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

Stock Assessment Workshop
New Jersey Delaware Bay Oyster Beds
(15th SAW)

February 11-12, 2013

Report

Presenters
David Bushek, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory

Stock Assessment Review Committee
Patrick Banks, Louisiana Department of Wildlife and Fisheries
Michael Celestino, New Jersey Department of Environmental Protection
Stephen Fegley, University of North Carolina
Juliana Harding, Coastal Carolina University
Jason Hearon, New Jersey Department of Environmental Protection
Barney Hollinger, Delaware Bay Section of the Shell Fisheries Council
Olaf Jensen, Rutgers University
William Riggin, Delaware Bay Oyster Industry
Richard Wong, Delaware Department of Natural Resources

Editors
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory
Eric Powell, Gulf Coast Research Laboratory

Distribution List
Scott Bailey, Chair, Delaware Bay Section of the Shell Fisheries Council
Russell Babb, Acting Chief, NJDEP Bureau of Shellfisheries
Stock Assessment Review Committee
Oyster Industry Science Steering Committee
Web archive: http://hsrl.rutgers.edu

Executive Summary

The natural oyster beds of the New Jersey portion of Delaware Bay have been surveyed annually since 1953 to develop management advice to sustain the fishery. Since 1989, Dermo disease has been a major factor limiting oyster abundance and harvests by more than doubling the annual rate of natural mortality. Management of the resource shifted from a 'seed fishery' controlled by limiting the time the beds were open for harvest to a quota-based system after 1996. Beginning in 1998, a formal Stock Assessment Workshop (SAW) has been convened each February to review the status of the New Jersey Delaware Bay oyster stock and develop management advice. Recommendations include: (1) exploitation levels for oyster harvest, (2) shell plant and intermediate transplant programs, (3) monitoring programs, and (4) other projects for improved management. This report of the 15th SAW, peer-reviewed by the Stock Assessment Review Committee (SARC), covers the status of the stock for the year 2012. The SARC concluded that the Delaware Bay oyster stock was not overfished and that overfishing did not occur during 2012, nor has either condition occurred since the inception of the port-sampling program in 2004. Both the absence of overfishing and the absence of indications of a stock being overfished are characteristic of and requirements for a sustainable stock per the definitions provided in the Magnuson-Stevens Fishery Conservation and Management Act. Details that led the SARC to this conclusion are provided within the report along with their findings. A summary of the stock status and recommendations is provided below.

The 23 natural oyster beds are grouped into six regions that follow the estuarine salinity gradient of the Delaware Bay (Figure 1). From upbay to downbay, the oysters experience increasingly higher salinity, growth rates, predation mortality, disease mortality, and generally higher recruitment. The region names reflect the oyster mortality rates and management practices for the beds within them. In 2011, extreme river flows produced low salinity conditions throughout much of the year culminating in floods during late August and September that resulted in freshwater induced mortality on the upper beds, a reduction in Dermo disease across the beds, and a reduction in condition of oysters entering winter. By contrast in 2012, reduced freshwater inflow returned salinity to average levels and enabled Dermo to spread back up the bay. Superstorm Sandy resulted in a precautionary public health closure of the fishery from October 29 to November 12 and damaged some public and private land-based infrastructure but did not impact the oyster resource itself. Following the closure, the fishery season was extended to the end of November. Except for the closure, beds were harvested continuously from April 9 to November 30. The number of single-dredge boats dropped from 19 to 17 as a result of continued license consolidation, but the number of dual-dredge boats stayed at 21 for a total of 38 active boats in the fishery during 2012. The total harvest of 74,887 bushels was above the 1996-2012 direct market period average, marking the sixth consecutive year with a harvest at or above the 17-year mean. Ten of 14 beds open to the Direct Market harvest were fished with 84% of the catch coming from just four beds: Cohansey and Ship John in the medium mortality market region (37%), Shell Rock (29%) and Nantuxent in the High Mortality region (18%). In April 2012, the Intermediate Transplant program moved 7,650 bushels of culled material from Arnolds bed in the Low Mortality region and 21,825 bushels of culled material from the Medium Mortality Transplant region to Nantuxent and Bennies Sand in the High Mortality region. The Very Low Mortality region was closed in 2012 as a result of the 2011 flood and subsequent oyster mortalities. This activity increased the High Mortality region quota by 52%.

Figure 59 summarizes the status of the oyster stock relative to the recent Dermo era beginning in 1989. Green indicates good or improving status whereas orange indicate poor or declining status. Note that the impact of the 2011 flood should be taken into consideration when assessing the changes between 2011 and 2012. As often occurs, there is a mixture of positive and negative indicators that may be distributed by region or by metric. Most apparent is the orange section across the middle of the figure encompassing a decline in the abundance and fraction of small oysters (< 2.5"), an increase or high level of Dermo disease and mortality rates, and a decrease in abundance positions relative to targets. The orange is balanced by several areas of green indicating good or improving conditions for spawning stock biomass (SSB), market abundance and recruitment. Exceptions to these generalities include the Very Low Mortality and Shell Rock regions. Abundance in the Very Low Mortality region has not recovered from the 2011 flood, although Dermo remains absent from this region and SSB and market-sized abundance have increased. Shell Rock experienced good recruitment and a strong replacement ratio of spat to adult (2.09), but abundance and biomass were down while Dermo and mortality were up.

Overall, abundance was above the recent five-year median in only three of the six regions (Low Mortality, Medium Mortality Market and High Mortality) and increased significantly (by >15%) since 2011 only in the High Mortality region. Nevertheless, abundance remained between target and threshold values everywhere except on the High Mortality beds where abundance has been down for several years. SSB on the other hand, was above or only slightly below target levels in four of the six regions and was near threshold on the Very Low Mortality and High Mortality beds. Market abundance was strong throughout, falling below the target only on the Very Low Mortality beds.

Fishery exploitation rates since 1996 have been low; <2% of total abundance per year, <5% of market abundance per year, and <4% of SSB per year excluding the Very Low Mortality region (Figures 48-50). By far, most oyster mortality (80-90%) is a result of natural causes like Dermo disease, not direct fishing removals (Figure 60). The Direct Market harvest for 2012 was near average since the initiation of this fishery in 1996 (Figure 43). The Very Low Mortality region was closed for transplanting in 2012 due to mortality from the freshwater flood of 2011. Intermediate transplants from the Low Mortality region accounted for only 1.2% of its total oysters (1.3% of its market-sized oysters). Transplants taken from the Medium Mortality Transplant region accounted for only 3% of total oysters there (4% of market-sized oysters) (Figure 51). Only 1.2% of all the Medium Mortality Market region's oysters (3.4% of market-sized) were harvested. The drop in abundance on Shell Rock in 2012 was due in part to fewer small oysters and more Dermo mortality. As a result, the direct market fishery took 5% of all oysters and 15% of market-sized oysters from Shell Rock under the 2012 regional quota allocation. The receipt of 29,475 bushels of intermediate transplant by the High Mortality region resulted in a net gain in total oysters after the removal of 6% of the market-sized oysters by the Direct Market fishery.

The fact that not one region fell above its abundance target indicates that actions to enhance abundance continue to be important. In contrast, SSB and market abundance continue to be in good shape relative to targets. The continued need for improving recruitment emphasizes the need to minimize shell loss and reinforces the importance of maintaining marketable abundance near or above target levels in each region to sustain the fishery. The most critical areas of concern in 2012 were the Very Low Mortality beds and Shell Rock. The Very Low Mortality beds have not recovered from the 2011 mortality event and Shell Rock sustained high mortalities in 2012. Given the value of Shell Rock as a core region for the population, attention to improving this bed is warranted.

Based on these observations as discussed in the full report, the SARC makes the following recommendations for 2013 for harvest and intermediate transplant (Tables 22 and 23). General management and science recommendations are listed separately.

- Oyster harvest should continue to be set using the abundance-based exploitation reference points established in 2006. Some effort, however, should be put forth to evaluate the relevance of the fixed time frame of 1989/90 to 2006 for establishing these reference points.
- The Very Low Mortality region should remain closed to allow recover from the 2011 mortality.
- The Low Mortality region could be used for transplanting at the 60th percentile of exploitation and the transplant targeted to Shell Rock. The SARC cautioned, however, against using the same bed in consecutive years. Arnolds was used in 2012.
- The Medium Mortality Transplant Region could be exploited at the 60th percentile and the oysters used to supplement the High Mortality region. Exploitation, however, must be split between Upper Middle, Middle, and Sea Breeze such that no more than 50% of the allocation is taken from Middle. If necessary, a suction dredge could be used to complete the harvest from Sea Breeze.
- The Medium Mortality Market region could continue to support exploitation at the 100th percentile given the relatively low exploitation of these beds for Direct Market harvest.
- Shell Rock requires considerable caution with direct market exploitation similar to that taken in 2009. That is, an exploitation rate at the 25th percentile should be invoked unless significant efforts are put forth to add abundance through intermediate transplanting as recommended above. Shell Rock has responded well to such management actions and the fact that market abundance remains above the target should enable an increase in exploitation to the 40th percentile but not higher, once a transplant been completed.
- The High Mortality Region exploitation rate should be no higher than the 40th percentile unless an intermediate transplant occurs to offset any increase in fishing harvest.
- No increases in quota should occur before transplants are completed and efforts should be made to complete a significant portion of the intermediate transplant program before harvesting is allowed on the region.

Management Recommendations

Total abundance is below the abundance target in all bay regions and near or below the threshold in four of six. A shell-planting program aimed at enhancing abundance by enhancing recruitment must continue with the aim of planting not less than 250,000 bushels annually.

The port-sampling program is required for SSB estimates of landings, improved abundance-to-bushel conversions, estimation of the shell budget, and evaluation of exploitation rates, as well as any development of size- or age-based models incorporating mortality. It must be continued to maintain these essential stock assessment estimates.

The ten-year resurvey program must be continued to permit re-evaluation of grid allocation to strata to take into account changes in oyster distribution on beds as a consequence of natural population dynamics and population enhancement programs.

Because Dermo is the primary factor controlling mortality, the Dermo monitoring program should continue. The collection of ancillary data on mortality, size-frequency distribution, and growth rate should be continued as part of this monthly monitoring program.

The heavy set on Beadons in 2010 resulted in a transplant of seed to Bennies. This was the second attempt at such an effort and results are equivocal at best. The SARC recommends abandoning these efforts in the future as they appear to be an inefficient use of resources.

A program moving spatted shell upbay should be implemented to return cultch and increase recruitment to beds where shell was removed during intermediate transplant operations. The SARC notes that the Athos shell planting on Middle is a useful precedent. Considerable concern is expressed regarding the Very Low Mortality beds. These beds may be an ephemeral resource and their exploitation should be limited to periods of high abundance so that the shell resource is not mined away eliminating their ability to function during periods of population expansion. Experimental efforts should be explored to consider ways to assist rapid recovery of these beds so that they can be used more routinely as a resource for the intermediate transplant program. The experimental plant of spatted shell to Hope Creek is an example.

The SARC recommended continuing to direct shell plants towards the Medium Mortality Market region in general and to Shell Rock in particular for 2013.

The SARC recommends developing a management strategy that moves away from percentiles of exploitation to utilizing exploitation rates directly. To assist with annual evaluations, the SARC requests that annual review of its prior recommendations for intermediate transplant and direct market harvest be presented at each SAW. Additional suggestions for new strategies included using the median +/- 25%, a box plot with the hinges set at a desired level, or 40% and 60% of the range bounded by the 0 and 100 percentiles.

The Gandy's Beach Oyster Restoration and Enhancement Area's (GBOREA) potential contribution to total oysters stock was considered. The SARC recommends using those data which are valuable to understanding population dynamics and avoiding the temptation to add Project PORTS oyster abundance estimates to the stock assessment.

If the large but late set in 2012 survives, its success should be evaluated relative to the recent sets in 2007 and 2010. If it persists, plans should be considered regarding the possibility of altering management to spread the fishery across any areas of increased abundance.

A long-range plan for reef management taking into account sea level rise, salinity shifts and other factors related to climate change, should be developed.

Science Recommendations

The SARC identified three top scientific priorities and several secondary priorities but refrained from any further prioritization. The importance of continuing the Dermo monitoring program to help advance understanding of this important disease was, however, singled out as an important objective.

Top Priorities

Re-evaluation of the stock-performance reference points should be undertaken consistent with the change in population dynamics observed between the decades of the 1990s and 2000s. The SARC recommends an evaluation be developed to examine whether or not the time period of 1990 to 2005 should continue to be used as a baseline for establishing stock performance targets and thresholds.

Further dredge calibration information is urgently needed to determine if a temporal change in dredge efficiency is occurring or has occurred. If possible, this study should use experiments occurring simultaneously with the survey to directly test the tow-based regressions. In addition, the relationship between dredge efficiency and oyster density should be investigated. The importance of the variables used in the dredge calibration multiple regression model should be examined to determine if any one variable is responsible for the tendency for tow-based dredge efficiencies to be estimated higher than experimental observations on the downbay beds.

Spat growth rates upbay of Shell Rock are needed to reconfigure the recruitment index and retire the 20-mm rule. The growth rates that are present from the 2005-2012 shell plants should be examined to develop an improved spat cut-off size for the high-mortality beds, Shell Rock, and the medium-mortality market beds. The same analysis should be used to update the growth indices.

Additional Science Recommendations

Further evaluation of the rate of box disarticulation throughout the regions, particularly in the Low and Very Low Mortality regions is needed.

Use of the GBOREA information on growth rates up through market sizes may prove valuable as the growth data on larger size classes within the fishery are difficult to obtain. Overset precludes the usefulness of early mortality data but data after the first year may prove useful.

A shell resource model should be developed to evaluate the importance of sources of clean shell (e.g., live animals, boxes) in influencing recruitment. This should include evaluation of the ratios of spat to cultch and spat to oyster, as well as the influence of dredging on recruitment.

The relationship between condition and other population and disease variables should be investigated and contrasted among different management areas.

A shell budget reference point should be developed. An external reference would be ideal and one may become available as a new model is developed by Powell and others.

Data on fecundity and spawning potential are needed for oysters on the Very Low Mortality region.

Table of Contents

Status of Oyster Stock

Historical Overview

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly beginning in 1953 in response to low oyster stocks. Circa-1989, Dermo became prevalent in the bay. In 1990, the survey protocol was updated to include the measurement of oysters permitting calculation of biomass as well as abundance. Throughout this report, except where noted, present-day conditions are compared to either the entire 1953-2012 survey time series and/or the 1989-2012 portion encompassing the period of time during which Dermo has been a primary source of mortality in the bay. Status of stock evaluations and management advice refer exclusively to this Dermo-controlled 1989-2012 time period. Two exceptions exist to the dependency on the 1989-2012 time series: all size-dependent indices begin in 1990 as already mentioned and evaluation of fishery exploitation by abundance focuses on the 1997-2012 time period during which the fishery has been conducted under a direct-marketing system. Prior to 1997, the natural oyster beds of New Jersey were used as a transplant source to private leases for a few weeks each year called 'Bay Season'. The direct-market program began in 1996 but the first full year of fishing under this program occurred in 1997. Throughout the report, the 23 natural oyster beds are grouped into six regions designated on the basis of their placement within the estuarine salinity gradient of the Delaware Bay (Figure 1). From upbay to downbay, the oysters experience increasingly higher salinity, growth rates, predation mortality, disease mortality, and generally higher recruitment. The region names reflect the oyster mortality rates and management practices for the beds within them.

Survey Design

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 2) have been surveyed yearly in the fall and/or winter since 1953. Since 1989, this period has been concentrated into a few days in a period from late October to mid-November and has been conducted using a stratified random sampling method. Each bed is divided into 0.2-min latitude x 0.2-min longitude grids, each having an area of approximately 25 acres. Three strata are designated: the bed core (high quality), the bed proper (medium quality), and the bed margin (low quality; not shown in Figure 2). Each grid on a bed is assigned to a stratum relative to the other grids on that bed. A subset of grids is randomly selected each year from the high-quality and medium-quality strata on each bed for the survey.

Each survey sample represents a composite 37-quart bushel[1] obtained from three $^1/_3$-bushel subsamples taken from each of three dredge tows within the target grid. The on-bottom distance for each one-minute dredge tow is measured using GPS. A one-minute tow covers about 100-125 m^2 and usually prevents the dredge from filling completely thus avoiding the 'bulldozer' effect. The current survey instrument is a standard 1.27-m commercial oyster dredge on a typical large Delaware Bay dredge boat, the *F/V Howard W. Sockwell,* towed from either port or starboard. The full haul volume is recorded. Each bushel sample is processed in the laboratory to quantify the following: volume of live oysters, boxes, cultch (black and brown), and debris; the number of spat[2], older oysters, and boxes per

---

[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) rather than 'by eye'.

composite bushel; the size of live oysters, spat, and boxes from the composite bushel; condition index; and the intensity of Dermo and MSX infections. Until 1999, the principal data used in management were based on the proportion of live oysters, excluding spat, in a composite 37-quart bushel[1], although spat set also entered the decision-making process. Beginning in 1998, dredge tow lengths were measured and recorded every 5 seconds by GPS navigation during the survey and, in 2000, 2003, 2005, and 2006 separate dredge calibration studies were undertaken to determine dredge efficiency. These data, integrated into the regular sampling, permit quantitative estimation of the number of oysters per square meter beginning in 1998. In 2005, at the behest of the 6th SAW, the entire survey time series from 1953 to the present-day was retrospectively quantitated. Also in 2004, a port-sampling program began to obtain fishery-dependent information on the size and number of oysters marketed, permitting the determination of exploitation based on spawning stock biomass as well as abundance. In 2006, sufficient information was available from the port-sampling program to reconstruct the 1996-2003 exploitation rates.

Through 2004, most beds were sampled yearly; however a selection of minor beds was sampled every other year. Subsequently, 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. Between 2005 and 2008, the primary oyster beds were resurveyed resulting in a change in strata definition and survey design from that used historically (HSRL, 2006). In the new system, the strata for resurveyed beds were based on ordering grids within beds by oyster abundance. Grids with the lowest densities that cumulatively contain 2% of the stock were designated low quality. The remaining grids were input into a Monte Carlo model in which grids were subsampled repeatedly without replacement under a given set of rules and the mean abundance estimated from the subsample was compared to the mean abundance obtained from the average of the other grids. Analysis of many simulations suggested that a random survey based on two strata would suffice (HSRL, 2006). These further two strata were defined by assigning grids ordered by increasing abundance that cumulatively accounted for the middle 48% of the stock to a `medium-quality' stratum and grids that cumulatively accounted for the upper 50% of the stock to a `high-quality' stratum. This has since become the standard resurvey analysis. The Monte Carlo model is also used to determine how many grids per stratum it is necessary to sample for a statistically adequate stock assessment survey on each newly resurveyed bed. Only two beds remain completely unsurveyed: Ledge and Egg Island. Full surveys of three upbay beds in early 2008 (data applicable to 2007) permitted their addition to the annual stock survey: Hope Creek, Liston Range, and Fishing Creek (Figures 1 and 2). The surveys were done based on bottom sediment mapping results conducted by the State of Delaware Department of Natural Resources and Environmental Control and provided by B. Wilson (2007, personal communication). No earlier data are present in the survey database; therefore, reconstruction of the 1953-2006 time series is not possible for these three beds. In the following data presentation, some analyses will exclude these beds as a consequence.

To minimize survey bias from changes in grid quality over time, a 10-year rotating resurvey schedule began in 2009 (Table 1). For the current assessment, the strata for Shell Rock and Sea Breeze have been updated based on a spring 2012 resurvey of all grids on these beds. Evaluation of oyster density on each grid was consistent with other resurveys in finding that a large number of low quality

---

1 Used for management decisions from the 1950s until the Direct Market era, the '40% Rule' was the first reference point in the time series. Beds were only open to harvest if survey sample bushels contained an average volume of $\geq$ 40% oyster.

grids could be deleted from the fall stock assessment survey to focus on the grids that support 98% of the stock on each bed (Figure 3). A comparison of the Shell Rock and Sea Breeze grid systems before and after the 2012 spring resurvey (Figure 4) shows that the distribution of high-quality and medium-quality grids changed such that those on Sea Breeze are now concentrated on the lower and inshore parts of the bed while those on Shell Rock are now on the upper portion of the bed. On Shell Rock, 9 of 93 grids increased in quality while 14 decreased (Table 2). On Sea Breeze, 8 of 48 grids increased in quality while 9 decreased. Overall, Shell Rock now has 5 fewer grids in the high+medium quality strata while Sea Breeze has 2 fewer. It is important to remember that grid quality is relative so that dropping to lower strata or increasing to higher does not necessarily imply any overall improvement or degradation. The strata designations are based on oyster abundance and grids that drop to a lower strata may do so because abundance overall has increased making the cutoff points for the grid quality designations higher.

The Fall 2012 survey was constructed by randomly choosing a designated number of grids from each medium-quality and high-quality stratum on each bed. Sampling was conducted October 18-19 and November 12-13 using the oyster dredge boat *F/V Howard W. Sockwell* with Lemmy Robbins as captain. The sampling intensity is shown in Table 3 and the specific grids sampled are shown in Figure 2. Total sampling effort in 2012 was 160 grids: 2 more than in 2010 and 2011. The transplant stratum consisted of 11 selectively sampled grids that included 8 grids used for 2010-2012 shell plants, 1 grid that received an intermediate transplant of spat in 2011, and 2 grids that received intermediate transplants of oyster in 2012. The transplant stratum is not included in the general estimates for the bed but is reserved for analyses involving shellplant recruitment enhancement and transplant quota enhancement. The intermediate transplant grids revert back to their original stratum after one year and the shellplant grids revert back after 3 years.

Evaluation of Survey Bias

All quantitative and post-1997 time series estimates are corrected for dredge efficiency using the dredge efficiency measurements made in 2000 and 2003 (Table 4)[1]. The measurements made in 2005, and 2006 were not comprehensive of the bay and did not differ significantly from the earlier measurements. The differential in dredge efficiency between the upper and lower beds was retained in all cases. No additional information on dredge efficiency was available for this assessment.

A retrospective analysis of dredge efficiency from data collected during the 2012 survey using the equations of Powell et al. (2007), estimated a value of q for total oysters for the upbay region as 12.42 which is in the range of previous estimates (Figure 5). The estimated upbay q values exceed the range of measured values from 2000 and 2003 (Table 4) in 8 of the 10 years for which they are calculated (Figure 5). The value of q for the downbay region from this retrospective is 9.33, also in the range of previous estimated q-values in contrast to a range of 2.83 to 4.87 from direct measurements. The estimated q-values for the downbay region have been higher than the measured values of 2002, 2003, 2005, and 2006 in all years from 2005 onward (Figure 5). Since 2008, all estimated values are greater than the measured values. If the estimated values imply a decrease in dredge efficiency (higher q, lower e) that is real, current oyster abundance estimates are biased low because the survey calculations use only the measured dredge efficiency q values.

---

[1] The catchability coefficient q as used herein is defined as the inverse of dredge efficiency e: $q = 1/e$.

Analytical Approach

Swept areas have been measured for each dredge tow since 1998, permitting estimation of oyster density directly. Bay region point-estimates are obtained by averaging the grid per-m^2 samples per stratum, expanding these averages for each bed according to the strata area for that bed, and then summing over strata and then beds in the bed regions as assigned in Table 3 and Figure 1. The three upbay regions; Very Low Mortality, Low Mortality, and Medium Mortality Transplant are managed as intermediate transplant regions with transplant of oysters going to the three downbay regions managed as direct market regions; Medium Mortality Market, Shell Rock, and High Mortality. Shell Rock which otherwise would qualify as a medium-mortality bed, is retained separate from the medium-mortality market region due to its consistent high productivity. In previous reports, all stock status data for the medium-mortality beds were compiled with Sea Breeze assigned to the market, rather than the transplant, group. However, management advice was provided in SAW-12 based on the assumption that Sea Breeze would be used as a transplant, rather than a direct-market, bed. As of SAW-14 (2011 data), all time series for the medium-mortality region have been reconstituted such that Sea Breeze is now included in the transplant, rather than the market category.

Throughout this report, the quantitative point estimates of abundance sum the high-quality, medium-quality, and transplant strata only. Low-quality areas are excluded. The exclusion of the low-quality grids underestimates abundance by approximately 2%. In 2005, the 1953-1997 survey time series was retrospectively quantitated. These estimates were obtained by using bed-specific cultch density determined empirically from 1998-2004. This quantification assumes that cultch density is relatively stable over time. 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 be biased 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. However, recent improvements in the understanding of shell dynamics on Delaware Bay oyster beds show that shell is the most stable component of the survey sample and support the assumption that a 2-fold error is unlikely to be exceeded. Accordingly, the quantitative time-series estimates are considered the best estimates for the 1953-1997 time period. Details of the retrospective quantification are provided by Powell et al. (2008).

Quantitative box-count mortality rates were obtained by calculating the number of boxes m^{-2} and summing over strata and beds within bay regions. Analytical details are in Powell et al.2008.

Throughout this report, `oyster' refers to all oysters $\geq$ 20 mm (0.8”). Oysters < 20 mm are referred to as `spat'. The 20 mm cutoff was chosen as the average size of a spat through the estuarine gradient of beds in the Delaware Bay. At the top of the gradient, e.g. Low and Very Low Mortality regions, the < 20 mm size class may include oysters that are older than their first season while in the High Mortality region, oysters in their first season may be > 35 mm (1.4”). Those $\geq$ 35 mm are considered to be adult oysters. Calculations of spawning stock biomass (SSB) are based on the $\geq$ 35 mm size class and were derived using bed-specific and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size oysters are divided into individuals $\geq$ 76 mm (3”) and individuals $\geq$ 63.5 mm (2.5”), but < 76 mm (3”). These two size categories are based on: 1) a knife-edge selection of oysters for market by the fishery that has been routinely observed since monitoring began in 2005 in which nearly all harvested oysters are $\geq$ 63.5 mm (2.5") and 2) the historical use of the 76-mm (3") boundary to define a market oyster.

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 2000-2006 efficiency estimates. Confidence-level values are obtained by sorting the simulated surveys on the number of all oysters and also on oysters $\geq$ 2.5". Dredge efficiency is less certain for oysters < 2.5" so this approach includes uncertainty that cannot be evaluated. However, smaller oysters make up much of the population and sorting on the larger size class sometimes fails to order the surveys in hierarchical position by total abundance.

Although the majority of the survey indices and analyses in the annual stock assessment survey are quantitative, basic volumetric data is summarized by grid and by bed in Table 5 with values from the previous two years for comparison. None of this data is corrected for dredge efficiency or normalized to swept area. The 'Percent Oyster' columns originate from the historical 40% Rule for the 'bay season' fishery (see Historical Overview and previous footnote). Tukeys tables (Tables 6-9) compare the volumetric oyster and spat abundance data for the current year to the period when Dermo has been a persistent source of mortality (1990-2012). Quantitative survey indices are the focus of most of the analyses reported hereafter.

Abundance

Oyster abundance in 2012 was at the 19th percentile of the 1953-2012 time series and the 27th percentile post-1988 excluding the Very Low Mortality Region, so abundance is well below historical values (Table 10). Quantitative estimates indicate that oyster abundance exclusive of the Very Low Mortality beds fell from the 2011 nine-year high abundance of 1.70 billion to 1.44 billion (Figures 6 and 7). The 2011 to 2012 decrease including the Very Low Mortality region was 1.96 to 1.69 billion oysters, a decrease of 14%. On a volumetric basis, 2012 overall oyster abundance was lower than that of the past two years but not significantly (Table 6). The 2012 average of 192 oysters per sample bushel was just below the 2010 average of 195 oysters and above the 1990-2012 mean of 170 oysters per bushel although not significantly.

The Very Low Mortality region suffered high levels of freshwater mortality in 2011 as a result of Hurricane Irene and Tropical Storm Lee resulting in a 35% decrease in abundance in that year (Figures 6 and 7). Abundance in 2012 continued to decline by another 1.4% that may be attributable to the lingering effects of poor oyster condition. Insufficient data are available to generate percentile comparisons to earlier years nor can long-term trends be evaluated at this time. This region contributed 19% of the total oyster abundance prior to 2011, 13% in 2011, and 15% in 2012 (Figure 8).

The Low Mortality region did not experience abundance declines following the freshwater flood of 2011 despite persistent low salinities in that region. Abundance on the Low Mortality region rose for the second year in a row in 2012 (Figures 6 and 7) although it remained consistent with most years since 1989 at a level that is low relative to the historical record; the 21st percentile for the 1953-2012 time series but higher post-1988 at the 40th percentile (Table 10). This region contributed 30% of the stock in 2012 (25% including the Very Low Mortality region) (Figures 8 and 9). The 322 oysters per sample bushel in 2012 was significantly lower than only four years in the early 1990s within the 1990-2012 time series (Table 7).

The combined Medium Mortality region including Shell Rock had an average of 257 oysters per sample bushel in 2012 deviating significantly from only two other years in the 1990-2012 time series; one higher and one lower (Table 8). It was not significantly different from the overall average of 243 oysters bu^{-1} or the higher 2011 value of 314 oyster bu^{-1}. Excluding the Very Low Mortality region, 50% of the oysters were on Medium Mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 9). This fraction is lower than that of 2011 primarily due to the increased proportion of oysters in the Low and High Mortality regions in 2012. Not including the Very Low Mortality region, the 50% fractional abundance of oysters on the Medium Mortality beds is well over the median value of about 39% in the 1953-2012 time series, continuing the pattern that began in 1996 (Figure 10). Abundance in both Medium Mortality regions decreased from 2011, particularly on the Market beds (Cohansey and Ship John) where abundance was down by 34% from approximately 738 million to 490 million in 2012 (Figures 6 and 7). Even so, of the Market and Transplant regions, 68% of the stock was on the Market portion in 2012. Abundance on the Medium Mortality beds ranked at the 23^{rd} percentile (Transplant) and 34^{th} percentile (Market) of the 60-yr time series, and at the 23^{rd} percentile (Transplant) and 40^{th} percentile (Market) for the post-1988 era (Table 10): all of which are distinctly lower than the 2011 percentiles.

Even more so than in the other Medium Mortality regions, oyster abundance on Shell Rock fell precipitously in 2012 to less than half of what it was in 2011 which was already lower than the 2010 abundance by a third (Figures 6 and 7). Abundance in 2012 is the lowest value since 2005. Shell Rock contributed 5% of the stock in 2012 (4% including the Very Low Mortality beds) down from 13% in 2011 due both to the decline in numbers on Shell Rock and the increase in oysters on the High and Low mortality regions (Figures 8 and 9). The low abundance on Shell Rock ranked at the 25^{th} and 15^{th} percentiles for the 60- and 24-year time series, respectively (Table 10).

Abundance was up 45% on the High Mortality beds from 2011, consistent with the previous 10 years, but lower than most years prior to 2002 (Figures 6 and 7). It increased in rank to the 23^{rd} and 40^{th} percentiles for the 60- and 24-year time series respectively (Table 10). The High Mortality region contributed 15% to the total stock (13% including the Very Low Mortality beds) in 2012 (Figures 8 and 9). The number of oysters per sample bushel was 119, above the longterm average of 106 and differing significantly only from the 1996 value (Table 9).

Spawning Stock Biomass (SSB)

Although still low in comparison to the 1990-2012 time series, spawning stock biomass in 2012 was at its highest level since 2008 (Figure 11). SSB in 2012 excluding the Very Low Mortality region was at the 28^{th} percentile of the 1990-2012 time series (Table 10). It increased everywhere except Shell Rock, with greatest increases in the two Low Mortality regions (Figure 11). Although the Very Low Mortality region has experienced large abundance losses since 2011, its SSB nearly tripled in 2012 rising from the 2011 low of 33,673 kg to 100,753 kg in 2012. The Low Mortality region more than tripled its SSB moving from 86,243 kg in 2011 to 286,260 kg in 2012. The Medium Mortality Transplant and High Mortality region had SSB increases of about 1.5x in 2012. The Medium Mortality Market region increase was not as dramatic and the SSB on Shell Rock decreased somewhat.

Percentiles for the Low Mortality and Medium Mortality Transplant and Market regions were the 67th, 54th, and 46th, respectively while the SSB percentiles for both Shell Rock and the high mortality region were the 15th (Table 10). The increases in SSB are partly attributable to increases in condition (see below).

SSB is highest on the Medium Mortality Market region in most years. In 2012, these beds contributed 33% of the SSB (30% including the Very Low Mortality region), similar to the years since 1997 (Figure 12). The Low Mortality beds contributed an additional 30% to the total SSB (27% including the Very Low Mortality region), the highest fraction since 2007. Shell Rock's contribution fell by half to 5% and the High Mortality region's SSB fraction dropped slightly.

Size Frequency

The abundance of oysters < 2.5" in the 1990-2012 time series, exclusive of the Very Low Mortality beds, was high in comparison to the upper size classes until the decade of the 2000s when persistent low recruitment resulted in a decline of smaller oysters (Figure 13). The proportion of the < 2.5" size class was high in the early 1990s, then declined somewhat but had been on the rise since 2007 (Figure 14). The abundance of this size class declined in 2012 (Figure 13) consistent with a decline in 2011 recruitment. The fraction of smaller oysters dropped from 75% of the overall population in 2011 to 60% in 2012 excluding the Very Low Mortality region. Including that region, the proportions were 77% in 2011 down to 64% in 2012. Conversely, the largest increase in the upper two size fractions in 2012 was in the 2.5-3" category indicating growth of the small 2011 oysters. The number of oysters > 3" also increased.

Recruitment on the High Mortality region increased from 2008 through 2011 providing higher abundance of the < 2.5" size class in this region between 2009 and 2012 than in the earlier 2000s although it is low compared to the earlier half of the time series (Figure 15). In contrast, numbers of <2.5" oysters decreased substantially in 2012 on Shell Rock and the Medium Mortality regions and to a lesser degree in the two Low Mortality regions. This is consistent with decreases in recruitment for all of these regions in 2011. Numbers of oysters in the two larger size classes increased in all cases aside from the 2.5-3" oysters on Shell Rock commensurate with the corresponding increases in SSB (Figure 11). Increased numbers of larger oysters were greatest in the Low Mortality region doubling in each of these size classes.

In 2012, the fraction of < 2.5" oysters was lower on all bed regions except the High Mortality region where it increased somewhat from 2011 (Figure 16). Percentages ranged from a high of 86% small oysters in the Very Low Mortality region to a low of 53% in the Medium Mortality Market beds. There were corresponding increases in the upper size classes throughout aside from the High Mortality region where the 2.5-3" percentage remained the same and the >3" percentage decreased. Changes were most marked in Shell Rock. The three central bed regions have the highest proportions of large oysters (> 3"); 18% for Medium Mortality Transplant, 21% for Medium Mortality Market and 20% for Shell Rock. The 2.5-3" size class percentage was greater than 24% from the Low Mortality region down to Shell Rock with percentages of less than 15% at the two salinity extremes, the Very Low Mortality region and the High Mortality region. Marketable oysters did not contribute the majority of the stock on any bed region, continuing the pattern of the last few years.

The overall number of market size (≥ 2.5”) oysters increased in 2012 (Figure 17) and contributed about 40% of the total stock excluding the Very Low Mortality region (Figure 14) and 36% including it, similar to 2009. The 2012 value for market-sized oysters was at the 77th abundance percentile in the 1990-2012 time series excluding the Very Low Mortality beds (Table 10). Market-sized oyster abundance increased in every region except Shell Rock where it is at the lowest level since 2005 falling at the 46th percentile of the 1990-2012 time series (Figure 18, Table 10). The number of market-sized oysters doubled in the Low Mortality region and increased substantially in the Medium Mortality Transplant region with abundances at the 82nd and 96th percentiles respectively. Market size abundance percentiles for the medium mortality market and the high mortality regions were 0.773 and 0.500 respectively.

Of all market-sized oysters ≥ 2.5", 40.6% were ≥ 3" in size (Figure 19). The proportion of small markets 2.5-3") relative to larger markets remained relatively stable from 2003 through this year but was much higher earlier in the 1990-2012 time series. The 2.5-3” size class of marketable oysters made up the majority of all marketable oysters in every region in 2012 (Figures 15, 16). This fraction was 51% on the high growth High Mortality region moving up the estuary to 54% on Shell Rock, 56% on Medium Mortality Market, 60% on Medium Mortality Transplant, 70% on Low Mortality, and finally, 84% on the slow growth Very Low Mortality region. This pattern has been fairly consistent for the last four years.

Condition and Growth

Condition index was back up from its all-time low of 0.0067 in the 1990-2011 time series to 0.0105 in 2012, an index similar to many previous years (Figure 20). The rise in condition is mirrored in the SSB; both are the highest values since 2008 (Figures 11 and 20). As was true with SSB, the largest increases in condition in 2012 were in the upbay regions, particularly both Low Mortality regions where condition approximately doubled from 2011 (Figure 21). In 2011, these areas experienced severe freshwater mortalities and poor condition after Hurricane Irene and Tropical Storm Lee. In the other four regions, condition rose and was in a range typical for other years in the time series.

No new growth rate data were available for this assessment. Growth rates were estimated from von-Bertalanffy relationships provided by Kraeuter et al. (2007). The von-Bertalanffy parameters (L_∞, k, and t_o respectively) are: for the Low Mortality beds (data from Arnolds), 110 mm, 0.175 yr^{-1}, 0.2 yr; for the Medium Mortality beds (data from Middle and Cohansey), 125 mm, 0.23 yr^{-1}, 0.2 yr; for Shell Rock, 125 mm, 0.25 yr^{-1}, 0.2 yr; and for the High Mortality beds (data from New Beds) 140 mm, 0.23 yr^{-1}, 0.2 yr. Minimum sizes reaching 3” in one season were found to be: high-mortality beds 2.34”, Shell Rock, 2.48”; medium-mortality beds, 2.51”; and low-mortality beds, 2.76” (Table 11).

Growth data are not available for the 1990s. Trends in size frequency suggest that growth rate may have been slower in the 1990s and faster recently (see Figures 15 and 16). In SAW-13, a population dynamics model, DyPoGEn (Powell et al., 2011) was used to evaluate a possible shift in the von-Bertalanffy growth curve. The Kraeuter et al. (2007) data come from 2000 and so may be representative of the transition time. Simulations with DyPoGEn suggested that the change in length frequency between the mid-1990s and mid-2000s would require a change of 35-45% in the von-Bertalanffy *k* parameter, assuming L_∞ remains unchanged. A similar effect comes from dropping the L_∞ about 25%.

Sex Ratio

A survey was conducted on each of the primary beds in June 2008 to determine the sex ratio of oysters as a function of size. The percent female increased with size and age as anticipated. Relationships between size and percent female by bed were applied to the size-frequency data from the Fall 2009 survey data by SAW-12. The population at that time was estimated in all bed regions to be about 40% female. Market-size oysters were estimated to be about 60- 65% female. Data from the 2012 monthly monitoring program (Bushek, 2013) have a similar pattern, although limited in sample size and spatial coverage (n = 20 oysters per 6 beds sampled along a bay-wide transect May-August). Oysters appear to have spawned between June and July in 2012 and were undergoing another round of gametogenesis in August which may account for the late set observed during the stock survey in October and November 2012.

Disease

Information on Dermo and MSX disease prevalence and infection intensity can be found in the accompanying report from the seasonal monitoring program (Bushek, 2013). Briefly, the flood-induced suppression of Dermo disease in 2011 continued on beds above Arnolds but Dermo returned elsewhere and was particularly high in the monthly monitoring program during the seasonal cycle peak in August and September on Cohansey and Shell Rock. Typically, Dermo prevalence and intensity increase in a down bay direction but this has not been the case in recent years. Explanations for this phenomenon include an abundance of older and larger oysters on Shell Rock and the Medium Mortality beds relative to beds further downbay, the development of resistance downbay, and/or faster elimination of susceptible oysters downbay. Concern is warranted over the concentration of Dermo on Shell Rock and the Medium Mortality beds.

Natural Mortality

Box-count mortality overall was 21.3% in 2012, up from 17.9% in 2011, excluding the Very Low Mortality beds (Figure 22). Although higher in 2012, this level of natural mortality is above the median but not unusual since Dermo entered the Delaware Bay around 1989. The percentile for box-count mortality in the 24-year time series is 0.604 (Table 10). For the long-term 60-yr time series, box-count mortality is at the 78th percentile.

The upbay low mortality to downbay high mortality gradient that has been evident throughout the Dermo era since 1989 was disrupted in 2011 with the freshwater floods that reversed the usual trend in all regions aside from the High Mortality region that experienced its usual high mortality (Figure 23). In 2012, the gradient pattern has reasserted itself somewhat although poor oyster condition at the end of 2011, a remnant of the flood, led to some additional mortality in the Very Low Mortality region leaving the overall rate high in that region. The monthly monitoring program (Bushek, 2013) described an unusually high box frequency of 75% at Hope Creek in the Very Low Mortality region in March 2012. These levels persisted through June after which they began to decline at a nearly linear rate of 5-10% per month to a value of 30% in November 2012 that corresponds with the fall stock assessment survey box count fraction of 0.30 (Figure 23). Mortality was also high in the Medium Mortality Market and Shell

Rock regions in 2012 each of which had box count fractions of 0.26. This too, is in agreement with the monthly monitoring data that show uncharacteristically high levels of new box mortality for Cohansey bed in the Medium Mortality Market region and for Shell Rock in comparison to beds in other regions by the end of 2012. The elevated mortality on Cohansey and Shell Rock is undoubtedly a result of uncharacteristically high Dermo levels on those beds. The year-end high box count on Hope Creek and by extension, the other Very Low Mortality Beds, is clearly a remnant of the 2011 flood mortality as very few new boxes were detected during the year on Hope Creek (Bushek, 2013).

Box count mortality was at the 81st percentile for the Medium Mortality Market region and the 77th percentile for Shell Rock in the 24-year time series and at the 86th and 78th percentiles respectively for the 60-year time series (Table 10). Mortality was at a four-year low fraction on the Low Mortality beds (0.12), presumably due to the decrease in Dermo after the 2011 flood (Figure 23 and Bushek, 2013). The percentile ranking for box-count mortality was still above the median for both the 24 and 60-year time series on the Low Mortality region at the 65th and 68th percentiles respectively (Table 10). The High Mortality region experienced a relatively low mortality rate in 2012 with a box count fraction of 0.21 (Figure 23) and fell at the 23rd percentile for the 24-year time series and the 58th for the 60-year time series (Table 10).

Mortality can also be calculated based on biomass. Excluding the Very Low Mortality region, overall biomass-based mortality was below 16% for much of the 2000s but has been over 22% since 2008. The value for 2012 is 22% and is at the 62nd percentile of the time series (Table 10). Including the Very Low Mortality beds raises overall biomass mortality to 24% in 2012, a value similar to that of 2010 in the short time series (2007-2011).

Mortalities based on biomass in Delaware Bay are generally higher than those based on numbers (Figure 24) for two possible reasons: because most mortality is the result of Dermo disease that affects larger oysters and/or because large boxes are more likely to remain intact. In the case of the Very Low Mortality area in 2011 and 2012, this differential resulted from the freshwater flood and its lingering effects. In 2012 this generality did not hold true in the three central bed regions (Medium Mortality Transplant, Medium Mortality Market, and Shell Rock) where numbers-based mortality was higher than biomass mortality indicating the death of proportionately more of the smaller oysters. This is borne out in Figures 15 and 16 where the numbers and proportions of < 2.5" oysters drop in relation to larger oysters. Comparison of box-count mortality percentiles versus biomass mortality percentiles further illustrates this disparity (Table 10). The percentile rankings for box-count mortality on the two Medium Mortality regions are the same, .812 while that of Shell Rock is .771. The corresponding biomass mortality percentile rankings are lower at .539, .692, and .769 for the Medium Mortality Transplant, the Medium Mortality Market, and Shell Rock regions, respectively.

