Haskin Shellfish Research Laboratory
Rutgers, The State University of NJ
6959 Miller Avenue, Port Norris, NJ 08349

Stock Assessment Workshop
New Jersey Delaware Bay Oyster Beds
(24th SAW)
February 7, 2022

Final Report

Editors (Haskin Shellfish Research Laboratory)
Jason Morson, David Bushek, and Jennifer Gius

Stock Assessment Review Committee
Carolina Bourque, Louisiana Department of Wildlife and Fisheries
Michael Celestino, New Jersey Department of Environmental Protection
David Eggleston, North Carolina State University
Daniel Hennen, National Marine Fisheries Service
Barney Hollinger, Delaware Bay Shellfish Council
Tim Reeves, Delaware Bay Oyster Industry
Craig Tomlin, New Jersey Department of Environmental Protection
John Wiedenmann, Rutgers University
Richard Wong, Delaware Department of Natural Resources and Environmental Control

Distribution List
Delaware Bay Section of the Shell Fisheries Council
NJDEP Bureau of Shell Fisheries
Stock Assessment Review Committee
Oyster Industry Science Steering Committee

Abbreviations Used in this Report

BRP	Biological reference point
CPUE	Catch per unit effort
Dermo	A parasitic oyster disease caused by the protozoan, *Perkinsus marinus*
HM	High Mortality region
HSRL	Haskin Shellfish Research Laboratory
LM	Low Mortality region
LPUE	Landings per unit effort
MMM	Medium Mortality Market region
MMT	Medium Mortality Transplant region
MSX	A parasitic oyster disease caused by the protozoan, *Haplosporidium nelsoni*
NJDEP	New Jersey Department of Environmental Protection
SARC	Stock Assessment Review Committee
SAW	Stock Assessment Workshop
SR	Shell Rock region
SSB	Spawning stock biomass
VLM	Very Low Mortality region
Vp	*Vibrio parahaemolyticus*
WP	Weighted prevalence, a measurement of the intensity of dermo

I. HISTORICAL OVERVIEW

The Population

The natural oyster beds of the New Jersey portion of Delaware Bay stretch for about 28 miles from Artificial Island at the upper end of the Bay to Egg Island, approximately midway down the Bay, and cover approximately 16,000 acres (Figures 1 and 2). From upbay to downbay, oysters on these beds experience increasingly higher salinity that generally corresponds to higher rates of growth, predation, disease, and recruitment.

The long-term dynamics of the surveyed population can be divided into several periods of high or low relative mortality, generally corresponding to periods of high or low levels of disease intensity (Figure 3a). MSX disease, caused by the parasite *Haplosporidium nelsoni* became a significant periodic source of mortality in 1957 (Ford and Haskin 1982) but has been of little consequence following a widespread epizootic in 1986 and subsequent spread of resistance through much of the stock thereafter (Ford and Bushek 2012). From 1969-1985, MSX and mortality were low and oyster abundance was high. Around 1990, dermo disease, caused by the parasite *Perkinsus marinus* became prevalent in the Delaware Bay and effectively doubled natural mortality rates (Powell et al. 2008b). It has been a major control on the oyster population in the Delaware Bay since 1990 although mortality has been declining since 2012 (Figure 3a).

Throughout the time series, fishing has usually taken a small fraction of the stock compared to natural mortality (Figure 3b). In addition, the whole-stock fishing mortality rate has fluctuated little since the inception of the Direct Market Fishery in 1996, hovering around 2% (Figure 3b).

In addition to disease and fishing, habitat has played a key role in driving the historical population dynamics. Oysters create their own habitat. It is well understood therefore that shell, whether as natural reef or planted, is critical to oyster population stability and growth (Abbe 1988, Powell et al. 2006). Moreover, oyster shell is not a permanent resource (Mann and Powell 2007). Chemical, physical, and biological processes degrade shell over time (Powell et al. 2006). The circular nature of the relationship between oysters and the habitat they create makes monitoring and enhancement of the shell resource critical to sustainable management (Powell and Klinck 2007; Powell et al. 2012b). For this reason, shellplanting has been employed throughout the time series when funding is available to enhance recruitment (Figures 4a, b). Shellplanting is an important management activity that adds clean substrate to oyster beds. In the Delaware Bay, it has been practiced with varying regularity and intensity throughout the Assessment Survey time series with the volumes of shell planted usually dependent on available funds (Figure 4a). Earlier programs planted large volumes of oyster or clamshell on NJ oyster beds, particularly in the 1960s and 70s. Efforts since 2003 have primarily used clamshell (quahog and surf clam), a by-product of local clam processing plants.

The Fishery

From the 19th century to 1996, the natural oyster beds of New Jersey were used as a source of young oysters (seed) that were transplanted to private leases each spring; a practice called 'Bay Season' (Ford 1997). Bay Season occurred over a period of months in the earliest days but over time, it was shortened to weeks to prevent overharvesting. From about 1953 to 1996, this transplant fishery was nominally managed by a loosely applied reference point called the '40% rule' that closed beds when the percentage by volume of oysters in a dredge haul went down to 40% (Ford, 1997). Other factors such as spat set and economics were also considered in making management decisions (Fegley et al. 2003). There were years of Bay Season closures due to MSX and dermo mortality in the 1950's, 60's, 80's, and early 90's (Figure 5).

In response to the increased number of Bay Season closures and the persistent high mortality of oysters transplanted to leased grounds, a Direct Market Fishery was created for the natural oyster beds in 1996. A quota-based system designed to sustain the abundance of market-sized oysters was implemented where market-sized oysters could be harvested and marketed directly from the twenty-three natural beds (that is, they did not need to be transplanted to leased grounds for subsequent harvest). Studies indicated that the impact of dermo decreased as salinity decreased so the twenty-three beds were grouped into six Management Regions that follow the estuarine salinity gradient of the Delaware Bay. Each region was named to reflect the dermo-related mortality rates experienced by oysters there (Figure 1). Since 1996, oysters of all sizes ('seed') in the upper three regions (VLM, LM, MMT; Transplant Regions) could be transplanted to enhance abundance on the lower three regions (MMM, SR, HM; Direct Market Regions); a management activity termed 'intermediate transplant'. Market-sized oysters could then be harvested directly from the Direct Market Regions according to the recommended quota for that year. The Shell Rock bed, which otherwise would be grouped in with the other beds in the MMM region, is separated due to its consistently high productivity. The VLM, LM, and MMT became intermediate transplant regions because oysters in these regions are generally smaller and of insufficient quality to market directly. Once moved, oysters from the Transplant regions quickly attain market quality, and enhance the quota in the receiving region. This system of transplanting and area management was instituted to make use of the whole resource and to avoid overfishing of any one region (see HSRL SAW reports 2001 to 2005).

From 1996-2000, direct market harvest generally occurred in two phases, each anywhere from 7 to 15 weeks long; April-June and September-December. Since 2001, the harvest generally begins in early April and runs through mid-November. Transplanting from the Transplant Regions into the Direct Market Regions generally occurs in late April or early May.

The total direct market harvest quota is divided by the approximately 80 licenses held. Until 2010, each license was tied to a separate harvesting boat with a limit of one license per. In 2010, rules were changed to allow a single boat to fish on up to 3 licenses. In 2014, this was changed again to allow up to 6 licenses per harvesting boat. This consolidation benefited harvesters because they no longer needed to maintain and work all boats during the season. It has also helped keep the historic, large boats maintained and working to capacity. These vessels are also needed to effectively operate the intermediate transplant program and other management activities.

The Assessment Survey

The oyster beds on the New Jersey side of Delaware Bay have been surveyed regularly since 1953, initially in response to historically low oyster abundance (Fegley et al. 2003). However, the Assessment Survey methodology and the number of beds surveyed and their groupings have changed over the years. The history of the Assessment Survey, including changes in survey methodology, are summarized in this section and in Table 1.

Survey timing and sampling gear

From 1953 through 1988, the annual oyster Assessment Survey was conducted from a small boat using a small dredge and occurred throughout a number of months in the fall, winter, and spring. In 1989, sampling was switched to a large traditional oyster boat, the *F/V Howard W. Sockwell,* using a 1.27m commercial dredge and sampling was completed in a few days. Annual sampling now occupies four days (usually not consecutive) between mid-October and mid-November.

Size definitions for oyster and spat

Prior to 1990, oysters were not measured but were categorized as groups defined as 'spat', 'yearling', and 'oyster'. Post-1990 survey protocols include measurements of yearlings and oysters permitting calculation of biomass as well as abundance. Spat were still classified based on morphology and were not measured. Boxes were not measured until 1998. Also in 1998, oysters < 20 mm (¾ in or less) that had been designated 'oyster' based on morphology, were relegated to the spat category. Although counted as oyster in the assessment, the yearling category was continued until 2002. In 2003, a 20 mm 'spat cutoff' was initiated to differentiate oysters counted as a spat (young-of-the-year recruits) from the oysters included in total abundance estimates and this cutoff is still used to separate "spat" from "oysters" in all samples.

Capture efficiency and catchability coefficients

Measurement of survey swept area and experiments to determine gear efficiency began in 1998 to allow oyster density to be estimated on each sampled grid (Powell et al. 2002, 2007). Catchability coefficients calculated from these experiments began being applied to correct for dredge capture efficiency and calculate density in 1998 (Table 2). Work from 1999 to 2003 to establish catchability coefficients for the oyster beds in Delaware Bay is described in Powell et al. (2002, 2007). Briefly, analyses of these earliest data revealed a differential in dredge efficiency between the upper (above Shell Rock) and lower oyster beds. It was also found that on average, the dredge caught oysters with greater efficiency than boxes, and boxes with greater efficiency than cultch. Concerns about the effect that natural benthic changes over time might have on dredge efficiency led to the application of different sets of catchability coefficients being applied to different parts of the Assessment Survey time series (Table 3 in Ashton-Alcox et al. 2016). In September 2013, dredge efficiency experiments were again conducted using the F/V Howard W. Sockwell and a commercial dredge, but instead of divers for the 100% efficiency numbers, patent tongs on the R/V Baylor were used (Morson et al. 2018). Spatial and temporal analyses compared the 2013 patent tong experiments to the 1999, 2000, and 2003 dredge-diver experiments (Morson et al. 2018). These updated analyses showed no statistically significant temporal trend in gear efficiency. Thus, the 2016 SARC advised that data from all experiment years be averaged together within bed groups and applied to the entire time series (Ashton-Alcox et al. 2016). The 2016 SARC also advised adoption of updated bed groupings (Table 2). Finally, in addition to the influence of region, data collected during the three separate experiments suggested that capture efficiency was density-dependent (Morson et al. 2018; Figure 6). Therefore, the continued recommendation of the SARC since 2016 is to re-evaluate capture efficiency when possible, including whether other forms of sampling (e.g., patent tongs) could be used in tandem with the survey dredge during the Assessment Survey to estimate capture efficiency each year.

Retrospective reconstruction of the time series

In 2005, by request of the 6th SARC, the Assessment Survey time series from 1953 to 1997 was retrospectively reconstructed. For a complete explanation of the time series reconstruction, see Powell et al. (2008b). In brief, survey samples were divided into volumes of oysters and cultch, and oysters per bushel[1] were calculated throughout the time series. The survey was quantified in 1998 using measured tows and dredge efficiency corrections, permitting estimates of oysters and cultch per m^2. Using the assumption that cultch density is relatively stable over time, oysters per m^2 for each survey sample can be estimated using the relationship between oysters per bushel and cultch per bushel in a sample and the relationship between the cultch per bushel and the average cultch density for each bed (see equation 3 in Powell et al. 2008b). The latter estimates were obtained by using bed-specific cultch density determined empirically from the 1998-2004 quantified surveys. Comparison of retrospective estimates for 1998-2004 (obtained using the `stable cultch' assumption) with direct measurements for 1998-2004, suggests that yearly time-series estimates prior to 1997 may differ by a factor of 2 or less. Cultch varies with input rate from

[1] The NJ bushel volume is the same as a US or DE bushel: 35 L; MD and VA bushels are larger (46 and 49 L respectively)

natural mortality and the temporal dynamics of this variation are unknown for the 1953-1997 time frame. An understanding of the shell dynamics on Delaware Bay oyster beds, however, indicates that shell is the most stable component of the survey sample supporting the assumption that a two-fold error is unlikely to be exceeded.

Survey sampling domain and strata definitions

Prior to 2005, each bed was divided into three strata based on oyster abundances. Grids of 0.2-min latitude X 0.2-min longitude were created for the primary beds and approximately 10% of them were sampled based on a stratified random sampling design (Fegley et al. 2003). On each bed, grids with 'commercial' abundances of oysters ≥ 75% of the time were called 'high'; grids with marginal or highly variable 'commercial' densities of oysters 25-75% of the time were called 'medium'; grids with abundances well below commercial densities were called 'low' (HSRL personnel; Fegley et al. 1994). Non-gridded areas between beds were never included in surveys. Information from oystermen in the early 2000's indicated that harvesting between beds was not uncommon. Therefore, from 2005 to 2008, the grid overlay was increased to cover all areas from the central shipping channel to the New Jersey Delaware Bay shoreline with every grid assigned to an existing bed. In 2007, an HSRL survey investigated the upbay extent of the New Jersey oyster resource based on bottom sediment mapping conducted by the Delaware Department of Natural Resources and Environmental Control and provided by B. Wilson (2007, personal communication). This survey resulted in the addition of three more beds termed the Very Low Mortality region (VLM) into the stock assessment (Figure 1). Earlier data for the VLM are not present in the survey database; therefore, reconstruction of its 1953-2006 time series is not possible.

From 2005-2008, all oyster beds were resurveyed except Ledge and Egg Island which have low oyster abundance with survey averages < 0.5 oysters per m^2. This resulted in a change of strata definition and survey design from that used historically (Kraeuter et al. 2006). The restratification kept the three strata system within beds and used oyster densities to determine High, Medium, and Low strata. Since 2002, a fourth 'Enhanced' stratum exists to temporarily identify grids that receive shellplants or transplants. A rotating schedule restratifies each bed approximately once per decade (Table 3, Appendix A). Analysis of many survey simulations suggested that a random survey based on High and Medium quality strata is sufficient (Kraeuter et al. 2006).

Through 2004, the Assessment Survey sampled most beds yearly although a selection of beds was sampled every other year. Since then, all beds have been sampled each year, except Egg Island and Ledge, which were sampled every other year until 2021. As of 2007, there are 23 surveyed beds grouped into six regions designated on the basis of relative oyster mortality and the current management scheme (Figure 7). Prior to 2007, the three beds at the upbay limit of the oyster resource (VLM region) were not included in the survey, thus most of the long-term time series and all of the retrospective analyses exclude them.

The Assessment

Management of the NJ Delaware Bay oyster fishery and the annual stock assessments for the oyster resource since 1999 include the participation of scientists from Rutgers University (HSRL), the NJDEP, the NJ Bureau of Shell Fisheries, members of the oyster industry, external academics, and resource managers (Table 4). The SARC is made up of nine members as follows: one member of the Delaware Bay section of the NJ Shell Fisheries Council; one from the NJ oyster industry; two NJDEP members; one from Delaware Department of Natural Resources & Environmental Control (DNREC); two outside academics; one outside resource management representative; and one non-HSRL Rutgers University representative. Appendix B lists SARC participants since the first SAW in 1999. The SAW is held over 1-2 days in the first half of February each year at HSRL following the Oct-Nov Assessment Survey and subsequent sample processing and data analyses.

Information available to the SARC to make recommendations includes: reporting on the status and trends of the stock, an estimate of current abundance relative to biological reference point targets/thresholds for each region, regional summaries, and a stoplight diagram representing the overall condition by region. The latter includes abundance, mortality, an index of recruitment, and trends in oyster disease (specifically dermo) which has been the leading cause of oyster mortality since about 1990. Control rules (management guidelines) that had been implicitly used at every SAW were articulated at the 18th SAW in 2016 (Table 5).

Discussion of stock status and recommendations from the SARC regarding the assessment, resource management, and quota allocation are reported to the Delaware Bay Section of the NJ Shell Fisheries Council on the first Tuesday in March. The Council then makes decisions about the direct market quota and any transplant and/or shellplant activities, the cost of which is borne by the industry via their self-imposed 'bushel tax'. Decisions are finalized by the NJDEP, including those made about harvest dates and area management schedule.

II. CURRENT METHODOLOGY

Bed Stratification and Resurveys

Each bed that makes up the surveyed population is on a rotating schedule that results in a restratification at least once per decade (Table 3, Appendix A). This stratification map delineates the sampling domain for that bed for all years between resurvey events. The current stratification method is based on ordering grids within beds by oyster abundance. Grids with the lowest oyster densities that cumulatively contain 2% of a bed's stock are relegated to the Low quality stratum.

This includes grids with no oysters. Those that cumulatively account for the middle 48% of a bed's stock are designated `Medium Quality' and the rest that cumulatively account for the upper 50% make up the `High Quality' stratum. The temporary Enhanced stratum includes transplant- or shellplant-receiving grids.

Assessment Survey Design

The complete extent of the natural oyster resource is divided into 0.2-min latitude X 0.2-min longitude grids of approximately 25 acres that are each assigned to one of 23 beds (Figure 7). On each bed, a random subset of grids is sampled from the High and Medium quality strata during the annual Assessment Survey to estimate abundance. Prior to the 2021 Assessment Survey, to determine how many grids to sample within a given strata, a simulation was used to estimate the strata variance for a given number of sampled grids. When the reduction in variance was minimal for a given increase in grids sampled on a stratum, the sample intensity for that stratum was deemed statistically adequate to assess the abundance. However, at the 2019 SARC, a Science Recommendation was made to evaluate whether alternatives for allocating survey effort might provide a better estimate of abundance by reducing overall survey error. After alternative methods were presented to the 2020 and 2021 SARCs, the 2021 SARC recommended adopting the Neyman optimal allocation formula for allocating survey effort going forward with the stipulation that a minimum of two grids be sampled within each strata on each bed (Kimura and Somerton 2006; Morson et al. 2021). In addition, all grids that receive enhancement (shellplanting or transplanting) are sampled each year for up to three years following the enhancement activity.

The survey dredge is a standard 1.27-m commercial oyster dredge towed from either port or starboard. The on-bottom distance for each one-minute dredge tow is measured using a GPS that records positions every 2 to 5 seconds. A one-minute tow covers about 100 m^2 and usually prevents the dredge from filling completely thus avoiding the 'bulldozer' effect. The entire haul volume is recorded. If the haul is 7 bushels or larger (a full dredge), the haul is not counted and the tow is redone at a duration of 45 seconds. Three tows are taken for each sampled grid and a $^1/_3$-bushel subsample is taken from each haul to create a composite 37-quart bushel[2].

Each composite bushel sample is processed to quantify the following: volume of live oysters, boxes, cultch, and debris; number of spat, oysters and boxes in the composite bushel; sizes of oysters and boxes from the composite bushel; condition index; and the intensity of dermo and MSX infections. As was described in the Historical Overview section, the term oyster refers to individuals ≥ 20 mm (> ¾ in) in longest dimension while the term spat refers to those < 20 mm. Market-size oysters are defined as those ≥ 63.5 mm (≥ 2.5 inches). Using total counts per bushel,

[2] The New Jersey standard bushel is 37 quarts (~35 liters).

total bushels per tow, and swept area per tow, the density of spat, sub-market size oysters, market size oysters, and boxes are estimated for each sampled grid.

Estimating Abundance of Oysters, Boxes, and Spat

To obtain the annual estimates of abundance for each region, the randomly chosen grids from the high and medium quality strata from each bed in the region are sampled as described above to generate a relative estimate of the numbers per m^2 (or density) on each grid of spat, oysters, and boxes. Catchability coefficients (Table 2), estimated by dredge efficiency experiments (see "Capture efficiency and catchability coefficients" section above), are applied to the relative density estimates to calculate corrected-density estimates for each grid. The corrected-density estimates for all grids within a stratum on a given bed are then averaged to generate stratum-specific density estimates for each bed. These estimates are then multiplied by the area of each stratum to generate the total abundance per stratum on each bed. Strata-specific abundances are summed across beds and beds are summed across regions to generate the annual estimate of abundance in a region. The quantitative point estimates of abundance in this report include the High quality, Medium-quality, and Enhanced strata only. Low-quality areas are excluded as described earlier.

Estimating Survey Error

Two potential sources of error associated with the annual abundance estimates for each region are accounted for by estimating the uncertainty using bootstrap simulation. The first source of error is variability in oyster density within each stratum, the survey error. The second is variability in the estimate of the catchability coefficient being applied to the relative oyster density measured on each grid, the dredge efficiency error. Uncertainty around the survey point estimate is calculated by conducting 1,000 simulated surveys, each with a selection of samples from each stratum on each bed and each corrected for dredge efficiency by a randomly chosen value from all efficiency estimates available within a bed's dredge efficiency group. Error in this report is expressed as the 10^{th} and 90^{th} percentiles of these simulated distributions.

Exploitation Rate Calculations and Reference Points

Exploitation, or the fraction of the stock removed in a given year by fishing, is calculated for each region and by size (market vs. total) for each year. The calculation of exploitation for Transplant Regions is done in four steps:

1. Calculate the average number per bushel (from the transplant monitoring program) moved from each donor bed in the current year.
2. Determine the total removals from a given donor bed by multiplying the average number per bushel on that bed by the total bushels moved from each donor bed.

3. Calculate total removals by region by summing all removals from all donor beds in each region.
4. Divide the total number removed for a given region by the total abundance in that region the previous year.

The calculation for market size exploitation on Direct Market Regions is more complicated than it is on Transplant Regions because (1) an adjustment needs to be made for any region that received donor oysters from the transplant program, and (2) the calculation is based on market size oysters instead of all oysters. For the Direct Market Regions, market size exploitation rate is calculated in seven steps

1. Calculate the average number per bushel (estimated from the Dock Monitoring Program and includes attached and smalls) from all direct market regions in the current year.
2. Multiply this average by the total catch in bushels in each market region to get total catch by region.
3. Calculate the proportion of oysters in each 0.5 inch size bin for each region from the size frequency data collected during the Dock Monitoring Program.
4. Distribute the total catch in numbers across the size frequency by region to get total numbers of oysters caught in each size bin by region.
5. Sum the numbers of oysters from all size bins 2.5 inches and above. This gets total numbers of markets removed by fishing in each region.
6. Subtract the total number of market size oysters transplanted to each region from this total number of removals. This gets total net removals by region.
7. Divide this number by the total market size abundance in each region the previous year.

The process described above was used to calculate the exploitation history for the fishery and in 2006, the SARC advised adoption of a quota system based on the 1996-2005 section of this history (later extended to 2006). These rates, herein referred to as Exploitation Reference Points, were thought to be from a period of conservative fishery management during a time of persistent, high disease pressure and were therefore deemed likely to provide conservative management goals. Initially, the 2006 SARC suggested reference points based on each Management Region's median (50^{th} percentile) exploitation rate. To provide flexibility in management, the SARC recommended using the 50^{th} percentile of exploitation as a base but to allow increasing exploitation to the 60^{th} percentile rate when the population was expanding or to reduce it to the 40^{th} percentile rate if the population was decreasing or appeared unstable.

Fishing activity during the 1996-2006 base time series was concentrated on the more downbay regions of the stock with limited data for the MMT and LM and none at all for the VLM since it did not enter the assessment until 2007. Data were so sparse for the Transplant Regions that it was decided that they should share the same set of exploitation rates. Because the exploitation percentiles were based on only eleven years of fishing data, they did not always transition linearly.

Therefore, the 2009 SARC made an adjustment to the original set of Exploitation Reference Points for the Transplant Regions in order to smooth a temporally biased change in exploitation rates at the 50th percentile that separated as high and low. The 50th and 60th percentile values from the original data were averaged. That average was used as the 50th percentile and the previous 50th percentile was then used as the 40th. Transitions between exploitation rates for the Direct Market Regions were similarly irregular. For example, in the HM, the change from the 40th to 50th percentile spanned a much larger range of exploitation rates than that of its 25th to 40th percentiles whereas SR's 40th and 50th percentiles were nearly identical. Consequently, if market-size oyster abundance was low on SR and other parameters were not promising, the choice for conservative exploitation was constrained to fishing below the 40th percentile.

The 2015 SARC specified a desire to have more regular changes between exploitation rates within each region. The 2016 SARC examined realized fishing exploitation rates since the adoption of the 1996-2006 baseline time period i.e., 2007-2015 and concluded that the median of the realized exploitation rates from 2007-2015 should be used as an exploitation target for each region going forward and that the target rate should be bounded by the range of realized rates from that period. This change from the previous Exploitation Reference Points to the new Exploitation Rate Reference Points is visualized in Figure 8. Further, the 2016 SARC agreed to allow percentage changes in either direction from no harvest up to the 2007-2015 maximum exploitation rate depending on stock status for each region.

SARC Exploitation Recommendations and Quota Projections

Each year the SARC will make a recommendation on the maximum allowable exploitation rate for each of the six Management Regions. This recommendation is presented to the New Jersey Delaware Bay Shellfish Council and the council makes the final decision about the highest allowed exploitation rate on each region. The total allowable quota is then the sum of the calculated bushels given a chosen exploitation rate for the three Direct Market Regions (plus additional quota as a result of any transplants from the Transplant Regions to the Direct Market Regions) allocated across the approximately 80 oyster licenses held. To estimate the total allowable quota from the SARC recommended exploitation rates, oysters in numbers are converted to projected catch in bushels using a grand mean of the average total oysters per landed bushel per year and the average market oysters per landed bushel per year from the Dockside Monitoring program time series (2004 to present). The rationale for using the grand mean is that the number of attached small oysters will vary between years depending on recruitment dynamics.

III. 2021 STATUS AND TRENDS

2021 Dockside Monitoring Program and Trends in Catch Composition

The Dockside Monitoring program counts and measures oysters at dockside from boats unloading direct market harvest. The results are used in the assessment to determine size frequency of the catch and harvested numbers per bushel so that beds can be appropriately debited, and exploitation rates can be determined (see section on "Exploitation Rate Calculations and Reference Points"). The overall average number of oysters per landed bushel in 2021 was 303 and the average number of market sized oysters per landed bushel was 275 (Figure 9). The proportion of small oysters attached to market-sized oysters remained unchanged in 2021, likely due to a third consecutive year of low spatfall events (Figures 9, 4b). The grand mean for all years, used to convert targeted removals in oysters to projected quota in bushels (see section on "SARC Exploitation Recommendations and Quota Projections) was 268 oysters.

Although catch per boat day has been historically recorded for the NJ Delaware Bay oyster fishery, it has not been presented in the HSRL stock assessment reports until recently. While in previous years landings per unit effort (LPUE) were reported as bushels landed per day (based on an 8-hour day), in this document, it is reported in bushels-per-hour. The number of hours worked, beds fished, and bushels landed are calculated from the compilation of daily and weekly captain reports as well as dealer records. In this report, LPUE is reported separately for single and dual dredge boats. There was a slight increase in both single and dual dredge LPUE in 2021 from 17 to 19 bushels landed per hour and from 28 to 31 bushels landed per hour, respectively (Figure 10). The number of vessels of each dredge type has remained mostly unchanged since 2015 (Figure 10).

Regardless of landings, the size structure landed by the fishery has consistently mirrored the size structure observed in the surveyed population. For example, in 2021, there was an increase in the frequency of 2.5-3.0-inch oysters within both fishery landings and all Direct Market Regions of the population (Figure 11). In addition, the frequency of 3.0-3.5-inch oysters within the population increased for the second year in a row. Similarly, the frequency of this size class landed by the fishery, although decreased from 2020, was high relative to previous years. Although the frequency of larger oysters (≥ 3.5 inches) within the population has remained stable over the last three years, the frequency of larger individuals landed by the fishery has decreased steadily since 2017 (Figure 12). Population size structure is just one factor that could influence changes in LPUE on the direct market beds. Other factors include license consolidation, increases or decreases in market or total abundance, and seasonal limits on harvest time dictated by *Vibrio* control rules. However, it is difficult to determine which of these is having the greatest influence on catch rates, and it is most likely a combination of factors driving trends in LPUE.

<u>*Science Advice: Determine if growth rates have changed in recent years*</u>

Understanding changes in oyster size structure is important for managing the fishery, and one way to explain these changes is by examining growth rate. A Science Recommendation carried over from the 2020 SAW was to carry out an additional year of growth experiments originally conducted in 2001 by Kraeuter et al. and again in 2018 and 2019. COVID-19 restrictions *prevented field experiments from taking place in 2020, and the final year of experiments was postponed until 2021.*

Growth racks were deployed in 2018, 2019, and 2021 to monitor incremental growth of oysters on four reefs: Hope Creek, Cohansey, Shell Rock, and New Beds. The methods for monitoring monthly and annual growth increments were first described in Kraeuter et al. (2007) for the 2001 experiment, and the same methodology was used in 2018, 2019, and 2021. Briefly, 10 oysters were collected in each of ten 10-mm size bins from each reef in April or May. These oysters were numbered with a unique ID, tethered to fishing leader, and tied off to a rack that could be placed on the bottom. Within one week of collection, oysters were returned to their reef of origin and the height of each oyster was measured monthly through November. While several experiments were lost in each year, experiments on two of the reefs where the same experiment was conducted in 2001 were monitored for all 7 months in 2018 (Cohansey and New Beds) and experiments on one of the reefs (New Beds) were monitored for all 7 months in all four years (Figure 13).

Across all sites, growth fractions indicate that smaller oysters added more shell over the course of the season than larger oysters (Figure 13b). Across all four years, growth fractions were higher on New Beds in the lower part of the Bay than on Cohansey or Shell Rock further upbay. Between years, growth fractions increased from 2001 to 2018 and again from 2018 to 2019. 2021 growth fractions on New Beds, while still higher than in 2001, were lower than in 2018 and 2019 (Figure 13b).

In 2021, HOBO® Conductivity Loggers were deployed on the Hope Creek, Cohansey, and New Beds racks. The loggers measured temperature and salinity every 15 minutes from May to November. Unfortunately, the Cohansey experiments were lost half-way through the deployment period. However, the racks on Hope Creek and New Beds survived, providing a continuous set of environmental data for the northern- and southernmost deployment sites (Figure 13a). With field experiments completed, research goals moving forward include incorporating temperature and salinity data into a growth model and to formally evaluate the impact of environment on growth.

2021 Catch Statistics and Fishery Exploitation

The 2021 direct market harvest occurred from April 5 to November 26 and included a period of curtailed harvest hours during summer months to comply with New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan.[3] Eighteen vessels (5 single- and 13 dual-dredge boats) fished the quota during 2021. The total direct market harvest in 2021 was 116,194 bushels, a 20% increase from the 96,490 harvested in 2020 (Figure 14). The harvest from the three Direct Market Regions

[3]See New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan here:
http://www.nj.gov/dep/bmw/docs/nj2021vibrioplan.pdf

broke down as follows: 40% from the HM; 36% from SR; 24% from the MMM (Table 6a). Of the 14 beds in the three Direct Market Regions, only 8 were fished during the 2021 harvest season. The HM has 11 beds, but 60% of its harvest came from just one bed, Nantuxent, which happens to be nearest to the primary landing port. Of the two beds in the MMM, 86% of its harvest came from Ship John and 14% from Cohansey.

Table 7a describes the 2021 SARC recommendations, the Shellfish Council decisions, and the achieved exploitation rates of market-sized oysters from the Direct Market Regions. Harvest on the MMM region did not require a transplant and resulted in an achieved exploitation rate of 3.00%, slightly lower than the median rate approved by the Shellfish Council. The achieved harvest on the SR region (4.66%) was higher than the Council-approved rate of 4.26% while the achieved rate on the HM region (9.34%) was lower than the maximum rate of 9.82% chosen by the Council. Both the SR and HM regions required a transplant.

With COVID-19 restrictions no longer suppressing market demand as they did in 2020, fishing effort was anticipated to return to pre-pandemic levels, and the decision was made to conduct an intermediate transplant in 2021. Table 7b describes the 2021 SARC recommendations and the Shellfish Council decisions for Transplant Region exploitation rates as well as the total oysters moved as a result of the chosen rates. A transplant took place in May 2021 from the LM region (Arnolds) to the Shell Rock region and from the MMT region (Upper Middle, Middle, Sea Breeze) to the HM region (Nantuxent and Bennies). The LM transplant moved a total of 5,400 bushels off Arnolds, resulting in an achieved exploitation rate of 0.94% instead of the targeted 0.76% (Tables 6b, 7b). The MMT transplant moved a total of 18,750 bushels off the three beds in that region, resulting in an achieved exploitation of 2.50%, just above the chosen rate of 2.46% (Tables 6b, 7b). Although the 2021 SARC approved a small transplant from the VLM region, the management decision was made not to move oysters off these beds. A detailed history of transplant activity can be found in Table 8.

