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Stock Assessment Workshop
New Jersey Delaware Bay Oyster Beds
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Final Report

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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). As explained below, the recent increase in 2019 is unrelated to disease.

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, the 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, a system called the Direct Market Fishery was adopted 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 were to be harvested directly from the twenty-three natural beds. This resulted in the twenty-three beds being grouped into six management regions that follow the estuarine salinity gradient of the Delaware Bay with each region 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 the lower three regions (MMM, SR, HM; Direct Market Regions) to enhance abundance there; 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 these regions are generally smaller and of insufficient quality to market directly. Intermediate transplanting helps alleviate harvest pressure on the direct market regions when natural mortality has been high and recruitment has been low in those regions. In addition, once moved, oysters from the Transplant regions quickly depurate, 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. Each oyster license must be associated with a boat. Until 2010, the licensed boat had to be the harvesting boat. 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.

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 included 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 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[1] 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 (eg. 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[2] 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

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[1] Chai et al. (1992) found divers and patent tongs were equally efficient at sampling oysters, however more recent work in the Chesapeake Bay suggests patent tongs could be much less efficienct than divers (personal communication, Mike Wilberg). Plans are underway to compare the efficiency of these two sampling gears in Delaware Bay.

[2] 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)

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 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 with the exception of

Egg Island and Ledge. The survey alternates sampling of these two beds each year due to their consistently low abundance. 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 Dept. 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 approximately 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. To determine how many grids to sample within a given strata, simulation is used to estimate the strata variance for a given number of sampled grids. When the reduction in variance is minimal for a given increase in grids sampled on a stratum, the sample intensity for that stratum is deemed statistically adequate to assess the abundance. However, a large number of samples is never dedicated to a bed known to have very low abundance. 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[3].

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 in longest dimension while the term spat refers to those < 20 mm. Market-size oysters are defined as those ≥ 63.5 mm. Using total counts per bushel, total bushels per tow,

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

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

Science Advice: How variable are the three tows taken on each sampled grid?

In the approach described above there is no way to track or propagate variability in the three random tows used to estimate density metrics on each grid because subsamples from each of the three tows are combined into a single, composite bushel sample. The 2019 SARC therefore made a Science Recommendation to evaluate how variable the three randomly placed tows are within a given grid and evaluate how including intra-grid variability affected survey error.

To address this recommendation, during the 2019 Resurvey, the 1/3 bushel sub-sample from each of the three randomly placed tows in each grid were kept separate. These three independent estimates of density were used to calculate a mean and coefficient of variation (CV) for each sampled grid (Figure 8). While variability decreased with density (and therefore strata), there were still relatively high CVs for some of the high and medium quality grids, suggesting that recording and propagating the within-grid variability may be important for accurately estimating total survey error. However, when total survey error was calculated for the two methods (separate samples for each tow on a grid vs. a single composite bushel for the whole grid), the increase in survey error associated with tracking tows separately was small relative to the increase in effort needed to keep the tows separate (Figure 9). The 2020 SARC therefore made a 2020 Science Recommendation to continue tracking within-grid variability during the Resurvey/Restratificaion program, but to wait to decide about whether or not to change methodology for the Fall Assessment Survey until there are more data to evaluate. In addition, the 2020 SARC suggested that the information obtained from tracking intra-grid variability during the Resurvey should be used to inform how sampling effort is allocated across the beds during the Fall Assessment Survey.

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.

Science Advice: How does increased sampling intensity affect survey error?

A Science Recommendation from the 2018 SARC suggested an evaluation of ways to reduce assessment uncertainty. To address this, an audit of all sample processing methodology, described above, was conducted to determine if there were opportunities to increase sample processing efficiency and thus increase the number of samples that could be collected in a given sampling season. This evaluation resulted in two adjustments: 1) only up to 100 oysters are measured to describe the size frequency of a sample and 2) total spat in a sample are estimated by counting spat on a subset of all material in the sample. Both adjustments are summarized in the final report from the 2019 SAW (Morson et al. 2019). The 2019 SARC then recommended an evaluation of how the increased efficiency, and subsequent increase in sampling intensity, during the 2019 Assessment Survey affected survey error.

As a result of increased sample processing efficiency, a total of 25 more grids were added to the standard 175 grids for the 2019 Assessment Survey. To evaluate the effect these added samples had on survey error, we calculated total abundance and survey error with and without the added samples (Figure 10). The added samples did not have a large influence on the total abundance estimate. However, on regions that received a significant increase in sampling intensity, like the Shell Rock Region and the Low Mortality Region, there was a significant decline in survey error. An additional 25 grids (225 grids in total) will be sampled during the 2020 Assessment Survey. The 2020 SARC requested that the influence of these added samples on survey error again be reported at the 2021 SAW.

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. Step one is to calculate the average number per bushel (from the transplant monitoring program) moved from each donor bed in the current year. Step two is to 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. Step three is to calculate total removals by region by summing all removals from all donor beds in each region. Finally, step four is to 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. Step one is to 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. Step two is to multiply this average by the total catch in bushels in each market region to get total catch by region. Step three is to 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. Step four is to 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. Step five is to 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. Step six is to 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. Finally, step seven is to 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 50^{th} percentile that separated as high and low. The 50^{th} and 60^{th} percentile values from the original data were averaged. That average was used as the 50^{th} percentile and the previous 50^{th} percentile was then used as the 40^{th}. Transitions between exploitation rates for the direct market regions were similarly irregular. For example, in the HM, the change from the 40^{th} to 50^{th} percentile spanned a much larger range of exploitation rates than that of its 25^{th} to 40^{th} percentiles whereas SR's 40^{th} and 50^{th} 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 40^{th} 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 11. 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. 2019 STATUS AND TRENDS

2019 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 2019 was 313 and the average number of market sized oysters per landed bushel was 245 (Figure 12). The proportion of small oysters attached to market size oysters declined in 2019 likely due to the low spatfall events in 2018 and 2019 (Figure 12). 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 266 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 annual LPUE index is calculated as the total number of harvested bushels divided by the total number of hours fished. 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. LPUE for both dredge types has increased steadily from 2012 to 2017, but has declined in both of the last two years (Figure 13). The number of vessels of each dredge type, single and dual, has remained mostly unchanged since 2015 (Figure 13).

Changes in LPUE on the direct market beds could be influenced by several factors: license consolidation, shifts in population size structure, increases or decreases in market or total abundance, and seasonal limits on harvest time dictated by *Vibrio* control rules. It is difficult to determine which of these is having the greatest influence on catch rates. Within both fishery landings and the population as a whole, there was a decrease in the frequency of large oysters (≥ 3.5 inches) during 2010 and 2011 (Figure 14). If changes in LPUE were influenced by oyster size alone, we would expect LPUE to closely mirror trends in size distribution. This is not always the case; LPUE remained stable in 2010 and 2011 for both dredge types (Figure 13). And while increases in LPUE do track with increases in large oysters for 2012 – 2016, it is important to note that license consolidation during this time would have allowed the most effective combinations of captains, crews, and boats to land oysters more efficiently. Looking more closely at the size frequency of market-size animals, the frequency of large oysters landed by the fishery increased in tandem with that of the population from 2014-2017, and has subsequently declined in 2018 and

2019 as did the frequency of large oysters in the population (Figure 15). Rather than any single factor, it is most likely a combination of license consolidation, changes in the size of the population and the size structure, and stricter seasonal limits on harvest times that is driving trends in LPUE.

Science Advice: Determine if growth rates have changed in recent years

One potential explanation for the change in size structure of the catch and the population described above and apparent in Figures 14 and 15 is that oysters are growing at faster rates in recent years. Therefore, a Science Recommendation from the 2018 and 2019 SARC was to evaluate whether growth rates have changed recently. To address this, experiments were conducted in 2018 and 2019 to monitor incremental growth of oysters on five reefs (Hope Creek, Cohansey, Shell Rock, Bennies, and New Beds). The methods for monitoring monthly and annual growth increments were first described in Kraeuter et al. (2007) for an experiment conducted in 2001. The same methodology was repeated in 2018 and 2019. Briefly, 10 oysters were collected in each of ten 10mm size bins from each reef in late 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. Three days after collection, oysters were returned to the reef where they came from and each oyster was measured monthly from June through November. While several experiments were lost, experiments on two of the reefs where the same experiment was conducted in 2001 were monitored for all 7 months in 2018 and in experiments on one of the reefs (New Beds) were monitored for all 7 months for all three years (Figure 16). Growth rates may have increased from 2001 to 2018 and again from 2018 to 2019. However, additional experiments will be conducted in 2020 and those results, along with the data collected in 2018 and 2019, should provide more conclusive evidence for whether oyster growth rates have changed throughout the Bay since 2001.

2019 Catch Statistics and Fishery Exploitation

The 2019 direct market harvest occurred from April 1 to November 22 and included a period of curtailed harvest hours during summer months to comply with New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan[4]. A total of 20 vessels including 5 single- and 15 dual-dredge boats were in operation. The number of boats has declined since 2009 when 74 boats harvested oysters. This decline in active harvest vessels is a result of a legislation change to allow license consolidation so boats can now harvest multiple quotas rather than one quota per boat. The total direct market harvest in 2019 was 109,108 bushels, a slight decline from the 119,342 harvested in 2018, but the fourth straight year the total quota was over 100,000 bushels (Figure 17). The harvest from the three Direct Market regions broke down as follows: 44% from the HM; 26% from SR; 30% from the MMM (Table 6a). Of the 14 beds in the three Direct Market regions, only 7 were

[4] See New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan here: http://www.nj.gov/dep/bmw/docs/nj2017vibrioplan.pdf

[4] In 2013, one boat strayed from LM transplanting for part of a day and dredged 550 bu from the VLM.

fished during the 2019 harvest season. The HM has 11 beds, but 80% of its harvest came from just three beds, Bennies, Bennies Sand, and Nantuxent. Of the two beds in the MMM, 22% of its harvest came from Cohansey and 78% from Ship John.

Table 7a describes the exploitation rates chosen by the SARC and approved by the Shellfish Council in 2019 for the Direct Market regions. The 2019 harvest on the Medium Mortality Market region resulted in an exploitation rate of 3.02%, less than the 3.70% maximum rate proposed by the 2019 SARC and approved by the Shellfish Council. On the Shell Rock region, the 2019 harvest resulted in an exploitation rate of 4.44%, also less than the 4.88% maximum rate proposed by the 2018 SARC and approved by the Shellfish Council. Finally, on the High Mortality region the 2019 harvest resulted in an exploitation rate of 9.49%. This achieved rate was higher than the 8.99% maximum rate proposed by the 2018 SARC and approved by the Shellfish Council.

Tables 7b and 6b[4] describe the exploitation rates chosen by the SARC and approved by the Shellfish Council in 2019 for the Transplant regions and the total bushels and oysters moved as a result of those chosen rates. While the SARC approved exploitation up to the rate of 2.26% on the Low Mortality region, the achieved exploitation rate was only 0.70%. The intermediate transplant program moved 2,837,705 oysters from Arnolds to the Shell Rock region in Spring 2019 (Table 8), but stopped moving oysters before the goal was reached because the market size fraction was low. The achieved exploitation rate on the Medium Mortality Transplant region was 2.79%, which was higher than the SARC approved maximum exploitation rate of 2.46%. A total of 13,956,501 oysters were moved from Middle and Sea Breeze to Bennies Sand in Spring 2019 (Table 8).

Finally, the exploitation rate of the total stock (excluding the VLM region) was approximately 1.34% (Figure 18a) while the achieved exploitation rate of market-sized oysters (>2.5") was 3.45% (Figure 18b). This level of exploitation is consistent with low exploitation rates achieved since initiating the direct market fishery.

2019 Enhancement Efforts

In 2019, there were four shell plants on NJ's Delaware Bay oyster beds, all funded by the NJ oyster industry through its self-imposed 'bushel tax'. 37,237 bushels of unspatted clamshell were put directly on the Medium Mortality Market Region (Cohansey); 40,622 bushels were put on SR (Shell Rock); and 79,162 bushels were put on the High Mortality Region (Bennies Sand and Nantuxent). 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.

Science Advice: Continue to evaluate enhancement (shellplant and transplant) performance

The 2019 SARC recommended continued evaluation of the performance of enhancement efforts. Building on the work presented in the 2019 SAW report, an effort was made to evaluate whether certain shell-planted locations in Delaware Bay perform better than others and whether certain locations are more likely to sustain production years after shell has been planted. To evaluate this, grid density was plotted as a function of elapsed time for shell-planted grids. Only shell-planted grids where density was measured no more than two years before the shellplant occurred were included (Figure 19). Some beds appear to do consistently poor (e.g., Bennies) and some appear to do consistently well (Shell Rock). In addition, for those beds that initially experience a bump in recruitment/production, either the increase in production is short-lived (e.g., Bennies Sand 4 2009 Plant), which is more common, or the production is sustained over a longer time period (eg. Bennies Sand 11 2011 plant), which is rare. The 2020 SARC recommended a more in-depth evaluation of what factors influence shellplant success/failure and suggested minimally including environmental conditions and fishing activity in any evaluation.

2019 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 (Table 9). It was concluded that this time period represented the scope of oyster population dynamics in the present climate and disease regime (aka the 'Dermo Era'). 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 200 grids were sampled to estimate the status of the stock in 2019 (Figure 20). For the first time in the last three years the total abundance fell below the target, though the market abundance remains well above the target (Figures 21a,b and 22). After natural mortality was in decline for seven consecutive years, there was an increase from 2018 to 2019 (Figure 21c). Spatfall declined sharply in both 2018 and 2019 relative to the large spatfall estimated in 2016 and 2017 (Figure 21d).

Transplant Regions

The three intermediate transplant regions (VLM, LM, MMT) all have similar acreage (Figure 2). Figures 23-25 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 23).

However, the region has, for two consecutive years (2018 and 2019), 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 23). These events resulted in the market abundance falling below the threshold in 2018 for the first time since 2015 and the total abundance falling below the threshold (solid line indicates target; dashed line indicates threshold) in 2019 for the first time since 2013 (Figures 23, 29). Since this region has a very slow growth rate compared to regions further downbay, it will likely take some time before the market abundance moves above the threshold again, although recovery following similar mortalities in 2011 occurred faster than expected (Munroe et al. 2013). In addition, the 2019 spat set in the VLM region was at only the 25th percentile for the 2007-2019 times series (Figure 23, Table 10), suggesting the abundance of small oysters may continue to decline in the future. Dermo remained undetectable indicating the increased mortality shown in Figure 23 was again a result of the persistent freshet during the latter half of 2019 (see Dermo monitoring report). No oysters have been transplanted from the VLM region since 2013.

Though not as extreme, the LM region also experienced an elevated rate of natural morality in 2018 and 2019. The 13% mortality rate observed in both years is the highest the natural mortality has been since 2011 (Figure 24). Given the low levels of dermo in the LM region in both years, it is likely the influx of freshwater accounted for the spike in natural morality in this region as it did in the VLM region. While natural mortality was higher relative to some more recent years, the total abundance increased to the highest it has been in the last ten years. The freshet may have had a size-dependent effect on oysters as the market abundance declined slightly from 2018 to 2019, though it remains above the target (Figures 24, 29). Recruitment in the LM region is low again in 2019 (Figure 24, Table 10). Although the 2019 SARC recommended a maximum allowable exploitation rate of 2.26%, the LM transplant was terminated early and only a fraction of the targeted number of oysters were transplanted resulting in an exploitation rate of 0.70% (Table 7b).

Natural mortality in the MMT region increased slightly from 2018 to 2019, but remained well below levels observed in the first half of the 2010s (Figure 25). After consecutive years (2017 and 2018) of the MMT total oyster abundance being above the target, a steep decline saw it fall between the target, and close to the threshold, in 2019 (Figure 25, 29). The 2019 market abundance on the MMT is average (51st percentile; Table 10) relative to the 1990-2019 times series and remains above the target (Figure 25). Recruitment on the MMT region in 2019 was extremely low (3rd percentile; Table 10) for a second consecutive year (Figure 25). Approximately 34,000 bushels of culled material were transplanted from the MMT region to the HM region (Table 8b), resulting in exploitation rates of 2.82% and 3.2% on total and market sized oysters, respectively (Figure 25).

Direct Market Regions

Direct market harvesting occurs in the two largest (HM, MMM) and the smallest (SR) regions (Figure 1). However regional acreage does not reflect the distribution of the oyster stock. For instance, in 2019, the HM made up nearly 50% of all oyster acreage but contained only about 11% of the total stock of all six regions while the SR and MMM that together make up approximately 25% of the total oyster acreage, made up 47% of the total oyster abundance (Figure 2). In 2019, SR, the smallest region, contained twice as many oysters as HM, the largest region. Figures 26-28 summarize the 10-year trends of the stock in these regions.

A similar set of trends were observed on the MMM region as was observed on the MMT region. Mortality increased slightly from 2018, but remained low relative to the recent times series (Figure 26). Total abundance on the MMM in 2019 saw a similarly sharp decline as was observed on the MMT. This put the 2019 total abundance on the MMM region between the target and threshold, but close to the threshold (Figure 26, 29). The 2019 market abundance on the MMM fell below the target for only the second time in the last ten years and recruitment was extremely low (3rd percentile; Table 10) for the second consecutive year (Figure 26). The 2019 exploitation rates on the MMM region were 1.1% and 3.0% respectively on all and market sized oysters, similar to most other years in the recent time series (Figure 26).

Natural mortality on the SR region was up slightly relative to 2017 and 2018, but remained low (27th percentile; Table 10) relative to the 1990 to 2019 time series (Figure 27). While total abundance declined slightly again from 2018 to 2019 on the SR region, both market and total abundance remain above their relative targets (Figures 27, 29). In fact, the market abundance on the SR region is the highest it has been (100th percentile; Table 10) since the survey began measuring size-specific abundance in 1990. Recruitment, as was the case in most other regions, was very low (14th percentile; Table 10) again in 2019 on the SR region (Figure 26). Exploitation rate of market sized oysters in the SR region increased slightly from 2018 to a value of 4.4% in 2019, while exploitation rate of all sizes declined from 2018 to a value of 1.1% in 2019 (Figure 26).

Finally, the HM region experienced relatively low levels of natural mortality again in 2019 (Figure 28). Total and market abundance on the HM region both increased from 2018 to 2019 and total abundance moved above the threshold for the first time in five years (Figure 28, 29). Recruitment on the HM region was low (10th percentile; Table 10), as it was in the rest of the regions in 2019 (Figures 23-27). The exploitation rate of all oysters (0.7%) was lower than it has been in six years (Figure 28), while the exploitation of markets sized oysters decreased slightly from 2018 to 9.5% in 2019 (Figure 28).

Science Advice: Include "bed metric" plots that show abundance and morality by bed

The 2019 SARC recommended that bed-level data be included in the report as an appendix in addition to the region trends plots. These plots now appear in the report as Appendix C-F.

Science Advice: Explore modeling of population dynamics

The 2019 SARC made a science recommendation to evaluate the utility of a population model that can be used to make annual predictions that can then be compared with our annual Assessment Survey index. Little progress was made in addressing this science advice item in 2019, however, a population viability analysis (PVA) was used to estimate the projected abundance in each region in five years given the rates of population change that have been observed in each region for the last ten years. For the analysis, the distribution of rates of population change (last ten years only) was resampled with replacement each year in succession for 5 years. This was repeated 1,000 times for each region and the resulting distribution for market and total abundance by region is in Figure 30. It suggests that if a similar distribution of population growth and decline is observed over the next 5 years as was observed over the last 10 years, the total number of oysters in each region will be relatively unchanged. However, it also suggests that the total number of market sized oysters could increase dramatically, especially on the Shell Rock and High Mortality regions (Figure 30). The 2020 SARC recommended further evaluation of this approach using hindcasting to evaluate accuracy of projections. In addition, the SARC recommended exploration of several alternative methods of population modeling and projections, including developing a transition probability matrix for different life stages and a full stock assessment model.

IV. SARC EXPLOITATION RATE AND AREA MANAGEMENT RECOMMENDATIONS

Upon review of the status of the stock, the 2020 SARC made the following recommendations that are summarized in Table 11.

- The Very Low Mortality region should be closed to fishing.
- The Low Mortality, Medium Mortality Transplant could be fished as part of the intermediate transplant program up to the maximum allowable exploitation rates for each region.
- Shell Rock can be fished up to its maximum allowable exploitation rate with no requirement for a transplant.
- The High Mortality and Medium Mortality Market regions can be fished up to their median exploitation rate, but be allowed to be increased to the maximum allowable exploitation rate if a successful transplant occurs on those regions.