Because the annual stock assessment survey takes place in the fall of each year and the data are used as the basis to determine fishing and transplant quotas for a season that begins in April there has been an unanswered question about the extent of overwinter mortality on the oyster stock. Powell and Ashton-Alcox (submitted 2012) used data from grids that were sampled both in the fall stock assessment survey and the following spring resurveys from 2005-2010 to investigate whether or not numbers of boxes increased or oysters decreased significantly between fall and spring. Figure 25 shows the relationship of oysters and boxes from spring survey to the previous fall survey. The data for both boxes and live oysters fall evenly about a line with slope=1 indicating essentially no difference between fall and spring surveys that would indicate a consistent overwinter mortality[1]. Monthly sampling data (Bushek, 2013), however, indicates a small increase in box counts as waters warm although variability is high from year to year making it difficult to detect above background mortality levels. Powell and Ashton-Alcox (submitted 2012) concluded that any overwinter mortality would have to be extreme in order to overwhelm the effect from the decline in dredge efficiency that occurs between fall and spring as the bottom compacts without biological or fishing activity during the winter months.

Recruitment and Recruitment Enhancement

Recruits (spat) are defined as oysters ≤ 20.00 mm in size for the purposes of these analyses. The estuarine gradient over the natural oyster beds in Delaware Bay corresponds to a gradient in growth rates in the various regions with faster growth rates in the downbay regions and slower rates upbay. A 20 mm oyster in the Low Mortality region may be past its first season; a 40 mm oyster in the High Mortality region may be in its first season. The average size of a first season oyster on the Delaware Bay beds is approximately 20 mm. Recruitment does not directly influence most status-of-the-stock metrics as abundance and biomass metrics are based on all oysters > 20 mm. All primary recruitment indices and indices based on spat-per-adult should be taken provisionally until further evaluation of recruitment index bias can be undertaken.

Spat set in 2012 was the highest since 1999 (Figures 26 and 27) and at the 63rd percentile for the 60-yr time series and the 81st percentile since 1989 (Table 10). The set was substantially higher in all regions, particularly in the High Mortality region where growth rates are highest. The 2012 recruitment percentiles increase from the upbay to downbay regions for both the 60-yr and 24-yr time series excluding the Very Low Mortality region (Table 10). On a per-bushel basis, the average baywide 2012 spat abundance at 258 bu^{-1} was significantly higher than all but four other years since 1990 and the second highest average in the time series (Table 6). Only 1991 had a higher value. The 23-year average is 97 spat bu^{-1}. Although the 2012 value of 36 spat bu^{-1} was below the long-term 74 spat bu^{-1} average on the Low Mortality beds (Table 7), it was higher than average on the Medium Mortality beds at 190 spat bu^{-1} compared to a mean of 105 spat bu^{-1} (Table 8) and the 2012 spat per bushel value was the highest value in the time series on the High Mortality beds (394 spat bu^{-1}) compared to a mean of 113 over the last 23 years (Table 9).

Figure 28 a and b shows the footprint of the natural oyster beds with the 2012 survey sites filled in with colors depicting the range of spat per sample bushel values. The color range covers 0 to 2,530 spat bu^{-1}. Of the 160 samples in the survey, only three had 0 spat bu^{-1} and nine had >1,000 spat bu^{-1}. The recruitment pattern is upbay to downbay with the darker colors (more spat bu^{-1}) more prevalent on the downbay regions. This trend is consistent with previous observations in Delaware Bay. A coupled larval-hydrodynamic model using ROMS (Regional Ocean Modeling System) and the Dekshenieks et al. (1993 and 1996) larval model indicates that this pattern results from a general downbay drift of oyster larvae combined with spatial variation in larval success rates showing that larvae produced upbay have

[1] Wilcoxon Signed Rank tests indicated no significant difference in the number of oysters or the box-to-live differential from the fall to the spring survey ($\alpha > 0.05$) and that boxes significantly declined from fall to spring ($p = 0.0041$). The latter is attributed to lower dredge efficiency in the spring.

less than a 40% chance of settling compared to an 80% chance for larvae produced downbay (Narváez et al., 2012).

Although the 2012 recruitment was one of the highest in recent history, the small size of the spat indicated that it occurred very late in the season. The first samples of the 2012 survey were taken on October 18th and the last were taken on November 13th. Four sample size frequency histograms illustrate the small size of most of the spat at the time of sampling (Figure 29). On Hope Creek 43, the most upbay sample site shown, growth rates are assumed to be slower than downbay. The peak of the spat size frequency is in the 4 mm size bin. The bimodal pattern of the histogram may result from two spat sets or the possibility of older oysters that are smaller than 20 mm. The next downbay site shown is Shell Rock 20 where the peak of the size frequency is 6 mm. Bennies 43 and Beadons 4 are both beds in the High Mortality region and have a spat size frequency peak in the 8 mm size bin. There was indication of an earlier set in some samples where small 6-8 mm spat had set on top of 10-15 mm diameter spat. However, most spat were quite small and may have difficulty surviving the winter.

Clamshell planting was conducted in the summer of 2012 at two sites on Ship John bed in order to provide clean substrate to enhance natural spat recruitment (Figure 30, Table 12). A third experimental planting was made on the furthest upbay bed, Hope Creek (Figure 30, Table 12). This was a replant; clamshell was initially planted downbay of the natural oyster beds in a high recruitment/low survival area after which a suction dredge was employed to move the spatted shell upbay to Hope Creek. There were 50,000 bu planted on each of the Ship John sites and 12,000 bu of spatted shell transferred up to the Hope Creek site (Table 12). There was no suction dredge sampling of the shell plants in 2012 although that is the preferred sampling method for shell plants as the suction dredge has a high efficiency for the small pieces of clamshell. Shell plant sites were included in the fall survey under the Transplant strata and were sampled with the standard dredge. Three additional shell plant sites from 2011 were also sampled (Table 13). Any clamshell found in the samples was separated and used to calculate spat per bushel of clamshell. Total spat were estimated for all shell plant samples except the site on Middle bed where no clamshell was found.

Spat numbers were used to project future potential market yield (Tables 12 and 13). The years to market size were calculated using von-Bertalanffy parameters as described earlier under Oyster Condition and Growth. The Low Mortality growth parameters were used to estimate growth for Hope Creek oysters. These indicate that it takes 5 years for a spat to grow to 2.5” on Hope Creek. For all regions downbay of the Low Mortality region, the estimates are $\pm$ 3 years to 2.5”. Mortality estimates used in the projections were 1 year at the 1989-2012 median juvenile mortality rate for each region (Low Mortality rate for Hope Creek) and 2 years (4 for Hope Creek) at the 1989-2012 median adult mortality rate. Bushel conversions used 266 oysters bu^{-1} from the port-sampling program. The downbay sites had more spat recruit to clamshell than the upbay sites, consistent with the spat set on other substrates. That and the faster growth rates result in the potential enhanced abundance of over 97,000 bu of market oysters from the Shell Rock and Bennies Sand shellplant sites and about 13,000 bu of market oysters from the two Ship John and the Hope Creek sites.

Figure 31 depicts the size frequency distribution for oyster spat set on clam shell on Bennies Sand 11 in 2011 and also the size frequency of oysters and spat on clamshell at that same site in 2012. Spat size frequency in 2011 peaked at about 20 mm in 2011 and at about 6 mm in 2012. The 2012 data also depicts the first year-class of oysters that have now reached a peak of about 50 mm in the year since they were first measured.

The overall number of spat recruiting per older oyster baywide in 2012 was 1.7 (excluding the Very Low Mortality region), a large increase over 0.46 in 2011 (Figure 32). The 2012 value was at the 86th percentile of the 60-yr time series and at the 90th percentile since 1989 (Table 10). The ratio of spat to oyster varies from region to region with simultaneous high recruitment events, defined as exceeding 1 spat per oyster, occurring infrequently (Figure 33). In 2012 high recruitment events occurred in Shell Rock with a ratio of 2.09 and on the High Mortality region where the 7.69 spat to adult ratio was the highest it has been since 1964. For both time series (60-yr and 24-yr), the spat to adult ratio percentiles were highest in the downbay regions and lower proceeding up the salinity gradient (Table 10). The 24-yr series High Mortality region's percentile was 0.999 and Shell Rock's was 0.896. Percentiles were 0.688, 0.604, and 0.438 for the Medium Mortality Market, Medium Mortality Transplant, and Low Mortality regions respectively. Similarly, the 60-yr percentiles were 0.958, 0.842, 0.625, 0.492, and 0.325 for the High Mortality, Shell Rock, Medium Mortality Market, Medium Mortality Transplant, and Low Mortality regions respectively. Shell planting on the Medium Mortality Market and Very Low Mortality regions had a very modest impact on the baywide spat-to-adult ratio in 2011, similar to previous years, raising it from 1.679 to 1.683. The shell plants on the Medium Mortality Market region raised the spat to adult ratio from 0.78 to 0.79 while that on the Very Low Mortality region raised the ratio from 0.29 to 0.30 (Table 14).

Shell Budget

Bed-specific half-life estimates for cultch were updated using the model of Powell et al. (2006). Half-lives ranged generally between 3 and 10 years, with a median of 7.68 years although a few beds had much higher values (Table 15). Half-lives for the beds of the Very Low Mortality region, Round Island, Upper Middle, and Ledge could not be estimated. The time series for which half-lives can be calculated is from 1999 to present and there is very little data for some beds compared to others. The analyses are subject to substantial yearly variations retrospectively due to limited sampling of some beds in some years prior to 2005, because some conversions are poorly known, and because the time series is still relatively short, being of the same order as many of the half-life estimates. Shell disappears due either to taphonomic processes or by being unavailable to the dredge. Half-lives estimated in 2012 are in the same range as estimates in 2011 and remain within the range originally estimated by Powell et al. (2006). Continued experience with this database confirms the original conclusions of Powell et al. (2006) that half-lives routinely fall well below 10 years. However, uncertainties of a factor of about two are present and this uncertainty will affect shell budget estimates because the accuracy of the half-life estimate is the principal source of uncertainty in that calculation.

A shell budget was constructed using bed-specific half-life estimates for cultch following Powell and Klinck (2007). Values for the six beds with uncertain half-lives (Table 15) were borrowed from neighboring beds. Shell inputs are counted when oysters die or when clamshell is planted. Shell is debited based on half-life values. New Jersey oyster beds have been losing on the order of 500,000 bushels of cultch annually since 1999, with loss rates significantly higher early in the time series (Figure 34). Since 1998 is the first year that full survey data are available, 1999 is the first year an estimate can be made. These estimates are somewhat modified using the 1998-2012 time series versus the 1998-2011 and 1998-2010 time series due to improved data for historically poorly-sampled beds and to survey variations. Two estimates are provided, one based on box volume and one based on box weight. The box-weight estimate is considered the better estimate as box weights are more precisely known thus conversions to shell volume are less speculative; however, the two estimates probably fairly represent the range of uncertainty. For comparison, estimates are made from the same datasets for mortality and cultch quantity using the updated half-lives estimated in this assessment and those estimated in 2010 and 2011 (SAW-13, SAW-14). The shell budget shows a gradual reduction in shell loss until 2008, the last year of large scale shell planting. The only years in the time series when at least one estimate was above zero were 2008-2010 suggesting that shell balance may have been achieved in those years. For 2012, all estimates are negative values but less so than in 2011, with shell loss falling between about 100,000 and 400,000 bushels. The 2012 shell loss estimates using the 2011 half-lives are nearly identical to those using the 2012 half-lives.

The high-mortality beds with their high acreage and low abundance, contribute about half of the entire shell loss in most years (Figure 35). In 2012 the High Mortality region accounted for all the loss while the regions upbay actually gained shell either due to increased mortality, shell plant additions, or both. The opposite case was true in 2008 when the High Mortality region gained shell. The Low Mortality region has similar acreage to the other upbay regions and a comparatively low level of shell loss is due to shell input rates that are usually low (Figure 36). This may be the case with the Medium Mortality Transplant beds as well. The decrease in shell loss on the Medium Mortality Transplant beds in 2012 is likely related to increased shell input from the increase in mortality (Figures 23 and 24). The Medium Mortality Market beds actually gained shell in 2012, likely due to the two shell plants on Ship John and increased mortality. Shell Rock also gained shell in 2012 from increased mortality in that region. Shell Rock shows net gains more frequently than other regions since 2004 due to shell planting. Over time, low oyster abundances will continually lead to low shell input and increased shell loss without shell planting.

Population Dynamics

The broodstock-recruitment diagram suggests that present-day abundance affects recruitment in some way (Figures 37, 37a, 37b). The shell-planting program suggests that the relationship does not involve fecundity and that the bay is not larvae-limited as setting potential far exceeds set. Oyster larvae tend to set preferentially on live oysters and boxes so that one cannot exclude the possibility that broodstock abundance modulates settlement success by being a principal source of clean shell. The relationship indicates that large recruitment events, defined as ≥ 1 spat per adult, occurred in 18 of 60 years or 30% (Figure 32). A recruitment rate at least half that occurs in 36 of 60 years or 60% of the time.[1] Since 1989, a 1 spat per older oyster replacement rate has occurred in 8 of 24 years or 33% of the time. A rate at least half that has occurred over 50% of the time.

For oysters in Delaware Bay, mortality is a major constraint on population size. The period of low mortality from 1966 to 1984 permitted a large expansion of the population manifested as abundances 5- to 10-fold higher than at other times in the long-term survey time series (Figures 6 and 22). Outside that period, disease epizootics have generally doubled average mortality rates across the entire region of oyster beds. An apparent relationship between broodstock abundance and subsequent

---

[1] Note that 1 spat-per adult results in about 0.5 spat per adult at market size on the medium-mortality beds, but only about 0.15 spat per adult at market size on the high-mortality beds.

mortality is characterized by an `epizootic hump' in the 1 to 5 billion oyster abundance range (Figures 38 and 38a). Configured this way, the association can be interpreted to indicate that large populations suppress mortality. A theoretical mechanism for this would be a reduction in the per oyster transmission rate. In 2012, abundance has declined to 1.4 billion (excluding the Very Low Mortality region) and the stock is increasingly concentrated in the central part of the bay as a result of increasing mortality down bay and limited recruitment upbay. Mortality generally decreases in an upbay direction, although freshets as occurred in 2011 can reverse this pattern to some degree depending on the timing, duration and magnitude of the event. Overall mortality in 2012 was 21.3%, an epizootic rate originating from Dermo disease as opposed to the freshwater flood mortalities of 2011. The broodstock versus mortality point for 2012 falls on the left portion of the epizootic hump. Per the curve drawn on Figures 38 and 38a, the 2012 decline in abundance should result in a decline in percent mortality in the coming year however, this relationship is counter-intuitive and remains an untested hypothesis. A more traditional interpretation of the relationship between mortality and abundance is that mortality will control abundance but because mortality remains somewhat unpredictable, we cannot use this interpretation to predict change in abundance.

A relationship between box-count mortality and recruitment remains unclear (Figure 39).

Oyster Fishery

Overview

During the Bay Season years (see historical information) 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 for replant to leased grounds further downbay (Figure 40). 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. Total harvest in 2012 was 78,140 bushels or approximately 20,785,240 oysters (Table 16).[1] Since 1997, an intermediate transplant program has moved oysters among beds. Total stock manipulation including transplant and direct-market, is identified as the apparent harvest; those oysters taken to market are identified as the real harvest (Figure 40). Real fishing mortality by region reflects the loss of oysters from upbay transplant regions and may be negative in downbay direct-market regions if the addition of oysters from transplant exceeds fishing loss (Figure 41 and 42). Very early in the time series, during Bay Season, fishing mortality rates were highest on the Medium Mortality beds; in the 1970s and 1980s, the High Mortality beds were fished the hardest (Figure 41). Since 1997, with area management, direct market harvest, and intermediate transplant, fishing impact has been spread more evenly amongst the regions (Figure 42).

Direct Market

Harvest

The total harvest in 2012 was above the 1996-2012 direct market average of 74,887 bushels although it was less than the 2011 harvest (Figure 43). This marks the sixth consecutive year with a harvest at or above the 17-year mean. Beds were harvested almost continually from April 9 to

[1] Catch and effort data provided by the New Jersey Department of Environmental Protection.

November 30, 2012. The fishery was closed from October 29 to November 12 as a precaution after Superstorm Sandy and the season was extended by two weeks to allow the industry time to harvest their quota. Ten beds were fished with 84% of the catch coming from four beds across the three Direct Market Regions (Table 16). The Medium Mortality Market beds, Cohansey and Ship John, provided 37% of the total harvest, Shell Rock provided 29%, and Nantuxent contributed the bulk of the High Mortality region harvest at 18%. There are eleven beds in the High Mortality region yet only six were fished and only Nantuxent provided more than 7% of the total harvest. There was no harvest at all from the four beds in the most downbay portion of the High Mortality region and very little from New Beds, the next bed upbay.

The total number of boats, particularly single-dredge boats, dropped significantly in 2011 due to license consolidation and that trend has continued. In 2012, the number of two-dredge boats stayed the same at 21 while the number of one-dredge boats dropped from 19 to 17. The catch per unit effort (CPUE) decreased in 2012 and is at its lowest level since 2006 (Figure 44). Dredging impact, evaluated using the methods described by Banta et al. (2003), was estimated to exceed bed area in five cases, four of them on the beds that contributed most of the harvest: Cohansey, Ship John, Shell Rock and Nantuxent (Table 16). Nantuxent was estimated to have had a swept area over four times its bed area (4.17) while the other four beds ranged from 1.00 to 3.10. A yearly swept area of no more than four times the area of a bed is unlikely to have significant negative impact on the oyster population (Powell et al., 2001). Bushels-harvested to fraction-covered ratios are 7,299 – 7,893 for Cohansey, Ship John, and Shell Rock but 3,437 for Nantuxent indicating a low CPUE on that bed. This ratio has ranged between 2,760 and 3,573 on Nantuxent since 2006 and was lower earlier than that. Nantuxent is the closest bed to the oyster boat docks at Money Island; possibly reason enough to fish there rather than steaming farther.

Port Sampling

The number of oysters per 37-qt marketed bushel averaged 307 in 2012, much lower than the 350 in 2011 and more like the rest of the 2004-2011 time series (Table 17). However, the average of 240 market-sized (≥ 2.5”) oysters per bushel in 2012 was nearly identical to the 238 per bushel in 2011 indicating that the difference was due to more small oysters per bushel. In 2011 there were, on average, 102 small oysters attached to larger oysters in the sampled bushels going to market while in 2012 there were 58, an average higher than earlier years in the program (Figure 45). High spat sets in 2007, 2009, and 2010 (Figure 27) leading to increases in the < 2.5” size class (Figure 15) on the Direct Market beds account for the higher 2010-2012 ‘incidental catch’ averages (Figure 45). The average and median sizes of oysters going to market in 2012 were 2.98” and 3.07” respectively (Table 17). Oysters > 2.5” made up a greater proportion of the size frequency going to market in 2012 than they did in either 2011 or 2010 (Figure 46).

Conversion of oysters to bushels for allocation projections used the value of 266 oysters bu^{-1}, the average of nine years’ worth of port-sampling (Table 17). This value is the mean of the total oysters and the chosen (≥ 2.5”) oysters per bushel. The rationale for using the mean is that the number of attached small oysters will vary widely 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 bu^{-1} since 2006.

Intermediate Transplant

In April 2012, the Intermediate Transplant program moved oysters from two upbay regions down to two grids on beds in the High Mortality region: Bennies Sand and Nantuxent using five large oyster boats (Figure 47). There were 7,650 bushels of culled material moved from Arnolds bed in the Low Mortality region to the Nantuxent grid and a total of 21,825 bushels of culled material moved from the Medium Mortality Transplant region to both grids. The Medium Mortality Transplant moved 2,100 bushels from Upper Middle bed, 8,625 bushels from Sea Breeze, and 11,200 bushels from Middle. The Nantuxent grid received a total of 12,850 bu and the Bennies Sand grid received 16,625 bu. The number of oysters per bushel from the Low Mortality region transplant ranged from 441 to 820 and averaged 587 bu^{-1} (Table 18). The oyster bu^{-1} from the Medium Mortality Transplant region ranged from 349-568 and averaged 424 bu^{-1}. The percentage of cultch by volume from the Low Mortality region transplant was 28%; slightly more than the long-term 2003-2011 mean of 27% and that of the Medium Mortality Transplant region was 26% which was somewhat below the long-term mean of 28%.

The 2012 Intermediate Transplant program used exploitation rates advised by the 2012 SARC and decided on by the Shellfish Council to set transplant goals for each region. The Very Low Mortality region was closed in 2012 as a result of the 2011 flood and subsequent oyster mortalities. The 40th percentile exploitation rate maximum of 4,730,022 oysters for the Low Mortality region was nearly met with 4,469,068 oysters moved downbay. Of those, 942,900 were large enough to include in the quota increase calculations adding 3,558 bu to the High Mortality region quota. The planned use of the Medium Mortality Transplant region's 50th percentile exploitation rate maximum of 7,245,772 oysters was overshot due to logistical reasons and ultimately, the 9,221,809 oysters moved was somewhat above the 60th percentile exploitation rate maximum. Of these oysters, 3,066,963 were included in the increased quota calculation and added 11,574 bushels to the quota for the High Mortality region. The overall quota increase for the High Mortality region was 15,132 bushels or 52% of its total quota (Table 19). The fraction of total quota for the High Mortality region from Intermediate Transplant has been 50-60% for the last four years. Overall, Intermediate Transplant has accounted for 17-36% of total Direct Market quotas since 2008. The increased use of intermediate transplant to support harvest downbay is in keeping with the SAW-11 recommendation to expand the intermediate transplant program to a scale routinely employed in the 1997-2003 timeframe.

Fishing Mortality

Real fishing mortality was 1.4% of total abundance in 2012 excluding the Very Low Mortality region (Figure 48) and 1.2% including it. Fishing mortality has been below 2% every year since 1996. Fishing mortality was at the 26th percentile of the 60-yr time series excluding closure years and at the 47th percentile of years post-1995 (Table 10). As a fraction of oysters ≥2.5", fishing mortality was 4.3% in 2012 excluding the Very Low Mortality region (Figure 49) and 4.1% including it. Fishing on the marketable size class of oysters over all regions has been below 5% since 1997 except in 1998 when it was 5.05%. In 2012, fishing mortality on marketable oysters was at the 80th percentile due to the narrow range of values in the time series (Table 10). Fishing mortality by SSB was 2.8% in 2012 excluding the Very Low Mortality region (Figure 50) and 2.7% including it. It has been between 1.8 and 3.5% of SSB throughout the 1997-2012 time series.

The Very Low Mortality region was closed in 2012 due to its continuing slow recovery from the 2011 flood mortalities. Removal of oysters from the Low Mortality and Medium Mortality Transplant regions is only done through intermediate transplanting that removed 1.2% and 3.1% of all sizes of oysters from them respectively in 2012 (Figure 51). The percentage of market-sized (>2.5") oysters removed from these regions was 1.3% and 3.9%. The Direct Market fishery harvested 1.2% and 4.7% of all oysters on the Medium Mortality Market region and Shell Rock respectively (3.4% and 14.7% of the market-sized oysters) in 2012. Overall, the High Mortality region had a net gain in oysters as the transplant recipient in 2012, resulting in a negative real fishing mortality percentage and 5.9% of its market-sized oysters were harvested.

There were three years of experimental exploitation on the Very Low Mortality region as per SAW-11, 12, &13 that recommended the use of the 40th percentile exploitation rate from the Medium Mortality Transplant beds for intermediate transplants from the Very Low Mortality region. This resulted in the removal of 1.2% to 1.4% of the total oysters in the region and removal of 1.8% of its market-sized oysters (Figure 51). Transplanting has removed under 3% of the oysters from the Low Mortality region in each of the last six years and generally under 4% of oysters from the Medium Mortality Transplant region.

A second experimental fishery proposed at SAW-11 and carried forward was exploitation at the 100th percentile of the time series on the Medium Mortality Market region. At this exploitation rate, the percentage of oysters directly marketed off this region has stayed under 3% of total oysters and has risen somewhat to approximately 4% of the market-sized oysters. The percentage of oysters taken has varied on Shell Rock that received intermediate transplants in 2005, 2006, and 2010. In 2010, intermediate transplants accounted for 34% of the quota on Shell Rock (Table 19) and harvesting accounted for 2% of all oysters on Shell Rock and 6% of market-sized oysters on Shell Rock (Figure 51). Since then, the fraction of oysters taken from Shell Rock has increased to about 5% of all oysters and 15% of the >2.5" oysters. The High Mortality region has received transplants every year so that the fraction of oysters going to market from this region has remained low as a percentage of all oysters or the region has gained oysters. As a fraction of the larger size classes, the percentage of oysters taken off the High Mortality region has ranged generally between 4-9%. Intermediate transplant additions account for approximately 50-60% of the total quota in the High Mortality region (Table 19).

The percentile ranks for fishing mortality of market-sized oysters use the 1997-2012 time series (Table 10). The values for the Direct Market regions include any intermediate transplant additions as well as direct harvest. In 2012, the percentiles for the direct market regions: High Mortality, Shell Rock, and Medium Mortality Market, were the 47th, the 80th, and the 73rd respectively. Percentiles for the two transplant regions, Medium Mortality Transplant and Low Mortality were the 80th and the 60th respectively in 2012, similar to 2011.

Submarket Surplus

Submarket surplus is defined here as the number of oysters available for harvest under the expectation of no net change in ≥3" oyster abundance over the year given a specified natural mortality rate and growth rate. If fishing mortality rate is set to zero, submarket surplus as calculated here is equivalent to the difference between the number of oysters expected to recruit to the ≥3" size class in a year minus the number of such oysters expected to die naturally. In the absence of fishing, a positive submarket surplus indicates that the ≥3" portion of the population is expected to expand in abundance. If negative, the ≥3" portion of the population is expected to contract, even in the absence of fishing. The model used for the calculation assumes an uneven distribution of mortality rate during the year as is observed (Bushek et al., 2012). However, this assumption is only noteworthy if the fishery removes oysters before the primary season of Dermo mortality in the late summer and early fall. The April to November fishery has routinely done so; thus, some component of natural mortality is compensatory. A detailed description is found in Klinck et al. (2001). Submarket surplus was estimated using the 50th and 75th percentiles of the natural mortality rate (Table 20). As a probabilistic application of growth rate cannot yet be done, surplus production projections used the size range of oysters expected to grow to 3" in one growing season obtained from the von-Bertalanffy curves of Kraeuter et al. (2007) (Table 11). Because the mortality rates for the smallest oysters are not well documented, the submarket surplus production projections continue to be based on 3" rather than 2.5" oysters.

Submarket surplus projections have been high relative to exploitation rates except for the High Mortality and Shell Rock regions. Concern over what were interpreted to be unrealistic submarket surplus rates upbay led to the abandonment of the original submarket surplus reference point used in the early SAWs and replacement with the present exploitation-based reference point system[1]

Baywide submarket surplus projections for 2013 are positive and generally higher than those of 2012 (Table 20). This is particularly true for the Low Mortality region where both the 50th and 75th percentile estimates are double those of 2012. The projections for Shell Rock are down nearly 50% from the 2012 estimates. However, the projection remains strongly positive. In previous years, the projection for the Very Low Mortality region was based on two assumptions. First, the growth rate was assumed to be similar to that observed in the Low Mortality region as no direct observations are available. Second, a low and a high mortality rate were chosen from the 2007-2011 time series as a surrogate for the 50th and 75th percentile rates used for the remaining bed regions. This year, with six sets of data (2007-2012), the mortality percentiles were calculated for the Very Low Mortality region and used in the submarket surplus abundance estimate although there are still no growth data for this region.

A retrospective analysis began with SAW-13. Its purpose was to evaluate how the implemented management measures for the year compared with the goal of stock sustainability. As documented in SAW-14, this evaluation focuses on the possibility that catch was forgone under the original assumption of no net change in ≥3" oyster abundance, i.e., the ≥3" size class abundance increased over a year. Comparisons are made between surplus predictions and realizations without and with fishing mortality to examine the appropriateness of previous management decisions. Positive numbers indicate that the quota was underestimated under this assumption. Negative numbers indicate that the quota was overestimated under this assumption.

Assuming that the goal is $N_{3''t} = N_{3''t+1}$, then:

$$NetSubmarketSurplus_{t+1} = N_{recruitt} - Deaths_{\geq 3''t+1} - Deaths_{recruitt+1} - Landings_{\geq 3''t+1} - Landings_{recruitt+1}$$

[1] The exploitation-based reference point system also stabilized year-to-year variability in the quota that was a byproduct of the more volatile submarket surplus projection.

where times t and $t+1$ represent consecutive Fall survey indices or for landings, the yearly harvest tally between surveys and $N_{recruits}$ is the number of oysters that recruit into the $\geq$3" size class.

A negative net submarket surplus would indicate landings higher than a sustainable level for the stock for that year under the assumed goal. A positive net submarket surplus would indicate forgone yield under the assumed goal of no net change and increase of the $\geq$3" size class.

The retrospective examination rests on several assumptions. The projections are based on the designation of $\geq$3" oysters as a size class to be conserved yearly so that the number of individuals neither increases nor declines. Thus, submarket surplus as defined in this analysis is equivalent to the number of oysters that will recruit into the $\geq$3" size class debited by the number that will die during the year in the recruit size class and in the $\geq$3" size class. The data for the retrospective examination includes known numbers of oysters in each of these size classes at the beginning and ending of the year (the previous and present years' surveys). The survey and fishing data provide the size frequencies of the deaths. Boxes and fished oysters $\geq$3" are clear as they came from one of the two initial size classes. Boxes or fished oysters of recruit size are ambiguous. They may have been of recruit size in the previous year's survey and thus used in the original projection. However, they may have been pre-recruits that grew into recruit size during the year but prior to their death or capture. These would not be in the previous year's projections. Thus, two retrospective calculations are required to bound the evaluation of the original projection: (a) boxes or fished oysters of recruit size were of recruit size in the previous year's survey; and (b) boxes or fished oysters of recruit size were smaller than recruit size in the previous year's survey. This results in high and low estimates of submarket surplus that must bound the true value.

In addition, intermediate transplants (oysters moved off one region and onto another) are included in the retrospective calculation. These are not present in the projections as no knowledge of that endeavor is available at that time. Thus, intermediate transplants introduce deviation between observation and projection. However, their inclusion provides a mechanism to evaluate the adequacy of the overall quota-setting process relative to the information available at the time of quota setting, namely the exploitation rate reference points and the submarket surplus projections.

To examine the outcome of management policies, it is important to evaluate uncertainties in mortality rate and growth rate. Because the survey tracks the sizes of boxes and because the port-sampling program tracks the sizes of the landings, a minimal estimate of mortality rate is available. Mortality rate cannot be less than this number. However, there is the possibility that some boxes are not included due to their disarticulation prior to sampling. Thus mortality rate may be higher than observed. How much higher is uncertain. We use the assumption of a 25% and a 50% underestimate to evaluate the outcome under alternative mortality rates. Growth rates may be over- or underestimated. Arguably, the growth rates provided by Kraeuter et al. (2007) were obtained during a period of rapid change in growth from a slow-growth decade to a faster-growth decade. Simulations using DyPoGEn suggest a possible 40% change in the Bertalanffy k parameter downbay of Shell Rock. We assume a $k\pm0.04$ for evaluation of uncertainty.

Results of this retrospective are first provided by simply examining whether the management measures imposed resulted in forgone yield. In Figure 52 (a and b), green indicates cases where the estimate of net submarket surplus exceeded the lower and upper bounds, indicating forgone yield. The quota might have been set higher for that bed region and year while still achieving the goal of $N_{3''t} = N_{3''t+1}$. Red indicates cases where the estimate of net submarket surplus fell below the upper and lower bounds, indicating that a fishing level occurred that was too high for the desired goal. Grey indicates an estimate that fell between the two bounds. Arguably, this is the desired outcome as the goal of $N_{3''t} = N_{3''t+1}$ exists between the two bounds.

The predominant green and gray shows that in most years and bay regions since 2008, either the outcome is as desired or that forgone yield occurred (Figure 52a and b). Thus, overall, management measures have been precautionary. The alternative states of nature on the figures show that faster growth did not much change the overall evaluation of the management strategy but slow growth and moderate or high increases in mortality resulted in additional years colored red in which the $\geq$ 3" size class was not conserved, an undesirable outcome. Red appears in the Very Low Mortality region for the first time in 2012, a year with no transplanting (the only fishing done in this region) but with natural mortality rates in 2011 and 2012 that exceeded previous years' 75^{th} percentile of mortality, presumably from the 2011 freshwater flood and its lingering effects in 2012. Sustainable submarket surplus was indicated in regions downbay. Care should be given to interpreting Figure 52a and b based on the uncertainty of the survey indices and the uncertainty in the assumptions underlying oyster growth rate.

Status of Stock Summary

Long-term patterns since formal assessments began in 1953 indicate that the Delaware Bay oyster stock is largely controlled by disease pressure. The overall abundance and biomass of the stock is generally driven by the intensity of disease and the related mortality it causes. The long-term 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 (e.g., Figure 6). At least three periods are indicated in the record the first being a period of low abundance on the natural oyster beds in the 1950s that continued as MSX invaded the Bay and caused significant mortality. MSX remained a factor in the lower bay over the privately leased grounds (Ford and Bushek 2012) in the 1960s but mortality rates on the natural beds declined beginning a new period marked by high abundance that lasted into the 1980s. An extended drought facilitated the spread of MSX upbay in 1985 causing extensive mortality that began the third period that exists today and is characterized by high mortality and low abundance. The MSX epizootic dissipated as the population responded via natural selection and became resistant (Ford and Bushek 2012) but abundance did not recover as Dermo disease became established in the bay and continued to suppress abundance by effectively doubling rates of mortality. Dermo disease and mortality is highly influenced by salinity along the upbay-downbay gradient that is controlled largely by freshwater inflow (Bushek et al. 2012) and creates regions of varying oyster mortality (Figure 1). The influence of Dermo disease on Delaware Bay oyster population dynamics has led the SARC to determine that population assessments should be set relative to the 'Dermo era', ie. since 1989 which is also when the survey protocol was updated. The previous time periods are useful for understanding this decision and what the population might do should the influence of Dermo subside.

Regional Stock Performance Targets

In 2006, the SARC set specific target and threshold abundances and spawning stock biomasses based on the 1989-2005 and 1990-2005 time periods, respectively, under the assumption that this time period likely represents the entire scope of oyster population dynamics in the present climate and disease regime. As a consequence, the median abundance and SSB values for these time periods were set as targets with values half these levels set as threshold levels (Table 21). Due to the absence of a time series for this period, the Very Low Mortality region targets and thresholds were established by applying low mortality conditions as follows: values were obtained based on an assumption that the per-area values for abundance, SSB, and market-size abundance on the Very Low Mortality beds should be equivalent to those on the Low Mortality region. Consequently, the values for the Low Mortality beds in Table 21 are multiplied by the ratio of the regional bed areas (0.849) to obtain reference-point estimates for the Very Low Mortality region. As the growth rate is likely slower in this region than on the Low Mortality region, average adult size is likely smaller, thus reference points for SSB and market-size abundance may be overestimated using this approach. An alternate examination was performed by examining the ratios between the two bed regions for abundance, biomass, and market abundance for the 2008-2010 time period. The ratios were highly variable but the 3-year averages were 1.23 (abundance), 0.94 (SSB), and 0.93 (market abundance). None were likely to be significantly different from the ratio based on acreage; however, the abundance value suggests that reference points based on acreage may be biased low. Considering this, the SARC at SAW-14 accepted the application of Low Mortality conditions adjusted by area to set targets for the Very Low Mortality region.

Time series data indicate that the first decade of the 2000s was very different from the 1990s. Particular examples include the dramatically lower recruitment rates for much of the 2000s in all bay regions (e.g., Tables 7-10), the increased stock consolidation upbay (Figure 9), the change in size composition from a small-oyster dominated stock to a stock enriched in oysters ≥ 2.5" in size (Figures 13-16), and the tendency towards the end of the 2000s for epizootics to be characterized by a higher fraction of mortality upbay of the High Mortality beds (Figures 22 and 23). Of particular interest is the long-term drop in abundance without an equivalent response in SSB. Simulations in 2010 with the oyster population dynamics model, DyPoGEn, reported in SAW-13 strongly imply that growth rates have risen between the 1990s and 2000s. These changes suggest that target and threshold values, particularly for abundance, based on a times series significantly influenced by 1990s abundances and biomasses may not be appropriate for the 2000s. More recent patterns, however, indicate a possible return to the earlier conditions. For example, recruitment trends are increasing (Figure 27) and size frequency distributions are beginning to look more as they did in the early part of the 24-yr time series as a result (Figures 14-16). The SARC discussed the appropriateness of the 1990-2005 timeframe for establishing abundance and biomass targets. It concluded that the uncertainty of recovery precluded changing the reference period but that alternative time frames should be investigated. Furthermore, it was suggested that some sort of reference external to the system, perhaps from a model, might be more appropriate. Such a model may be available from ongoing NSF-funded research in the next 3-5 years. Until then, it may be reasonable to examine the time series for shifts in population dynamics.

Volatility in oyster condition can result in a large change in SSB relative to marketable abundance (oysters ≥ 2.5"). This was evident in 2009 when oyster condition fell from a relatively high value in 2008 leading to a drop in SSB. A drop in condition certainly played a supporting role in the SSB decline of 2011 and appears to have played a role in returning SSB toward target levels in 2012, Shell Rock being an exception (Figure 53). A less volatile analogue to the comparison between abundance and biomass might be a comparison between abundance and marketable abundance. Regional reference points for this third axis are provided in Table 21.

In 2012, total oyster abundance on the Very Low Mortality beds remained near but above the threshold (Figure 53). Abundance has been below the target during the short time series for which data are available, 2008-2012, suggesting that this target may be too high. However, the same can be said for all regions except Shell Rock for the 2008 to 2012 time period and the Medium Mortality Transplant region in 2011. Although we don't have data for the Very Low Mortality beds prior to 2007, the low abundance elsewhere is explained in part by poor recruitment earlier in the decade coupled with increased Dermo mortality from 2007 onward. In contrast, SSB on the Very Low Mortality beds recovered well in 2012 from 2011 levels as oysters grew and condition markedly improved (Figure 53). Market-sized oyster abundance increased to near target level but remains well below levels that were more than double the target in all four of the preceding years (Figure 54). Recruitment was about five times that of 2011 but still an order of magnitude less than the high recruitment event of 2010 (Table 5, Figure 27).

The Low Mortality beds improved following a trend of increasing total abundance above the threshold and moving towards the target level. Biomass moved from the threshold value in 2011 to well above the target value in 2012, largely as a result of improved condition (Figure 53). Market-sized oyster abundance remains well above the target as it has been since 2004, despite the higher mortality due to the 2011 flood. The 2012 value represents a considerable increase from 2011, exceeding 2010 levels and matching the value from 2009 (Figure 54). Market-sized abundance on the Low Mortality region fell at the 82^{nd} percentile of the 23-yr time series (Table 10). Recruitment was twice that of 2011 and fell at the 40^{th} percentile of the 24-yr time series (Figure 27, Table 10).

The Medium Mortality Transplant and Market beds behaved similarly relative to 2011, declining in abundance, but increasing in SSB (Figure 53). The Transplant region abundance fell back below the target where it had been prior to 2011. Total abundance on the medium-mortality market beds fell closer to the threshold. SSB in both regions increased to near target levels. Market-sized abundance increased further above the target in 2012 in both regions (Figure 54). Market-sized oyster abundance was at the 96^{th} percentile in the Transplant region and the 77^{th} in the Market region (Table 10). Recruitment in 2012 on the Transplant region was 2.75 times higher than that of 2011, was twice as high on the Market region, and both fell approximately at the median value of the 24-yr time series (Table 10).

Declines in total abundance and SSB on Shell Rock were dramatic compared to 2011 and were nearly identical to 2009 values (Figure 53). However, both remain above threshold values. Total abundance and SSB on Shell Rock fell only at the 15^{th} percentile for each category (Table 10). The same decline is true for market-sized abundance but it remained above the target value (Figure 54) and fell at a much higher (46^{th}) percentile (Table 10) consistent with the abundance decline being due to loss of small oysters (Figure 15). Recruitment in 2012 on Shell Rock was four times that of 2011 and fell at the 56^{th} percentile (Table 10).

The High Mortality region improved to reach or nearly reach both total abundance and biomass thresholds (Figure 53). This improvement may result from a combination of increased survival following depression of Dermo disease in 2011, increased growth, a strong 2010 year-class, and the receipt of 29,475 bushels of intermediate transplant. As a likely result of these factors, market abundance increased above the target in 2012 (Figure 54). Market abundance has remained above or near the target for the last seven years. Recruitment was the highest on record on a per bushel basis since 1990 (Table 9), and third highest in absolute abundance and on a per-adult basis (Figures 27 and 33). Recruitment to the High Mortality region was at the 90th percentile of the 24-yr time series and the 80th percentile of the 60-yr time series in 2012 (Table 10).

The relationship of the abundance and market-abundance reference points provided in Table 21 and displayed in Figures 53 and 54 are compared to the uncertainty surrounding the 2012 point-estimate for each bay region in Figures 55 and 56. These generally confirm the significance of the position of the 2012 point-estimate relative to the Table 21 stock-performance reference points. Using the central 80% of the envelope as an indication of significance, four of six regions fall above the threshold values whereas 2012 estimates for the Very Low Mortality and the High Mortality regions are indistinguishable from the threshold values (Figure 55). Note that the Low Mortality point estimate is not significantly below the target. In contrast, the market-size abundance threshold reference points fall below the survey uncertainty envelope for all but the Very Low Mortality region and even that threshold is significantly below the survey point estimate while the estimate is not different from the target value (Figure 56). Survey estimates for both the Low and Medium Mortality Transplant regions fall significantly above their targets and the uncertainty in the remaining regions includes the target values with point estimates slightly above the target. Thus, all bed regions meet stock-performance market-sized oyster abundance goals by this measure in 2012 (Figure 56). These measures of uncertainty validate the qualitative observations described above.

Surplus-production and Whole-stock Performance Targets

Whereas, area management continues to be a priority as addressed by the regional stock performance targets, the oyster population is a single stock and thus whole-stock reference points are important criteria upon which to judge 2012 stock status. The SARC considered three whole-stock abundance targets. The first two are the sums of the regional total oyster abundances and marketable-abundances targets listed in Table 21. The third was derived more theoretically from an analysis of biological relationships and formulation of a surplus production model published by Powell et al. (2009) and described in previous stock assessment reports (e.g., HSRL 2012). Briefly, the model produces two stable states in abundance resulting from the impact of disease mortality that creates a minimum of surplus production between two maxima as population abundance increases. Since 1986, the population has been in the low abundance state with Dermo disease maintaining this state since 1990.