Finally, across all regions excluding the VLM, fishing mortality was 2.28% relative to total oyster abundance and 3.62% relative to market-sized (≥ 2.5”) oyster abundance (Figure 15). These rates are consistent with the exploitation rates achieved since the inception of the direct market fishery in 1996 and remain low relative to natural mortality (Figure 3a).

Science Advice: Calculate bed-level exploitation; does high exploitation lead to population decline?

While the total population-level and region-level exploitation rates are low (Figure 15), the total fishing effort will often be distributed disproportionately amongst beds within a Management Region (Table 6). Therefore, a Science Advice Recommendation was made by the 2021 SARC to *calculate bed-level exploitation rates and evaluate whether at high exploitation rates there are negative impacts to the bed.*

Bed-level exploitation rates are typically near or below 2% on beds in the Shell Rock, Medium Mortality, Medium Mortality Transplant, and Low Mortality regions, however, exploitation rates on beds in the Very Low Mortality and High Mortality regions can sometimes be significantly higher (Figure 16). To evaluate whether there is evidence of any negative impact to beds at higher exploitation rates, population growth rates (calculated as the change in population size between this year and last year divided by the population size last year) were plotted as a function of exploitation rates and a linear model was used to determine whether there was a significant relationship ($p < 0.05$) between these two variables separately for each bed (Figure 17). Only one bed, Middle, had a significant trend, but the trend was positive (Figure 18). That is, population growth rate increased with increasing exploitation rate.

The 2022 SARC recommended a time series of both total exploitation rate and market-size exploitation rate be plotted, presented each year, and included with the rest of the bed-level trends in Appendix C in final reports going forward. This will allow SARCs to evaluate whether there appear to be impacts to a bed in years when bed-level exploitation rate is high relative to the exploitation rate for the entire Management Region.

<u>*Science Advice: Is there evidence that higher levels of fishing activity lead to large spatfall events?*</u>

For several recent SAWs (2019-2021) there has been discussion amongst the SARC about whether the act of fishing a bed cleans shell and promotes recruitment relative to areas that are un-fished. Therefore, a Science Advice Recommendation from the 2021 SARC was to calculate fishing intensity on each bed and evaluate whether there is any evidence that fishing activity promotes recruitment.

Fishing intensity (for each year and bed) was calculated by multiplying the total hours fished in a given year, on a given bed, by two for dual dredge vessels and by one for single dredge vessels, summing them, and dividing that by the sum of the high and medium quality area for each bed. Fishing intensity was then categorized as "none" if no fishing occurred on a bed and, for beds that were fished, as "low" or "high" if a bed was fished above or below the 50^{th} percentile of the "fishing intensity" distribution, respectively. Spatfall appeared to be influenced by fishing intensity (Figure 19). Beds that had high fishing intensity had high relative spatfall, those with low fishing intensity had medium relative spatfall, and those with no fishing had low relative spatfall. However, fishing activity is highly confounded with oyster density, abundance, and productivity (Figure 20). In other words, the most productive beds also receive the most fishing pressure. To more appropriately address this Science Advice Recommendation an experiment would need to be conducted where half of a productive bed is fished while half is not. Such an *experiment would be an expensive endeavor and would require limiting fishing access. There were no SARC recommendation to conduct such an experiment. There was, however, some discussion about how the timing of fishing might impact spatfall and a subsequent Science Advice Recommendation to evaluate this for the subset of beds that are both productive and fished regularly.*

2021 Enhancement Efforts

In 2021, there were two shell plants on NJ's Delaware Bay oyster beds funded by the NJ oyster industry through its self-imposed 'bushel tax'. A total of 48,043 bushels of crushed, unspatted clamshell were put directly on the High Mortality Region (Nantuxent). The Shell Rock region also received a total 47,566 bushels of clamshell. A formal evaluation of the increase in productivity that results from enhancement efforts (shellplanting and transplanting) was made in 2018 by comparing the change in oyster density on enhanced grids on Shell Rock to adjacent, non-enhanced grids on the same reef. Results from that analysis are in the 2019 SAW Report (Morson et al. 2019) and suggest that oyster density is, on average, 25 oysters per square meter higher on enhanced grids relative to adjacent, non-enhanced grids.

2021 Stock Status

At the 8th SAW in 2006, the SARC established target and threshold abundance references points based on the 1989-2005 time series for total abundance and the 1990-2005 time series for market abundance for each region. It was concluded that this time period represented the scope of oyster population dynamics in the present climate and disease regime. Targets for each region were therefore calculated as the median values of total and market-size oyster abundance and the threshold was calculated as ½ the target. The only exception to this was on the VLM region where the time series only just began in 2007. The 2017 SARC designated targets and thresholds for the VLM as the 75th and 50th percentiles respectively of its 2007-2016 time series.

A total of 238 grids were sampled to estimate the status of the stock in 2021 (Figure 21). The total abundance was again below the target, though the market abundance remains well above the target (Figures 22.1a, b, 22.2a, b, 22). Natural mortality was relatively unchanged from 2019 to 2021 (Figure 22c) and remained low relative to the current decade and the 'dermo era' that began in 1990 (Figure 3). Spatfall was low for the fourth consecutive year relative to the large spatfall estimated in 2016 and 2017 (Figure 22d).

The three Intermediate Transplant Regions (VLM, LM, MMT) all have similar acreage (Figure 2). Figures 24-26 summarize the 10-year trends of the stock in these regions. The uppermost region, VLM, was at the highest abundance in 2017 since it was first surveyed in 2007 (Figure 24a).

However, for two consecutive years (2018 and 2019), the region experienced an influx of freshwater over a long duration resulting in massive die-offs (34% mortality and 35% mortality, respectively in 2018 and 2019; Figure 24d). Natural mortality declined some in 2020 and again in 2021 relative to the previous two years. This reduction in natural mortality has likely contributed to the increase in both total and market abundance between 2020 and 2021. However, both total and market abundance remain well below the threshold (Figure 24c, Table 10). Total abundance on this region has been demonstrated to increase quickly during periods of low natural mortality and high recruitment (Figure 24a, d, e; 2013-2016). However, this region also has a very slow growth rate compared to regions further downbay, and it will therefore likely take some time before the market abundance moves above the threshold again (Figures 24c, 30, Table 10). In addition, while the 2021 spat set in the VLM region is up from 2019 and 2020, it was still low relative to the large spatfall that occurred in 2016 and 2017 (Figure 24e). Dermo remained nearly undetectable (Figure 24b) and no oysters have been transplanted from the VLM region since 2013 (Figure 24f).

As was the case on the VLM region, natural mortality on the LM region declined slightly in 2021 relative to 2018-2020, but a second consecutive year of significant decline in sub-market abundance resulted in total abundance falling near the threshold (Figures 25a, c, d, 30). Market abundance declined slightly relative to 2020 but remains above the target as it has been for all of the recent time series (Figure 25c, Table 10). Recruitment and natural mortality in the LM region were both low again in 2021 (Figure 25d, e). After the Shellfish Council chose not to transplant oysters from the LM region in 2020 due to impacts of COVID-19 on market demand, a transplant did occur in 2021 resulting in an exploitation rate of 0.94% (Figure 25f).

Total abundance, market abundance, recruitment, and natural mortality on the MMT region was relatively unchanged from what was observed in 2020 (Figures 26a, c, d, e). This resulted in little change in where the stock (total abundance and market abundance) stands relative to the target and threshold reference points (Figures 26c, 30, Table 10). As indicated above, the Shellfish Council chose to forego a transplant in 2020 despite the SARC recommendation that one could occur. However, oysters were again moved from the MMT region in 2021 resulting in an exploitation rate there of 2.50% (Figure 26f).

Direct market harvesting occurs in the two largest (HM, MMM) and the smallest (SR) regions (Figure 2). Figures 27-29 summarize the 10-year trends of the stock in these regions. Natural mortality on the MMM region continues to be low relative to the recent time series (Figure 27d). Market abundance on this region remains above the target in 2021, although total abundance declined slightly (Figures 27a, c). The status of both relative to their reference points remains unchanged from 2020 (Figures 27a, c, 30, Table 10). Recruitment increased slightly relative to 2020, but was low again relative to the recent time series (Figure 27e). The 2021 exploitation rates on the MMM region were 1.7% and 3.0% respectively on all and market sized oysters, similar to most other years in the recent time series (Figure 27f).

After two years (2017-2018), of lower than average natural mortality on the SR region, there have been three consecutive years of increasing natural mortality from 2018-2021 and natural mortality on the SR region is now similar to what was observed in the first half of the recent time series (Figure 28d). Although dermo levels decreased from 2020, they remain above 1.5, the threshold at which dermo-related mortality increases (Figure 28b). Total abundance and market abundance declined for the third consecutive year (Figures 28a, c). Total abundance is now between the target and threshold for the first time since 2015 (Figures 28a, 30, Table 10). Recruitment has been low since the 2016/2017 spatfall that caused a large increase in sub-markets and total oysters (Figure 28e). That large spatfall, and subsequent increase in small oysters, was likely what lead to two years of record high numbers of market-sized oysters on the SR region. While the market abundance on the SR region declined in 2021 relative to these two most recent years, it still remains well above the target market abundance (Figure 28c, Table 10). Exploitation rate of market-sized oysters in 2021 in the SR region was 4.7% relative to market-sized oysters and 3.2% relative to all sizes (Figure 28f).

Similar to the MMT region, relatively little changed with respect to abundance, mortality, or recruitment from 2020 to 2021 on the HM region and this resulted in no change in stock status relative to reference points for either the market or total abundance (Figures 29a, c, d, e, 30). The total abundance remains below the threshold while the market abundance remains well above the target (Figures 29a, c, Table 10). The exploitation rate of all oysters in 2021 was 4.1% while the exploitation of market-sized oysters was 9.3% (Figure 29f).

<u>*Science Advice: Is there any evidence the population is near carrying capacity?*</u>

A discussion point at several recent SAWs has been the apparent lack of agreement between recruitment, sub-market and/or total abundance, and market abundance data from the Assessment Survey. For instance, on occasion large recruitment events will cause a temporary spike in sub-market abundance, but the spike will be short-lived, sub-market abundance will rapidly decline, and there will be little to no subsequent impact on market abundance. Additionally, steep declines in sub-market abundance do not always translate into subsequent declines in market abundance. A recent example of this can be seen in Figure 22.1 beginning in 2016. There was a large recruitment event in 2016 and 2017 (Figure 22.1d) that lead to a spike in sub-market abundance in 2017 and 2018 (Figure 22.1b), but no subsequent change in market abundance (Figure 22.1b). In other words, most of the spat from 2016 and 2017 grew to small oysters size, but did not survive to market size. Another similar, but more extreme example of this can be seen from ~1998-2002 in Figure 22.2. These patterns of stable market abundance while spat/total/sub-market abundance fluctuate (sometimes by nearly an order of magnitude) also occur within individual Management

Regions. The recent trends on the Medium Mortality Markets beds show this well (Figures 27.1a, c, e). These patterns could suggest a population that is near carrying capacity under current conditions. Therefore, a Science Advice Recommendation from the 2021 SARC was to evaluate whether there was any evidence the population could be near carrying capacity.

One way to estimate carrying capacity (K) for a time series of population data is with a logistic model of population growth,

$$N_{t+1} = N_t + rN_t\left(\frac{1 - N_t}{K}\right)$$

where N_t is the population metric now, N_{t+1} is the population metric next year, r is the maximum population growth rate, and K is the carrying capacity. For a time-series of N_t and N_{t+1}, r and K can be estimated. Given oysters in the different Management Regions in Delaware Bay experience very different conditions (salinity, temperature, resources, available habitat) that lead to very different individual and population responses and demographics (growth, mortality, recruitment), it makes sense to use a standardized population metric so carrying capacity can be compared across all beds or Management Regions. For instance, total abundance might not be a useful population metric to compare K across Management Regions because some regions are larger than others and would therefore, all else being equal, have higher capacity to support larger populations. Using a density metric instead of absolute numbers helps account for these differences because it describes resource limitations within a specific fixed area. Furthermore, calculating a density-based metric using numbers is also not useful because 100 oysters within a given area in the lower Delaware Bay will be much larger on average, and require much more resources on average, than 100 oysters in the upper Delaware Bay. Therefore, the population metric time series that was used to estimate K and r for each bed using the equation above was biomass/area (g/m^2) where grams of biomass is estimated from measurements of oyster dry meat weight.

For each bed, and in each year, and on each sampled grid, the Assessment Survey provides an estimate of the total number of oysters on the grid, the size frequency of oysters on the grid, and a relationship between dry meat weight and size for a subset of oysters. This allows calculation of mean biomass/area for each bed and year. Note that for this initial analysis, to convert size to biomass a single biomass-length equation was used that estimates allometric scaling parameters from all dry meat-length data, but this could be adjusted to be bed- or even bed-year-specific.

When population growth is plotted as a function of N_t, for many beds the data and trend appear to fit the theoretical expectation of logistic population growth (Figure 31). That is, below some value for N_t the bed is likely to accumulate biomass and above some value for N_t a decline in biomass is likely on a bed. Parameter estimates of K follow a familiar pattern along the salinity gradient (Figure 32). In the middle of the salinity gradient (Shell Rock up to Arnolds) carrying *capacity ranges from about 30-50 g/m² and is lower at either end of the gradient (Very Low and High Mortality Regions). Parameter estimates for maximum population growth rate range mostly from ~0.5 to 0.75 with standard errors falling between 0.3 and 1.0. When the time series of mean density data is plotted with parameter estimates of K for each bed, population growth up to K and subsequent decline below it is apparent for beds in the middle of the salinity gradient (Shell Rock up to Arnolds, but less apparent at either end of the gradient.*

The analysis suggests that under current conditions (available habitat, disease regime), there are likely limits to how much biomass a given bed can accumulate within a given area. In addition, the tendency for a bed to accumulate biomass does not appear to be related to fishing exploitation as mean biomass/area on beds in the middle of the salinity gradient has fluctuated above and below carrying capacity when fishing has remained fixed at a low rate (~2%; Figures 16, 33).

A quota-based system with a cap on total allowed catch, and a low level of exploitation, was instituted in 1996 to sustain the abundance of market-sized oysters and reduce fishery closures. Ten years later, in 2006, constant abundance-based referenced points were put in place and a couple of years after that exploitation was constrained even further to fall within a small range so that presently exploitation each year is nearly fixed at ~2%. These management measures have had the intended impact on the population. There have been no fishery closures since the quota-based system went into effect and market abundance has fluctuated around 600 million oysters since the constant abundance-based reference points were instituted in 2006 (Figures 5, 23). If a new management goal is to accumulate more biomass and increase market abundance further (instead of the current goal which is to maintain a constant market abundance), perhaps focus should shift to increasing and/or restoring new habitat.

The SARC expressed concern that 1.) this is an equilibrium analysis applied to a system that is likely not in equilibrium and 2.) the estimates of r are high and suggest levels of Fmsy that would likely not be sustainable. These in combination suggest this analysis, and the parameters estimated from it, should not be used in forming a management tool for the stock, but may be interesting as descriptive analyses to help explain observed stock dynamics. A science recommendation was made for 2022 to evaluate pooling beds that share similar characteristics and exploring time-varying K and r in the model.

IV. SARC EXPLOITATION RATE AND AREA MANAGEMENT RECOMMENDATIONS

Upon review of the status of the stock, the 2022 SARC made the following recommendations that are summarized in Table 11.

- A transplant up to a 0.0193 exploitation rate could be moved from the Very Low Mortality region to the Low Mortality region.

- A transplant of up to 0.0076 exploitation rate can occur on the Low Mortality region with no requirement for a transplant. If a transplant to the Low Mortality region occurs, the exploitation rate could be increased to 0.0149.
- A transplant up to a 0.0246 exploitation rate could be moved from the Medium Mortality Transplant region.
- The Medium Mortality Market region can be fished up to its median exploitation rate (0.0303) with no requirement for a transplant.
- The Shell Rock region can be fished up to its median exploitation rate (0.0370) with no requirement for a transplant. If a transplant to Shell Rock occurs, the exploitation rate could be increased to 0.0488.
- The High Mortality region can be fished up to its median exploitation rate (0.0749) with no requirement for a transplant. If a transplant to the High Mortality region occurs, the exploitation rate could be increased to its maximum rate (0.0982).

V. STATEMENT OF SUSTAINABILITY

There has been general consensus by the Stock Assessment Review Committee (SARC) over recent years that the New Jersey Delaware Bay oyster fishery is being managed sustainably although there has been some debate about the language used to describe it and how it should be evaluated. A point of discussion has been the definition of sustainability used in the Magnuson-Stevens Act for federal fisheries that depends on population models and theory in the absence of strong empirical data on abundance and mortality. The Delaware Bay, NJ oyster stock assessment contains robust measures of abundance, natural mortality, and fishing mortality. Upon review of the oyster stock abundance, the exploitation time series, and management practices from 1996 to present, the 2022 SARC recommended continued acceptance of the following statement for the New Jersey Delaware Bay oyster fishery initially crafted by the 2017 SARC:

> The New Jersey Delaware Bay oyster fishery is sustainable under current fishery management strategies and prescribed exploitation rates.

VI. SARC SCIENCE ADVICE

In addition to continuing the core assessment and monitoring programs, including the Assessment Survey, the Resurvey/Restratification Program, the Dockmonitoring Program, the Dermo Monitoring Program, and the Shellplant and Transplant Monitoring Program, the 2022 SARC recommended the following list of science advice (not ordered by priority):

2022 SARC Science Advice:

- Plot both exploitation and market-size exploitation by bed for bed-level trends plots.

- Is there a relationship between timing of fishing effort (within a season) and recruitment?

- Test expectation that high and medium quality strata make up the upper and lower 50% of sampled grids, respectively.

- Create a bed simulator to test impact of mis-stratification on the assessment.

- Test for autocorrelation for key stock indicators.

- Include reference years (for targets/thresholds) in the longer-term appendices

- Include fishing exploitation in longer-term appendices

- For carrying capacity analyses, consider pooling beds with similar characteristics (eg. M, growth rate) and consider using time-varying estimates of r an K

- Use the Oyster Industry Science Steering Committee to form a sub-committee that explores re-evaluation of the VLM reference points with an emphasis on management goal(s) for this region relative to the others

Unfinished from 2021 SARC Science Advice:

- Coordinate with NJDEP as time and funds permit to address two items related to dredge capture efficiency:
  - Evaluate whether patent tongs are really 100% efficient on the Delaware Bay reefs.
  - Take patent tong grabs during the Assessment Survey to get annual estimates of capture efficiency on each bed.

- Survey error:
  - Report on how survey error changes if we use the combined survey and gear CVs instead of bootstrapping.
  - After splitting apart survey and gear efficiency error, how much has increased sampling intensity over the last several years reduced survey error?

- Explore mechanisms (environmental, disease resistance) driving declines in natural mortality.

- Continue to explore population models using the Assessment Survey data.

- Re-evaluate application of current reference points on the VLM region.

- Develop specific, testable hypotheses for why Shell Rock is so productive. For example, are there synergistic effects leading to more dramatic patterns than one would expect from the gradient(s) alone.

References

Abbe, G.R., 1988. Population structure of the American oyster, *Crassostrea virginica*, on an oyster bar in central Chesapeake Bay: changes associated with shell planting and increased recruitment. *J. Shellfish Res.,* 7, 33-40.

Ashton-Alcox, K.A., E.N. Powell, J.A. Hearon, C.S. Tomlin, R.M. Babb. 2013. Transplant Monitoring for the New Jersey Delaware Bay Oyster Fishery. *J. Shellfish Res.,* 32: 2, 459-469.

Ashton-Alcox, K.A., D. Bushek, J.E. Gius, 2014. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (16th SAW) Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 105pp.

Ashton-Alcox, K.A., D. Bushek, J.E. Gius, 2015. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (17th SAW) New Jersey Delaware Bay Oyster Beds Final Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 117pp.

Ashton-Alcox, K.A., D. Bushek, J.E. Gius, J. Morson, D. Munroe, 2016. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (18th SAW) New Jersey Delaware Bay Oyster Beds Final Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 153pp.

Ashton-Alcox, K.A., D. Bushek, J.E. Gius, J. Morson, D. Munroe, 2017. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (19th SAW) New Jersey Delaware Bay Oyster Beds Final Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 120pp.

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.

Bushek, D., I. Burt, E. McGurk. 2019. Delaware Bay New Jersey Oyster Seedbed Monitoring Program; 2018 Status Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 27pp.

Fegley, S. R., S. E. Ford, J. N. Kraeuter & D. R. Jones. 1994. *Relative effects of harvest pressure and disease mortality on the population dynamics of the Eastern oyster (Crassostrea virginica) in Delaware Bay*. NOAA, Final Rpt # NA26FL0588. Bivalve, NJ: Haskin Shellfish Research Laboratory, Rutgers University. 36pp text, 28 tables, 58 Figures.

Fegley, S.R., S.E. Ford, J.N. Kraeuter, and H.H. Haskin, 2003. The persistence of New Jersey's oyster seedbeds in the presence of oyster disease and harvest: the role of management. *J. Shellfish Res.* 22:451-464.

Ford, S.E. 1997. History and present status of molluscan shellfisheries from Barnegat Bay to Delaware Bay. In: *The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe, Vol. 1, North America* (MacKenzie, C.L., Jr., V.G. Burrell Jr., A. Rosenfield and W.L. Hobart, Eds.) pp. 119-140. U.S. Dept. of Commerce, NOAA Tech. Report NMFS, Seattle, WA.

Ford, S.E. and H.H. Haskin. 1982. History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen in Delaware Bay, 1957-1980. *J. Invertebr. Pathol.* 40:118-141.

Ford, S.E. and D. Bushek. 2012. Development of resistance to an introduced marine pathogen by a native host. *J. Mar. Res*. 70:205-223.

Hofmann, E., D. Bushek, S. Ford, X. Guo, D. Haidvogel, D. Hedgecock, J. Klinck, C. Milbury, D. Narvaez, E. Powell, Y. Wang, Z. Wang, J. Wilkin and L. Zhang. 2009. Understanding how disease and environment combine to structure resistance in estuarine bivalve populations. *Oceanography.* 22:212-231.

Kimura, D. K. and D. A. Somerton. 2006. Review of statistical aspects of survey sampling for marine fisheries. Reviews in Fisheries Science 14: 245-283.

Kraeuter, J.N., E.N. Powell, K.A. Ashton-Alcox, 2006. Report of the 2006 Stock Assessment Workshop (8th SAW) for the New Jersey Delaware Bay Oyster Beds. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 95pp.

Kraeuter, J.N., E.N. Powell, K.A. Ashton-Alcox, 2007. Oyster growth analysis: a comparison of methods. *Journal of Shellfish Research* 26: 479-491.

Mann, R. and E.N. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. *J. Shellfish Res*. 26:4, 905-917.

Mann, R., M. Southworth, R. B. Carnegie, and R. K. Crockett. 2014. Temporal variation in fecundity and spawning in the Eastern oyster, *Crassostrea virginica*, in the Piankatank River, Virginia. *Journal of Shellfish Research* 33: 167-176.

Morson, J. M., D. M. Munroe, K. A. Ashton-Alcox, E. N. Powell, D. Bushek, and J. Gius. 2018. Density-dependent capture efficiency of a survey dredge and its influence on the stock assessment of eastern oysters (*Crassotrea virginica*) in Delaware Bay. Fisheries Research 205: 115-121.

Morson, J. M., D. Bushek, and J. Gius. 2019. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (21st SAW) Final Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 80pp.

Morson, J. M., D. Bushek, and J. Gius. 2021. Stock Assessment Workshop New Jersey Delaware Bay Oyster Beds (23rd SAW) Final Report. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 71pp.

Munroe, D., A. Tabatabai, I. Burt, D. Bushek, E.N. Powell & J. Wilkin. 2013. Oyster mortality in Delaware Bay: Impacts and recovery from Hurricane Irene and Tropical Storm Lee. *Estuarine, Coast. & Shelf Sci*. 135:209-219.

Munroe, D., S. Borsetti, K. Ashton-Alcox, & D. Bushek. 2017. Early post-settlement growth in wild Eastern oyster (*Crassostrea virginica* Gmelin 1791) populations. *Est. & Coasts* 40:880-888.

Powell, E.N., J.N. Kraeuter, S.E. Ford, 2001. Report of the 2001 Stock Assessment Workshop (3rd SAW) for the New Jersey Delaware Bay Oyster Beds. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 53pp.

Powell, E.N., K.A. Ashton-Alcox, J.A. Dobarro, M. Cummings, and S.E. Banta. 2002. The inherent efficiency of oyster dredges in survey mode. *J. Shellfish Res*. 21:691-695.

Powell, E.N., J.J. Gendek, K.A. Ashton-Alcox. 2005. Fisherman choice and incidental catch: Size frequency of oyster landings in the New Jersey oyster fishery. *J. Shellfish Res.* 24:469-476.

Powell, E.N., J.N. Kraeuter and K.A. Ashton-Alcox. 2006. How long does oyster shell last on an oyster reef? *Estuar. Coast. Shelf Sci.* 69:531-542.

Powell, E.N. and J.M. Klinck. 2007. Is oyster shell a sustainable estuarine resource? *J. Shellfish Res.* 26:181-194.

Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter. 2007. Re-evaluation of eastern oyster dredge efficiency in survey mode: application in stock assessment. *N. Am. J. Fish. Manage.* 27:492-511.

Powell, E.N., J.N. Kraeuter, K.A. Ashton-Alcox, 2008a. Report of the 2008 Stock Assessment Workshop (10th SAW) for the New Jersey Delaware Bay Oyster Beds. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 131pp.

Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter, S.E. Ford and D. Bushek. 2008b. Long-term trends in oyster population dynamics in Delaware Bay: regime shifts and response to disease. *J. Shellfish Res.* 27:729-755.

Powell, E.N., J.M. Klinck, K.A. Ashton-Alcox, J.N. Kraeuter. 2009. Multiple stable reference points in oyster populations: implications for reference point-based management. *Fish. Bull.* 107:133-147.

Powell, E.N., K.A. Ashton-Alcox, D. Bushek, 2012a. Report of the 2012 Stock Assessment Workshop (14th SAW) for the New Jersey Delaware Bay Oyster Beds. *Haskin Shellfish Res. Lab.*, Port Norris, NJ. 190pp.

Powell, E.N., J.M. Klinck, K.A. Ashton-Alcox, E.E. Hofmann, & J. Morson. 2012b. The rise and fall of *Crassostrea virginica* oyster reefs: The role of disease and fishing in their demise and a vignette on their management. *J. Mar. Res.*, 70, 505-558.

Table 1. Timeline of surveys and monitoring programs that comprise the data presented in this report. For a detailed explanation of survey design changes see "The Assessment Survey" in the "Historical Overview" section of this report.

Annual Stock Assessment Survey – Timeline and Changes	
1953 – 1988	Small boat/dredge used for the survey; no size data collected; no sampling of VLM region; no swept area data collected; not all high/medium quality strata sampled
1989 – 1998	Changes: Commercial boat/dredge used for the survey; began collecting size data; remaining methods the same as above
1999 – 2007	Changes: Began collecting swept area; remaining methods the same as above
2008 – present	Changes: Restratified the beds; all high/medium quality strata now sampled; VLM region now sampled

Other Annual Programs	
2009 – Present	Resurvey/Restratification Program
1990 – Present	Dermo Monitoring Program
2004 – Present	Port Sampling Program

Harvest Methods	
Pre-1996	Bay Season Fishery
1996 - Present	Direct Market Fishery

Table 2. 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

Table 3. Restratification survey (resurvey) schedule. Middle, Beadons, Vexton, and Ledge were resurveyed in 2021. Fishing Creek and Sea Breeze are scheduled for resurvey in 2022. Egg Island has never been resurveyed.

Region	Bed	# Grids	# Full Resurveys	Latest Resurvey	10-Year Schedule
VLM	Hope Creek	97	2	2017	2027
	Fishing Creek	67	1	2007-2008	**2022**
	Liston Range	32	2	2016	2026
LM	Round Island	73	2	2018	2028
	Upper Arnolds	29	2	2013	2023
	Arnolds	99	2	2015	2025
MMT	Upper Middle	84	1	2020	2030
	Middle	51	1	2021	2031
	Sea Breeze	48	1	2012	**2022**
MMM	Cohansey	83	1	2019	2029
	Ship John	68	1	2020	2030
SR	Shell Rock	93	3	2016	2026
HM	Bennies Sand	49	1	2019	2029
	Nantuxent	68	3	2018	2028
	Bennies	171	2	2014	2024
	Hog Shoal	23	2	2016	2026
	Strawberry	29	2	2015	2025
	Hawk's Nest	28	2	2017	2027
	New Beds	112	2	2013	2023
	Beadons	38	2	2021	2031
	Vexton	47	2	2021	2031
	Egg Island	125	0	-	-
	Ledge	53	1	2021	2031

Table 4. Groups and responsibilities for managing the oyster fishery of Delaware Bay, NJ.

Group	Members	Duties
Rutgers Haskin Shellfish Research Laboratory	HSRL faculty and staff	Design/analyze stock assessment. Execute surveys with industry and NJDEP assistance. Address science needs. Host and facilitate SAW. Prepare SAW report.
Oyster Industry Science Steering Committee	HSRL Shellfish Council NJDEP	Prioritize science agenda and mgmt. strategies. Nominate SARC membership.
Stock Assessment Review Committee	Academics: RU & other Managers: NJDEP & other Industry	Peer review of assessment. Recommend harvest rates & area mgmt. by region. Provide science advice.
Shellfish Council	Industry	Select harvest rate & area mgmt. activities from SARC recommendations. Plan/approve disbursement of industry-imposed harvest taxes.
New Jersey Department of Environmental Protection	Biologists Managers Statisticians Enforcement Administrators	Approve decisions impacting public oyster resource. Lead/coordinate mgmt. activities. Monitor harvest and enforce regulations. Collect, maintain & disperse industry-imposed harvest taxes.

Table 5. Control Rules and Management Program. Control Rules were formally adopted at the 2016 SAW and contain updates from the 2017 SAW. They articulate the basic process used to manage the New Jersey Delaware Bay Oyster Fishery.

1. *Area Management*: Harvest and transplant activities are set by region (3 harvest and 3 transplant regions) to help ensure that no area receives more harvest pressure than it can sustain and enhancement efforts are appropriately directed.

2. *Baseline Abundance Targets*: The 2006 SARC set the target and threshold total abundances for each region as the median and ½ the median for the time series 1989-2005, inclusive. Those for market-size oyster (>2.5") abundances are set the same way using 1990-2005 because length measurements for oysters began in 1990. Both time series represent the beginning of the current Dermo era to the year prior to the institution of the reference points. Both periods include highs and lows of recruitment, growth, disease and mortality. For the VLM, the 2017 SARC advised use of the 75th percentile of its 2007-2016 time series as a target and the 50th percentile as the threshold for total and market-size abundance with the proviso that this be re-evaluated in three to five years.

3. *Additional Population Indicators*: Trends in abundance, recruitment, disease, mortality and other factors are examined and summarized (regional panels and stoplight table) to develop expectations of population change in the coming year(s) and to inform harvest and management decisions.

4. *Exploitation Targets*: The 2006 SARC set regional exploitation rate targets as the medians of the realized exploitation rates from the beginning of the Direct Market in 1996 to 2005 (later 2006). The 2016 SARC updated the targets as the median exploitation rate realized from 2007-2015.

5. *Exploitation rate flexibility*: The 2006 SARC set flexibility around the regional median exploitation rates (1996-2006) generally as the 40th and 60th percentiles. The 2016 SARC set flexibility between the bounds of the 2007 – 2015 max and min realized exploitation rates. Movement away from the median requires justification based upon the status of the stock, its position relative to targets and thresholds, anticipated changes to the stock, or management activities. Movement away from the median should be in percentage points, generally increments of 10% for simplicity. Strong justification is required for movement above these bounds since they have proven sustainable for the fishery.

6. *Enhancement Tools*: Shellplanting and transplanting are enhancement tools used to facilitate sustainable management. Shellplanting places non-spatted or spatted shell in areas where additional cultch can enhance recruitment. Transplanting relocates culled oysters from non-harvestable regions to Direct Market regions via the Intermediate Transplant Program.

7a. *Transplant Recipient Exploitation*: For any market region, the SARC may recommend two exploitation rates. The first would be the maximum recommended rate without a transplant. The second would be a higher rate allowed if a transplant occurs. Harvest in the region may begin at the lower rate and move to the higher rate only after a transplant has occurred. Market-size oysters that are transplanted to the region are added to the region's quota.

7b. *Transplant Donor Exploitation*: Annual exploitation rate recommendations for transplant regions are made by the SARC. Resource managers will direct transplant harvests to minimize the cultch fraction transplanted, ideally to < 25%, directing transplant vessels to new sites in the region as necessary.