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 fisheries population modeling 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 2019 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 management strategies; prescribed fishing exploitation rates implemented since 1996 have had no observed negative impact on production.

However, the 2019 SARC also recommended a simplified version of the Statement of Sustainability be drafted and circulated to the SARC for review prior to the 2020 SAW. Upon review of the status of the oyster population on the New Jersey side of the Delaware Bay, the 2020 SARC subsequently approved acceptance of the following edited version of the original Statement of Sustainability:

> The New Jersey Delaware Bay oyster population 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 2020 SARC recommended the following list of science advice (not ordered by priority):

1. Continue to estimate intra-grid variability during the Resurvey program. In addition, evaluate how this information could be used to inform allocation of effort during the Assessment Survey. * See *Science Advice: How Variable Are The Three Tows Taken On Each Sampled Grid?* section from this report for additional details.

2. Add shellplant and transplant history to Resurvey maps to evaluate whether beds that receive enhancement are changing at a different rate then non-enhanced beds.

3. Coordinate with NJDEP as time and funds permit to address two items related to dredge capture efficiency:

   a. Evaluate whether patent tongs are really 100% efficient on the Delaware Bay reefs.

   b. Take patent tong grabs during the Assessment Survey to get annual estimates of capture efficiency on each bed.

4. Report on how survey error is influenced by adding an addition 25 grids to the 200 sampled in 2019.

5. Evaluate alternative methods for sub-sampling spat, including collecting a sub-sample of cultch from each sample.

6. Further explore mechanisms (environmental, resistance) driving declines in natural mortality and evaluate whether there are management actions we can take that can affect these mechanisms. For example, can we coordinate with DRBC for controlled releases of freshwater?

7. Show history of targeted vs. achieved exploitation rates and evaluate whether there are trends (over- or under-harvest) by management region? If so, why?

8. Updated growth experiments:

a. Continue experiments for one more year

b. Fit growth models and evaluate including environmental covariates in the growth models

c. Incorporate growth model data in a population/projection model

9. Continue to evaluate the influence of enhancement program efforts. Consider applying a mixed effects model to evaluate what environmental (or other) conditions are leading to successes/failures. Collaborate with DEP to include fishing effort in this analysis.

10. Include a detailed history of transplanting effort (#'s of bushels and oysters, location moved to/from) in the SAW presentation and in the report.

11. Evaluate how much size-selective fishing would be required to shift the population size frequency. Estimate what this level of fishing translates to in exploitation rate.

12. Continue to explore population models using the Assessment Survey data:

a. Run hind-cast simulations using the PVA approach outlined in this report

b. Evaluate the use of a probability transition matrix for different life stages

c. Evaluate if the survey data could be used in a similar modeling framework as is being applied in Maryland

d. Do these modeling exercises suggest anything about how appropriate the current biological reference points (targets and thresholds) are?

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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. Cohansey and Bennies Sand were resurveyed in 2019. Upper Middle and Ship John are scheduled for resurvey in 2020. Egg Island and Ledge have 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**	**2007**	**2020**
	Middle	51	1	2011	2021
	Sea Breeze	48	1	2012	2022
MMM	Cohansey	83	2	2019	2029
	Ship John	**68**	**1**	**2010**	**2020**
SR	Shell Rock	93	3	2016	2026
HM	Bennies Sand	49	2	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	2011	2021
	Vexton	47	2	2011	2021
	Egg Island	125	0	-	-
	Ledge	53	0	-	-

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 2010-2019. 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. =Note: Sea Breeze was part of the MMM until 2011; it is now MMT. Beds without removals were omitted.

a. Direct Market

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Middle	56									
Sea Breeze	220		170	5,454	542					
Cohansey	2,806	19,074	11,288	10,583	8,652	10,669	12,475	20,687	8,709	7,253
Ship John	20,409	19,212	17,755	19,279	24,295	19,837	19,938	16,331	22,021	25,037
Shell Rock	17,493	24,112	22,628	24,280	23,589	29,629	31,794	38,189	31,872	28,761
Bennies Sand	10,147	8,825	5,836	10,841	3,038	6,301		22,339	23,395	13,911
Bennies	5,526	4,997	2,155	870	8,010	10,712	29,293	23,071	21,626	7,126
Nantuxent	6,572	5,467	14,332	10,218	5,154	5,267	2,101	628	11,347	17,575
Hog Shoal	7,281	9,049	1,965	2,385	3,425	103		1,756	283	9,445
New Beds	1,075	1,778	443	226		4,912	4,494	1,143	89	
Strawberry	25			140						
Hawk's Nest	2,693	1,954	1,568		205					
Beadons	72									
Vexton		2								
Total	74,375	94,470	78,140	84,276	76,910	87,430	100,095	124,144	119,342	109,108

b. Transplants

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Hope Creek	1,200	6,150								
Fishing Creek	2,000									
Liston Range	4,750	1,800		550						
Round Island		3,350		2,250						
Upper Arnolds	18,250	2,800		15,550		10,200				
Arnolds		4,000	7,650	2,700	15,500		4,800			7,200
Upper Middle			2,100	3,200				3,200	4,750	
Middle		17,750	11,200	5,200	6,600	5,550	8,150	21,350	27,500	25,000
Sea Breeze	11,050		8,525	6,200	7,300	10,800	2,400	4,700	7,700	8,800
Cohansey	1,500									
Beadons		500								
Total	38,750	36,350	29,475	35,650	29,400	26,550	15,350	29,250	39,950	41,000

Table 7. Council-chosen and fishery-achieved exploitation rates for 2019 for (a) Direct Market regions and (b) Transplant regions. Direct market exploitation rates include market-size oysters only. Transplant exploitation rates include all sizes of oysters. Small oysters and shell are culled during both transplant and harvest.

a. Direct Market

Region	Max SARC Expl. Rate	Chosen Expl. Rate	Achieved Expl. Rate	Chosen Market (bu)	Add'l Transpl Alloc (bu)	Achieved Total (bu)
MMM	3.70%	3.70%	3.02%	35,217	0	32,290
SR	4.88%	4.88%	4.44%	26,734	0	28,761
HM *transpl. req'd*	8.99%	8.99%	9.49%	33,667	14,935	48,057
			Total	95,618	14,935	109,108

Total Quota (bu)	Un-harv. Quota (bu)
110,553	1,445

b. Transplant

Region	Max SARC Expl. Rate	Chosen Expl. Rate	Achieved Expl. Rate	Chosen Trans (# oys)	Achieved Trans (# oys)	Under/Over #
VLM	CLOSED	NA	NA	NA	NA	NA
LM	2.26%	2.26%	0.70%	8,941,378	2,837,705	-6,103,673
MMT	2.46%	2.46%	2.79%	12,158,274	13,956,501	1,798,227

Table 8. Summary of intermediate transplant data. Transplant conducted in April and May 2019 from the Low Mortality (a) and Medium Mortality Transplant regions (b). Data derived from daily samples taken from each boat and measured deckloads throughout the transplant. Market-Equivalent bushels used the number of oysters moved that were ≥ 2.5" (63.5mm) and the Fall 2018 port-sampling result of 263 market oysters per bushel. The fraction of oysters < 2.5" did not enter into additional quota allocations for 2019. The fraction of cultch is based on volume and includes shell only, not boxes.

a.

Donor	Receiver	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5"	Number Oysters ≥ 2.5"	Mkt-Equiv. Bu (>2.5")	Fraction Cultch
Arnolds	Shell Rock	7,200	2,837,705	0.828	489,430	1,861	0.449
LM	**Totals**	7,200	2,837,705		489,430	1,861	

b.

Donor	Receiver	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5"	Number Oysters ≥ 2.5"	Mkt-Equiv. Bu (>2.5")	Fraction Cultch
Middle	Bennies Sand	25,000	9,890,349	0.748	2,496,843	9,494	0.288
Sea Breeze	Bennies Sand	8,800	4,066,152	0.768	941,483	3,580	0.206
MMT	**Totals**	33,800	13,956,501		3,438,326	13,074	

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 2019. See key at the bottom for definitions of what each color represents for each metric.

2019 Metrics	*Transplant* Very Low Mortality	*Transplant* Low Mortality	*Transplant* Medium Mortality	*Market* Medium Mortality	*Market* Shell Rock	*Market* High Mortality
Total Abundance						
2019 Percentile (1990-2019)	0.083	0.793	0.241	0.310	0.724	0.482
2019 vs. Target-Threshold						
Market Abundance						
2019 Percentile (1990-2019)	0.000	0.310	0.517	0.275	1.000	0.827
2019 vs. Target-Threshold						
Sub-Market Abundance (< 2.5")						
2019 Percentile (1990-2019)	0.250	0.827	0.586	0.413	0.482	0.413
Spatfall						
2019 Percentile (1990-2019)	0.250	0.137	0.034	0.034	0.137	0.103
Mortality						
2019 Percentile (1990-2019)	0.916	0.793	0.275	0.172	0.275	0.068
Dermo WP						
2019 vs. Category	0.000	0.000	0.417	0.500	1.600	1.600

	Green	**Yellow**	**Orange**
2019 Percentile (1990-2019)	Above the 60th	40th - 60th	Below the 40th
2019 vs. Target/Threshold	Above Target	b/w Target and Threshold	Below Threshold
2019 vs. Category	<1.5	1.5-2	>2

Table 11. 2020 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	-	CLOSED	-	-	-	-	-	-
LM	Max	2.26%	516,200,745	11,666,137	447	26,099	9%	2,349
MMT	Max	2.46%	245,386,434	6,036,506	329	18,348	24%	4,404

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	142,356,428	4,313,400	266	16,216	No
MMM*	Max	0.0370	142,356,428	5,267,188	266	19,801	Yes
SR	Max	0.0488	256,101,368	12,497,747	266	46,984	No
HM*	Median	0.0749	120,402,292	9,018,132	266	33,903	No
HM*	Max	0.0982	120,402,292	11,823,505	266	44,449	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.

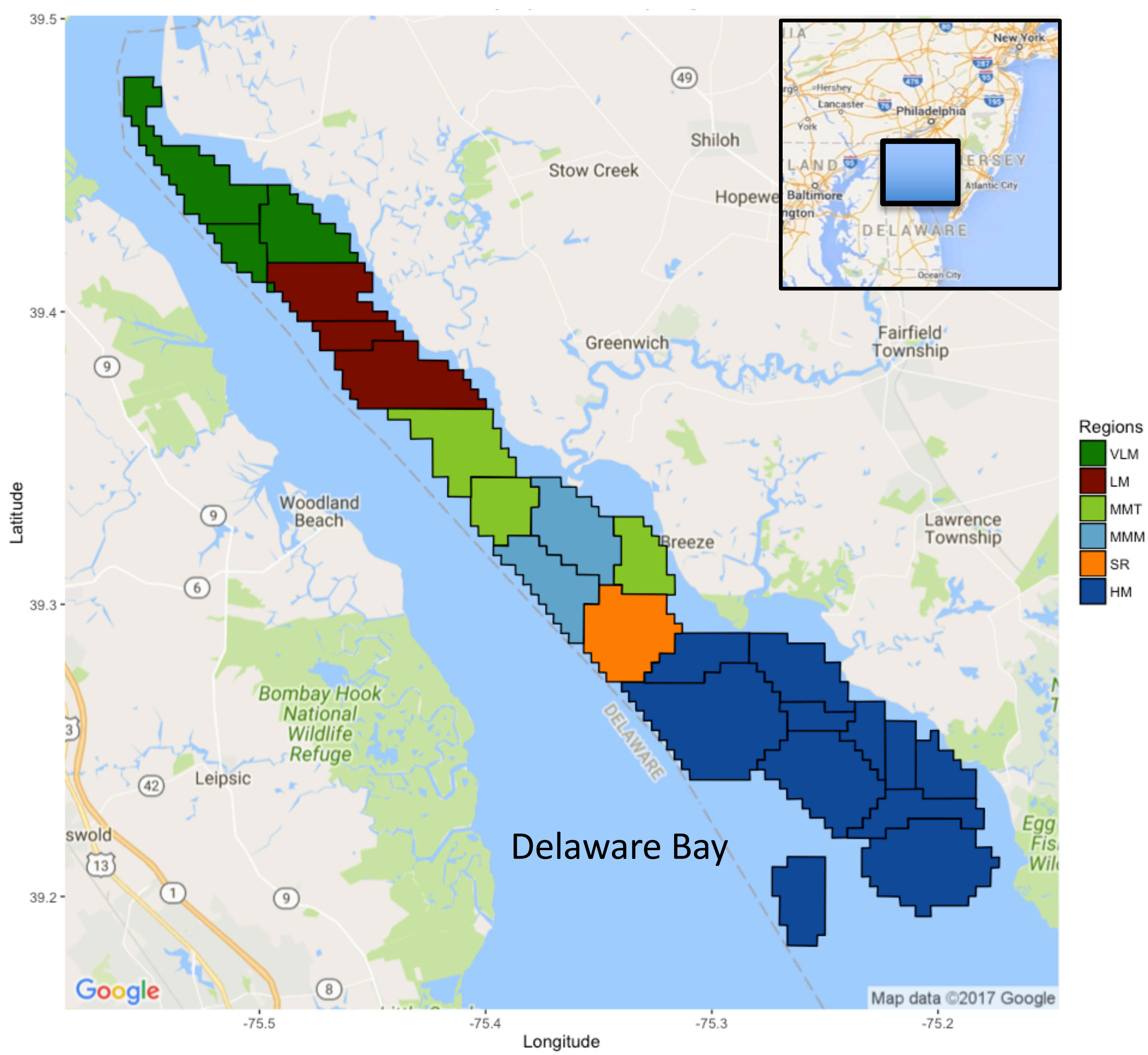


Figure 2. Regional acreage and proportional distribution of the assessed NJ Delaware Bay oyster resource. Regions are listed upbay to downbay from left to right. The VLM, LM, and MMT contain three beds each and are termed Transplant regions. The Direct Market regions are the MMM made up of two beds, the SR (one bed), and the HM with eleven beds.

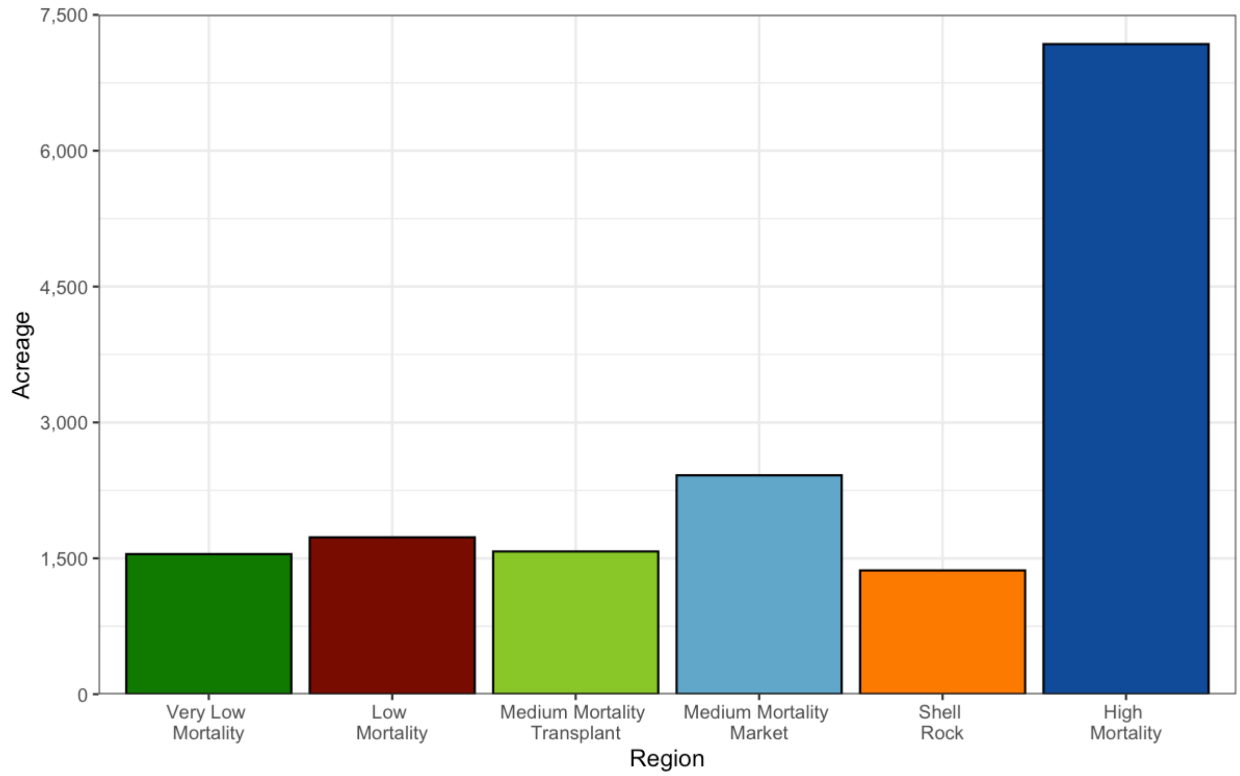
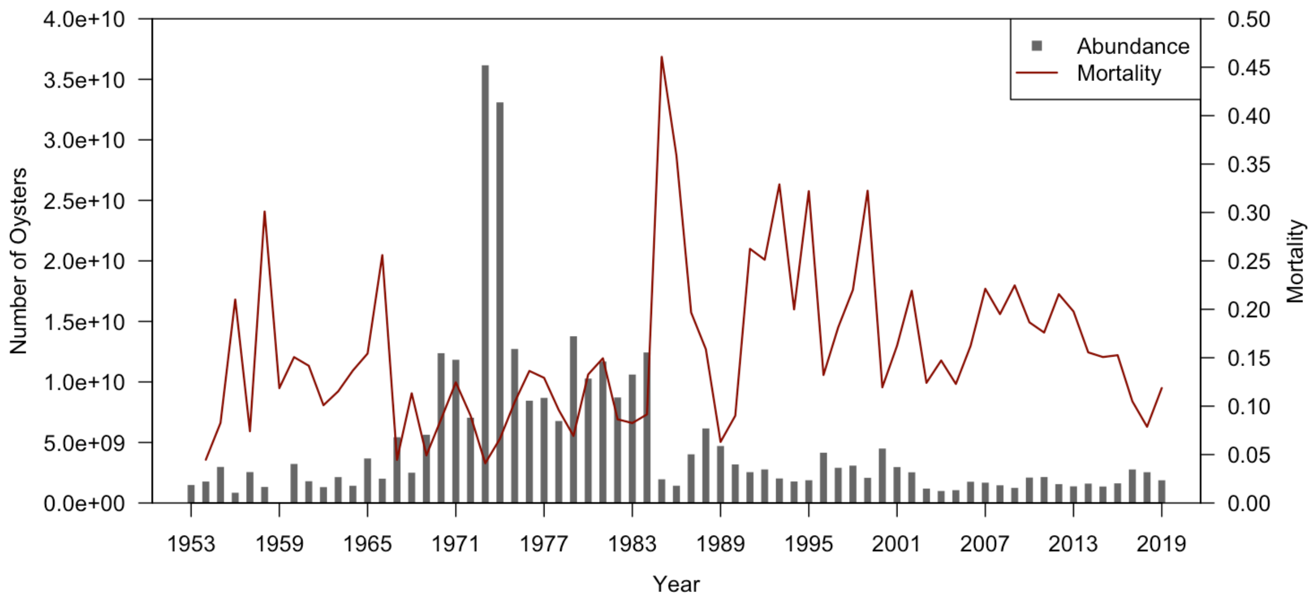


Figure 3. Time series of total oyster abundance (left axes) compared to natural mortality rate (a, right axis) and fishing mortality (b, right axis). Time series of 1953–2019 stock surveys excludes the VLM.

a.



b.