Several SARCs have debated the validity or relevance of using the surplus production model to identify whole stock reference points. Five simulations have been run to mimic different states of nature including low juvenile mortality, high recruitment, low recruitment, low Dermo mortality and 10% lower recruitment. Results show relative stability in abundance with respect to uncertainty in the survey time series, but that surplus production values vary widely. Thus, n_{msy} values can be obtained but f_{msy} values cannot. Several SARCs have been unable to identify a preferred simulation but have settled on using the median of the four best estimates of the n_{msy} for the low-abundance state as a representative target value and a threshold set at half that value for comparison with the stock performance model. The target and threshold values from the surplus production model are: 1.628 billion and 0.814 billion. Stock-performance reference points are derived as described above from the regional stock performance data for the 1989-2005 time period by summing the regional target values (Table 21). For total abundance, the target is the sum of the median stock abundances from 1989-2005 and the threshold is half that value. The two respective values are 2.311 billion and 1.156 billion. The equivalent reference points based on marketable (≥2.5" oysters) abundance from Table 21 are 334 million and 167 million.

Applying the Powell et al. (2009) surplus production model as a reasonable portrayal of the behavior of the NJ Delaware Bay natural oyster bed stock, SAW-10 expressed concern that the stock-performance target for the whole stock (2.311 billion) may be too high to be used as an abundance goal because the value falls near the surplus production minimum between the two stable states and may therefore be difficult to achieve. On the other hand, the n_{msy} estimate from the surplus production model, by falling at the surplus-production peak, indicates that a Dermo epizootic would push the population to a lower state of surplus production and delay recovery. Considering these predictions, SAW-10 recommended an abundance goal be set between these two values so that a Dermo epizootic or other mortality event occurring near the abundance goal would actually increase surplus production despite the decrease in abundance, and therefore facilitate stock recovery as long as fishing mortality was not increased to the point of consuming the increase in surplus production and as long as the increased mortality subsided. SAW-10 also evaluated the two thresholds that are taken as half the targets in keeping with the precedent established in the management of federal fisheries. The threshold for the stable-point surplus-production model is at an abundance level lower than observed in the time series where stock dynamics are unknown. SAW-10 recommended against using any abundance threshold below observed abundance levels. The threshold obtained from the stock-performance model falls within known stock dynamics and was therefore preferred. Despite this and subsequent SARC discussions, no SAW has resulted in adopting surplus production model estimates of n_{msy} as a target, preferring to keep both the stock performance target and threshold values defined by the period 1989 – 2005. Note that the Very Low Mortality beds have been excluded from all stock-wide reference point estimates and comparisons because time series data are insufficient to include them at this time.

The 2012 total abundance was 1.44 billion oysters (excluding the Very Low Mortality beds) of which 574 million are ≥ 2.5" in size. As calculated, the 2012 point-estimate of 1.44 billion oysters falls slightly, though not significantly below the n_{msy} target, but significantly below the whole-stock stock-performance reference point (Figure 57). In contrast to whole-stock abundance, market abundance across the entire stock has increased during 2012 and sits significantly above the stock performance target (334 million oysters) at 574 million oysters. The marketable abundance of 574 million falls near the 60th percentile of the survey uncertainty envelope with the 90% confidence limits being 475 and 660 million oysters (Figure 58).

In summary, the n_{msy} reference point target falls just above the 60th percentile of the whole stock survey index, suggesting that 2012 abundance is very likely to be near this reference point (Figure 57). A similar comparison against the stock-performance reference points for total abundance shows that the 2012 point-estimate falls significantly below the target but significantly above the threshold value (Figure 57). Application of the marketable abundance reference point to an equivalent set of percentiles (Figure 58) reveals a better situation with the 2012 point-estimate significantly above the stock-performance target.

Summary of Stock Status and Population Management Goals

Figure 59 summarizes the status of the oyster stock throughout the New Jersey waters of Delaware Bay by region. All percentiles are based on the 1989-2012 (or 1990-2012) period (Table 10).

This period is chosen due to the controlling influence of Dermo disease as described previously. In particular, average mortality rates are up, the frequency of epizootics is up, the average abundance is down, and the average recruitment rate is down with respect to the 1953-1988 time period. These changes commenced in the first part of the 1990s when the fishery was closed in most years. Harvest was significant during the 1989-1996 period in only two years, 1990 and 1991 (Figure 40).

A major freshwater flood in 2011 modified recent trends in the status of the stock and this should be taken into consideration when assessing the 2011-2012 trends. As often occurs, there is a mixture of positive and negative indicators that may be distributed by region or by metric. Most apparent in Figure 59 is the orange section, indicating unfavorable situations, across the middle of the figure encompassing the fraction of small oysters (< 2.5") in the population, the level of Dermo disease, mortality rates, and abundance positions relative to targets. Balancing this are green areas indicating good or improving situations for SSB, market abundance and recruitment. Exceptions to these generalities include the Very Low Mortality and Shell Rock regions. The Very Low Mortality region has not recovered from the 2011 flood, although Dermo remains absent from this region and SSB and market-sized abundance have increased over 2011. Shell Rock experienced good recruitment and a strong replacement ratio of spat to adult (2.09), but abundance and biomass were down while Dermo and mortality were up.

Overall, abundance was up in only three of the six regions (Low Mortality, Medium Mortality Market and High Mortality) relative to the median over the past five years and increased significantly (by >15%) since 2011 only on the High Mortality region. In contrast, SSB has increased everywhere except Shell Rock in 2012. Likewise, market abundance and recruitment have increased. A strong, albeit late, recruitment event occurred with numbers increasing from upbay to downbay. This pattern is typical and helps offset mortality rates that increase in the same direction. The spat per adult numbers are lower upbay because of the lower recruitment numbers and a higher density of oysters on the upbay beds. The fraction of small oysters (<2.5") remains low. Dermo disease levels were high this year, particularly in the Medium Mortality and Shell Rock regions. This may be partially explained by the bias in size frequency distribution towards larger oysters on those beds as the Dermo monitoring collects samples that represent the size frequency distribution (see Bushek 2013 for details). Because mortality is strongly influenced by Dermo intensity, these same beds in the central portion of the overall population experienced higher mortality with percentiles in the 65-80 range for the Dermo era (1990-2012). Although abundance was generally down, it remained between target and threshold levels everywhere except on the High Mortality beds where abundance has been down for several years. SSB on the other hand, was only slightly below target levels except on the Very Low Mortality and High Mortality beds. Market abundance was relatively strong relative to targets, falling below target levels only on the Very Low Mortality beds.

Fishery exploitation rates since 1996 have been low; <2% of total abundance per year, <5% of market abundance per year, and <4% of SSB per year excluding the Very Low Mortality region (Figures 48-50). By far, most oyster mortality (80-90%) on the natural oyster beds of Delaware Bay, New Jersey is not a result of fishing removals but rather a result of natural causes like Dermo disease (Figure 60). The Direct Market harvest for 2012 was barely above average since the initiation of this fishery in 1996 (Figure 43). There are three Direct Market regions, all of which may receive intermediate transplant from one or more of the three Transplant regions upbay during a year to augment regional quotas and coincidentally provide additional smaller oysters in these faster growth (and higher mortality) regions. The Very Low Mortality region was closed for transplanting in 2012 as it is still recovering from the mortalities due to the freshwater flood of 2011. Transplants were conducted from the Low Mortality and Medium Mortality Transplant regions and placed on the High Mortality region in 2012. Only 1.2% of total oysters and 1.3% of market-sized oysters were taken from the Low Mortality region and 3% of total oysters and 4% of market-sized oysters were taken off the Medium Mortality Transplant region (Figure 51). Only 1.2% of all oysters (3.4% of market-sized) were taken from the Medium Mortality Market region. The drop in abundance on Shell Rock in 2012 was due in part, to fewer small oysters and more Dermo mortality. As a result, the direct market fishery took 5% of all oysters and 15% of market-sized oysters from Shell Rock under the 2012 regional quota allocation. The receipt of 29,475 bushels of intermediate transplant by the High Mortality region resulted in a net gain in total oysters and the removal of 6% of the market-sized oysters by the Direct Market fishery.

In summary, the fact that not one region fell above its abundance target indicates that actions to enhance abundance continue to be important. In contrast, the Low and Medium Mortality regions were near or above their SSB targets. Shell Rock's SSB was closer to the target than the threshold and even on the Very Low Mortality beds, SSB improved following the 2011 flood-induced mortality. This situation is driven in part by a continuing deficit of small oysters relative to the abundance of market oysters. In fact, market abundance exceeds target values in all but the Very Low Mortality region, and even that lies near the target value. Nevertheless, total abundance remains below target levels. The continued need for improving recruitment emphasizes the need to minimize shell loss and reinforces the importance of maintaining marketable abundance near or above target levels in each region. The most critical areas of concern in 2012 are the Very Low Mortality beds and Shell Rock. The Very Low Mortality beds have not recovered from the 2011 mortality event and Shell Rock remains an important bed but sustained high mortalities in 2012. Given the value of Shell Rock as a core region for the population, attention to improving this bed is warranted. A similar situation occurred in 2009 and the bed responded well to both transplants and shell plants. This has been a consistent response over the years and Shell Rock would likely respond well to such efforts again.

Sustainability

The concept of a sustainable stock under federal guidelines articulated by the Magnuson-Stevens Fishery Conservation and Management Act is expressed in the concepts of `overfishing' and an `overfished' stock. The term `overfishing' represents a comparison of the current fishing mortality rate relative to the rate permitted at maximum sustainable yield, $f_{msy}$. The term `overfished' refers to the biomass of the stock relative to the biomass at maximum sustainable yield, b_{msy}. These concepts do not depend on the history of the stock or the fishery prior to the year of the assessment; rather, the concepts are yearly designations that express the conditions that exist in the assessment year (or the year of most recent survey data).

The concepts of b_{msy} and f_{msy} have not been applied to populations strongly influenced by disease such as the Delaware Bay oyster population. Thus, SAW-13 considered a number of metrics to judge sustainability that provide analogies to the federal criteria. The federal concept of b_{msy} is a whole-stock characteristic that relates the biomass B that supports maximal surplus production to carrying capacity K; typically $B_{msy} = K/2$. The application of b_{msy} to the Delaware Bay oyster stock is impeded by a minimal range in biomass observed over the time span that biomass estimates can be made: 1990-2012 (Figure 11). Furthermore, until very recently, mortality of this stock could not be expressed on a biomass basis. Thus, the dataset does not permit a ready estimate of K on a biomass basis. However, the 60-yr time series (Figure 6) provides a wide range of abundance values (easily a factor of 5) permitting the analogous parameter, n_{msy}, to be calculated (Powell et al. 2008). In 2012, the survey point estimate of whole-stock abundance was not significantly different from the n_{msy} target (Figure 57), indicating that, by this measure, the stock is not overfished.

SAW-13, SAW-14 and the present SAW considered the efficacy of relying on this measure and noted the uncertainty posed by the uncertain shape of the epizootic hump in the abundance-mortality relationship (Figure 38). As a consequence, SAW-13 recommended greater reliance on alternative metrics of a well-managed stock that would not be expected to be present in an overfished stock. The most important of these is the trend in market-size abundance (eg. Figure 14). Market-size abundance is the least volatile of the stock metrics (abundance, SSB, market abundance) and so may be most likely to provide unambiguous evidence of over-exploitation were it to occur. The premise that an important management goal is the conservation of market-size abundance has underpinned management of the resource since SAW-1. This premise is based on the recognition that natural mortality rate has risen by a factor of about two during the Dermo era (Figure 22) and that much of this mortality is concentrated on the larger size classes (Figure 24). The first evidence of an overfished stock would be a decline in market-size abundance from one epizootic cycle to the next as recovery of abundance during periods of disease remission would be limited by fishery removals. The Delaware Bay stock has traversed three epizootic cycles since 1990 (Bushek et al., 2012). The 1990-2012 time series shows that the abundance of market-size oysters has remained relatively stable over this period of two decades (Figure 17). This stability comes from two sources. First, a balance exists between the death of larger oysters primarily caused by disease and the recruitment potential of the population. Second, the fishing mortality rate has been constrained such that removals by the fishery have not exceeded the replacement capacity of the population. As a consequence, the population has been able to recover from epizootic events during periods of reduced mortality from disease. The SARC continues to consider this characteristic indicative of a stock that is not in an overfished state.

The stability in market-size abundance in 2012 and over the past several years at or above target levels in the face of flood-induced mortality and epizootics provides additional confidence that the stock is not overfished. This stability over time appears to result from opposing processes in different regions of the stock and from compensatory density-dependent processes. For example, in 2011, flooding caused extensive mortality on the upper beds that was offset by reduced disease pressure also due to the flooding on the lower beds. Likewise, high survival of a 2010 set appears to have been boosted by faster growth rates allowing more oysters to reach market size sooner.

A second metric of importance that permits a determination of overfishing is surplus production. A characteristic of overfishing is a negative surplus production in a stock. For oysters under the management goal of conserving marketable abundance, this is best expressed by submarket surplus as defined in an earlier section. In populations controlled by epizootic disease, submarket surplus potential will cycle transiently between negative and positive states during the epizootic cycle, lending a degree of uncertainty to the potential of the stock from one year to the next. The Delaware Bay stock has been managed since SAW-1 under the expectation that natural mortality will be at epizootic levels (the 75th percentile). This is a distinctly precautionary approach that should minimize the number of years in which the population cannot achieve positive submarket surplus. A retrospective examination of the surplus production under this management approach shows that net submarket surplus has been near zero or positive in every year since port-sampling began (Figure 61): the calculation of net submarket surplus requires information on the size frequency of landings for which data collection began in 2004. It is this surplus that has sustained market size abundance above target levels. The retrospective is based on observed stock dynamics as measured in the survey including observed abundance, size frequency, and mortality, rather than being based on any theoretical stock relationships. Thus, the retrospective focuses on actual stock performance under the 2005-2012 management program. Further support comes from a comparison of the natural mortality rate with the fishing mortality rate (Figure 60). In this case, the fishing mortality rate has been distinctly less than 20% of the total mortality rate (natural + fishing) throughout this time period and typically between 10 and 15%. A rule of thumb is that the natural mortality rate of the stock is an estimate of the fishing mortality rate that can be sustained. The fishing mortality rate has been well below the natural mortality rate consistently over the time period for which the calculation can be made (2005-2012). As a consequence, neither surplus production nor fishing mortality rates provide evidence that overfishing has occurred under the present management regime.

Finally, a new carbonate reef budget model suggests that habitat integrity may be compromised at fishing mortality rates much exceeding 5% per year (Powell et al, 2012). Simulations with this model remain uncertain due to inadequate information from Delaware Bay on the small-scale spatial structure of carbonate on the oyster beds. Nevertheless, simulations covering a range of conditions suggest that fishing rates much above 5% may result in long-term degradation of the reef framework. Fishing mortality rates have remained below 5% consistently over much of the 1953-2012 times series post-1960. This is likely one important reason that excessive reef loss has not occurred in Delaware Bay as it has in other bays throughout the oyster's range.

Based on these lines of evidence, the SARC concludes that the Delaware Bay oyster stock is not overfished and that overfishing is not occurring in 2012, nor has either condition occurred since the inception of the port-sampling program in 2004. Both are characteristic of and requirements for a sustainable stock.

Management Goals

Cultch Management

Shell planting serves a dual purpose of enhancing recruitment and maintaining shell balance. In the past, shell-planting goals have attempted to respond simultaneously to both needs. Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Shell budgets lost ground in 2011, but improved overall in 2012, particularly on the upper beds. Nevertheless, without an expanding population that can contribute an increasingly larger volume of shell via mortality, shell budgets will continue to run a deficit unless shell planting occurs. The reduction in shell planting in 2009-2012 has resulted in a deterioration of shell balance that will continue unless redressed. Shell plants substantially increase the annual incremental addition of native shell from natural mortality positively impacting the shell budget and typically result in a measureable increase in recruitment across the bed, particularly in low recruitment years. Thus, the program has proven to be a useful habitat enhancement tool. Design of a 2013 program, funds permitting, should consider the following recommendations.

- Oyster abundance has declined on Shell Rock. Intermediate transplants and possibly shell plants are likely to increase abundance if pursued in 2013 as was successfully achieved in 2009. The

SARC specifically recommends transplants from the Low Mortality region be placed on Shell Rock.

- The High Mortality region remains a concern as total shell loss is normally highest in this region, in part due to low marketable abundance due to persistently high mortality from Dermo disease. Recruitment enhancement and the small oysters that arrive incidentally from intermediate transplants can mitigate low abundance in this region. The SARC recommends a portion of the intermediate transplant program as well as shell planting be directed to this region. Specifically, transplants from the Medium Mortality Transplant beds should be placed on the upper portion of the High Mortality beds.
- Ship John and Cohansey will continue to be important to the industry in 2013. The SARC continues to recommend that shell planting and/or intermediate transplant target these beds generally but acknowledge that the declines in abundance and biomass on Shell Rock compared to conditions on Ship John and Cohansey warrant focusing efforts on Shell Rock during 2013.
- The SARC notes that the Very Low Mortality beds, due to the 2011 flood, should continue to be targeted for a spatted shell replant program. Direct shell planting is discouraged based on the recruitment time series of the Low Mortality region that indicates infrequent and unpredictable recruitment events (eg. Figure 33).
- The SARC continues to note that an unfortunate consequence to the transplant of oysters downbay is the movement of cultch downbay and the potential negative impact this may have on the donor region's shell budget. The SARC recommends continuing effort to minimize the downbay transplant of cultch. Data collected in 2011 show that cultch fractions below 25% are routinely achievable, thus the transplant program should emphasize the goal of limiting cultch fraction to < 25% in 2013.

Fishery Management

Abundance-based Exploitation Reference Points

SAW-8 in 2006 established exploitation-based reference points to be used to set recommended fishing goals. Implementation of the exploitation reference points recognizes that the fishery has been successfully managed at relatively low exploitation levels since 1995. SAW-8 suggested exploitation-based reference points based on the median exploitation rate defined in terms of the fraction of abundance removed per bay region for the years 1996 to 2005, the latest data year at that time. Since then, SARCs have retained the precedent that the 40th, 50th, and 60th percentiles of abundance-based exploitation in that time series normally be employed.

Exploitation rates can be calculated based on real (net) removals and apparent (total) removals. Real (net) removals are defined as the net of the market catch, increased or debited by the removals or additions from intermediate transplant. Apparent (total) removals are defined as the market catch plus removals by intermediate transplant. The use of real exploitation rates can result in negative numbers if an intermediate transplant added more oysters than were removed for market. The use of the apparent (total) exploitation rates overestimates the inherent productivity of beds that receive intermediate transplants and would permit potentially unsustainable harvest levels without careful implementation of the intermediate transplant program. The two values are identical for beds upbay of Shell Rock because transplants to these beds did not occur during the time frame used for establishing the exploitation rates. The precedent set in 2007 to use the real (net) exploitation rate reference points has been retained since.

The basic approach was revised in 2007 based on the 1996-2006 time series using estimates of size-dependent exploitation rates because direct market fishing and intermediate transplants remove size classes differently. Therefore, two sets of exploitation percentiles were calculated: one using the assumption that all size classes were removed proportionately and one using a knife-edge assumption that all size classes ≥ 2.5" were removed proportionately. The SARC maintained that reference points used for direct market exploitation should be based on the 1996-2006 abundance values for the ≥ 2.5" size class, as this is the target of the direct market fishery and the port sampling program validates this assumption (Figure 46). This precedent continues to be retained.

Although the oyster boats use culling devices when conducting intermediate transplants, the deckloading activity prohibits further hand culling as happens during direct market fishing. Therefore, the SARC advised that all intermediate transplant estimates use exploitation rate reference points based on all sizes of oysters and not just the ≥ 2.5" size class. This 2007 precedent also continues to be retained.

Because these abundance-based exploitation reference points are derived from a period of conservative fishery management characterized by low exploitation rates, they are likely to provide conservative management goals. The SARC maintains that these reference points be retained until the Terms of Reference permits formal review based on new information.

Regional Application of Abundance-based Exploitation Reference Points

Evidence indicates that population dynamics vary by region for the Delaware Bay natural beds oyster stock and that management goals should be established separately for each region. The regional 40th, 50th, and 60th percentile exploitation rates are generally those considered by the SARC when making recommendations.

Low and Very Low Mortality Regions

Insufficient data are available for the Low Mortality and Very Low Mortality regions to set abundance-based exploitation rates. Since 2006, SARCs have recommended that the exploitation indices for the original Medium Mortality Transplant region (Middle and Upper Middle beds) be used for these two regions with the adjustments described below.

In 2012, the Very Low Mortality region continued to suffer the effects of the extreme mortality event in 2011. Modeling using DyPoGEn indicates a 10-yr recovery time frame. Some increase in SSB in 2012 may be attributable to improvements in oyster condition. The SARC recommends keeping this region closed for 2013.

The Low Mortality region was in relatively good shape at the end of 2012 having responded well to reductions in Dermo following the 2011 flooding. Market-sized oyster abundance is above target as is SSB (Figures 54 and 53) and total abundance is not significantly below target abundance (Figure 55). Based on this response, the SARC expressed confidence in utilizing the 60th percentile of exploitation for transplant off the Low Mortality region. The SARC cautioned, however, against using the same bed in consecutive years to provide the transplant quota. The 2013 SARC advised that the Low Mortality region transplant should be directed towards Shell Rock.

Medium Mortality Transplant Region

In the early years of the Direct Market fishery until 2004, all beds on the Medium Mortality Transplant and Market regions were used primarily for intermediate transplant rather than direct market. The two Medium Mortality Market beds (Ship John and Cohansey) were targeted most often for transplanting which kept exploitation of beds further upbay very low. In 2009, SAW-11 evaluated the Medium Mortality Transplant region exploitation rates. It was found that the exploitation rates for this region divided into two groups, a very-low group and a high group that was temporally biased and dichotomized at the 50th percentile. To provide a range of outcomes for management, an intermediate value, 0.188, was added between the 40th and 60th percentiles by averaging the original 50th and 60th percentile values. The percentiles now listed as the 40th, 50th and 60th actually represent the 50th (which is roughly equivalent to the 40th), the average of the 50th and 60th, and the 60th. Those values are carried forward in Intermediate Transplant projections.

In 2010, at SAW-12, the SARC recommended that Sea Breeze be reassigned from the Medium Mortality Market region to the Medium Mortality Transplant region. This was due to the long-term trend of minimal direct market exploitation on this bed and the desire to limit intermediate transplant from Middle bed to alternate years. Transplant from Sea Breeze was attempted in 2010. Results of this program discussed at SAW-13 in 2011 show that using Sea Breeze or Upper Middle as the sole target beds for a transplant presents a challenge due to patchiness on Sea Breeze and the small area of Upper Middle. As a consequence, SAW-14 recommended that the 2012 transplant be distributed 50% from Middle and 50% from Upper Middle/Sea Breeze. This SARC further stressed that limited success on Sea Breeze would result in a reduction of the total number of oysters moved and hence, a reduction in the quota increase that might otherwise be achieved. The current SARC maintains this recommendation as a mechanism to ensure that Sea Breeze and Upper Middle contribute proportionately to avoid excessive exploitation on Middle. Although the SARC of SAW-14 strongly urged that all effort be made to accomplish the 50% transplant from Sea Breeze using the standard methods, it allowed that if these prove inadequate, a suction dredge may be used.

In 2013, the Medium Mortality Transplant region is just within the 90th percentile survey error of the abundance target (Figure 55) and significantly above the market-size abundance target (Figure 56). Mortality rate was high in 2012; however, condition was also high at survey time and SSB is very near the stock-performance target. A delayed impact of the 2011 flood on these beds was not evident, but a resurgence of Dermo disease has occurred. Whereas SAW-14 recommended caution in case of delayed flood mortality and an intermediate transplant removal not to exceed the 50th percentile level, the 2013 SARC recommends the 60th percentile of exploitation to capture a greater number of the more heavily infected oysters before they die and remove them from the region. The risk is that harvesting cannot select more or less heavily infected oysters and so mortality may increase beyond levels that will permit use of these beds in 2014. Of course, Dermo may create this situation by itself, therefore, taking advantage of these beds first seems a reasonable course of action. The SARC recommends utilizing this transplant to supplement the High Mortality region.

Medium Mortality Market Region

SAW-8 recommended that management should emphasize increased direct marketing on the Medium Mortality Market region to reduce the exploitation rate downbay. In 2005, the beds on this region were Cohansey, Ship John, and Sea Breeze. As part of the SAW-11 evaluation of the Medium Mortality regions' exploitation rates, the large inequity between the historical exploitation values and the submarket surplus projections that routinely exceeded the historical values by a significant margin, was examined. Unfortunately, no theoretical analysis has permitted a determination of f_{msy} for these beds. However, the highest measured exploitation rate since 1996 on this region fell below the 10th percentile for Shell Rock which is the bed directly downbay of Ship John[1]. In 2009, the SARC recommended an experimental fishery at the 100th percentile for the Medium Mortality Market region to evaluate the region's response to increased exploitation rates. This has continued to be SARC advice in subsequent SAWs. Since then, despite higher than average mortalities in 2012 and the four-year epizootic of 2007-2010, substantial catches in 2007-2012 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance. Thus, this region has been relatively resilient and the 2013 SARC continues the recommendation of direct market harvest from the Medium Mortality Market region at the 100th percentile rate of exploitation.

The SARC advice from 2010 forward continues to support the recommendation that Sea Breeze stay reassigned from the Medium Mortality Market region to the Medium Mortality Transplant region and that Cohansey and Ship John continue to be the only two beds in the Medium Mortality Market region.

Shell Rock Region

Due to the uniqueness of historical medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed independently as its own region. In 2009, total abundance, market abundance, and SSB on Shell Rock dropped precipitously from 2008 levels. At the following SAW, the SARC considered exploitation rates lower than those at the 40th – 60th percentiles as a response. If no intermediate transplant to Shell Rock were to occur, the SARC recommended that fishing be limited to the 25th percentile rate. With a transplant, the SARC recommendation was for fishing at the 40th percentile exploitation rate. The transplant to Shell Rock was conducted and in 2010, total abundance had increased over 2008 numbers although without as much of an increase in SSB or market-sized abundance indicating the addition of smaller oysters from the transplant.

In 2012, Shell Rock fell dramatically from a favorable position well above all target levels to below abundance and biomass targets although not below the market abundance target. The SARC recommends considerable caution with direct market exploitation from this region similar to that taken in 2009. That is, an exploitation rate at the 25th percentile should be invoked unless significant efforts are put forth to add abundance through intermediate transplanting as was done in 2009. Shell Rock has responded well to such management and the fact that market abundance remains above the target should enable an increase in exploitation to the 40th percentile but not higher once a transplant been completed.

High Mortality Region

The SARC recognizes that the High Mortality region is toward the edge of the stock's range rather than near the center and that the continuing high natural mortality rate limits the success of stock rebuilding on these beds. However, these beds can be managed to augment abundance and increase fishery yield in the short term. Use of the real (net) exploitation rates for the High Mortality region represents a precautionary approach to management. However, the SARC advises that the precautionary value of these reference points is retained only as long as an intermediate transplant program is

---

[1] Both Shell Rock and the Medium Mortality Market region have received shellplants and intermediate transplants over the years in order to enhance abundance.

incorporated into the management plan. The goal of transplanting is to move proportionately more marketable oysters downbay. In this way, most oysters moved to the High Mortality region will be available for harvest within 18 months, thus minimizing their loss to Dermo disease.

The 2013 SARC considers that this region, although improved to near-threshold levels of abundance and SSB and with market abundance above target level (probably helped by 29,475 bu of transplant moved into the region in 2012), still needs continuing attention. It recommends that a direct market fishing level above the 40th percentile not be used without receiving intermediate transplant to reduce realized exploitation rate on this region as happened in 2012 when the High Mortality region had a negative real exploitation rate. In the event the transplant occurs, exploitation should not exceed that associated with the 60th percentile.

Abundance-based Exploitation Reference Point Projections

Allocation projections for the 2013 direct market fishery (Table 22) are based on the exploitation records from 1996-2006 using the abundance of ≥2.5" oysters in each Direct Market region as the basis for estimation of the exploitation index. The SARC recommendations for exploitation rates higher than the 40th percentile on the High Mortality region or the 25th percentile on the Shell Rock region come with the proviso that intermediate transplant to the region also occurs. A significant portion of the intermediate transplant program should be carried out prior to harvest commencing on the receiving regions. The SARC is sensitive, however, to the closure rules associated with the transplant program and recognizes that the Council and NJDEP will need to maintain some beds open for harvest at the beginning of the season.

Intermediate transplant projections (Table 23) use exploitation rates based on all size classes of oysters because the deck-loading process and the bed areas used for transplanting result in catch covering the full range of size classes despite the use of culling devices. Transplant options will require transplant to occur before the additional quota allocation from the transplant can be set due to our inability to accurately predict the numbers and sizes of oysters that will be deck-loaded by transplant vessels. 'Real-Time' transplant monitoring tracks the progress of the transplant toward the abundance-based all-sizes exploitation percentile goal in numbers of oysters. Oysters in bushel samples from each boat each day are measured and quota is allocated based on the size frequency of the transplant and the 2012 port sampling bushel conversion of 266 oysters per bushel.

Management and Science Recommendations

Management

Total abundance is below the abundance target in all bay regions and near or below the threshold in four of six. A shell-planting program aimed at enhancing abundance by enhancing recruitment must continue with the aim of planting not less than 250,000 bushels annually.

The port-sampling program is required for SSB estimates of landings, improved abundance-to-bushel conversions, estimation of the shell budget, and evaluation of exploitation rates, as well as any development of size- or age-based models incorporating mortality. It must be continued to maintain these estimates that are essential for stock assessment.

The ten-year resurvey program must be continued to permit re-evaluation of grid allocation to strata to take into account changes in oyster distribution on beds as a consequence of natural population dynamics and population enhancement programs.

Because Dermo is the primary factor controlling mortality, the Dermo monitoring program should continue. As funding permits, the collection of ancillary data on mortality, size-frequency distribution, and growth rate should be continued as part of this monthly monitoring program.

The heavy set on Beadons in 2010 resulted in a transplant of seed to Bennies. This was the second attempt at such an effort and results are equivocal at best. The SARC recommends abandoning these efforts in the future as an inefficient use of resources.

A program moving spatted shell upbay should be implemented to return cultch and increase recruitment to beds where shell was removed during intermediate transplant operations. The SARC notes that the Athos shell planting on Middle is a useful precedent. Considerable concern is expressed regarding the Very Low Mortality beds. These beds may be an ephemeral resource and their exploitation may be limited to periods of high abundance such that the shell resource is not mined away eliminating their ability to function during periods of population expansion. Experimental efforts should be explored to consider ways to assist rapid recovery of these beds so that they can be used more routinely as a resource for the intermediate transplant program. The experimental plant of spatted shell to Hope Creek is an example.

The SARC recommended continuing to direct shell plants towards the Medium Mortality Market region in general and to Shell Rock in particular for 2013.

The SARC recommends developing a management strategy that moves away from percentiles of exploitation to utilizing exploitation rates directly. To assist with annual evaluations, the SARC requests that annual review of its prior recommendation for intermediate transplant and direct market harvest be presented at each SAW. Additional suggestions for new strategies included using the median +/- 25%, a box plot with the hinges set at a desired level, or 40% and 60% of the range bounded by the 0 and 100 percentiles.

The Gandy's Beach Oyster Restoration and Enhancement Area's (GBOREA) potential contribution to the total oyster stock was considered. The SARC recommends using those data which are valuable to understanding population dynamics and avoiding the temptation to add Project PORTS oyster abundance estimates to the stock assessment.

If the large but late set in 2012 survives, its success should be evaluated relative to the recent sets in 2007 and 2010. If it persists, plans should be considered regarding the possibility of altering management to spread the fishery across any areas of increased abundance.

Science

The SARC identified three top scientific priorities and several secondary priorities. Recommendations within the two categories are not prioritized. The SARC recognizes that the ability to complete science objectives is dependent upon available funding. The SARC notes the importance of continuing the Dermo monitoring program to help advance understanding of this important disease that is a dominant factor in controlling mortality across much of the stock.

Top Priorities

Re-evaluation of the stock-performance reference points should be undertaken consistent with the change in population dynamics observed between the decades of the 1990s and 2000s. The SARC recommends an evaluation be developed to examine whether or not the time period of 1990 to 2005 should continue to be used as a baseline for establishing stock performance targets and thresholds. Until then, evaluation will need to rely on exploring patterns in the long-term datasets of abundance, mortality, and recruitment to determine if sufficient change has occurred to warrant using a different portion of the time series.

Further dredge calibration information is urgently needed to determine if a temporal change in dredge efficiency is occurring or has occurred. If possible, this study should use experiments occurring simultaneously with the survey to directly test the tow-based regressions. In addition, the relationship between dredge efficiency and oyster density should be investigated.

Spat growth rates upbay of Shell Rock are needed to reconfigure the recruitment index and retire the 20-mm rule. The growth rates that are present from the 2005-2012 shell plants should be examined to develop an improved spat cut-off size for the High Mortality beds, Shell Rock, and the Medium Mortality Market beds. The same analysis should be used to update the growth indices.

Additional Science Recommendations

The importance of the variables used in the dredge calibration multiple regression model should be examined to determine if any one variable is responsible for the tendency for tow-based dredge efficiencies to be estimated higher than experimental observations in the High Mortality region.

Further evaluation of the rate of box disarticulation throughout the regions, particularly in the Low and Very Low Mortality regions is needed.

Use of the GBOREA information on growth rates up through market sizes may prove valuable as the growth data on larger size classes within the fishery are difficult to obtain. Mortality data from early size classes are not useful but those after the first year may prove useful.

A shell resource model should be developed to evaluate the importance of sources of clean shell (e.g., live oysters, boxes) in influencing recruitment. This should include evaluation of the ratios of spat to cultch and spat to oyster as well as the influence of dredging on recruitment rate.

A field experiment should be undertaken to evaluate the influence of dredging on recruitment.

The relationship between condition and other population and disease variables should be investigated and contrasted among different management areas.

A shell budget reference point should be developed. An external reference would be ideal and one may become available as a new model is developed by Powell and others.

Data on fecundity and spawning potential are needed for oysters on the Very Low Mortality region.

A long-range plan for reef management taking into account sea level rise, salinity shifts and other factors related to climate change, should be developed.

References

Banta, S.E., E.N. Powell, and K.A. Ashton-Alcox. 2003. Evaluation of dredging effort by the Delaware Bay oyster fishery in New Jersey waters. *N. Am. J. Fish. Manag.* 23:732-741.

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

Bushek, D. 2013. *Delaware Bay New Jersey Oyster Bed Monitoring Program 2012 Status Report*. Haskin Shellfish Research Laboratory, Port Norris, NJ.

Dekshenieks, M.M., E.E. Hofmann and E.N. Powell, 1993. Environmental effects on the growth and development of Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), larvae: a modeling study. *J. Shellfish Res.* 12:241-254.

Dekshenieks, M.M., E.E. Hofmann, J.M. Klinck and E.N. Powell, 1996. Modeling the vertical distribution of oyster larvae in response to environmental conditions. *Mar. Ecol. Prog. Ser.* 136:97-110.

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

HSRL. 2006. *Report of the 2006 Stock Assessment Workshop (8th SAW) for the New Jersey Delaware Bay Oyster Beds*. Haskin Shellfish Research Laboratory, Port Norris, NJ.

HSRL. 2012. *Report of the 2012 Stock Assessment Workshop (14th SAW) for the New Jersey Delaware Bay Oyster Beds*. Haskin Shellfish Research Laboratory, Port Norris, NJ.

Klinck, J.M., E.N. Powell, J.N. Kraeuter, S.E. Ford and K.A. Ashton-Alcox. 2001. A fisheries model for managing the oyster fishery during times of disease. *J. Shellfish Res.* 20:977-989.

Kraeuter, J.N., S. Ford, & M. Cummings. 2007. Oyster growth analysis: a comparison of methods. *J. Shellfish Res*. 26:479-491.

Narváez, Diego A., John M. Klinck, Eric N. Powell, Eileen E. Homann, John Wilkin and Dale B. Haidvogel. 2012. Modeling the dispersal of Eastern oyster (*Crassostera virginica*) larvae in Delaware Bay. *J. Mar. Res.* 70:381-409.

Powell, E.N., K.A. Ashton-Alcox, S.E. Banta and A.J. Bonner. 2001. Impact of repeated dredging on a Delaware Bay oyster reef. *J. Shellfish Res*. 20:961-975.

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

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

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

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

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

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

Powell, E.N., J.M. Klinck and E.E. Hofmann. 2011. Generation time and the stability of sex-determining alleles in oyster populations as deduced using a gene-based population dynamics model. *J. Theor. Biol.* 271:27-43.

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

Powell, E.N., K.A. Ashton-Alcox. Submitted 2012. Is overwinter mortality commonplace in Delaware Bay oyster populations? *J. Shellfish Res.*

Table 1. Ten year resurvey schedule for NJ Delaware Bay oyster beds and number of grids on each bed. All beds were resurveyed prior to 2009 when the current schedule was implemented. One grid is 0.2" latitude x 0.2" longitude and approximately 25 acres (101,175 m^2 or 10.1 hectares).

Bed	# Grids	# Grids/Year	Year Resurveyed
Year 1		132	2009
Cohansey	83		
Bennies Sand	49		
Year 2		136	2010
Ship John	68		
Nantuxent Point	68		
Year 3		136	2011
Beadons	38		
Middle	51		
Vexton	47		
Year 4		141	2012
Sea Breeze	48		
Shell Rock	93		
Year 5		141	Scheduled~2013
Upper Arnolds	29		
New Beds	112		
Year 6		171	
Bennies	171		
Year 7		128	
Arnolds	99		
Strawberry	29		
Year 8		139	
Upper Middle	84		
Hog Shoal	23		
Liston Range	32		
Year 9		125	
Hawk's Nest	28		
Hope Creek	97		
Year 10		140	
Fishing Creek	67		
Round Island	73		

Table 2. Grid restratification on Sea Breeze and Shell Rock after resurveying in Spring 2012. Strata are determined on a per-bed basis after ranking grids by oyster density. Low quality grids have no oysters or very low oyster density and account for the first 2% of the cumulative oyster abundance on a bed. Grids that account for the middle 48% of cumulative abundance on a bed are Medium quality and grids that account for the upper 50% of cumulative abundance on a bed are High quality. Sea Breeze has 48 grids total and Shell Rock has 93 grids total.

Increase in Grid Quality (2011-2012)	Sea Breeze	Shell Rock
Low to High	0	0
Low to Medium	3	3
Medium to High	5	6

Decrease in Grid Quality (2011-2012)	Sea Breeze	Shell Rock
High to Low	1	1
High to Medium	4	6
Medium to Low	4	7

Table 3. Sampling scheme for the 2012 Fall survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of sampled grids devoted to that bed stratum. The strata designations are described in Table 2. The Transplant stratum includes those grids that received transplant in the survey year or shell plant within the previous two years. Egg Island and Ledge are sampled in alternate years.

Region	Bed	High Quality	Medium Quality	Low Quality	Transplant
Very Low	Hope Creek	4	4	0	1
Mortality	Fishing Creek	2	3	0	0
	Liston Range	2	4	0	0
Low	Round Island	2	3	0	0
Mortality	Upper Arnolds	2	3	0	0
	Arnolds	3	3	0	0
Medium	Upper Middle	1	3	0	0
Mort.Trans.	Middle	3	4	0	1
	Sea Breeze	3	4	0	0
Medium	Cohansey	5	5	0	0
Mort.Mkt.	Ship John	6	5	0	2
Shell Rock	Shell Rock	4	6	0	2
High	Bennies Sand	3	6	0	3
Mortality	Bennies	3	9	0	1
	Nantuxent Pt.	3	3	0	1
	Hog Shoal	3	3	0	0
	Strawberry	1	3	0	0
	Hawk's Nest	2	3	0	0
	New Beds	2	7	0	0
	Beadons	2	3	0	0
	Vexton	2	2	0	0
	Egg Island	0	0	0	0
	Ledge	1	4	0	0
Total		59	90	0	11

Grand Total:
160

Table 4. Dredge efficiency estimates expressed as *q*, the reciprocal of the efficiency *e*: $q = 1/e$. The value *q* is the multiplier by which swept area catches are converted to m^{-1} values. Dredge efficiency experiments were conducted on various beds between 2000 and 2006. The results split into two groups; one upbay and one downbay. The upper bay group includes all beds upbay of Shell Rock[1].

	Live Juvenile	Live Sub-market	Live Market	Live Total	Box Juvenile	Box Sub-market	Box Market	Box Total	Cultch
2003 Upbay	7.39	7.07	12.27	7.30	14.04	10.69	13.27	10.87	13.71
2000 Upbay	10.46	6.89	6.93	9.40	11.26	18.98	11.00	11.47	21.49
2006 Downbay	4.93	4.42	3.25	3.93	3.63	8.22	6.36	6.01	9.05
2005 Downbay	5.25	3.60	3.85	4.87	12.94	6.87	3.85	6.69	9.70
2003 Downbay	3.19	3.26	3.93	3.11	4.03	6.78	10.09	4.64	8.14
2000 Downbay	3.33	2.57	1.54	2.83	6.78	4.03	8.85	6.50	9.55

[1] 2003 and 2000 values are taken from Powell et al., 2002 and Powell et al., 2007.

Table 5. Results of the 2012 Fall survey for the Delaware Bay natural oyster beds of New Jersey. Data from 2010 and 2011 are included for comparison. Data are displayed by bed from upbay to downbay. Bushels/haul are the average number of bushels brought up by the three dredge hauls from each grid. With the exception of information on Dermo, all bed-average data are weighted averages based on the relative proportion of High and Medium quality grids on the bed[1]. Transplant grids are not included in bed-average estimates. In no case are samples normalized to swept area, nor are dredge efficiency corrections included; all analyses are on a per bushel basis. For each bed, Percent Oyster is ranked by sample from highest to lowest and is based on the volume of oyster in the sample divided by the total volume of shell, oyster, and debris. H, High quality; M, Medium quality; T transplant or shell plant grids. Per bushel numbers are based on counts adjusted to a 37-quart bushel. Percent Mortality is based on the box count in the sample. Dermo Prevalence is the percentage of oysters with detectable infections. Dermo Weighted Prevalence is the average infection intensity (scored from 0 to 5) of all sampled oysters. Condition index is a measure of the dry meat weight of an oyster relative to its hinge-to-lip (longest) dimension.

