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Stock Assessment Workshop
New Jersey Delaware Bay Oyster Beds
(20th SAW)
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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

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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

Time Series Used in this Report

ANNUAL SURVEYS

Longterm	1953→ present	
'Dermo Era'	1990→ present	
Small boat/dredge	1953 - 1988	
Commercial boat/dredge	1989 – 1998	historic stratification (pre-2005)
Commercial boat/dredge	1999→ present	as above; survey quantified
Initial Stratification Updates	2005 – 2008	entire resource gridded; new stratifications
VLM region included	2007→ present	

OTHER ANNUAL PROGRAMS

Restratification surveys	2009→ present
Dermo monitoring	1990→ present
Port Sampling	2004→ present

HARVEST

Bay Season	Pre-surveys – 1995
Direct Market	1996→ present

REFERENCE POINTS

Biological		
Oysters All Sizes based on:	1989-2005	Targets = median; Thresholds = ½ median
Market Sizes based on:	1990-2005	Targets = median; Thresholds = ½ median
VLM based on:	2007-2016	Target = 75^{th} percentile; Threshold = 50^{th}
Exploitation Rate based on:	1996-2006	Median
Revised Exploitation Rate:	2007-2015	Median

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Appendices

Statement of Sustainability

There has been general consensus by the 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[1] 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 2018 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.

Historical Overview

The Stock

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 (Figure 1). The beds have been surveyed regularly since 1953, initially in response to historically low oyster abundance (Fegley et al. 2003). From upbay to downbay, oysters on these beds experience increasingly higher salinity that generally corresponds to higher rates of growth, predation, disease, mortality, and recruitment. The number of beds surveyed and their groupings have changed over the years but as of 2007, there are 23 surveyed beds grouped into six regions designated on the basis of relative magnitude of average oyster mortality and the current management scheme. Approximately 16,000 acres of the oyster beds are now assessed annually (Figure 2). Prior to 2007, the three beds at the upbay limit of the oyster resource (VLM) were not included in the survey, thus most of the long-term time series and all of the retrospective analyses exclude them.

The long-term time series 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 after which resistance spread through much of the stock (Ford and Bushek 2012). From 1969-1985, MSX and mortality were low and oyster abundances were

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[1] The Delaware Bay oyster fishery is not subject to the Magnuson-Stevens Act.

high. Circa-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 this relationship has not been as strong in recent years. Throughout the time series, fishing has usually taken a small fraction of the stock compared to disease (Figure 3b). Shell planting to enhance spat recruitment has been employed throughout the time series when funding is available (Figures 4a and b).

The three upbay regions; Very Low Mortality (VLM), Low Mortality (LM), and Medium Mortality Transplant (MMT) are managed as intermediate transplant regions meaning, oysters are moved (transplanted) to one or more of the three downbay, direct-market regions [Medium Mortality Market (MMM), Shell Rock (SR), and High Mortality (HM)]. The VLM, LM, and MMT became intermediate transplant regions because oysters there are generally smaller and of insufficient quality to market directly. Use of them by 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.

Shell Rock, which otherwise would qualify as a medium-mortality bed, is separated from the MMM due to its consistent high productivity. Until 2011, Sea Breeze, a medium-mortality bed, was assigned to the market, rather than the transplant, group. As a direct market bed, Sea Breeze was rarely used for harvest. Following the 14th Stock Assessment Workshop (SAW) that reported and analyzed the 2011 season, all time series data for the medium-mortality region have been reconstituted such that Sea Breeze is now included in the MMT, rather than the MMM.

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. This allowed the industry to market oysters directly off the natural beds and avoid the high mortality rates present on the more downbay leases. In the early years, the direct market harvest was based on constant market-size oyster abundance estimations (Powell et al. 2001). In 2004, a port-sampling program began to obtain fishery-dependent information on the size and number of oysters marketed, permitting the calculation of exploitation rates on spawning stock biomass as well as abundance (Powell et al. 2005). Eventually, a submarket surplus model was developed by Powell et al. (2009). Ultimately, empirically derived abundance-based exploitation rates were adopted to establish a quota system (see below). The direct market harvest is currently conducted in three regions: HM, SR, and MMM (Figure 1).

As explained above, three of the six regions are designated for Intermediate Transplant: VLM, LM, and MMT (Figure 1). Intermediate transplanting moves an allocation of oysters from the non-marketable upbay regions to the more saline, direct market regions where they quickly depurate, attain market quality, and enhance the quota in the receiving region. Transplanting and area management were instituted to make use of the whole resource and to avoid overfishing of any one region (see HSRL SAW reports 2001 to 2005).

At the 8th SAW in 2006, the SARC established target and threshold abundance reference points based on the 1989-2005 time series for each survey region. During that SAW, concern over potentially unrealistic submarket surplus' in upbay regions led to the abandonment of the original submarket surplus reference point used earlier. The 2006 SARC advised adoption of a quota system based on the evaluation of fishery exploitation by abundance for the time period 1996-2005 (later extended to 2006). It suggested that quotas be determined on a regional basis based on the median exploitation rates from 1996-2006 applied to current abundances using the 40th to 60th percentiles as general boundaries. The exploitation-based reference point system stabilized year-to-year variability in the quota that was a byproduct of the more volatile submarket surplus projection. The 2016 SARC refined this system to use the median of realized exploitation rates from 2007-2015 as the starting point for quota decision-making and allowing percentage changes in either direction from no harvest up to the 2007-2015 maximum exploitation rate depending on stock status for each region. The same process is used to establish quotas on both direct market and transplant regions except that the direct market region exploitation rates are based on market-sized (≥2.5"; 63.5mm) oysters and those for the transplant regions are based on all sizes of oysters (≥0.8"; 20mm).

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 upper regions of the oyster resource into the direct market regions generally occurs in late April or early May. The total quota is the sum of the calculated bushels resulting from the exploitation decisions for the three direct market regions (plus additional quota as a result of transplants from the transplant regions to direct market regions) allocated across the approximately 80 oyster licenses held. As discussed earlier, it is a simple abundance-based calculation. For each region, the fall survey market-size oyster abundance is multiplied by a chosen exploitation rate and divided by the average number of oysters per market bushel derived from the port-sampling program (in the Transplant regions, total oyster abundance is used, not market-size abundance). This protocol began in 2007 as a result of previous years of SARC and Oyster Industry Science Steering Committee (OISSC) recommendations and assessment evolution.

The total direct market harvest quota is divided by the number of licenses held in this closed fishery of approximately 80 licenses. 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. Consolidation benefits harvesters who no longer have 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

From 1953 through 1988, the annual oyster survey was conducted from a small boat using a small dredge and occurred throughout a number of months in the fall, winter, and spring. Over time, 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). In 1989, sampling was switched to a large traditional oyster boat, the *F/V Howard W. Sockwell,* using a 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 with samples returned to the lab for intensive processing. Through 2004, the stock survey assessed 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 that continue to alternate due to their consistent low abundance.

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.

Measurement of survey swept areas and experiments to determine gear efficiency began in 1998 allowing survey results to be quantified per square meter (Powell et al. 2002, 2007). Results of dredge efficiency experiments performed between 1998 and 2003 indicated that the oyster beds could be divided into two groups; upbay and downbay with Shell Rock in the downbay group. The dredge captured oysters, boxes, and cultch more efficiently on the downbay beds than on those upbay. Catchability coefficients[1] calculated from these experiments were applied to survey dredge hauls to correct for dredge efficiency thus accounting for what the dredge leaves behind for more accurate density estimates, eg. oysters per m^2 on the bay bottom. Additional dredge efficiency data was collected in 2013 that led to changes in the way dredge efficiency is now applied in the stock assessment (Ashton-Alcox et al. 2016). The changes include: 1) the determination that temporal variability has not been a factor in dredge efficiency, allowing averaged catchability coefficients to be applied by groups across the entire time series; and 2) the refinement of the spatial pattern in dredge efficiency resulting in Shell Rock moving to the upbay catchability coefficient group and the creation of a third group including the VLM plus Round Island, a bed in the LM region (Table 1). The entire time series was reconstituted with these changes as of the 18th SAW in 2016.

In 2005 by request of the 6th SARC, the survey time series from 1953 to 1997 was retrospectively quantitated. 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 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. Understanding of 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. Accordingly, the quantitative time-series estimates are considered the best for 1953 to 1997.

Prior to 2005, each bed was divided into three strata based on oyster abundances. On each bed, grids with 'commercial' abundances of oysters ≥ 75% of the time were called 'high' (or 'test'); grids with marginal or highly variable 'commercial' densities of oysters 25-75% of the time were called 'medium' (or 'high'); grids with abundances well below commercial

[1] The catchability coefficient (q) as defined in Powell et al. (2002) is the reciprocal of dredge efficiency *e*: q =*1/e*.
[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)

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 (Appendix B). 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 (see Stratification and Bed Resurveys). A rotating schedule restratifies each bed approximately once per decade (Table 2, Appendix B). Analysis of many survey simulations suggested that a random survey based on High and Medium quality strata is sufficient (Kraeuter et al. 2006).

The SARC and SAW

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 3). 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 A lists SARC participants since the first SAW in 1999. The SAW is held over 2-3 days in the first half of February each year at HSRL following the Oct-Nov. stock 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 indicators, spat settlement success (recruitment potential for the following year), and trends in oyster disease (specifically Dermo) which has been the leading cause of oyster mortality since about 1990, far outweighing fishing mortality. Control rules (management guidelines) that had been implicitly used at every SAW were articulated at the 18th SAW in 2016 (Table 4a). The 2018 SARC approved amendments to Control Rule 6 as described in Table 4b.

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 NJDEP acceptance and also include those made about harvest dates and area management schedules.

Stock Assessment Design

Sampling Methodology

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 6) have been surveyed yearly since 1953 using a stratified random sampling method. 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. Each grid on a bed is assigned to a stratum (Low, Medium, or High quality) based on its relative density of oysters. A subset of grids from the High and Medium quality strata on each bed is randomly selected each year for the survey (Egg Island and Ledge are sampled in alternate years). Grids that received 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. 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[1].

Each bushel sample is processed in the laboratory to quantify the following: volume of live oysters, boxes, cultch (normal and blackened from burial), and debris; number of spat[2], older oysters, and boxes per composite bushel; sizes of spat, older oysters, and boxes from the composite bushel; condition index; and the intensity of Dermo and MSX infections.

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

[2] Beginning in 2003, oyster spat are defined based on size (< 20 mm, the average first-season size on the Delaware Bay natural oyster beds). Prior to 2003, oysters were classified as spat based on morphology.

Stratification and Bed Resurveys

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. Initial analyses of restratification surveys (resurveys) showed that this stratum could be deleted from the fall stock assessment survey to focus on the grids that support 98% of the stock on each bed. The remaining grids were input into a Monte Carlo model in which they were subsampled repeatedly without replacement. The mean abundance estimated from the subsample was compared to the mean abundance obtained from the average of all grids. Analysis of many simulations suggested that a random survey based on two further strata would suffice. These are defined by ordering the remaining grids by increasing abundance. 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. Transplant grids are sampled only in the year they receive transplant and then are reassigned to their original stratum. At the 19th SAW (2017), this was increased to two years. Shellplant grids are sampled for three years after which they return to their original stratum.

The Monte Carlo model is also used after each resurvey to determine how many grids per High and Medium quality stratum must be sampled for a statistically adequate assessment of abundance on the resurveyed bed. Only two beds remain unsurveyed: Ledge and Egg Island. To minimize survey bias from changes in grid quality over time, a 10-year rotating spring resurvey schedule began in 2009. The basic premise of the schedule is: 1) to resurvey beds at least every decade and 2) when multiple beds are scheduled, they are in separate regions in case of differential change throughout the resource (Table 2, Appendix B). The basic schedule may sometimes be revised as was the case for Shell Rock in 2016 when multiple enhancement activities had occurred since the previous resurvey changing oyster distribution (Ashton-Alcox et al. 2017). Round Island in the LM and Nantuxent in the HM are scheduled for resurvey in Spring 2018.

Gear Efficiency Corrections

Densities of oysters, boxes, and cultch from each survey sample are calculated from the area swept by the dredge, the total haul from which the sample was taken, and the appropriate catchability coefficients (q) to correct for dredge efficiency[1]. Work from 1999 to 2003 to establish these coefficients for the oyster beds in Delaware Bay is described in Powell et al. (2002, 2007). Briefly, differences between bottom samples from parallel transects of measured tows by a commercial dredge from the *F/V Howard W. Sockwell* and quadrat samples collected by divers presumed to be 100% efficient were calculated. Analyses of the earliest data revealed

[1] The catchability coefficient (q) as defined in Powell et al. (2002) is the reciprocal of dredge efficiency *e*: q =*1/e*.

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 survey time series (Table 3 in Ashton-Alcox et al. 2016).

In September 2013, dredge efficiency experiments were again conducted using the *F/V Howard W. Sockwell* and a commercial dredge but instead of divers for the 100% efficiency numbers, patent tongs on the *R/V Baylor* were used (Ashton-Alcox et al. 2014). Parallel transects were sampled to compare numbers of oysters caught in measured tows versus those collected by the tongs. Spatial and temporal analyses compared the 2013 patent tong experiments to the 1999, 2000, and 2003 dredge-diver experiments (Ashton-Alcox et al. 2015). 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 (Ashton-Alcox et al. 2016). The spatial analyses showed that the original Upbay dredge efficiency bed group should be further divided for a total of three catchability coefficient groups (Table 1). This result is due to the 2013 dredge-tong comparisons on Hope Creek and Round Island. These beds are farther upbay than Arnolds, the previous most upbay bed used for gear efficiency experiments. The spatial analyses also indicated that Shell Rock should be included with the Upbay group of beds rather than the Downbay group. The 2016 SARC advised adoption of these new bed groupings for gear efficiency applications.

The entire time-series was reconstructed for the 2016 SARC using a single set of catchability coefficients as detailed above.[1] This change resulted in an abundance shift along the time series equivalent to the shift from previously-calculated to newly-calculated catchability coefficients. Similarly, previously-calculated exploitation rates shifted equivalently as did target and threshold biological reference points for each region. Because of this, relationships such as stock abundance relative to reference points do not change but the calculated level of exploitation on the stock in any region does. This is because bushels removed in any year are fixed but the fraction removed changes when abundance estimates change with the application of different catchability coefficients.

Analytical Approach

To obtain the annual estimates of abundance for each region, grids from the high and medium quality strata are chosen randomly from each bed in the region and sampled to generate a relative estimate of the oysters per m^2 on each grid. Catchability coefficients estimated by

[1] All estimates throughout the survey time series were updated to reflect the updates in catchability coefficients as of the Fall 2015 assessment survey. Data for all years in this document will follow comparable trends to that in reports earlier than the 2016 report but the scales will not match.

dredge efficiency experiments (see Gear Efficiency Corrections) 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 of oysters 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, underestimating abundance by approximately 2%.

Throughout this report, 'oyster' refers to individuals ≥ 20 mm (0.8") in longest dimension while 'spat' refers to those < 20 mm. The 20 mm cutoff was chosen as the average spat size through the estuarine gradient of beds in the Delaware Bay. The result of this is that in upbay regions, e.g. Low Mortality, the < 20 mm size class may include oysters that are older than their first season while in the High Mortality region (HM), oysters in their first season may be > 35 mm (1.4"). Analyses have shown that using the 20mm spat size cutoff as opposed to physical morphology for region-specific spat sizes did not yield a statistically significant difference in spat vs older oyster abundance estimates for any of the regions (Ashton-Alcox et al, 2017). Prior to 2003, spat were categorized by shell morphology rather than size. Spat abundance is not included in the estimates of oyster abundance but is shown separately. Oysters ≥ 35 mm are considered to be adults. Calculations of spawning stock biomass (SSB) are based on the ≥ 35 mm size class and were derived using bed-specific and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size oysters are sometimes divided into individuals ≥ 76 mm (3") and individuals ≥ 63.5 mm (2.5") but < 76 mm (3"). These two size categories are based on a knife-edge selection of oysters for market by the fishery. Routine observations since dockside monitoring began in 2004 suggest that nearly all harvested oysters are ≥ 63.5 mm (2.5"). Therefore, in this report, market-size oysters are considered to be those ≥ 63.5 mm (2.5").

There are two potential sources of error associated with the annual abundance estimates for each region. First, there is variability in oyster density within each stratum, the survey error. Second, there 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 bed and each corrected for dredge efficiency by a randomly chosen value from all efficiency estimates available within a bed's dredge efficiency group (Powell et al. 2008a). Confidence-level values are obtained by sorting the simulated surveys on the number of all oysters and also on oysters ≥ 2.5". Dredge efficiency is less certain for oysters < 2.5" so this approach includes uncertainty that cannot be evaluated. Smaller oysters however, make up much of the population and sorting by the larger size class sometimes fails to order the surveys in hierarchical position by total abundance. Prior to the 2016 SAW, the dredge efficiency choices included those calculated for three oyster size classes (< 2.5", 2.5-3", and >3"). Because of the tendency of oysters of different sizes to clump together, this system of choice resulted in biases such that the survey point estimate did not usually fall near the 50th percentile of the simulated surveys (eg. Ashton-Alcox et al. 2015, Figure 27). The 2016 SARC agreed that it was appropriate to use the 'all-size' suite of oyster dredge efficiency estimates from which the random pulls are drawn. This group of catchability coefficients was updated at the 2016 SAW and now incorporates 69 estimates generated from dredge efficiency experiments conducted from 1999-2013. Error in this report is expressed as the 10th and 90th percentiles of the simulated distributions or as confidence envelopes (eg. Figures 28 and 29 in this report).

2017 Spring Resurvey

In Spring 2017, two beds in separate regions were restratified after all grids were sampled: Hope Creek (VLM) with 97 grids and Hawk's Nest (HM) with 28 grids. Hope Creek was partially surveyed in September 2007 with the rest of the grids surveyed in spring 2018 (Table 2, Appendix B). The 2017 resurvey revealed that most grids in Hope Creek remain in the low-quality stratum with ~83% of those having no oysters or cultch (Figure 7a). Of the 33 grids in the high and medium quality strata, almost ¼ of them are high-quality where densities ranged from 46 - 84 oysters per m^2. Densities on the medium quality grids of Hope Creek during the spring resurvey ranged from 6 - 45 oysters per m^2. The number of grids in both the high and medium quality strata increased after the resurvey with five grids moving up from the low to the medium quality stratum. The 2017 Hope Creek resurvey map indicates a spread of the resource into previously low quality grids (Figure 7b). A comparison of grid densities ranked as percentiles for Hope Creek shows that 2017 densities on all grids were consistently greater than those from the initial 2008 resurvey aside from the highest density grids (Figure 7c). This verifies that the redistribution of grids in the strata indicate a spreading of the oyster stock on Hope Creek.

Hawk's Nest was initially resurveyed in 2006 (Appendix B). The 2017 Hawk's Nest resurvey resulted in oyster densities ranging from 8 – 12 oysters per m^2 on the high quality stratum and 0.3 – 6.5 oysters per m^{2}on the medium quality stratum (Figure 8a). Unlike the 2017 picture on Hope Creek, Hawk's Nest oyster distribution has decreased over the interim between resurveys with fewer grids in both its high (4 grids to 3) and medium (15 grids to 8) quality strata (Figure 8b). Unlike on Hope Creek, Hawk's Nest oyster densities were consistently lower in 2017 than in 2006 across a series of percentiles (Figure 8c).

2017 Fall Assessment Survey

The fall survey is constructed by randomly choosing a designated number of grids from each medium and high quality stratum on each bed plus any transplant and shellplant grids as described above for the enhanced stratum (Table 5). Sampling for the 2017 assessment survey was conducted October 20th, 26th, 27th, and November 2nd using the oyster dredge boat *F/V Howard W. Sockwell* with Lemmy Robbins as captain. Total sampling effort in 2017 was 170 grids (Figure 9). The enhanced stratum consisted of 12 selectively sampled grids. These included 2 grids that received intermediate transplants in 2016 and 1 in 2017 and 9 grids that received shellplants over the last three years (Table 5). Prior to 2017, intermediate transplant grids reverted back to their original stratum after one year but the 2017 SARC recommended that placement in the enhanced stratum for transplant grids be increased to two years. Shellplant grids revert back after 3 years. These grids are then subject to random choice within strata for following stock assessment surveys. Any effects of the transplant or shellplant on oyster density in a grid get assessed in the next resurvey of that bed.

Status of the Stock in 2017[1]

Whole stock 2017

The total acreage of the surveyed oyster beds includes the area of the high, medium, and enhanced strata on each bed; the area of the low quality stratum is not included (Figure 6). The area can change somewhat each year due to strata reassignments of resurveyed grids and the inclusion of previously low quality grids in the enhanced stratum. Each grid is approximately 25 acres. In 2017, the area of the beds was 15,999 acres (64,746,653 m^2) (Figure 2). Whole stock oyster abundance in 2017 was 2.95 billion oysters at an average density of 56 oysters per m^2, well over the 2016 average of 37 oysters per m^2. This is the highest total abundance since the VLM was incorporated into the assessment survey in 2007 (Figure 10a). Not including the VLM, oyster abundance in 2017 was at the 73rd percentile of the 1990-2017 time series (Table 6) and was the highest it has been since 2001. For comparison, the 2016 abundance was at the 35th percentile. Abundances of both small (≤2.5”) and market-size oysters (>2.5”) were at their highest since the VLM was first included in the stock (Figure 10b). Of the 2017 abundance, 853 million or 29% were market-size. This percentage is much less than that of 2016 (44%) and is due to increased numbers of small oysters in 2017 compared to markets. Excluding the VLM, 2017 market-size abundance is at its highest in the 28-year time series, the 100th percentile (Table 6). This size group has been at or above the median value since the current fishery management scheme went into effect ca. 2007 (Figure 11a). In recent years, market-size oyster abundance has been helped by higher survival. Natural mortality has been decreasing since 2012 and has been generally lower since 2000. Not including the VLM, the range of mortality from 1990 to 1999 was 9-33% (23% average) which has since narrowed to 10-22% averaging 17% (Figure 11b). The 2017 box-count mortality is the lowest it has been since 1990 and is at the 5th percentile of the Dermo era time series (Table 6). Mortality rates have steadily decreased since 2012 and in 2017, box-count mortality was 9.3%, the lowest level since the VLM was included (Figure 10c). Adding spat recruitment to the picture makes it even brighter. The increased

[1] All estimates of stock throughout the time series were updated in 2016 to reflect the update of catchability coefficients (see Gear Efficiency Applications). Data, figures, and tables prior to the 2016 report will not match those of earlier reports.

abundance of small oysters in 2017 indicates the survival of the high 2016 set; and the set for 2017 was even higher Figure 10d). Not including the VLM, spat recruitment for 2017 was at the 87th percentile for 1990-2017 (Table 6). As a whole, the 2017 picture for the oyster population is very positive.

Stock by regions[1234]

As initially described in this report (Historical Overview), the Delaware Bay, NJ oyster stock is divided into six regions with the three uppermost regions managed as transplant sources for the lower regions from which the direct market harvest comes (Figure 1). The transplant regions (VLM, LM, MMT) all have similar acreage while the direct market regions vary from the small SR to the HM that accounts for nearly half of all oyster acreage (Figure 12a). Regional acreage does not reflect the distribution of the oyster stock. In 2017 for example, the large HM contained about 6% of the total stock while the SR and MMM that together make up approximately 25% of the total oyster acreage, made up 50% of the oyster abundance (Figure 12b). Most of the total and market-size oyster abundance in 2017 is contained in the central regions (SR, MMM, MMT; Figure 12b,c) as it has been in most years since 1990. The HM contained a very small fraction of the overall spat abundance in 2017 and also had the highest fraction of the overall mortality (Figure 12d,e).

Very Low Mortality region (VLM)—*Figure 13, Table 6)*

The VLM is the uppermost extent of the Delaware Bay, NJ oyster resource and its time series began in 2007 (Figure 6). In 2017 it had 1,547 acres, approximately 100 more than in 2016 reflecting the restratification of its largest bed, Hope Creek (Figure 2). The VLM contained 182 million oysters in 2017 comprising 6% of the total stock (Figure 12b). This is the highest assessed abundance for the VLM and the fourth consecutive year of increases. The average oyster density over all grids sampled on the VLM in the Fall 2017 survey (Figure 9) was 34 per m^2, close to that of the last two years[3]. The range of oyster densities in sampled grids was 0.2-103 oysters per m^2. The increase in abundance can be seen in the steady rise in the numbers of oysters < 2.5" but is not as obvious in the market-size oysters which were at the 50th percentile of market-size abundance for the 2007-2017 time series. It is assumed that this region has a very slow growth rate compared to regions further downbay so it likely takes much longer for a spat set to translate into market oysters. This region has been rebuilding with good spat sets and increased survival since the late 2011 freshwater event that caused approximately 45% mortality but also a sharp decrease in Dermo disease. No Dermo was found in the VLM in 2017 and mortality rates continue to decrease and were at the 14th percentile in 2017. Adding to the

[1] Extended percentile tables: Appendix C

[2] Regional Comparisons 1990-2017: Appendix D

[3] 2017 sampled grid densities (per m^2) for oyster, spat, cultch: Appendix E

[4] SSB by region, 1990-2017, overlaid on small and large oyster abundance: Appendix F

favorable outlook, the 2017 spat set was the highest in the VLM time series. The VLM has only been specifically used for transplants three times and not since early 2011.[1]

Low Mortality region (LM) —*Figure 14, Table 6*

In 2017, the LM covered 1,679 acres and contained 459 million oysters comprising 16% of the total stock (Figures 2 and 12b). After being closed to transplanting in 2017 due to the decreasing abundance of oysters, the LM has rebounded with a doubling in abundance that shows up in oysters of both size groups. The LM abundance in 2017 was the highest since 2007, a level that put it in the 73rd percentile for the 1990-2017 time series. The average density on grids sampled in 2017 on the LM was 81 oysters per m^2, nearly twice that of 2016 with a range from 0.7 - 376 oysters per m^2.[2] The increase in total abundance on the LM likely resulted from survival of the increasingly high spat sets and older oysters as both Dermo and mortality rates continued their pattern of decrease over the last few years. Dermo weighted prevalence continued its sharp decline since 2012 and is far below the 1.5 level that can cause mortality. Using percentiles to illustrate: spat abundance was at the 100th percentile since 1990 while market-size oyster abundance was at the 89th percentile. Meanwhile, Dermo was at the 17th percentile and mortality was the lowest it has been since 1990, replacing 2016's previous 0 percentile. Transplant exploitation has decreased since 2014 on the LM and the SARC chose not to do any transplants from the LM in 2017. As predicted in 2016, these favorable conditions allowed for a substantial increase in oyster abundance in 2017. The same favorable factors exist in 2017 so that, barring unforeseen natural disasters, this should allow for an increase in oyster abundance in 2018.

Medium Mortality Transplant region (MMT)—*Figure 15, Table 6*

The MMT is comprised of three beds, one of which (Sea Breeze) is separated from the other two by the MMM (Figure 6). At 1,576 acres, the area of the MMT is similar to that of the LM (Figure 2). Like abundance in the LM, oyster abundance in the MMT approximately doubled from 2016 to 2017 to 642 million or 22% of the stock (Figure 12b). This was likely due to the high 2016 spat set and the continued decrease in mortality. Abundance on the MMT has steadily risen since 2013 to its highest point since 2000. It was at the 87th percentile in 2017. Survival of both small and larger oysters contributed to the abundance increase. In 2017, market-size oyster abundance was at its highest point since 1990. Oyster density on the sampled grids of the MMT averaged 110 per m^2 in 2017, far above the 2016 average of 59, and ranged from 3-189 per m^2.[2] The 2017 spat set was at the 91st percentile, close to that of 2016 when recruitment was the highest since 1998. Dermo remains at levels capable of impacting mortality but despite this, mortality has continued to decrease over the last few years and in 2017 was at

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

[2] Average densities calculated from Appendix E data.

the 9th percentile for the Dermo era.[1] Transplant exploitation rates in the MMT were higher in 2017 but still low at 2.4% for all oysters and 3.9% for market-size.

Medium Mortality Market region (MMM)—*Figure 16, Table 6*

The MMM consists of two beds (Ship John and Cohansey) and is the uppermost of the direct market regions. It is the second-largest region (Figures 2 and 6). Its 2,443 acres held 27% of the total stock (784 million oysters) and 29% of the market-size oysters in 2017 (Figure 12b,c). This is the second-highest total abundance on the MMM since 2002 and is at the 70th percentile for the 1990-2017 time series. The average oyster density on non-enhanced grids sampled on the MMM for the Fall 2017 survey was 87 per m^2 (ranging from 6-167 per m^2), much higher than in 2016.[2] Average oyster density on enhanced grids was 168 per m^2, ranging from 86-244 per m^2. Market-size oyster abundance in the MMM has been relatively steady since 2010 and in 2017 was at the 78th percentile for the 28-yr time series. As predicted last year, the high 2016 spat set did reset the pattern for more smaller vs. larger oysters in 2017. Oysters <2.5" were the reason for the increase in total abundance. If it survives, the similarly high spat set in 2017 will continue the pattern. Spat abundance in 2017 was at the 87th percentile. Dermo weighted prevalence more than doubled from 2016 to 2017 to the highest level since the 2011 low, well over the level capable of impacting mortality. Counterbalancing this is the steady decrease in mortality since 2012 (see footnote). The 2017 mortality rate was at the 12th percentile of the 1990-2017 time series, the lowest rate since 2002. The 2017 exploitation rate of market-size oysters remained near 3% as in most recent years.

Shell Rock (SR)—*Figure 17, Table 6*

At 1,471 acres, SR is the smallest region but in 2017 it contained nearly 4x as many oysters (700 million) as the largest: 24% of the whole stock (Figures 2 and 12b). The stock metric patterns discussed in the previous regions also hold true for SR in 2017. Its 2017 abundance was the highest since 1996 and at the 91st percentile of the 1990-2017 time series, continuing a generally increasing trend since 2012. Oyster density on the non-enhanced sampled grids of SR, like the rest of the regions, averaged higher in 2017 at 127 per m^2, ranging from 15-248 per m^2.[2] Because of its importance to the fishery, SR regularly receives shellplants and transplants. Of the four recently enhanced grids sampled in 2017, average oyster density was 104 per m^2 ranging from 16-259 per m^2. The ratio of smaller vs. market-size oyster abundance is high in 2017 from the high 2016 spat set. Numbers of market-sized oysters for 2017 in the SR are at the 89th percentile and similar to their abundance in 2016. Spat set was not quite as high as in 2016 but was at the 84th percentile for the 28-yr time series. As in the MMT and the MMM, Dermo disease correlating with mortality rates has been uncoupled on the SR (see footnote).

[1] The current hypothesis is a favorable confluence of temperature and freshwater flow from rainfall leading to late onset of elevated Dermo levels limiting the exposure of oysters to Dermo, thus limiting mortality.

[2] Average densities calculated from Appendix E data.

favorable outlook, the 2017 spat set was the highest in the VLM time series. The VLM has only been specifically used for transplants three times and not since early 2011.[1]

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

[2] Average densities calculated from Appendix E data.

Despite Dermo levels being high again in 2017, mortality rates have declined since 2012 and are at the 9th percentile since 1990. If this continues, the two good spat sets of 2016 and 2017 should translate into another year of increased abundance on the SR. The exploitation rate of market-sized oysters was approximately 4% in 2017 as it has been since the direct market began in 1996.

High Mortality Region (HM)—*Figure 18, Table 6*

The HM is a direct market region consisting of the eleven lowermost beds in the assessed stock (Figure 6). It is the largest region, making up 46% of the oyster acreage (Figure 2). Conversely, it contains only 186 million oysters only slightly more than the much smaller VLM. The HM contributed only 6% of the stock in 2017 (Figure 12b). Large portions of the HM have low densities of oysters compared to the other regions. In 2017, the average oyster density on the 68 non-enhanced grids sampled was the same as that of the 4 enhanced grids: 9.2 per m^2.[1] The enhanced grids densities ranged from 3-22 oysters per m^2 and the non-enhanced grids, 0-100 oysters per m^2. Total abundance on the HM was at the lowest percentile level of all the regions in 2017, the 37th. While that is below the median for the 1990-2017 times series, abundances have been higher in recent years unlike the prolonged low abundance period from 2002-2009. There was a reasonable spat set on the HM in 2016 that appeared to translate into a small increase of oysters <2.5". Unfortunately, the spat abundance on the HM in 2017 was not nearly as high and was below the 28-yr median at the 41st percentile. More positively, although the Dermo level has crept up in the last 3 years, the mortality rate has not changed substantially. The 2017 mortality rate was at the 23rd percentile, well below the median rate for the 1990-2017 time series. There was a transplant to the HM in 2017, the first since 2013. This may or may not have influenced overall oyster abundance in this region and/or the fishing mortality rate: the latter decreased slightly in 2017 and the former increased slightly.

Primary Influences on the Oyster Stock

Habitat

Oysters are unusual in terms of stock assessment because they create their own habitat. It is well understood that shell, whether as natural reef or planted, is critical to oyster population stability or growth (Abbe 1988, Powell et al. 2006). Spat settlement requires hard surfaces and oyster shell is generally the hard surface available in their environment. Without spat recruitment and survival there are no oysters; without oysters, there is no habitat for spat recruitment. Moreover, oyster shell is not a permanent resource for potential oyster spat (Mann and Powell 2007). Chemical, physical, and biological processes degrade the shell over time (Powell et al. 2006). Burial of shell by sediment or fouling by epibionts make shell inaccessible to recruits. As described in the Historical Overview, Dermo disease became prevalent in the Delaware Bay ca. 1990 and effectively doubled natural mortality rates (Powell et al. 2008b). Fewer oysters produce less shell and therefore, less habitat. Similarly, smaller oysters provide

[1] Average densities calculated from Appendix E data.

less shell than larger oysters and degrade faster. The circular nature of this relationship between oysters and the habitat they create makes evaluation and management of the shell resource critical (Powell and Klinck 2007; Powell et al. 2012b). Without a balance between habitat and oysters, the population will decline.

Powell et al. (2006) developed a model to estimate surficial shell (cultch) half-lives for each oyster bed. The model was developed during an extended period of low recruitment accompanied by a decline in both oyster abundance and in cultch that suggested loss of shell resource over time. A shell budget was constructed using the half-life estimates for surficial shell following the model of Powell and Klinck (2007). Shell inputs included oyster shell once oysters died and became boxes as well as planted shell from outside the system, eg. clam shell. Shell was debited based on the estimated half-life values. At the 2016 SAW, the SARC requested a simpler approach of plotting the efficiency-corrected cultch volumes from each assessment survey. In this version of cultch availability, volumes include native shell and boxes but not planted shell. It should be noted that the assessment survey uses a bed stratification based on oyster density and does not survey the low quality stratum of any bed. It is likely that at least some low quality grids with few or no oysters contain large amounts of shell that are not counted. The three transplant regions are approximately the same acreage and bushels of cultch on them vary from an average of 1.2 million on the VLM to 1.8 million on the MMT (Figure 19a). All three regions follow a similar pattern of highs and lows throughout the 18-year time series without a consistent increase or decrease aside from a slight increase over time in the MMT. The addition of cultch in the VLM due to the freshwater mortality of 2011 can be seen in its 2011-2012 peak. The direct market regions in Figure 19b do not have similar acreage yet the largest region (HM), has a similar average volume of cultch as the MMM with 1/3 the acreage. The smallest region (SR) has a similar average volume of cultch to the MMT (Figure 19a) which has similar acreage. The patterns of highs and lows throughout the time series is similar between all three direct market regions without a consistent direction (Figure 19b). The average number of bushels per direct market region ranges from 1.8 million on SR to 4.2 million on HM.

