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Stock Assessment Workshop
New Jersey Delaware Bay Oyster Beds
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Final Report

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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

OISSC Oyster Industry Scientific Steering Committee

SARC Stock Assessment Review Committee

SAW Stock Assessment Workshop

SR Shell Rock region

SSB Spawning stock biomass

VLM Very Low Mortality region

WP Weighted prevalence, a measurement of the intensity of dermo

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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 2017 SARC recommended the following statement for the New Jersey Delaware Bay oyster fishery:

> 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 16,026 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 high. Circa-1990, Dermo disease, caused by the parasite *Perkinsus marinus* became prevalent in

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

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. 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 periodically 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. 2001a). 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 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 this 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 by region based on the median exploitation rate from 1996-2006 applied to current abundance with 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 May. The total quota is the sum of 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 result of previous years of SARC and Oyster Industry Science Steering Committee recommendations and assessment evolution.

The Assessment

From 1953 until 1989, 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;

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

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

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

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 (survey averages < 0.5 oysters per m^2). This resulted in a change of strata definition and survey design from that used historically (Kraeuter et al. 2006). The restratification kept the three strata system within beds and used oyster densities to determine High, Medium, and Low strata. Since 2002, a fourth 'Enhanced' stratum exists to temporarily identify grids that receive shellplants or transplants (see Stratification and Bed Resurveys). A rotating schedule restratifies each bed approximately once per decade (Table 2). 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 on 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 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 that had been implicitly used at every SAW were articulated at the 18th SAW in 2016 (Table 4).

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.

2016 Science Advice Progress

LPUE[1] and Large Oysters

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 fished along with the beds fished and 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 been decreasing for a variety of possible reasons: limits on harvest timing due to *Vibrio* control protocols[2]; 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.

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.

Since 2002, the highest number of 2-dredge boats in the fishery was 38 in 2006 while the number of 1-dredge boats peaked at 43 between 2007-2009 (Figure 6a). Since then, the number of 1-dredge boats has steadily dropped to 8 in the last two years while 2-dredge boats decreased to 21 during the first years of 3-license consolidation and then dropped to 12 since 2014. LPUE (bushels caught per hour) rose very slightly from 2002 through 2013 from an average of 5 to 9 bu/h for 1-dredge boats and from 7 to 14 bu/hr for 2- dredge boats. LPUE increased sharply since then, however. By 2016, 1-dredge boats harvested an average of 20 bu/h while 2-dredge boats harvested 32 bu/h.

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[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.

[2] See New Jersey's FDA-approved *Vibrio parahaemolyticus* Control Plan here: http://www.nj.gov/dep/bmw/Reports/2016vibrioplan.pdf

The marked rise in LPUE is likely not due to consolidation alone. Industry reports of a plethora of large oysters led to the examination of size structure in the market-size population and its relationship to LPUE. The trend in LPUE closely reflects the trend in abundance of the largest oysters in recent years (Figure 6b). Preliminary results from a model of the relationship between LPUE and size frequency indicate that size distribution alone can have a large influence on catch rates.[1] The conclusion of the SARC is that both the availability of large oysters and the advent of license consolidation have contributed to the recent sharp increase in LPUE.

Exploitation vs. Abundance

For several years, questions had been raised at the SAW about whether prescribed fishing exploitation rates lead to noticeable responses in abundance under the current management strategy. As a result, the 2016 SARC requested an evaluation of changes in oyster abundance that occur over different realized fishing exploitation rates. Change in abundance during fishing year was regressed on exploitation rate by region and a linear model was fit to the data (Figures 7a,b). This was done for each of five regions for both the entire direct market time series (1997-2016) and also for the current management time series (2007-2016). Among all ten cases, only one significant trend was observed: MMM market abundance increased significantly with fishing rate ($p=0.006$; Figure 7a). Based on this analysis, the SARC agreed that the prescribed fishing exploitation rates under the current management approach have not negatively influenced the oyster stock abundance. The SARC recommended that biomass-dynamics models be employed to estimate optimal fishing rates for each region and the stock as a whole.

Resurvey Analyses

Anecdotal evidence provided by the oyster industry and the NJDEP at the 2016 SAW led to a discussion about possible underestimation of oyster abundance on Shell Rock in the Fall 2015 assessment survey. This prompted a SARC recommendation to move Shell Rock ahead six years in the resurvey schedule to Spring 2016 to evaluate whether the stratification done in 2012 led to a Fall 2015 survey design that no longer represented the distribution of oysters on Shell Rock. The Spring 2016 Shell Rock resurvey indicated that changes in oyster distribution had indeed occurred between 2012 and 2016. The earlier 2012 stratification placed the high and medium quality strata (dark and light orange grids) in the upper half of Shell Rock with most of the low quality stratum grids (blue areas) in the lower half of the bed (Figure 8). Because the fall assessment surveys only sample the high and medium quality strata, no grids from the lower portion of the bed were available for the random pick of sites from the high and medium quality strata in the design of the 2015 fall survey. The new 2016 stratification on Shell Rock showed that the resource had spread into the lower part of the bed and that the numbers of grids in both the high- and medium- quality strata had increased (Figure 8). It is possible that shellplanting enhancement activities (sample sites shown as green dots) that occurred between the two resurveys played a large part in the oyster redistribution seen in the 2016 resurvey. Enhanced

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

grids are not part of the standard assessment survey design but are specifically targeted during the Fall assessment for 3 years post-planting.

Statistics to determine sampling intensity based on the new stratification are employed after each resurvey. The 2016 resurvey results showed that sampling intensity in the 2015 assessment survey likely missed some grids into which the stock had spread. Based on the outdated stratification and a possible insufficiency of samples, it is likely that oyster abundance on Shell Rock was underestimated in the 2015 assessment. Further details can be found in this document in the 2016 Resurvey section of Stock Assessment Design.

Other restratification surveys were then evaluated to see how often this situation may have occurred and whether a change in resurvey scheduling for all or some of the beds might be necessary. Fall assessment sampling designs were used to subsample beds using the data collected during Spring resurveys.[1] An estimate of abundance from these subsamples was compared to the estimate generated from sampling all grids in the resurvey (Figure 9). If the two estimates are similar, this suggests that the relative stock distribution has not changed between restratification surveys; if they are not, then the current survey schedule for restratifications might need alternation. Of 16 abundance comparisons, only two showed significant differences using this approach: Shell Rock in 2016 and Ship John in 2009. Both of these beds receive more regular transplant and shellplant enhancements than many other beds. In particular, shell planting targeted at a specific area of Shell Rock between 2012 and 2015 appears to have altered the 2012 stratification to such an extent that it affected the presumed 2015 distribution of oysters and thus, the assessment survey abundance estimates.

The SARC recommended no changes be made in the current 10-year resurvey scheduling at this time but that any reports of mismatches between abundance estimated by stock assessment and anecdotal observations by oystermen and the NJDEP be investigated. Some SARC members suggested that particular attention be paid to Bennies bed in the upcoming season to see whether or not an anecdotal productivity spike may have altered its stratification. Another suggestion was to include random grids from the low quality stratum for some beds during the Fall 2017 assessment survey to monitor for possible anomalies in the low quality stratum. The SARC will evaluate any results at the 2018 SAW.

VLM Targets and Thresholds

When the VLM entered the assessment in 2007, there was no history on which to base biological reference points. At the 2012 SAW, an assumption was made that this region mimicked the LM well enough to adjust the LM targets for acreage and apply them to the VLM (see p. 34, 2012 SAW report). Catchability coefficients from the LM were also applied to the

[1] Fall assessment surveys sample a randomly chosen subset of grids in the medium and high quality strata of each bed; Spring resurveys sample all grids on selected beds.

VLM. Upon analyzing the results of the 2013 dredge calibration experiments, it became apparent that catchability coefficients for the VLM differed from those of the LM and thus, the biological reference point targets being used for the VLM were similarly suspect. The 2016 SARC advised the development of region-appropriate targets and thresholds for the VLM. The VLM assessment time series now has 10 years of observations that include a wide range of population influences. The first two years had high abundance with no exploitation; the next three included transplant exploitation after which there was a severe freshwater mortality event followed by a three-year fishery closure. Since then there has been a continuing recovery period without exploitation (Figure 10). The SARC debated various applications of the 10-year time series values as potential targets and thresholds (Figure 11a-c). Ultimately, the SARC advised use of the 75th percentile of the VLM 2007-2016 abundance time series as a target and the 50th percentile as the threshold with the proviso that this be re-evaluated in three to five years (Figure 11a).

Spat transition sizes

The current stock assessment uses 20mm (0.8”) as the delineation between spat and oyster when calculating abundance although it is known that this varies across regions, increasing in size moving downbay. Analyses presented at the 2016 SAW provided regional transition sizes from data collected in 2014 and 2015. The sensitivity of regional abundance estimates to region-specific changes in the spat size definition was assessed for this report using assessment data from 2011-2015 (Figure 12). For most regions, the 20mm spat-to-oyster cutoff resulted in less than a 10% change in total abundance. This is well within total abundance error estimates (e.g. Figure 38). The only region that evinced a noticeable change in abundance is the HM, the most downbay region where using a region-specific cutoff size would raise spat abundance and decrease total oyster abundance by 15-20% although even this is within the estimate of error. While it seems intuitive to use region-based transition sizes, the lack of data prohibits regional cutoffs from being applied retrospectively through the time series. Going forward, however, the SARC suggested that future environmental change might render the 20mm cutoff less appropriate. The SARC also mentioned that spat recruitment in the HM is likely underestimated due to the 20mm cutoff. Since spat and small oyster recruitment are used as secondary rather than primary metrics on which to judge the stock in this assessment, the SARC generally felt that keeping the 20mm cutoff is adequate with the proviso that it be re-evaluated as salinity and temperature changes occur.

Stock Assessment Design

Sampling Methodology

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 13) 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; the number of spat[2], older oysters, and boxes per composite bushel; the size of live oysters, spat, and boxes from the composite bushel; condition index; and the intensity of Dermo and MSX infections.

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. 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 as the `Medium Quality' stratum 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. 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

[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.

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 18th SARC (2016) revised this schedule to resurvey Shell Rock in 2016 rather than in 2022 when it would otherwise have been due (see earlier 2016 Science Advice, Resurvey Analyses). To accommodate the change, other shifts occurred to maintain the original premise of the schedule: 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). Hope Creek and Hawk's Nest are scheduled for resurvey in Spring 2017.

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 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 (see Table 3 in Ashton-Alcox et al. 2016).

In September 2013, dredge efficiency experiments were conducted again using the *F/V Howard W. Sockwell* and a commercial dredge but with patent tongs on the *R/V Baylor* instead of divers (Ashton-Alcox et al. 2014). Parallel transects were sampled to compare numbers of oysters caught in measured tows versus those collected by the tongs that were presumed to be 100% efficient. Spatial and temporal analyses of these data 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

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

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 entire 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 the 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 the oysters per m^2 on each grid. Catchability coefficients estimated by 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"). 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

[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 reports earlier than the 2016 report but the scales will not match.

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 37 and 38).

2016 Spring Resurvey

In Spring 2016, three beds in separate regions were restratified after all grids were sampled: Liston Range (VLM); Shell Rock (SR); and Hog Shoal (HM). Shell Rock was moved ahead in its resurvey schedule by the request of the 2016 SARC (Ashton-Alcox et al 2016) which led to a few changes in the overall resurvey schedule (Table 2). Some of the Shell Rock results are described earlier in this report under the 2016 Science Advice, Resurvey Analyses.

The 2016 resurvey revealed that over half of the 32 grids on Liston Range are in the low quality stratum (Figure 14a). Densities for these low-quality grids ranged from 0.02 - 1.3 oysters per m^2 plus one grid that had no oysters. Approximately one-third of the grids fell into the medium quality stratum where densities reached 39 oysters per m^2. Three grids made up the high quality stratum and contained half of all oysters on Liston Range with the highest density grid at 93 oysters per m^2. The number of grids in the high quality stratum remained the same before and after the resurvey although their placement on the bed changed (Figure 14b). The number of grids in the medium quality stratum increased after the 2016 resurvey with a concurrent decrease in the number of low quality grids. A comparison of grid densities ranked as percentiles for the Liston Range grids shows that 2016 densities on all grids were consistently greater than those from the initial 2008 resurvey (Figure 14c).

Shell Rock has 93 grids and 20% of them are in its high-quality stratum after the 2016 resurvey (Figure 15a) as opposed to 12% prior to the 2016 resurvey (Figure 15b). Nearly 40% of Shell Rock's grids are in its medium-quality stratum as of 2016; this is up from 34% in the 2012 resurvey. This change indicates a substantial spread of the Shell Rock oyster resource and means that the Fall assessment surveys will encompass almost 60% of Shell Rock's footprint. Additionally, statistics done after the resurvey indicated that an increase in sampling intensity was needed to adequately assess the high and medium quality strata on Shell Rock in the Fall Survey. The numbers of grids sampled in the Fall assessment from the high quality stratum increased from 4 to 7 while those in the medium quality stratum increased from 6 to 7 (Table 5). The fraction of grids that make up Shell Rock's low quality stratum decreased from 54% to 41% between 2012 and 2016. Three resurveys of all grids on Shell Rock were compared using each grid's oyster density ranked in percentiles (Figure 15c). Up to the 60^{th} percentile, the 2016 resurvey had the highest densities which then leveled off through the 95^{th} percentile indicating that although the resource had spread by the 2016 resurvey, there were not higher numbers of oysters on Shell Rock than in previous resurveys. Maps of Shell Rock resurveys stratified by density groups clearly show the decrease in the number of grids shaded black (>100 oysters per m^2) from the 2012 to the 2016 resurvey as well as the resource spread with a substantial increase in numbers of dark gray grids (20-100 oysters per m^2) in the 2016 resurvey (Figure 16).

The final bed in the 2016 resurvey was Hog Shoal in the HM. Hog Shoal is a small bed made up of only 23 grids with relatively low oyster densities (Figure 17a). There are 4 grids in Hog Shoal's high quality stratum after the 2016 resurvey, the same number as in its previous 2006 resurvey in approximately the same area of the bed. The number of medium quality grids has fallen from 13 to 10 (Figure 17b). This does not mean, however, that the densities of oysters on Hog Shoal grids have fallen. In fact, the comparison of densities ranked as percentiles show that all densities for 2016 from the 50^{th} percentile and up are higher than those of 2006 (Figure 17c). Although the range of oyster densities on Hog Shoal grids is relatively small over the three strata, the 2006 resurvey range was lower (0.01 - 21 oysters per m^2) than that of 2016 (0.04 - 36 oysters per m^2).

2016 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 2016 assessment survey was conducted October 14th and November 2nd, 3rd and 9th using the oyster dredge boat *F/V Howard W. Sockwell* with Lemmy Robbins as captain. Total sampling effort in 2016 was 168 grids (Figure 18). The Enhanced stratum consisted of 12 selectively sampled grids including 2 grids that received intermediate transplants in 2016, 3 grids that received shellplants in 2016, 3 grids that received shellplants in 2015, and 4 grids that received shellplants in 2014 (Table 5). The intermediate transplant grids revert back to their original stratum after one year and the shellplant grids revert back after 3 years. These grids are then subject to random choice within strata for following stock assessment surveys. Any transplant or shellplant effects on oyster density in a grid get assessed in the next resurvey of that bed.

Status of the Stock in 2016[1]

Whole stock 2016

The total acreage of the surveyed oyster beds includes the area of the high, medium, and enhanced strata on each bed (Figure 13). This can change somewhat each year due to strata reassignments of resurveyed grids and the inclusion of grids in the enhanced stratum. Each grid is approximately 25 acres. In 2016, the total area of the beds was 16,026 acres (64,854,608 m^2). Whole stock oyster abundance in 2016 was 1.79 billion oysters at an average density of 37 oysters per m^2, well over the 2015 average of 24 oysters per m^2. This is the highest total abundance since 2010 and 2011 when there were 2.23 billion oysters both years. Of the 2016 abundance, 662 million or 37% were market-size (>2.5”), approximately the same as in 2015. Since the inclusion of the VLM to the assessment in 2007, the fraction of market-size oysters has ranged from 24-53% averaging 38%. In 2016, box-count mortality was 12.9% as it was in 2015 (13.0%), continuing a steady decrease since 2012 when mortality was 23%. Spat recruitment in 2016 was the highest it has been since the inclusion of the VLM. At 4.7 billion, it was far beyond the 2014 and 2015 lows of 0.3 and 0.8 billion, respectively. Continued lower mortality rates in 2017 could lead to an increase of oysters given the large number of spat.

Whole stock ‘dermo era’ 1990-2016

Due to the short time series of the VLM, it is necessary to exclude this region from the section to make time-series comparisons of ‘whole stock’ data. Oyster abundance in 2016 was at the 35th percentile of the 1990-2016 ‘dermo era’ time series (Table 6). Abundance remains in the range of recent years and above the lows of 2003-2005 (Figure 19). The 2016 market-oyster abundance is at its highest since 2007 and is at the 89th percentile of the time series (Table 6).

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

This size group has been relatively stable at or above the median value since the current fishery management scheme went into effect around 2007 (Figure 20). From 1990 to 2002, SSB tracked the usual dynamic of a much higher proportion of small oysters than market-size in the population (Figure 19a). Since then, the proportions of market-size and smaller oysters have been nearly equal and the larger oysters have positively influenced SSB. Spat abundance in 2016 is the highest it has been since 1999 and fell at the 91st percentile (Figure 19b, Table 6). Ideally, this will increase the proportion of smaller oysters in the population. The natural mortality range of the 1990 to 1999 dermo era was 9-33% (23% average) which has since narrowed to 12-22% averaging 17% (Figure 19c). The 2016 box-count mortality is at the 28th percentile of the dermo era time series reflecting this decrease in mortality (Table 6).

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 13). 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 21a). Regional acreage does not reflect the distribution of the oyster stock. In 2016 for example, the large HM contained less than 10% of the total stock while the SR and MMM that together make up less than a quarter of the total oyster acreage, made up over 50% of the oyster abundance (Figure 21b). Most of the oyster abundance in 2016 is contained in the central regions (SR, MMM, MMT), a trend that has been evident since the dermo era of 1990-2016 (Figure 21b,c,d). Also continuing a dermo era pattern, the majority of natural mortality in 2016 was on the three lowest regions (Figure 21e).

Very Low Mortality region (VLM)—*Figure 22, Table 6*

The VLM is the uppermost extent of the Delaware Bay, New Jersey oyster resource and its time series began in 2007 (Figure 13). In 2016 it had 1,416 acres and contained 174 million oysters comprising 10% of the total stock (Figure 21a,b). This is the highest assessed abundance for the VLM and the third consecutive year of increases. The average oyster density over all grids sampled on the VLM in the Fall 2016 survey (Figure 18) was 33 per m^2, close to that of 2015 and sampled grids ranged from 0-91 oysters per m^2. 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. Like oyster abundance, the 2016 spat set was the highest in the VLM time series. Dermo weighted prevalence remains far below levels observed prior to 2012 and far below the 1.5 level that causes mortality in the

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1 Extended percentile tables: Appendix B

2 Regional metrics; grouped by exploitation type (transplant or direct market): Appendix C

3 2016 sampled grid densities (per m^2) for oyster, spat, cultch: Appendix D

4 By-region SSB data overlaid on small and large oyster stacked bars: Appendix E

population. The VLM has only been specifically used for transplants three times and not since early 2011.[1]

Low Mortality region (LM) —*Figure 23, Table 6*

In 2016, the LM covered 1,679 acres and contained 212 million oysters comprising 12% of the total stock (Figure 21a,b). This is the lowest abundance on the LM since 2003 and falls at a very low 6th percentile for the 1990-2016 time series. The low abundance is due to decreasing numbers of small oysters since 2014 while the number of market-size oysters remained steady and was at the median in 2016. The average density on grids sampled in 2016 on the LM was 45 oysters per m^2, similar to that of 2015, and sampled grids ranged from 0.1-167 oysters per m^2. Since 2007, the pattern of spat sets on the LM has been a high year followed by two low years, a pattern somewhat reflected in the numbers of small oysters a year later. Spat set was high in 2016, at the 94th percentile. Dermo has been very low on the LM since 2011 with correspondingly low mortality rates, particularly in 2016 when the 5% mortality rate was in the 0th percentile for the 1990-2016 time series. Transplant exploitation has decreased over the past two years on the LM. Barring unforeseen natural disasters, all of the preceding factors may allow for an increase in oyster abundance.

Medium Mortality Transplant region (MMT)—*Figure 24, Table 6*

The MMT is comprised of three beds, one of which (Sea Breeze) is separated from the other two by the MMM (Figure 13). At 1,576 acres, the area of the MMT is similar to that of the LM although it holds more oysters (333 million); 18% of the stock (Figure 21a,b). Abundance on the MMT has been steadily rising since 2013 and was at the 57th percentile in 2016. Both small and larger oysters have contributed to the increasing abundance and market-size oysters were at the 96th percentile in 2016, second only to the 2006 number of market-size oysters. Oyster density on the non-enhanced sampled grids of the MMT averaged 59 per m^2, ranging from 2-198 per m^2. The density of oysters on the one enhanced grid shellplanted in 2014 was 133 per m^2. The 2016 spat recruitment on the MMT was the highest since 1998 and like the LM, was at the 94th percentile. Dermo has remained at levels capable of impacting mortality rates but mortality has decreased over the last few years and in 2016 was at the 28th percentile for the dermo era. Transplant exploitation rates in the MMT were low in 2016 at less than 1% for all oysters and at about 1.2% for market-size.

Medium Mortality Market region (MMM)—*Figure 25, Table 6*

The MMM consists of two beds (Ship John and Cohansey) at the uppermost part of the direct market regions and is the second largest region (Figures 13 and 21a). Its 2,443 acres held 28% of the total stock (513 million oysters) and 35% of the market-size oysters in 2016 (Figure 21b,c). Total abundance on the MMM has been steady since 2012 and was below the median at the 46th percentile in 2016. The pattern of having more small than large oysters has shifted on

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

this region over the last few years so that now there are more market-size oysters with the 2016 numbers falling at the 92nd percentile. The average oyster density of non-enhanced grids sampled on the MMM for the Fall 2016 survey was slightly higher than in 2015 at 54 per m^2, ranging from 5-102 per m^2. The MMM has received multiple shellplants and transplants over the past few years, four of which were sampled in 2016. Average oyster density on enhanced grids was 106 per m^2 with densities >100 per m^2 on the two older shellplants and <100 per m^2 on the 2016 shellplant and transplant grids. Spat abundance on the MMM was the highest since 1999 and at the 91st percentile in 2016 which may reset the pattern of more smaller vs. larger oysters in the upcoming year. Dermo was below the level capable of impacting mortality in 2016 and since 2012, natural mortality in the MMM has been on a steady decline and is at the 35th percentile. The 2016 exploitation rate remained at about 3% of the market-size oysters as it has in most recent years.

Shell Rock (SR)—*Figure 26, Table 6*

At 1,445 acres, SR is the smallest region but contains more oysters (404 million) than the largest and 28% of the stock in 2016 (Figure 21a,b). Its 2016 abundance was at the 69th percentile following a generally increasing trend since 2012. Oyster density on the non-enhanced sampled grids of SR averaged 74 per m^2, ranging from 15-133 per m^2. Because of its importance to the fishery, SR regularly receives shellplants and transplants. For the four enhanced grids sampled in 2016, average oyster density was 80 per m^2 ranging from 13 oysters per m^2 on a 2015 shellplant to 185 per m^2 on a 2016 shellplant. Oyster counts include all animals ≥20mm and it is possible that some of the oysters in the 2016 shellplanted grid may have set in 2016 but grew larger than 20mm. As with the MMM, there have been more large oysters on SR recently than in earlier years and the 2016 market-size oyster abundance is the 100th percentile of the 1990-2016 record. The 2016 SR spat abundance is also at the 100th percentile for the 1990-2016 time series with over 1 billion spat, a number not surpassed since 1986. Mortality has been steady at about 18% since 2014 which was the 35th percentile in 2016. The only unfavorable metric in 2016 for SR was the much-higher dermo level. SR is an important harvest region and exploitation rates have recently been around 1.5% of all sizes but in 2016 it was about 3%. Exploitation of market-sized oysters has been 2-5% since 2007.

High Mortality Region (HM)—*Figure 27, Table 6*

The HM is a direct market region consisting of the eleven lowermost beds in the assessed stock (Figure 13). It is the largest region, making up 47% of the oyster acreage (Figure 21a). Conversely, it contains the fewest oysters (166 million) and contributed only 9% of the stock in 2016 (Figure 21b). Large portions of the HM have low densities of oysters compared to the other regions. In 2016, oyster densities on sampled, non-enhanced grids averaged 7 per m^2 and ranged from 0-58 per m^2. Since 1998, the HM has received almost annual enhancements of transplanted oysters or clamshell. Table 7 shows the 2016 densities for the three enhanced grids compared to bed-averages for the non-enhanced grids sampled, indicating that results can vary widely depending on site. Abundance has continuously decreased on the HM since 2013, the last year that it received oyster transplants, and in 2016, was at the 28th percentile. This is due to the decreased number of small oysters. As in the other direct market regions, market-size oyster abundance is outpacing small oyster abundance and is at the 73rd percentile in 2016. The HM did not receive the same very large spat recruitment that other regions did although 2016 spat abundance was above the median at the 65th percentile. Although dermo has been at lower levels for the HM in recent years, mortality has risen from its 2014 low of 15% up to 22% in 2016 and was at the 39th percentile. Corresponding to the small vs. market-size oyster abundances; without its usual transplants, the HM fishing mortality on all sizes of oyster has steadily risen since 2013 to about 4% while exploitation on the market-sized oysters has remained steady at about 8%.

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 has effectively doubled natural mortality rates since then (Powell et al. 2008b). Fewer oysters produce less shell and therefore, less habitat. Similarly, smaller oysters provide 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. Figure 28 shows total bushels of surficial cultch from 2000-2016 excluding the VLM. Using this approach, the volume of cultch has not fluctuated very much since 2000, aside from the lows of 2003-2005 and the highs of 2006-2007. The median number of bushels (13.8 million) occurred in 2015 and the number of bushels in 2016 was similar (13.4 million).

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 F). 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 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. 2017) 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 2016, there were three shell plants on NJ's Delaware Bay oyster beds, all funded by the NJ oyster fishery. Each plant consisted of 44,000 bushels of unspatted clamshell put directly on grids in each of three regions: HM (Bennies), SR (Shell Rock), and MMM (Ship John) (Figure 18, Table 8a). Spat recruitment varied widely from 4 spat per bu of clamshell at Bennies to 1336 spat per bu at Shell Rock. Three sites in the same regions were similarly planted in 2015 and sampled in the Fall 2016 assessment survey for 2016 spat on the clamshell (Table 8b). Again, results varied with no spat found on clamshell at the HM (Bennies) site or the SR site but 925 spat per bushel of clamshell was present at the MMM (Cohansey) site. Curiously, the three oldest plant sites (2014) showed more consistent results with 159 spat per bu clamshell at the HM (Nantuxent) site, 496 on the SR site, and 546 on the MMM (Ship John) site (Table 8c). It is generally believed that the longer clamshell is on the bottom, the more fouled and less accessible to spat it becomes.

The impact of first-year shellplants in the direct market regions is shown in Figure 29. For each shellplant, the fraction of a region's area that was planted is plotted with the fraction of the region's spat that recruited to the planted shell. The results show an upbay-downbay pattern with the MMM having less overall difference between the fraction of total acreage planted and the fraction of total spat accruing to that plant and the HM having the most. The average fraction of total spat accruing to first-year plants in the MMM was 4.3% (Figure 29a); the average in the SR was 13% (Figure 29b); and that for the HM was 19% (Figure 29c). In most cases, the fraction of a region's spat contributed by the planted area was far greater than the fraction of the region's area planted indicating the effectiveness of shellplants. In the HM, the fraction of recruitment to shellplants was greater than the fraction of area planted in 10 of 11; in 2010, it was 87x greater. In the SR, this was true 8 out of 9 times with the highest difference being 12x in 2011. In the MMM, this relationship was only true in 3 of 6 years with a maximum factor of 9x in 2008. It should be noted when discussing the success of shellplants that the mortality rates for both smaller and larger oysters increase from upbay to downbay so ultimate survival of spat recruits will likely not be as different among regions as this initial recruitment suggests.

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). For the purposes of the NJ stock assessment, oysters < 20 mm are defined as spat. This assumes 20 mm to be 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, placement of the 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 was generally larger than the 20mm cutoff that is currently employed. In general, the transition size increased moving downbay with more upbay regions (VLM, LM, MMM) having an average morphological transition size of about 22 mm and more downbay regions (MMT, SR, HM) having an average transition size of about 30 mm (Figure 30).

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 the appearance of *Haplosporidium nelsoni* (the agent of MSX disease) in 1957 however, disease mortality has been the primary concern (Powell et al. 2008b). 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). Samples for MSX have been routinely taken since 1988 during the fall assessment from 6 beds: 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 2016, MSX was found in two of the three HM beds but nowhere else and the intensity of the disease was low (Bushek et al. 2017). Routine monitoring continues to detect the MSX parasite in Delaware Bay but it does not appear to be impacting the native population.

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. 2017). 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. Studies have indicated that it is largely controlled by temperature and salinity so those parameters are tracked closely. In 2016 water temperatures and salinity exceeded the 17-yr average late in the summer and remained high well into the fall (Bushek et al. 2017). Dermo prevalence and intensity began at low levels in 2016 but followed the physical parameters and increased to higher-than-average levels towards the end of the season (Bushek et al. 2017). Dermo prevalence at the time of the assessment was low on the most upbay regions (VLM, LM) as it has been in recent years, remaining below the weighted prevalence known to cause mortality (about 1.5 on the Mackin scale) and in fact, mortality continued to decrease on those regions in 2016 (Figure 31). Prevalence on the MMT, MMM, and HM was 80% in Fall 2016 and remained well above 90% on SR for the second year. Weighted prevalence decreased on the MMM but increased sharply on the SR and HM. This was accompanied by increased mortality on the HM but not the SR although that is a possibility for Spring 2017 when water temperatures begin to rise.

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[1] See Bushek et al. 2017 for full disease monitoring report.

Oyster Fishery

Direct Market Harvest

The 2016 direct market harvest occurred from April 4th 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 20 vessels including 8 single- and 12 dual-dredge boats were in operation, the same as in 2015. The number of boats has declined since 2009 when 74 boats harvested (Figure 6a). This is a result of a change in legislation that allows license consolidation so boats can now harvest multiple quotas rather than one quota per boat (see LPUE and Large Oysters section earlier). LPUE in 2016 was the highest recorded since at least 2002 (Figure 6a). The average LPUE over all boats fishing, all beds, and all months of harvest was 20 bu/hr and 32 bu/hr for one- and two-dredge boats respectively. LPUE ranged from 14 - 77 bu/hr.

Total direct market harvest in 2016 was 100,095 bushels; 12,665 bushels more than in 2015 and the third highest harvest since the direct market began in 1996 (Table 9, Figure 32)[2,3]. This harvest includes the initial quota allocation of 91,299 bushels from the three direct market regions: MMM, 32,086 bu; Shell Rock, 24,442 bu; and HM, 34,771 bu plus an additional 9,993 bushel allocation resulting from intermediate transplants (Table 10a). The final 2016 harvest was nearly 1,200 bushels below the allocation. Similarly, the final 2015 harvest was 1,231 bushels below the allocation.

Of the 14 beds opened to the 2016 Direct Market harvest, 6 were fished with 32% of the catch from the two beds on the MMM, 32% from SR, and 36% from the HM. Since the inception of the Direct Market in 1996, HM harvests have been taken from fewer beds. For the first 10 years of the direct market program, harvests came from 7-10 beds of the 11 in the HM. From 2007 to 2011, 6-8 beds were utilized and since then, the harvest has dropped from 6 down to 3 beds in 2016 with 82% of it from Bennies bed (Table 9a). The beds in Table 9a are arranged in upbay to downbay order and it is evident that oystering in the HM has consolidated in a generally upbay direction in recent years.

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 exploitation rates can be determined. The overall average number of oysters per harvested bushel in 2016 was 268; of those, 246 were market-size (Figure 33). In general, the number per bushel of market-sized oysters (>2.5", 63.5 mm) has remained relatively constant since port

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[1] http://www.nj.gov/dep/bmw/Reports/2016vibrioplan.pdf

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

[3] 1996-2006 harvest and transplant volumes in Appendix G.

sampling began in 2004. Conversion of oysters to bushels for allocation projections used the value of 264 oysters per bu in 2016, the average of 13 years of port sampling. This value is the mean of the total oysters and the presumably targeted (≥ 2.5") oysters per bushel. The rationale for using the 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 overall mean has ranged from 259-266 oysters per bu since 2006.

Figure 34 illustrates the 2016 size frequency of marketed oysters compared to the average size frequency for the years since port sampling began (2004) until 2015. As shown in Figure 6b, the proportion of the largest market-size oysters in the population of the three Direct Market regions has sharply increased over the past two years and in 2016, made up 60% of market-size oysters. The size frequency of the 2016 landings in Figure 34 reflects that increase. In the 3-4" size fractions, the 2016 values are much higher than the 2004-2015 averages.

Intermediate Transplant[1]

The three most upbay regions of the New Jersey Delaware Bay oyster resource are considered 'intermediate transplant' regions from which oysters may be moved downbay to annually-specified grids in chosen direct market regions in an NJDEP-HSRL monitored program that usually occurs in late April and/or early May. Two transplants were conducted in April and May of 2016. One moved 4,800 bu from Arnolds in the LM to Cohansey in the MMM and the other moved 8,150 bu from Middle and 2,400 bu from Sea Breeze in the MMT to Shell Rock (Table 11).

Boats deckloading oysters for transplant use automatic 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%. In 2016, oysters were moved from one LM bed (Arnolds) and the small oysters made up a large (64%) proportion of the 2.2 million oysters moved (Table 11). The cullers likely removed at least some of these smaller oysters, however, because this size group made up 73% of all oysters on the LM in the Fall 2015 assessment (Figure 23). In direct contrast to the LM transplant, the MMT transplant had about half the percentage of small oysters (Table 11). The Middle transplant contained 39% small oysters and that from Sea Breeze contained 32%.

[1] Intermediate transplant memoranda in Appendix H.

Correspondingly, in the 2015 Fall assessment survey, the ratio of small to market-size oysters in the MMT population was much closer at 55:45 (Figure 24). 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 2016 transplants were converted to market bushel equivalents using the number of market oysters per bushel (265) derived from the port sampling longterm mean of 2004 to 2015 (Ashton-Alcox et al. 2016) and were added to the quota for the receiving regions in May 2016. The 2016 intermediate transplant program increased the quota on the MMM by 2,972 bushels and the quota on SR by 7,021 (Table 10a).

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 used as transplant donors in 2016 were higher than 20%. In the case of Sea Breeze, it was much higher at 44% (Table 11) although it should be noted that the Sea Breeze transplant consisted of two boats deckloading for one day, ie, two monitoring samples of 51% and 38% cultch.

***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 (50th 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 50th percentile of exploitation as a base but to allow increasing exploitation to the 60th percentile rate when the population was expanding or to reduce it to the 40th 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 50^{th} percentile that separated as high and low. The 50^{th} and 60^{th} percentile values from the original data were averaged. That average was used as the 50^{th} percentile and the previous 50^{th} percentile was then used as the 40^{th}. In the HM, the change from the 40^{th} to 50^{th} percentile spanned a much larger range of exploitation rates than that of its 25^{th} to 40^{th} percentiles whereas SR's 40^{th} and 50^{th} percentiles were nearly identical (Figure 35a). Consequently, if market-size oyster abundance was low on SR and other parameters were not promising, the choice for conservative exploitation was constrained to fishing below the 40^{th} percentile. Finally, there was such a narrow range of exploitation rates on the MMM (the 100^{th} percentile exploitation rate on the MMM was below the 10^{th} percentile exploitation rate on nearby SR) that the SARC had regularly recommended an 'experimental' fishery at the 100^{th} percentile rate of exploitation on the MMM (Figure 35a).