---

[1] The use of weighted averages represents a change from SAW reference documents prior to 2007 (the 10th SAW). Prior to 2007, averages were simple averages of the bushel samples taken on each bed

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted			#/bushel (> 2.5")			% oysters (> 2.5")			Condition Index Dry-Meat/Height		
		2012	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010
Hope Creek	1.8	40.1 T	37.0 M	64.2 H																								
Hope Creek	3.6	39.5 H	30.5 H	58.8 H																								
Hope Creek	2.0	33.0 M	29.6 H	58.3 H																								
Hope Creek	2.8	32.8 H	27.1 H	57.2 M	266	317	453	52	10	290	35	46	8	0	10	20	0	0.3	0.2	27	33	87	10	10	19	0.007	0.003	0.007
Hope Creek	3.6	30.5 H	24.8 M	52.4 H																								
Hope Creek	3.2	29.6 H	24.7 M	41.0 M																								
Hope Creek	4.7	25.5 M	23.7 M	34.1 M																								
Hope Creek	2.3	23.0 M	22.9 H	32.9 M																								
Hope Creek	3.7	15.1 M																										
Liston Range	2.4	57.3 H	54.2 M	75.2 H																								
Liston Range	2.8	53.6 M	39.1 H	42.7 H																								
Liston Range	0.2	24.8 M	35.9 H	39.7 M	222	352	316	41	19	164	15	21	4	0	10	10	0	0.3	0.5	59	72	83	27	20	26	0.009	0.004	0.008
Liston Range	0.2	13.3 M	30.0 M	35.2 M																								
Liston Range	0.9	9.7 M	28.5 M	34.7 M																								
Liston Range	0.1	1.1 H	13.0 M	12.3 M																								
Fishing Creek	2.6	46.2 H	41.1 M	62.8 M																								
Fishing Creek	0.8	23.7 M	36.1 H	54.6 H	166	224	350	15	4	190	28	48	12	0	0	50	0	0	0.1	39	23	113	23	10	32	0.009	0.005	0.007
Fishing Creek	0.2	23.6 M	28.3 M	51.3 H																								
Fishing Creek	1.0	22.3 H	21.1 M	36.3 M																								
Fishing Creek	0.5	8.5 M	14.6 H	31.2 M																								
Round Island	3.1	55.5 M	48.8 H	64.5 H																								
Round Island	0.8	54.1 M	42.7 M	54.3 M	301	294	348	29	15	203	16	28	19	0	0	70	0	0	1.1	131	39	130	44	13	37	0.011	0.004	0.007
Round Island	0.1	45.5 M	35.3 M	50.6 M																								
Round Island	3.9	39.9 H	32.6 H	47.5 M																								
Round Island	5.2	34.0 H	2.2 M	40.4 H																								
Upper Arnolds	4.3	63.0 H	54.0 H	58.5 H																								
Upper Arnolds	4.1	60.9 M	46.7 M	58.3 H	358	295	288	47	24	141	14	28	21	45	15	90	0.9	0.4	1.1	118	75	85	33	25	29	0.011	0.005	0.007
Upper Arnolds	3.3	60.0 H	38.7 H	45.0 M																								
Upper Arnolds	1.5	58.4 M	36.7 M	32.6 M																								
Upper Arnolds	4.7	23.2 M	20.6 M	18.5 M																								
Arnolds	3.0	65.1 H	62.9 H	72.1 H																								
Arnolds	4.1	65.0 H	59.6 H	66.7 H																								
Arnolds	3.6	56.5 H	57.7 H	61.4 H	224	279	302	24	23	126	9	20	17	45	15	75	1.1	0.2	1.2	79	52	87	35	19	29	0.012	0.005	0.009
Arnolds	3.6	46.4 M	35.8 M	57.8 M																								
Arnolds	0.8	17.5 M	18.6 M	25.9 M																								
Arnolds	0.6	9.1 M	10.2 M	18.3 M																								
Upper Middle	5.2	43.0 M	40.3 H	57.4 M																								
Upper Middle	4.3	39.1 M	25.1 M	50.2 H	224	118	212	22	5	109	13	21	20	80	15	65	2.6	0.3	0.9	94	31	67	42	26	32	0.01	0.007	0.01
Upper Middle	4.7	34.1 H	6.1 M	27.2 M																								
Upper Middle	3.3	33.4 M	5.1 M	0.0 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			#/bushel (> 2.5")			% oysters (> 2.5")			Condition Index Dry-Meat/Height		
		2012	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010
Middle	2.8	62.5 H	74.5 H	57.3 H																											
Middle	3.5	61.9 H	59.1 H	48.2 M																											
Middle	3.7	59.9 H	39.1 M	34.9 M																											
Middle	1.2	49.1 T	33.7 H	33.1 H	194	216	187	98	32	118	25	17	22	75	40	65	1.8	1.1	1.4	97	64	62	50	30	33	0.01	0.006	0.011
Middle	0.4	40.2 M	31.0 M	5.6 M																											
Middle	2.2	39.8 M	29.8 M																												
Middle	0.7	27.5 M	28.8 T																												
Middle	1.5	18.8 M	16.6 M																												
Ship John	1.9	75.4 H	71.4 H	72.0 H																											
Ship John	2.6	69.0 H	68.6 H	69.8 M																											
Ship John	4.3	67.7 M	67.3 M	69.1 H																											
Ship John	2.1	64.7 H	63.0 H	60.6 M																											
Ship John	1.5	63.8 H	62.0 H	59.1 M																											
Ship John	1.3	63.3 T	59.2 M	58.6 H	251	299	255	170	77	167	26	14	22	80	75	95	1.9	1.5	2.4	110	69	91	44	23	36	0.009	0.006	0.011
Ship John	3.2	60.4 H	57.2 H	57.6 H																											
Ship John	3.6	56.3 H	55.8 H	56.9 H																											
Ship John	3.6	55.6 M	52.1 M	52.0 H																											
Ship John	1.5	52.0 M	9.8 M	44.2 M																											
Ship John	3.0	49.1 M	8.0 M	23.8 M																											
Ship John	1.6	34.0 T																													
Ship John	2.0	28.9 M																													
Cohansey	2.4	83.5 H	75.1 H	74.6 T																											
Cohansey	3.2	64.5 M	73.5 H	63.7 M																											
Cohansey	4.1	61.1 H	69.4 H	59.2 H																											
Cohansey	2.1	58.4 H	65.1 T	57.6 M																											
Cohansey	4.1	57.0 M	64.3 H	53.1 H	208	253	228	109	25	131	23	15	19	80	70	95	1.5	0.9	2.1	98	78	67	47	31	29	0.011	0.008	0.01
Cohansey	3.2	51.9 H	62.9 M	46.5 H																											
Cohansey	1.4	43.6 H	61.2 H	41.2 H																											
Cohansey	3.4	34.5 M	42.3 M	36.0 M																											
Cohansey	4.3	30.2 M	31.9 M	30.4 H																											
Cohansey	2.1	22.5 M	31.9 M	27.9 M																											
Cohansey			19.3 M	27.7 M																											
Sea Breeze	2.8	71.9 M	61.9 M	74.3 H																											
Sea Breeze	1.1	57.1 H	50.6 H	64.9 M																											
Sea Breeze	2.6	56.5 H	45.3 H	64.0 H	251	413	250	139	71	277	20	13	13	95	70	95	2.4	1.6	1.6	120	64	68	48	16	27	0.013	0.008	0.01
Sea Breeze	1.3	54.9 M	31.9 M	18.4 M																											
Sea Breeze	1.8	49.2 M	28.9 H	18.0 H																											
Sea Breeze	1.1	44.4 H																													
Sea Breeze	0.1	36.4 M																													
Shell Rock	1.6	78.4 T	81.9 T	85.2 T																											
Shell Rock	1.2	76.4 M	79.9 H	82.1 T																											
Shell Rock	0.7	74.0 M	76.7 T	82.0 M																											
Shell Rock	2.6	72.5 T	72.1 H	80.0 T																											
Shell Rock	2.3	71.9 M	71.2 M	76.8 H																											
Shell Rock	4.2	70.2 H	69.8 H	76.5 H	306	367	482	383	77	481	24	15	11	100	85	85	2.5	1.6	1.8	136	76	97	44	21	20	0.011	0.009	0.008
Shell Rock	0.8	66.6 H	67.8 M	75.4 H																											
Shell Rock	2.1	63.5 H	56.5 H	72.5 H																											
Shell Rock	1.0	59.8 M	54.7 T	64.8 M																											
Shell Rock	0.7	59.3 H	36.1 M	55.1 M																											
Shell Rock	1.8	57.5 M	18.3 M	39.4 M																											
Shell Rock	1.9	42.6 M																													

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted			#/bushel (> 2.5")			% oysters (> 2.5")			Condition Index Dry-Meat/Height		
		2012	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010
Bennies Sand	1.3	77.4 T	74.1 T	81.0 T																								
Bennies Sand	0.5	73.1 H	41.2 H	54.4 T																								
Bennies Sand	1.2	66.9 M	39.1 T	50.2 T																								
Bennies Sand	1.4	53.7 H	33.1 H	45.6 M																								
Bennies Sand	2.0	53.6 T	32.9 H	43.1 T																								
Bennies Sand	3.5	48.5 H	19.7 M	39.8 H	204	117	208	332	101	129	18	25	22	85	60	90	1.5	0.8	2.3	70	37	58	34	32	28	0.011	0.009	0.01
Bennies Sand	2.7	41.6 M	18.4 M	27.8 M																								
Bennies Sand	4.3	40.9 M	17.1 M	25.8 M																								
Bennies Sand	2.1	40.7 T	16.9 M	25.8 M																								
Bennies Sand	2.8	26.1 M	16.3 M	23.0 M																								
Bennies Sand	0.6	20.7 M	9.3 T	21.6 H																								
Bennies Sand	2.2	20.1 M	5.6 M	14.3 M																								
Bennies	4.0	52.9 H	21.2 T	43.8 T																								
Bennies	3.2	39.6 H	20.9 T	39.4 M																								
Bennies	1.2	26.4 H	19.4 H	35.0 H																								
Bennies	0.5	23.0 T	17.8 M	24.4 T																								
Bennies	0.1	12.4 M	9.2 H	16.6 M																								
Bennies	4.3	9.0 M	3.3 M	13.4 H																								
Bennies	1.9	4.6 M	2.7 T	11.9 M	74	16	44	213	36	20	14	32	34	65	80	100	1.8	1.5	3.6	12	10	19	17	59	43	0.009	0.011	0.015
Bennies	3.9	3.9 M	1.2 M	11.6 M																								
Bennies	0.5	2.9 M	0.9 M	10.4 M																								
Bennies	0.7	0.9 M	0.6 M	5.7 H																								
Bennies	2.8	0.7 M	0.3 M	4.0 M																								
Bennies	3.6	0.6 M	0.1 H	1.3 M																								
Bennies	2.3	0.3 M	0.0 M	0.3 M																								
Bennies			0.0 M	0.2 M																								
Bennies			0.0 M																									
Hog Shoal	4.1	54.2 H	43.3 M	48.2 H																								
Hog Shoal	1.0	40.4 M	36.8 M	44.1 M																								
Hog Shoal	2.7	32.9 H	28.8 H	33.2 H	110	97	119	371	90	103	31	22	24	100	95	85	2.1	2.3	1.5	51	35	29	46	36	24	0.012	0.01	0.01
Hog Shoal	6.2	23.2 M	21.9 H	6.7 H																								
Hog Shoal	2.8	8.7 H	7.9 H	2.8 M																								
Hog Shoal	4.5	6.6 M	3.5 M	0.7 M																								
Nantuxent Point	1.4	62.5 H	72.9 H	72.5 H																								
Nantuxent Point	1.9	62.3 H	38.1 M	67.2 T																								
Nantuxent Point	4.6	51.2 T	31.6 T	60.8 T																								
Nantuxent Point	3.1	29.2 H	29.7 H	58.4 M	147	146	329	175	69	340	26	30	22	100	95	100	2.3	2.2	1.8	63	35	58	43	24	18	0.011	0.011	0.012
Nantuxent Point	4.7	26.5 M	25.6 H	57.9 H																								
Nantuxent Point	3.7	26.4 M	11.5 M	50.4 T																								
Nantuxent Point	1.9	5.4 M	4.0 M	45.4 H																								
Nantuxent Point				31.3 M																								
Nantuxent Point				23.8 M																								
New Beds	2.4	34.9 H	18.4 H	27.8 H																								
New Beds	1.5	21.7 M	17.3 M	22.7 M																								
New Beds	4.1	14.6 M	10.1 H	17.8 M																								
New Beds	2.1	14.0 H	9.9 M	17.2 H	78	36	43	437	93	17	13	25	38	80	100	100	2	2.8	2.6	15	20	22	19	54	51	0.011	0.014	0.018
New Beds	2.8	13.8 M	9.5 M	15.0 M																								
New Beds	3.4	2.6 M	9.2 M	6.1 M																								
New Beds	3.8	1.6 M	8.6 M	5.5 M																								
New Beds	1.9	1.1 M	3.4 M	2.2 M																								
New Beds	3.4	0.5 M	3.2 M	0.5 M																								

Bed	**Bushels/ Haul**	**Percent Oyster**			**Oysters/ Bushel**			**Spat/ Bushel**			**Percent Mortality**			**Dermo Prevalence**			**Dermo Weighted Prevalence**			**#/bushel (> 2.5")**			**% oysters (> 2.5")**			**Condition Index Dry-Meat/Height**		
		2012	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010	**2012**	2011	2010
Strawberry	1.6	5.6 H	37.2 M	4.6 M																								
Strawberry	1.3	2.3 M	7.9 M	3.4 H	15	71	7	7	40	4	22	27	51	80	55	90	2.4	1.3	2.4	3	21	3	17	30	44	0.007	0.015	0.011
Strawberry	2.0	1.9 M	4.1 M	0.4 M																								
Strawberry	1.9	0.8 M	2.8 H	0.0 M																								
Hawk's Nest	1.2	42.0 M	57.7 M	85.6 M																								
Hawk's Nest	2.1	34.7 H	39.1 H	32.7 H	94	186	278	361	104	252	34	23	23	95	75	90	2.5	1.3	1.7	37	47	60	39	26	21	0.011	0.011	0.01
Hawk's Nest	2.2	30.5 H	36.6 H	14.0 H																								
Hawk's Nest	1.3	2.2 M	10.8 M	12.0 M																								
Hawk's Nest	2.6	0.0 M	0.4 M	1.7 M																								
Vexton	3.0	25.6 H	31.7 H	15.5 H																								
Vexton	2.7	4.4 H	6.6 H	4.4 H	30	31	31	312	94	46	30	29	16	95	85	80	2.4	2.5	1.3	9	6	5	31	21	15	0.011	0.011	0.009
Vexton	0.4	3.5 M	2.9 M	2.0 M																								
Vexton	1.4	2.9 M	0.0 M	0.7 M																								
Vexton				0.0 M																								
Beadons	2.9	27.8 H	48.6 M	78.4 H																								
Beadons	0.5	18.1 M	26.6 M	67.1 H																								
Beadons	0.8	12.1 M	14.9 H	19.0 H	118	182	315	917	362	300	26	15	9	65	65	70	1.5	1.4	1.5	14	21	10	12	11	3	0.008	0.007	0.006
Beadons	3.6	7.9 H	11.6 M	2.5 M																								
Beadons	4.5	0.3 M	10.5 H	2.5 M																								
Beadons				2.3 M																								
Beadons				1.5 M																								
Ledge	5.4	1.0 M		0.5 M																								
Ledge	4.5	0.4 M		0.3 M	2		1	3		0	47		63	45		80	0.9		1.8	1		1	35		87	0.011	0.043	0.035
Ledge	4.9	0.2 H		0.2 H																								
Ledge	7.5	0.1 M		0.0 M																								
Ledge	0.1	0.0 M		0.0 M																								
Egg Island			2.1 M																									
Egg Island			2.0 M																									
Egg Island			0.3 M			4			8			31			71			2			1			29		0.007	0.015	0.005
Egg Island			0.3 H																									
Egg Island			0.0 M																									
Egg Island			0.0 M																									

Table 6. Average annual bay-wide oyster and spat abundance per 37-qt. bushel for 1990-2012. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Years within a category with the same underlying letter designation are not significantly different at α = 0.05. Mean of the annual abundance values for 1990-2012: oyster = 170; spat = 97.

Oyster Abundance

Tukey's Rankings								Mean	Year
A								262.18	1996
A	B							242.10	1990
A	B	C						236.95	1992
A	B	C	D					233.30	2011
A	B	C	D	E				210.55	1991
A	B	C	D	E	F			195.80	1995
A	B	C	D	E	F			195.41	2010
A	**B**	**C**	**D**	**E**	**F**			**191.58**	**2012**
A	B	C	D	E	F			186.57	1997
A	B	C	D	E	F	G		182.63	1998
	B	C	D	E	F	G		178.10	1993
	B	C	D	E	F	G		168.92	2000
		C	D	E	F	G	H	154.69	1994
			D	E	F	G	H	153.01	2009
				E	F	G	H	148.80	1999
				E	F	G	H	144.89	2001
				E	F	G	H	143.64	2008
				E	F	G	H	133.92	2002
					F	G	H	122.98	2003
					F	G	H	122.59	2007
					F	G	H	113.30	2004
						G	H	101.08	2006
							H	81.46	2005

Spat Abundance

Tukey's Rankings								Mean	Year
A								266.61	1991
A	**B**							**257.96**	**2012**
A	B	C						209.11	1997
A	B	C						204.37	1999
	B	C	D					174.72	1994
		C	D	E				156.34	1995
		C	D	E				154.05	1990
		C	D	E	F			141.37	2010
		C	D	E	F	G		125.80	1998
			D	E	F	G	H	87.71	2009
				E	F	G	H	81.24	2007
					F	G	H	64.84	2011
						G	H	46.13	2002
						G	H	44.73	1993
							H	35.12	2000
							H	29.12	2008
							H	25.00	1992
							H	24.17	1996
							H	22.62	2004
							H	20.37	2003
							H	19.18	2005
							H	18.75	2006
							H	12.18	2001

Table 7. Average annual oyster and spat abundance per 37-qt. bushel for the Low Mortality beds for 1990-2012. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Years within a category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean of the annual abundance values for 1990-2012: oyster = 378; spat = 74.

Oyster Abundance									Spat Abundance							
Tukey's Rankings							Mean	Year	Tukey's Rankings						Mean	Year
A							698.22	1992	A						370.54	1991
A	B						662.89	1991		B					227.59	1990
A	B	C					587.68	1993		B	C				179.47	2010
A	B	C	D				574.69	1990			C	D			116.91	1999
A	B	C	D	E			482.69	1995			C	D	E		98.58	1998
	B	C	D	E	F		450.44	1994				D	E	F	84.06	1995
		C	D	E	F	G	405.47	2002				D	E	F	83.54	1994
		C	D	E	F	G	375.39	2001				D	E	F	80.09	2007
			D	E	F	G	353.05	1996				D	E	F	52.81	2005
				E	F	G	345.84	2010				D	E	F	51.88	1996
				E	F	G	336.80	2009				D	E	F	51.83	1997
				E	F	G	329.78	2011				D	E	F	47.50	2008
				E	F	G	327.77	1999				D	E	F	44.67	2002
				E	**F**	**G**	**322.21**	**2012**				D	E	F	38.29	1992
				E	F	G	318.13	2000				D	E	F	35.93	2009
				E	F	G	310.92	1997				**D**	**E**	**F**	**35.63**	**2012**
				E	F	G	309.79	2003					E	F	23.00	1993
				E	F	G	302.39	2008					E	F	22.41	2011
				E	F	G	262.81	2005					E	F	20.15	2000
				E	F	G	258.54	1998					E	F	15.72	2006
					F	G	254.58	2004						F	13.96	2001
						G	220.83	2006						F	10.63	2003
						G	199.00	2007						F	4.95	2004

Table 8. Average annual oyster and spat abundance per 37-qt. bushel for the combined Medium Mortality beds including Shell Rock for 1990-2012. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Years within a category with the same underlying letter designation are not significantly different at α = 0.05. Mean of the annual abundance values for 1990-2012: oyster = 243; spat = 105.

Oyster Abundance

Tukey's Rankings								Mean	Year
A								433.61	1996
A	B							363.77	2000
A	B	C						328.04	1990
A	B	C	D					314.30	2011
	B	C	D	E				304.43	1992
	B	C	D	E	F			290.91	1997
	B	C	D	E	F	G		270.36	1998
	B	C	D	E	F	G		257.91	2003
	B	**C**	**D**	**E**	**F**	**G**		**256.53**	**2012**
	B	C	D	E	F	G		254.75	1991
		C	D	E	F	G	H	234.45	2010
		C	D	E	F	G	H	232.99	2001
		C	D	E	F	G	H	226.94	1993
		C	D	E	F	G	H	211.90	2002
			D	E	F	G	H	207.60	1999
			D	E	F	G	H	197.28	1995
			D	E	F	G	H	195.53	1994
				E	F	G	H	191.16	2005
					F	G	H	179.59	2008
					F	G	H	171.88	2006
						G	H	168.45	2009
						G	H	157.24	2004
							H	132.04	2007

Spat Abundance

Tukey's Rankings							Mean	Year
A							302.38	1999
A	B						268.28	1991
A	B	C					195.48	1995
A	B	C					194.59	1998
A	**B**	**C**					**189.94**	**2012**
	B	C					181.78	1994
	B	C	D				161.20	2010
		C	D	E			140.16	1990
		C	D	E	F		127.47	1997
		C	D	E	F	G	114.47	2007
		C	D	E	F	G	88.92	2002
		C	D	E	F	G	84.23	2009
			D	E	F	G	53.89	1993
			D	E	F	G	47.43	2000
			D	E	F	G	47.28	2011
				E	F	G	37.42	1996
				E	F	G	34.86	2006
				E	F	G	29.97	2004
				E	F	G	28.33	2003
				E	F	G	27.77	1992
				E	F	G	27.27	2005
					F	G	25.39	2008
						G	11.65	2001

Table 9. Average annual oyster and spat abundance per 37-qt. bushel for the High Mortality beds for 1990-2012. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Years within a category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean of the annual abundance values for 1990-2012: oyster = 106; spat = 113.

Oyster Abundance

Tukey's Rankings						Mean	Year
A						230.33	1996
A	B					161.61	1995
A	B	C				159.26	1998
A	B	C				157.79	1990
A	B	C				152.35	1992
A	B	C	D			148.86	2010
A	B	C	D	E		132.09	1997
	B	**C**	**D**	**E**	**F**	**119.53**	**2012**
	B	C	D	E	F	117.31	2009
	B	C	D	E	F	114.23	1994
	B	C	D	E	F	112.27	1991
	B	C	D	E	F	106.20	1999
	B	C	D	E	F	96.88	2011
	B	C	D	E	F	87.58	2000
	B	C	D	E	F	83.71	2008
	B	C	D	E	F	77.42	2001
	B	C	D	E	F	74.96	1993
	B	C	D	E	F	67.03	2006
	B	C	D	E	F	62.90	2005
		C	D	E	F	61.87	2004
			D	E	F	50.32	2007
				E	F	45.74	2003
					F	29.03	2002

Spat Abundance

Tukey's Rankings							Mean	Year
A							**394.05**	**2012**
A	B						306.63	1997
A	B	C					272.61	1991
A	B	C	D				247.31	1994
	B	C	D	E			201.29	1999
	B	C	D	E	F		182.36	1995
	B	C	D	E	F	G	160.97	1990
		C	D	E	F	G	135.27	1998
		C	D	E	F	G	126.68	2010
			D	E	F	G	110.87	2011
			D	E	F	G	110.18	2009
				E	F	G	66.20	2007
				E	F	G	48.98	1993
				E	F	G	43.96	2000
					F	G	29.25	2008
					F	G	26.61	2002
						G	24.77	1992
						G	24.00	2004
						G	20.13	2003
						G	17.35	1996
						G	15.20	2005
						G	13.83	2001
						G	13.49	2006

Table 10. Percentile positions in the indicated time series for the given bay regions and stock variables. A lower percentile equates to a lower value of the variable relative to the entire time series. Table is divided into the 60-year time series (1953-2012) and the 24-year time series (1989-2012). Very Low Mortality beds are not included in the percentile evaluations of the time series. Recruitment values do not include the enhancements from shell planting. ND, no data.

1953 – 2012

	Abundance	Spawning Stock Biomass	Market >2.5″ Abundance	Recruitment	Spat to Adult Ratio	Box-count Mortality	Biomass Mortality	Fishing Mortality	Market Fishing Mortality
Baywide	.192	ND	ND	.625	.858	.775	ND	.260	ND
Low mortality	.208	ND	ND	.258	.325	.675	ND	.788	ND
Medium Mortality Transplant	.225	ND	ND	.358	.492	.875	ND	.703	ND
Medium Mortality Market	.342	ND	ND	.442	.625	.858	ND	.534	ND
Shell Rock	.242	ND	ND	.575	.842	.775	ND	.551	ND
High Mortality	.225	ND	ND	.792	.958	.575	ND	.050	ND

1989 – 2012

	Abundance	Spawning Stock Biomass[1]	Market >2.5″ Abundance[1]	Recruitment	Spat to Adult Ratio	Box-count Mortality	Biomass Mortality[2]	Fishing Mortality[3]	Market Fishing Mortality[3]
Baywide	.271	.283	.773	.812	.896	.604	.615	.469	.800
Low Mortality	.396	.674	.818	.396	.438	.646	.692	.700	.600
Medium Mortality Transplant	.229	.543	.955	.479	.604	.812	.539	.833	.800
Medium Mortality Market	.396	.457	.773	.562	.688	.812	.692	.433	.733
Shell Rock	.146	.152	.455	.562	.896	.771	.769	.567	.800
High Mortality	.396	.152	.500	.896	.999	.229	.231	.167	.467

[1]SSB and market abundance values used the 1990-2012 time series
[2]Biomass mortality used the 1999-2012 time series
[3]Whole-stock and market-size fishing mortality used the 1997-2012 time series

Table 11. Average one-year growth increment for animals reaching market (3″) size, the average minimal size of oysters reaching market size in one year, and age-to-market size for oysters from four bay regions, based on von Bertalanffy growth curves of Kraeuter et al. (2007).

Bed Group	Data Source	Average Growth Increment	Average Minimal Size Reaching Market	Age to Market
Low Mortality	Arnolds	0.24″	2.76″	7.0 yr
Medium Mortality	Middle, Cohansey	0.49″	2.51″	4.3 yr
Shell Rock	Shell Rock	0.52″	2.48″	4.0 yr
High Mortality	Bennies Sand, New Beds	0.66″	2.34″	3.6 yr

Table 12. Summary of shell planting activities for 2012. Shell planting was carried out in early summer, 2012. Direct plants occurred on Ship John grids. The Hope Creek replant of spatted shell was moved up from downbay by suction dredge in August 2012. Spat per bushel estimates are from the clamshell volumes in Fall 2012 survey dredge samples. Projections of marketable bushels used natural mortality at the juvenile rate in year 1 and at the adult rate in following years. The mortality rates used were the 50th percentiles of the 1989-2012 time series for the Low Mortality beds (Hope Creek) and the Medium Mortality Market beds (Ship John). Calculation of years to market size used von Bertalanffy parameters (see text; Oyster Condition and Growth) for the Low Mortality region (Hope Creek) and the Medium Mortality region (Ship John). Bushel conversion used 266 oysters per bushel from port sampling data.

	Plant Type	Clamshell Planted (bu)	Clamshell Spat bu^{-1}	Clamshell Total Spat	Median Juvenile Mortality Rate	Juvenile Years	Median Adult Mortality Rate	Adult Years	Potential Mkt-Size Abund.(bu)
Hope Creek 59	replant	12,000	109	1,309,034	0.088	1	0.106	4	2,585
Ship John 36	direct	50,000	27	1,334,810	0.251	1	0.169	2	2,488
Ship John 53	direct	50,000	85	4,260,606	0.251	1	0.169	2	7,942
Total		112,000		6,904,450					13,015

Table 13. Summary of 2012 recruitment on 2011 shell plants. Shell planting was carried out in summer, 2011. Spat per bushel estimates are from the clamshell volumes in Fall 2012 survey dredge samples. Projections of marketable bushels used natural mortality at the juvenile rate in year 1 and at the adult rate in following years. The mortality rates used were the 50th percentiles of the 1989-2012 time series for Shell Rock and the High Mortality beds (Bennies Sand). Calculation of the years to market size used von Bertalanffy parameters (see text; Oyster Condition and Growth) for Shell Rock and the High Mortality region (Bennies Sand). Bushel conversion used 266 oysters per bushel from port sampling data. ---, no clamshell found in the sample.

	Plant Type	Clamshell Planted (bu)	Clamshell Spat bu^{-1}	Clamshell Total Spat	Median Juvenile Mortality Rate	Juvenile Years	Median Adult Mortality Rate	Adult Years	Potential Mkt-Size Abund.(bu)
Middle 26	replant	18,000	---	---	---	---	---	---	---
Shell Rock 11	direct	50,000	575	28,759,091	0.483	1	0.187	2	67,636
Bennies Sand 11	direct	50,000	313	15,669,277	0.475	1	0.242	2	29,672
Total		118,000		44,428,368					97,308

Table 14. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

Year	Very Low Mortality	Low Mortality	Medium Mortality Transplant	Medium Mortality Market	Shell Rock	High Mortality
1996		0.19	0.13	0.08	0.09	0.12
1997		0.20	0.48	0.70	0.92	3.06
1998		0.92	1.68	1.91	1.64	2.03
1999		0.59	1.93	2.19	4.04	4.54
2000		0.15	0.27	0.17	0.79	1.08
2001		0.05	0.05	0.09	0.22	0.44
2002		0.20	0.73	0.35	4.59	0.86
2003		0.05	0.15	0.16	0.38	1.28 (1.54)
2004		0.05	0.21	0.23	1.85	2.07
2005		0.31	0.17	0.21	0.46 (1.01)	0.54 (0.62)
2006		0.14	0.40	0.33	0.32 (0.64)	0.42 (1.00)
2007	0.37	0.18	0.78 (0.88)	1.71 (1.80)	1.53	2.54 (2.59)
2008	0.39	0.22	0.12	0.09 (0.10)	0.50	0.86 (1.64)
2009	0.11	0.15	0.71	0.66	1.89 (2.75)	2.12 (2.56)
2010	0.87	0.74	0.97	0.81	1.37 (1.94)	1.57 (2.12)
2011	0.05	0.10	0.22 (0.27)	0.27	0.31 (0.46)	3.03 (3.15)
2012	0.29 (0.30)	0.17	0.60	0.78 (0.79)	2.09	7.69

Table 15. Average half-lives for surficial oyster shell on Delaware Bay oyster beds for 1999-2012.

Region	Location	Half-life (yr)
Very Low Mortality	Hope Creek	Insufficient data
	Fishing Creek	Insufficient data
	Liston Range	Insufficient data
Low Mortality	Round Island	Insufficient data
	Upper Arnolds	8.27
	Arnolds	5.69
Medium Mort.Trans.	Upper Middle	Insufficient data
	Middle	4.72
	Sea Breeze	6.63
Medium Mort.Mkt.	Cohansey	5.84
	Ship John	2.83
Shell Rock	Shell Rock	2.95
High Mortality	Bennies Sand	5.35
	Bennies	8.76
	Nantuxent Point	3.58
	Hog Shoal	5.42
	Strawberry	9.06
	Hawk′s Nest	5.73
	New Beds	109.78
	Beadons	13.18
	Vexton	7.25
	Egg Island	84.18
	Ledge	Insufficient data

Table 16. Harvest statistics for 2012. Fraction covered indicates the estimated fraction of bed area swept by industry dredges during the harvest season. Fractions above 1 indicate a total swept area greater than the bed area. Bed areas are for the Medium quality and High quality grids only.

Region	Bed	Bed Area (m^2)	Fraction Covered	Bushels Harvested	Harvest Fraction
Very Low Mortality	Hope Creek	2,970,947	0.00	0	0
	Fishing Creek	1,273,459	0.00	0	0
	Liston Range	1,167,525	0.00	0	0
Low Mortality	Round Island	1,910,960	0.00	0	0
	Upper Arnolds	1,911,274	0.00	0	0
	Arnolds	2,548,739	0.00	0	0
Medium Mort.Trans.	Upper Middle	956,159	0.00	0	0
	Middle	3,294,561	0.00	0	0
	Sea Breeze	2,126,067	0.05	170	0
Medium Mort.Mkt.	Cohansey	4,995,452	1.43	11,288	0.14
	Ship John	4,890,278	2.34	17,755	0.23
Shell Rock	Shell Rock	4,572,252	3.10	22,628	0.29
High Mortality	Bennies Sand	3,190,495	1.00	5,836	0.07
	Bennies	8,404,238	0.18	2,155	0.03
	Nantuxent Point	2,552,807	4.17	14,332	0.18
	Hog Shoal	1,808,455	0.77	1,965	0.03
	Strawberry	1,808,668	0.00	0	0
	Hawk's Nest	2,021,560	0.67	1,568	0.02
	New Beds	4,788,189	0.12	443	0.01
	Beadons	851,243	0.00	0	0
	Vexton	1,277,106	0.00	0	0
	Egg Island	4,045,293	0.00	0	0
	Ledge	1,916,423	0.00	0	0
	Total or Mean	64,325,991	1.38	78,140	1.00

Table 17. Statistics for oysters going to market obtained from port sampling. Sizes are given in inches. Percentiles refer to the percentile sizes of the size-frequency distribution. Numbers are per 37-qt bushel.

	Mean size	25th percentile	50th percentile	75th percentile	Mean Number per bushel	Number ≥ 2.5″ per bushel
2004	3.04	2.79	3.08	3.37	302	265
2005	3.05	2.73	3.13	3.42	275	235
2006	3.22	2.95	3.24	3.54	260	238
2007	3.23	2.94	3.26	3.59	262	235
2008	3.12	2.77	3.17	3.50	299	252
2009	3.14	2.74	3.21	3.58	277	230
2010	2.52	1.67	2.87	3.40	318	204
2011	2.78	2.13	2.99	3.38	350	238
2012	2.98	2.59	3.07	3.42	307	240

Table 18. Intermediate transplant records for number of oysters per bushel and proportions of oysters, cultch, and boxes moved downbay from the listed bed regions targeted between 2003 and 2012. Three gear types were used: a suction dredge; a standard industry dredge without the automatic culler engaged, and a standard industry dredge with the automatic culler engaged. Percentages are based on bushel volume.

	Region	Oys bu^{-1}	Oys	Cultch	Box
Suction Dredge Transplants (2004)	Low Mortality	438	35%	61%	5%
Unculled Transplants (2004-2011)	Low Mortality	378	36%	61%	3%
	Medium Mortality Transplant	391	68%	28%	5%
	High Mortality	543	37%	59%	5%
Culled Transplants (2003-2011)	Very Low Mortality	575	70%	25%	5%
	Low Mortality	440	66%	27%	7%
	Medium Mortality Transplant	332	66%	28%	6%
	Medium Mortality Market	325	75%	18%	7%
Culled Transplants (2012)	Low Mortality	587	63%	28%	8%
	Medium Mortality Transplant	424	69%	26%	5%
	Overall Suction	438	35%	61%	5%
	Overall Unculled	437	47%	49%	4%
	Overall Culled	447	68%	25%	6%

Table 19. Intermediate transplant as a proportion of the total Direct Market quota from 2008 to 2012. Quota and transplant decisions are based on SARC recommendations of several abundance-based exploitation rate projections for each region. Some regional options for the lower bay regions come with SARC advice to transplant from upbay regions prior to direct market fishing. Additional quota from transplants is determined post-transplant from the proportion of marketable oysters in the transplants converted to bushels using the latest average number of oysters per bushel from the port-sampling program.

Year	Region*	Direct Market Quota (bu)	Trans. Quota Add'n (bu)	Total Quota (bu)	Trans. Fract of Quota
2008	Med.Mort.Mkt.	16,710	8,161	24,871	0.33
	Shell Rock	29,889	0	29,889	0
	High Mortality	22,150	6,337	28,487	0.22
	TOTAL	**68,749**	**14,498**	**83,247**	**0.17**
2009	Med.Mort.Mkt.	16,444	7,699	24,143	0.32
	Shell Rock	21,858	0	21,858	0
	High Mortality	15,971	17,578	33,549	0.52
	TOTAL	**54,273**	**25,277**	**79,550**	**0.32**
2010	Med.Mort.Mkt.	23,472	0	23,472	0
	Shell Rock	10,938	5,678	16,616	0.34
	High Mortality	13,793	21,548	35,341	0.61
	TOTAL	**48,203**	**27,226**	**75,429**	**0.36**
2011	Med.Mort.Mkt.	31,551	6,540	38,091	0.17
	Shell Rock	24,775	0	24,775	0
	High Mortality	16,995	16,647	33,642	0.49
	TOTAL	**73,321**	**23,187**	**96,508**	**0.24**
2012	Med.Mort.Mkt.	30,219	0	30,219	0
	Shell Rock	22,071	0	22,071	0
	High Mortality	14,006	15,132	29,138	0.52
	TOTAL	**66,296**	**15,132**	**81,428**	**0.19**

*Sea Breeze was a Med.Mort.Mkt. bed prior to 2011

Table 20. Submarket surplus as projected for 2011 and 2012 by SAW-13 and SAW-14 and as projected for 2013. Projections for 2013 used the 50th and 75th percentiles of natural mortality and a conversion of 266 oysters bu^{-1}. Growth rate on the Very Low Mortality beds was assumed to be similar to that on the Low Mortality beds.

SAW-13 Submarket Surplus Estimate for 2011

Bay Region	50th Percentile Estimate Submarket Surplus (market-equivalent bushels)	75th Percentile Estimate Submarket Surplus (market-equivalent bushels)
Very Low Mortality	88,330	85,072
Low Mortality	81,672	75,492
Medium Mortality		
Transplant	121,813	108,432
Market	277,391	221,042
Shell Rock	61,744	52,777
High Mortality	64,793	35,344
Total	695,743	578,159

SAW-14 Submarket Surplus Estimate for 2012

Bay Region	50th Percentile Estimate Submarket Surplus (market-equivalent bushels)	75th Percentile Estimate Submarket Surplus (market-equivalent bushels)
Very Low Mortality	24,903	24,170
Low Mortality	61,567	58,526
Medium Mortality		
Transplant	149,274	133,297
Market	304,149	265,258
Shell Rock	87,424	80,712
High Mortality	73,821	57,988
Total	701,138	619,951

SAW-15 Submarket Surplus Estimate for 2013

Bay Region	50th Percentile Estimate Submarket Surplus (market-equivalent bushels)	75th Percentile Estimate Submarket Surplus (market-equivalent bushels)
Very Low Mortality	30,163	19,895
Low Mortality	122,506	116,614
Medium Mortality		
Transplant	193,377	175,086
Market	362,734	314,442
Shell Rock	48,720	42,758
High Mortality	121,581	99,439
Total	879,081	768,234

Table 21. Area-specific stock performance biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass for 1989-2005 (1990-2005 for biomass) with the exception of the Very Low Mortality beds. The threshold is taken as half of these values. Reference point estimates for the Very Low Mortality beds are obtained by assuming the equivalent condition on a per-area basis to the Low Mortality beds and using the Low Mortality bed numbers so-corrected as the base values (see text).

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Abundance						
Target (50th Percentile)	451,681,800	531,733,632	342,824,960	850,364,224	113,350,896	473,125,088
Threshold (1/2 Target)	225,840,900	265,866,816	171,412,480	425,182,112	56,675,448	236,562,544
Spawning Stock Biomass						
Target (50th Percentile)	149,078,151	175,499,360	178,104,672	337,117,920	62,450,392	267,982,768
Threshold (1/2 Target)	74,539,075	87,749,680	89,052,336	168,558,960	31,225,196	133,991,384
Market (≥ 2.5″) Abundance						
Target (50th Percentile)	36,856,056	43,388,077	46,366,382	167,407,462	25,622,244	51,205,771
Threshold (1/2 Target)	18,428,028	21,694,039	23,183,191	83,703,731	12,811,122	25,602,886

Table 22. Allocation projections for direct marketing on the High Mortality beds, Shell Rock, and the Medium Mortality Market beds based on the exploitation record from 1996-2006 using the abundance of ≥2.5″ oysters in each bay region as the basis to estimate an exploitation index. Upper and lower bounds are taken as the 40th and 60th percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest). The Medium Mortality Market region includes the 100th percentile exploitation rate. Projections use the average oysters per marketed bushel (266) derived from the 2004-2012 port-sampling program. Arrows (→) indicate SARC-recommended direct-market options. Shaded percentiles require that Intermediate Transplant must occur.

Bay Region	Percentile	Exploitation Rate	Number of Oysters Removed	Direct-market Bushels
High Mortality	→ 40th	.0122	730,049	2,745
	→ 50th	.0652	3,901,574	14,668
	→ 60th	.0782	4,679,494	17,592
Shell Rock	→ 25th	.0531	1,603,191	6,027
	→ 40th	.0870	2,626,696	9,875
	50th	.0880	2,656,888	9,988
	60th	.1140	3,441,878	12,939
Medium Mortality Market	→ 40th	.0178	4,113,325	15,464
	→ 50th	.0214	4,945,234	18,591
	→ 60th	.0267	6,169,988	23,195
	→ 100th	.0398	9,197,210	34,576

Table 23. Projections for intermediate transplants conducted on the Very Low Mortality, Low Mortality, and Medium Mortality Transplant beds. Numbers to be removed are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading with standard dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel for these regions from the 2012 intermediate transplant program or other as noted. Cullers were used for these transplants. The proportion of oysters available for market is estimated based on the fraction of oysters ≥ 2.5″ converted to bushels using the 266 oyster/bu conversion from the port-sampling program. Percentiles for the Very Low Mortality and Low Mortality beds use the exploitation reference points for the Medium Mortality Transplant beds. The 50th percentile exploitation rate of 0.0188 is the average of the 50th and 60th percentiles (0.0127 and 0.0233) from Table 24, consistent with the decision made in earlier SAWs that the original gap between these two percentiles was too large for effective management. Footnotes identify alternatives available under specified conditions.

Bay Region	Percentile	Exploitation Rate	Oysters to be Removed	Deck-load Oysters/Bu[1]	Trans-plant Bushels[1]	Marketable Bushel Equivalents
Medium Mortality Transplant	[2]40th	.0127	2,978,854	424	7,026	5,073
	[2]50th	.0188	4,409,642	424	10,400	7,510
	[2]60th	.0233	5,465,140	424	12,889	9,307
Low Mortality	[3]40th	.0127	5,429,970	587	9,250	7,022
	[3]50th	.0188	8,038,066	587	13,693	10,395
	[3]60th	.0233	9,962,070	587	16,971	12,883
Very Low Mortality	Closed					

[1] Oysters/Bu taken from 2012 intermediate transplant samples, numbers for 2013 may not be similar. Because of this, Transplant Bushels for 2013 intermediate transplant will differ, perhaps by a lot.

[2] Recommended options for 2013 with the proviso that no more than 50% of the recommended number be taken from Middle. This transplant should go to the upper High Mortality region.

[3] Recommended options for 2013. This transplant should go to Shell Rock.

Figure 1. The natural oyster beds of Delaware Bay, NJ and their regional designations. The 23 oyster beds are grouped into six regions based on the estuarine gradient of salinity that influences growth, disease, and mortality rates. Dark green, Very Low Mortality; yellow, Low Mortality; light green, Medium Mortality Transplant; light blue, Medium Mortality Market; tan, Shell Rock; dark blue, High Mortality. Beds included in each region are listed in Table 3. Bed footprints include grids from the High and Medium quality strata. Strata designation described in Table 2. Each grid is 0.2" latitude x 0.2" longitude; approximately 25 acres (101,175 m^2 or 10.1 hectares).