Shellplanting

Shellplanting is an important management activity that adds clean substrate to oyster beds. In the Delaware Bay oyster system, it has been practiced with varying regularity and intensity throughout the survey time series with the volumes of shell planted usually dependent on available funds (Appendix G). 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. There are two types of plantings: direct and replant. Both are dependent on careful timing and site selection. Direct planting places the bare, dry shell directly on a chosen site while replanting first puts the shell downbay in a high recruitment but low survival area. Once it catches a set, the spatted shell is moved upbay by suction dredge to its final site. Shellplants are monitored monthly from April to November using a small (0.81m toothbar) lined dredge (Bushek et al. 2018) and annually for their first three years in the Fall assessment survey with the commercial dredge. Planted shell will continue to recruit spat for some years subsequent to the initial planting.

In 2017, there were three shell plants on NJ's Delaware Bay oyster beds, all funded by the NJ oyster industry through its self-imposed 'bushel tax'. Unspatted clamshell was put directly on one grid in each of three regions: 65,522 bushels on HM (Bennies Sand); 42,090 bushels on SR (Shell Rock); and 40, 572 bushels on MMM (Cohansey) (Figure 6, Table 7a, Appendix G). Spat recruitment was about 200 per bushel for the Bennies Sand and Shell Rock sites but was over 4x that much for the Cohansey site. Three sites in the same regions were similarly planted in 2016 and sampled in the Fall 2017 assessment survey for 2017 spat on the older clamshell (Table 7b). Results varied with relatively few spat found on clamshell at the HM (Bennies) site, approximately 200 per bushel again at the SR site and 302 spat per bushel of clamshell were present at the MMM (Ship John) site. Three sites planted in 2015 and sampled in Fall 2017 had relatively few spat per bu clamshell at the HM (Bennies) and SR sites, but over 200 spat per bushel on the MMM (Cohansey) site (Table 7c). It is generally believed that older clamshell on the bottom becomes fouled and less accessible to setting spat.

Spat and Small Oyster Morphology

Commonly, spat (recruits in their first season or 'young of the year') of unknown age are delineated from older oysters by morphology. The transition is typically identified as an increase in inflation of the valves and/or a separation of the growing bill edge from the substrate. Technician experience and skill combined with the size and morphology differences that occur across the extensive salinity gradient in Delaware Bay can result in differing evaluations. Spat sets can occur at different times and locations resulting in variable sizes by the time of the Fall assessment survey (Ashton-Alcox et al. 2015, Munroe et al. 2017). In the NJ stock assessment, spat are defined as oysters < 20 mm. This assumes 20 mm as the average size an oyster attains in its first season of growth across all regions. Consequently, application of the single 20 mm size cutoff to define a spat classifies a 40 mm spat as a small oyster or a 19 mm, second-year oyster as a spat. While spat are not included in oyster abundance or biomass estimates in the stock assessment, their size cutoff affects both. Further, spat abundance enters deliberations when establishing quota allocations for an upcoming season. Finally, quota allocations for transplant regions are currently based on the abundance of all oysters >20 mm. For these reasons, a better understanding of average regional sizes at which spat transition to oysters is needed for more precise estimates of post-spat oyster abundance and transplant region quotas.

In a study conducted throughout 2014 and 2015, the 'transition size' at which an oyster is no longer considered a spat was determined based on morphology of individual oysters using logistic regression (Ashton-Alcox et al. 2016). The study found that during the Fall assessment period, the size of transition from spat to oyster is generally larger than the 20mm cutoff that is currently employed. Transition sizes increase moving downbay: the more upbay regions (VLM, LM, MMM) have an average morphological transition size of about 22 mm and more downbay regions (MMT, SR, HM) have an average transition size of about 30 mm (Figure 20). A sensitivity analysis of regional abundance estimates to region-specific changes in definition of spat size was done in 2016 and did not yield a statistically significant difference in spat vs older oyster abundance estimates for any of the regions (Ashton-Alcox et al. 2017).

Spat : Oyster Relationship

Broodstock-recruitment relationships for the New Jersey Delaware Bay oyster survey time series have been illustrated in earlier reports and suggest a positive relationship between broodstock abundance and recruitment of spat that may occur in a stepwise fashion. Shellplants suggest that the bay is not larvae-limited as recruitment to newly planted shell is typically high, regardless of the abundance of broodstock. Oyster larvae may tend to set preferentially on live oysters and boxes that are generally more exposed in the water column and often have a larger, cleaner surface area than cultch that may be lying flat on the bottom so one cannot exclude the possibility that broodstock abundance modulates settlement success by being a principal source of habitat (clean shell).

Disease and Mortality[1]

Oyster mortality on the Delaware Bay oyster beds is caused by a variety of factors including predation, siltation, freshets, disease and fishing. Since *Haplosporidium nelsoni* (the agent of MSX disease) appeared in 1957 however, disease mortality has been the primary concern (Powell et al. 2008b). Although detected in the Bay decades earlier, *Perkinsus marinus* (the agent of Dermo disease) spread through much of the Bay around 1990 and has been prevalent ever since. Both diseases are monitored for their impact on the oyster population.

Following a severe and widespread MSX epizootic in 1986, the Delaware Bay population as a whole appears to have developed significant resistance to it (Ford and Bushek 2012). It remains present in the Bay, however. Samples for MSX have been routinely taken from 6 beds during the fall assessment since 1988: 1 in the LM, 1 in the MMM, 1 in the SR, and 3 in the HM; and from 1 bed in the VLM since 2008. In 2017, MSX was found in only 1 of 140 oysters sampled although monitoring in the lower Bay found higher prevalences (Bushek et al. 2018).

The establishment of Dermo disease in 1990 effectively doubled average oyster mortality in Delaware Bay, NJ and it continues to be the primary cause of disease mortality (Bushek et al. 2012). Dermo is tracked monthly from April-October along a transect of 5-6 oyster beds from Hope Creek to New Beds and annually on all beds during the fall assessment survey. This monitoring and other studies have indicated that it is largely controlled by temperature and salinity so those parameters are tracked closely. In 2017, water temperatures were below the 18-

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[1] See Bushek et al. 2018 for full disease monitoring report.

yr average until mid-summer and then exceeded averages into the fall (Bushek et al. 2018). In what appears to be a response to salinity, Dermo prevalence and intensity remained below average until fall. Dermo prevalence at the time of the assessment was low on the most upbay regions (VLM, LM), remaining below the weighted prevalence known to cause detectable population-level mortality (about 1.5 on the Mackin scale) and mortality was low, continuing a decreasing trend in those regions since 2011 (Figure 21). Dermo disease continues to be prevalent on lower regions but its impacts have declined in recent years. Prevalence on the MMT, MMM, and SR approached 100% in Fall 2017 and was 83% on the HM region. Fall 2017 weighted prevalences increased relative to Fall 2016 yet mortality decreased on each of these regions. The likely explanation is the relatively short period of time with above-average weighted prevalences prior to the assessment survey. The effect of rapid cooling and early freeze from December 2017 to January 2018 on Dermo-induced oyster mortality is unclear at this time and will depend on the rate of spring warming and the timing of the spring bloom to provide food for oysters once they become active. If the oysters are unable to purge infections over the winter, early spring mortality could occur.

Oyster Fishery

Direct Market Harvest

The 2017 direct market harvest occurred from April 3rd to November 17th and included a period of curtailed harvest hours during summer months to comply with New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan[1]. A total of 21 vessels including 9 single- and 12 dual-dredge boats were in operation. The number of boats has declined since 2009 when 74 boats harvested (Figure 22a). This is a result of a change in legislation allowing license consolidation so boats can now harvest multiple quotas rather than one quota per boat (see Historical Overview, The Fishery).

Total direct market harvest in 2017 was 124,144 bushels, marking the third straight year of increases (Table 8a, Figure 23). This harvest was 24,049 bushels more than in 2016 and the highest since the current exploitation and management strategy took effect in 2007[2,3]. The initial quota allocation of 104,784 bushels came from decisions made by the Shellfish Council based on direct market region options offered by the SARC in accordance with the Control Rules (Tables 3 & 4). The breakdown of the initial quota was as follows: MMM, 38,404 bu; Shell Rock, 36,782 bu; and HM, 29,598 bu (Table 9a). The allocation for the HM was augmented by 19,346 bu of additional quota resulting from the intermediate transplant also in accordance with SARC-adopted procedures. The final harvest was 14 bushels above the total allowable catch.

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

[2] Harvest data provided by the New Jersey Department of Environmental Protection.

[3] 1996-2007 harvest and transplant volumes in Appendix H.

The final harvest from the three Direct Market regions broke down as follows: 39% from the HM; 31% from SR; 30% from the MMM (Table 8a). Of the 14 beds in the three Direct Market regions, 8 were fished during the 2017 harvest season. The HM has 11 beds and 93% of its harvest came from 2 of them: Bennies (47%) and Bennies Sand (46%) (Figure 6). Of the 2 beds in the MMM, 56% of its harvest came from Cohansey and 44% from Ship John.

Port Sampling

The port-sampling program counts and measures oysters at dockside from boats unloading direct market harvest. The results are used in the assessment to determine size frequency and harvested numbers per bushel so that beds can be appropriately debited and realized exploitation can be determined. The overall average number of oysters per landed bushel in 2017 was 275 (Figure 24), similar to that of 2016. The fraction of market-size oysters per landed bushel in 2017 however, was quite a bit lower than in 2016 due to the increased number of smaller oysters attached to those of target size. The conversion of oysters to bushels for allocation projections uses the grand mean of the annual average total oysters per landed bushel with the annual average number of targeted oysters per landed bushel from the dockmonitoring 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 so that using the total number per bushel risks underestimating the allocation. On the other hand, the smaller number does not account for all of the oyster removals and this undervalues the fishing mortality rate. The grand mean has been around 265 oysters per market bushel in recent years but it is 263 oysters per market bushel for 2017.

As shown in Figure 22b, the proportion of the largest market-size oysters (those >3") in the population of the three Direct Market regions has increased steadily over the past three years and in 2017, was 64% of all market-size oysters. The size frequency of the 2017 landings in Figure 25 reflects that increase with the proportion of oysters in size bins 3.5" and larger increasing over the 4 years shown and those in the size bins < 3" decreasing. The 2017 increase in the proportion of smaller oysters due to recent spat sets can also be seen in the higher dark-blue 2017 bars for size bins from 0.5-2.0".

LPUE[1]

Catch per boat day has been recorded historically in the NJ Delaware Bay oyster fishery but not necessarily in the HSRL reports. Beginning with the 2002 SAW report (2001 data), landings per unit effort (LPUE) were reported on the basis of an 8-h day by adding up the estimated number of hours fished and dividing the total by 8. The number of hours and beds fished along with the bushels harvested are determined from a combination of daily captain call-in reports, reports filed weekly by captains, and dealer records. In recent years, the 8-h day has

[1] LPUE is more appropriate than CPUE in this report since LPUE does not include the total volume of dredged material as some of it is discarded during on-deck processing.

been decreasing for a variety of possible reasons: limits on harvest timing due to *Vibrio* control protocols; consolidation permitting more than one license to be fished per boat allowing larger, possibly more efficient boats to load more quickly; and a proportional shift towards larger oysters that may make dredging and culling more efficient. In this report, LPUE is reported as bushels per-hour rather than per-day. As has been the practice in these reports, LPUE for one-dredge boats and two-dredge boats is presented separately. Landings-per-unit-effort (LPUE) have continued to increase since approximately 2012 and were at their highest average since 2002 in 2017 at 21 and 37 bushels per hour for 1- and 2-dredge boats respectively (Figure 22). The 2017 LPUE does seem to be leveling off after the steep yearly increases since 2014. This may be related to the decreased number of boats due to license consolidation (Figure 22a) but the marked rise in LPUE is likely not due to consolidation alone. As indicated by the shift in size frequency of landed oysters discussed above in Figure 25, the increased abundance of larger oysters in the size fraction has also tracked with increasing LPUE (Figure 22b). Preliminary results from a model of the relationship between LPUE and size frequency presented at the last SAW indicated that size distribution alone can have a large influence on catch rates.[1]

Intermediate Transplant

The three most upbay regions of the New Jersey Delaware Bay oyster resource are considered ‘intermediate transplant’ regions from which oysters may be moved to annually-specified grids in chosen direct market regions in an NJDEP-HSRL monitored program that usually occurs in late April to early May. In 2017, the SARC recommended closure of the LM, a modest exploitation rate for the VLM, and a maximal transplant option for the MMT (Table 9b). The Shellfish Council chose to conduct one transplant from April 17-May 1, 2017 from the MMT at the maximum SARC-recommended 2.5% exploitation rate using proceeds from their ‘self-imposed’ bushel tax as always. Three boats participated and moved 29,250 bushels of culled material (primarily oysters) to Bennies bed in the HM (Table 8b). The original Control Rule 6 in effect at that time (Table 4a) states that no more than 50% of an MMT transplant should come from Middle bed but in this transplant, that proportion was 75% (Appendix I).

Boats deckloading oysters for transplant use mechanical cullers as the only sorting device because of the large volumes to be moved. Due to this, exploitation rates in the Transplant regions are based on all sizes of oysters because the proportion of oysters smaller than market size that get moved can be high, particularly from the LM and VLM where oysters do not grow as large or as fast as those further downbay. Although the premise of these transplants is to move market-size oysters to the Direct Market regions in order to add them to the current year’s quota allocation, a 2011 study of the intermediate transplant program (Ashton-Alcox et al. 2013) found that the proportion of small oysters < 2.5” (63.5mm) in the transplant can be as high as 60%. The 2017 MMT transplant included oysters from all three beds in the region (Table 8b). The fraction of small oysters (< 2.5”) moved from Upper Middle and Middle was 36% and 31%

[1] LPUE model presented by J. Wiedenmann during the 19th SAW.

of those transplants respectively but for Sea Breeze, more than half of the transplant consisted of smaller oysters (Table 10). The cullers likely removed at least some of these smaller oysters, however, because this size group made up >60% of all oysters on the MMT in the Fall 2016 assessment (Figure 15). The small oysters moved do not enter into the calculations for the quota increase in the receiver regions although they are included in the next Fall's assessment survey of those regions. Oysters ≥2.5" contained in the 2017 transplants were converted to market bushel equivalents using the number of market oysters per bushel (264) derived from the port sampling long-term mean of 2004 to 2016 (Ashton-Alcox et al. 2017) and were added to the quota for the receiving regions in May 2017. The 2017 intermediate transplant program reached about 97% of its goal and increased the quota on the HM by 19,346 bushels, approximately 7,000 bushels more than predicted during the quota-setting process (Appendix I).

Ideally during a transplant, the cullers remove most cultch from the deckloaded volume of material and an onsite NJDEP monitoring boat will instruct transplanting boats to change location if cultch fractions exceed much more than 20% of the deckload volume. Boxes are not included in the calculation of cultch fraction because they are generally the same size as oysters or are attached to oysters and thus, will not be culled. In most cases, boxes make up no more than 10% of the transplant volume. The cultch fractions on all beds in the 2017 MMT transplant were higher than 20% and the box fractions were well below 10% (Appendix I).

***Exploitation Rates*[1]**

As explained earlier (Historic Overview, The Fishery), the regional exploitation rates used in the NJ oyster stock assessment were originally based on percentiles from the 1996-2006 exploitation records. These abundance-based rates were 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 region's median (50^{th} percentile) exploitation rate defined in terms of the fraction of abundance removed per region for the years since the direct market fishery began in 1996 through 2005, the latest data year at that time. 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, e.g., during periods of increased disease mortality. The basic approach and time period was revised in 2007 using estimates of size-dependent exploitation rates because direct market fishing and intermediate transplants remove size classes differently. Two sets of exploitation percentiles were calculated: one using the assumption that all size classes are removed proportionately in deckloading transplants and one using a knife-edge assumption that size classes ≥ 2.5" were removed proportionately for direct market by pickers on the boat crews.

[1] Exploitation rates calculated as # caught / # from prior assessment

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. The 2009 SARC made an adjustment to the original set of exploitation percentiles for the transplant regions in order to smooth a temporally biased change in exploitation rates at the 50th percentile that separated as high and low. The 50th and 60th percentile values from the original data were averaged. That average was used as the 50th percentile and the previous 50th percentile was then used as the 40th. In the HM, the change from the 40th to 50th percentile spanned a much larger range of exploitation rates than that of its 25th to 40th percentiles whereas SR's 40th and 50th percentiles were nearly identical (Figure 35a in Ashton-Alcox et al. 2017). Consequently, if market-size oyster abundance was low on SR and other parameters were not promising, the choice for conservative exploitation was constrained to fishing below the 40th percentile. Finally, there was such a narrow range of exploitation rates on the MMM (the 100th percentile exploitation rate on the MMM was below the 10th percentile exploitation rate on nearby SR) that the SARC had regularly recommended an 'experimental' fishery at the 100th percentile rate of exploitation on the MMM (Figure 26a).

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 (Figure 26). The fishery will thus continue to operate within the original bounds of the 1996-2006 time period. 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 (Table 4).

It should be noted that with the 2015 reconstruction of the abundance time series based on updated gear efficiency analyses, the transplant regions no longer have the same scale of exploitation rates although the pattern from the 1996-2006 harvest data remains the same (Figure 26b). In the case of the VLM, it was not possible to apply the same initial logic when it was assumed that gear efficiency was the same as on the LM or MMT (see Gear Efficiency Corrections earlier in this report). All three years of transplant exploitation on the VLM occurred prior to the gear efficiency updates and resulted in overestimation of stock abundance leading to higher rates of exploitation than were intended, the highest being 4.3%. Otherwise, the 2007-2015 ranges of exploitation increase in a downbay direction with a total stock rate maximum of 2.3% for the LM and 2.5% for the MMT and a maximum market-size oyster exploitation rate of 3.7% for the MMM, 4.9% for SR, and 9.8% for the HM (Figure 26).

Questions since the 18th SAW about whether fishing exploitation results in noticeable abundance change under the current management strategy led to an evaluation of this over different realized fishing exploitation rates. Analyses presented at the 19th SAW (Ashton-Alcox et al. 2017) led the SARC to conclude that the prescribed fishing exploitation rates under the current management approach have not negatively influenced the oyster stock abundance.

Each year's quota for the direct market regions is based on the assessed abundance from the previous Fall. For each market region, chosen exploitation rates are multiplied by the abundance of market-size oysters and divided by the number of oysters per bushel as determined from the previous year's port sampling program (Figure 24). The sum of regional quotas is divided by the number of active licenses (~80) to determine individual allocations. Additional quota from intermediate transplants is based on the number of market-size oysters moved and gets allocated about six weeks after the oysters are moved to the recipient regions. Annual harvest and management plans are the result of SARC recommendations for a range of exploitation options and the choices made by the Council at its post-SAW March meeting (Table 3).

In 2017, the SARC did not require transplants in the MMM and SR while all options for the HM required a transplant. The Council choices for direct market harvest were the maximum allowable recommendation from the SARC (Table 9a). The SARC includes academics, resource managers, and industry members (Table 3 and Appendix A) while the Council is made up of industry members under the auspices of the NJDEP. These two groups regard the quota somewhat differently. The SARC considers regional quotas and the Council considers the total quota for the Direct Market regions divided by the number of licenses, first without and then with potential transplant additions. The 2017 achieved harvest was nearly identical to the total of the original quota plus the addition from a transplant (Table 9a). Despite this, the achieved market-size exploitation was lower than predicted by the 2017 SARC recommendation on all direct market regions. For the HM region, this was partially the result of oysters added by the transplant (Table 10). It should be noted that with area management, the HM is the first region of the year opened for harvest in April and is generally open into June. Any grid area that receives transplant is closed for 6-8 weeks but the closure does not include the whole region. Shell Rock is usually opened for harvest by the beginning of June and remains open until its quota is harvested generally by the end of July. In 2017, the achieved market-size exploitation on SR was 3.8% which was less than the 4.9% chosen yet it included an over-harvest of ~1400 bushels (Table 9a). One explanation for this could be that oysters counted as small oysters in Fall 2016 grew into market-size by summer 2017. Another may be found in the higher proportion of non-targeted smaller oysters per 2017 harvested bushel than expected (Figure 24), perhaps in concert with the increased proportion of >3" oysters (Figure 25) taking up more space in the bushel volume and decreasing the total number of market oysters landed. The same explanation can be used for the MMM that is generally harvested from August through

November each year and where in 2017, the chosen exploitation rate was 3.7% and the achieved was 3.0% although ~1400 fewer bushels were harvested than allowed by the quota.

Council decisions about transplanting options are complicated by various logistical and funding issues. The industry uses its self-imposed bushel tax to fund transplanting but the fund is administered by the state of NJ and there are requirements and limits with respect to boat contracts and insurance issues that add a non-scientific aspect to this activity. In March 2017, the Council made the decision not to transplant from the VLM despite SARC advice that the VLM could be opened for transplant exploitation of up to 3.0% of its oysters (Ashton-Alcox et al. 2017). The VLM had previously been closed since 2012 due to a late 2011 freshwater mortality (Munroe et al. 2013). Instead, the Council chose to transplant from the much-closer-to-port MMM with its larger oysters at the maximum SARC-recommended rate of 2.46% (Table 9b). Because of the uncertainty in projecting numbers of bushels to transplant, quotas for Intermediate Transplant are based on a goal number of oysters to be moved to an allotted Direct Market region grid. The 2017 transplant achieved an exploitation rate of 2.37%, below the maximum rate of 2.46% that the SARC agreed upon and the Council chose.

Fishing Mortality[1]

During the Bay Season years (see Historical Overview) from 1953 until the start of the Direct Market era in 1996, the oyster fishery commonly took well over 200 million oysters off the natural oyster beds of Delaware Bay, NJ (Figure 5). Since the inception of the Direct Market fishery, the number of oysters landed from the natural oyster beds in Delaware Bay, NJ has been an order of magnitude less than that; around 20 million oysters. The total harvest in 2017 was approximately 34.1 million oysters based on the average number of oysters per harvested bushel (Figure 24). This represents a fishing mortality of 1.89% of all oysters in 2017 (not shown) and about 2.09% of all oysters excluding the VLM (Figure 27a). This is the highest fraction of the 5-region stock fished since the direct market began. The fraction of market-sized oysters fished in the 5-region stock in 2017 was 3.61% of all market-size oysters (Figure 27b) and 3.51% including the VLM.

Regional fishing mortality is shown in Figures 13-18 as both the fraction of all oysters and fraction of market-size (≥2.5”) oysters. The numbers reflect the addition of oysters in regions that received transplant so that some years may have negative values if more oysters were added in the transplant than were removed by the fishery. By vote of the Shell Fisheries Council, the VLM was closed in 2017 for a sixth year despite the SARC supporting a low level of exploitation in that region and exploitation on the LM was not recommended by the SARC for 2017. Transplant exploitation on the MMT in 2017 was higher than in 2016 reflecting both

[1] Fishing mortality is equivalent to exploitation rate due to this fishery’s low exploitation rates

SARC advice and Council decisions. As mentioned in the previous section, transplant decisions go beyond scientific considerations. Fishing mortality on all oysters in the MMM is generally a low fraction of its abundance. It was about 2% in 2017 but for market-size oysters, fishing mortality remained at ~3% for the fourth year in a row (Figure 16). The MMM received transplants in 2014, 2015, and 2016 from the LM to help maintain abundance and provide market oysters. Shell Rock has received transplants regularly since 2013 for the same reasons although not in 2017. Instead, a high spat set in 2016 translated into higher abundance of small oysters and fishing mortality on this region decreased to 2.6% of all oysters and 3.8% of market-size in 2017 (Figure 17). The HM had not received transplants since 2013 and fishing mortality on all oysters had steadily risen from a negative value in 2012 to 4.4% in 2016 (Figure 18). The 2017 transplant to the HM appears to have reversed that trend at least temporarily; fishing mortality on all sizes of its stock was 3.3% in 2017 and on market sizes, fishing mortality dropped from 8.2% to 7.5%.

Biological Reference Points

Overview

Long-term patterns since assessments began in 1953 indicate that disease mortality exerts significant control over the Delaware Bay oyster stock. Overall abundance and biomass of the stock is often limited or reduced by the intensity of disease and the mortality it causes. The record provides evidence of decadal or longer shifts in disease regimes driven by MSX from the 1950s to the 1980s and by Dermo disease since 1990 (Figure 3a). The first period was low abundance on the oyster beds in the 1950s that continued as MSX caused significant mortality. MSX and mortality rates declined in the 1960s and shellplanting increased (Figure 4a) in a period of high abundance that lasted into the 1980s. An extended drought facilitated the spread of MSX upbay ca. 1985 causing extensive mortality beginning another period characterized by high disease-induced mortality and low abundance. Although the MSX epizootic had dissipated by 1990 and the oyster population became resistant to it (Ford and Bushek 2012), abundance did not recover as Dermo disease immediately became established and effectively doubled natural mortality (Powell et al. 2008b). Dermo and mortality are highly influenced by salinity along the upbay-downbay gradient creating the regions of varying oyster mortality identified in Figure 1 (Bushek et al. 2012). The continuing influence of Dermo disease on Delaware Bay oyster population dynamics has generally led the SARC to determine that management goals should be set relative to population assessments made during the 'Dermo era' that began around 1990. It should be noted however, that the mortality peaks of the 1990s where >30% of the stock died modulated to around 20% since 2000 and have declined to 10% in 2017 (Figure 3a).

Whole-stock

Although the oyster resource is managed by region, the population is a single stock (Hofmann et al. 2009) and thus whole-stock reference points are important criteria upon which to judge stock status. From 2006 to 2010, SARCs considered three whole-stock abundance targets.

The first two were empirically derived as the sums of the regional median abundances (excluding the VLM) of the total and market-size oyster targets (2.306 billion and 401 million) that are listed in Table 11 (with the thresholds at half those values 1.153 billion and 200 million). The third was derived theoretically from an analysis of biological relationships and formulation of a surplus production model (Powell et al. 2009) and is described in previous stock assessment reports. Several SARCs debated the validity or relevance of using the surplus production model to identify whole stock reference points and have agreed to use the medians of the sums of regional total and market abundance from the period 1989-2005 as whole stock reference points. The VLM is excluded from all stock-wide reference point estimates and comparisons because time series data are considered insufficient to include them at this time.

The 2017 total abundance (excluding the VLM) of 2.77 billion oysters was 1.7 times larger than that of 2016 (1.62 billion oysters). Of those, 833 million were market-size in 2017 compared to 759 million in 2016, the fourth year of higher abundance. The 2017 point-estimate of 2.77 billion falls above the whole-stock target reference point of 2.3 billion (Figure 28a) for the first time in many years. This point-estimate falls between the 50th and 60th percentiles of the survey uncertainty envelope and the whole-stock abundance threshold of 1.2 billion falls well below the low end of the survey uncertainty. As it has for many years, market abundance across the 5-region stock sits significantly above the stock performance target of 401 million oysters (Figure 28b). The 5-region whole stock market-sized abundance estimate of 833 million oysters, like the total abundance point-estimate, is between the 50th and 60th percentiles of survey uncertainty. The difference between the total and market-size oyster whole stock abundance with regard to the target reference points indicates a current population structure skewed towards the larger oysters. As described earlier (Stock Assessment Design, Analytical Approach), the gear efficiency portion of the confidence percentile calculations in Figure 28 use a set of catchability coefficients based on catchability of all sizes of oysters as of the 2016 SAW instead of the size-class separated catchability coefficients used before.

Regional[1]

In 2006, the SARC set specific targets and thresholds for regional total abundance and market-size abundance based on the 1989-2005 (total) and 1990-2005 (market-size) time periods under the assumption that this time period likely represents the entire scope of oyster population dynamics in the present climate and disease regime (Table 11). For each region except the VLM, the median abundances from these time periods were set as targets with values half these levels set as thresholds. VLM reference points were originally established at the 2012 SAW by applying LM conditions adjusted for region area (Powell et al. 2012a). Updated catchability coefficient analyses caused the 2016 SARC to deem these inappropriate (Ashton-Alcox et al. 2016). The 2017 SARC evaluated the VLM time series and advised the use of the 75th percentile of the 2007-2016 VLM time series for both total and market-size abundances as the VLM targets

[1] Confidence limit graphics by region in Appendix J.

and the medians as the threshold. This included a proviso that these be reevaluated in three to five years.

Figure 29 illustrates the position of the 2017 total and market-size stock in each region relative to four previous years and to the targets and thresholds for the region and includes error bars on the 2017 position. The error bars are the 10th and 90th percentiles of 1,000 estimate simulations (see Analytical Approach). The 2017 error bars overlap the 2016 and 2015 values at both ends of the stock, the VLM and the HM. In the case of the HM, the error bars encompass the last 3 years. Otherwise, there has been a relatively significant improvement in the stocks of the other regions with the 2017 point residing in the desired upper right quadrant of each graph. Stocks are above both the total abundance and the market-size abundance targets in the LM, the MMT, the MMM, and the SR. In the VLM, whose target values are determined differently, the 2017 total abundance is above the target value as it was in 2016 but market-size abundance remains below target as it has for at least the last 5 years. The HM market-size abundance is above target as it has been since 2013 but total abundance remains below the threshold.

Summary of Stock Status

Table 12 is a 'stoplight' table summarizing the 2017 status of the oyster stock by region relative to either the 1990-2017 time period, the previous five years or other metrics. Parameters of the regional stocks are designated as improved (green), neutral (yellow), or degraded (orange). They include total and market-size abundance, spat recruitment, natural mortality, and Dermo disease. Metrics include percentile ranks (40th-60th percentiles are considered neutral), comparison to the previous 5-yr median, comparison to biological reference points, comparison of the 3-yr average to the longterm median (recruitment), comparison to average longterm mortality rate (mortality), or comparison to Dermo levels known to cause mortality (Dermo WP). Aside from the percentiles, most of the metrics use boundaries of +/- 15% or within 1 SEM. The VLM target/threshold values are different than other regions' as previously mentioned.

The stoplight table can be read horizontally for a single parameter across all regions or vertically for all parameters within a single region. For 2017, most of the table is green or at least yellow across all parameters and regions indicating that the 2017 status of the NJ Delaware Bay oyster stock is positive. The few degraded (orange) sections are primarily in the Dermo Weighted Prevalence section for the three medium mortality regions, MMT, MMM, and SR. As has been noted throughout this report, the mortality expected with high levels of Dermo has not occurred recently so these medium mortality regions have positive stock status indicators. The one region that continues to be somewhat degraded is the HM with low total abundance and poor recruitment indicators. As with other regions however, mortality and market-size oyster abundance indicators for the HM are relatively favorable.

Figures 13-15 summarize the 10-yr trends of the stock in the three transplant regions. The VLM is at its highest abundance since it was first surveyed in 2007. This region has been rebuilding with good spat sets and increased survival since the late 2011 freshwater event that caused approximately 45% mortality but also a sharp decrease in Dermo disease. The 2017 spat set was more than twice that of the previous two years. Dermo was absent in the VLM in 2017 and the decreasing mortality rates indicate good possibility for the survival of all the spat. A very good spat set in 2016 in the LM led to a large increase in the small oyster abundance that translated into an overall abundance increase for 2017 as predicted. A very high spat set in 2017 augurs well for the LM again as Dermo rates have continued to fall along with the mortality and there was no fishing mortality for 2017. Aside from Dermo which increased on the MMT, all other metrics were similar to those of the LM. The high 2016 spat set survived and translated into a lot of small oysters for an already increasing abundance and there was a second, high spat set in 2017. Mortality rates have fallen every year since 2013 despite high Dermo weighted prevalence. The MMT was the only region from which transplant quota was taken in 2017 and although that level of fishing mortality was higher than in previous years, it remains below 4% for market-size oysters and around 2% for all sizes.

Figures 16-18 summarize the 10-yr trends of the stock in the three direct market regions. Like the LM and MMT, the MMM had survival of its very high 2016 spat set and a strong increase in the abundance of small oysters and total abundance. A second, high spat set in 2017 may add to abundance. As in the LM and MMT, Dermo has been high while mortality rates drop. The MMM provides about 1/3 of the total quota and although fishing mortality on the market-size oysters has remained steady for about 6 years now at around 3%, fishing mortality on total abundance has risen over the past couple of years but remains very low overall at < 2% in 2017. The 2017 status of the MMM is good without having received transplants in 2017 although there was a shellplant there. Continuing the positive theme, SR is similar to the 3 previously described regions. Survival of the high 2016 spat set translated to increased oyster abundance in 2017 and there was also another good set. There were high levels of Dermo but mortality decreased nonetheless. Fishing mortality on both size groups of SR decreased from 2016 without a transplant and there was a shellplant in 2017. The HM does not exhibit the same patterns in its oyster population. There was a modest increase in total abundance from a modest spat set in 2016 but the 2017 set was not very high. Dermo ticked up again in 2017 but as in other regions, mortality decreased somewhat. There was both a shellplant and a transplant to the HM in 2017 and fishing mortality was slightly lower in both size categories.

Harvest and Management Advice

Direct Market *(Table 13)*

Exploitation rates for the three direct market regions are based on the abundance of market-size (>2.5”) oysters. Given the high abundance of market-size oysters and other positive indicators, the SARC felt that harvest at any of the exploitation rates described by Control Rules

4 and 5 (Table 4a) could safely be taken from the MMM (1.80 - 3.70%) and SR (2.34 - 4.88%) without requiring transplants. Although there was a small increase in abundance of both market-size and smaller oysters on the HM in 2017, the SARC felt that it could not recommend exploitation rates any higher than last year's (8.99%) given the position of the 2017 total abundance relative to target and the error bars overlapping total abundances since 2014 in Figure 29. As in 2017, the 8.99% exploitation rate should only be allowed after a transplant to the HM occurs as described in the newly-amended Transplant Control Rules 6 and 7 (Table 4b). Any rate of exploitation on the HM above 5.50% was recommended after a transplant occurs.

Intermediate Transplant *(Table 14)*

Exploitation rates for the three transplant regions are based on total abundance (all oysters ≥20mm). Transplants must be done with the use of mechanical cullers. The SARC commented on the limited number of previous exploitation rates available (3) for the VLM and noted that they were much higher than those of the LM and MMT (Figure 26). The original catchability coefficients used for the VLM were based on those for the LM and MMT and were set too high, leading to overestimation of stock abundance for several years. Conditions on the VLM continue to improve as they have since 2012 although the SARC noted that market-size abundance has not increased despite a steady increase in small oyster abundance. This coupled with lack of sufficient data for effects on the stock at higher exploitation rates led the SARC to advise that any 2018 transplant from the VLM be at or below 2.32% exploitation. In early 2017, the SARC advised closure for the LM due to lack of increase in the number of >2.5" oysters and the decreasing abundance of ≤ 2.5" oysters over the previous few years. The late 2017 assessment survey showed that the abundance of both total and market-size increased and that numbers of small oysters more than doubled over the 2016 abundance. The error bars associated with total abundance are sufficiently large for the SARC to recommend a precautionary approach, however. The advice for transplanting from the LM was to not exceed an exploitation rate of 2.01% of total oyster abundance. Conditions for oysters on the MMT were such that the SARC had no problem with recommending the maximum exploitation rate of 2.46% of total abundance there. The general consensus of the SARC was to place any transplants onto the HM to provide market oysters to be added to the quota (Control Rule 7a, Table 4a) and smaller oysters to bolster abundance on that region. Specific locations to receive transplants will be determined by the NJDEP staff in conjunction with the Shell Fisheries Council.

Shellplanting

No specific advice was given by the SARC for shellplanting in 2018 however, the possibility of some sort of program to 'clean up' the six beds in the lower portion of the HM to provide exposed shell for recruitment was discussed (see Science Advice). Recommendations from the 2017 SARC included discussion about whether transplants or shellplants are the better option for the HM. Also at the 2017 SAW, the example of Virginia's state legislators being brought to recognize shellplants' 'bang for the buck' potential through economic analyses was suggested as an example for proposals and a multi-state economic analysis with Delaware was suggested.

