Limit Reductions Without TAC
Fishery-wide bushel limit reductions inside Maryland's current Public Shellfish Areas (PSFAs) would significantly and negatively impact oyster harvesters who currently depend on Maryland's wild oyster fishery. For example, if a Maryland harvester currently harvests 15 bushel per day and a limit of 8 bushel per day is established, that harvester's income could potentially be reduced by 50%. In contrast, limiting the fishery reliant harvester would increase access to the fishery for oystermen whose harvest is less than 8 bushel per day. In effect this would reallocate the current fishery to those who are not legitimately dependent on the wild fishery.

If daily bushel limit reductions without the establishment of a TAC are deemed an effective management tool, catch history can be used to determine individual, daily bushel limits fairly and equitably. This management tool is currently used in Maryland's blue crab fishery. 50, 300, *600, and 900 pot licenses have varying harvest bushel limits for sooks, female crabs. A similar management tool in the oyster fishery would consider setting separate oyster bushel limits for the following categories based on average harvest between the 2010-2017 time series:*

1. *paid oyster surcharge;*
2. *< 100 bushels per year;*
3. *> 101 < 500 bushels per year; and*
4. *> 501 bushels per year.*

Option D: Reduced Bushel Limits with Rotational Harvest within PSFAs- Not Supported

Bushel limit reductions inside Maryland's current PSFAs because of the implementation of rotational harvest would significantly impact oyster harvesters who currently depend on Maryland's wild fishery. For example, if a Maryland harvester currently harvests 15 bushel per day and a limit of 8 bushel per day is established on rotational grounds, that harvester's income could potentially be reduced by 50%. In contrast, limiting the fishery reliant harvester would increase access to the fishery for oystermen whose average harvest is less than 8 bushel per day. In effect this would reallocate the current fishery to those who are not legitimately dependent on the wild fishery. Furthermore, rotational harvest would focus efforts in a concentrated area thereby increasing the potential for:

- *localized depletion;*
- *reduced bushel limits as the result of concentrated efforts;*
- *restricted vessel lengths; and/or*
- *shortened harvest periods.*

Conclusion

As the State of Maryland moves forward with identifying management strategies to address the maintenance of a sustainable oyster population and fishery, it is critical that oysterman who are economically reliant on the oyster fishery are affected fairly and equitably.

The options and justifications presented in this paper provide insight into the potential impacts of oyster fishery management action. These options and justifications contained within are not submitted on behalf of an organization, committee, association, commission, or group.

Feedback #15

Thank you for the opportunity to provide input and feedback on the management strategies to address the maintenance of a sustainable oyster population and fishery.   As recreational anglers, the members of CCA Maryland fully recognize the importance of oysters as a keystone species in the Chesapeake Bay. The many ecosystem services that oyster provide directly impact the finfish species that the recreational angling community pursues, and therefore directly supports the economic engine that is recreational fishing in Maryland and beyond.

As the stock assessment is incorporated into the management of Maryland's oyster resource and fishery, it is extremely important that a focus goes beyond the fishery and simply sustaining wild harvest. Unfortunately, Maryland's wild oyster resource and fishery has gone through a number of boom and bust cycles over the last many decades, causing major economic and ecological swings, and failing to find true sustainability. Given recent declines in the population and fishery, it is of the utmost importance to the future of the Chesapeake Bay that efforts to improve the science based management of the oyster stocks succeed. The management toolbox has a number of tools that can lead to an ecological and economic balance for the oyster resource and fishery, but these tools must be fully understood by all stakeholders if new management techniques are expected to succeed.

Maryland's oyster fishery and resources have been burdened with over 150 years of conflict fueled by regional conflict, overharvest, disease, ecological and environmental impacts, regulatory and legal changes, and more. This has all lead to a divide amongst the many stakeholder groups, including divides within the oyster industry itself. This history increases the complexity of using a stock assessment and any toolbox to work towards a fishery that is truly sustainable both economically and ecologically, but does not make success unachievable.

Managing the stakeholders in a fishery can be as difficult as managing mother nature and our publicly held natural resources. Transparency and an opportunity for deliberative and structured conversations will be a key to truly utilizing any tools available, and building a process beyond the existing advisory commissions should be a priority.

As you are likely aware, a number of partners and a diverse group of stakeholders worked through an oyster focused consensus building workshop over the last 2+ years called Oyster Futures. As a participant in the process, I entered the first meeting with a good deal of skepticism, and concern to the true value that a discussion amongst such a diverse number of stakeholders could provide.   After the first meeting, it became very clear to me that having well trained team of facilitators and clear scientific modeling to lead the way for conversation was a very powerful way to work through the difficult and long-standing challenges associated with oyster management. As the process unfolded over a number of meetings, and the participants could quickly see that their questions and input was considered by other stakeholders, and built upon in scientific models to provide a long-term view for certain management strategies. The process required all participants to be willing to be open minded, and compromise.

One of the major causes of conflict amongst varying stakeholders related to the oyster fishery and resource is the tunnel vision that each stakeholder group naturally has. It is human nature to trust what you see and experience, but through a process like Oyster Futures, each stakeholder is provided an opportunity to better understand and accept varying viewpoints and experiences.

The scientific guidance provided at each meeting helped each participant understand the very complex components of the natural equation that drives our wild oyster population and fishery, and allowed a focus on policies and practices for the fishery that could compliment the known natural challenges. The final product of the Oyster Futures process has been presented to Maryland DNR at this time, and should be used as a complete package for possible management concepts in the Choptank Region, but the recommendations are not meant to be used in a piece meal fashion, nor should it be assumed that the concepts contained in the report can be replicated for use in other regions. A full review of the oyster futures process and the final report can be viewed here: https://oysterfutures.wordpress.com/

A consensus building process like Oyster Futures does come at a cost and will take a strong commitment from academics, stakeholders, and state leadership, but given the importance of the oyster both ecologically and economically to Maryland, but the return on consensus based management policies will reap many rewards well into the future. Without ecological stability, we cannot have the economic stability in any fishery in the region, and without an economic incentive for ecological health, it is extremely difficult to focus on solutions that provide a benefit to all.

CCA Maryland has always worked to support management practices that place the health of the resource first, and to focus on the concept that a healthy resource can provide the maximum benefit to the general public, and subsequently all stakeholders. It is with this idea in mind that I provide the strong recommendation that a consensus stakeholder process like Oyster Futures be the first step that both DNR, the Maryland General Assembly, and all interested stakeholders agree to work within, as the new stock assessment and management tools are considered for our wild oyster resource and fishery.

11 Independent Peer Review

As mandated by the guiding legislation, all analytical approaches involved in the stock assessment model and in the development of biological reference points were submitted to an independent peer review. The full peer review report is attached as Appendix I to this report.

The peer review was conducted with the logistical support of the Atlantic States Marine Fisheries Commission and was funded through an EPA Chesapeake Bay Implementation Grant. The panelists were selected via an objective process in which the Maryland Department of Natural resources submitted a request to the director of the Northeast Fisheries Science Center (NOAA, National Marine Fisheries Service) Population Dynamics Branch to provide a list of stock assessment scientists within the continental United States who would be qualified to review the oyster assessment.

The review was conducted in Annapolis, Maryland from August 27 through August 29, 2018 following Terms of Reference reviewed by the Maryland Oyster Advisory Commission.

Three panelists were selected from the list based on their experience, availability and willingness to do the work:

Dr. Paul Rago (Panel Chair)

Paul Rago is a member of the Scientific and Statistical Committee of the Mid-Atlantic Fishery Management Council (MAFMC). Prior to his retirement in 2016, he was Chief of the Population Dynamics Branch of the Northeast Fisheries Science Center of the National Marine Fisheries Service (NMFS) in Woods Hole where he led over 40 fishery scientists to assess the status of finfish and shellfish stocks in the Northeast U.S. His stock assessment experience includes nearly all the stocks in the Northeast U.S. and several in other countries. Research interests include quantitative analyses of populations, graphical methods for exploratory data analysis, experimental estimation of gear efficiency, design of bycatch monitoring programs, and cooperative research programs with industry. With the U.S. Fish and Wildlife Service (1978-1992), Dr. Rago served as research coordinator of the Emergency Striped Bass Study and a variety of Atlantic salmon studies. Dr. Rago received his PhD from the University of Michigan.

Dr. Daniel Hennen

Dan Hennen is a Research Operations Analyst for the Population Dynamics Branch of the Northeast Fishery Science Center in Woods Hole, where he has worked since 2009. He serves as lead analyst for stock assessments of Atlantic surfclam, ocean quahog and Atlantic halibut. Dr. Hennen was Research Biometrician for the Alaska Sea Life Center in Seward Alaska from 2004-2009. His research interests include, population simulation, automation, parameter estimation, survey analysis, and design. Hennen received his PhD from Montana State University in 2004.

Dr. Daphne Munroe

Daphne Munroe is an Associate Professor at Rutgers University in the Department of Marine and Coastal Science, Haskin Shellfish Research Laboratory. Dr. Munroe has a PhD from the University of British Columbia where she studied ecological interactions of intertidal clam farming. She has over 15 years of experience doing research in shellfish ecology, focusing on shellfish fisheries and aquaculture and has participated in federal and state assessments for clams and oysters.

11.1 Primary Conclusions

Overall, the Review Panel concluded that all Terms of Reference had been met. The Review Panel supported the conclusions of the assessment and agreed that it had fully utilized the available data at an appropriate temporal and spatial resolution. The modeling approach is innovative and the results can serve as an adequate basis for management decisions. All stock assessments, however, represent a compromise between the ideal and the realized. Changes in data quality over time, lack of sufficient spatial resolution in the characterization of removals, significant but variable impacts of disease, observation error in monitoring programs, habitat loss, and trends in ecosystem conditions all influence the oyster assessment. It is the opinion of the Review Panel that this assessment deals with these compromises in a rigorous and scientifically credible way.

11.2 Review Process

The review process comprised several conference calls prior to the onsite review, a three-day meeting attended by the Assessment Team which included staff from Maryland DNR and from UMCES, and a follow up writing period by the Review Panel. A complete list of the participants at the meeting and their roles may be found in the Appendix 3 of the full peer review report (Appendix 1). The Review Panel's report was submitted to Maryland DNR for review but only factual errors were revised. No changes were made to the opinions or conclusions of the Review Panel. Any factual errors remaining in the report are the responsibility of the Review Panel.

11.3 Data Considered

A thorough review of all primary sources of data for oysters in Maryland was conducted. These included both fishery-dependent and fishery-independent data as far back as 1889. Not surprisingly, the utility of these time series for stock assessment and modeling purposes varied over time. After extensive analyses, the stock assessments were based on 36 spatially discrete units based on removals recorded at the level of NOAA codes. Oysters are harvested from well-known beds, defined over a century ago by Yates. One or more oyster beds occur within the NOAA code subareas but official landings could not be resolved to a finer scale. Conversely, fishery independent time series of relative abundance which might have been disaggregated to a finer spatial scale, could be combined in a scientifically credible way for consistent measures of trend. Based on these considerations, the assessment period is restricted to 1999 onward.

11.4 Modeling Approaches

In contrast to most stock assessments, the natural mortality rate of oysters is both variable and high relative to fishing mortality. Diseases (MSX and Dermo) vary in intensity over time and along salinity gradients within the Bay (Bushek et al., 2012). Consistent long-term monitoring of oyster boxes (i.e., dead oysters whose shells remain hinged) allowed for the independent estimation of annual natural mortality rates apart from the stage-based model. Three separate methods were used, allowing for valuable insights into model performance.

Oyster growth varies seasonally and annually, making age determination difficult (Kraeuter et al., 2007). The assessment relies on a novel stage-based population model that also includes the dynamics of habitat. Inclusion of habitat allows for prediction of increases due to shell supplementation programs, but otherwise habitat is assumed to decline based on contemporary analyses of Bay-wide habitat degradation. An equally novel model for determination of fishing mortality reference points is developed. It also models habitat changes but in a conceptually different manner (i.e., density dependent dynamics). In contrast to the population model, the habitat state variable in the reference point model can increase in response to an intrinsic rate of growth as well as habitat supplementation. The Panel expressed some reservations about these differing conceptual bases and the use of stage-based model results as input to the biological reference point model. At the current level of oyster abundance, these concerns are considered minor but future assessments should attempt to reconcile these differences. Moreover, reliance on external parameters derived from the literature and use of strong penalty functions in the estimation methods should be reviewed in future assessments.

Restriction of the assessment period to 1999 onward precludes the ability to estimate historical abundance levels, say in the late 1890's. Any such exercise is unlikely to yield precise estimates. Moreover, it can be argued that the environmental and ecological conditions that obtained nearly 150 years ago are unlikely in 2018 onward and are therefore not useful as biomass targets. Despite these limitations and differences in size limits over time, it is relevant to note that the estimates of market oyster abundance of about 300 million market oysters in 2018 is less than 10% of the quantity ***harvested*** annually before 1900.

The minimum abundance estimated between 1999 and 2017 was applied as the abundance threshold for each NOAA code. This was based on the assumption that if abundances as low as those observed previously have not so far caused a population crash, they should be sufficient to prevent a crash in the future. This approach is often used in European assessments where the lowest observed abundance provides an estimate of the threshold for recruitment failure. Recruitment failure per se is unlikely in oysters but the Review Panel agreed that this threshold criterion appropriately balanced the information content of the assessment with a longer term perspective on abundance. The Review Panel concluded that a determination of the carrying capacity of Chesapeake Bay under prevailing environmental conditions (particularly disease prevalence) is beyond the scope of existing data sources and scientific understanding.

Terms of Reference 4 and 5 (see Appendix 2) were particularly challenging and an exceptional job was done of assessing the efficacy of various management policies implemented by the State. Where data allow, the quantitative impacts of these measures are explicitly incorporated into the model's interpretation of habitat changes, exploitation estimation, and reference point determination. The MD DNR has in place a number of long term studies that may ultimately allow for quantification of the utility of these measures and improvements in approaches. Rigorous monitoring will be essential. Well designed and monitored management experiments within NOAA code areas may prove useful for improving management interventions. The Review Panel recommended that sanctuary and habitat plantings, and aquaculture operations should not be considered a part of the standing stock of the fishery, nor part of the reproductive capacity of the fishery. Doing so will overestimate the spawning potential, and the contributions of sanctuaries, habitat plantings and aquaculture are as yet unclear and likely vary greatly by source.

11.5 Research Recommendations

The Review Panel endorsed the recommendations laid out in the assessment. In addition, the Panel's recommendations include:

1. Implement an annual dockside monitoring program to establish the number of small oysters being caught per bushel, and to estimate the size and number of oysters per bushel for each NOAA code over the course of a fishing season.
2. Conduct experiments to estimate of dredge efficiency for the survey.
3. Compare existing independent experimental estimates by gear type of abundance within some NOAA codes.
4. Consider re-running the Bayesian model using data from the patent tong survey. Results could be compared to the existing estimates of mortality from the Bayesian model that uses the fall dredge survey.
5. Conduct a detailed examination of trends from survey based disease incidence and rates of natural mortality. Any evidence of disease resistance or changes in virulence should be thoroughly examined.
6. Examine potential retrospective patterns in terminal year estimates of biomass and fishing mortality to address uncertainty concerns for management.

7. Review the performance of the assessment and reference point models by examining likelihood profiles for key parameters and the influence of penalty functions on parameter estimates. Further simulation testing would be valuable.

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13 Tables

Table 1. Oyster harvest from the Maryland portion of Chesapeake Bay beginning with the 1889-1890 season through the 2017-2018 season.

Season	Bushels Harvested	Season	Bushels Harvested	Season	Bushels Harvested
1889-90	10,450,087	1945-46	2,322,185	1983-84	1,076,884
1890-91	9,945,058	1946-47	2,157,838	1984-85	1,142,493
1891-92	11,632,730	1947-48	2,027,381	1985-86	1,557,091
1892-93	10,142,500	1948-49	2,702,814	1986-87	976,162
1897-98	7,254,934	1949-50	2,495,787	1987-88	363,259
1900-01	5,685,561	1950-51	2,170,556	1988-89	397,180
1904-05	4,500,000	1951-52	2,339,976	1989-90	413,113
1906-07	6,232,000	1952-53	2,642,147	1990-91	416,720
1910-11	3,500,000	1953-54	2,129,115	1991-92	318,128
1916-17	4,120,819	1954-55	2,878,755	1992-93	123,618
1917-18	2,461,603	1955-56	2,799,788	1993-94	78,817
1918-19	3,743,638	1956-57	2,259,882	1994-95	164,673
1919-20	4,592,001	1957-58	2,190,074	1995-96	193,629
1920-21	4,959,962	1958-59	1,968,894	1996-97	171,630
1921-22	4,435,186	1959-60	2,114,899	1997-98	278,292
1922-23	3,687,489	1960-61	1,635,123	1998-99	413,010
1923-24	3,440,810	1961-62	1,495,235	1999-00	345,850
1924-25	2,787,047	1962-63	1,243,498	2000-01	316,630
1925-26	2,367,122	1963-64	1,383,617	2001-02	109,175
1926-27	2,571,540	1964-65	1,340,177	2002-03	47,141
1927-28	2,260,898	1965-66	1,645,144	2003-04	19.028
1928-29	1,993,591	1966-67	3,014,670	2004-05	57,558
1929-30	1,839,772	1967-68	3,000,272	2005-06	130,323
1930-31	1,775,738	1968-69	2,509,701	2006-07	154,236
1931-32	2,041,043	1969-70	2,533,275	2007-08	66,807
1932-33	1,626,214	1970-71	2,395,528	2008-09	87,358
1933-34	1,835,364	1971-72	2,900,547	2009-10	114,236
1934-35	2,100,233	1972-73	2,925,236	2010-11	103,608
1935-36	2,407,693	1973-74	2,845,924	2011-12	101,398
1936-37	3,081,063	1974-75	2,559,112	2012-13	330,064
1937-38	3,245,816	1975-76	2,449,440	2013-14	417,784
1938-39	3,403,549	1976-77	1,891,614	2014-15	375,244
1939-40	3,129,403	1977-78	2,311,434	2015-16	380,163
1940-41	3,430,269	1978-79	2,197,457	2016-17	213,397
1941-42	2,792,069	1979-80	2,111,080	2017-18*	179,779
1942-43	2,328,541	1980-81	2,532,321		
1943-44	2,413,349	1981-82	2,308,619	*preliminary	

Table 2. Estimated market abundance in millions (1999 – 2000) in each NOAA code relative to the threshold abundance reference point (N_{ref}). 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 1999-2000 in each NOAA code relative to the threshold (U_{crash}) and target (U_{msy}) 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 1999-2000 in each NOAA code relative to the threshold (U_{crash}) and target (U_{msy}) 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

14 Figures

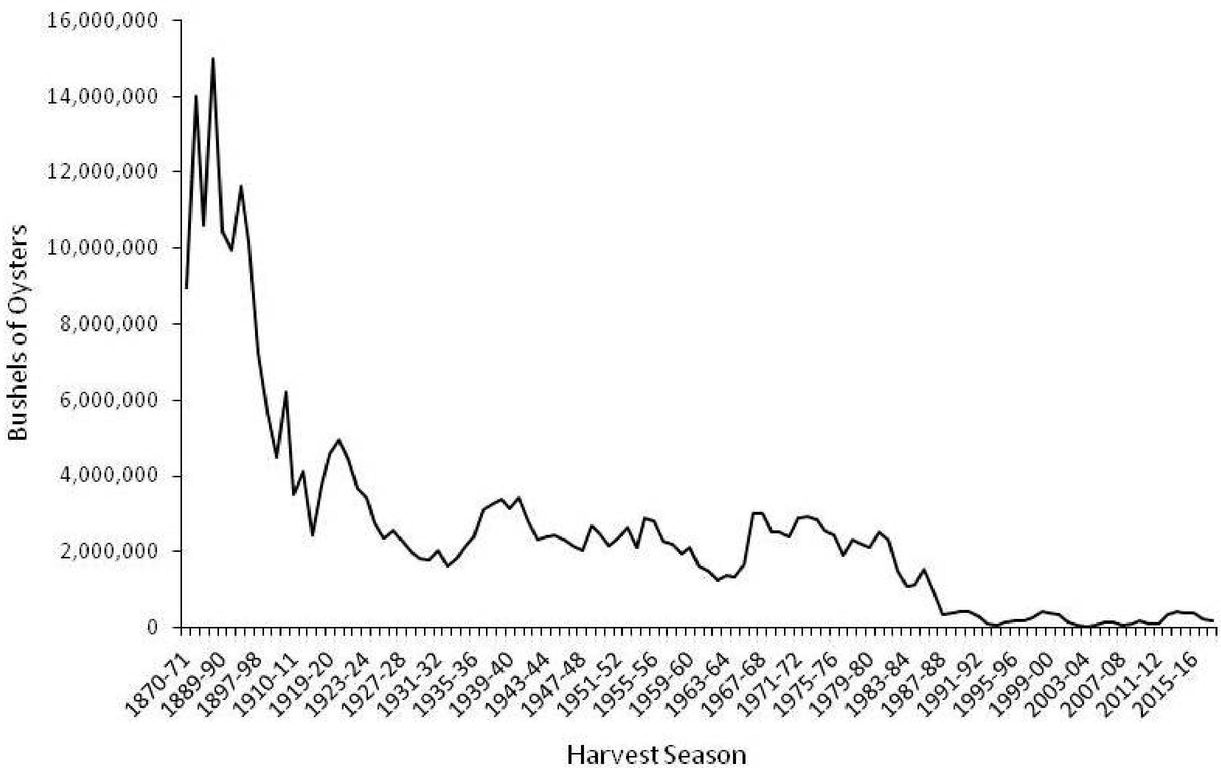

Figure 1. The harvest of oysters (bushels) from the Maryland portion of Chesapeake Bay from the 1870-71 through the 2017-2018 seasons.

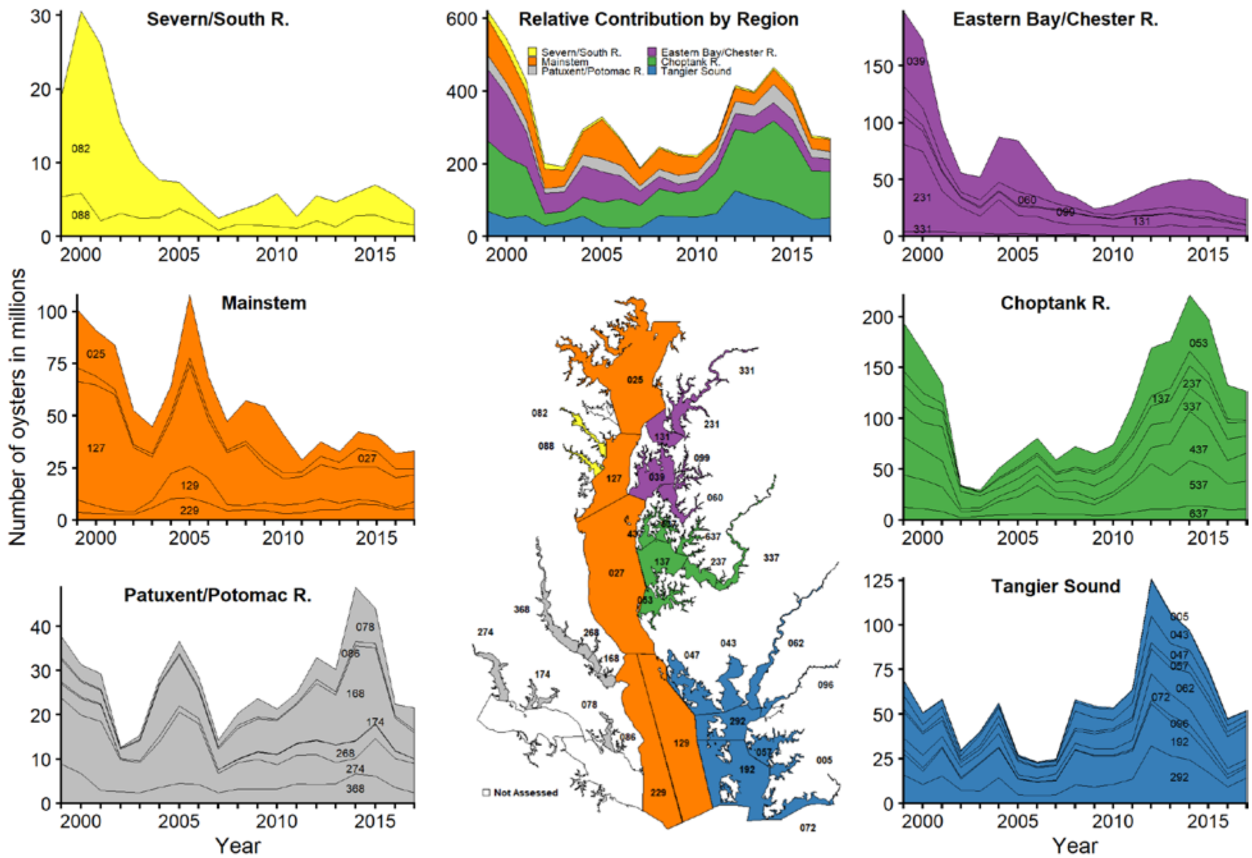

Figure 2. Estimated number of market size oysters (in millions) by region, during 1999-2017. Trends in abundance are presented by NOAA code within six regions. The regions are displayed on the map as well as the NOAA code locations.

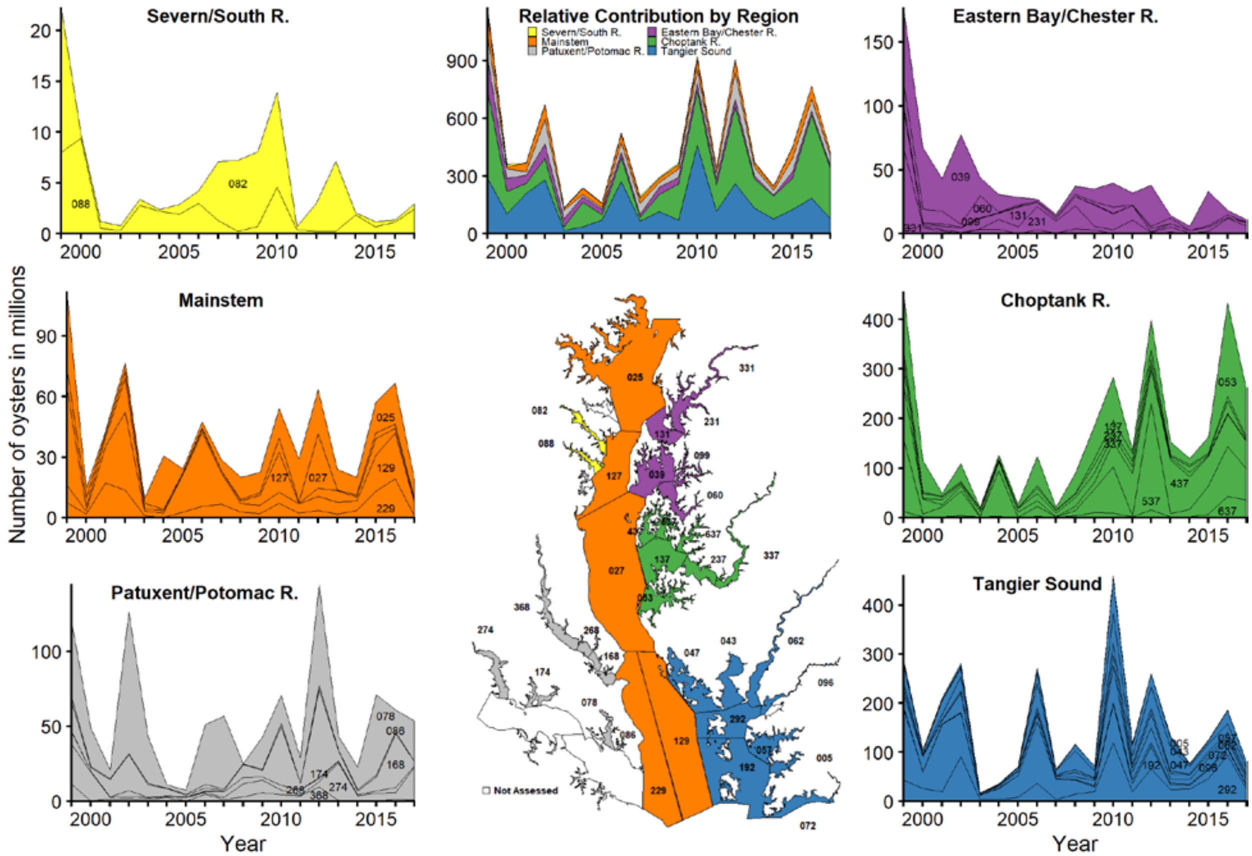

Figure 3. Estimated number of oyster spat (in millions) by region (i.e., spat), during 1999-2017. Trends in abundance are presented by NOAA code within six regions. The regions are displayed on the map as well as the NOAA code locations.

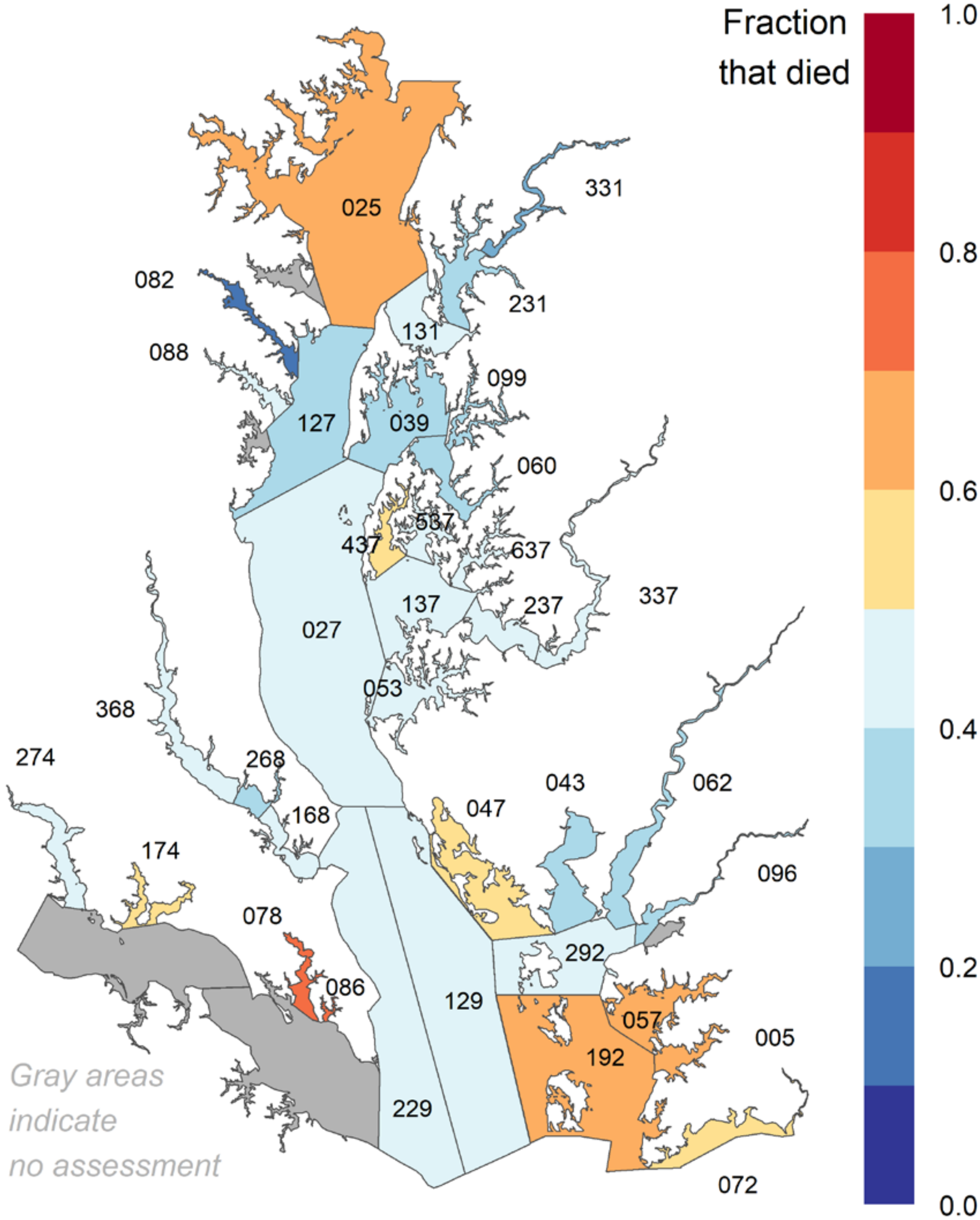

Figure 4. Estimated natural mortality rates (including disease) by NOAA code during 2000.