Table 6. Direct market and transplant bushel summaries 2012-2021. Beds arranged upbay to downbay and color-coded by region. (a) Direct market bushels harvested, including those replanted to leases. (b) Intermediate transplant bushel removals. Sea Breeze was part of the MMM until 2011; it is now MMT. Beds without removals were omitted. A transplant did not take place in 2020.

a. Direct Market

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Sea Breeze	170	5,454	542							
Cohansey	11,288	10,583	8,652	10,669	12,475	20,687	8,709	7,253	12,238	3,760
Ship John	17,755	19,279	24,295	19,837	19,938	16,331	22,021	25,037	2,751	23,611
Shell Rock	22,628	24,280	23,589	29,629	31,794	38,189	31,872	28,761	46,765	42,033
Bennies Sand	5,836	10,841	3,038	6,301		22,339	23,395	13,911	6,014	8,145
Bennies	2,155	870	8,010	10,712	29,293	23,071	21,626	7,126	60	8,223
NantuxentP	14,332	10,218	5,154	5,267	2,101	628	11,347	17,575	26,461	28,254
Hog Shoal	1,965	2,385	3,425	103		1,756	283	9,445	2,201	758
New Beds	443	226		4,912	4,494	1,143	89			1,410
Strawberry		140								
Hawk's Nest	1,568		205							
Total	**78,140**	**84,276**	**76,910**	**87,430**	**100,095**	**124,144**	**119,342**	**109,108**	**96,490**	**116,194**

b. Transplants

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Liston Range		550								
Round Island		2,250								
Upper Arnolds		15,550		10,200						
Arnolds	7,650	2,700	15,500		4,800			7,200	0	5,400
Upper Middle	2,100	3,200				3,200	4,750		0	2,650
Middle	11,200	5,200	6,600	5,550	8,150	21,350	27,500	25,000	0	13,400
Sea Breeze	8,525	6,200	7,300	10,800	2,400	4,700	7,700	8,800	0	2,700
Total	**29,475**	**35,650**	**29,400**	**26,550**	**15,350**	**29,250**	**39,950**	**41,000**	**0**	**24,150**

Table 7. Council-chosen and fishery-achieved exploitation rates for 2021 for (a) Transplant regions and (b) Direct Market regions. Transplant exploitation rates include all sizes of oysters. Small oysters and shell are culled during both transplant and harvest. Direct market exploitation rates include market-size (≥ 2.5”) oysters only.

a. Direct Market

Region	Highest SARC Exploit. Option	Council Choice	Achieved Expl. Rate	Chosen Market Bushels	Add’l Quota Bushels	Achieved Total Bushels
MMM	Median 3.03% *no transplant req’d.*	3.03%	3.00%	27,500	0	27,371
SR	4.26% *transplant req'd*	4.26%	4.66%	39,805	845	42,033
HM	Max 9.82% *transplant req'd*	9.82%	9.34%	36,375	10,144	46,790
			Totals	103,680	10,989	116,194
					Estimated Quota	**Unharvested Bushels**
					114,669	0

b. Transplant

Region	Highest SARC Exploit. Option	Council Choice	Achieved Expl. Rate	Chosen Oysters Moved	Achieved Oysters Moved	Under/Over
VLM	1.93%	NA	NA	NA	NA	NA
LM	0.76%	0.76%	0.94%	2,097,973	2,601,798	503,825
MMT	2.46%	2.46%	2.50%	6,297,118	6,401,396	104,278

Table 8. Detailed history of transplant efforts since 2014. Due to COVID-19 restrictions, a transplant did not take place in 2020.

Year	Region	Donor Bed	Receiver Bed	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5"	Number Oysters ≥ 2.5"	Added Quota Allocation	Fraction Cultch	Chosen Expl. Rate	Achieved Expl. Rate	# Oysters at Chosen (all sizes)	# Oysters at Achieved (all sizes)
2021	LM	Arnolds	Shell Rock	5,400	2,601,798	0.900	260,180	974	0.472	0.76%	0.94%	2,097,973	2,601,798
	MMT	Upper Middle	Bennies	2,650	659,794	0.733	176,218	660	0.573	2.46%	2.50%	6,297,118	6,401,396
		Middle	Bennies	2,700	997,139	0.481	517,274	1,937	0.199				
		Middle	Nantuxent	10,700	3,935,479	0.535	1,829,275	6,851	0.263				
		Sea Breeze	Bennies	2,700	808,984	0.279	583,363	2,185	0.206				
2020	*NO TRANSPLANT CONDUCTED*												
2019	LM	Arnolds	Shell Rock	7,200	2,837,705	0.828	489,430	1,861	0.449	2.26%	0.70%	8,941,378	2,837,705
	MMT	Middle	Bennies Sand	25,000	9,890,349	0.748	2,496,843	9,494	0.288	2.46%	2.79%	12,158,274	13,956,501
		Sea Breeze	Bennies Sand	8,800	4,066,152	0.768	941,483	3,580	0.206				
2018	MMT	Upper Middle	Bennies	4,750	973,690	0.527	460,846	1,752	0.566	2.46%	1.76%	15,785,722	12,310,312
		Middle	Bennies	27,500	8,230,069	0.507	4,054,033	15,415	0.329				
		Sea Breeze	Bennies	7,700	3,106,553	0.759	749,703	2,851	0.290				
2017	MMT	Upper Middle	Bennies	3,200	948,685	0.365	602,546	2,282	0.408	2.46%	2.37%	8,184,564	7,887,414
		Middle	Bennies	21,350	5,625,257	0.312	3,868,205	14,652	0.299				
		Sea Breeze	Bennies	4,700	1,313,472	0.515	636,920	2,412	0.219				
2016	LM	Arnolds	Cohansey	4,800	2,168,012	0.637	787,816	2,972	0.290	0.76%	0.96%	1,712,353	2,168,012
	MMT	Middle	Shell Rock	8,150	2,556,215	0.386	1,569,932	5,925	0.280	1.49%	0.97%	3,958,253	2,979,901
		Sea Breeze	Shell Rock	2,400	426,443	0.319	290,458	1,096	0.440				
2015	LM	Upper Arnolds	Ship John	10,200	4,474,515	0.721	1,247,128	4,688	0.330	1.30%	1.30 - 1.90%	3,598,514	4,474,515
	MMT	Middle	Shell Rock	5,550	1,726,335	0.604	682,813	2,567	0.310	2.30%	> 2.30%	4,360,643	4,475,247
		Sea Breeze	Shell Rock	10,800	2,748,912	0.422	1,590,121	5,978	0.250				
2014	LM	Arnolds	Ship John	15,500	6,168,587	0.485	3,174,627	12,025	0.220	2.33%	2.25%	6,403,869	6,134,370
	MMT	Middle	Shell Rock	6,600	1,553,053	0.381	961,033	3,640	0.250	2.33%	2.41%	3,517,430	3,473,086
		Sea Breeze	Shell Rock	7,300	1,922,420	0.390	1,173,115	4,444					

Table 9. Region-specific stock performance targets and thresholds. The targets are the median of total abundance for 1989–2005 and the median of market-size (≥ 2.5”) abundance for 1990–2005. The threshold is taken as half of each target value. VLM values here represent 2017 SARC Science Advice to use the 75th percentiles of the 2007-2016 total and market-size abundance time series as targets and the 50th percentiles as thresholds with the proviso that they be re-evaluated in three to five years.

	Very Low Mortality	Low Mortality	Medium Mortality Transplant	Medium Mortality Market	Shell Rock	High Mortality
Abundance						
Target	150,632,432	391,877,696	414,560,096	747,234,944	313,595,904	438,391,488
Threshold	120,130,688	195,938,848	207,280,048	373,617,472	156,797,952	219,195,744
≥ 2.5” Abund.						
Target	32,061,787	42,075,297	46,566,027	175,051,502	72,910,219	64,446,071
Threshold	16,872,067	21,037,649	23,283,014	87,525,751	36,455,110	32,223,036

Table 10. Color coded summary status of the stock by region in 2021. See key at the bottom for definitions of what each color represents for each metric.

2021 Metrics	*Transplant* Very Low Mortality	*Transplant* Low Mortality	*Transplant* Medium Mortality	*Market* Medium Mortality	*Market* Shell Rock	*Market* High Mortality
Total Abundance						
2021 Percentile (1990-2021)	0.214	0.032	0.193	0.225	0.161	0.419
2021 vs. Target-Threshold						
Market Abundance						
2021 Percentile (1990-2021)	0.142	0.258	0.870	0.580	0.645	0.806
2021 vs. Target-Threshold						
Sub-Market Abundance (< 2.5")						
2021 Percentile (1990-2021)	0.142	0.129	0.290	0.129	0.000	0.193
Spatfall						
2021 Percentile (1990-2021)	0.357	0.483	0.419	0.387	0.193	0.000
Mortality						
2021 Percentile (1990-2021)	0.285	0.225	0.322	0.290	0.580	0.032
Dermo WP						
2021 vs. Category	0.020	0.110	0.700	1.330	1.830	1.740

	Green	**Yellow**	**Orange**
2021 Percentile (1990-2021)	Above the 60th	40th - 60th	Below the 40th
2021 vs. Target/Threshold	Above Target	b/w Target and Threshold	Below Threshold
2021 Dermo Levels	Low (<1.5)	Medium (1.5-2)	High (>2)

Table 11. 2022 SARC recommendations for maximum exploitation rates for each region and the projected quota associated with each decision. *Note that for the Medium Mortality Market and the High Mortality regions two rates are listed. The first does not require a transplant while the second requires a transplant. **The estimated potential quota bushels from the transplant will always be low relative to what is achieved because the deckloads are culled (removing some of the smaller oysters) before being transplanted to the recipient region.

Transplant Regions[1]

Region	Label	Exploitation Rates of All Sizes	Regional Abundance	Removals	Oysters /Bushel	Approx. Deck Bushels	Proportion Of Oysters That Are Markets From Survey	Estimated Potential Quota Bushels**
VLM		0.0193	76,912,803	1,484,417	503	2,951	10%	295
LM	Min	0.0076	203,366,048	1,545,582	449	3,442	21%	723
LM	*w/ transplant*	0.0149	203,366,048	3,030,154	449	6,749	21%	1,417
MMT	Max	0.0246	224,563,154	5,524,254	330	16,740	54%	9,040

Direct Market Regions[2]

Region	Label	Exploitation Rates of Market Sizes	Regional Market Abundance	Removals	Oysters/ Market Bushel	Quota Bushels	Transplant Required?
MMM	Median	0.0303	220,765,767	6,689,203	268	24,960	No
SR*	Median	0.0370	132,054,042	4,886,000	268	18,231	No
SR*	Max	0.0488	132,054,042	6,444,237	268	24,046	Yes
HM*	Median	0.0749	117,420,284	8,794,779	268	32,816	No
HM*	Max	0.0982	117,420,284	11,530,672	268	43,025	Yes

[1]For transplant regions, oysters per bushel is an average from all previous transplants in that region.

[2]For each year the dock monitoring program has been in place, an average total number and an average market number are calculated per market bushel. A grand average is then calculated using all these data.

Figure 1. The natural oyster beds of Delaware Bay, NJ grouped by regional designations. The six regions are named based on long-term disease mortality patterns and management categories that follow the estuarine salinity gradient. From upbay to downbay: Very Low Mortality (dark green), Low Mortality (red), Medium Mortality Transplant (light green), Medium Mortality Market (light blue), Shell Rock (orange), High Mortality (dark blue). Black outlines indicate complete footprint of each bed including grids in the High, Medium, and Low oyster density strata.

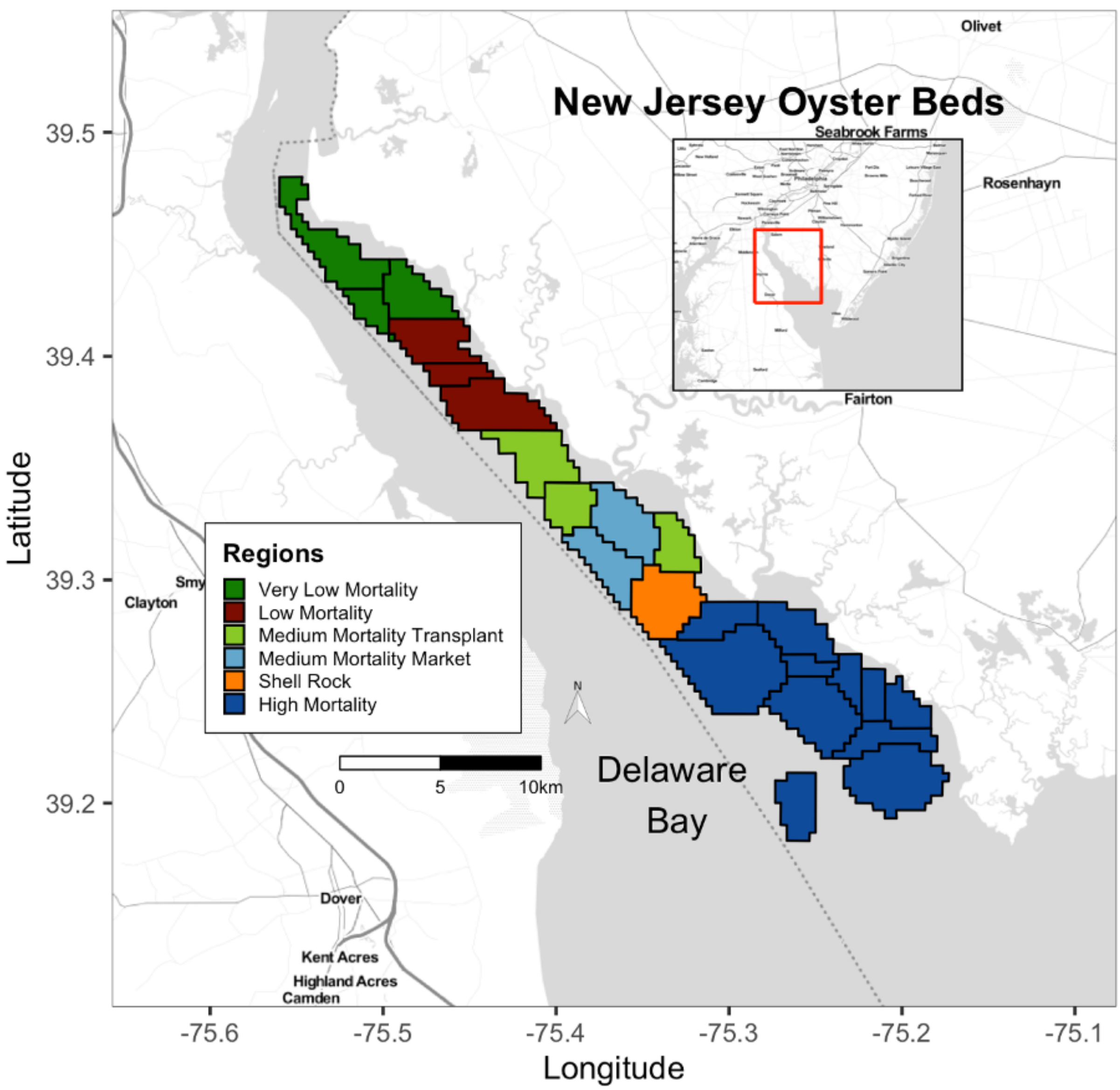


Figure 2. Regional acreage of the assessed NJ Delaware Bay oyster resource. Regions are listed upbay to downbay from left to right. The VLM, LM, and MMT contain three beds each and comprise the Transplant region. The Direct Market region includes the MMM made up of two beds, SR (one bed), and HM with eleven beds. Resource density, population characteristics and population dynamics vary among regions as described elsewhere in this document.

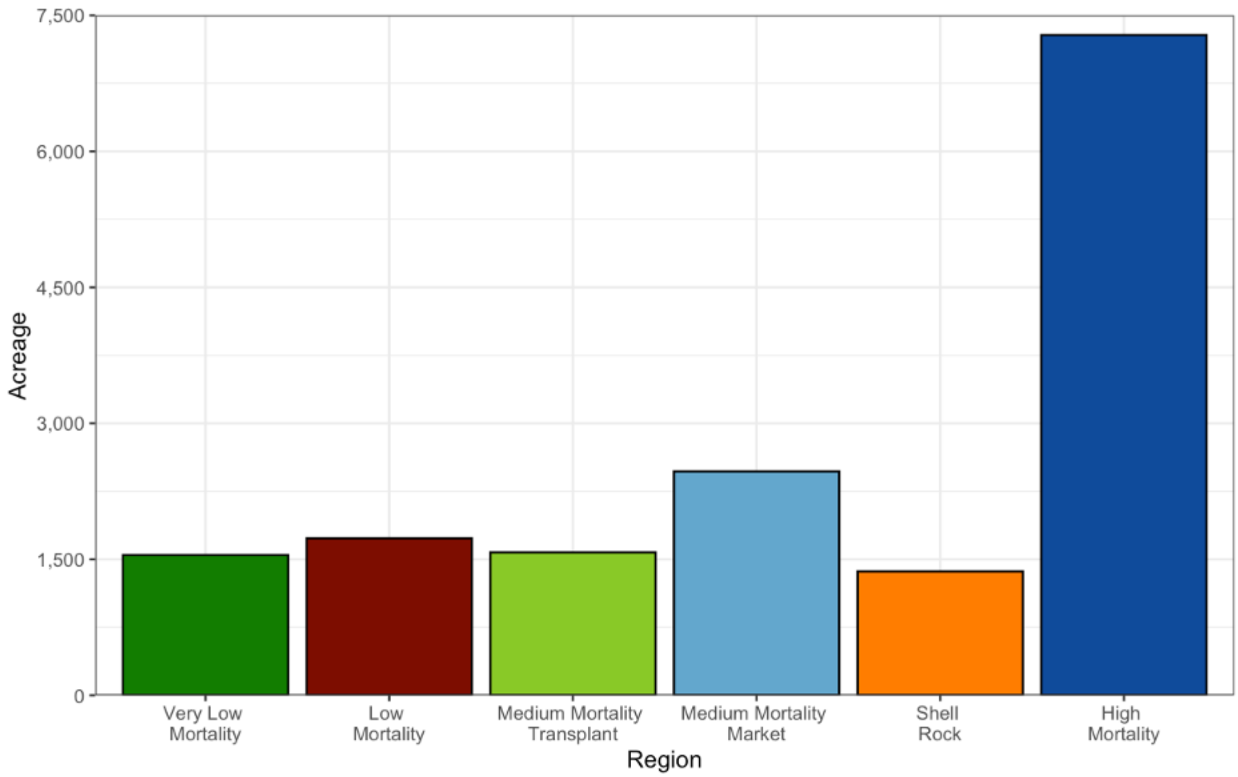
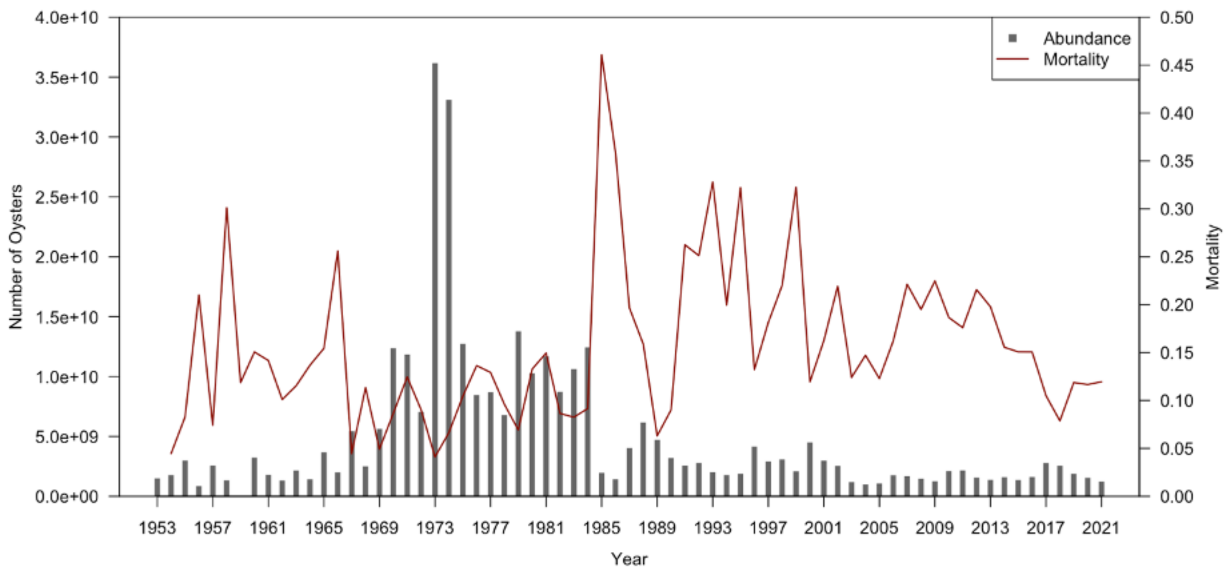


Figure 3. Time series of total oyster abundance (left axes) compared to natural mortality rate (a, right axis) and fishing mortality (b, right axis). Both figures exclude the VLM which was not quantitively surveyed until 2007.

a.



b.

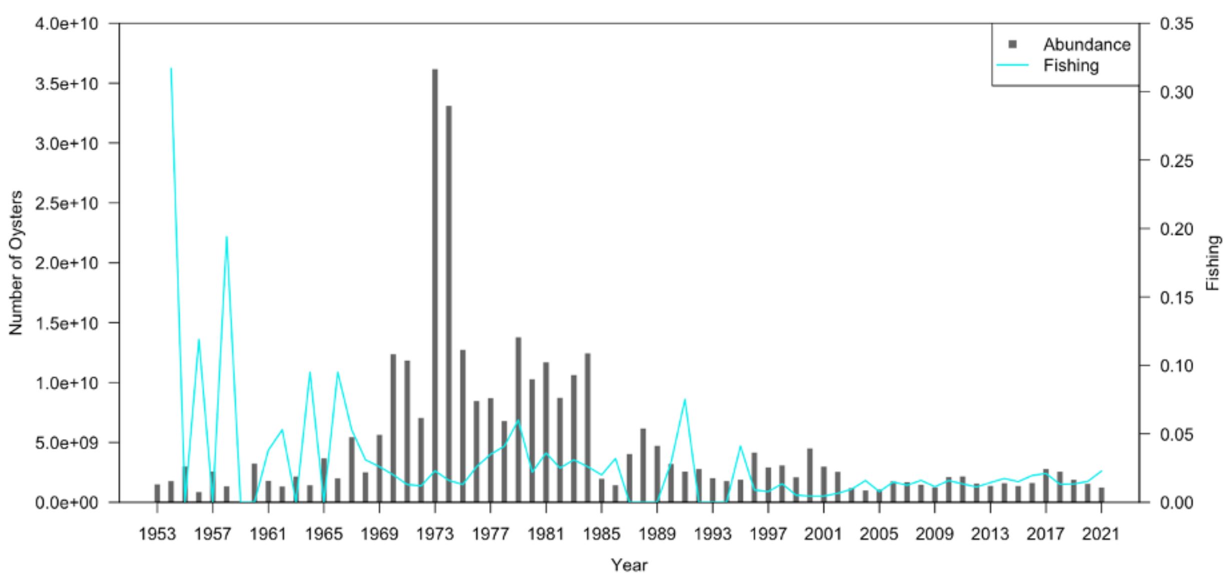
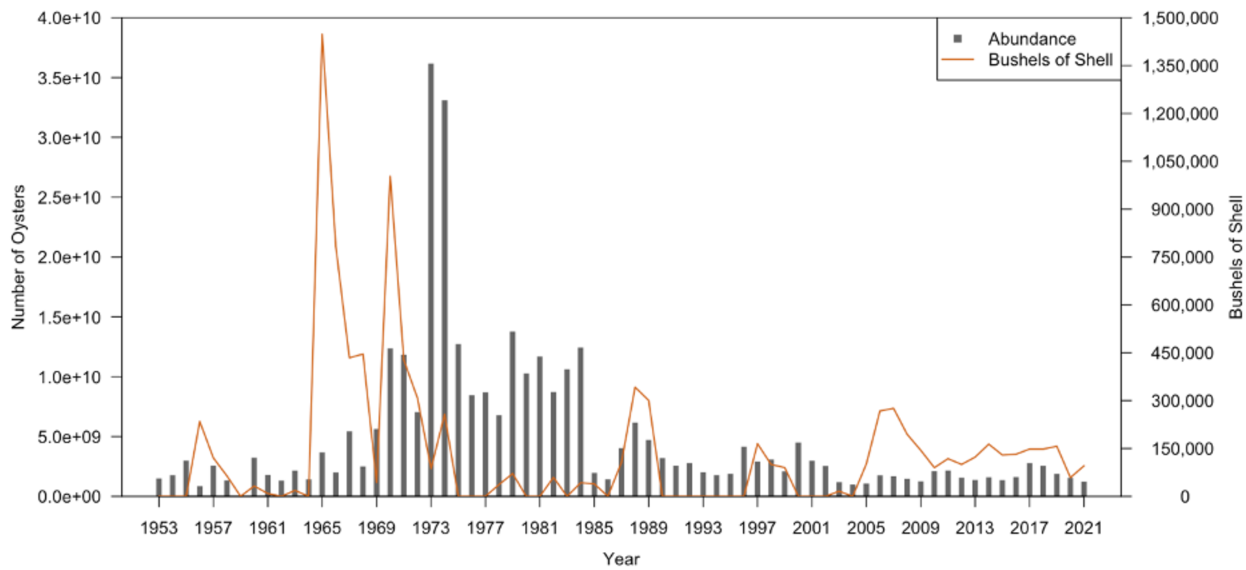


Figure 4. Time series of total oyster abundance (left axes) compared to bushels of shell planted (a, right axis) and total spat abundance from the stock assessment time series (b, right axis). Both figures exclude the VLM which was not quantitively surveyed until 2007.

a.



b.

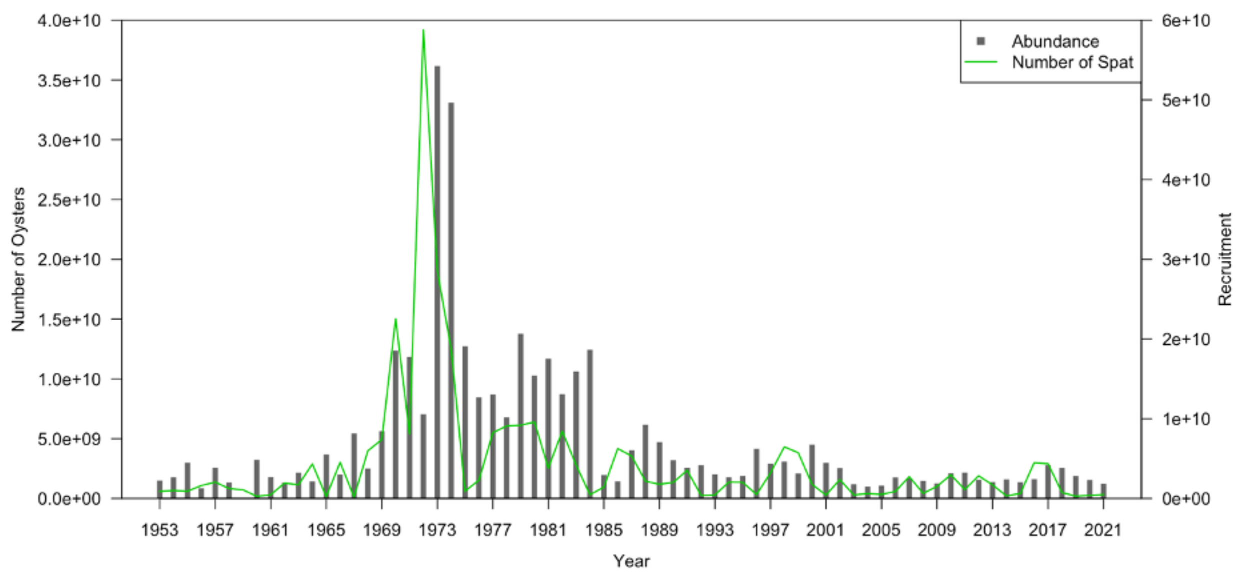


Figure 5. Number of oysters harvested from the natural oyster beds of Delaware Bay, NJ from 1953–2021. Prior to 1996, the bay-season fishery permitted removed oysters of all sizes from the natural beds and required transplanting them downbay to leased grounds for subsequent harvest. Since 1996, the direct market fishery has restricted harvest to market-size oysters without any transplant requirement. Zeros represent years of fishery closure.

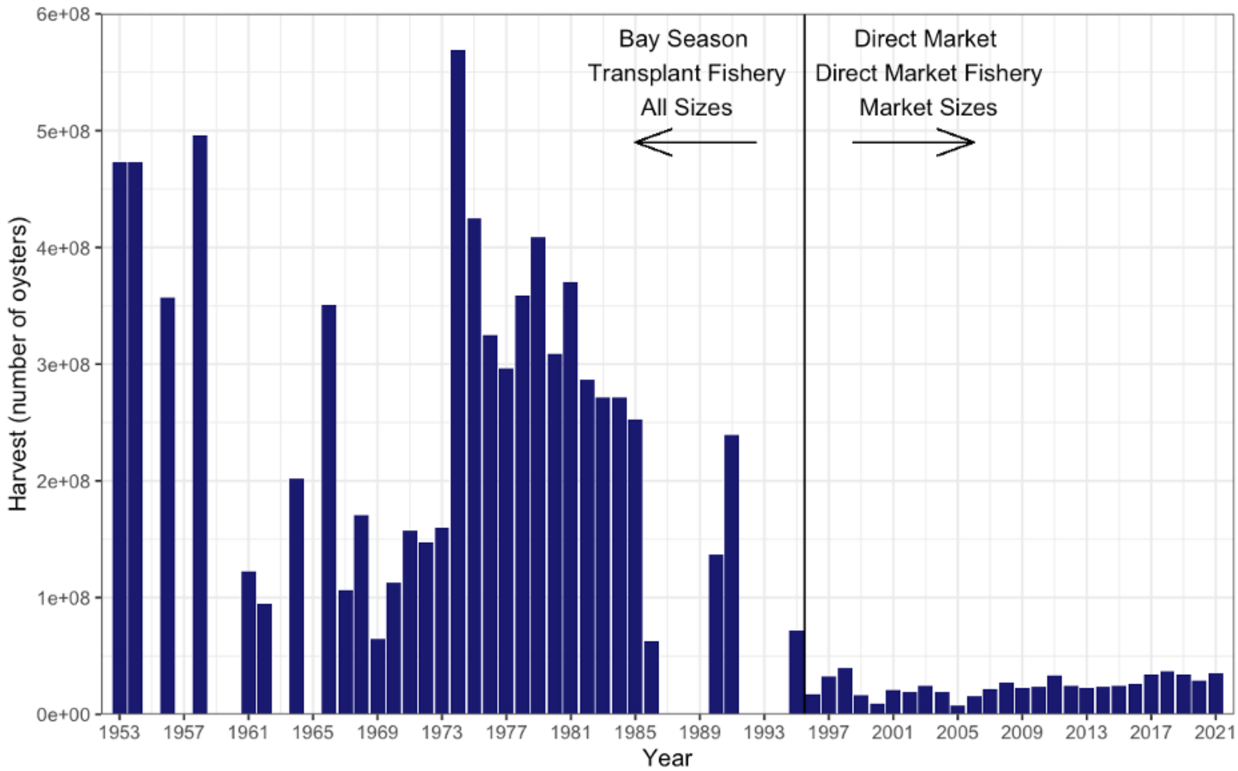


Figure 6. Survey gear capture efficiency as a function of true oyster density. Error bars represent the standard deviation from 1,000 bootstrap simulations. Line indicates the best fit power model estimated by weighted nonlinear least squares. *Adapted from Morson et al. (2018)*

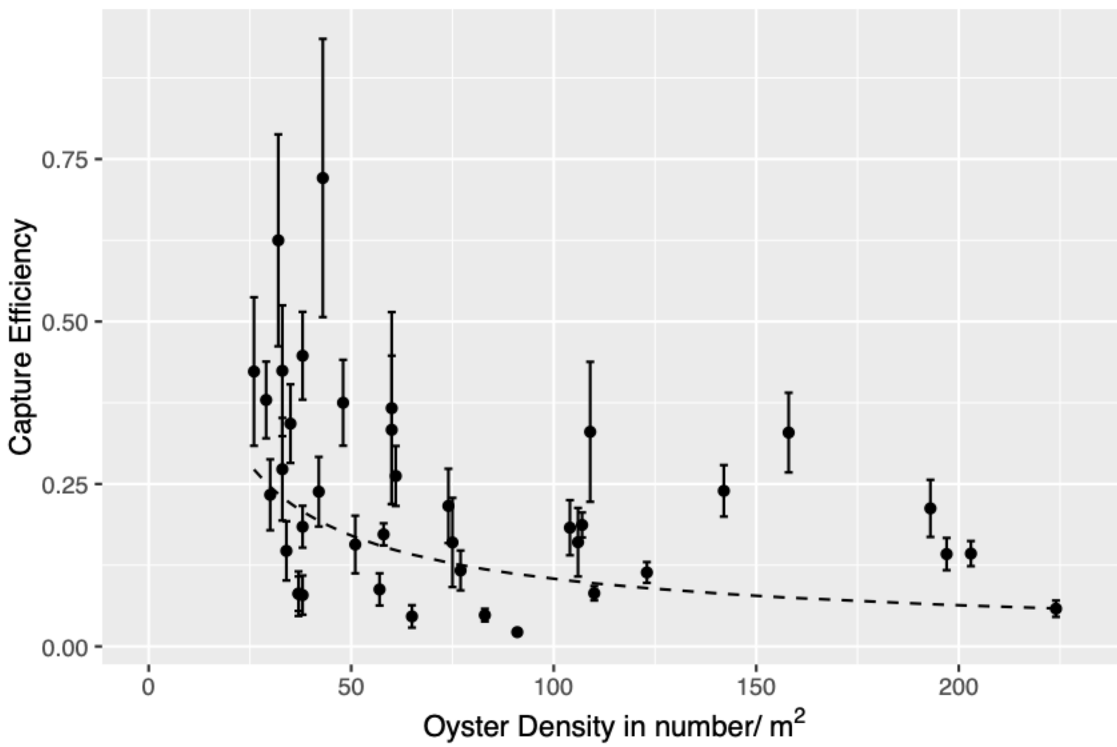


Figure 7. The assessed oyster beds of Delaware Bay, NJ colored by region (see Legend) with the 2021 strata designations. White outlines indicate the complete boundary of each bed with the high and medium quality strata grids in dark and light colors, respectively; black outlines indicate beds that were resurveyed in 2021. Strata designations are calculated within-bed not within-region. Gray areas in each bed indicate low quality strata. Annual assessments include samples from each bed's high and medium quality strata only. Each grid is 0.2" latitude x 0.2" longitude, approximately 25 acres (10.1 hectares).