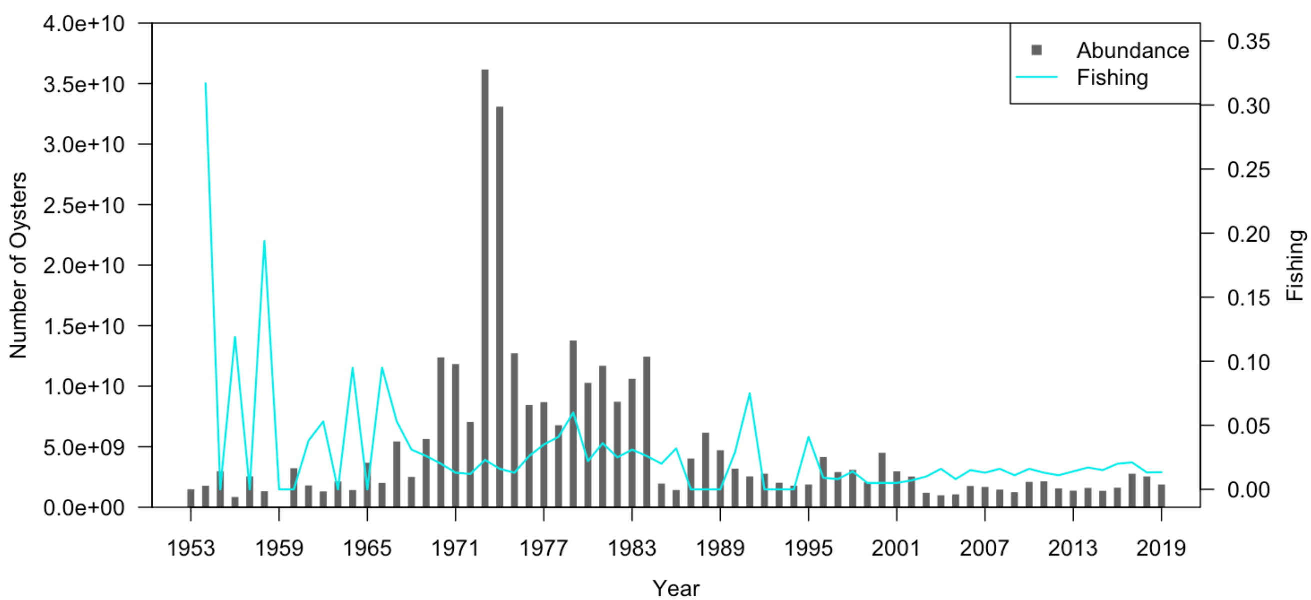
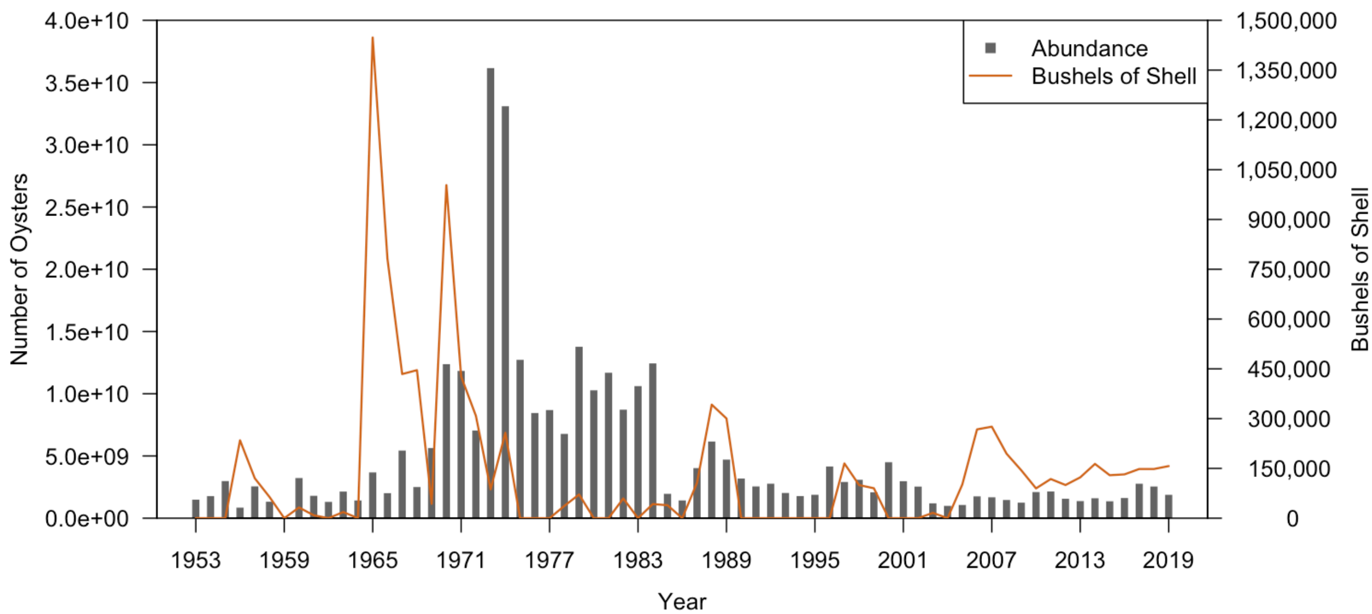


Figure 4. Time series of total oyster abundance (left axes) compared to bushels of shell planted (a, right axis) and total spat abundance from the stock assessment time series (b, right axis). Time series of 1953–2019 stock surveys excludes the VLM.

a.



b.

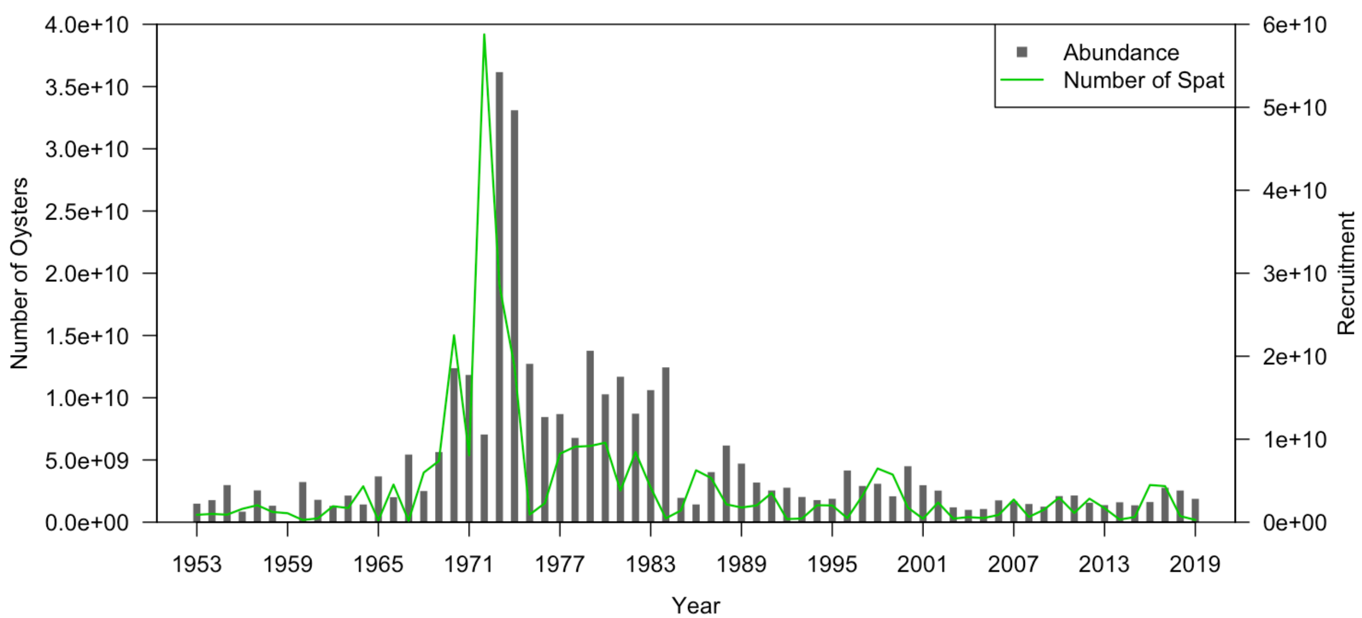


Figure 5. Number of oysters harvested from the natural oyster beds of Delaware Bay, NJ from 1953–2019. Prior to 1996, the bay-season fishery removed oysters from the natural beds and transplanted them downbay to leased grounds. Zeros represent years of fishery closure.

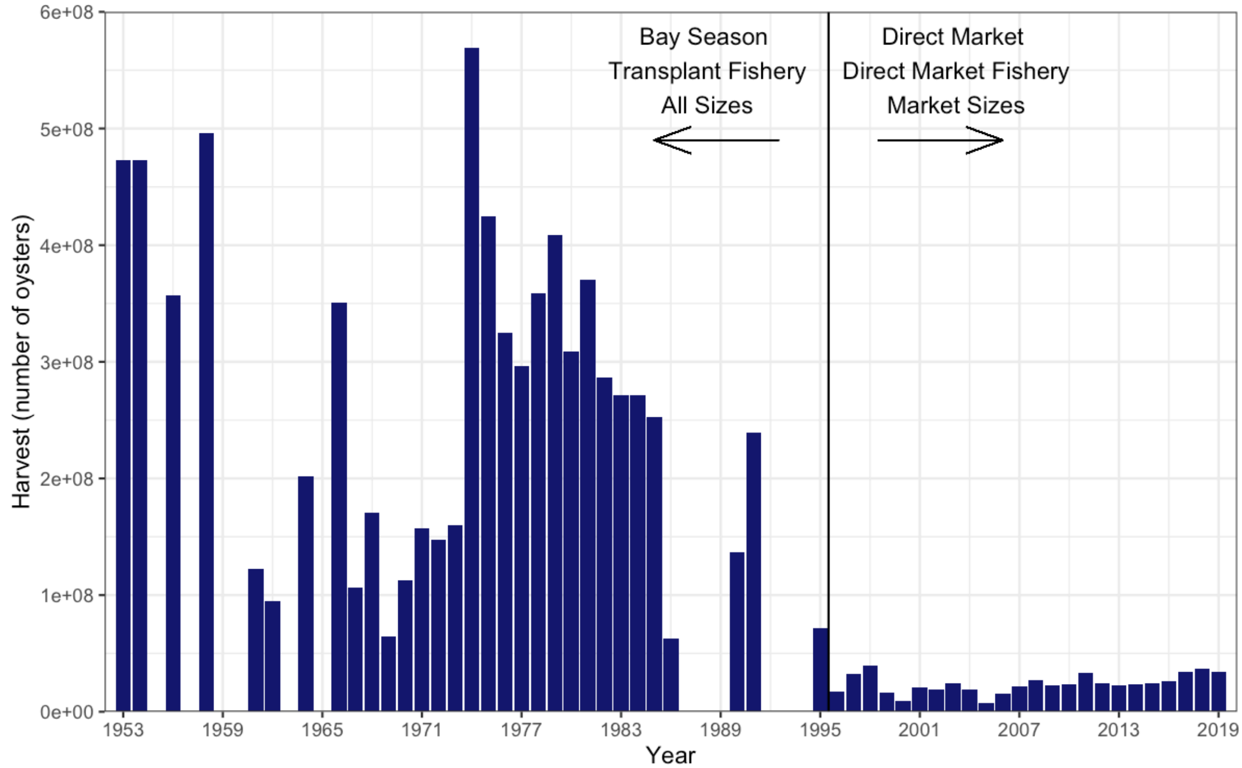


Figure 6. Survey gear capture efficiency as a function of true oyster density. Error bars represent the standard deviation from 1,000 bootstrap simulations. Line indicates the best fit power model estimated by weighted nonlinear least squares. *Adapted from Morson et al. (2018)*

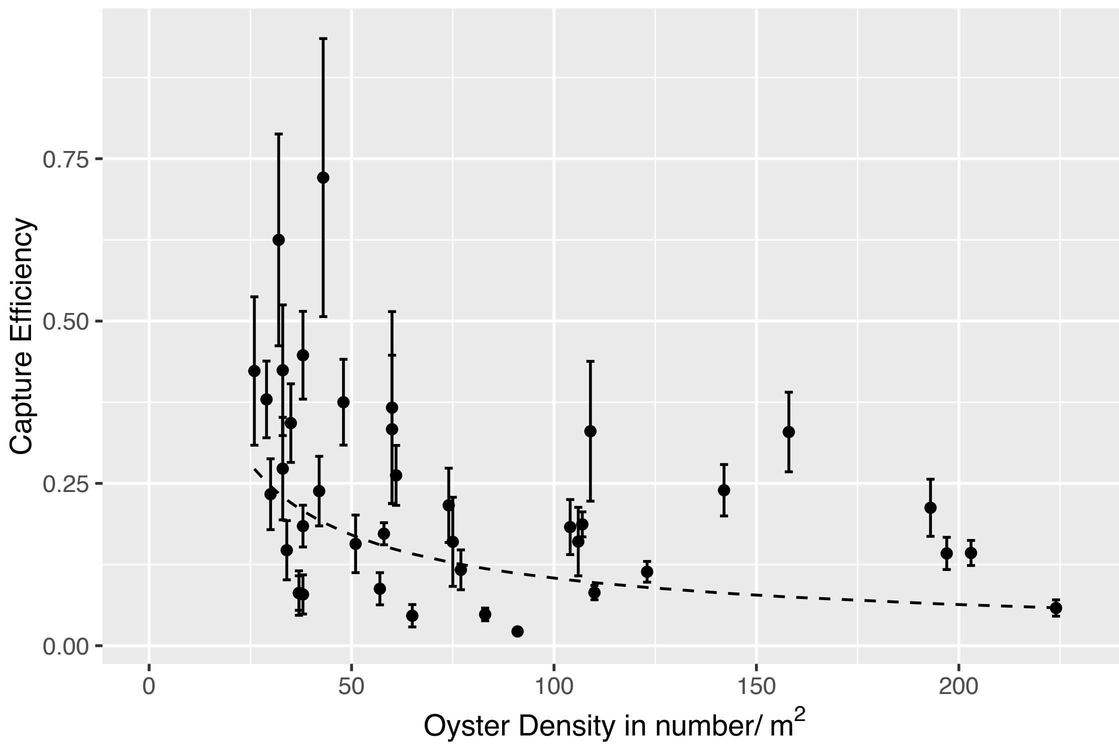


Figure 7. The assessed oyster beds of Delaware Bay, NJ grouped as regions (see Legend) with the 2019 strata designations. White outlines indicate complete boundary of each bed with the high and medium quality strata grids in dark and light colors, respectively. The colors indicate region groupings although strata designations are within-bed not within-region. Clear blue areas in each bed indicate its low quality stratum. 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 (101,175 m^2 or 10.1 hectares).

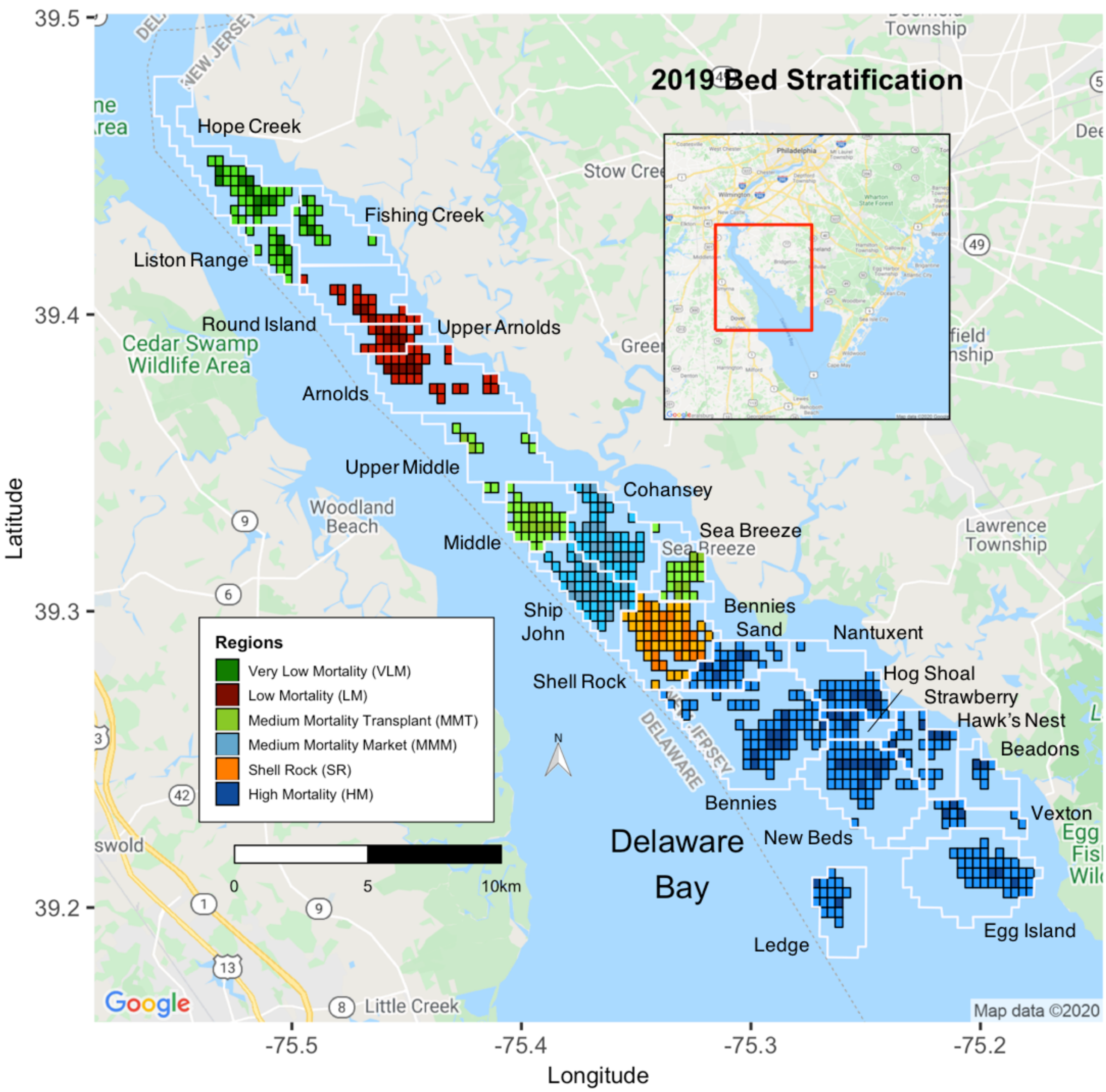
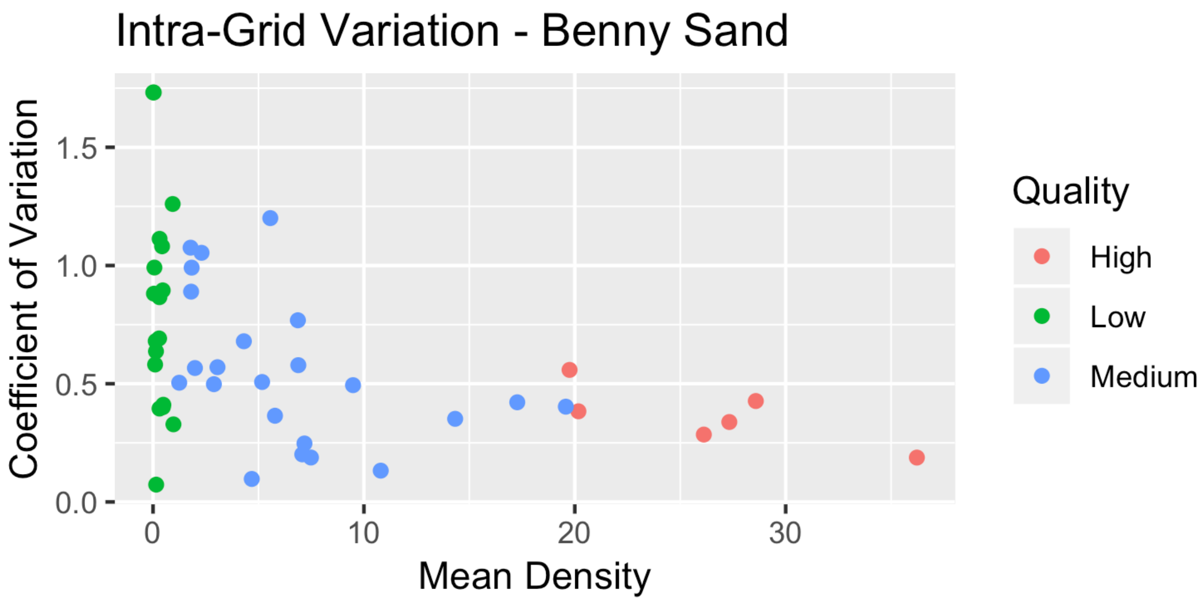


Figure 8. Coefficient of variation (CV) as a function of mean density for each sampled grid during the 2019 Resurvey on Benny Sand and Cohansey. Colors indicate different strata (High, Medium, and Low quality). Each 1/3 bushel sub-sample from each of the three tows were kept separate, and a mean and CV was calculated for each grid.