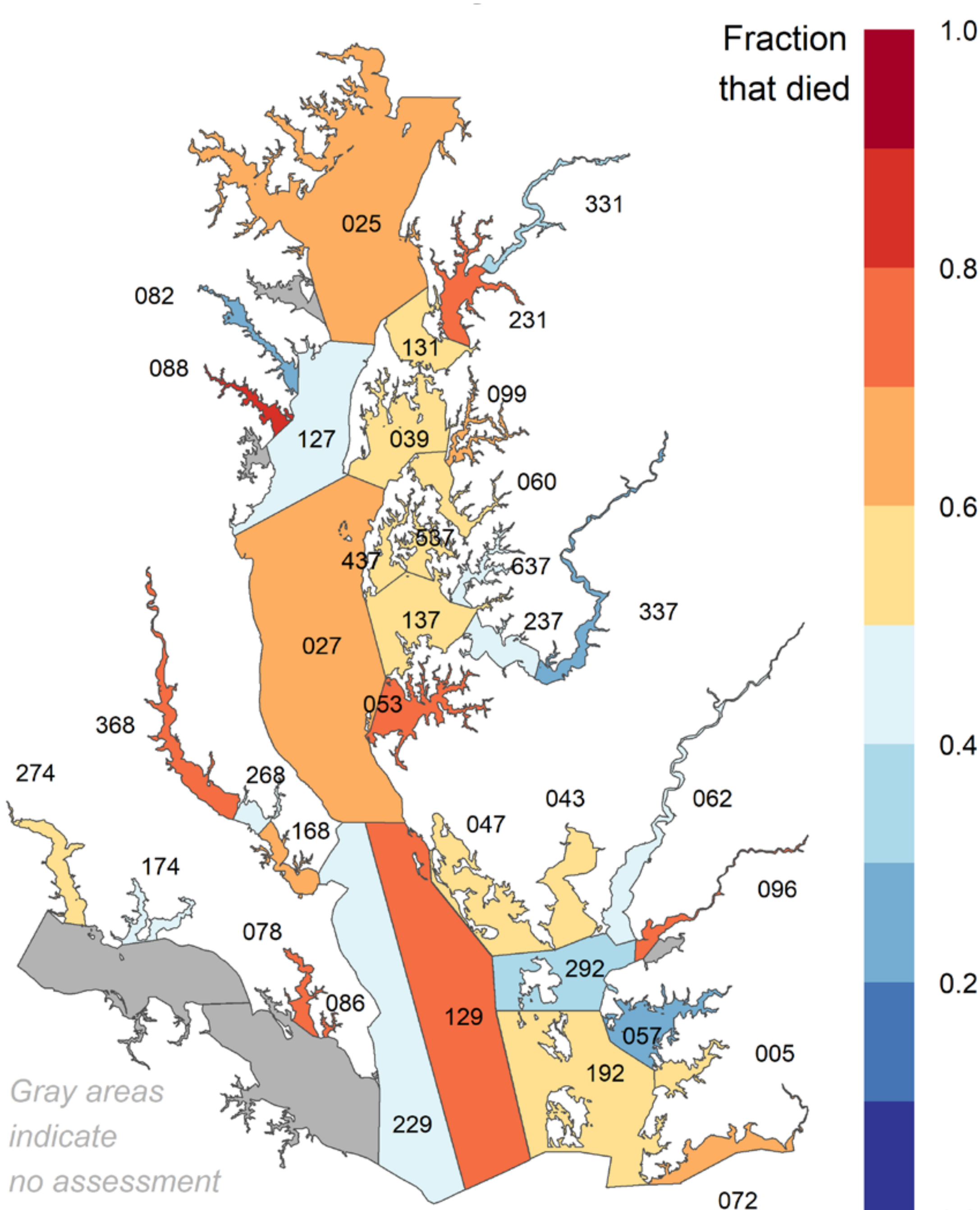

Figure 5. Estimated natural mortality rates (including disease) by NOAA code during 2001.

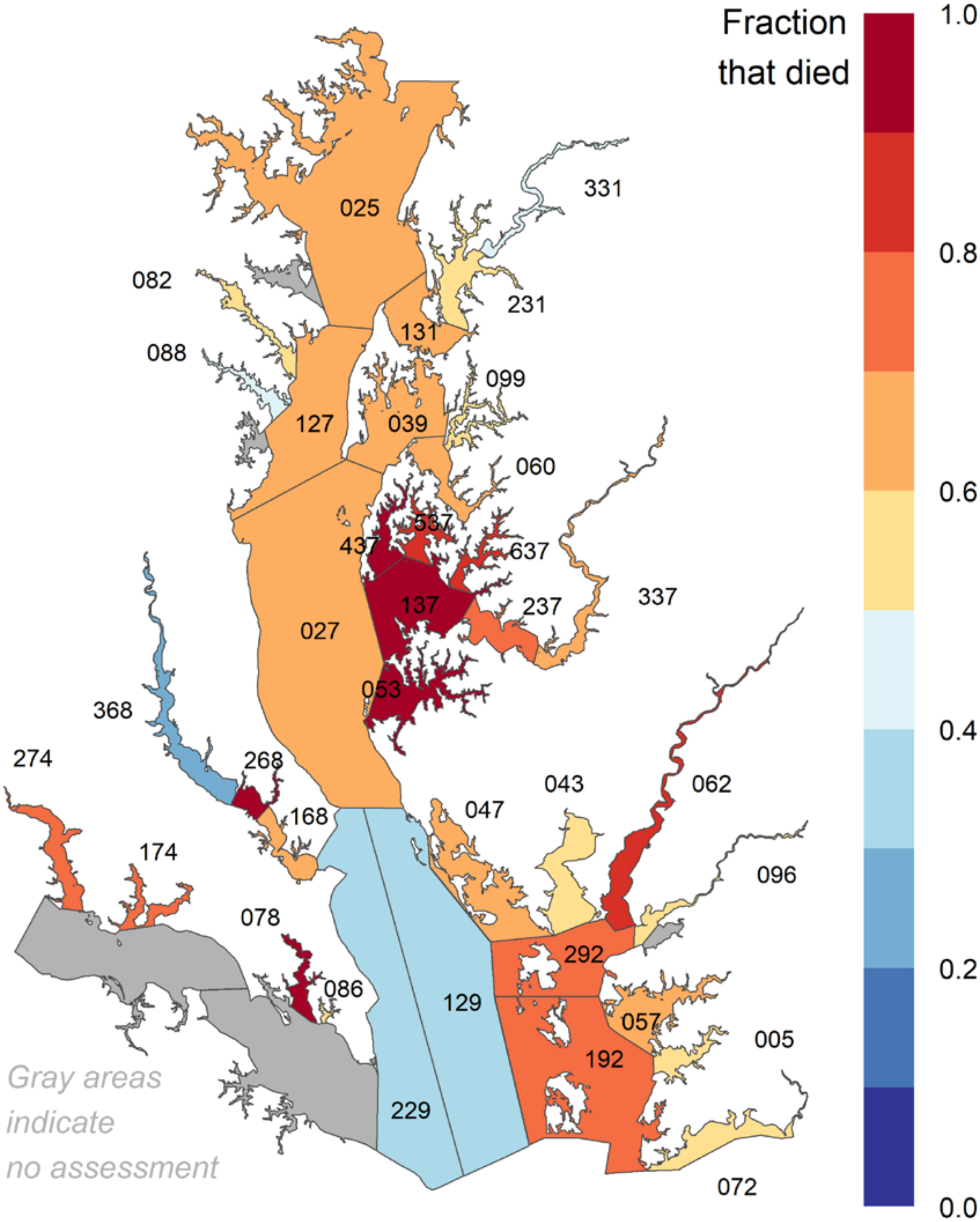

Figure 6. Estimated natural mortality rates (including disease) by NOAA code during 2002.

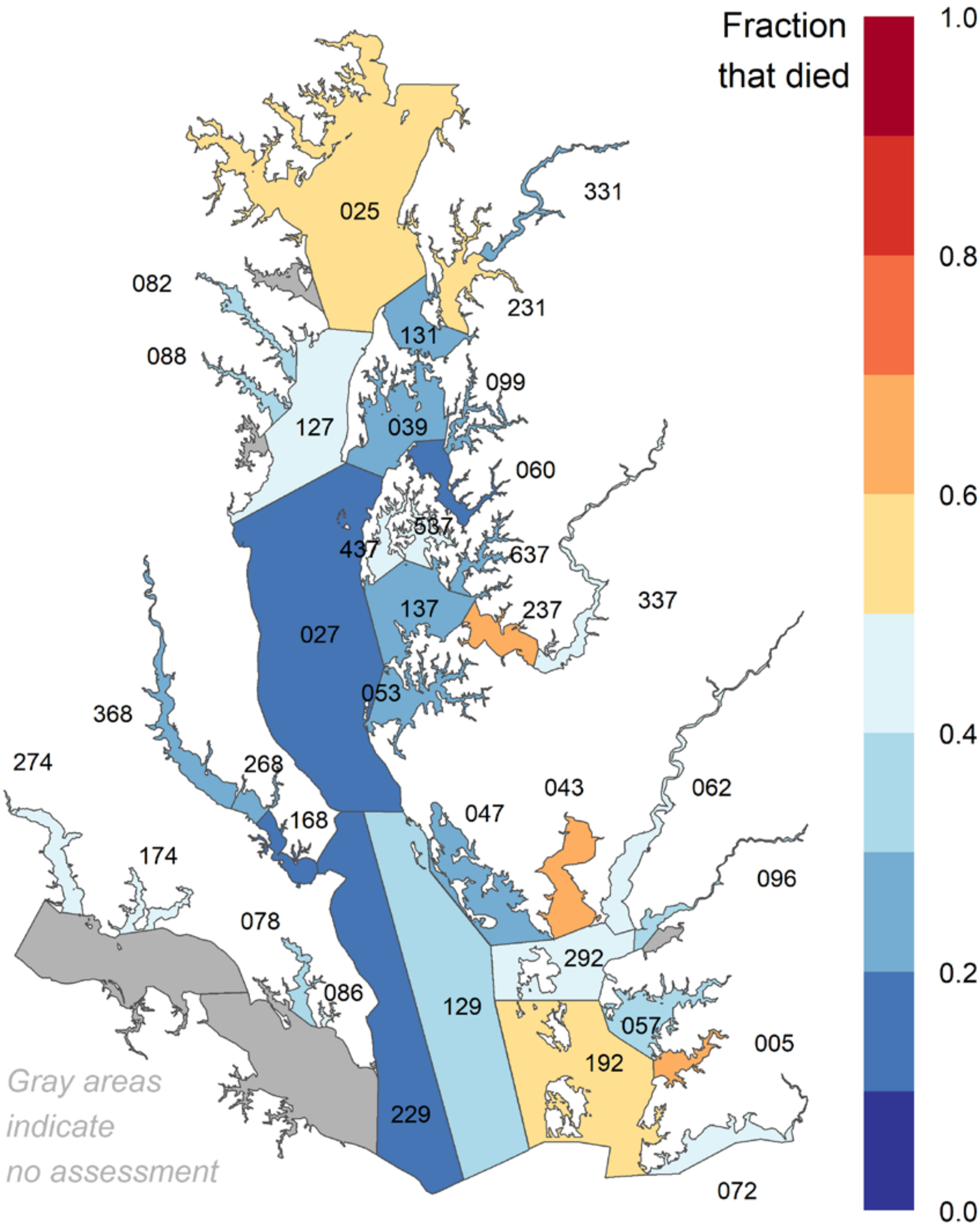

Figure 7. Estimated natural mortality rates (including disease) by NOAA code during 2003.

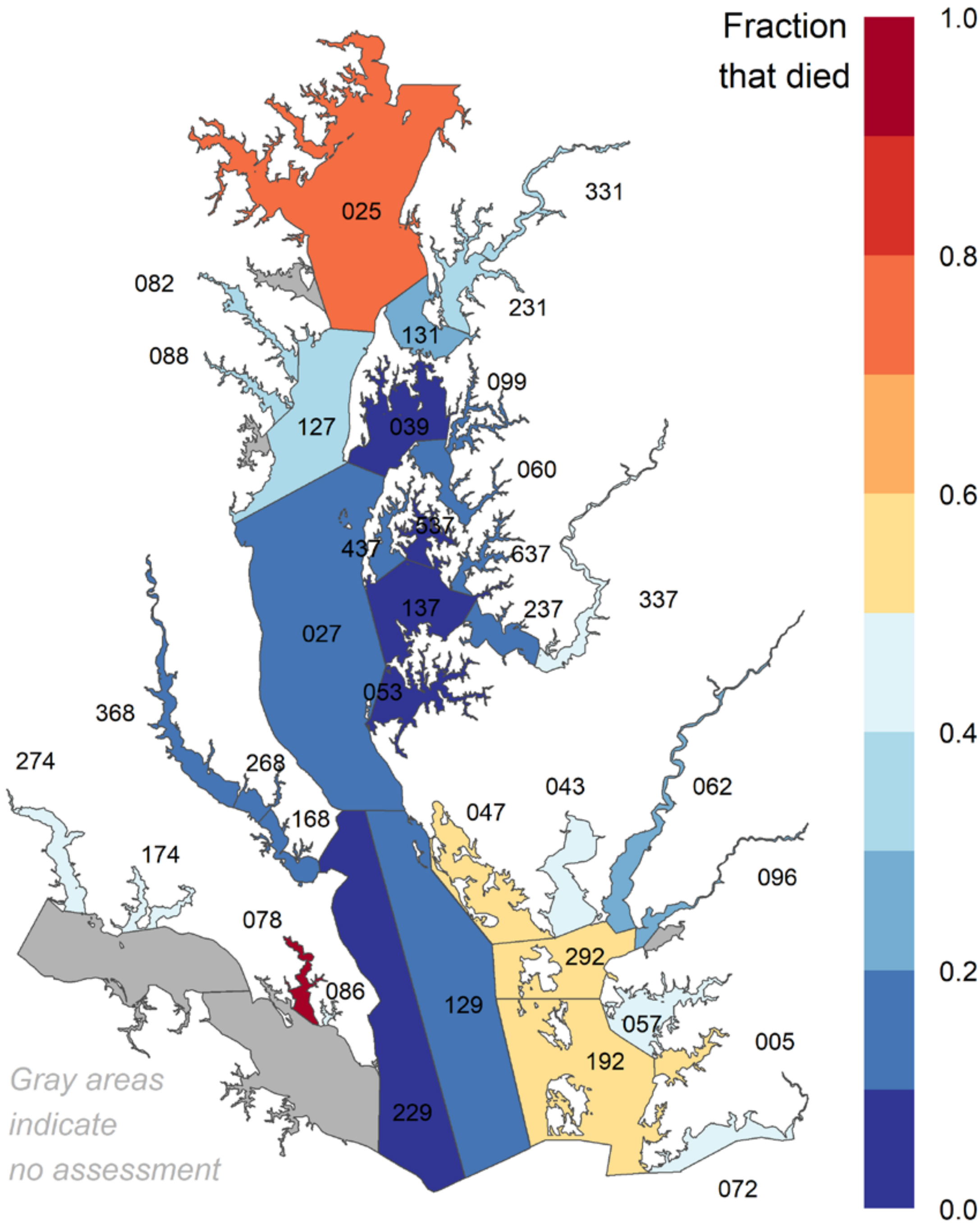

Figure 8. Estimated natural mortality rates (including disease) by NOAA code during 2004.

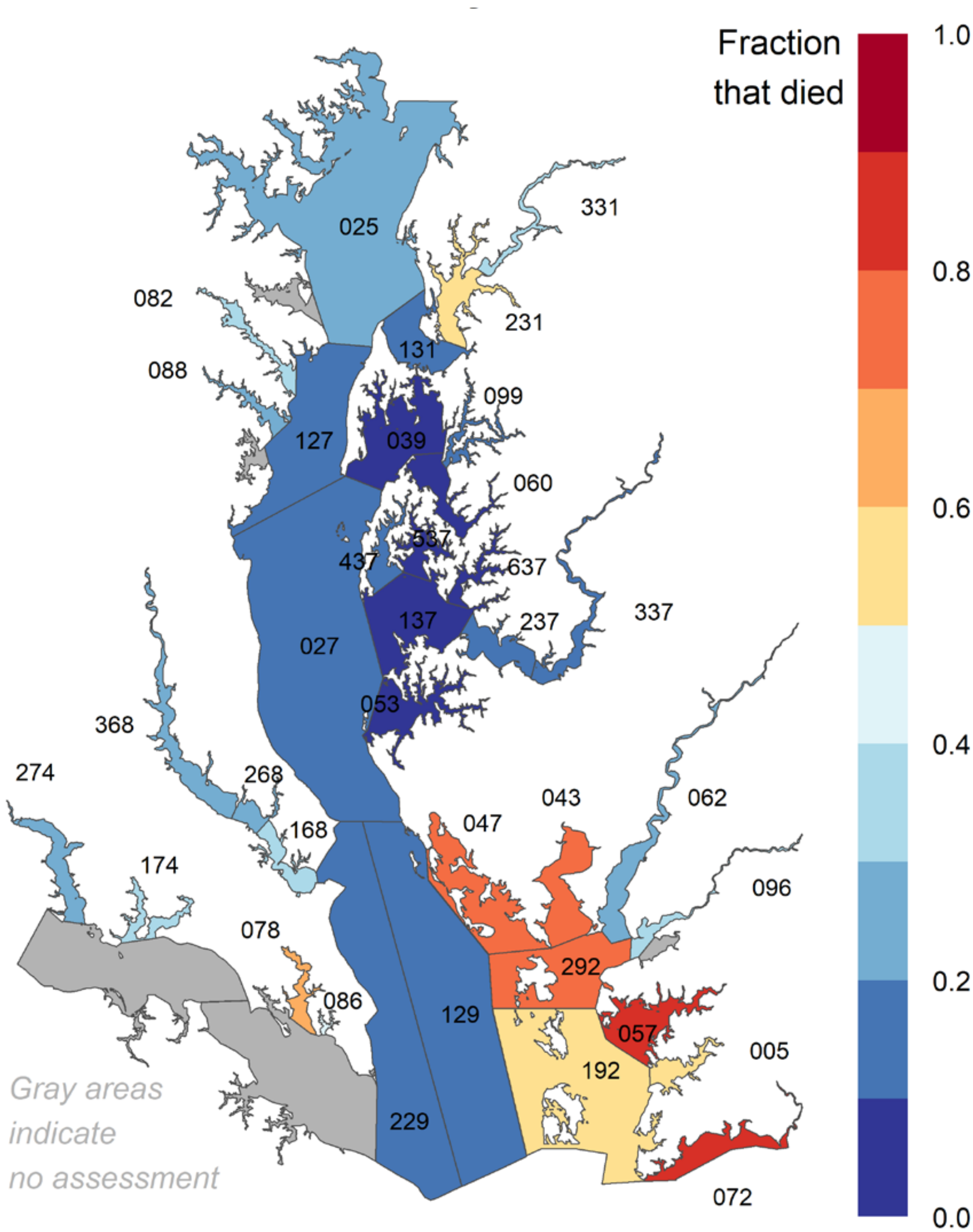

Figure 9. Estimated natural mortality rates (including disease) by NOAA code during 2005.

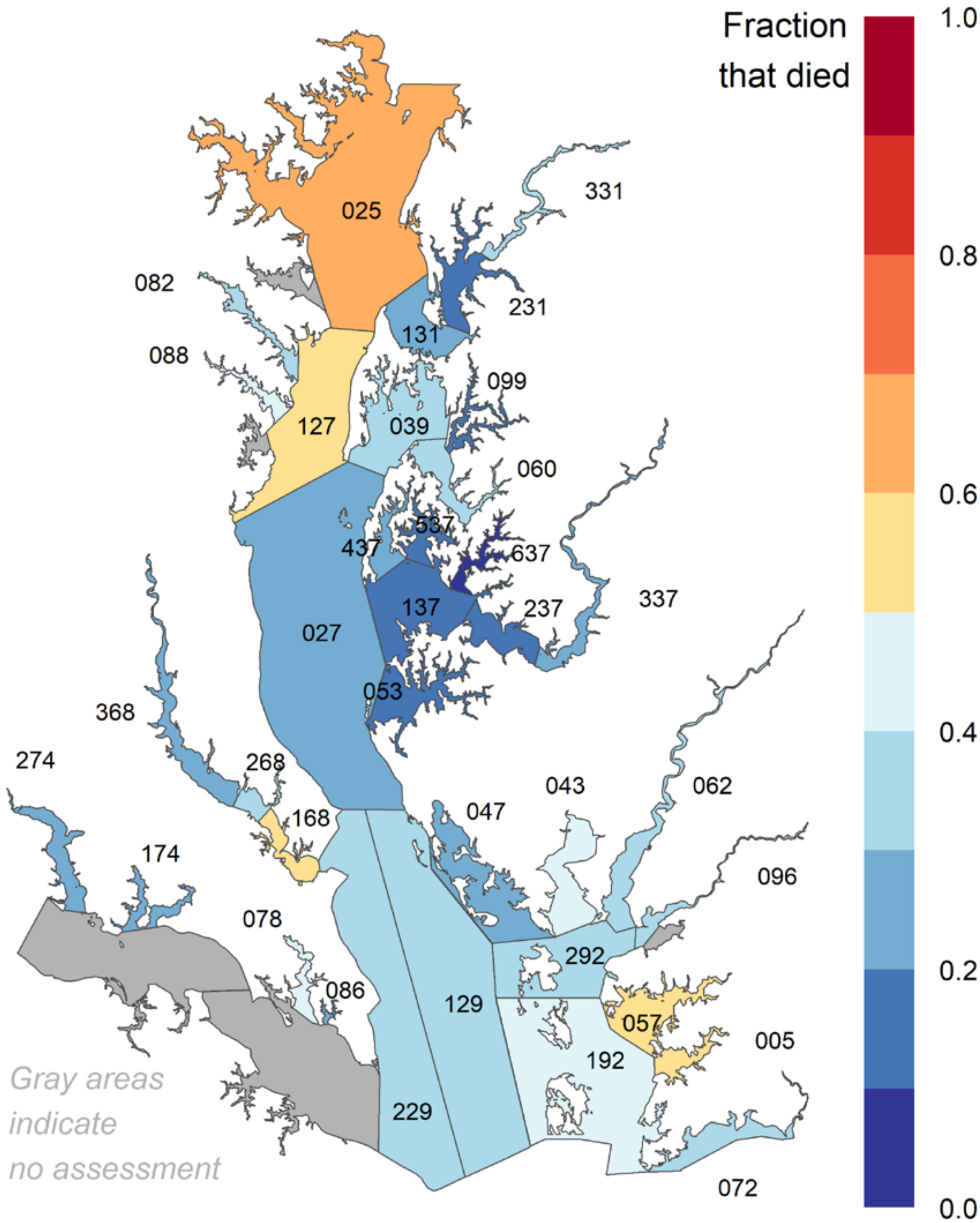

Figure 10. Estimated natural mortality rates (including disease) by NOAA code during 2006.

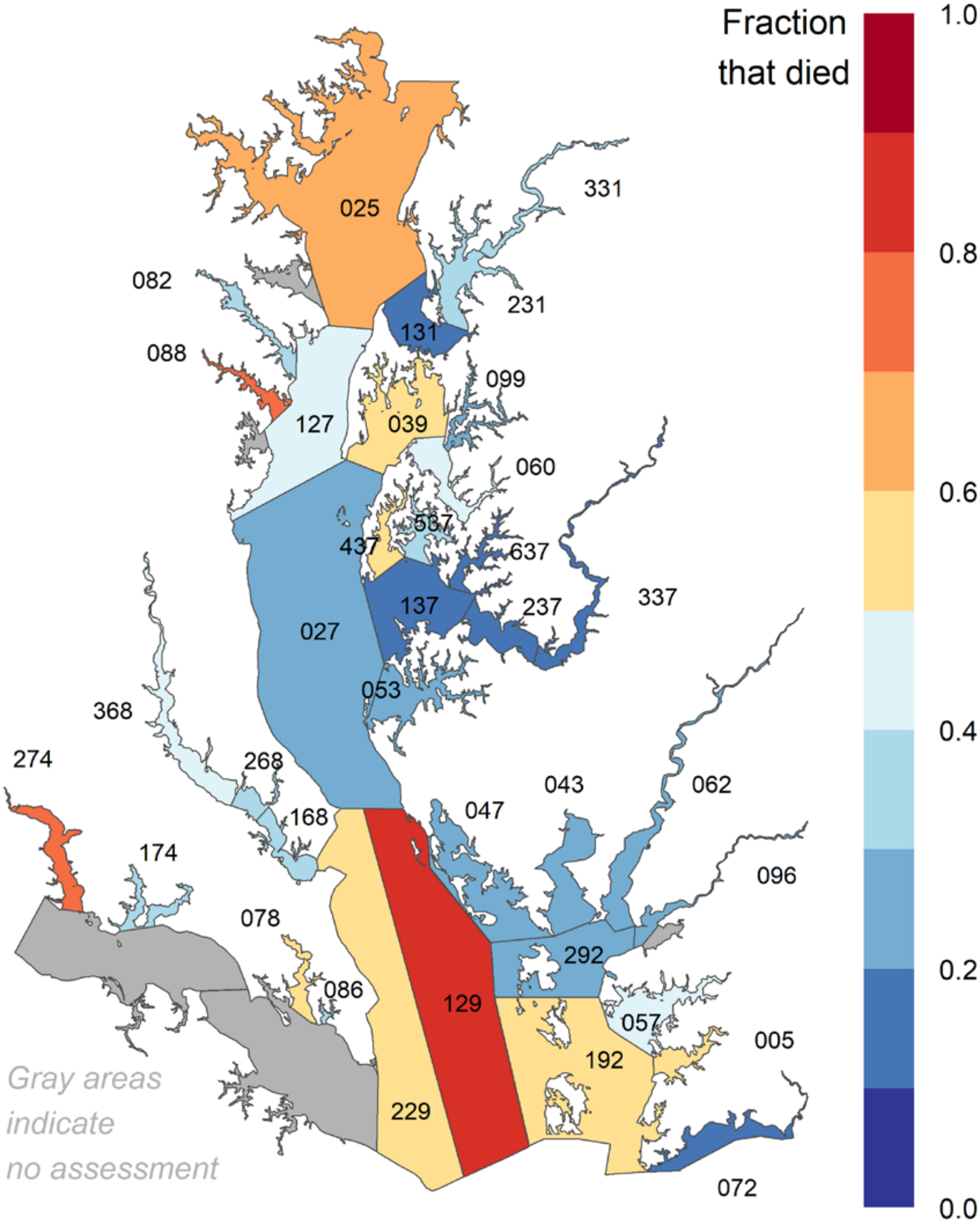

Figure 11. Estimated natural mortality rates (including disease) by NOAA code during 2007.

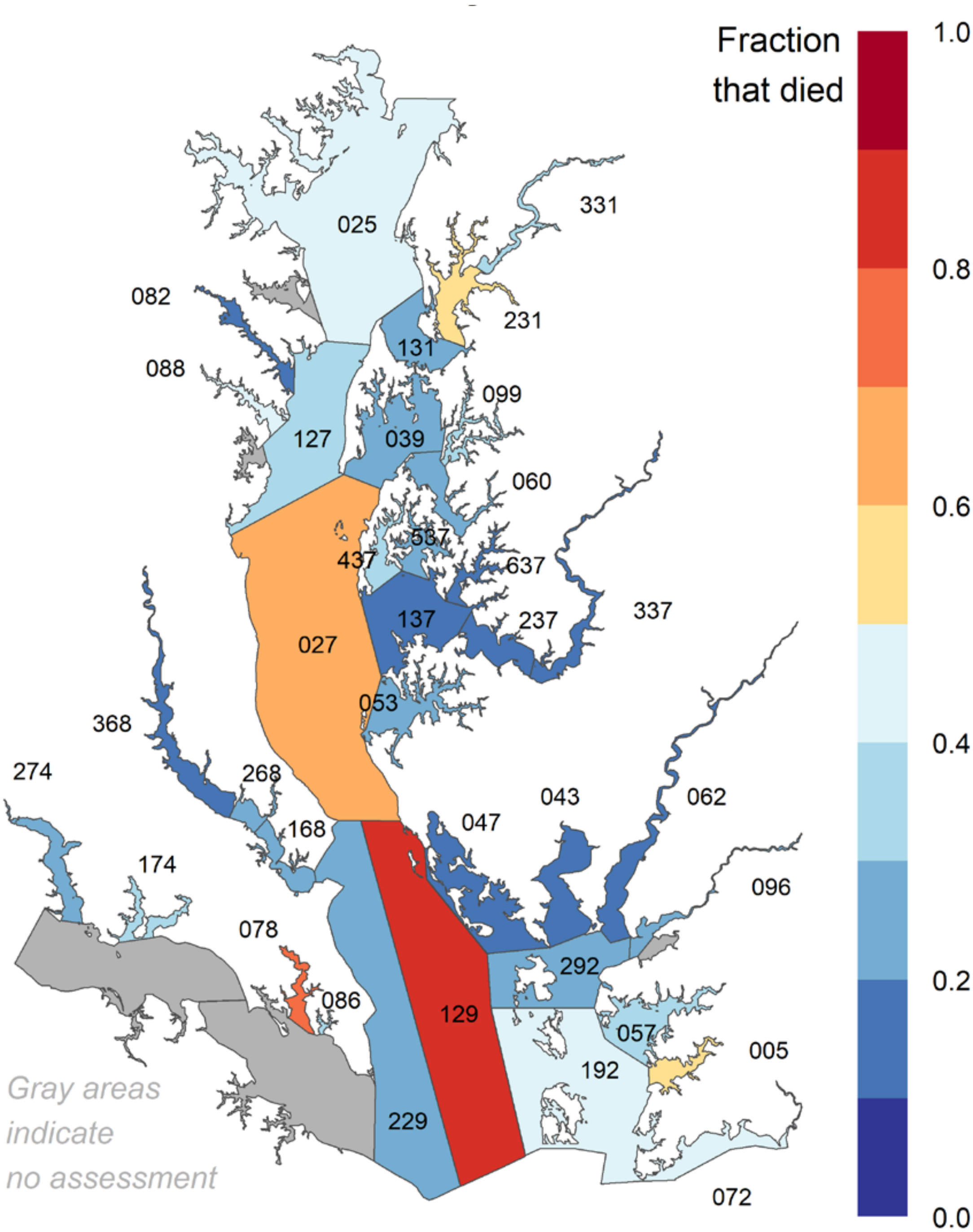

Figure 12. Estimated natural mortality rates (including disease) by NOAA code during 2008.