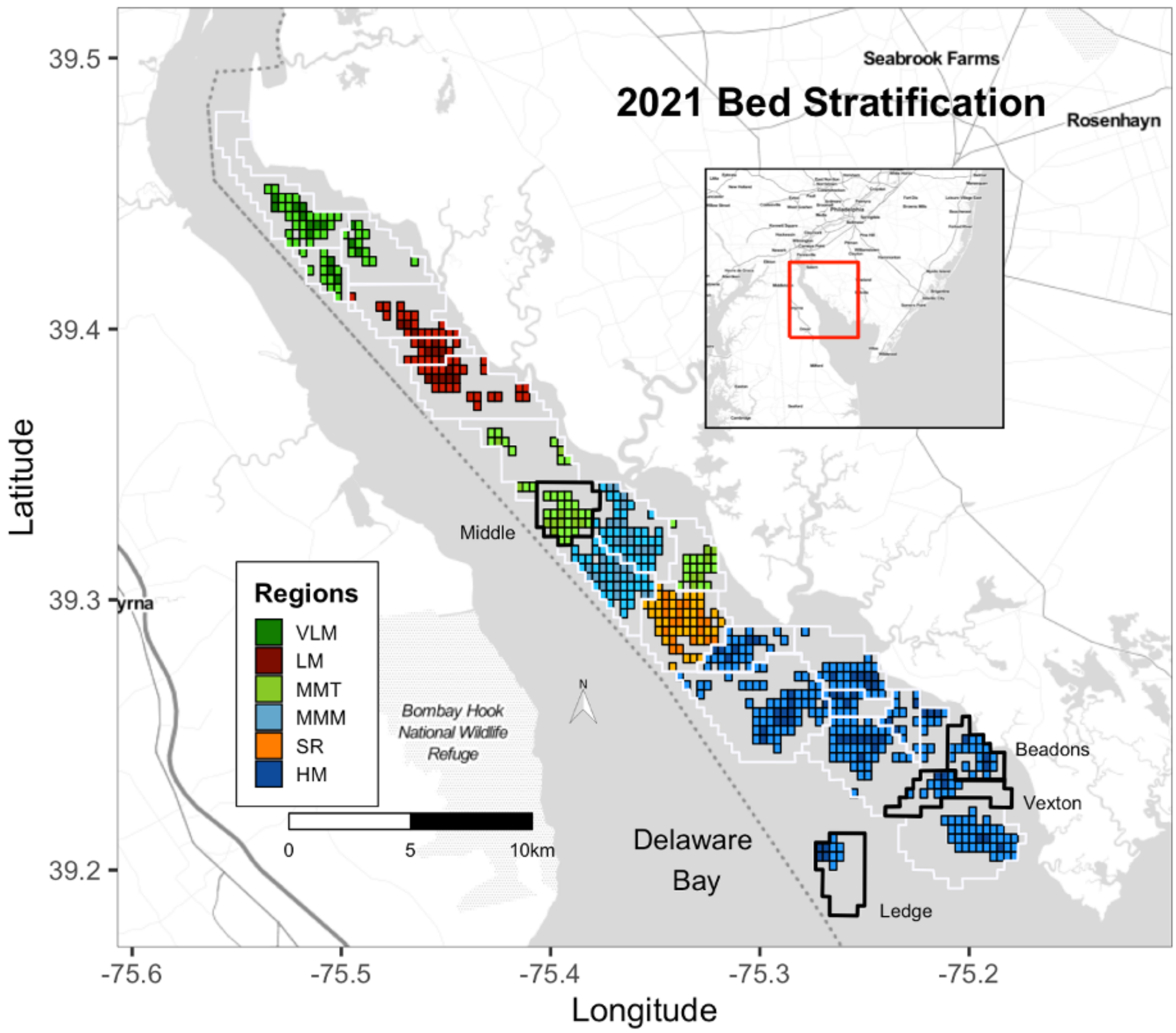


Figure 8a. Realized exploitation fractions of the >2.5" oyster stock on the Direct Market regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. The 2007-2015 median (dotted line) is based on the realized exploitation values with shading indicating the range. Negative values reflect oysters added through intermediate transplanting.

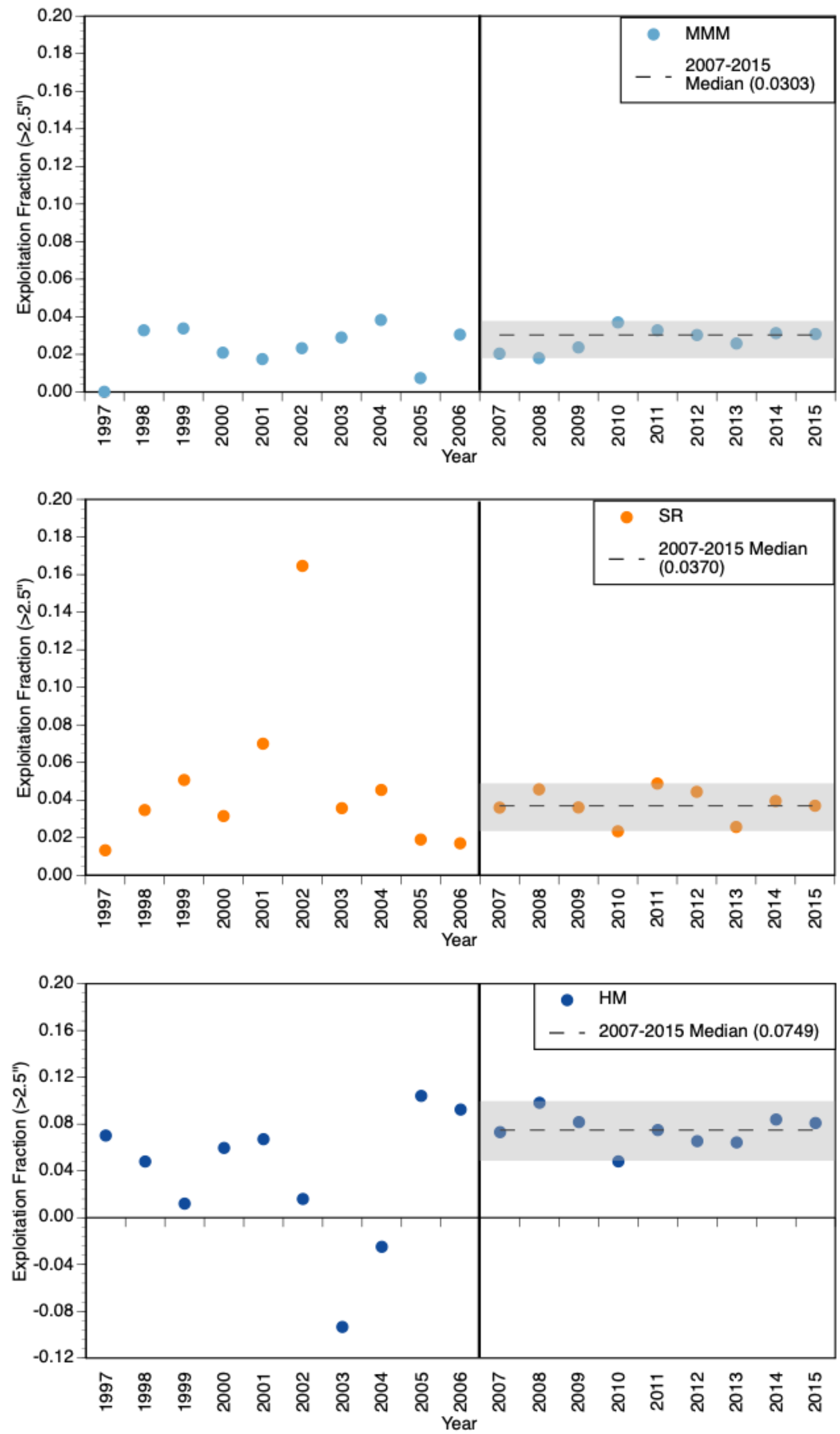


Figure 8b. Realized exploitation fractions of the whole oyster stock, excluding spat, on the Transplant regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. The 2007-2015 median (dotted line) is based on the realized exploitation for each region with shading indicating the range. The VLM abundance time series began in 2007 and the region has only 3 years of exploitation. Due to sparse data in the earlier time series, the LM and MMT share the same set of data.

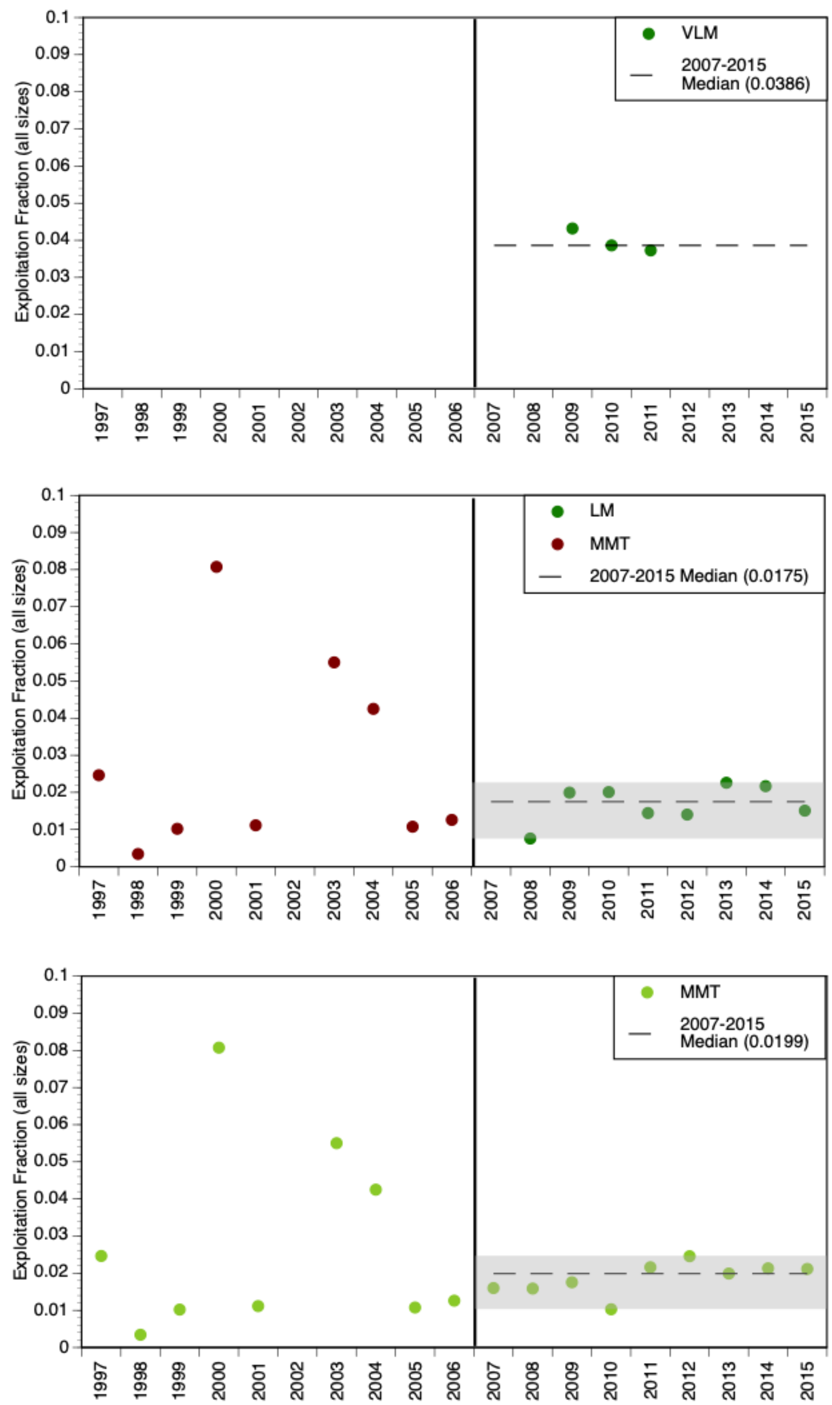


Figure 9. Landed oysters per bushel in three groups: market-size (≥2.5"), smaller attached oysters, and smaller unattached oysters. The number of market-size oysters per landed bushel in 2021 averaged 275, while the total oysters per landed bushel averaged 303. The long-term mean of all oysters and market oysters per landed bushel (268) is shown as an orange line.

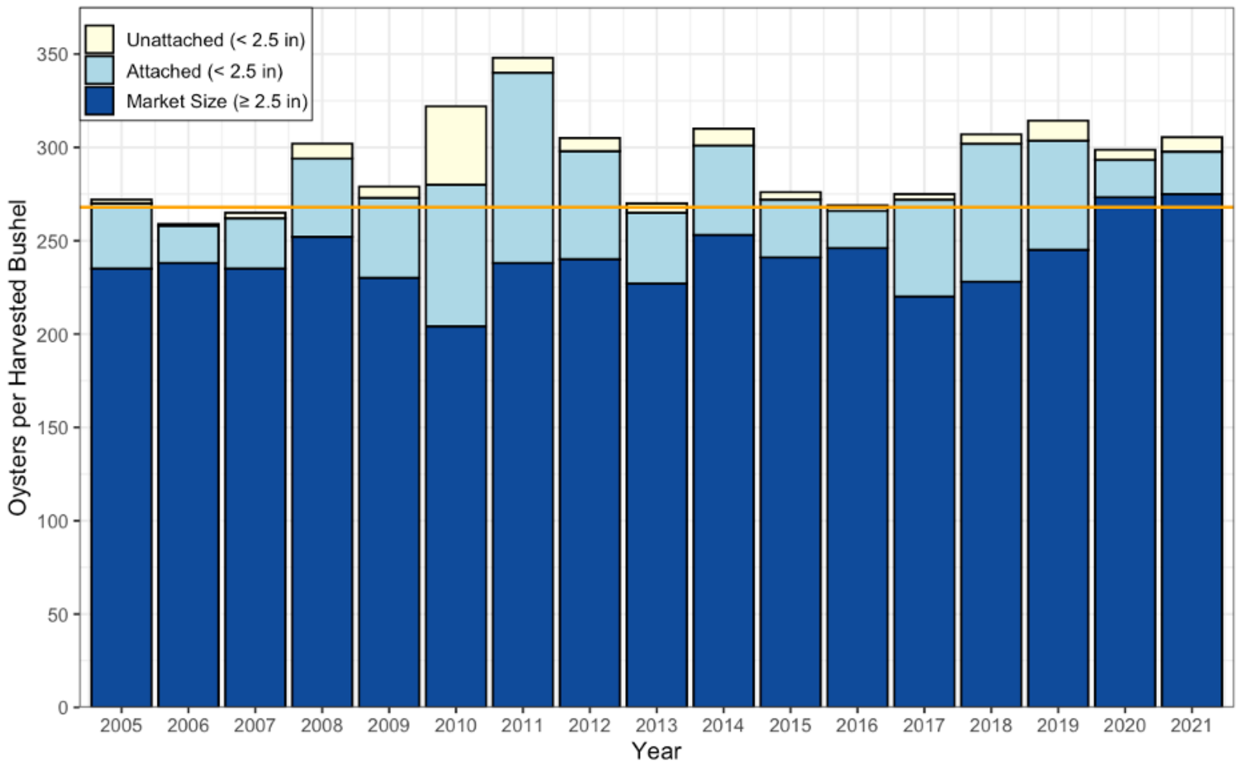


Figure 10. Numbers of single and dual dredge boats (stacked bars) participating in the NJ Delaware Bay oyster harvest overlaid with LPUE (total number of harvested bushels/total hours worked) for each dredge type.

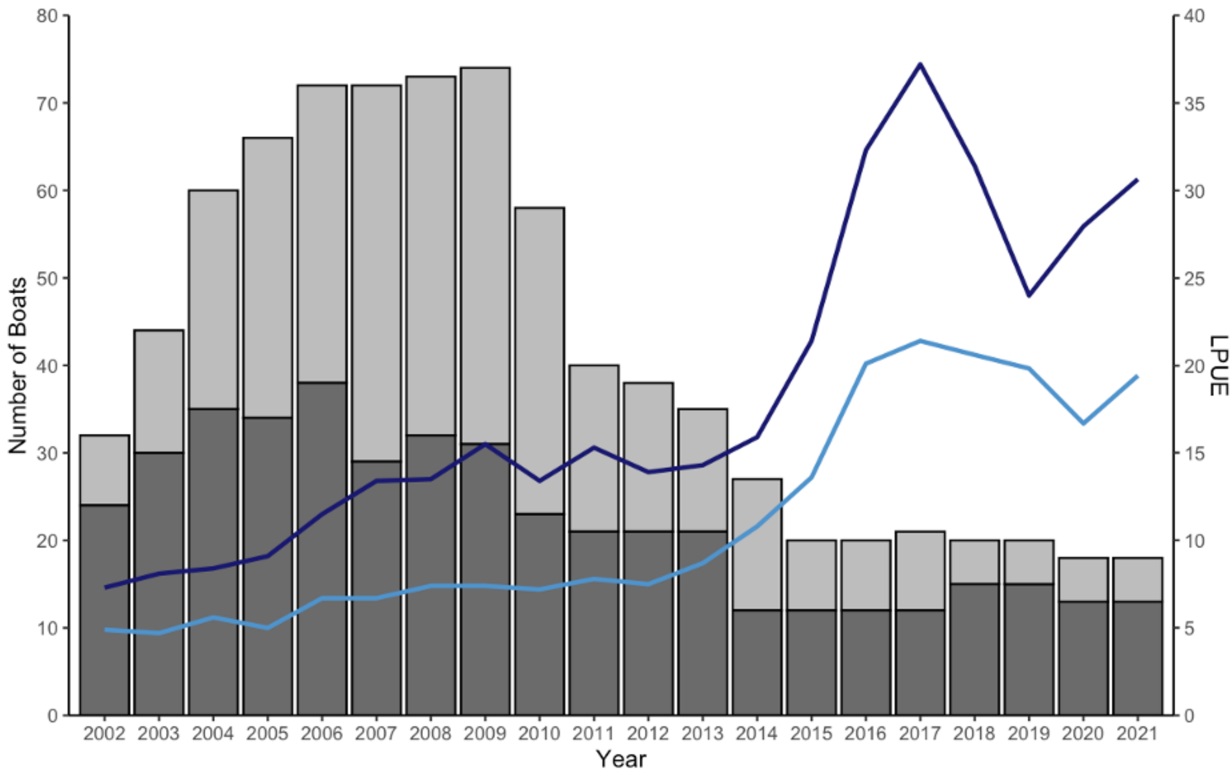


Figure 11. Size frequency of oysters landed by the fishery in direct market regions (top panel) and within the direct market regions of the surveyed population (bottom panel). Vertical line indicates the market-size cutoff (≥ 2.5 inches).

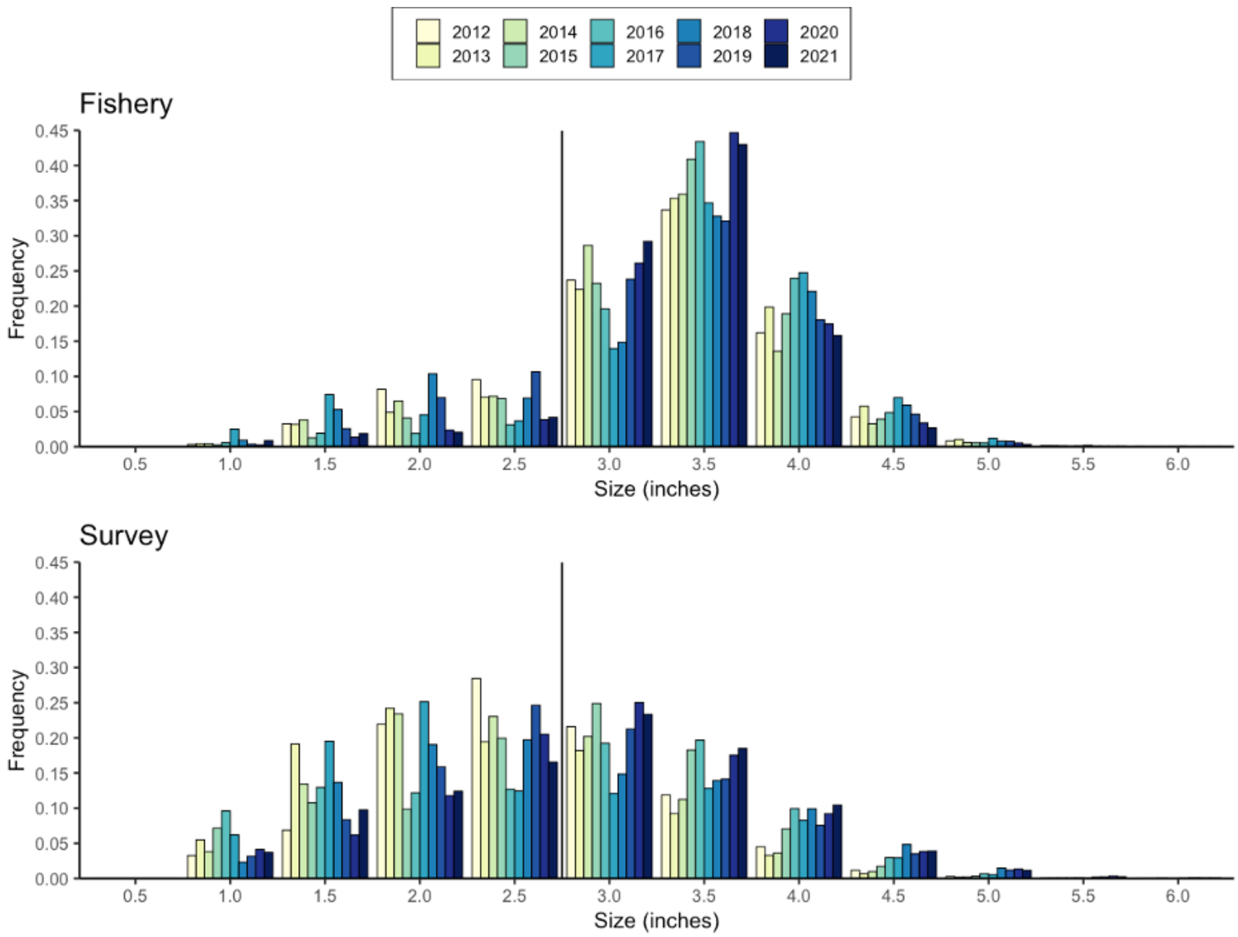


Figure 12. Frequencies of large (≥ 3.5 inches) oysters landed by the fishery in direct market regions (top panel) and within the surveyed population (bottom panel).

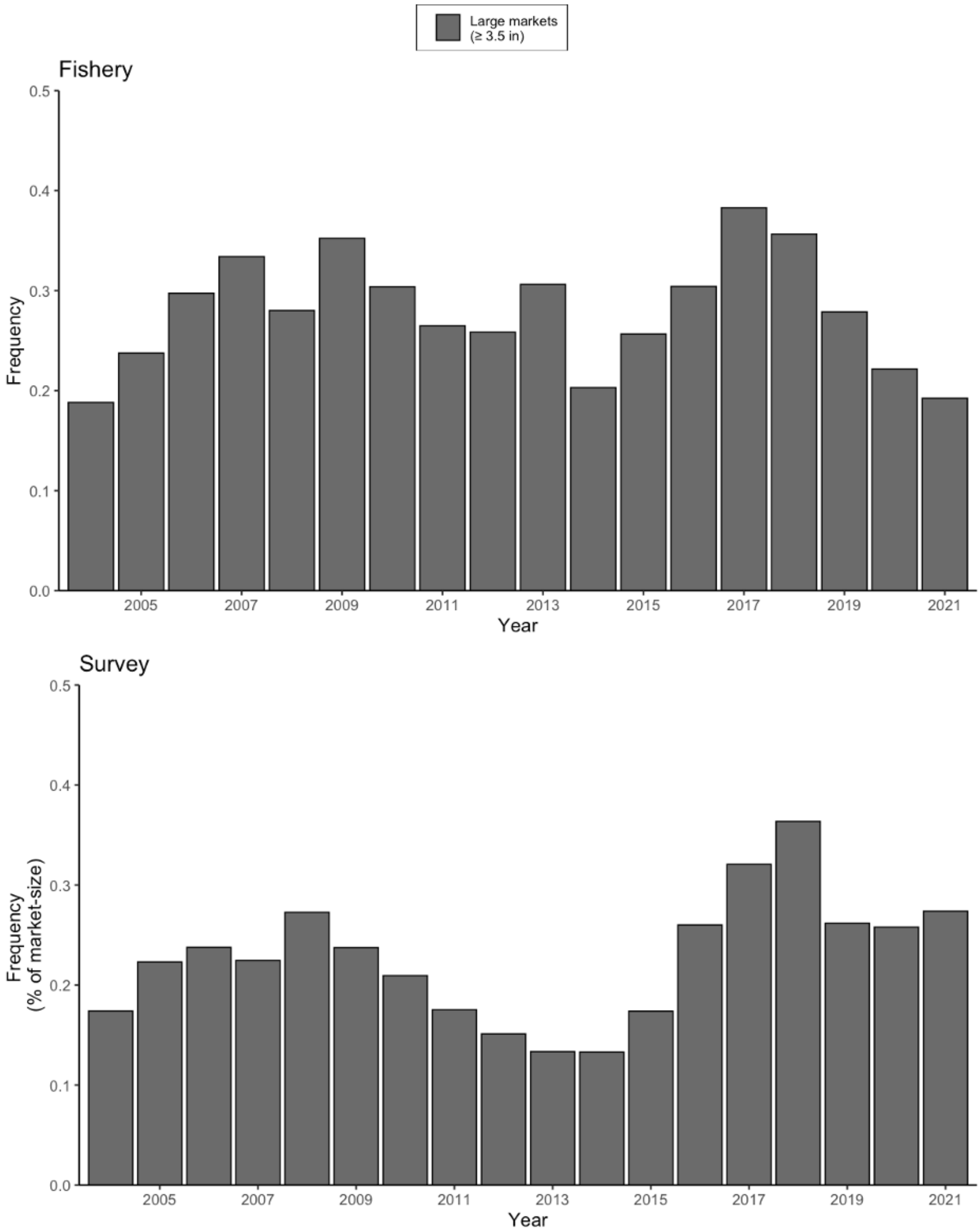
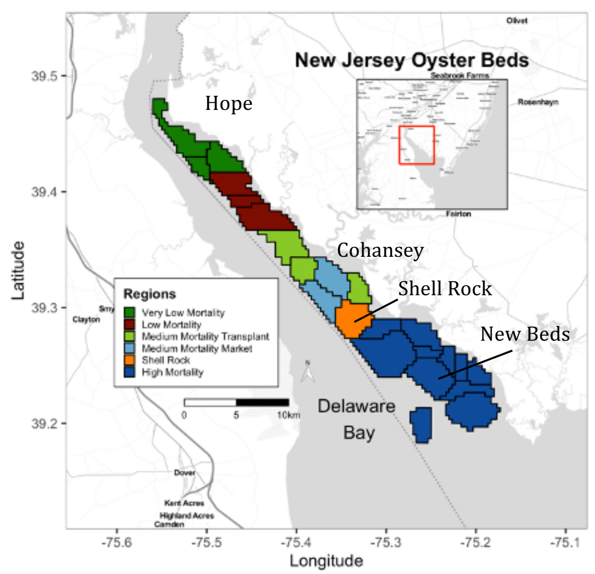


Figure 13. Growth experiment deployment sites (a) and percentage growth from May to November (b). Oysters were grouped into three size bins based on initial height (mm). Y-axis is total growth represented by the proportional change from the first measurement to the final measurement.

a.



b.

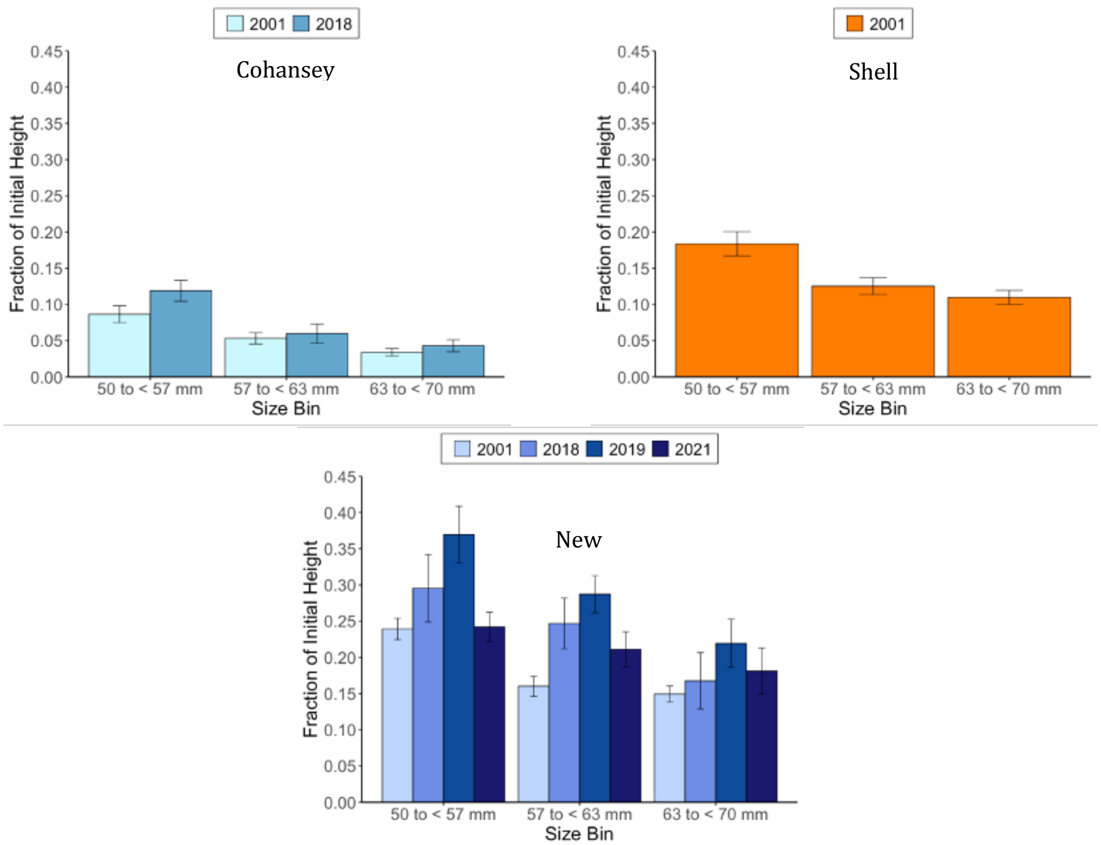

2001
2018
Cohansey
Fraction of Initial Height
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
50 to < 57 mm
57 to < 63 mm
63 to < 70 mm
Size Bin
2001
Shell
Fraction of Initial Height
50 to < 57 mm
57 to < 63 mm
63 to < 70 mm
Size Bin
2001
2018
2019
2021
New
Fraction of Initial Height
50 to < 57 mm
57 to < 63 mm
63 to < 70 mm
Size Bin

Figure 14. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program in 1996. The 25-year average harvest is 84,130 bushels. The vertical line shows the beginning of the current exploitation and management strategy in 2007. The achieved quota for 2021 was 116,194 bushels after transplant (orange line).