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 35). 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 35b). 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% (Figure 35b). 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 ≥2.5" rate of 3.7% for the MMM, 4.9% for SR, and 9.8% for the HM (Figure 35).

Each year's quota for the direct market regions is based on the previous Fall's assessed abundance. For each of the three market regions, 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 33). The sum of regional quotas is divided by the number of active licenses (75-80) to determine individual allocations. Additional quota from intermediate transplants is determined based on the number of market-size oysters moved and gets allocated about six weeks after the oysters are moved to the direct market 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 meeting in March (Table 3).

In 2016, the Council chose quota options for which the SARC required transplants in the MMM and SR and an option that did not require a transplant in the HM (Table 10a). Both the MMM and HM Council choices were less than those allowed by the SARC. 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 generally looks at 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. In the MMM, the 2016 achieved harvest was below the total of the original quota plus the addition from a transplant (Table 10a). The 'underharvest' (2,645 bu) was approximately equivalent to the additional quota from the transplant (2,972 bu). In the SR, the total quota including transplant (31,463 bu) was overharvested by about 300 bushels. The achieved exploitation rate on SR (5.27%) was somewhat higher than the chosen rate (4.88%) after the additional transplant quota was harvested but it should be remembered that transplants also add submarket-sized oysters (Table 11) and the direct market region exploitation rates consider market-sized oysters only. The 2016 realized exploitation rate on SR when considering all sizes of oysters was 3.14% (Figure 26). The HM quota did not have a transplant associated with it in 2016 and this region was also overharvested by about 1,100 bu although this was not enough to affect the achieved exploitation rate. On the whole, the total 2016 allowed quota (101,292 bu) was underharvested by 1,197 bushels, approximately the same underharvest as in 2015.

Council decisions about transplanting options are complicated by various logistical and funding issues. The industry uses its self-imposed bushel tax to fund transplants 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 2016, 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 2.8% of its oysters (Ashton-Alcox et al. 2016). 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 LM at a very conservative exploitation rate (0.76%) that was less than half the maximum SARC-recommended rate of 1.75% (Table 10b). Similarly, the Council chose to transplant at a lower-than-maximum-recommended rate from the MMT (1.49% vs. 1.99%). Because of the uncertainty in projecting numbers of bushels to transplant, these quotas are based on a goal number of oysters to be moved to an allotted Direct Market region grid. The 2016 transplants were conducted in April and May and moved 127% of the goal number of oysters from the LM (Arnolds) to the MMM (Cohansey) and only 75% of the goal number of oysters from the MMT (Middle and Sea Breeze) to Shell Rock (Table 10b). In both cases, the achieved exploitation rates were well under the maximum rates that the SARC agreed upon.

***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 2016 was approximately 26.6 million oysters. This number of oysters represents a fishing mortality of 1.48% of all oysters in 2016 and about 1.96% of all oysters excluding the VLM (Figure 36a). 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 2016 was 3.8% of all market-size oysters and at the higher end of the range since the direct market began (Figure 36b).

Regional fishing mortality is shown in Figures 22-27 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 2016 for a fifth year to allow continued recovery from the freshwater mortality it suffered in 2011 despite the SARC supporting a low level of exploitation in that region. Exploitation for transplant purposes was conducted on the LM and MMT in 2016 at lower levels than in 2015 reflecting both 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 increased to 1.4% in 2016 but remained at 3.1% for market-size oysters for the third year in a row (Figure 25). 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 annually since 2013 for the same reasons and fishing mortality on this region rose in 2016 to 3.1% of all oysters and 5.3% of market-size (Figure 26). The HM has not received any transplants since 2013 and the fishing mortality on all oysters has steadily risen

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

from a negative value in 2012 to 4.4% in 2016 (Figure 27). On the other hand, lower mortality rates may have helped the market-size oyster fishing mortality to remain steady since 2014 at about 8%.

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. The 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). At least three periods are indicated in the record. The first was low abundance on the oyster beds in the 1950s that continued as MSX caused significant mortality. In the 1960s, MSX and mortality rates declined on the beds while shellplanting increased (Figure 4a) corresponding to a period marked by high abundance that lasted into the 1980s. Circa 1985, an extended drought facilitated the spread of MSX upbay causing extensive mortality that began a third 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 became established and effectively doubled natural mortality (Powell et al. 2008b). This state of low abundance and high mortality has persisted. 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 peaks of mortality to >30% of the stock in the 1990s have since modulated to just over 20% since 2000 (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 12 (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 2016 total abundance (excluding the VLM) of 1.629 billion oysters was a 20% increase over that of 2015 (1.361 billion oysters). Of those, 758 million were market-size in 2016 compared to 645 million in 2015, an 18% increase. The 2016 point-estimate of 1.63 billion falls significantly below the whole-stock reference point of 2.3 billion (Figure 37a) as it has at least since 2009. 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 1st percentile confidence limit so the survey is considered to be statistically over the whole-stock abundance threshold. In contrast to total abundance, market abundance across the stock sits significantly above the stock performance target of 401 million oysters as it has in recent years (Figure 37b). The whole stock market-sized abundance estimate of 758 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 37 use a set of catchability coefficients based on catchability of all sizes of oysters as of the 2016 SAW instead of size-class separated catchability coefficients.

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 12). 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 (see VLM Targets and Thresholds earlier in this report) 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 and the medians as the threshold. This included a proviso that these be reevaluated in three to five years.

Figure 38 illustrates the position of the 2016 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 2016 position. The error bars are the 10th and 90th percentiles of 1,000 estimate simulations (see Analytical Approach). In the four upper regions, the 2016 error bars overlap the

[1] Confidence limit graphics in Appendix I.

2015 values but this is not the case for SR or HM. In the latter case, the error bars are relatively small and the 2015 value is just outside the upper error bars. In the case of SR, the 2015 value is low for both market-size and total abundances and is far outside the 2016 error bars. The 2015 value also does not follow the previous three years' trajectory and is likely due to survey stratification discussed earlier in this report (see Resurvey Analyses).

In all cases except the VLM whose target values were determined differently, the 2016 market-size abundances were well over the target value as they have been in recent years. In the case of SR, the total oyster abundance is also above the target. In the two Medium Mortality regions, total abundance is approximately centered between the target and threshold but in the LM and HM, total abundance is near and below threshold levels, respectively. As previously mentioned, the HM value is likely due to poor spat sets and the recent lack of transplants.

Summary of Stock Status

Table 13 is a 'stoplight' table summarizing the 2016 status of the oyster stock by region relative to the 1990-2016 time period or the previous five years. Parameters of the regional stocks are designated as improving (green), neutral (beige), or degrading (orange). Parameters include total abundance, market-size abundance, spat recruitment abundance, natural mortality, and dermo disease. Metrics include percentile ranks (40^{th} - 60^{th} 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 general mortality rates in the absence of disease (mortality), or comparison to dermo levels known to cause mortalities (dermo WP). The VLM target/threshold values were determined differently than the other regions' as previously mentioned.

The stoplight table can be read horizontally to look at a single parameter across all regions or vertically to examine all parameters within a single region. This sometimes clarifies the big picture if one region is suffering, eg. the 2011 freshwater mortality in the VLM or if there is one metric that stands out, eg. high market-size abundance for the past few years. For 2016, it does not matter which way the stoplight table is perused, most of it is green or at least beige indicating that the 2016 status of the NJ Delaware Bay oyster stock is positive. The few degraded (orange) sections are primarily total abundance on the LM and HM which is low by all metrics considered along with high dermo WP for SR.

Figures 22-24 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. Dermo WP remains far below levels observed prior to 2012 and far below the 1.5 level that causes mortality in the population. Abundance on the LM has decreased since 2014 due to fewer small oysters.

Both dermo and mortality levels have decreased in the LM over the last few years so low spat sets in 2014 and 2015 combined with slower growth on LM are likely the reason for its decreasing abundance. The high spat set in 2016 may ameliorate this problem if mortality and disease remain low. The MMT has had increasing abundance of both large and small oysters over the past few years and in 2016 received very good spat set. Dermo has remained at levels capable of impacting mortality rates but mortality has decreased over the last few years.

Figures 25-27 summarize the 10-yr trends of the stock in the three direct market regions. Abundance on the MMM has been stable over the past few years but the ratio of small to large oysters has gradually changed from the usual higher proportion of small oysters to a higher proportion of large oysters. The strong 2016 spat set may help reset this. Lower dermo in 2016 and decreasing mortality may increase survival and abundance on the MMM in 2017. The MMM has received multiple shellplants and transplants over the past few years. Abundance on SR in 2016 is at its highest since 2011 and its very high spat set may help bolster the number of small oysters in 2017. The dermo level was at its highest in many years although mortality has remained steady around 18%. Because of its importance to the fishery, SR regularly receives shellplants and transplants. The HM is experiencing lower abundance from sharply decreasing numbers of smaller oysters. This can be attributed to recent poor spat sets and the lack of transplants since 2013. Decreasing mortality on HM from 2011-2014 led to increased survival of all sizes of oysters over that period and allowed small oysters to grow to market size, maintaining the abundance of that group. Mortality increased in 2015 and again in 2016. That fact, combined with the lack of transplants and spat set indicates that the steady increase in fishing mortality on all sizes since 2013 can be directly attributed to the decline in small oyster abundance since exploitation rates on market oysters have not increased over this period.

Harvest and Management Advice

Direct Market *(Table 14)*

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 any of the exploitation rates established in Control Rules 4 and 5 (Table 4) could safely be taken from the MMM (1.8 - 3.7%) and SR (2.3 - 4.9%) without requiring transplants. The relatively high dermo levels on Shell Rock going into the winter may indicate increased mortality for late summer 2017 by which time any harvest will have been taken. The SARC advised that the HM receive a transplant regardless of exploitation rate due to the lack of small oysters there. The SARC agreed there are adequate numbers of market-size oysters on the HM to allow up to a 9.0% exploitation rate, a rate between the median and maximum exploitation rates for the HM.

Intermediate Transplant *(Table 15)*

Exploitation rates for the three transplant regions are based on total abundance (all sizes of oyster ≥20mm). All transplants must be done with the use of mechanical cullers. Conditions on the VLM continue to improve and the SARC advised that a Spring 2017 transplant could be conducted in this region up to the 3.0% rate of exploitation. Further, it was agreed that this transplant could be placed as low in the estuarine system as Bennies Sand in the upbay portion of the HM (Figure 13). The SARC commented on the limited number of previous exploitation rates available (3) and that they were higher than those of the LM and MMT. This is because 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. The favorable 2016 status of the MMT stock led the SARC to advise 2017 transplant exploitation rates up to the 2007-2015 maximum rate of 2.5% on this region with the suggestion that any transplant be placed on Bennies in the HM. In 2016, 82% of the HM harvest came from Bennies. As noted in the Control Rule 6 formalized at the 2016 SAW (Table 4), not more than half of any MMT transplant may come from Middle bed. The remainder of any MMT transplant should be from Sea Breeze and/or Upper Middle in any combination. Due to several years of decreasing abundance on the LM, the SARC advised closure of this region for 2017 transplanting. Specific locations to receive transplants will be determined by the NJDEP staff in conjunction with the Shell Fisheries Council.

Shellplanting

Given several years of decreasing small oyster abundance on the HM, the SARC advises shell planting efforts in 2017 to enhance this part of the stock. There was some discussion about whether a transplant would be the better option in this region to enhance the number of small oysters since previous shell plants have not always performed well this far down in the system. The SARC then recommended review of shellplant and transplant cultch results in individual areas prior to decisions for shellplant sites. These should be discussed at the Spring OISSC meeting. Funding mechanisms for continuous shellplant funds should be reviewed: particularly through the state of New Jersey. The example of Virginia's state legislators being brought to recognize the 'bang for the buck' potential through economic analyses was suggested as an example for proposals. A multi-state economic analysis with Delaware was suggested.

2017 SARC Science Advice (items not prioritized)

- Continue standard monitoring and assessment programs
  - Annual Fall Survey – this is the basis for the entire assessment. The SARC suggested that to inform decisions about the need for complete resurveys of individual beds out of rotation when multiple enhancement activities have occurred between scheduled resurveys, a sampling intensity for the Low quality stratum be statistically determined. This would add some sites to some beds in the Fall survey but may avoid whole resurveys out of rotation.

  - Resurvey Program - permits re-evaluation of grid stratification to take into account changes in oyster distribution on beds as a consequence of natural population dynamics and enhancement programs. The SARC recommended keeping the proposed 2017 schedule for restratification of Hope Creek and Hawk's Nest beds. It also advised specific evaluation of Bennies bed, perhaps during the Fall assessment survey after potential 2017 transplants with respect to whether or not the spatial distribution of oysters on this bed has shifted since its last stratification in Spring 2014.

  - Monthly Monitoring Program - monitors and evaluates factors influencing disease, mortality, growth and survival.

  - Monthly monitoring of transplant and shellplants - assesses performance of these management activities. The SARC suggested adding a year to transplant site monitoring.

  - Intermediate transplant monitoring and evaluation - daily estimates of oysters moved are provided to managers to gauge duration of transplanting activities. Final numbers and additional quota allocation reports given to managers and Council.

  - Port Sampling Program - provides estimates required for accurate size-related landings information and abundance-to-bushel conversions in the stock assessment.

- Use the 75th percentile of the VLM 2007-2016 abundance time series as a target and the 50th percentile as the threshold with the proviso that this be re-evaluated in three to five years. A Control Rule should be set into place prior to this.

- Re-evaluate the 1989/1990 - 2005 time series baseline regarding BRP targets and thresholds on all regions other than VLM. Plot the baseline time series with current targets and thresholds. Evaluate that against management strategies that transpired, e.g. closures. Pay particular attention to decisions near or below thresholds.

- Look at entire 1990-present assessment time series with respect to BRPs to investigate patterns of change. 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.

- Add a biomass measure to LPUE data.
- Track LPUE back in time on a per-boat basis as possible. Investigate connections between consolidation and individual boat LPUE
- Investigate how fishing trends on the lower beds track with disease, temperature, and salinity as well as with the Vp harvest time restrictions.
- Apply biomass-dynamics models to attempt an estimate of optimal fishing rates for each region and the population as a whole.
- Devise experiment to re-evaluate susceptibility of LM and VLM oysters to disease via transplanting by moving them downbay, perhaps to Capeshore.
- Continue to estimate gear efficiency whenever possible.
- Investigate whether or not the 20mm spat cutoff creates a misleading impression of spat failure in the HM or unusually low recruitment.
- Continue to monitor spat transition sizes as environmental conditions change.
- Conduct growth experiments and analyze existing data to ascertain whether or not currently used growth rates are still viable as climate change occurs.
- Explore potential methods to tag shellplanted clam shell eg. specifically-colored dyes, pit tags, etc. in order to track successful recruitment, growth, and mortality on the planted shell. Consider incentives for returning oysters attached to tagged shell.

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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) records and schedule. Partial resurveys, not included here, were done on many beds in 2005 and 2006. Full resurveys were completed on Hope Creek and Fishing Creek between Fall 2007 and Spring 2008. Egg Island and Ledge have never been resurveyed. Hope Creek and Hawk's Nest are scheduled for resurvey in 2017.

Region	Bed	# Grids	# Full Resurveys	Last Resurvey	10-Year Schedule
VLM	Hope Creek	97	1	2007-2008	**2017**
	Fishing Creek	67	1	2007-2008	2020
	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	2022
	Middle	51	1	2011	2021
	Sea Breeze	48	1	2012	2018
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	2022
	Bennies	171	2	2014	2024
	Hog Shoal	23	2	2016	2026
	Strawberry	29	2	2015	2025
	Hawk's Nest	28	1	2006	**2017**
	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 4. 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. The 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 5. Sampling scheme for the Fall 2016 survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of sampled grids devoted to that bed stratum. Strata designations are described in the text. The Enhanced stratum includes those grids that received transplant (T) or shellplant (S) in the current survey year or received shell plant within the previous two 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	4	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	1	14 S
	Sea Breeze	3	4	0		
Medium Mort. Mkt.	Cohansey	5	5	0	2	15 S, 16 T
	Ship John	6	5	0	2	14 S, 16 S
Shell Rock	Shell Rock	7	7	0	4	14 S, 15 S, 16 S, 16 T
High Mortality	Bennies Sand	3	6	0		
	Bennies	5	9	0	2	15 S, 16 S
	Nantuxent Pt.	3	3	0	1	14 S
	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	-	-	-		
	Ledge	1	2	0		
Total		67	89	0	12	

Grand Total: 168

Table 6. Percentile positions and stock variables for the 27-year time series (1990 – 2016) for five bay regions and for VLM's 2007-2016 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 27-year and the 64-year time series (1953 – 2016) can be found in Appendix B.

1990 – 2016	Oyster Abundance	Market >2.5" Abundance	Spat Abundance	Box-Count Mortality
Low Mortality	0.056	0.500	0.944	0.000
Medium Mortality Transplant	0.574	0.962	0.944	0.278
Medium Mortality Market	0.463	0.923	0.907	0.352
Shell Rock	0.685	1.000	1.000	0.352
High Mortality	0.278	0.731	0.648	0.389
5-Region Area	0.352	0.885	0.907	0.278

2007 – 2016	Oyster Abundance	Market >2.5" Abundance	Spat Abundance	Box-Count Mortality
Very Low Mortality	1.000	0.550	1.000	0.150

Table 7. 2016 densities of oysters and spat on HM grids that received enhancements of non-spatted clamshell compared to 2016 average densities for non-enhanced grids on those beds. Note: All oysters and spat are counted whether on native substrate or clamshell.

Plant Year	Bed	Enh # Bu.	2016 oys m^{-2} Enh grid	2016 oys m^{-2} Non-enh Avg	2016 spat m^{-2} Enh grid	2016 spat m^{-2} Non-enh Avg
2014	Nantuxent	42,704	137	24	461	141
2015	Bennies	43,038	3	5	0.5	6
2016	Bennies	44,000	6	5	3	6

Table 8. Summary of shellplant results with projected oyster production. Sites sampled as part of 2016 assessment survey. (a) 2016 spat recruitment to 2016 clamshell. (b) 2016 spat recruitment to 2015 clamshell. (c) 2016 spat recruitment to sites planted in 2014. Set on clam planted in 2016 considered spat regardless of size. Set on clam planted earlier used 20mm spat cutoff. Projections used 1990-2016 regional medians for mortality at the juvenile rate in year 1 and the adult rate for two following years. Regions include: the MMM (Cohansey, Ship John), SR (Shell Rock), and the HM (Bennies, Nantuxent). Years to market size based on von Bertalanffy parameters (Kraeuter et al. 2007).

a. Sites planted and sampled in 2016.

	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	4	181,242	0.484	0.242	53,734
Shell Rock 15	44,000	1,336	58,770,800	0.442	0.187	21,675,888
Ship John 28	44,000	248	10,917,176	0.249	0.181	5,499,435

b. Sites planted in 2015; sampled in 2016.

	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	0	0	0.484	0.242	0
Shell Rock 52	47,913	0	0	0.249	0.181	0
Cohansey 56	38,539	925	20,319,688	0.442	0.187	7,494,322

c. Sites planted in 2014; sampled in 2016.

	Clamshell Planted (bu)	Clamshell Spat/bu	Clamshell Total Spat	Median Juvenile Mortality Rate	Median Adult Mortality Rate	Potential Mkt-Size Individuals
Nantuxent 23	42,704	159	6,797,188	0.484	0.242	2,015,196
Shell Rock 31	55,394	496	27,488,458	0.442	0.187	10,138,312
Ship John 33	52,740	546	28,788,594	0.249	0.181	14,502,010

Table 9. Direct market and transplant bushel summaries 2007-2016. Beds arranged upbay to downbay and color-coded by region. (a) Direct market bushels harvested, excluding those replanted to leases. (b) Intermediate transplant bushel removals (normal font) and non-landed direct market bushels replanted to leases *(italics)*. 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 are not shown in these tables.

a. Direct Market (landed bu.)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Middle		1120	33	56						
Sea Breeze		170	627	220		170	5454	542		
Cohansey	19947	2611	5909	2806	19074	11288	10583	8652	10321	12475
Ship John	8468	21469	17989	20409	19212	17462	19097	24295	18540	19938
Shell Rock	16816	29736	22918	17493	24112	20457	22397	22299	28180	31794
Benny Sand	10232	14806	13529	9851	8825	5836	9921	3038	6301	
Bennies	5462	7192	9599	5299	4997	1820	870	7741	10712	29293
Nantuxent	6289	4637	2631	6507	5467	11294	10218	5154	5267	2101
Hog Shoal	950	1069	3804	7281	9049	1965	2385	3425	103	
New Beds	5270	6956	2778	897	1778	443	226		3816	4494
Strawberry			618	25			140			
Hawk's Nest	2351	116	173	2435	1954	1002		205		
Beadons	14		82	72						
Vexton					2					
Total	75,799	89,882	80,690	73,351	94,470	71,737	81,291	75,351	83,240	100,095

b. Transplants (intermediate and *direct market bu. replanted to leases*)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Hope Creek			9100	1200	6150					
Fishing Creek				2000						
Liston Range				4750	1800		550			
Round Island					3350		2250			
Upper Arnolds				18250	2800		15550		10200	
Arnolds		9450	10400		4000	7650	2700	15500		4800
Upper Middle			2100			2100	3200			
Middle	15182	8200	12000		17750	11200	5200	6600	5550	8150
Sea Breeze				11050		8525	6200	7300	10800	2400
Cohansey				1500					*348*	
Ship John	*4051*					*293*	*182*		*1297*	
Shell Rock	*1226*					*2171*	*1883*	*1290*	*1449*	
Benny Sand	*74*			*296*			*920*			
Bennies				*227*		*335*		*269*		
Nantuxent				*65*		*3038*				
New Beds				*178*					*1096*	
Hawk's Nest	*85*			*258*		*566*				
Beadons					500					
Total	20,618	17,650	33,600	39,774	36,350	35,878	38,635	30,959	30,740	15,350

Table 10. Council-chosen and fishery-achieved exploitation rates for 2016 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	3.03%					
transpl req'd	3.70%	3.64%	3.07%	32,086	2,972	32,413
SR	3.70%					
transpl req'd	4.88%	4.88%	5.27%	24,442	7,021	31,794
HM	8.61%	8.24%	8.18%	34,771	0	35,888
transpl req'd	>8.61%					
			Total	91,299	9,993	100,095

Total Quota (bu)	Un-harv. Quota (bu)
101,292	1,197

b. Transplant

Region	Max SARC Expl. Rate	Chosen Expl. Rate	Achieved Expl. Rate	Chosen Trans (# oys)	Achieved Trans (# oys)	Under/ Over #
VLM	2.80%	None	NA	0	NA	NA
LM	1.75%	0.76%	0.96%	1,712,353	2,168,012	+455,659
MMT	1.99%	1.49%	0.97%	3,958,253	2,979,901	-978,352

Table 11. Summary of intermediate transplant data. Transplants conducted in April and May 2016 from the LM (Arnolds) to the MMM (Cohansey) and from the MMT (Middle, Sea Breeze) to the SR (Shell Rock). 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 2015 port-sampling result of 265 market oysters per bushel. The fraction of oysters < 2.5” did not enter into additional quota allocations for 2016. The fraction of cultch is based on volume and includes shell only, not boxes.

Donor	Receiver	Bushels Moved	Total # Oysters	Fraction Oysters < 2.5”	Fraction Oysters ≥ 2.5”	Market-Equiv. Bu (>2.5”)	Fraction Cultch
Arnolds	Cohansey	4,800	2,168,012	0.64	0.36	2,972	0.29
Middle	Shell Rock	8,150	2,556,215	0.39	0.61	5,925	0.28
Sea Breeze	Shell Rock	2,400	426,443	0.32	0.68	1,096	0.44

Table 12. 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 13. Summary status of the stock for 2016. Recruitment uses 2014-2016 average vs. 1990-2016 median. Mortality uses 2016 rate vs. 1990-2016 mean. Dermo WP compares 2016 rate known to cause mortality. VLM reference points are not based on same parameters as other regions' (see text for details).

2016 Metrics	*Transplant* Very Low Mortality	*Transplant* Low Mortality	*Transplant* Medium Mortality	*Market* Medium Mortality	*Market* Shell Rock	*Market* High Mortality
Total Abundance						
Percentile	[Green]	[Orange]	[Neutral]	[Neutral]	[Green]	[Orange]
vs. 5-yr Median	[Green]	[Orange]	[Green]	[Neutral]	[Green]	[Orange]
vs. Target-Thresh	[Green]	[Orange]	[Neutral]	[Neutral]	[Green]	[Orange]
Market Abundance						
Percentile	[Neutral]	[Neutral]	[Green]	[Green]	[Green]	[Green]
vs. 5-yr Median	[Green]	[Neutral]	[Green]	[Green]	[Green]	[Green]
vs. Target-Thresh	[Green]	[Green]	[Green]	[Green]	[Green]	[Green]
Recruitment						
Percentile	[Green]	[Green]	[Green]	[Green]	[Green]	[Green]
vs. 5-yr Median	[Green]	[Green]	[Green]	[Green]	[Green]	[Neutral]
3-yr Avg vs. Median	[Green]	[Green]	[Green]	[Green]	[Green]	[Orange]
Mortality						
Percentile	[Green]	[Green]	[Green]	[Green]	[Green]	[Green]
vs. 5-yr Median	[Green]	[Green]	[Green]	[Green]	[Neutral]	[Orange]
Rate	0.03 [Green]	0.05 [Green]	0.11 [Green]	0.15 [Green]	0.18 [Green]	0.22 [Green]
Dermo WP						
Percentile	0.45 [Neutral]	0.36 [Green]	0.46 [Neutral]	0.29 [Green]	0.82 [Orange]	0.29 [Green]
vs. 5-yr Median	[Orange]	[Neutral]	[Green]	[Neutral]	[Green]	[Neutral]
Level	0.03 [Green]	0.23 [Green]	1.67 [Neutral]	1.30 [Neutral]	2.98 [Orange]	1.84 [Neutral]

Color Key:

Green	Improved relative to 1990–2016 time series (2007-2016 for VLM), 2011–2015 median, or biological reference points.
Orange	Variables judged to be degraded for the comparisons.
Neutral	Near-average; within the 40^{th} - 60^{th} percentiles of the time series; within 15% or 1 SEM of the metric, or 1.5-2.0 for dermo WP.

Table 14. Direct Market quota projections for 2017. Numbers to be removed are based on the abundance of ≥2.5" oysters in each region and realized exploitation rates from 2007-2015. Projections use the average oysters per marketed bushel (264) derived from the 2004-2016 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.

Direct Market Regions	Label	Exploit. Rate	# Oys Removed	Quota bu
Med Mort Mkt	Min	1.8%	4,932,337	18,683
		2.0%	5,480,374	20,759
		2.5%	6,850,468	25,949
	Median	3.0%	8,302,767	31,450
		3.5%	9,548,182	36,167
	→Max	3.7%	10,138,692	38,404
Shell Rock	Min	2.3%	4,656,183	17,637
		3.0%	5,889,873	22,310
		3.5%	6,994,224	26,493
	Median	3.7%	7,362,341	27,888
		4.0%	7,959,287	30,149
		4.5%	8,954,198	33,917
	→Max	4.9%	9,710,330	36,782
High Mortality	Min	4.8%	4,181,610	15,839
		5.5%	4,781,466	18,112
		6.0%	5,209,190	19,732
		6.5%	5,650,824	21,405
		7.0%	6,085,503	23,051
	Median	7.5%	6,511,488	24,665
		8.0%	6,954,860	26,344
		8.5%	7,389,539	27,991
	→	9.0%	7,813,785	29,598
		9.5%	8,258,896	31,284
	Max	9.8%	8,537,091	32,337

Table 15. Projections for intermediate transplanting in 2017. Exploitation rate and numbers to remove are based on all sizes of oysters and realized exploitation rates from 2007-2015. The estimated number of bushels to move is derived from the mean of the number of oysters per bushel by region from the 2016 transplant program or other as noted.[1] Cullers are used for transplants. Market equivalent bushels are based on the fraction of oysters ≥2.5" converted to bushels using the average 264 oysters/bu derived from the 2004-2016 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. # Trans bu	Quota bu
Very Low Mort.		1.5%	2,602,674	4,542	1,240
		2.0%	3,470,232	6,056	1,653
		2.5%	4,337,790	7,570	2,066
	→	3.0%	5,205,348	9,084	2,479
		3.5%	6,027,793	10,520	2,871
	Min	3.7%	6,471,983	11,295	3,082
	Middle	3.9%	6,697,548	11,689	3,190
		4.1%	7,032,425	12,273	3,349
		4.2%	7,287,487	12,718	3,471
	Max	4.3%	7,495,701	13,082	3,570
Low Mortality		0.5%	1,058,320	2,341	1,258
CLOSED	Min	0.8%	1,608,646	3,559	1,912
		1.0%	2,116,640	4,683	2,515
		1.5%	3,148,502	6,966	3,741
	Median	1.8%	3,704,119	8,195	4,402
		2.0%	4,259,737	9,424	5,062
	Max	2.3%	4,783,606	10,583	5,685
Med Mort Trans.		1.0%	3,310,423	11,698	4,967
	Min	1.5%	3,426,870	12,109	5,142
		1.7%	5,627,720	19,886	8,445
	Median	2.0%	6,620,847	23,395	9,935
		2.3%	7,613,974	26,905	11,425
	→Max	2.5%	8,184,564	28,921	12,281

[1] VLM deckload oys/bu is an estimate based on averages from three years of transplants. LM and MMMT oysters/bu taken from 2016 intermediate transplant samples; actual numbers for 2017 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.

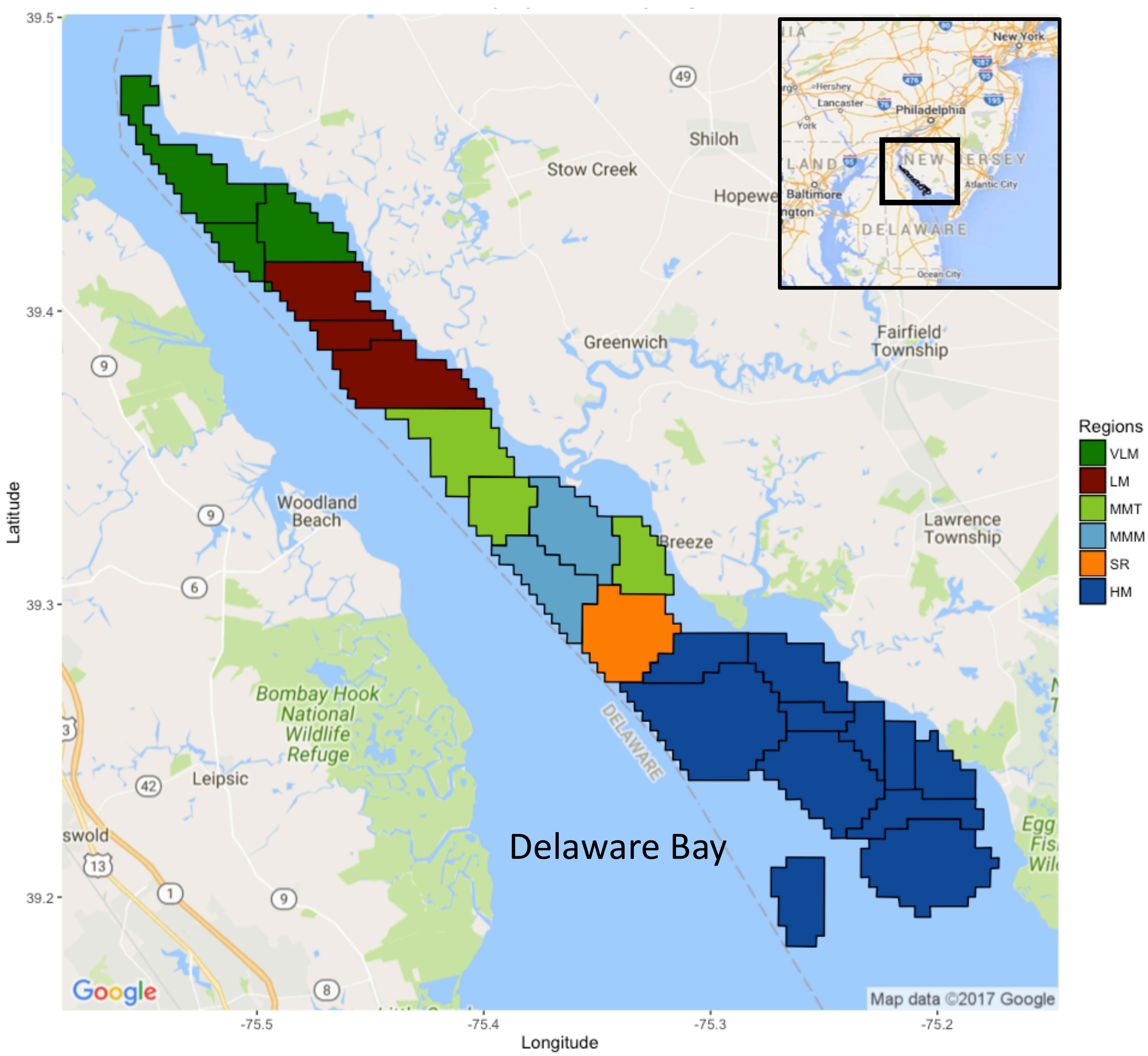


Figure 2. Regional acreage and proportional distribution of the assessed NJ Delaware Bay oyster resource. Regions are organized upbay to downbay clockwise from the VLM. The VLM, LM, and MMT contain three beds each and are termed Transplant regions. The Direct Market regions are the MMM made up of two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

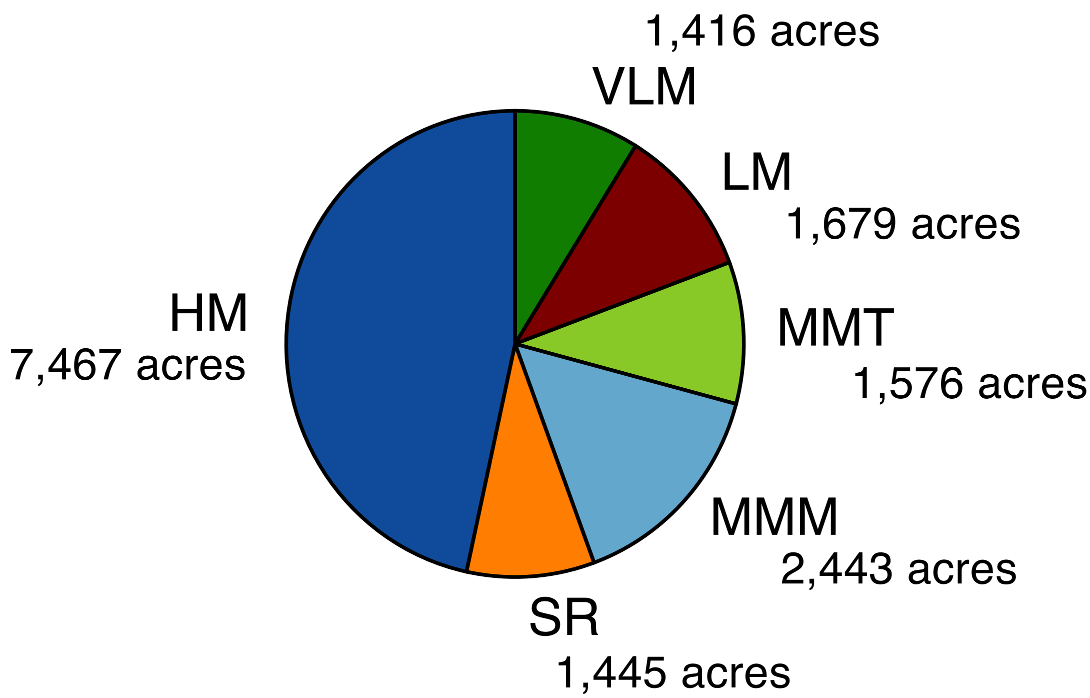
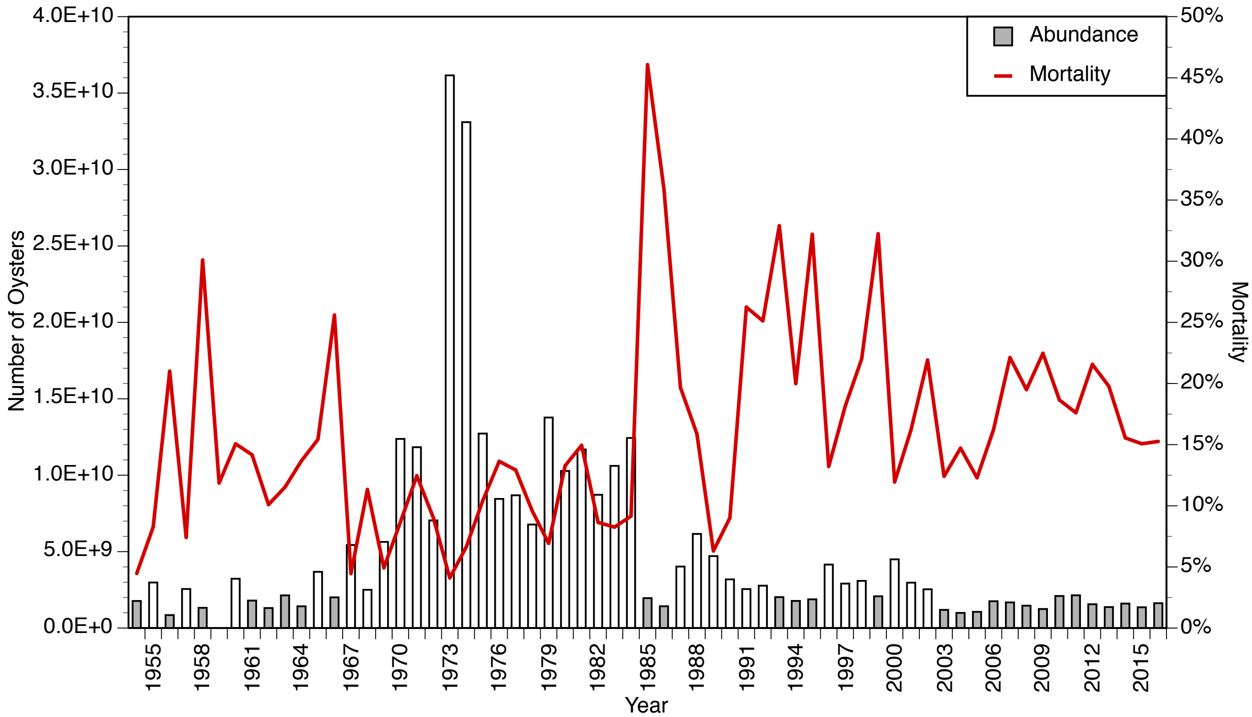


Figure 3. Time series of total oyster abundance (left axes) compared to natural mortality rate (a, right axis) and fishing mortality (b, right axis). Time series of 1953–2016 stock surveys excludes the VLM.

a.



b.