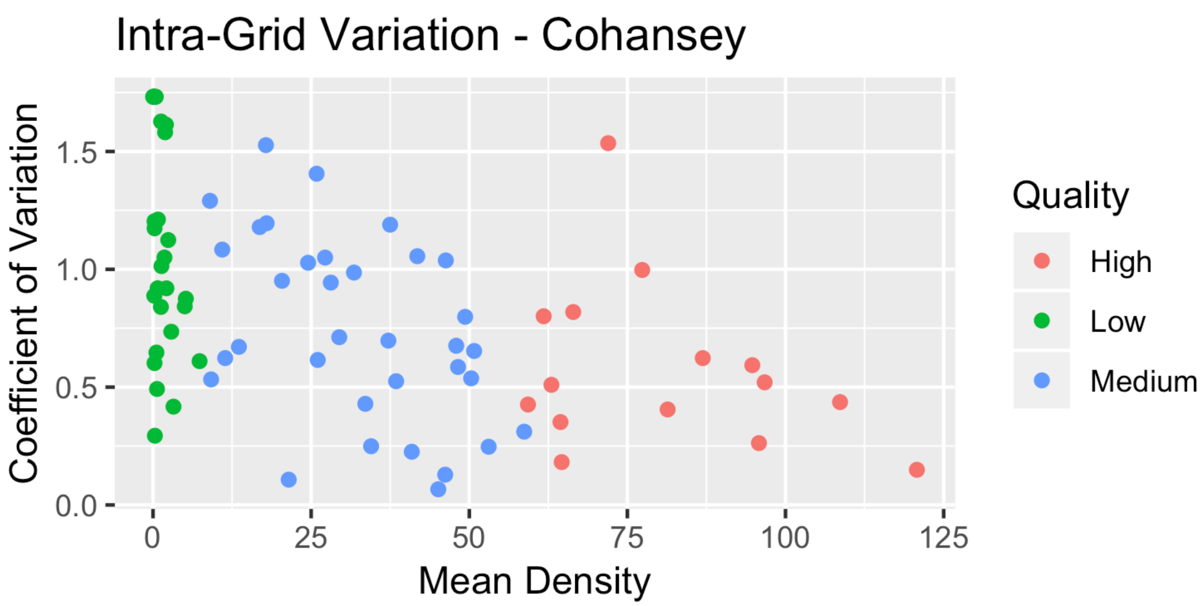


Figure 9. Total abundance calculated during the 2019 Resurvey on Benny Sand and Cohansey. Survey error is calculated two ways. For "Composite" (bars on the left side of each panel), the 1/3 bushel subsample from each tow is combined into a single composite bushel. In this instance, only *intra-strata* variability is included in the survey error estimate (see section on "Estimating Survey Error" for more details). For "Separate" (bars on the right hand side of each panel"), the 1/3 bushel subsample from each tow is treated as an independent sample and the variation across these tows is included in the bootstrap calculation of survey error. Therefore, the "Separate" method accounts for both *intra-strata* and *intra-grid* variability. Error bars are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error.

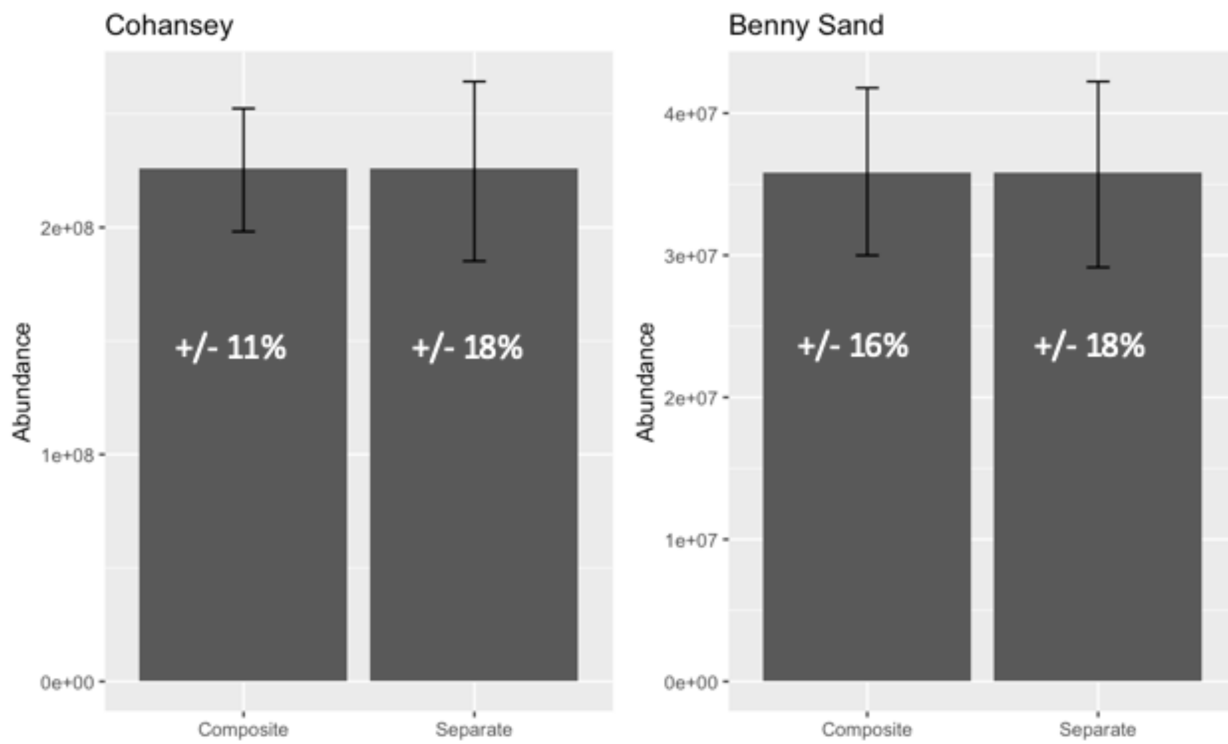


Figure 10. Total abundance and survey error (error bars and red text) for each management region estimated using "No Extra Samples" (bars on the right-hand side of each panel) and with "Extra Samples" (bars on the left-hand side of each panel). "No Extra Samples" indices were estimated using the standard 175 grids. "Extra Samples" indices were estimated using the standard 175 grids plus an additional 25 grids. The total number of extra grids sampled in each region is in parentheses next to each region name. Error bars are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error. Solid lines represent the target reference point and dashed lines represent the threshold reference point for each region.

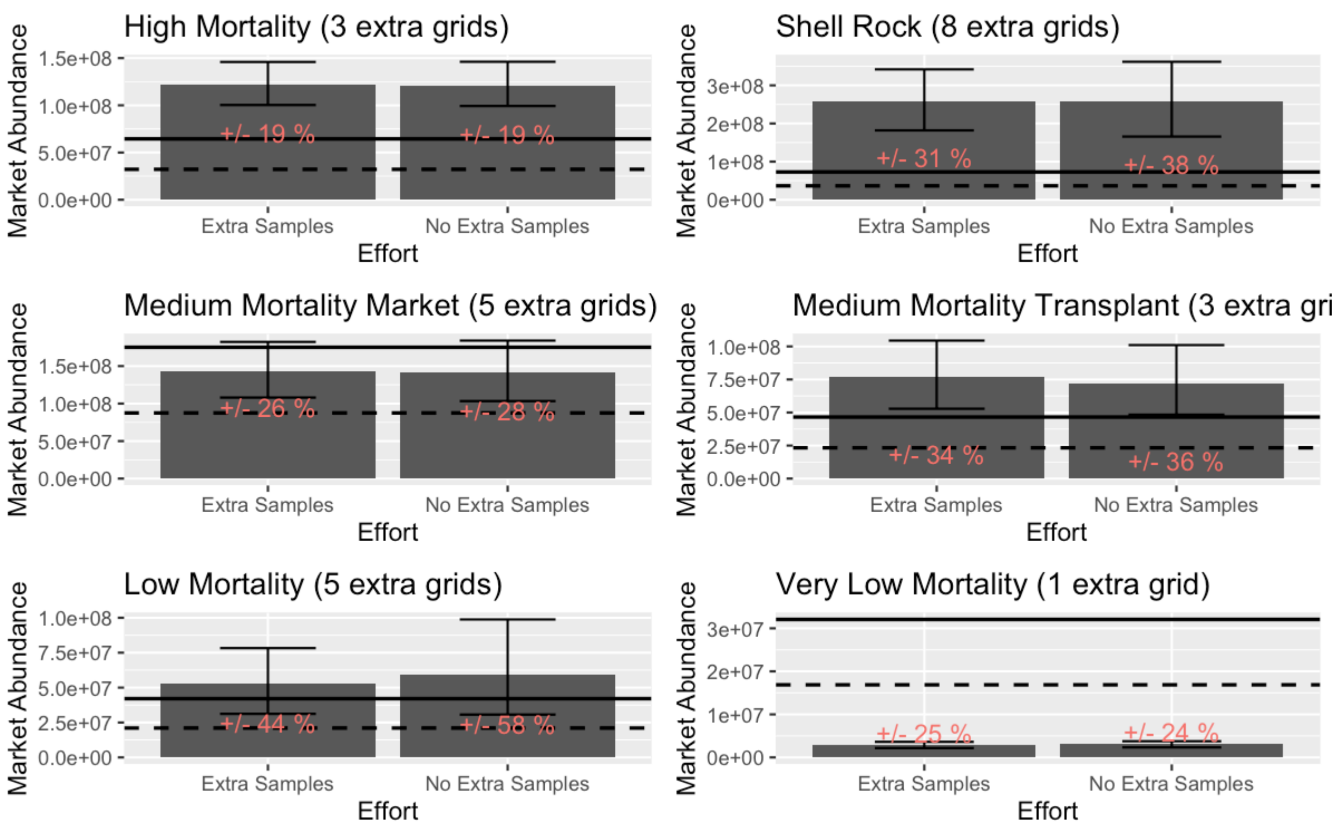


Figure 11a. Realized exploitation fractions of the >2.5" oyster stock on the Direct Market regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. The 2007-2015 median (dotted line) is based on the realized exploitation values with shading indicating the range. Negative values reflect oysters added through intermediate transplanting.

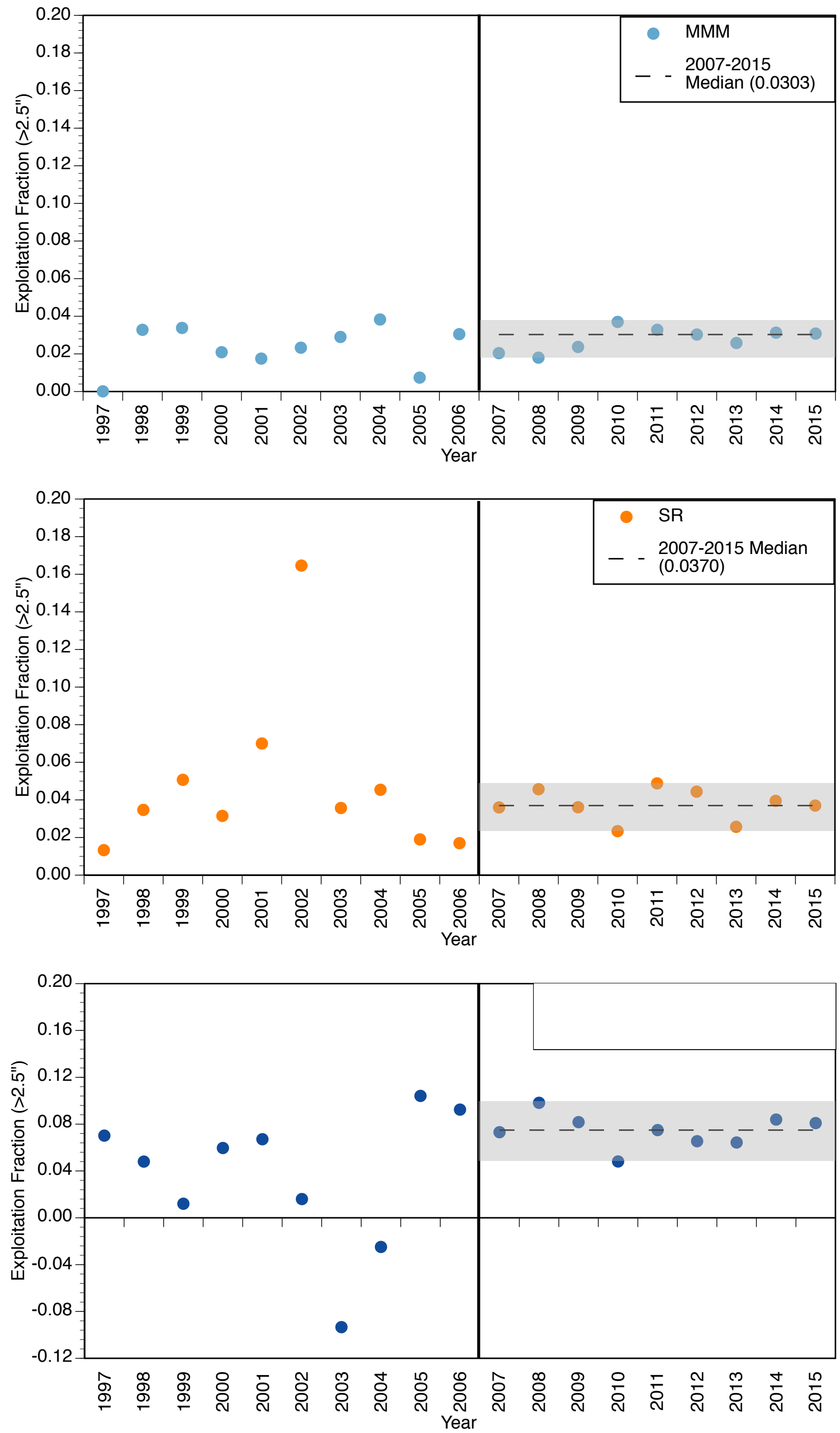


Figure 11b. Realized exploitation fractions of the whole oyster stock, excluding spat, on the Transplant regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. The 2007-2015 median (dotted line) is based on the realized exploitation for each region with shading indicating the range. 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.

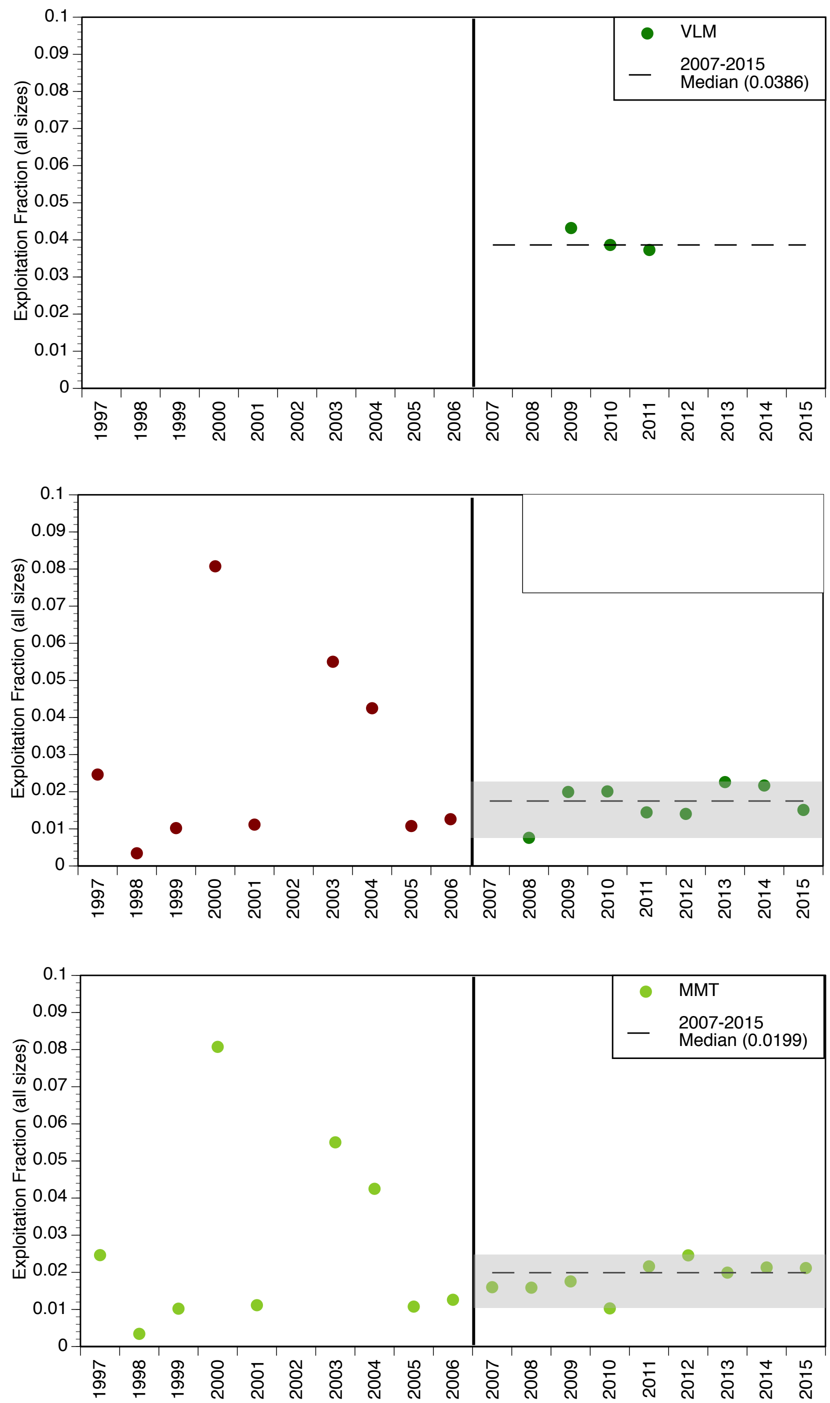


Figure 12. Landed oysters per bushel in three groups: market-size (>2.5"), smaller attached oysters, and smaller unattached oysters. The number of market-size oysters per landed bushel in 2019 averaged 245, while the total oysters per landed bushel averaged 313. The long-term mean of all oysters and market oysters per landed bushel (266) is shown as an orange line.

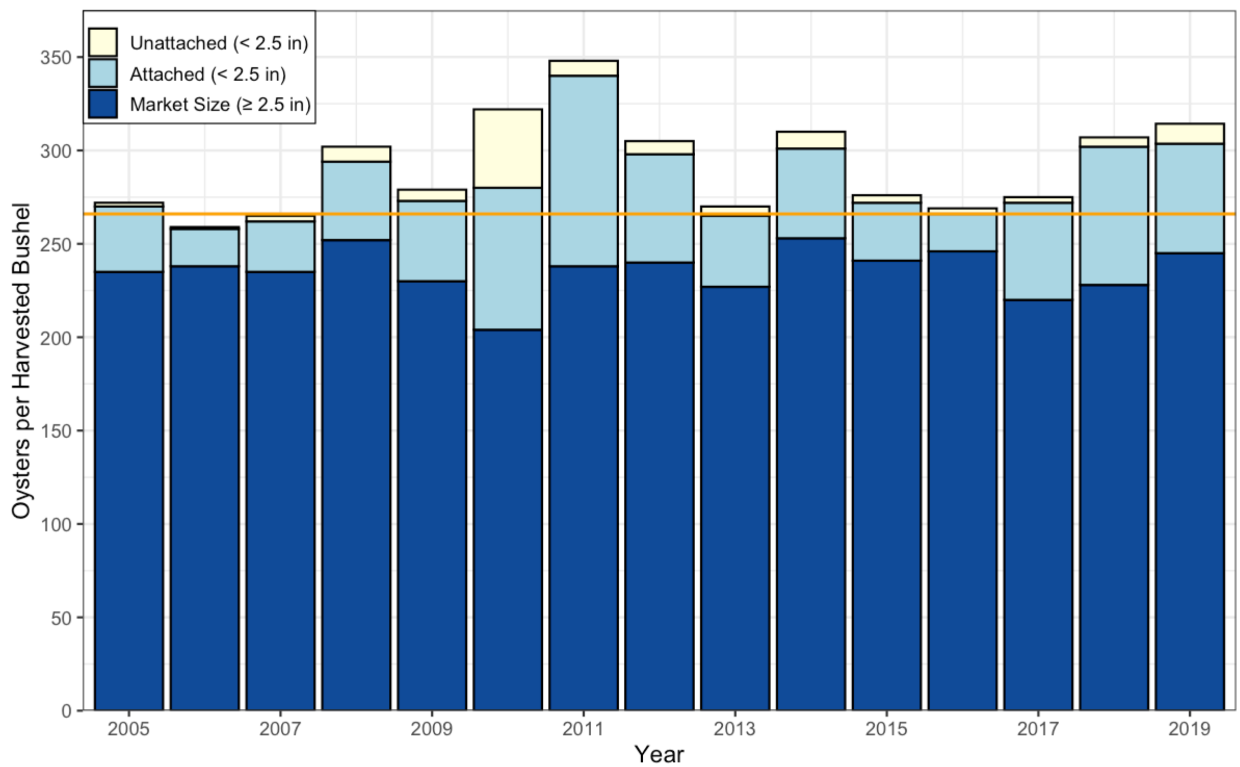


Figure 13. Numbers of single and dual dredge boats (stacked bars) participating in the NJ Delaware Bay oyster harvest overlaid with LPUE (total number of harvested bushels/total hours worked) for each dredge type.