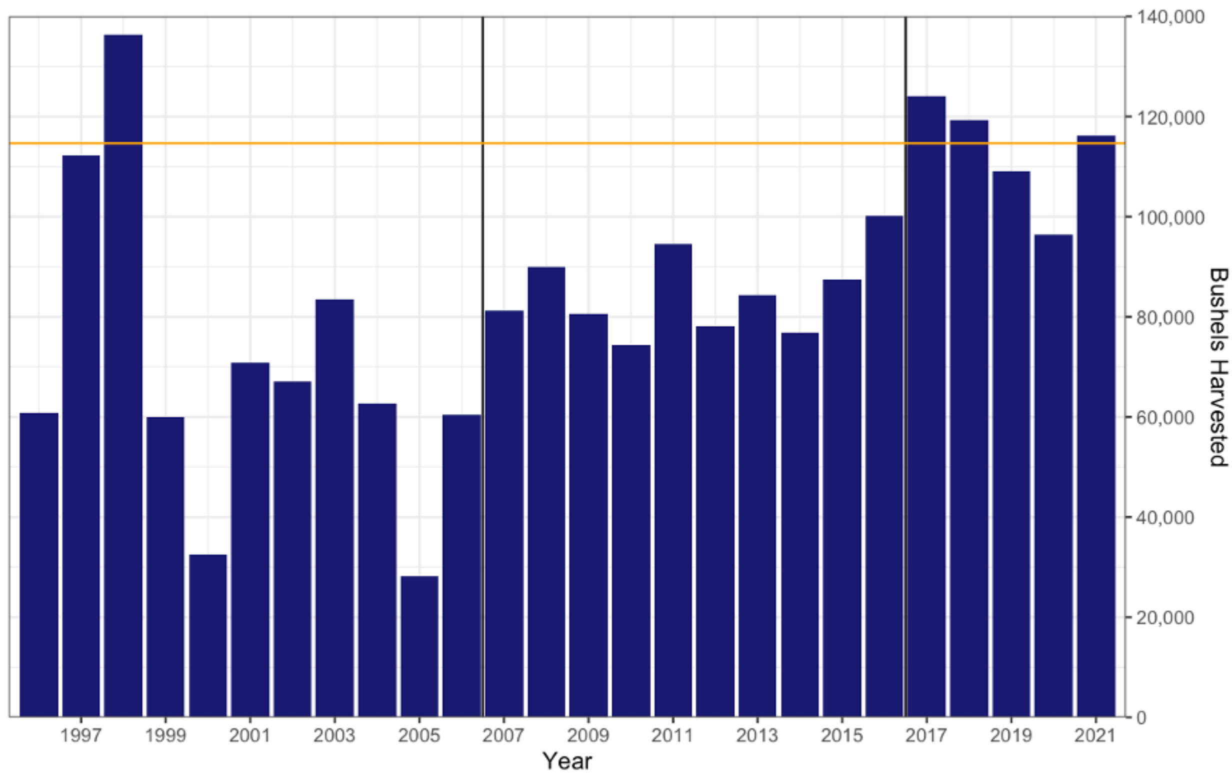
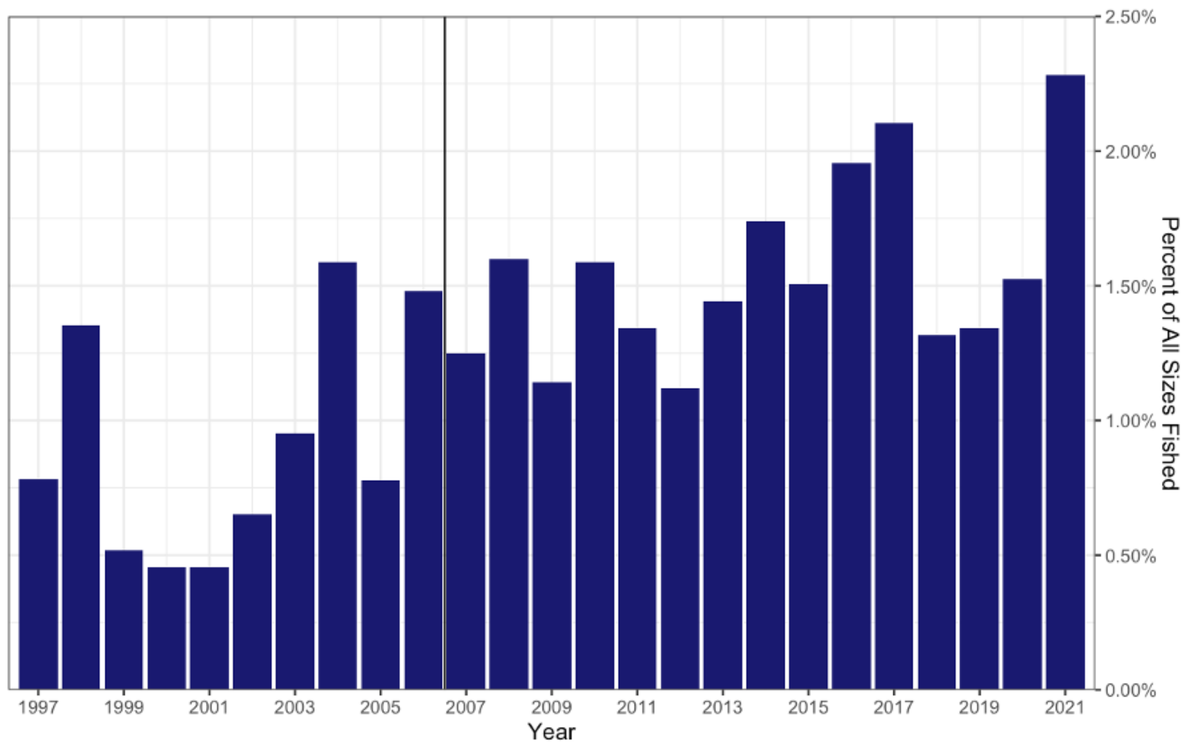


Figure 15. Fishing mortality as a percentage of (a) total oyster abundance and (b) the market-sized oyster abundance (≥2.5”) over all regions excluding the VLM. Regional abundance-based quotas began in 2007 (vertical line).

a.



b.

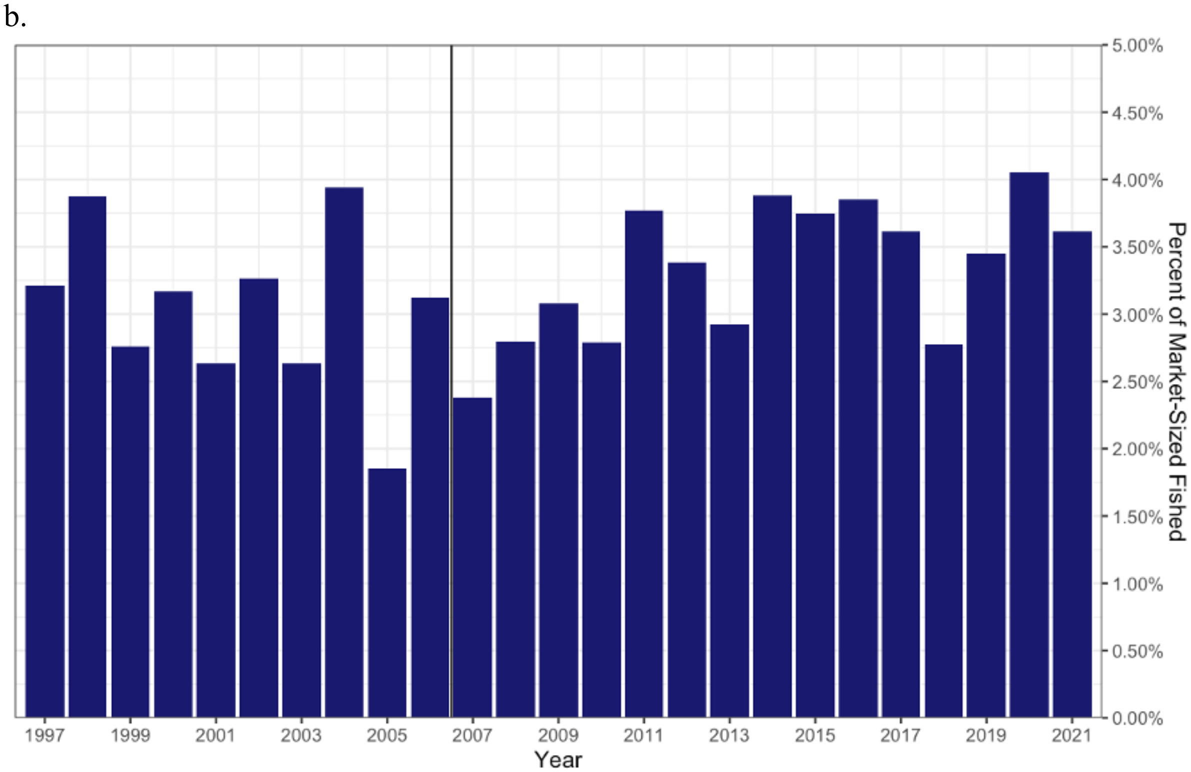


Figure 16. Boxplots showing oyster exploitation rate for each bed since 1996 (beginning of the direct market fishery; see Figure 5). The red vertical line represents 2% exploitation. Beds are organized from upper to lower bay. Negative exploitation rates occur when more oysters are transplanted to a given region than are removed by fishing.

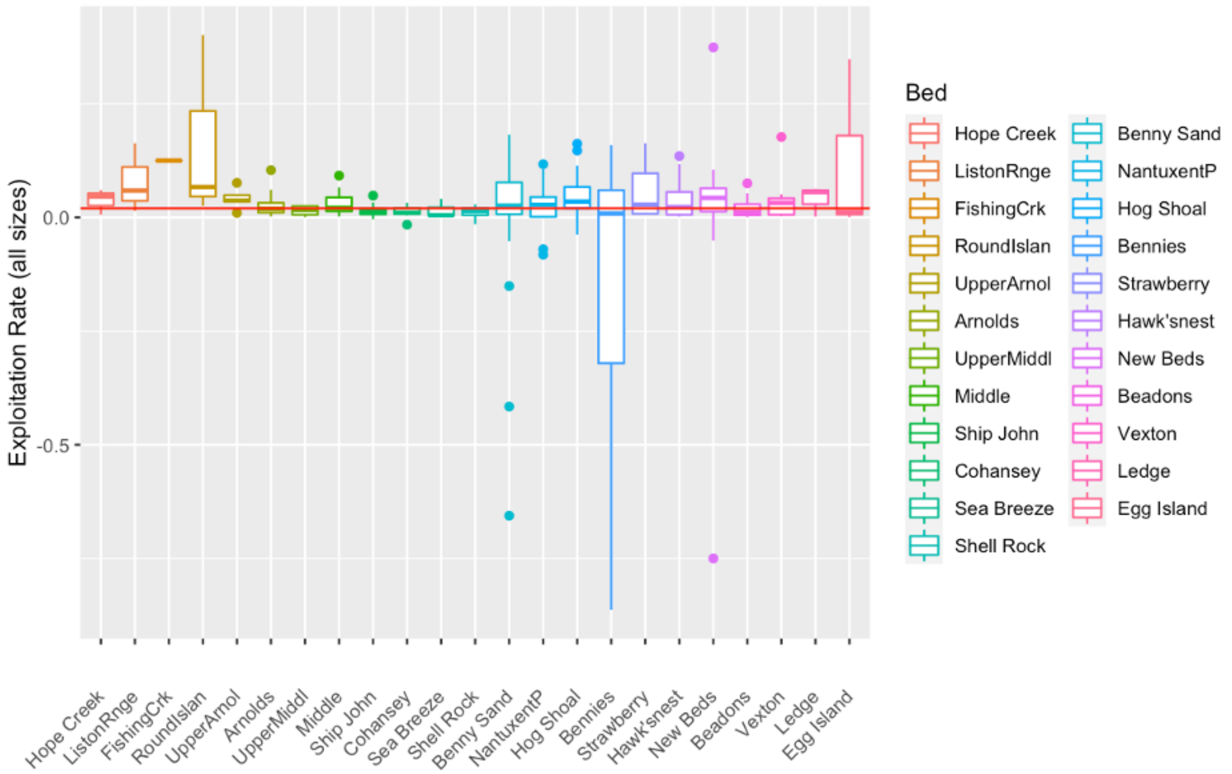


Figure 17. Population growth rate as a function of exploitation rate for each bed since 1996 (beginning of the direct market fishery; see Figure 5). The red vertical line represents 2% exploitation. The red horizontal line represents population growth =0. Negative exploitation rates occur when more oysters are transplanted to a given region than are removed by fishing. Lines for each bed represent the best fit linear model.

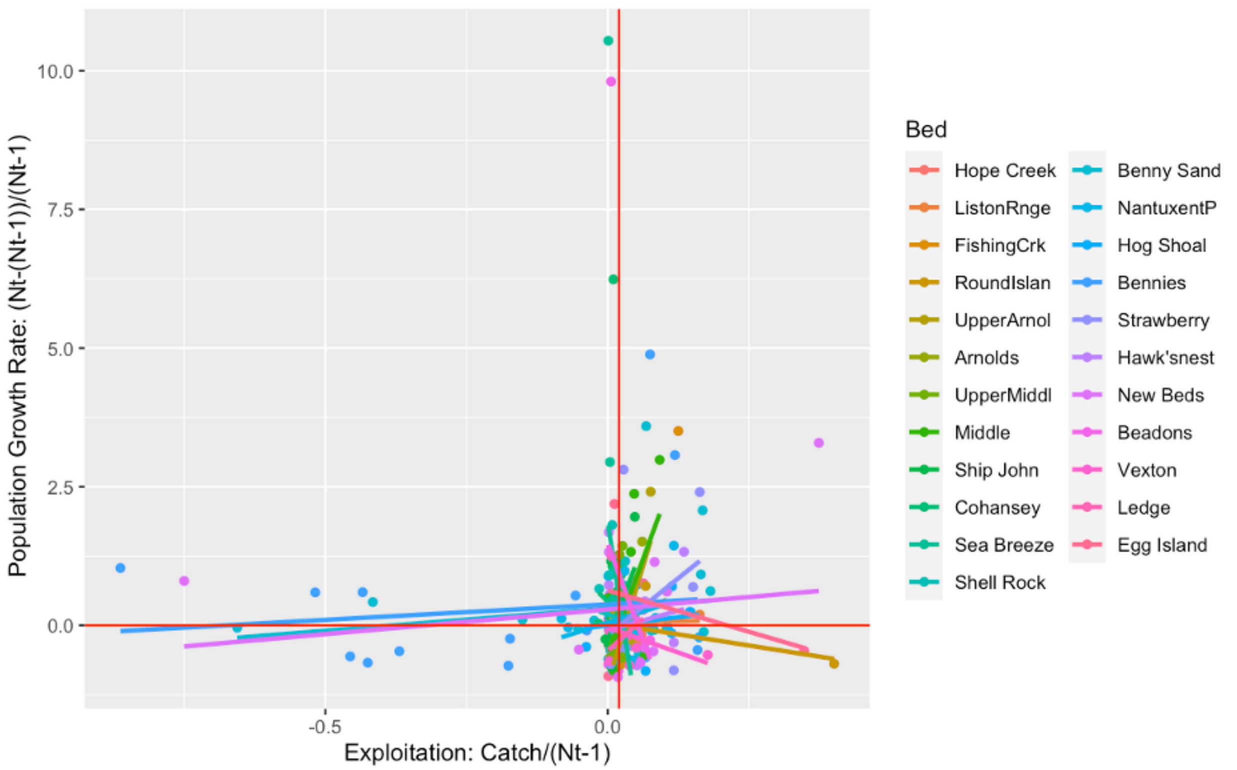


Figure 18. Population growth rate as a function of exploitation rate for Middle bed since 1996 (beginning of the direct market fishery; see Figure 5). The red vertical line represents 2% exploitation. The red horizontal line represents population growth =0. The red diagonal line is the best fit linear model.

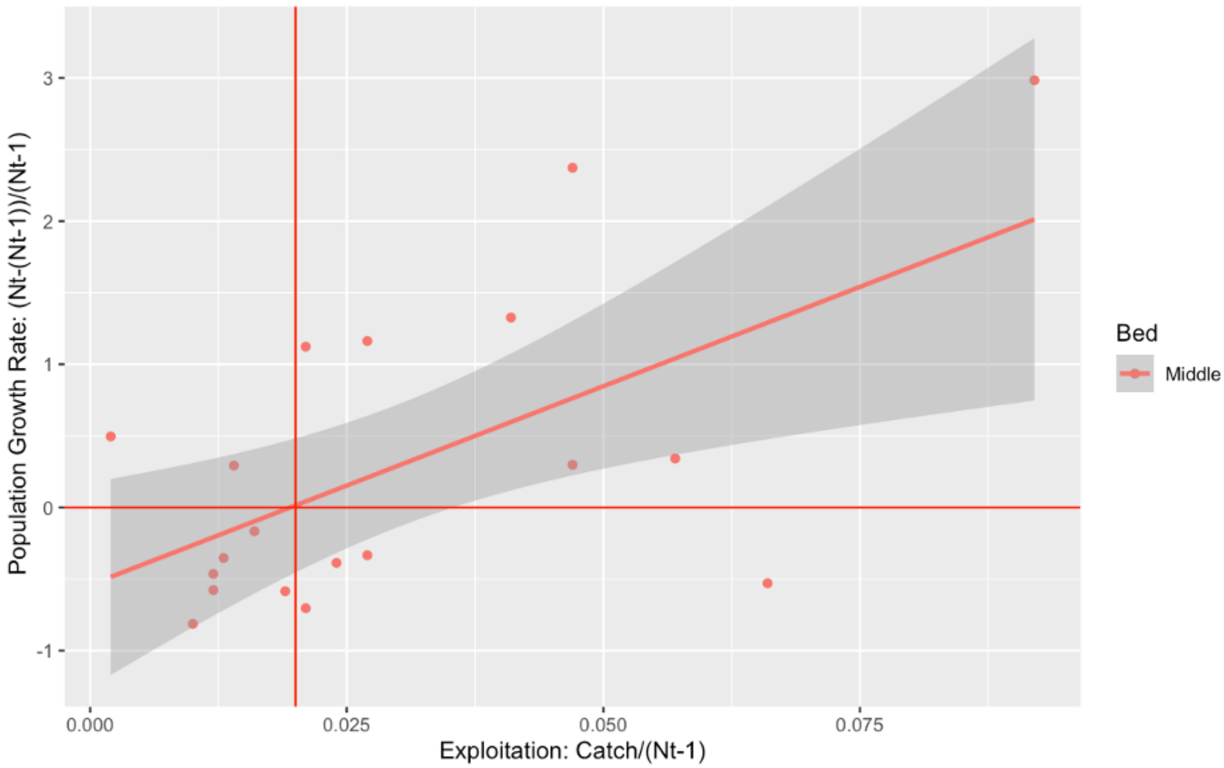


Figure 19. Boxplots of spatfall (A) and log(spatfall) (B) estimated during the fall Assessment Survey for each of three types of fishing that occurred during the fishing season (April – November) that same year: none = no fishing; low = low intensity fishing; high = high intensity fishing.

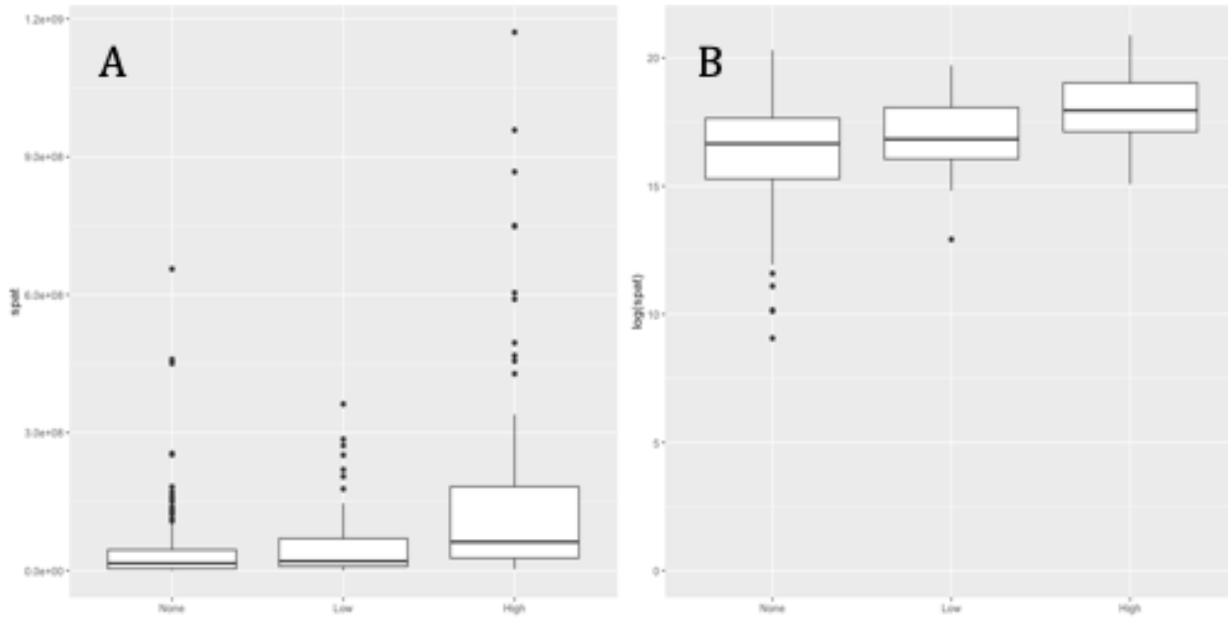


Figure 20. Boxplots of log(spatfall) estimated during the fall Assessment Survey for each bed for each of three types of fishing that occurred during the fishing season (April – November) that same year: none (red boxes) = no fishing; low (green boxes) = low intensity fishing; high (blue boxes) = high intensity fishing. Beds are organized from the upper to the lower Bay. Shaded box represents the middle portion of the bay where most of the fishing activity occurs.

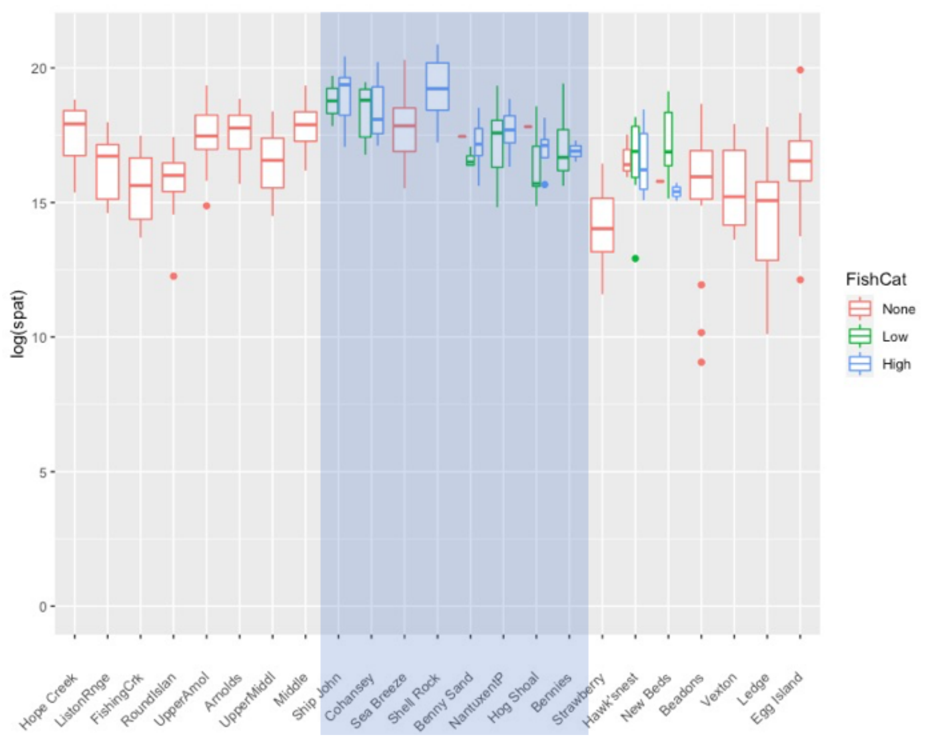


Figure 21. Map of the 2021 oyster stock assessment sample sites. Black dots are sites from high quality stratum on each bed and white dots are sites from medium quality stratum on each bed. Black x's indicate transplant enhancement sites and black triangles indicate shellplant enhancement sites.

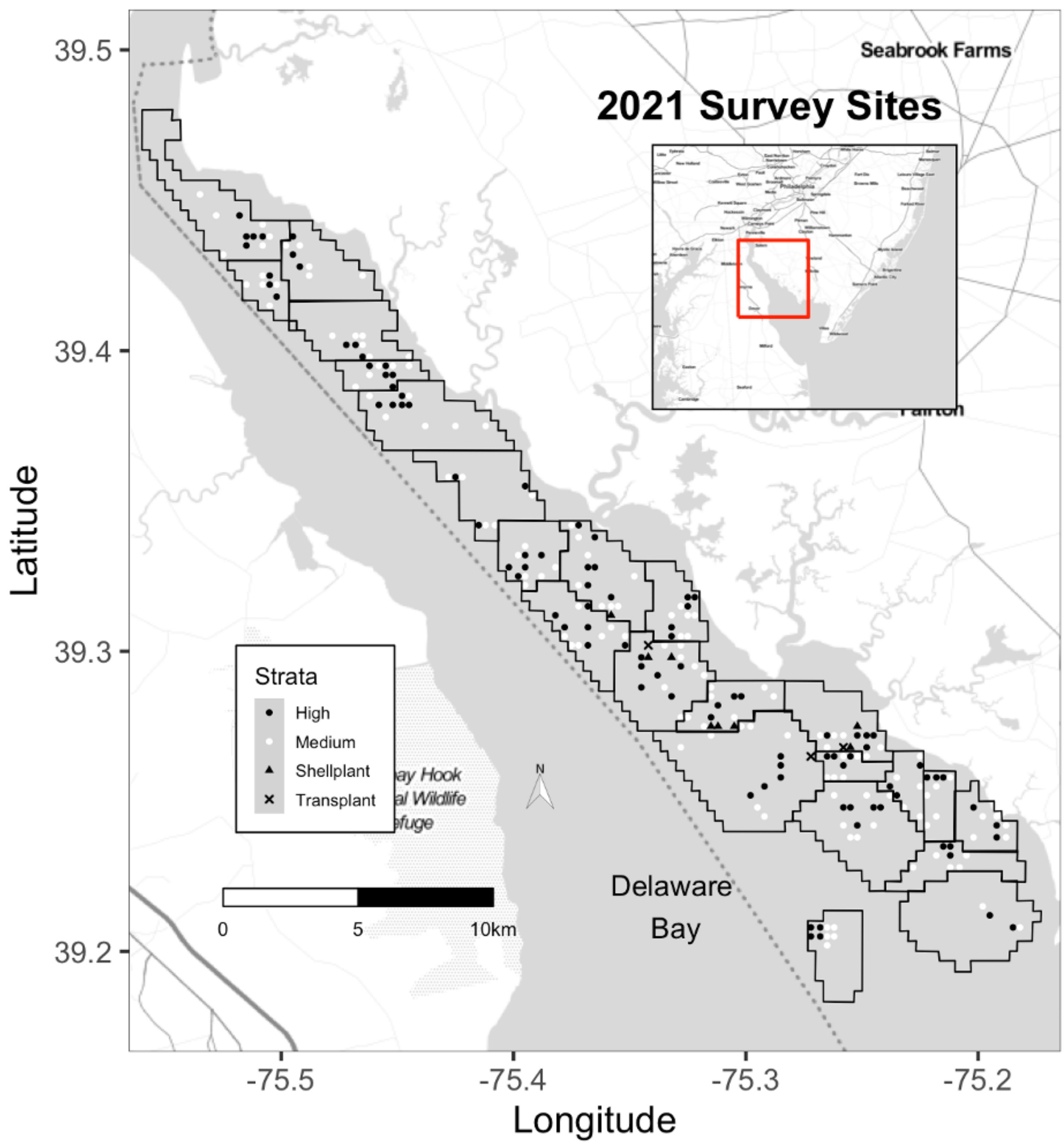


Figure 22.1. Ten-year time series summary for the population, excluding the VLM. Top panels: total abundance (≥ 20 mm) and size class abundances (≥ 20 mm). Bottom panels: mortality rate and spat abundance (< 20 mm). Dashed horizontal lines represent the threshold and solid horizontal lines represent the target for abundance in panel A and for market abundance in panel B.

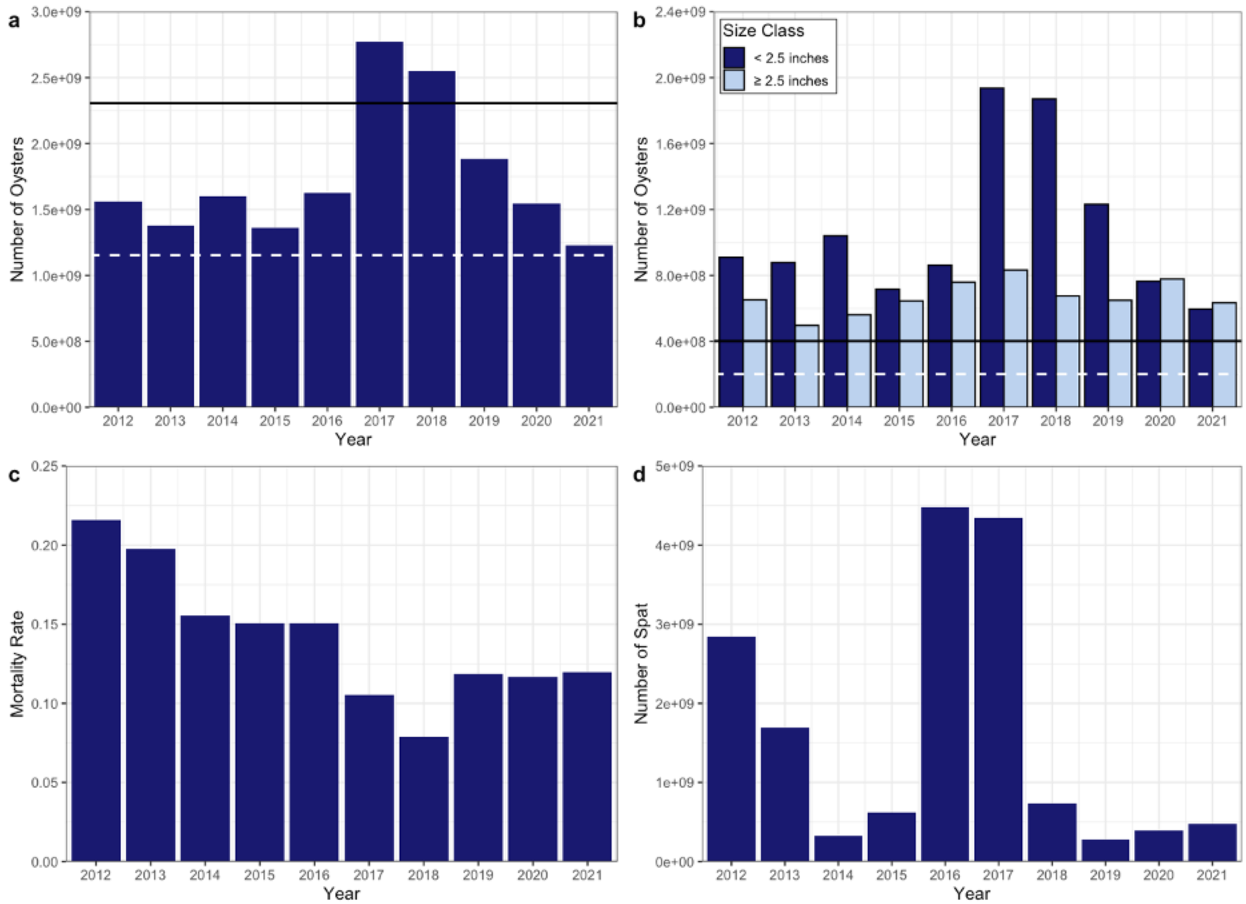
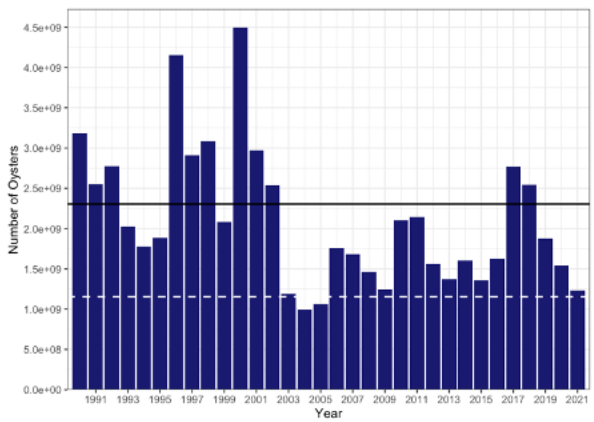
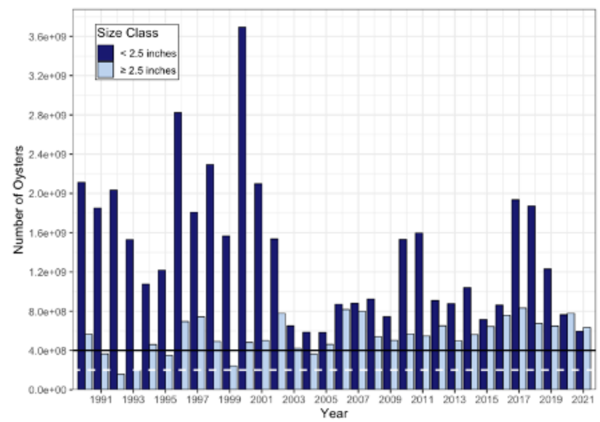


Figure 22.2. Long-term time series summary for the population, excluding the VLM. Top panels: total abundance (≥ 20 mm) and size class abundances (≥ 20 mm). Bottom panels: mortality rate and spat abundance (< 20 mm). Dashed horizontal lines represent the threshold and solid horizontal lines represent the target for abundance in panel A and for market abundance in panel B.