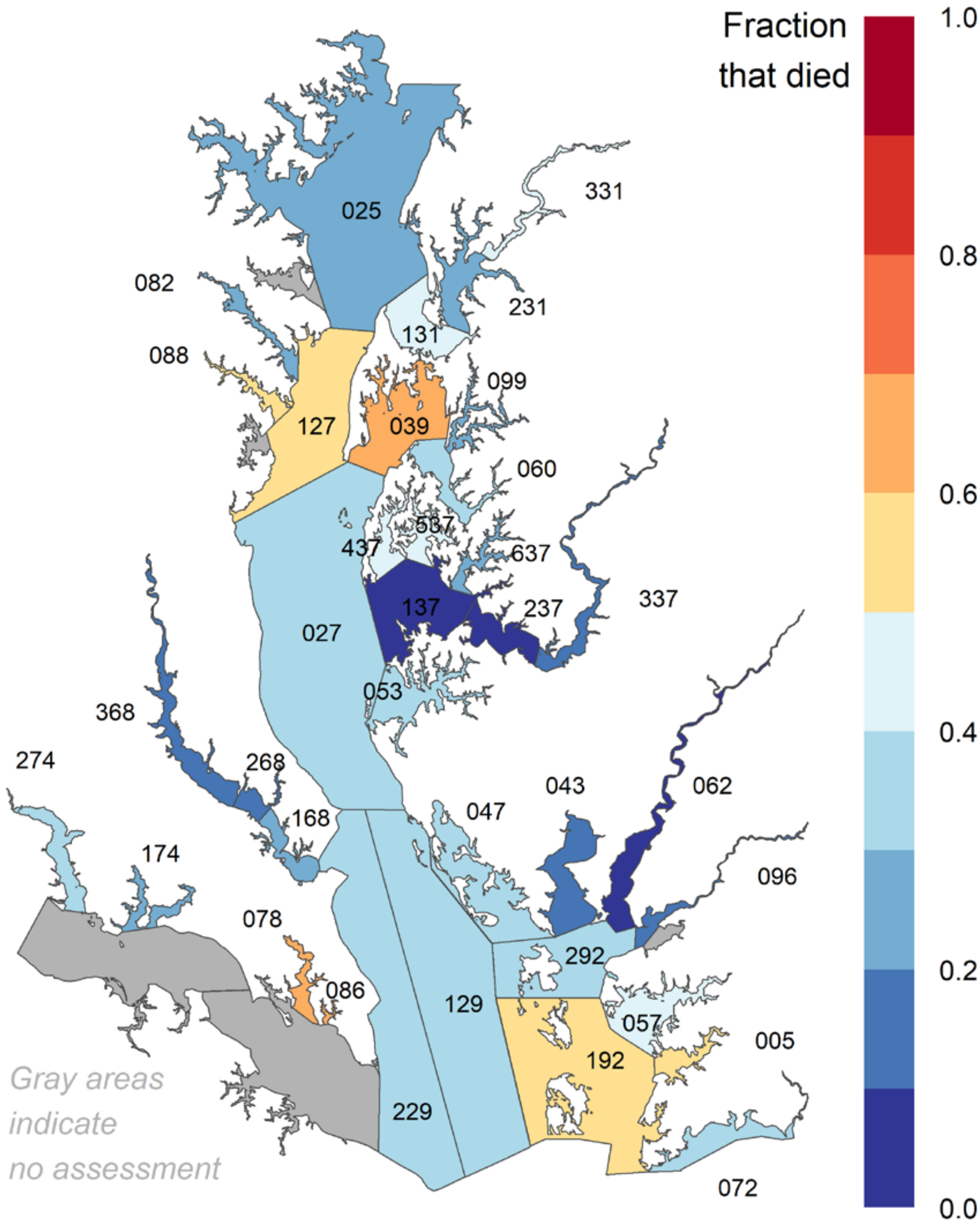

Figure 13. Estimated natural mortality rates (including disease) by NOAA code during 2009.

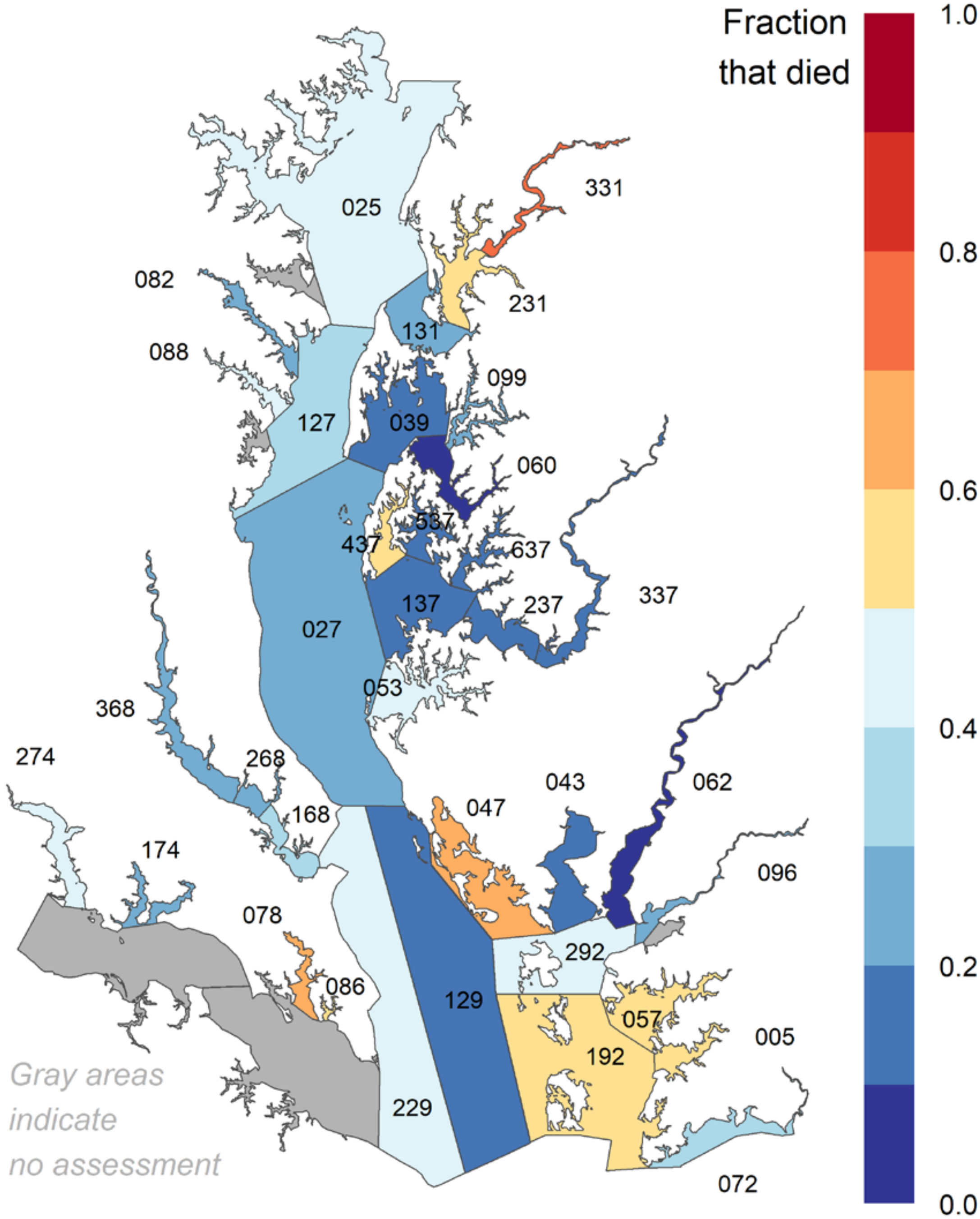

Figure 14. Estimated natural mortality rates (including disease) by NOAA code during 2010.

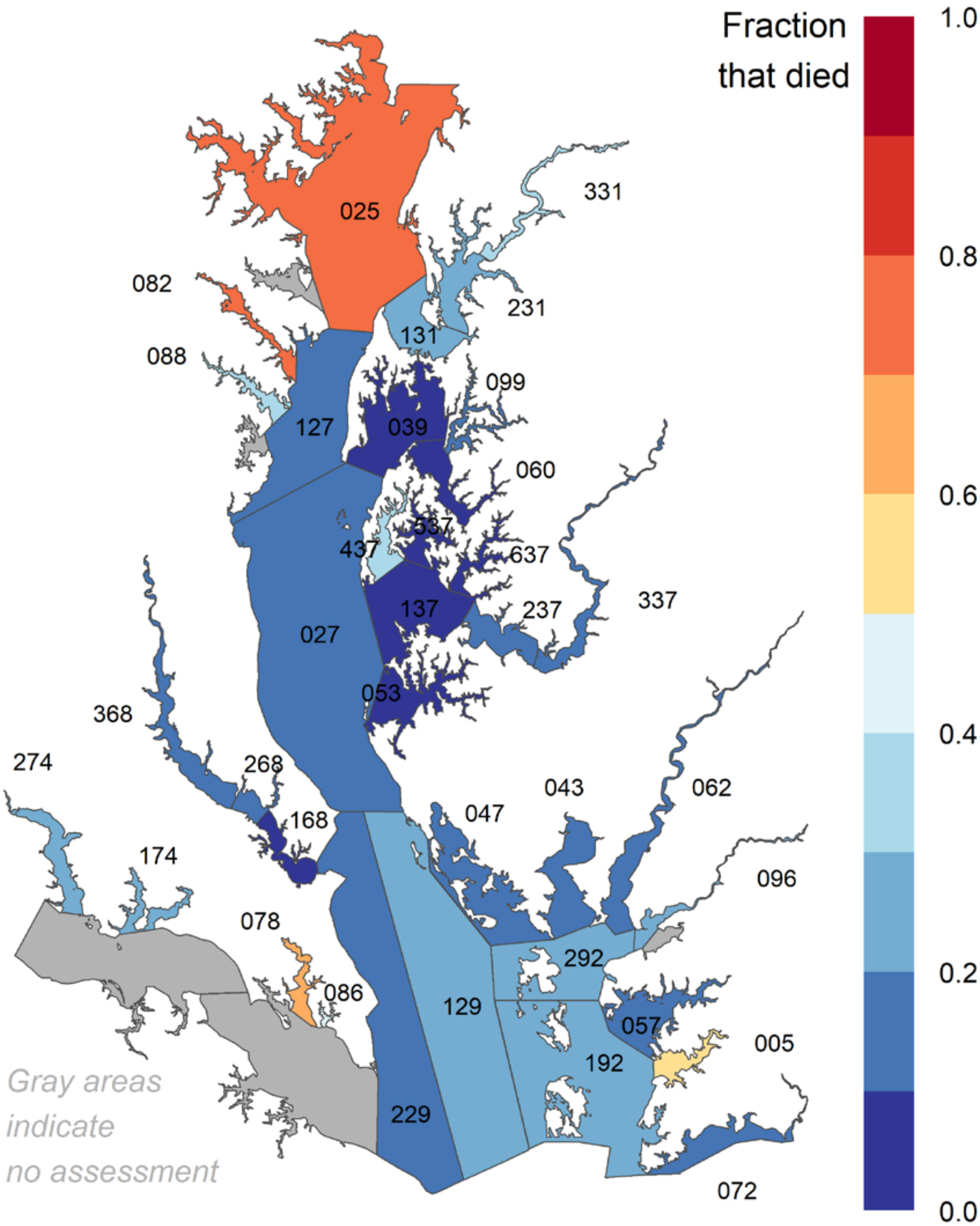

Figure 15. Estimated natural mortality rates (including disease) by NOAA code during 2011.

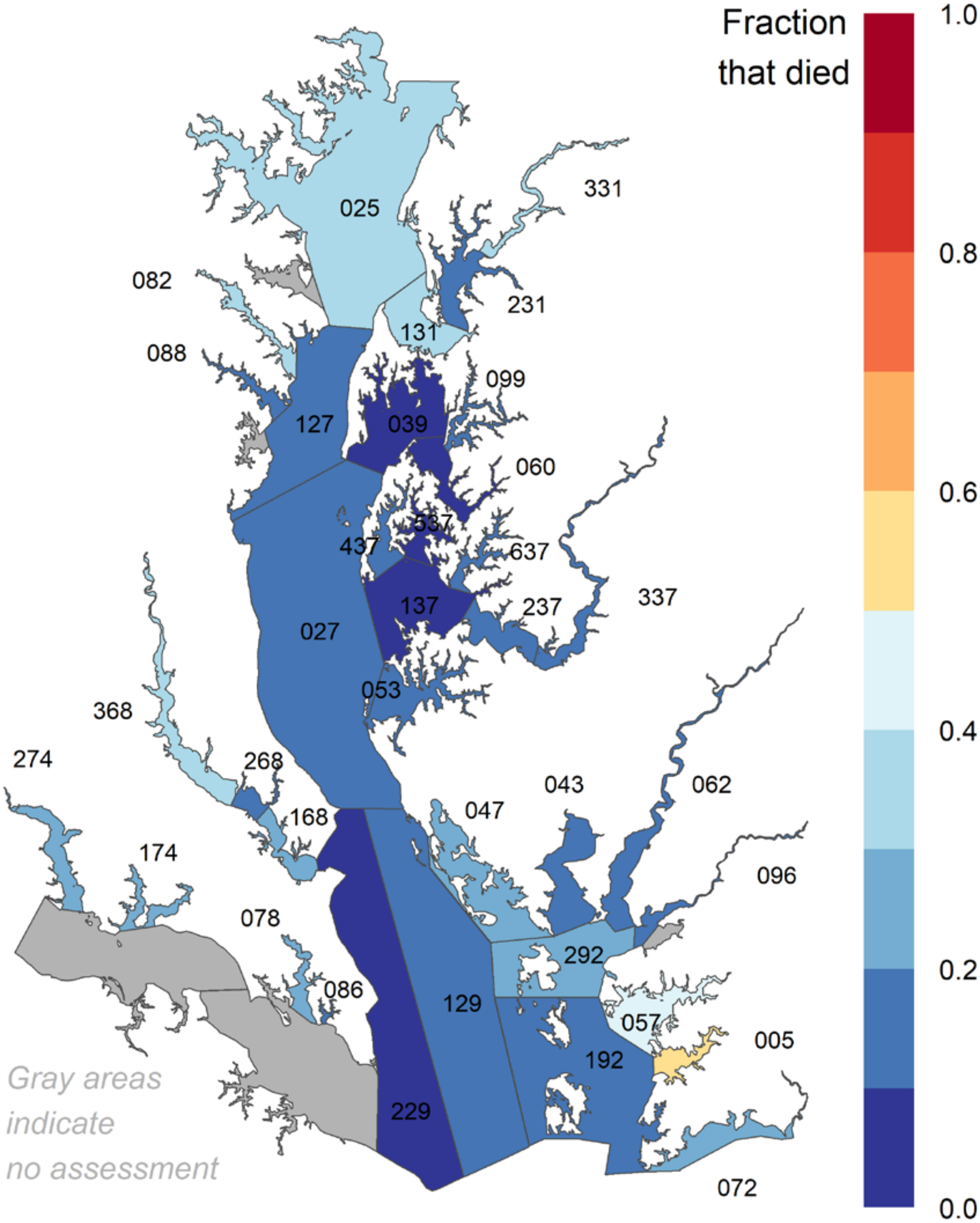

Figure 16. Estimated natural mortality rates (including disease) by NOAA code during 2012.

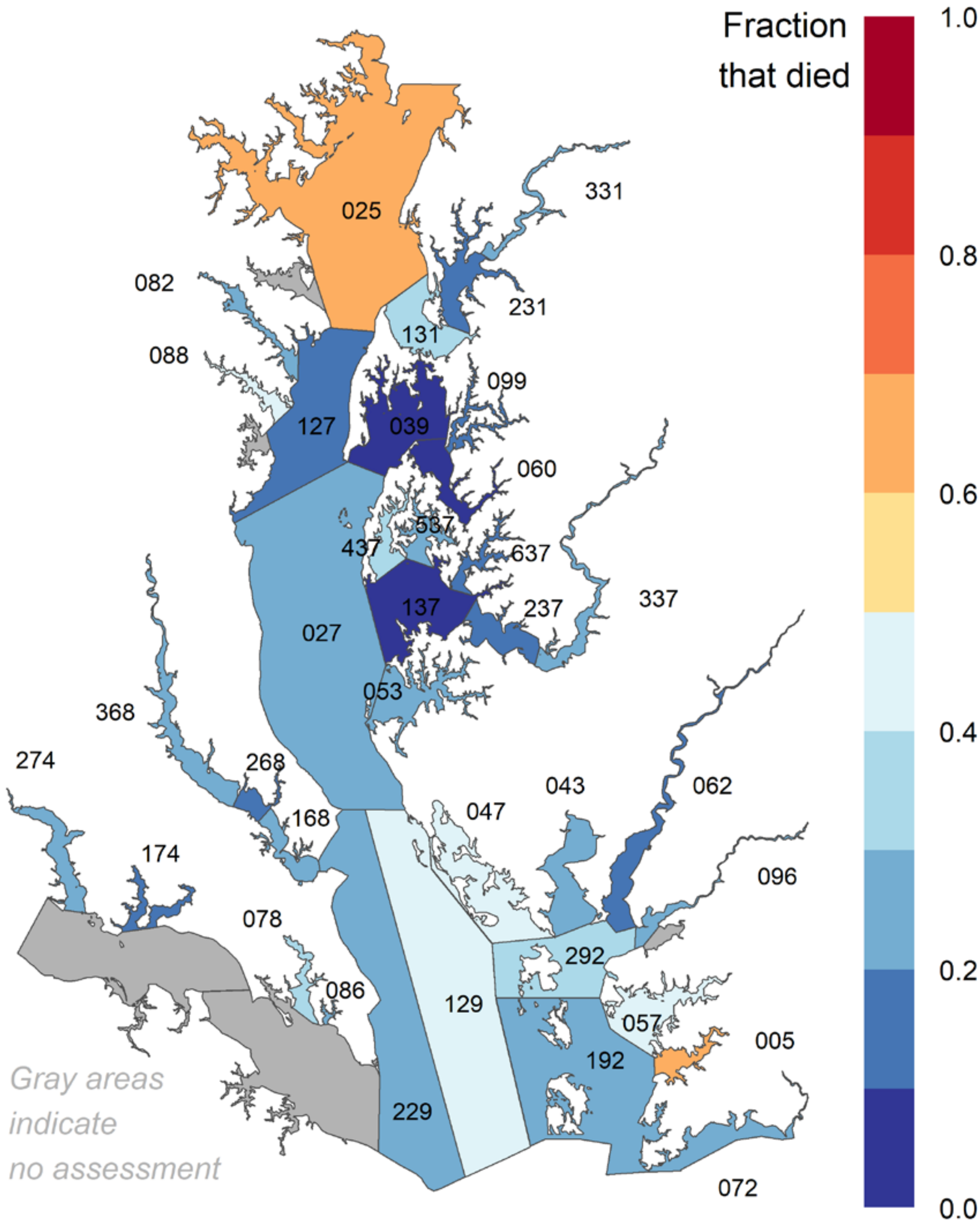

Figure 17. Estimated natural mortality rates (including disease) by NOAA code during 2013.

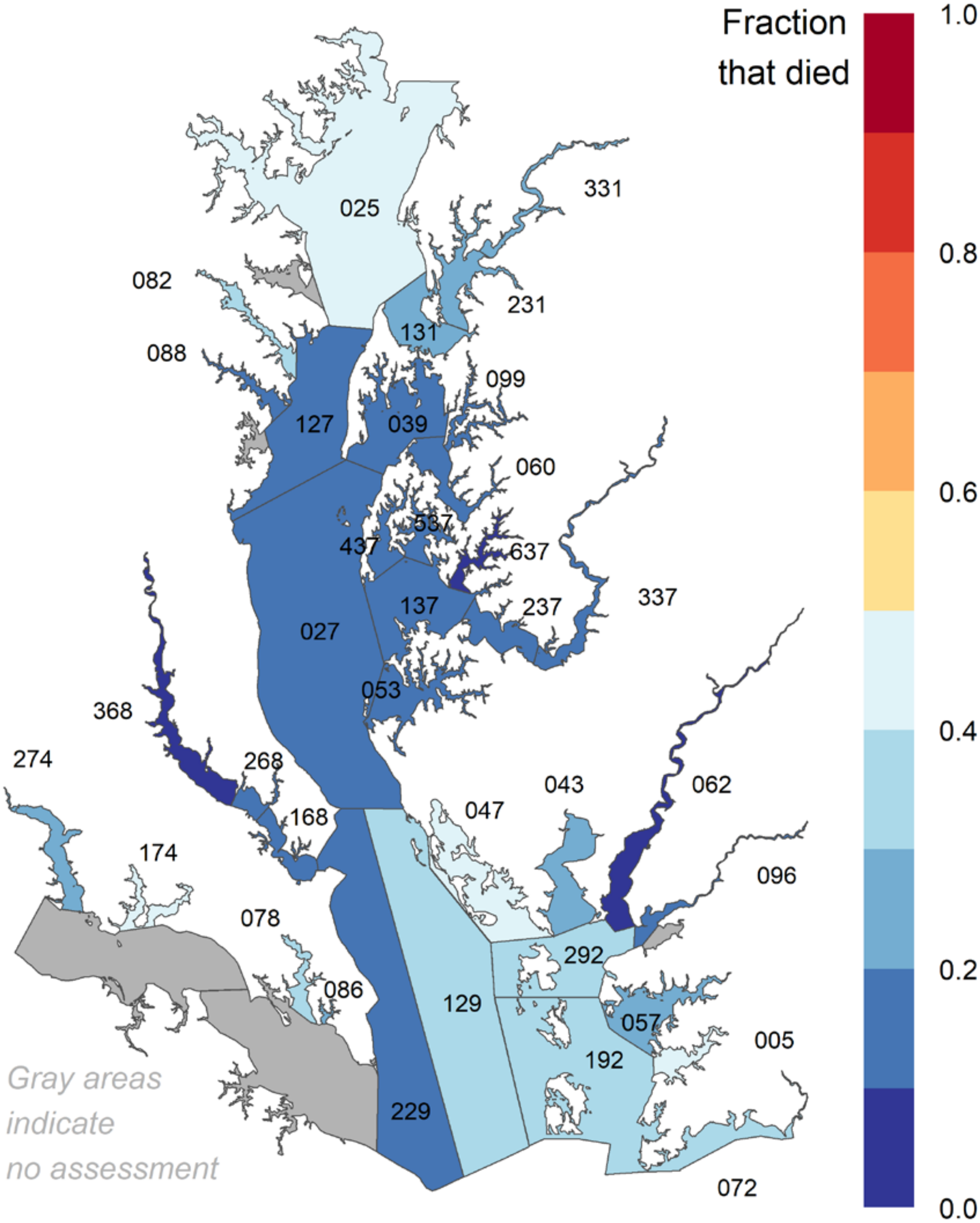

Figure 18. Estimated natural mortality rates (including disease) by NOAA code during 2014.

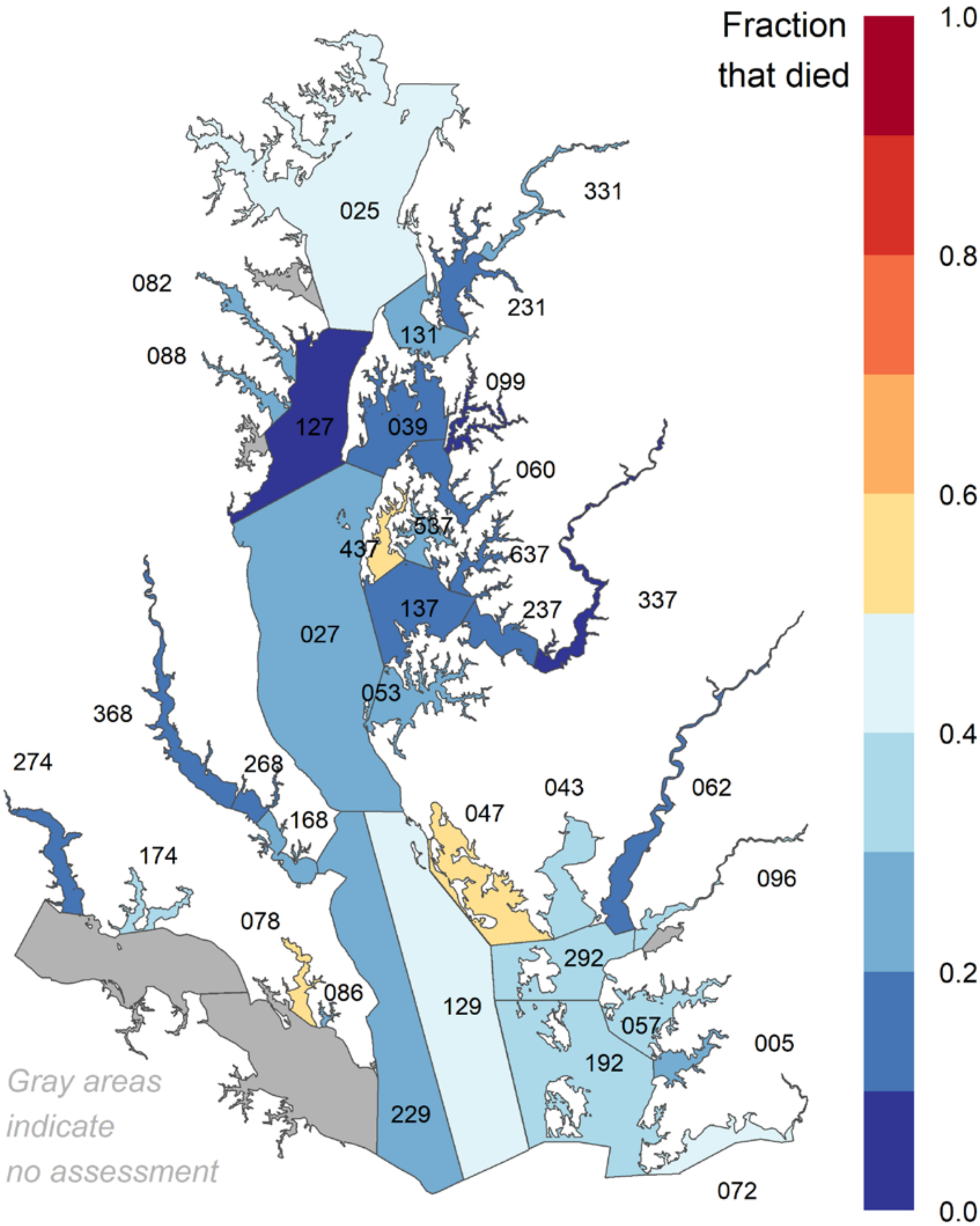

Figure 19. Estimated natural mortality rates (including disease) by NOAA code during 2015.

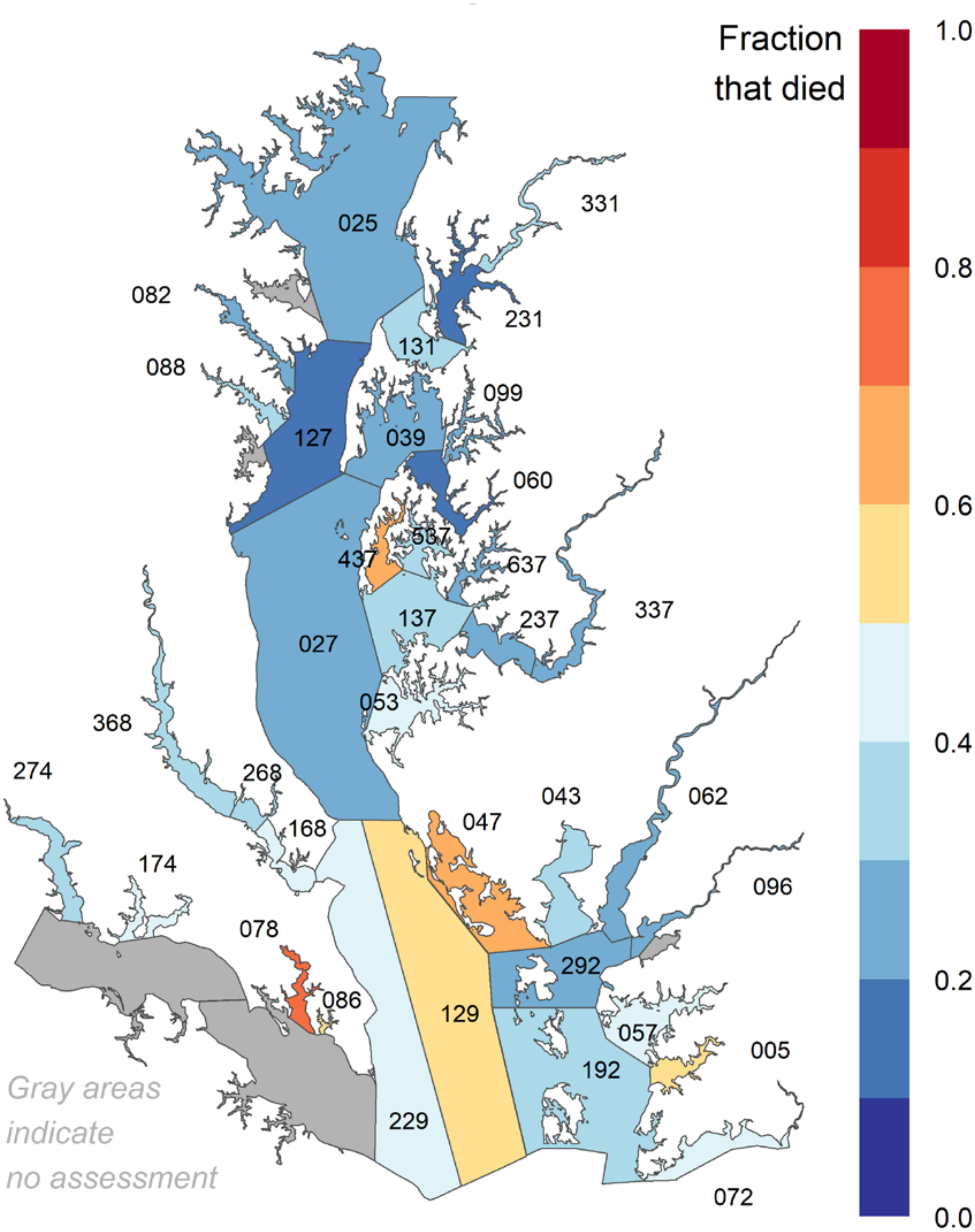

Figure 20. Estimated natural mortality rates (including disease) by NOAA code during 2016.

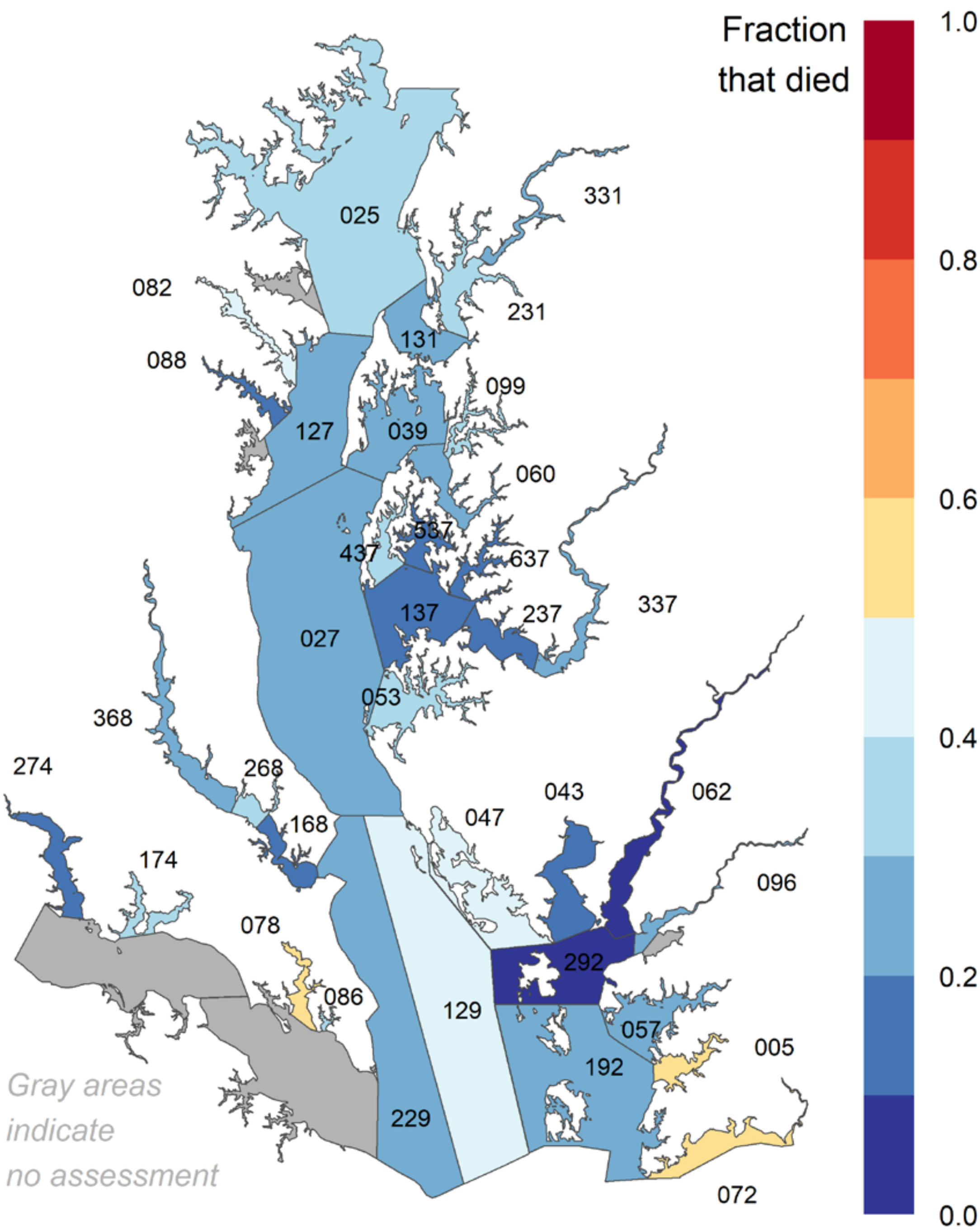

Figure 21. Estimated natural mortality rates (including disease) by NOAA code during 2017.