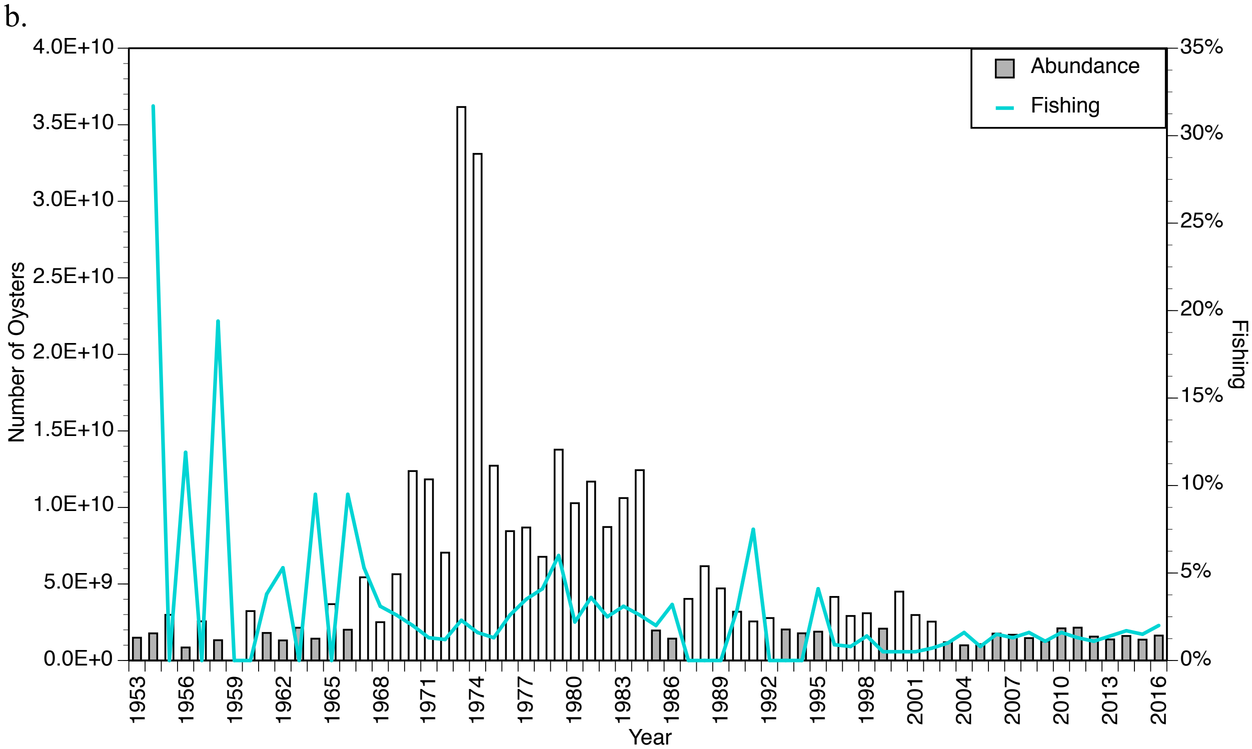
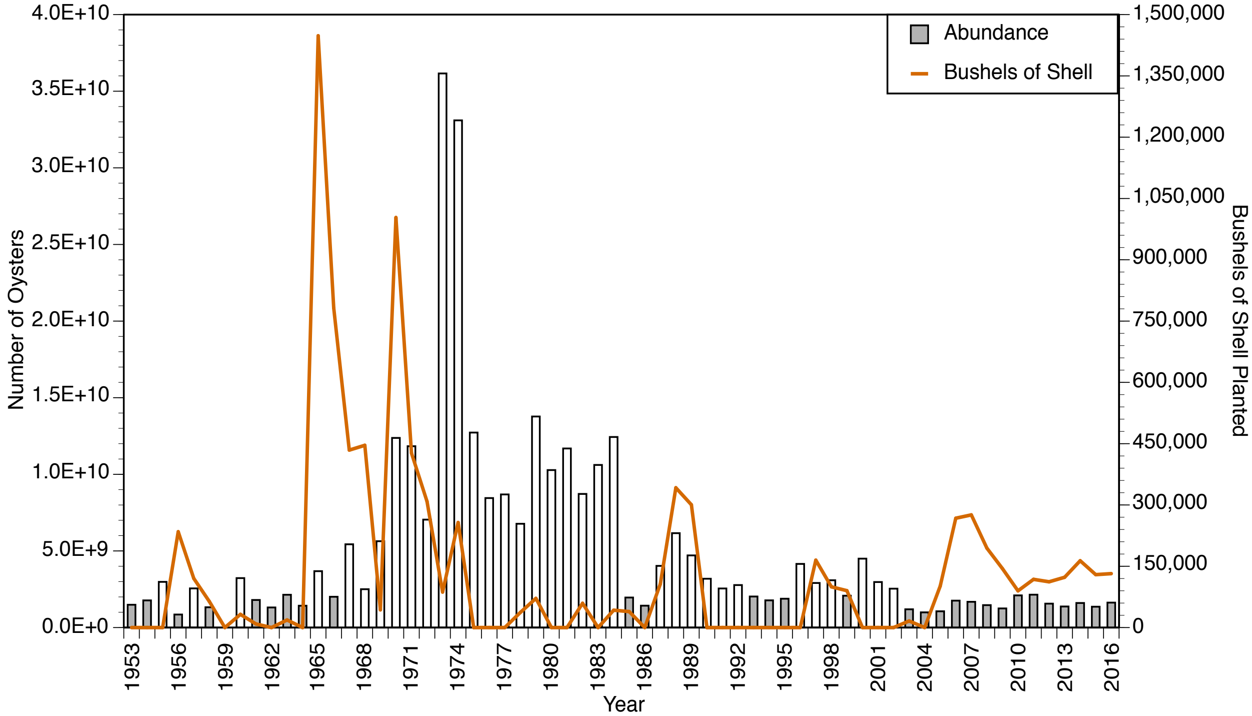


Figure 4. Time series of total oyster abundance (left axes) compared to bushels of shell planted for spat recruitment (a, right axis) and number of spat from the stock assessment time series (b, right axis). Time series of 1953–2016 stock surveys excludes the VLM.

a.



b.

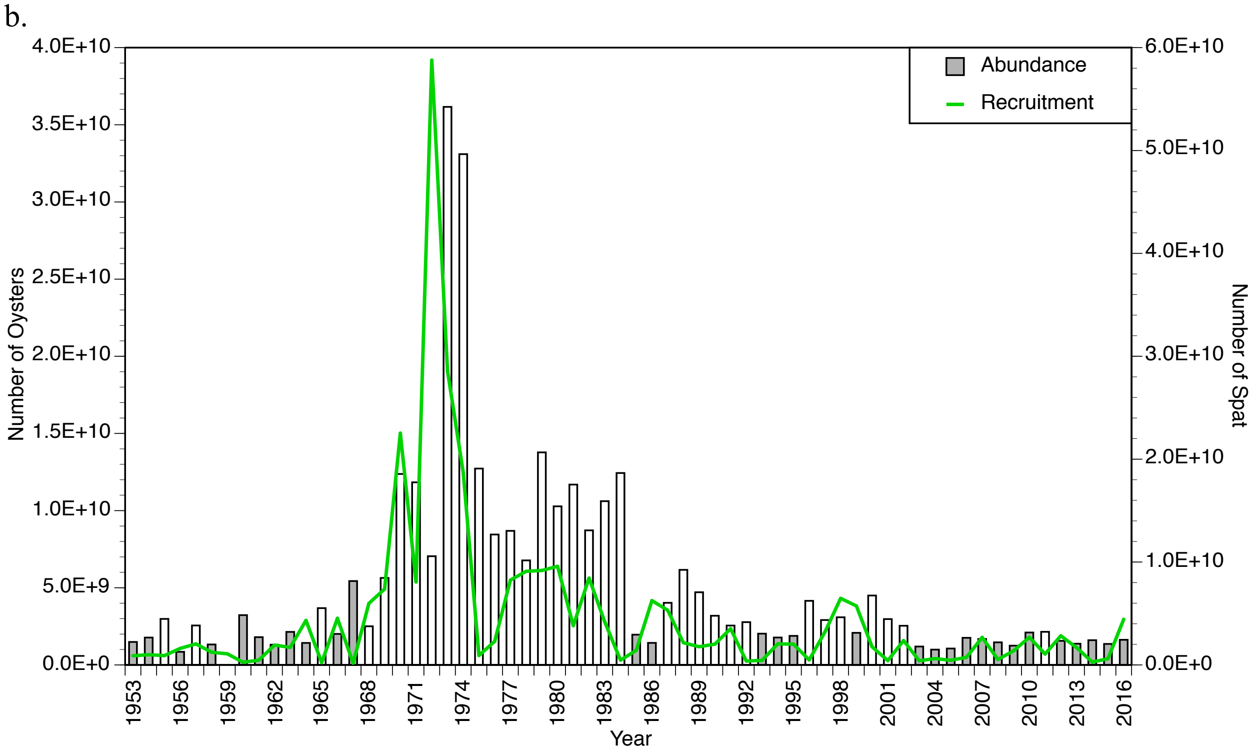


Figure 5. Number of oysters harvested from the natural oyster beds of Delaware Bay, NJ from 1953–2016. Prior to 1996, the bay-season fishery removed oysters from the natural beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996 and an intermediate transplant program began in 1997. Zeros represent years of fishery closure.

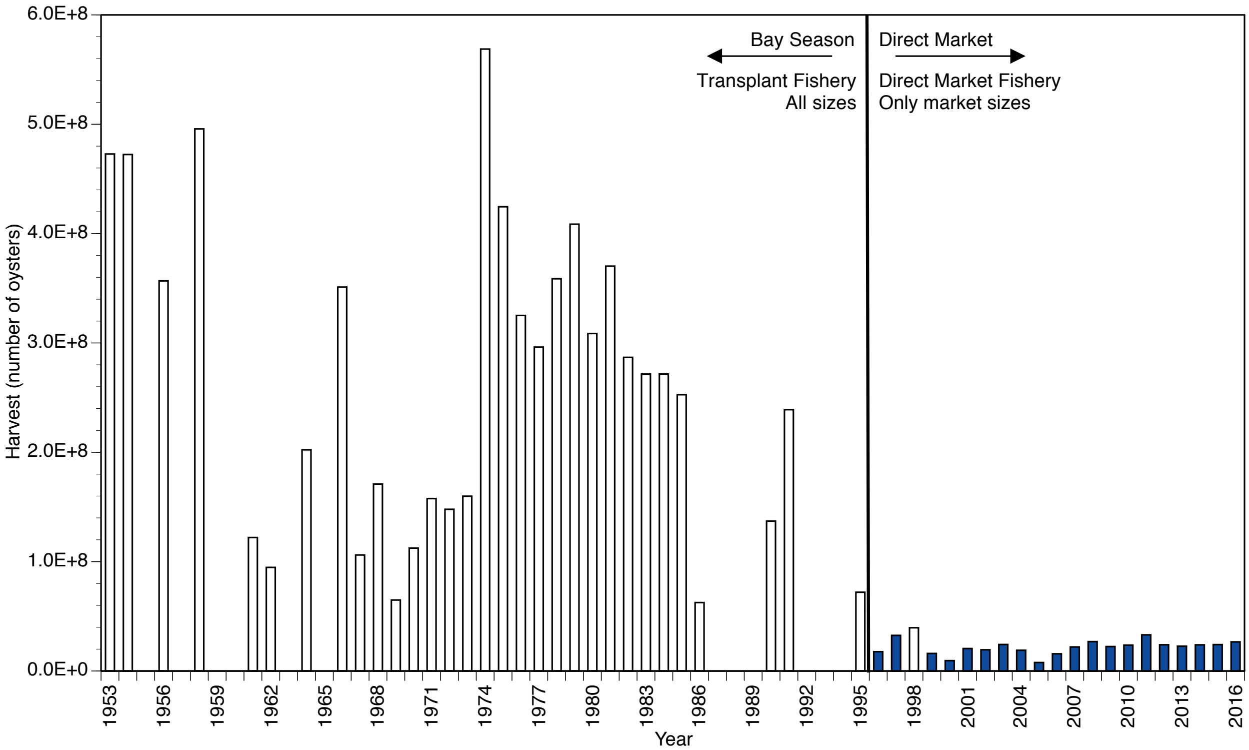
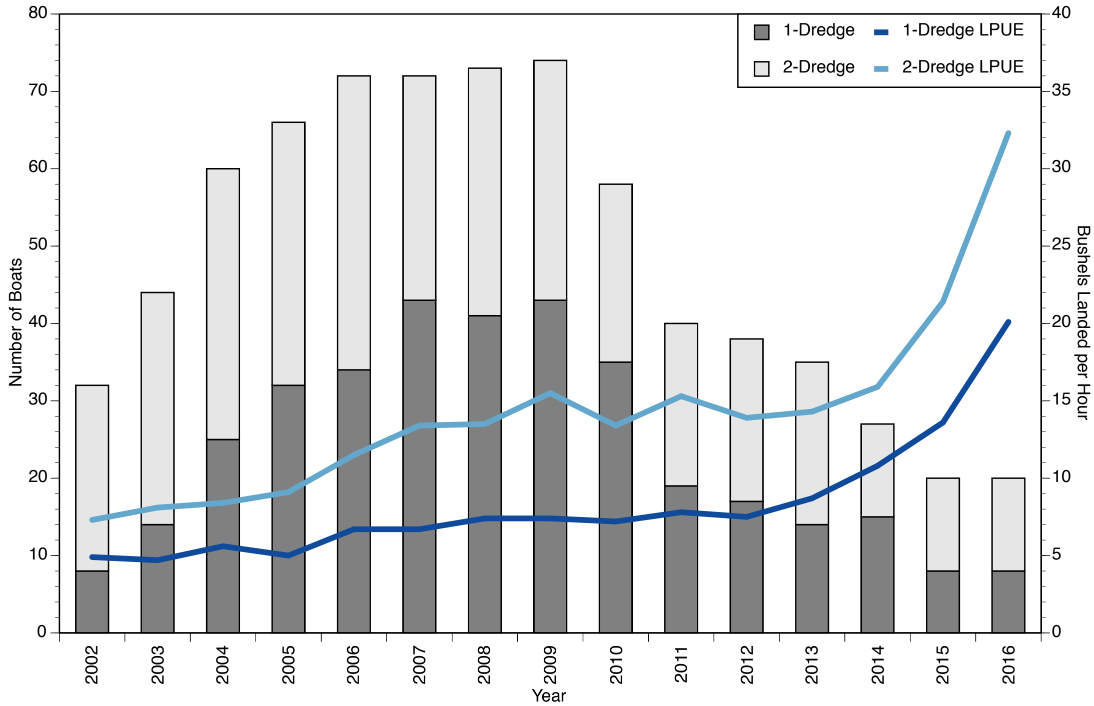


Figure 6. (**a)** Numbers of 1- and 2-dredge boats (stacked bars) participating in the NJ Delaware Bay oyster harvest since 2002 overlaid with landings-per-unit-effort (LPUE) calculated as bushels landed per hour for 1- and 2-dredge boats. **(b)** Fraction of market-size (>2.5") abundance in direct market regions (MMM, SR, HM) that is >3" (bars) overlaid with LPUE lines.

a.



b.

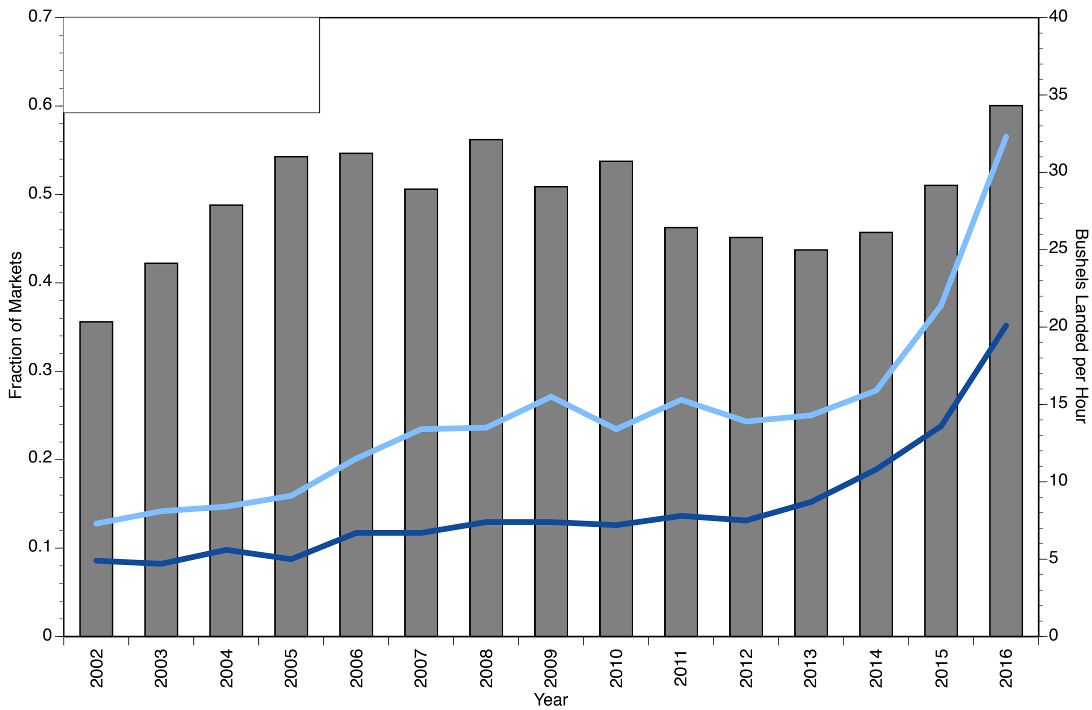
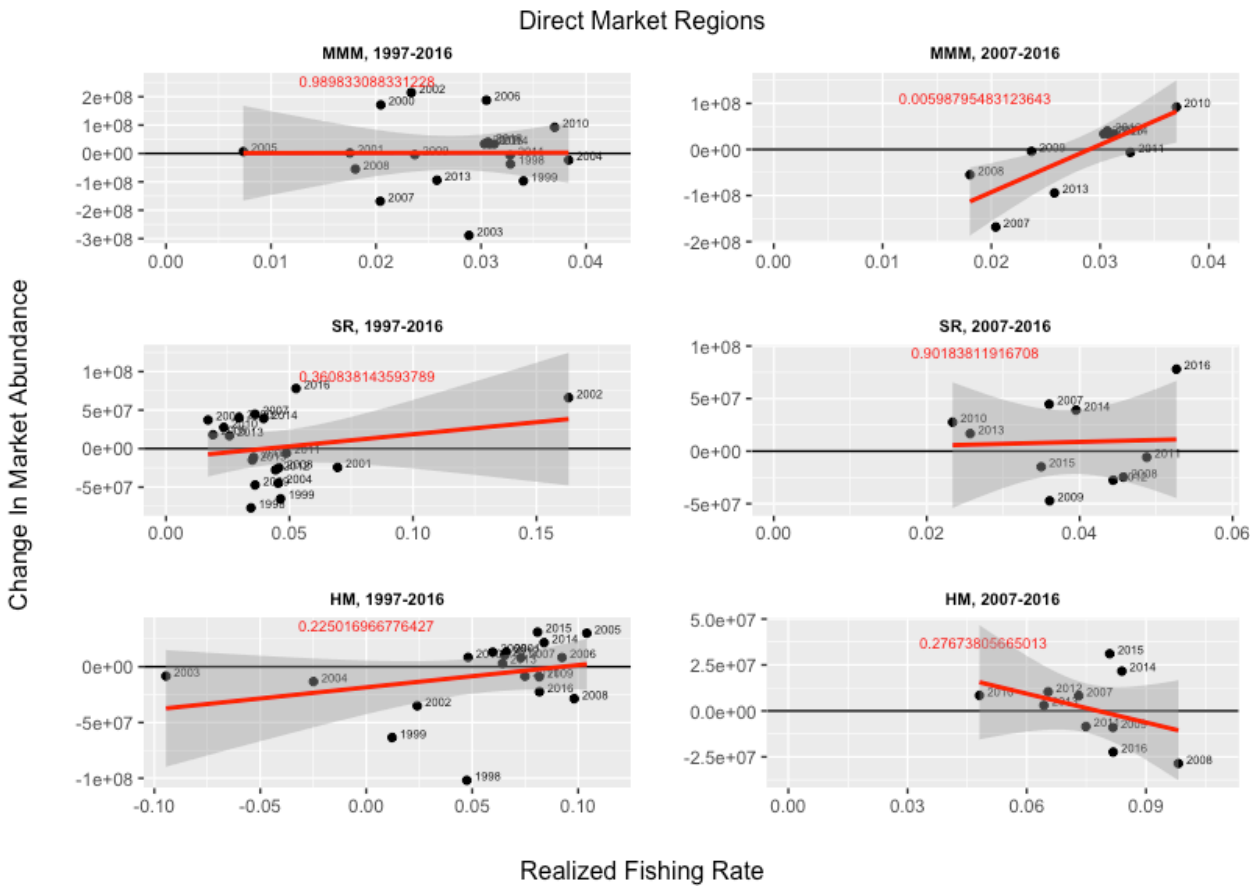
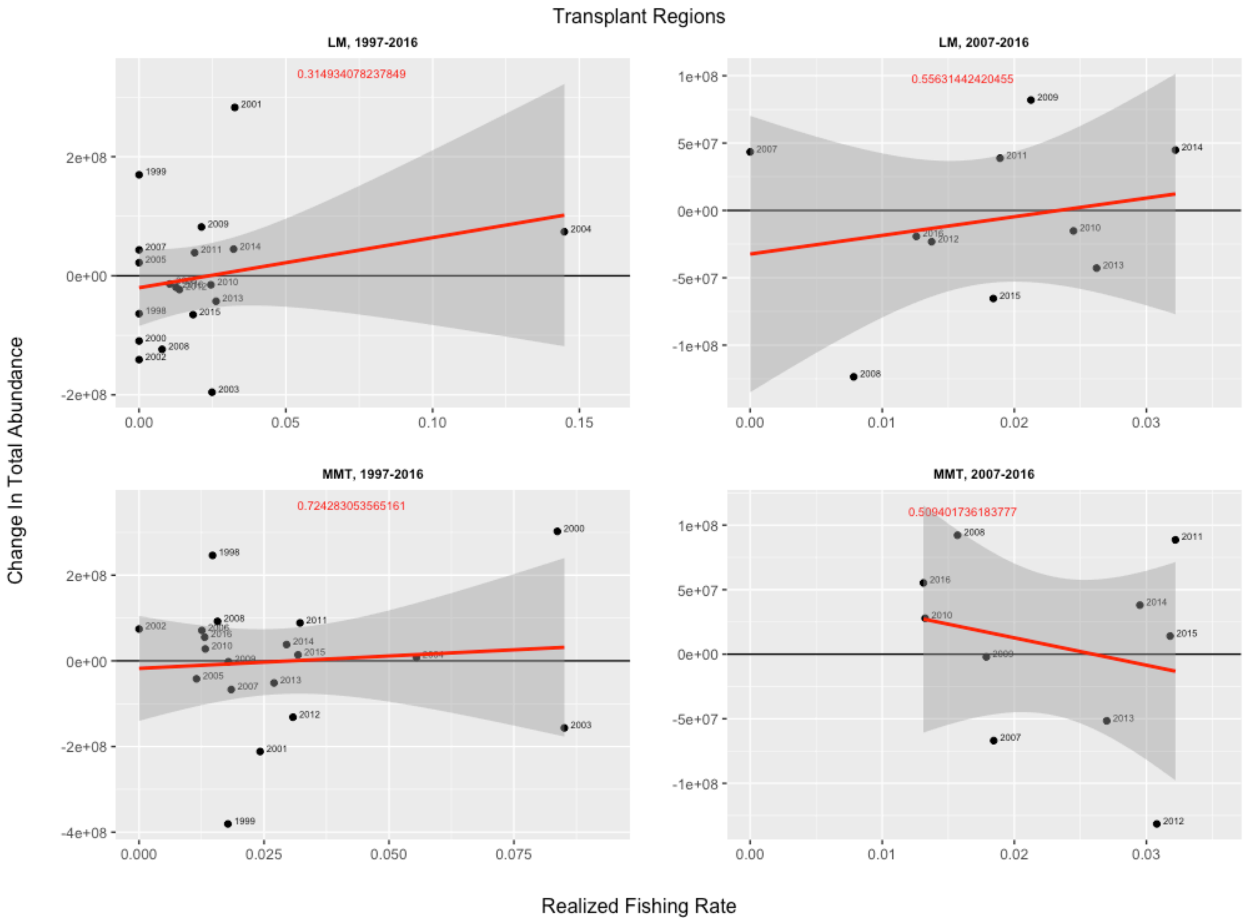


Figure 7. Change in (a) market abundance on the direct market regions and (b) total abundance on the transplant regions as a function of a given realized fishing exploitation rate during the entire direct market time series (left panels) and during the current management strategy (right panels). Red lines represent the best-fit linear regression and red text indicates the p-value associated with that regression.

a.



b.



Transplant Regions
LM, 1997-2016
0.314934078237849
LM, 2007-2016
0.55631442420455
MMT, 1997-2016
0.724283053565161
MMT, 2007-2016
0.509401736183777
Change In Total Abundance
Realized Fishing Rate

Figure 8. Shell Rock stratifications resulting from the 2012 and the 2016 resurveys. Dark orange grids are those defined as 'high abundance' based on the stratification scheme, light orange grids are defined as 'medium abundance', blue areas represent grids defined as 'low quality'. Black dots represent the Fall 2015 stock assessment sampling design based on the 2012 stratification. Green dots represent samples from grids that received shellplants 2013-2015 that would not otherwise have been sampled in Fall 2015. Low quality grids are not sampled in assessments.

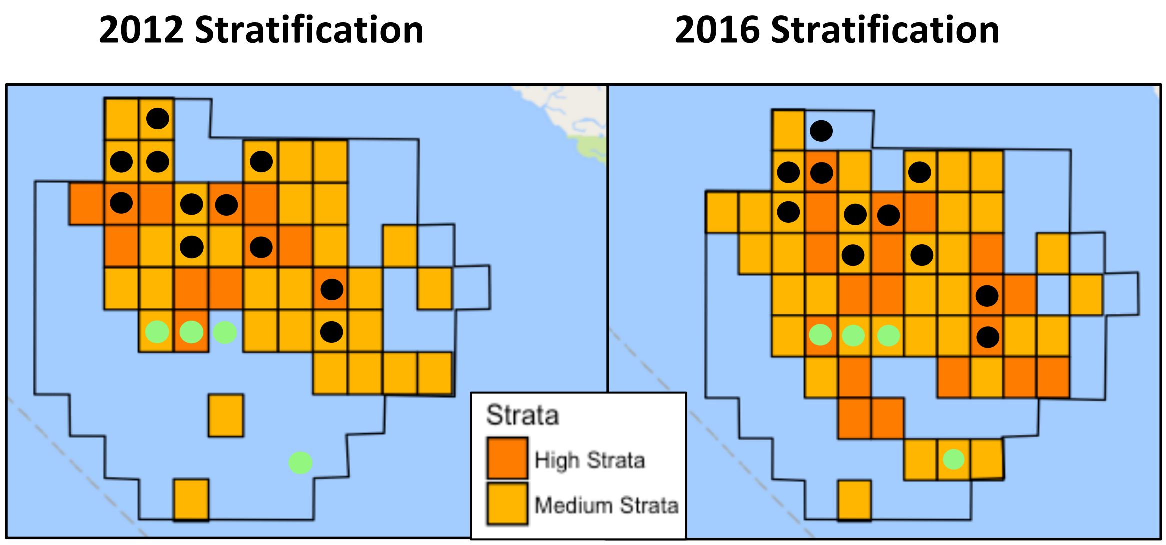


Figure 9. Comparison of abundance estimates made by sampling all grids on a bed in Spring restratification surveys (dots) vs. estimates made from a subset of the sampled grids (bars) using the design from the previous Fall's assessment survey based on an earlier stratification. Error bars represent the 80% confidence interval around the grid subset estimates. Note that Shell Rock had 3 Spring resurveys to use for comparisons with their previous Fall assessment survey designs.

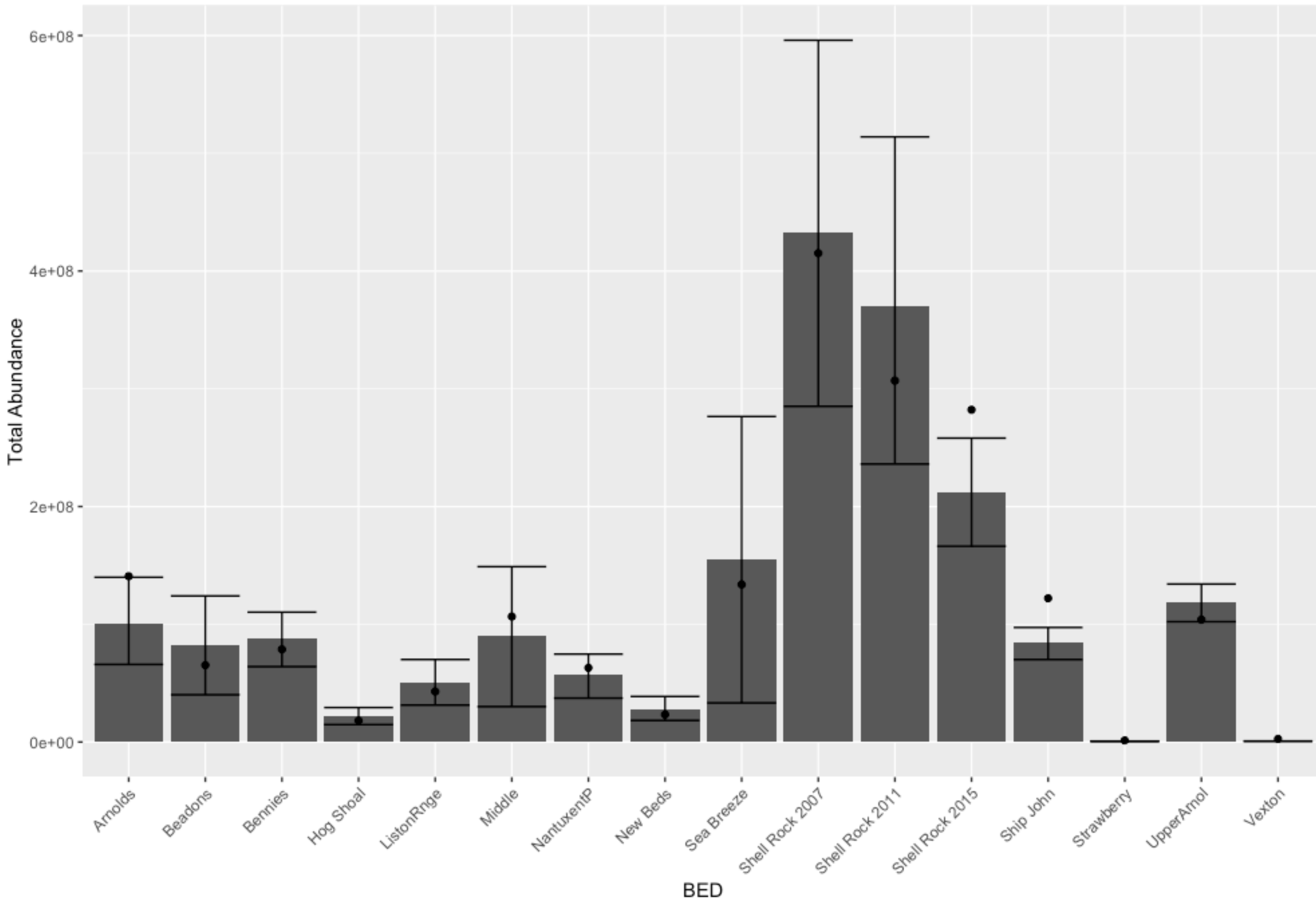


Figure 10. VLM abundance and market-size abundance time series (2007-2016). Red dots show the first years the VLM was included in the assessment (no exploitation). Green dots show the first two years of intermediate transplant exploitation. Orange dots, the third year of exploitation plus freshwater mortality event (2011) and the following two years when the region was closed. Blue dots represent the three latest recovery years (no exploitation).