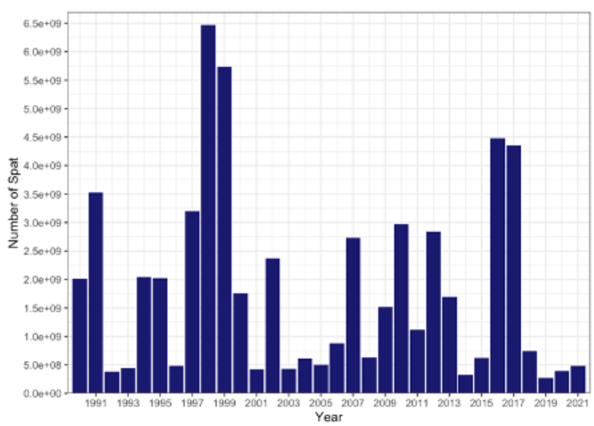
a.



b.



c.



d.

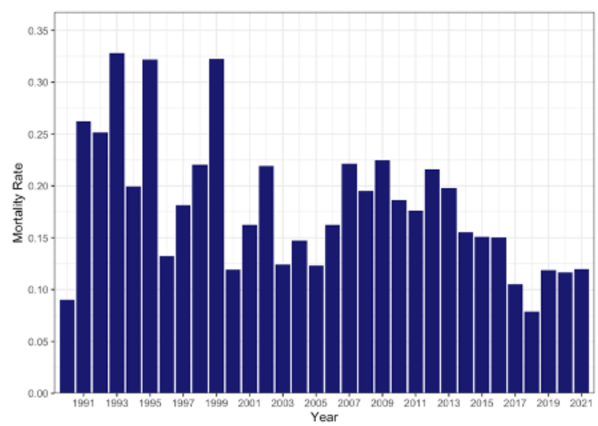
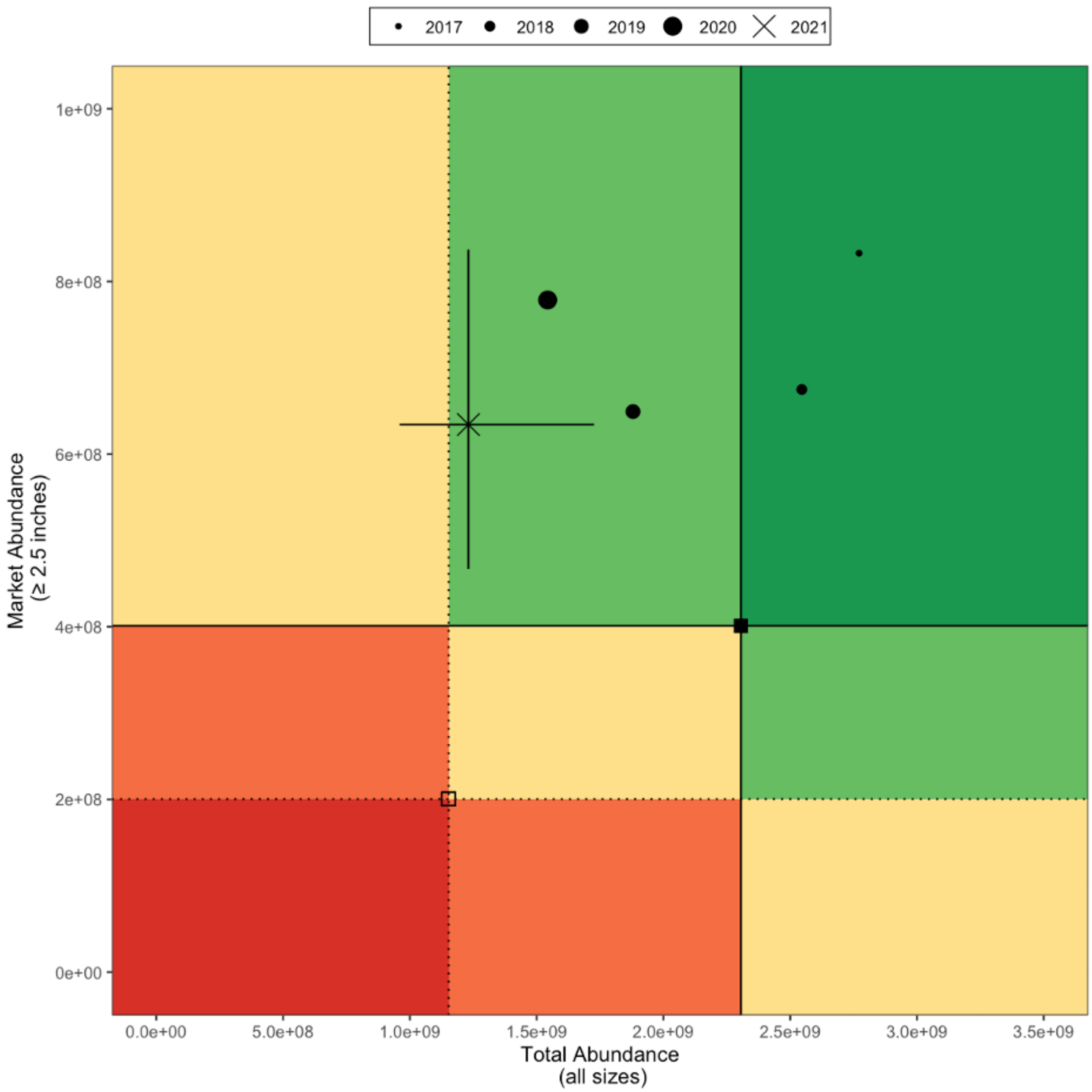


Figure 23. Position of the oyster stock 2017–2021 with respect to abundance and market abundance (≥ 2.5”) targets and thresholds, excluding the VLM. Targets and thresholds are defined in Table 9. Error bars on the 2020 values are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error. *Shading: Green, above all 4 cutoffs*; *Light green, above 3 cutoffs*; *Yellow, above 2 cutoffs*; *Orange, above 1 cutoff*; *Red, below all 4 cutoffs.*



Figures 24 – 29. Ten-year and long-term time series summaries by region. Left panels: a) total abundance (≥ 20 mm), c) size class abundances (≥ 20 mm), and e) spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Solid and dashed horizontal lines demarcate target and threshold abundances, respectively (a, c). Target and threshold lines on size class abundance plots (c) refer to market-sized oysters only. Right panels: b) Dermo levels, d) box-count mortality rate and f) fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance. Horizontal line on Dermo plots (b) indicates threshold above which natural mortality begins to increase due to Dermo.

Figure 24.1. Ten-year time series summary for the VLM.

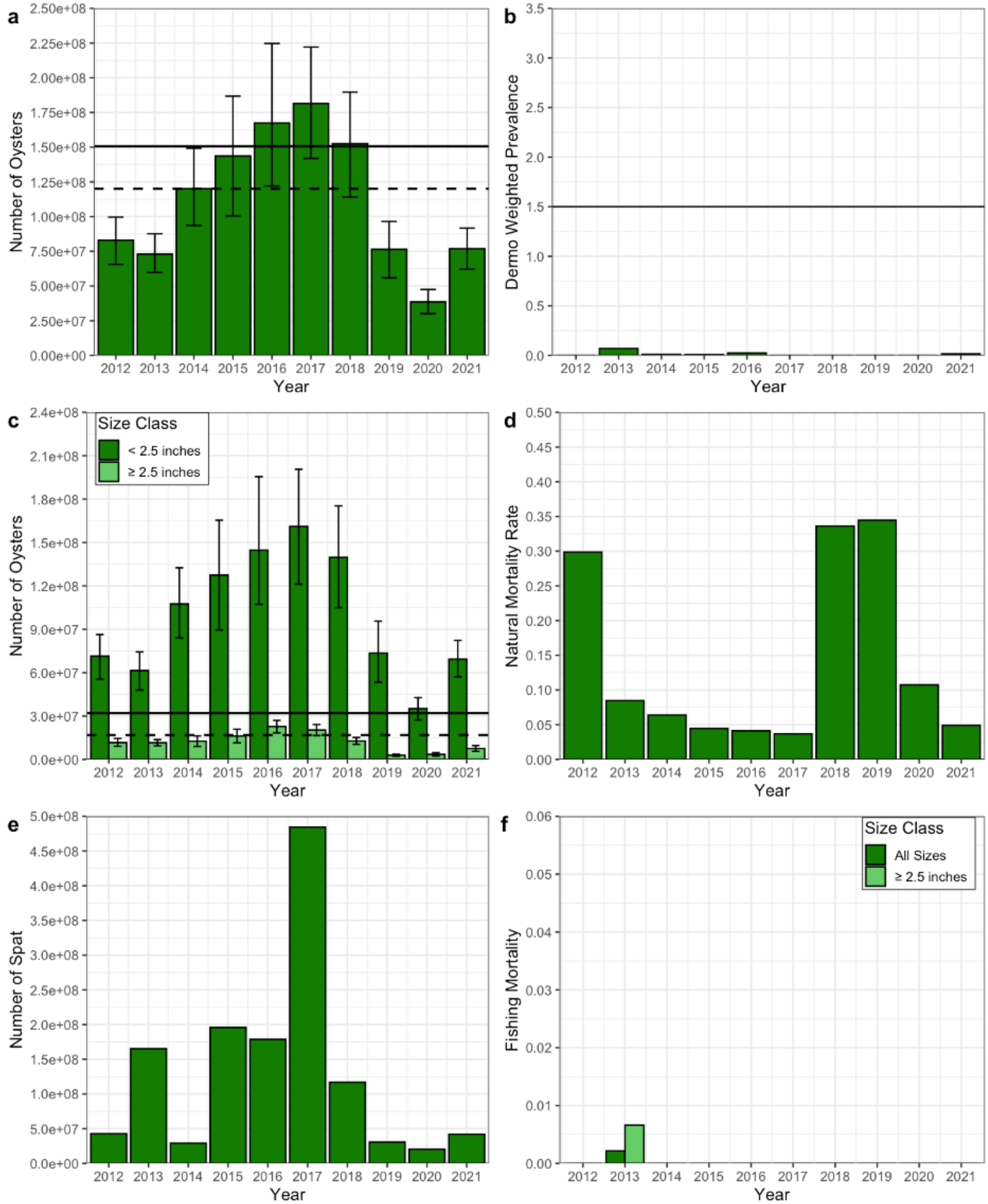


Figure 24.2. Long-term time series summary for the VLM.

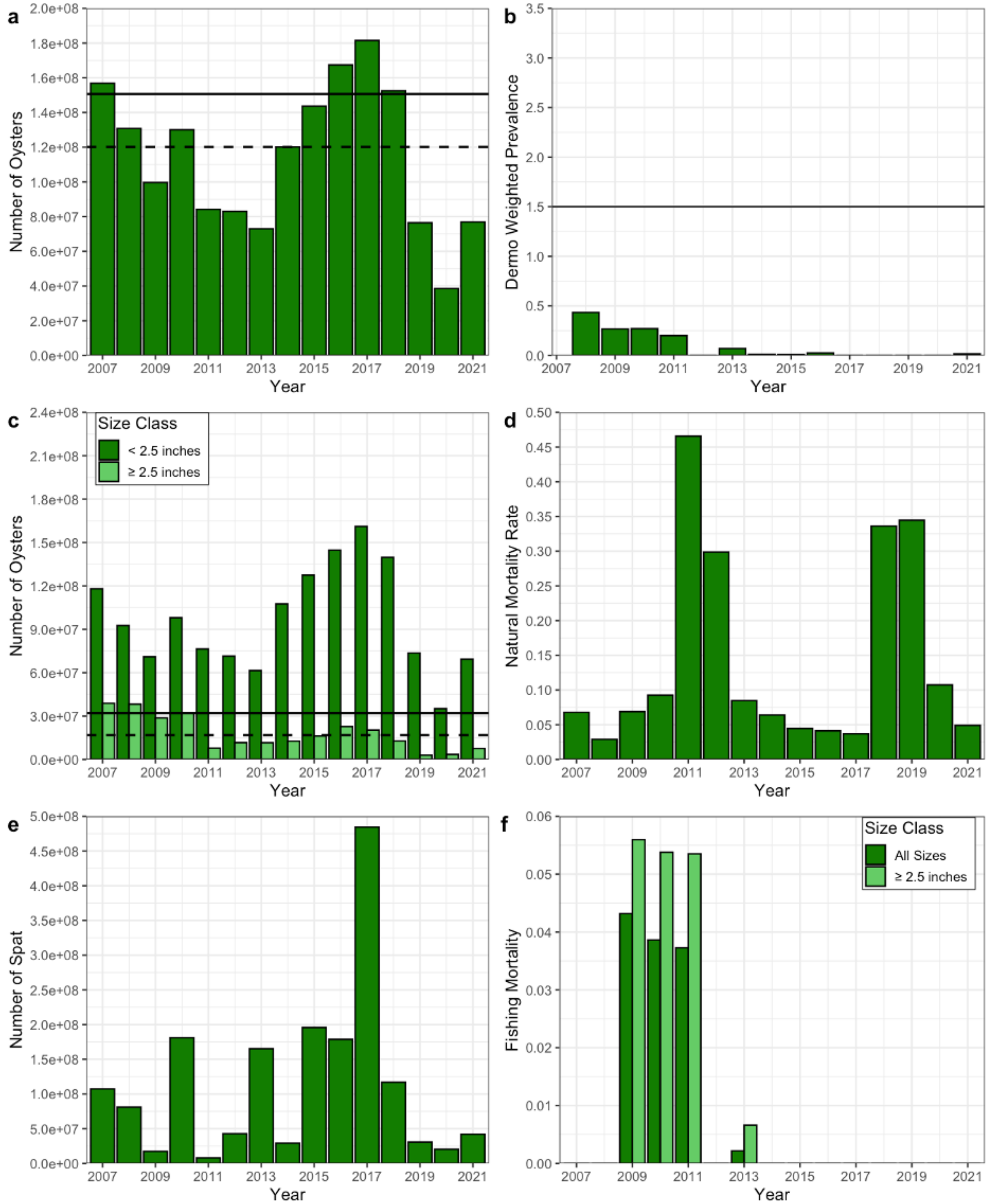


Figure 25.1. Ten-year time series summary for the LM.

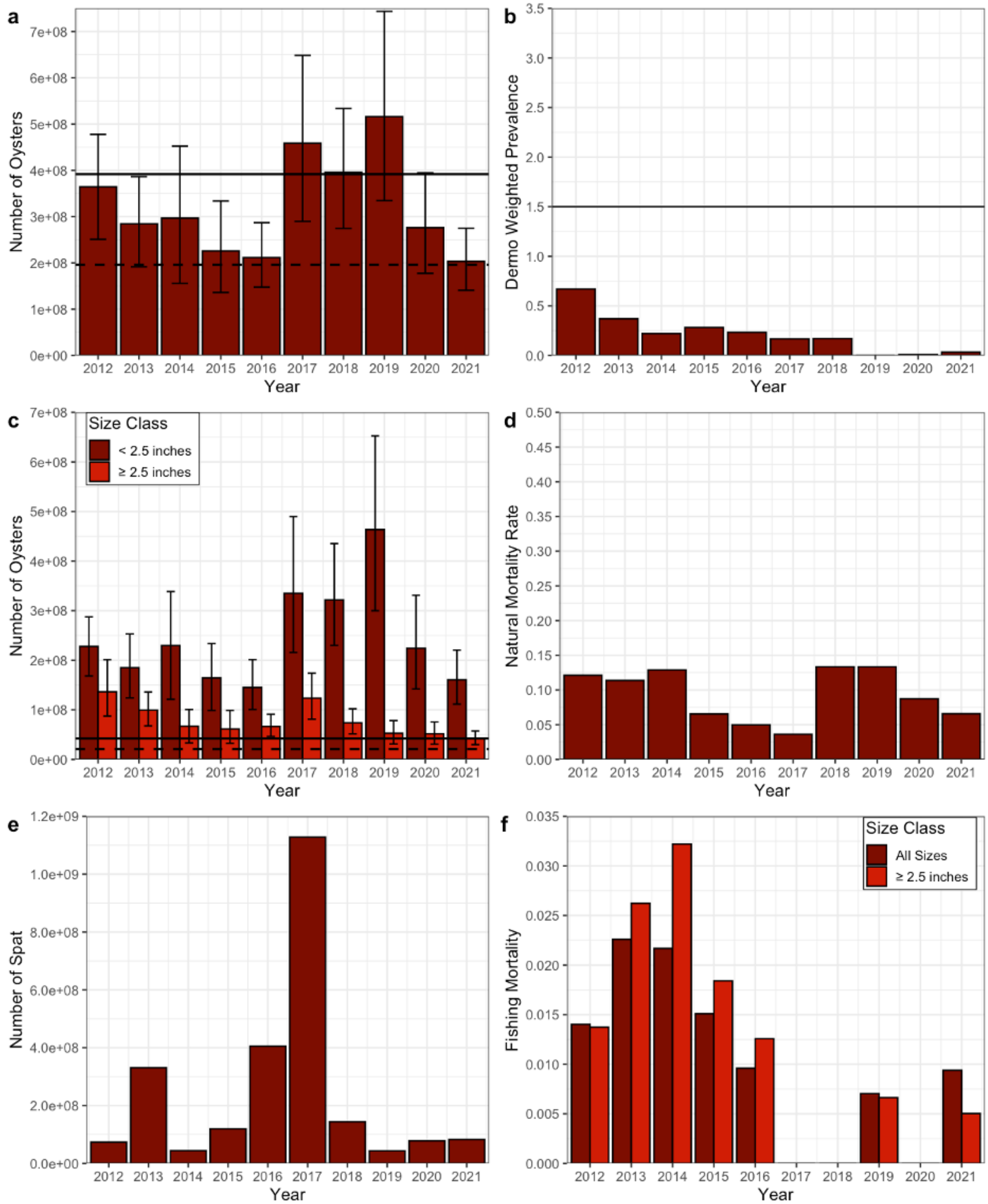


Figure 25.2. Long-term time series summary for the LM.

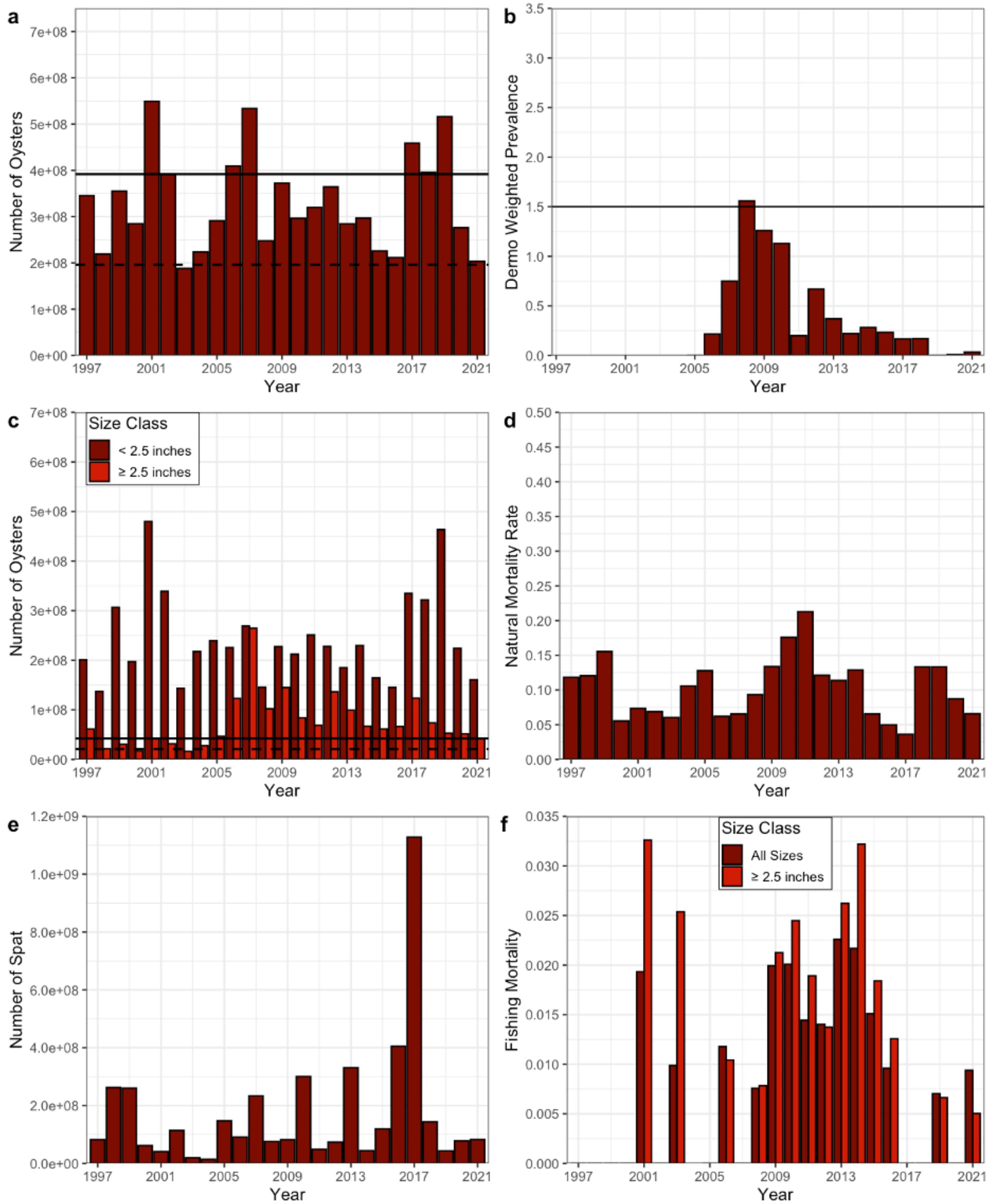


Figure 26.1. Ten-year time series summary for the MMT.

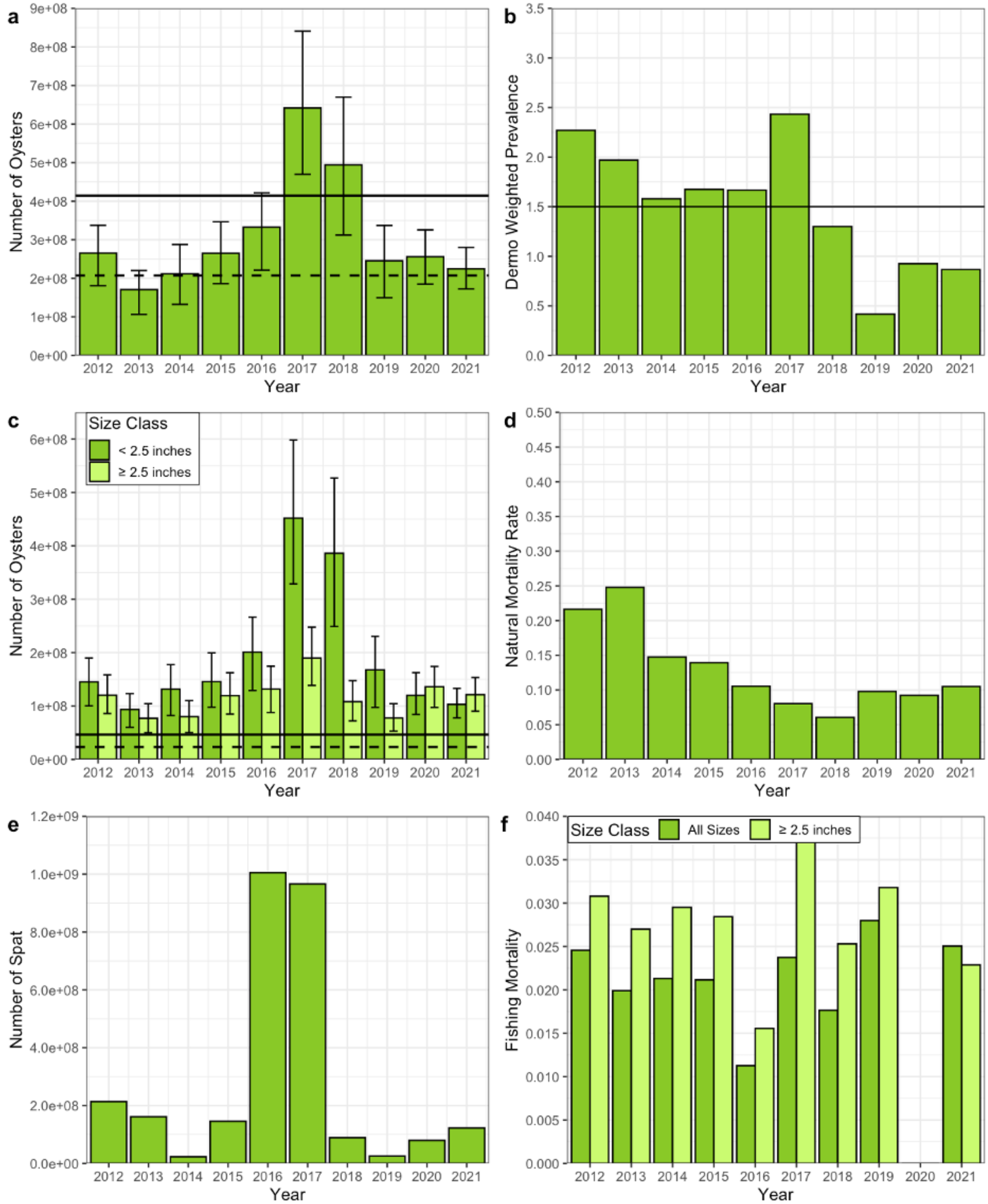


Figure 26.2. Long-term time series summary for the MMT.

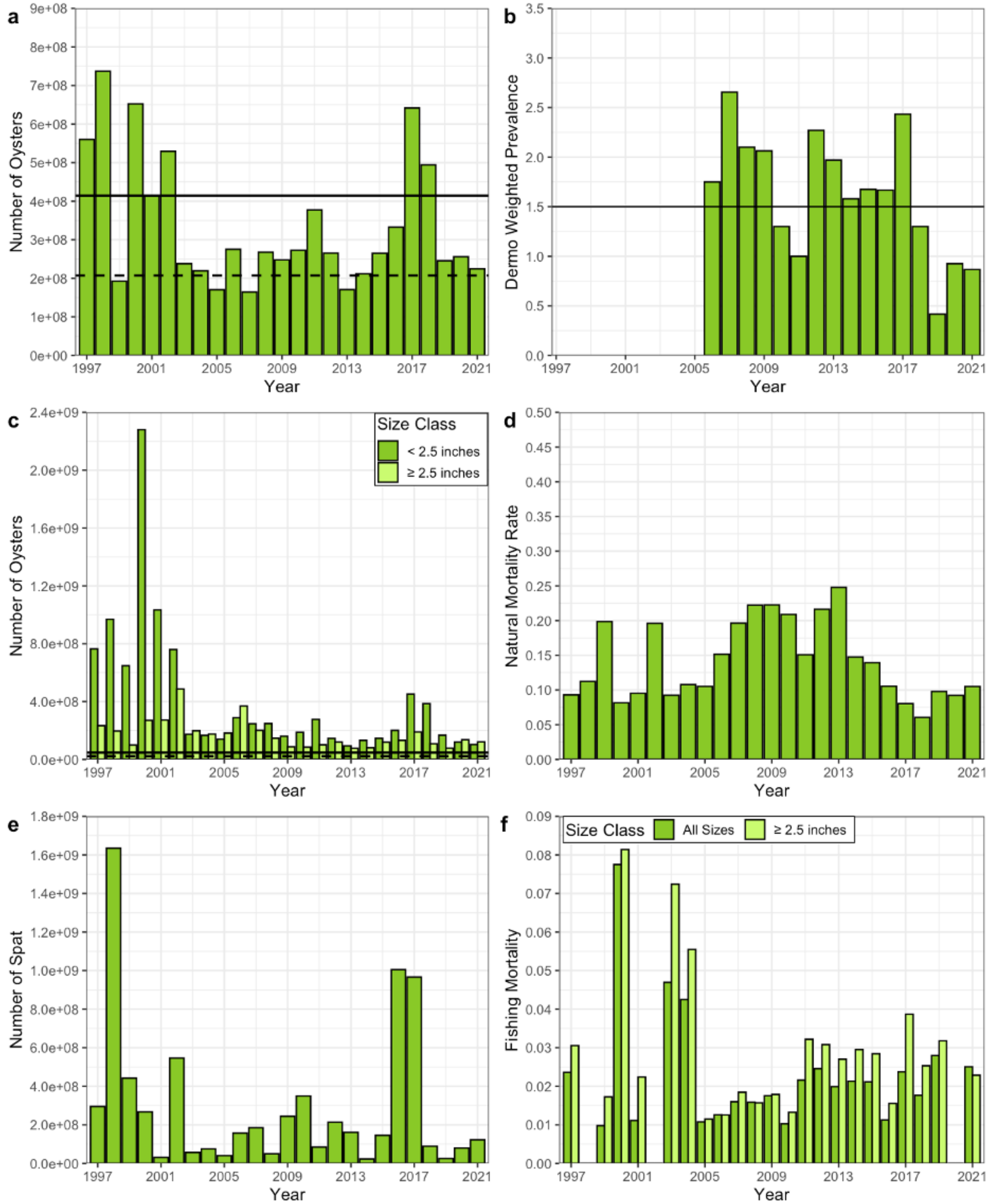


Figure 27.1. Ten-year time series summary for the MMM.