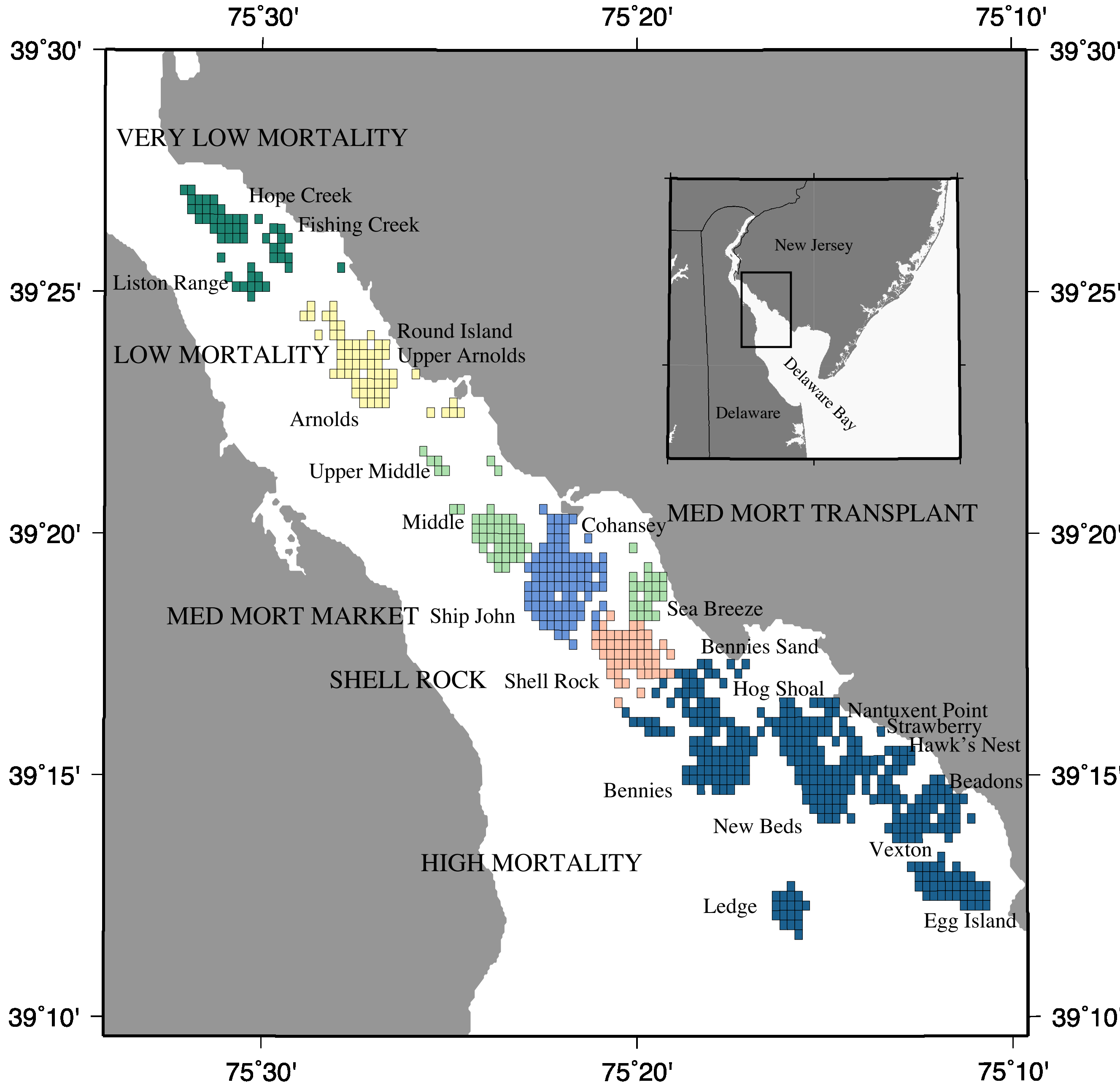


Figure 2. The footprint of the Delaware Bay, NJ natural oyster beds showing the locations of the High quality (dark shade) and Medium quality (light shade) grids. Grid strata designation described in Table 2. Each grid is 0.2" latitude x 0.2" longitude; approximately 25 acres (101,175 m^2 or 10.1 hectares). The 160 survey sites for 2012 are indicated by white stars. The depicted bed footprints are based on resurveys that began in 2005. Shell Rock and Sea Breeze were resurveyed in 2012 and their footprints updated on this map. Ledge and Egg Island beds do not have many oysters and have not been resurveyed.

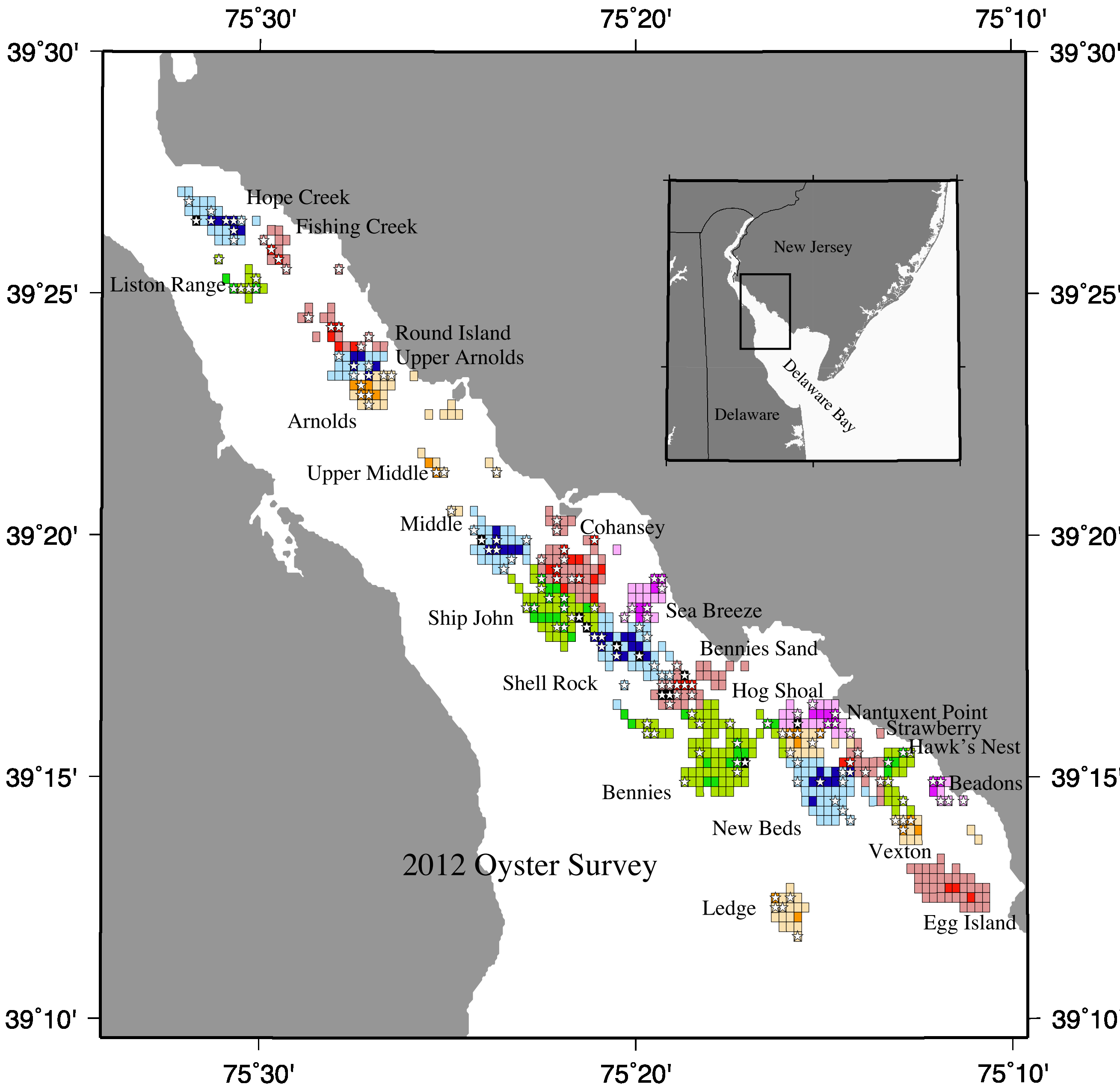
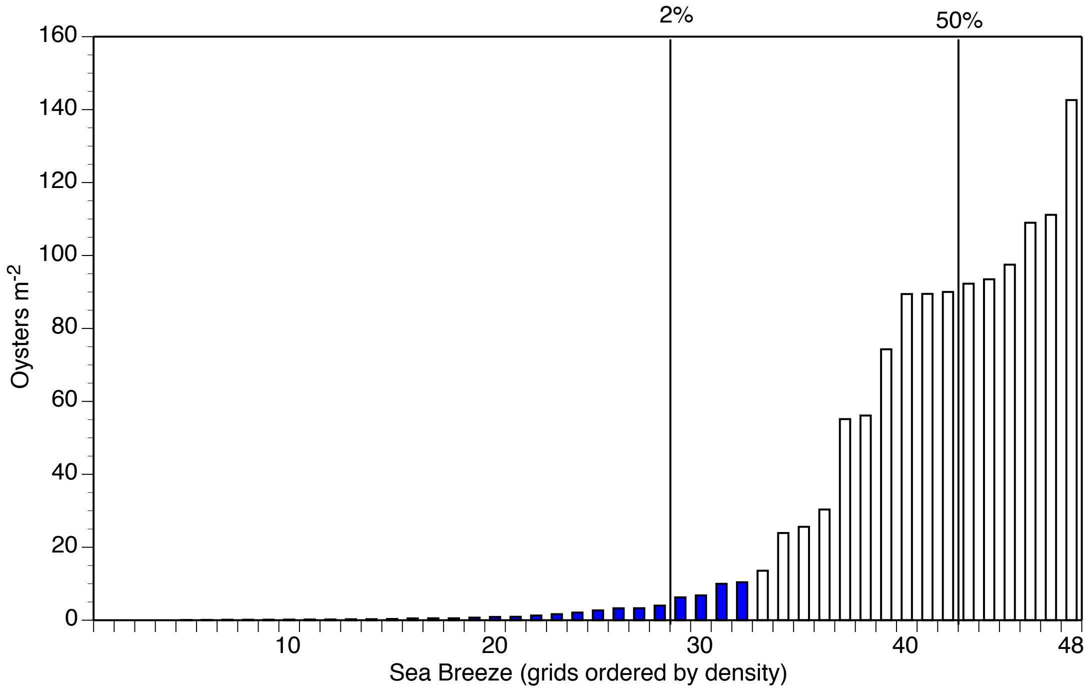
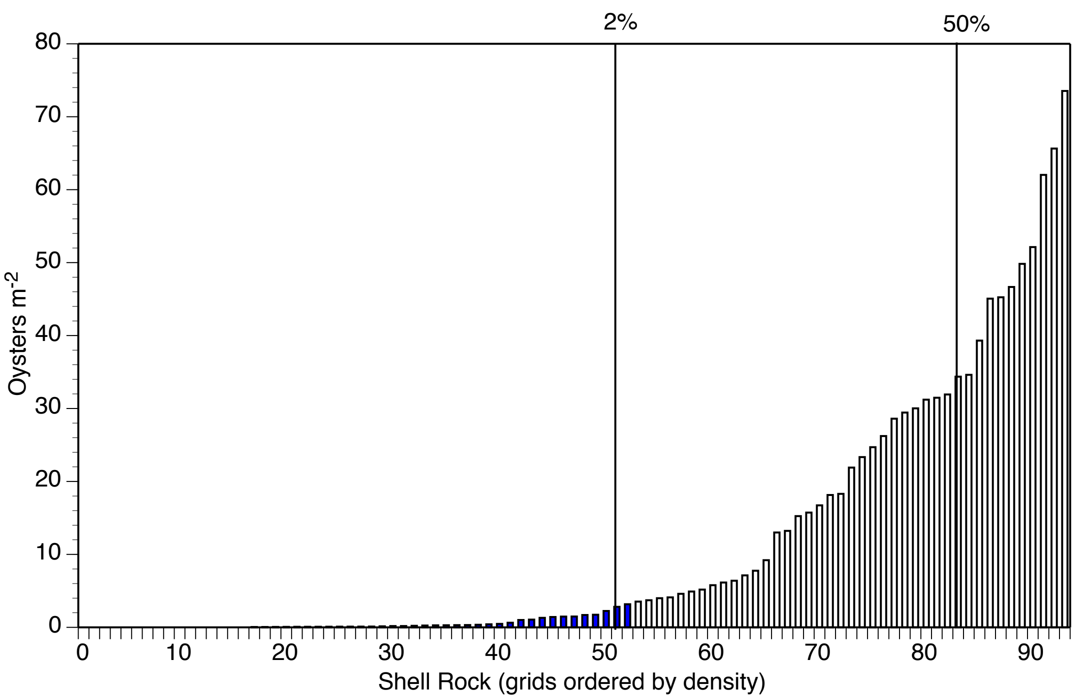
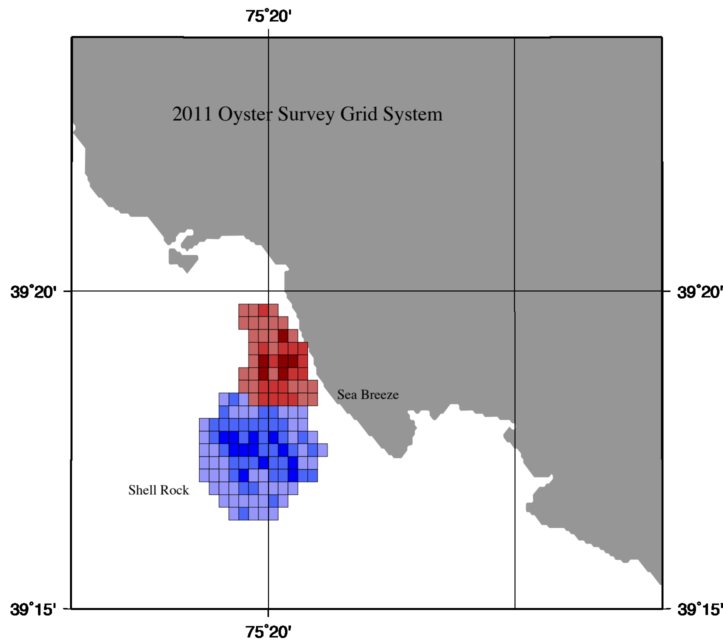


Figure 3. Relationship of cumulative oyster abundance versus density for grids ordered by increasing abundance on Sea Breeze and Shell Rock for the 2012 resurvey. The 2012 resurvey program covered all navigable grids associated with these beds. The vertical lines mark the boundary between the Low, Medium, and High quality strata. Low quality grids have no oysters or very low oyster density and account for the first 2% of the cumulative oyster abundance on a bed. Grids that account for the middle 48% of cumulative abundance on a bed are Medium quality and grids that account for the upper 50% of cumulative abundance on a bed are High quality.





Figures 4. Distribution of grids for Shell Rock and Sea Breeze in 2011 before and in 2012 after the spring 2012 resurvey shaded accordingly to oyster density. The 2012 survey program covered all navigable grids associated with these beds. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded a light color. Sea Breeze has 48 grids and Shell Rock has 93 grids.



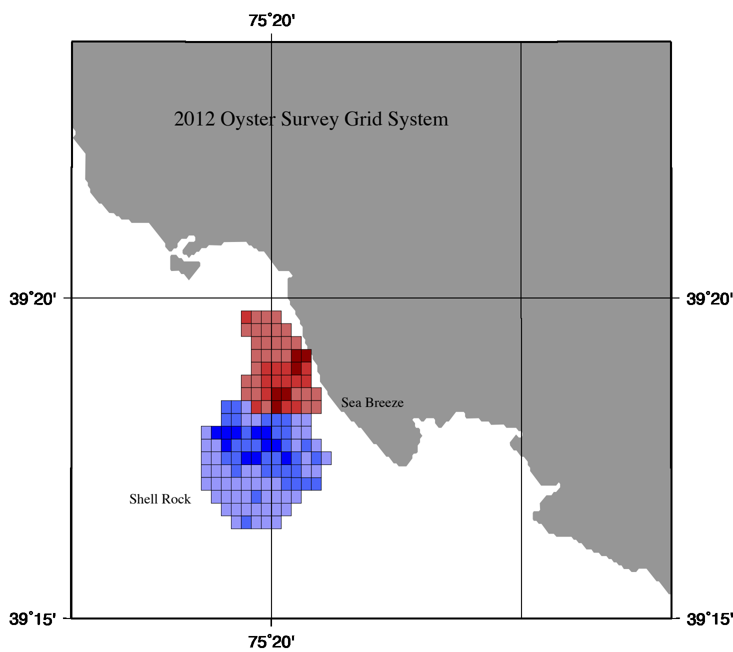


Figure 5. Estimate of q, the reciprocal of dredge efficiency, from retrospective analyses described in Powell et al. (2007) compared with directly measured values. The upbay estimates do not include the Very Low Mortality region as no direct measurements are available.

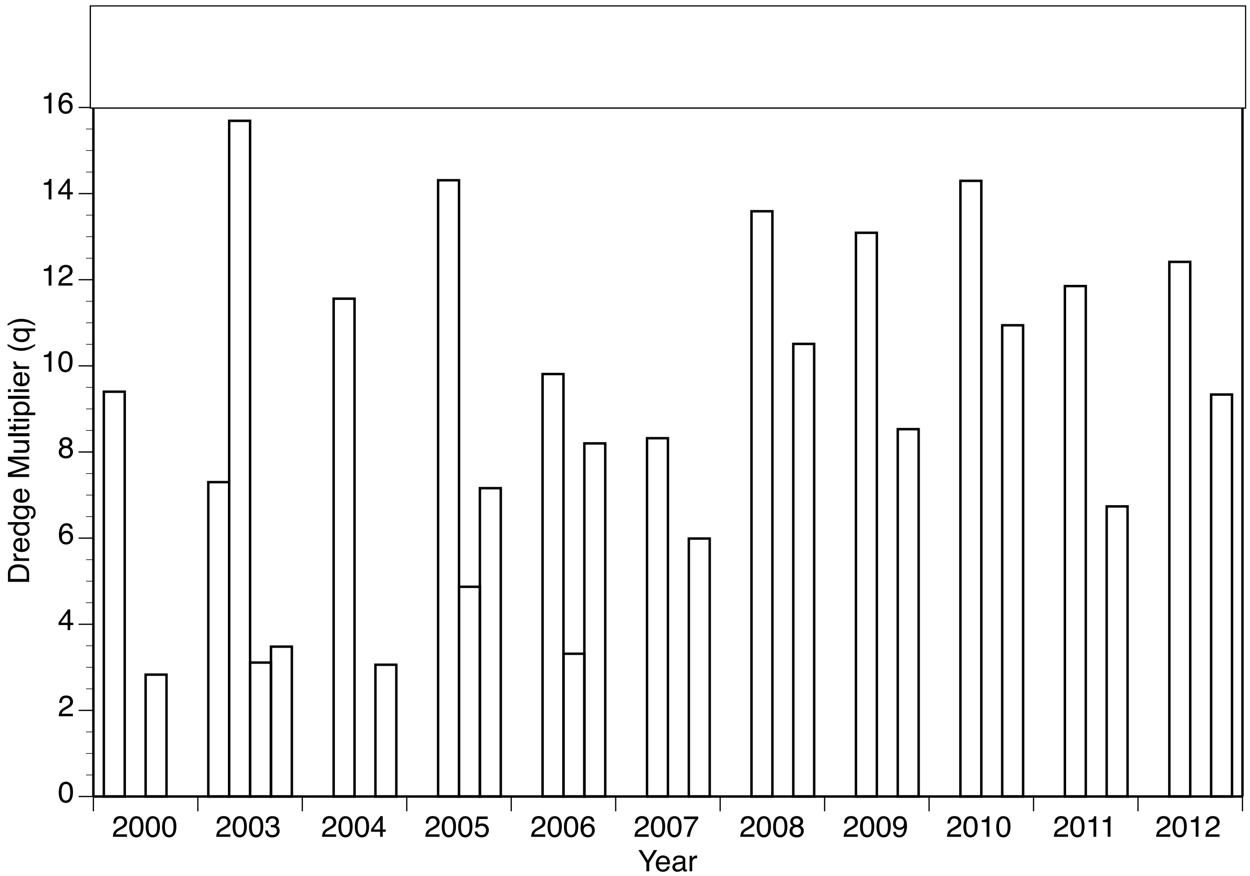


Figure 6. Oyster abundance by bay region from 1953 to 2012. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007. Large peak in High Mortality region for 1959 is due to survey artifact rather than actual region-wide abundance.

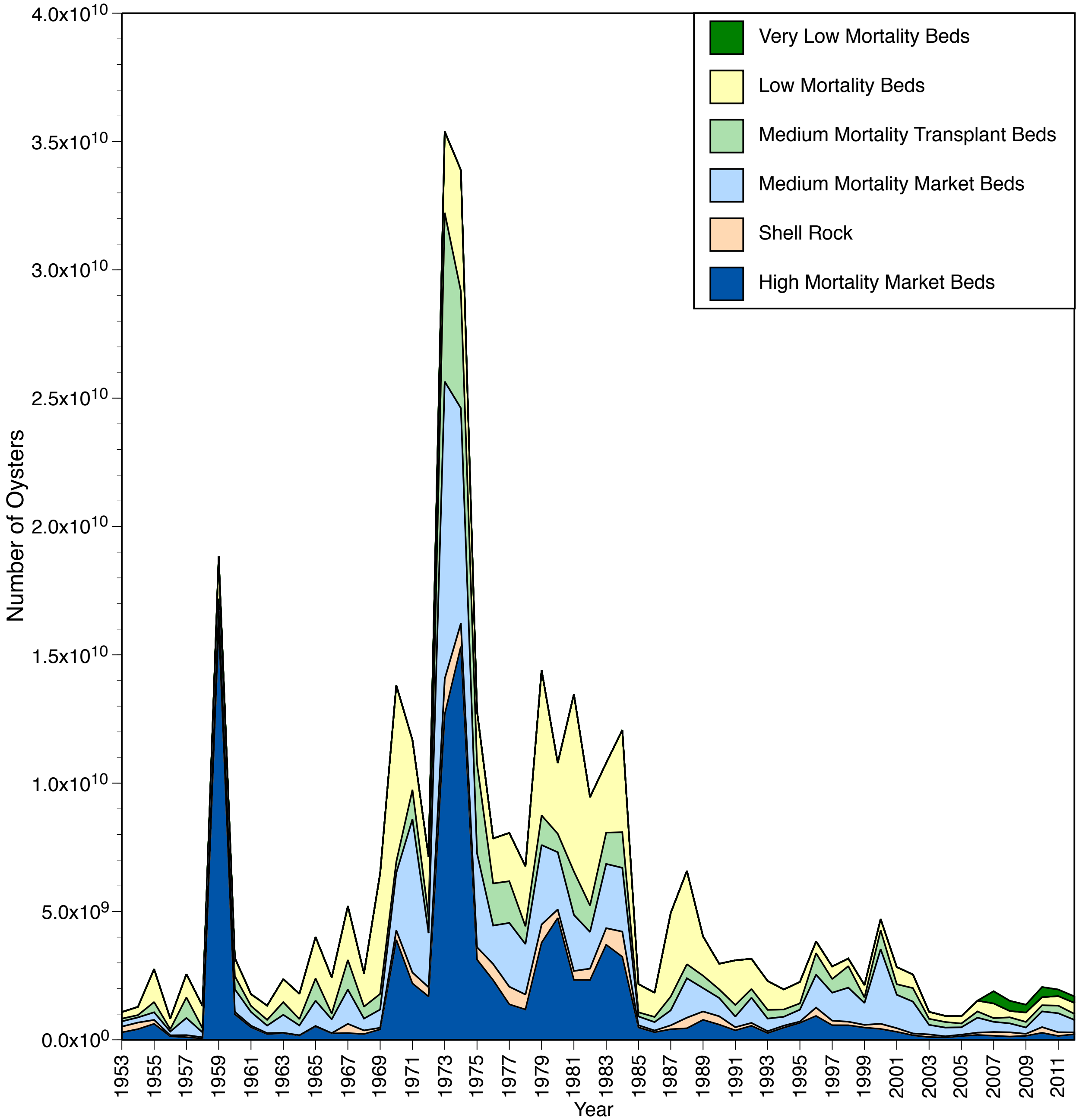


Figure 7. Time series of oyster abundance by bay region for the Dermo era, 1989-2012. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

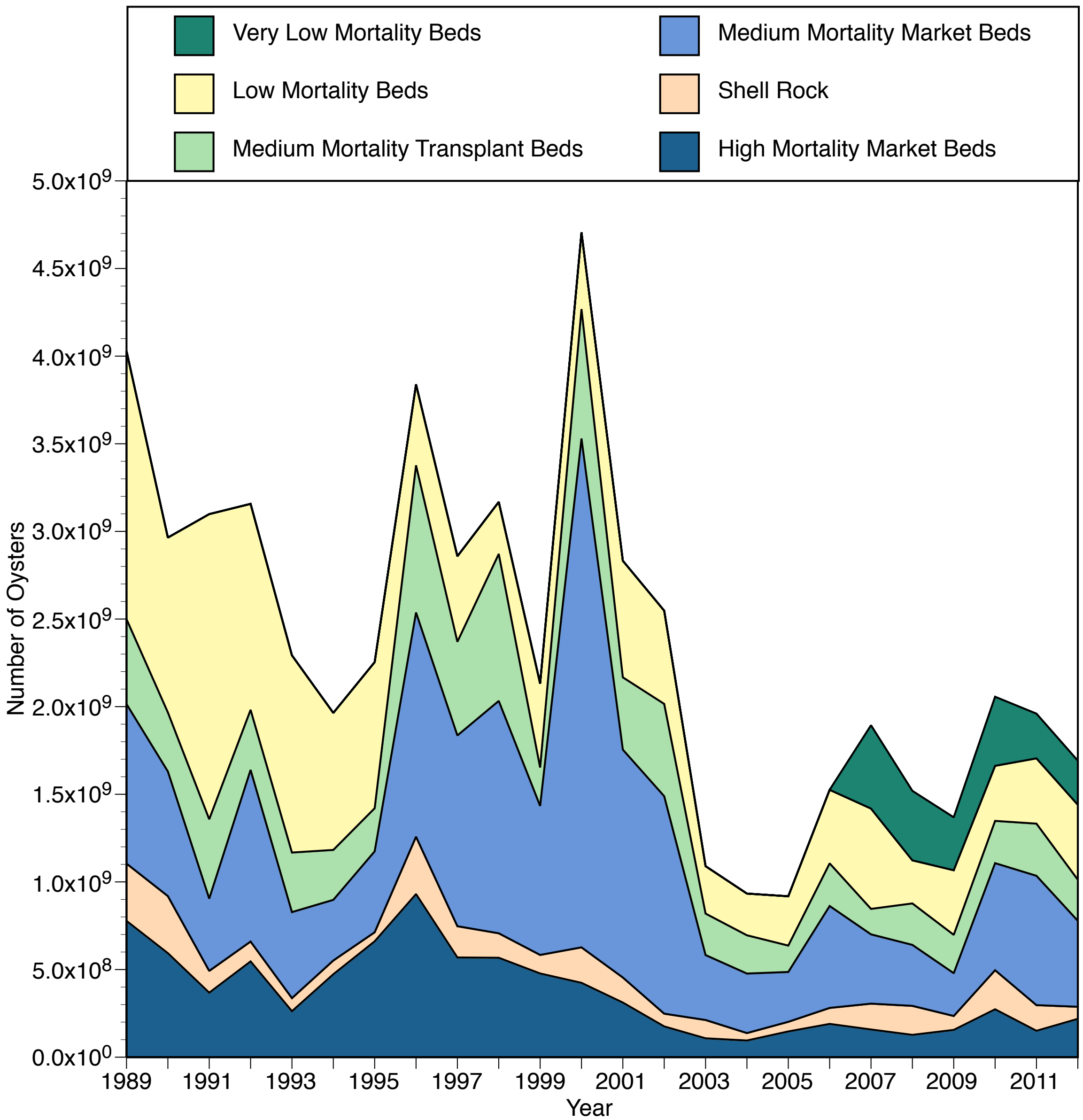


Figure 8. Fractional distribution of oyster abundance among bay regions 2007-2012 including the Very Low Mortality region. Beds included in each region are shown in Figure 1 and listed in Table 3.

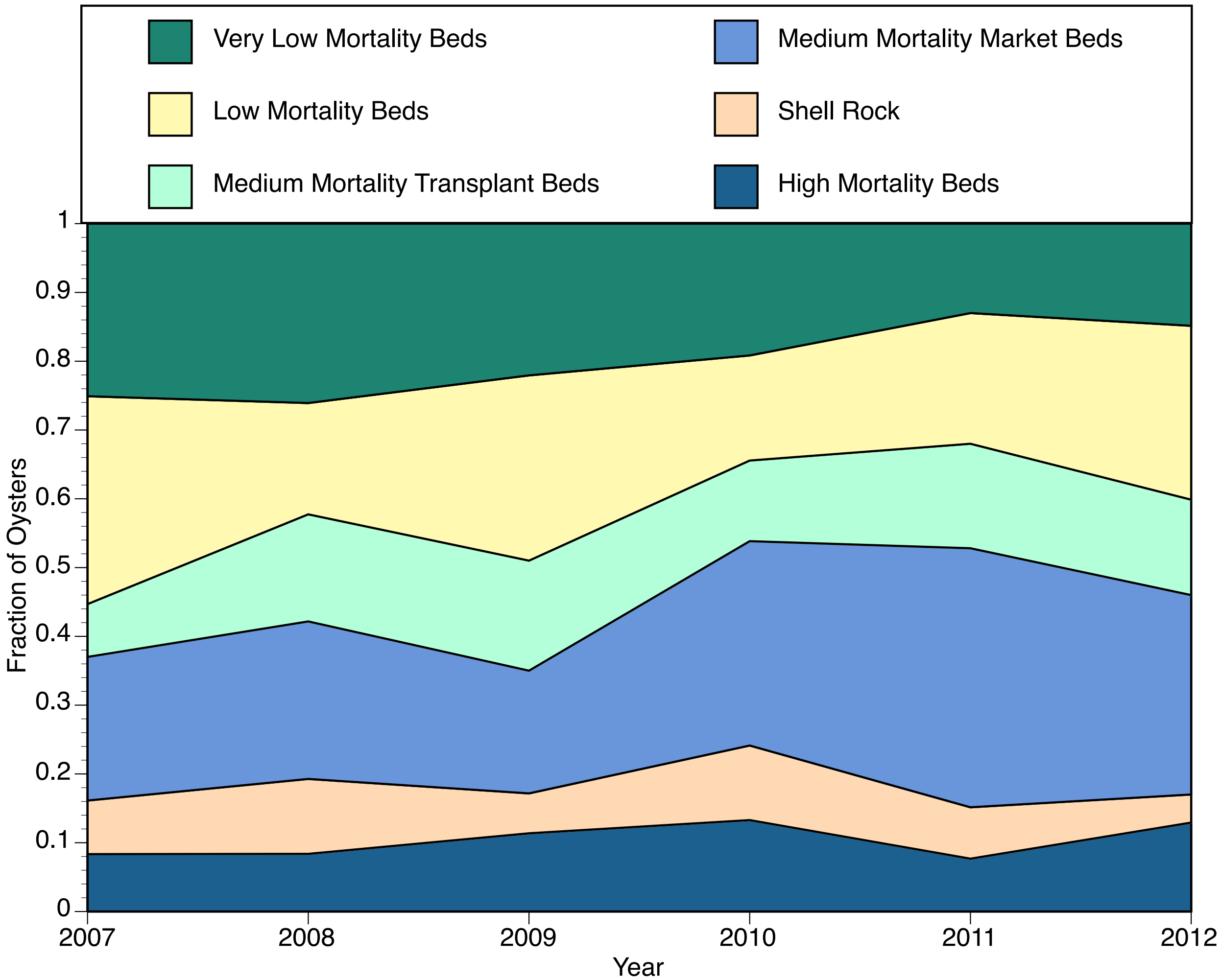


Figure 9. Fractional distribution of oyster abundance among bay regions 1953-2012. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007; they are not included here.

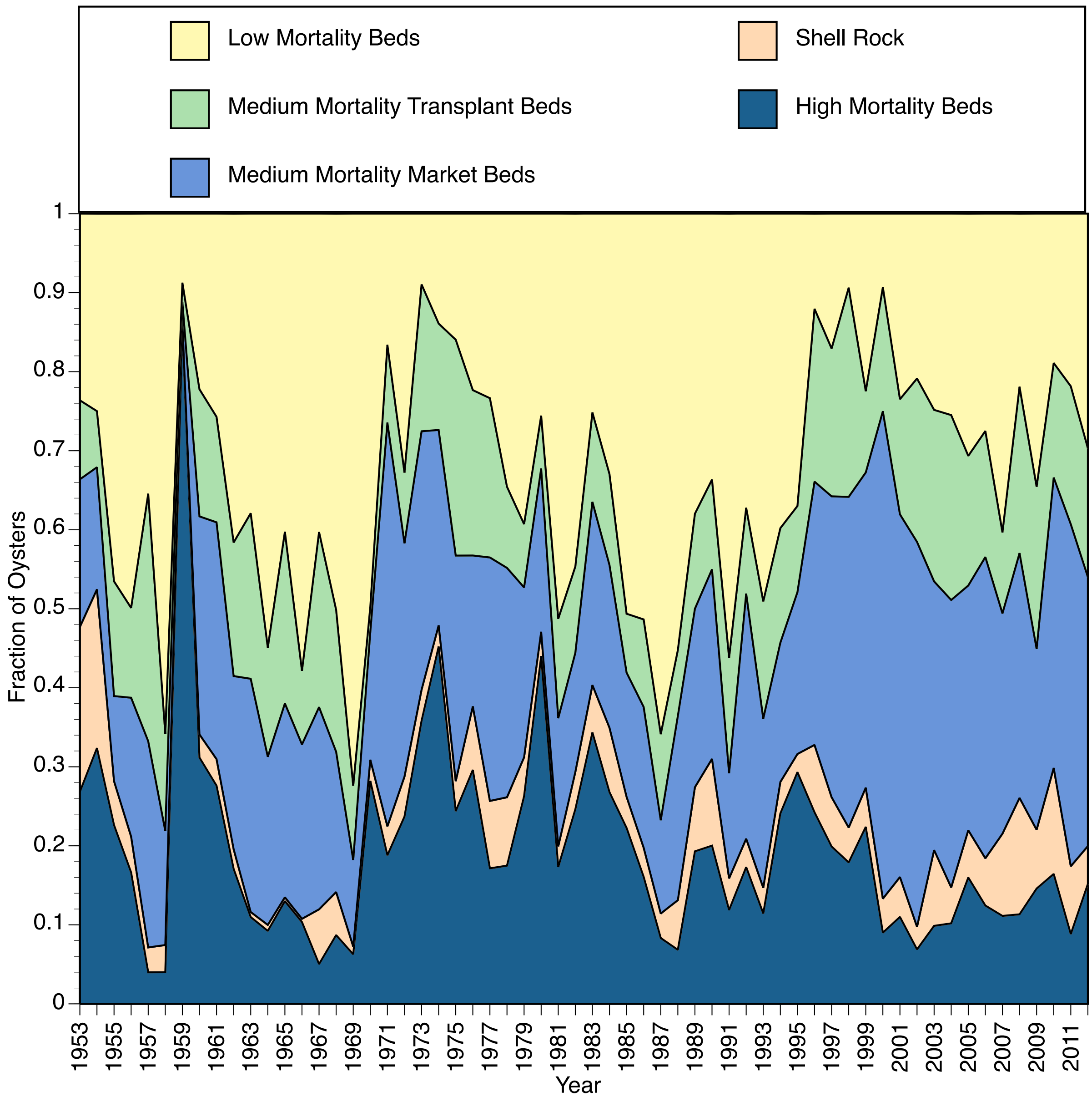


Figure 10. Fraction of oysters on the Medium Mortality beds, 1953-2012. The horizontal line identifies the median value of 0.386. The combined region Medium Mortality beds are: Upper Middle, Middle, Sea Breeze, Cohansey, and Ship John.

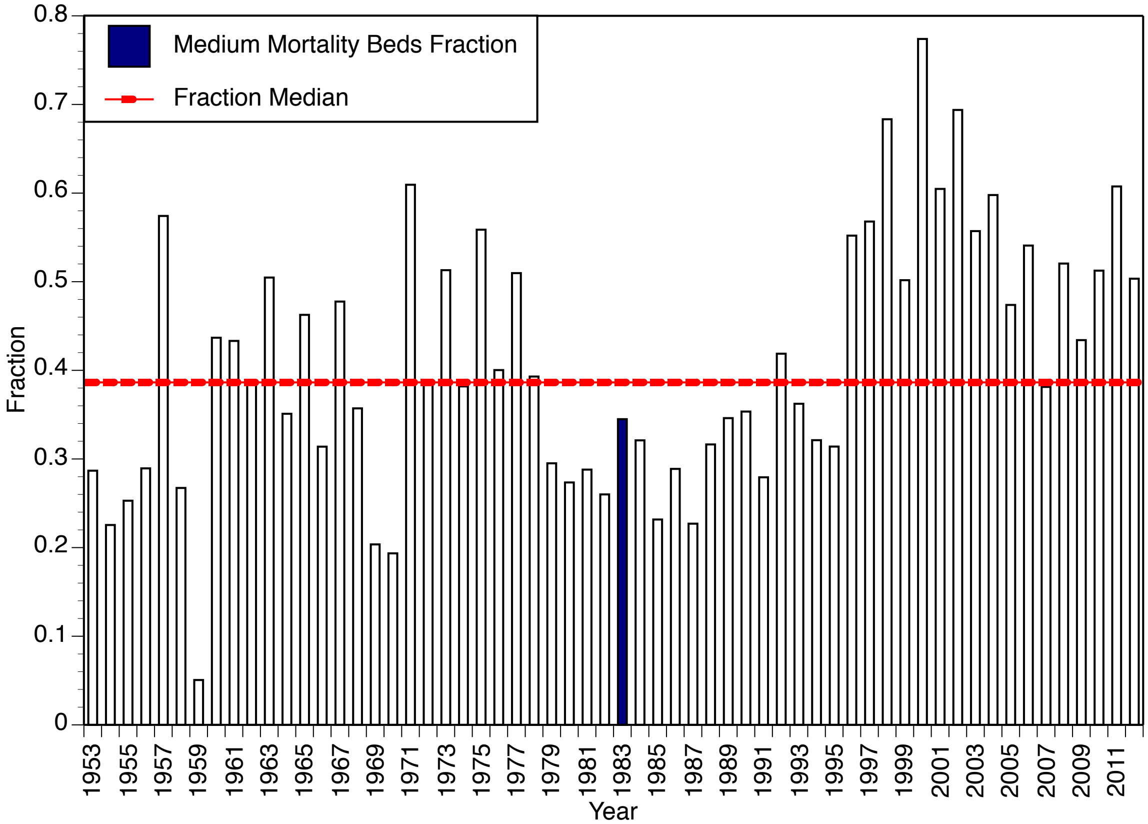


Figure 11. Spawning stock biomass (SSB) by bay region 1990-2012. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

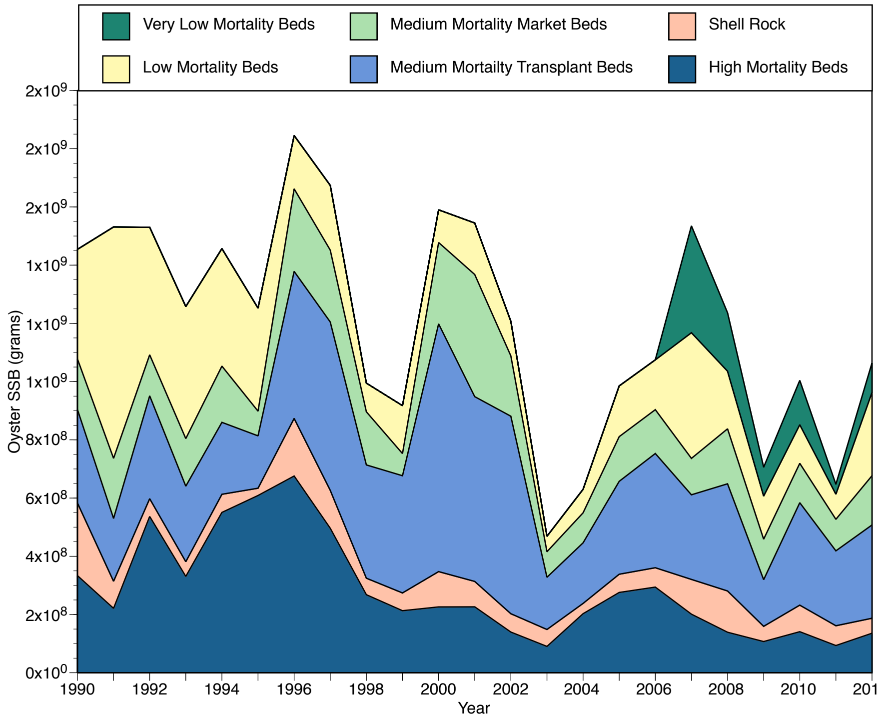


Figure 12. Fractional distribution of spawning stock biomass (SSB) among the bay regions excluding the Very Low Mortality beds. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

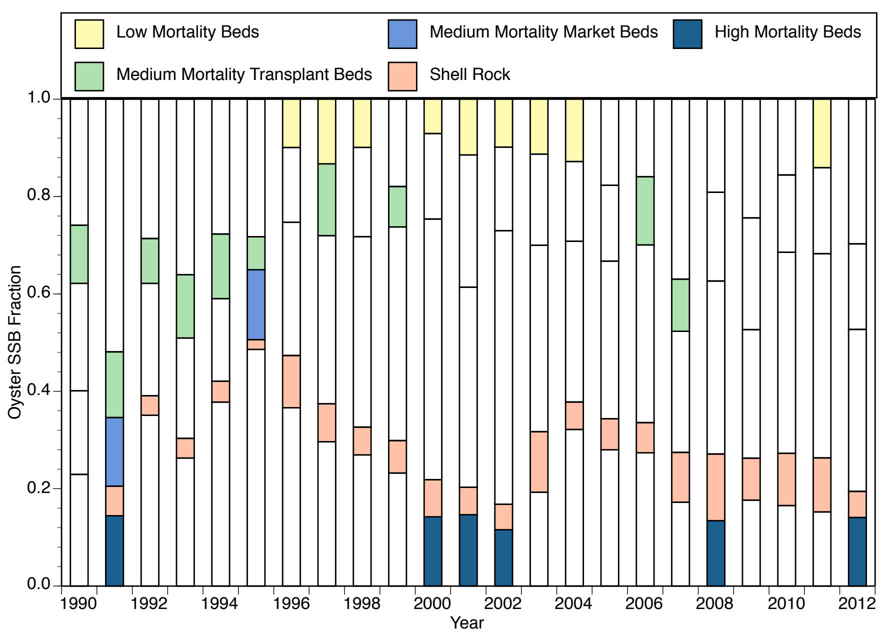


Figure 13. The abundance of small, small market, and large market-size oysters since 1990, excluding the Very Low Mortality beds.