2018 SARC Science Advice (items not prioritized)

- Continue standard monitoring and assessment programs
  - Annual Fall Survey – the basis for the entire assessment. New programs to determine survey sampling intensities after bed restratifications are being developed.
  - Resurvey Program – grid restratification of individual beds to take into account changes in oyster distribution due to natural population dynamics and enhancement programs.
  - Monthly Monitoring Program – monitor and evaluate factors influencing disease, mortality, growth and survival.
  - Monthly monitoring of transplant and shellplants – assess performance of enhancement activities.
  - Intermediate transplant monitoring and evaluation – daily estimates of oysters moved provided to managers for transplant logistics. Final results and additional quota allocation report to managers and Council.
  - Port Sampling Program – measurement of landed oysters for size-related information and abundance-to-bushel conversions in the stock assessment.
- Evaluate alternatives to 10-year resurvey schedule, e.g. collecting low quality stratum samples from highly manipulated beds (shellplants and transplants) or analyzing trends in CV by stratum.
- Optimization of sampling intensity; develop benchmarks (e.g. acceptable error level) for Monte Carlo simulations to determine sampling intensity.
- Develop method to appropriately reassign enhanced grids to High, Medium, or Low stratum after the 2-3 years of tracking. Current method is to return them to their original stratum but the enhancement may increase oyster density such that this is not correct. Use 3rd year of monitoring data for shellplant to see if stratum reassignment is necessary. Use past data to see if or where this made difference.
- Stratify beds on market abundance, not total. How much variability is due to the stratification scheme? Would this change sampling scheme and potentially abundance estimates? Remember that quota for transplant regions is based on total abundance.
- Evaluate the influence of regional bushel conversions on exploitation history. Bushel conversions from port sampling and transplant program are used to project quota for

upcoming year and to calculate realized exploitation at end of year. Transplant region calculations are done by-region. Current method for market regions combines #/bu landed from all regions. Do same calculations by region to see how they change both total and market-size exploitation rates and projections.

- Add ≤ 2.5”oyster abundance to stoplight and percentile tables.

- Shellstock:recruitment curve and Shell budget vs. cultch. Decide how to include all the available habitat (oysters, boxes, shell, etc)? Use total haul volumes minus non-rock debris? Consider using resurvey data for low quality grids that do not get sampled in assessment survey to evaluate their cultch contribution.

- Evaluate the effect of splitting the current HM to create a new Very High Mortality region (VHM) consisting of: Strawberry, Hawk’s Nest, Beadons, Vexton, Egg Island, and Ledge leaving Bennies Sand, Bennies, Nantuxent, New Beds, and Hog Shoal as HM. Industry question is initially whether this might give them additional quota but also includes a reason to work VHM to ‘clean it up’, making it more accessible to spat set. Note: Recalculation of abundance and exploitation rate history, etc. would be required. Points to consider:
  - Should Egg and Ledge be resurveyed and also both sampled each year?

  - May be able to accomplish part of this by area management. Split HM quota by bed groups and/or by time of year. The fishery would need to be willing to work the six less productive beds in question.

  - A controlled experiment to test the efficacy of dredging to improve oyster recruitment and production. NOTE: does it help to bring material on deck and back over the side or just dragging? Could ‘cultch fund’ be used? Should it be regular fishing activity towards quota?

- Consider other ways to make quota decisions such as including the error estimates into the quota-setting process. Came up after this question: why doesn’t SARC recommend higher exploitation when metrics like spat set, small oysters, and mortality are positive when lower exploitation rates are recommended when those same things are not positive. It had to do with slightly lower market abundances that resulted in slightly lower potential quota. Note: Error bars go both ways: positive and negative.

- Re-evaluate VLM target and threshold set at 2017 SAW in 2-4 years

- Continually evaluate whether current BRPs are appropriate. Develop control rules to define what warrants change and when changes to BRPs should be implemented. Examples of what may lead to changes include new disease, temperature, or salinity regimes or alternative methods for development of BRPs, e.g. MSY-based estimates.

- Evaluate impact of Dermo phenology on changes in mortality

- Investigate relationship between oyster size and fecundity. Largest oyster fraction and fecundity curve, analyze or model?

- Conduct growth experiments and analyze existing data to determine whether growth rates are changing with climate and how this affects the assessment.
    - Will this change how to evaluate extra transplant quota? Will some oysters ≤ 2.5" grow into mkt-size within the harvest season and if so, should they be added to transplant quota?

    - Models of how population size structure is changing over time, are we seeing systematic changes in growth rates?

- Conduct an experiment to re-evaluate susceptibility of LM and VLM oysters to disease via transplanting by moving them downbay (Capeshore) and monitoring them post-transplant.

- Investigate how fishing trends on the lower beds track with disease, temperature, and salinity as well as with the Vp harvest time restrictions.
    - Water temperature, sea level, salinity upbay have all increased. Look at trends downbay based on gauges, channel deepening effects.

    - Disease and drills increase with increased salinity. Evaluate significance of predation on recruitment success.

- LPUE
    - Add a biomass measure to look at volume of oysters per unit area rather than number of oysters for why LPUE changed. Combine abundance and biomass. Note: We have biomass data for Fall Survey but not condition indices throughout the year to calculate biomass in the spring for the HM harvest, in June-July for the SR harvest, or Aug-Oct for the starting MMM harvest.

    - Compare % oysters in haul to LPUE.

    - Oyster density and LPUE by region or bed: If all vessels equally efficient, then it should be proportional. Trends may be due to who's fishing and how. Note: Some of this has already been started.

- Continue to estimate gear efficiency whenever possible.

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

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

Table 2. Restratification survey (resurvey) schedule. Hope Creek and Hawk's Nest were resurveyed in 2017. Round Island and Nantuxent are scheduled for resurvey in 2018. 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	1	2007	**2018**
	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	1	2009	2019
	Ship John	68	1	2010	2020
SR	Shell Rock	93	3	2016	2026
HM	Bennies Sand	49	1	2009	2019
	Nantuxent	68	2	2010	**2018**
	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 3. 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 4a. Control Rules. These 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. *Management Tools*: Transplanting oysters from non-harvestable regions to Direct Market regions (Intermediate Transplant Program) and shellplanting (either directly or via replanting) are used to enhance or rebuild abundance as needed in any given region. Transplanting makes market-size oysters available to the fishery while also rebuilding abundance. It may be used to justify increased rates of exploitation on recipient Direct Market regions. No more than half of any transplant from the MMT should originate from Middle bed with the remainder from Upper Middle and/or Sea Breeze in any proportion. Transplants from LM should alternate in sequence between Arnolds and Round Island/Upper Arnolds.

Table 4b. The 2018 SARC has accepted the following amendments of Control Rule 6 to better describe the management strategy for enhancement activities, particularly for the intermediate transplanting of oysters from upbay regions to market regions.

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 5. Sampling scheme for the Fall 2017 survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of sampled grids devoted to that bed stratum. The strata designations are described in the text. The Enhanced stratum includes those grids that received transplant (T) in the current and previous survey year or shellplant (S) in the current year or within the previous two survey years. Egg Island and Ledge are sampled in alternate years.

Region	Bed	High Quality	Medium Quality	Low Quality	Enhanced	Enhanced Details
Very Low Mortality	Hope Creek	3	4	0		
	Fishing Creek	2	3	0		
	Liston Range	2	4	0		
Low Mortality	Round Island	2	3	0		
	UpperArnolds	3	4	0		
	Arnolds	3	4	0		
Medium Mort. Transplant	Upper Middle	1	3	0		
	Middle	3	4	0		
	Sea Breeze	3	4	0		
Medium Mort. Mkt.	Cohansey	5	5	0	3	2015-2017 S, 2016 T
	Ship John	6	5	0	1	2016 S
Shell Rock	Shell Rock	7	7	0	4	2015-2017 S, 2016 T
High Mortality	Bennies Sand	3	6	0	1	2017 S
	Bennies	5	9	0	3	2015-2016 S, 2017 T
	Nantuxent Pt.	3	3	0		
	Hog Shoal	2	3	0		
	Strawberry	2	3	0		
	Hawk's Nest	2	3	0		
	New Beds	4	5	0		
	Beadons	2	3	0		
	Vexton	2	2	0		
	Egg Island	1	5	0		
	Ledge	-	-	-		
Total		66	92	0	12	

Grand Total: 170

Table 6. Percentile positions and stock variables for the 28-year time series (1990 – 2017) for five bay regions and for VLM's 2007 – 2017 time series. A lower percentile equates to a lower value of the variable relative to the entire time series. Spat abundance does not include the enhancements from shell planting. Full sets of percentiles for the 28-year and the 65-year time series (1953 – 2017) can be found in Appendix B.

1990 – 2017	Oyster Abundance	Market >2.5" Abundance	Spat Abundance	Box-Count Mortality
Low Mortality	0.732	0.889	1.000	0.000
Medium Mortality Transplant	0.875	1.000	0.911	0.089
Medium Mortality Market	0.696	0.778	0.875	0.125
Shell Rock	0.911	0.889	0.839	0.089
High Mortality	0.375	0.778	0.411	0.232
5-Region Area	0.732	1.000	0.875	0.054

2007 – 2017	Oyster Abundance	Market >2.5" Abundance	Spat Abundance	Box-Count Mortality
Very Low Mortality	1.000	0.500	1.000	0.136

Table 7. Summary of shell plant results with projected oyster production. Sites sampled as part of 2017 assessment survey. 2017 spat recruitment to (a) sites planted in 2017, (b) sites planted in 2016, and (c) sites planted in 2015. Set on clamshell planted in 2017 used 35mm spat cutoff. Set on clamshell planted earlier used 20mm cutoff. Projections used 1990 – 2017 regional medians for mortality at the juvenile rate in year 1 and the adult rate for two following years. Years to market size based on von Bertalanffy parameters (Kraeuter et al. 2007). Regions include: the MMM (Cohansey, Ship John), SR (Shell Rock), and the HM (Bennies, Bennies Sand).

a. Sites planted and sampled in 2017.

	Clamshell Planted (bu)	Clamshell Spat/bu	Clamshell Total Spat	Median Juvenile Mortality Rate	Median Adult Mortality Rate	Potential Mkt-Size Individuals
Bennies Sand 41	65,522	216	14,172,895	0.493	0.228	4,277,657
Cohansey 50	40,572	890	36,097,876	0.273	0.169	18,103,750
Shell Rock 37	42,090	212	8,922,588	0.507	0.183	2,939,338

b. 2016 shell plant sites sampled in 2017.

	Clamshell Planted (bu)	Clamshell Spat/bu	Clamshell Total Spat	Median Juvenile Mortality Rate	Median Adult Mortality Rate	Potential Mkt-Size Individuals
Bennies 99	44,000	49	2,158,047	0.493	0.228	651,341
Shell Rock 15	44,000	222	9,768,000	0.507	0.183	3,217,839
Ship John 28	44,000	302	13,306,596	0.273	0.169	6,673,503

c. 2015 shell plant sites sampled in 2017.

	Clamshell Planted (bu)	Clamshell Spat/bu	Clamshell Total Spat	Median Juvenile Mortality Rate	Median Adult Mortality Rate	Potential Mkt-Size Individuals
Bennies 110	43,038	62	2,669,622	0.493	0.228	805,744
Cohansey 56	38,539	238	9,184,040	0.273	0.169	4,605,965
Shell Rock 52	47,913	13	605,081	0.507	0.183	199,330

Table 8. Direct market and transplant bushel summaries 2008-2017. 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. Quotas decided by Council after SARC advice. Direct market decisions made within-region by harvesters. All area management directed by NJDEP. Note: Sea Breeze was part of the MMM until 2011; it is now MMT. Beds without removals were omitted.

a. Direct Market

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Middle	1,120	33	56							
Sea Breeze	170	627	220		170	5,454	542			
Cohansey	2,611	5,909	2,806	19,074	11,288	10,583	8,652	10,669	12,475	20,687
Ship John	21,469	17,989	20,409	19,212	17,755	19,279	24,295	19,837	19,938	16,331
Shell Rock	29,736	22,918	17,493	24,112	22,628	24,280	23,589	29,629	31,794	38,189
Bennies Sand	14,806	13,529	10,147	8,825	5,836	10,841	3,038	6,301		22,339
Bennies	7,192	9,599	5,526	4,997	2,155	870	8,010	10,712	29,293	23,071
NantuxentP	4,637	2,631	6,572	5,467	14,332	10,218	5,154	5,267	2,101	628
Hog Shoal	1,069	3,804	7,281	9,049	1,965	2,385	3,425	103		1,756
New Beds	6,956	2,778	1,075	1,778	443	226		4,912	4,494	1,143
Strawberry		618	25			140				
Hawk's Nest	116	173	2,693	1,954	1,568		205			
Beadons		82	72							
Vexton				2						
Total	89,882	80,690	74,375	94,470	78,140	84,276	76,910	87,430	100,095	124,144

b. Transplant

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hope Creek		9,100	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	9,450	10,400		4,000	7,650	2,700	15,500		4,800	
Upper Middle		2,100			2,100	3,200				3,200
Middle	8,200	12,000		17,750	11,200	5,200	6,600	5,550	8,150	21,350
Sea Breeze			11,050		8,525	6,200	7,300	10,800	2,400	4,700
Cohansey			1,500							
Beadons				500						
Total	17,650	33,600	38,750	36,350	29,475	35,650	29,400	26,550	15,350	29,250

Table 9. Council-chosen and fishery-achieved exploitation rates for 2017 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%	2.97%	38,404	0	37,018
SR	4.88%	4.88%	3.82%	36,782	0	38,189
HM *transpl req'd*	8.99%	8.99%	7.50%	29,598	19,346	48,937
			Total	104,784	19,346	124,144

Total Quota (bu)	Un-harv. Quota (bu)
124,130	-14

b. Transplant

Region	Max SARC Expl. Rate	Chosen Expl. Rate	Achieved Expl. Rate	Chosen Trans (# oys)	Achieved Trans (# oys)	Under/ Over #
VLM	3.00%	NONE	NA	0	NA	NA
LM	CLOSED	NONE	NA	0	NA	NA
MMT	2.46%	2.46%	2.37%	8,184,564	7,887,414	-297,150

Table 10. Summary of intermediate transplant data. Transplant conducted in April and May 2017 from the Medium Mortality Transplant region (Upper Middle, Middle, Sea Breeze). 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 2016 port-sampling result of 264 market oysters per bushel. The fraction of oysters < 2.5” did not enter into additional quota allocations for 2017. The fraction of cultch is based on volume and includes shell only, not boxes.

Donor	Receiver	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5”	Number Oysters ≥ 2.5”	Mkt-Equiv. Bu (>2.5”)	Fraction Cultch
Upper Middle	Bennies	3,200	948,685	0.365	602,546	2,282	0.408
Middle	Bennies	21,350	5,625,257	0.312	3,868,205	14,652	0.299
Sea Breeze	Bennies	4,700	1,313,472	0.515	636,920	2,412	0.219
MMT	**Totals**	29,250	7,887,414		5,107,671	19,346	

Table 11. 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. Updated gear efficiency analyses resulted in scalar changes as of the 2016 SAW and inappropriate values for the VLM. 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 12. Color coded summary status of the stock for 2017 using percentiles, 5-year medians, and other reference points. See text for detailed explanation. Note: recruitment uses 2015-2017 average vs. 1990-2017 median; mortality rate uses 2017 rate vs.1990-2017 mean; Dermo WP compares 2017 level to those known to cause mortality. VLM time series and reference points are not based on same parameters as other regions'.

2017 Metrics	*Transplant* Very Low Mortality	*Transplant* Low Mortality	*Transplant* Medium Mortality	*Market* Medium Mortality	*Market* Shell Rock	*Market* High Mortality
Total Abundance						
Percentile	1.000	0.732	0.875	0.696	0.911	0.375
vs. 5-yr Median						
vs. Target-Thresh						
Market Abundance						
Percentile	0.500	0.889	1.000	0.778	0.889	0.778
vs. 5-yr Median						
vs. Target-Thresh						
Recruitment						
Percentile	1.000	1.000	0.911	0.875	0.839	0.411
vs. 5-yr Median						
3-yr Avg vs. Median						
Mortality						
Percentile	0.136	0.000	0.089	0.125	0.089	0.232
vs. 5-yr Median						
Rate	0.037	0.036	0.081	0.102	0.097	0.182
Dermo WP						
Percentile	0.227	0.161	0.865	0.839	0.875	0.375
vs. 5-yr Median						
Level	0.00	0.17	2.43	2.85	3.00	1.96

Color Key:

Green	Improved relative to 1990–2017 time series (2007-2017 for VLM), 2012–2016 median, or other reference points.
Orange	Degraded relative to 1990–2017 time series (2007-2017 for VLM), 2012–2016 median, or other reference points.
Yellow	Unchanged; 40th - 60th percentiles of 28-yr time series (11-yr for VLM); within 15% or 1 SEM of reference points, 1.5-2.0 for dermo WP.

Table 13. Direct Market quota projections for 2018. Exploitation rates based on realized rates from 2007-2015 harvests (Min=lowest rate; Median=middle rate; Max=highest rate). Numbers to be removed based on survey abundance of ≥2.5" oysters by region. Quota projections use the average oysters per marketed bushel (263) derived from the 2004-2017 port-sampling program. Arrows indicate highest SARC-recommended option in each region. Lower exploitation rates are implicitly acceptable to the SARC; higher rates are not. Shaded areas require that Intermediate Transplant must occur at any rate down to the transplant-not-required arrow.

Direct Market Regions	**Label**	**Exploit. Rate**	**# Oys Removed**	**Quota bu**
Med Mort Mkt	Min	1.80%	4,491,810	17,079
		2.50%	6,238,625	23,721
	Median	3.03%	7,561,213	28,750
		3.48%	8,695,395	33,062
	Max→	3.70%	9,233,165	35,107
Shell Rock	Min	2.34%	3,973,418	15,108
		2.96%	5,026,204	19,111
	Median	3.70%	6,282,755	23,889
		4.26%	7,225,168	27,472
	Max→	4.88%	8,286,444	31,507
High Mortality	Min	4.81%	4,802,018	18,259
	→	5.50%	5,490,873	20,878
		6.50%	6,489,213	24,674
	Median	7.49%	7,477,570	28,432
		8.50%	8,485,894	32,266
	→	8.99%	8,973,084	34,118
	Max	9.82%	9,803,704	37,276

Table 14. Projections for intermediate transplanting in 2018. Exploitation rates based on realized rates from 2007-2015 transplants (Min=lowest rate; Median=middle rate; Max=highest rate).[1] Numbers to remove based on all sizes of oysters from current survey. Conversion to deck bushels derived from mean oysters per bushel from past transplants.[2] Cullers are used for transplants. Estimated quota bushels based on current survey fraction of oysters ≥2.5", using 263 oysters/bu derived from the 2004-2017 port-sampling program. Arrows indicate highest SARC-recommended option in each region. Lower exploitation rates are implicitly acceptable to the SARC; higher rates are not.

Transplant Regions	Label	Exploit. Rate	# Oys Removed	Approx. Deck bu	Estimated Quota bu
Very Low Mort.		1.93%	3,503,086	6,114	1,493
	→	2.32%	4,203,703	7,336	1,791
		2.70%	4,904,320	8,559	2,090
	Min	3.73%	6,770,212	11,815	2,885
	Middle	3.86%	7,006,171	12,227	2,985
	Max	4.32%	7,841,103	13,684	3,341
Low Mortality	Min	0.76%	3,486,696	7,731	3,572
		1.49%	6,824,289	15,131	6,990
	Median	1.75%	8,028,576	17,802	8,224
	→	2.01%	9,232,862	20,472	9,458
	Max	2.26%	10,368,332	22,990	10,621
Med Mort Trans.	Min	1.03%	6,609,469	20,400	7,436
		1.69%	10,854,288	33,501	12,211
	Median	1.99%	12,769,750	39,413	14,366
		2.29%	14,685,213	45,325	16,521
	Max→	2.46%	15,785,722	48,721	17,759

[1] VLM-3 rates; LM-8 rates; MMT-9 rates. VLM rates are higher; they occurred prior to gear efficiency estimates for VLM so abundance was miscalculated.

[2] Estimates of deckload oys/bu determined from all previous culled transplants: VLM-average of 3; LM-average of 15; MMT-average of 26. Actual numbers for 2018 may not be similar.

Figure 1. The natural oyster beds of Delaware Bay, NJ grouped by regional designations. The six regions are named based on mortality patterns 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.

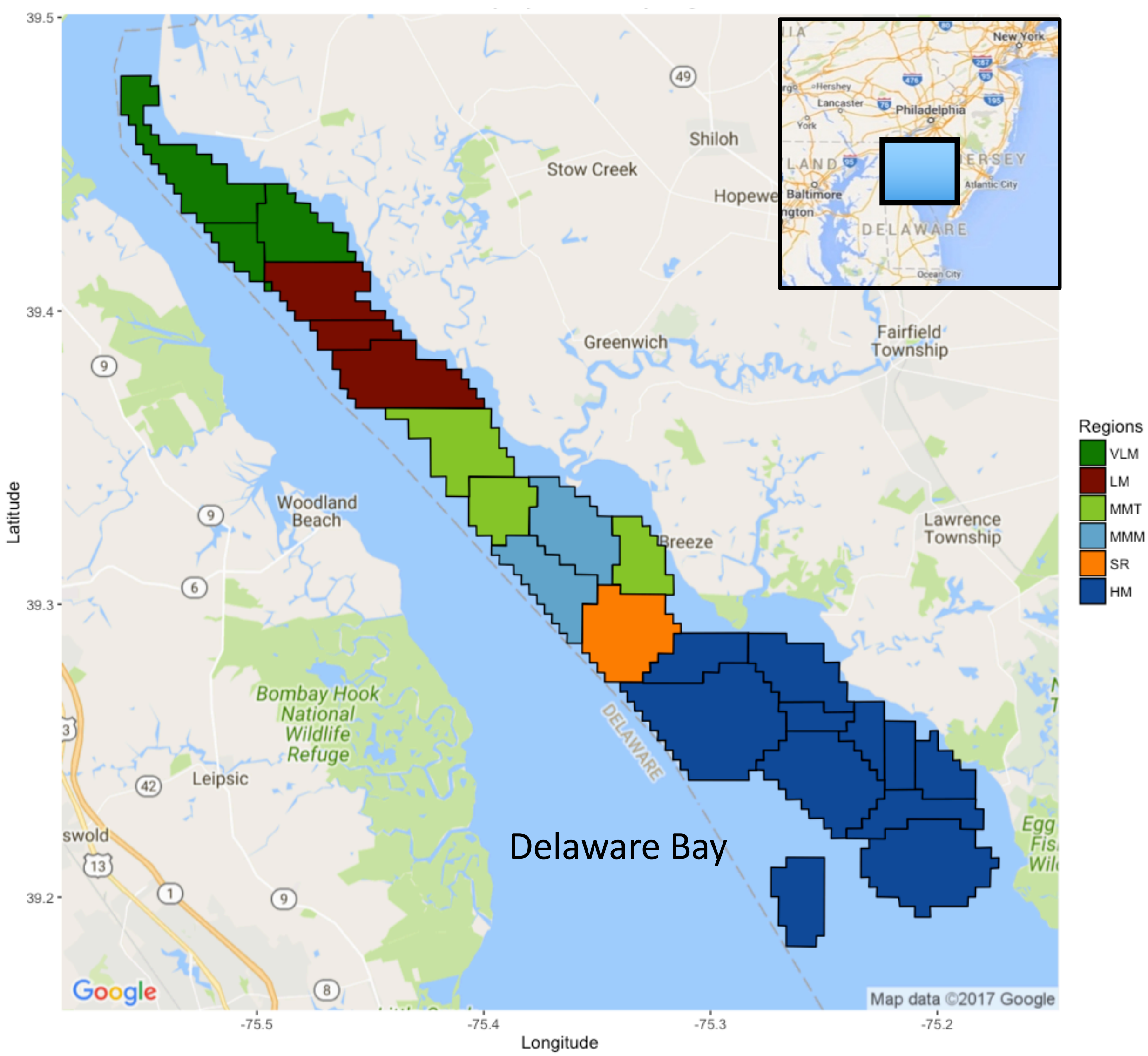


Figure 2. Regional acreage and proportional distribution of the assessed NJ Delaware Bay oyster resource. Regions are organized upbay to downbay clockwise from the VLM. The VLM, LM, and MMT contain three beds each and are termed Transplant regions. The Direct Market regions are the MMM made up of two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

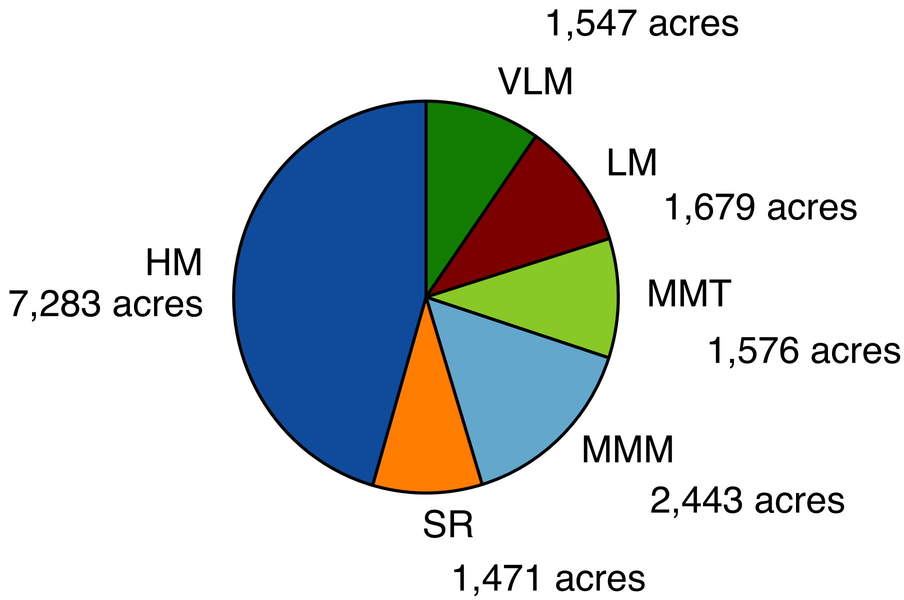
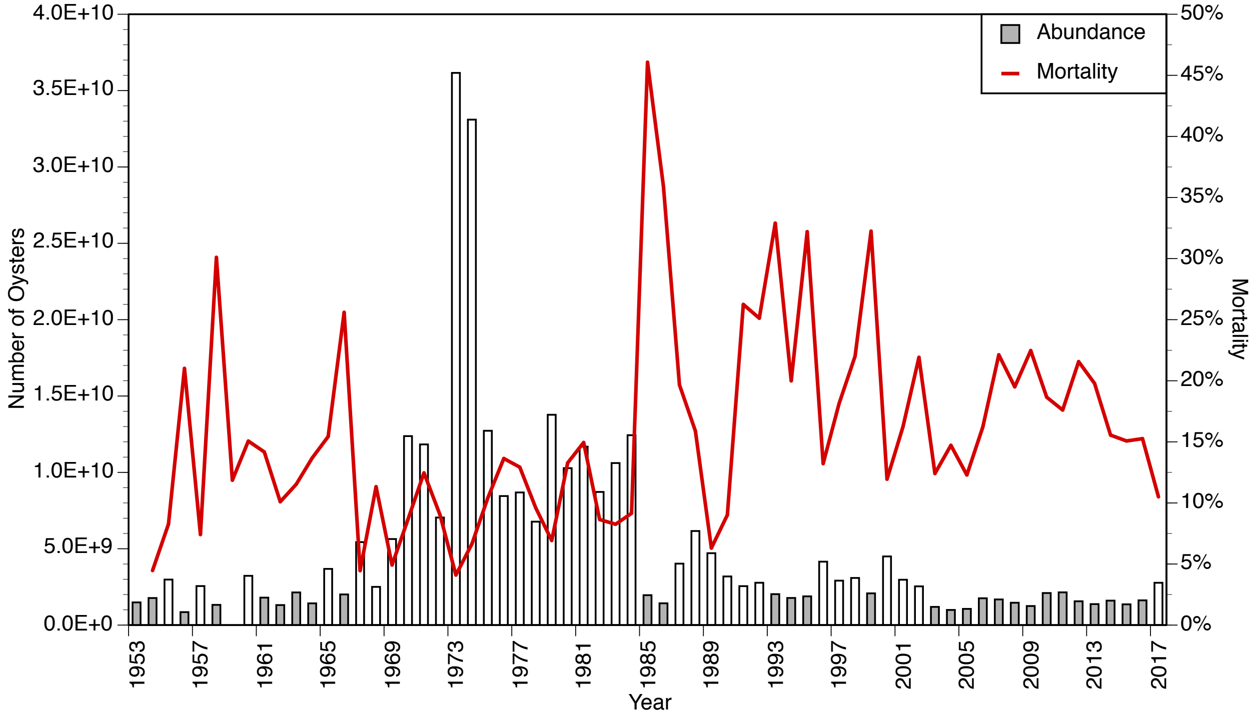


Figure 3. Time series of total oyster abundance (left axes) compared to natural mortality rate (a, right axis) and fishing mortality (b, right axis). Time series of 1953–2017 stock surveys excludes the VLM.

a.



b.

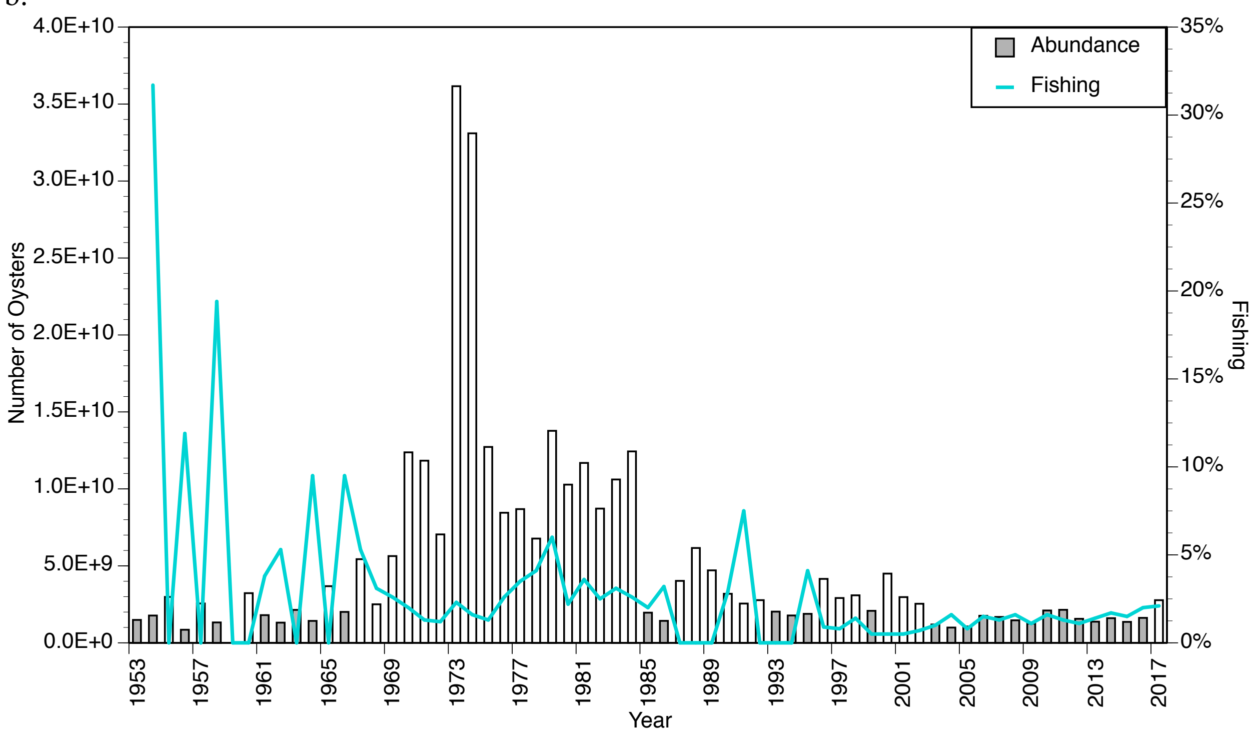
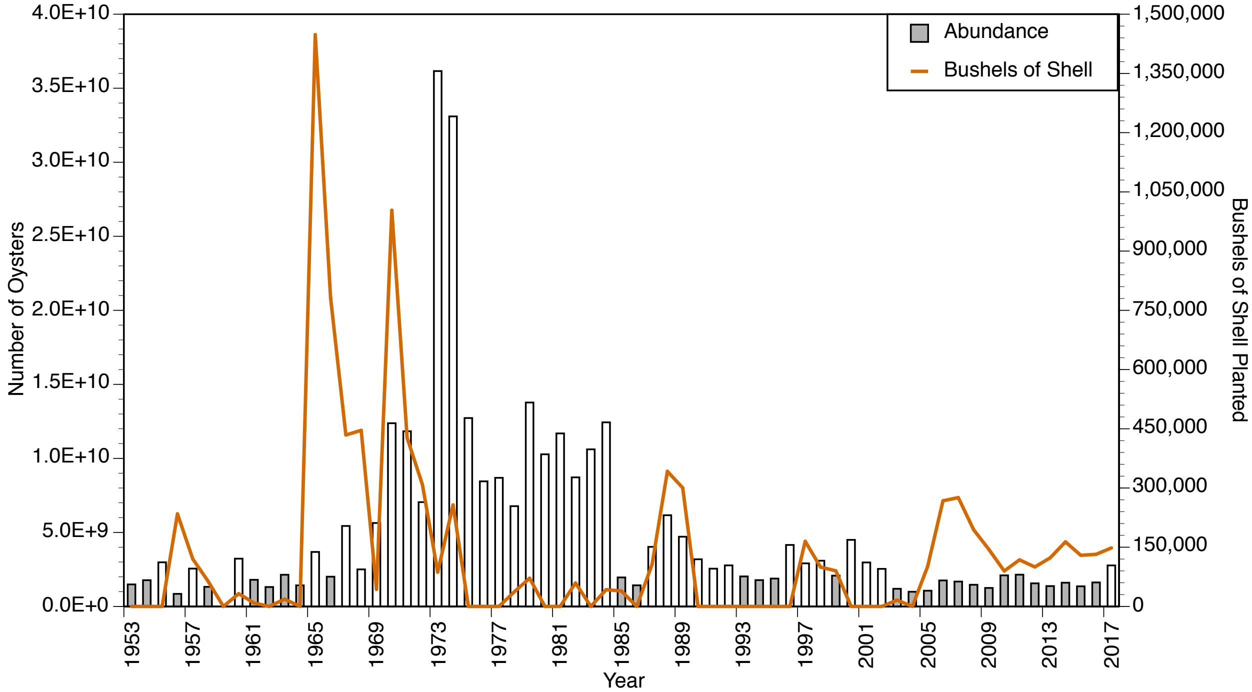


Figure 4. Time series of total oyster abundance (left axes) compared to bushels of shell planted for spat recruitment (a, right axis) and number of spat from the stock assessment time series (b, right axis). Time series of 1953–2017 stock surveys excludes the VLM.

a.



b.