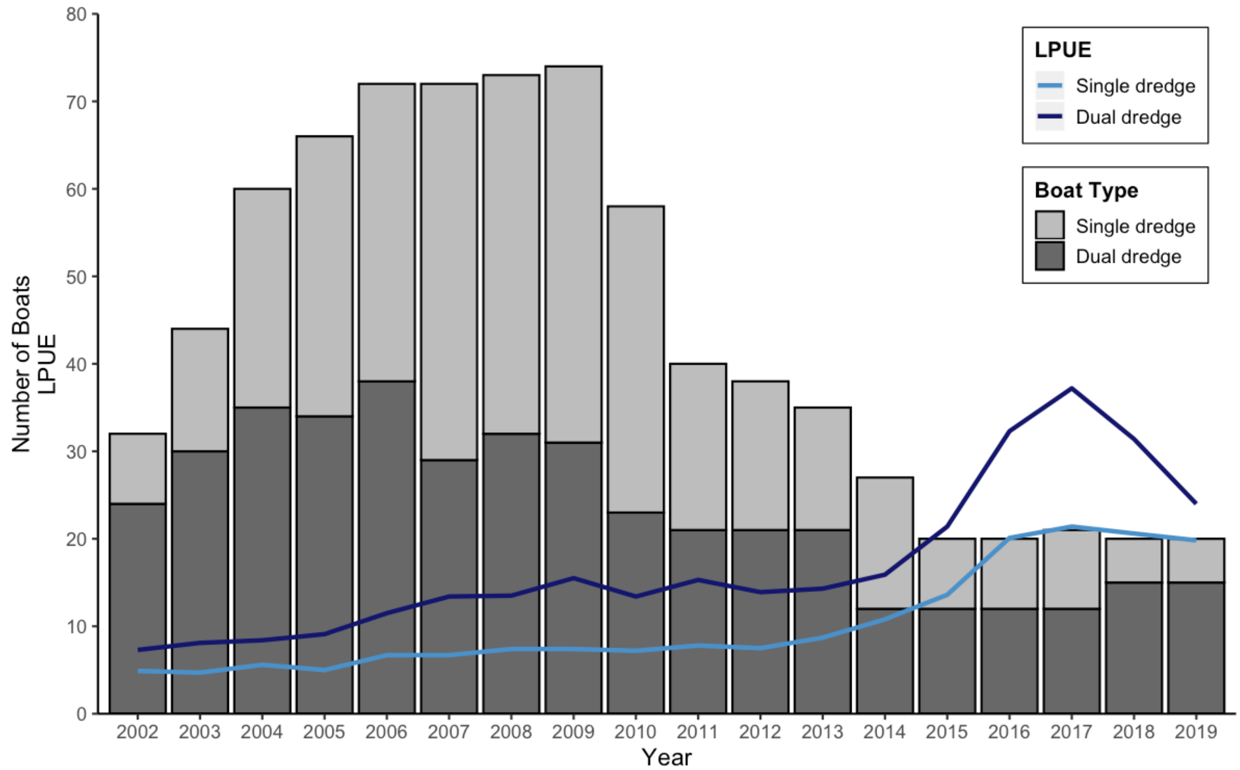


Figure 14. Size frequency of oysters landed by the fishery in direct market regions (top panel) and within the surveyed population (bottom panel). Vertical line indicates the market-size cutoff (≥ 2.5 inches).

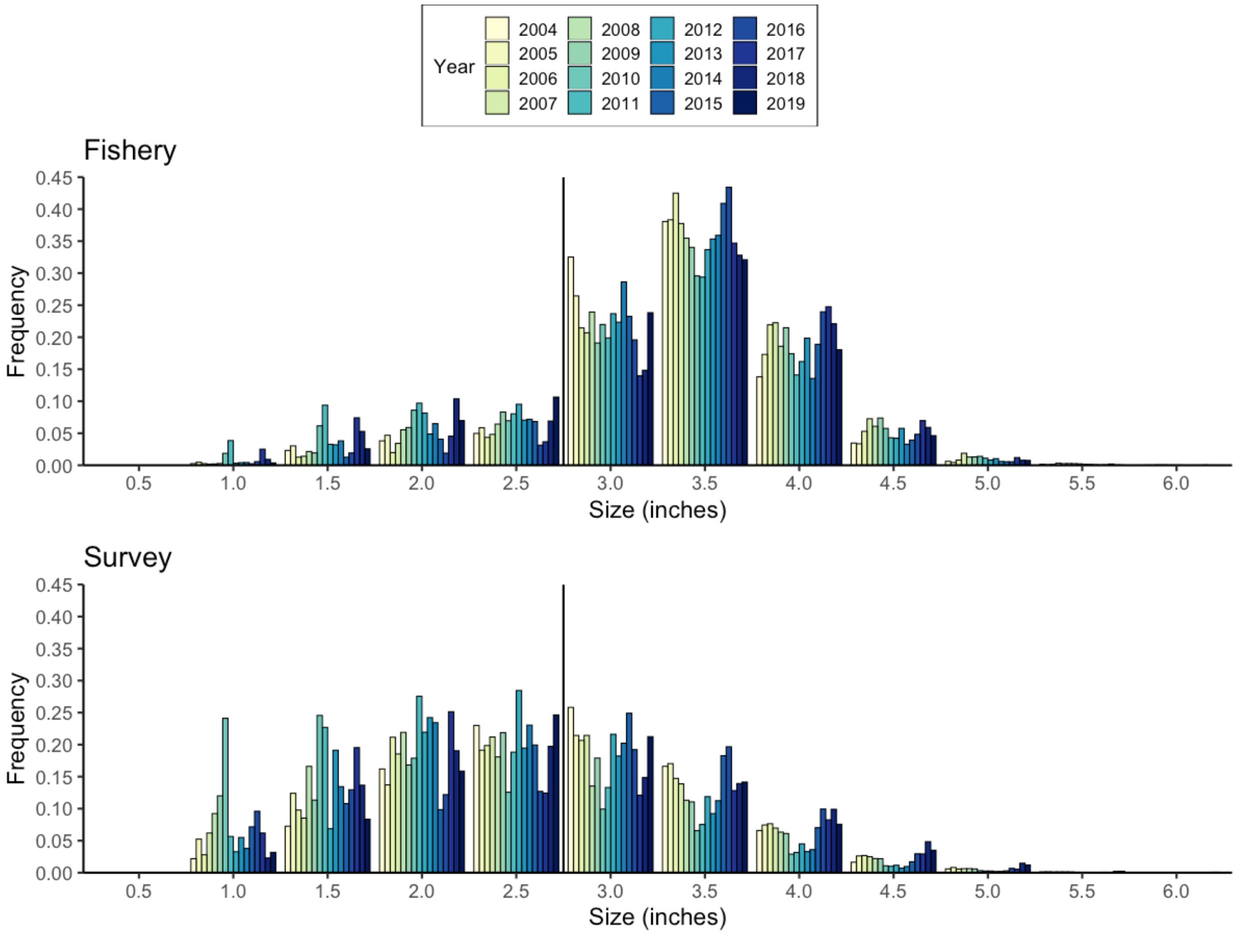


Figure 15. Frequencies of large and small market-size (≥ 2.5 inches) oysters landed by the fishery in direct market regions (top panel) and within the surveyed population (bottom panel).

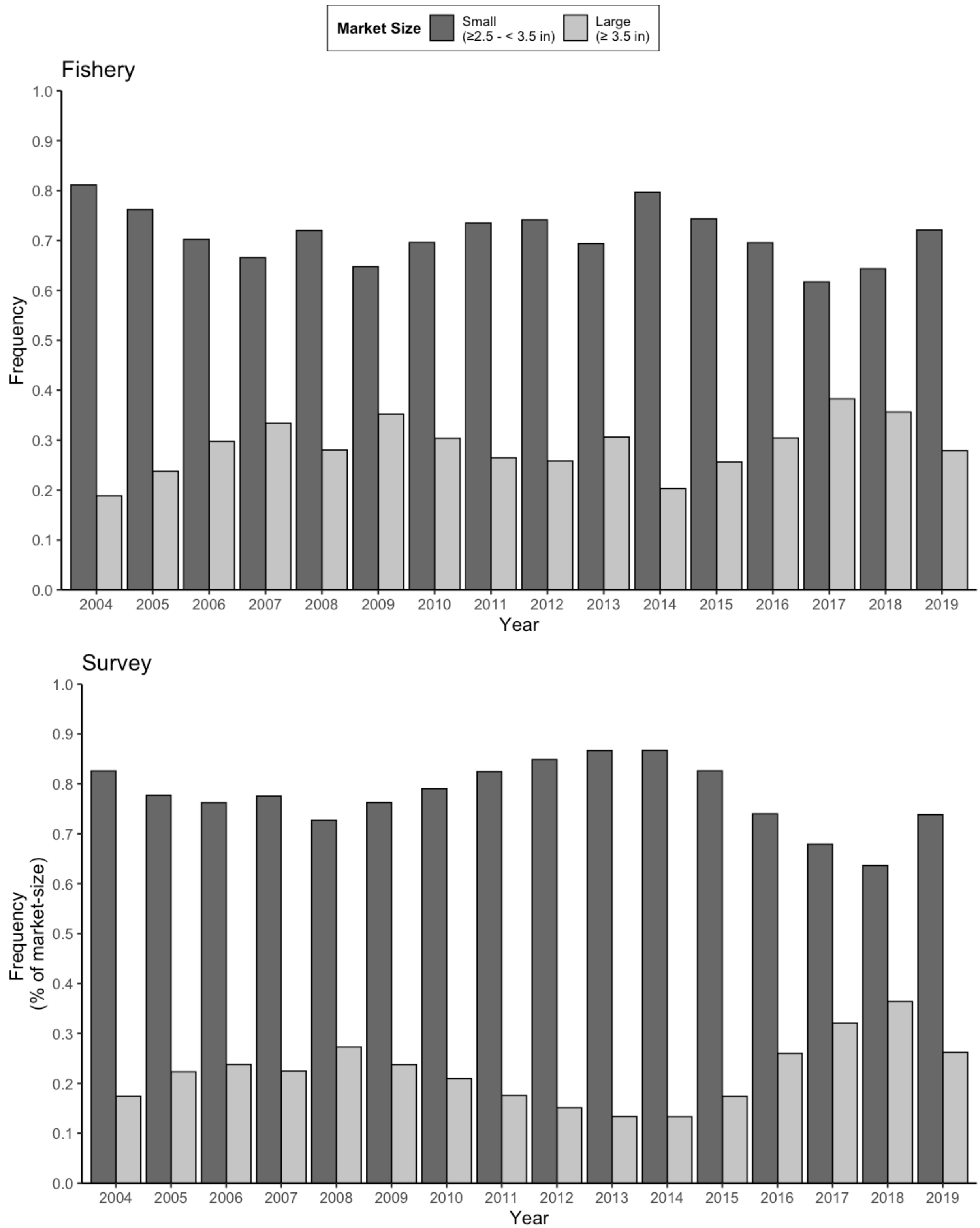


Figure 16. Mean cumulative growth increment for different sized oysters measured during experiments conducted in 2001 (Kraeuter et al. 2007), 2018, and 2019. Error bars represent standard error of the mean.

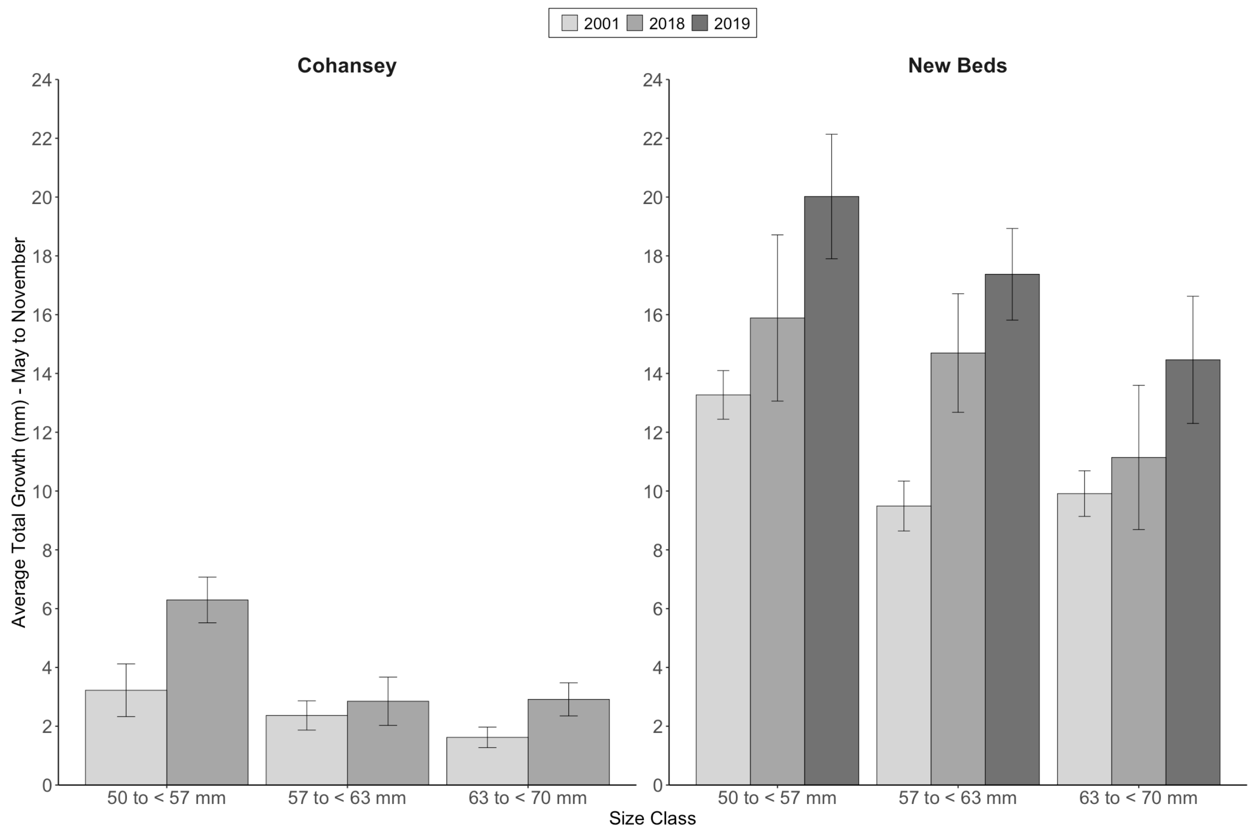


Figure 17. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program in 1996. The 24-year average harvest is 82,279 bushels. The 2006-2007 line shows the beginning of the current exploitation and management strategy.

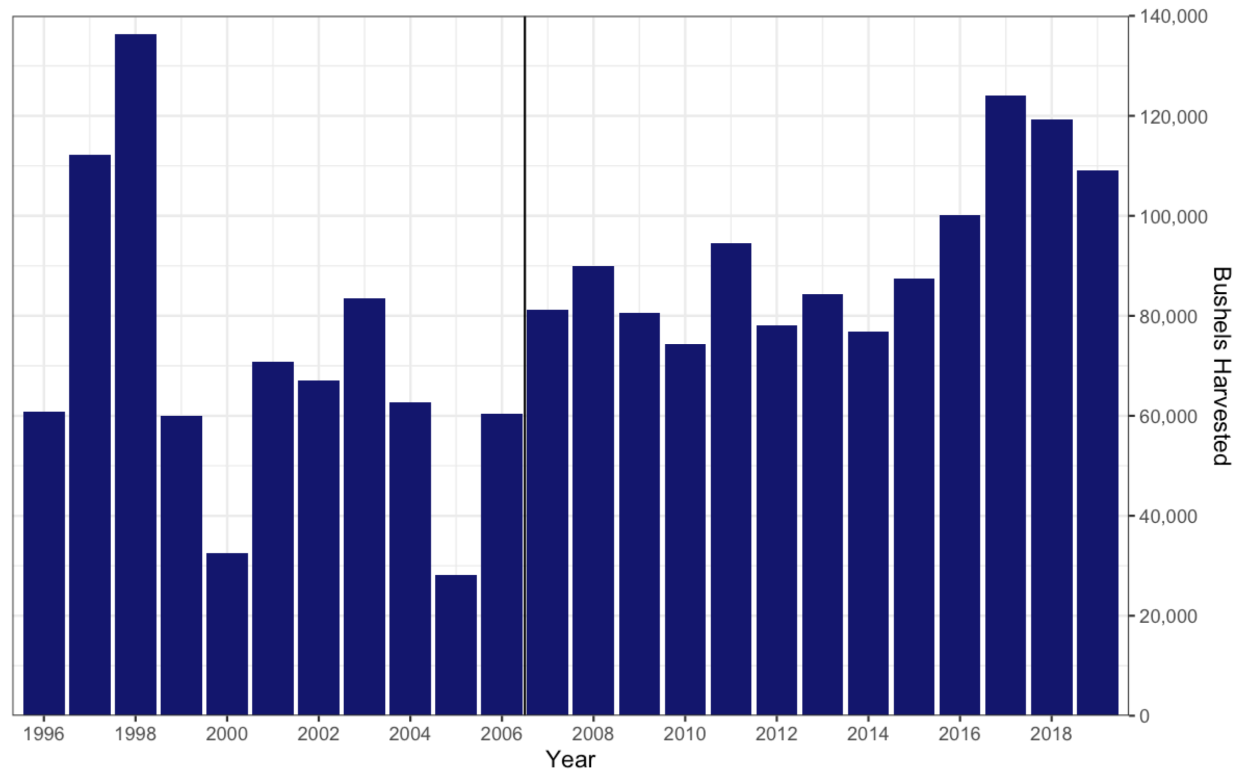
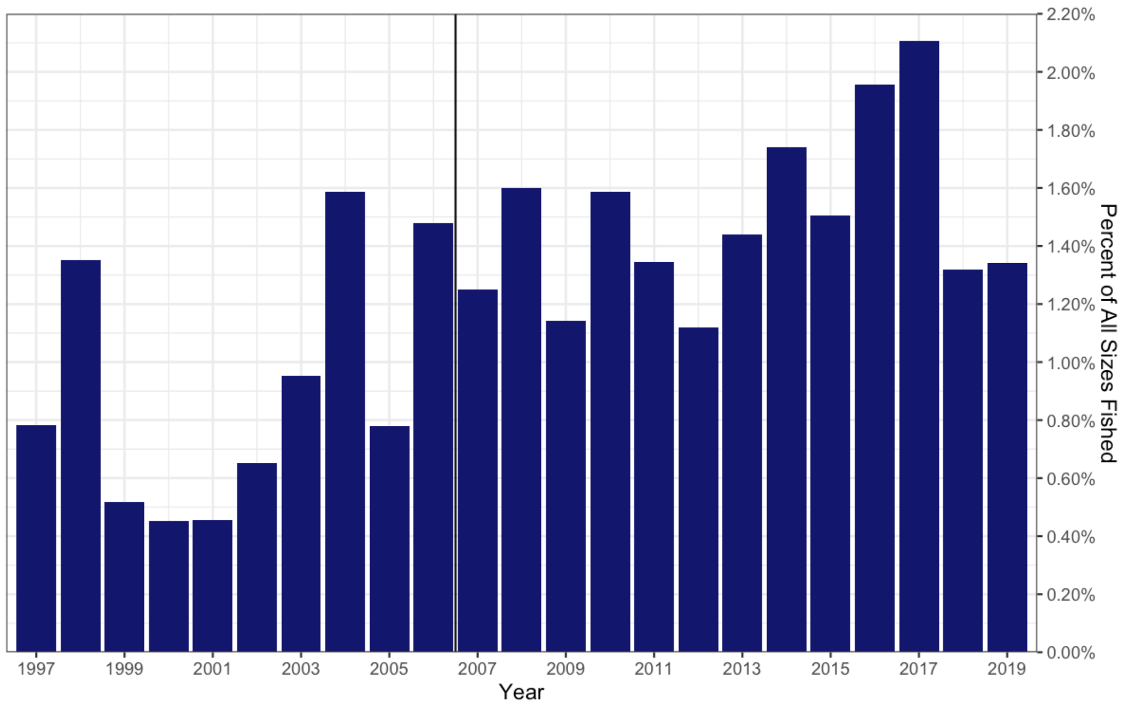


Figure 18. Fishing mortality as a percentage of (a) total oyster abundance and (b) the market-sized oyster abundance (>2.5") over all regions excluding the VLM. Regional abundance-based quotas began in 2007 (vertical line).

a.



b.