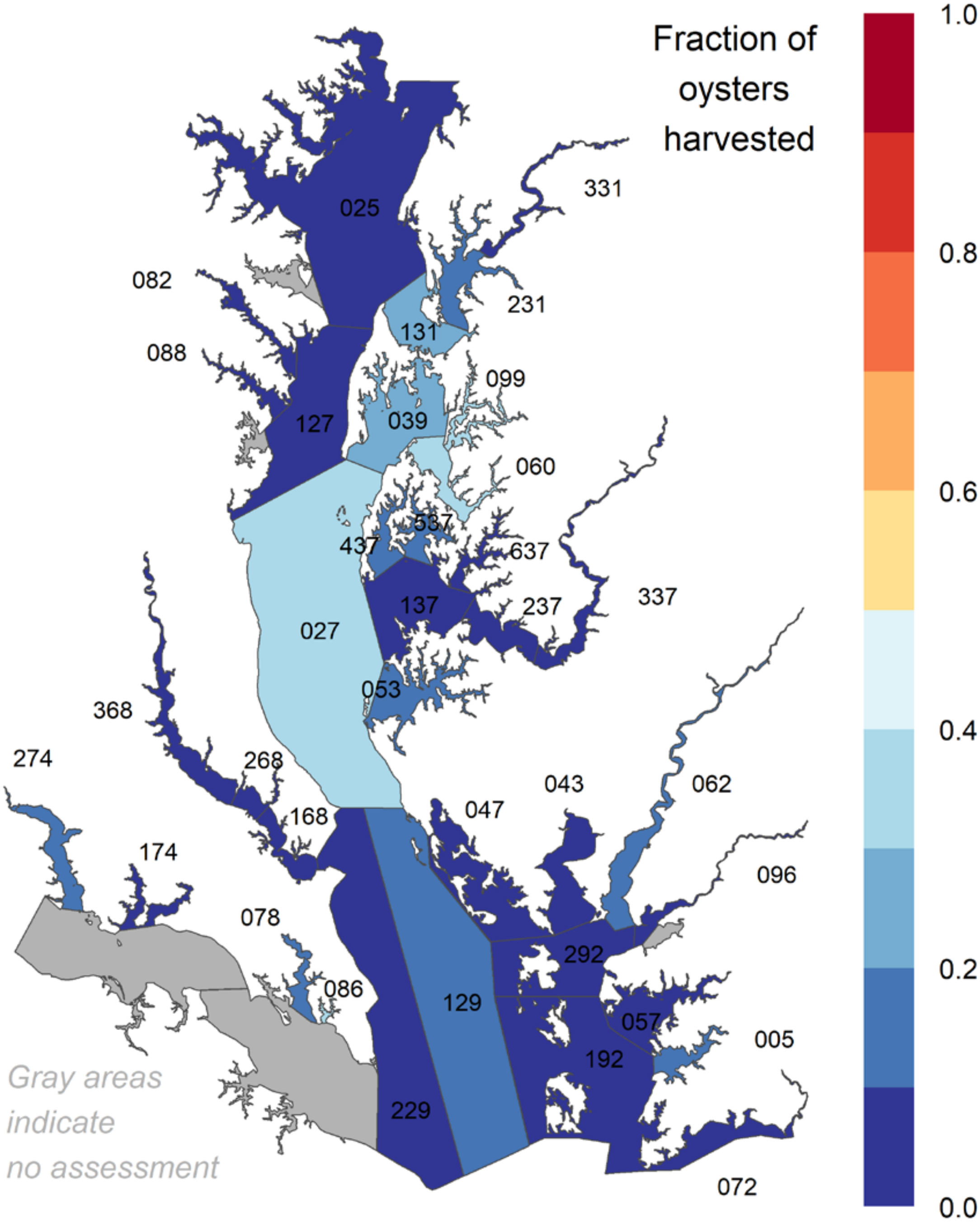

Figure 22. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 1999-2000 season.

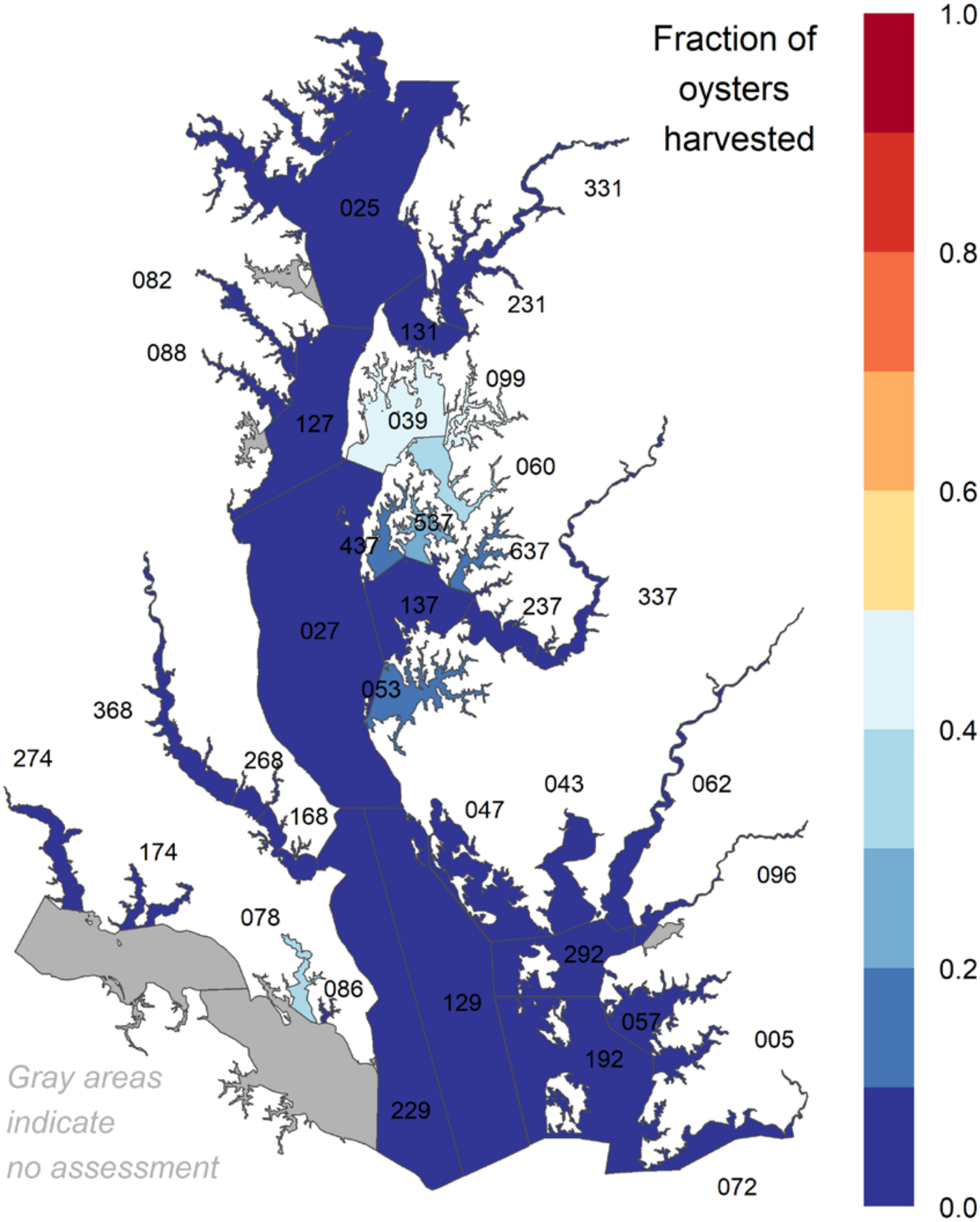

Figure 23. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2000-2001 season.

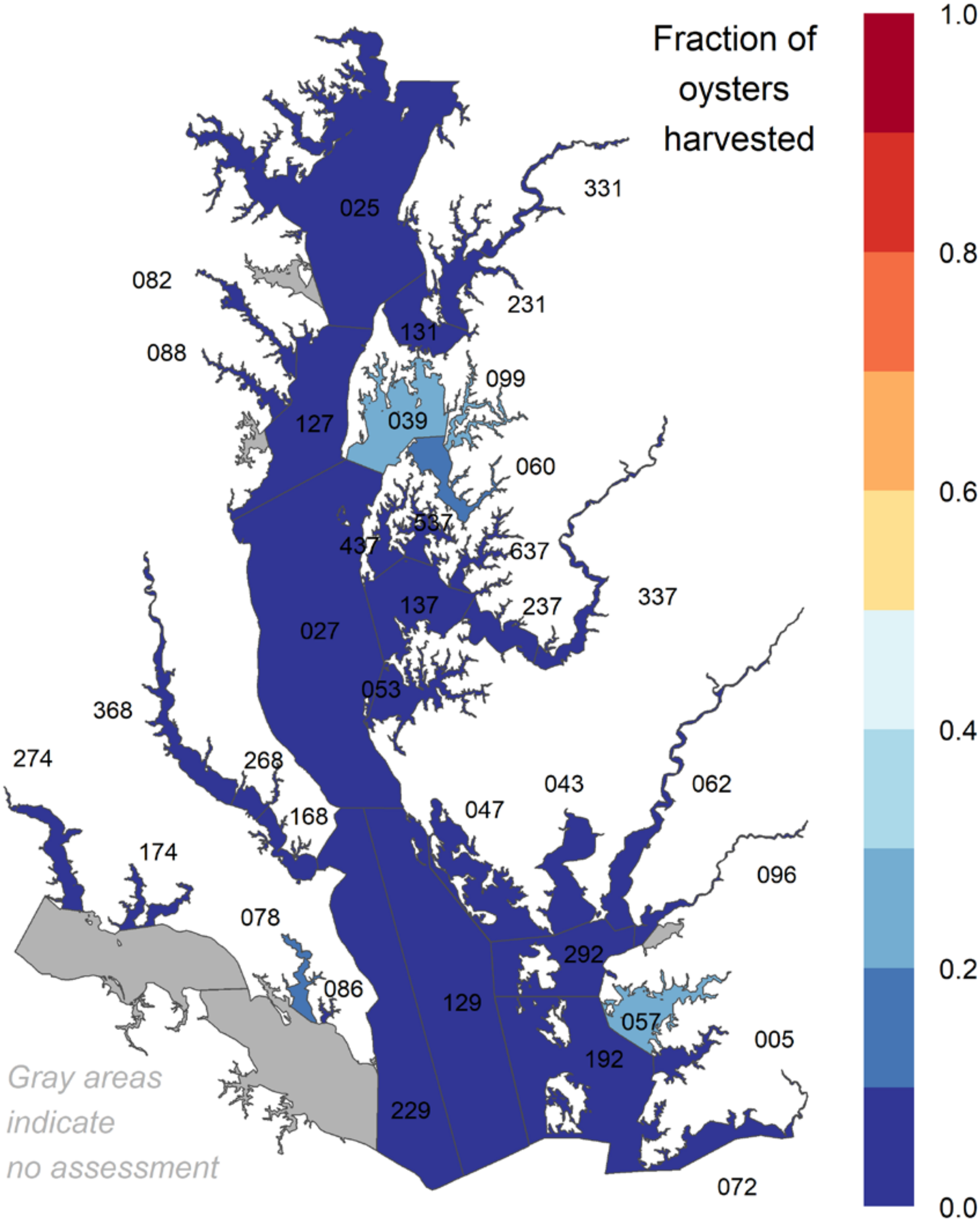

Figure 24. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2001-2002 season.

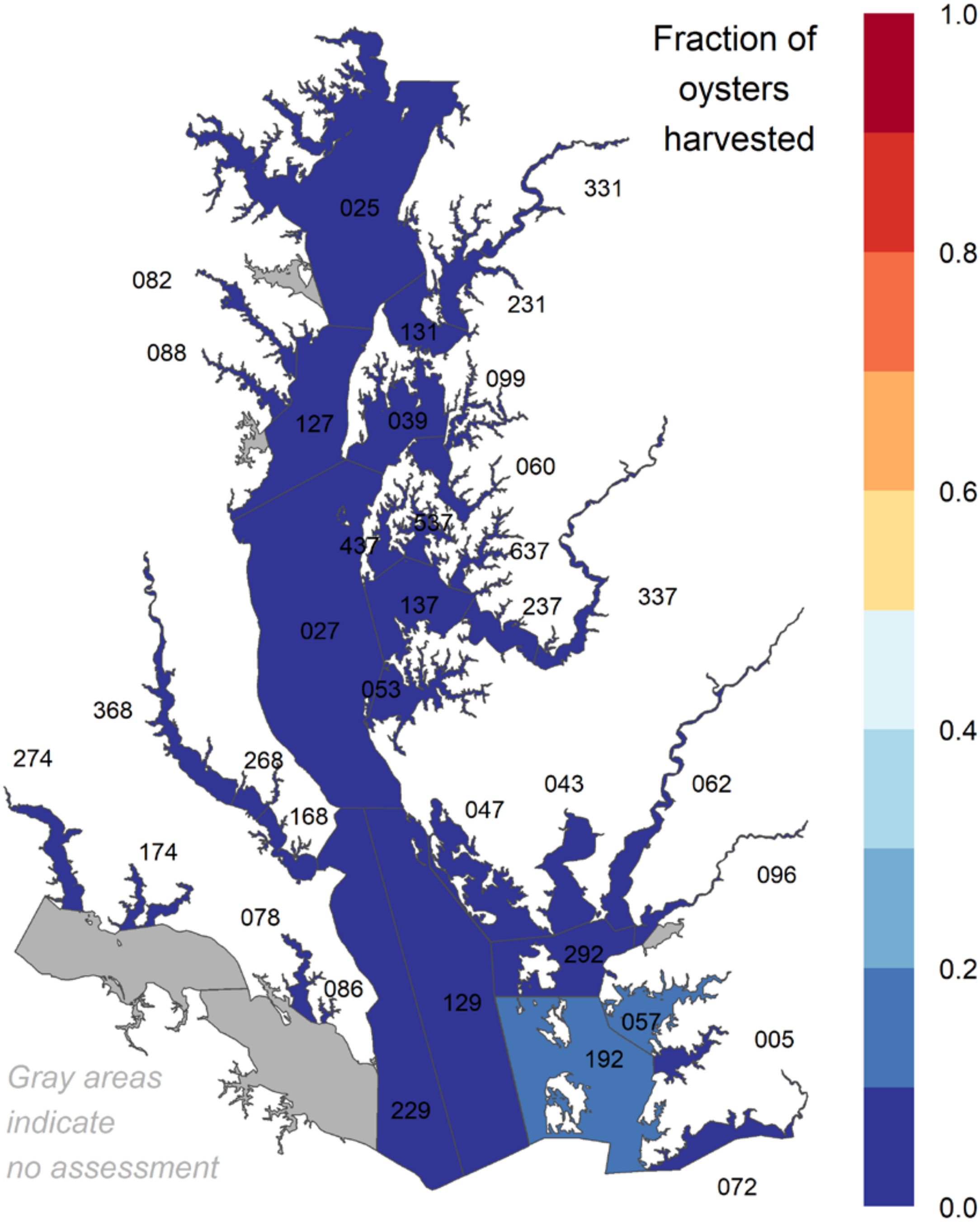

Figure 25. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2002-2003 season.

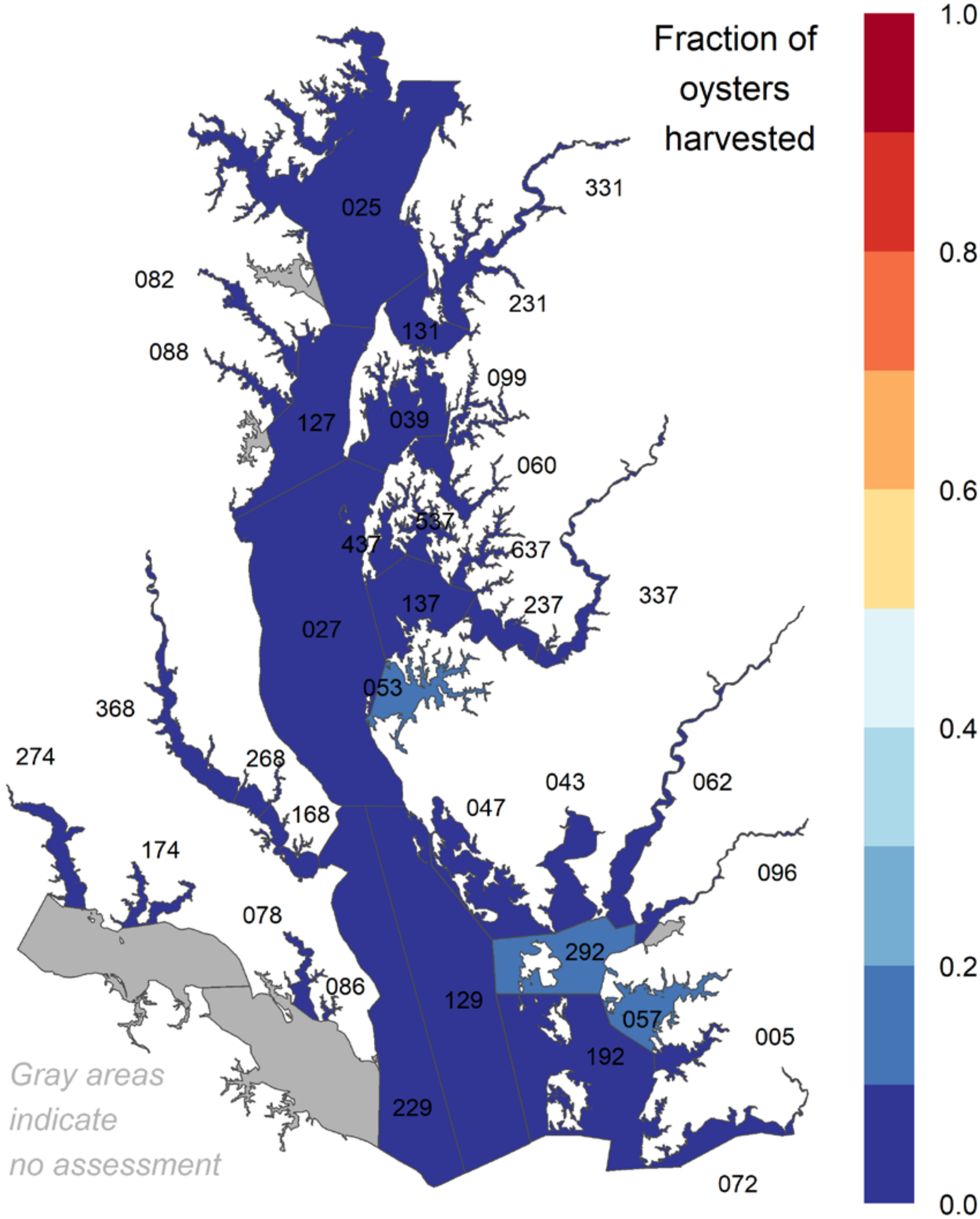

Figure 26. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2003-2004 season.

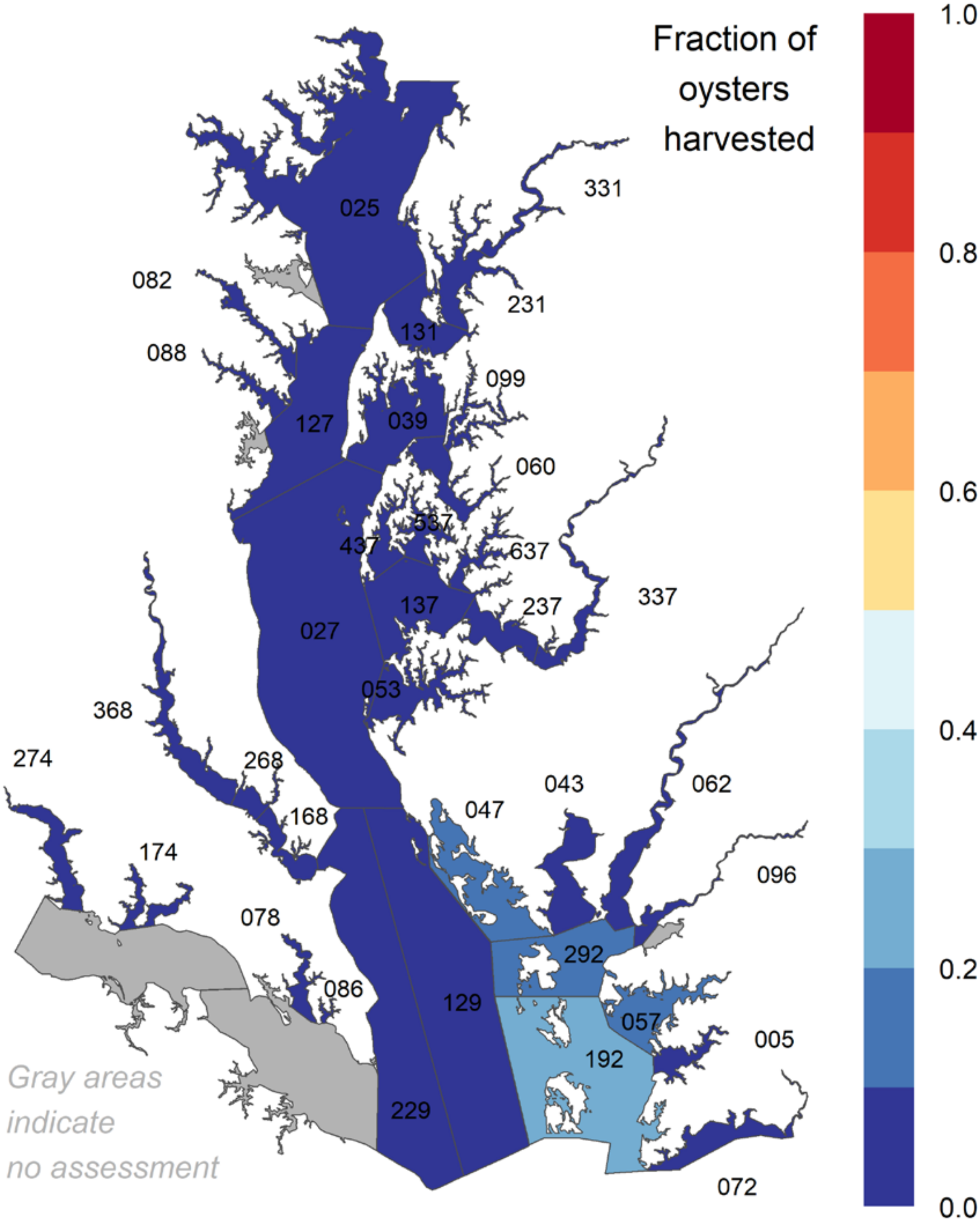

Figure 27. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2004-2005 season.

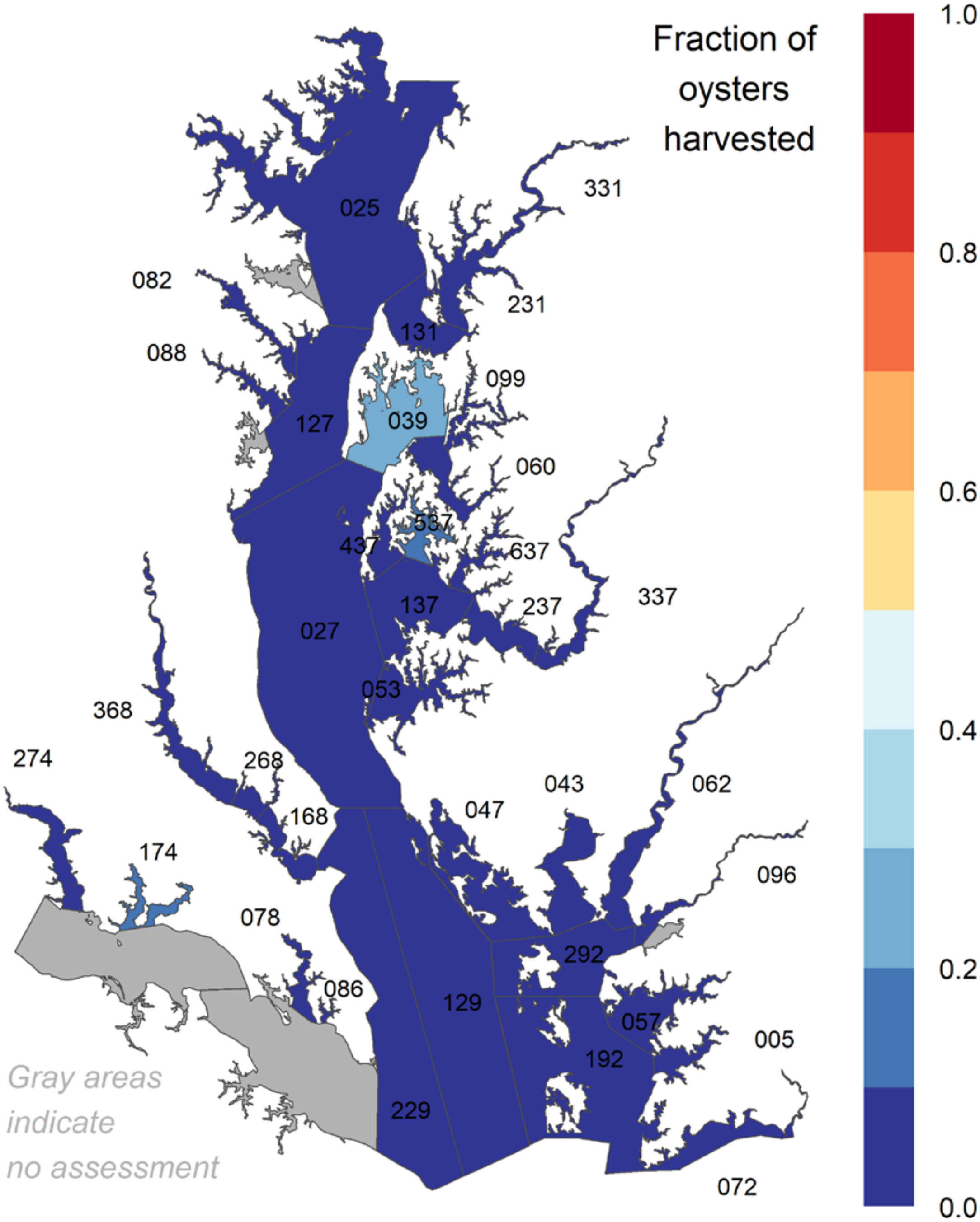

Figure 28. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2005-2006 season.

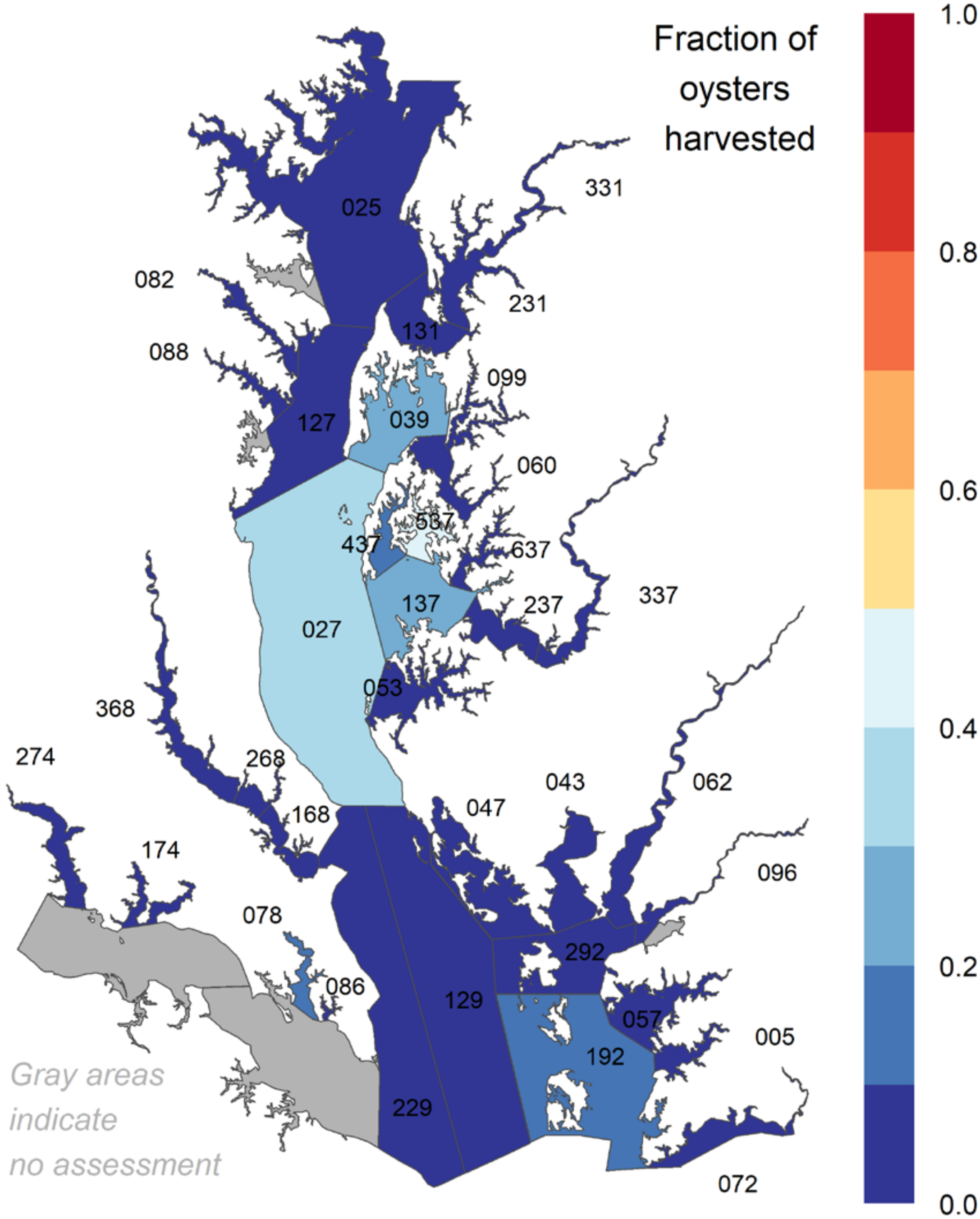

Figure 29. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2006-2007 season.