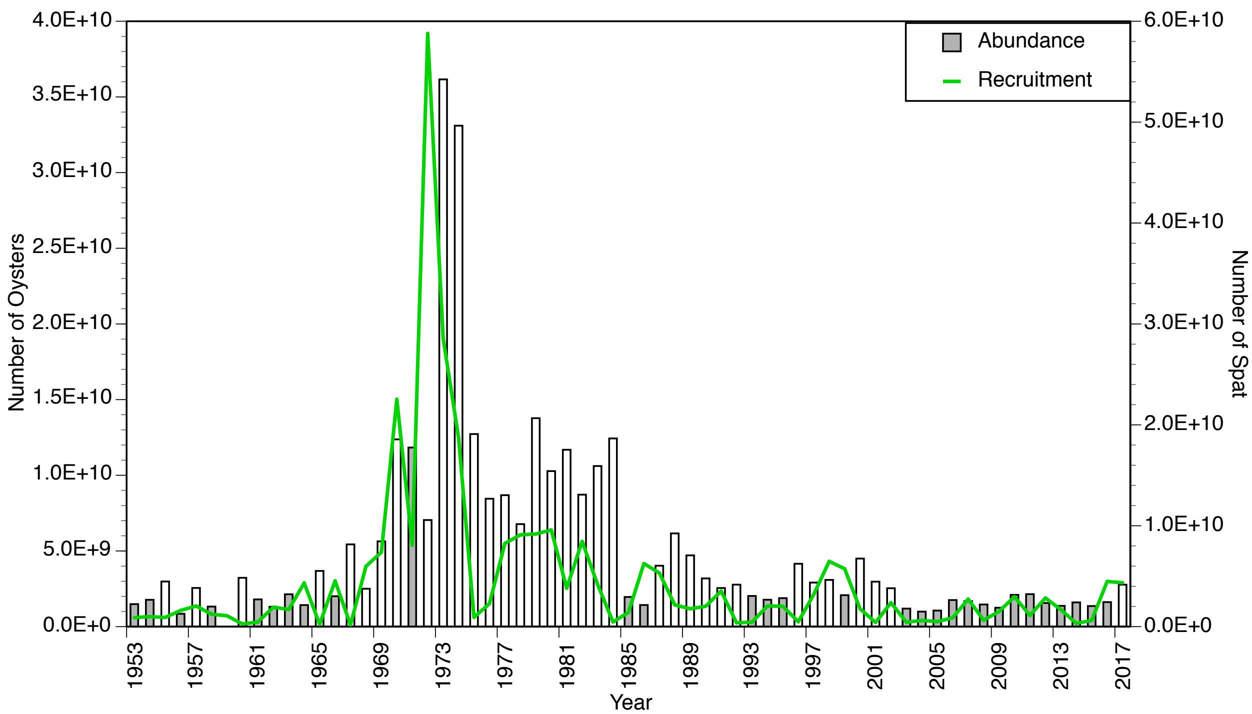


Figure 5. Number of oysters harvested from the natural oyster beds of Delaware Bay, NJ from 1953–2017. Prior to 1996, the bay-season fishery removed oysters from the natural beds and transplanted them downbay to leased grounds. Zeros represent years of fishery closure.

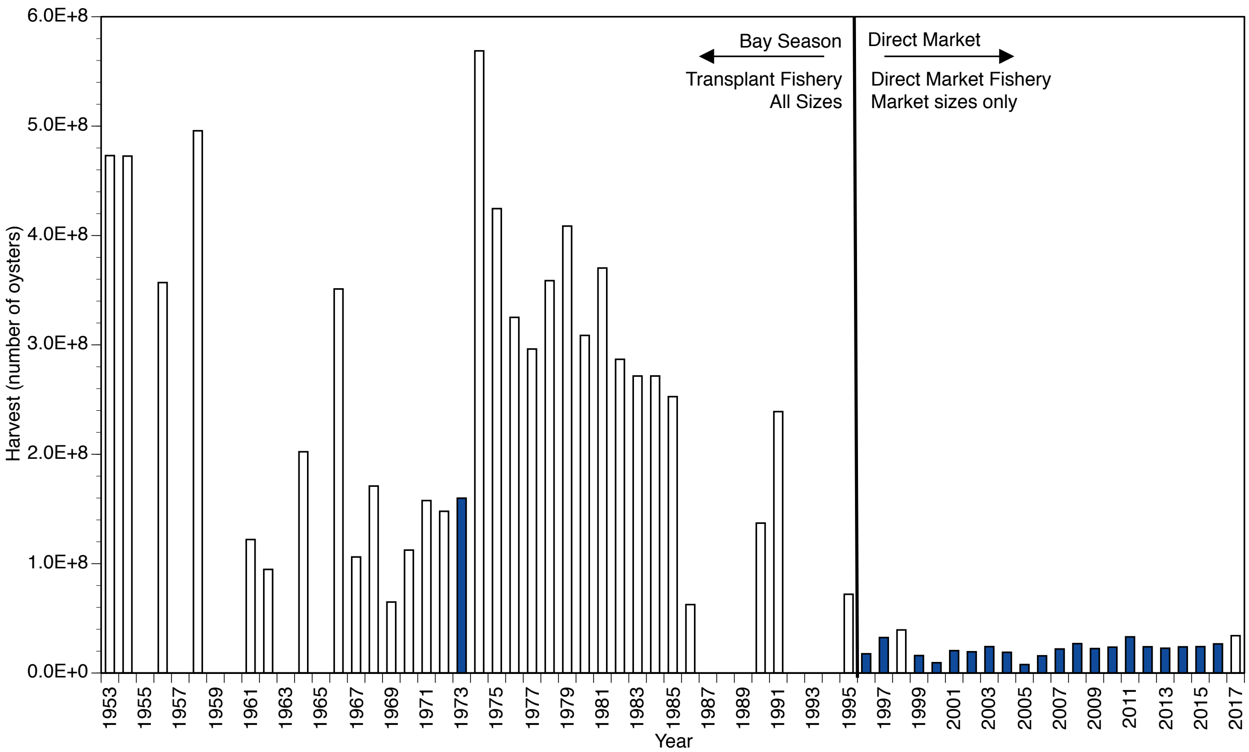


Figure 6. The assessed oyster beds of Delaware Bay, NJ grouped as regions (see Legend) with the 2017 strata designations. White outlines indicate complete boundary of each bed with the high and medium quality strata grids in dark and light colors, respectively. The colors indicate region groupings although 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).

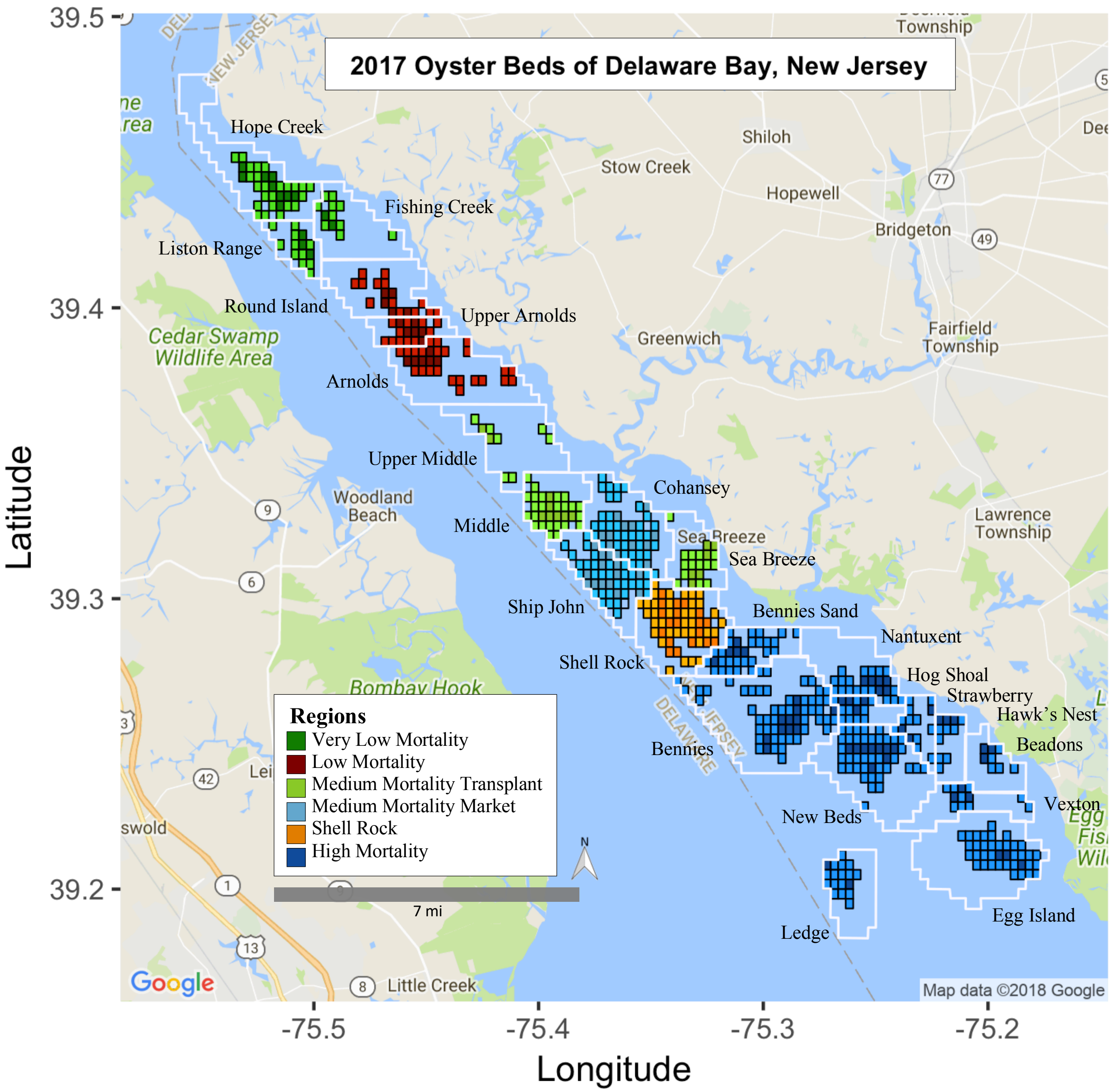
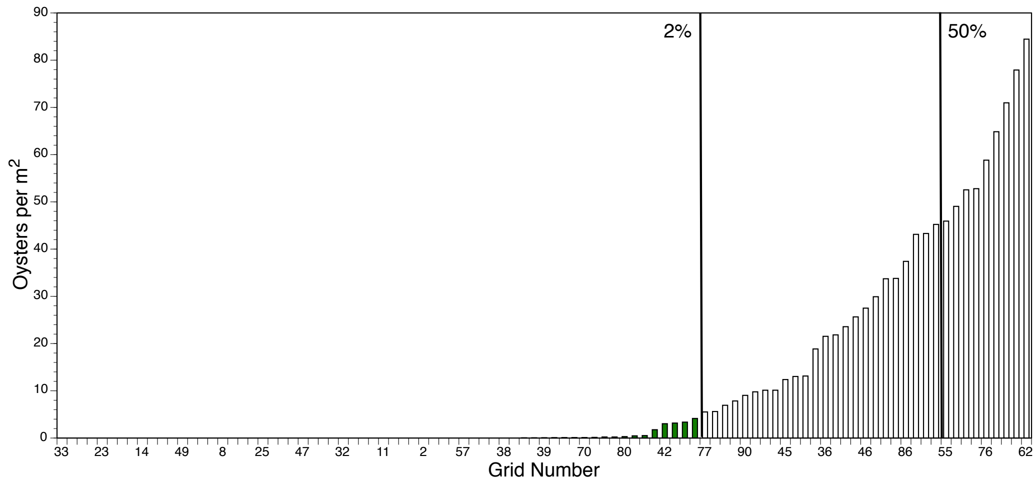
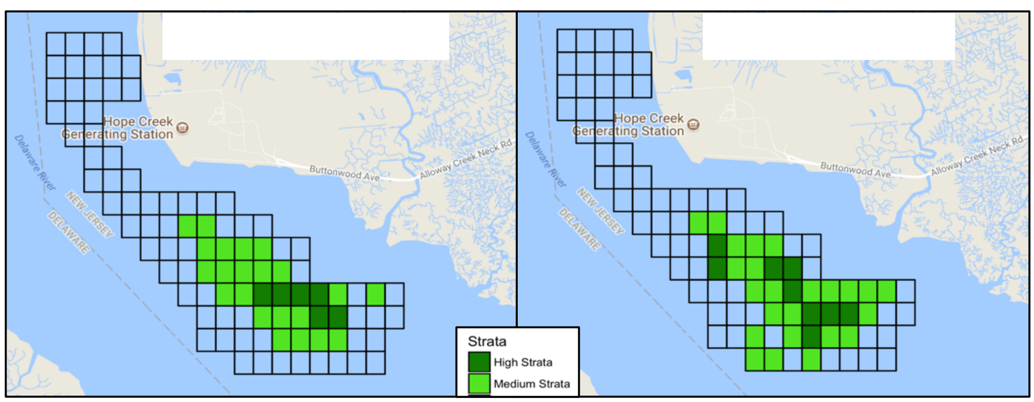


Figure 7. Hope Creek 2017 restratification survey results. (a) Grids arranged in cumulative oyster per m^2 density order with low (2%) and high (50%) quality stratum cutoffs marked. (b) Grid map strata for resurveys done in 2007-2008 and in 2017. Light blue grids make up the low quality stratum. (c) Percentiles of oyster densities per m^2 for the 2007-2008 and 2017 resurveys.

a.



b.



c.

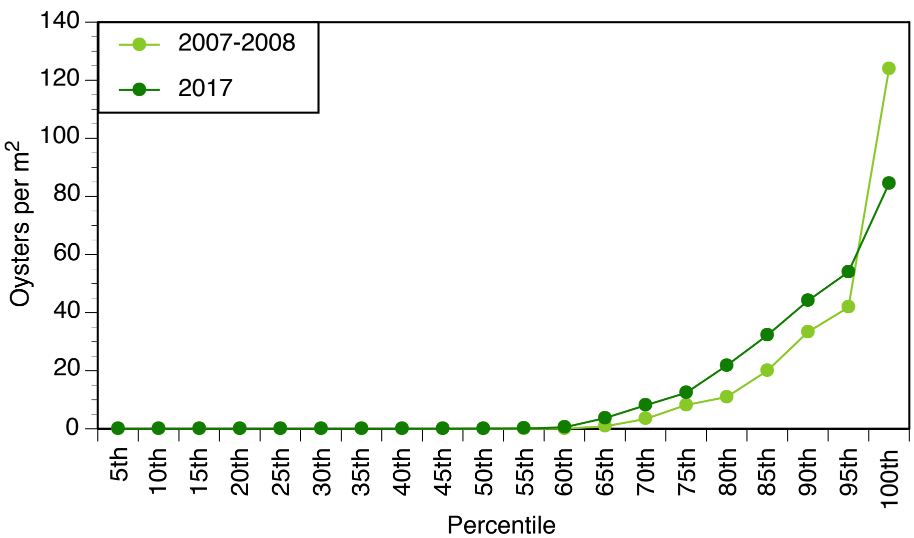
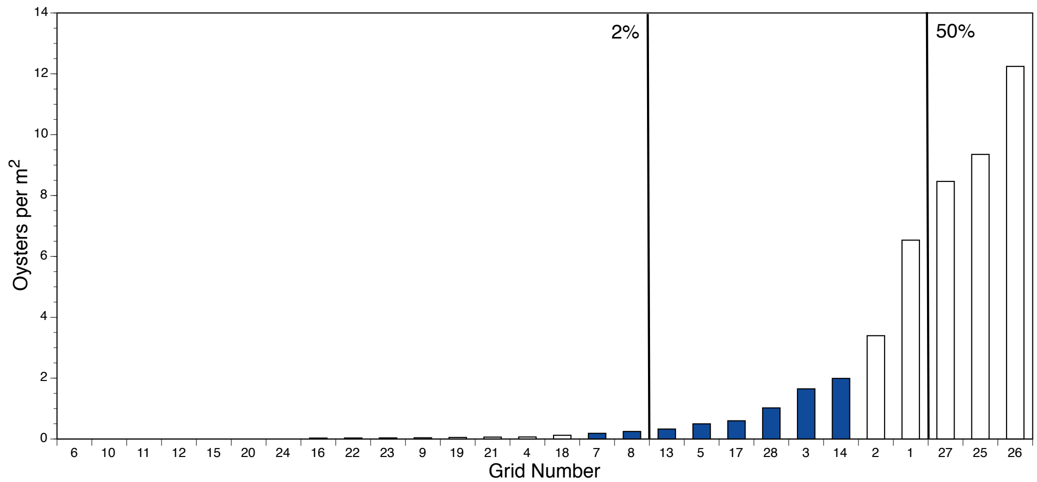
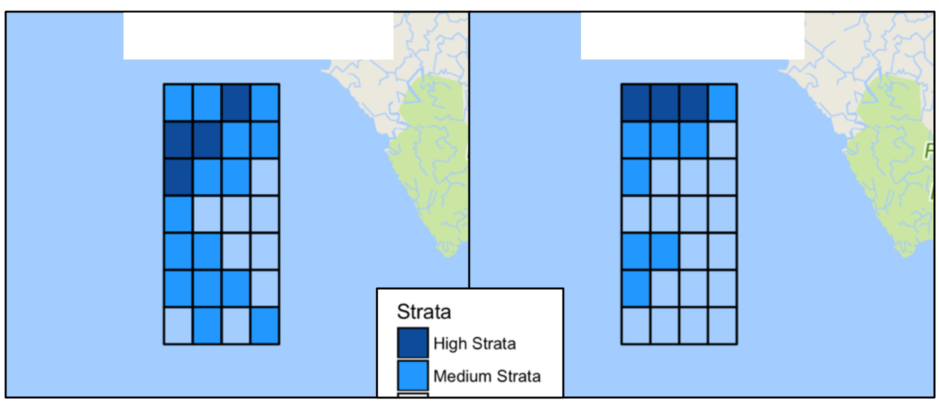


Figure 8. Hawk's Nest 2017 restratification survey results. (a) Grids arranged in cumulative oyster per m^2 density order with low (2%) and high (50%) quality stratum cutoffs marked. (b) Grid map strata for resurveys done in 2006 and in 2017. Lightest blue grids make up the low quality stratum. (c) Percentiles of oyster densities per m^2 for the 2006 and 2017 resurveys.

a.



b.



c.

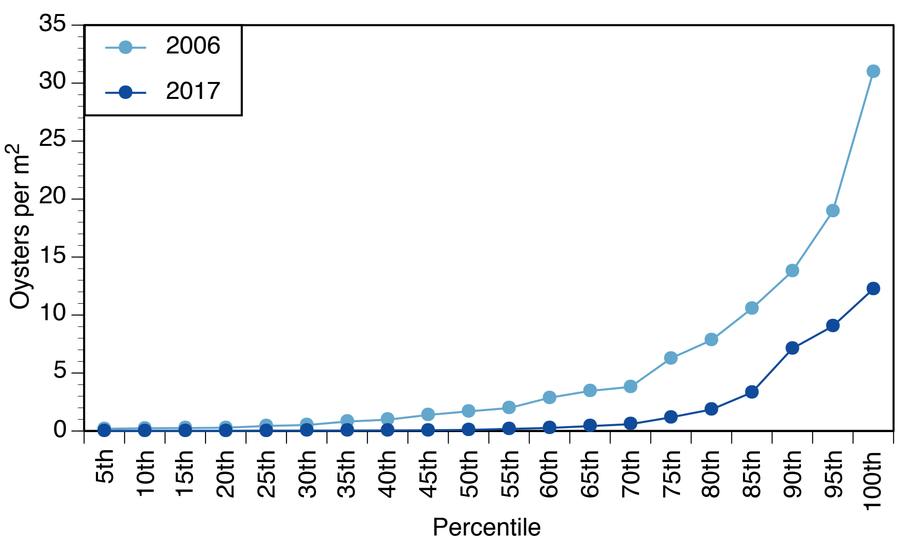


Figure 9. Map of the 2017 oyster stock assessment sample sites. Sampling intensity and types correspond to those found in Table 5. Black dots are sites from the high quality stratum on each bed and white dots are sites from the medium quality stratum on each bed. Red dots indicate transplant enhancement sites and green dots indicate shellplant enhancement sites.

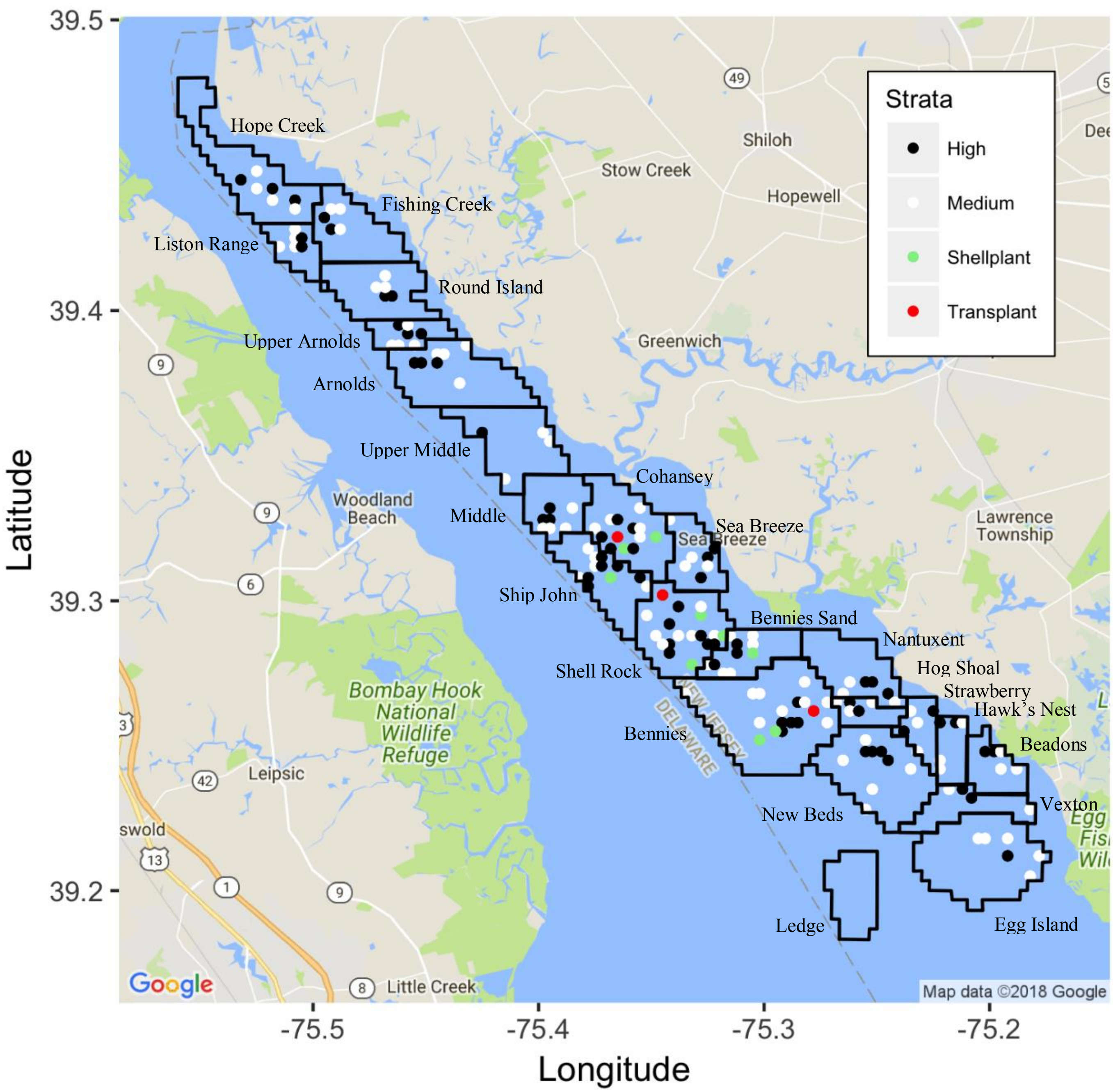


Figure 10. Total stock metrics for all regions 2007-2017: a. total abundance (≥ 20 mm), b. size class abundances (≥ 20 mm), c. box-count mortality rate, and d. spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell.

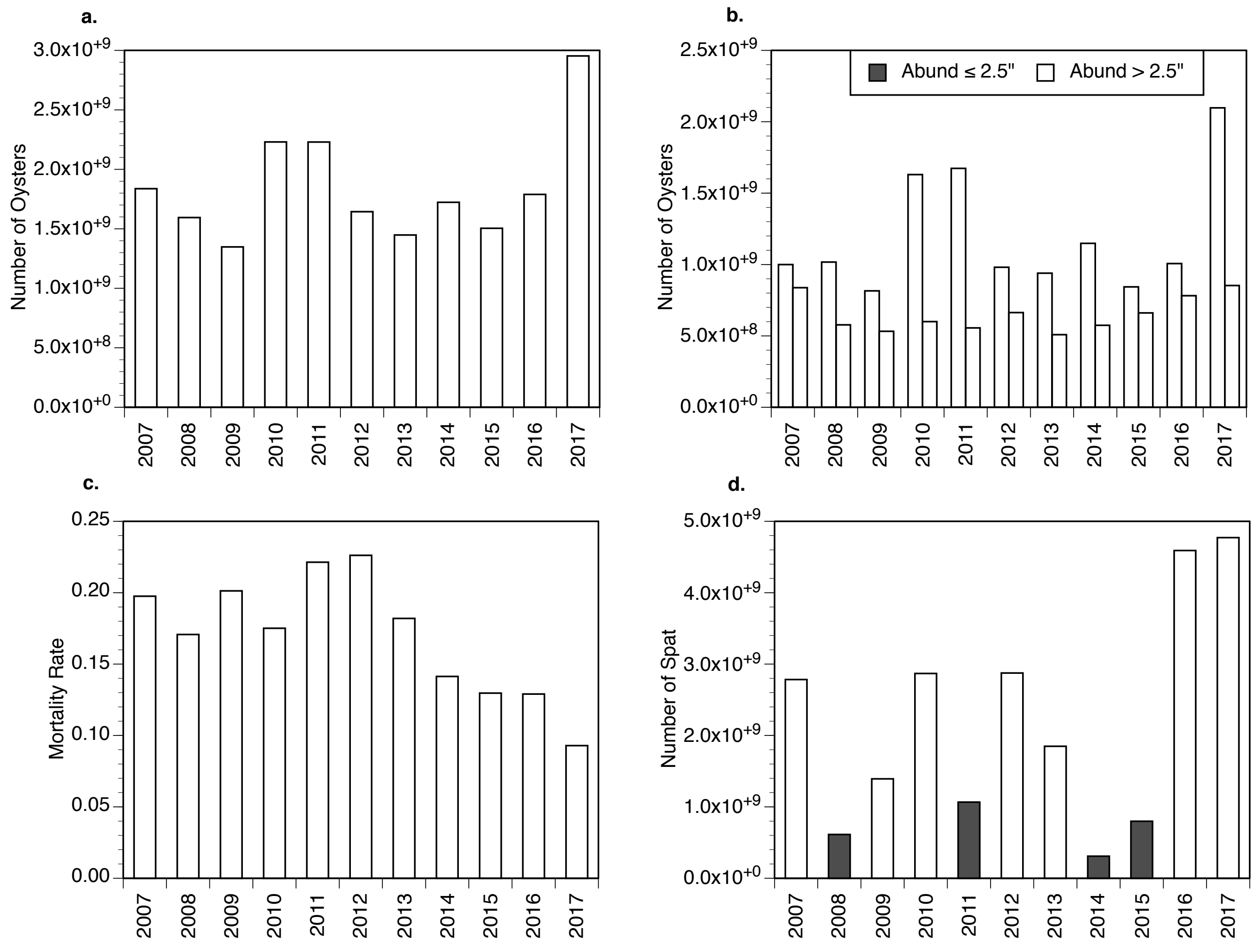
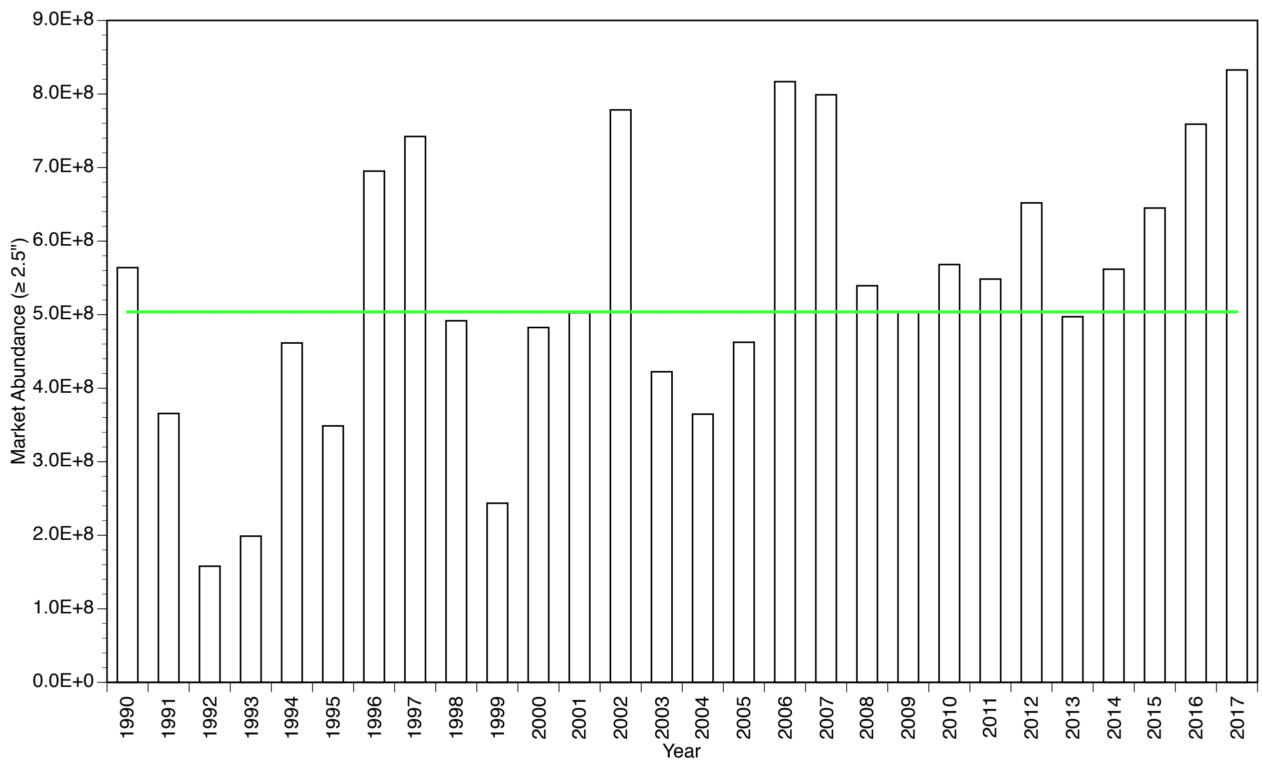


Figure 11. Total stock metrics not including VLM for the 1990-2017 time series: a. Number of market-size oysters (> 2.5 inches). Green line is the median value for the time series, 5.04 x 10^8, b. abundance of small and market size oysters (stacked bars) overlaid with box-count mortality.

a.



b.

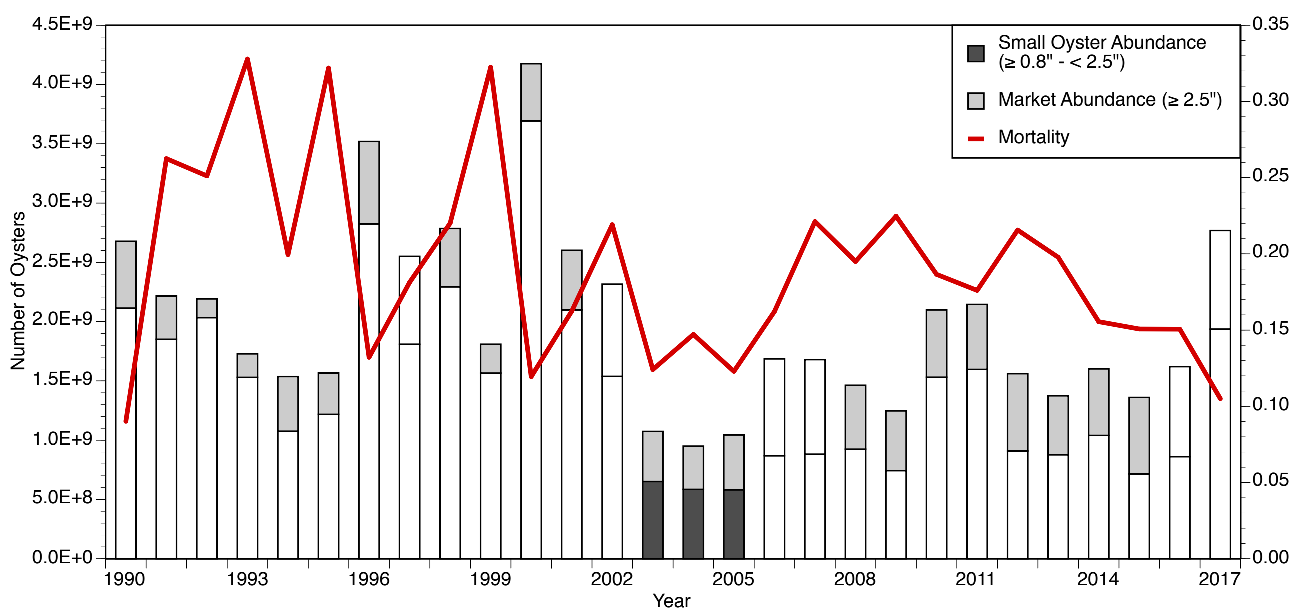
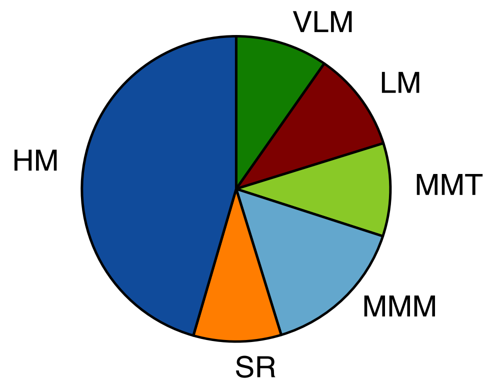
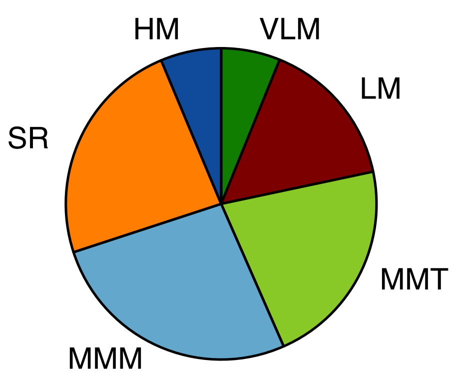


Figure 12. 2017 Oyster metrics. (a) acreage, (b) total abundance, (c) market abundance (≥ 2.5"), (d) spat abundance (< 0.8"), and (e) mortality by region.