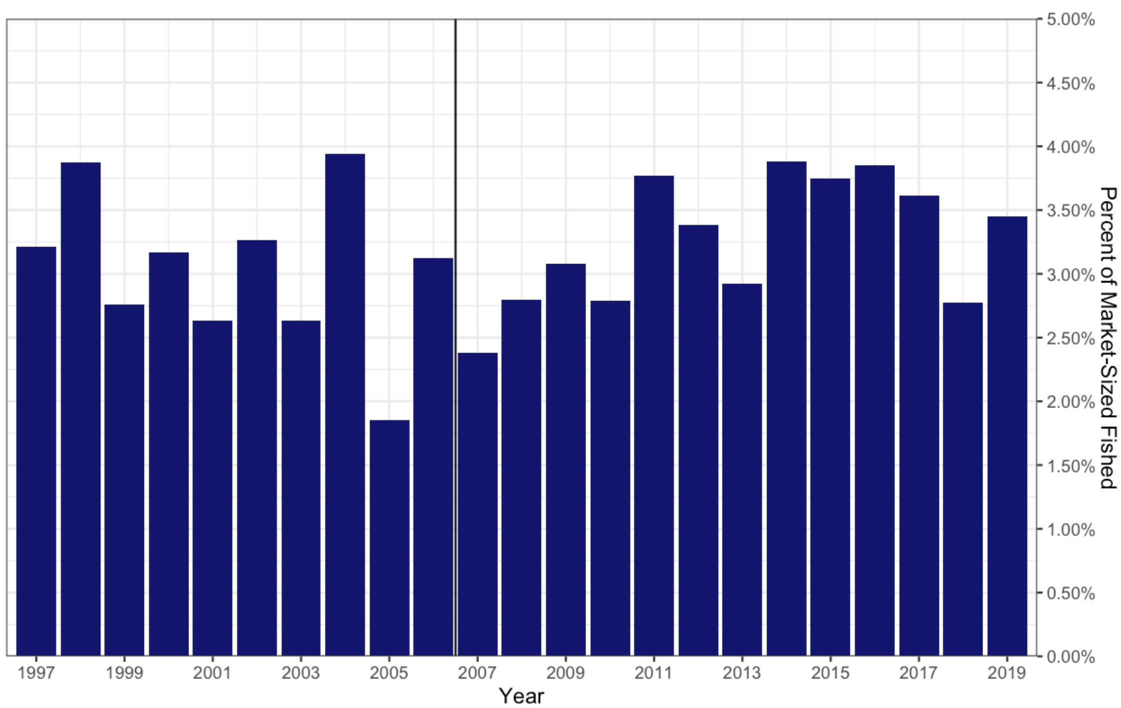
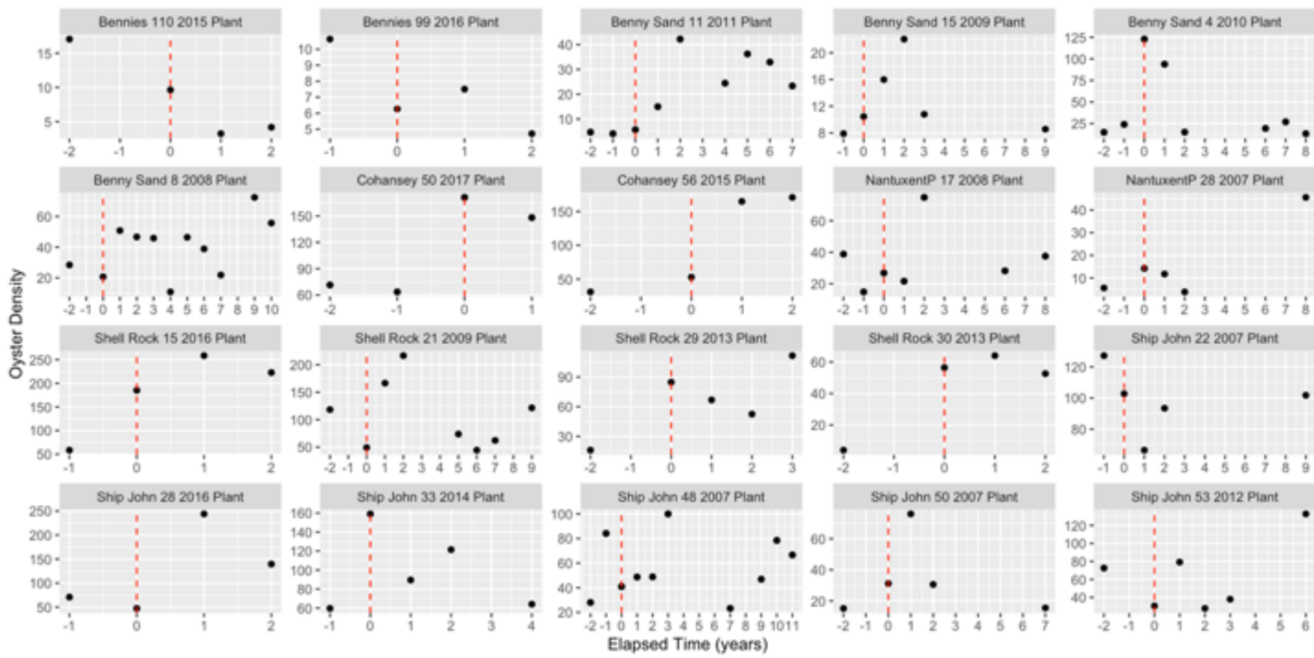


Figure 19. Grid density as a function of years before/after shell was planted for a select number of shell-planted grids. For shell-planted grids to be included in the figure, the density would have needed to be measured on the grid no less than two years before shell was planted on the grid.



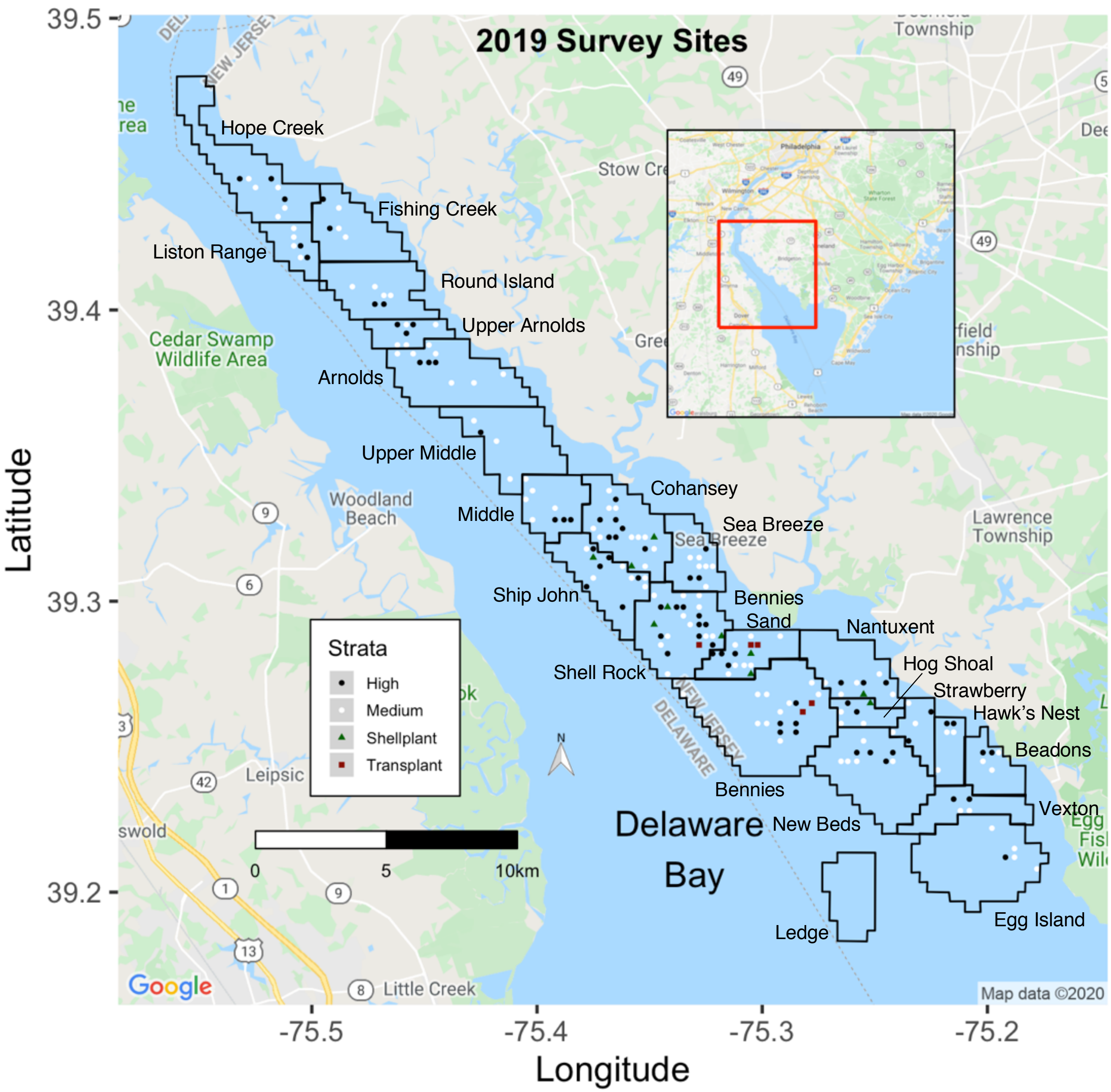


Figure 20. Map of the 2019 oyster stock assessment sample sites. Black dots are sites from the high quality stratum on each bed and white dots are sites from the medium quality stratum on each bed. Red squares indicate transplant enhancement sites and green triangles indicate shellplant enhancement sites.

Figure 21. 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.

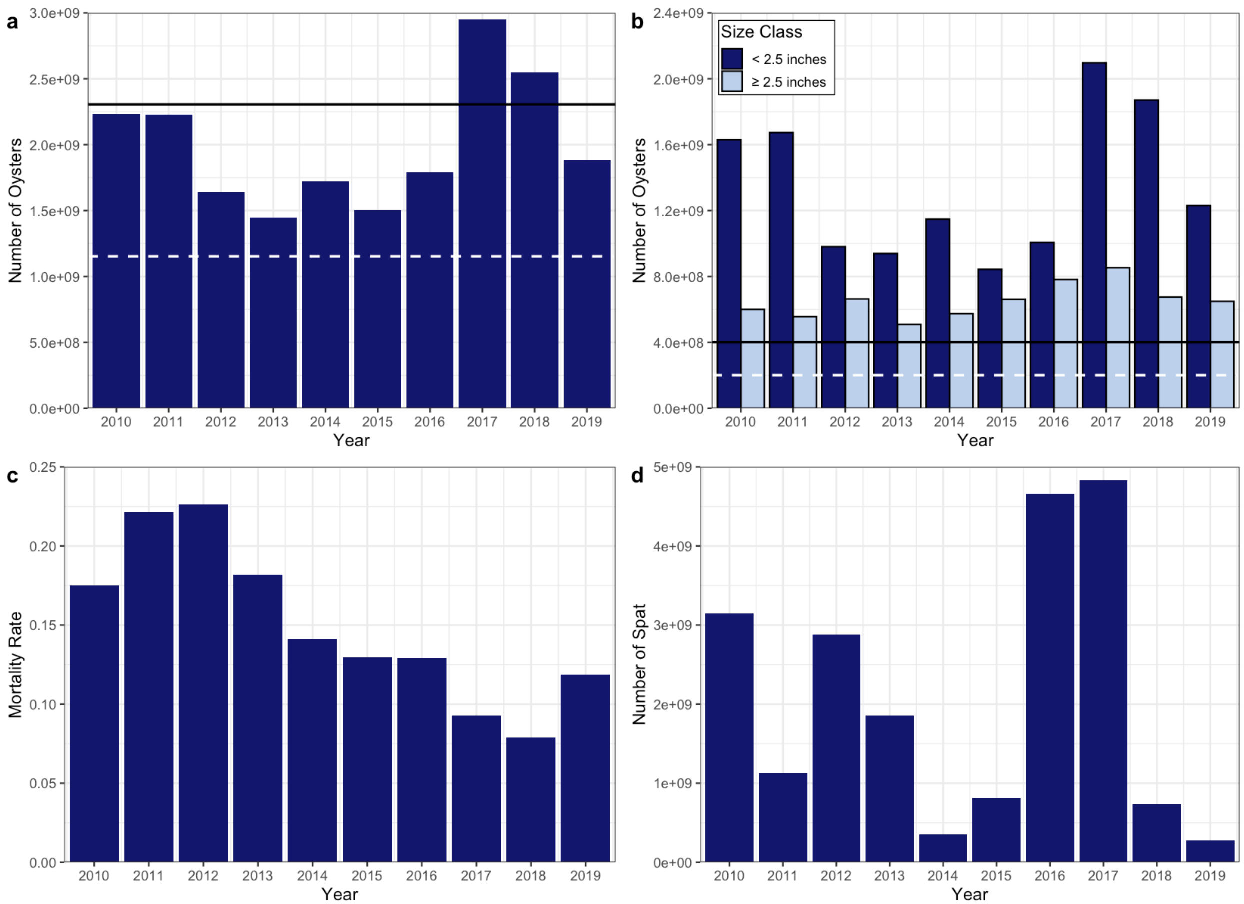


Figure 22. Position of the oyster stock 2015–2019 with respect to abundance and market abundance (≥ 2.5”) targets and thresholds, excluding the VLM. Targets and thresholds are defined in Table 9. Error bars on the 2019 values are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error.

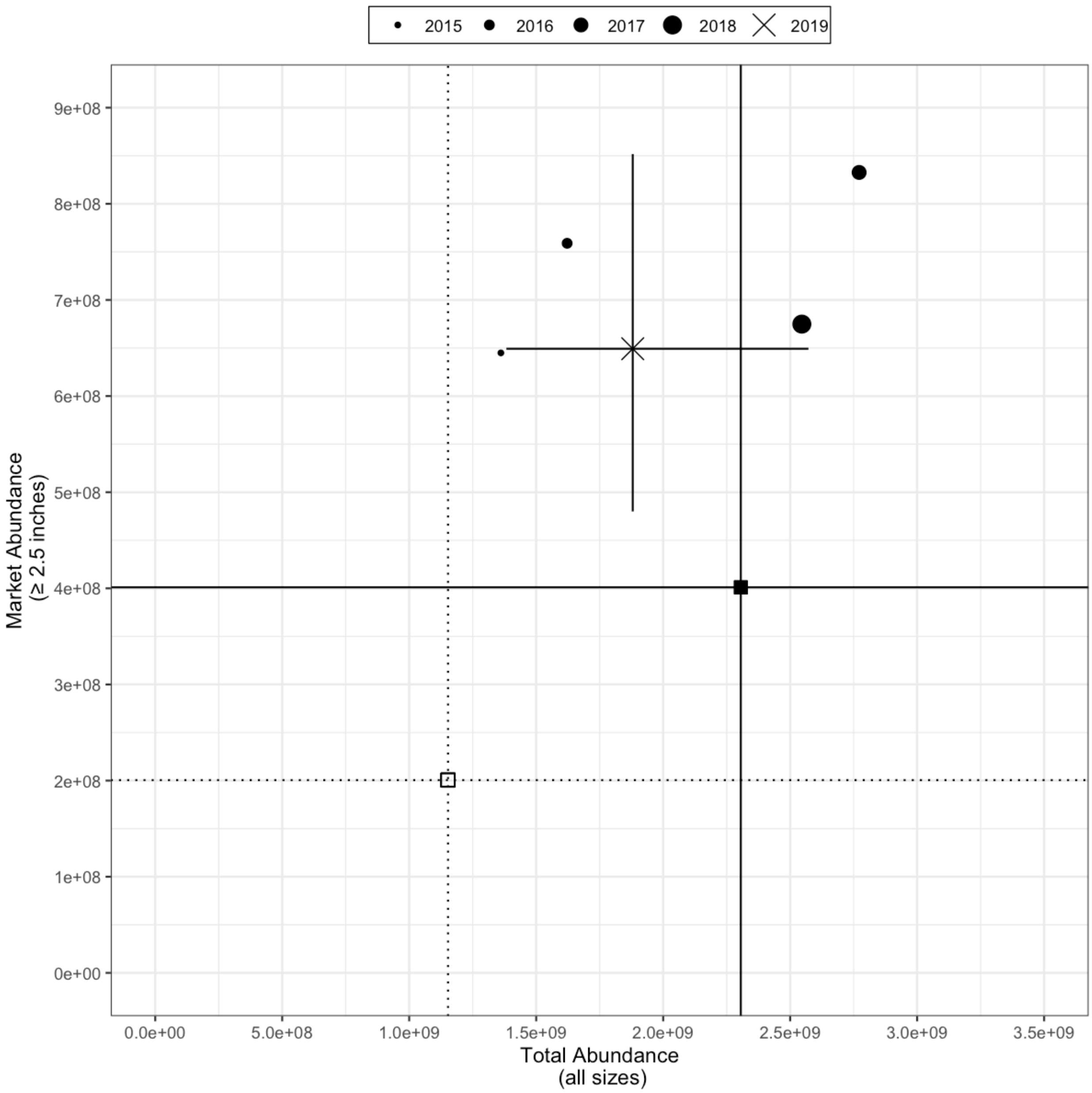


Figure 23. Ten-year time series summary for the VLM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

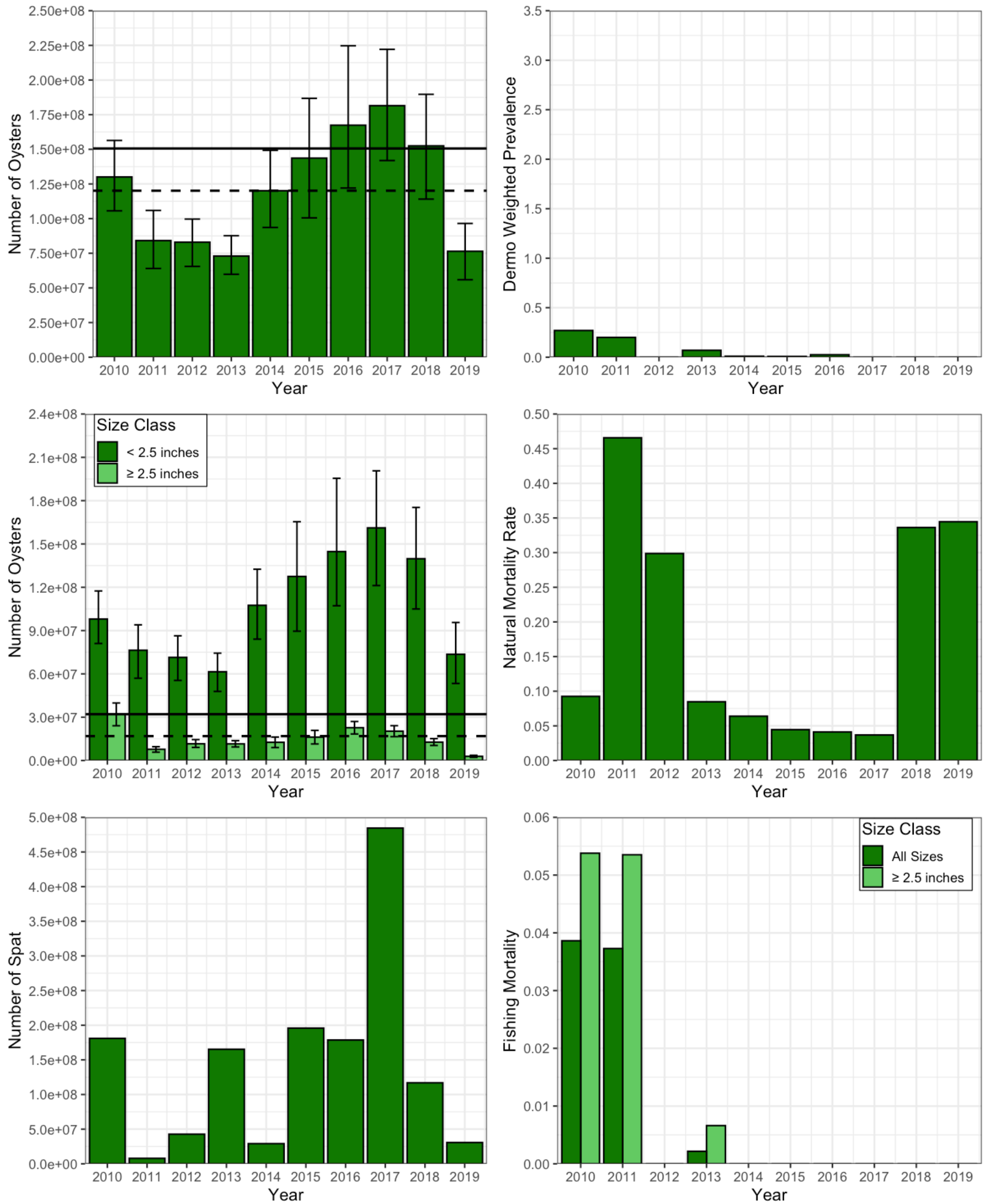


Figure 24. Ten-year time series summary for the LM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