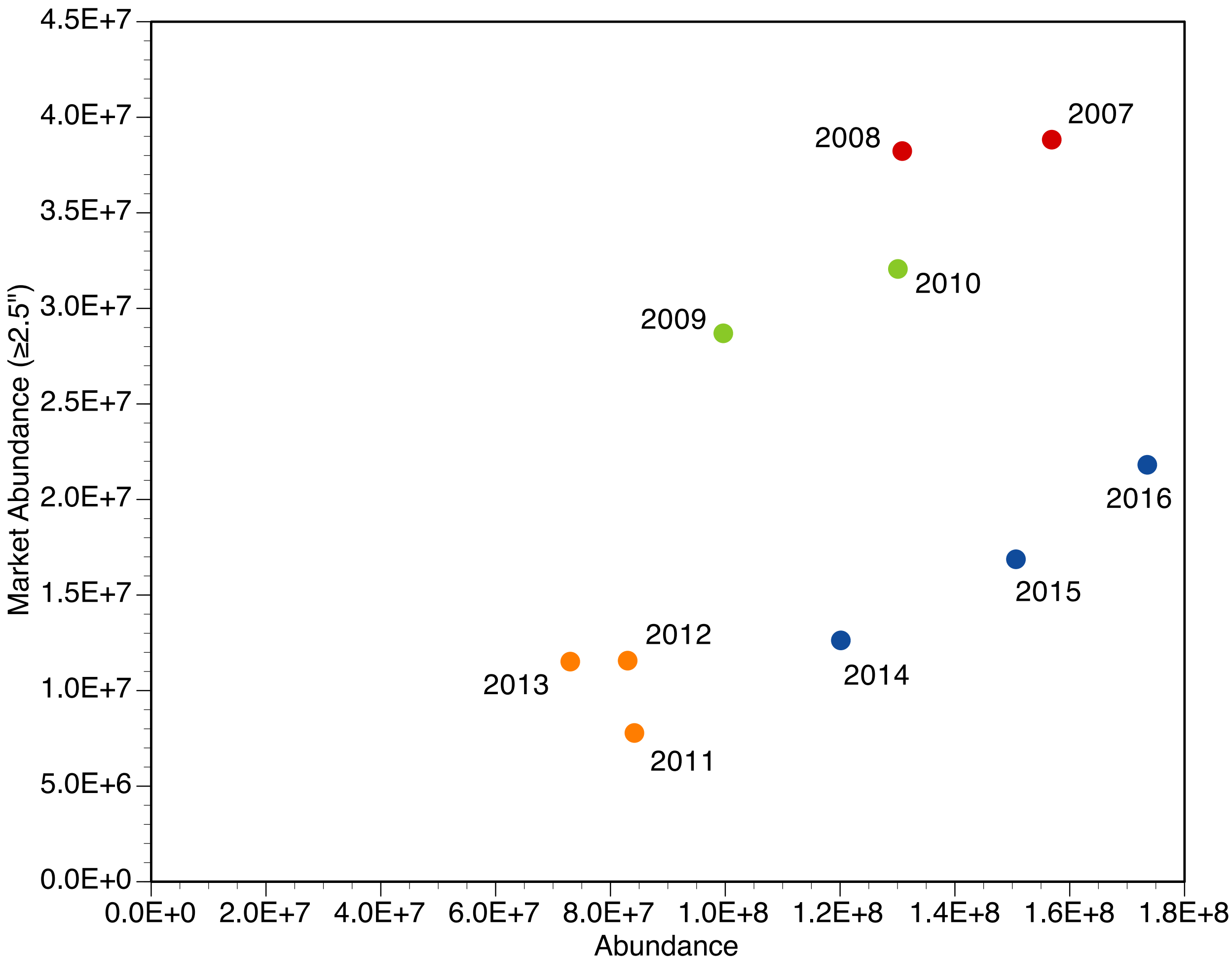
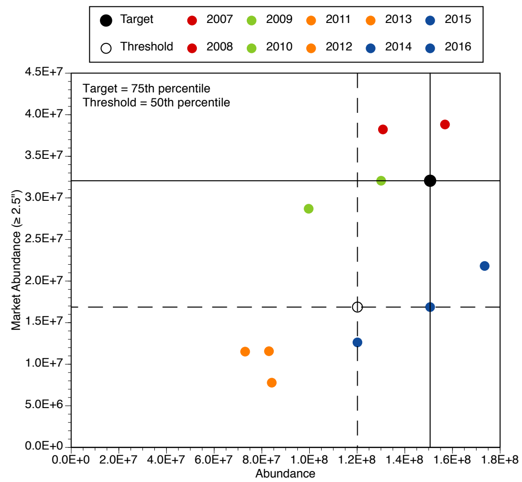
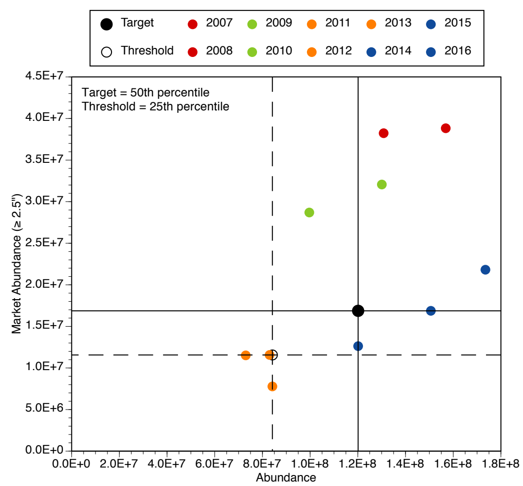


Figure 11. BRP target-threshold options for VLM. Dots as in Figure 10. Solid lines are targets; dashed lines are thresholds. (a) 75th percentile as target and 50th as threshold. (b) 50th percentile as target, 25th as threshold; (c) no target, 2014 values used as threshold.

a.



b.



c.

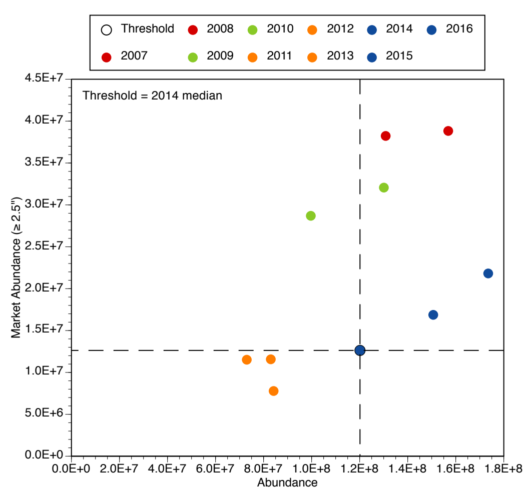


Figure 12. Percent change in regional abundance estimates using the alternative spat size cutoff (from data collected in 2014 and 2015) relative to the currently applied 20mm cutoff. Boxes represent the annual variability in the percent change. Negative values represent a decrease in total abundance (oysters ≥20mm) using a regional spat-to-oyster cutoff rather than 20mm; the positive VLM represents an increase in total abundance using a regional cutoff.

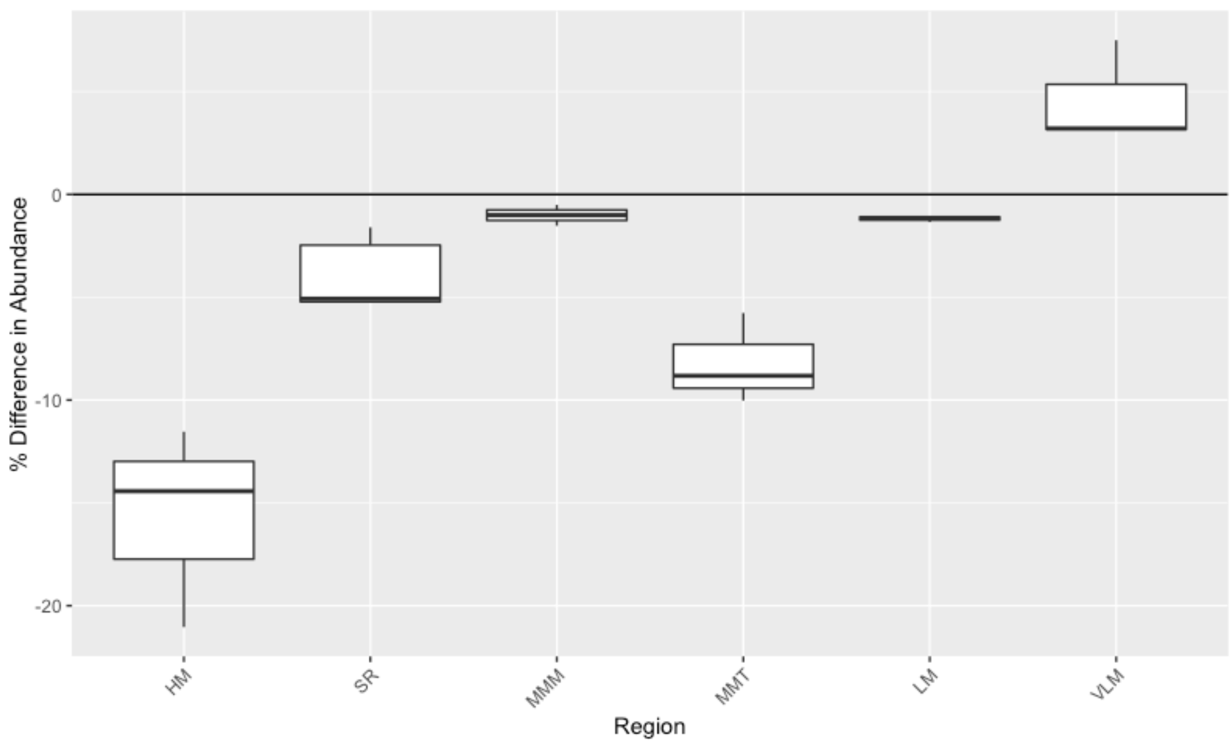


Figure 13. The assessed oyster beds of Delaware Bay, NJ grouped as regions (see Legend) with the 2016 strata designations. Black outlines indicate complete boundary of each bed with the high and medium quality strata grids in dark and light colors, respectively. The colors indicate region groupings although 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).

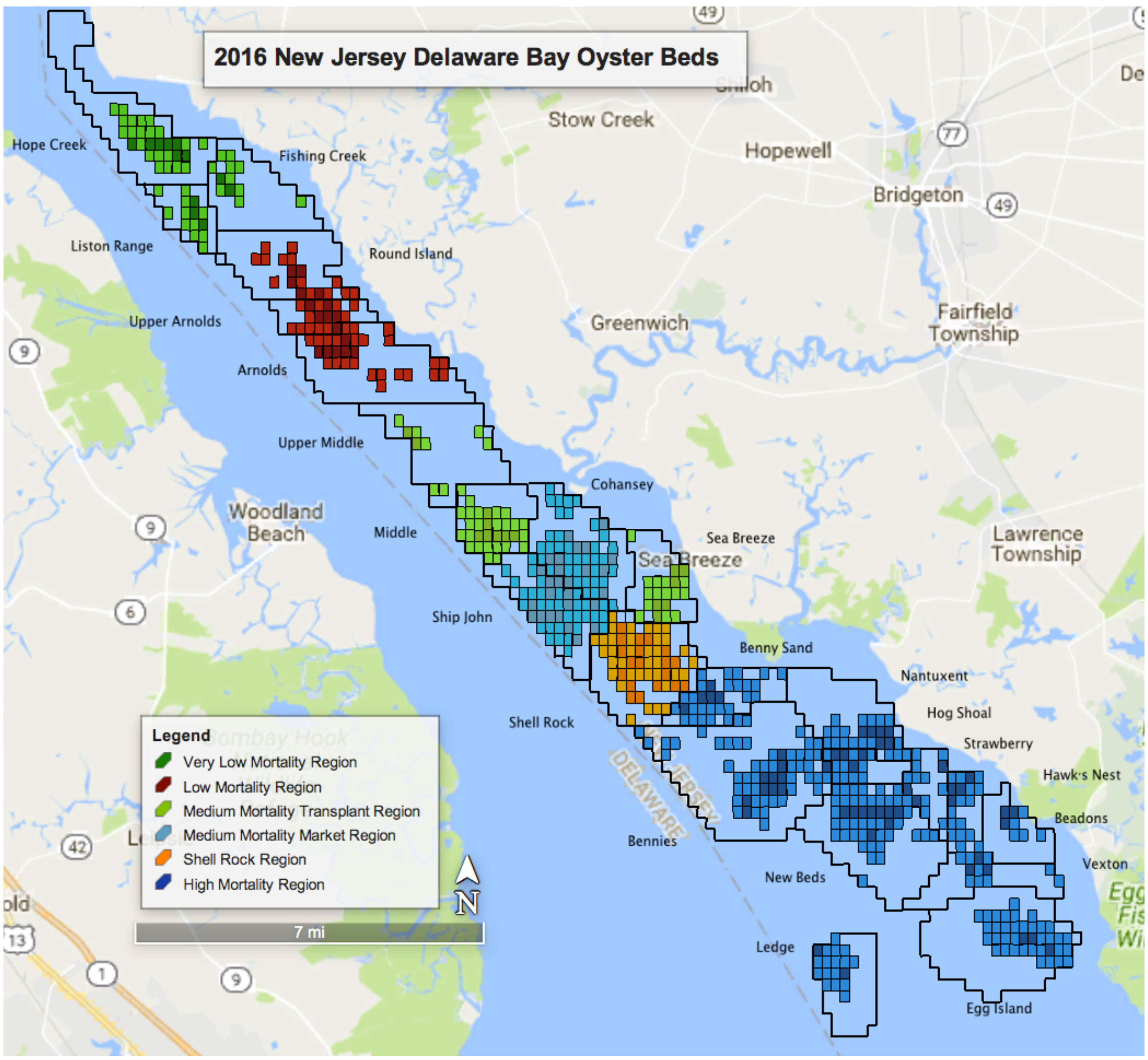
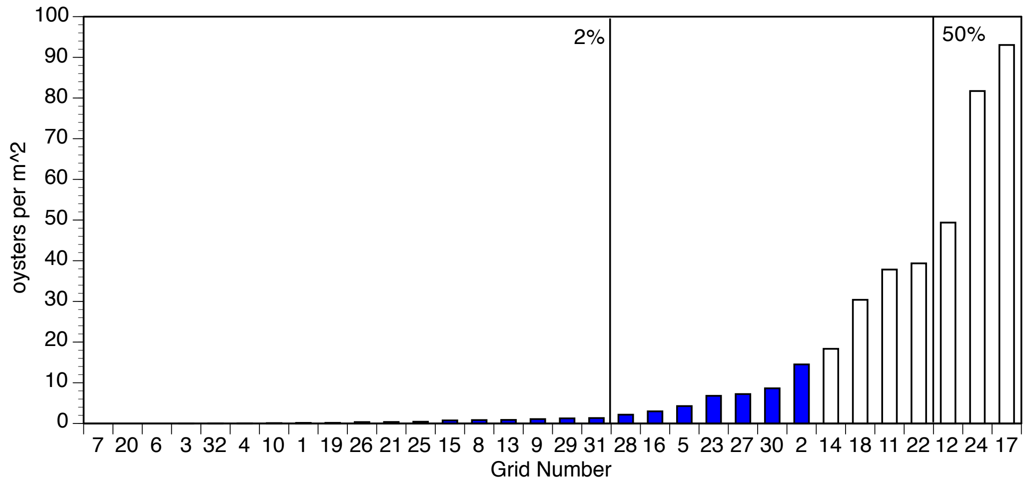
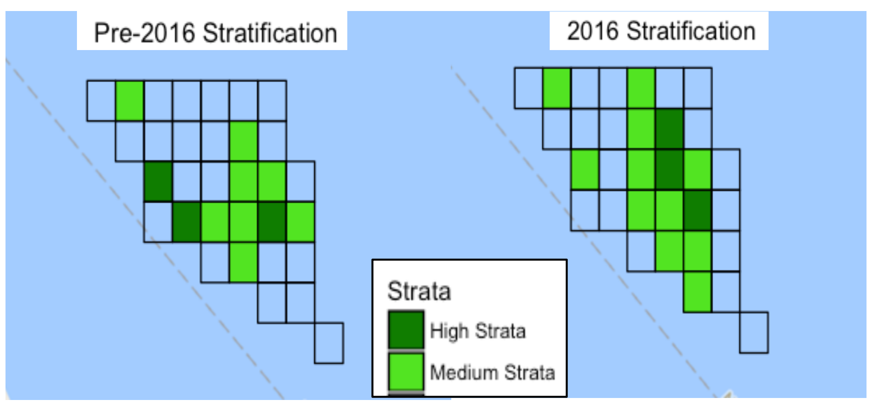


Figure 14. Liston Range Spring 2016 restratification survey results. **a**. Grids arranged in density order with low (2%) and high (50%) quality stratum cutoffs marked. **b.** Grid map strata changes between resurveys done in 2008 and in 2016. High and medium quality strata as on legend; low quality stratum is light blue grids. **c**. Percentiles of grid oyster densities per m^2 for the 2008 and 2016 resurveys.

a.



b.



c.

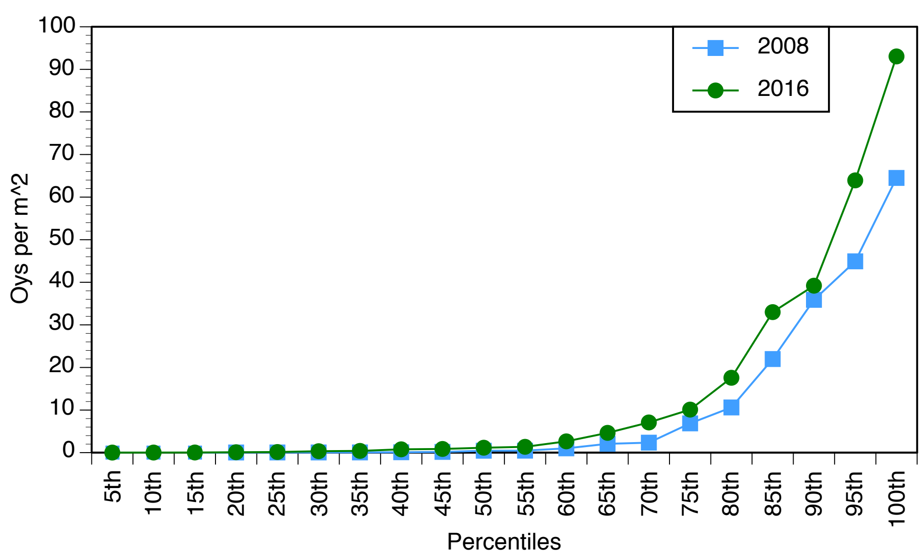
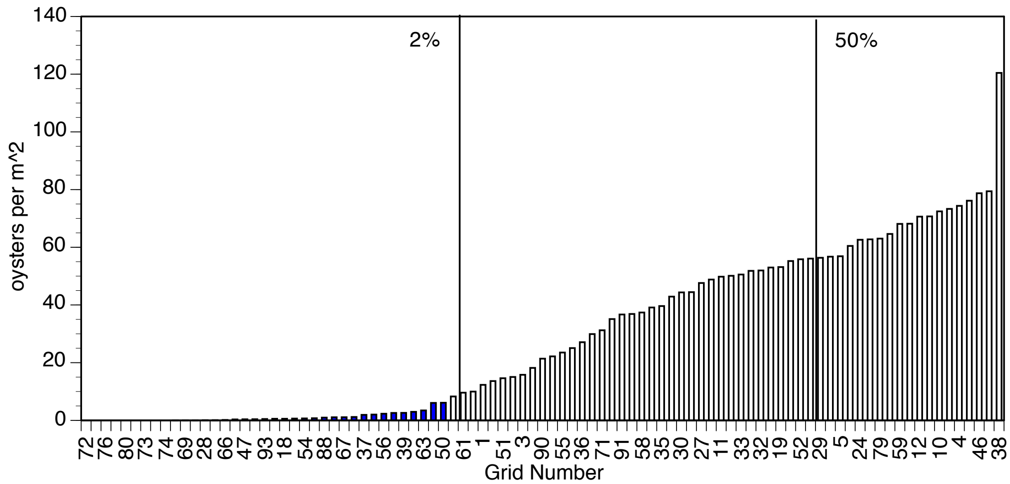
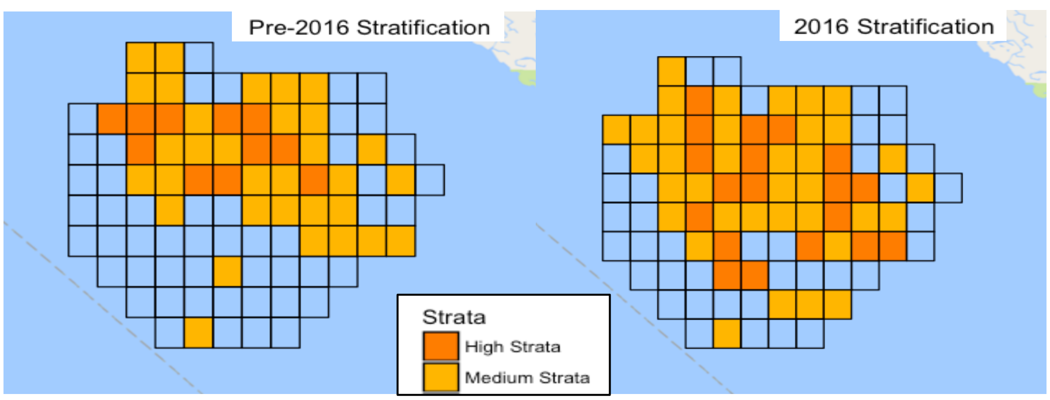


Figure 15. Shell Rock Spring 2016 restratification survey results. **a**. Grids arranged in density order with low (2%) and high (50%) quality stratum cutoffs marked. **b.** Grid map strata changes between resurveys done in 2012 and in 2016. High and medium quality strata as on legend; low quality stratum is light blue grids. **c**. Percentiles of grid oyster densities per m^2 for the 2008, 2012, and 2016 resurveys.

a.



b.



c.

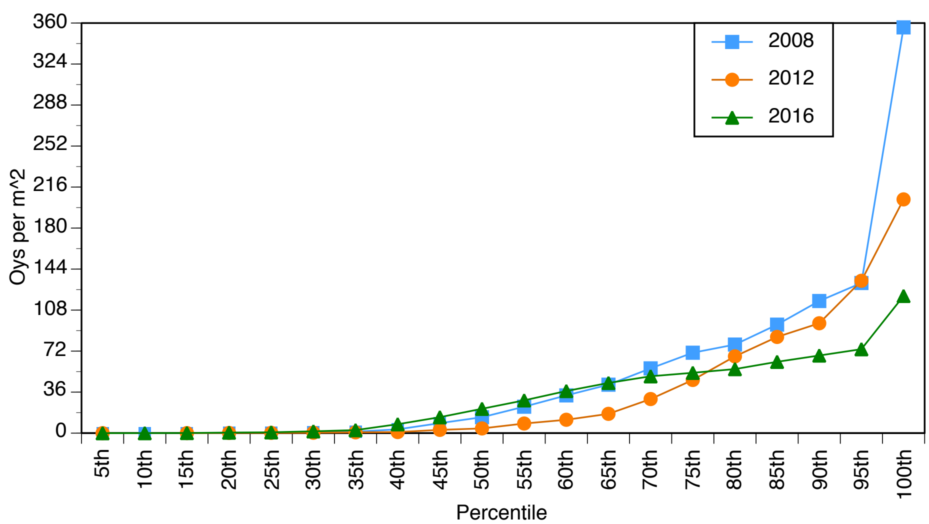


Figure 16. Maps of Shell Rock oyster densities by grid from four restratification surveys conducted in Spring 2005, 2008, 2012, and 2016. Grid shades indicate oyster (>20mm) per m^2 density for each grid. White, < 1 oyster per m^2; light gray, approximately 1-20 per m^2; dark gray, approximately 20-100 per m^2; and black, >100 per m^2; ND, no data. The 2005 survey was done on part of Shell Rock to verify oyster densities in grids that are not sampled annually in the stock assessment survey and to include new areas not previously in the dataset.

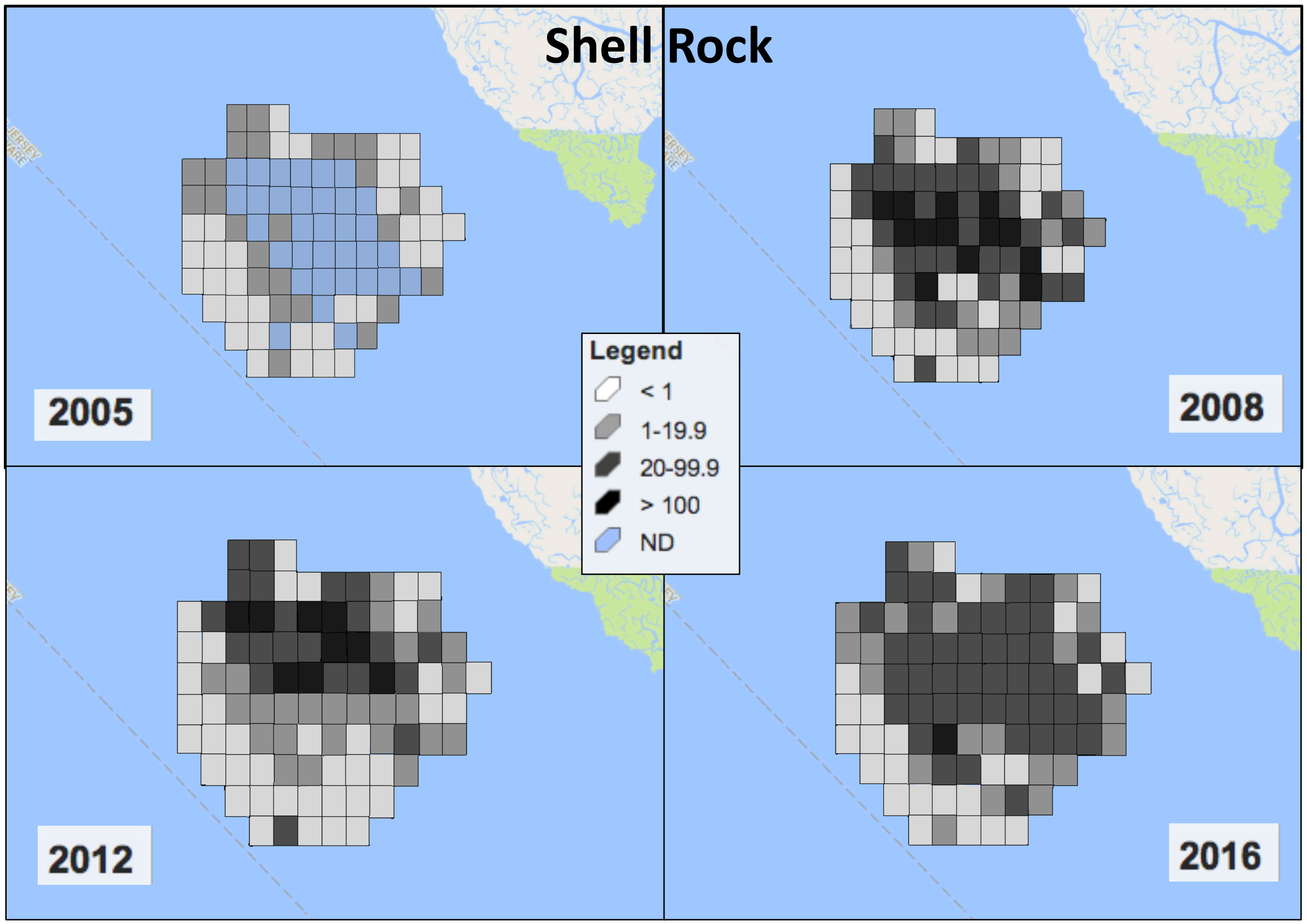
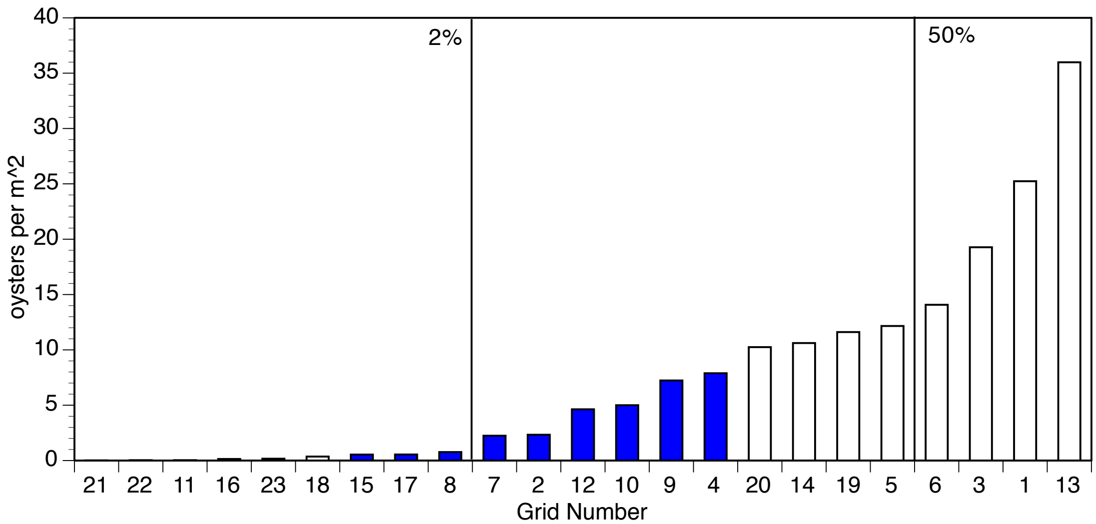
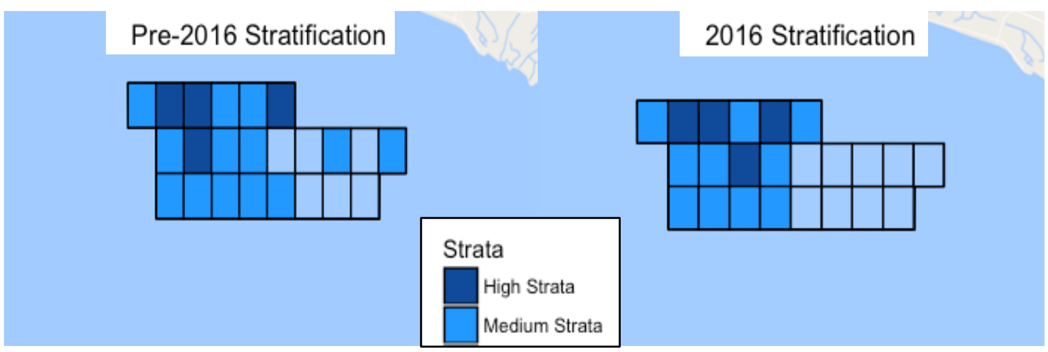


Figure 17. Hog Shoal 2016 restratification survey results. **a**. Grids arranged in density order with low (2%) and high (50%) quality stratum cutoffs marked. **b.** Grid map strata changes between resurveys done in 2006 and in 2016. High and medium quality strata as on legend; low quality stratum is lightest blue grids. **c**. Percentiles of grid oyster densities per m^2 for the 2006 and 2016 resurveys.

a.



b.



c.

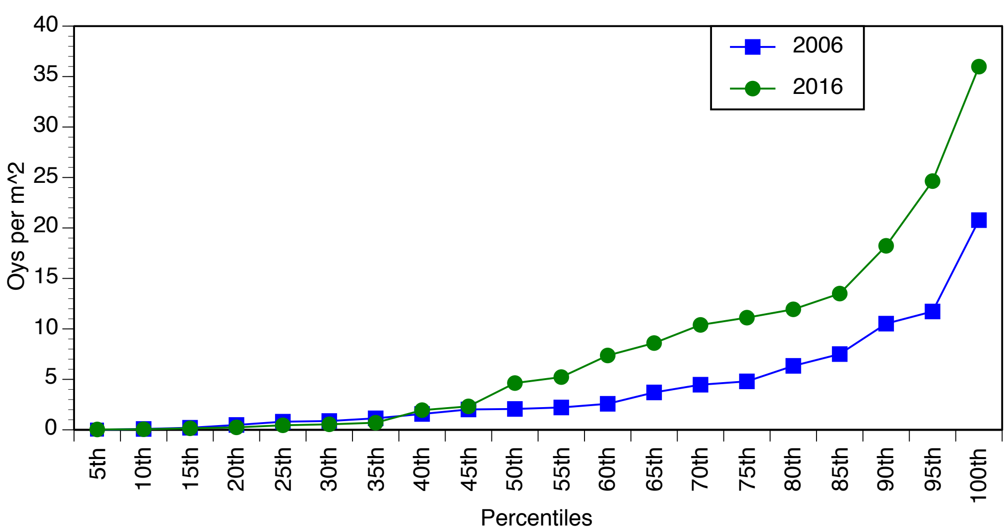


Figure 18. Map of the 2016 oyster stock assessment sample sites. Sampling intensity and types correspond to those found in Table 5. Black dots are sites from the high quality stratum on each bed and white dots are sites from the medium quality stratum. Red dots indicate transplant sites in the enhanced stratum and green dots are shellplant-enhanced sites.

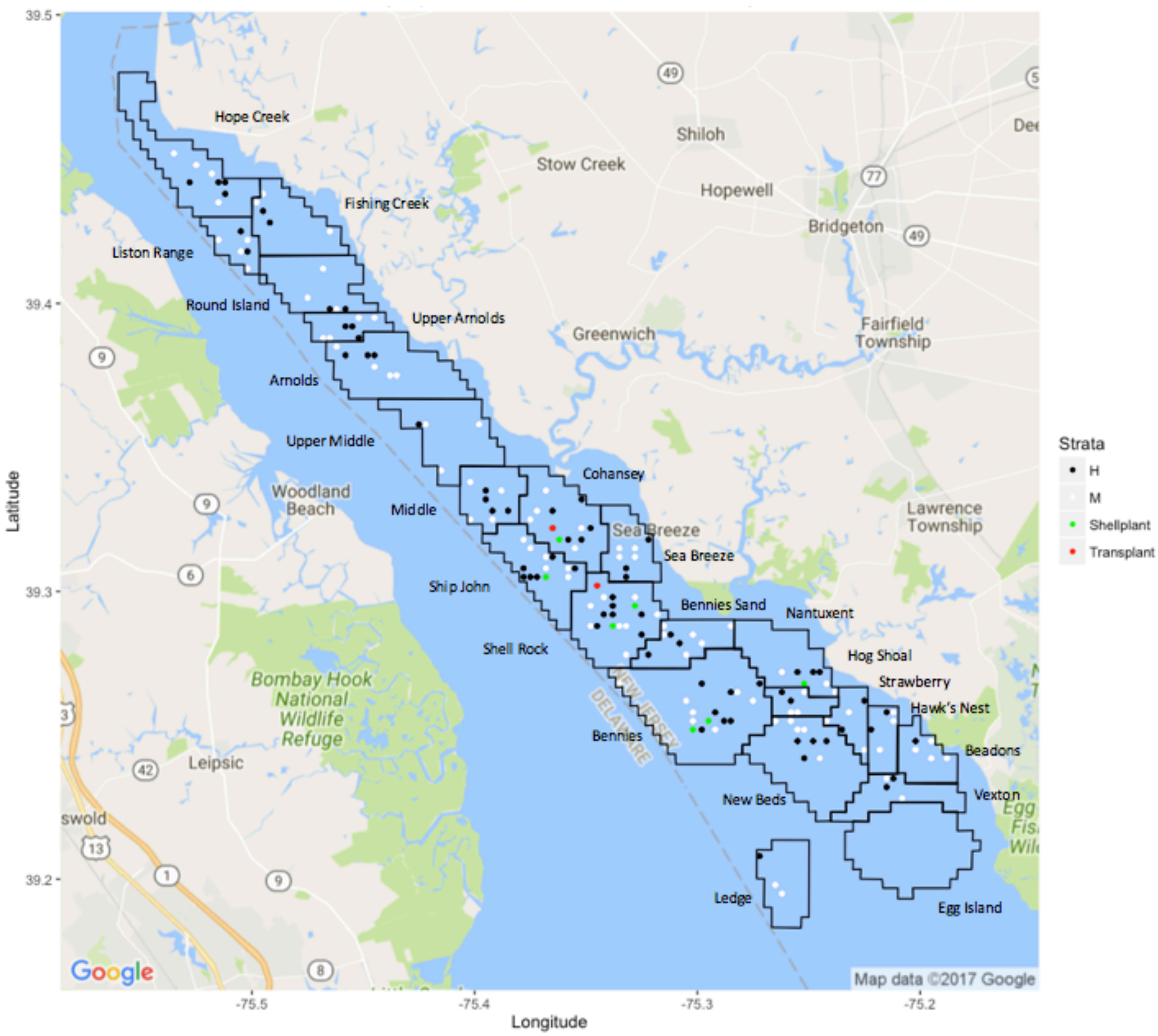
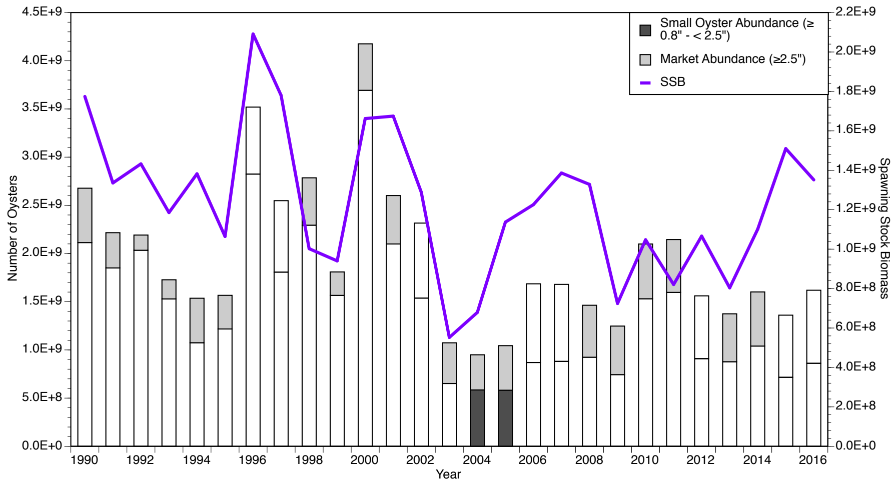
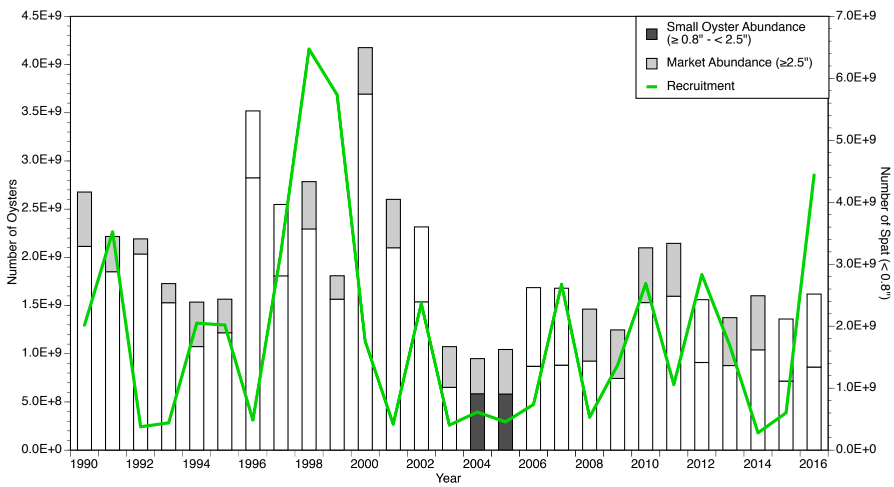


Figure 19. Abundance of small and market-size oysters (stacked bars) for the 1990 – 2016 time series, excluding the VLM. Overlay lines show (a) spawning stock biomass (SSB) which is based on oysters > 35 mm, (b) number of spat, and (c) box-count mortality.

a.



b.



c.