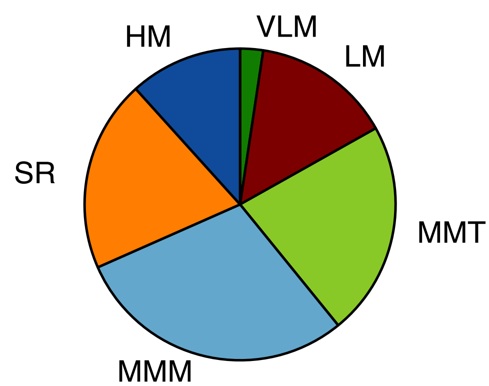
a. Acreage



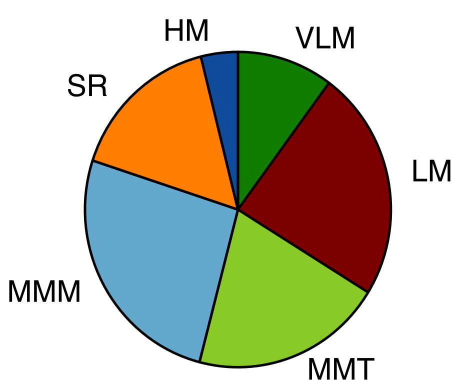
b. Total Abundance



c. Market Abundance



d. Spat Abundance



e. Box-count Mortality

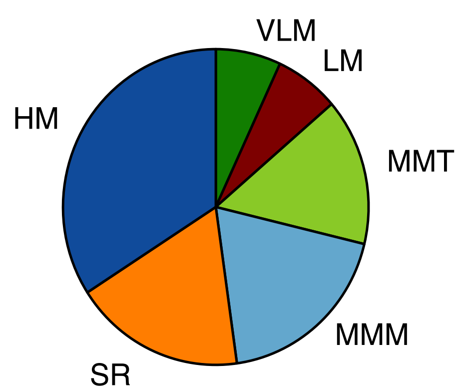


Figure 13. Ten-year time series summary for the VLM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

Very Low Mortality

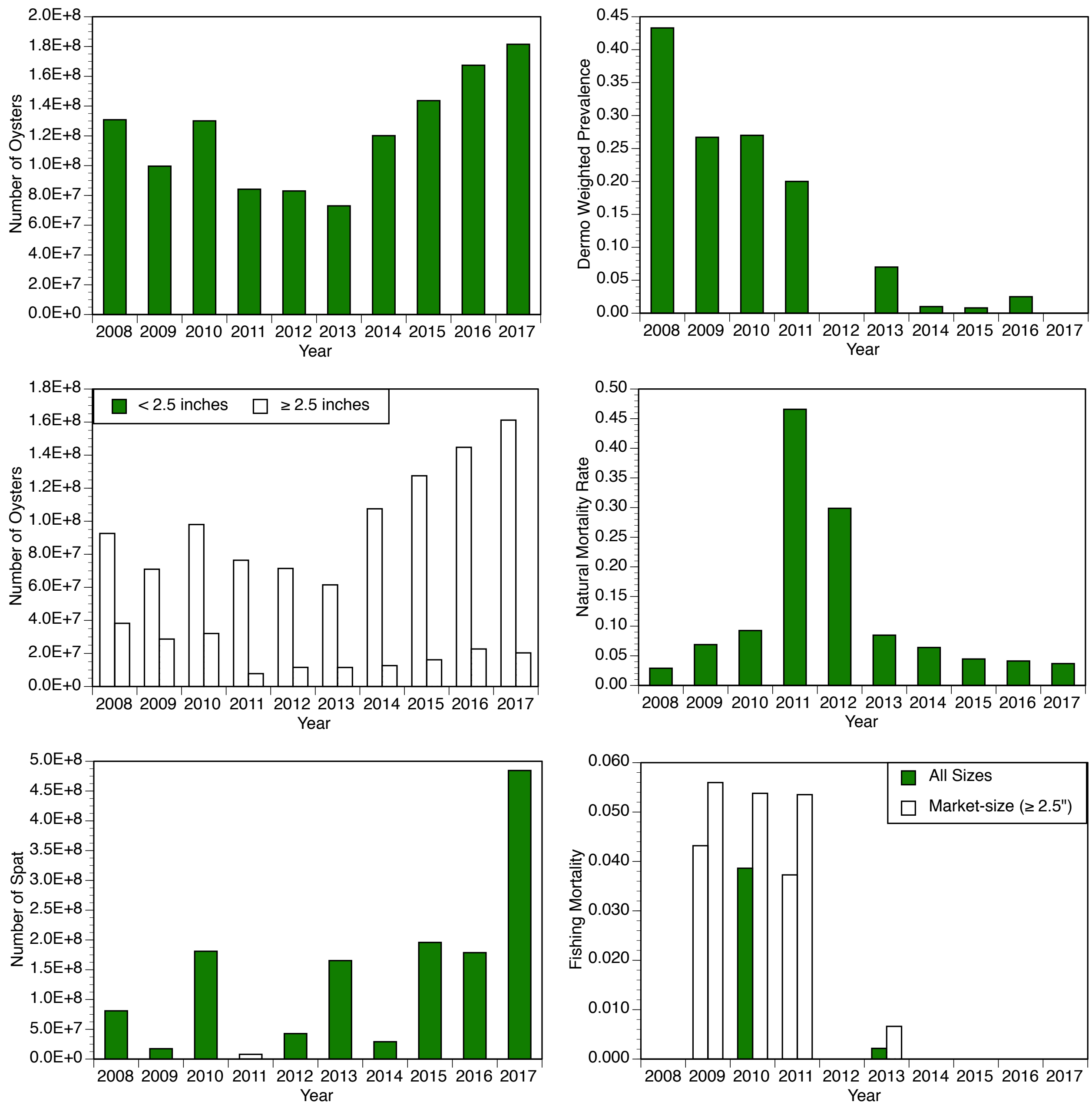


Figure 14. Ten-year time series summary for the LM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

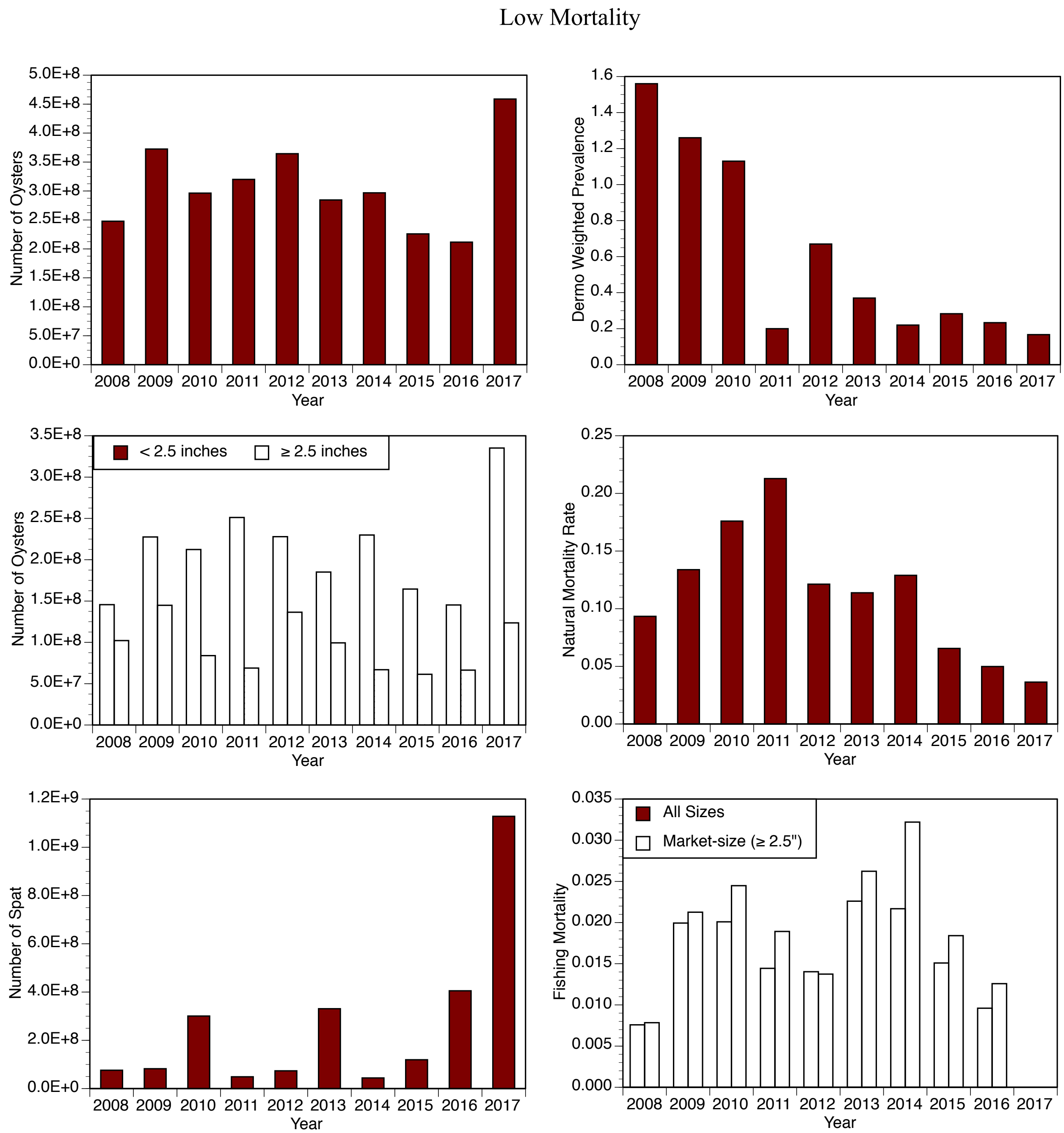


Figure 15. Ten-year time series summary for the MMT. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

Medium Mortality Transplant

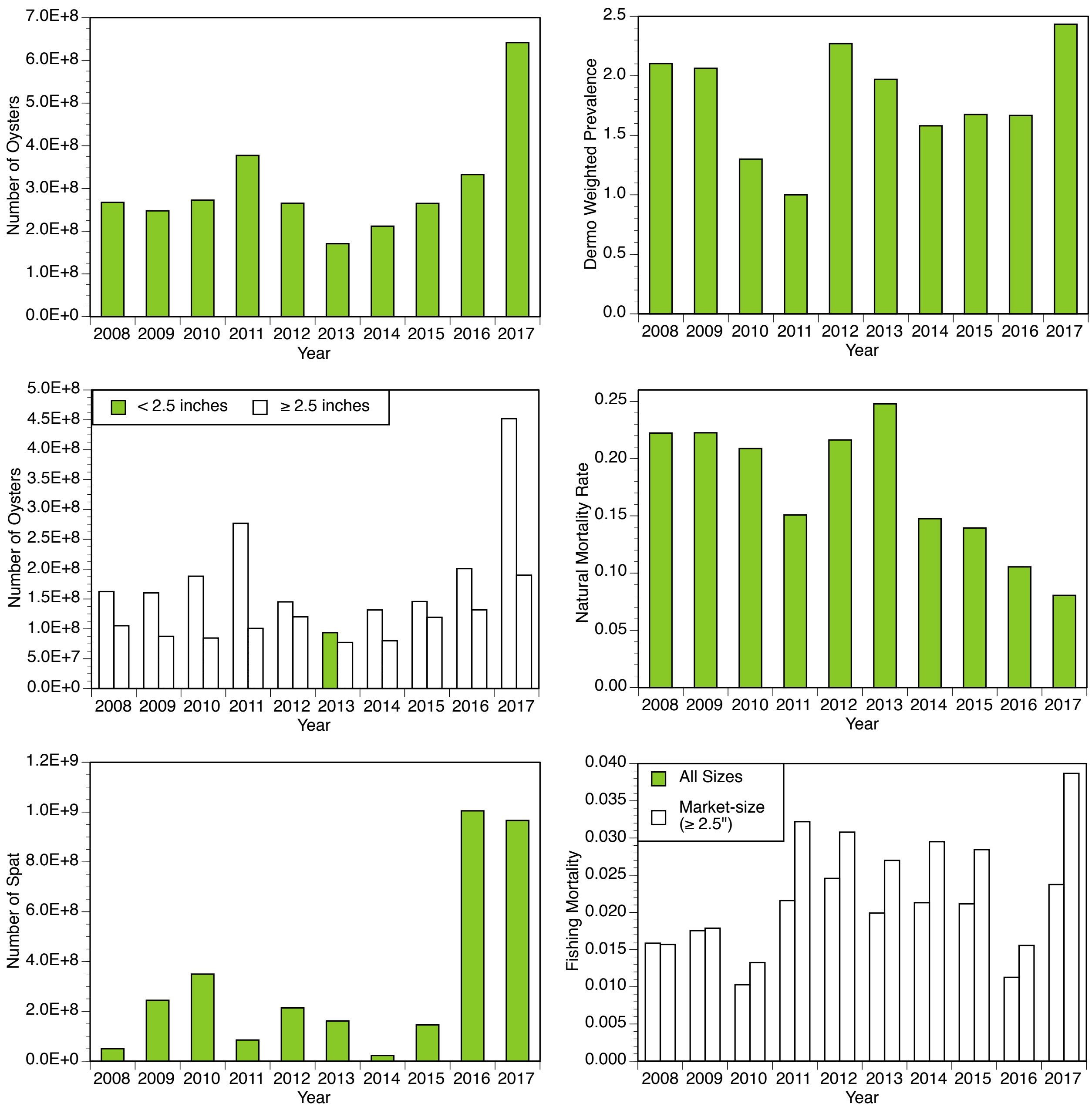


Figure 16. Ten-year time series summary for the MMM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5") abundance.

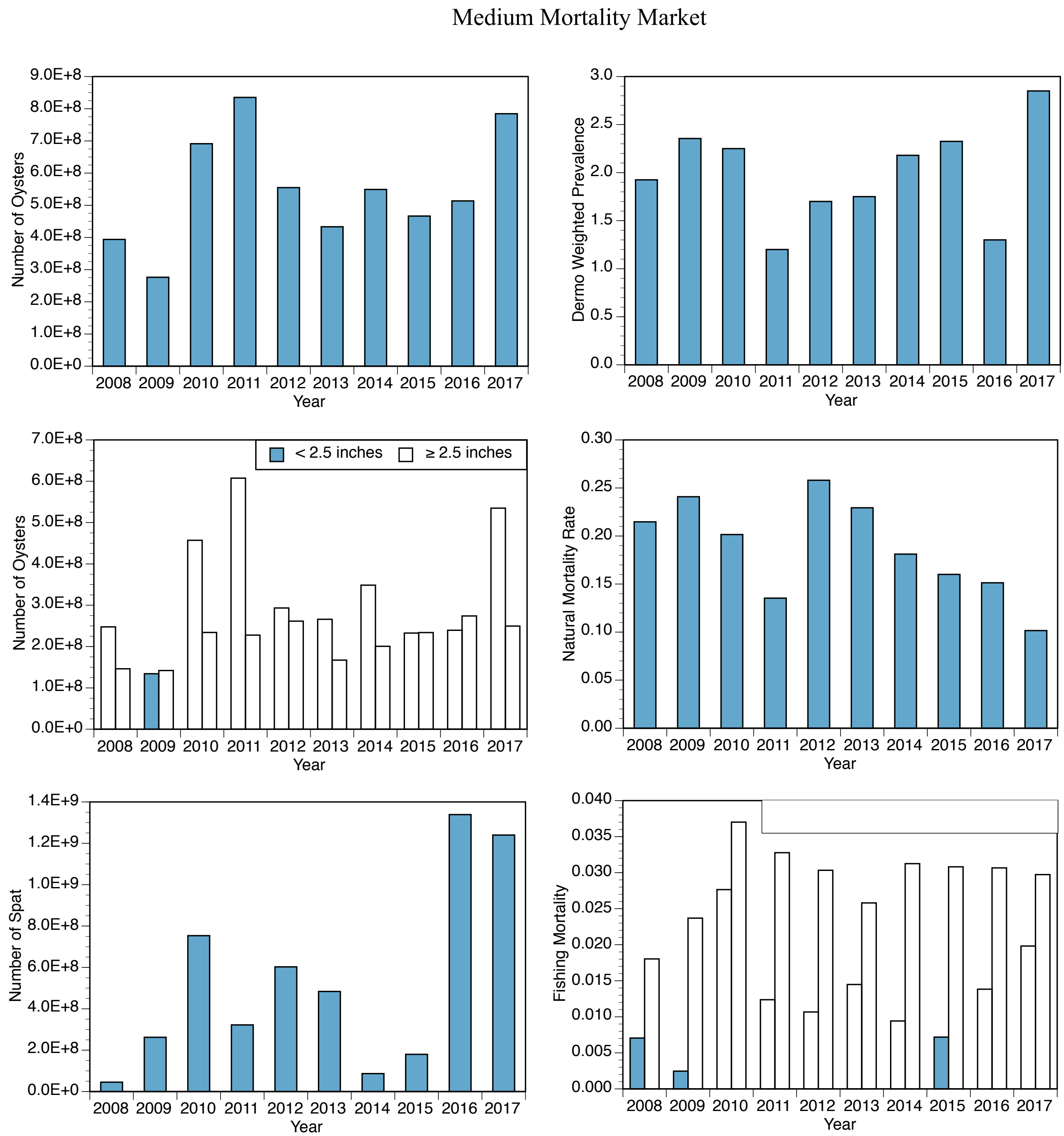


Figure 17. Ten-year time series summary for the SR. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

Shell Rock

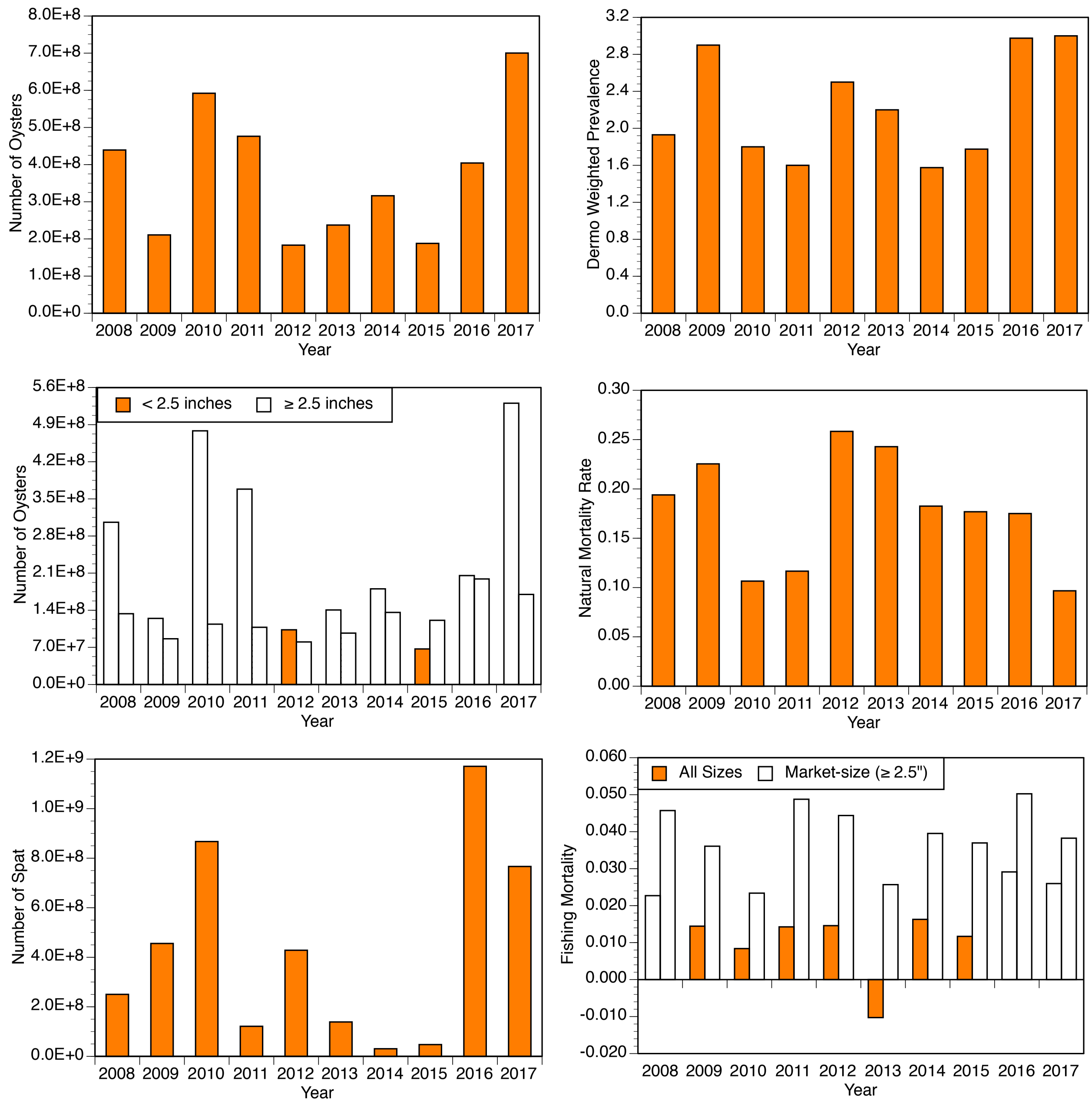


Figure 18. Ten-year time series summary for the HM. Left panel: total abundance (≥ 20 mm), size class abundances (≥ 20 mm), and spat abundance (< 20 mm). Spat abundance does not include spat recruited to planted clamshell. Right panel: Dermo levels, box-count mortality rate and fishing mortality rate relative to both total (≥ 20 mm) and market-size (≥2.5”) abundance.

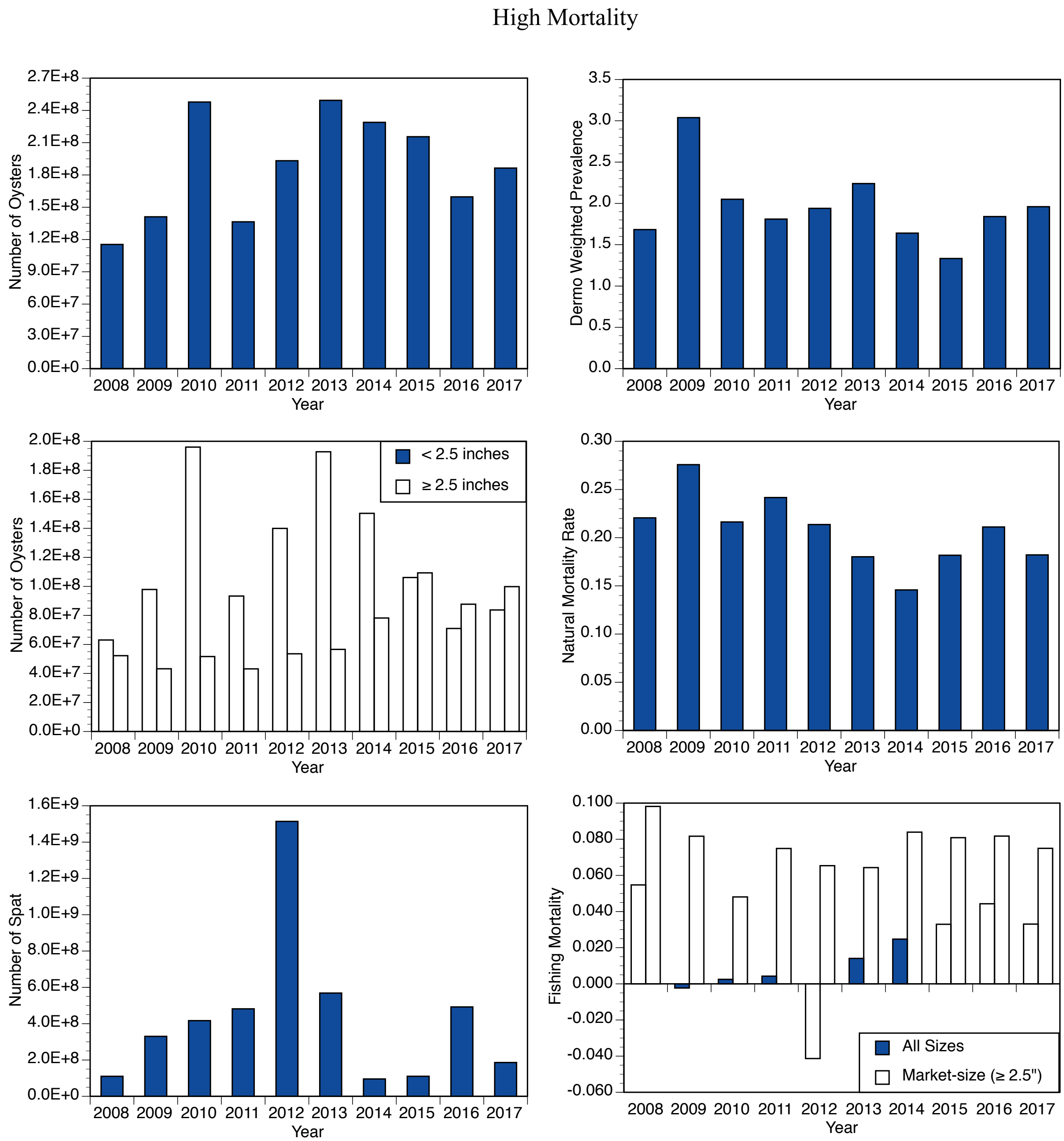
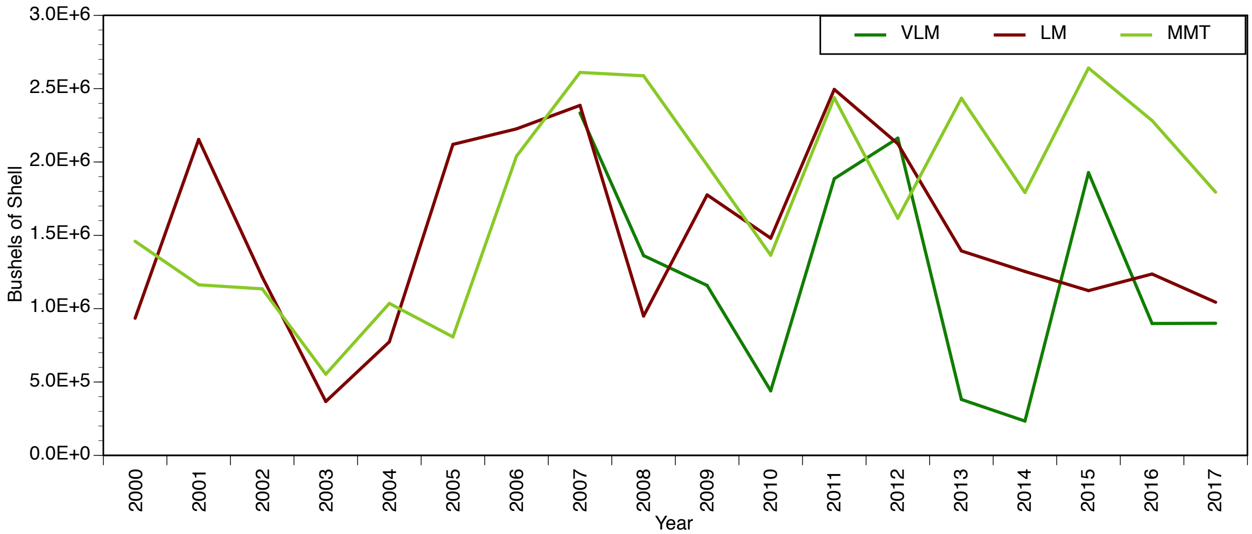


Figure 19. Total bushels of cultch (native shell and boxes) from 2000-2017 on (a) transplant regions (VLM, LM, MMT) and (b) market regions (MMM, SR, HM). Note that assessment stratum designations are based on oyster densities and that low quality strata are not sampled but it is possible that they contain significant amounts of shell.

a.



b.

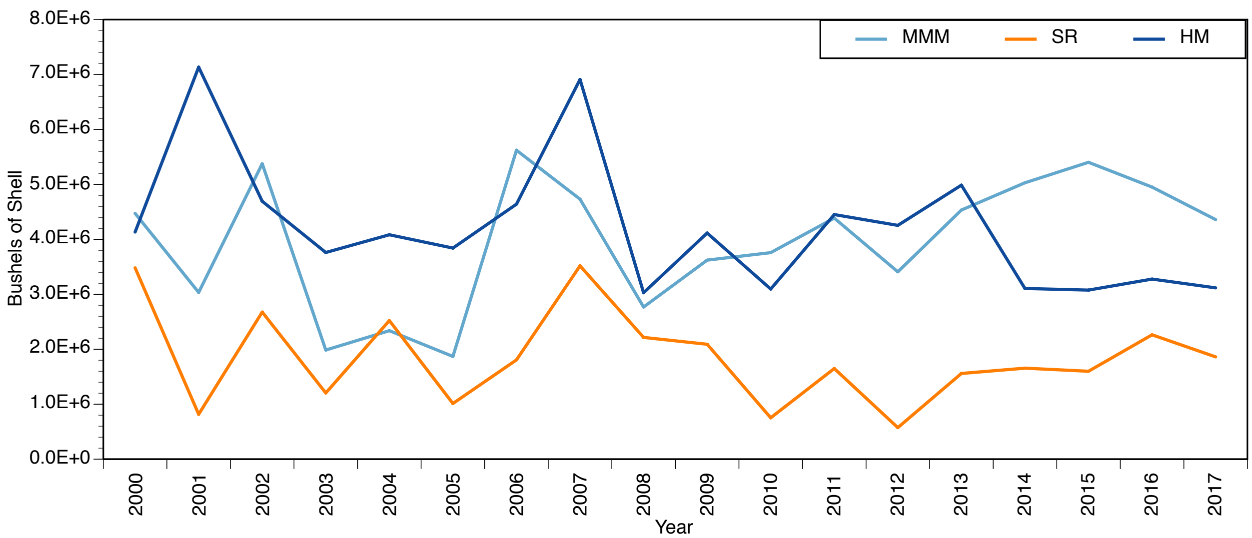


Figure 20. Spat transition size study results. Shell height at which logistic regression models predict 50% probability of morphological transition from spat to oyster for each region. Line at 20mm indicates the spat cutoff size used in the assessment.

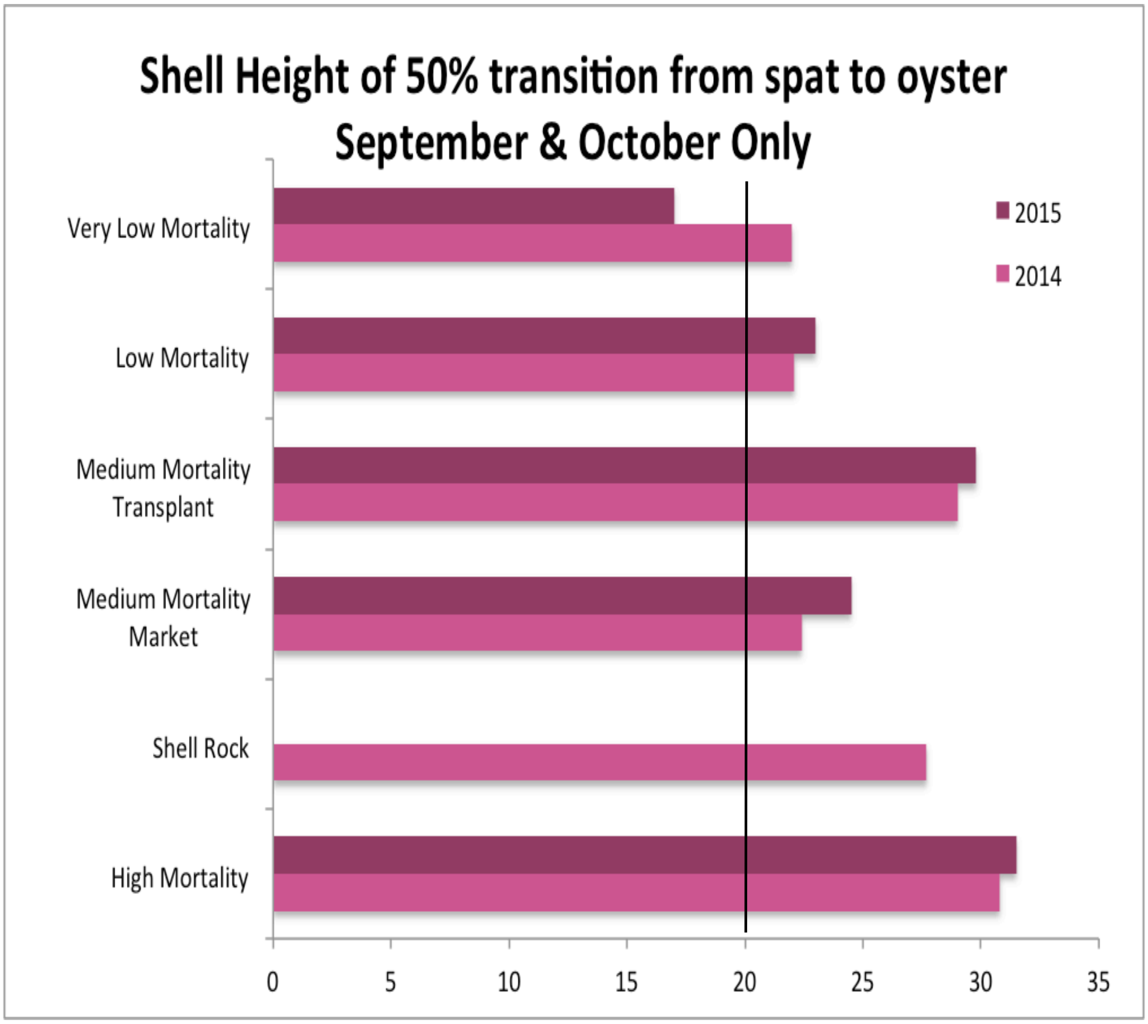


Figure 21. Fall Dermo disease as weighted prevalence (line) and natural mortality (bars) on transplant and market regions in Delaware Bay, NJ.