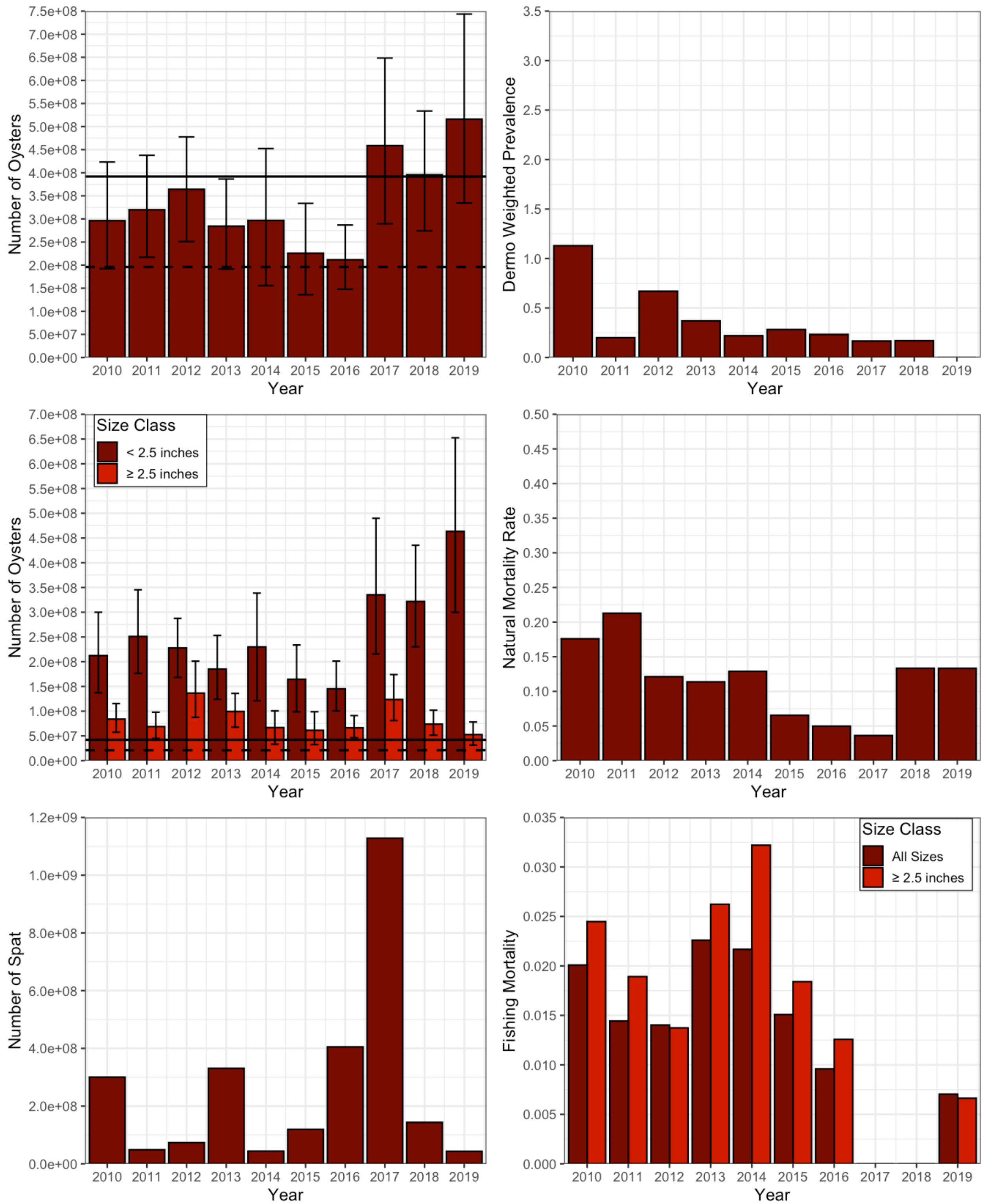


Figure 25. Ten-year time series summary for the MMT. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

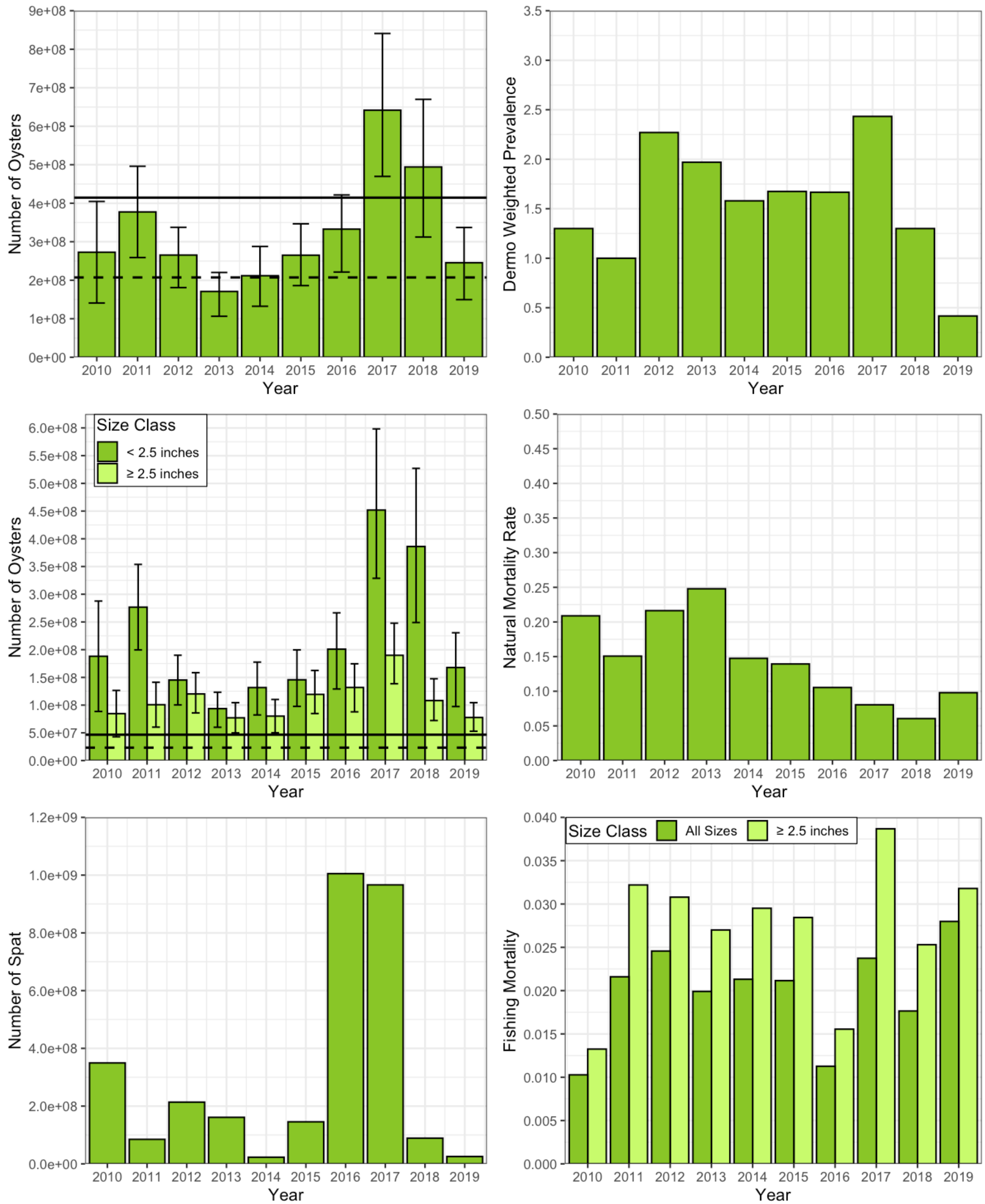


Figure 26. Ten-year time series summary for the MMM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

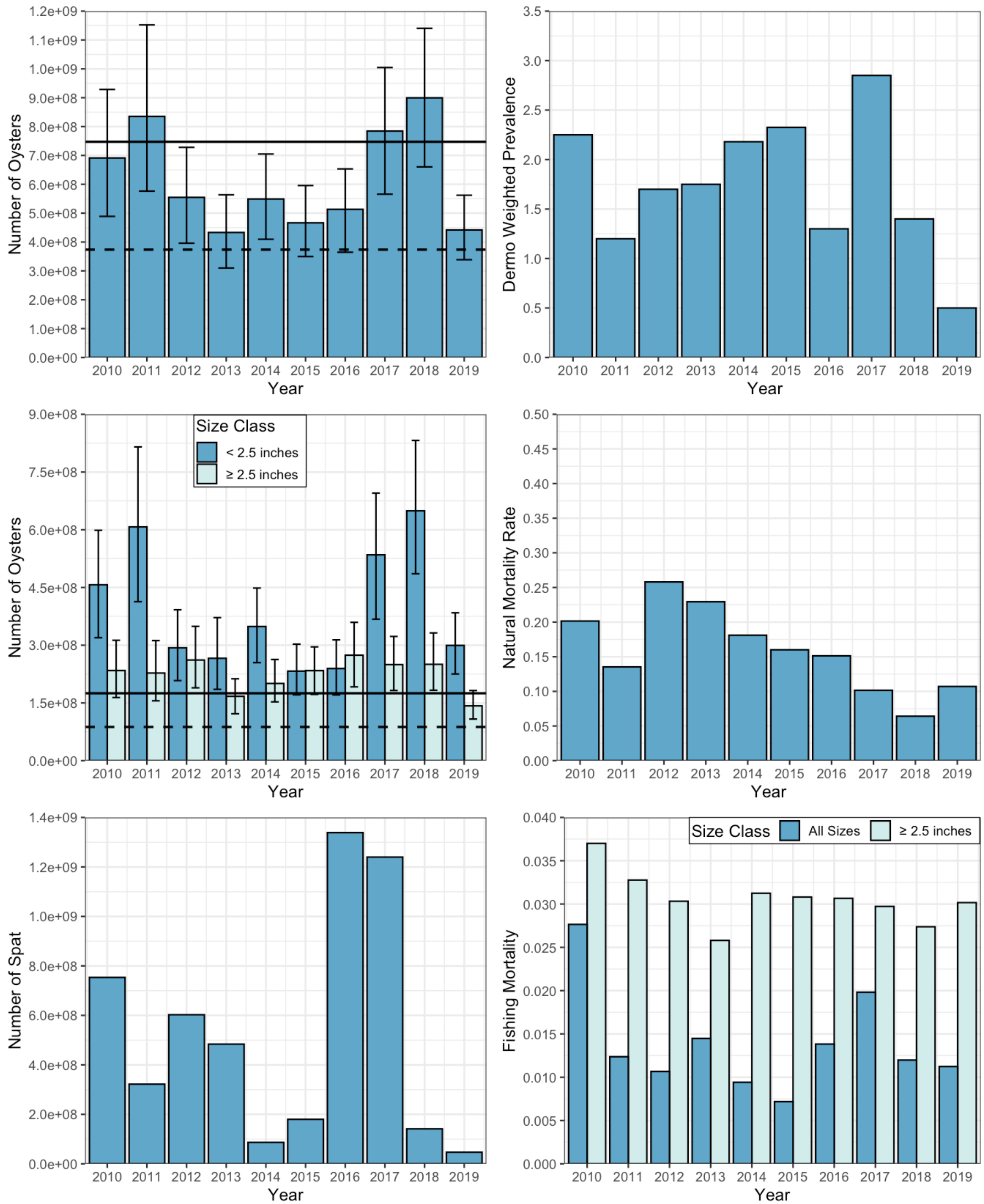


Figure 27. Ten-year time series summary for the SR. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

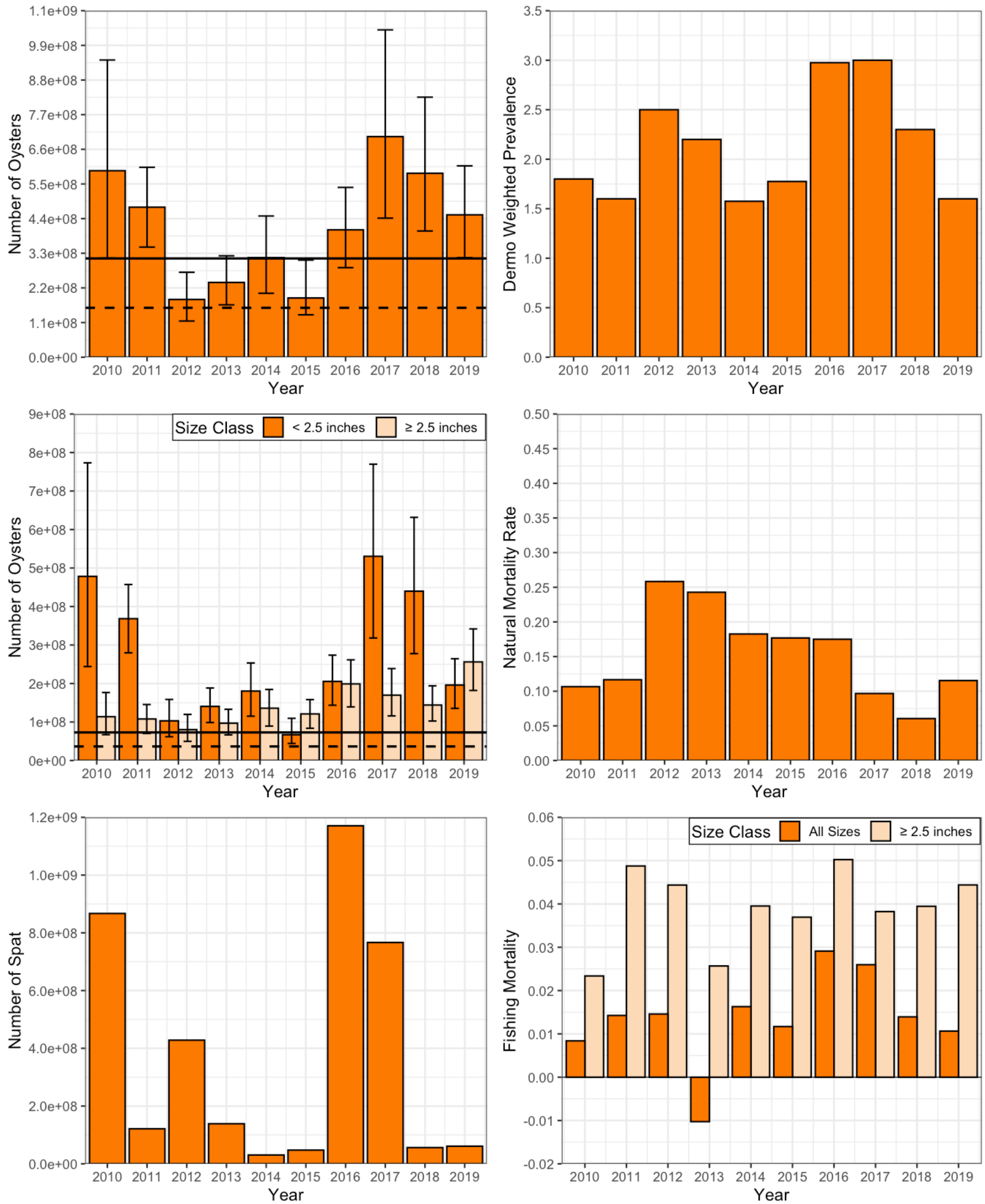


Figure 28. Ten-year time series summary for the HM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

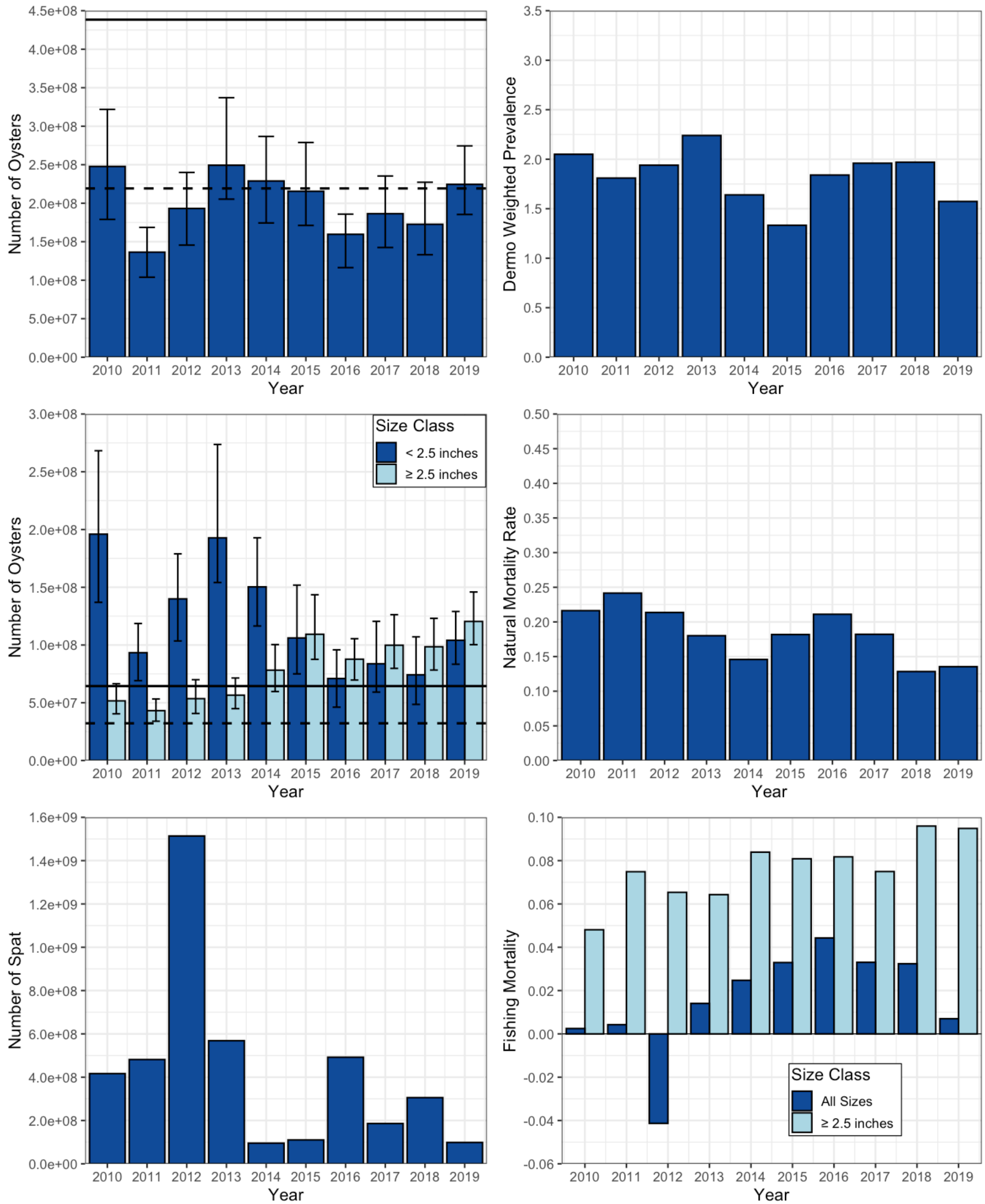


Figure 29. Position of the oyster stock 2015–2019 with respect to abundance and market abundance (≥ 2.5") targets and thresholds for each region. Targets and thresholds are defined in text. Error bars on the 2019 values are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error.