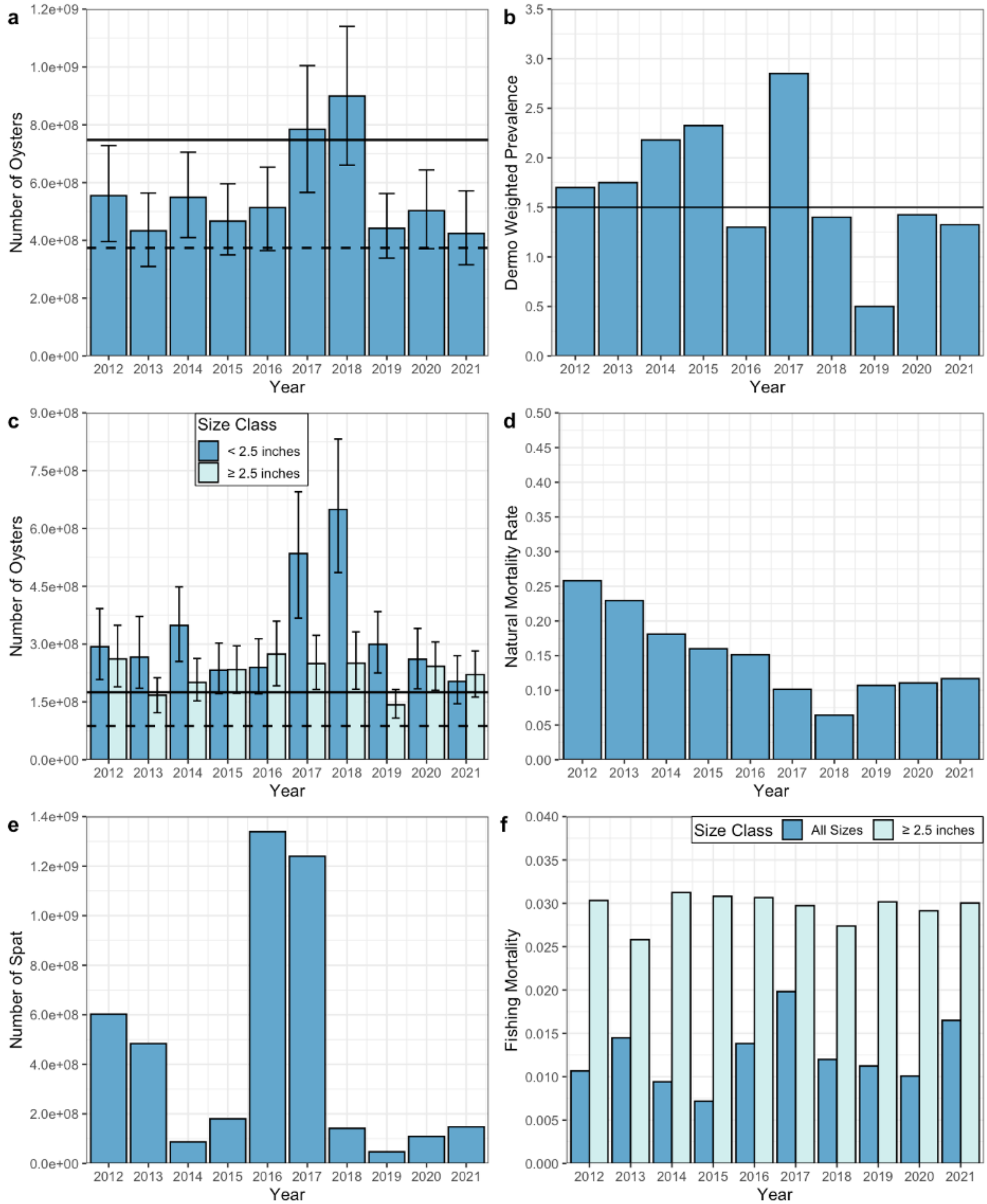


Figure 27.2. Long-term time series summary for the MMM.

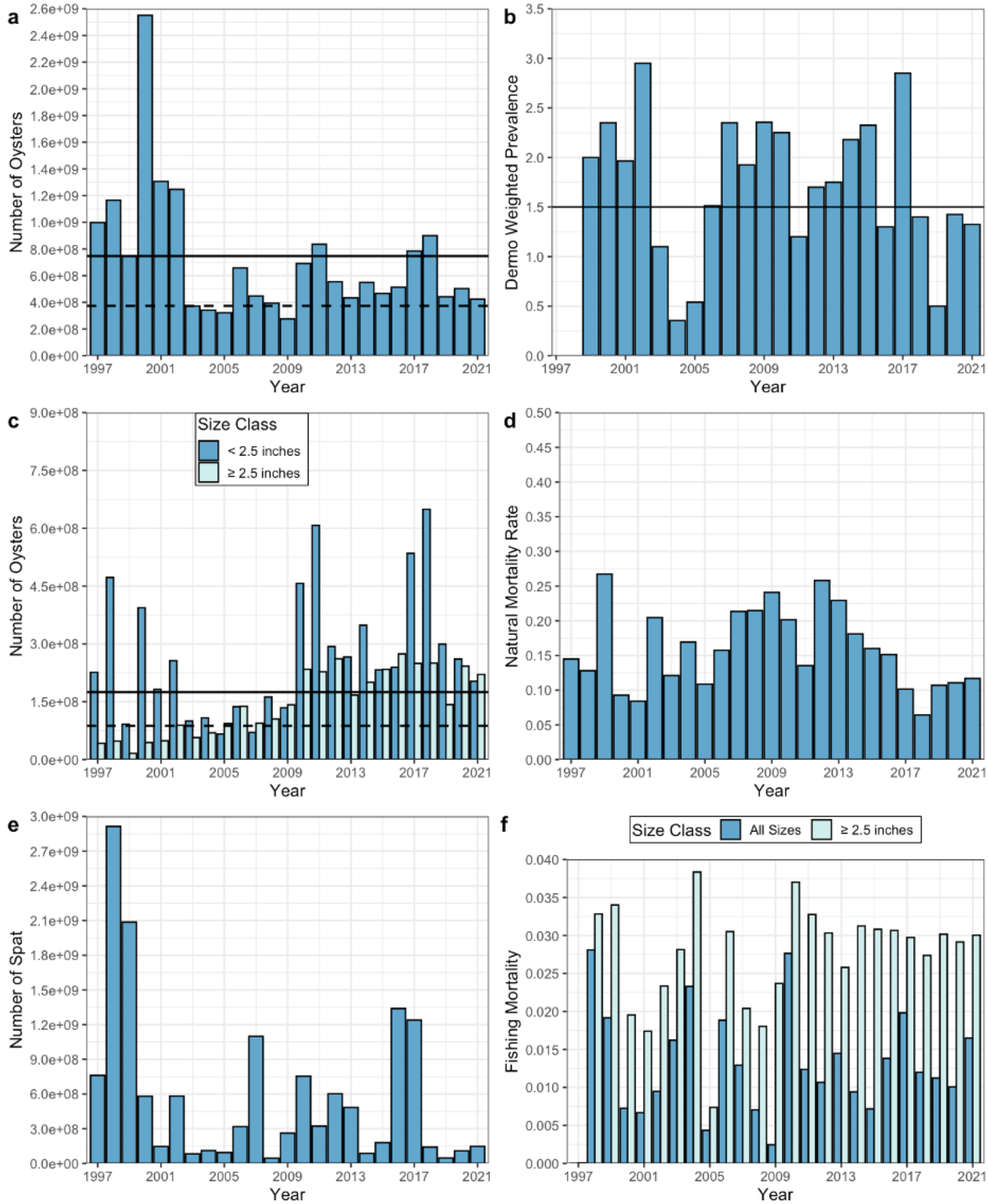


Figure 28.1. Ten-year time series summary for the SR.

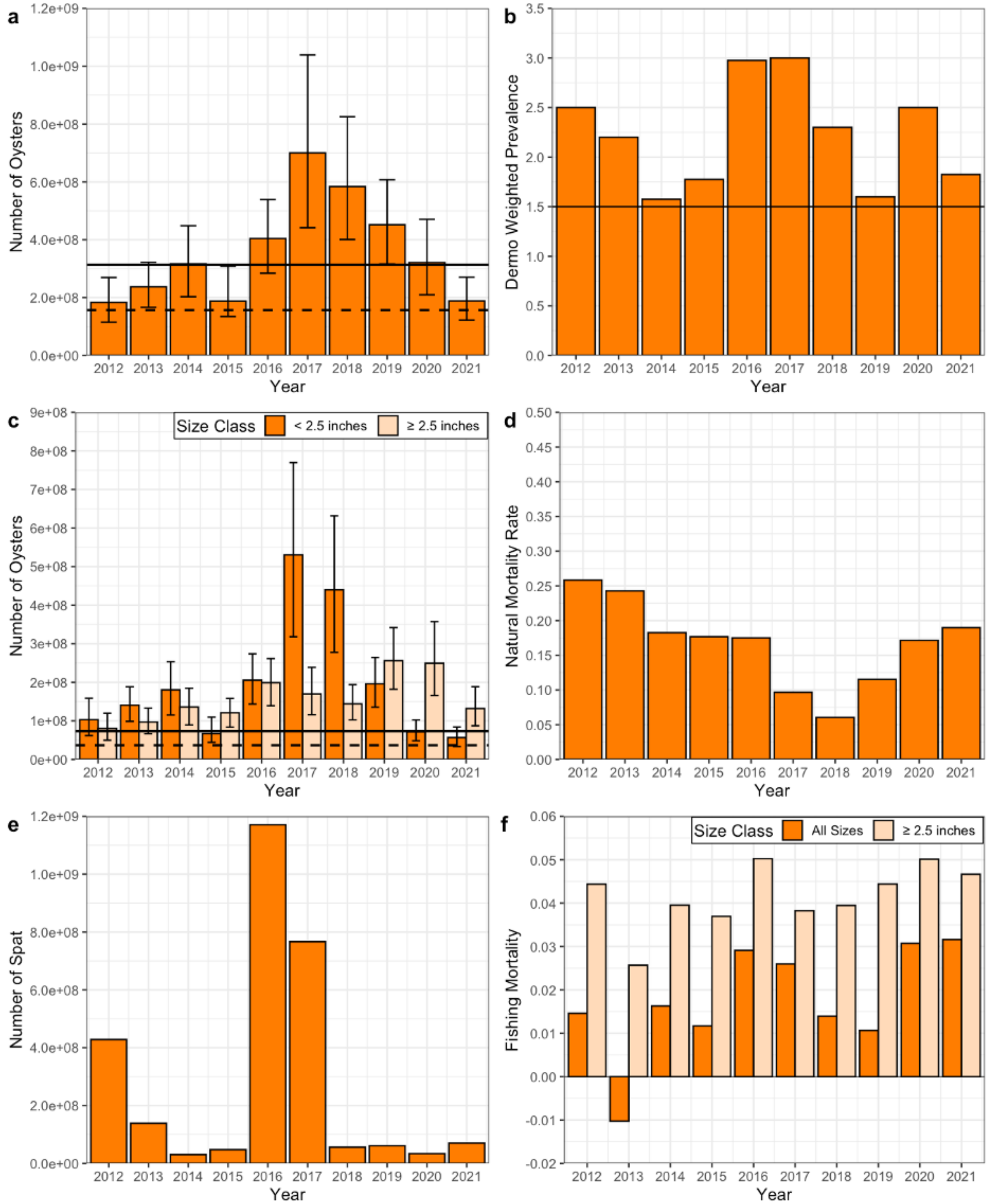


Figure 28.2. Long-term time series summary for the SR.

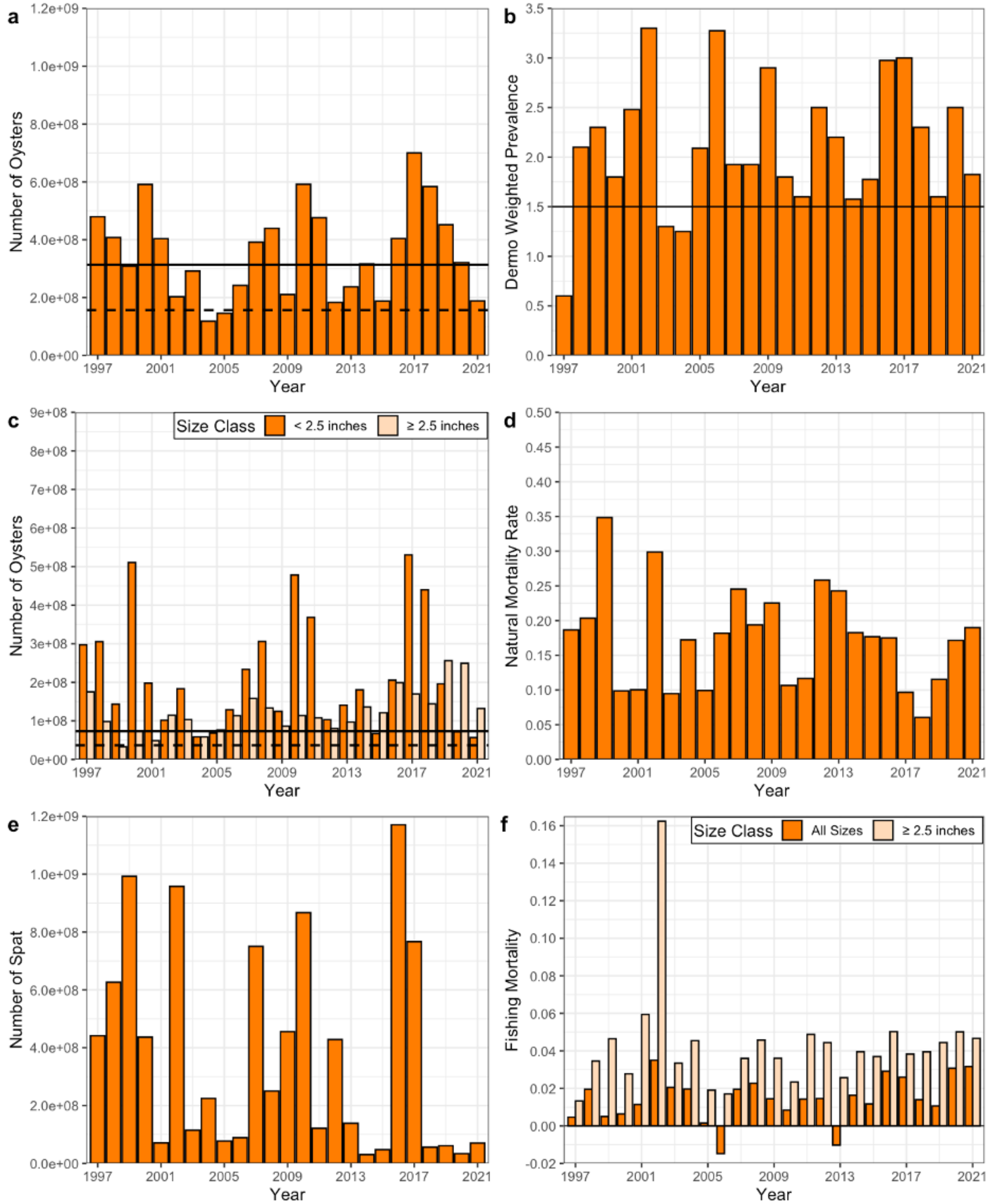


Figure 29.1. Ten-year time series summary for the HM.

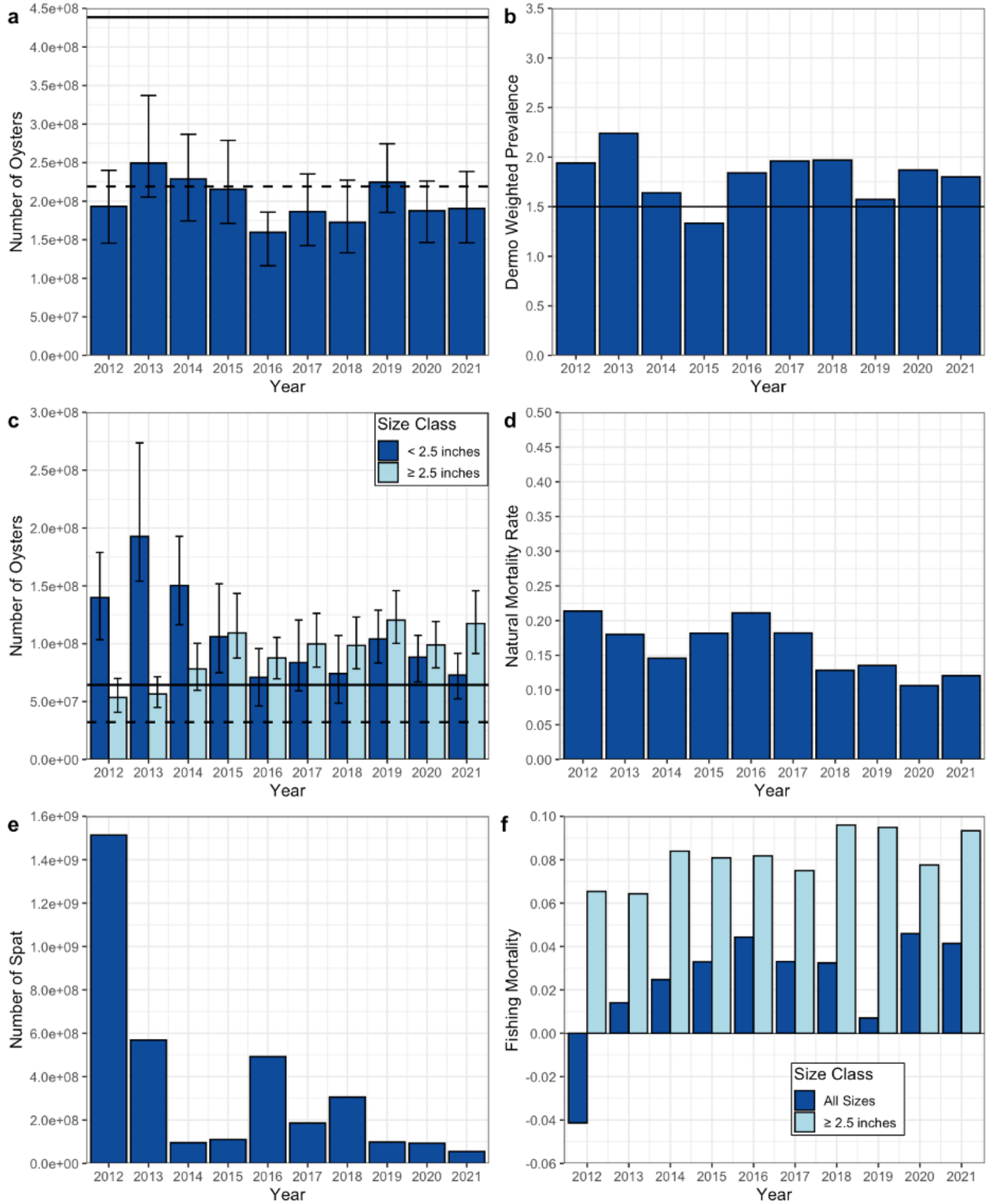


Figure 29.2. Long-term time series summary for the HM.

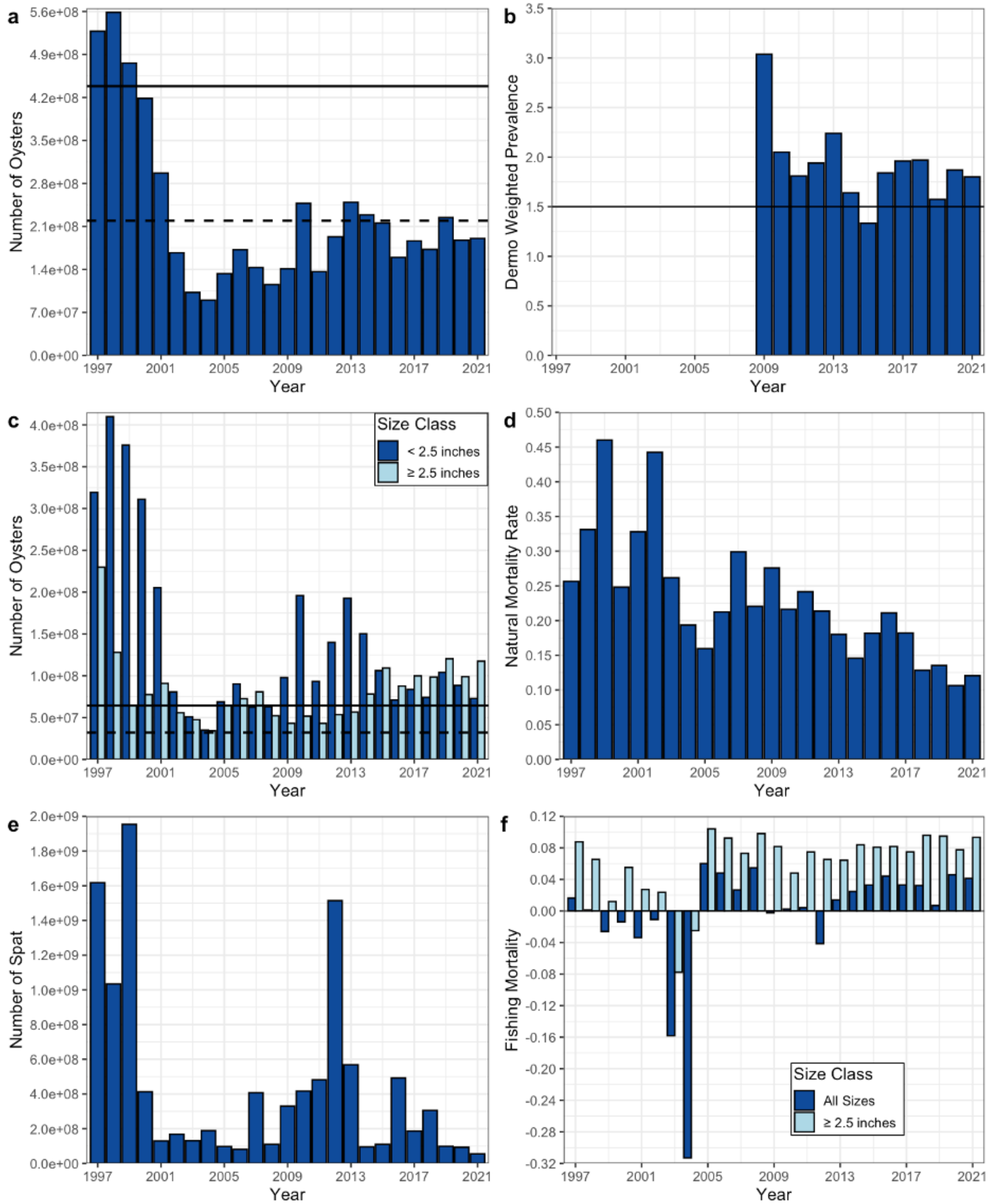


Figure 30. Position of the oyster stock 2017–2021 with respect to abundance and market abundance (≥ 2.5") targets and thresholds for each region. Targets (solid lines) and thresholds (dashed lines) are defined in text. Error bars on the 2020 values are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error. *Shading: Green, above all 4 cutoffs*; *Light green, above 3 cutoffs*; *Yellow, above 2 cutoffs*; *Orange, above 1 cutoff*; *Red, below all 4 cutoffs.*

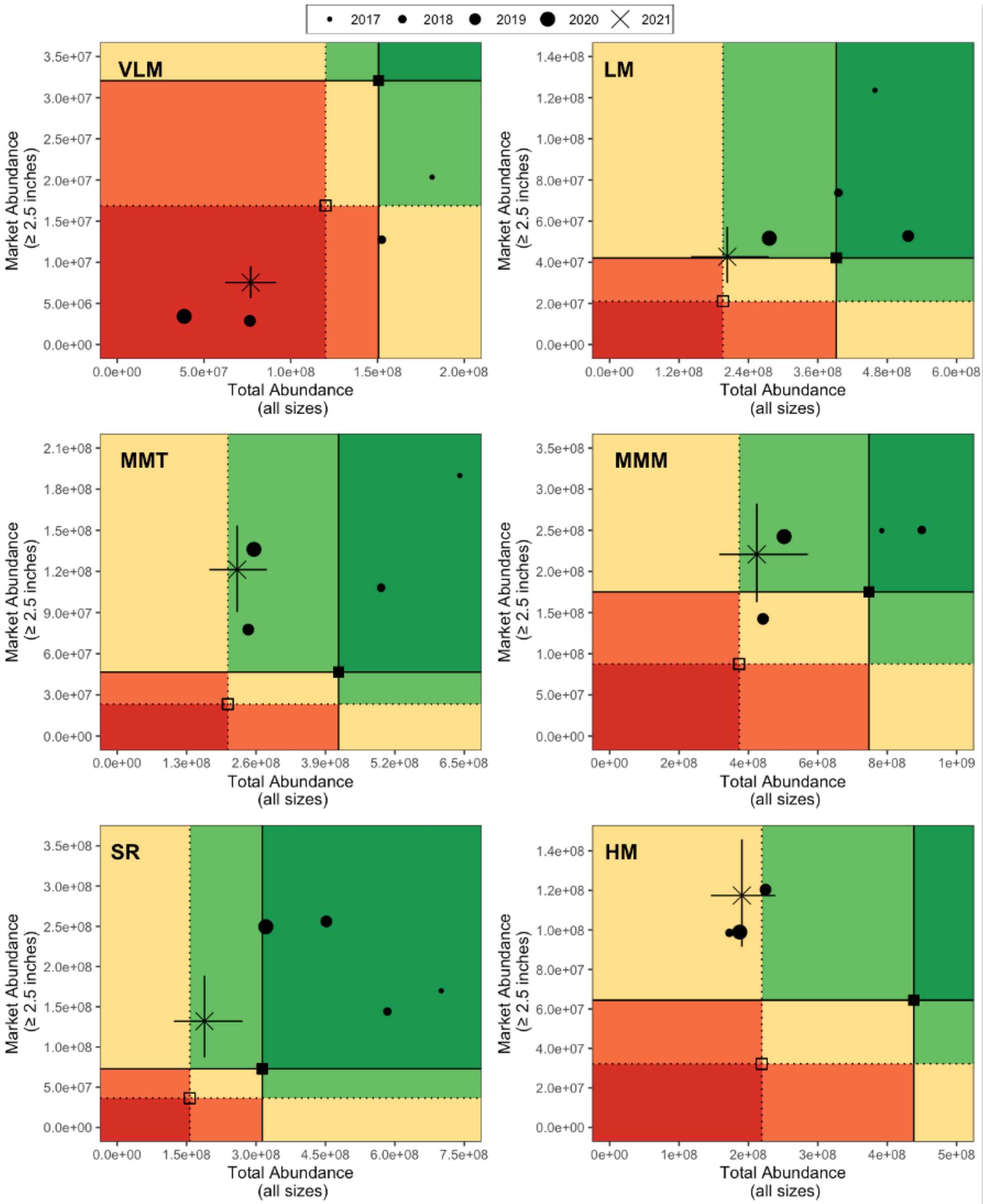


Figure 31. Population growth (change in mean density (g/m^2)) as a function of mean density (g/m^2) for all beds since 1999 (when the Assessment Survey began collecting density data on individual grids). The black horizontal line represents population growth =0.

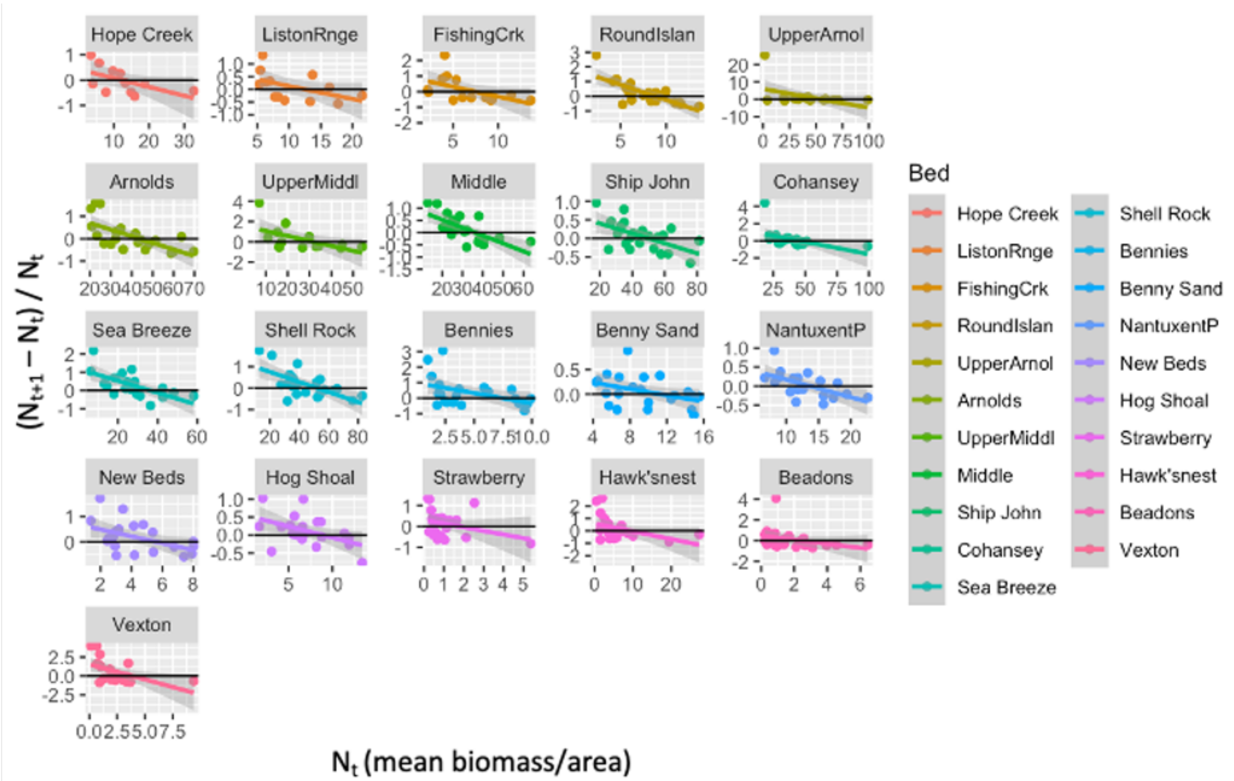


Figure 32. Parameter estimates for carrying capacity (k) and maximum population growth rate (r_{max}) for logistic models of population growth fit to a time series (1999-2021) of mean density (g/m^2) on each bed. Models were fit using nls() function in the base R package. Non-significant ($p>0.05$) parameter estimates are not plotted here. See text in report for "Science Advice – Is there any evidence the population is near carrying capacity?" for additional details.