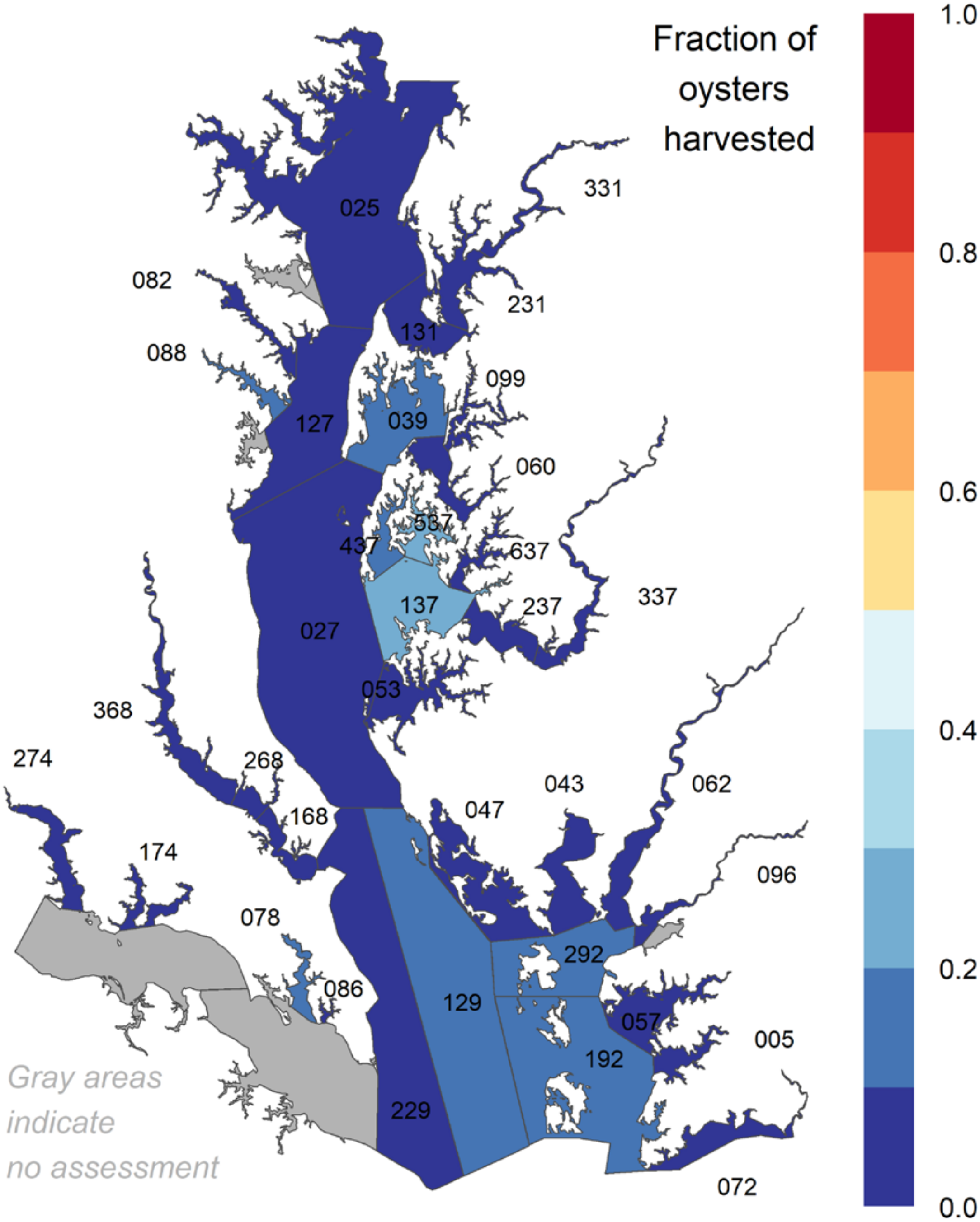

Figure 30. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2007-2008 season.

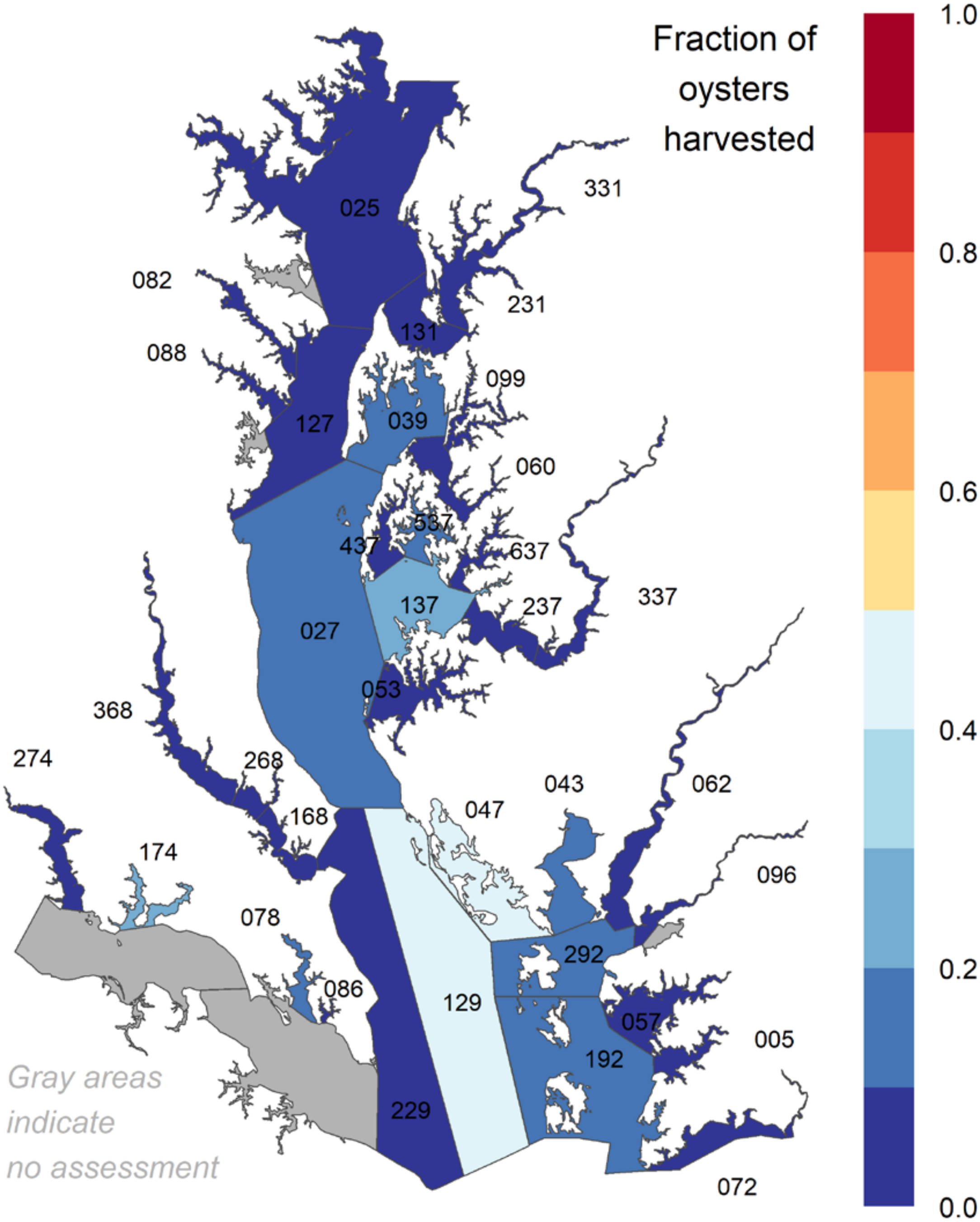

Figure 31. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2008-2009 season.

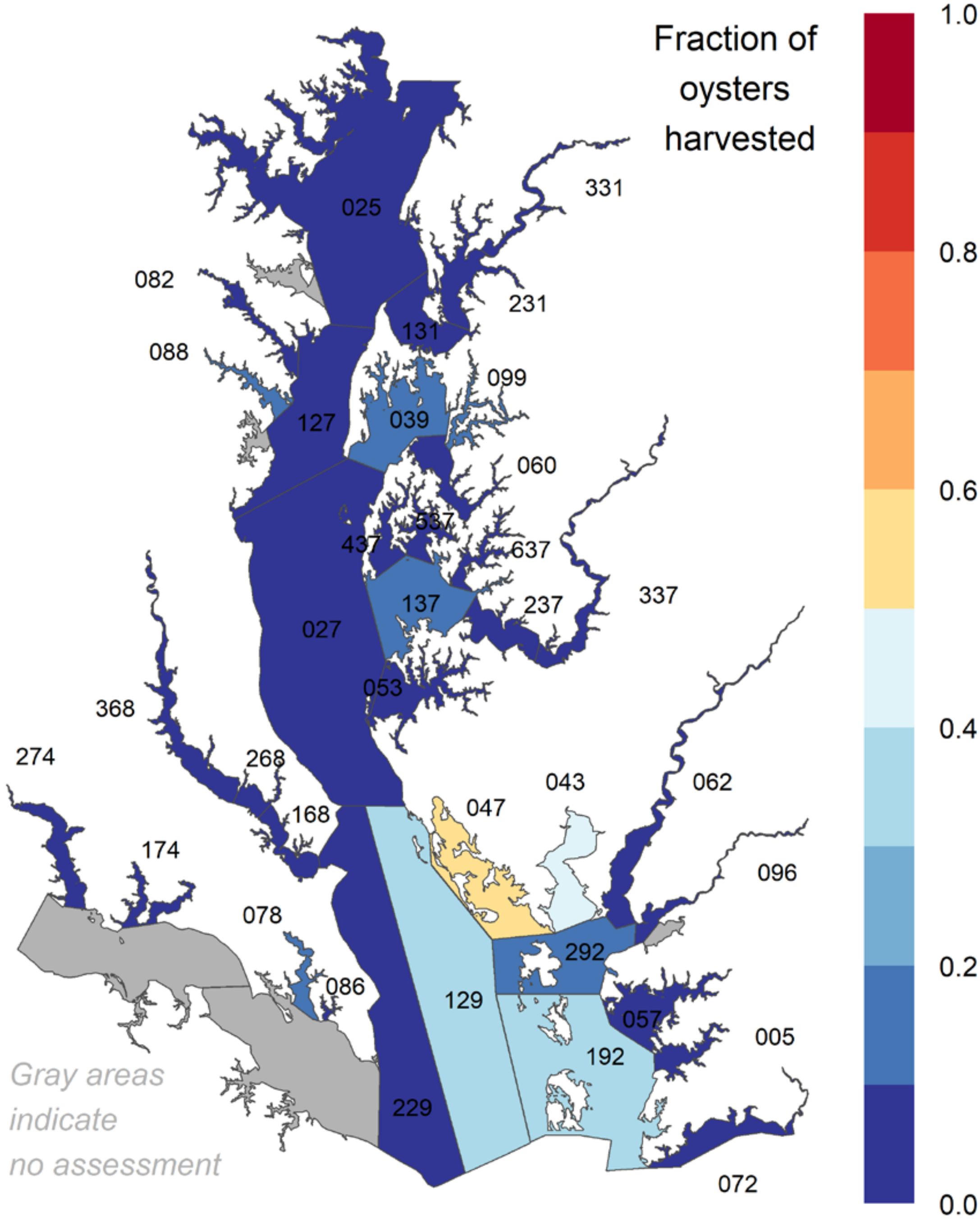

Figure 32. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2009-2010 season.

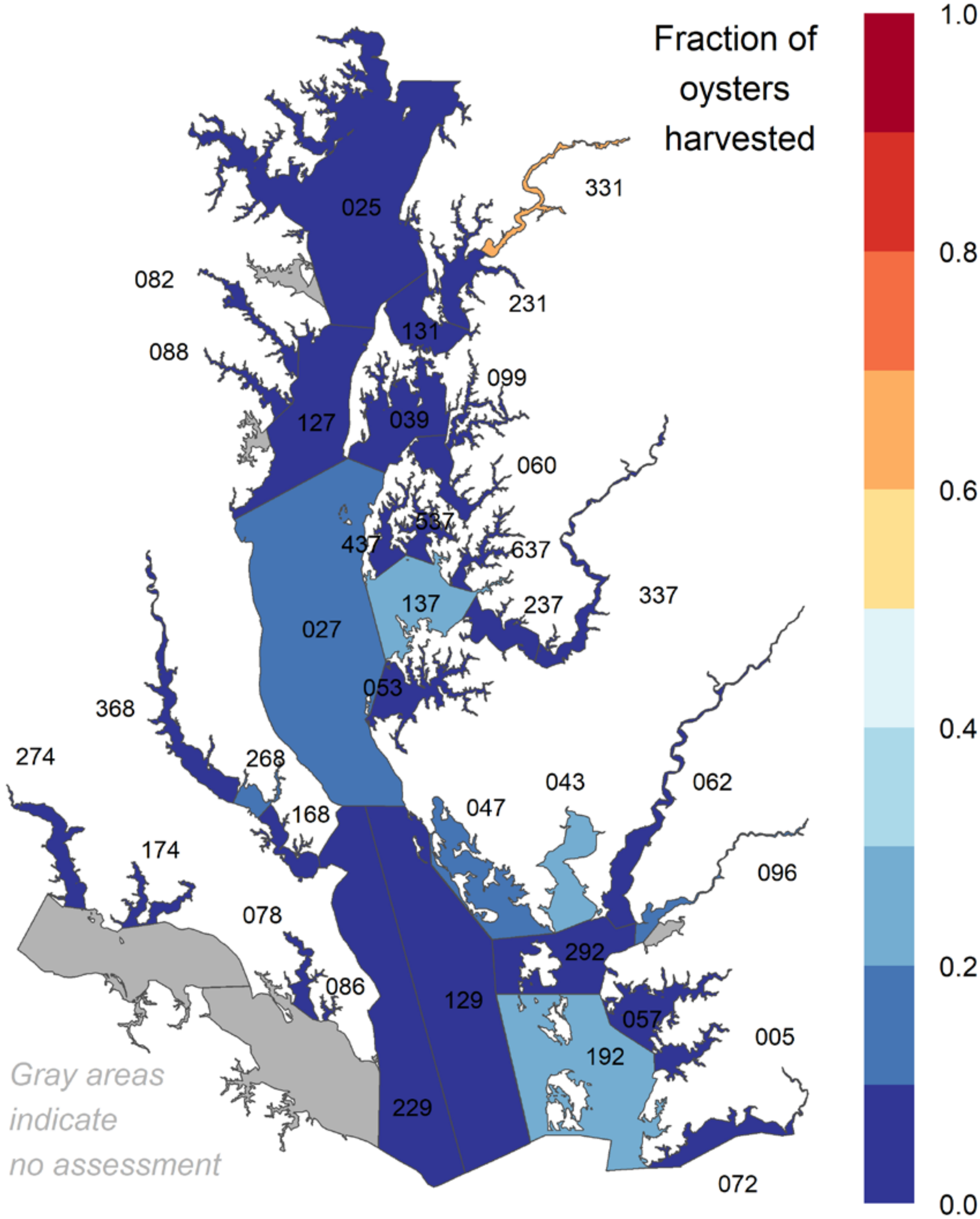

Figure 33. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2010-2011 season.

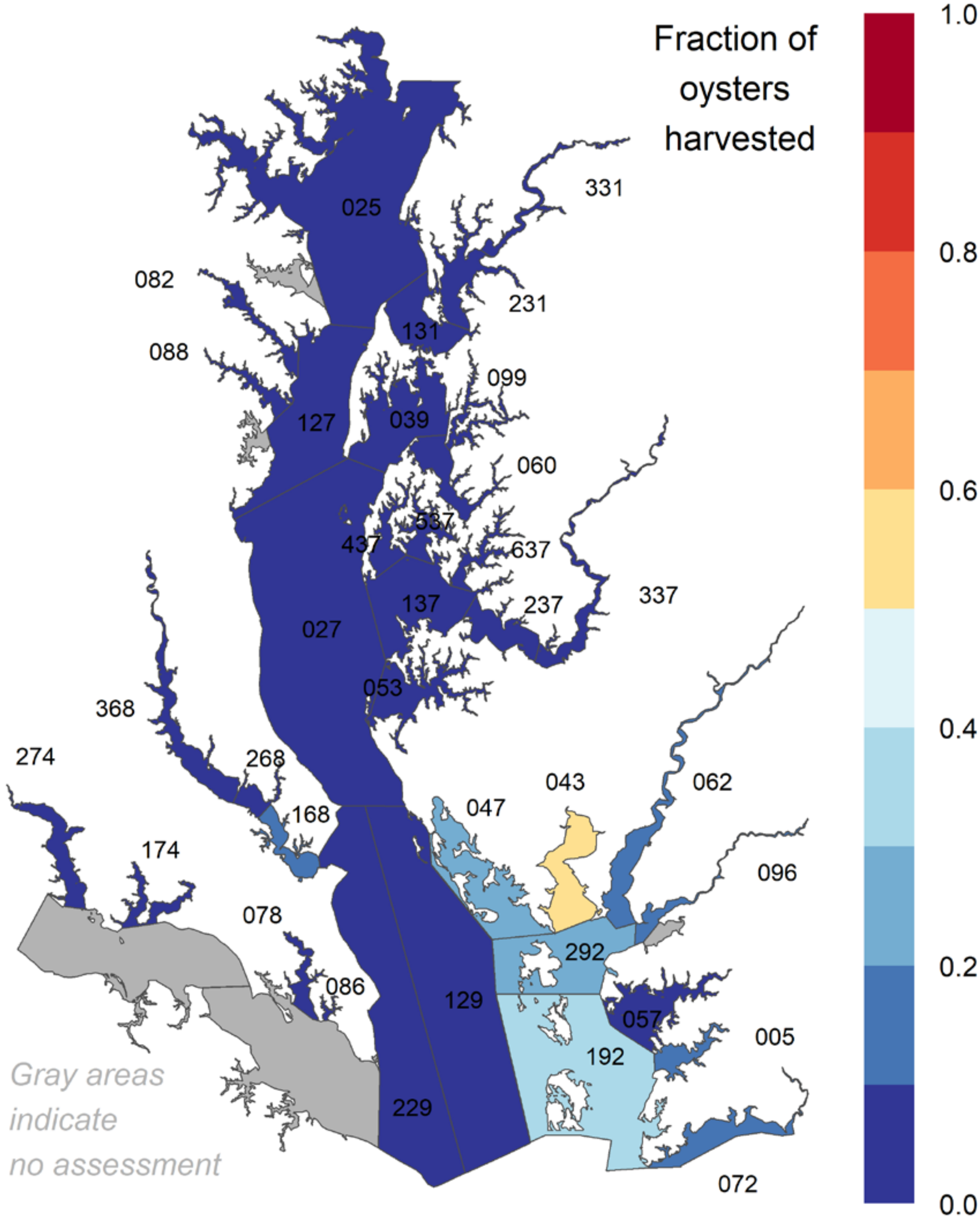

Figure 34. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2011-2012 season.

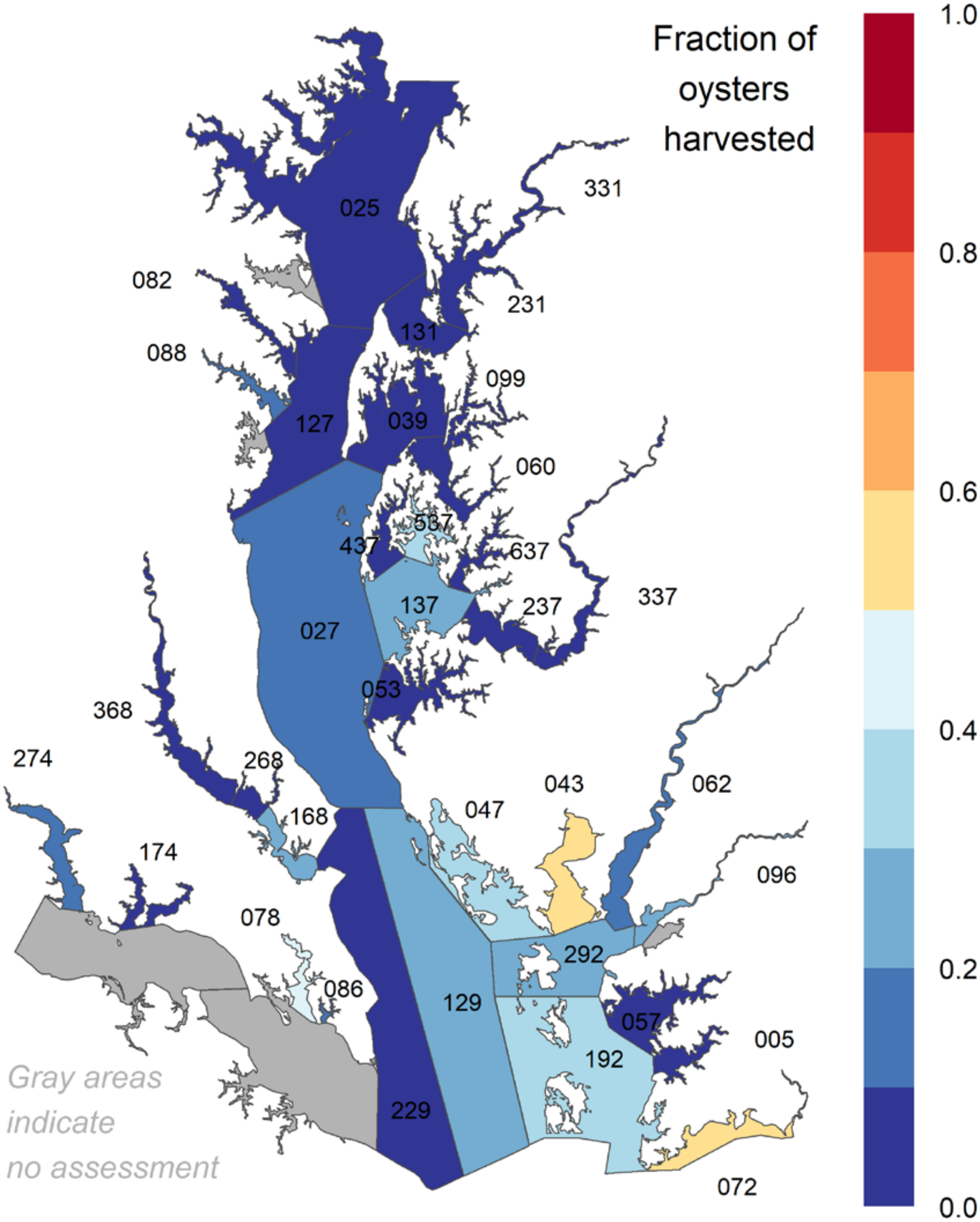

Figure 35. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2012-2013 season.

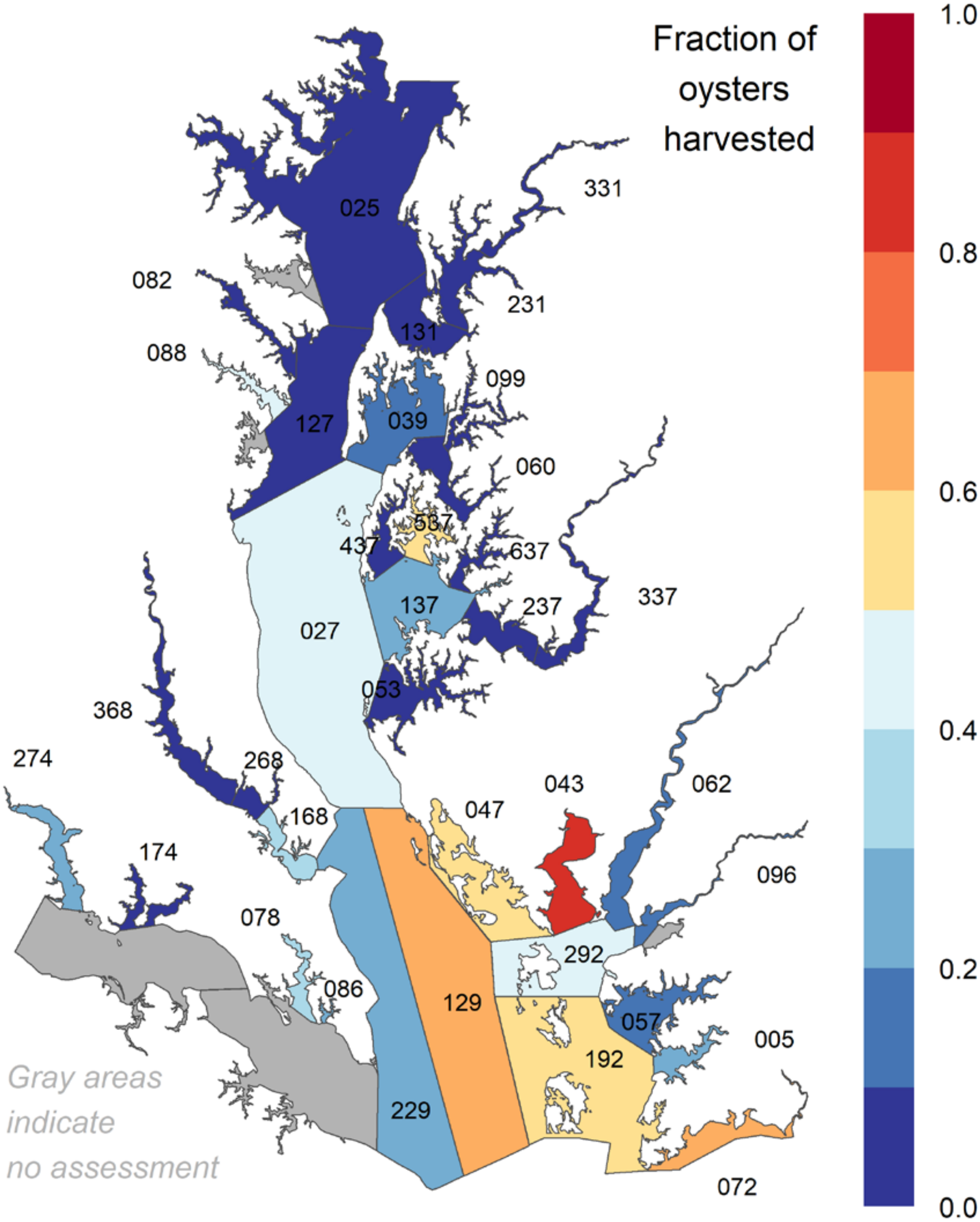

Figure 36. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2013-2014 season.

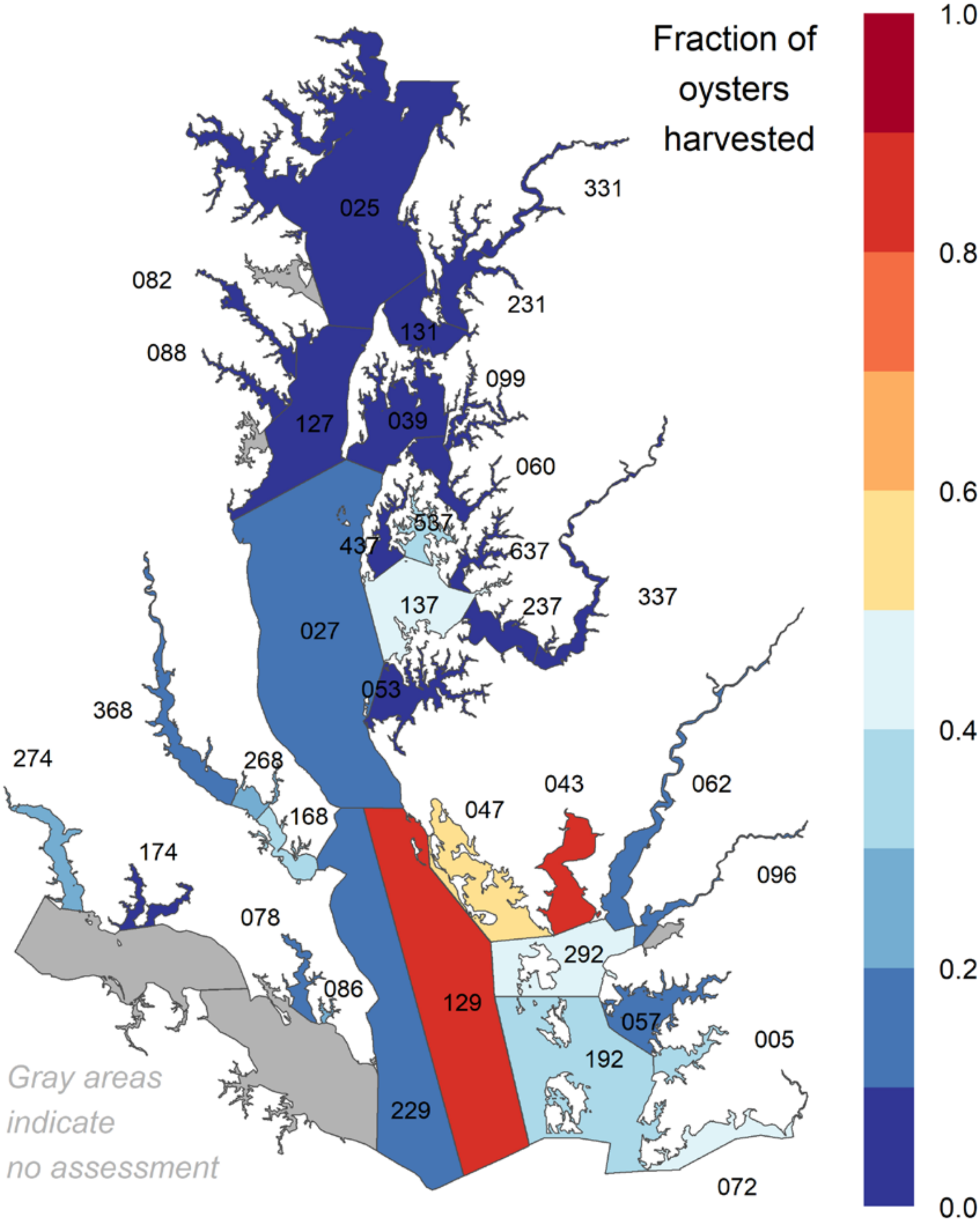

Figure 37. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2014-2015 season.

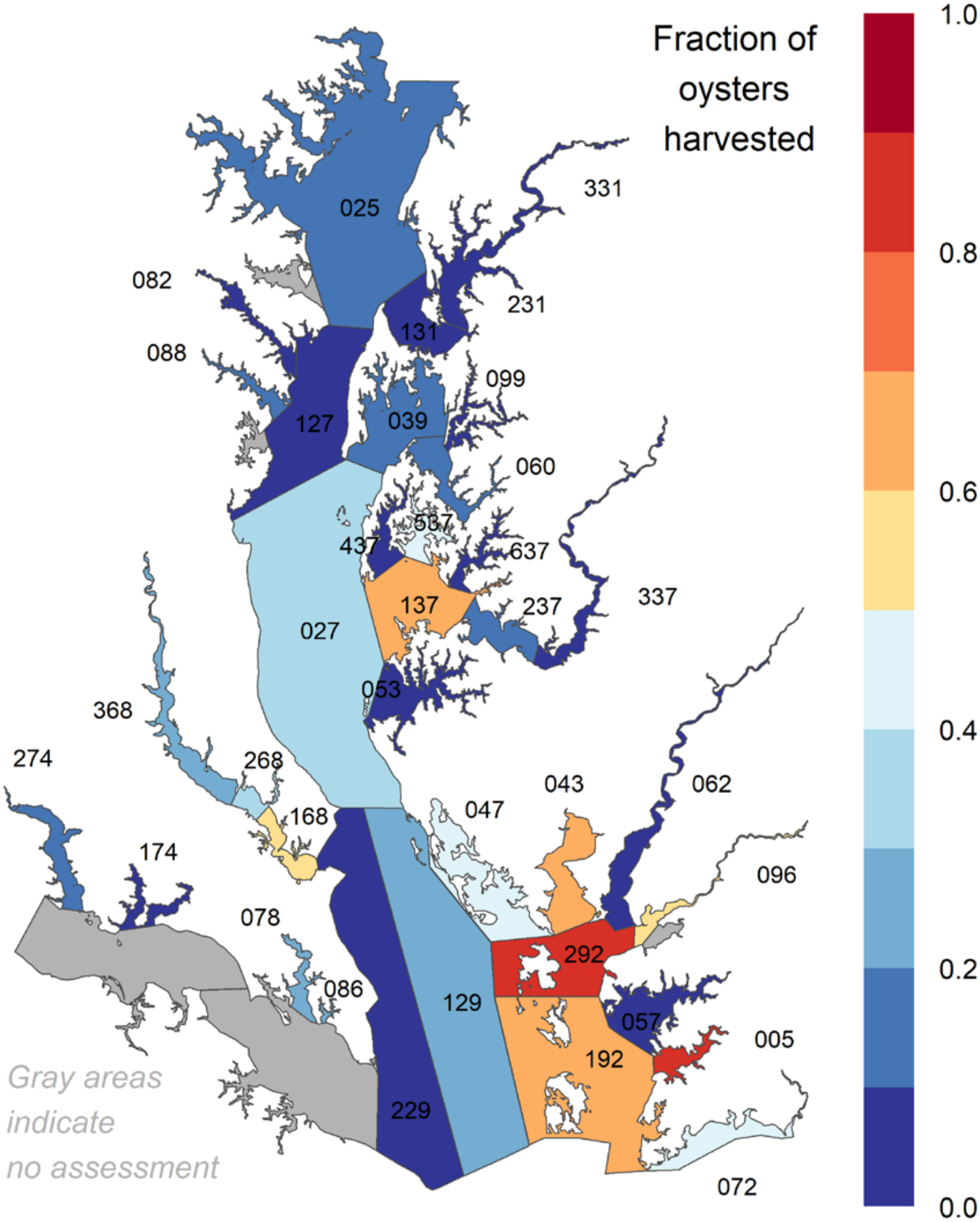

Figure 38. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2015-2016 season.