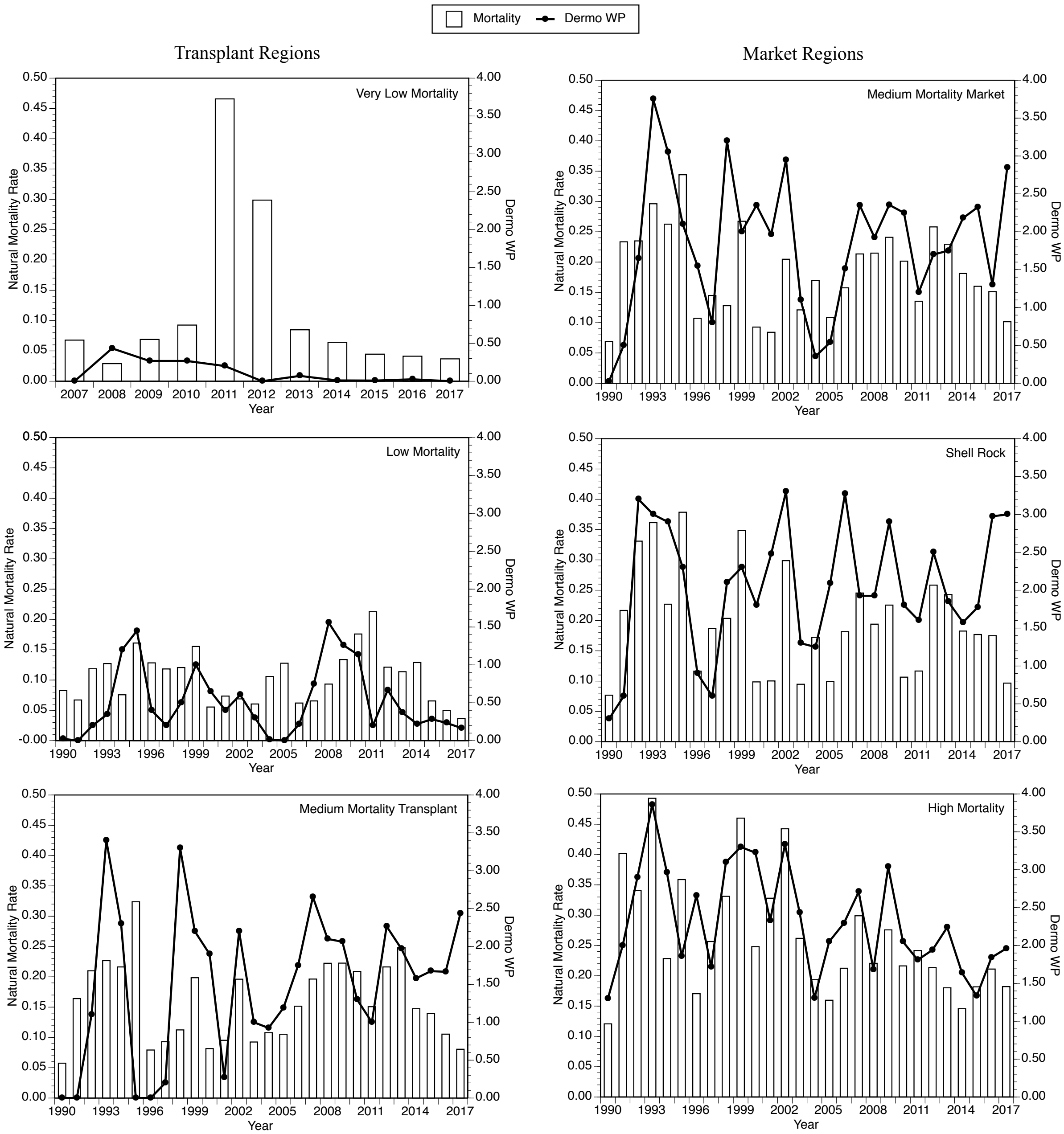
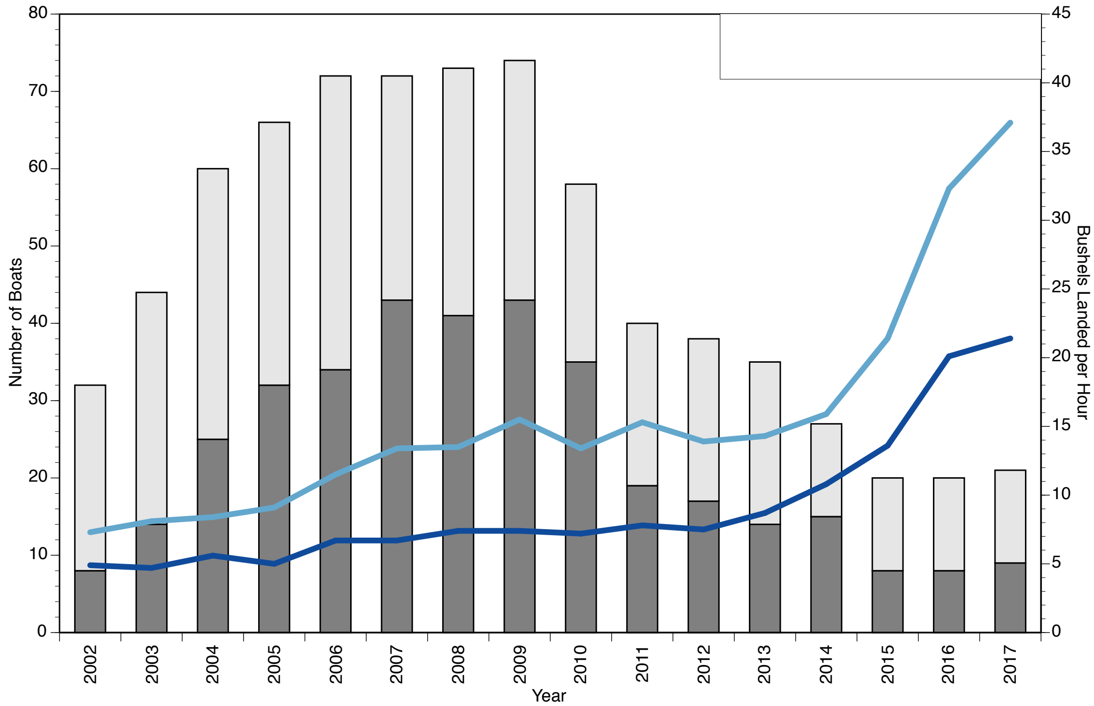


Figure 22. a. Numbers of 1- and 2-dredge boats (stacked bars) participating in the NJ Delaware Bay oyster harvest overlaid with landings-per-unit-effort (LPUE) calculated as bushels landed per hour for 1- and 2-dredge boats. b. Fraction of market-size (>2.5") abundance that is >3" (bars) in direct market regions (MMM, SR, HM) overlaid with LPUE lines.

a.



b.

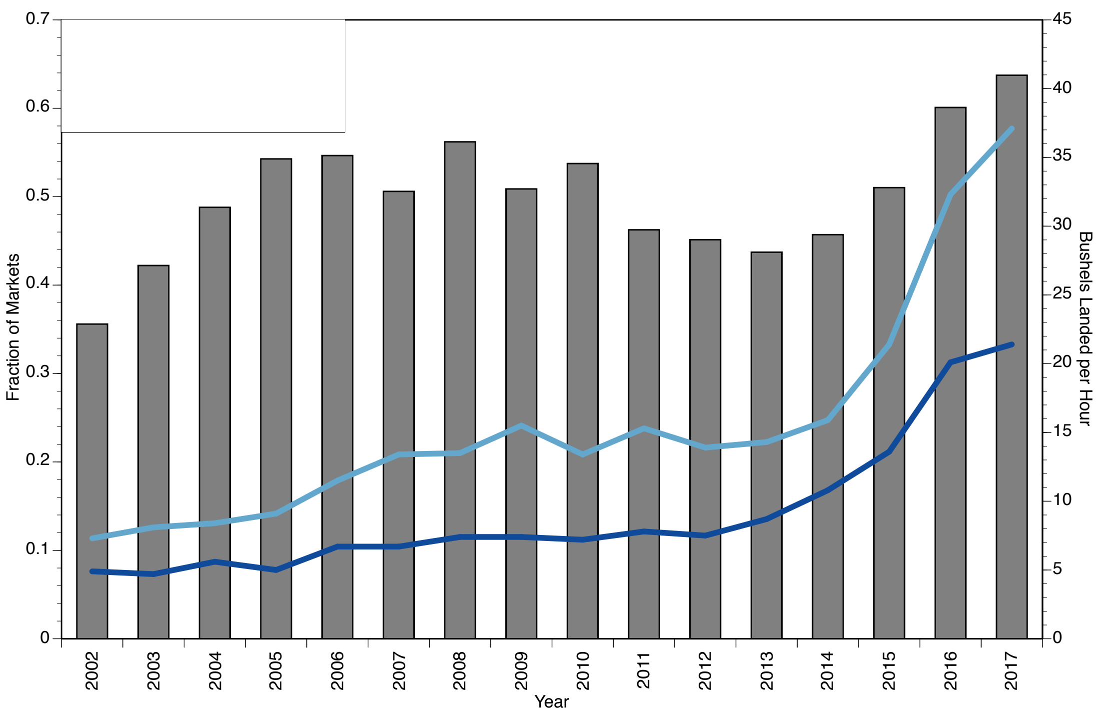


Figure 23. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program in 1996. The 22-yr average harvest is 79,375 bushels. The 2006-2007 line shows the beginning of the current exploitation and management strategy.

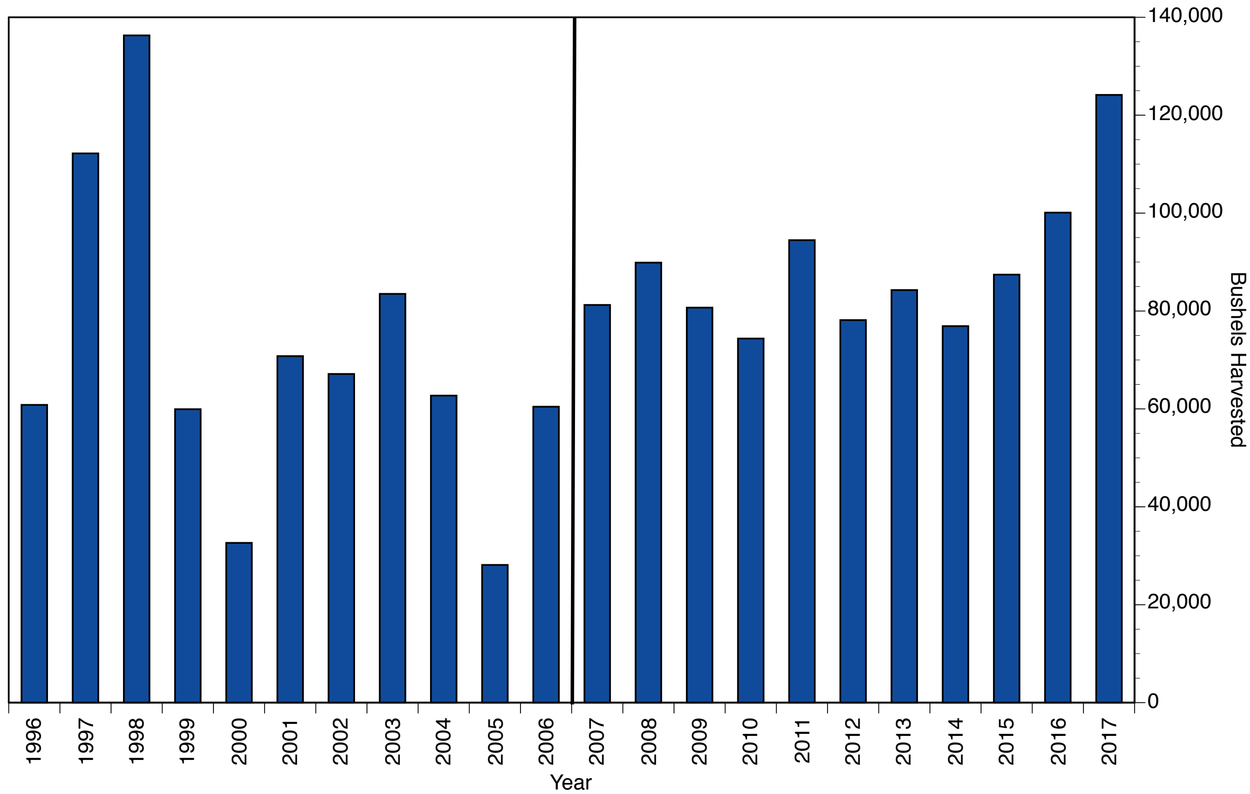


Figure 24. Landed oysters per bushel in three groups: market-size (>2.5”), smaller attached oysters, and smaller unattached oysters. The number of market-size oysters per landed bushel in 2017 averaged 220. The long-term mean of all oysters (263) per landed bushel is shown as an orange line.

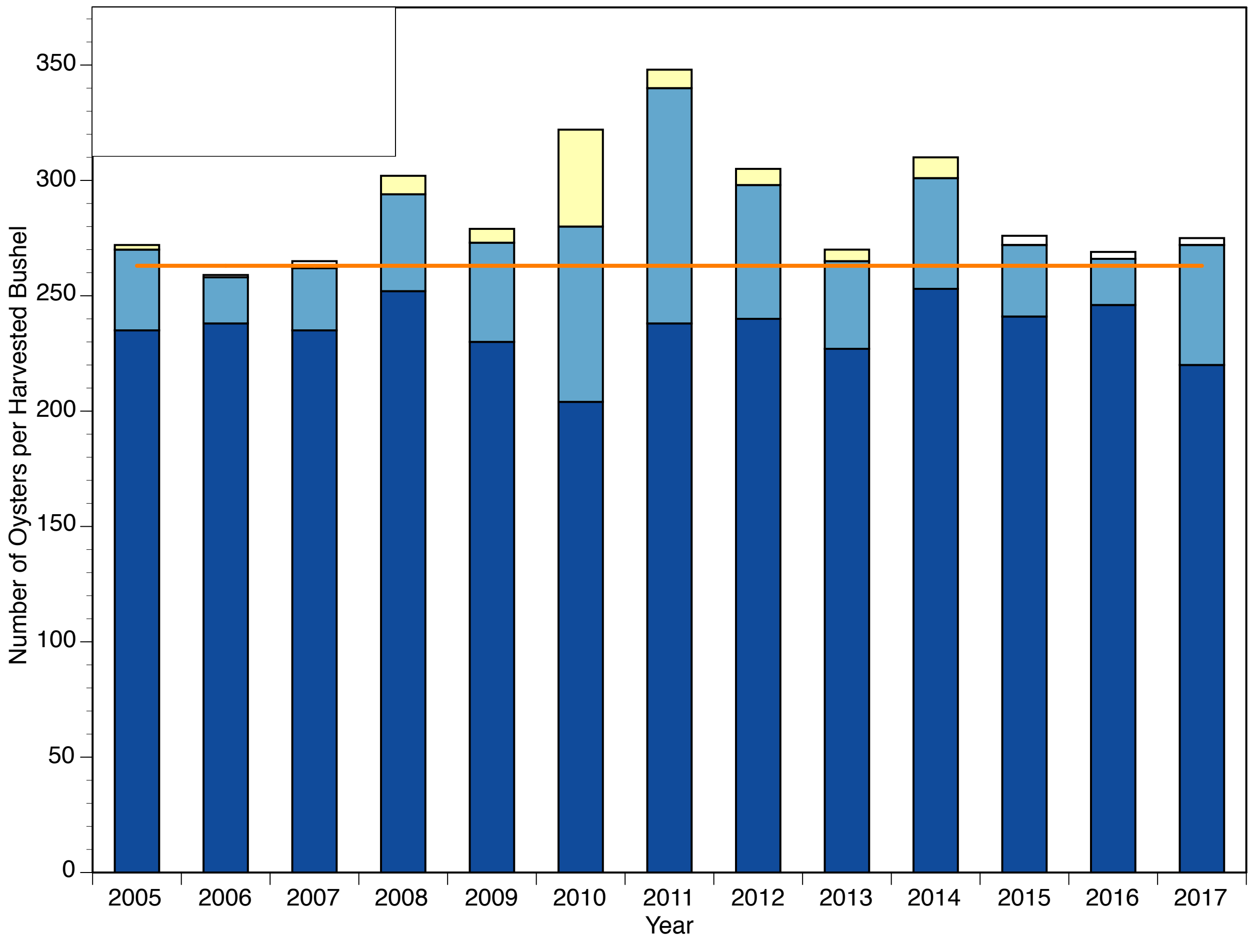


Figure 25. Size frequency of oysters landed in 2017 compared to the size frequencies from the previous 3 years (2014-2016). Size class values are the lower bounds of the size class.

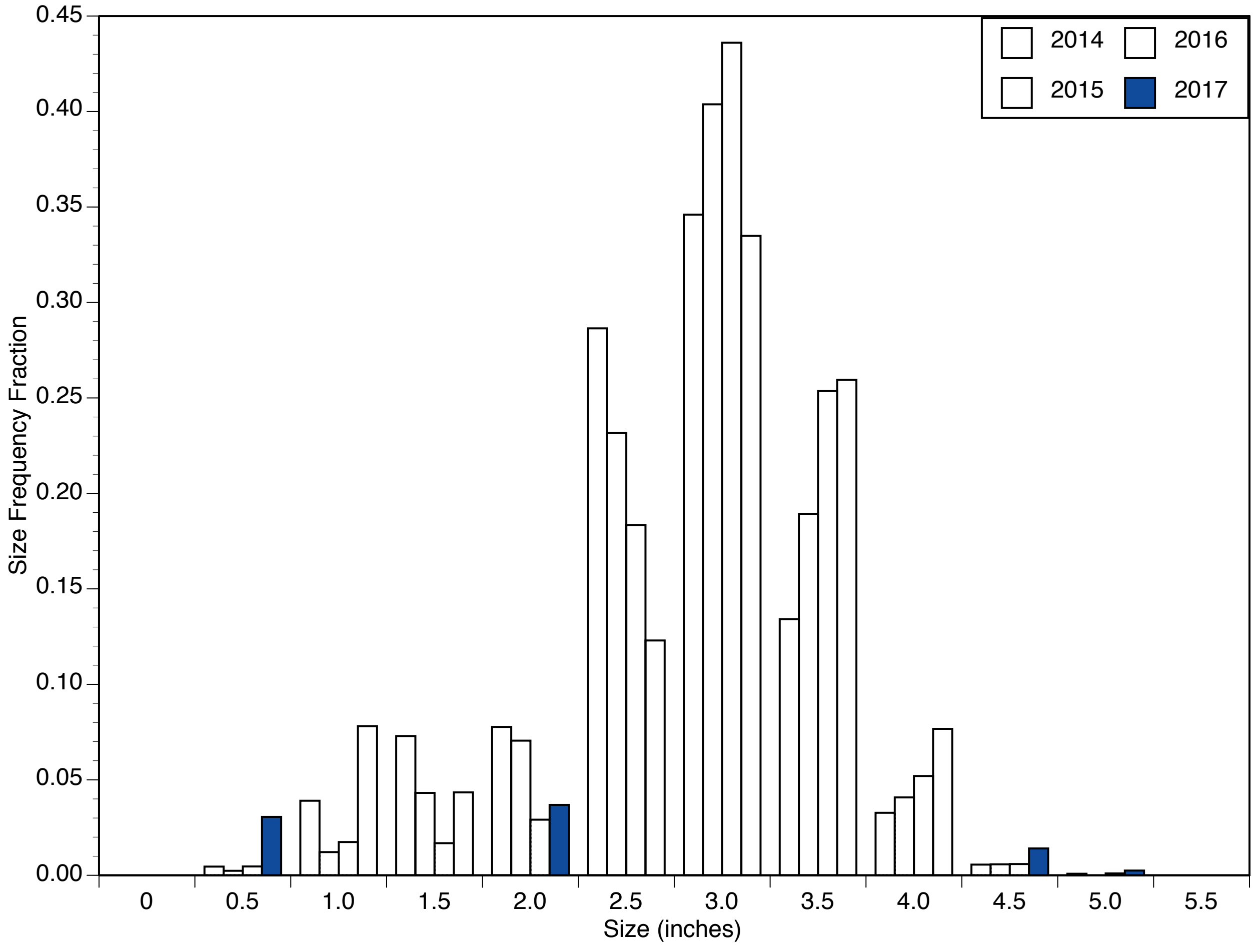


Figure 26a. Realized exploitation fractions of the >2.5" oyster stock on the Direct Market regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. Values use the current, temporally-consistent dredge efficiencies. The 2007-2015 median (dotted line) is based on the realized exploitation values shown. Negative values reflect oysters added through intermediate transplanting.

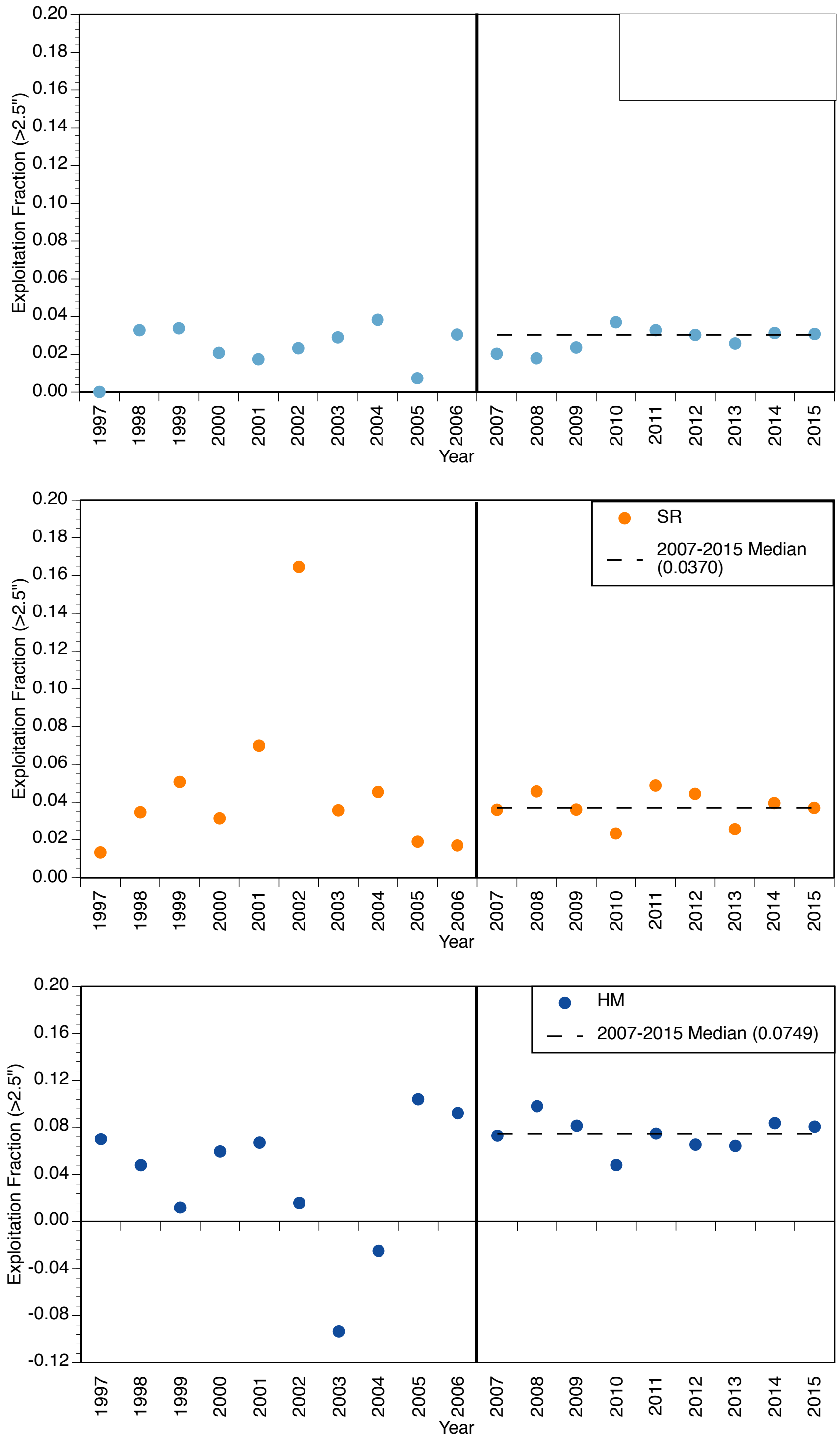


Figure 26b. Realized exploitation fractions of the whole oyster stock, excluding spat, on the Transplant regions in Delaware Bay NJ for two time periods: 1996-2006 and 2007-2015. Values use the current, temporally-consistent dredge efficiencies. The 2007-2015 median (dotted line) is based on the realized exploitation shown. 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 for 1997-2006.

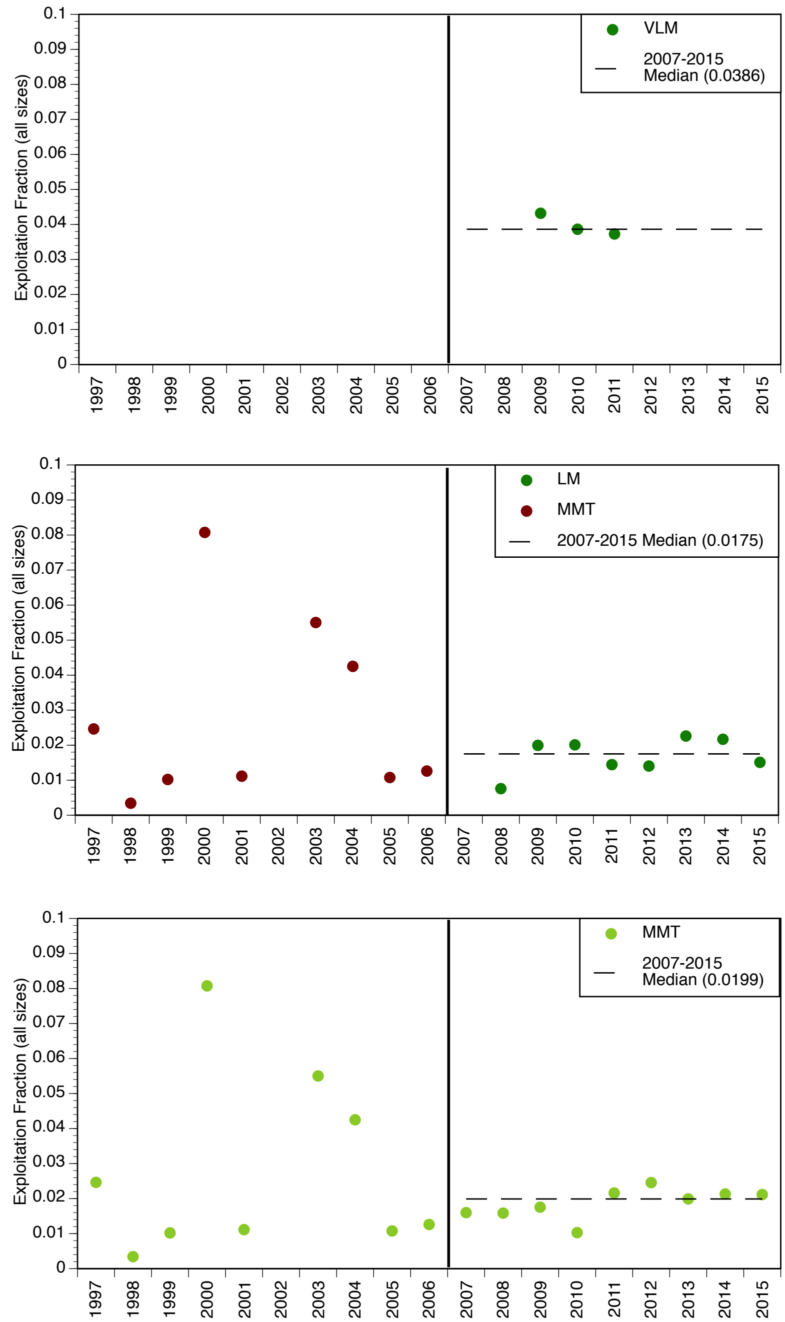
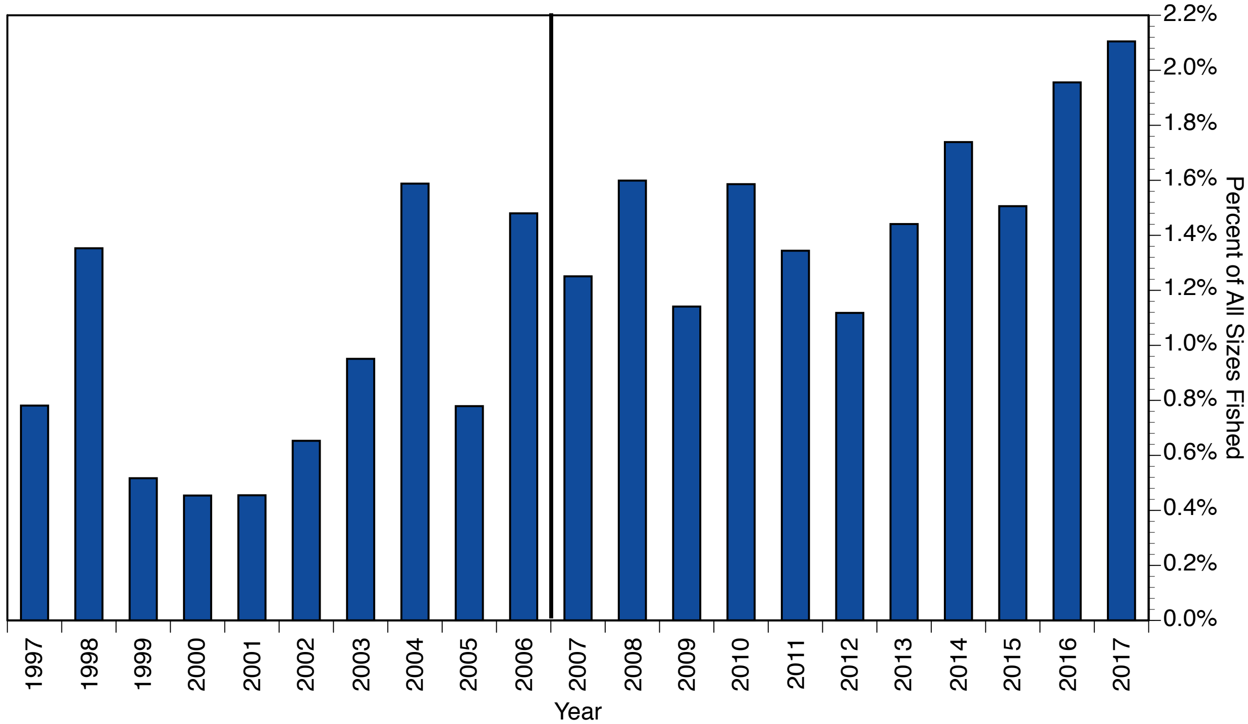


Figure 27. Fishing mortality as a percentage of (a) total oyster abundance and (b) the market-sized oyster abundance (>2.5") over all regions excluding the VLM. Regional abundance-based quotas began in 2007 (vertical line).

a.



b.

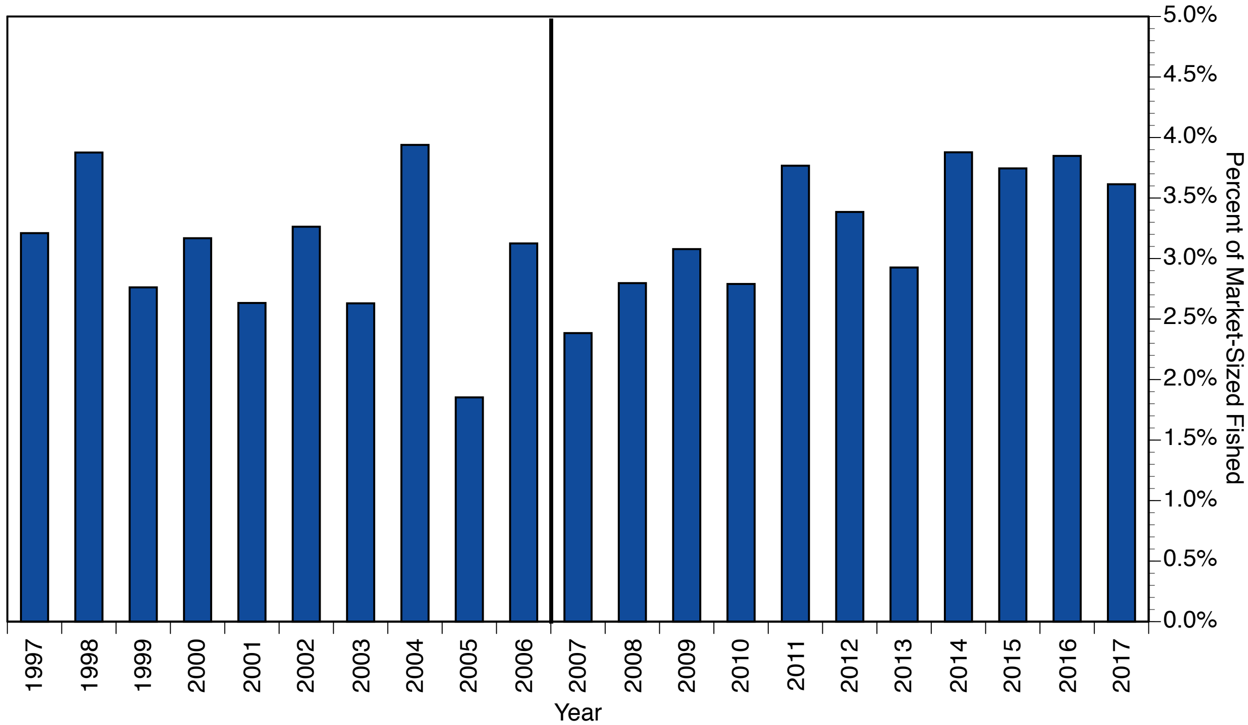
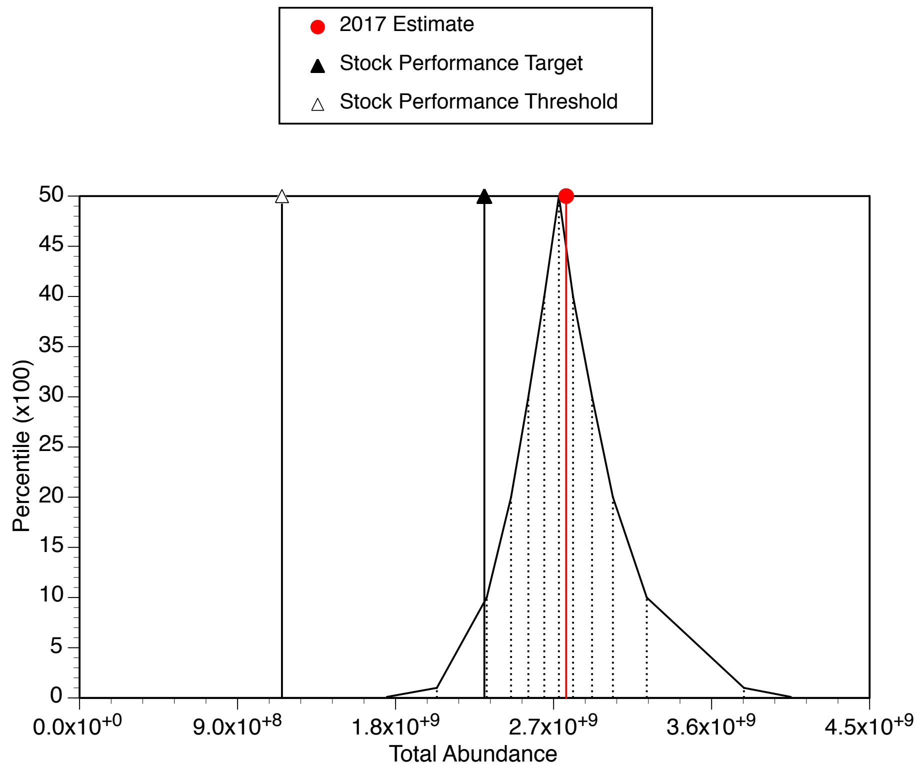


Figure 28. 2017 whole-stock (minus the VLM) for (a) total and (b) market-sized abundance estimates within confidence percentiles for the 2017 survey taking into account survey and gear efficiency error (see Analytical Approach in this report). Whole stock reference points are included for comparison. Note that the percentiles (P) above the 50th are shown as 1 – P so that, for example, the 60th percentile is indicated as the 40th percentile but on the right-hand side of the curve.

a.



b.