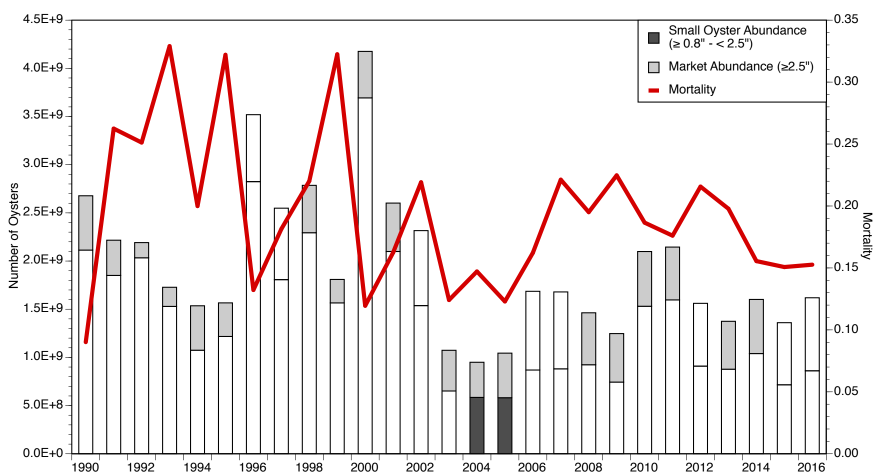


Figure 20. Number of market-size oysters (> 2.5 inches) for the 1990–2016 time series. Green line is the median value for the time series, 5.02 x 10^8. Data from the VLM is not included.

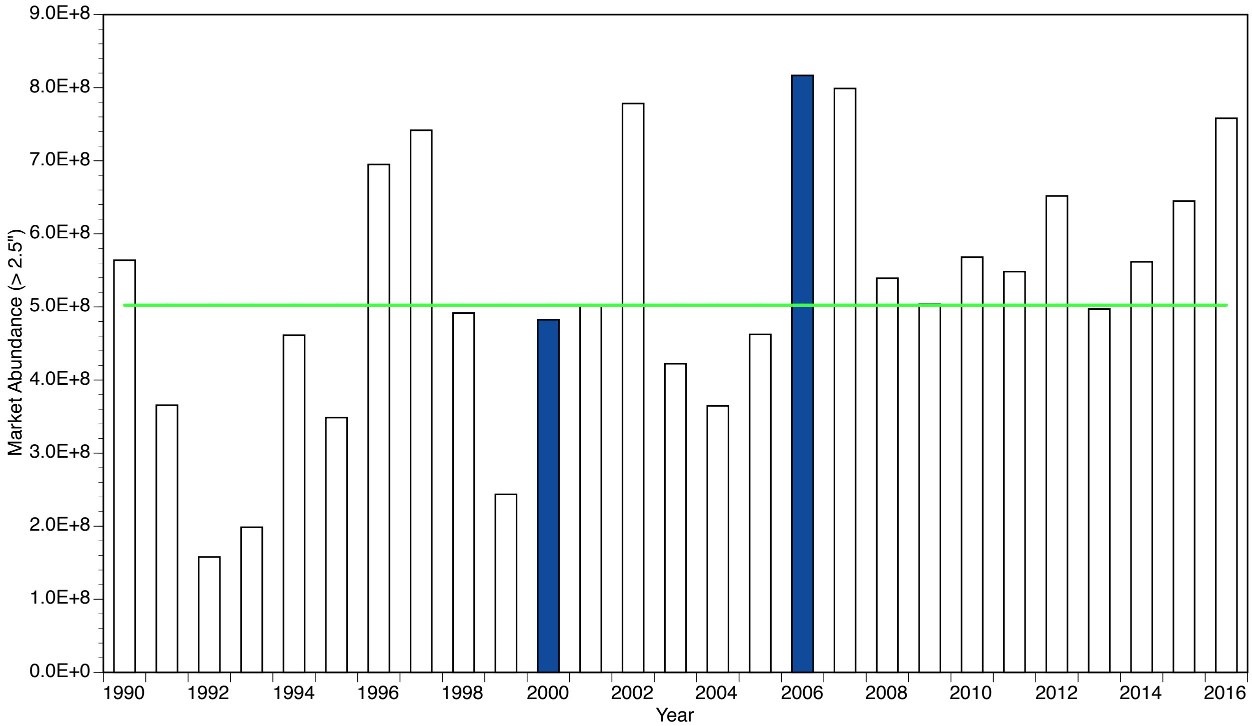


Figure 21. 2016 Oyster metrics. (a) acreage, (b) total abundance, (c) market abundance (≥ 2.5”), (d) spat abundance (< 0.8”), and (e) mortality by region.

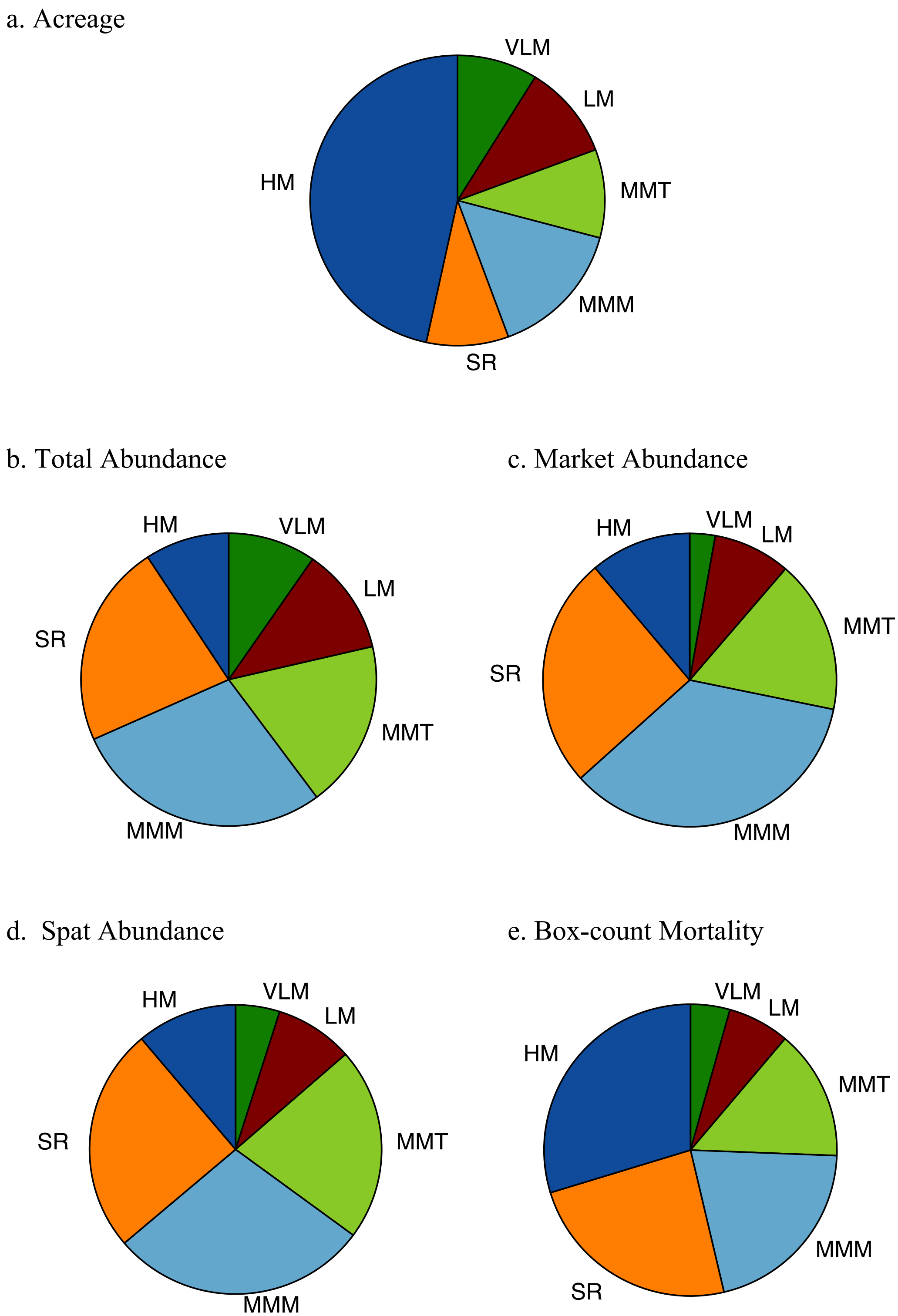


Figure 22. Ten-year time series for the VLM. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5”) abundance.

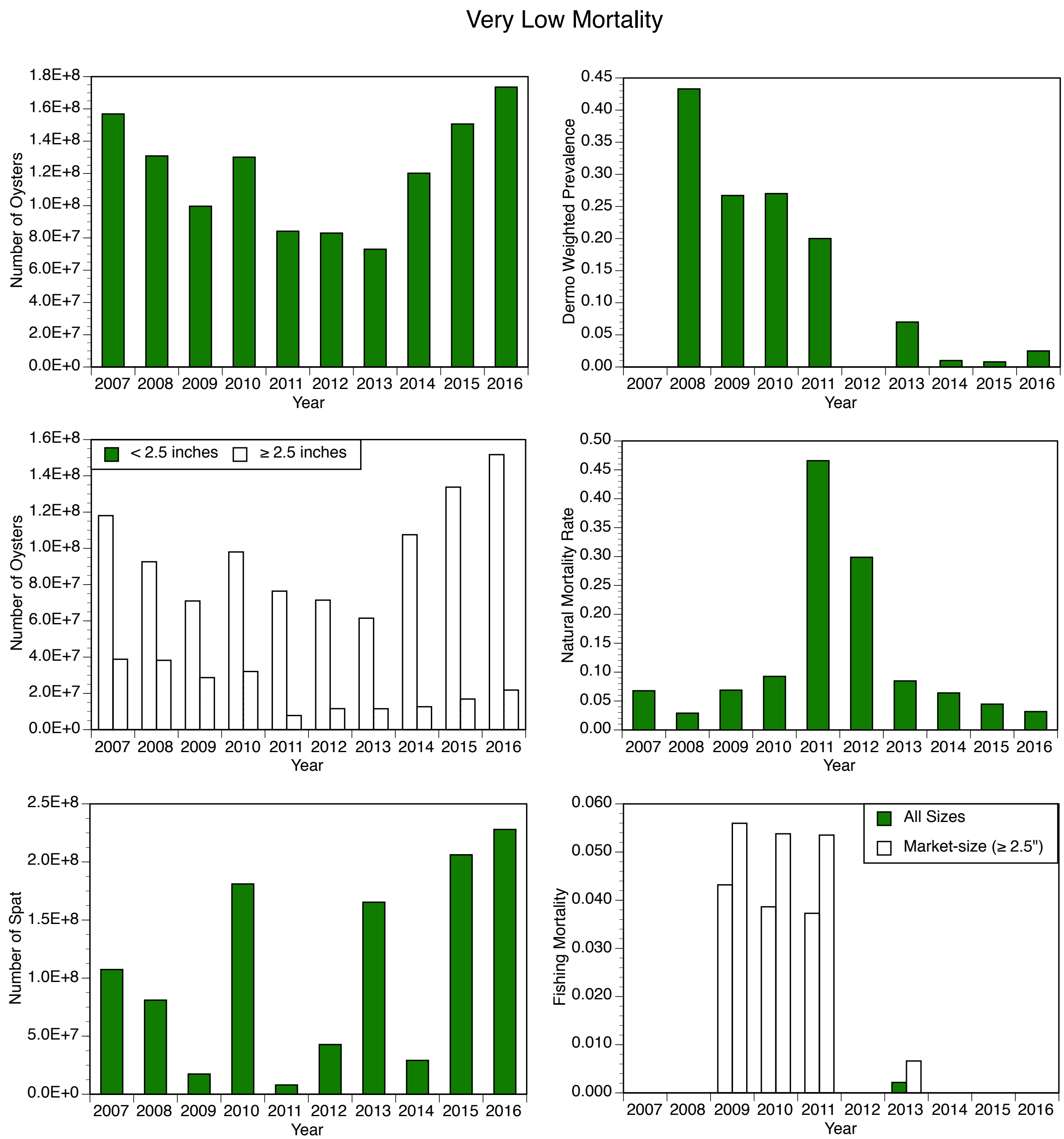


Figure 23. Ten-year time series for the LM. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5”) abundance.

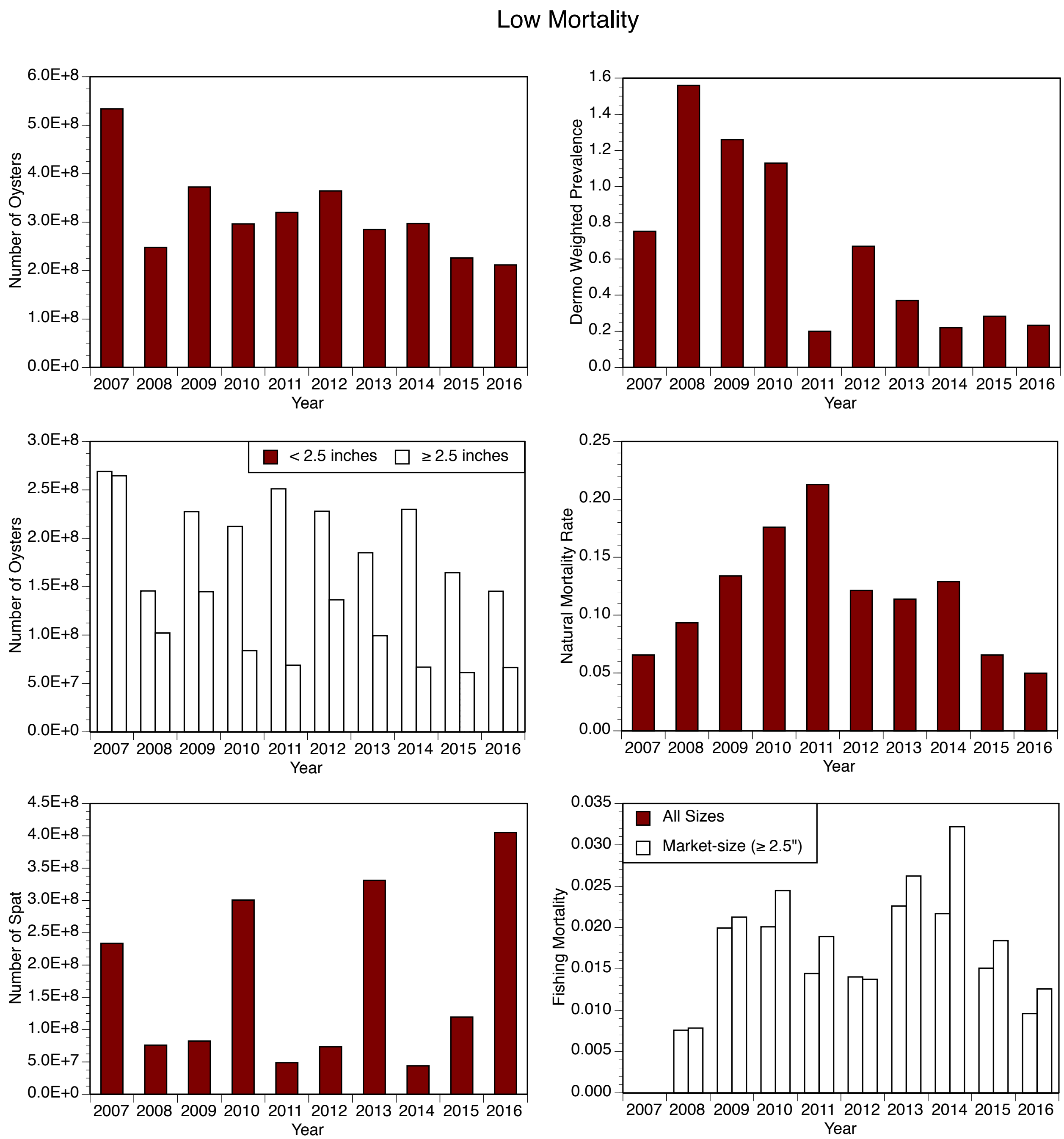


Figure 24. Ten-year time series for the MMT. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5") abundance.

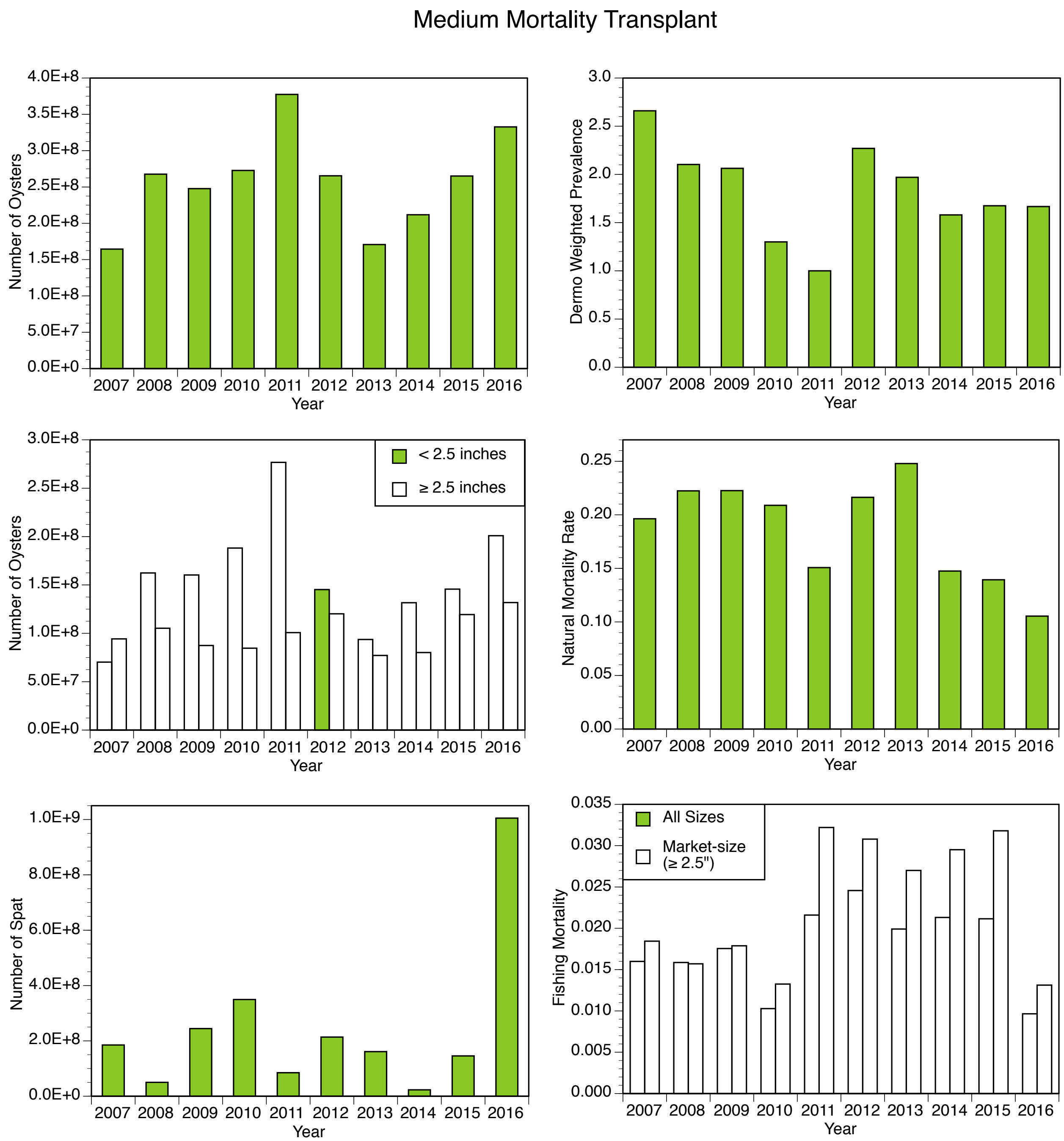


Figure 25. Ten-year time series for the MMM. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5") abundance.

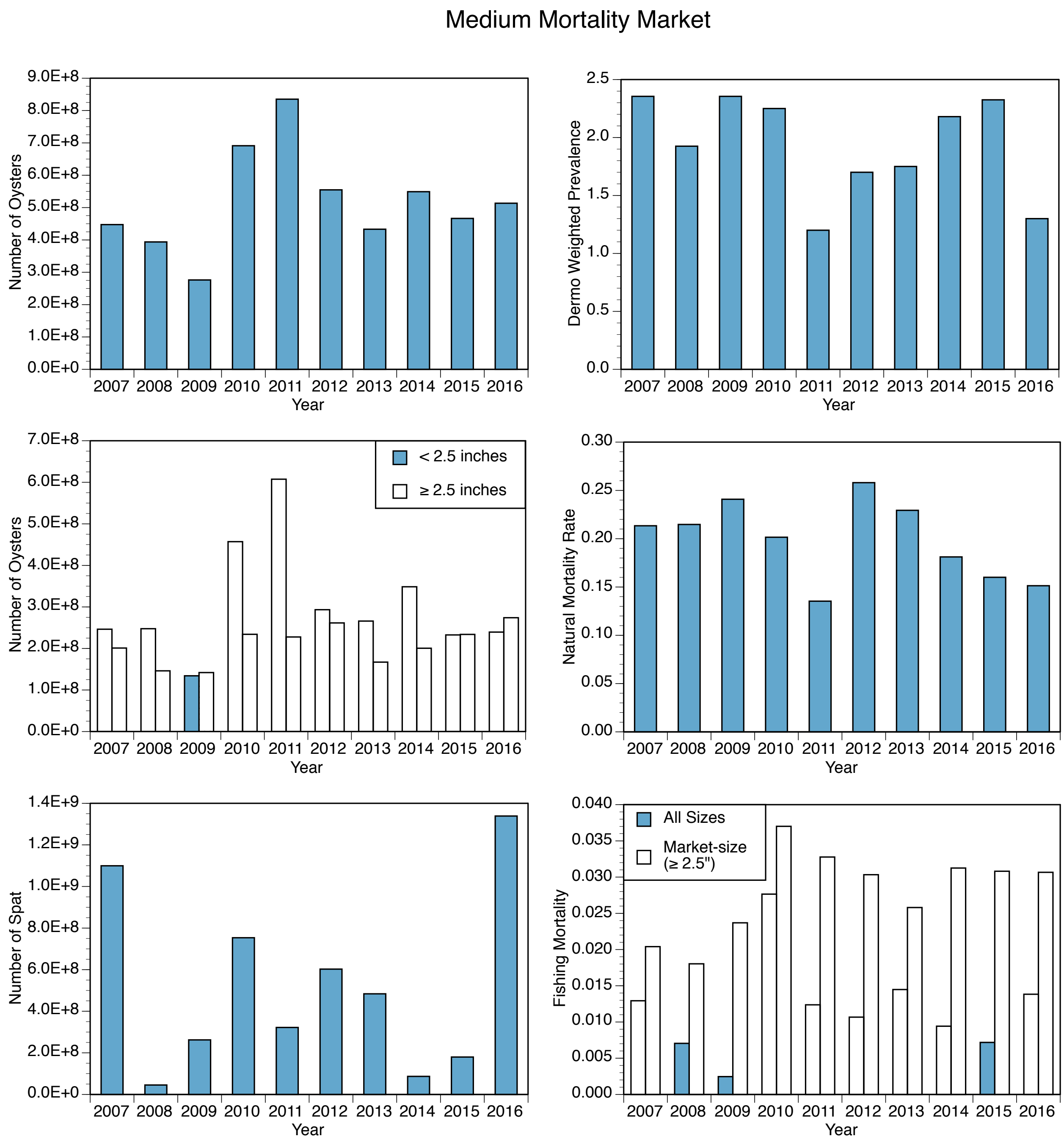


Figure 26. Ten-year time series for the SR. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5”) abundance.

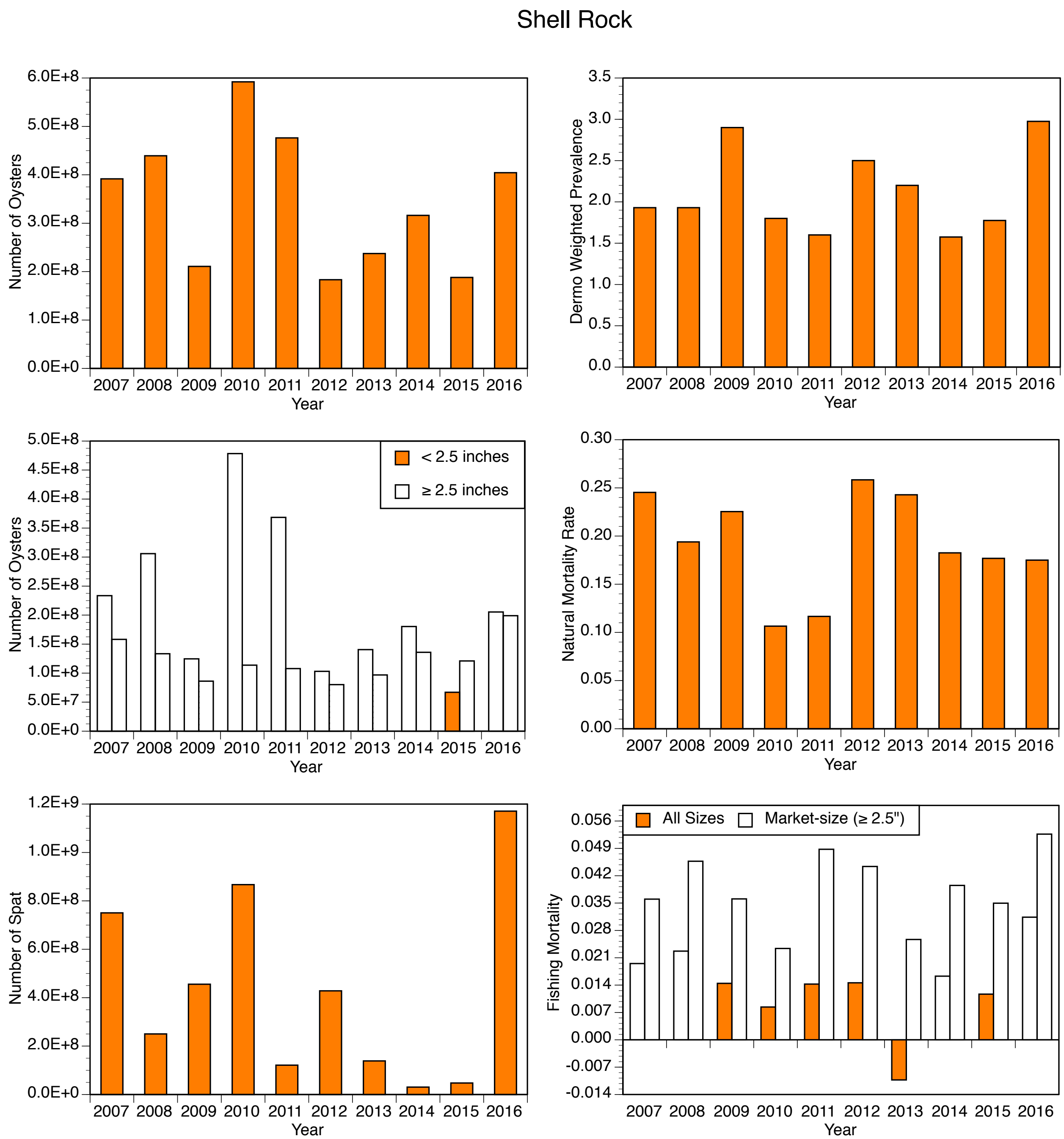


Figure 27. Ten-year time series for the HM. Left panel: total abundance (≥20mm), size class abundances (≥20mm), and spat abundance (<20mm). Right panel: dermo levels, box-count mortality rate, and fishing mortality rate relative to both total (≥20mm) and market-size (≥2.5") abundance.

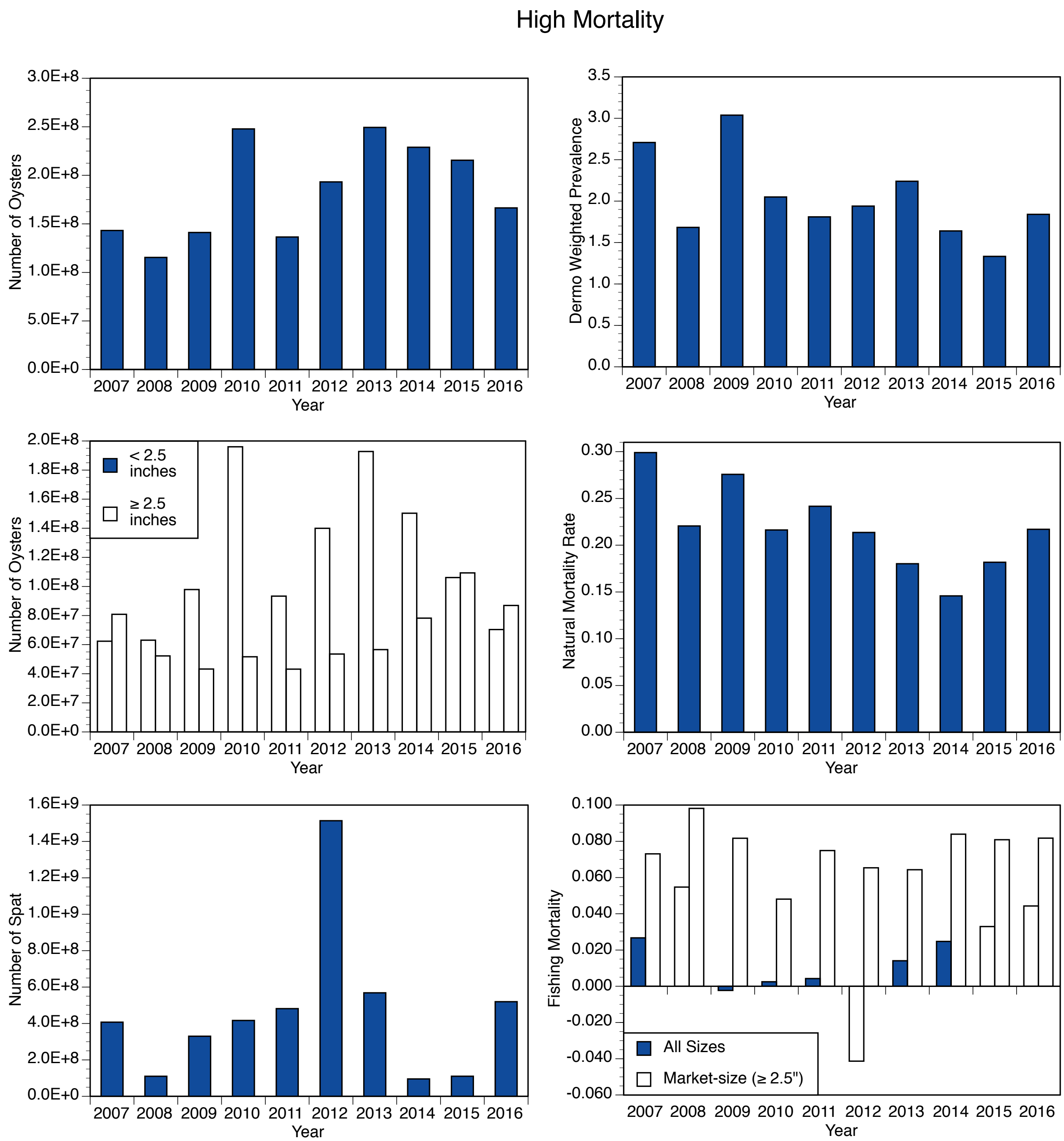


Figure 28. Total bushels of cultch (native shell and boxes) from 2000-2016 on assessed regions, excluding the VLM. Note that assessment stratum designations are based on oyster densities and that low quality strata are not sampled but it is possible that they contain significant amounts of shell.