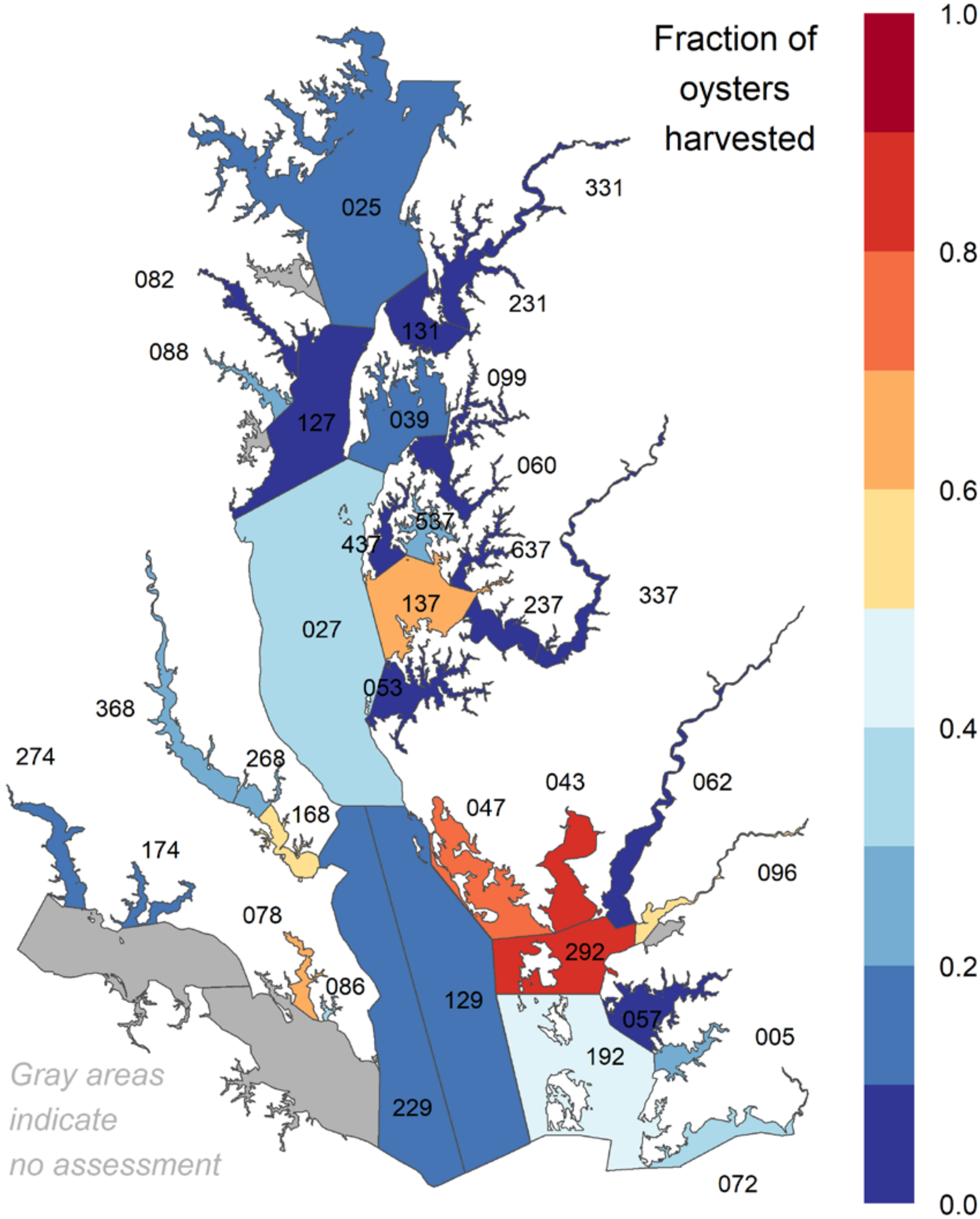

Figure 39. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2016-2017 season.

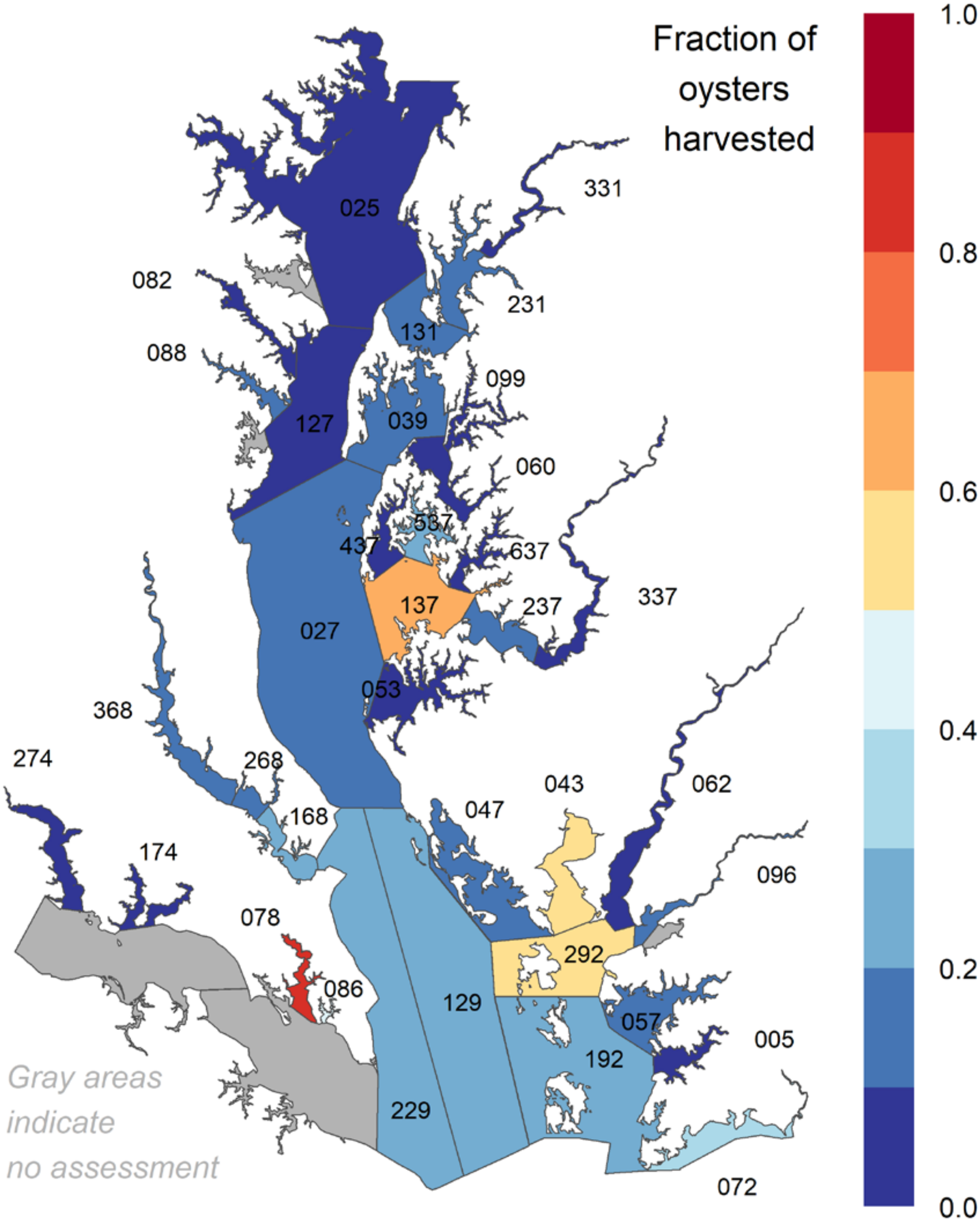

Figure 40. Estimated exploitation rates (fraction of oysters above the size limit that were harvested during the 2017-2018 season.

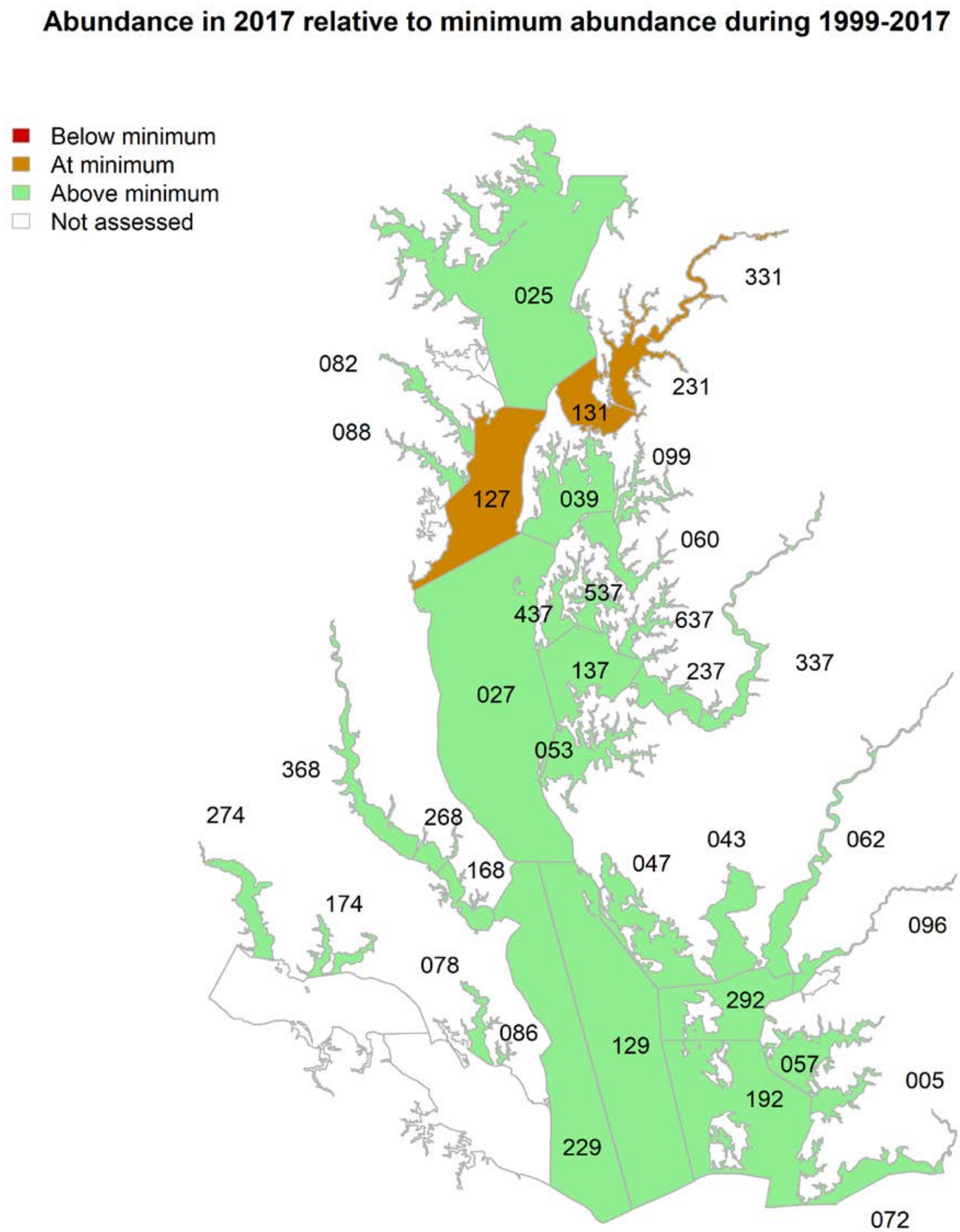

Figure 41. Status of market oyster abundance in the last year of the assessment (2017) relative to the threshold abundance reference point which is the lowest estimate of abundance since 1999.

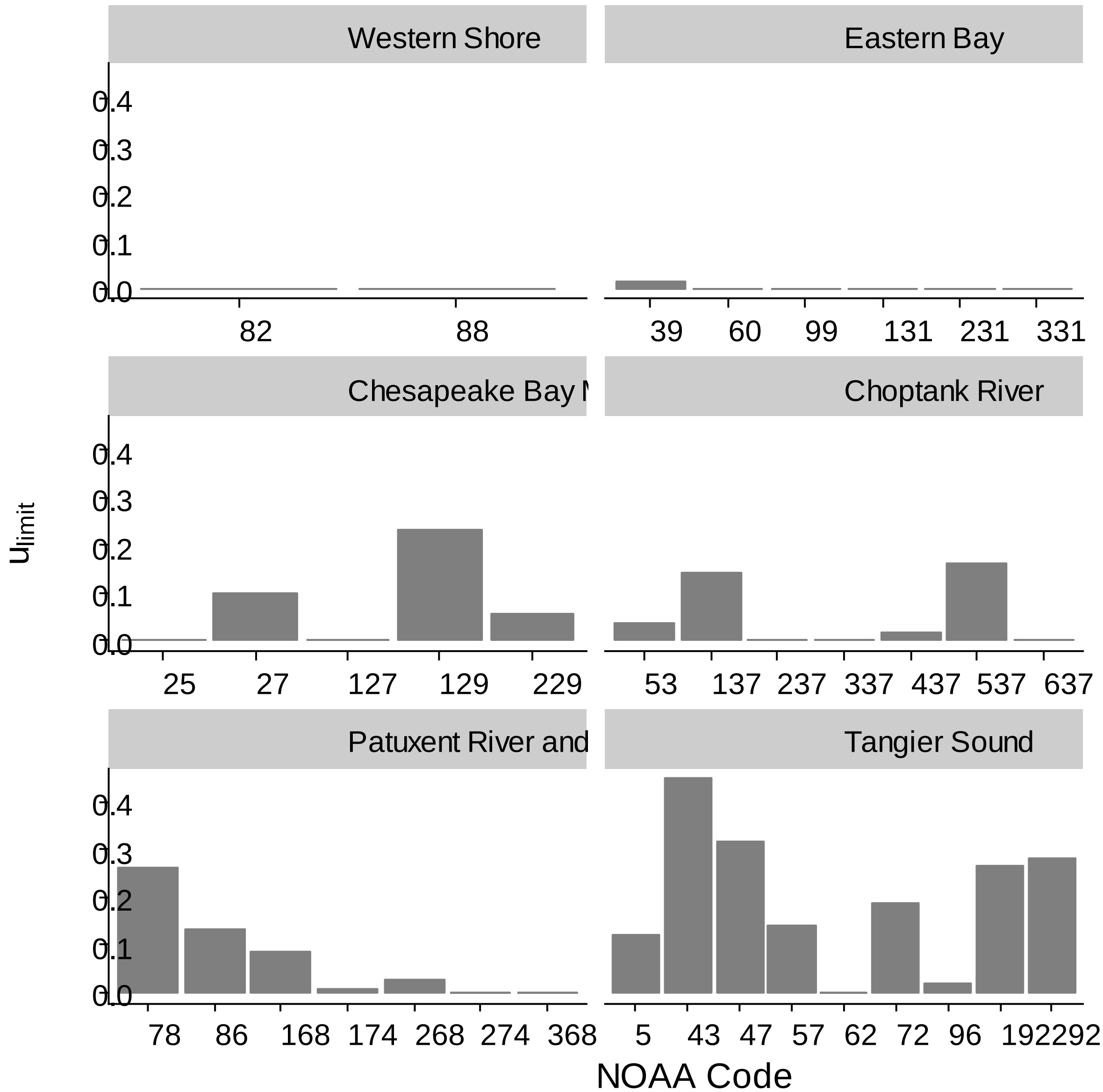

Figure 42. Estimates of U_{crash} which is the upper limit (threshold) harvest fraction reference point (bars) from the linked population-shell dynamics model by NOAA code. Estimates are grouped by region (panels) and panels are arranged geographically with upper panels representing the northern NOAA codes and the right-most panels representing the eastern most NOAA codes.

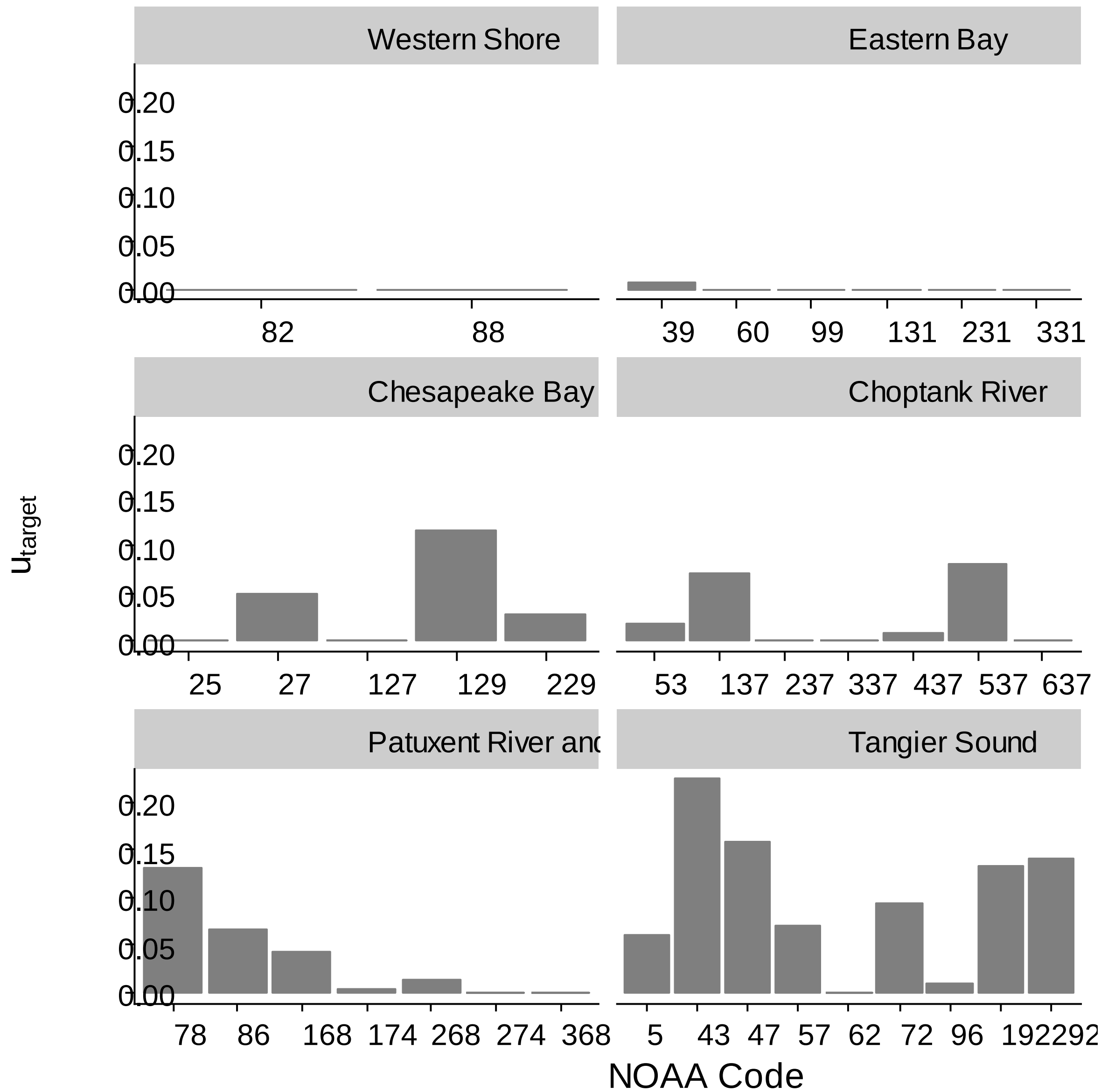

Figure 43. Estimates of U_{MSY} which is the target harvest fraction reference point (bars) from the linked population-shell dynamics model by NOAA code. Estimates are grouped by region (panels) and panels are arranged geographically with upper panels representing the northern NOAA codes and the right-most panels representing the eastern most NOAA codes.

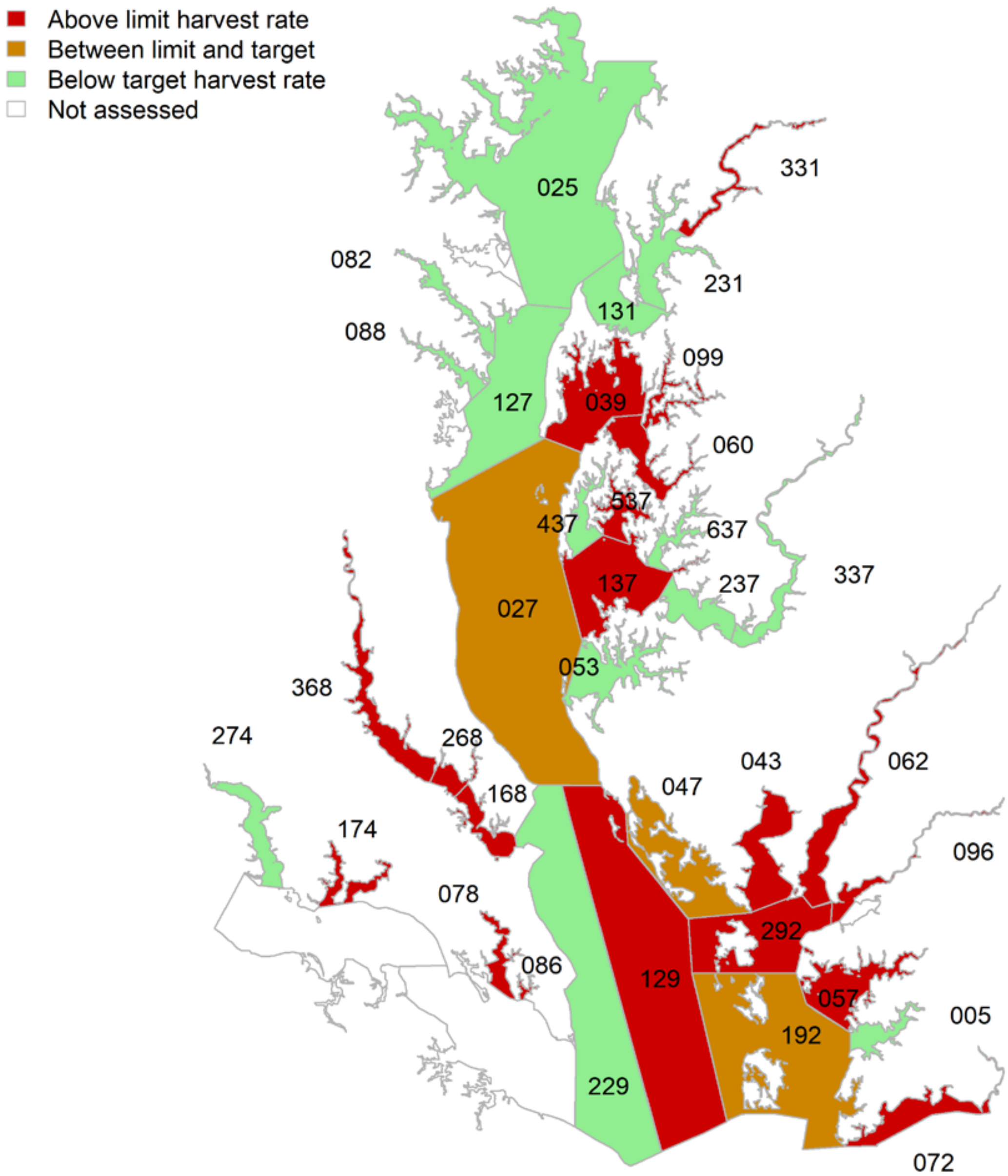

Figure 44. Estimated harvest fractions compared to target (U_{MSY}) and upper limit (U_{crash}) reference points for the 2017-2018 season. The estimates of harvest fraction have been adjusted for planted spat which implies that the objective for the area is to enhance the fishery. If the objective is to increase the oyster population (restoration) then the estimates of U should not be adjusted for plantings.

15 Appendix 1 – Full Peer Review Panel Report

Review of

A Stock Assessment of Eastern Oyster, *Crassostrea virginica*, in Maryland Waters of Chesapeake Bay

August 27-29, 2018

Annapolis, MD

Panel Members

Paul Rago[1] (Chair)

Daniel Hennen[2]

Daphne Munroe[3]

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15.1 Peer Review Executive Summary

The decline of oyster abundance in Chesapeake Bay is well known and significant public and private resources have been invested to support its revival (Kennedy et al., 2011). With considerable foresight, Maryland began a program to monitor abundance in 1939. Ironically there have been no stock assessments of the overall resource. This report represents the results of an external peer review by a panel of independent experts of an assessment of oysters in Maryland's portion of Chesapeake Bay. The assessment and review were mandated by the Sustainable Oyster Population and Fishery Act of 2016 (Maryland General Assembly). The assessment was conducted by the Maryland DNR in consultation with the University of Maryland Center for Environmental Science (UMCES) and was completed in early August, 2018. The review was conducted in late August, 2018 following Terms of Reference reviewed by the Maryland Oyster Advisory Commission.

15.1.1 Primary Conclusions

Overall, the Review Panel concluded that all Terms of Reference had been met. The Review Panel supported the conclusions of the Assessment Team and agreed that they had fully utilized the available data at an appropriate temporal and spatial resolution. The modeling approach is innovative and the results can serve as an adequate basis for management decisions. All stock assessments, however, represent a compromise between the ideal and the realized. Changes in data quality over time, lack of sufficient spatial resolution in the characterization of removals, significant but variable impacts of disease, observation error in monitoring programs, habitat loss, and trends in ecosystem conditions all influence the oyster assessment. It is the opinion of the Review Panel that this assessment deals with these compromises in a rigorous and scientifically credible way.

15.1.2 Review Process

The review process comprised several conference calls prior to the onsite review, a three-day meeting attended by the Assessment Team which included staff from Maryland DNR and from UMCES, and a follow up writing period by the Review Panel. A complete list of the participants at the meeting and their roles may be found in Appendix 3. The Review Panel's report was submitted to Maryland DNR for review but only factual errors were revised. No changes were made to the opinions or conclusions of the Review Panel. Any factual errors remaining in the report are the responsibility of the Review Panel.

15.1.3 Data Considered

The Assessment Team conducted a thorough review of all primary sources of data for oysters in Maryland. These included both fishery-dependent and fishery-independent data as far back as 1889. Not surprisingly, the utility of these time series for stock assessment and modeling purposes varied over time. After extensive analyses, the stock assessments were based on 36 spatially discrete units based on removals recorded at the level of NOAA codes. Oysters are harvested from well-known beds, defined over a century ago by Yates. One or more oyster beds occur within the NOAA code subareas but official landings could not be resolved to a finer scale. Conversely, fishery independent time series of relative abundance which might have been disaggregated to a finer spatial scale, could be combined in a scientifically credible way for consistent measures of trend. Based on these considerations, the assessment period is restricted to 1999 onward.

15.1.4 Modeling Approaches

In contrast to most stock assessments, the natural mortality rate of oysters is both variable and high relative to fishing mortality. Diseases (MSX and Dermo) vary in intensity over time and along salinity gradients within the Bay (Bushek et al., 2012). Consistent long-term monitoring of oyster boxes (i.e., dead oysters whose shells remain hinged) allowed the Assessment Team to independently estimate annual natural mortality rates apart from the stage-based model. Three separate methods were used, allowing for valuable insights into model performance.

Oyster growth varies seasonally and annually, making age determination difficult (Kraeuter et al., 2007). The assessment relies on a novel stage-based population model that also includes the dynamics of habitat. Inclusion of habitat allows for prediction of increases due to shell supplementation programs, but otherwise habitat is assumed to decline based on contemporary analyses of Bay-wide habitat degradation. An equally novel model for determination of fishing mortality reference points is developed. It also models habitat changes but in a conceptually different manner (i.e., density dependent dynamics). In contrast to the population model, the habitat state variable in the reference point model can increase in response to an intrinsic rate of growth as well as habitat supplementation. The Panel expressed some reservations about these differing conceptual bases and the use of stage-based model results as input to the biological reference point model. At the current level of oyster abundance these concerns are considered minor but future assessments should attempt to reconcile these differences. Moreover, reliance on external parameters derived from the literature and use of strong penalty functions in the estimation methods should be reviewed in future assessments.

Restriction of the assessment period to 1999 onward precludes the ability to estimate historical abundance levels, say in the late 1890's. Any such exercise is unlikely to yield precise estimates. Moreover, it can be argued that the environmental and ecological conditions that obtained nearly 150 years ago are unlikely in 2018 onward and are therefore not useful as biomass targets. Despite these limitations and differences in size limits over time, it is relevant to note that the estimates of market oyster abundance of about 300 million market oysters in 2018 is less than 10% of the quantity ***harvested*** annually before 1900.

The Assessment Team used the minimum abundance estimated between 1999 and 2017 as the abundance threshold for each NOAA code. This was based on the assumption that if abundances as low as those observed previously have not so far caused a population crash, they should be sufficient to prevent a crash in the future. This approach is often used in European assessments where the lowest observed abundance provides an estimate of the threshold for recruitment failure. Recruitment failure per se is unlikely in oysters but the Review Panel agreed that this threshold criterion appropriately balanced the information content of the assessment with a longer term perspective on abundance. The Review Panel concluded that a determination of the carrying capacity of Chesapeake Bay under prevailing environmental conditions (particularly disease prevalence) is beyond the scope of existing data sources and scientific understanding.

Terms of Reference 4 and 5 (see Appendix 2) were particularly challenging and the Assessment Team did an exceptional job of assessing the efficacy of various management policies implemented by the State. Where data allow, the quantitative impacts of these measures are explicitly incorporated into the model's interpretation of habitat changes, exploitation estimation, and reference point determination. The MD DNR has in place a number of long term studies that may ultimately allow for quantification of the utility of these measures and improvements in approaches. Rigorous monitoring will be essential. Well designed and monitored management experiments within NOAA code areas may prove useful for improving management interventions. The Review Panel recommended that sanctuary and habitat plantings, and aquaculture operations should not be considered a part of the standing stock of the fishery, nor part of the reproductive capacity of the fishery. Doing so will overestimate the spawning potential, and the contributions of sanctuaries, habitat plantings and aquaculture are as yet unclear and likely vary greatly by source.

15.1.5 Research Recommendations

The Review Panel endorsed the recommendations of the Assessment Team. In addition, the Panel's recommendations include:

1. Implement an annual dockside monitoring program to establish the number of small oysters being caught per bushel, and to estimate the size and number of oysters per bushel for each NOAA code over the course of a fishing season.
2. Conduct experiments to estimate of dredge efficiency for the survey.
3. Compare existing independent experimental estimates by gear type of abundance within some NOAA codes

4. Consider re-running the Bayesian model using data from the patent tong survey in key areas if and when sufficient data are available. Results could be compared to the existing estimates of mortality from the Bayesian model that uses the fall dredge survey.
5. Conduct a detailed examination of trends from survey based disease incidence and rates of natural mortality. Any evidence of disease resistance or changes in virulence should be thoroughly examined.
6. Examine potential retrospective patterns in terminal year estimates of biomass and fishing mortality to address uncertainty concerns for management.
7. Review the performance of the assessment and reference point models by examining likelihood profiles for key parameters and the influence of penalty functions on parameter estimates. Further simulation testing would be valuable.
8. Improve the habitat dynamics model, possibly allowing for regeneration of habitat through population growth and replenishment of shells through natural mortality of live oysters.
9. Develop an assessment model with the capability of estimating the reference point parameters internally.

In summary, the Review Panel commends the Assessment Team for a job well done. The assessment is an important step forward for improving the management of oysters in Maryland. Further work on improving data, enhancing monitoring, conducting experiments and model structure will improve our understanding of oyster dynamics.