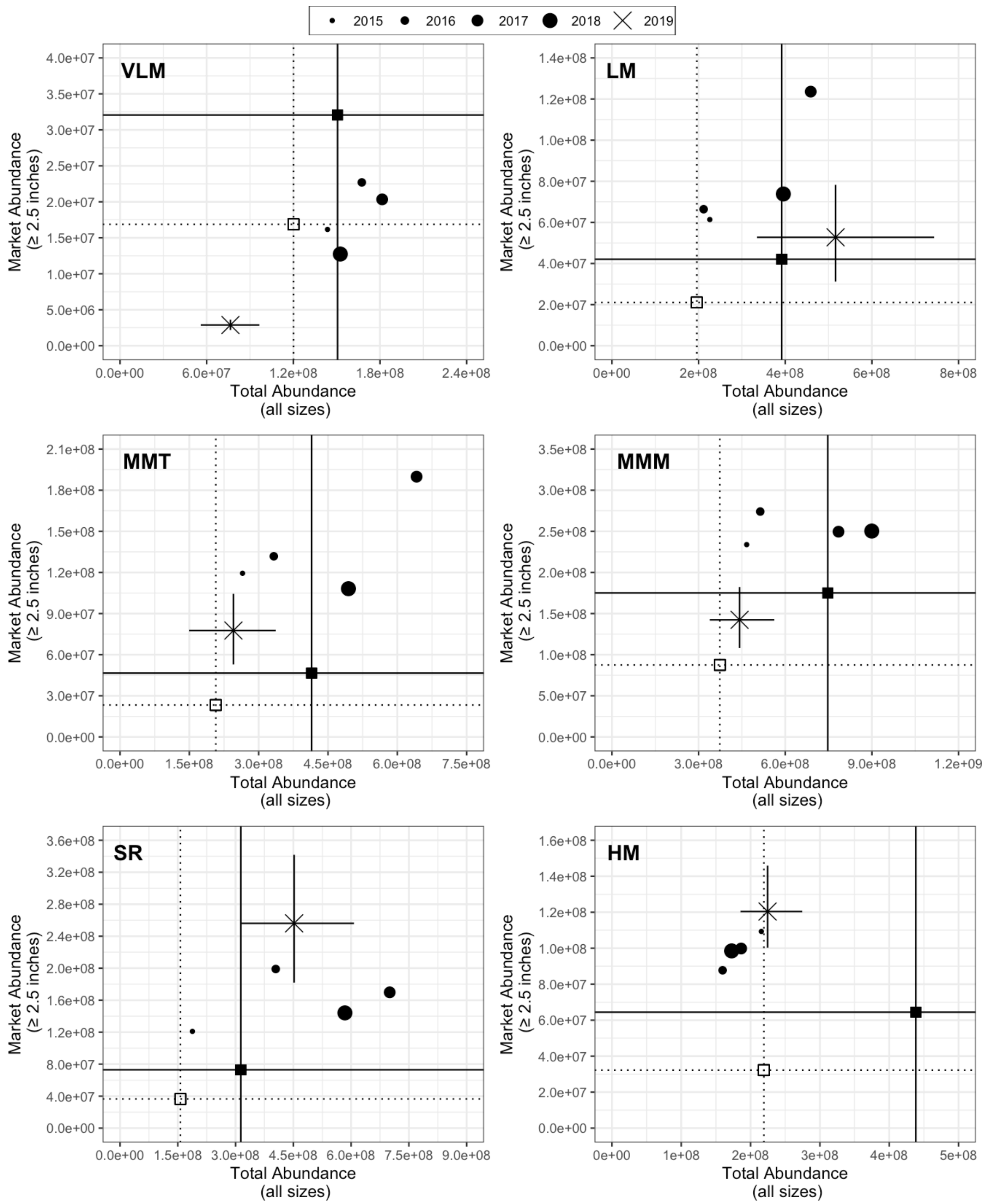
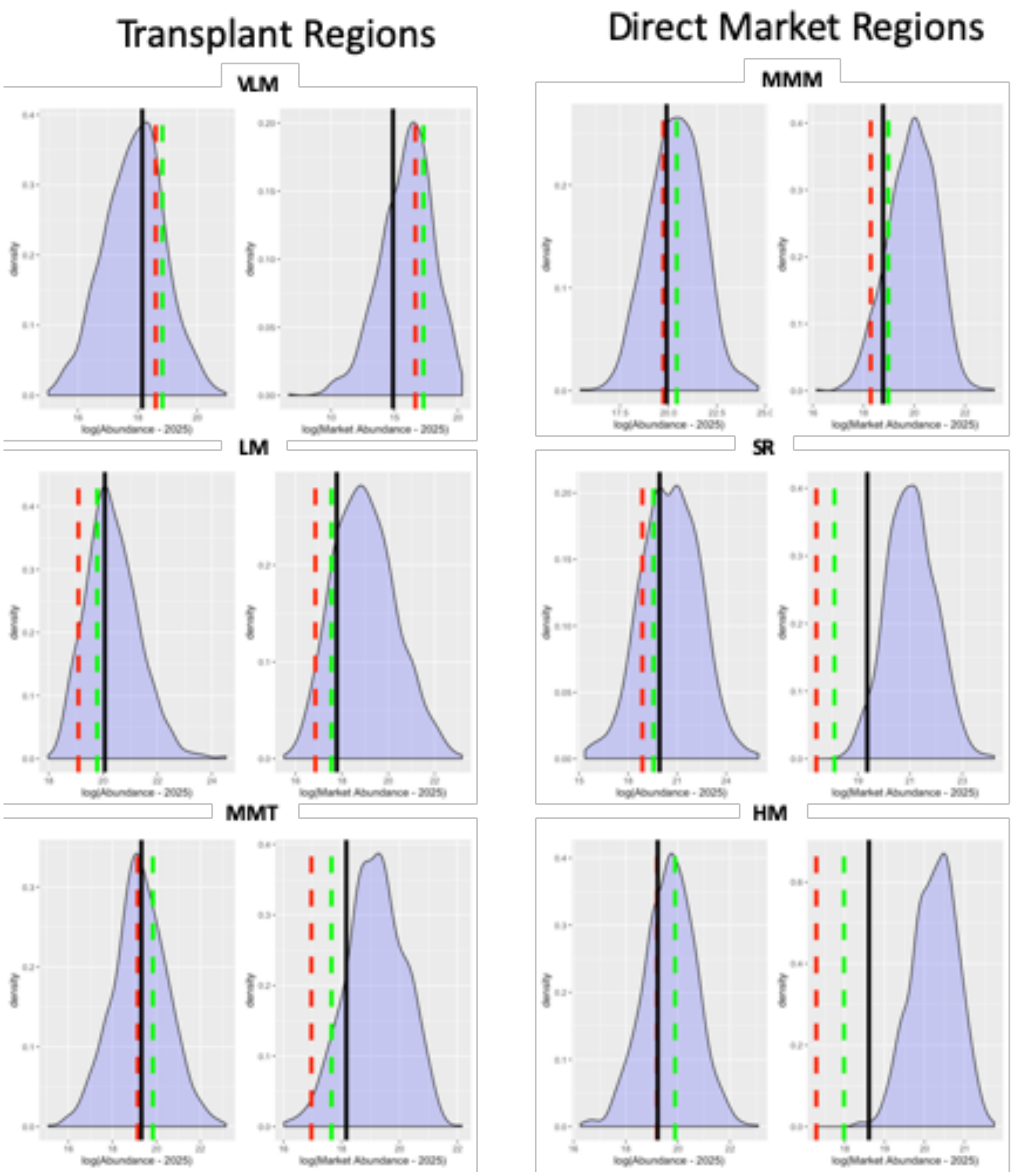


Figure 30. Population viability analysis (PVA) for each management region (VLM = Very Low Mortality; LM = Low Morality; MMT = Medium Mortality Transplant; MMM = Medium Mortality Market; SR = Shell Rock; HM = High Mortality). Distributions are projected abundance (left panels) and market abundance (right panels) for each region in 2025 based on population growth rates from the last ten years. Solid black lines are the estimates from the 2019 assessment. Biological reference points are represented by dashed red (threshold) and green (target) lines.



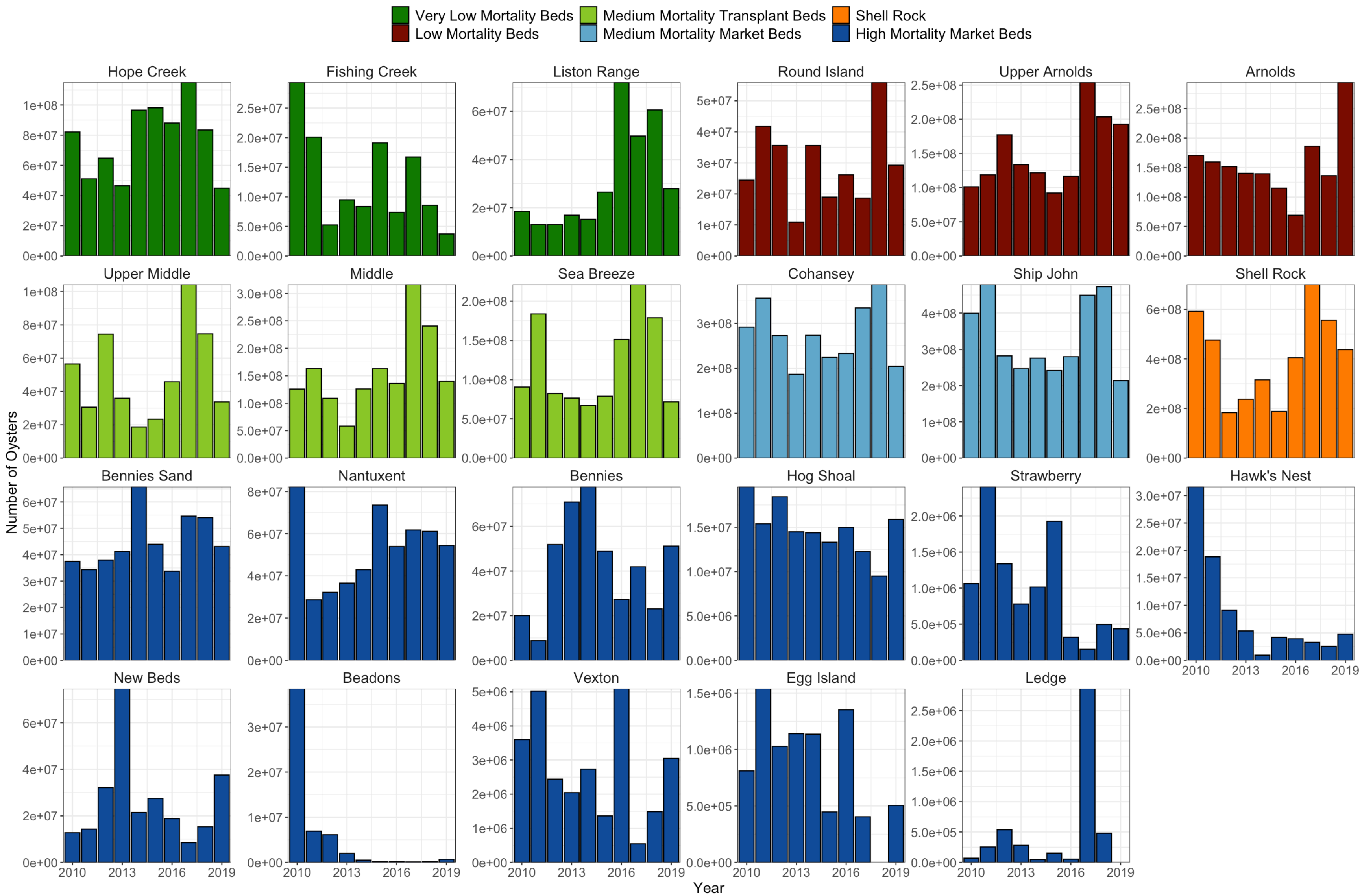
Appendix A. History of partial (P) and full (F) resurveys for all beds, grouped by region. The entire resource was gridded and stratified between 2005 and 2008. The current 10-year resurvey schedule was implemented in 2009.

Region	Bed	# Grids	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19
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												
MMT	Middle	51	P						F								
MMT	Sea Breeze	48	P							F							
MMM	Cohansey	83	P				F										F
MMM	Ship John	68	P					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								
HM	Vexton	47		F					F								
HM	Egg Island	125															
HM	Ledge	53															

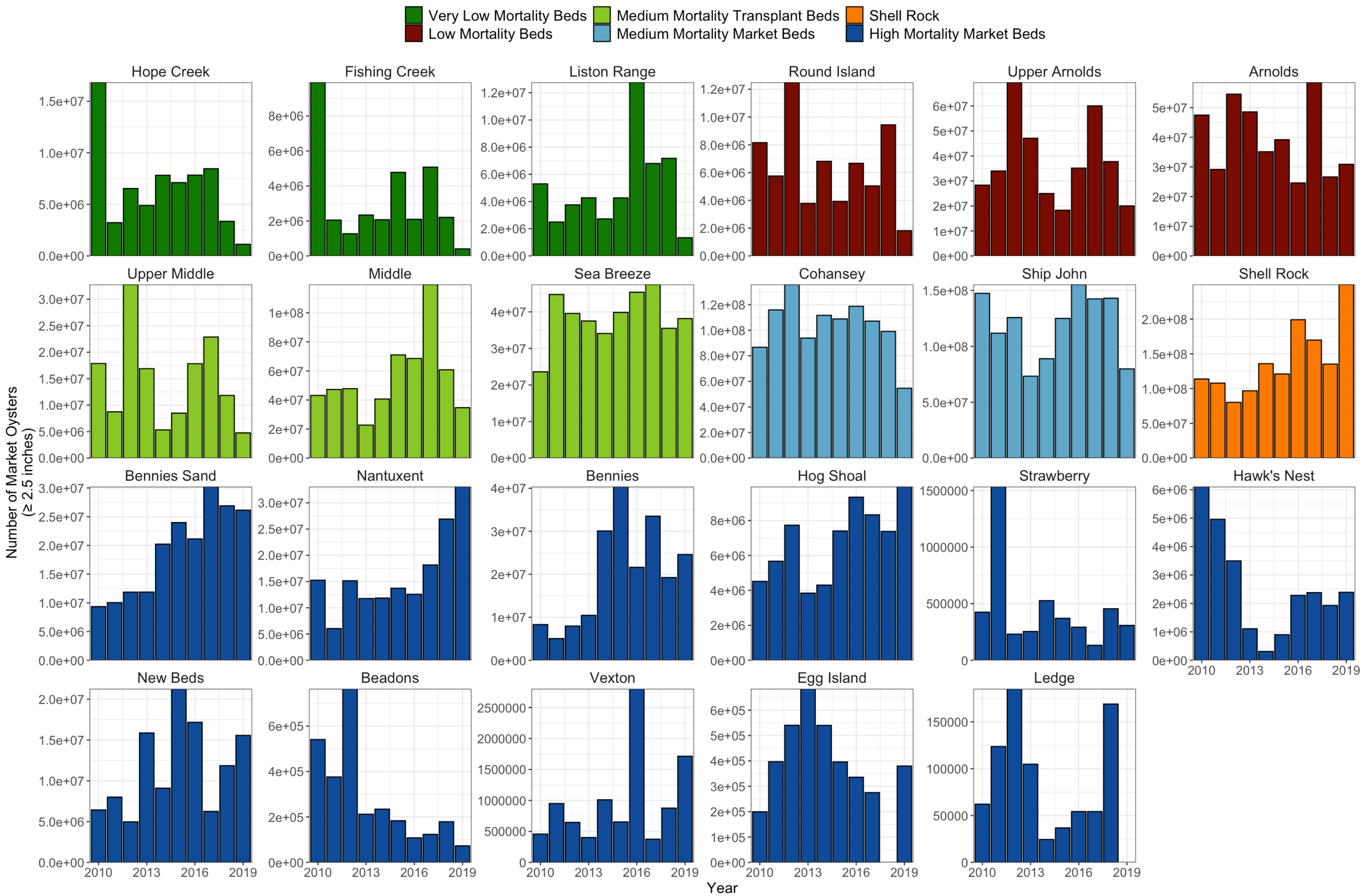
Appendix B. SARC members listed by affiliation. SAW year refers to when the February workshop was held to discuss the previous year's data. Names in parentheses indicate that the appointed member did not attend the meeting.

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

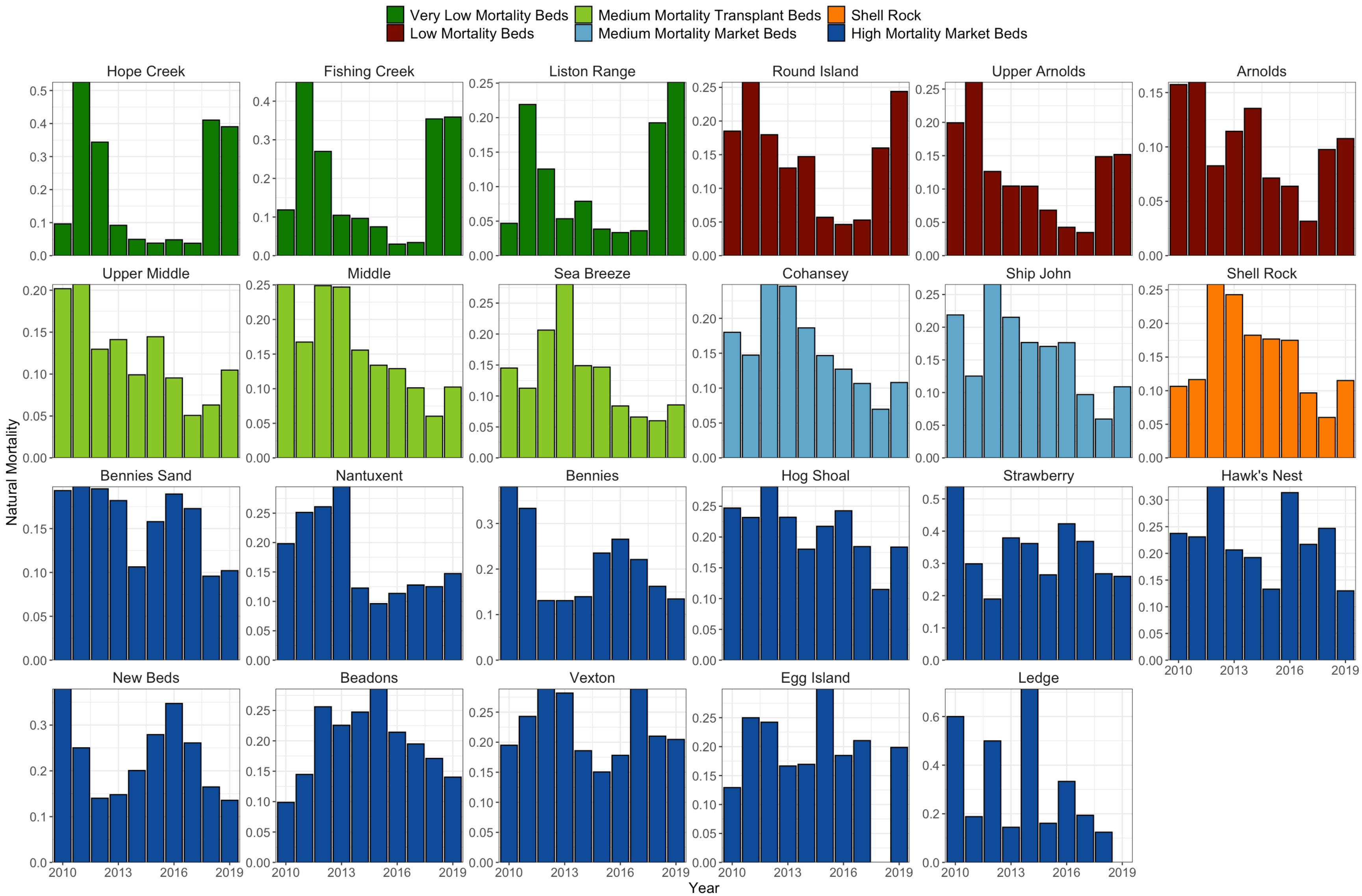
Appendix C. Bed-level oyster abundance for each region.



Appendix D. Bed-level market abundance for each region.



Appendix E. Bed-level mortality for each region.



Appendix F. Bed-level spat abundance for each region.