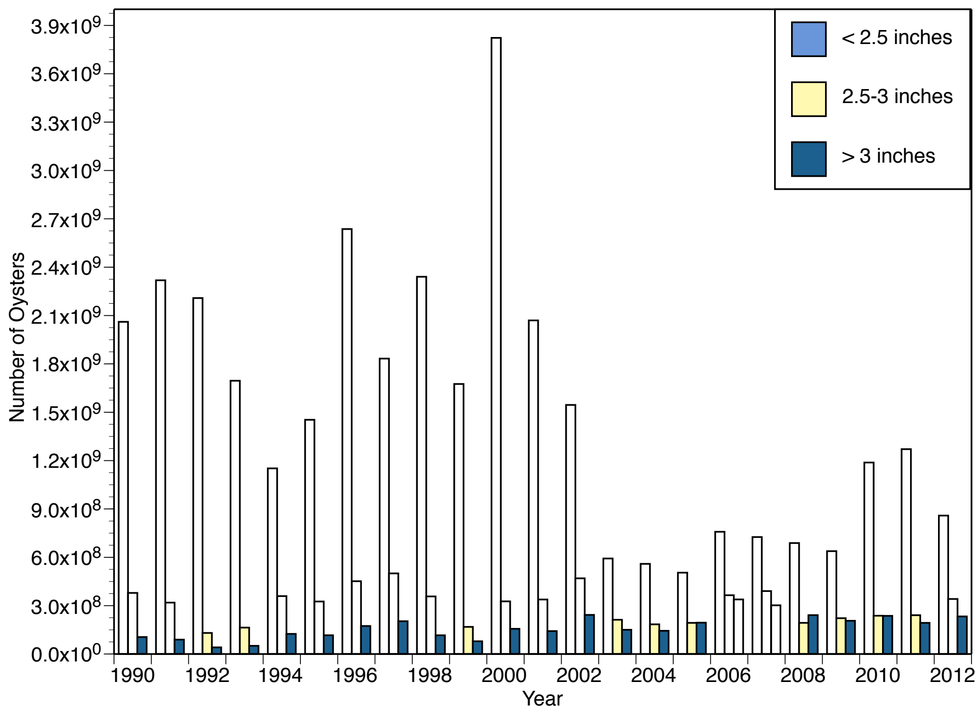


Figure 14. The fraction of small, small market, and large market-size oysters since 1990, excluding the Very Low Mortality beds.

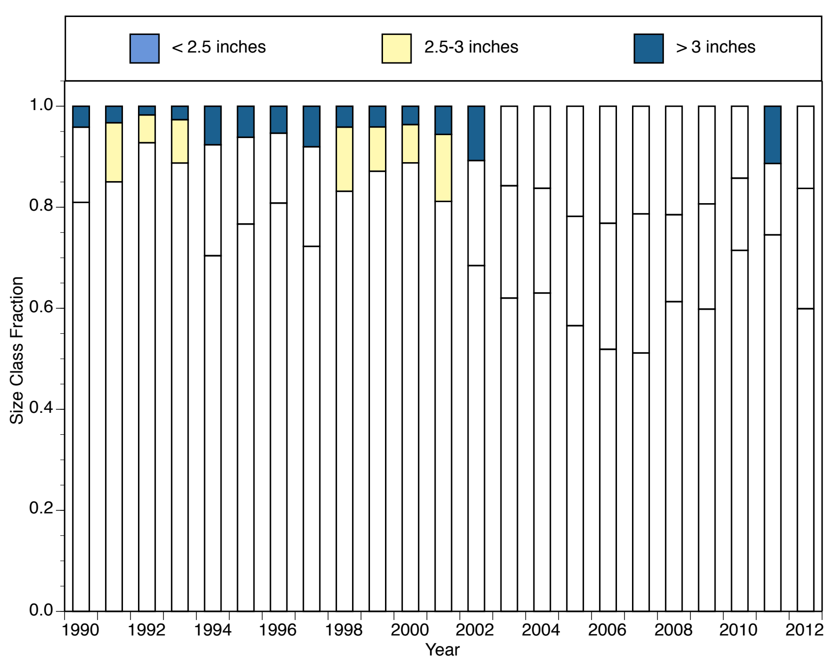


Figure 15. The abundance of small, small market and large market-size oysters since 1990 by bay region. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

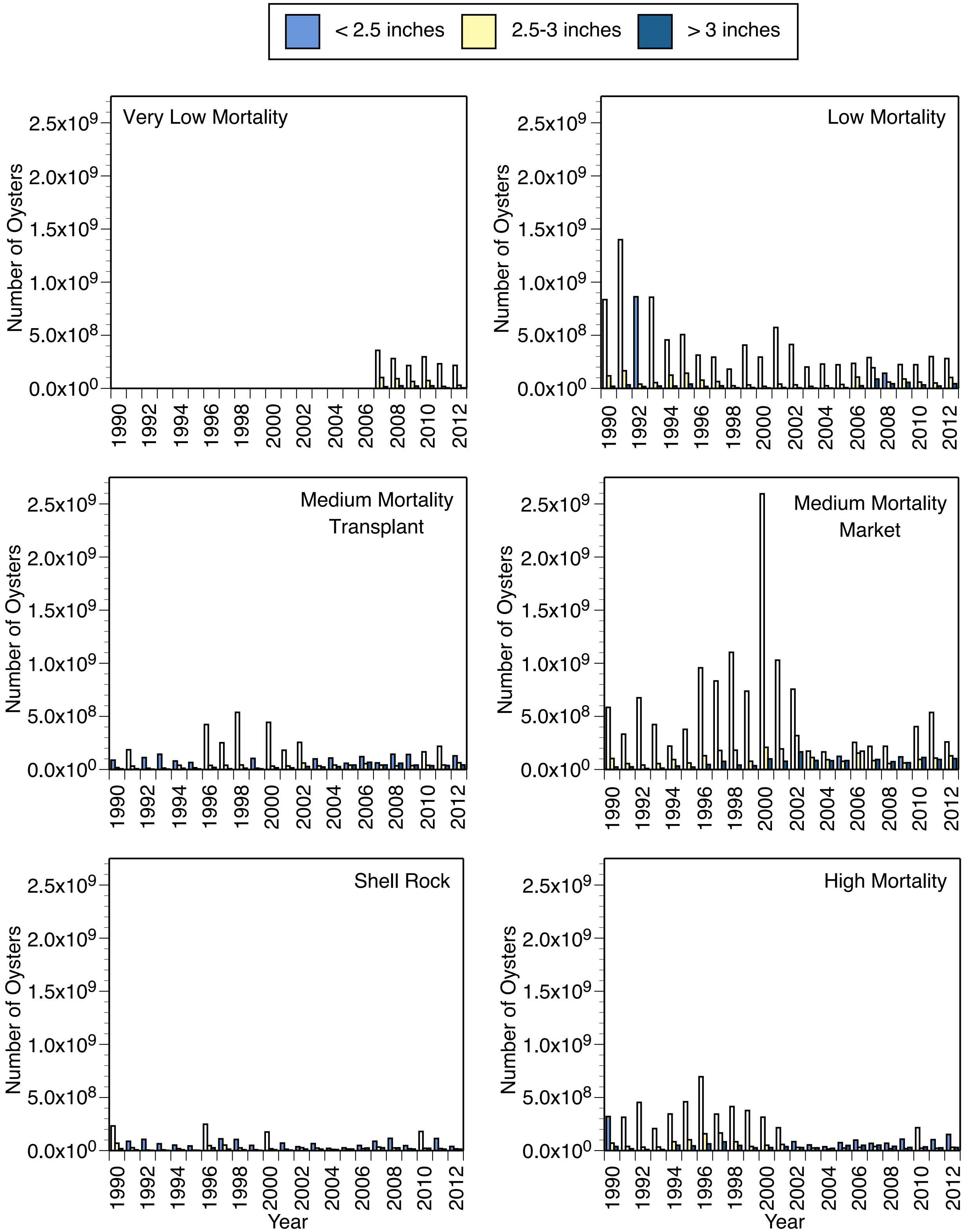


Figure 16. The percentage of small, small market, and large market-size oysters by bed region. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

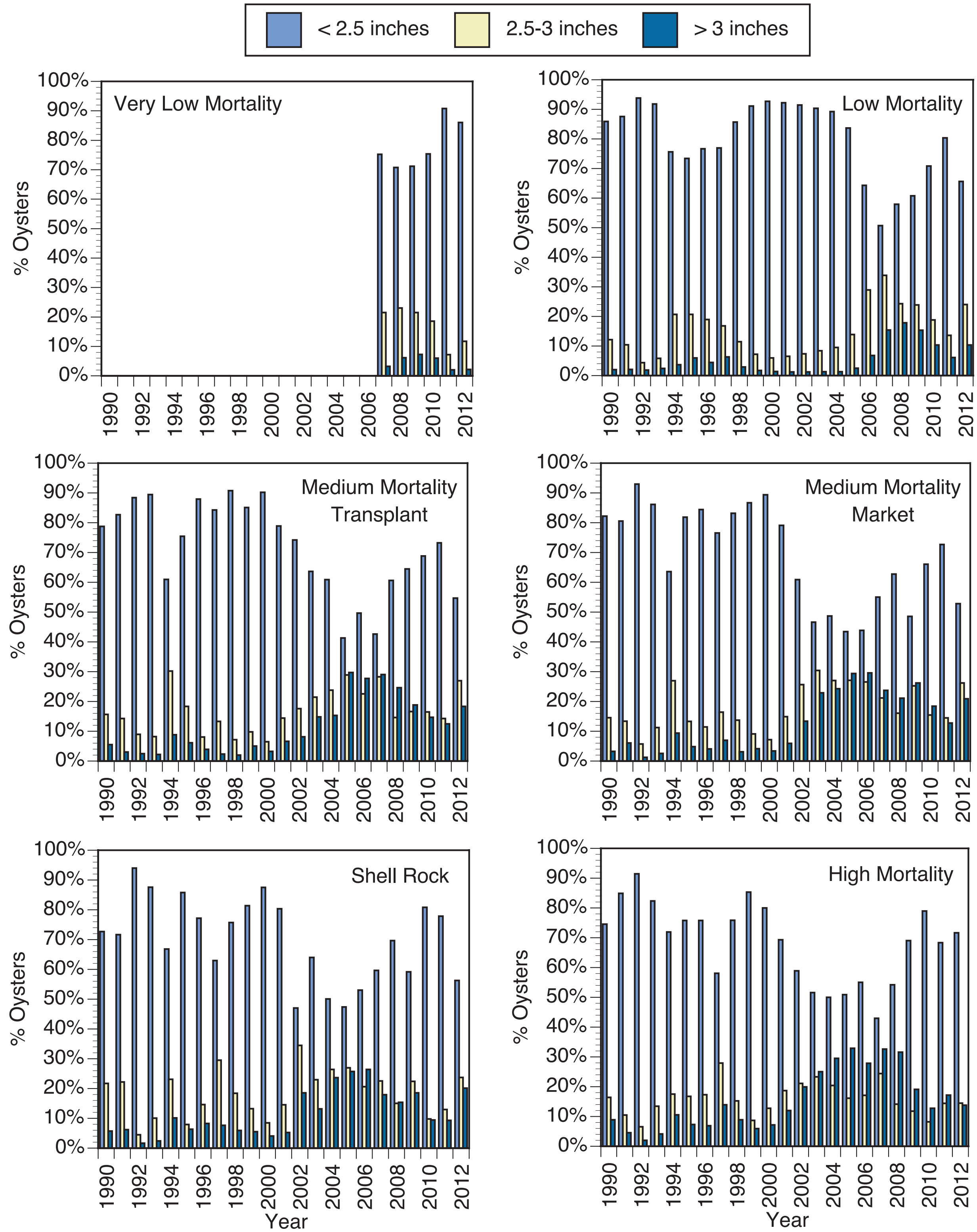


Figure 17. Abundance of market-size (≥2.5”) oysters excluding the Very Low Mortality beds.

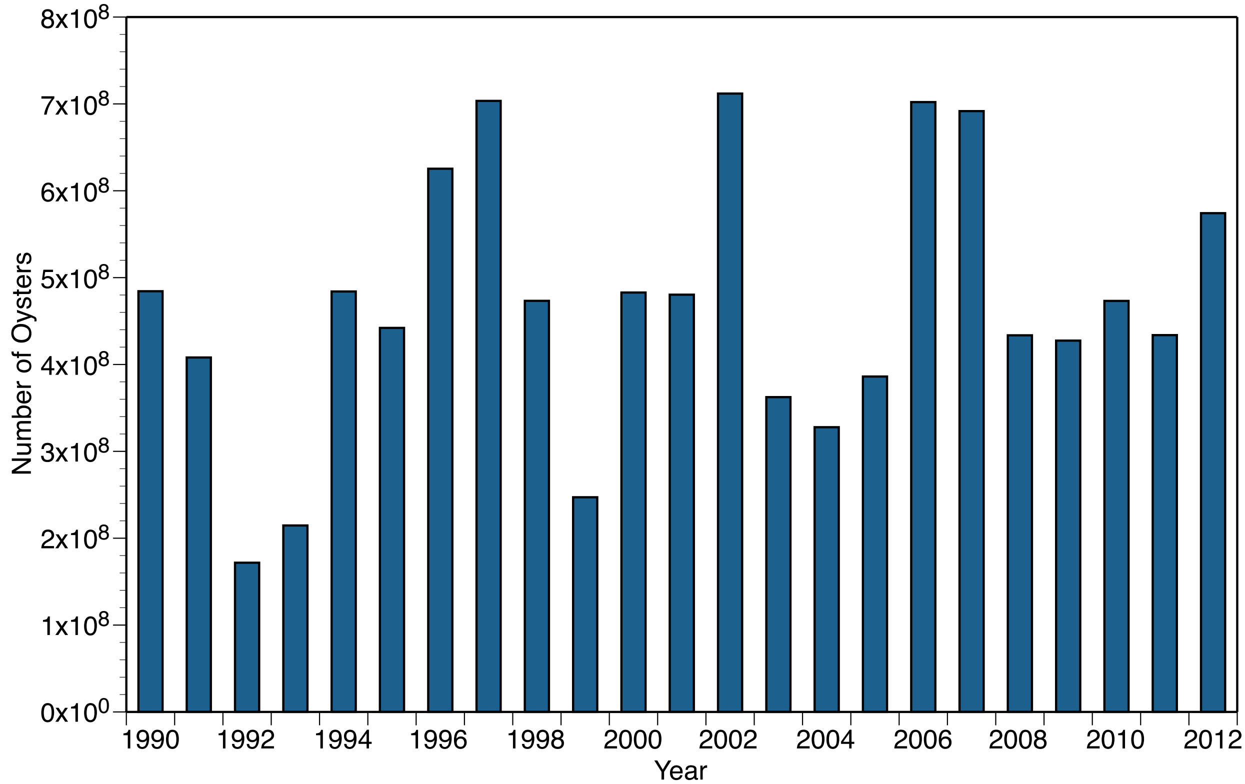


Figure 18. Abundance of market-size (≥2.5") oysters by bay region. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007. Note variation in y-axis scale between graphs.

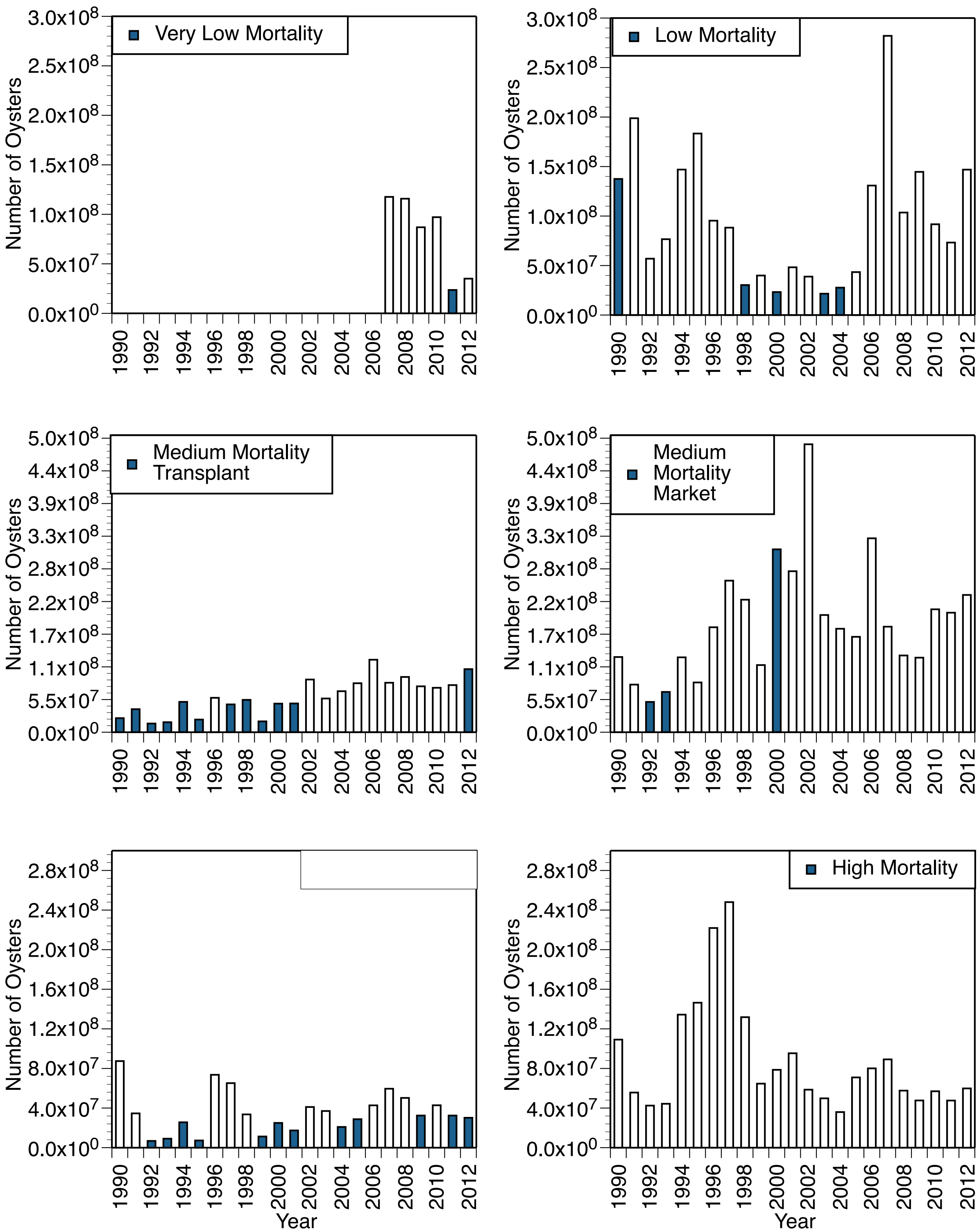


Figure 19. The fraction of marketable oysters that were ≥2.5” - < 3” and ≥3” excluding the Very Low Mortality beds.

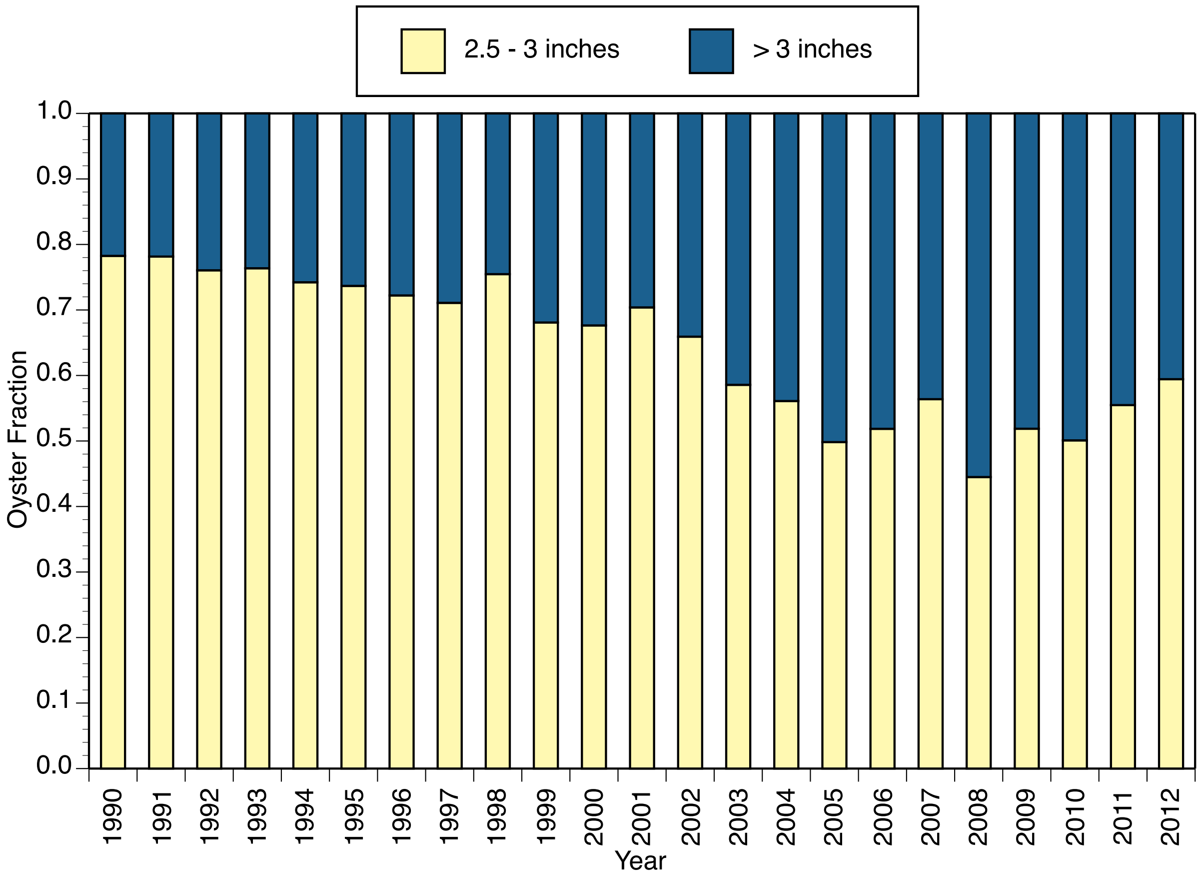


Figure 20. Average condition index [dry meat weight (g) / hinge-to-lip shell length (mm)] in Fall 2012 excluding the Very Low Mortality beds.

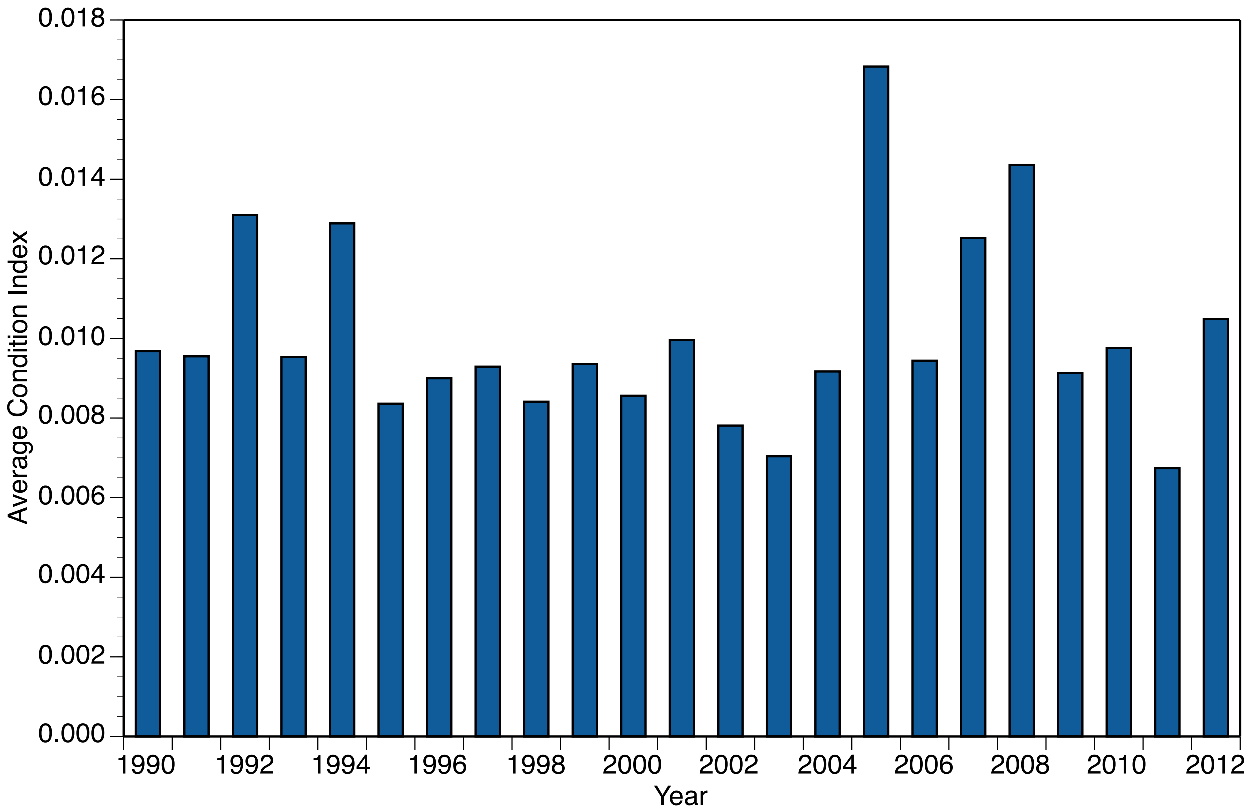


Figure 21. Average condition index [dry meat weight (g) / hinge-to-lip shell length (mm)] at the time of the survey by region. Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

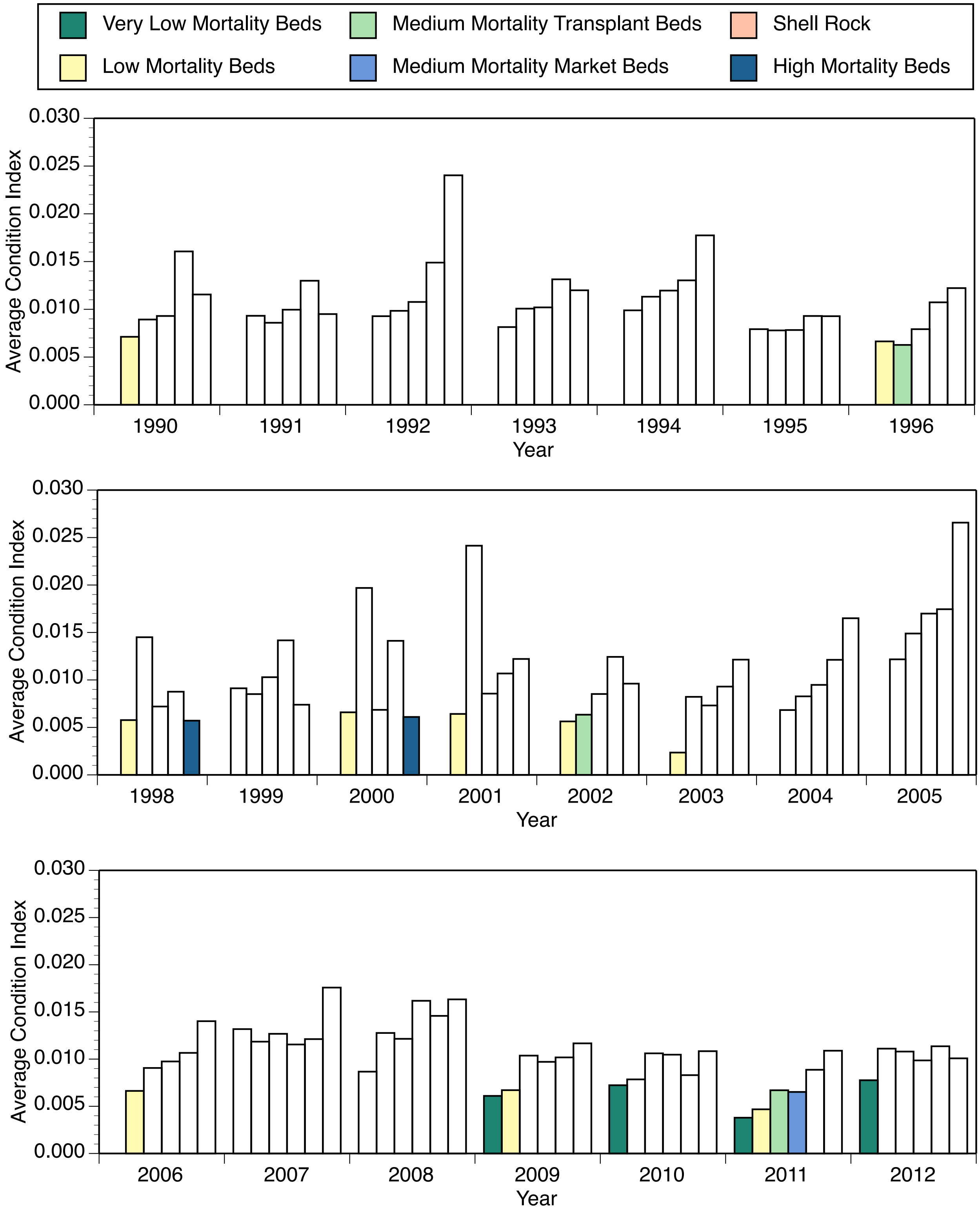


Figure 22. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section not including the Very Low Mortality beds. Beds included in each region are shown in Figure 1 and listed in Table 3. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the regions measures the bay-wide mortality rate for that year.

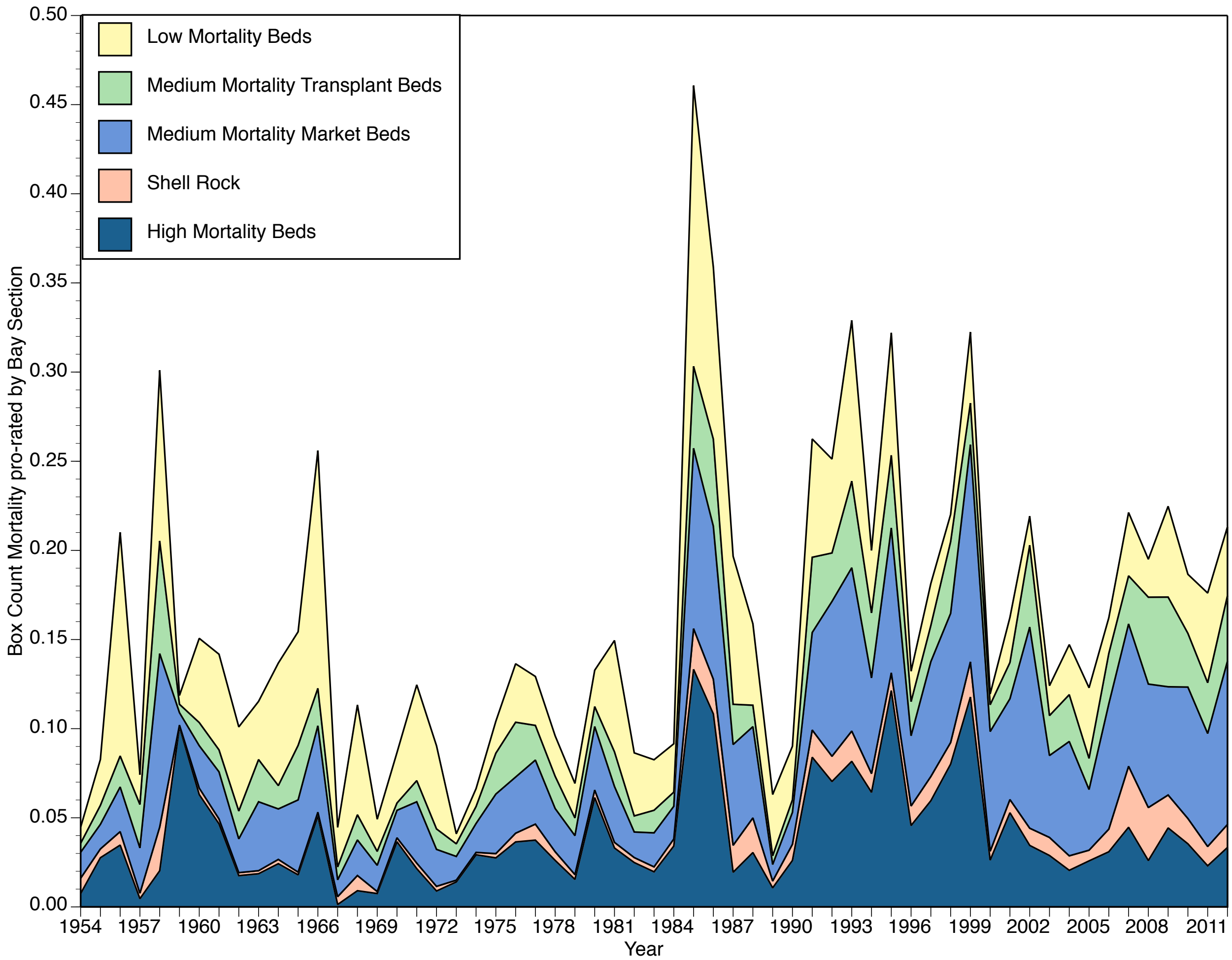


Figure 23. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by region (15 years per graph). Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

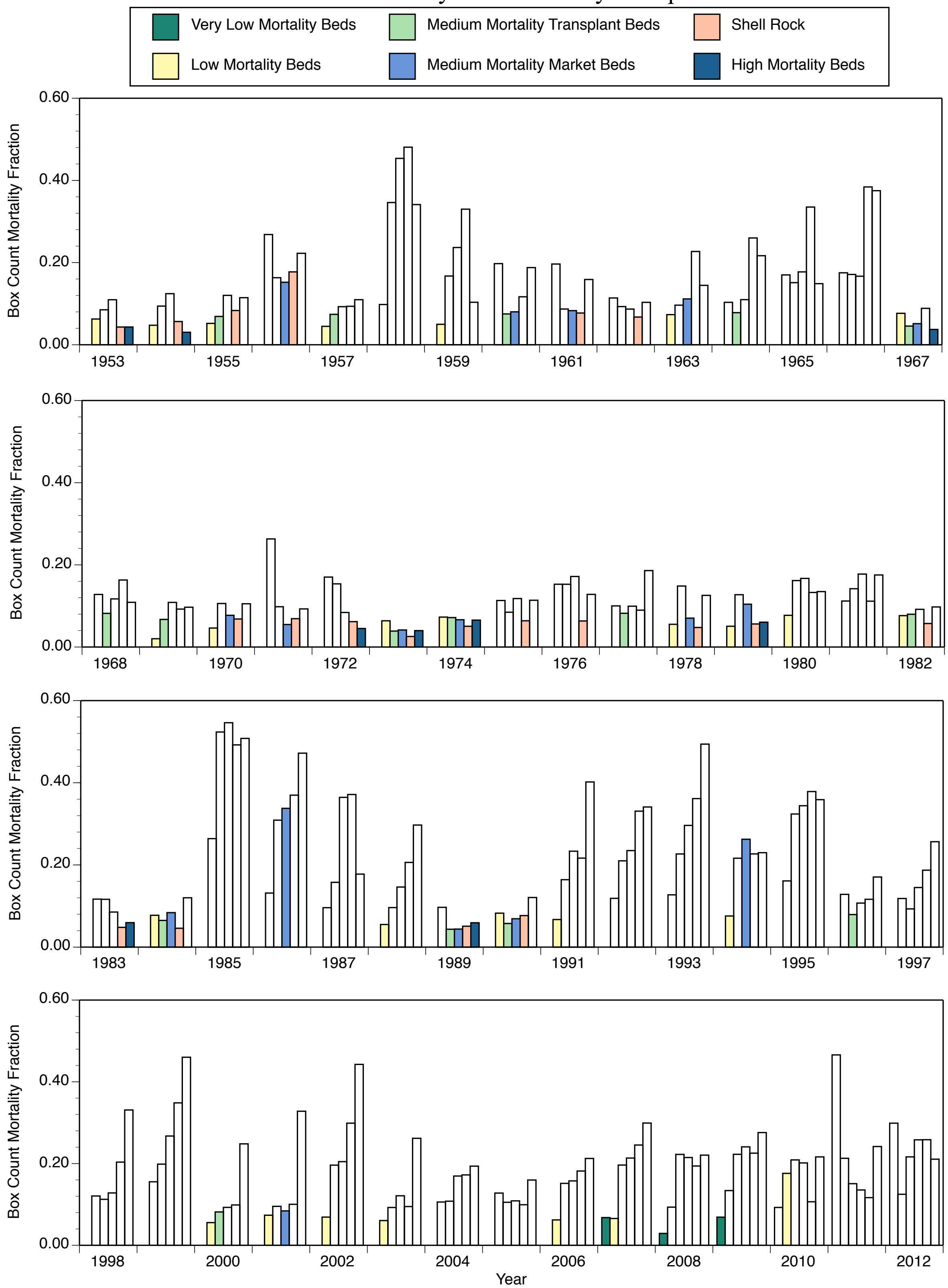


Figure 24. Comparison of the mortality rate by number and by biomass for the six regions 2007-2012. Beds included in each region are shown in Figure 1 and listed in Table 3.

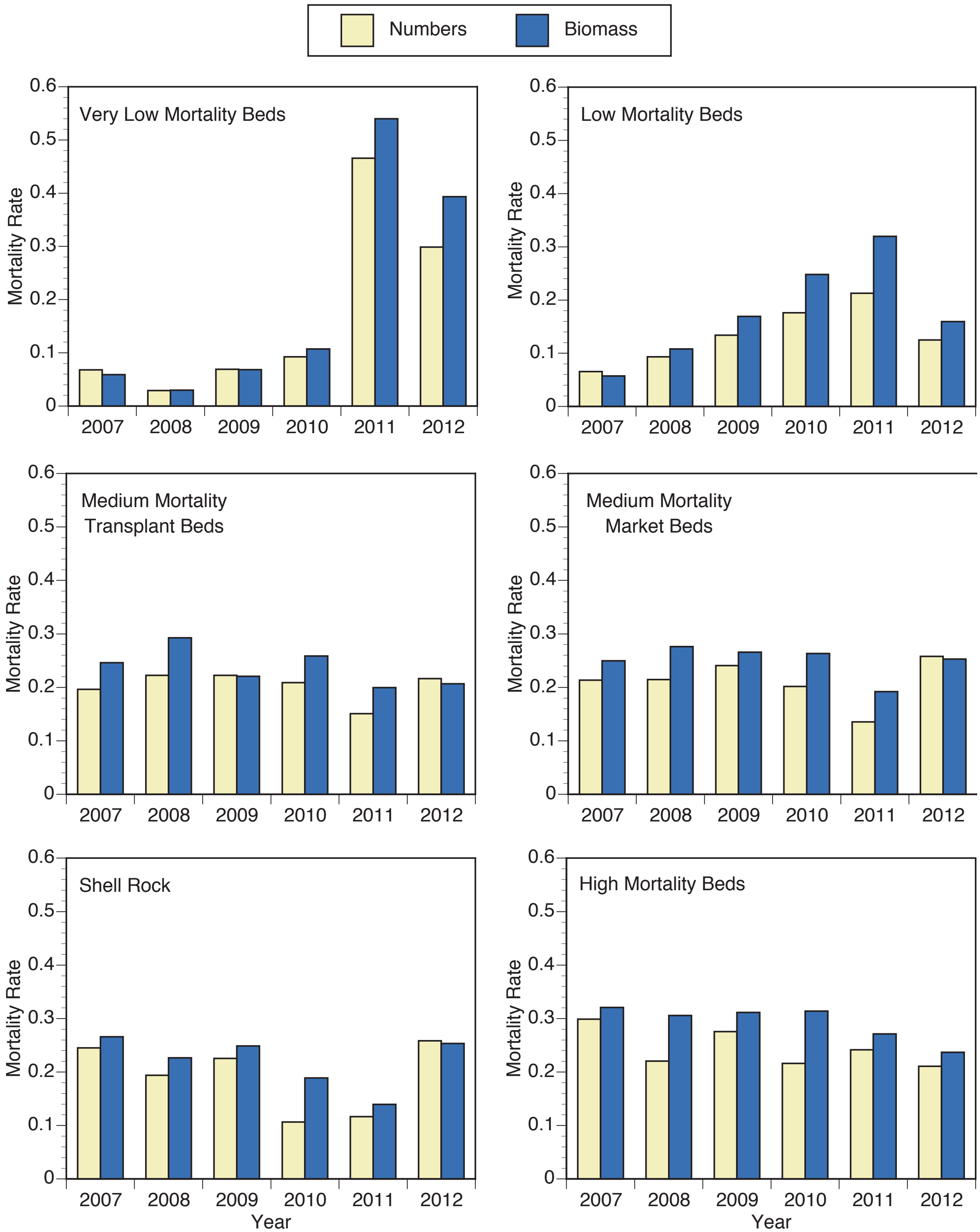


Figure 25. The relationship between the Fall survey and the following Spring resurvey of the same sites in terms of boxes or oysters m^{-2}. The dotted line is the 1:1 line indicating no change. Note that axes are log scaled.