15.2 Section 2.0 Introduction

15.2.1 Call for Stock Assessment

Nearly 150 years ago the Chesapeake Bay was the world's leading producer of oysters. Overexploitation, changes in water quality and the introduction of diseases led to a century long decline with recent landings at only about 3% of historic peaks (Rothschild et al., 1994; Kennedy et al., 2011). The decline in the resource has led to initiation of several long-term monitoring studies, a variety of intensive efforts to rehabilitate the resource (Kennedy et al. 2011), and many concerns about the health of the Chesapeake Bay ecosystem. In 2016 the Maryland General Assembly passed the Sustainable Oyster Population and Fishery Act which in turn led to a request for a formal assessment of the Maryland oyster stock. The request included explicit terms of reference (Appendix 2) and a review by an external independent panel of experts (this report).

The stock assessment was completed and a report was prepared by a stock assessment team consisting of shellfish scientists, statisticians and stock assessment experts from Maryland DNR and the University of Maryland Center for Environmental Science (UMCES). A complete list of participants in the stock assessment project is provided in Appendix 3. The Assessment Team's report (MD Department of Natural Resources, 2018) represents the first formal assessment of the Maryland oyster population. As such it provides the quantification of current stock size, rates of exploitation and target biological reference points. Current **stock sizes** are estimated to be less than 10% of the peak historic landings, suggesting that the decline in landings mirrors a comparably precipitous decline in overall abundance.

This report provides a record of the review conducted August 27 to 29, 2018 in Annapolis, MD. The Review Panel considered a wealth of written material and presentations made by the Assessment Team. The Assessment Team responded to our written and oral questions and provided additional analyses when requested. We have attempted to chronicle the sequence of events leading up to the assessment, the materials reviewed, the details of the discussions during the meeting, and our primary findings and recommendations. This report has been reviewed by the Assessment Team for factual errors but opinions and conclusions of the Review Panel have not been altered.

15.2.2 Section 3.0 Background Material

Planning for the assessment review began on June 12, 2018 with a conference call between the Assessment Team (MD DNR and UMCES), and Atlantic States Marine Fisheries Commission (ASMFC) staff, and the Review Panel. Lynn Fegley provided an overview of the request for review and gave a general overview of expectations and deliverables. Three weeks prior to the review meeting the Review Panel received the draft report from Assessment Team on August 6. The computer code for the assessment model, data files and various output files were shared with the Review Panel on August 10. On August 14, another conference call for all parties was held to discuss final preparations and to request initial feedback from reviewers to the Assessment Team. Additional supporting documentation was provided to the Review Panel on August 14 and 15. Review Panel members sent their written questions to the Assessment Team between August 15 and 24. A consolidated list of questions from the panel is presented in Appendix 5. These helped the Assessment Team to focus on key concerns of the Review Panel.

The meetings were held in Annapolis MD at the offices of the EPA on Monday (8/27) and Tuesday (8/28) and at the MD DNR offices on Wednesday (8/29). Support from the Assessment Team was excellent providing expertise in oyster biology, survey operations, and fisheries. The Assessment Team was well prepared and gave detailed effective summaries of the data and models. Moreover, they rapidly responded to detailed questions about the report and to conduct additional analyses requested by the Panel. All decisions about the data quality and model structure were open and transparent.

The facilities were highly conducive to a thorough review of the materials, and there were no glitches in computer service or presentations. Onsite refreshments and lunches allowed the Team to effectively work without interruption.

15.3 Review of Activities

15.3.1 Proceedings Day 1

The meeting convened at 9:00 am on August 27 with opening remarks and introductions of the Assessment Team, and the external review panel. The agenda listed in Appendix 1 was modified slightly to allow flexibility in time allotments for various topics. Paul Rago gave a brief overview of the importance of the peer review in stock assessments and an outline of the how presentations and discussions would proceed.

The meeting was opened with a thorough summary of the data used in the assessment. The primary fishery-dependent data sources included Dealer Buy tickets, Harvester Reports and bushel tax receipts. The Assessment Team applied rigorous data quality standards to ensure that these data could be consistently interpreted over the assessment time series. Comparison of landings by dealer buy tickets and harvester reports in 2009 and 2010 suggested dealer records were underestimated by 10%; overall landings were adjusted by this ratio for the period 1999-2017. When asked about the sensitivity of the overall assessment to this underestimation correction, the Assessment Team noted that sensitivity analyses were performed testing higher and lower corrections, neither of which altered the trends in the assessment greatly. The Review Panel noted the value in this sensitivity analysis and requested that the results be conveyed within the report. The historical records for landings were important determinants of the spatial resolution of the assessment. Although landings are generally taken from known oyster beds, the historical landings are only recorded at the resolution of NOAA codes. These subareas comprise one or more oyster beds and have varying productivity depending on their salinity and temperature regimes.

Oysters are harvested by multiple gears which vary in magnitude of landings both regionally and temporally. A total of 21 port samples were taken from catch sourced from several different NOAA code and gears. The primary objective of the port sampling was to estimate the number of oysters harvested per bushel as a basis for converting historical landings recorded in bushels to numbers of oysters. The relatively small sample size was probably insufficient to attribute differences in bushel counts to area or gear but they probably reflect the overall range of possible values. The samples were taken at one dealer location on a single event, yet encompassed a wide range of values of oysters per bushel. It was noted that variations observed by area and gear may also occur over time. Based on the port samples, the Assessment Team used the overall average of 227 oysters per bushel. The Assessment Team suggested there was little evidence of high grading in oyster landings, owing to the absence of a price differential for small and market oysters.

Commercial effort was measured in terms of number of trips, number of licenses per trip, and number of hours fished per trip. Multiple licenses can be used on a single trip. The number of hours fished was found to be an unreliable measure of effort because trips are not often reported to the hour, so relative abundance from commercial landings was measured as catch per license per trip.

During the course of the fishing season, CPUE often declined sharply, thereby allowing application of standard Leslie-Davis depletion models. Standard regression methods were modified to account for the truncation of catch rates when trip limits were attained. This occurred early in the season when oysters were more abundant. Simulation studies, reported but not reviewed by the Panel, suggested that the censored regression models were relatively unbiased. Owing to the typical magnitude of within season declines and discussions with harvesters, the Assessment Team felt confident that the declines in CPUE were attributable to true changes in abundance and not regulations or fishing behaviors. Nonetheless about 15% of the depletion estimates had positive slopes, possibly attributable to changes in catchability over the season.

Depletion analyses were used primarily to estimate exploitation rates which were defined as the ratio of total catch over the initial population size. Where two or more gears were used in a NOAA code area, the estimates were summed if the fishing activity was known to be spatially distinct. Otherwise the gear with the most number of years and valid estimates were used for a particular area. A paired t-test of differences exploitation rate estimates between gears was reported but deemed inconclusive since none of estimates could be validated.

The discussion continued with a description of the fishery-independent data. A fall dredge survey using fixed stations began in the 1930s but sampling methodology was not consistent overtime. The most reliable and consistent survey data began in the late 1990s and tow distance was standardized in the mid 2000's. The standard survey sampled an average of 261 bars with an average of 347 samples per year. To account for missing samples over time, relative density estimates were obtained by using a mixed effects GLM model with a negative binomial distribution. In general, the GLM predictions differed little from the raw means.

A patent tong survey began in 2010 in sanctuary areas of the bay. This survey uses a stratified random design based on substrate type. These data were used to inform the assessment in some NOAA code areas.

Discussion moved to a description of the stage-specific population model used. This model includes three size classes of oysters, spat, smalls (submarket adults) and markets (oysters greater than 3"). Oyster age and growth is difficult to determine and few datasets exists. Transition probabilities among size classes were obtained from a Von Bertalanffy growth function collected by the Paynter Lab who measured size at age from oysters reared in a hatchery and planted at a known time/location in sanctuaries and managed reserve areas. The model assumes 15% survival of 2mm spat, and that all spat transition to smalls by the subsequent year, and about 60% of smalls transition to markets in the subsequent year. The transition rate is estimated in the model but is constrained by a penalty function in the likelihood function. The Review Panel notes that these transition probabilities are consistent with those listed in Rothschild et al (1994) for the Chesapeake, and Munroe et al (2017) for the Delaware Bay.

The stage-specific model assumes 15% annual survival of 2mm spat to the "small" oyster stage. This assumption is based on data from hatchery plantings of spat-on-shell at many restoration sites over several years. This estimate of spat survival may be an overestimate for wild spat, and for planted spat in general as Harris Creek is a low salinity region where predation losses and other mortality factors may be low. One natural mortality rate is applied to small oysters, transplanted seed and market oysters in the stage-specific model, regardless of location within the bay, meaning no spatial pattern in mortality is applied across NOAA codes.

An exponential decay of habitat is applied to the stage-specific model. This habitat loss function is based on data provided in Rothschild et al. (1994), and assumes the loss estimated previously continues through today. The rate of habitat loss is estimated in the model at approximately 4% per year from 1980 onwards, but this value is highly informed by a penalty function in the likelihood function. Habitat within a NOAA code is credited in the model when shell or spat-on-shell is planted in that region.

Maryland law requires three reference points in its fishery management plans. These include abundance and exploitation rate limits, as well as a target exploitation rate. The Assessment Team introduced a model designed to estimate the exploitation reference points for each NOAA code in the oyster fishery.

The reference point model was a modified from the production model developed in Wilberg et al. (2013). The model calculated a carrying capacity that was based on the amount of available habitat. Habitat is increased by production from living oysters, planted oysters (spat-on-shell, or transplanted seed from other areas) and other added substrate. Habitat was decreased by habitat loss, which occurred at a constant rate. The model estimated an intrinsic rate of population increase and habitat production. These were used to generate estimates of the exploitation rate expected to generate maximum sustainable yield and the maximum limit on sustainable exploitation rate.

The Assessment Team used the minimum abundance estimated between 1999 and 2017 as the abundance threshold for each NOAA code. This was based on the assumption that if abundances as low as those observed previously have not so far caused a population crash, they should be sufficient to prevent a crash in the future. The Review Panel noted that the use of 2017 as a terminal year for this time window may be problematic given that 2017 is the year being assessed.

The Panel noted that these reference points represent a substantial advancement in the oyster management for Maryland, where no previous reference points existed. The Panel pointed out that, although it is common practice in fisheries, the separation of the stock assessment model and reference point model is not ideal and can introduce some potential statistical problems. For example, the reference point model uses the outputs of abundance and habitat from the stock assessment model as “data”, which can be problematic (Brooks and Deroba 2015). The Panel recommended that in future assessments, the stock assessment and reference point models should be combined, although the Panel recognized that the available data does not currently support such a model.

The first day’s review finished with several recommendations from the Panel to the Assessment Team to provide an overview of the general principles governing the model development, and some insights into the path of model development. The Panel also requested a presentation of the Bayesian mortality model.

15.3.2 Proceedings Day 2

Per the Reviewers’ request, the Assessment Team opened with a summary of the basic tenets governing the stock assessment model development. The Assessment Team tried to use as much relevant data as possible, including the dredge survey, patent tong survey, estimates of stage based natural mortality rates, and matching of fishery dependent estimates of fishing mortality. Generalized models were applied to 36 separate spatial units with varying degrees of underlying productivity and fishery characteristics. Despite the availability of high resolution information on the locations of oyster beds and knowledge of current and historical management practices the finest resolution possible was the NOAA code area because of reporting characteristics of the fishery.

The stage-based model used in the assessment was based on earlier work by Wilberg et al. 2011. Additional model features were included to incorporate box count mortality rates, indices of natural mortality, and survey data from relatively unbiased patent tong surveys in some areas. Wilberg provided additional information on how habitat was modeled in the assessment model and its utility in evaluating the effects of management interventions and hatchery supplements to the stock.

The Review Panel noted that the dredge survey improvements since 2005 may ultimately lead to improved use of the fall survey as a measure of swept area abundance. Owing to historical survey practices and recording procedures, the long-term data cannot be used for direct abundance estimation.

Kathryn Doering presented her Bayesian model for estimation of natural mortality. The model incorporates information from the dredge survey on the numbers of live and recently dead (box) oysters in both the small and market size groups. The model allows for use of external information from experiments, and addresses the important time series information for box dynamics.

Dead oysters do not remain as 'boxes' permanently, and the two valves that make the box will disarticulate from one another over time. This rate of disarticulation is not well defined in general but is likely to vary widely with biological and environmental characteristics, and little data from the Chesapeake exists upon which to constrain model parameters. Uncertainty information from the model suggests that durations of boxes estimated from experiments may not be representative of durations observed in fishery operations. Overall the Assessment Team and the Review Panel felt that incorporation of additional information into the natural mortality estimator represented an important advance.

At the Panel's request the Assessment Team reviewed some of the stage model results in more detail focusing on model runs with poor model performance. It was expected that such results would provide insights into model performance when data conflicts were present. For the most part, the NOAA codes in which poor model performance occurred (#5, 82, 129 and 331) were ones where fishing is no longer occurring and data are sparse or non-existent. In general, the Panel felt these additional investigations demonstrated reliable model performance over a range of data quality conditions.

The definition of overfishing depends on a parameter, *d*, the intrinsic rate of habitat loss, which is based on Wilberg et al. (2013) and is near the value estimated in Powell and Klink (2007). In many cases, this parameter drives the intrinsic rate of population increase (*r)* to its lower limit (zero). As the *d* parameter is fixed rather than estimated, the Panel requested additional sensitivity runs of the model to estimate the effects of a 50% reduction and 100% increase in that parameter.

The Panel considered the Assessment Team's progress in answering TOR 4 and 5 at length. Both of these TOR were considered difficult to answer because of data limitations and uncertainty about key biological processes of reproduction, settlement, post stock growth and mortality, and hydrological processes. For example, larval behavior in the water column interacts with tidal transport and salinity gradients in ways that are poorly understood and difficult to measure. Consequently, quantification of how hatchery plantings affect spawning potential is challenging.

The day concluded with a review of the questions submitted by the Panel in writing prior to the meeting (Appendix 5). In particular, it was important to determine that all questions had been satisfactorily answered. The Panel agreed that all of the questions had been addressed. A number of recommendations regarding the content and formatting of the Assessment Report were made by the Review Panel.

15.3.3 Proceedings Day 3

The Panel met in closed session at the MD DNR offices in Annapolis from 9:00 a.m. to noon to write initial conclusions. At noon, the Assessment Team and MD DNR staff met with the Review Team to summarize the initial conclusions of the Review Panel for each Term of Reference. The meeting adjourned about 1:30 pm with some closing remarks by the Chair on a job well done by the Assessment Team and a review of the timetable for preparing a final report.

15.4 Summary of Terms of Reference

1) Complete a thorough data review: survey data, reported harvest and effort data, studies and data related to population rates (growth, mortality and recruitment), available substrate, shell budgets, and sources of mortality.

   Panel Conclusion: *The Assessment Team met this TOR.* Overall, the Assessment Team did an outstanding job of reviewing the existing data sources. Their thoughtful and scholarly reviews paid close attention to the data collections procedures and how they may have changed over time. Each change was considered with respect to its implications for deriving consistent measures of scale and trend. The uncertainty of observations was also evaluated where possible. Collectively these approaches led to a focus on more recent data (i.e., 1999 onward) rather than the very long time series of catch records. While this approach restricts inferences to a more contemporary history, it preludes inferences that may be less reliable and driven by sharp contrasts in landings and strong, but ultimately unverifiable assumptions about historical productivity. The Review Panel agreed with the decisions of the Assessment Team.

   The Review Panel did note that relatively recent time series on disease trend data are provided in the report at a Bay-wide resolution. In some cases, the fall dredge survey collects these data at NOAA code level. It may be useful to examine disease status and trends at NOAA code level in the future.

   a) List, review, and evaluate the strengths and weaknesses of all available data sources for completeness and utility for stock assessment analysis, including current and historical fishery-dependent and fishery-independent data.

   Panel Conclusions: *The Assessment Team met this TOR.*

   - As noted above, the Assessment Team did an exemplary job of reviewing the available data sources. Appendix I of their report contains a thorough review of the data sources available for fishery-dependent and fishery-independent data. For each data source, strengths and weaknesses of the data, utility for the assessment and important changes in how data were collected (if any) through each time series are listed.

- The fall MD DNR dredge surveys for abundance, mortality and disease provide important data for the assessment. The MD DNR patent tong survey in the spring also provides useful data including shell heights.

- The fishery-dependent data includes dealer buy tickets, harvester reports and bushel tax receipts. These three time series are generally coherent but differ in terms of the spatial resolution of each. Those strengths and weaknesses are well laid out in Appendix I, and described in the report.

- Appendix II of their report has details time series of oyster seed (both hatchery and wild spat) and shell plantings by source
    - For some plantings, in particular those being done for restoration, other sources may provide additional information content that could be explored. This may be the case if these plantings are being monitored by other groups apart from DNR; however, we note that data sources outside of DNR may have sampling error that may be problematic so should be reviewed cautiously.

b) Identify the relevant spatial and temporal application of data sources.

Panel Conclusions: *The Assessment Team met this TOR.* All stock assessments are ultimately limited by the availability of data collected consistently over time and at a relevant spatial scale. This principle is especially relevant to sessile species. For this assessment, the limiting factor was the recording of removals as the NOAA code level of spatial resolution. Finer scale information at the resolution of oyster beds would be desirable but is not possible. The Review Panel does not endorse imputation methods that might result in finer spatial resolution but would definitely increase the overall uncertainty and ultimately, the utility of the assessment for management.

- Appendix I contains a review of the data sources available for fishery-dependent and fishery-independent data. For each data source, the spatial and temporal extent of coverage are listed.

c) Document changes in data collection protocols and data quality over time.

Panel Conclusions: *The Assessment Team met this TOR.*

- An excellent summary of changes in survey design and methodology is provided in Appendix I.

- The Assessment Team provided detailed information about differences among surveys and their objectives which provide important context to these data sources and how they can be used.

- In the case of the fall dredge survey, an important change in protocol is missing from Appendix I. The survey prior to 2005 did not record swept area, likewise records of overfull dredge hauls show approximately 20% of tows overfilled the dredge. Since 2005, swept area is being tracked and therefore the time series since 2005 may be useful for swept area calculations and abundance estimates.

d) Justify inclusion or elimination of each data source.

Panel Conclusions: *The Assessment Team met this TOR.*

- The Panel had minor concerns regarding some decisions for exclusion, e.g. 50 samples per year in CPUE, or the number of years of data when multiple gears present in depletion analyses.

- Swept area estimation from 2005 onward might have been used but the time series was not long enough. Comparisons with the patent tong survey might be useful as patent tong samples index absolute abundance on the bottom. Some caveats and concerns regarding the patent tong survey is the design in terms of sampling repeat sentinel stations versus a random sample design.

2) Develop stock assessment model or index based approach that estimates biological reference points and document status of the stock relative to estimated reference points. To the extent possible, quantify sources of uncertainty within model.

Panel Conclusions: *The Assessment Team met this TOR.*

- The Panel endorsed the reference point model and stock assessment model as useful for estimating biological reference points and determining the status of the stock.

- The reference point model developed by the stock Assessment Team incorporated habitat, which is unusual in fishery stock assessment, but necessary for oysters in Maryland. The Review Panel noted the innovative nature of the reference point model and endorsed it for management, but noted some potential improvements for future stock assessments, particularly with regard to the use of habitat.

- The stock Assessment Team developed a custom stock assessment model that leveraged the available data on oysters in Maryland. Most modern stock assessments are implemented using existing model frameworks, but that was not an option in this case. Oyster stock dynamics, including the dependence on existing habitat for successful recruitment, as well as the peculiarities of the fishery and the data, required a model specifically tailored to Maryland oysters. The Review Panel found this approach to be innovative and well adapted to the available data.

- The separation of the reference point model and the stock assessment model was necessary due to limitations of the data, but introduced some concerns for the Review Panel. These included the use of output from the stage-structured model as data in the reference point model. This can be problematic because there is uncertainty, typically some degree of autocorrelation, and potentially retrospective bias in model output, that may not be accounted for. Incorporating the reference point model into the stage-structured stock assessment model, perhaps implementing a cultch dynamics component, would be an improvement, but would require additional data.

- The Panel expressed some reservations regarding the modeling of habitat in the stock assessment model. The model uses an exponential decay function to model habitat, which results in a predisposition to decline. Likewise, the model does not include dead oysters nor cultch as habitat, although these are measured and estimated elsewhere. The panel noted that while this is currently appropriate given limitations in the data, it may not sufficiently represent future conditions if the stock abundance were to grow to the point that live, dead, and cultch creates habitat that is self-sustaining.

- The stock Assessment Team applied a general model framework across each of the 36 NOAA code regions in the Maryland oyster fishery, rather than tuning individual models to each region. The Review Panel noted that this approach is preferred because it reduces the probability of undetected aberrant model behavior. Tuning the model to individual NOAA codes could produce instabilities that would be inefficient to diagnose. In addition, tuning to each NOAA code would likely require unique modeling choices for each region, which would have to be justified and documented. These alternative approaches would have complicated the stock assessment and review considerably.

- The stock Assessment Team chose to use global penalty functions to constrain the estimation of model parameters, rather than directed tuning in problematic regions. While the Review Panel agrees that this was the better approach, the implications of relaxing the penalty constraints were not fully explored during the review and may bear further investigation in the future.

- The Panel had some difficulty interpreting the various q (typically referred to as catchability) parameters in the stock assessment model. The dimensionality of these parameters might be determined with some additional work, which would help with interpretation and might lead to some useful diagnostic tools, such as describing a reasonable range for each q parameter given the data.

- Among the few tuning choices made by the stock Assessment Team were the imposition of fixed effective sample sizes on the fishery dependent depletion time series and the mortality time series. The fishery depletion data were given a relatively low weight such that the model was not forced to precisely match them. This decision was justified by evidence that the depletion data were probably less precise than they appeared. The natural mortality time series was given a relatively high weight, such that the stock assessment model was forced to fit them better than it otherwise would have. This decision was justified by comparison between the mortality index and an external Bayesian model designed to estimate natural mortality in Maryland oysters. The Panel was not shown sensitivity runs demonstrating the effect of alternative weighting decisions. These should be explored in the future.

3) Compare estimates of stock status generated by index and model-based approaches. Justify selected approach.

Panel Conclusions: *The Assessment Team met this TOR*.

- The Panel notes that regardless of the method used, the conclusions regarding stock status in most NOAA codes are clear. Abundances in many NOAA codes are near time series low values and harvest rates are likely above long term sustainable levels.
- Index methods for estimating natural mortality indicate lower natural mortality than the stock assessment model in some NOAA codes. This may result from mortality due to harvest occurring before the fall dredge survey in these areas (the model assumes that harvest occurs after the survey). This theory was not analytically explored however, and the Panel could not verify the root cause of the discrepancy. The Panel notes that the Assessment Team did attempt to align the model estimates with the index-based estimates of natural mortality by increasing the relative importance of the natural mortality index in the estimation of model parameters.
- An index based abundance trend was presented in Appendix IV, and used to support the choice of spatial scale in the assessment. The index-based trends were however, not directly compared to model estimates of abundance. A direct comparison between these components of the assessment report might be useful in evaluating this TOR further in future assessments.
- The fishery depletion time series was down-weighted in the estimation of model parameters. This contributed to a misfit between the (index based) depletion estimates of harvest rate and the model estimates of harvest rate in some NOAA codes. In other NOAA codes the fit was quite close. The Panel noted that the decision to down-weight the depletion index, and thus sacrifice fit to the data, was justified by inconsistencies in the data.

4) Include sanctuaries and restoration efforts in sanctuaries in the development of stock assessment approaches.

Panel Conclusions: *The Assessment Team partially met this TOR.*

- Sanctuaries are difficult to evaluate since many of the key biological processes are poorly understood. The approaches used by the Assessment Team are innovative and appropriately utilize available data. The Review Panel did not recommend specific alternative approaches.
- In an ideal data world it would be appropriate to partition removals between sanctuary and open areas within NOAA codes, and model consistently within those boundaries. However, data limitations preclude such an approach within the NOAA code areas. Hence the dynamics of oysters within areas that contain sanctuaries represent a mixture of habitats that may be improving due to

hatchery plantings, substrate improvements or protection from harvest, and habitats that are subject to exploitation. Strictly speaking, this compromises the utility of the assessment model estimates of exploitation because part of the population is not subject to harvest.

- The Panel notes that sanctuaries are often implemented for the purpose of establishing subpopulations of oysters that are intentionally excluded from fishery access. Because of this distinction, we question the utility of including sanctuaries in the calculation of assessment metrics as they are, by definition, not part of the fishery. The one practical issue with parsing sanctuaries that were traditionally part of the fishery is the problem of retrospectively adjusting the fishery-dependent and fishery-independent time series. For new sanctuaries, that were never part of a fishery, this should be an easier distinction.

5) Examine how hatchery plantings (aquaculture and public fishery) impact spawning potential in the fishery.

Panel Conclusions: *The Assessment Team met this TOR to the extent possible. This was an exceptionally difficult problem for reasons described by the Assessment Team. In general it is difficult to track fate of hatchery plantings and several different life stages stocked. A variety of methods were used to stock hatchery plantings which further complicates the analyses. For these reasons the Assessment Team heavily qualified their conclusions. The Panel concurs with Assessment Team's concerns.*

- The Panel had difficulty with wording of the TOR, in particular, it is unclear how hatchery-reared oysters can contribute directly to the spawning potential of the animals that are part of the fishery. We limit our discussion here to the 'spawning potential in the fishery' and make a distinction below between the role that may be played by aquaculture oysters (those sourced from hatcheries and placed on privately owned farms) versus the role played by hatchery sourced oysters that are used to supplement the wild fishery.

- Aquaculture oysters are livestock (or shellstock in this case) and not part of the public fishery. They should have no bearing on the spawning potential of the oysters in the public fishery. There is no mechanism that we are aware of, by which the presence of a farm, and livestock therein, will increase the fecundity or fertilization success of the oysters in the public fishery.

- In terms of hatchery plantings on public fishing grounds, these spat-on-shell will contribute to future conditions, assuming those plantings survive to reach maturity. These data are tracked in both the habitat and live oyster portions of the model and in the fall dredge survey, so as these animals grow into size classes that can spawn, their contributions would/could be accounted for then along with the other wild set oysters in the fishery.

- In general, the Review Panel believes that larval contributions from hatchery-sourced oysters, whether in sanctuaries or fished grounds, and from farms should not be considered part of the spawning potential for the fishery. These sources cannot be verified as regular and reliable sources of larvae and accounting for them will only overestimate the capacity of the stock Bay-wide.

- Despite the challenges, the Assessment Team made some accounting for standing stock in both aquaculture and hatchery sourced contributions to the fishery and compared those to the standing stock in the fishery. The Panel found the assumptions made in these calculations to be acceptable given the circumstances, and appropriate caveats were made in the report.

15.5 PEER REVIEW SUMMARY CONCLUSIONS

The Review Panel endorses the methodologies used by the Assessment Team to assess the Maryland oyster stock. The modeling approach addresses the essential features of oyster biology and historical data collection procedures. Our endorsement hinges on several unique aspects of the assessment, including:

- Evaluation of Existing Data Sources
  - The Assessment Team conducted a thorough review of all existing fishery independent data for evaluation of trends.
  - Historical information on landings were evaluated with respect to changes in reporting practices over time and spatial resolution.
  - Data sources were integrated into overall assessment where possible. When such integration was not possible, results of analyses apart from the assessment model were compared with model results.
- Biological Processes
  - Atlantic estuarine oyster stocks are strongly influenced by the presence of two lethal diseases, MSX and Dermo. These diseases vary in intensity with both temperature and salinity.
  - Oyster growth and mortality due to predation likewise varies with temperature and salinity.
  - Environmental gradients in the estuary imply that the dynamics of the resource will vary spatially.
  - The result of variable natural mortality can be tracked by monitoring of empty, but articulated shells (known as boxes). Newly articulated boxes (those without fouling) can provide an estimate of recent mortality, whereas old boxes (those still articulated but covered with fouling organisms) are a less reliable estimate of mortality because of uncertainty and variability in the time it takes for a given box to disarticulate.

- Removals
    - The Yates study from nearly a century ago provides a rigorous quantitative description of historical benthic habitats and a basis for defining the desired level of resolution for removals. Unfortunately, data on removals by bar do not exist. The analysts have appropriately used the existing data at the resolution of NOAA code area.
    - The analysts have restricted the assessment time series to a period where data quality issues are minimized.
    - Concerns about the use of commercial CPUE data are well founded since it is difficult to derive a meaningful measure of effort that can be used across all assessment areas and over all time periods.
- Monitoring
    - The assessment benefits from a long time series of fishery-independent data monitoring studies that allow tracking of relative abundance.
    - As these methods have changed and improved over time, the Team has used appropriate measures to restrict the data to a period where consistent inferences are possible.
- Assessment Model
    - The assessment model addresses the key biological processes and removals in a realistic way.
    - The model explicitly accounts for the role of spatial and temporal variation in natural mortality.
    - The stage based model is consistent with the historical data on landings and fishery independent survey monitoring.
    - Assessment model results are compared with index models.
    - The spatial units are all assessed under a consistent but flexible modeling framework. This allows for rapid analyses of overall stock condition while accounting for spatial and temporal variation. While it may be argued that models for individual NOAA codes might be improved with detailed tuning, the Panel feels that this could ultimately lead to overfitting and inconsistencies among spatial units.
- Biological Reference Points
    - A study from nearly a century ago provides a rigorous quantitative description of historical habitats and a basis for potential rebuilding. Any rebuilding will require habitat enhancement, and would benefit from biological shifts such as relaxation of natural disease mortality rates, improved recruitment and continued improvement to water quality.
    - The rationale for excluding biomass rebuilding targets is justified because the known peak abundances likely occurred more than 150 years ago when

Chesapeake Bay was a very different ecosystem and diseases were not a dominant factor in the oyster life history.
    - The biological reference point for exploitation appears to be a useful starting point for characterizing the relative magnitude of contemporary fishing mortality. Future modeling refinements may improve this but we agree with the Assessment Team that substantial improvements are not possible in the short term.
    - Parameters that are assumed constant in the current model should be tested regularly and updated as appropriate. In particular, parameters that imply habitat declines consistently over time (in both the assessment and BRP models) with only limited biological contributions to habitat growth (such as the inclusion of dead oyster shell in habitat capacity) should be updated as new information becomes available.
- Effects of Sanctuaries, Habitat Augmentation, and Hatchery Plantings
    - The Assessment Team did an exceptional job of assessing the efficacy of various management policies implemented by the State.
    - Where data allow, the quantitative impacts of these measures are explicitly incorporated into the model's interpretation of habitat changes, exploitation estimation, and reference point determination.
    - The MD DNR has in place a number of long term studies that may ultimately allow for quantification of the utility of these measures and improvements in approaches. Rigorous monitoring will be essential. Well designed and monitored management experiments within NOAA code areas may prove useful for improving management interventions.
    - Sanctuary and habitat plantings, and aquaculture operations should not be considered a part of the standing stock of the fishery, nor part of the reproductive capacity of the fishery. Doing so will overestimate the spawning potential, and the contributions of sanctuaries, habitat plantings and aquaculture are as yet unclear and likely vary greatly by source.

15.6 PEER REVIEW RESEARCH RECOMMENDATIONS

The Review Panel endorsed the recommendations of the Assessment Team (Appendix 4). In addition, the Panel's recommendations include:

1. An annual dockside monitoring program is recommended to establish the number of small oysters being caught per bushel, and to estimate the size and number of oysters per bushel for each NOAA code over the course of a fishing season. Samples should be collected randomly of the catch coming from a range of bars, NOAA codes, gear types and time of the fishing season as all of these factors may generate differences in the catch composition.
2. The stage based model assumes that recruitment is independent of stock size, whereas the BRP model assumes recruitment is proportional to stock size as a

time invariant scalar and reduced by the ratio of abundance to a time varying carrying capacity. Developing an assessment model with the capability of estimating the reference point parameters internally is desirable. The Panel is well aware that this is a significant challenge, unfulfilled in many stock assessments worldwide.