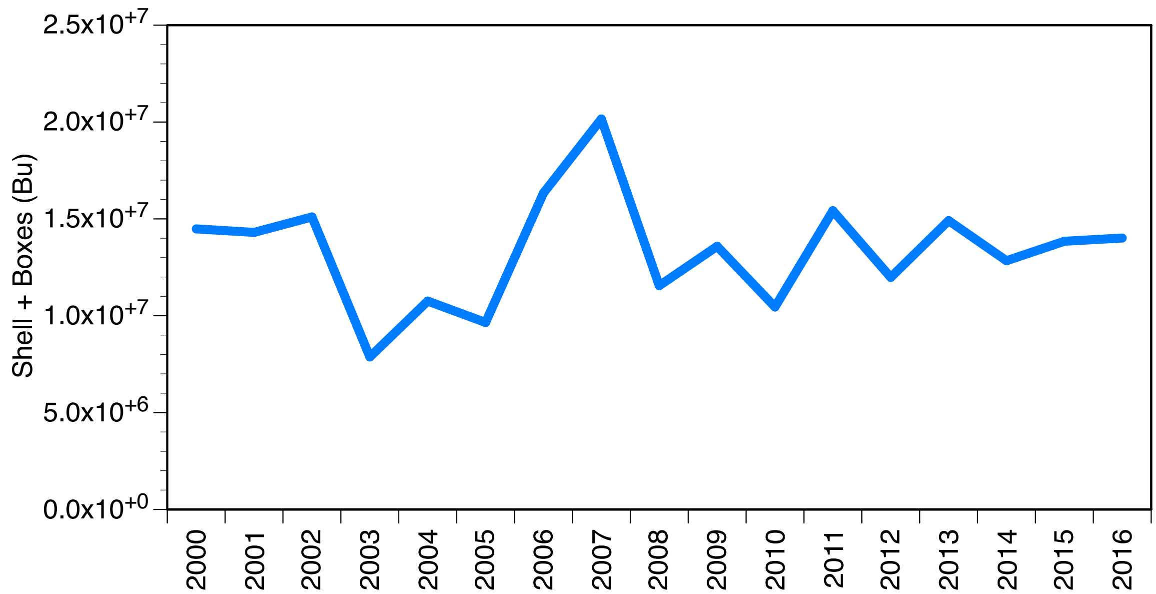
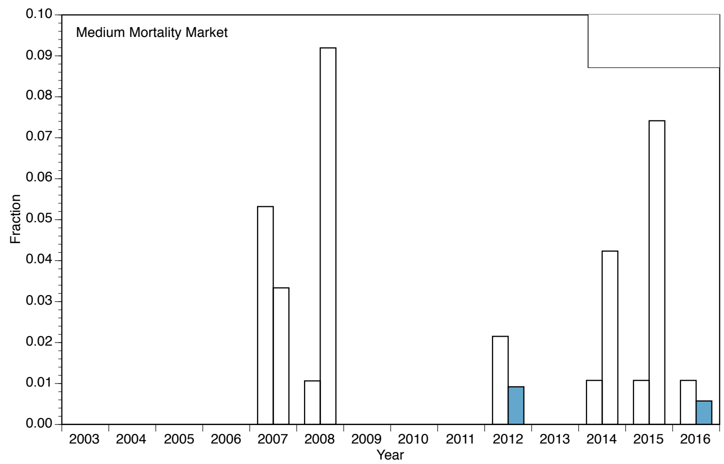
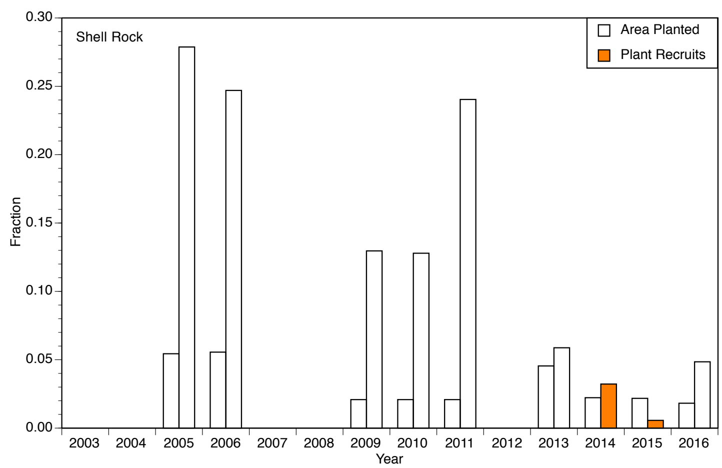


Figure 29. Shellplant performance on the a) MMM, b) SR, and c) HM direct market regions. For each year, the fraction of a region's area that was planted light bars) is plotted with the fraction of the region's spat that recruited to the planted shell (dark bars). Comparison is from the first year of each shellplant. Plants routinely recruit additional spat in subsequent years. Details of 2014–2016 plants are shown in Table 8; those from previous years are in earlier reports.

a.



b.



c.

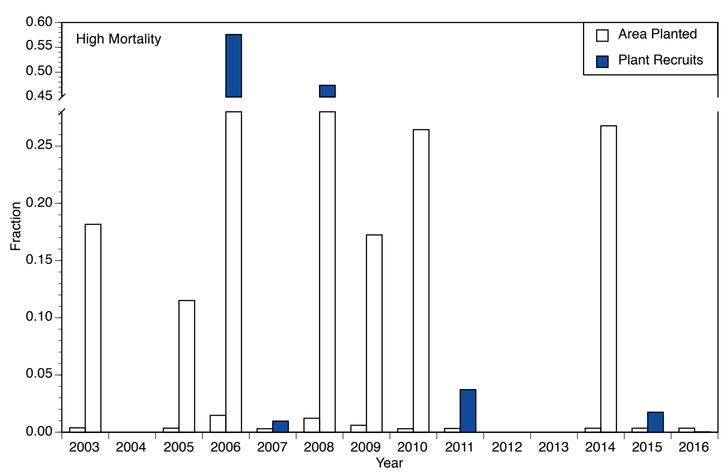


Figure 30. Spat transition size study results. Shell height at which logistic regression models predict 50% probability of morphological transition from spat to oyster for each region. Line at 20mm indicates the spat cutoff size used in the assessment.

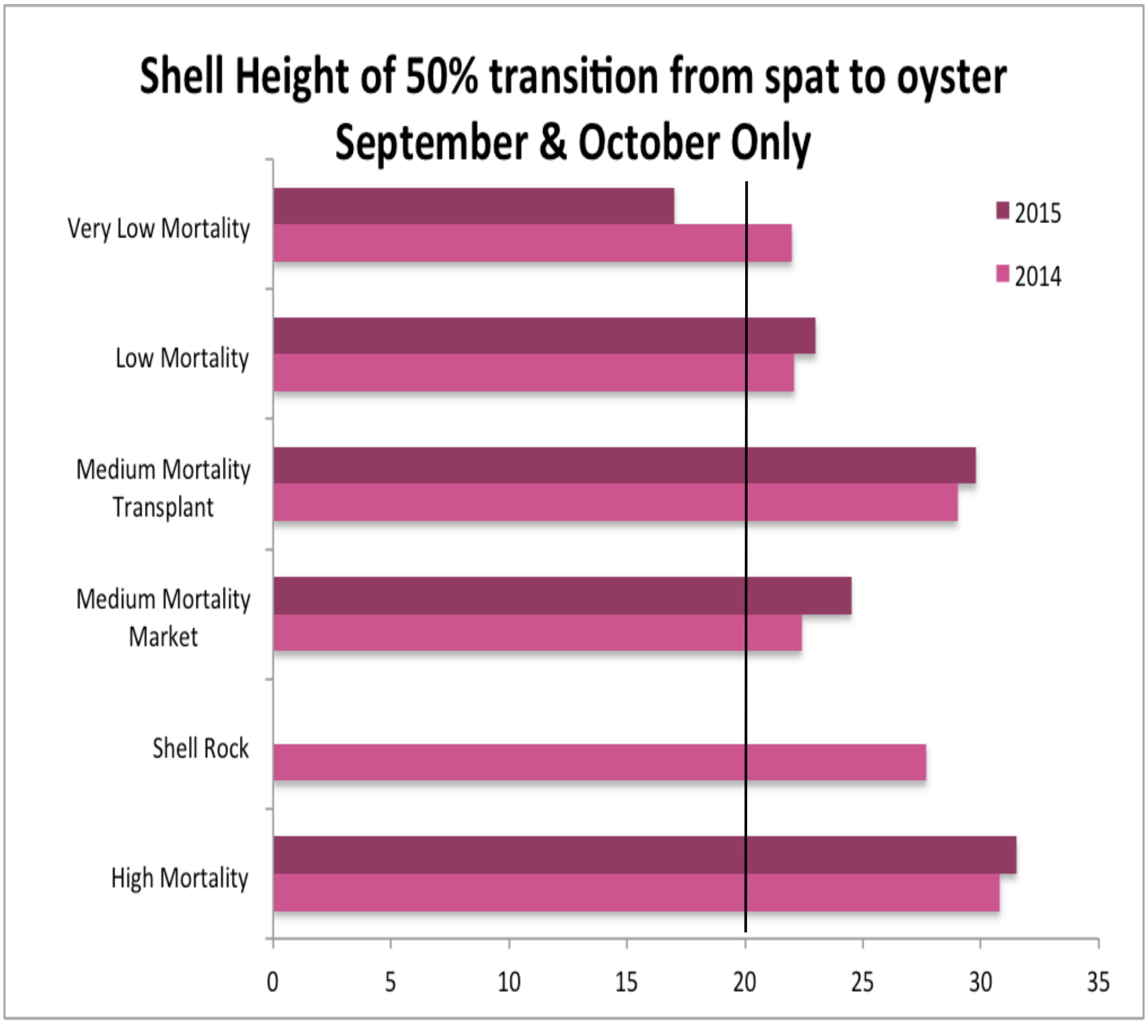


Figure 31. Fall dermo disease and mortality on assessed regions in Delaware Bay, NJ.

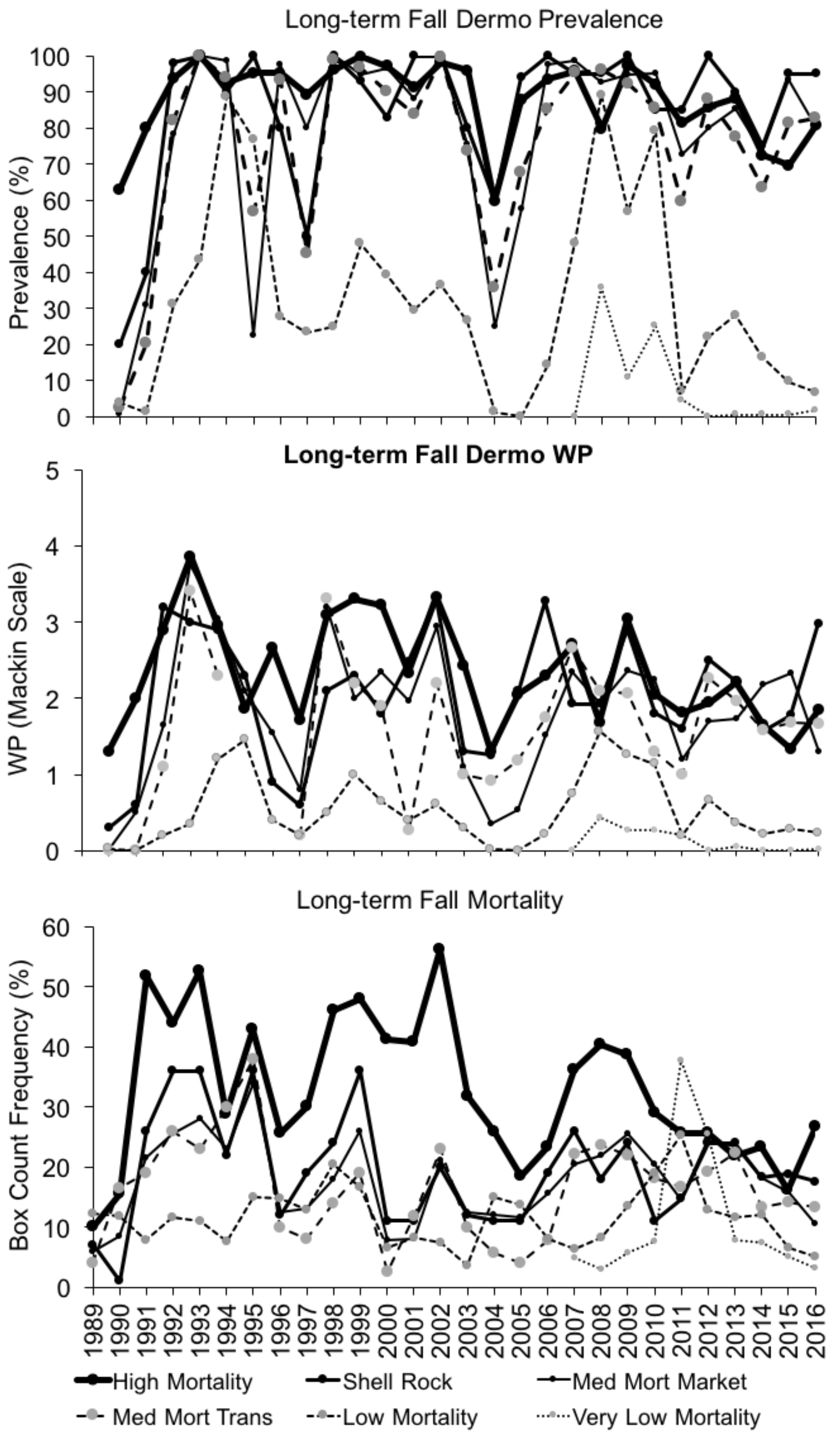


Figure 32. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program in 1996. The 21-yr average harvest is 77,228 bushels. The 2006-2007 line shows the beginning of the current exploitation and management strategy.

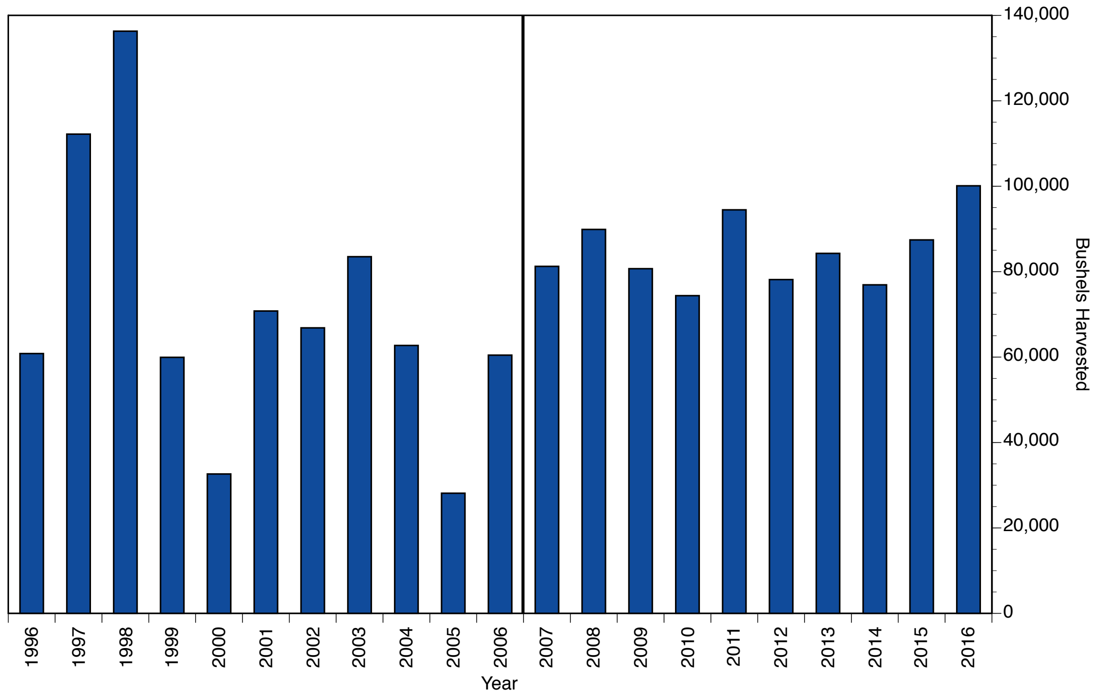


Figure 33. Landed oysters per bushel in three groups: market-size (>2.5"), smaller attached oysters, and smaller unattached oysters. The 2016 number of market-size oysters per landed bushel averaged 246. The long-term mean of all oysters (264) is shown as an orange line.

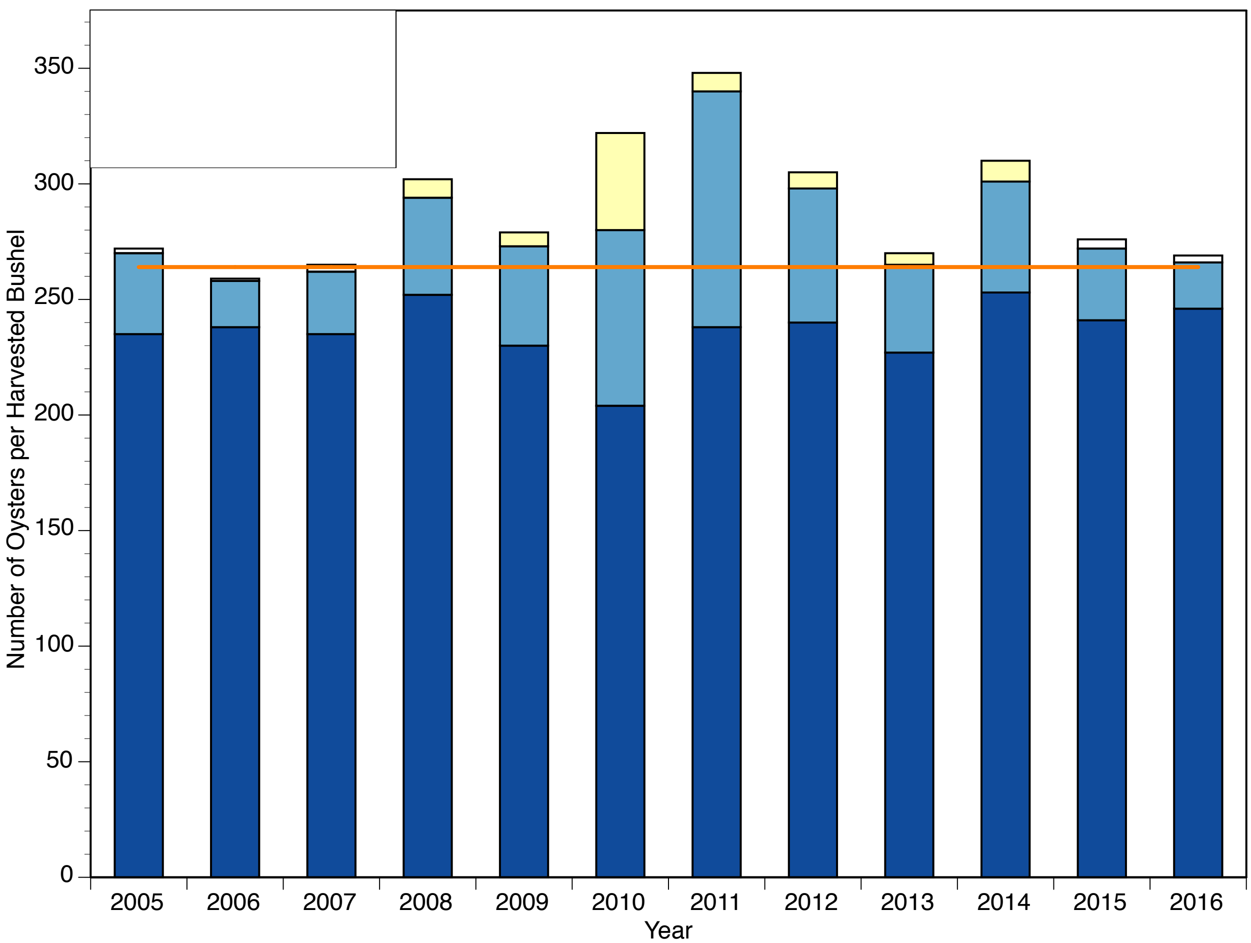


Figure 34. Size frequency of oysters landed in 2016 compared to the mean size frequency from the previous 12 years. Size class values are the lower bounds of the size class.

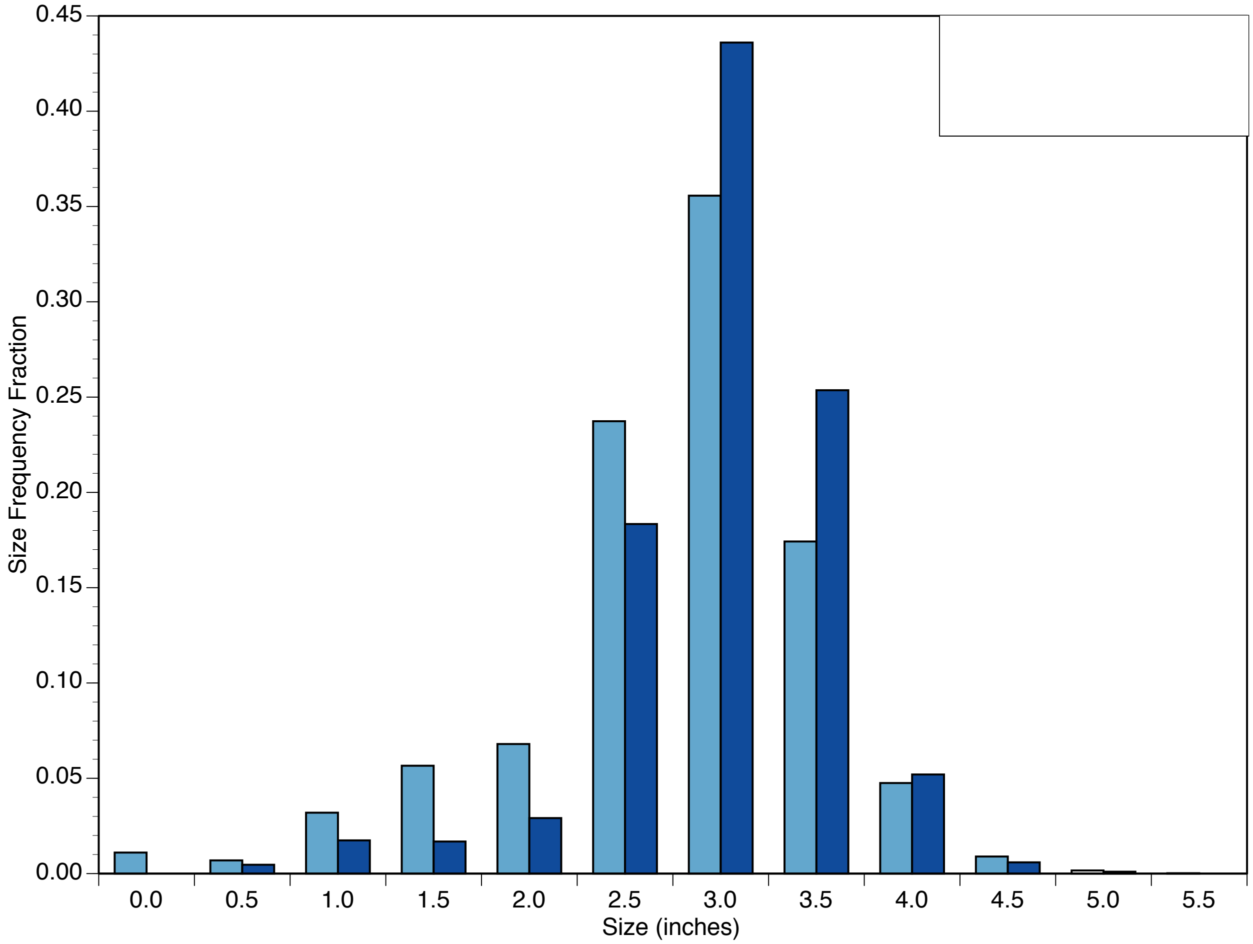
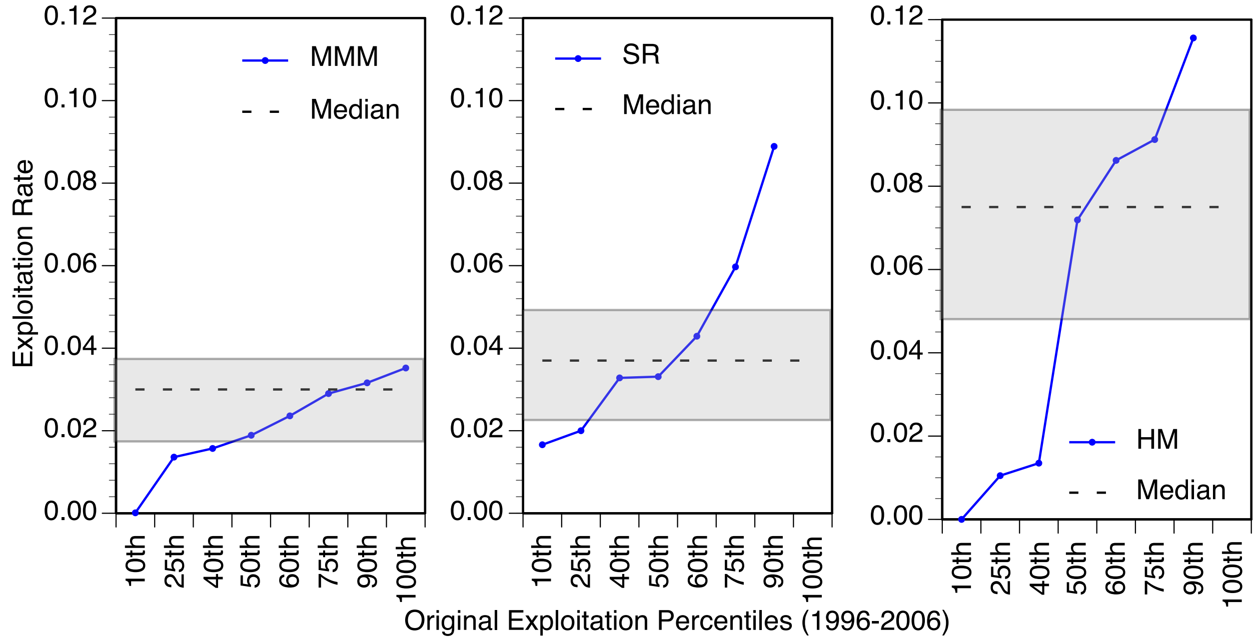


Figure 35. Original exploitation percentiles and associated rates derived from the 1996-2006 fishing record for each region (blue line) with 2007-2015 realized exploitation rate ranges (gray box) and medians (dotted line) for: (a) the >2.5” oyster stock on Direct Market regions and (b) the whole stock on Transplant regions. Note: VLM exploited 3 times; gray box is range, dotted line is middle value.

a. Direct Market Regions



b. Transplant Regions

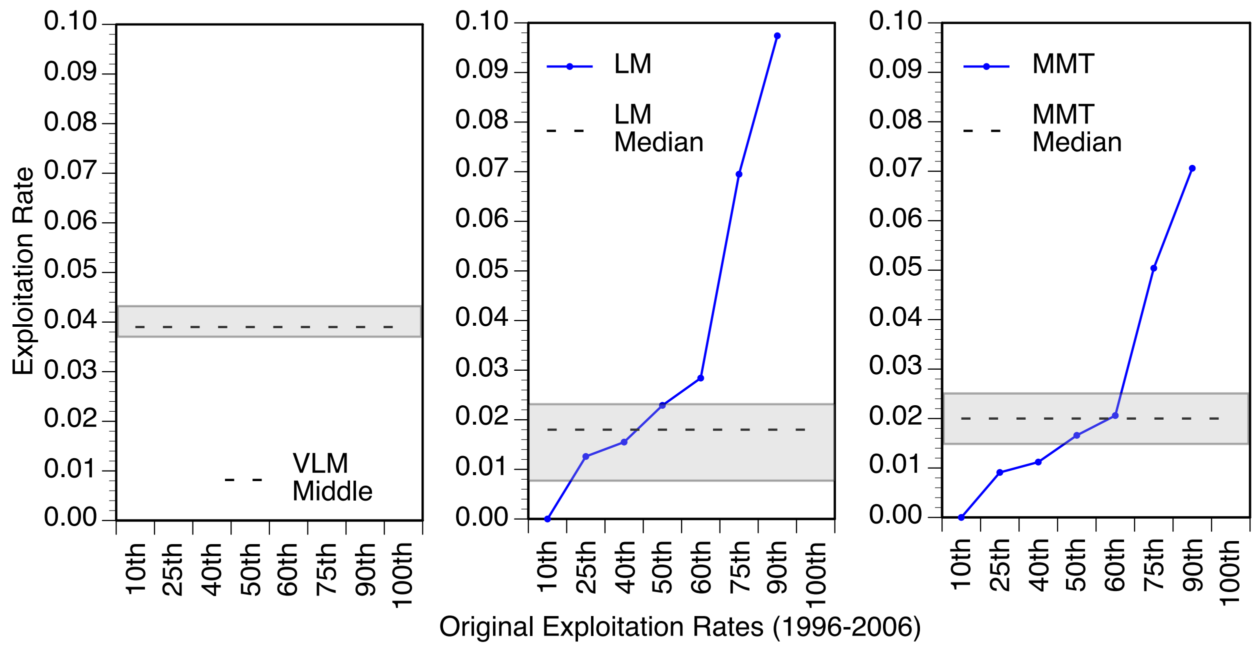
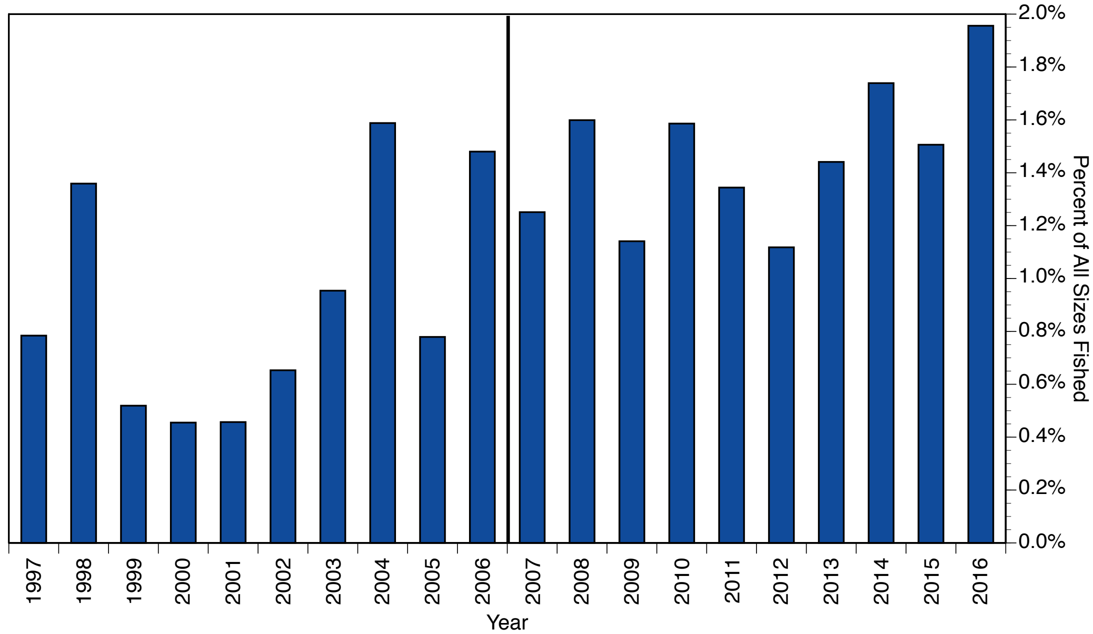


Figure 36. Fishing mortality as a percentage of (a) total oyster abundance and (b) the market-sized oyster abundance (>2.5”) over all regions excluding the VLM. Regional abundance-based quotas began in 2007 (vertical line).

a.



b.

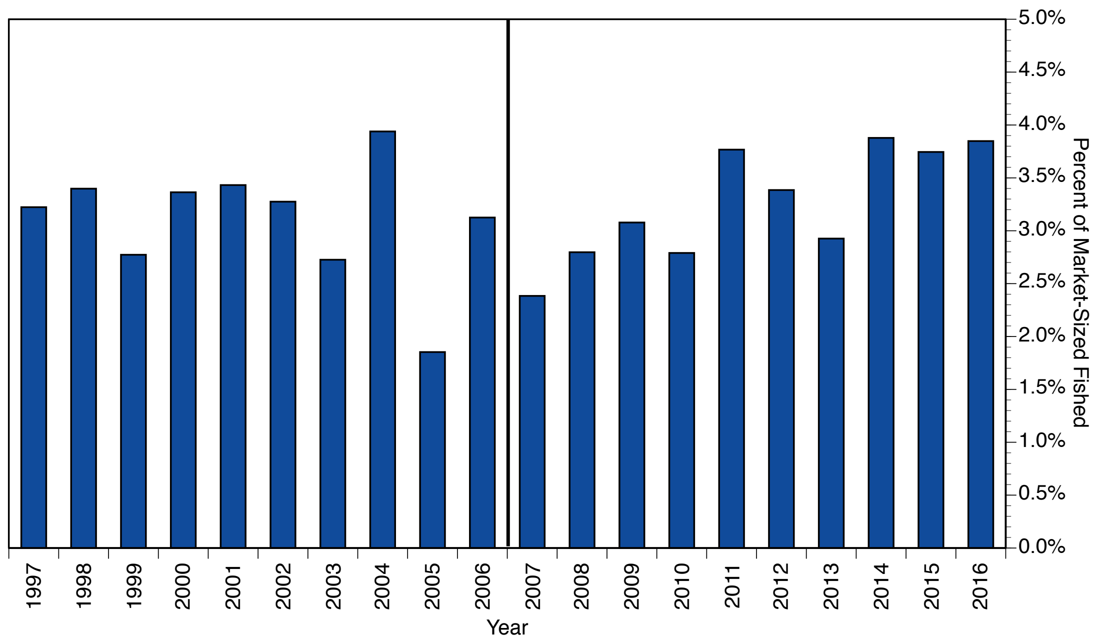
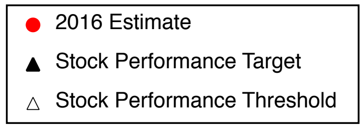
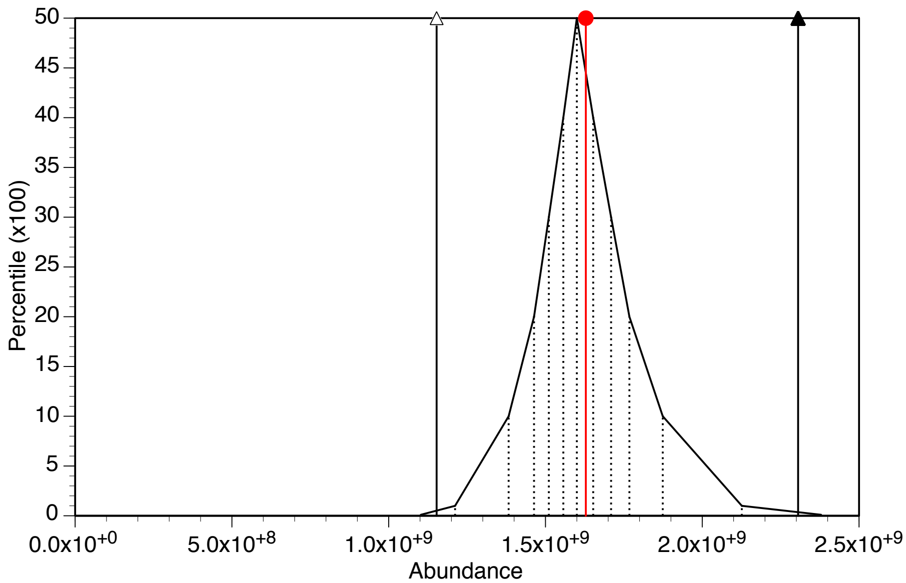


Figure 37. 2016 whole-stock (minus the VLM) total (a) and market-sized (b) abundance estimates within confidence percentiles for the 2016 survey taking into account survey and gear efficiency error (see Analytical Approach in this report). Whole stock reference points are included for comparison. Note 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.