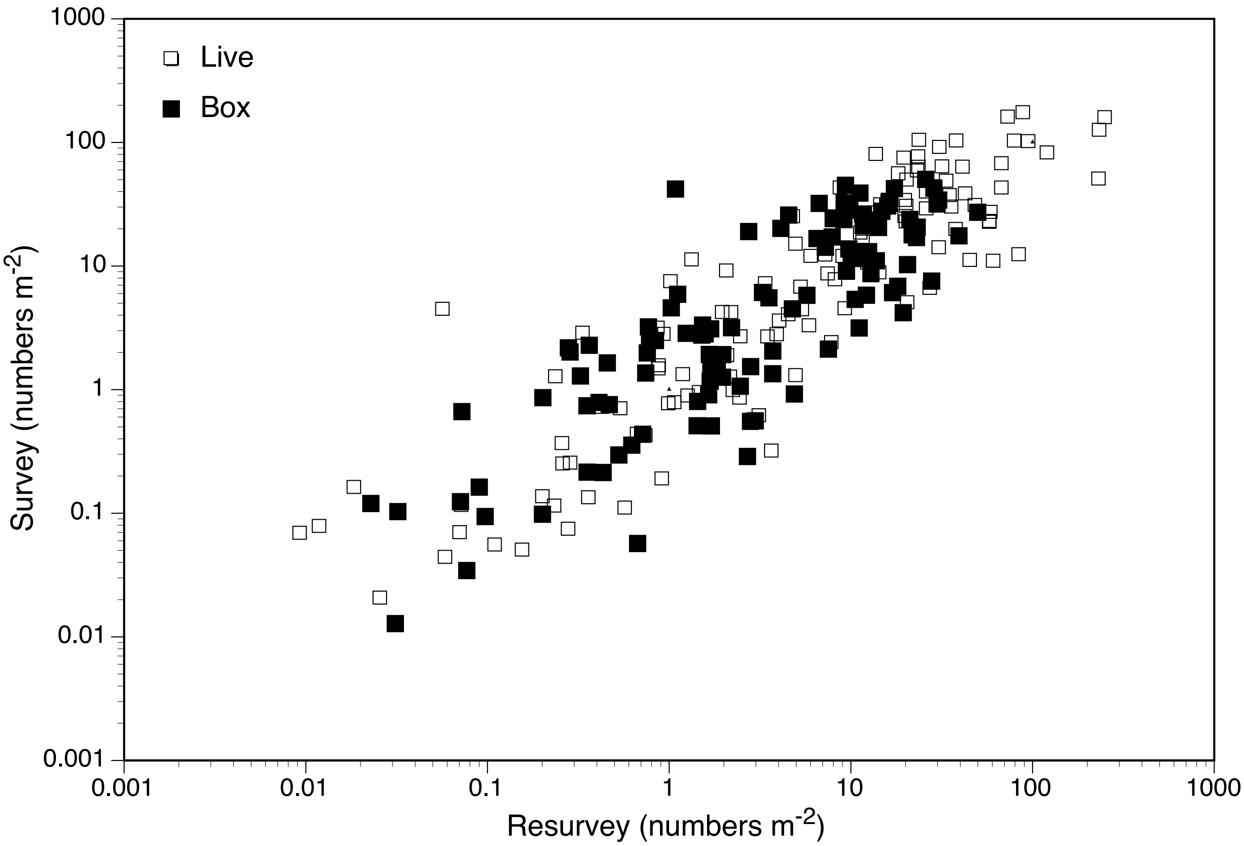


Figure 26. Number of spat recruiting per year for the 1953-2012 time series. Numbers are cumulative by bay region. In the NJ stock assessment survey, the term 'spat' refers to oysters ≤20 mm (0.79"). Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

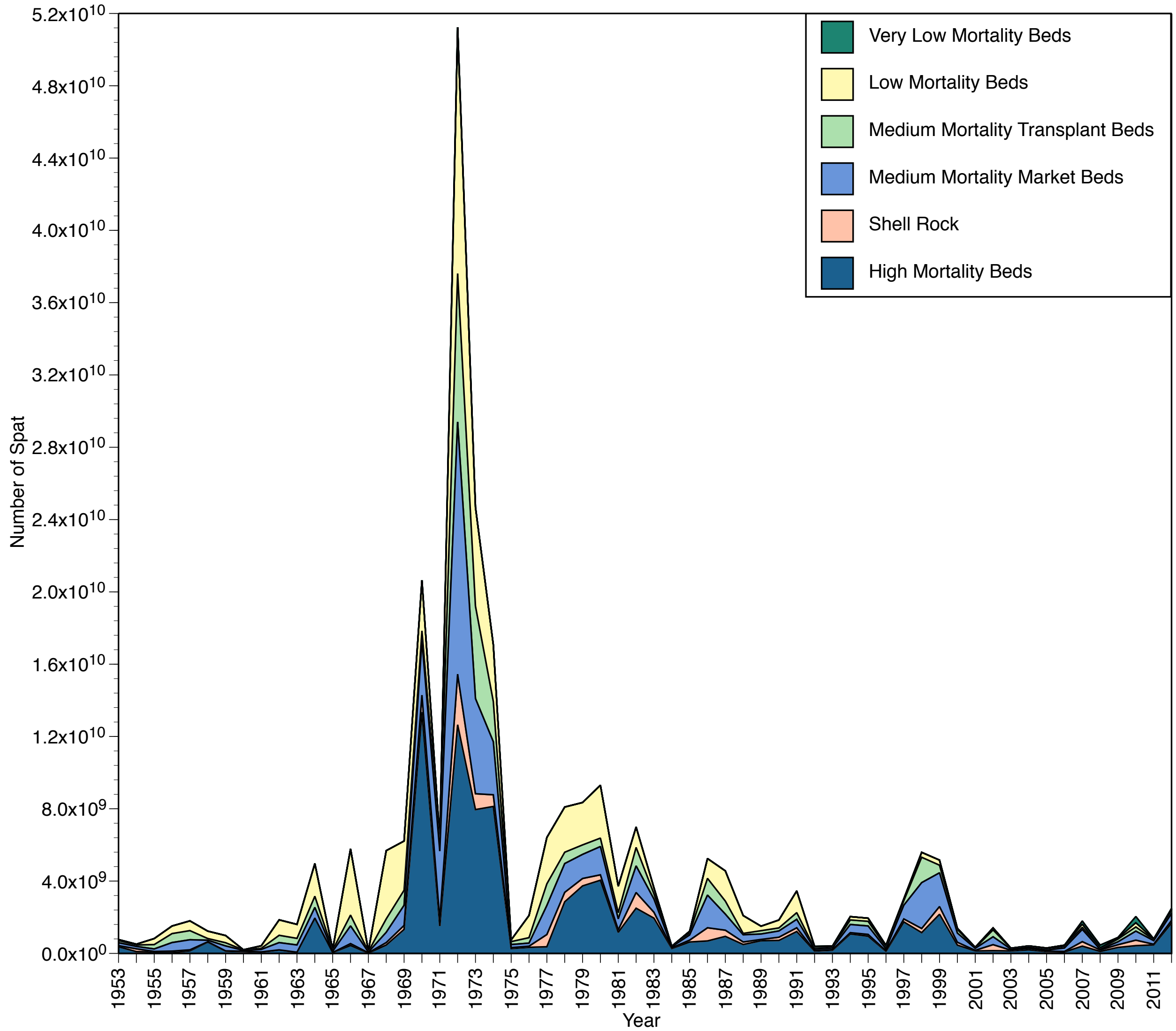


Figure 27. Number of spat recruiting per year for the 1989-2012 time series. In the NJ stock assessment survey, the term 'spat' refers to oysters ≤ 20 mm (0.79"). Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007.

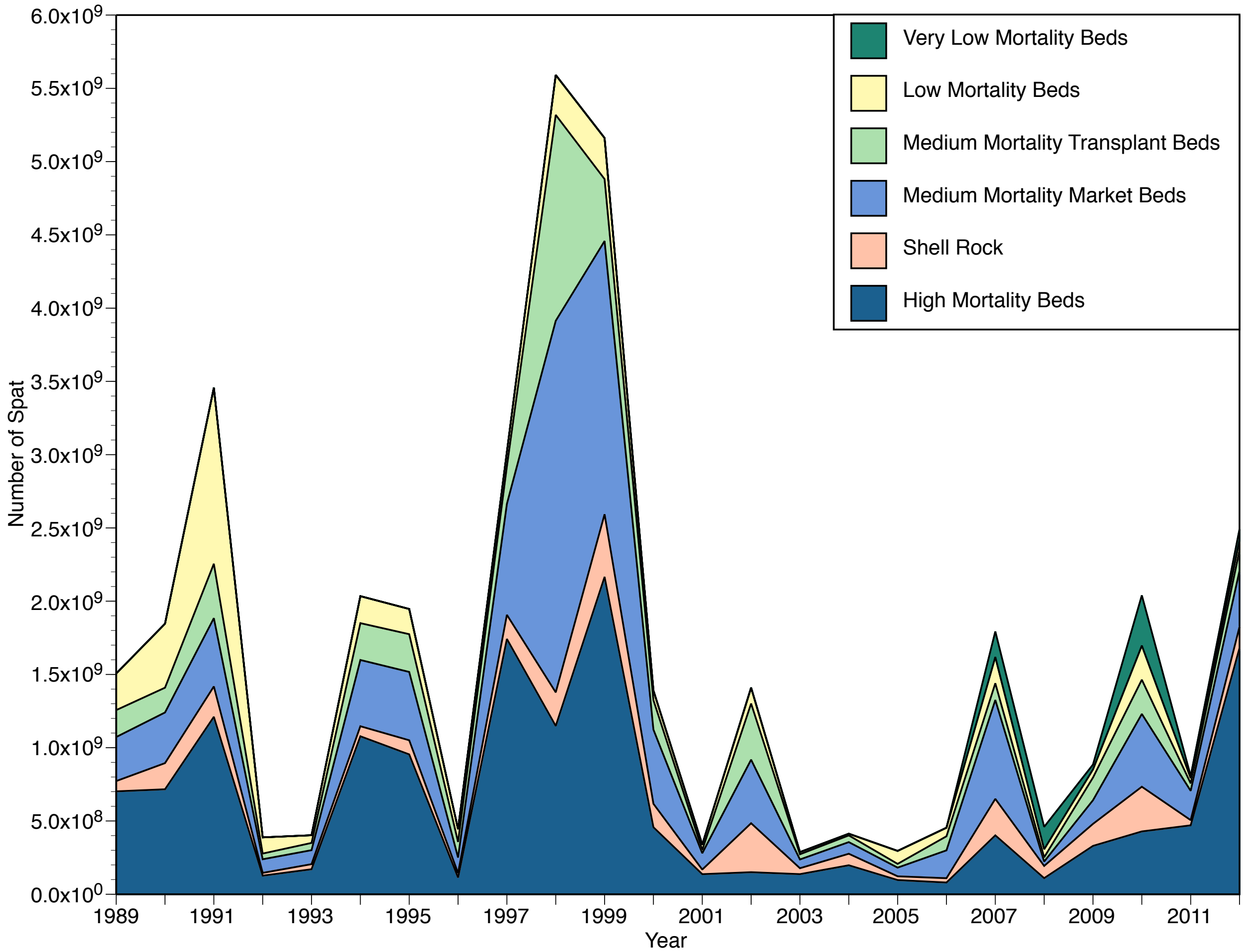
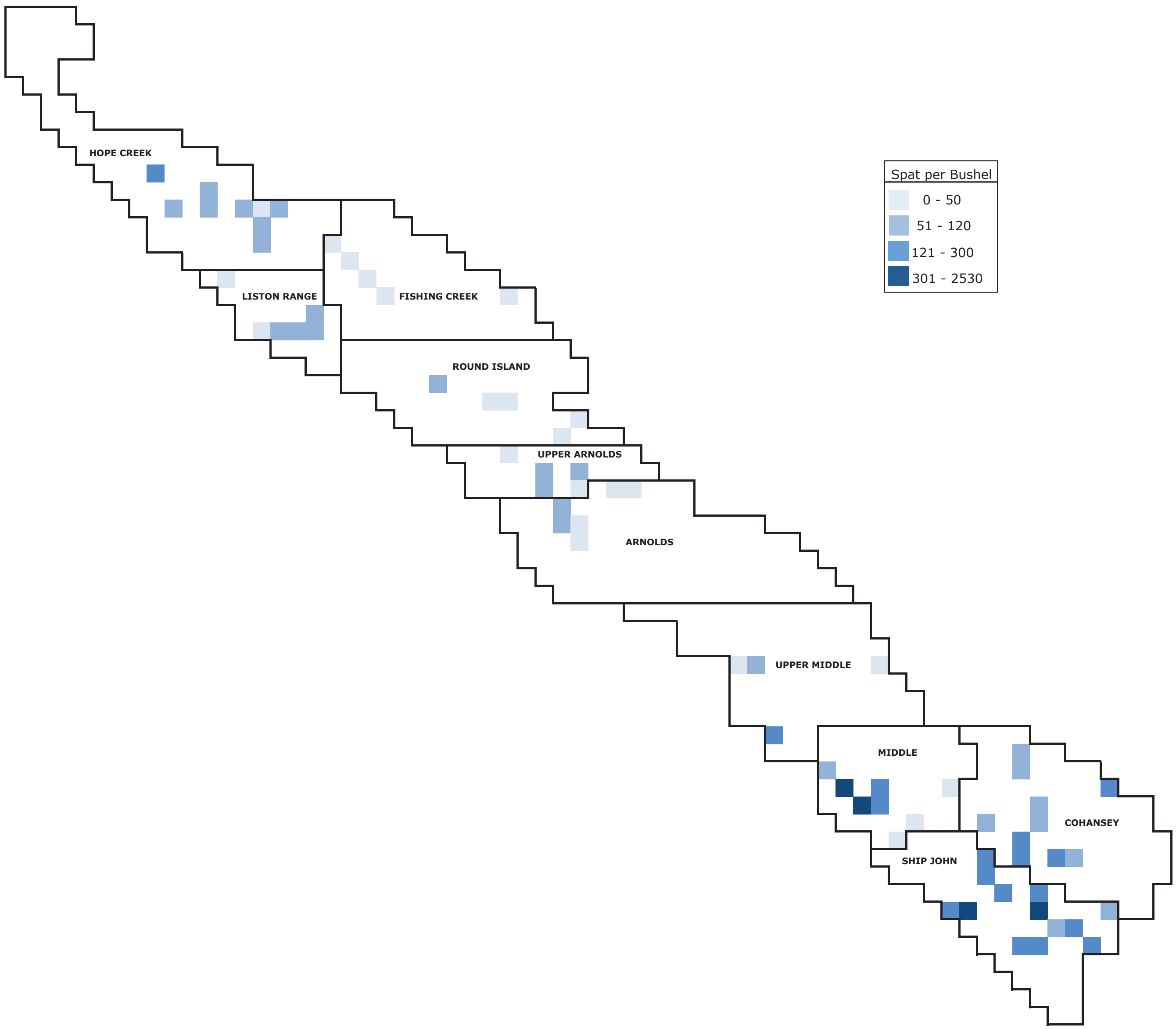


Figure 28 (a and b). Spat per bushel at each site sampled in the 2012 Fall survey. Darker colors indicate higher numbers of spat per bushel as indicated in legend. Ranges on legends are the same on both maps.

a. Upbay beds



b. Downbay beds.

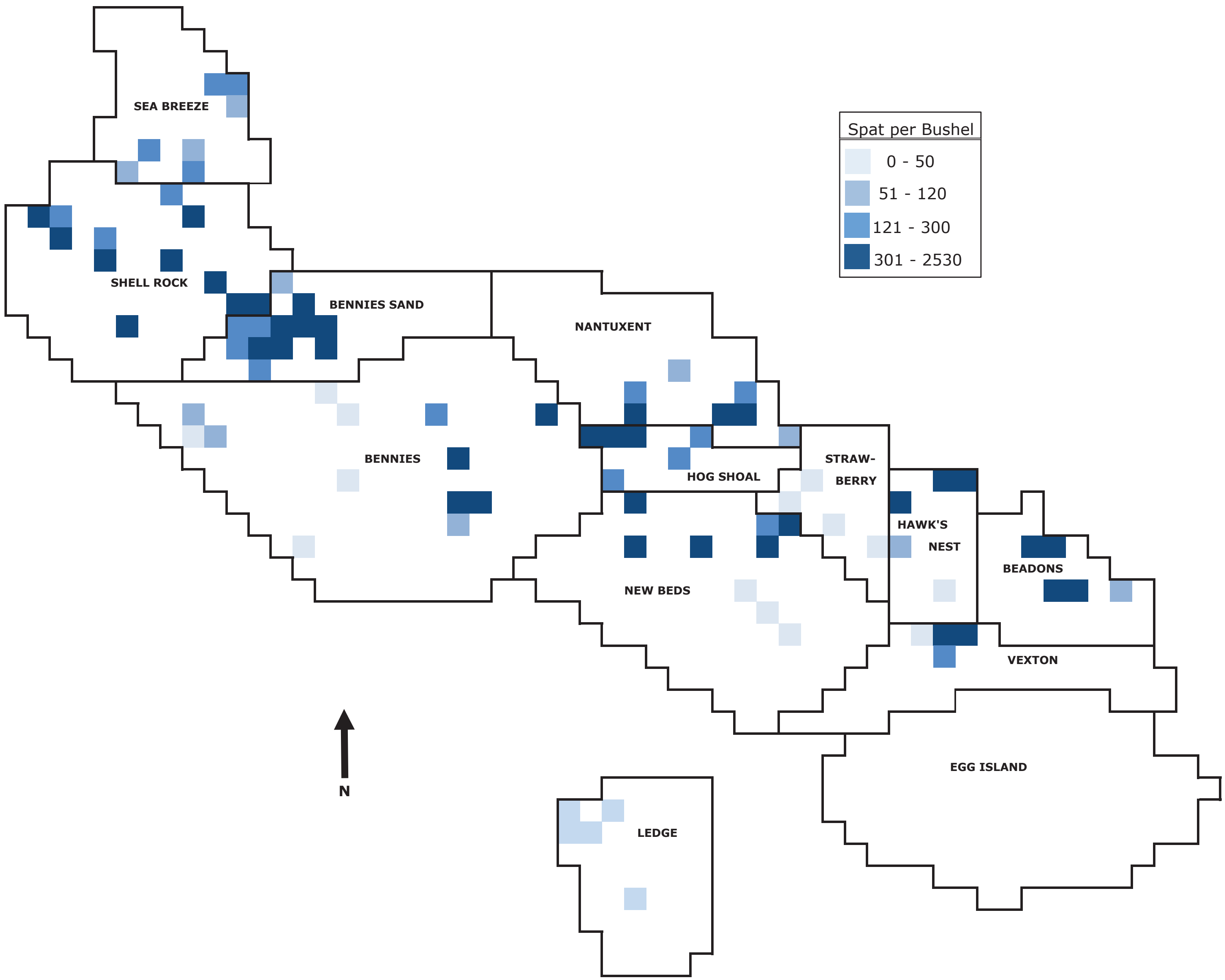


Figure 29. Four sites representing upbay, mid-bay, and downbay spat size frequencies in Fall 2012. See Figure 1 for bed locations. In the NJ stock assessment survey, the term 'spat' refers to oysters ≤ 20 mm (0.79"). X-axis size bins indicate the upper bound of each size class.

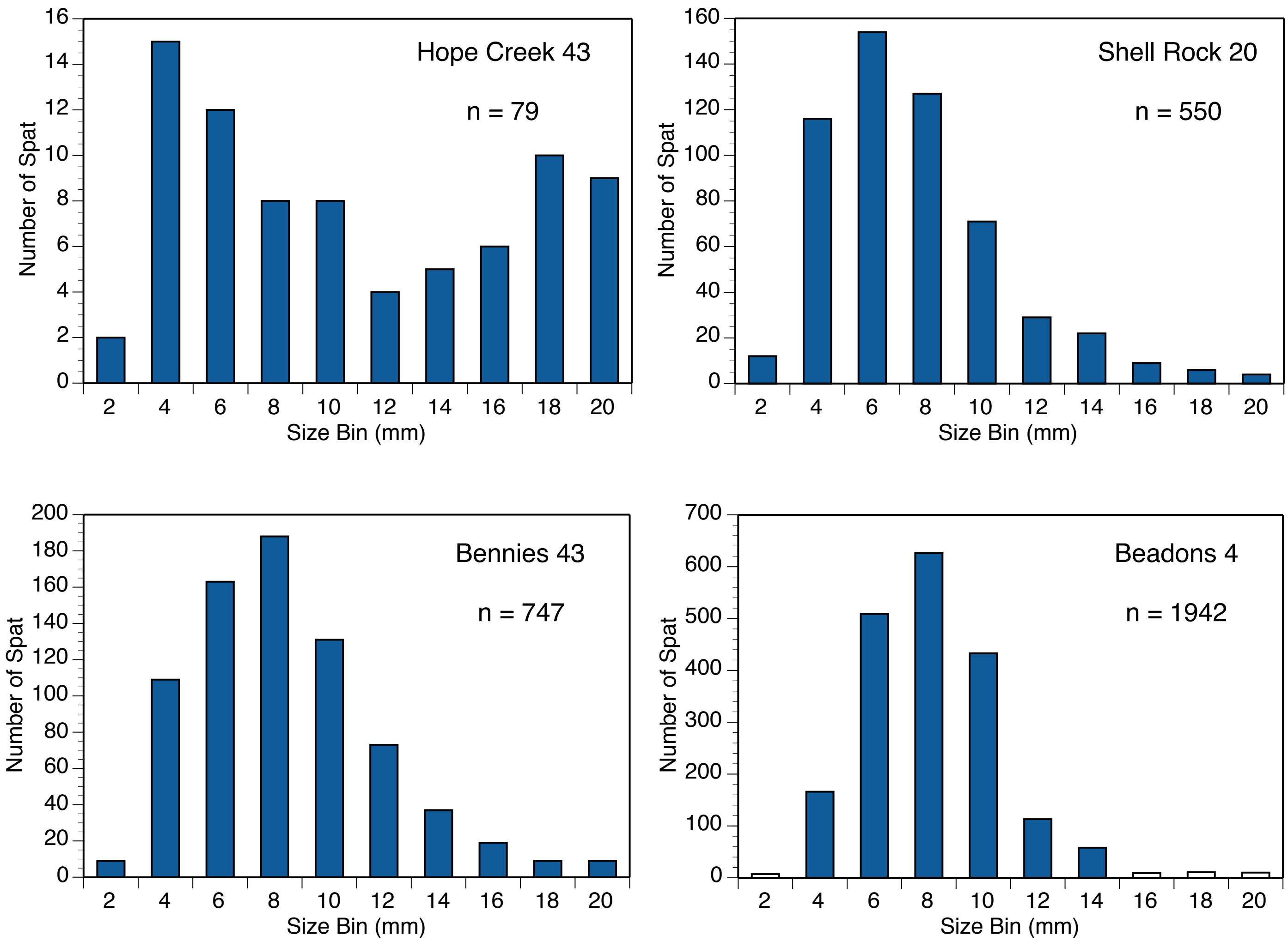


Figure 30. Locations of 2012 shell plants denoted by white stars. The Hope Creek shellplant was a replant of spatted clamshell from an area downbay of the depicted beds. The two Ship John shellplants were direct plants of unspatted clamshell. See Table 12 for further shell plant details.

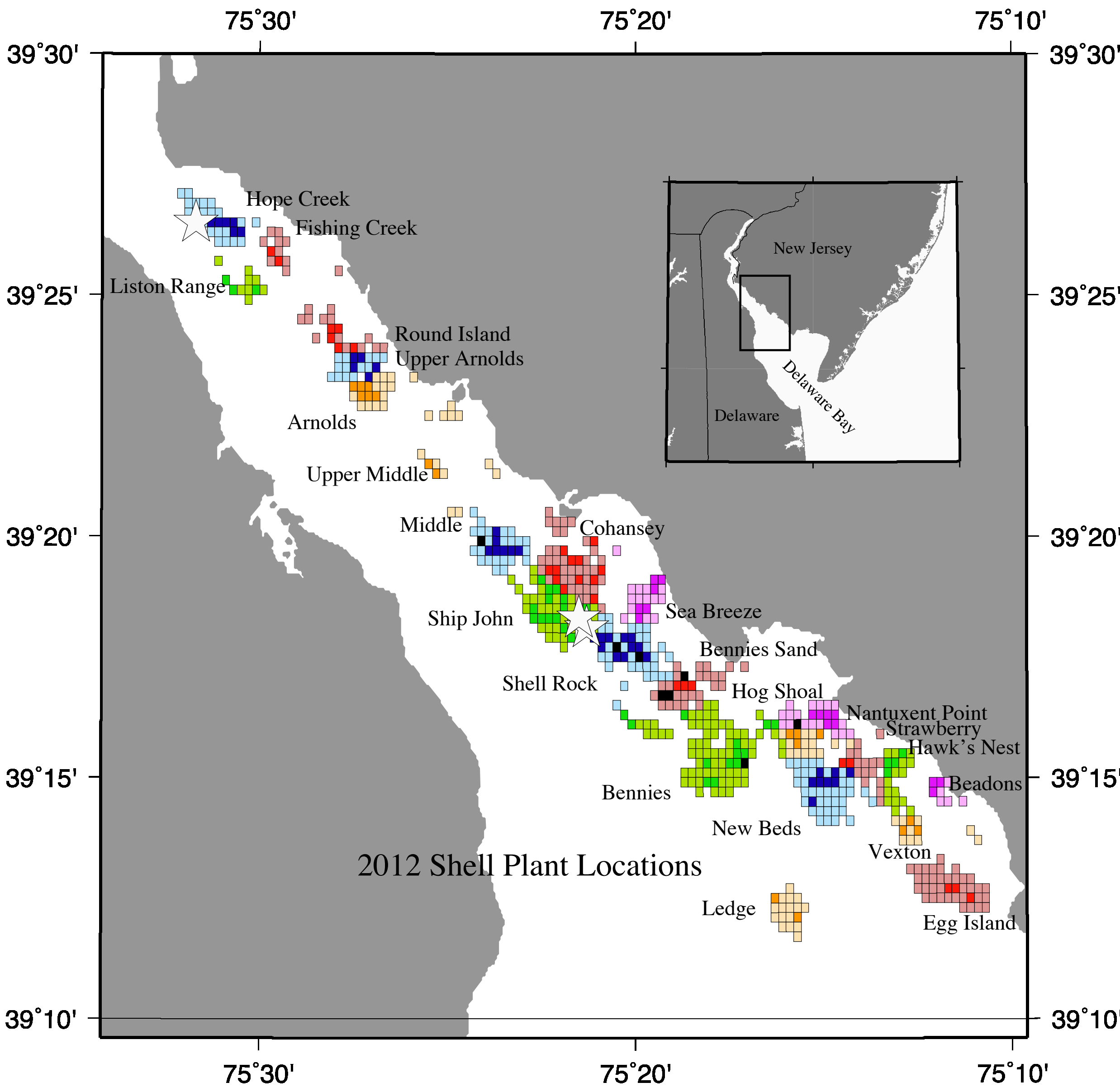
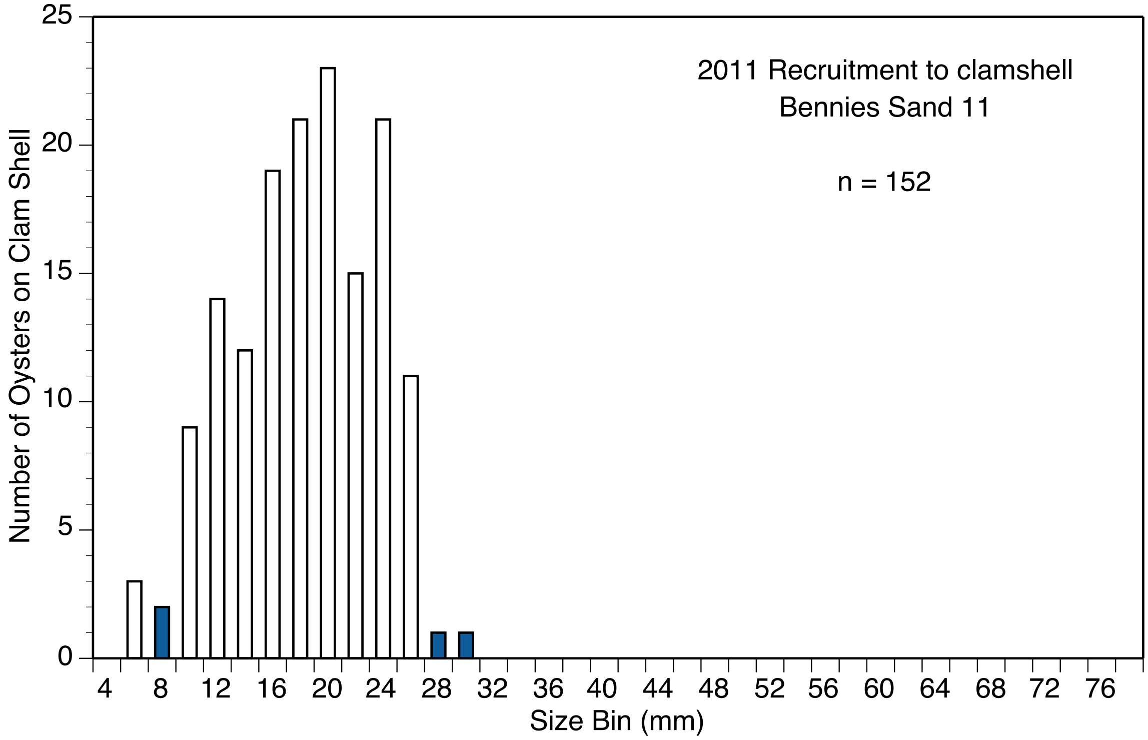


Figure 31. Size-frequency distributions for spat recruiting in 2011 to clamshell planted on Bennies Sand 11 (upper graph) and for all spat and oysters found on clamshell in dredge samples from Bennies Sand 11 in Fall 2012 (lower graph). X-axis size bins indicate the upper bound of each size class.



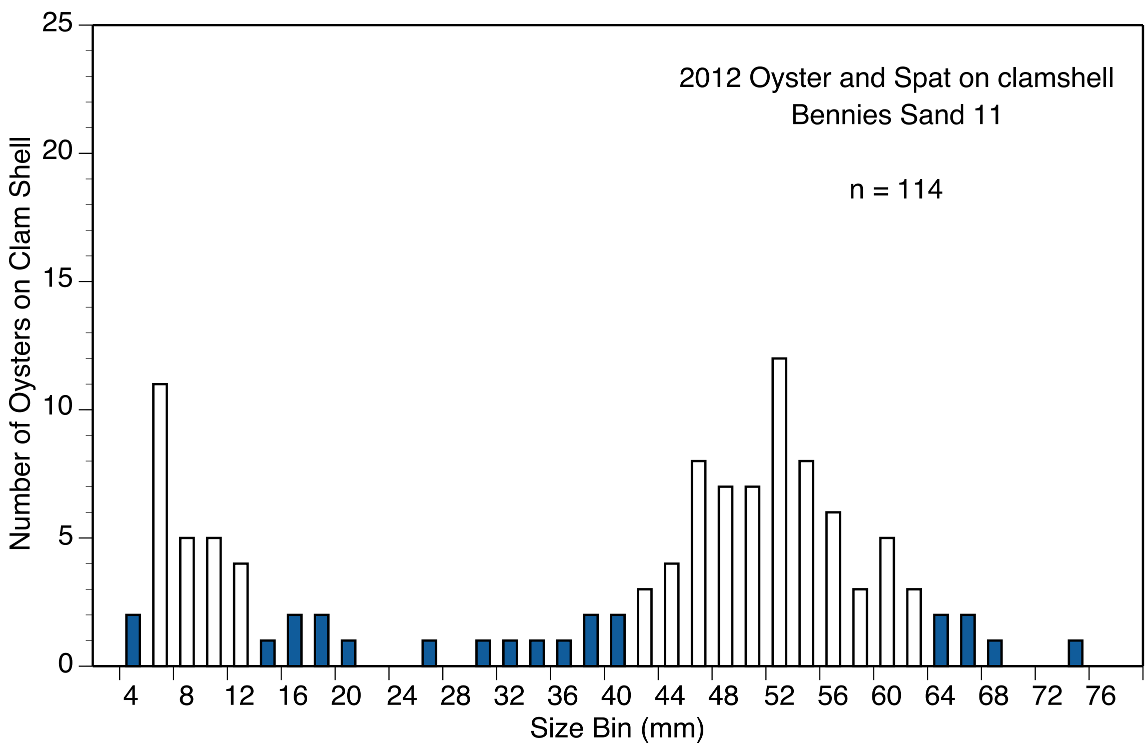


Figure 32. The annual number of spat recruiting per >20-mm oyster per year from 1953-2012 excluding the Very Low Mortality region. A line is drawn to indicate a 1:1 ratio. Ratios higher than 1 are considered to be high recruitment events.

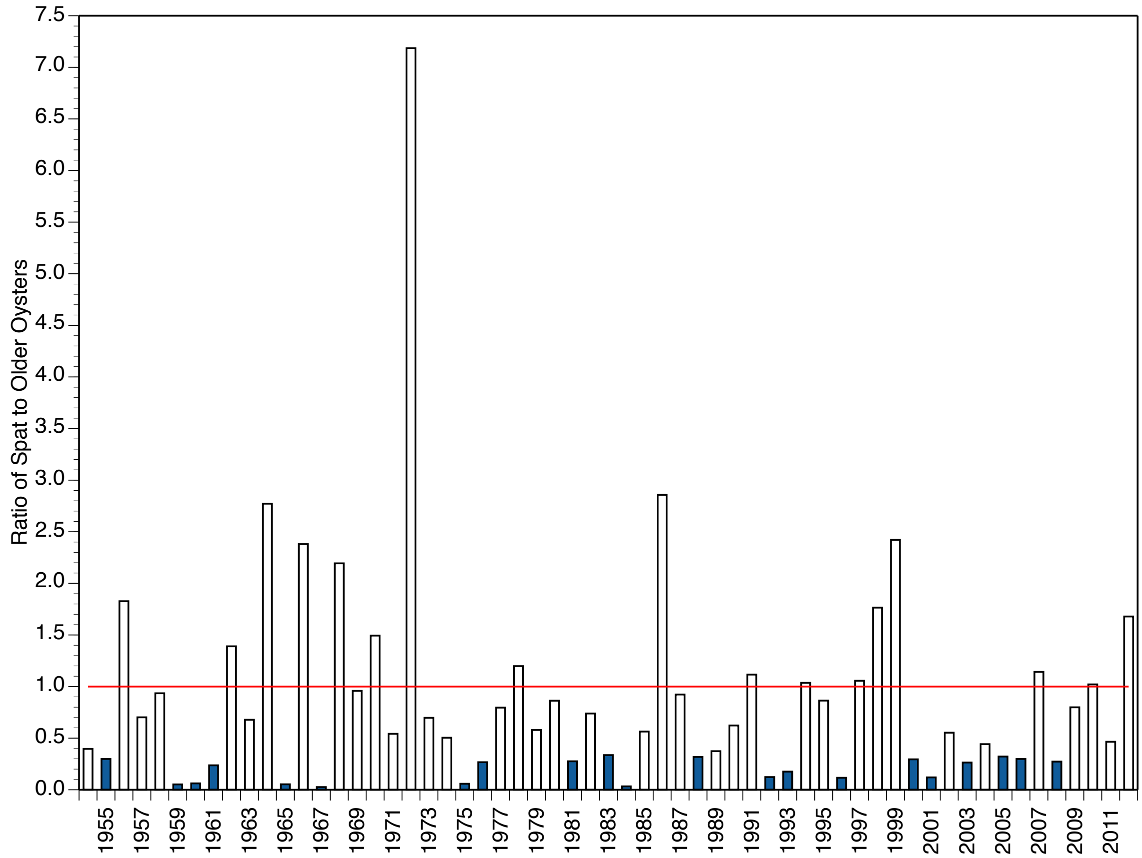


Figure 33. Spat-to-adult oyster ratio for each bay region. In the NJ stock assessment survey, the term 'spat' refers to oysters ≤ 20 mm (0.79"). Beds included in each region are shown in Figure 1 and listed in Table 3. No data are available for the Very Low Mortality beds prior to 2007. Note variation in y-axis scale for Very Low Mortality region. A line is drawn to indicate a 1:1 ratio. Ratios higher than 1 are considered to be high recruitment events.

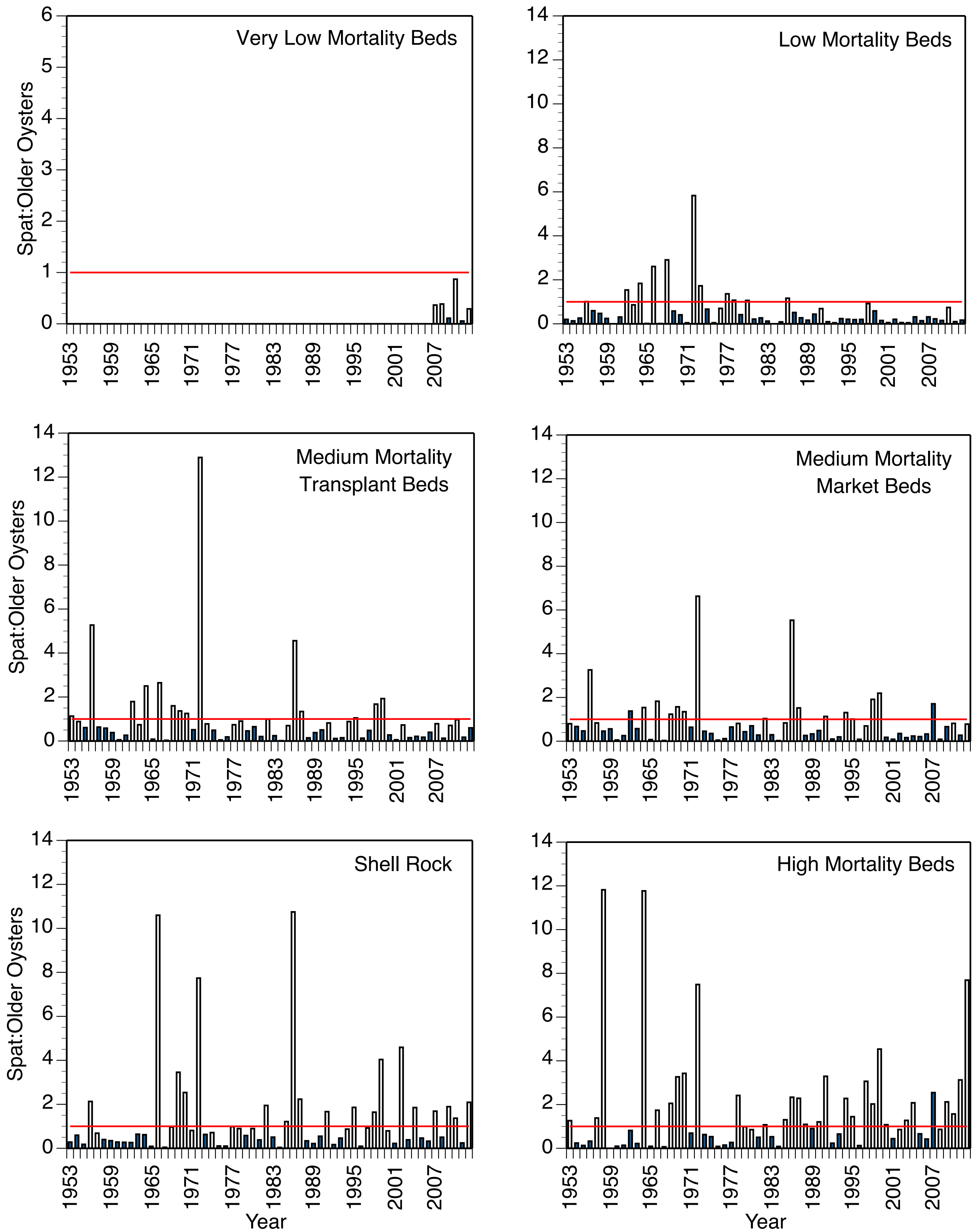


Figure 34. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2012. Shell planting began in 2005 and increased in 2006-2008 but declined again in 2009-2011. Shell budgets are calculated using the updated half-lives estimated in this assessment and using the half-lives estimated in 2010 and 2011 for comparison.

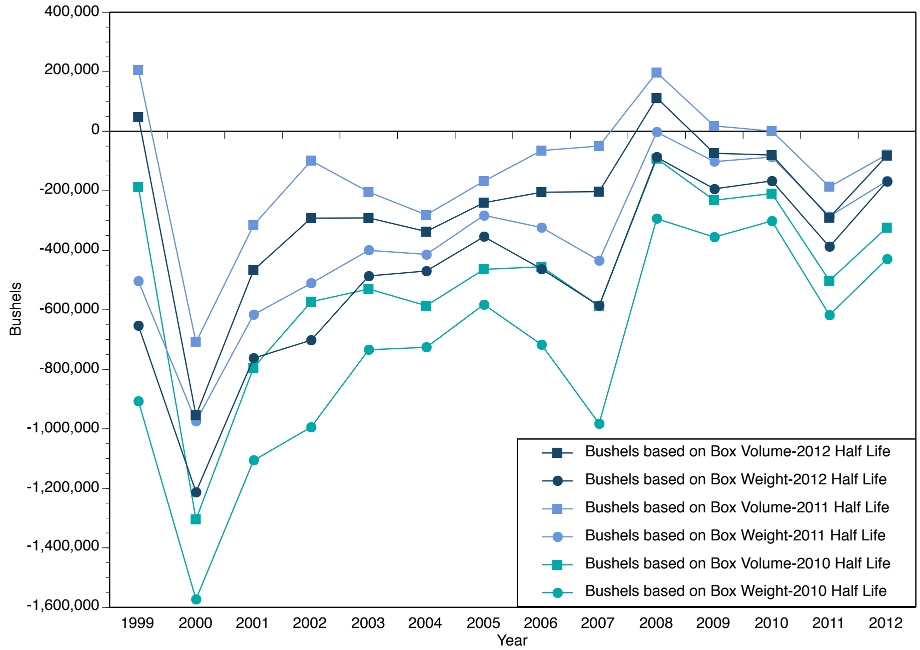


Figure 35. Estimated net change in surficial shell content in bushels for the New Jersey High Mortality beds and for the remaining oyster beds for the time period 1999-2012.

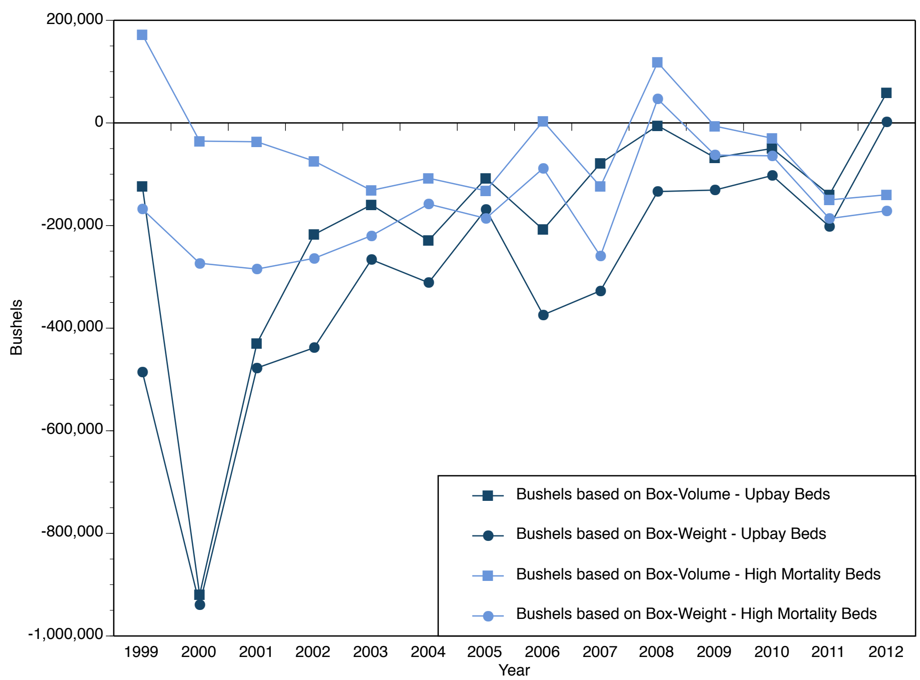


Figure 36. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2012.