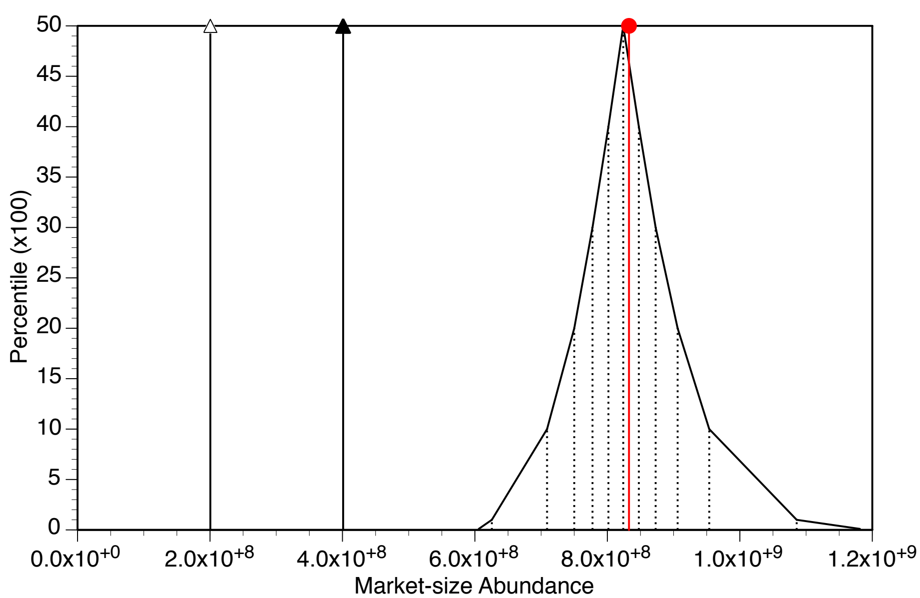
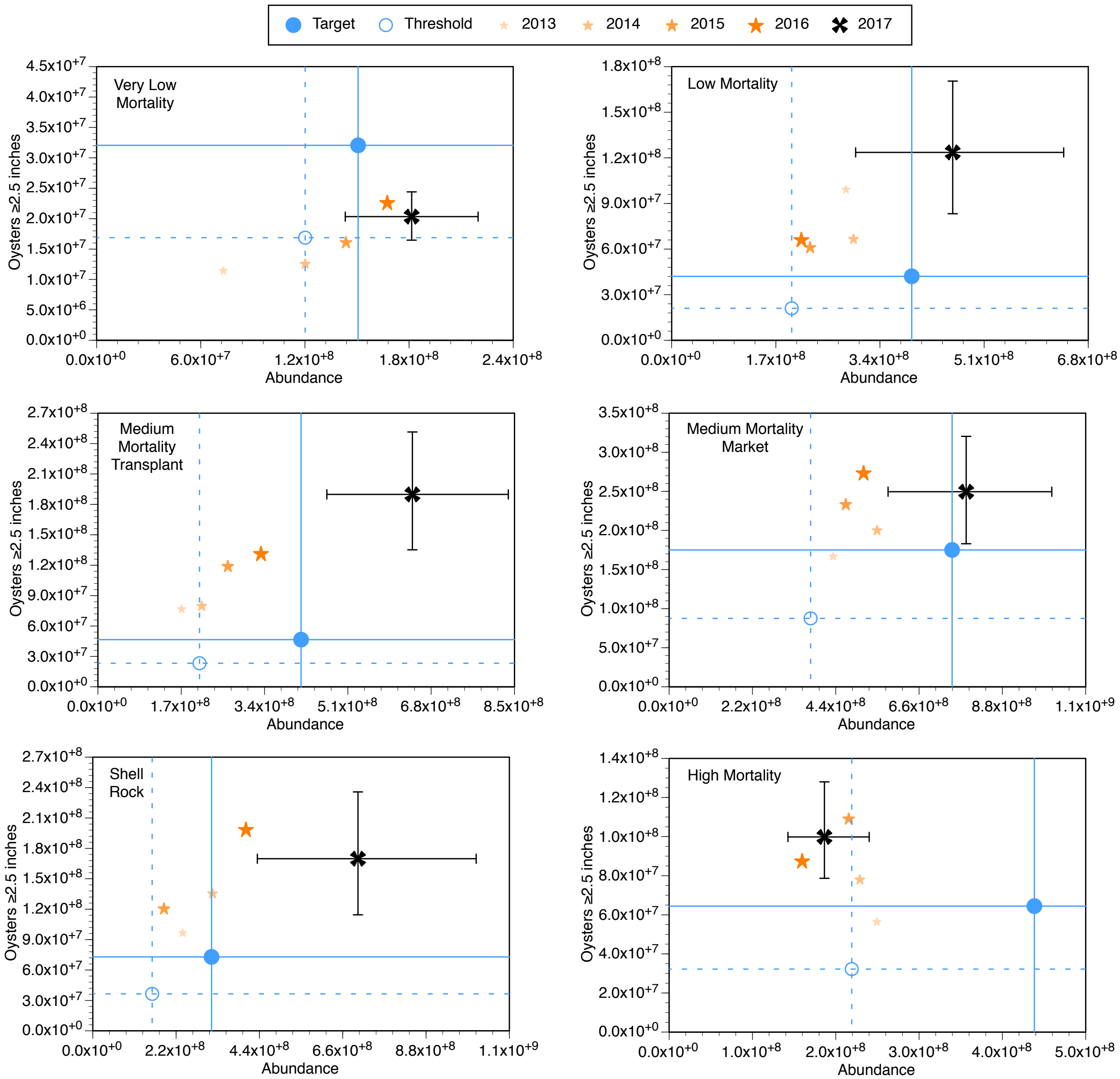


Figure 29. Position of the oyster stock 2013–2017 with respect to abundance and market abundance (≥ 2.5”) targets and thresholds for each region. Targets and thresholds are defined in text. Error bars on the 2017 values are the 10th and 90th percentiles of 1,000 simulations of estimates incorporating both survey error and gear efficiency error.



Appendix A. 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

Appendix B. 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
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										
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								
MMM	Ship John	68	P					F							
SR	Shell Rock	93	P			F				F				F	
HM	Bennies Sand	49	P	P			F								
HM	Nantuxent	68	P	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 C.1.1

Oyster abundance percentiles by region for time series 1953 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 oyster abundance and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	188,146,624	2003	83,505,968	1954	133,347,448	1956	26,446,584	1966	70,609,376	1958
0.050	219,267,584	1998	99,238,416	1956	183,269,568	1954	40,437,220	1963	102,509,488	2003
0.075	225,457,648	1953	164,479,664	2007	266,421,504	1962	88,314,440	1962	133,158,280	2005
0.100	247,801,632	2008	170,442,320	2005	276,226,816	2009	118,273,056	2004	140,189,088	1957
0.175	291,092,512	2005	211,773,392	2014	341,242,944	2004	145,852,928	2005	158,428,128	1964
0.250	345,433,408	1997	237,771,552	2003	393,779,584	1991	187,965,408	2015	193,216,800	2012
0.333	409,420,288	2006	267,645,232	2008	458,448,064	1993	237,353,056	2013	247,722,496	1963
0.375	431,545,920	1995	275,256,448	2006	486,386,368	1961	249,282,112	1985	249,346,832	2013
0.400	462,866,368	1986	332,705,856	2016	513,482,752	2016	291,713,472	2003	273,462,784	1986
0.500	677,346,368	1992	433,659,904	1955	658,064,512	2006	403,824,640	2001	418,439,296	2000
0.600	803,602,816	1957	515,284,032	1987	835,126,656	2011	476,265,920	2011	497,618,560	1965
0.625	1,015,315,072	1991	529,299,360	2002	937,948,864	1965	591,178,624	2000	518,696,896	1954
0.667	1,189,356,544	1955	560,161,920	1997	1,083,503,104	1989	603,986,624	1953	556,456,192	1990
0.750	1,534,448,896	1977	676,591,488	1980	1,343,717,376	1982	959,588,928	1981	986,874,240	1960
0.825	1,759,764,992	1983	1,070,379,264	1971	2,117,523,712	1970	1,155,372,672	1971	2,170,004,736	1976
0.900	2,935,392,000	1982	1,318,795,776	1984	2,411,669,504	1983	1,763,810,176	1983	3,443,166,208	1983
0.925	3,042,920,448	1984	1,545,844,480	1977	2,550,822,656	2000	1,764,919,168	1976	3,514,286,848	1979
0.950	3,816,468,736	1969	1,738,814,976	1981	3,638,521,600	1975	1,962,986,496	1979	4,454,327,808	1980
0.990	4,638,983,168	1981	4,446,481,408	1974	8,394,828,800	1974	2,699,857,920	1984	14,419,853,312	1974
2017	458,775,744	0.377	641,696,000	0.700	784,427,456	0.562	700,263,104	0.685	186,399,024	0.223

Appendix C.1.2

Box-count mortality fraction percentiles by region for time series 1953 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 mortality and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	0.02015	1969	0.03880	1973	0.04148	1973	0.02566	1973	0.03040	1954
0.050	0.04478	1957	0.04543	1967	0.05134	1967	0.04591	1984	0.03992	1973
0.075	0.04744	1954	0.06493	1984	0.06637	1974	0.04808	1983	0.04511	1972
0.100	0.04983	2016	0.06887	1955	0.07032	1978	0.05089	1989	0.05954	1983
0.175	0.05527	1978	0.07806	1964	0.08389	1984	0.06178	1972	0.09688	1969
0.250	0.06384	1973	0.08193	1968	0.09174	1982	0.06899	1971	0.10878	1968
0.333	0.07331	1963	0.09290	1962	0.10716	1996	0.09229	1969	0.12570	1978
0.375	0.07574	1994	0.09407	1954	0.10869	2005	0.09478	2003	0.13490	1980
0.400	0.07649	1967	0.09618	1988	0.10975	1964	0.09869	2000	0.14580	2014
0.500	0.09791	1958	0.11242	1998	0.12808	1998	0.11670	1960	0.18018	2013
0.600	0.11379	2013	0.14843	1978	0.15751	2006	0.17736	1956	0.21110	2016
0.625	0.11683	1983	0.15112	1965	0.16678	1966	0.18256	2014	0.21362	2012
0.667	0.11869	1992	0.15274	1976	0.16943	2004	0.19393	2008	0.21667	1964
0.750	0.12834	1996	0.16726	1959	0.20465	2002	0.22699	1963	0.25654	1997
0.825	0.15540	1999	0.20887	2010	0.23492	1992	0.29877	2002	0.32799	2001
0.900	0.17597	2010	0.22259	2009	0.26732	1999	0.36147	1993	0.37494	1966
0.925	0.19646	1961	0.22673	1993	0.29622	1993	0.36980	1986	0.40197	1991
0.950	0.21286	2011	0.30899	1986	0.34412	1995	0.37861	1995	0.46011	1999
0.990	0.26397	1985	0.34611	1958	0.45355	1958	0.48086	1958	0.49283	1993
2017	0.03631	0.023	0.0805	0.208	0.10158	0.300	0.09669	0.377	0.18214	0.531

Appendix C.1.3

Spat abundance percentiles by region for time series 1953 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 spat abundance and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	6,333,817	1984	23,093,696	2014	45,219,860	1967	4,605,388	1965	23,748,702	1967
0.050	14,083,137	2004	31,122,898	2001	48,534,808	1960	23,145,720	1962	62,806,244	1963
0.075	24,880,106	1967	40,091,896	2005	74,083,680	1984	30,515,622	2014	72,903,192	1956
0.100	40,992,476	2001	44,580,316	1992	85,952,096	1958	43,435,908	1961	83,698,664	1955
0.175	46,648,752	1953	68,642,088	1961	96,014,672	1992	52,128,692	1992	105,425,488	1996
0.250	75,127,984	1996	97,215,760	1958	146,489,072	2001	80,942,648	1996	129,302,976	2001
0.333	92,048,680	1971	157,208,992	2006	262,277,056	2009	138,297,408	1975	186,109,216	2017
0.375	113,754,272	2002	185,140,928	2007	307,102,528	1985	148,552,320	1957	231,477,440	1954
0.400	119,495,024	2015	201,475,168	1990	322,078,112	2011	169,873,856	1976	264,238,080	1975
0.500	262,578,944	1998	267,226,256	2000	449,109,632	1956	280,309,184	1966	416,641,536	2010
0.600	383,572,960	1956	400,069,216	1963	580,947,264	2000	428,249,216	2012	568,575,104	2013
0.625	417,908,864	1958	425,233,600	1981	590,630,080	1964	441,318,592	1997	589,182,592	1985
0.667	572,411,328	1957	442,342,496	1999	692,766,656	1981	481,982,784	1990	677,926,528	1989
0.750	935,990,720	1991	605,145,856	1964	1,099,550,592	2007	826,971,392	1980	1,122,550,656	1991
0.825	1,381,483,264	1987	797,304,192	1968	1,619,488,384	1982	963,304,320	1987	1,617,988,096	1997
0.900	2,638,539,520	1980	1,005,056,320	2016	2,086,584,576	1999	1,770,790,912	1974	2,654,484,736	1978
0.925	2,937,662,976	1974	1,271,248,768	1982	2,913,591,808	1998	1,866,195,072	1977	3,432,518,144	1979
0.950	3,338,800,640	1969	1,634,833,536	1998	3,702,969,344	1974	2,340,961,024	1982	7,516,831,744	1974
0.990	5,593,945,600	1973	6,409,227,264	1973	6,631,005,184	1973	2,523,629,568	1970	12,548,471,808	1970
2017	1,128,367,104	0.762	966,269,504	0.869	1,239,893,504	0.777	766,476,608	0.731	186,109,216	0.331

Appendix C.2.1

Oyster abundance percentiles by region for time series 1990 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 oyster abundance and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	188,146,624	2003	164,479,664	2007	276,226,816	2009	118,273,056	2004	89,990,688	2004
0.050	188,146,624	2003	164,479,664	2007	276,226,816	2009	118,273,056	2004	89,990,688	2004
0.075	211,663,968	2016	170,442,320	2005	321,760,000	2005	141,664,160	1995	102,509,488	2003
0.100	219,267,584	1998	170,753,888	2013	322,111,360	1994	145,852,928	2005	115,430,248	2008
0.175	225,904,032	2015	211,773,392	2014	372,326,464	2003	187,965,408	2015	136,463,744	2011
0.250	284,511,936	2013	237,771,552	2003	393,779,584	1991	204,478,960	1993	143,180,608	2007
0.333	291,092,512	2005	254,142,528	1995	441,452,672	1995	210,770,288	2009	167,147,040	2002
0.375	296,810,560	2014	265,401,040	2012	458,448,064	1993	242,152,400	2006	186,399,024	2017
0.400	296,810,560	2014	265,401,040	2012	458,448,064	1993	242,152,400	2006	186,399,024	2017
0.500	345,433,408	1997	275,256,448	2006	549,132,160	2014	313,595,904	1992	228,897,136	2014
0.600	372,427,136	2009	337,801,856	1993	658,064,512	2006	391,652,864	2007	249,346,832	2013
0.625	391,877,696	2002	373,223,040	1992	691,196,416	2010	403,824,640	2001	296,903,456	2001
0.667	409,420,288	2006	377,448,064	2011	747,234,944	1999	404,353,120	2016	340,871,424	1991
0.750	458,775,744	2017	424,013,120	1990	835,126,656	2011	439,337,120	2008	439,216,192	1994
0.825	533,791,808	2007	529,299,360	2002	998,075,136	1997	479,586,656	1997	506,526,496	1992
0.900	677,346,368	1992	641,696,000	2017	1,189,726,592	1996	592,071,232	2010	556,456,192	1990
0.925	679,089,408	1990	652,267,392	2000	1,246,804,864	2002	700,263,104	2017	558,553,920	1998
0.950	782,048,128	1993	737,089,792	1998	1,306,350,080	2001	878,491,392	1990	614,061,568	1995
0.990	1,015,315,072	1991	896,213,632	1996	2,550,822,656	2000	884,210,816	1996	863,462,976	1996
2017	458,775,744	0.732	641,696,000	0.875	784,427,456	0.696	700,263,104	0.911	186,399,024	0.375

Appendix C.2.2
Box-count fraction percentiles by region for time series 1990 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 mortality and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	0.03631	2017	0.05750	1990	0.06908	1990	0.07670	1990	0.12069	1990
0.050	0.03631	2017	0.05750	1990	0.06908	1990	0.07670	1990	0.12069	1990
0.075	0.04983	2016	0.07924	1996	0.08414	2001	0.09478	2003	0.14580	2014
0.100	0.05551	2000	0.08050	2017	0.09274	2000	0.09669	2017	0.15964	2005
0.175	0.06208	2006	0.09246	2003	0.10716	1996	0.09919	2005	0.18018	2013
0.250	0.06556	2007	0.09528	2001	0.12112	2003	0.10651	2010	0.18214	2017
0.333	0.06895	2002	0.10541	2016	0.13533	2011	0.11661	2011	0.21110	2016
0.375	0.07574	1994	0.11242	1998	0.15131	2016	0.17502	2016	0.21362	2012
0.400	0.07574	1994	0.11242	1998	0.15131	2016	0.17502	2016	0.21362	2012
0.500	0.10585	2004	0.15073	2011	0.16943	2004	0.18256	2014	0.22844	1994
0.600	0.11869	1992	0.19608	2002	0.20465	2002	0.20348	1998	0.25654	1997
0.625	0.12066	1998	0.19632	2007	0.21339	2007	0.21657	1991	0.26176	2003
0.667	0.12126	2012	0.19854	1999	0.21474	2008	0.22539	2009	0.27575	2009
0.750	0.12777	2005	0.21000	1992	0.23345	1991	0.24283	2013	0.32799	2001
0.825	0.12893	2014	0.21633	2012	0.24085	2009	0.25834	2012	0.34089	1992
0.900	0.15540	1999	0.22259	2009	0.26253	1994	0.33091	1992	0.40197	1991
0.925	0.16109	1995	0.22673	1993	0.26732	1999	0.34845	1999	0.44257	2002
0.950	0.17597	2010	0.24787	2013	0.29622	1993	0.36147	1993	0.46011	1999
0.990	0.21286	2011	0.32394	1995	0.34412	1995	0.37861	1995	0.49283	1993
2017	0.03631	0.000	0.0805	0.089	0.10158	0.125	0.09669	0.089	0.18214	0.232

Appendix C.2.3

Spat abundance percentiles by region for time series 1990 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 spat abundance and percentile are listed at the bottom of the table. Very Low Mortality region is not listed due to the short time series.

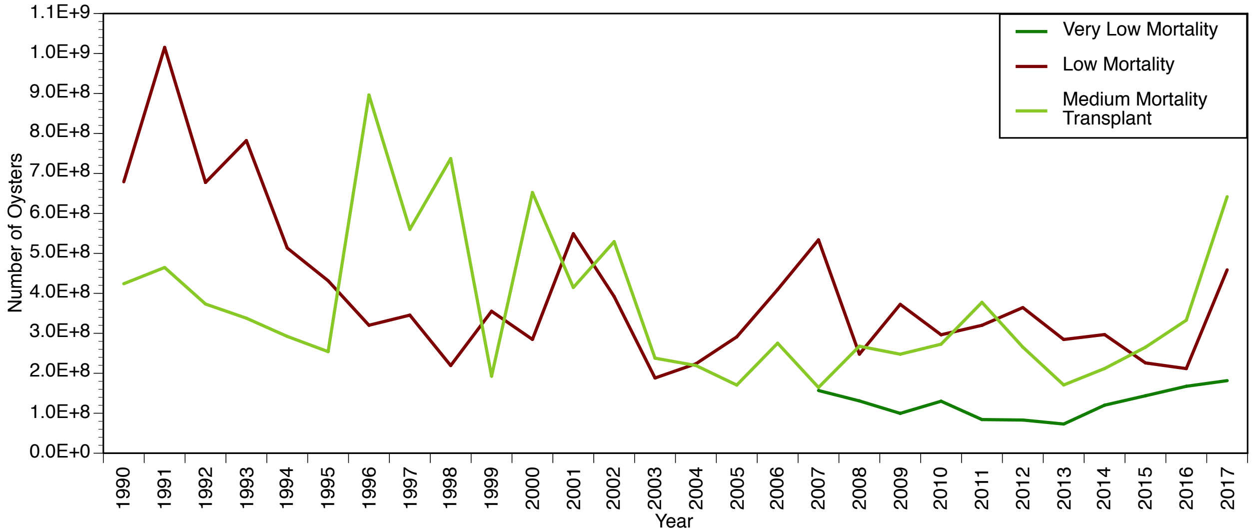
	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	14,083,137	2004	23,093,696	2014	45,299,616	2008	30,515,622	2014	81,395,376	2006
0.050	14,083,137	2004	23,093,696	2014	45,299,616	2008	30,515,622	2014	81,395,376	2006
0.075	19,418,498	2003	31,122,898	2001	82,737,920	2003	47,388,624	2015	95,493,184	2014
0.100	40,992,476	2001	40,091,896	2005	86,778,824	2014	52,128,692	1992	97,781,496	2005
0.175	44,109,368	2014	50,158,556	2008	93,363,584	2005	77,211,640	2005	110,184,936	2008
0.250	61,874,824	2000	56,356,680	2003	110,848,936	2004	89,092,624	2006	118,348,792	1992
0.333	73,598,896	2012	84,934,808	2011	146,489,072	2001	114,865,792	2003	130,487,440	2003
0.375	76,045,016	2008	145,636,704	2015	262,277,056	2009	138,675,168	2013	167,951,984	2002
0.400	76,045,016	2008	145,636,704	2015	262,277,056	2009	138,675,168	2013	167,951,984	2002
0.500	91,136,816	2006	185,140,928	2007	335,858,048	1990	250,140,528	2008	330,150,176	2009
0.600	119,495,024	2015	244,443,680	2009	472,144,160	1991	436,437,920	2000	416,641,536	2010
0.625	147,088,064	2005	258,999,008	1994	483,832,640	2013	441,318,592	1997	481,662,880	2011
0.667	161,884,768	1994	267,226,256	2000	580,947,264	2000	455,612,992	2009	492,262,592	2016
0.750	260,206,560	1999	295,195,040	1997	602,631,616	2012	560,660,160	1991	684,034,048	1990
0.825	300,650,624	2010	430,370,048	1991	760,809,920	1997	750,414,080	2007	994,432,512	1994
0.900	330,993,632	2013	546,450,880	2002	1,239,893,504	2017	867,099,136	2010	1,122,550,656	1991
0.925	405,289,728	2016	966,269,504	2017	1,338,809,088	2016	957,817,216	2002	1,513,959,168	2012
0.950	935,990,720	1991	1,005,056,320	2016	2,086,584,576	1999	992,921,856	1999	1,617,988,096	1997
0.990	1,128,367,104	2017	1,634,833,536	1998	2,913,591,808	1998	1,170,753,792	2016	1,953,821,056	1999
2017	1,128,367,104	1.000	966,269,504	0.911	1,239,893,504	0.875	766,476,608	0.839	186,109,216	0.411

Appendix C.3
Oyster abundance, box-count fraction, and spat abundance percentiles for the Very Low Mortality region only. The time series represented ranges from 2007 to 2017. A series of 19 percentile rankings are listed with their associated values and years. The specific 2017 values and percentiles are listed at the bottom of the table.

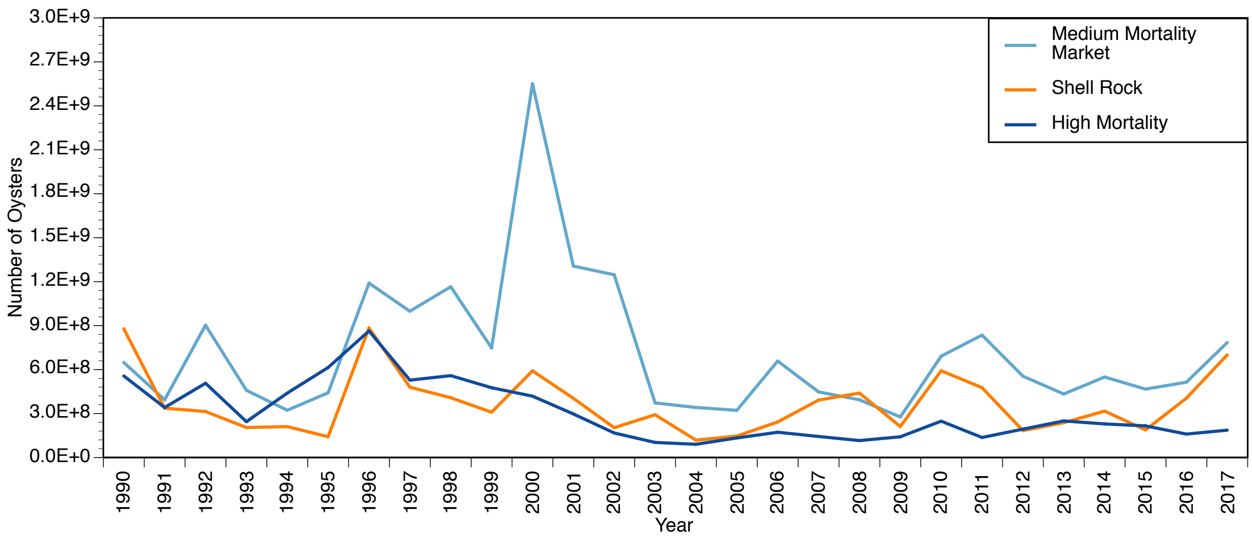
	Oyster Abundance		Box-count Mortality		Spat Abundance	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.010	73,001,808	2013	0.0290	2008	7,952,177	2011
0.050	73,001,808	2013	0.0290	2008	7,952,177	2011
0.075	73,001,808	2013	0.0290	2008	7,952,177	2011
0.100	73,001,808	2013	0.0290	2008	7,952,177	2011
0.175	82,998,968	2012	0.0369	2017	17,395,486	2009
0.250	84,173,968	2011	0.0412	2016	29,115,064	2014
0.333	99,657,008	2009	0.0446	2015	42,783,604	2012
0.375	99,657,008	2009	0.0446	2015	42,783,604	2012
0.400	99,657,008	2009	0.0446	2015	42,783,604	2012
0.500	120,130,688	2014	0.0640	2014	81,006,312	2008
0.600	130,828,856	2008	0.0689	2009	165,331,968	2013
0.625	130,828,856	2008	0.0689	2009	165,331,968	2013
0.667	130,828,856	2008	0.0689	2009	165,331,968	2013
0.750	143,658,400	2015	0.0848	2013	178,673,680	2016
0.825	156,869,712	2007	0.0926	2010	181,031,616	2010
0.900	167,420,496	2016	0.2988	2012	195,858,432	2015
0.925	167,420,496	2016	0.2988	2012	195,858,432	2015
0.950	18,150,7024	2017	0.4658	2011	484,499,168	2017
0.990	18,150,7024	2017	0.4658	2011	484,499,168	2017
2017	181,507,024	1.000	0.0369	0.136	484,499,168	1.000

Appendix D.1. Oyster abundance for the 1990–2017 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

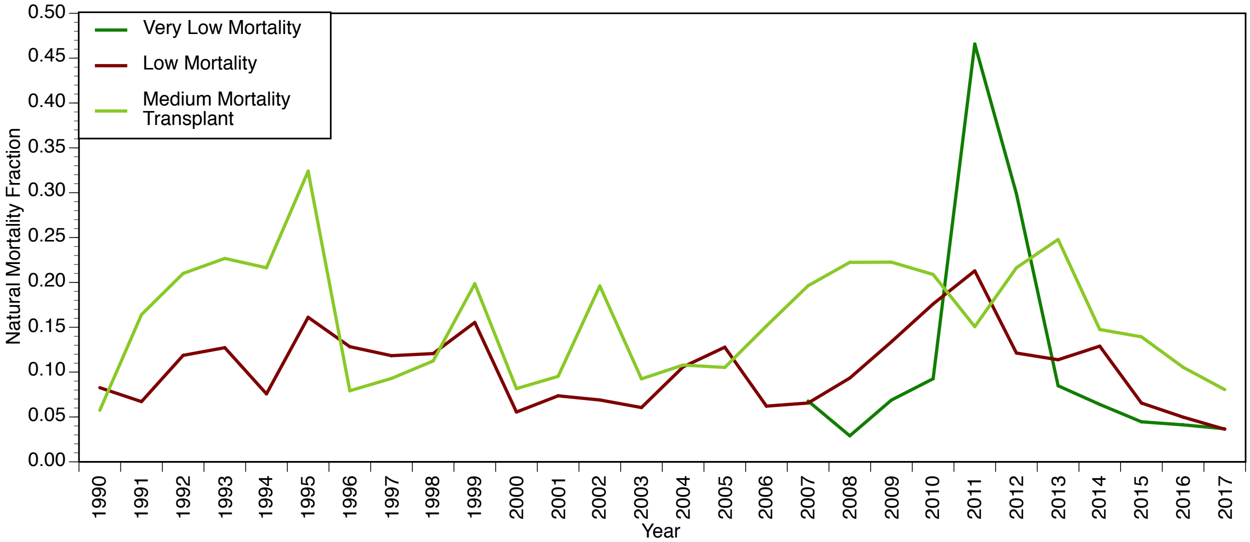


b.

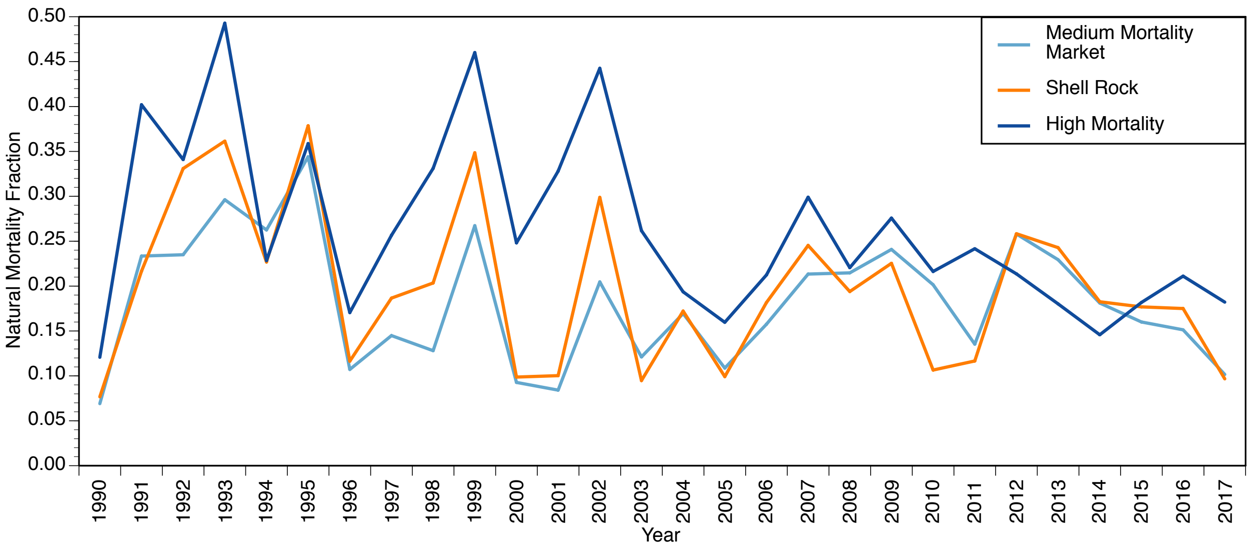


Appendix D.2. Box-count mortality rate for the 1990–2017 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

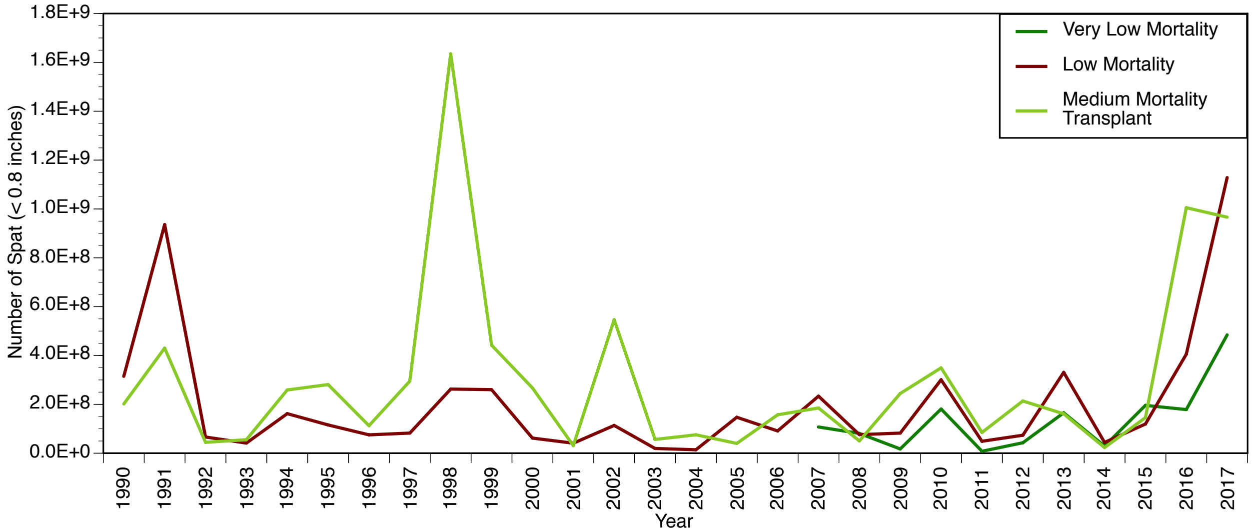


b.

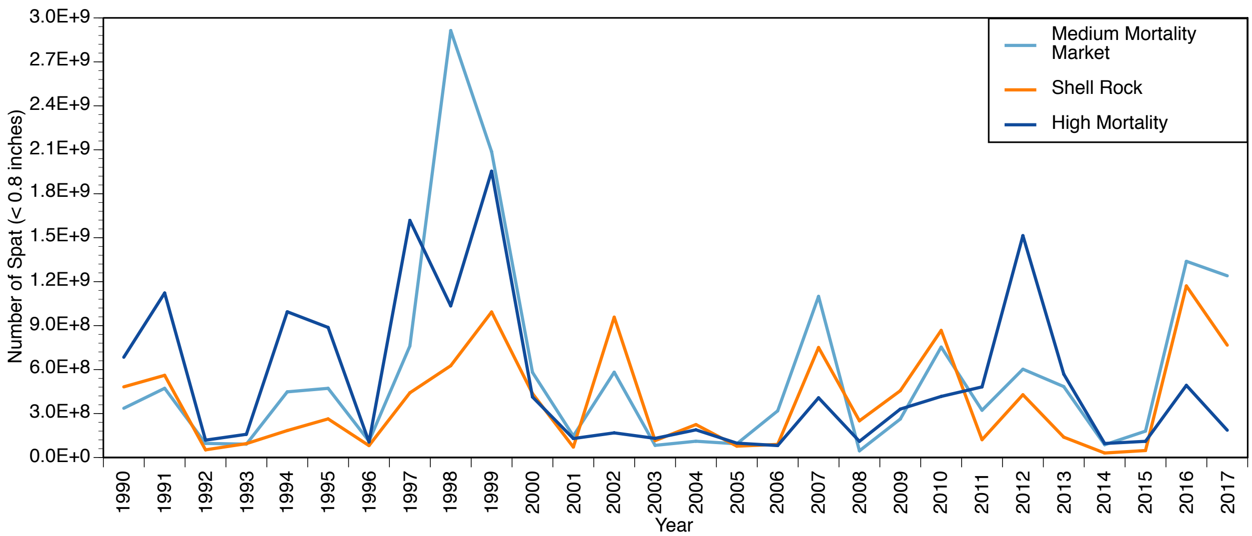


Appendix D.3. Spat abundance (< 0.8 inches) for the 1990–2017 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

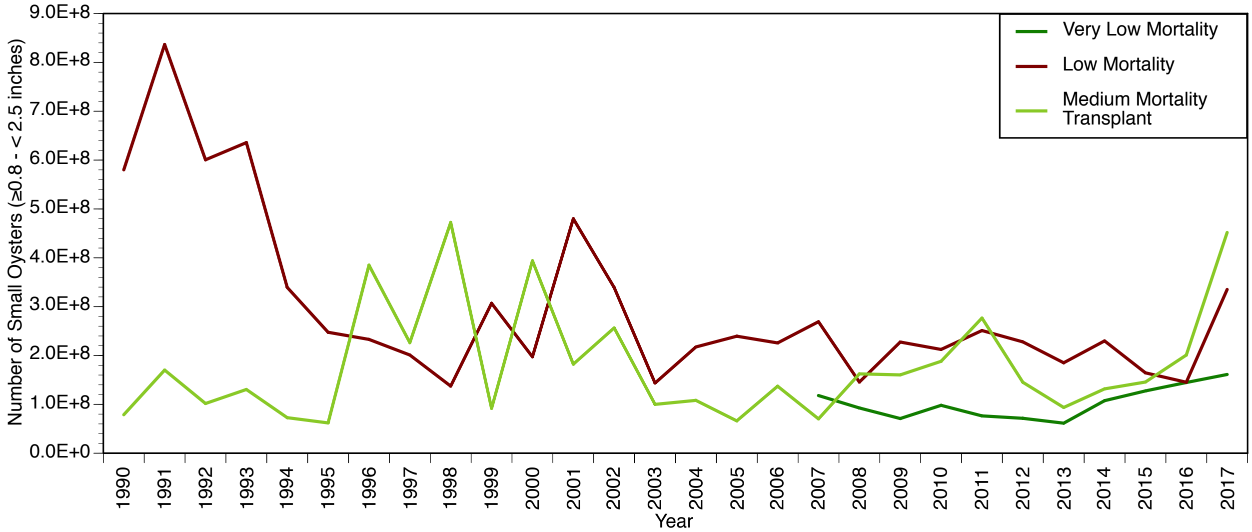


b.