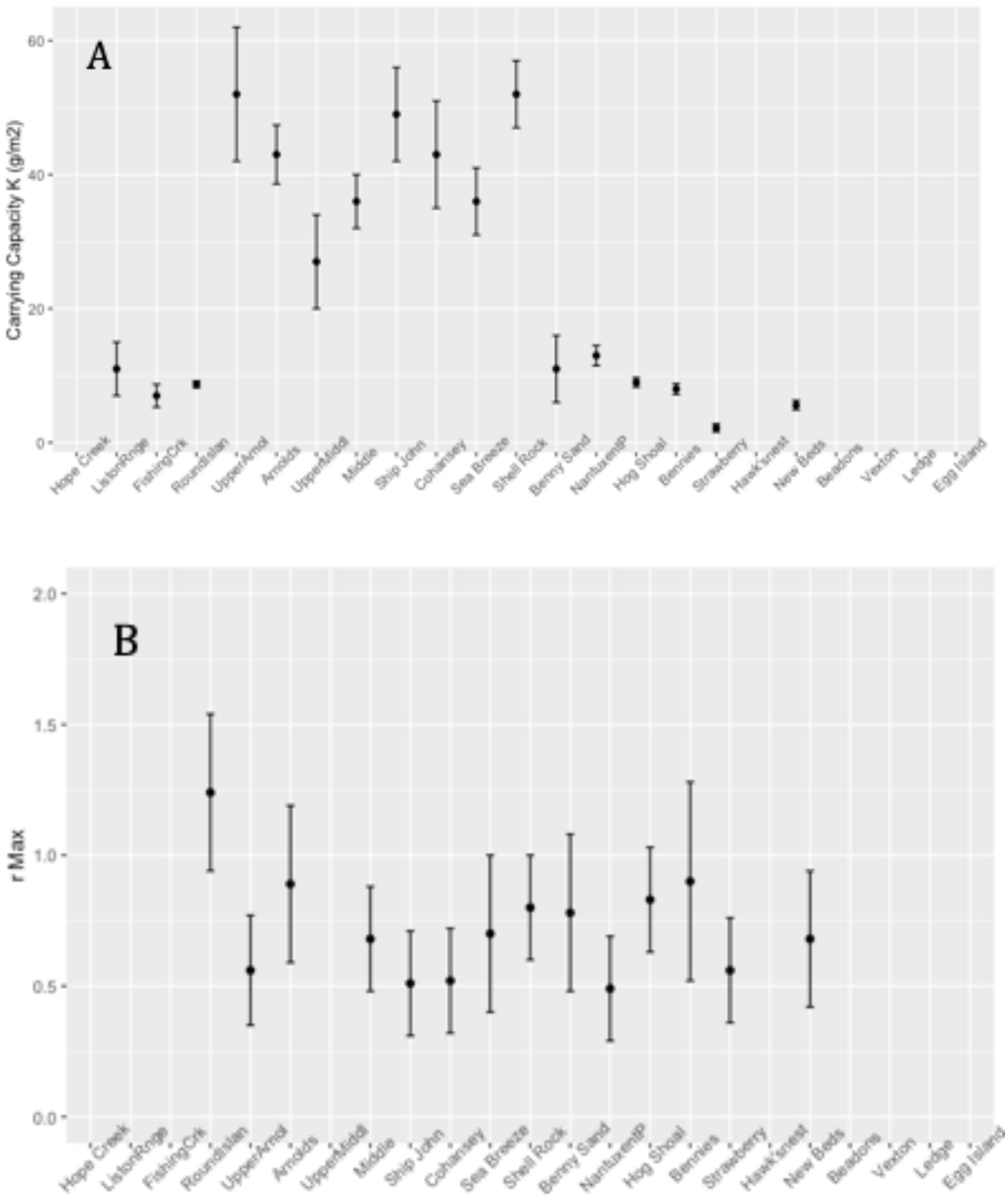
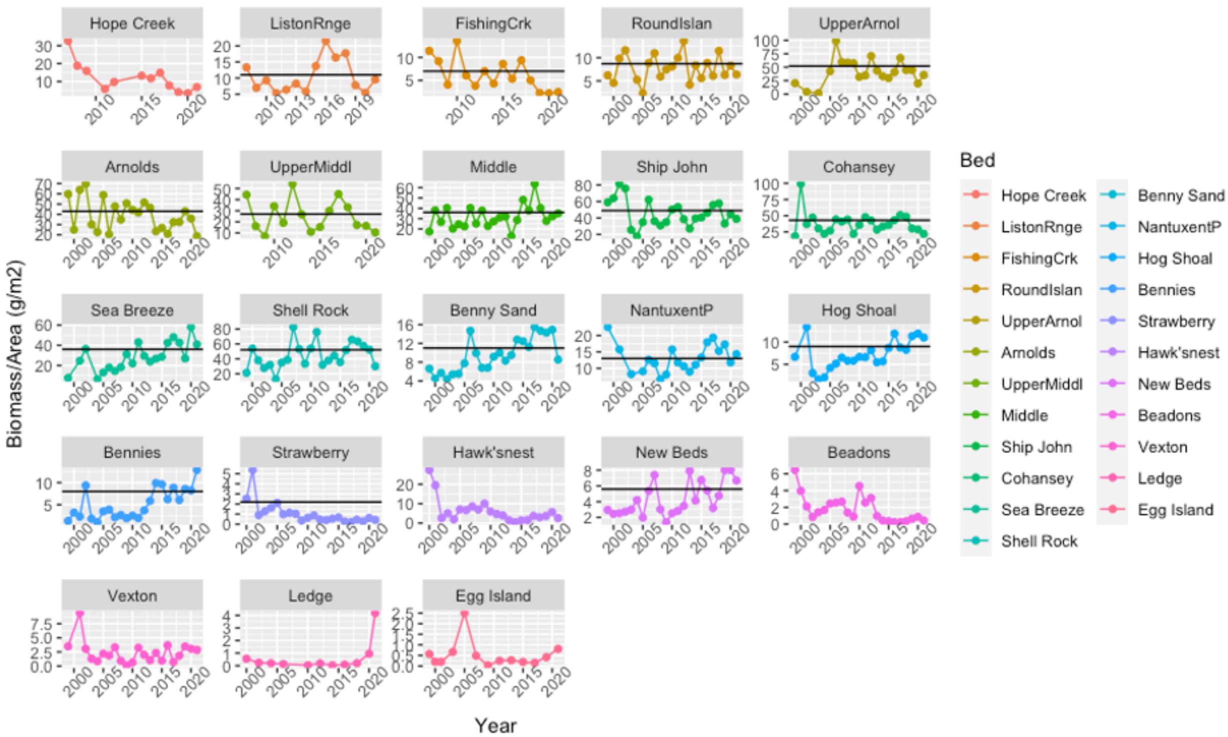


Figure 33. Mean grid density (g/m^2) on each bed from 1999 to 2021. Black horizontal line represents carrying capacity estimated from logistic model of population growth fit to time series of mean density for each bed.



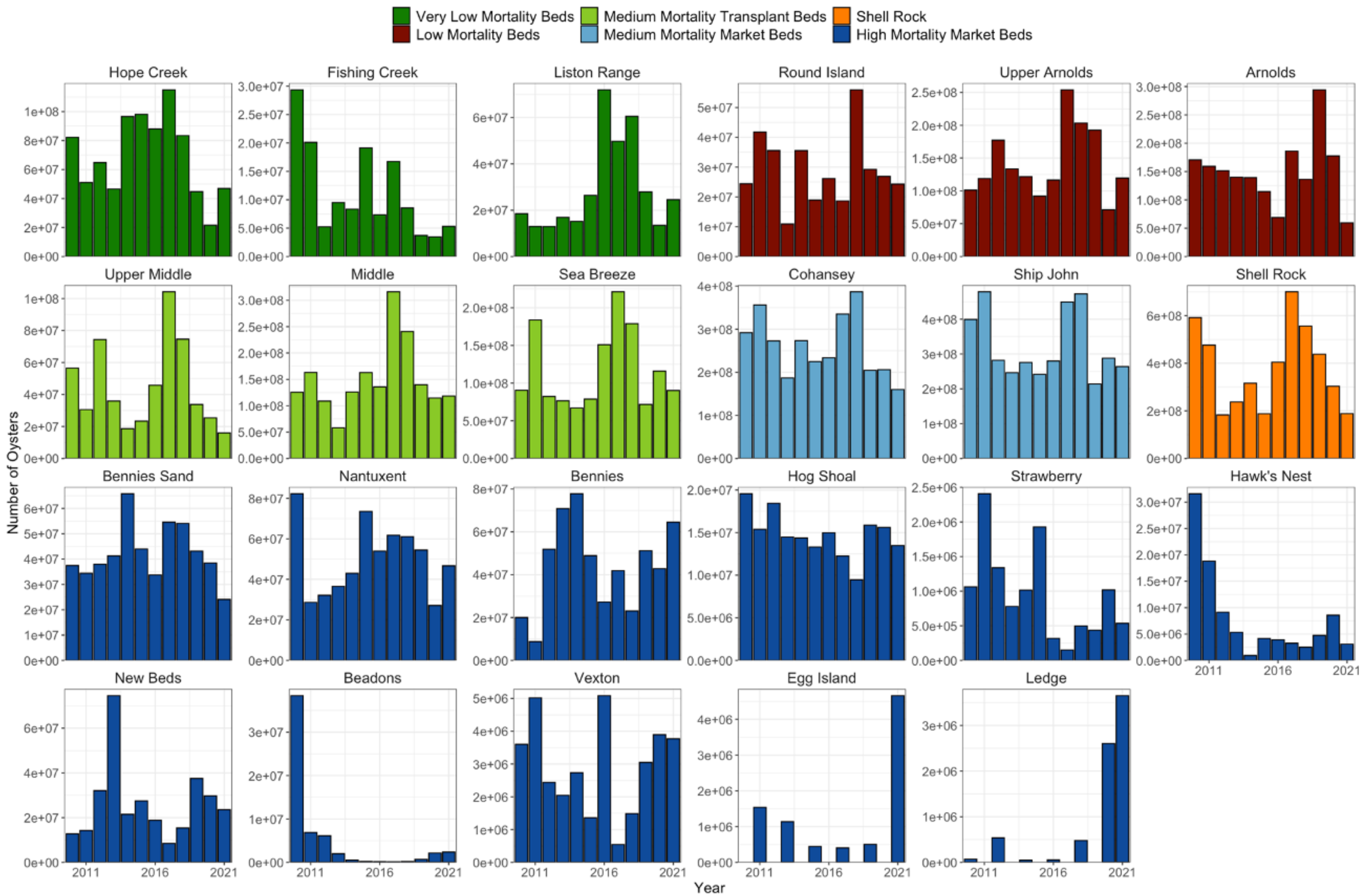
Appendix A. History of partial (P) and full (F) resurveys for all beds, grouped by region. The entire resource was gridded and stratified between 2005 and 2008. The current 10-year resurvey schedule was implemented in 2009.

Region	Bed	# Grids	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21
VLM	Hope Creek	97			P	P									F				
VLM	Fishing Creek	67			P	P													
VLM	Liston Range	32			P	P								F					
LM	Round Island	73			F											F			
LM	Upper Arnolds	29			F						F								
LM	Arnolds	99			F								F						
MMT	Upper Middle	84			F													F	
MMT	Middle	51	P						F										F
MMT	Sea Breeze	48	P							F									
MMM	Cohansey	83	P				F										F		
MMM	Ship John	68	P					F										F	
SR	Shell Rock	93	P			F				F				F					
HM	Bennies Sand	49	P	P			F										F		
HM	Nantuxent	68	P	F				F								F			
HM	Bennies	171	P	F								F							
HM	Hog Shoal	23	P	F										F					
HM	Strawberry	29		F									F						
HM	Hawk's Nest	28		F											F				
HM	New Beds	112			F						F								
HM	Beadons	38		F					F										F
HM	Vexton	47		F					F										F
HM	Egg Island	125																	
HM	Ledge	53																	F

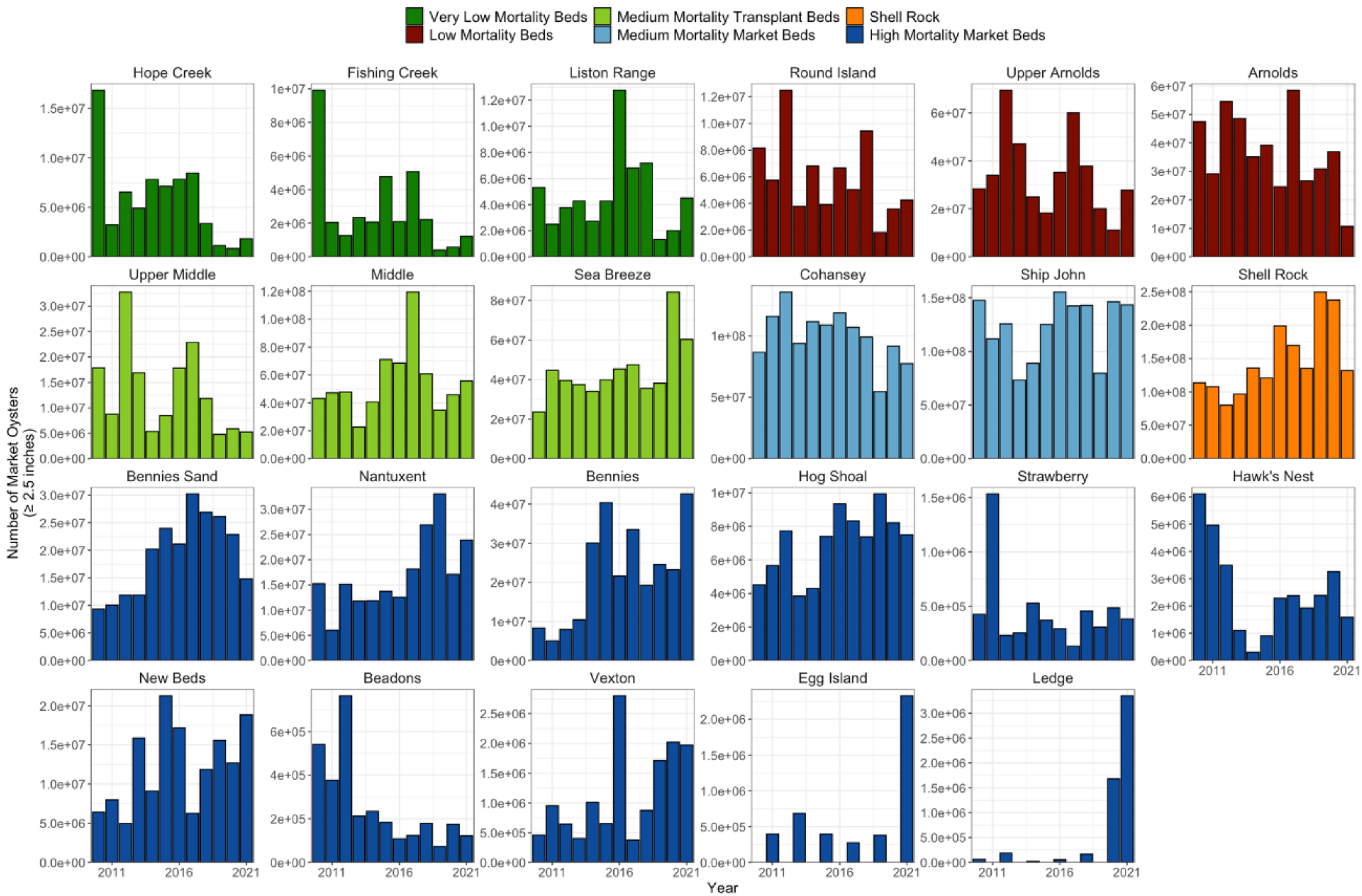
Appendix B. SARC members listed by affiliation. SAW year refers to when the February workshop was held to discuss the previous year's data. Names in parentheses indicate that the appointed member did not attend the meeting.

SAW Year	Council	Industry	NJDEP	NJDEP	Academic	Academic	Management	Rutgers (non-HSRL)	DNREC
1999			Don Byrne	Jim Joseph	Eleanor Bochenek	Judy Grassle	Paul Rago	Joe Dobarro	
2000			Paul Scarlett	Jim Joseph	Steve Jordan		Paul Rago	Joe Dobarro	
2001	Scott Bailey		Bruce Halgren	Jim Joseph	Steve Jordan	Roger Mann	Jim Weinberg	Joe Dobarro	
2002	Scott Bailey	Steve Fleetwood	Bruce Halgren	Jim Joseph	Tom Soniat	Roger Mann	Larry Jacobsen	Joe Dobarro	
2003	Scott Bailey	Scott Sheppard	Tom McCloy	Jim Joseph	Tom Soniat	Joe DeAlteris		John Quinlan	Desmond Kahn
2004	Scott Bailey	Scott Sheppard	Russ Babb	Jim Joseph	Ken Paynter	Joe DeAlteris		John Quinlan	Desmond Kahn
2005	Scott Bailey	Steve Fleetwood	Russ Babb	Brandon Muffley	Ken Paynter	Joe DeAlteris	Jim Weinberg	John Quinlan	Desmond Kahn
2006	Scott Bailey	Steve Fleetwood	Russ Babb	Brandon Muffley	(Ken Paynter)	Roger Mann	Larry Jacobsen	Joe Dobarro	Desmond Kahn
2007	Barney Hollinger	Steve Fleetwood	Russ Babb	Mike Celestino	Steve Jordan	Roger Mann	Tom Landry	Joe Dobarro	Rich Wong
2008	Barney Hollinger	Steve Fleetwood	Russ Babb	Mike Celestino	Steve Jordan	Roger Mann	Tom Landry	Gef Flimlin	
2009	Scott Bailey	Steve Fleetwood	Russ Babb	Mike Celestino	Steve Jordan	Ken Paynter	Tom Landry	Francisco Werner	
2010	Barney Hollinger	Steve Fleetwood	Russ Babb	Mike Celestino	Ken Paynter	(Roger Mann)	Tom Landry	Francisco Werner	Rich Wong
2011	Barney Hollinger	Bill Riggin	Russ Babb	Mike Celestino	Danielle Kreeger	Roger Mann	Patrick Banks	Olaf Jensen	Rich Wong
2012	Barney Hollinger	Bill Riggin	Jason Hearon	Mike Celestino	Steve Fegley	Roger Mann	Patrick Banks	Olaf Jensen	Rich Wong
2013	Barney Hollinger	Bill Riggin	Jason Hearon	Mike Celestino	Steve Fegley	Juli Harding	Patrick Banks	Olaf Jensen	Rich Wong
2014	Barney Hollinger	Scott Bailey	Jason Hearon	Mike Celestino	(Steve Fegley)	(Juli Harding)	Mitch Tarnowski	John Wiedenmann	Rich Wong
2015	Steve Fleetwood	Scott Bailey	Jason Hearon	Mike Celestino	Pat Sullivan	Juli Harding	Mitch Tarnowski	John Wiedenmann	Rich Wong
2016	Steve Fleetwood	Scott Bailey	Jason Hearon	Mike Celestino	Pat Sullivan	(Jerry Kauffman)	Mitch Tarnowski	John Wiedenmann	Rich Wong
2017	Steve Fleetwood	Barney Hollinger	Craig Tomlin	Mike Celestino	Pat Sullivan	Jerry Kauffman	Missy Southworth	John Wiedenmann	Rich Wong
2018	Barney Hollinger	Scott Sheppard	Craig Tomlin	Mike Celestino	Mike Wilberg	Jerry Kauffman	Missy Southworth	John Wiedenmann	Rich Wong
2019	Barney Hollinger	Scott Sheppard	Craig Tomlin	Mike Celestino	Mike Wilberg	Matthew Hare	Missy Southworth	John Wiedenmann	Rich Wong
2020	Steve Fleetwood	Scott Sheppard	Craig Tomlin	Mike Celestino	Mike Wilberg	Matthew Hare	Carolina Bourque	John Wiedenmann	Rich Wong
2021	Steve Fleetwood	Tim Reeves	Craig Tomlin	Mike Celestino	Daniel Hennen	Matthew Hare	Carolina Bourque	John Wiedenmann	Rich Wong
2022	Barney Hollinger	Tim Reeves	Craig Tomlin	Mike Celestino	Daniel Hennen	Dave Eggleston	Carolina Bourque	John Wiedenmann	Rich Wong

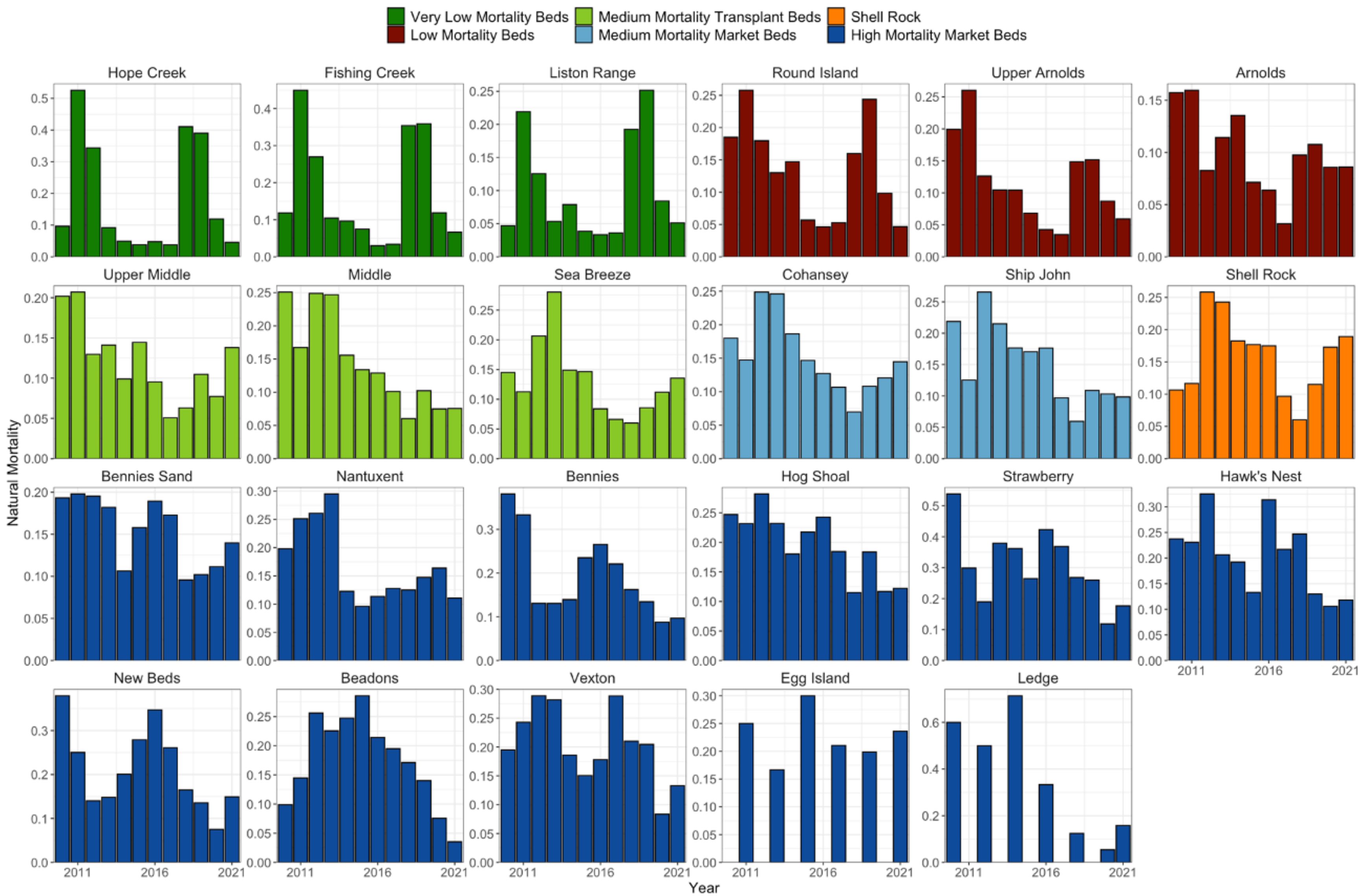
Appendix C. Bed-level oyster abundance for each region. Note y-scale varies.



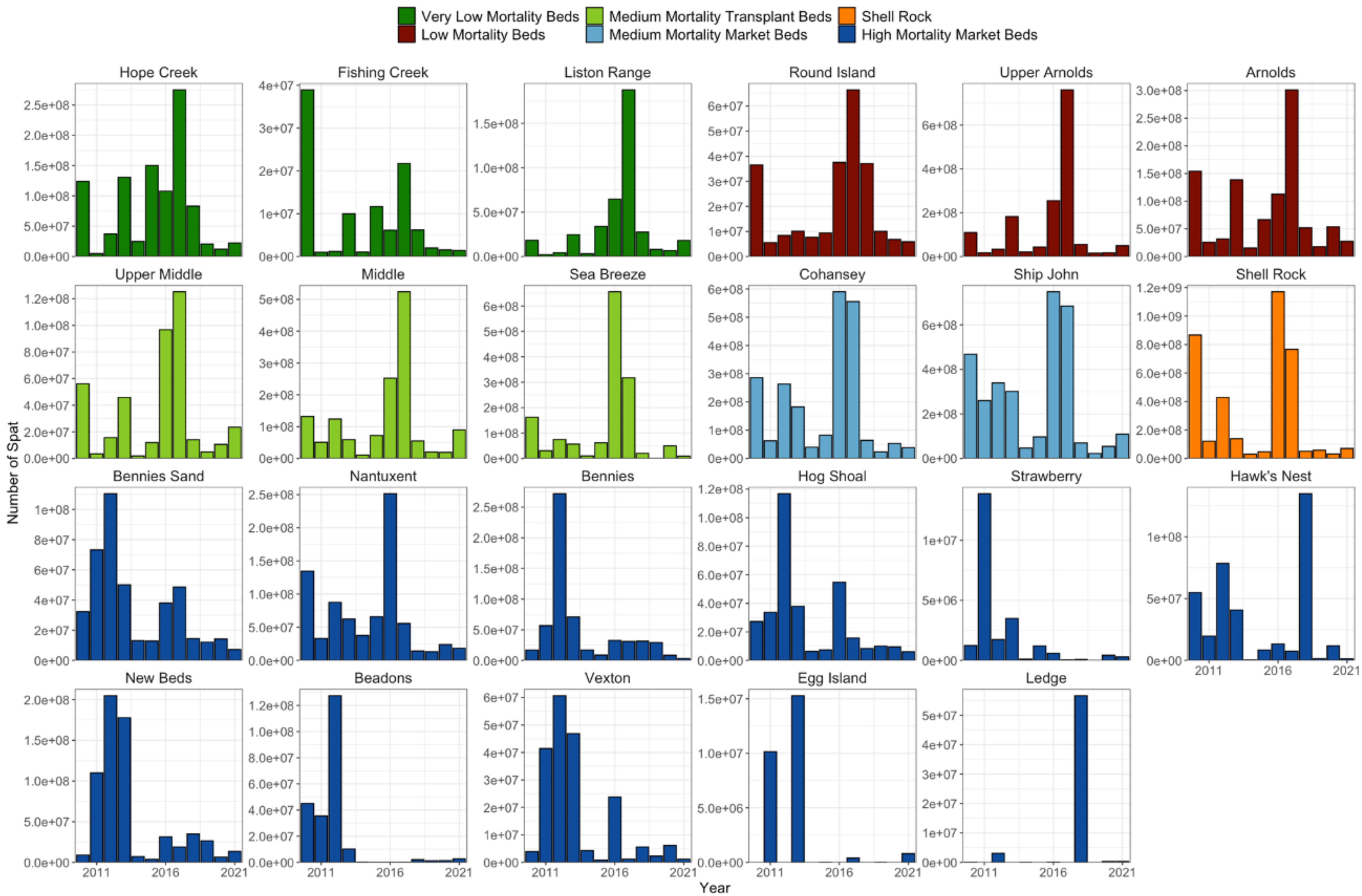
Appendix D. Bed-level market abundance for each region. Note y-scale varies.



Appendix E. Bed-level mortality for each region. Note y-scale varies.



Appendix F. Bed-level spat abundance for each region. Note y-scale varies.



Appendix G. Detailed history of transplant efforts since 2007. A transplant was initially planned for 2020, but due to the COVID-19 pandemic and associated impacts on the market the transplant program was canceled.

Year	Region	Donor Bed	Receiver Bed	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5"	Number Oysters ≥ 2.5"	Added Quota Allocation	Fraction Cultch	Chosen Expl. Rate	Achieved Expl. Rate	# Oysters at Chosen (all sizes)	# Oysters at Achieved (all sizes)
2021	LM	Arnolds	Shell Rock	5,400	2,601,798	0.900	260,180	974	0.472	0.76%	0.94%	2,097,973	2,601,798
	MMT	Upper Middle	Bennies	2,650	659,794	0.733	176,218	660	0.573	2.46%	2.50%	6,297,118	6,401,396
		Middle	Bennies	2,700	997,139	0.481	517,274	1,937	0.199				
		Middle	Nantuxent	10,700	3,935,479	0.535	1,829,275	6,851	0.263				
		Sea Breeze	Bennies	2,700	808,984	0.279	583,363	2,185	0.206				
2020						*NO TRANSPLANT CONDUCTED*							
2019	LM	Arnolds	Shell Rock	7,200	2,837,705	0.828	489,430	1,861	0.449	2.26%	0.70%	8,941,378	2,837,705
	MMT	Middle	Bennies Sand	25,000	9,890,349	0.748	2,496,843	9,494	0.288	2.46%	2.79%	12,158,274	13,956,501
		Sea Breeze	Bennies Sand	8,800	4,066,152	0.768	941,483	3,580	0.206				
2018	MMT	Upper Middle	Bennies	4,750	973,690	0.527	460,846	1,752	0.566	2.46%	1.76%	15,785,722	12,310,312
		Middle	Bennies	27,500	8,230,069	0.507	4,054,033	15,415	0.329				
		Sea Breeze	Bennies	7,700	3,106,553	0.759	749,703	2,851	0.290				
2017	MMT	Upper Middle	Bennies	3,200	948,685	0.365	602,546	2,282	0.408	2.46%	2.37%	8,184,564	7,887,414
		Middle	Bennies	21,350	5,625,257	0.312	3,868,205	14,652	0.299				
		Sea Breeze	Bennies	4,700	1,313,472	0.515	636,920	2,412	0.219				
2016	LM	Arnolds	Cohansey	4,800	2,168,012	0.637	787,816	2,972	0.290	0.76%	0.96%	1,712,353	2,168,012
	MMT	Middle	Shell Rock	8,150	2,556,215	0.386	1,569,932	5,925	0.280	1.49%	0.97%	3,958,253	2,979,901
		Sea Breeze	Shell Rock	2,400	426,443	0.319	290,458	1,096	0.440				
2015	LM	Upper Arnolds	Ship John	10,200	4,474,515	0.721	1,247,128	4,688	0.330	1.30%	1.30 - 1.90%	3,598,514	4,474,515
	MMT	Middle	Shell Rock	5,550	1,726,335	0.604	682,813	2,567	0.310	2.30%	> 2.30%	4,360,643	4,475,247
		Sea Breeze	Shell Rock	10,800	2,748,912	0.422	1,590,121	5,978	0.250				
2014	LM	Arnolds	Ship John	15,500	6,168,587	0.485	3,174,627	12,025	0.220	2.33%	2.25%	6,403,869	6,134,370
	MMT	Middle	Shell Rock	6,600	1,553,053	0.381	961,033	3,640	0.250	2.33%	2.41%	3,517,430	3,473,086
		Sea Breeze	Shell Rock	7,300	1,922,420	0.390	1,173,115	4,444					
2013	VLM	Liston Range	Shell Rock	550			*VLM CLOSED in 2013, accidental transplant from this region*						
	LM	Round Island	Shell Rock	2,250	888,151	0.535	412,848	1,552	0.280	2.33%	< 2.33%	9,962,070	8,459,940
		Upper Arnolds	Shell Rock	15,550	6,238,792	0.553	2,787,160	10,478					
		Arnolds	Shell Rock	2,700	1,109,073	0.609	433,783	1,631					
	MMT	Upper Middle	Bennies Sand	3,200	890,008	0.338	588,950	2,214	0.270	2.33%	< 2.33%	5,465,140	3,798,531
		Middle	Bennies Sand	5,200	1,346,337	0.423	777,424	2,923					
		Sea Breeze	Bennies Sand	6,200	1,587,589	0.268	1,161,796	4,368					
2012	LM	Arnolds	Nantuxent	7,650	4,489,153	0.790	942,900	3,558	0.280	1.27%	< 1.27%	4,730,022	4,469,068
	MMT	Upper Middle	Nantuxent	2,100	797,489	0.648	280,788	1,060	0.260	1.88%	> 1.88%	7,245,772	9,221,809
		Middle	Bennies Sand	11,200	4,406,878	0.602	1,755,084	6,623					
		Sea Breeze	Bennies Sand	5,425	2,563,782	0.751	638,647	2,410					
		Sea Breeze	Nantuxent	3,100	1,463,987	0.733	391,610	1,478					
2011	VLM	Hope Creek	Cohansey	6,150	3,766,429	0.658	1,289,314	4,940	0.180	1.27%	< 1.27%	5,003,664	4,871,104
		Liston Range	Cohansey	1,800	1,085,283	0.615	417,586	1,600					
	LM	Round Island	Bennies	3,350	1,630,191	0.603	646,914	2,479	0.270	1.27%	> 1.27%	3,991,178	4,252,834
		Upper Arnolds	Bennies	2,800	1,008,104	0.608	394,902	1,513					
		Arnolds	Bennies	4,000	1,638,736	0.665	549,631	2,106					
	MMT	Middle	Bennies	17,750	5,900,036	0.533	2,753,351	10,549	0.250	1.88%	> 1.88%	5,255,322	5,848,372
2010	VLM	Hope Creek	Bennies	1,200	*NA*	*NA*	*NA*	1,232	0.400	1.27%	~1.27%	3,833,693	*NA*
		Fishing Creek	Bennies	200	*NA*	*NA*	*NA*						
		Fishing Creek	Shell Rock	1,800	*NA*	*NA*	*NA*						
		Liston Range	Shell Rock	4,750	*NA*	*NA*	*NA*	4,839					
	LM	Upper Arnolds	Shell Rock	1,200	*NA*	*NA*	*NA*	839	0.250	2.33%	< 2.33%	8,587,511	*NA*
		Upper Arnolds	Bennies	17,050	*NA*	*NA*	*NA*	14,814					
	MMM	Sea Breeze	Bennies	11,050	*NA*	*NA*	*NA*	5,502	0.390	1.88%	< 1.88%	4,155,570	
		Cohansey	Bennies	1,500	*NA*	*NA*	*NA*			NA	NA	*NA*	*NA*
2009	VLM	Hope Creek	Ship John	9,100	5,780,080	0.651	2,017,030	7,699	0.240	1.27%	> 1.27%	5,032,780	5,722,475
	LM	Arnolds	Bennies	10,400	4,942,416	0.485	2,544,755	9,713	0.250	1.88%	> 1.88%	4,621,870	4,946,939
	MMT	Upper Middle Middle	Bennies	14,100	4,559,705	0.548	2,060,715	7,865	0.270	2.33%	> 2.33%	4,716,070	4,566,296
2008	LM	Arnolds	Cohansey	9,450	4,089,861	0.483	2,113,742	8,161	0.350	1.27%	> 1.27%	3,664,083	4,012,758
	MMT	Middle	Bennies Sand	8,200	2,577,406	0.363	1,641,413	6,337		2.33%	> 2.33%	2,291,480	2,553,726
2007	MMT	Middle	Nantuxent	12,982	3,819,176	0.460	2,064,242	7,849	0.360	1.48%	~1.48%	*NA*	3,819,176