3. Experiments should be performed to estimate of dredge efficiency for the survey. This may be done with coordination of patent tong and dredge surveys at known locations. These data could help in transforming the fall dredge survey data to swept area abundance estimates.
4. In some NOAA codes, relative oyster abundance is estimated independently for more than one gear type. It may be informative to investigate how often do those estimates disagree, and by how much? These comparisons may help in understanding reliability of the estimates that are being generated from each gear type.
5. The BRP model implicitly assumes that Dermo and MSX are here to stay and that future dynamics will be dominated by them. Evidence of trends in these diseases could be important for reference points. Detailed examination of trends from survey based disease incidence and rates of natural mortality should be conducted. Any evidence of disease resistance or changes in virulence should be thoroughly examined.
6. Many assessment models exhibit patterns of over or under estimation of biomass and fishing mortality rates in the terminal year. Reasons for this bias are not completely known but are often attributed to changes in an underlying rate that are not accounted for in the model. This tendency can often be detected by examining the pattern of terminal year estimates as the time series is progressively shortened one year at a time and by comparing those estimates with the estimates from the entire time series. An analysis similar to this would be useful for oysters and could reveal whether further precaution was warranted when utilizing exploitation rates for evaluation of management measures.
7. The recommended reference points may be subject to a shifting baseline bias. In particular, the abundance reference points are predicated on the assumption that time series minima have not previously induced population crashes within a NOAA code, and should therefore be sufficient to maintain abundance over time in the future. This assumption is somewhat problematic for two reasons. The first reason is that some of the NOAA codes reached time series minima in the last or near to last years of their respective time series. The resilience of populations at these abundances has not been demonstrated by continued existence over time. The second issue is a logical circularity induced by the separation of the exploitation rate model and the stock assessment model. The reference point model for exploitation reference points describes abundance as a function of available habitat. The stock assessment model describes habitat as an exponential decay function, such that habitat this year is greater than habitat next year (assuming artificial habitat additions do not swamp the decay rate). Therefore, by inference between the reference point model for exploitation and the stock

assessment model for population abundance, the resilience of a NOAA code to historical abundance minima will not be the same as the resilience of that NOAA code in the future, because the habitat in the future will be less than it was. The Panel recommends that merging the stock assessment and reference point models and internally estimating an abundance threshold based directly on model results would be preferable.

8. The assessment model introduces many technical innovations, appropriately considers the information content of existing data sets, and incorporates many external sources of information for model parameterization. The resulting penalized likelihood function is complicated and may induce unexpected variations in model parameters. Further simulation testing of model performance and application of likelihood profile analyses to examine model performance in the vicinity of the optimal values is desirable.
9. Improve the habitat dynamics model, possibly allowing for regeneration of habitat through population growth and replenishment of shells through natural mortality of live oysters.
10. The Bayesian model could be re-run using data from the patent tong survey in key areas if and when sufficient data are available. Doing this would eliminate the need for efficiency correction in that model because patent tongs are assumed 100% efficient. The patent tong survey also has sentinel sites surveyed over time. Results of this could be compared to the existing estimates of mortality from the Bayesian model that uses the fall dredge survey.

15.7 Documentation

15.7.1 Peer Review Referenced Citations

Brooks, Elizabeth N., and Jonathan J. Deroba. When "data" are not data: the pitfalls of post hoc analyses that use stock assessment model output. *Canadian Journal of Fisheries and Aquatic Sciences.* 72(4): 634-641.

Bushek, D., S.E. Ford and I. Burt. 2012. Long-term patterns of an estuarine pathogen along a salinity gradient. J. Mar. Res. 70:225-251. DOI: 10.1357/002224012802851968

Kennedy, V.S., Breitburg, D.L., Christman, M.C., Luckenbach, M.W., Paynter, K., Kramer, J., Sellner, K.G., Dew-Baxter, J., Keller, C. and Mann, R., 2011. Lessons learned from efforts to restore oyster populations in Maryland and Virginia, 1990 to 2007. Journal of Shellfish Research, *30*(3): 719-731.

Kraeuter, J.N., S.E. Ford and M.J. Cummings 2007. Growth measurement in oysters: A comparison of methods. Journal of Shellfish Research, 26:479-491.

Munroe, D**.,** S. Borsetti, K. Ashton-Alcox, and D. Bushek. 2017. Early post-settlement growth in wild Eastern oyster (*Crassostrea virginica* Gemlin 1791) populations. *Estuaries and Coasts*. 40(3): 880-888. DOI: 10.1007/s12237-016-0185-y

Powell, Eric N., and John M. Klinck. Is oyster shell a sustainable estuarine resource? *Journal of Shellfish Research.* 26(1): 181-194.

Rothschild, B.J., Ault, J.S., Goulletquer, P., Heral, M. 1994. Decline of the Chesapeake Bay oyster population: a centure of habitat destruction and overfishing. *Marine Ecology Progress Series.* 111: 29-39.

Wilberg, M. J., Livings, M. E., Barkman, J. S., Morris, B. T., & Robinson, J. M. (2011). Overfishing, disease, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay. *Marine Ecology Progress Series*, *436*, 131-144.

Wilberg, M. J., Wiedenmann, J. R., & Robinson, J. M. (2013). Sustainable exploitation and management of autogenic ecosystem engineers: application to oysters in Chesapeake Bay. *Ecological applications*, *23*(4), 766-776.

15.7.2 Reports

Maryland Department of Natural Resources. 2018. A stock assessment of the eastern oyster, *Crassotrea virginica*, in Maryland waters of Chesapeake Bay. Draft Report for Peer Review, July 2018. Annapolis MD. 341 pages.

http://dnr.maryland.gov/fisheries/Pages/oysters/Oyster_Stock_Assess.aspx

Oyster Metrics Workgroup**. 2011.** Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries. Report to Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program.
https://www.chesapeakebay.net/channel_files/17932/oyster_restoration_success_metrics_final.pdf

15.8 Peer Review Appendix 1: Agenda

Oyster Stock Assessment Peer Review.
EPA Fish Shack: 410 Severn Ave., Annapolis, Maryland August 27- August 28, 2018
Maryland DNR - August 29, 2018

Panelists: Dr. Daphne Munroe, Rutgers University; Dr. Paul Rago, Woods Hole Massachusetts; Dr. Dan Hennen, Woods Hole Massachusetts

Day 1 - August 27

9:00 - Coffee, continental breakfast

9:15 - Welcome and introductions

The intent for this meeting is to provide opportunity for plenty of discussion and iterative exploration of questions pertaining to the model and its results.

9:30 - Presentation focusing on TOR1 - data. Includes context of assessment time frame, treatment and processing of data for input to assessment, development of priors for model, and experiments of box disarticulation rates.

11:00 - Questions / discussion

12:00 - Working lunch (provided)

12:30 - Presentation of model fit and diagnostics including sensitivity analyses

1:30 - Questions / discussion

5:00 - Adjourn

Day 2 - August 28

9:00 - Coffee, continental breakfast

9:15 - Resolution of any issues from previous day

10:00 - Presentation of biological reference points focusing on TOR2

11:00 - Questions from peer Review Panel

12:00 - Working lunch (provided).

2:00 - Overview presentation of index based approaches and comparison of utility of index vs model-based approaches, focusing on TOR 3.

2:30 - Questions / discussion

4:00 - Discussion of TORS 4 and 5.

5:00 - Adjourn

Day 3 - August 20

Change of venue *- MD DNR building 580 Taylor Ave. Annapolis, Md. Conference Room C1. Please have photo ID for security desk.*

This will be a closed session for the Panel to begin synthesizing conclusions. The stock Assessment Team will be on call. Team will re-convene with Panel for overview of conclusions. I have left time for lunch, but we can be flexible depending on travel plans. I can provide guidance on quick nearby places to get a bite.

9:00 - Closed session for peer Review Panel to begin drafting report.

Stock Assessment Team - on call.

11:30 - Lunch (not provided)

1:00 Reconvene with Assessment Team to go over initial conclusions.

2:00 - Adjourn

15.9 Peer Review Appendix 2: Terms of Reference

The terms of reference for this stock assessment were developed by the stock Assessment Team based on the Sustainable Oyster Population and Fishery Act of 2016 and were reviewed by Maryland's Oyster Advisory Commission:

1) Complete a thorough data review: survey data, reported harvest and effort data, studies and data related to population rates (growth, mortality and recruitment), available substrate, shell budgets, and sources of mortality.

> a) List, review, and evaluate the strengths and weaknesses of all available data sources for completeness and utility for stock assessment analysis, including current and historical fishery-dependent and fishery-independent data.
>
> b) Identify the relevant spatial and temporal application of data sources.
>
> c) Document changes in data collection protocols and data quality over time.
>
> d) Justify inclusion or elimination of each data source.

2) Develop stock assessment model or index based approach that estimates biological reference points and document status of the stock relative to estimated reference points. To the extent possible, quantify sources of uncertainty within model.

3) Compare estimates of stock status generated by index and model-based approaches. Justify selected approach.

4) Include sanctuaries and restoration efforts in sanctuaries in the development of stock assessment approaches.

5) Examine how hatchery plantings (aquaculture and public fishery) impact spawning potential in the fishery.

15.10 Peer Review Appendix 3: List of Participants

Name	*Affiliation*	*Email*	Dates at Review		
			8/27	*8/28*	*8/29*
Review Panel					
Paul Rago	Mid Atlantic Fisheries Management Council Scientific and Statistical Committee	Paulrago22@gmail.com	X	X	X
Dan Hennen	NOAA Fisheries, Northeast Fisheries Science Center	Daniel.hennen@noaa.gov	X	X	X
Daphne Munroe	Rutgers University	dmunroe@hsrl.rutgers.edu	X	X	X
Assessment Team					
Mike Wilberg	University of Maryland Center for Environmental Science (UMCES); Professor	Wilberg@umces.edu	X	X	X
Kathryn Doering	UMCES; Graduate Research Assistant	Kdoering@umces.edu	X	X	X
Trey Mace	UMCES/Maryland DNR; Assistant Research Scientist	Marvin.Mace@maryland.gov	X	X	X
Lynn Fegley	Maryland DNR; Director Stock Health, Data Management and Analysis Division	Lynn.Fegley@maryland.gov	X	X	X
Alexei Sharov	Maryland DNR; Stock Assessment Scientist	Alexei.Sharov@maryland.gov	X	X	X
Linda Barker	Maryland DNR; Research Statistician	Linda.Barker@maryland.gov		X	
Mitch Tarnowski	Maryland DNR; Shellfish Biologist - surveys	Mitch.Tarnowski@maryland.go	X	X	X
Frank Marenghi	Maryland DNR; Shellfish Biologist – commercial fisheries	Frank.Marenghi@maryland.gov	X	X	X
Amy Larimer	Maryland DNR; Shellfish Biologist	Amy.Larimer@maryland.gov	X	X	X
Jodi Baxter	Maryland DNR; Deputy Director Shellfish Division	Jodi.Baxter@maryland.gov	X	X	X
Support Staff / Peer Review Panel Note Takers					
Rachel Pierce	Maryland DNR	Rachel.Pierce@Maryland .gov//	X	X	
Laurinda Serafin	Maryland DNR; Shellfish Division	Laurinda.Serafin@Maryland.gov	X	X	

15.11 Peer Review Appendix 4: Research Recommendations of Assessment Review Team

The following research recommendations were developed by the stock Assessment Team (Maryland Department of Natural Resources and University of Maryland Center for Environmental Studies) in the process of completing this stock assessment. They are arranged by category rather than in order of priority.

15.11.1 Data

- Develop mechanisms to improve accuracy and resolution of reported harvest data including bar level data, the number of licensed individuals on a vessel, and the hours spent harvesting.
- Conduct fishery dependent sampling of oyster size distribution to better quantify the number of oysters per bushel and the number of under-sized oysters per bushel.
- Conduct research to better quantify growth rates that can be incorporated into stock assessment models.
- Conduct research to better quantify natural mortality of wild and hatchery -planted spat.
- Develop a means to mark hatchery-reared planted spat so that the proportion of planted versus wild oysters can be determined in subsequent surveys.

15.11.2 Natural Mortality

- Studies to improve estimates of box decay rate. Because 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 harvest relative to when fall survey is occurring to see if explains some of the difference 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.

15.11.3 Exploitation Rates

- A survey conducted just prior to and directly following the fishery would provide a direct means to estimate exploitation within a given year and could provide a snap shot of conditions relative to selected reference points.

15.11.4 Habitat

- Conduct more ground-truthing surveys on unverified current SONAR data so that existing sonar data can be accurately utilized in determining oyster habitat.
- Develop comprehensive maps of current oyster habitat within the Maryland portion of Chesapeake Bay.

- Studies designed to quantify the rate of habitat decay would better inform the assessment and reference point models; and would contribute to development of a shell budget.

- Develop a mechanism to better understand how shell plantings contribute to habitat and how habitat is quantified.

- Conduct research examining how harvest gears impact oyster habitat.

15.11.5 Sanctuaries and Spatial Scale

- The contribution of sanctuaries to oyster population and fishery dynamics within a NOAA code is an important question for management and will require finer scale spatial survey data within and outside of sanctuaries as well as more accurate bar-level harvest data than is currently available.

- Conduct research to help elucidate 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 stock assessment model that incorporates feedback among areas rather than the current assessment which treats each NOAA code as though it is an isolated population.

15.11.6 Assessment Model

- Incorporate a shell budget into stage structured assessment in order to allow internal estimation of biological reference points.

- Continue to improve the stock assessment model based on lessons learned from this assessment and as new information becomes available.

- Examine alternative spatial structure for stock assessment.

15.11.7 Biological Reference Points

- Fishing reference points for oysters should account for the accretion and loss of shell since oysters produce their own habitat that is required for population growth. Developing a spawner per-recruit type analysis that instead of egg production represents shell per recruit. Research is needed to determine the ratio of shell per recruit that is suitable for target and threshold reference points.

- Research on target levels of abundance including biological limits of abundance (e.g. necessary conditions for successful fertilization).

15.11.8 Aquaculture

- Developing an aquaculture data base that tracks plantings, standing stock and harvest of diploid and triploid oysters at the NOAA code spatial scale would be improve the model's ability to quantify the contribution of aquaculture plantings to the population dynamics within the NOAA code.

15.12 Peer Review Appendix 5: Composite Questions from Review Panel

Last updated August 25, 2018

Munroe comments noted with italics
`Hennen comments noted in typewriter font`
Rago comments noted in regular font

ADDRESSED 8-27-18

Longevity

1. How important is the lack of longevity estimate (p.2)? Given the high Z's it seems unlikely that MD oysters would have much chance to realize their natural lifespans, but it knowing the maximum age might inform/constrain realized biological reference points. Given information on the incidence and lethalilty of the diseases, could you compute an expected lifespan in the absence of other sources of mortality?
2. *Regarding longevity: the cited longevity (20 years) is likely a pre-disease condition, meaning that in today's oyster world of disease and fishing, we would rarely see oysters older than 7 years. As an example, Harding et al. (2010) saw very few age 3+ oysters, and none older than that, in her Piankatank survey. Oysters are notoriously hard to age as well. I wonder how important this might be here and whether it should be constrained to a lower value for longevity given that oysters exist today in a world that likely constrains the oldest age classes to somewhere closer to 7.*

Growth—none

Disarticulation

1. Based on experimental evidence the box disarticulation rate reveals mu_d=0.51 and sd=0.04, p. 27. This would imply a low probability of exceeding 1 yr of hinge. P(d>~1) would be at 1-cdf_PHI(0.51+12*0.04). The results from the posterior distribution suggest the model fits better if the half life is twice that measured in the experiments (Fig 22). Does that seem reasonable? You mention that boxes may not survive the dredging process. Quick test--If observed box catches were doubled to account for the breakage of half of the shells during dredging, what is the impact on the posterior of the disarticulation rate?
2. *The corrections for boxes persisting longer than one year is a difficult issue. Mortality estimates from observations of boxes is important. Your model gives you an estimate that 67% of boxes disarticulate in one year. We have 4 years of data across the Del Bay stock that shows that the disarticulation rate varies spatially and by season. It appears much more complicated than initially thought. It seems that some boxes disarticulate rapidly, while others persist. How sensitive is your model to the result that about 2 thirds disarticulate within one year?*

Natural Mortality

1. *There are cases where it is assumed natural mortality occurs outside of the fishing season (during summer), however, it is also noted (see page 22, top paragraph) that disease mortality occurs during winter. I think it is true that you see natural mortality year round. How consequential is this to the assumption in the model that natural mortality does not occur in winter when the fishing season occurs.*

Habitat

1. Does the fixed d=0.16 (p. 60) compare favorably to the multiple d estimates by area estimated in stage-based model (p. 38)?
2. What is effect of assumed exponential decline in habitat in the assessment model? (p. 38, second eqn.) Why does habitat appear to have small positive slopes in some cases? Is this the effect of shell planting?

3. Is there a conflict between the habitat trajectory on page 38 for the stage based model and the habitat model for BRP on page 60? In the stage based model, H_y is independent of stock size and it inexorable march to oblivion is only a function of time, a time invariant constant (d), and intermittent replenishment. Shouldn't the potential for self-generated habitat (as function of density) exist in both models?
4. *I would like to have some discussion about the conversion of the calculated oyster habitat to areal habitat. What are the data that inform this conversion? If I understand, you use 20 live oysters/m2 as a max value? This is definitely not a max in terms of ecological carrying capacity. As an example, in Delaware Bay we measured, on average across the entire stock, 56 oysters/m2 in 2017. Our highest density grids were in excess of 380 oysters/m2. Additionally, there would be more than just the live oysters on the bottom providing habitat – dead shell, other cultch etc. Can the data from the tong survey be used to help inform this conversion?*
5. *Shell and habitat are certainly important in oyster dynamics. Having habitat doesn't necessitate catching spat – catching spat is a magical mystery. Nonetheless, I think it is good that you are trying to find a way to include habitat in the assessment model. In the habitat calculation on page 60, I don't see a term for dead oyster shell or shell planted with or without spat? Dead oysters are pretty effective habitat and shell persists. Should be included.*
6. Your insights on habitat will be helpful. The habitat component of the stage based model is pretty much going along for the ride in the Likelihood fcn since it is not coupled to stock dynamics. As you note, the creation of new habitat from natural mortality (ie box density) does not affect the trajectory of H_y. I'll need to triple check this but that's what it looks like now.
7. *Section 1.2 discusses importance of substrate and the fact that siltation can be a problem. This is most certainly true and is known by baymen who plant shell. There are many anecdotal cases where it is noted that dredging will help to clean cultch, allowing it to catch set more effectively. This should be noted here as it pertains to the idea that silt is a problem.*

Data Issues/Decisions

1. Spatial questions (p. 18)
    a. Do any of the Yates bars span multiple NOAA codes?
    b. Do any of the sanctuary areas span multiple NOAA codes?
    c. Are harvesters free to move about all NOAA code areas?

d. Is there any evidence that the CPUE within a NOAA code follows an Ideal Free Distribution? Highest local concentrations fished first followed by rapid decline in average CPUE as fleet spreads to less profitable areas. This would tend to give overly pessimistic results for depletion (high exploitation).

2. Any relationships between the natural mortality estimates, box densities and the disease incidence estimates from the disease bar survey? (p.35)
3. *An annual dockside monitoring program is probably worthwhile to help you pin down number of small oysters being caught per bushel, and to estimate the size and number of oysters per bushel. Appendix 3 gives you some useful information, but sample size is small and only captures one point in time during the season. We find in our dockside monitoring that count/bushel and size/bushel varies through the season as the fishery targets different beds, and can be pretty different one year to the next.*
4. *Harvest reporting adjustment assumes 10% underreporting. The assumption here is that the first 2 years of harvest reports represent 'true behavior'. I am not convinced that is the case and would argue that the tax values may be a better representation of 'true behavior'. Could the tax be used to represent the harvest timeseries, with harvest allocation proportional by NOAA code based on harvest reports of buyer tags?*
    a. *Either way, the sensitivity analysis relative to the 10% adjustment should be shown.*
5. *You estimate, using the model, differences in efficiency between live oysters and boxes. We have data from multiple gear efficiency experiments that put some hard numbers on this. Observations show that it varies, and that dredge gear will catch boxes more efficiently than live oysters, and cultch more efficiently than both. Here is a table from the most recent assessment document.*

Table 1. Catchability coefficients for oysters, boxes, and cultch by region. The entire time series since 1953 was reconstituted using these catchability coefficients as of 2016 SAW.

	Catchability Coefficient		
Region	**Oyster**	**Box**	**Cultch**
Very Low Mortality	2.41	6.82	9.11
Low Mortality - *Round Island*	2.41	6.82	9.11
Upper Arnolds, Arnolds	8.26	12.69	25.79
Medium Mortality Transplant	8.26	12.69	25.79
Medium Mortality Market	8.26	12.69	25.79
Shell Rock	8.26	12.69	25.79
High Mortality	2.82	5.10	8.46

Mortality Model

Is it a little strange that M has high variance early in the time series and then stabilizes later in all codes? It could be that this model is tracking real and interesting changes in M bay wide, or could this be an artefact of the modeling?

Assessment Model

1. Model building process
    a. Will likely need some description of evolution of model by the assessment team.
        i. Nat Mortality model

ii. Assessment model

iii. BRP

b. The current text gives some insights about the assessment teams deliberations. A short description/presentation on your tortuous path might prevent annoying reviewers from asking about things you already did.

2. Quick check. If timing of survey is cause of model conflict and gear efficiency is low, how much effort would be required to create an exploitation rate of 35%? (p. 111)
   a. Simple calculation. Given density estimates from model and estimated efficiency, how much effort would be needed to obtain observed yield? Does this relate well with what is known about fishing activity (e.g., #trips, #person hours, etc.)?
3. Differences in timing of surveys are mentioned as a source of model conflict (p. 41-42). Could the Ricker Type 1 fishery be a source of problem (vs Type 2)?
4. The disparity between the Stock Model estimates of M and the Bayesian natural mortality model (p. 41, Fig 61-66) suggests that the model is reducing the abundance by increasing M. Since M and q are inversely related it would be valuable to look at likelihood profile over a range of fixed q.
5. The stage based model assumes that recruitment is independent of stock size, whereas the BRP model assumes recruitment is proportional to stock size as a time invariant scalar and reduced by the ratio of abundance to a time varying carrying capacity. I see the utility of using coupled logistic models for the BRP but shouldn't some of the rationale be extended to the stage based model?
6. Effect of additive constant (0.001) in p.39 bottom eqn. Such constants often cause mischief in estimation and it may we worthy of a quick test or two.
7. *Section 2.2.2 explains how exploitation and fishing mortality are calculated. I am not sure I agree with two assumptions for this.*
   a. *One is that removals are large enough to cause a decline in abundance, or CPUE. Is this always the case? If I follow the logic here, the assumption is being made that because harvesters catch their max daily rate most often at the early part of the season, that means that CPUE is dropping off. I can think of other reasons that this behavior may be seen that are not related to CPUE. One is market driven. The fishery in Delaware Bay is primarily a summer fishery, and the fishery ends around the time that MD opens. That would mean that there is market incentive to fill the gap left by NJ catches. Also, the weather and conditions would be best early, and would decline as you move into December, Jan/Feb. We see a similar trend in clam fisheries. And I would guess that the fishers who have general permits would move onto fishing other stocks (stripers start in December in MD??) and so effort would shift because other stock dynamics, and not because of declines in CPUE. Have any of these alternatives been explored through conversations with fishers, or other means?*
   b. *The constant catchability assumption is likely invalid. Summer harvest is closed, and that is when oysters grow. Reefs would aggregate during that time and that means catchability declines. So when the fishery starts, that is when catchability would be at its lowest, and as the fishery works beds, the catchability tends to increase.*
8. *You calculate separate efficiency ratios for different life stages. This would be a correct approach for animals that live independently (are not attached to one another), however oysters attach to one another, so what we actually see is that efficiency is the same for all life stages. You are equally efficient at catching a live large oyster as you are a spat because the spat is probably*

attached to a big piece of shell or a live oyster. Can the efficiency for all life stages be constrained to a single efficiency, and if so how does that affect results?

9. *Section 4.2, model outputs. Many of these exploitation rates seem very high. Is this because of the small scale that it is being estimated on (the NOAA code region). How might these look if exploitation was estimated regionally, or stock-wide? Do fishers move among beds or NOAA code areas within a season, or from one year to the next? For example, would they hit one area very heavily, then move to another place in a subsequent year leaving that heavily fished area fallow?*
   a. *Overall this gets me wondering whether it is worth exploring ways to group NOAA codes that better capture broader fishing activity and resource use. Maybe regionally?*
10. *The assessment model estimates higher mortality than the box counts or the mortality model. This is interesting, and it is something that we also see in the Delaware Bay assessment. You would see this result if there are unaccounted sources of mortality out there. This may happen with small oysters as small boxes may pass through the dredge, or as you point out for boxes that disarticulate quickly. In our experiments, we have noted up to 20-40% disarticulation within the first 60 days after death, so definitely could be a source of this discrepancy. You might also see this discrepancy if you have growth that means some oysters skip a stage, or stay too long in a stage. This could happen if growth is slower than expected (small oysters remaining small), or faster (spat jumping all the way up to market size). Thoughts on whether that may be the case?*
    a. *Growth is a very difficult thing to get at with oysters. In research recommendations you propose to study this to get a better idea of realized growth rates in your system. This will be highly variable by bed and year. It is worth doing, but it takes a good deal of work and needs multiple years of experiments.*
11. *You calculate an exploitation rate that accounts for planted oysters (pg. 62). In it, you assume that mortality is the same for wild and planted oysters. I think that would be ok to assume if plantings are seed that were wild collected elsewhere, but not if they are hatchery oysters (spat-on-shell). Likewise, using wild estimates of growth and mortality for aquacultured oysters may not be valid. Farmers may use selected lines to produce spat that would grow/survive differently, or they may tend their plants such that growth is different.*
    a. *I suggest adding this as a caveat in the list on page 68.*
12. I would like to see a little more on the sensitivities that were done. That section of the report is sparse and a little confusing. How much were parameters changed? Why choose to change those parameters? Why choose the performance metrics that were chosen? Are the histograms reflecting some sort of time series average, terminal year point estimates, something else? Model stability is hard to judge from this section.

13. As Paul notes the fit to the CPUE data is not great in many NOAA codes and it appears that is on purpose, as there is mention of sensitivity testing being used to down weight the CPUE trend data in the likelihood. I am a little surprised that the fit to CPUE makes any difference given it's tiny contribution to the total likelihood. Am I missing a scaling component somewhere? Perhaps I am looking at the wrong likelihood component?

14. I am unclear on how habitat is used in the model. It is the denominator in the density index, but what data is informing the model? There must be something as d is estimated (and appears to be fitting to something).

15. I expect we will hear a little more about the q's? I am confused about how to interpret them. Should there, for example, be a tighter correspondence between the R in the mortality model (describing the ratio of catchability between lives and boxes) and the ratio of q_sm,mk to q_B? Particularly since q_sm,mk and q_B penalized if they diverge very much? Probably this isn't important, as the quantities appear to serve different purposes, but I would appreciate some help in wrapping my brain around the differences!

16. Is recruitment constrained? Other parameters not discussed in the report? The implementation section doesn't talk much about the set up. I will attempt to dig into the TMB code on Sunday, but I am not an expert.
17. Is it a little weird that the patent tong survey densities are fit better than the dredge survey? I worry some about the fixed survey design coupled with changing habitat.

18. There don't seem to be any results from the fall dredge standardization model presented.
19. The model also creates a disparity between the experimental results for disarticulation and the posterior dist estimated by the model. This probably occurs since the model needs to match the observed box counts.

Index Methods

1. The natural mortality model and assessment model are state-of-the-art state-space models but the depletion analyses use simple linear regression estimators (p.70). While these are good starting points, the better MLE estimators (Gould and Pollock 1997, Seber 1973) are not used. Wholescale revision is not recommended but it might be worth checking a few examples and seeing if it makes a difference. If exploitation is low and observation error is high then neither method will work very well. Theoretically the MLE methods are better, but in practice there may not be too much difference!
    a. Could devise MLE with common N_o and multiple q_i for each gear.
    b. In the DeLury, Ricker and Leslie-Davis models, N_o and q_i have strong negative sampling covariance. This occurs since the intercept is the product of the two parameters of interest.
    c. Error structure is not IID because variance of binomial varies as removal continues. Multinomial, or multinomial with inflated variance may be more appropriate.
    d. Gould, W. R. and K. H. Pollock. 1997. Catch-effort maximum likelihood estimation of important population parameters. Can. J. Fish. Aquat. Sci 54: 890-897.
    e. R code = https://rdrr.io/cran/fishmethods/man/deplet.html I haven't worked with this code but Gary Nelson wrote it so it is probably pretty good.
    f. Could you provide a little more detail on your 50 report threshold for estimation feasibility (p. 71)
2. *An important piece of data that is missing is an estimate of dredge efficiency for the survey. Do you have any data for this? In our work in Delaware Bay, we have found that this is critical to estimate, and it can vary spatially and (importantly) with oyster density making low density*

estimates problematic. I have provided Jason Morson's paper about this issue and would like to discuss this in terms of the abundance estimates being made here for low density samples.

3. *In some cases, where possible, for a given NOAA code, abundance is estimated independently for gear types. How often do those estimates disagree, and by how much?*
4. The disparity between the model estimates of exploitation and the depletion analyses suggests some concerns with model driving down abundance by inflating M during the "M-only" part of the year.

5. 2. If exploitation is as high as suggested, then how much effort would be required to reduce overall abundance by that amount given expected dredge efficiency?

6. The authors provide the depletion estimates (ie slopes) in the .csv file "DepEst..." but the units of the slope are not specified. These have a phenomenological interpretation (ie known dimensions) so we should pursue this. See above.

Reference Points Model

1. The BRP model implicitly assumes that Dermo and MSX are here to stay and that future dynamics will be dominated by them. I agree with this decision. Is there any evidence of trends in these diseases that might be important for the reference points?
2. How often did model parameters hit penalty bounds? How are these runs treated? It looks like the q parameter in the BRP model (p.60) approaches the boundary often (Table 13, p 104-5). High values of q would tend to increase the dynamic $K=H_y$ in second eqn on p. 60. This in turn would lead to higher rates of population growth because of the N_y/H_y term gets smaller. Taken together, wouldn't this tend to result in higher u_{MSY} and u_{crash} values (p. 62)?
3. I am a little concerned about shifting baselines. I don't have a better solution, but some of the abundance limits are being set in the terminal year (in codes experiencing a one way trip to the toilet), which doesn't seem like a great way to do business. If I am interpreting correctly shifting baselines may also be a problem for the exploitation rate reference points depending on where r and q (production rates of oysters and habitat) come from.
4. Should there be a linkage between M_y and habitat production?

Hatchery Contributions

1. *On page 69 you note that it is likely that based on overall abundance, because wild oysters are much more abundant they will contribute more to spawning capacity of the stock and lease oysters would be negligible. This would be valid if the density on the bottom is the same across both types. But your wild oyster density seems very low (you mention a max of 20/m2). A leaseholder would likely plant at a higher density on a lease so that it is easier to tend etc. The higher density may mean that fewer oysters overall could be more effective spawners because in closer proximity fertilization efficiency goes up. Do you have data on this?*

Picky Notation/Format Issues

1. Picky notation/format Issues
    a. Multiple uses of n
        i. Use n as an index for observation on page 24
        ii. Use n as number of planted market oysters (p. 62)
    b. Multiple uses of q
        i. Slope of DeLury depletion estimator= catchability (P. 14)
        ii. Catchability estimates in Assessment model (p. 40-41, p. 100).
        iii. Penalty function for catchability
        iv. Intrinsic rate of habitat production (p. 60)
        v. Use q_h = 1/20 as conversion factor for Yates estimate (p. 60)
        vi.
    c. Use H_hat_t in second equation on p. 60 but use H_hat_y in next line.
    d. It would be useful to have units of parameters. E.g., Table 12 for q, d etc. Some of these look like there may be some scaling factors eg x 100, etc.
    e. Figures 47-60 seem to have a formatting problem. Can the labels be aligned better?

- *Perhaps Mitch Tarnowski could attend the meeting at least for a period during which we will discuss data in case there are questions or discussion that he could help with.*
- *In section 2.2.1, there is reference to depletion analysis in 6.1, but I think it is actually found in 2.2.2.*
- *In figure 5, could the NOAA codes on the x-axis be grouped by region and have the region names listed below?*
- *In figure 7, why are there 2 colors being used for the bars?*

2. At the risk of making complicated graphs more complicated, it seems like the time series of annual landings could be added to Figures 25-60. (You left a space for it on the lower right corner!)