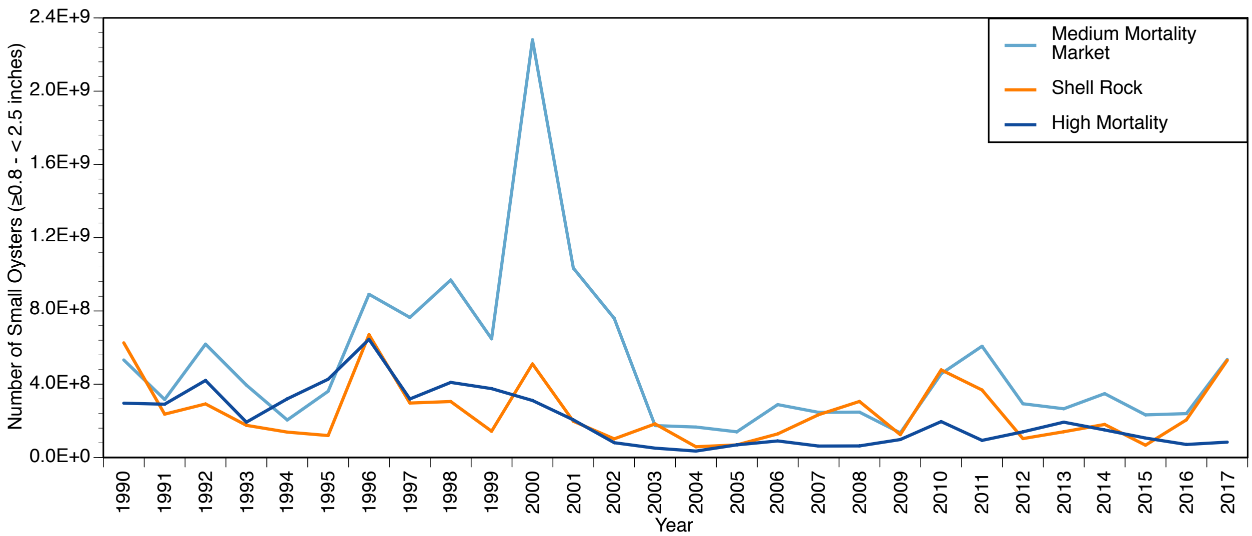


Appendix D.4. Abundance of small oysters (≥ 0.8 - < 2.5 inches) for the 1990–2017 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

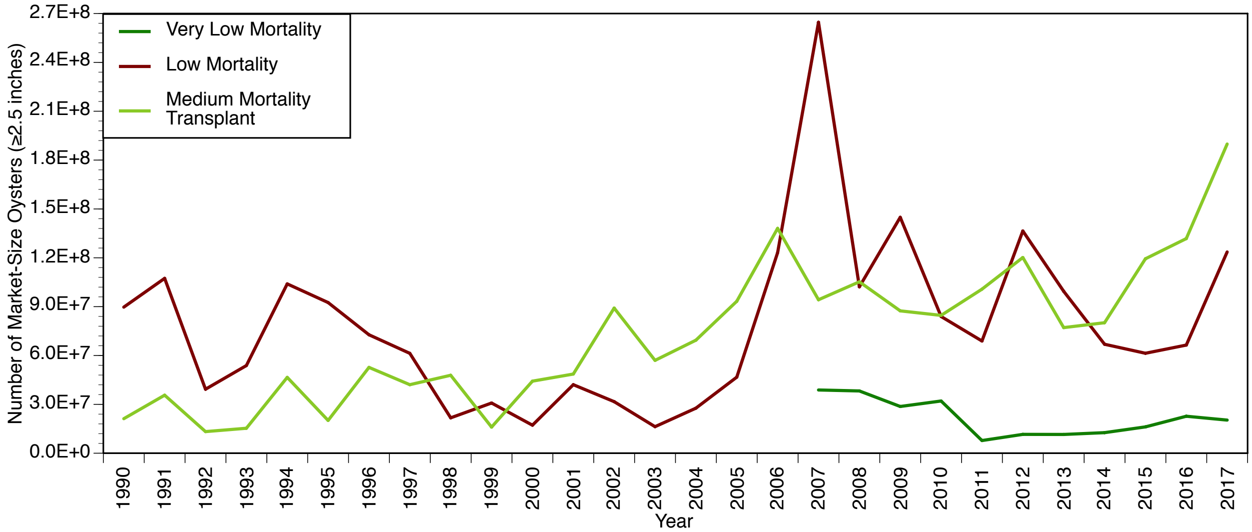


b.

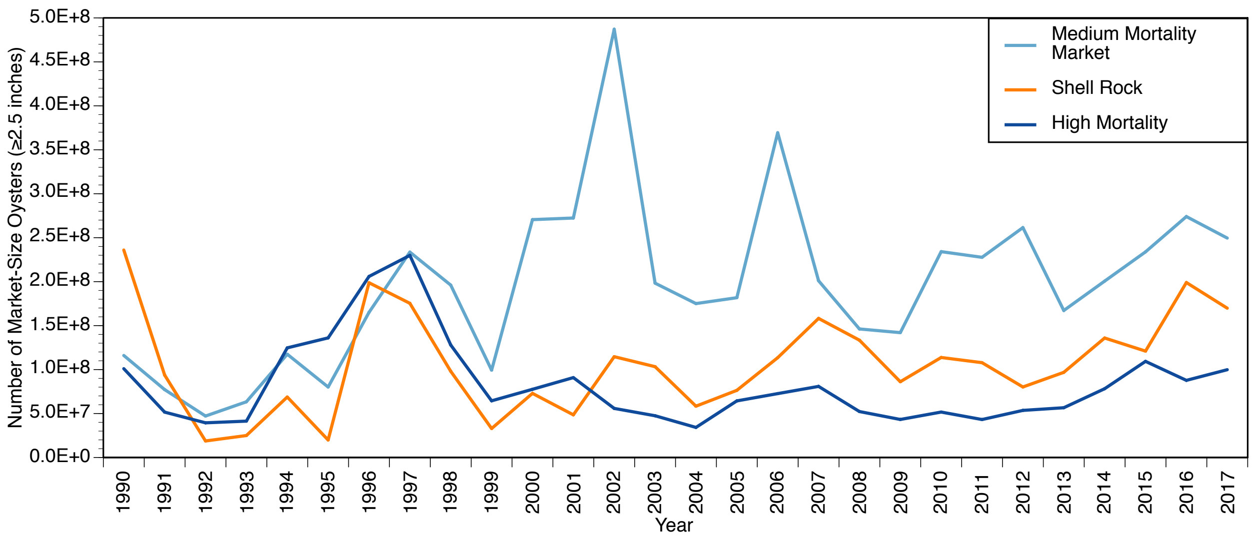


Appendix D.5. Market-size oyster abundance (≥ 2.5 inches) for the 1990–2017 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.



b.



Appendix E. 2017 assessment survey densities as numbers of oysters and spat per m^2 and quarts of cultch per m^2. Stratum designations are bed-specific. Enh-S are grids that have received shellplants, and Enh-T are grids that have received transplants.

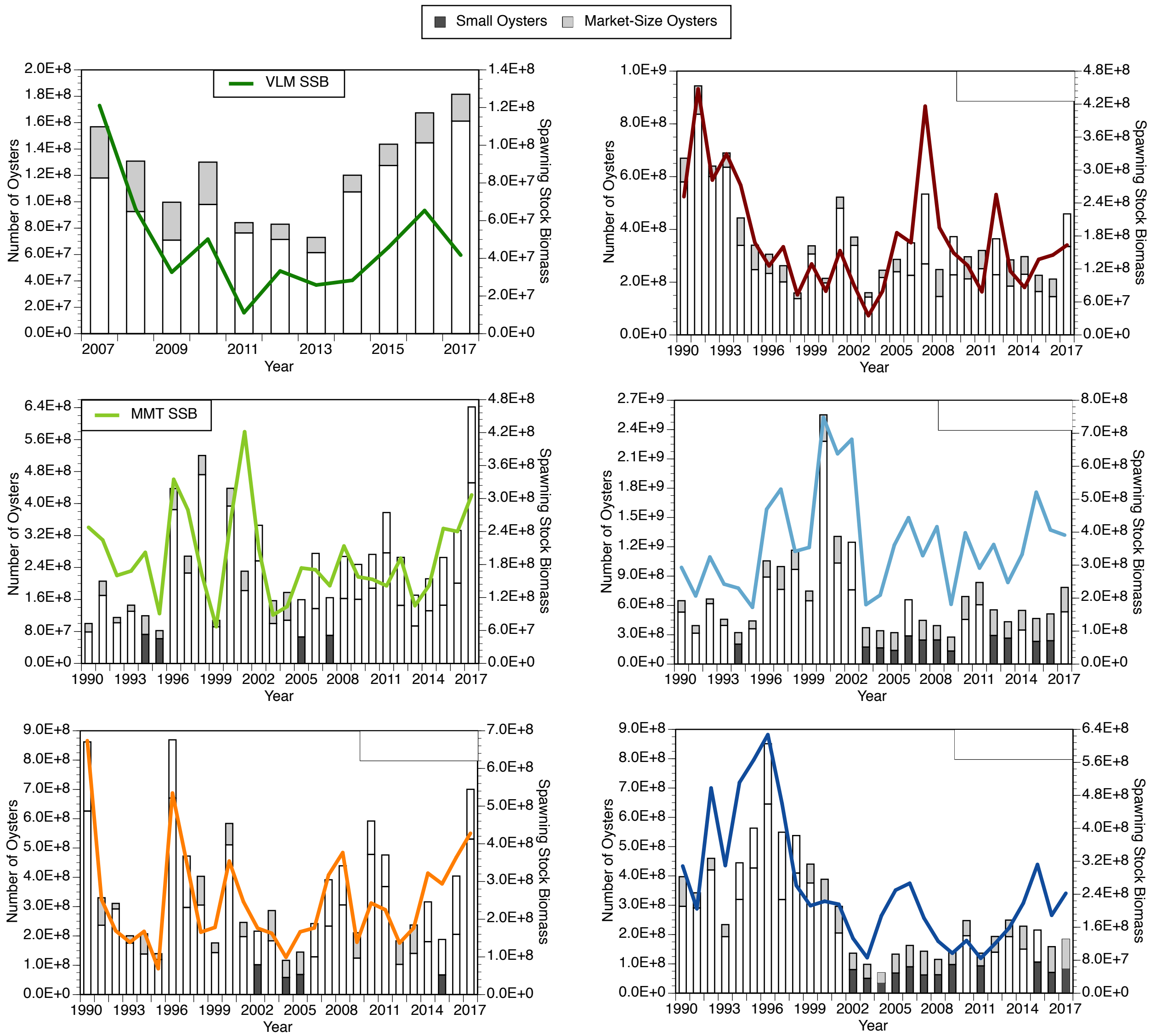
Data Year	Region	Bed	Grid	Stratum	Oyster/m^2	Spat/ m^2	Cultch/m^2
2017	VLM	Hope Creek	62	High	102.716	292.898	5.616
2017	VLM	Hope Creek	76	High	82.185	108.181	3.965
2017	VLM	Hope Creek	73	Med	29.665	80.697	2.471
2017	VLM	Hope Creek	60	Med	28.926	96.922	3.623
2017	VLM	Hope Creek	51	High	20.276	62.557	2.405
2017	VLM	Hope Creek	87	Med	13.757	11.455	1.000
2017	VLM	Hope Creek	45	Med	5.715	11.003	0.649
2017	VLM	Fishing Creek	25	High	43.139	52.942	5.101
2017	VLM	Fishing Creek	16	High	18.767	23.224	3.105
2017	VLM	Fishing Creek	26	Med	14.900	20.480	1.673
2017	VLM	Fishing Creek	10	Med	13.623	17.463	1.767
2017	VLM	Fishing Creek	11	Med	0.203	0.651	0.036
2017	VLM	Liston Range	17	High	87.865	363.036	3.053
2017	VLM	Liston Range	12	High	72.493	188.804	2.359
2017	VLM	Liston Range	14	Med	63.074	287.060	3.039
2017	VLM	Liston Range	11	Med	16.326	48.765	0.708
2017	VLM	Liston Range	16	Med	2.550	5.612	0.234
2017	VLM	Liston Range	5	Med	1.083	0.980	0.045
2017	LM	Round Island	12	High	25.902	62.455	3.738
2017	LM	Round Island	11	High	23.635	123.463	5.761
2017	LM	Round Island	5	Med	8.351	30.299	1.337
2017	LM	Round Island	50	Med	1.961	1.866	0.621
2017	LM	Round Island	4	Med	1.673	5.129	1.109
2017	LM	Upper Arnolds	10	High	376.439	1662.948	13.246
2017	LM	Upper Arnolds	4	Med	189.715	285.701	6.279
2017	LM	Upper Arnolds	12	High	164.812	325.260	6.212
2017	LM	Upper Arnolds	17	Med	121.830	332.009	15.399
2017	LM	Upper Arnolds	14	Med	83.181	393.432	14.439
2017	LM	Upper Arnolds	3	High	73.304	85.534	5.534
2017	LM	Upper Arnolds	15	Med	28.357	85.352	6.857
2017	LM	Arnolds	57	Med	119.159	111.053	3.297
2017	LM	Arnolds	19	High	100.317	181.607	16.054
2017	LM	Arnolds	16	High	66.418	249.596	3.364
2017	LM	Arnolds	11	Med	62.135	85.431	3.908
2017	LM	Arnolds	17	High	49.965	156.927	2.290
2017	LM	Arnolds	10	Med	47.374	91.794	3.852
2017	LM	Arnolds	43	Med	0.660	0.567	0.176
2017	MMT	Upper Middle	71	Med	170.958	100.234	3.171
2017	MMT	Upper Middle	63	Med	112.981	227.145	18.654
2017	MMT	Upper Middle	56	Med	108.730	76.047	3.385
2017	MMT	Upper Middle	48	High	32.611	118.727	2.853

Data Year	Region	Bed	Grid	Stratum	Oyster/m^2	Spat/ m^2	Cultch/m^2
2017	MMT	Middle	35	High	163.770	414.345	10.330
2017	MMT	Middle	28	High	147.834	227.990	9.115
2017	MMT	Middle	40	Med	89.644	99.314	10.062
2017	MMT	Middle	31	Med	72.397	182.719	14.598
2017	MMT	Middle	41	Med	69.512	76.012	17.162
2017	MMT	Middle	43	Med	69.477	76.270	16.360
2017	MMT	Sea Breeze	22	Med	188.850	234.214	10.285
2017	MMT	Sea Breeze	15	High	168.858	295.495	4.720
2017	MMT	Sea Breeze	19	High	136.588	405.896	11.922
2017	MMT	Sea Breeze	17	Med	96.310	80.373	10.592
2017	MMT	Sea Breeze	25	Med	83.982	83.035	10.452
2017	MMT	Sea Breeze	31	High	83.175	88.233	6.937
2017	MMT	Sea Breeze	39	Med	3.420	3.375	0.063
2017	MMM	Cohansey	50	Enh-S	171.204	161.607	7.429
2017	MMM	Cohansey	56	Enh-S	170.721	184.459	11.980
2017	MMM	Cohansey	37	High	137.603	269.869	25.388
2017	MMM	Cohansey	38	Med	120.880	197.054	10.729
2017	MMM	Cohansey	54	High	116.554	154.709	10.842
2017	MMM	Cohansey	43	High	92.204	77.291	13.397
2017	MMM	Cohansey	45	Enh-T	86.139	134.496	11.814
2017	MMM	Cohansey	25	High	85.426	302.218	25.512
2017	MMM	Cohansey	57	High	68.345	101.302	40.575
2017	MMM	Cohansey	19	Med	64.715	89.750	10.938
2017	MMM	Cohansey	24	Med	39.776	85.046	18.065
2017	MMM	Cohansey	32	Med	14.641	16.932	11.413
2017	MMM	Cohansey	48	Med	5.923	28.391	8.793
2017	MMM	Ship John	28	Enh-S	244.016	211.169	10.489
2017	MMM	Ship John	42	High	166.876	406.474	15.525
2017	MMM	Ship John	25	High	131.306	163.420	20.322
2017	MMM	Ship John	24	Med	121.810	123.679	21.279
2017	MMM	Ship John	20	Med	121.603	233.648	19.721
2017	MMM	Ship John	23	High	114.903	192.308	17.025
2017	MMM	Ship John	21	High	111.705	214.333	15.575
2017	MMM	Ship John	15	High	109.186	226.567	13.585
2017	MMM	Ship John	48	High	78.467	59.641	33.811
2017	MMM	Ship John	14	Med	53.136	61.742	20.468
2017	MMM	Ship John	8	Med	52.602	78.381	23.707
2017	MMM	Ship John	51	Med	17.965	14.273	8.280
2017	SR	Shell Rock	15	Enh-S	258.631	208.980	10.432
2017	SR	Shell Rock	31	Med	247.968	389.571	17.692
2017	SR	Shell Rock	43	High	227.245	159.059	11.441
2017	SR	Shell Rock	44	High	217.559	162.580	12.137
2017	SR	Shell Rock	20	High	203.190	178.424	11.839
2017	SR	Shell Rock	33	Med	198.159	364.534	17.836

Data Year	Region	Bed	Grid	Stratum	Oyster/m^2	Spat/ m^2	Cultch/m^2
2017	SR	Shell Rock	4	High	146.563	102.780	8.020
2017	SR	Shell Rock	7	Med	143.683	143.690	10.907
2017	SR	Shell Rock	59	Enh-T	106.924	55.674	15.750
2017	SR	Shell Rock	36	Med	56.478	21.839	4.810
2017	SR	Shell Rock	38	High	42.612	31.924	4.902
2017	SR	Shell Rock	75	Med	38.061	39.510	19.257
2017	SR	Shell Rock	79	High	35.626	36.429	29.897
2017	SR	Shell Rock	37	Enh-S	33.877	14.168	2.371
2017	SR	Shell Rock	71	Med	20.671	10.793	7.836
2017	SR	Shell Rock	52	Enh-S	16.403	6.795	16.423
2017	SR	Shell Rock	65	Med	15.443	13.487	6.407
2017	HM	Benny Sand	8	High	72.448	89.167	5.295
2017	HM	Benny Sand	11	High	32.958	50.737	4.571
2017	HM	Benny Sand	4	High	26.998	26.998	3.883
2017	HM	Benny Sand	1	Med	22.517	4.691	4.638
2017	HM	Benny Sand	21	Med	16.943	14.232	4.753
2017	HM	Benny Sand	10	Med	11.507	8.793	4.364
2017	HM	Benny Sand	20	Med	9.964	10.311	6.178
2017	HM	Benny Sand	26	Med	5.394	4.473	3.899
2017	HM	Benny Sand	41	Enh-S	3.246	1.443	0.133
2017	HM	Benny Sand	34	Med	3.210	0.117	2.118
2017	HM	Bennies	73	Enh-T	21.863	2.954	2.003
2017	HM	Bennies	35	Med	20.841	19.130	5.289
2017	HM	Bennies	86	High	15.291	12.694	7.857
2017	HM	Bennies	87	High	14.151	5.930	7.545
2017	HM	Bennies	60	Med	14.132	10.502	6.867
2017	HM	Bennies	34	Med	8.029	4.612	4.610
2017	HM	Bennies	99	Enh-T	7.504	11.930	4.814
2017	HM	Bennies	56	High	7.024	5.403	3.280
2017	HM	Bennies	100	High	6.949	6.288	9.453
2017	HM	Bennies	85	High	6.333	3.473	2.488
2017	HM	Bennies	110	Enh-S	4.181	4.124	3.362
2017	HM	Bennies	146	Med	1.954	2.687	8.017
2017	HM	Bennies	69	Med	1.797	0.640	1.110
2017	HM	Bennies	57	Med	1.042	0.288	0.879
2017	HM	Bennies	91	Med	0.509	0.017	1.246
2017	HM	Bennies	82	Med	0.393	0.505	4.580
2017	HM	Bennies	26	Med	0.355	0.341	1.164
2017	HM	NantuxentP	25	High	100.424	62.742	2.925
2017	HM	NantuxentP	15	High	59.763	48.430	1.728
2017	HM	NantuxentP	16	High	40.742	55.547	2.834
2017	HM	NantuxentP	13	Med	10.961	6.773	8.158
2017	HM	NantuxentP	68	Med	10.557	17.904	5.311
2017	HM	NantuxentP	29	Med	8.312	7.157	7.975

Data Year	Region	Bed	Grid	Stratum	Oyster/m^2	Spat/ m^2	Cultch/m^2
2017	HM	Hog Shoal	1	High	10.982	13.225	8.136
2017	HM	Hog Shoal	12	Med	8.639	10.097	3.096
2017	HM	Hog Shoal	5	Med	8.019	14.835	8.497
2017	HM	Hog Shoal	4	Med	3.373	0.606	1.540
2017	HM	Strawberry	5	High	0.330	0.000	7.750
2017	HM	Strawberry	28	High	0.117	0.000	5.278
2017	HM	Strawberry	2	Med	0.079	0.119	2.506
2017	HM	Strawberry	14	Med	0.070	0.000	0.377
2017	HM	Strawberry	25	Med	0.056	0.000	3.621
2017	HM	Hawk's Nest	27	High	9.027	5.677	5.063
2017	HM	Hawk's Nest	25	High	7.317	36.079	9.194
2017	HM	Hawk's Nest	28	Med	1.299	1.794	2.648
2017	HM	Hawk's Nest	13	Med	0.890	1.112	11.272
2017	HM	Hawk's Nest	17	Med	0.105	0.000	4.353
2017	HM	New Beds	25	High	7.297	26.930	3.678
2017	HM	New Beds	41	High	4.482	13.541	6.475
2017	HM	New Beds	26	High	4.137	14.646	7.514
2017	HM	New Beds	24	High	3.323	13.567	11.323
2017	HM	New Beds	35	Med	3.073	1.866	6.004
2017	HM	New Beds	12	Med	0.859	0.184	3.766
2017	HM	New Beds	58	Med	0.610	1.098	12.931
2017	HM	New Beds	79	Med	0.217	0.000	7.207
2017	HM	New Beds	98	Med	0.067	0.000	0.056
2017	HM	Beadons	5	Med	0.307	0.000	3.084
2017	HM	Beadons	4	High	0.223	0.084	1.977
2017	HM	Beadons	3	High	0.210	0.210	5.618
2017	HM	Beadons	16	Med	0.000	0.000	2.656
2017	HM	Beadons	18	Med	0.000	0.000	3.066
2017	HM	Vexton	4	High	2.381	5.476	5.834
2017	HM	Vexton	2	Med	0.279	0.557	1.386
2017	HM	Vexton	11	High	0.207	0.398	0.374
2017	HM	Vexton	33	Med	0.000	0.000	1.460
2017	HM	Egg Island	63	High	0.450	0.270	7.433
2017	HM	Egg Island	28	Med	0.265	0.345	0.816
2017	HM	Egg Island	31	Med	0.086	0.077	0.107
2017	HM	Egg Island	27	Med	0.000	0.000	8.204
2017	HM	Egg Island	67	Med	0.000	0.000	0.177
2017	HM	Egg Island	100	Med	0.000	0.000	0.672

Appendix F. Regional abundance of small (≥ 0.8 inches - < 2.5 inches) and market-size (≥ 2.5 inches) oysters overlaid with spawning stock biomass (SSB). SSB is based on oysters > 35mm.



Appendix G. Bushels of oyster or clam shell planted by region. Years in which no shell was planted are excluded and indicated by lines.

	HM	SR	MMM	MMT	LM	VLM	TOTAL
1956	119,462	47,172	27,462	40,411	0	0	234,507
1957	63,112	0	53,157	4,000	0	0	120,269
1958	0	0	0	63,917	0	0	63,917
1960	0	8,235	12,630	11,440	0	0	32,305
1961	8,800	0	0	0	0	0	8,800
1963	16,528	0	0	2,029	0	0	18,557
1965	33,658	101,950	657,238	362,763	292,539	0	1,448,148
1966	73,273	47,621	251,201	164,002	246,039	0	782,136
1967	0	52,041	48,075	32,091	302,056	0	434,263
1968	0	202,090	59,920	183,999	0	0	446,009
1969	0	0	43,398	0	0	0	43,398
1970	71,479	0	221,042	710,843	0	0	1,003,364
1971	232,247	0	194,656	0	0	0	426,903
1972	0	0	223,667	84,856	0	0	308,523
1973	86,913	0	0	0	0	0	86,913
1974	213,964	0	0	0	43,098	0	257,062
1978	36,940	0	0	0	0	0	36,940
1979	71,418	0	0	0	0	0	71,418
1982	59,400	0	0	0	0	0	59,400
1984	42,500	0	0	0	0	0	42,500
1985	39,116	0	0	0	0	0	39,116
1987	106,432	0	0	0	0	0	106,432
1988	0	131,504	100,000	110,604	0	0	342,108
1989	300,465	0	0	0	0	0	300,465
1997	83,000	0	0	82,000	0	0	165,000
1998	99,742	0	0	0	0	0	99,742
1999	90,226	0	0	0	0	0	90,226
2003	16,130	0	0	0	0	0	16,130
2005	12,250	89,337	0	0	0	0	101,587
2006	142,207	125,354	0	0	0	0	267,561
2007	43,360	0	188,523	43,800	0	0	275,683
2008	172,487	0	21,898	0	0	0	194,385
2009	86,072	58,233	0	0	0	0	144,305
2010	49,645	40,199	0	0	0	0	89,844
2011	50,000	50,000	0	18,000	0	0	118,000
2012	0	0	100,000	0	0	12,000	112,000
2013	0	100,000	0	23,050	0	0	123,050
2014	42,704	55,394	52,740	12,709	0	0	163,547
2015	43,038	47,913	38,539	0	0	0	129,490
2016	44,000	44,000	44,000	0	0	0	132,000
2017	65,522	42,090	40,572	0	0	0	148,184

Appendix H. (a) Direct market bushels landed (oysters ≥ 2.5”) and (b) intermediate transplant bushels removed (all sizes) 1996-2007. Beds are arranged upbay to downbay. Beds without removals during these years were omitted.

a.

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Arnolds			420	1,219			550					
Upper Middle							300					
Middle		158			1,334		925	264				
Sea Breeze			3,144	158	25	1,535		72	931			
Cohansey			1,068	687	1,350	80	3,122	14,491	9,751	2,723	12,925	19,947
Ship John		69	42	2,057	2,086	577	528	16,795	18,978	2,691	10,405	12,519
Shell Rock		13,917	31,911	24,372	3,883	23,029	29,818	15,338	18,655	7,571	12,447	18,042
Bennies Sand	5,369	2,712	16,037	6,284	10,739	8,618	6,312	16,201	5,574	1,315	2,323	10,306
Bennies	11,798	28,269	40,515	17,567	5,993	9,486	3,958	10,604	4,120	2,939	1,326	5,462
Nantuxent			157			560	152	420	1,133	5,302	12,324	6,289
Hog Shoal	1,022	5,771	7,333	214	1,054	14,800	7,533	405	435	477	1,838	950
New Beds	42,633	47,368	33,411	5,839	5,349	7,580	8,032	1,554	224	1,613	525	5,270
Strawberry			793	656		154		394	1,194	543	46	
Hawk's Nest			469	249	30	1,238	2,196	2,928	1,260	2,954	6,291	2,436
Beadons				20	508	110	821	652	26			14
Vexton		4,270	382	346	272	3,015	2,680	3,379	439			
Egg Island		8,307		88			48					
Ledge		1,352	616	183	9		163					
Total	60,822	112,193	136,298	59,939	32,632	70,782	67,138	83,497	62,720	28,128	60,450	81,235

b.

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Round Island									30,392			
Upper Arnolds									3,771			
Arnolds						6,500		7,650	31,018		12,350	
Upper Middle								1,200				
Middle		30,000		14,650	24,210	6,395		42,923	17,602	5,000	5,550	15,182
Cohansey			36,125	40,200	4,146	18,400	7,253	2,635	33,019			
Ship John			33,765	17,350	6,572	14,650	22,416					
Nantuxent					225	6,250			6,200			
Hawk's Nest			13,500									
Beadons					4,900				1,200			
Total		30,000	83,390	72,200	40,053	52,195	29,669	54,408	123,202	5,000	17,900	15,182

Appendix I. 2017 MMT intermediate transplant program memorandum.

THE STATE UNIVERSITY OF NEW JERSEY

RUTGERS

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REPLY TO:

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May 4, 2017

MEMORANDUM

TO: Craig Tomlin, Russ Babb

FROM: Kathryn Alcox

Haskin Shellfish Research Laboratory

SUBJECT: Intermediate Transplant – Medium Mortality Region

An intermediate transplant from Middle, Upper Middle, and Sea Breeze beds in the Medium Mortality Transplant region (MMT) was conducted from April 17 to May 1, 2017. The goal for this transplant, decided at the March 7, 2017 Shellfish Council meeting, was to move 8,184,564 oysters: the maximum SARC recommended 2.5% exploitation rate for the MMT listed in Table 5 of the 19th SAW Executive Summary. A total of 29,250 bushels of culled material was removed from the MMT by three boats as follows:

21,350 bushels from Middle	to Bennies 73
4,700 bushels from Sea Breeze	to Bennies 73
3,200 bushels from Upper Middle	to Bennies 73

Control Rule 6 in Table 1 of the SAW Summary states that no more than half the amount should be taken from Middle bed. In this transplant, that fraction was 73%.

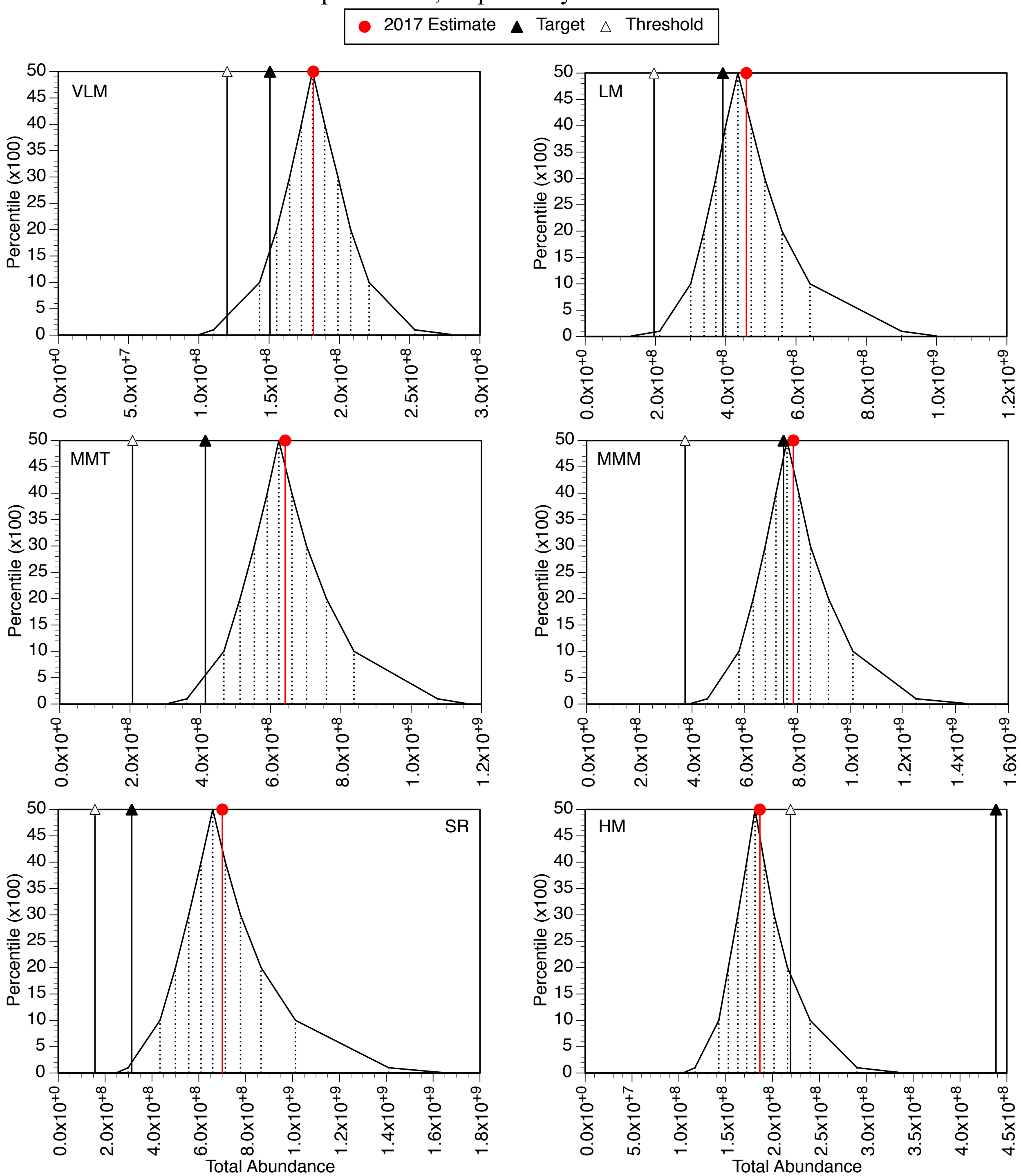
Deck samples were obtained from each boat each day with boatloads either measured or estimated by NJDEP. The number of oysters per bushel ranged from 210 to 327 with an average of 270. The per-sample percent cultch (not including boxes) in this transplant ranged from 8-44% with an average of 30%. Of the total 29,250 bushels of culled material moved, 30% was cultch, 5% was boxes and 65% was oyster.

In 27 boat-days, 97% of the goal exploitation was reached with 7,902,815 oysters moved. Market-size oysters made up 69% and 64% of those moved off Middle and Upper Middle respectively. Only 48% the oysters moved from Sea Breeze were market size. Of all oysters moved, 35% were small and not included in the quota increase calculations while 5,107,671 oysters were over 2.5" and were included. Using the conversion of 264 market-size oysters per bushel, this transplant can increase the quota by up to 19,346 bushels. This is approximately 7,000 bushels more than predicted in Table 5 of the SAW Summary Report.

Table 1. Daily sample metrics from each deckload for each transplant boat. Boats are identified by number: 1, 2, and 3. NS indicates that no sample was taken. - - indicates that the boat did not transplant that day.

		Oysters Per Bushel			Cultch % Per Bushel			Box % Per Bushel		
DATE	BED	1	2	3	1	2	3	1	2	3
4/17/17	Middle	296	303	241	22%	33%	29%	4%	4%	5%
4/18/17	Middle	254	251	--	18%	33%	--	3%	5%	--
4/19/17	Middle	293	283	NS	24%	34%	NS	6%	5%	NS
4/20/17	Middle	278	210	--	27%	44%	--	7%	3%	--
4/21/17	Middle	260	271	275	30%	28%	32%	5%	5%	3%
4/24/17	Sea Breeze	312	277	--	24%	8%	--	7%	6%	--
4/25/17	Sea Breeze	281	248	--	29%	23%	--	6%	4%	--
4/26/17	Upper Middle	327	286	276	39%	43%	41%	4%	2%	4%
4/27/17	Middle	269	212	--	33%	44%	--	6%	4%	--
4/28/17	Middle	296	260	220	24%	30%	21%	4%	7%	7%
5/1/17	Middle	--	250	240	--	29%	33%	--	5%	5%

Appendix J.1. 2017 regional total abundance estimates within confidence percentiles for the 2017 survey accounting for between-sample variation and uncertainty in dredge efficiency (see Analytical Approach in this report). Reference points are included for comparison. Note that the percentiles (P) above the 50th are shown as 1 –P so that, for example, the 60th percentile is indicated as the 40th percentile but on the right-hand side of the curve. Note also that the VLM target and threshold are the 75th and 50th percentiles, respectively.



Appendix J.2. 2017 regional market-size abundance estimates within confidence percentiles for the 2017 survey accounting for between-sample variation and uncertainty in dredge efficiency (see Analytical Approach in this report). Reference points are included for comparison. Note that the percentiles (P) above the 50th are shown as 1 –P so that, for example, the 60th percentile is indicated as the 40th percentile but on the right-hand side of the curve. Note also that the VLM target and threshold are the 75th and 50th percentiles, respectively.