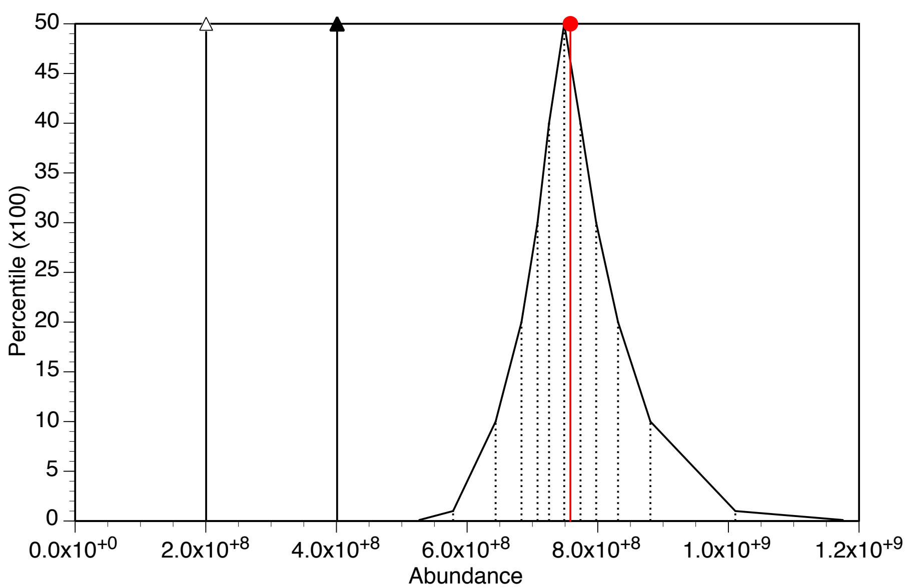
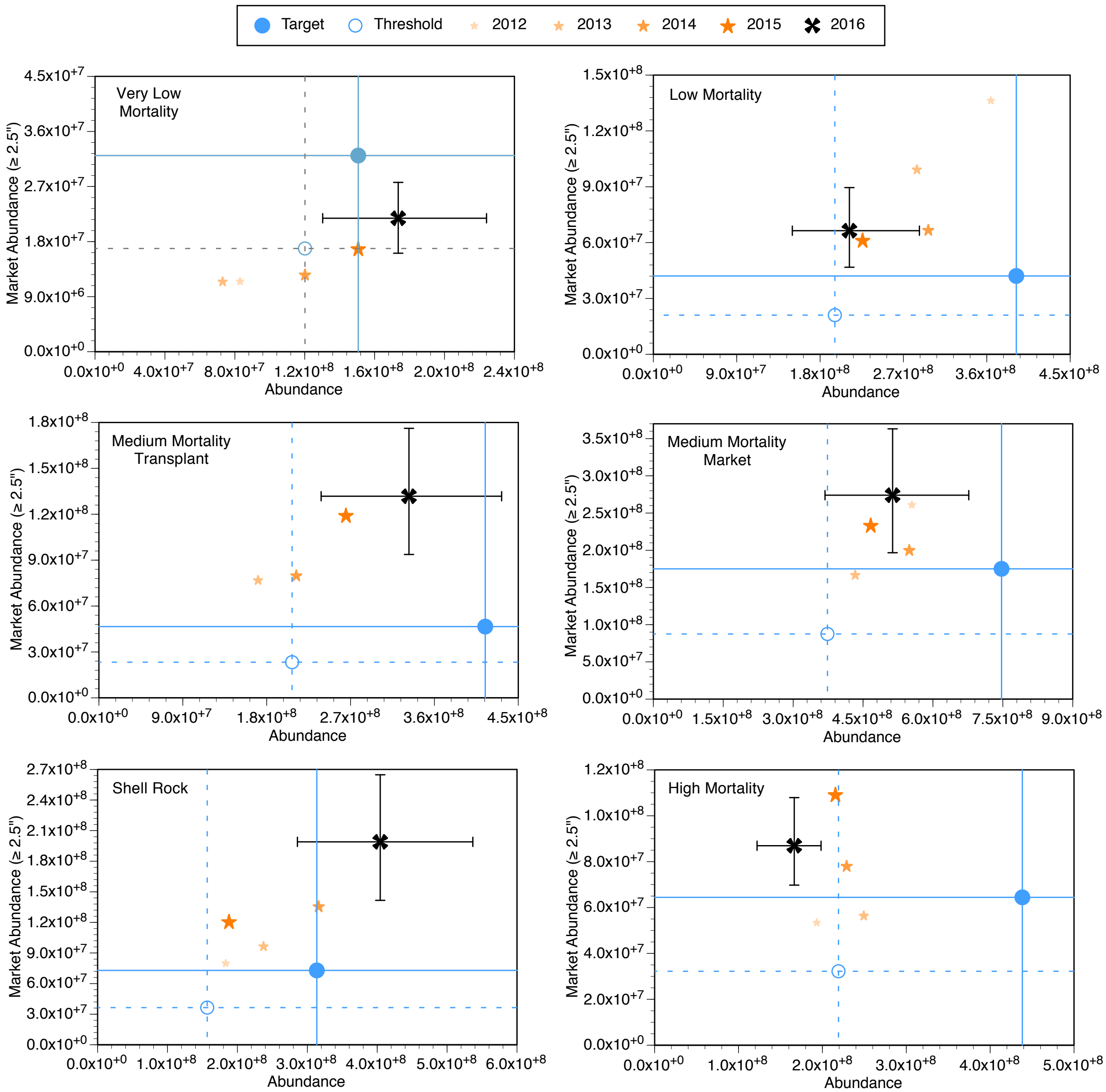


Figure 38. Position of the oyster stock 2012–2016 with respect to abundance and market abundance (≥ 2.5”) targets and thresholds for each region. Targets and thresholds are defined in text. Error bars on the 2016 values are the 10^{th} and 90^{th} percentiles of 1,000 simulations of estimates incorporating 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

Appendix B.1.1

Oyster abundance percentiles by region for time series 1953 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its 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**
0.01	188,146,624	2003	83,505,968	1954	133,347,448	1956	26,446,584	1966	70,609,376	1958
0.05	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
0.1	225,904,032	2015	167,121,600	1958	273,047,040	1955	100,462,672	1956	136,463,744	2011
0.175	291,092,512	2005	211,773,392	2014	341,242,944	2004	145,852,928	2005	158,428,128	1964
0.25	345,433,408	1997	237,771,552	2003	393,779,584	1991	187,965,408	2015	215,537,008	2015
0.333	391,877,696	2002	265,401,040	2012	457,992,320	1959	215,947,104	1957	247,722,496	1963
0.375	431,545,920	1995	275,256,448	2006	486,386,368	1961	249,282,112	1985	254,538,784	1968
0.4	513,350,656	1994	332,705,856	2016	513,482,752	2016	291,713,472	2003	296,903,456	2001
0.5	677,346,368	1992	424,013,120	1990	648,437,504	1990	391,652,864	2007	418,439,296	2000
0.6	803,602,816	1957	508,082,048	1960	835,126,656	2011	439,337,120	2008	497,618,560	1965
0.625	1,015,315,072	1991	522,474,112	1988	937,948,864	1965	478,759,936	1997	518,696,896	1954
0.667	1,216,428,032	1989	560,042,304	1997	1,165,114,240	1998	603,986,624	1953	558,553,920	1998
0.75	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
0.9	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
0.95	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
0.99	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
2016	211,663,968	0.023	332,705,856	0.398	513,482,752	0.398	404,353,120	0.523	166,443,296	0.18

Appendix B.1.2
Box-count mortality fraction percentiles by region for time series 1953 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its 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**
0.01	0.02015	1969	0.03880	1973	0.04148	1973	0.02566	1973	0.03040	1954
0.05	0.04619	1970	0.04543	1967	0.05134	1967	0.04591	1984	0.03992	1973
0.075	0.04975	1959	0.06493	1984	0.06637	1974	0.04808	1983	0.04511	1972
0.1	0.04983	2016	0.06718	1969	0.06908	1990	0.05047	1974	0.05923	1989
0.175	0.05551	2000	0.07806	1964	0.08389	1984	0.06178	1972	0.09688	1969
0.25	0.06554	2015	0.08212	1977	0.09174	1982	0.06899	1971	0.10878	1968
0.333	0.07331	1963	0.09290	1962	0.10716	1996	0.08974	1977	0.12069	1990
0.375	0.07637	1982	0.09528	2001	0.10952	1953	0.09478	2003	0.13490	1980
0.4	0.07716	1980	0.09634	1963	0.11159	1963	0.09919	2005	0.14580	2014
0.5	0.09791	1958	0.11242	1998	0.12808	1998	0.11670	1960	0.17763	1987
0.6	0.11379	2013	0.14843	1978	0.15751	2006	0.17736	1956	0.21242	2006
0.625	0.11683	1983	0.15112	1965	0.16678	1966	0.18256	2014	0.21629	2010
0.667	0.12066	1998	0.15374	1972	0.17171	1976	0.20348	1998	0.22055	2008
0.75	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
0.9	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
0.95	0.21286	2011	0.30899	1986	0.34412	1995	0.37861	1995	0.46011	1999
0.99	0.26397	1985	0.34611	1958	0.45355	1958	0.48086	1958	0.49404	1993
2016	0.04983	0.086	0.10541	0.445	0.15131	0.555	0.17502	0.555	0.21701	0.648

Appendix B.1.3

Spat abundance percentiles by region for time series 1953 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its 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**
0.01	6,333,817	1984	23,093,696	2014	45,219,860	1967	4,605,388	1965	23,748,702	1967
0.05	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
0.1	26,818,624	1965	41,617,620	1967	82,737,920	2003	42,820,056	1959	81,395,376	2006
0.175	46,648,752	1953	68,642,088	1961	96,014,672	1992	52,128,692	1992	105,425,488	1996
0.25	75,127,984	1996	97,215,760	1958	146,489,072	2001	80,942,648	1996	129,302,976	2001
0.333	91,136,816	2006	145,636,704	2015	206,651,872	1975	121,193,680	2011	181,565,088	1957
0.375	113,754,272	2002	185,140,928	2007	307,102,528	1985	148,552,320	1957	251,242,752	1984
0.4	119,495,024	2015	201,475,168	1990	322,078,112	2011	169,873,856	1976	313,666,944	1976
0.5	260,206,560	1999	258,999,008	1994	448,024,352	1994	263,318,752	1995	416,641,536	2010
0.6	357,406,752	1955	364,378,592	1976	579,703,680	1957	415,485,472	1954	568,575,104	2013
0.625	405,289,728	2016	405,090,624	1962	582,054,592	2002	436,437,920	2000	589,182,592	1985
0.667	572,411,328	1957	442,342,496	1999	692,766,656	1981	481,982,784	1990	684,034,048	1990
0.75	932,318,016	1962	600,756,096	1966	950,478,144	1987	826,971,392	1980	1,122,550,656	1991
0.825	1,381,483,264	1987	733,910,144	1971	1,619,488,384	1982	963,304,320	1987	1,618,010,368	1997
0.9	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
0.95	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
0.99	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
2016	405,289,728	0.617	1,005,056,320	0.898	1,338,809,088	0.789	1,170,753,792	0.867	519,787,136	0.57

Appendix B.2.1

Oyster abundance percentiles by region for time series 1990 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its 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
0.01	188,146,624	2003	164,479,664	2007	276,226,816	2009	118,273,056	2004	89,990,688	2004
0.05	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
0.1	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
0.25	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	296,315,776	2010	265,076,384	2015	447,398,976	2007	237,353,056	2013	172,121,440	2006
0.4	296,810,560	2014	265,401,040	2012	458,448,064	1993	242,152,400	2006	193,216,800	2012
0.5	345,433,408	1997	275,256,448	2006	549,132,160	2014	313,595,904	1992	243,472,176	1993
0.6	364,371,072	2012	332,705,856	2016	648,437,504	1990	336,587,840	1991	249,346,832	2013
0.625	372,427,136	2009	337,801,856	1993	658,064,512	2006	391,652,864	2007	296,903,456	2001
0.667	391,877,696	2002	373,223,040	1992	691,196,416	2010	403,824,640	2001	340,859,008	1991
0.75	431,545,920	1995	414,560,096	2001	835,126,656	2011	407,662,816	1998	438,391,488	1994
0.825	533,791,808	2007	464,617,344	1991	997,140,096	1997	476,265,920	2011	506,168,544	1992
0.9	677,346,368	1992	560,042,304	1997	1,189,617,536	1996	591,178,624	2000	556,456,192	1990
0.925	679,089,408	1990	652,267,392	2000	1,246,804,864	2002	592,071,232	2010	558,553,920	1998
0.95	782,048,128	1993	737,089,792	1998	1,306,350,080	2001	878,491,392	1990	613,422,656	1995
0.99	1,015,315,072	1991	896,213,632	1996	2,550,822,656	2000	884,210,816	1996	862,921,984	1996
2016	211,663,968	0.056	332,705,856	0.574	513,482,752	0.463	404,353,120	0.685	166,443,296	0.278

Appendix B.2.2
Box-count fraction percentiles by region for time series 1990 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its 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**
0.01	0.04983	2016	0.05750	1990	0.06908	1990	0.07670	1990	0.12069	1990
0.05	0.04983	2016	0.05750	1990	0.06908	1990	0.07670	1990	0.12069	1990
0.075	0.05551	2000	0.07924	1996	0.08414	2001	0.09478	2003	0.14580	2014
0.1	0.06050	2003	0.08160	2000	0.09274	2000	0.09869	2000	0.15964	2005
0.175	0.06554	2015	0.09299	1997	0.10869	2005	0.10025	2001	0.18018	2013
0.25	0.06712	1991	0.10520	2005	0.12808	1998	0.11640	1996	0.19363	2004
0.333	0.07357	2001	0.10787	2004	0.14503	1997	0.17219	2004	0.21362	2012
0.375	0.07574	1994	0.11242	1998	0.15131	2016	0.17502	2016	0.21629	2010
0.4	0.08264	1990	0.13936	2015	0.15751	2006	0.17685	2015	0.21701	2016
0.5	0.11379	2013	0.15148	2006	0.18113	2014	0.18721	1997	0.24163	2011
0.6	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
0.75	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	0.34105	1992
0.9	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
0.95	0.17597	2010	0.24787	2013	0.29622	1993	0.36147	1993	0.46011	1999
0.99	0.21286	2011	0.32394	1995	0.34412	1995	0.37861	1995	0.49404	1993
2016	0.04983	0.00	0.10541	0.278	0.15131	0.352	0.17502	0.352	0.21701	0.389

Appendix B.2.3
Spat abundance percentiles by region for time series 1990 to 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table. The VLM is not listed due to its short time series.

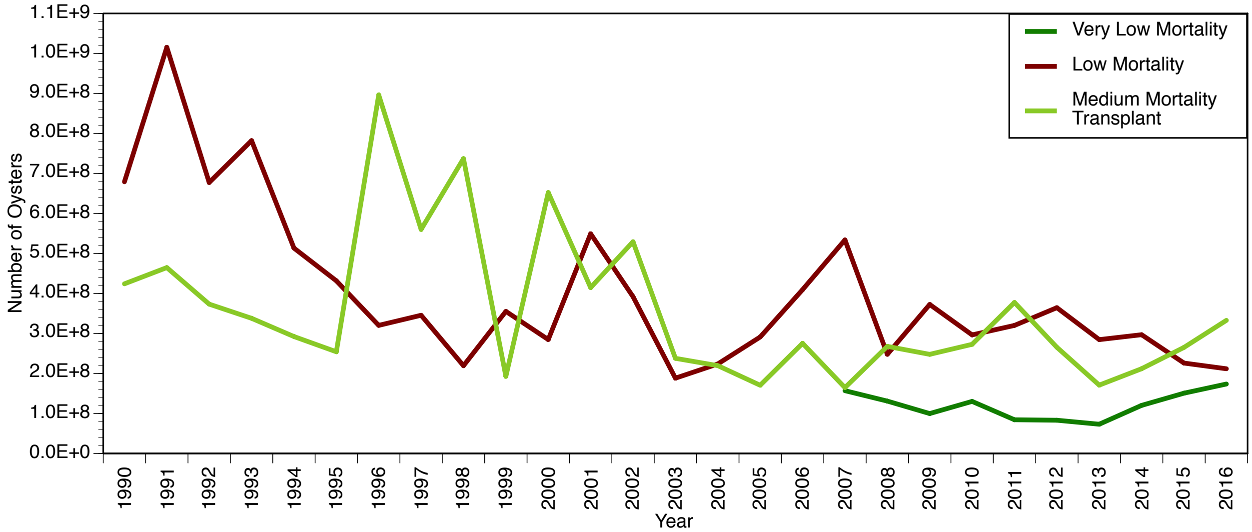
	Low Mortality		Medium Mortality Transplant		Medium Mortality Market		Shell Rock		High Mortality	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.01	14,083,137	2004	23,093,696	2014	45,299,616	2008	30,515,622	2014	81,395,376	2006
0.05	14,083,137	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
0.1	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
0.25	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	75,127,984	1996	112,689,656	1996	179,844,768	2015	121,193,680	2011	158,191,392	1993
0.4	76,045,016	2008	145,636,704	2015	262,277,056	2009	138,675,168	2013	167,951,984	2002
0.5	91,136,816	2006	185,140,928	2007	335,858,048	1990	250,140,528	2008	407,336,960	2007
0.6	115,737,616	1995	213,788,848	2012	471,906,624	1995	428,249,216	2012	416,641,536	2010
0.625	119,495,024	2015	244,443,680	2009	472,144,160	1991	436,437,920	2000	481,662,880	2011
0.667	147,088,064	2005	258,999,008	1994	483,832,640	2013	442,333,056	1997	519,787,136	2016
0.75	233,658,288	2007	281,019,104	1995	582,054,592	2002	481,982,784	1990	684,034,048	1990
0.825	262,578,944	1998	349,528,864	2010	753,542,400	2010	626,343,360	1998	996,042,752	1994
0.9	314,637,184	1990	442,342,496	1999	1,099,550,592	2007	867,099,136	2010	1,122,550,656	1991
0.925	330,993,632	2013	546,450,880	2002	1,338,809,088	2016	957,817,216	2002	1,513,959,168	2012
0.95	405,289,728	2016	1,005,056,320	2016	2,086,584,576	1999	992,921,856	1999	1,618,010,368	1997
0.99	935,990,720	1991	1,634,833,536	1998	2,913,591,808	1998	1,170,753,792	2016	1,953,821,056	1999
2016	405,289,728	0.944	1,005,056,320	0.944	1,338,809,088	0.907	1,170,753,792	1.00	519,787,136	0.648

Appendix B.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 2016. A series of 19 percentile rankings are listed with their associated values and years. The specific 2016 abundance and percentile are listed at the bottom of the table.

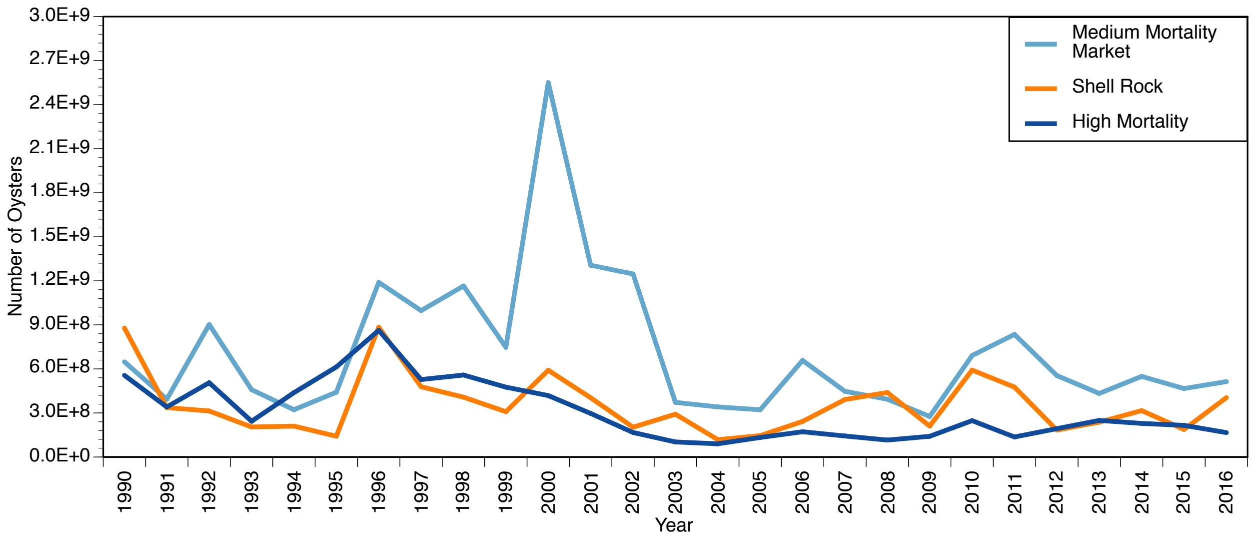
	Oyster Abundance		Box-count Mortality		Spat Abundance	
Percentile	**Value**	**Year**	**Value**	**Year**	**Value**	**Year**
0.01	73,001,808	2013	0.02900	2008	7,952,177	2011
0.05	73,001,808	2013	0.02900	2008	7,952,177	2011
0.075	73,001,808	2013	0.02900	2008	7,952,177	2011
0.1	73,001,808	2013	0.02900	2008	7,952,177	2011
0.175	82,998,968	2012	0.03175	2016	17,395,486	2009
0.25	84,173,968	2011	0.04460	2015	29,115,064	2014
0.333	84,173,968	2011	0.04460	2015	29,115,064	2014
0.375	99,657,008	2009	0.06399	2014	42,783,604	2012
0.4	99,657,008	2009	0.06399	2014	42,783,604	2012
0.5	120,130,688	2014	0.06777	2007	81,006,312	2008
0.6	130,071,712	2010	0.06886	2009	107,362,816	2007
0.625	130,071,712	2010	0.06886	2009	107,362,816	2007
0.667	130,828,856	2008	0.08479	2013	165,331,968	2013
0.75	150,632,432	2015	0.09259	2010	181,031,616	2010
0.825	150,632,432	2015	0.09259	2010	181,031,616	2010
0.9	156,869,712	2007	0.29875	2012	206,142,144	2015
0.925	156,869,712	2007	0.29875	2012	206,142,144	2015
0.95	173,511,600	2016	0.46578	2011	227,994,720	2016
0.99	173,511,600	2016	0.46578	2011	227,994,720	2016
2016	173,511,600	1.00	0.03175	0.15	227,994,720	1.00

Appendix C.1. Oyster abundance for the 1990–2016 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.

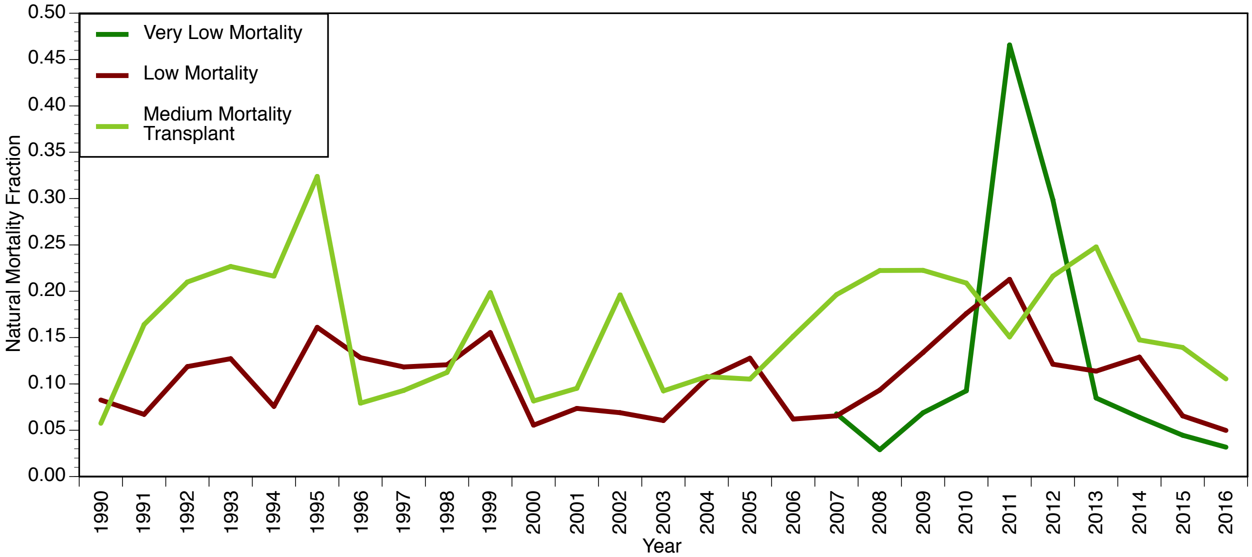


b.

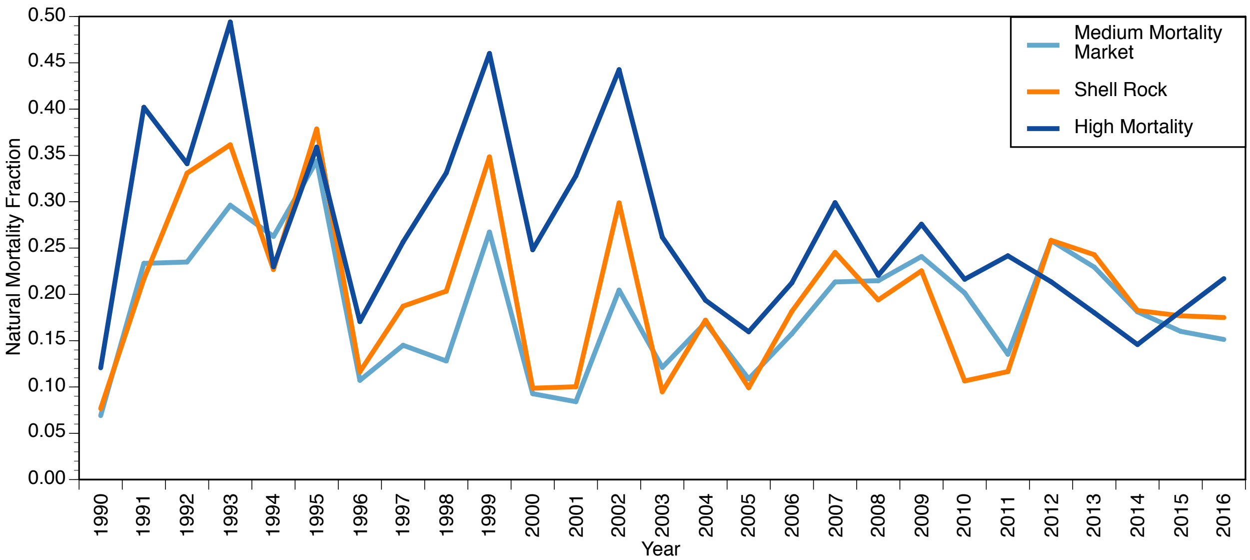


Appendix C.2. Box-count mortality rate for the 1990–2016 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

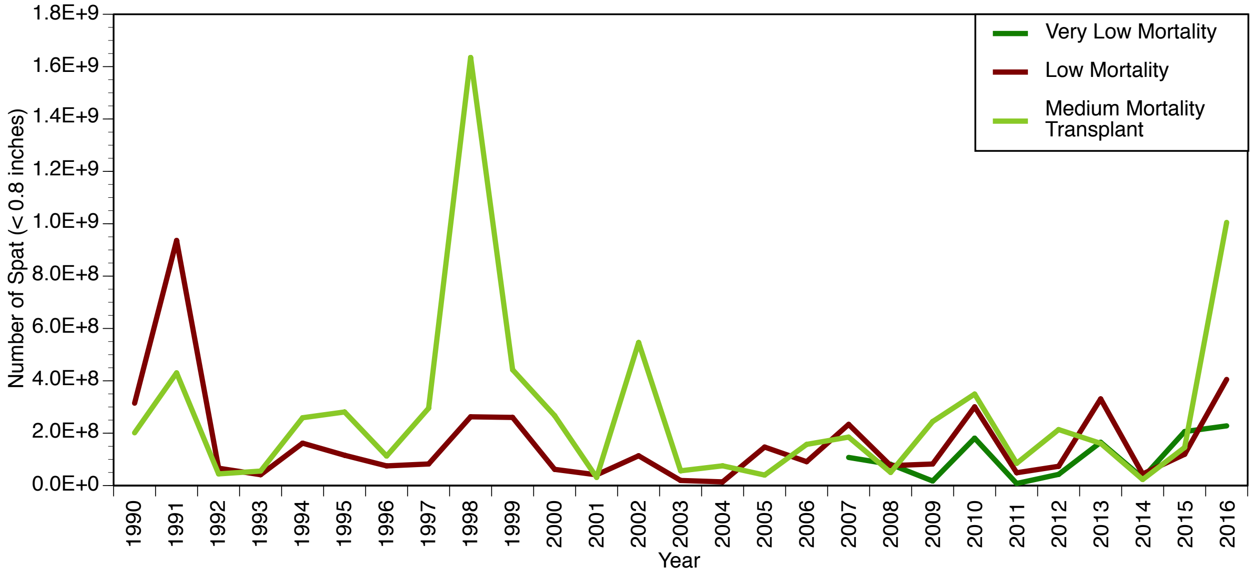


b.

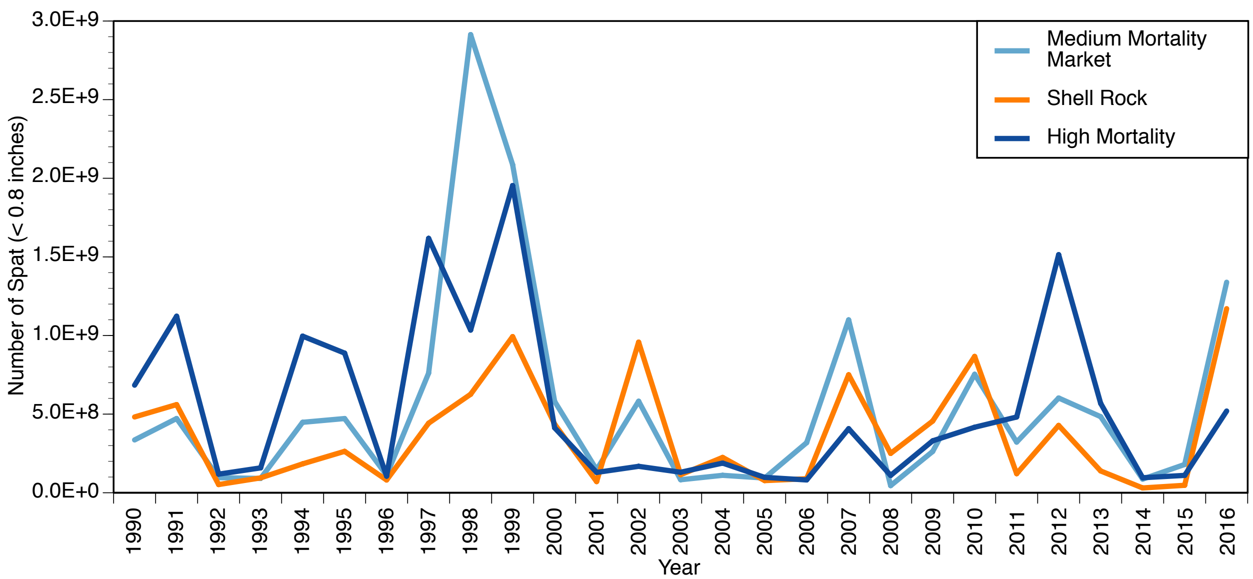


Appendix C.3. Spat abundance (< 0.8 inches) for the 1990–2016 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

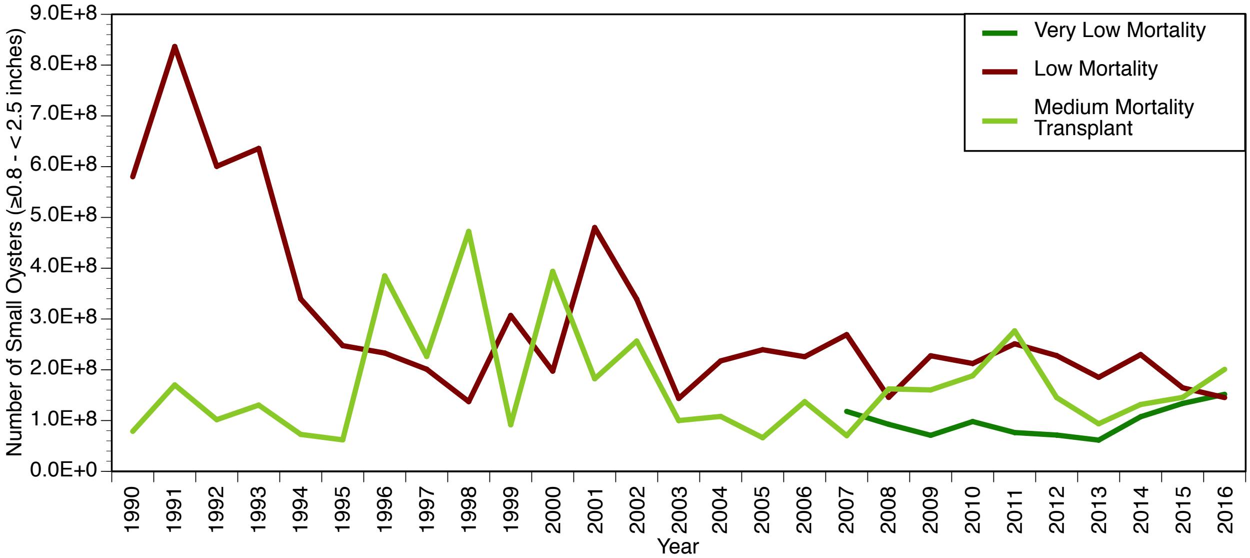


b.

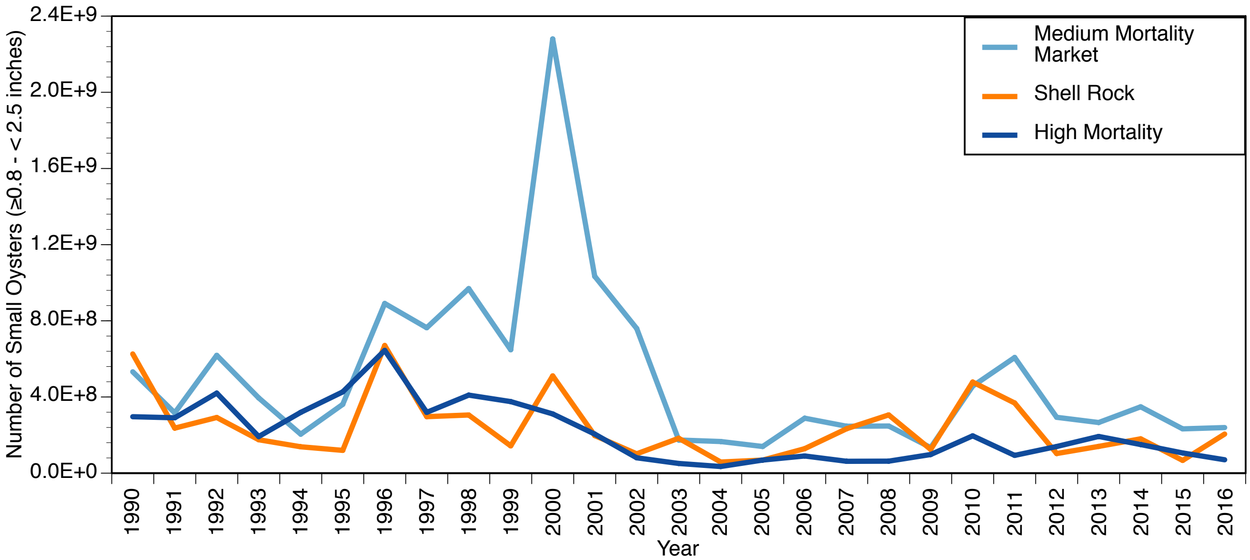


Appendix C.4. Abundance of small oysters (≥ 0.8 - < 2.5 inches) for the 1990–2016 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.

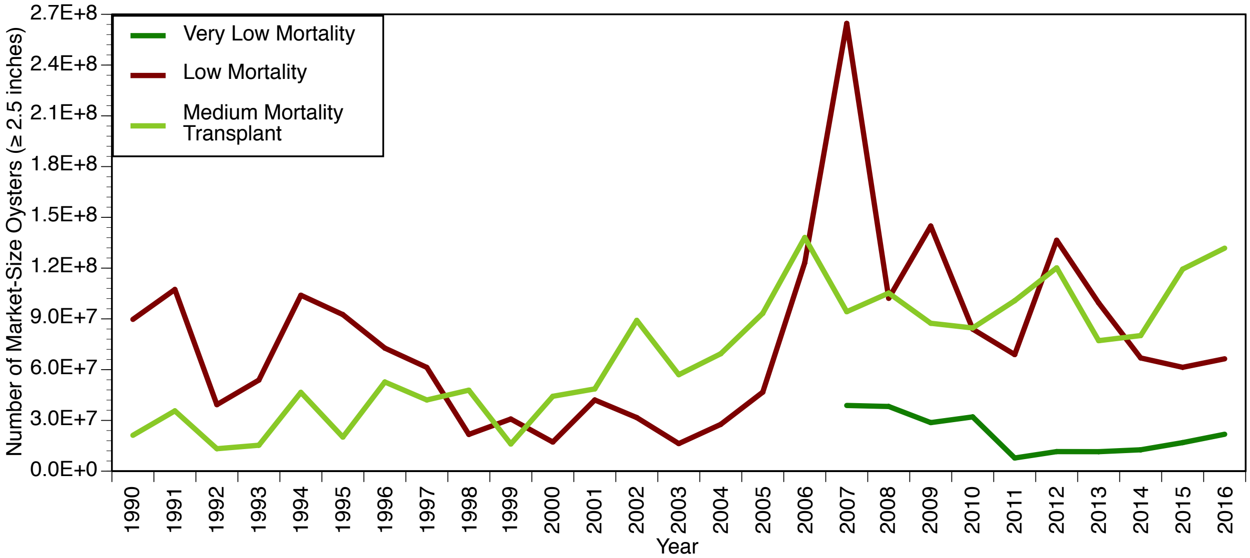


b.

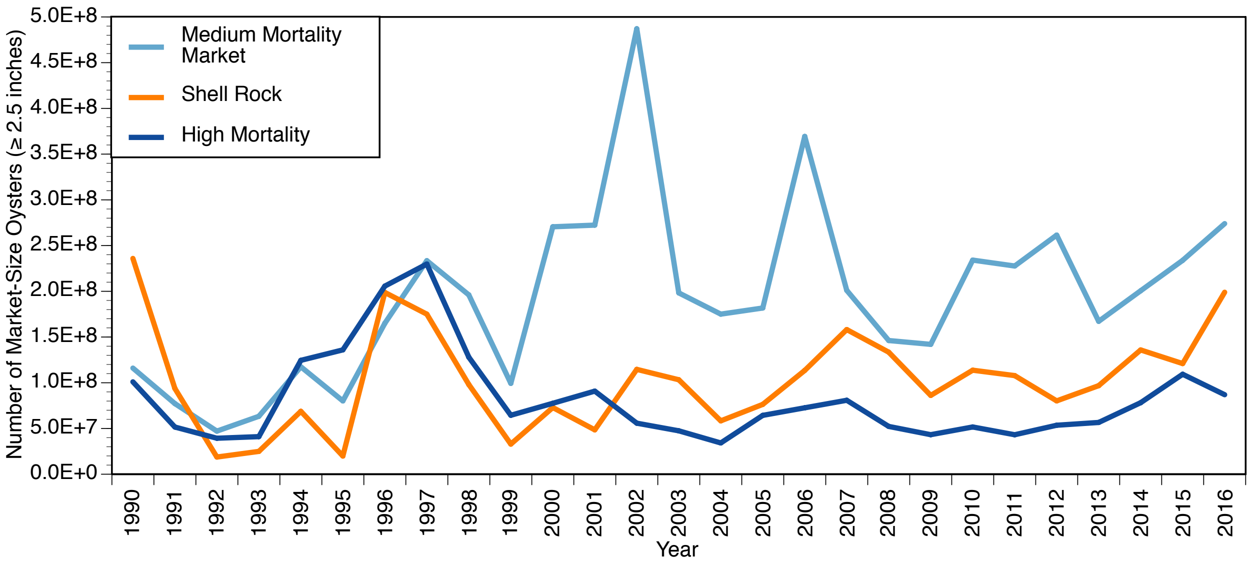


Appendix C.5. Market-size oyster abundance (≥ 2.5 inches) for the 1990–2016 survey time series in (a) transplant regions (VLM, LM, MMT) and (b) direct market regions (MMM, SR, HM). Regions are color-coded as in Figure 1.

a.



b.



Appendix D. 2016 Assessed grid sampling densities: oysters, spat, cultch.

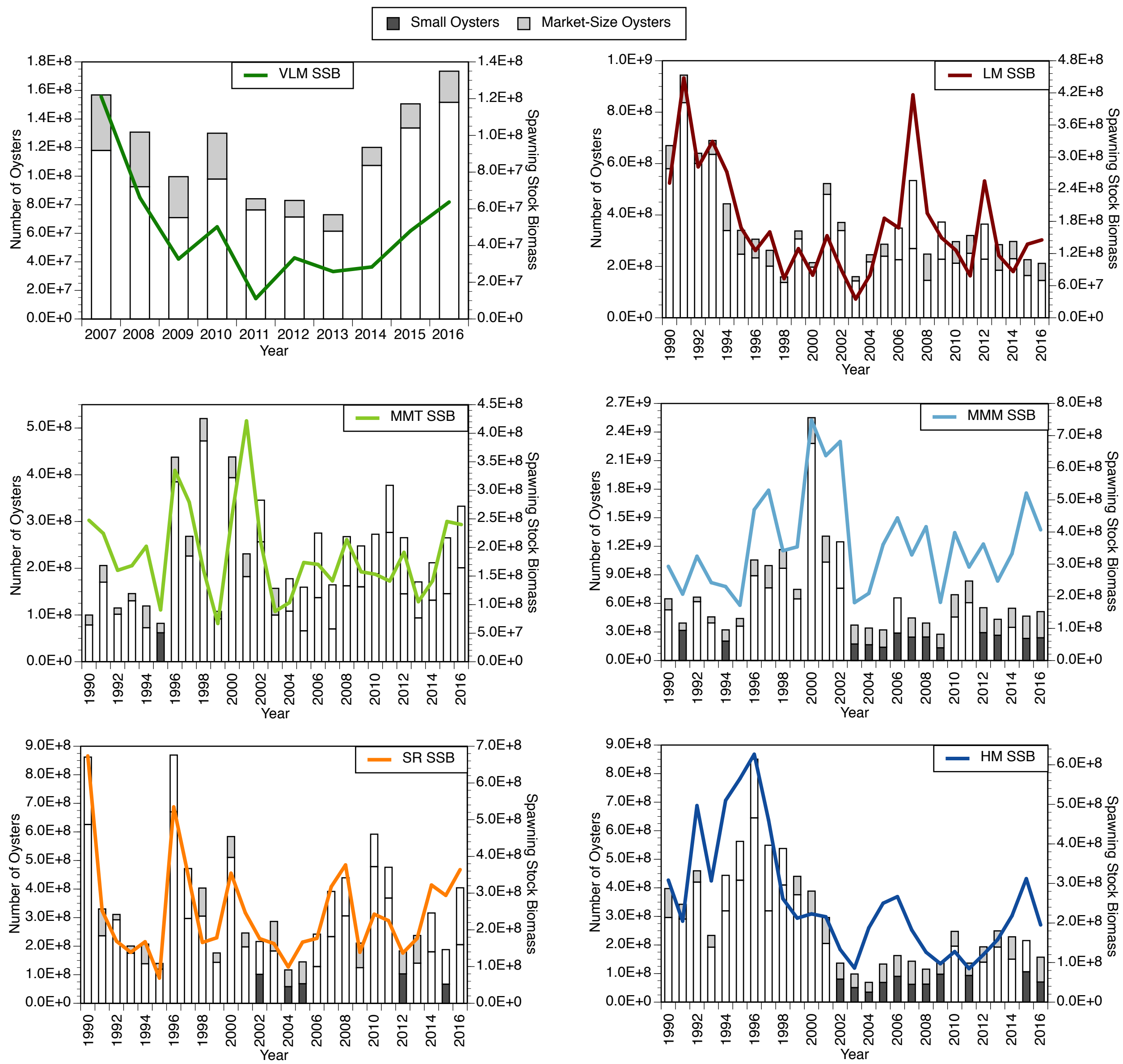
DataYr	Region	Bed	Grid	Stratum	Oys#/m^2	Spat#/m^2	Cul-qt/m^2
2016	VLM	Hope Creek	63	High	74.112	159.315	4.331
2016	VLM	Hope Creek	55	Med	65.345	156.122	6.530
2016	VLM	Hope Creek	75	High	50.692	45.884	3.590
2016	VLM	Hope Creek	85	Med	36.076	25.796	1.813
2016	VLM	Hope Creek	64	High	28.603	33.398	1.131
2016	VLM	Hope Creek	35	Med	16.266	20.498	2.001
2016	VLM	Hope Creek	45	Med	0.219	0.163	0.030
2016	VLM	Hope Creek	59	High	0	0	0
2016	VLM	Fishing Creek	16	High	24.290	18.817	3.455
2016	VLM	Fishing Creek	25	High	16.787	18.551	1.425
2016	VLM	Fishing Creek	4	Med	7.494	5.704	0.501
2016	VLM	Fishing Creek	8	Med	0.670	0.267	0.126
2016	VLM	Fishing Creek	43	Med	0.300	0.208	0.168
2016	VLM	Liston Range	24	High	90.680	56.075	3.039
2016	VLM	Liston Range	18	Med	79.541	63.025	2.769
2016	VLM	Liston Range	14	Med	74.636	91.742	2.467
2016	VLM	Liston Range	12	High	32.069	29.052	1.236
2016	VLM	Liston Range	23	Med	25.039	20.202	1.711
2016	VLM	Liston Range	30	Med	0.481	0.240	0.038
2016	LM	Round Island	26	High	35.135	64.990	1.588
2016	LM	Round Island	24	High	33.029	50.921	4.821
2016	LM	Round Island	25	Med	17.398	14.555	0.932
2016	LM	Round Island	15	Med	0.107	0.088	0.090
2016	LM	Round Island	50	Med	0.088	0.162	0.004
2016	LM	Upper Arnolds	11	High	166.866	392.355	11.248
2016	LM	Upper Arnolds	10	High	127.435	243.127	4.614
2016	LM	Upper Arnolds	18	High	110.668	259.784	12.002
2016	LM	Upper Arnolds	22	Med	64.182	155.778	10.750
2016	LM	Upper Arnolds	6	Med	24.072	55.685	2.860
2016	LM	Upper Arnolds	14	Med	15.868	10.491	2.903
2016	LM	Upper Arnolds	13	Med	0.562	0.042	0.114
2016	LM	Arnolds	18	High	92.879	306.205	19.209
2016	LM	Arnolds	15	High	77.942	56.242	9.063
2016	LM	Arnolds	19	High	53.285	85.947	20.717
2016	LM	Arnolds	42	Med	18.009	16.339	12.552
2016	LM	Arnolds	29	Med	10.394	6.030	7.842
2016	LM	Arnolds	43	Med	5.730	5.942	8.177
2016	LM	Arnolds	56	Med	0.766	0.402	0.241

DataYr	Region	Bed	Grid	Stratum	Oys#/m^2	Spat#/m^2	Cul-qt/m^2
2016	MMT	Upper Middle	48	High	92.588	85.245	18.382
2016	MMT	Upper Middle	63	Med	76.326	194.670	16.602
2016	MMT	Upper Middle	56	Med	27.443	119.046	9.577
2016	MMT	Upper Middle	49	Med	1.638	3.469	2.144
2016	MMT	Middle	28	Enh-S	132.631	424.645	15.767
2016	MMT	Middle	36	High	85.260	177.224	18.215
2016	MMT	Middle	20	High	49.747	142.214	19.242
2016	MMT	Middle	42	Med	48.948	64.220	14.895
2016	MMT	Middle	38	High	39.763	56.426	18.742
2016	MMT	Middle	10	Med	34.576	42.296	19.324
2016	MMT	Middle	22	Med	32.439	24.500	14.602
2016	MMT	Middle	49	Med	16.804	68.657	12.004
2016	MMT	Sea Breeze	15	High	198.030	1320.952	13.577
2016	MMT	Sea Breeze	22	Med	104.677	527.474	15.210
2016	MMT	Sea Breeze	36	High	82.851	229.176	10.602
2016	MMT	Sea Breeze	30	High	55.236	114.011	4.994
2016	MMT	Sea Breeze	16	Med	53.922	149.422	8.062
2016	MMT	Sea Breeze	24	Med	42.391	104.110	6.567
2016	MMT	Sea Breeze	18	Med	12.793	31.132	1.917
2016	MMM	Cohansey	56	Enh-S	164.722	427.961	22.116
2016	MMM	Cohansey	25	High	93.724	180.719	21.145
2016	MMM	Cohansey	45	Enh-T	92.068	213.757	15.749
2016	MMM	Cohansey	8	Med	89.825	252.828	11.667
2016	MMM	Cohansey	50	High	63.542	230.231	7.956
2016	MMM	Cohansey	59	High	47.574	162.240	9.504
2016	MMM	Cohansey	57	High	42.740	73.546	17.337
2016	MMM	Cohansey	23	Med	41.956	70.598	23.329
2016	MMM	Cohansey	66	Med	36.773	83.281	17.326
2016	MMM	Cohansey	20	High	29.970	116.756	5.058
2016	MMM	Cohansey	32	Med	19.693	40.188	20.894
2016	MMM	Cohansey	49	Med	4.831	19.663	6.156
2016	MMM	Ship John	33	Enh-S	121.462	613.982	24.261
2016	MMM	Ship John	22	Med	101.772	330.839	24.093
2016	MMM	Ship John	32	High	97.648	280.964	21.664
2016	MMM	Ship John	23	High	94.177	236.487	25.975
2016	MMM	Ship John	25	High	84.576	211.200	17.013
2016	MMM	Ship John	31	High	65.266	224.840	23.769
2016	MMM	Ship John	14	Med	55.596	145.361	18.415
2016	MMM	Ship John	28	Enh-S	47.360	136.006	7.248
2016	MMM	Ship John	48	High	46.917	62.435	18.874
2016	MMM	Ship John	47	Med	36.624	53.321	27.466
2016	MMM	Ship John	8	Med	28.470	38.585	21.617
2016	MMM	Ship John	42	High	27.701	124.395	7.221
2016	MMM	Ship John	36	Med	26.395	36.976	13.630

DataYr	Region	Bed	Grid	Stratum	Oys#/m^2	Spat#/m^2	Cul-qt/m^2
2016	SR	Shell Rock	15	Enh-S	185.364	463.578	9.215
2016	SR	Shell Rock	12	High	133.418	539.403	25.458
2016	SR	Shell Rock	20	High	117.449	408.956	15.020
2016	SR	Shell Rock	29	High	111.647	186.008	20.792
2016	SR	Shell Rock	4	High	96.394	298.231	30.571
2016	SR	Shell Rock	43	High	93.678	228.130	10.692
2016	SR	Shell Rock	33	Med	91.730	278.810	13.555
2016	SR	Shell Rock	7	Med	87.886	207.223	7.762
2016	SR	Shell Rock	59	Enh-T	64.169	135.754	11.764
2016	SR	Shell Rock	21	High	62.130	290.900	9.618
2016	SR	Shell Rock	31	Enh-S	56.239	186.815	6.007
2016	SR	Shell Rock	27	Med	55.686	184.138	6.671
2016	SR	Shell Rock	9	Med	48.124	158.962	9.708
2016	SR	Shell Rock	32	Med	41.538	151.507	6.044
2016	SR	Shell Rock	71	Med	41.487	76.555	20.491
2016	SR	Shell Rock	3	Med	36.007	52.072	15.151
2016	SR	Shell Rock	25	High	15.095	38.144	2.893
2016	SR	Shell Rock	52	Enh-S	12.542	3.783	18.513
2016	HM	Benny Sand	11	High	36.222	39.559	5.083
2016	HM	Benny Sand	4	High	19.418	23.700	1.546
2016	HM	Benny Sand	35	Med	15.433	4.395	3.374
2016	HM	Benny Sand	3	Med	12.050	33.427	1.492
2016	HM	Benny Sand	9	High	10.028	12.576	1.534
2016	HM	Benny Sand	1	Med	9.247	5.548	1.112
2016	HM	Benny Sand	43	Med	6.388	3.732	3.501
2016	HM	Benny Sand	16	Med	6.359	8.348	1.016
2016	HM	Benny Sand	32	Med	0.440	0.037	1.143
2016	HM	Bennies	101	High	13.660	4.623	5.828
2016	HM	Bennies	102	High	13.042	4.101	3.021
2016	HM	Bennies	44	Med	10.667	39.731	2.316
2016	HM	Bennies	56	High	9.705	14.192	6.721
2016	HM	Bennies	85	High	8.380	8.258	2.713
2016	HM	Bennies	99	Enh-S	6.264	3.089	4.981
2016	HM	Bennies	36	Med	5.721	1.052	4.697
2016	HM	Bennies	111	High	5.596	3.762	6.974
2016	HM	Bennies	110	Enh-S	3.246	0.541	10.581
2016	HM	Bennies	57	Med	2.257	0.079	3.095
2016	HM	Bennies	65	Med	2.107	0.816	6.125
2016	HM	Bennies	113	Med	1.346	0.144	3.906
2016	HM	Bennies	74	Med	1.140	0.197	1.106
2016	HM	Bennies	146	Med	1.053	0	9.952
2016	HM	Bennies	97	Med	1.008	1.375	8.412
2016	HM	Bennies	82	Med	0.679	0	7.815

DataYr	Region	Bed	Grid	Stratum	Oys#/m^2	Spat#/m^2	Cul-qt/m^2
2016	HM	NantuxentP	23	Enh-S	137.164	460.974	4.135
2016	HM	NantuxentP	15	High	58.170	216.962	4.899
2016	HM	NantuxentP	17	High	37.542	380.669	4.725
2016	HM	NantuxentP	18	High	23.711	194.982	2.393
2016	HM	NantuxentP	13	Med	17.475	50.286	4.619
2016	HM	NantuxentP	30	Med	4.664	1.140	2.831
2016	HM	NantuxentP	26	Med	1.017	4.536	1.299
2016	HM	Hog Shoal	1	High	25.417	107.581	9.602
2016	HM	Hog Shoal	6	High	15.671	76.033	7.467
2016	HM	Hog Shoal	10	Med	12.469	41.914	7.317
2016	HM	Hog Shoal	4	Med	3.756	1.670	6.242
2016	HM	Hog Shoal	9	Med	1.368	0.644	1.687
2016	HM	Strawberry	28	High	0.480	3.145	1.243
2016	HM	Strawberry	2	Med	0.333	0.111	3.870
2016	HM	Strawberry	10	High	0.283	0.283	5.903
2016	HM	Strawberry	18	Med	0.170	0	10.990
2016	HM	Strawberry	29	Med	0	0	5.437
2016	HM	Hawk's Nest	27	High	6.942	56.413	3.737
2016	HM	Hawk's Nest	14	Med	0.912	1.885	4.870
2016	HM	Hawk's Nest	4	Med	0.838	28.000	8.832
2016	HM	Hawk's Nest	28	Med	0.148	0.164	0.344
2016	HM	Hawk's Nest	5	High	0	0.936	5.835
2016	HM	New Beds	24	High	8.803	35.385	11.718
2016	HM	New Beds	3	Med	8.141	14.473	5.844
2016	HM	New Beds	26	High	6.475	2.998	7.838
2016	HM	New Beds	1	Med	5.487	6.636	9.995
2016	HM	New Beds	28	High	4.893	8.101	2.575
2016	HM	New Beds	13	Med	2.814	2.877	3.627
2016	HM	New Beds	53	High	1.351	0.579	8.367
2016	HM	New Beds	12	Med	0.362	0.181	4.328
2016	HM	New Beds	55	Med	0.135	0.810	10.272
2016	HM	Beadons	8	High	0.252	0.054	0.916
2016	HM	Beadons	3	High	0.430	0	5.115
2016	HM	Beadons	18	Med	0.030	0	0.979
2016	HM	Beadons	16	Med	0	0	1.413
2016	HM	Beadons	5	Med	0.187	0	2.009
2016	HM	Vexton	4	High	7.176	62.126	5.242
2016	HM	Vexton	3	Med	5.059	15.178	3.926
2016	HM	Vexton	9	High	2.831	8.917	11.041
2016	HM	Vexton	19	Med	2.228	10.860	0.737
2016	HM	Ledge	6	High	0.183	0.275	7.730
2016	HM	Ledge	35	Med	0.018	0.009	0.007
2016	HM	Ledge	28	Med	0	0	0.118

Appendix E. 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 > 35 mm.



Appendix F. 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

Appendix G.1 Direct market bushels landed (a) or replanted to leases (b) 1996-2006. Beds are arranged upbay to downbay. Beds without removals during these years are not listed. Replant years in gray indicate no available data on replants. Regional management was not practiced 1996-2006.

a.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Arnolds			420								
Upper Middle							300				
Middle		158						264			
Sea Breeze			3144	158	25	1535		72	931		
Cohansey			1068	344	1350	80	485	13531	9751	2723	12735
Ship John		69	42	317	2086	577	528	10481	18978	2202	7259
Shell Rock		13917	31911	24372	3883	22773	29615	14992	18655	7571	12447
Benny Sand	5369	2712	16037	6284	10739	8618	6312	15547	5574	1315	2323
Bennies	11798	28269	40515	17567	5993	9486	3958	10604	4120	2939	1326
Nantuxent			157			235	76	420	1133	5302	11969
Hog Shoal	1022	5771	7333	214	1054	14800	7527	405	435	477	1838
New Beds	42633	47368	33411	5839	5349	7580	8032	1554	224	1613	525
Strawberry			793	656		154		394	1194	543	46
Hawk's Nest			469	249	30	1238	2196	2649	1260	2954	5966
Beadons				20		110	557	600	26		
Vexton		4270	382	346	272	3015	2680	3379	439		
Egg Island		8307		88			48				
Ledge		1352	616	183	9		163				
Total	60,822	112,193	136,298	56,637	30,790	70,201	62,477	74,892	62,720	27,639	56,434

b.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Arnolds				1219			550				
Middle					1334		925				
Cohansey				343			2637	960			190
Ship John				1740				6314		489	3146
Shell Rock						256	203	346			
Benny Sand								654			
Nantuxent						325	6				355
Hog Shoal							6				
Hawk'snest								279			325
Beadons					508		264	52			
Total				3,302	1,842	581	4,661	8,605		489	4,016

Appendix G.2 Intermediate transplant bushels removed 1996-2006. Beds are arranged upbay to downbay. All sizes of oysters are removed during intermediate transplants although mechanical cullers are used. Regional management was not practiced 1996-2006.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Round Island									30392		
Upper Arnolds									3771		
Arnolds						6500		7650	31018		12350
Upper Middle								1200			
Middle		30000		14650	24210	6395		42923	17602	5000	5550
Sea Breeze											
Cohansey			36125	40200	4146	18400	9888	33019			
Ship John			33765	17350	6572	14650	22416				
Shell Rock											
Benny Sand											
Bennies											
Nantuxent					225	6250			6200		
Hog Shoal											
New Beds											
Strawberry											
Hawk's Nest			13500								
Beadons					4900				1200		
Vexton											
Egg Island											
Ledge											
Total		30,000	83,390	72,200	40,053	52,195	32,304	84,792	90,183	5,000	17,900

Appendix H.1. 2016 LM intermediate transplant program memorandum.

THE STATE UNIVERSITY OF NEW JERSEY

RUTGERS

HASKIN SHELLFISH RESEARCH LABORATORY

Department Of Marine And Coastal Sciences - New Jersey Agricultural Experiment Station

6959 Miller Avenue, Port Norris, NJ 08349-3617

REPLY TO:

Kathryn A. Ashton-Alcox

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May 6, 2016

MEMORANDUM

TO: Craig Tomlin, Russ Babb

FROM: Kathryn Alcox

Haskin Shellfish Research Laboratory

SUBJECT: Intermediate Transplant – Low Mortality Region

An intermediate transplant from Arnolds in the Low Mortality region was conducted May 2-3, 2016. The goal for this transplant, decided at the March 3, 2016 Shellfish Council meeting, was to move 1,712,353 oysters: the 0.76% (Min) exploitation rate for the Low Mortality region listed in Table 5 of the 18th SAW Executive Summary. It should be noted that this level of exploitation was well under the maximum advice from the 2016 SARC of 1.75% (Median). The SARC advised that the transplant occur on Arnolds and not Upper Arnolds or Round Island. Two boats participated in the transplant and moved:

4,800 bushels of culled material from Arnolds to Cohansey 45

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 398 to 503 with an average of 452. The percent cultch (not including boxes) in this transplant ranged from 15-40% with an average of 29%. Of the 4,800 bushels of culled material moved, 1,374 bushels were cultch and 32 were boxes.

The transplant goal of moving 1,712,353 oysters was overshot with 2,168,012 oysters moved (127% of the goal) in 4 boat-days. This number of oysters was still well under the maximum advice from the SARC of 3,956,709 oysters. Of the oysters moved, 64% were small and were not included in the quota increase calculations while 787,816 oysters were over 2.5" and were included. Using the conversion of 265 market-size oysters per bushel, this transplant can increase the quota by up to 2,972 bushels.

OYSTERS PER BU	Arnolds BOAT 1	Arnolds BOAT 2
5/2/16	492	503
5/3/16	414	398

PERCENT CULTCH	Arnolds BOAT 1	Arnolds BOAT 2
5/2/16	34%	15%
5/3/16	26%	40%

PERCENT BOXES	Arnolds BOAT 1	Arnolds BOAT 2
5/2/16	0.7%	0.2%
5/3/16	1%	0.8%

Appendix H.2. 2016 MMT intermediate transplant program memorandum.

THE STATE UNIVERSITY OF NEW JERSEY

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May 6, 2016

MEMORANDUM

TO: Craig Tomlin, Russ Babb

FROM: Kathryn Alcox

Haskin Shellfish Research Laboratory

SUBJECT: Intermediate Transplant – Medium Mortality Region

An intermediate transplant from Middle and Sea Breeze beds in the Medium Mortality Transplant region was conducted from April 25-29, 2016. The goal for this transplant, decided at the March 3, 2016 Shellfish Council meeting, was to move 3,958,253 oysters: the 1.49% (-25% of the median) exploitation rate for the Medium Mortality Transplant beds listed in Table 5 of the 18th SAW Executive Summary. The SARC advised that that no more than half the amount be taken from Middle bed. It should be noted that this level of exploitation was under the maximum advice from the 2016 SARC of 1.99% (Median). There were a total of 10,550 bushels of culled material removed from the Medium Mortality Transplant region by two boats as follows:

8,150 bushels from Middle	to Shell Rock 59
2,400 bushels from Sea Breeze	to Shell Rock 59

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 149 to 363 with an average of 283. The percent cultch (not including boxes) in this transplant ranged from 14-51% with an average of 31%. Of the 10,550 bushels of culled material moved, 3289 bushels were cultch and 215 were boxes.

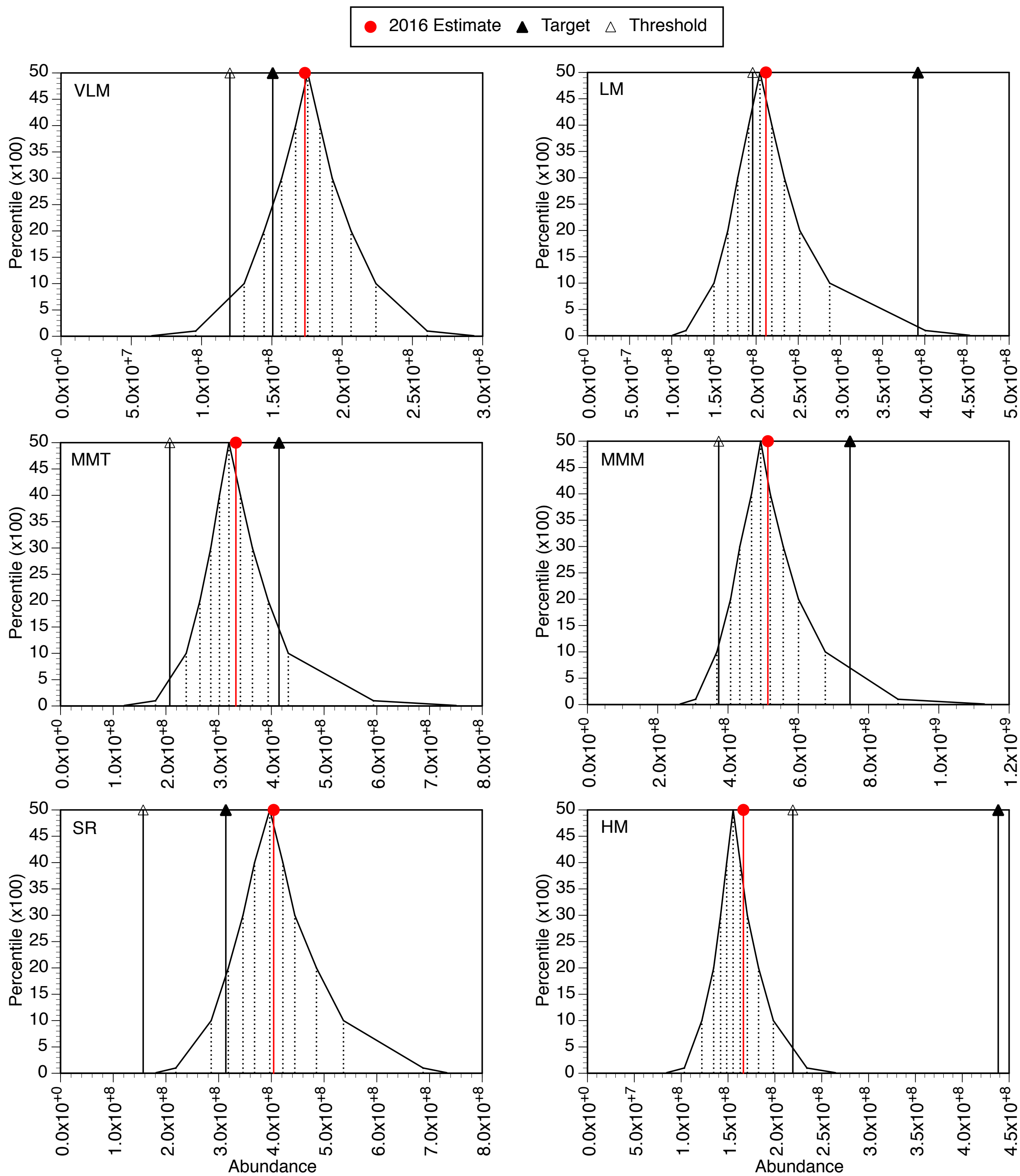
In 9 boat-days, 75% of the goal exploitation was reached with 2,979,901 oysters moved. Of the oysters moved, only 39% of the Middle oysters and 32% of the Sea Breeze oysters were small and not included in the quota increase calculations while 1,860,390 oysters were over 2.5" and were included. Using the conversion of 265 market-size oysters per bushel, this transplant can increase the quota by up to 7,021 bushels.

OYSTERS PER BU	BED	BOAT 1	BOAT 2
4/25/16	Middle	281	325
4/26/16	Middle	332	256
4/27/16	Middle	309	363
4/28/16	Middle	328	--
4/29/16	Sea Breeze	149	207

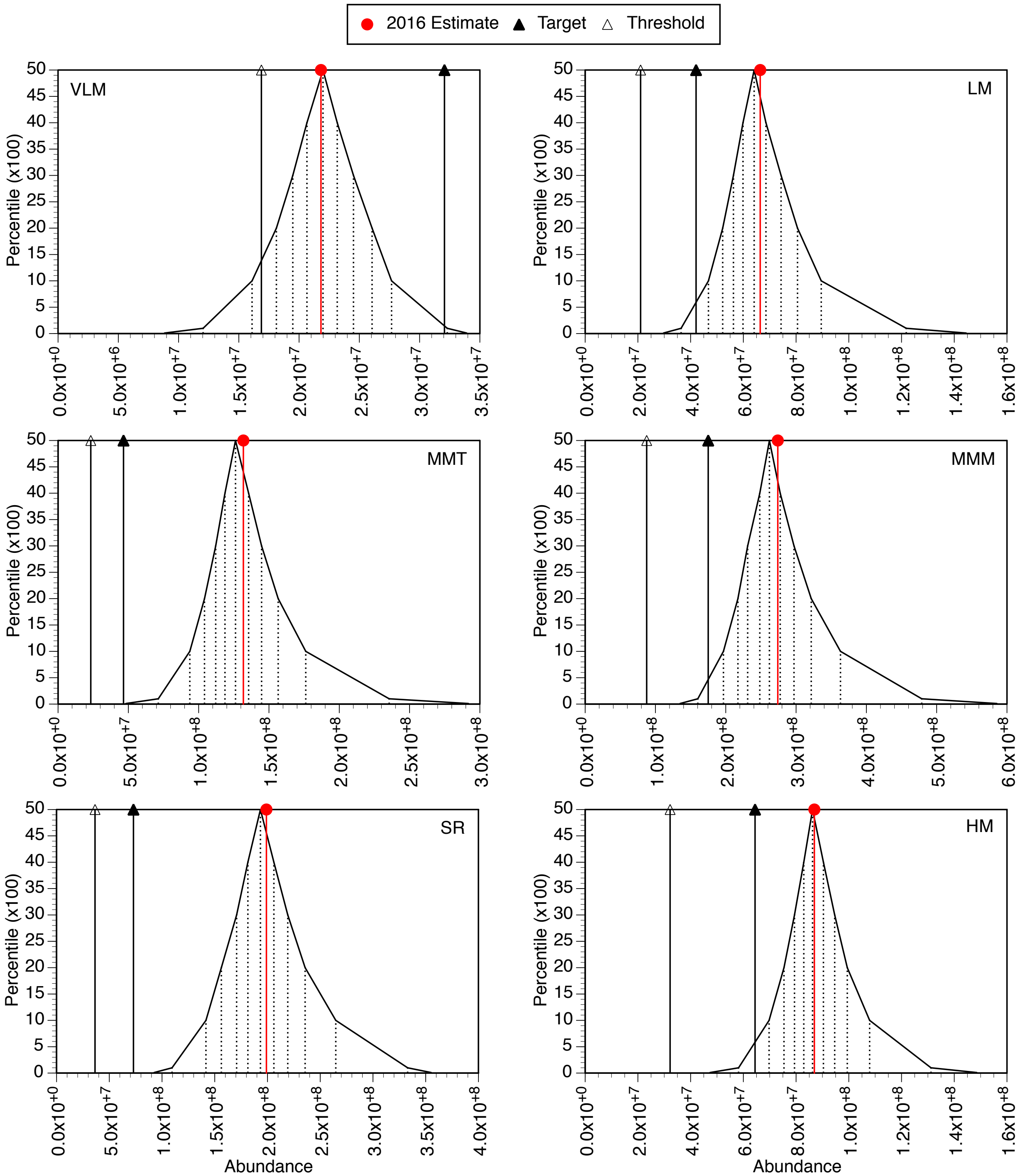
PERCENT CULTCH	BED	BOAT 1	BOAT 2
4/25/16	Middle	39%	37%
4/26/16	Middle	19%	38%
4/27/16	Middle	14%	29%
4/28/16	Middle	18%	--
4/29/16	Sea Breeze	51%	38%

PERCENT BOXES	BED	BOAT 1	BOAT 2
4/25/16	Middle	1.2%	1.0%
4/26/16	Middle	2.4%	2.4%
4/27/16	Middle	0.9%	1.9%
4/28/16	Middle	1.8%	--
4/29/16	Sea Breeze	4.3%	2.4%

Appendix I.1. 2016 regional total abundance estimates within confidence percentiles for the 2016 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 percentile, respectively (see VLM Targets and Thresholds in this report).



Appendix I.2. 2016 regional market-size abundance estimates within confidence percentiles for the 2016 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 percentile, respectively (see VLM Targets and Thresholds in this report).



Appendix J. Time Series used in the NJ Delaware Bay Oyster Stock Assessment

SURVEYS

Longterm	1953→ present
'Dermo Era'	1990→ present
Small boat/dredge	1953 - 1988
Commercial boat/dredge (orig. strata)	1989 – 1998
Commercial boat/dredge (orig. strata, quantified)	1999→ present
Initial Stratification Updates (grids over entire resource+new stratification scheme)	2005 – 2008
VLM region included	2007→ present

OTHER PROGRAMS

Resurvey (restratify 1-3 beds annually)	2009→ present
Dermo monitoring	1990→ present
Port Sampling	2004→ present

HARVEST

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

REFERENCE POINTS

Biological (Targets = median)	
All Sizes of Oysters	1989-2005
Market Sizes	1990-2005
VLM Target = 75th perc.	2007-2016
Exploitation Rate (median)	1996-2006
Revised Exploitation Rate (median)	2007-2015