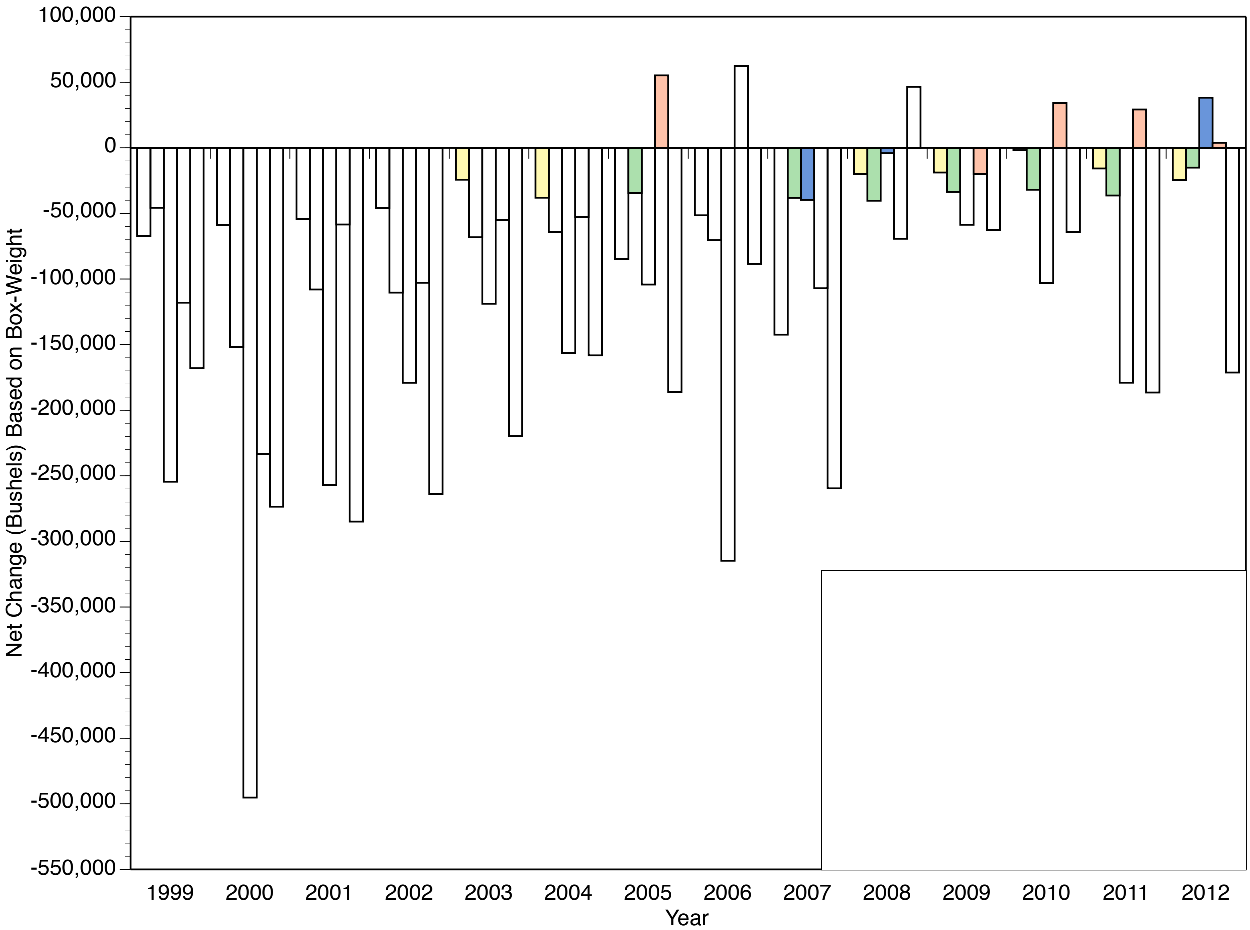


Figure 37. Broodstock-recruitment relationship for the 1953-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Latest year listed as 2011 because the plot compares end-of-2011 oyster abundance with 2012 recruitment. Blue lines identify the 60-year medians. The Ricker curve fit is in green.

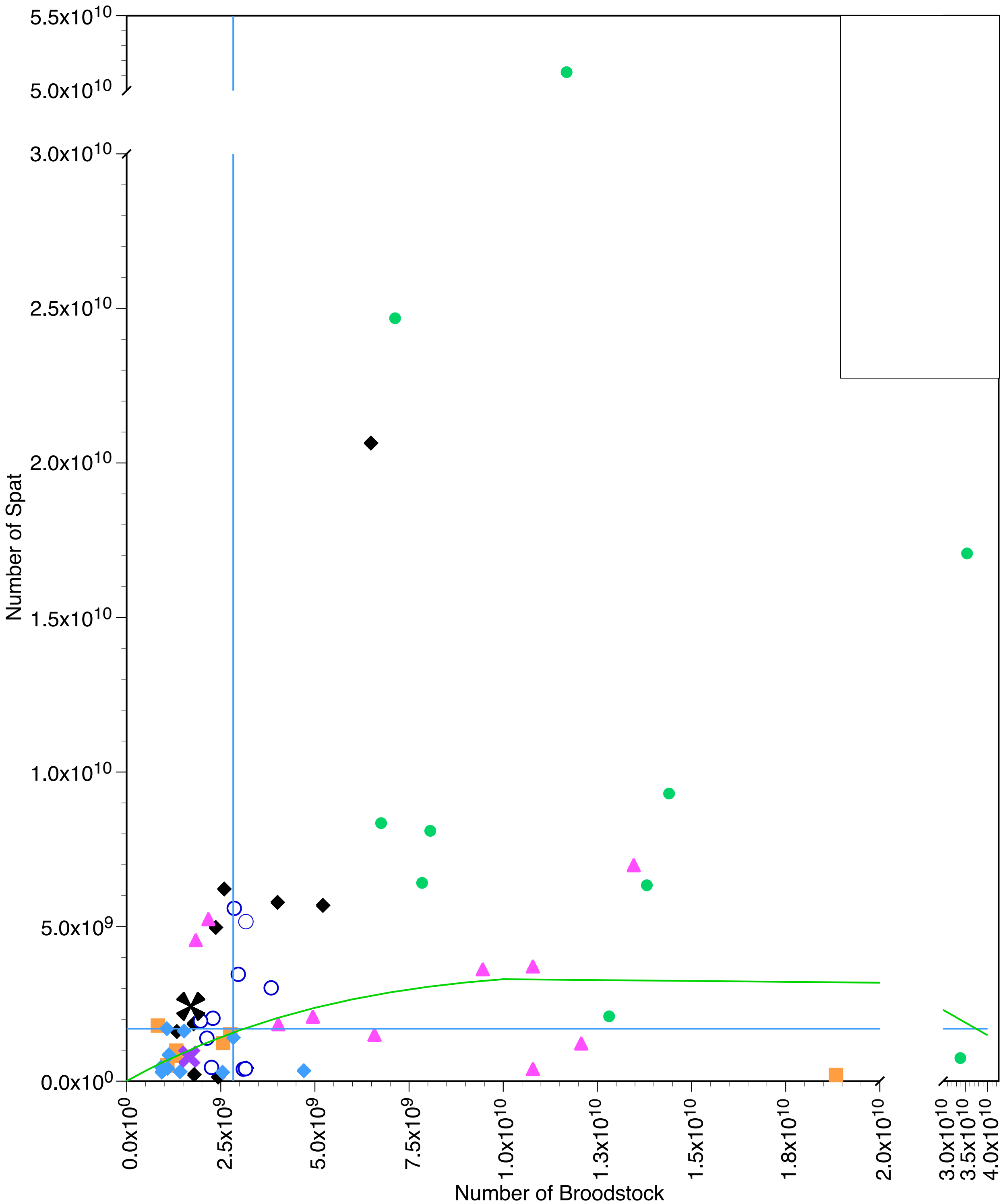


Figure 37a. Lower left section of broodstock-recruitment relationship for the 1953-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Latest year listed as 2011 because the plot compares end-of-2011 oyster abundance with 2012 recruitment. Blue lines identify the 60-year medians. The Ricker curve fit is in green.

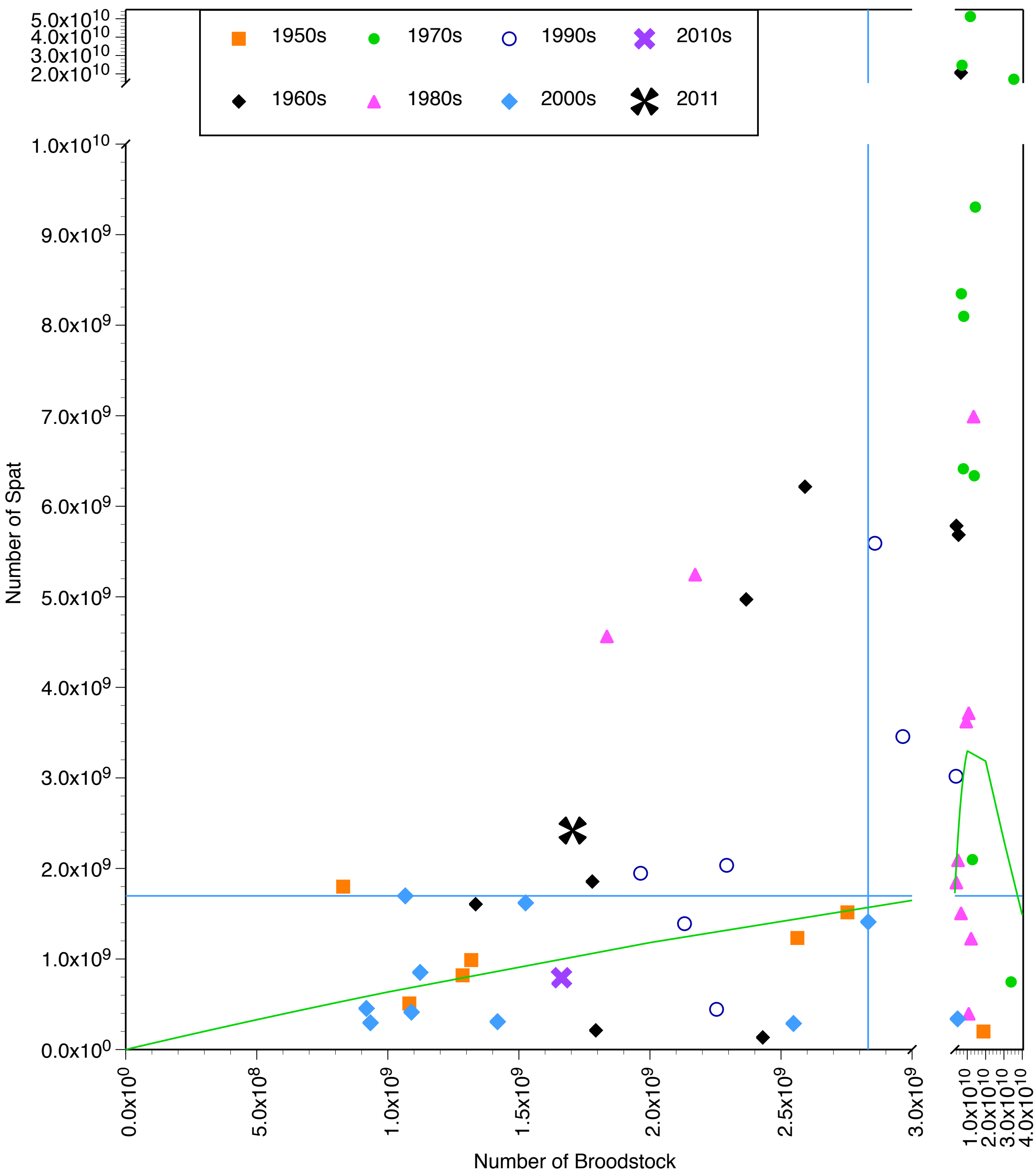


Figure 37b. Broodstock-recruitment relationship for the 1989-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Latest year listed as 2011 because the plot compares end-of-2011 oyster abundance with 2012 recruitment.

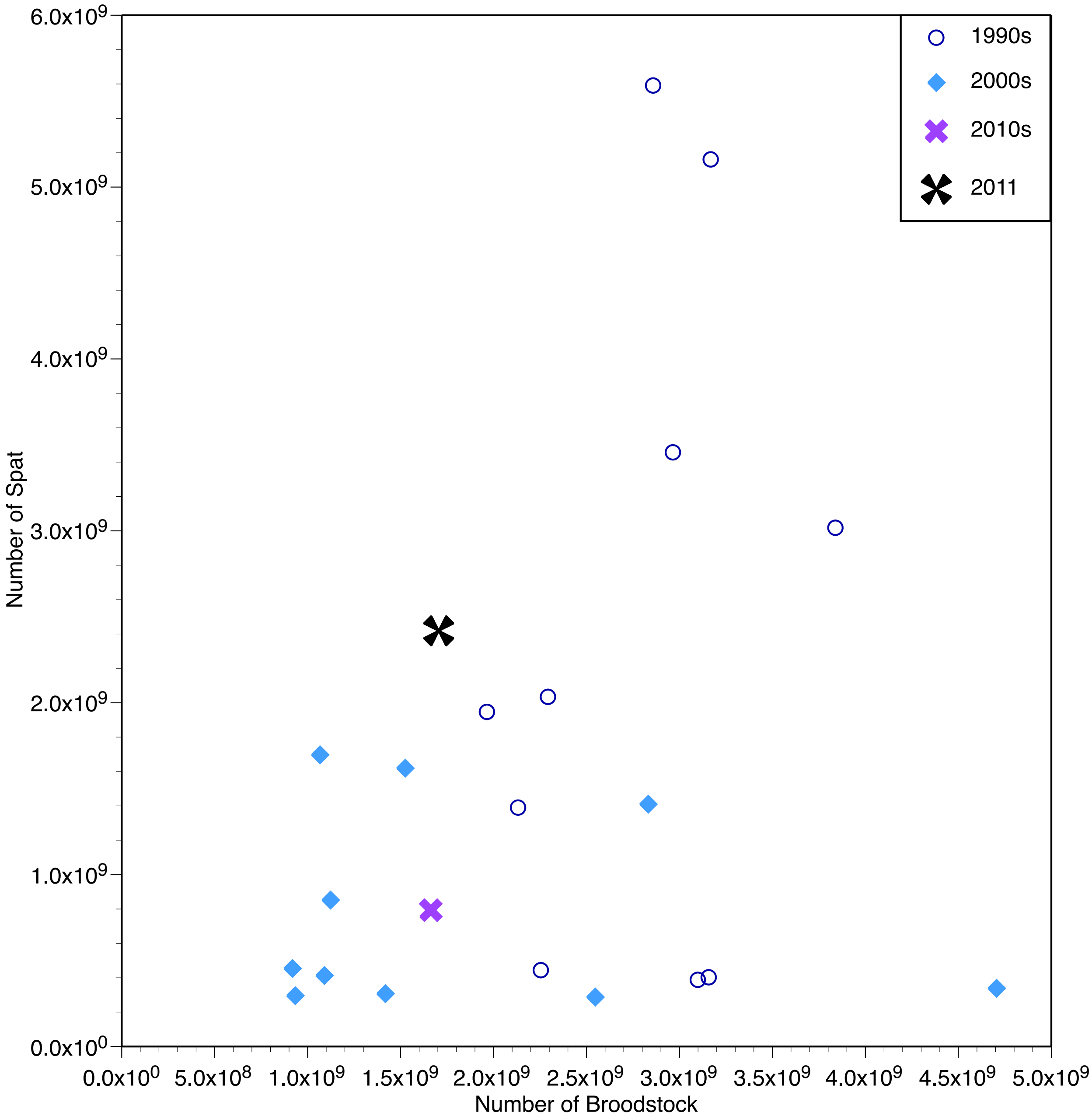


Figure 38. The relationship between oyster abundance and box-count mortality for the 1953-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Latest year listed as 2011 because the plot compares end-of-2011 oyster abundance with 2012 mortality. Blue lines identify the 60-year medians. The nonlinear curve used for modeling surplus production is in green.

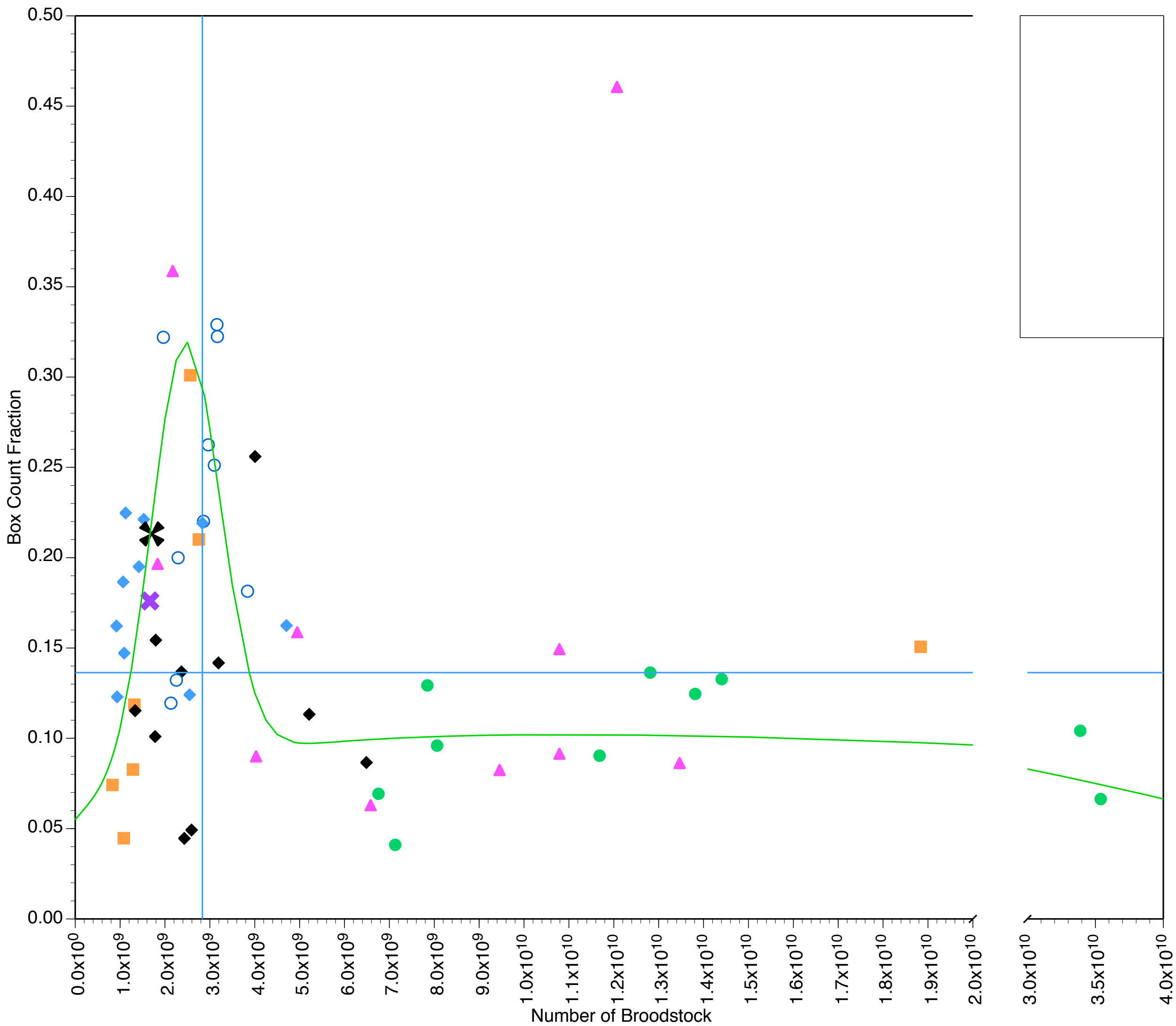


Figure 38a. Another view of the relationship between low oyster abundance and box-count mortality for the 1953-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Latest year listed as 2011 because the plot compares end-of-2011 oyster abundance with 2012 mortality. Blue lines identify the 60-year medians. The nonlinear curve used for modeling surplus production is in green.

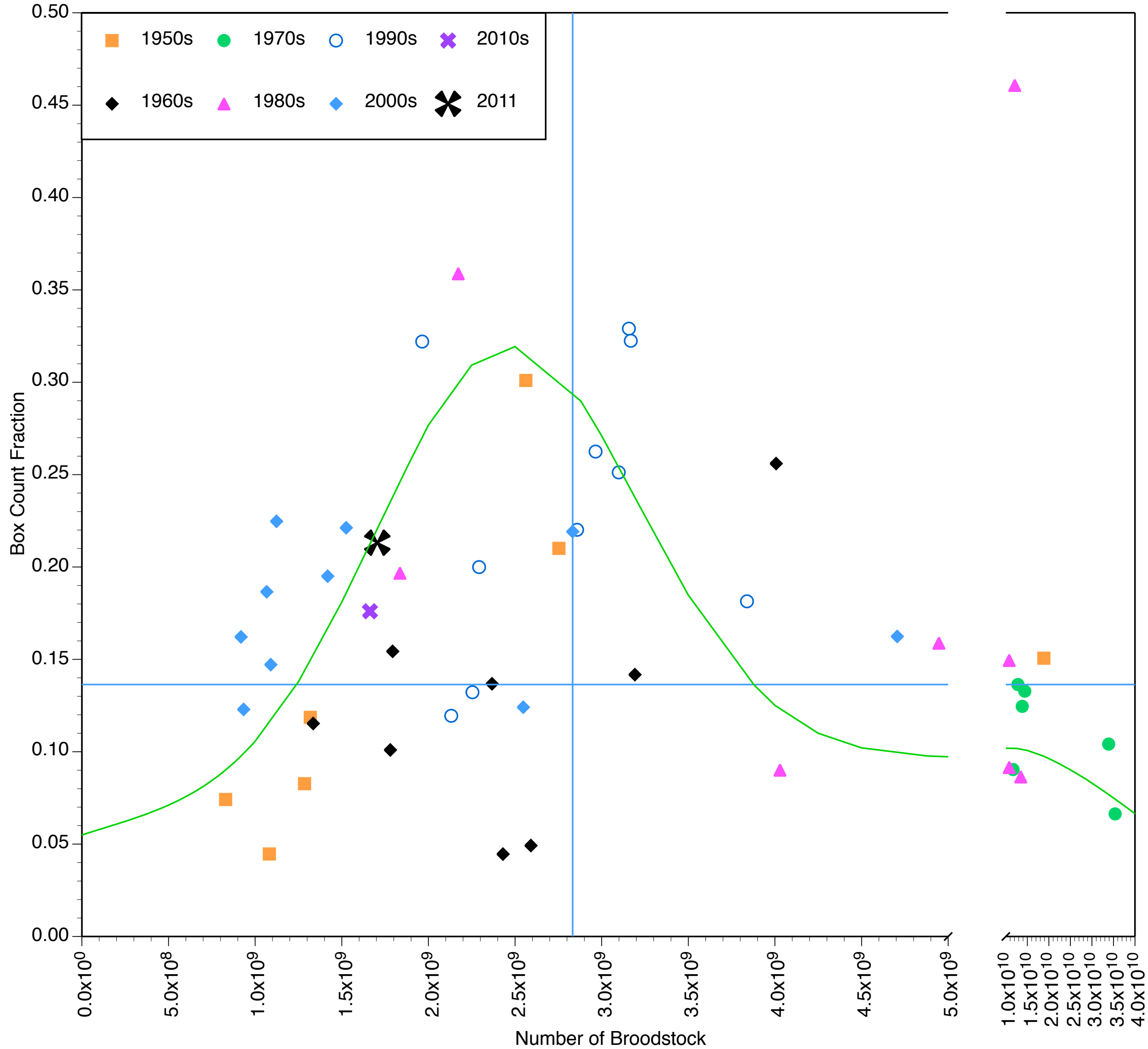


Figure 39. The relationship between box-count mortality and recruitment for the 1953-2012 time period for the natural oyster beds of Delaware Bay excluding the Very Low Mortality region. Blue lines identify the 60-year medians.

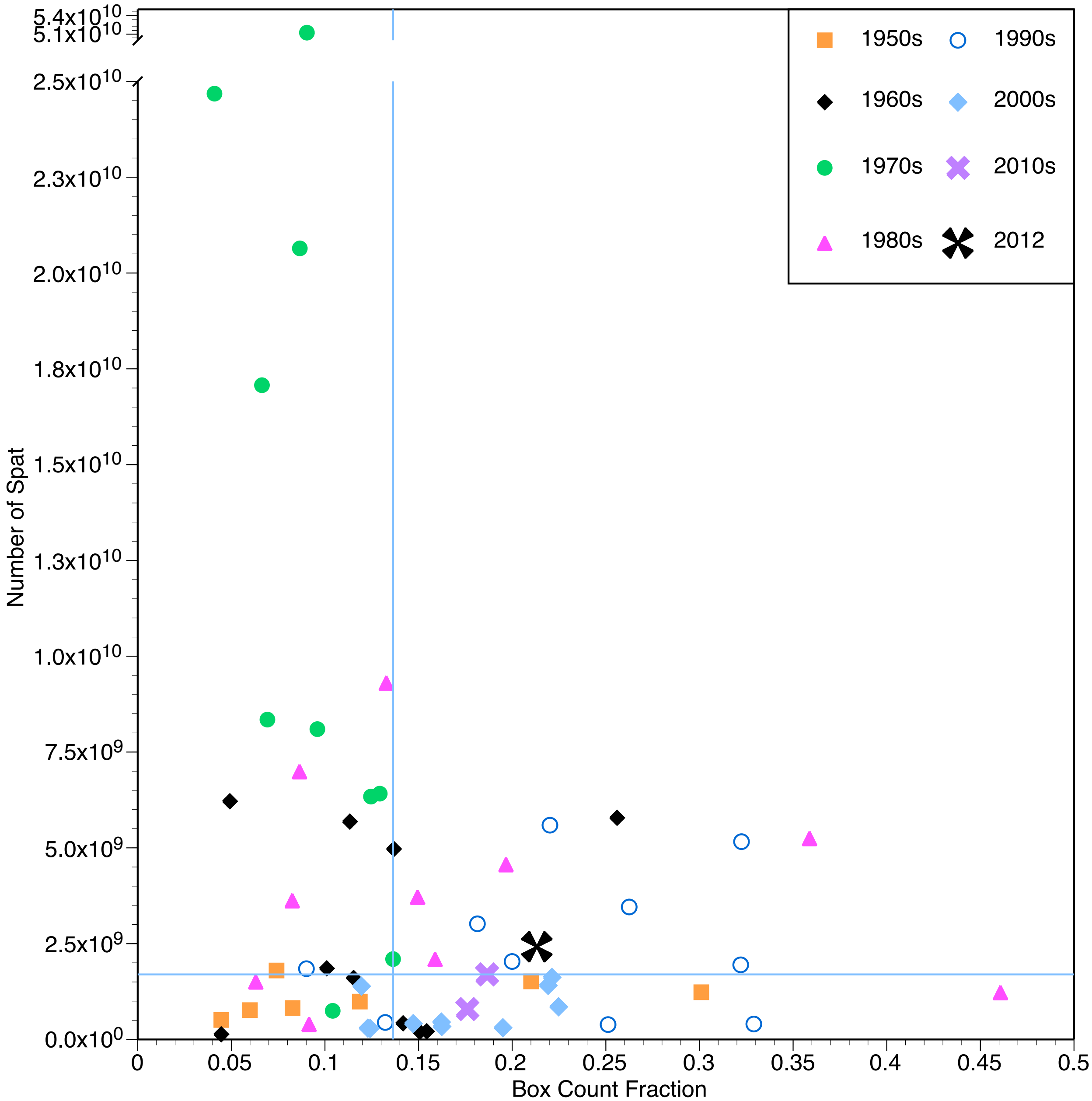


Figure 40. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. Since 1996, the total stock manipulation, including transplant and direct-market is identified as the apparent harvest; those oysters landed are identified as the real harvest. Zeros represent years of fishery closure.

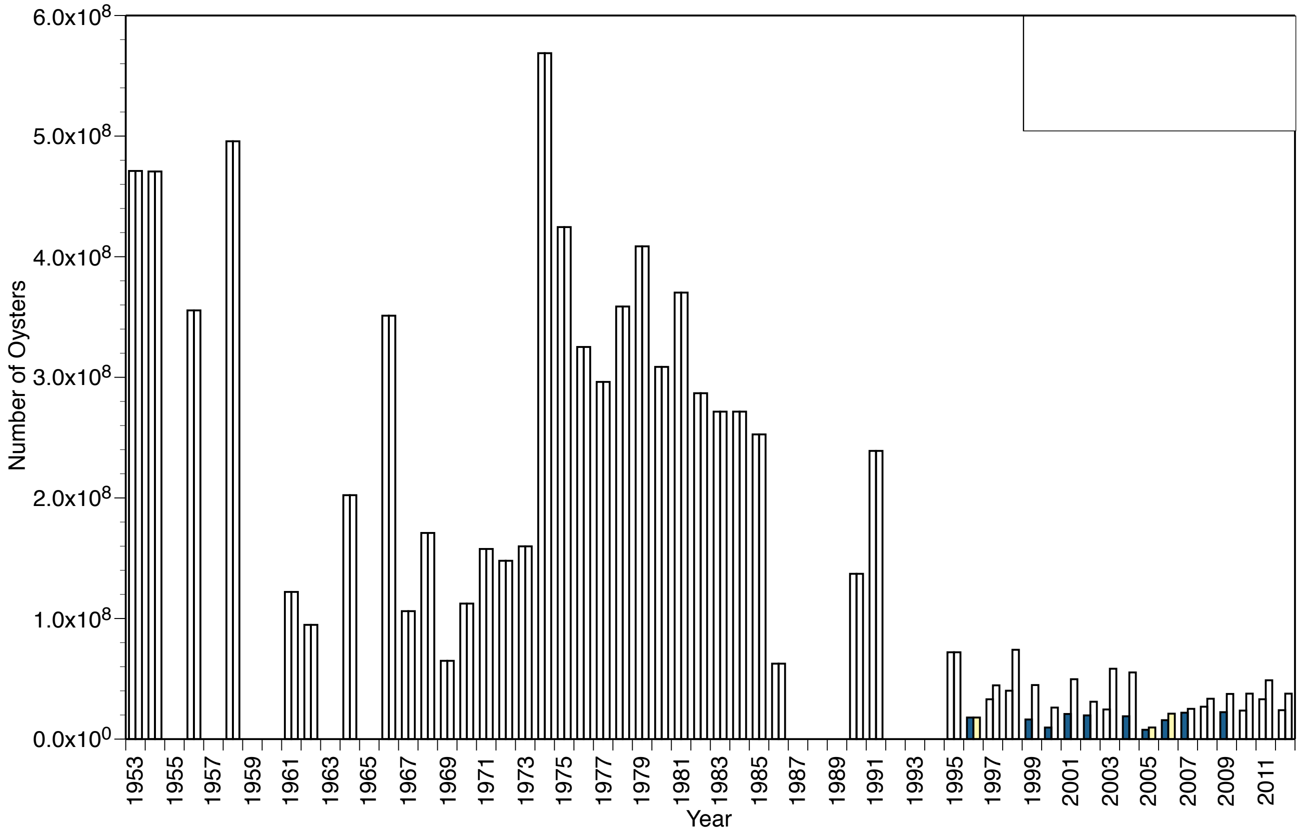


Figure 41. Fishing mortality rates by bay region during the 1954 – 2012 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Beds included in each region are shown in Figure 1 and listed in Table 3. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality rate in that bay region. The total column height is the total fraction for the year.

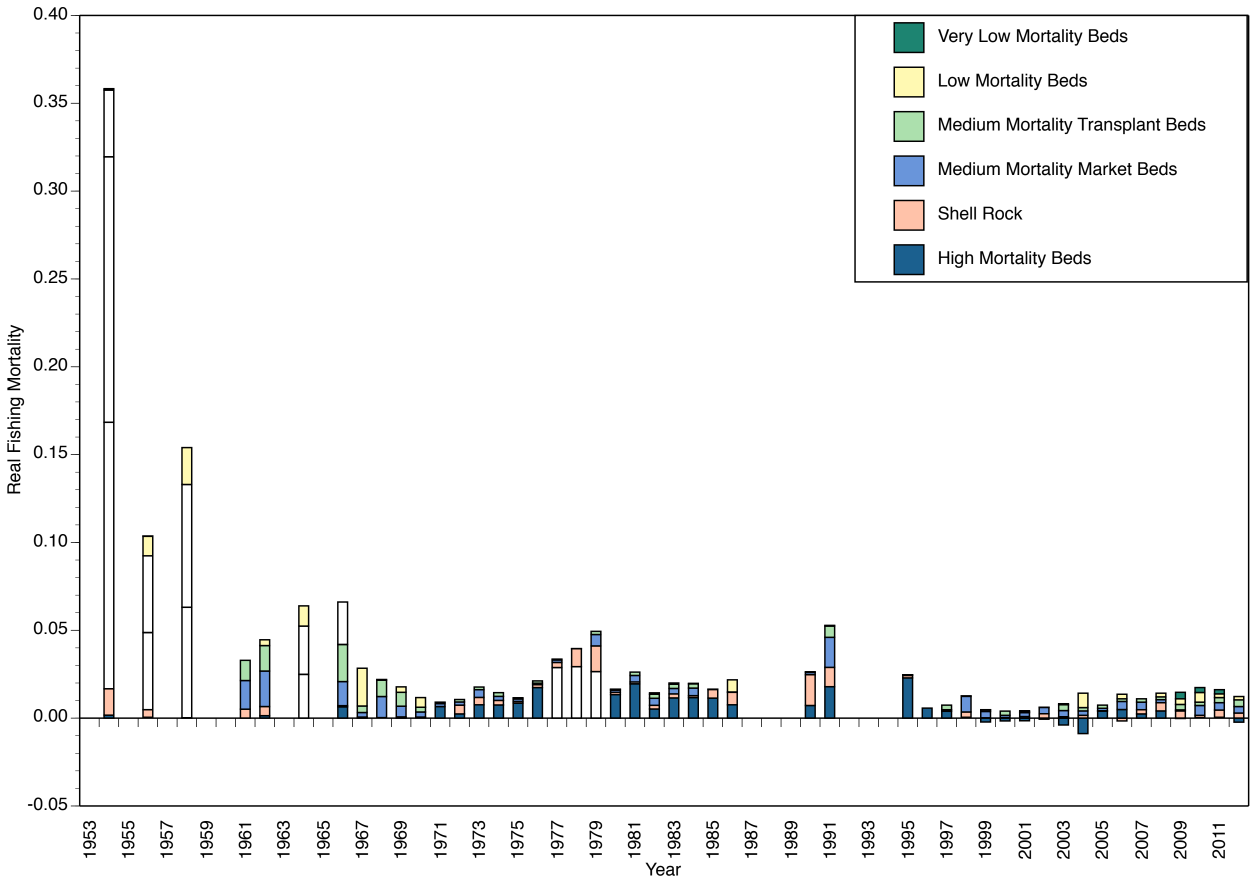


Figure 42. Fishing mortality rates by bay region during the 1989 – 2012 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Beds included in each region are shown in Figure 1 and listed in Table 3. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality in that bay region. The total column height is the total fraction for the year.

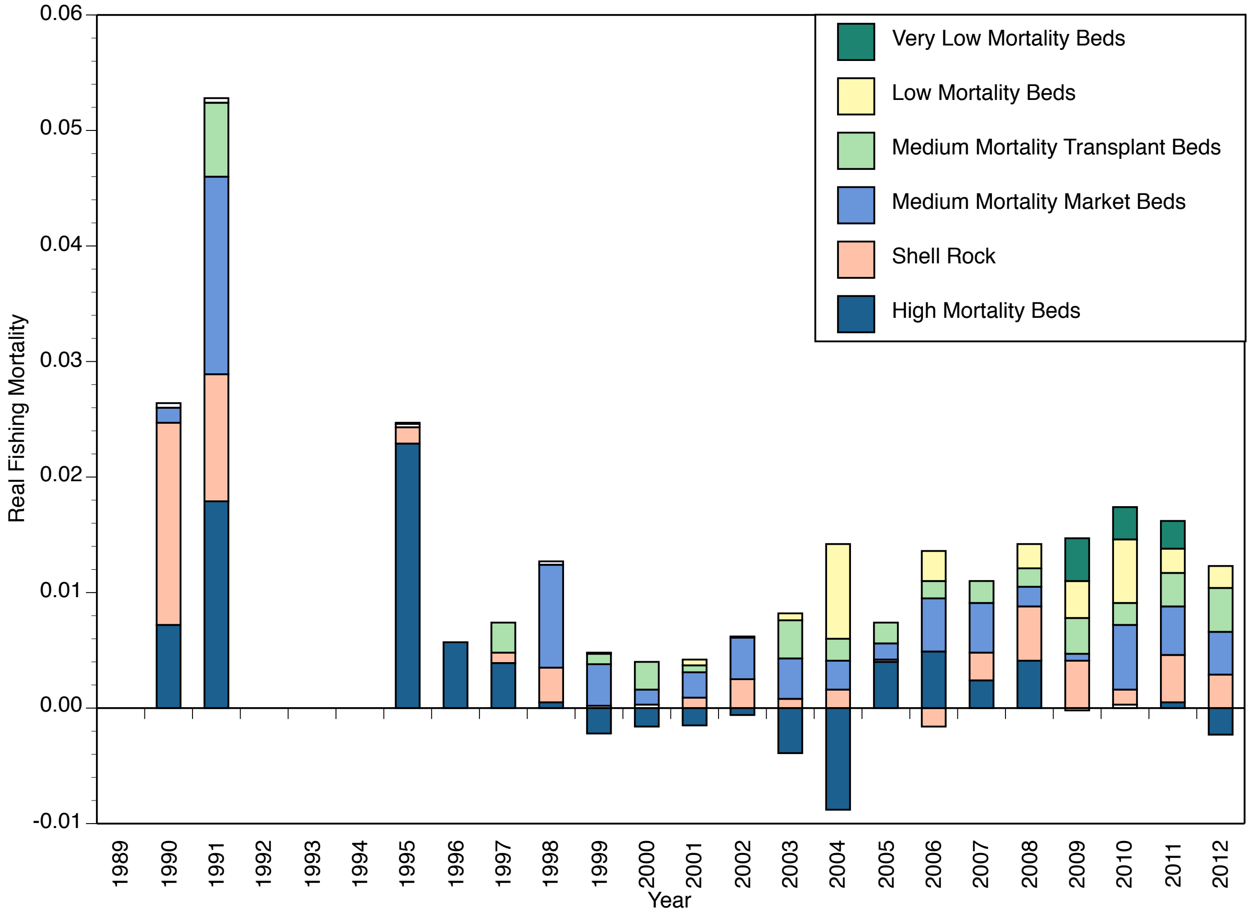


Figure 43. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program in 1996. Orange line, time-series average harvest = 74,887 bushels.

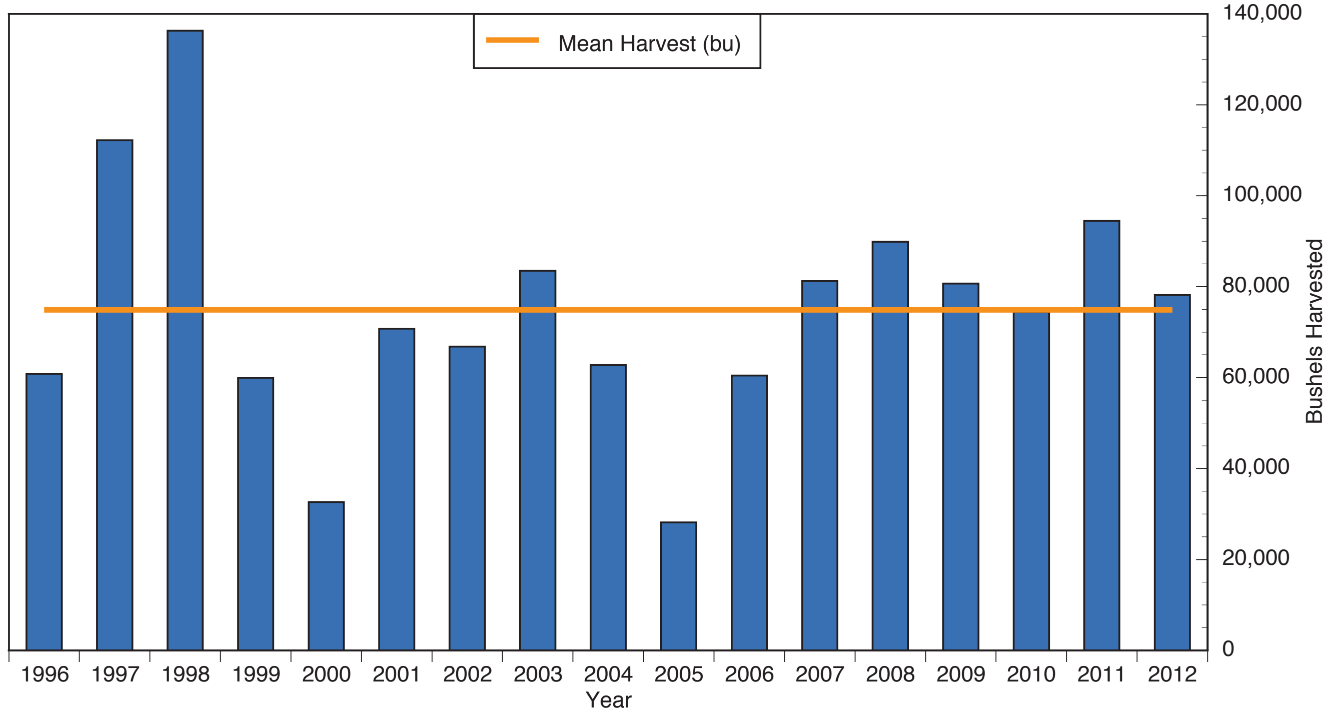


Figure 44. Catch (in bushels) per boat day by vessel type.

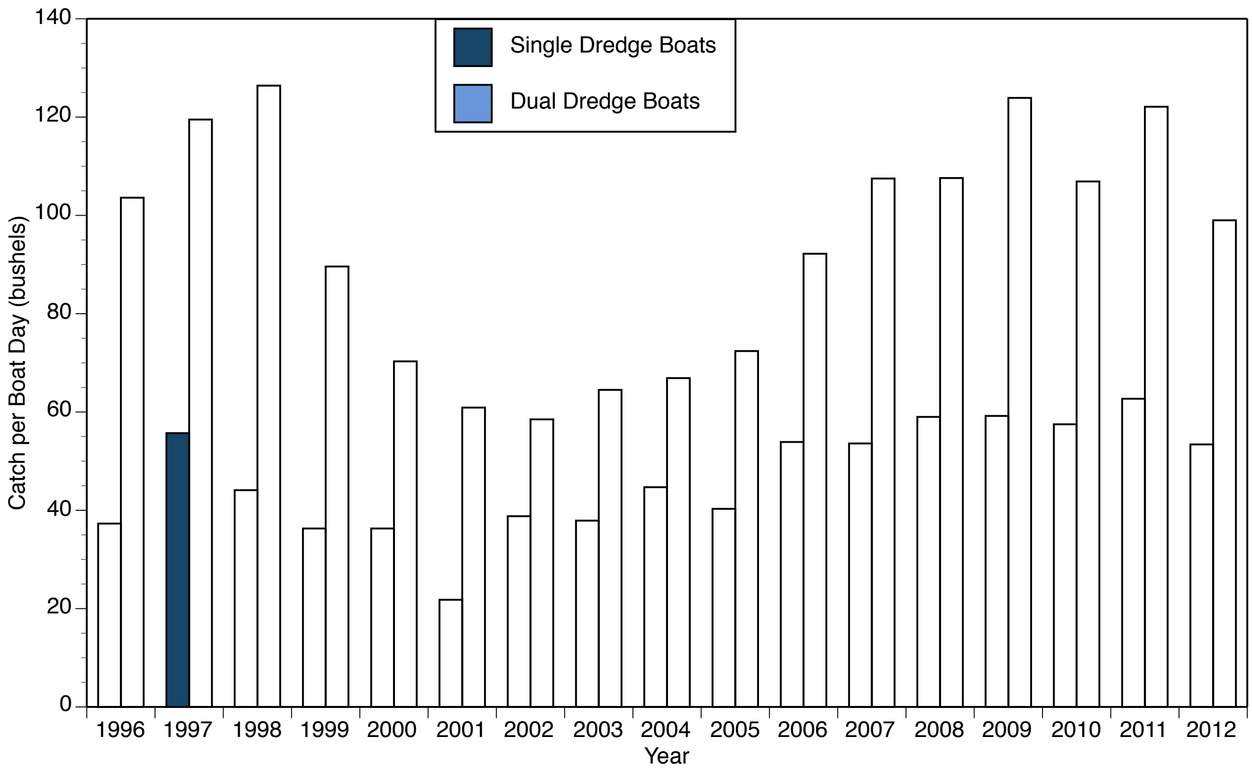


Figure 45. The number of oysters per landed bushel judged to have been landed due to failure to cull small, attached oysters from those of market size (attached) and unattached oysters judged to have been too small to be targeted for market (< 2.5”).

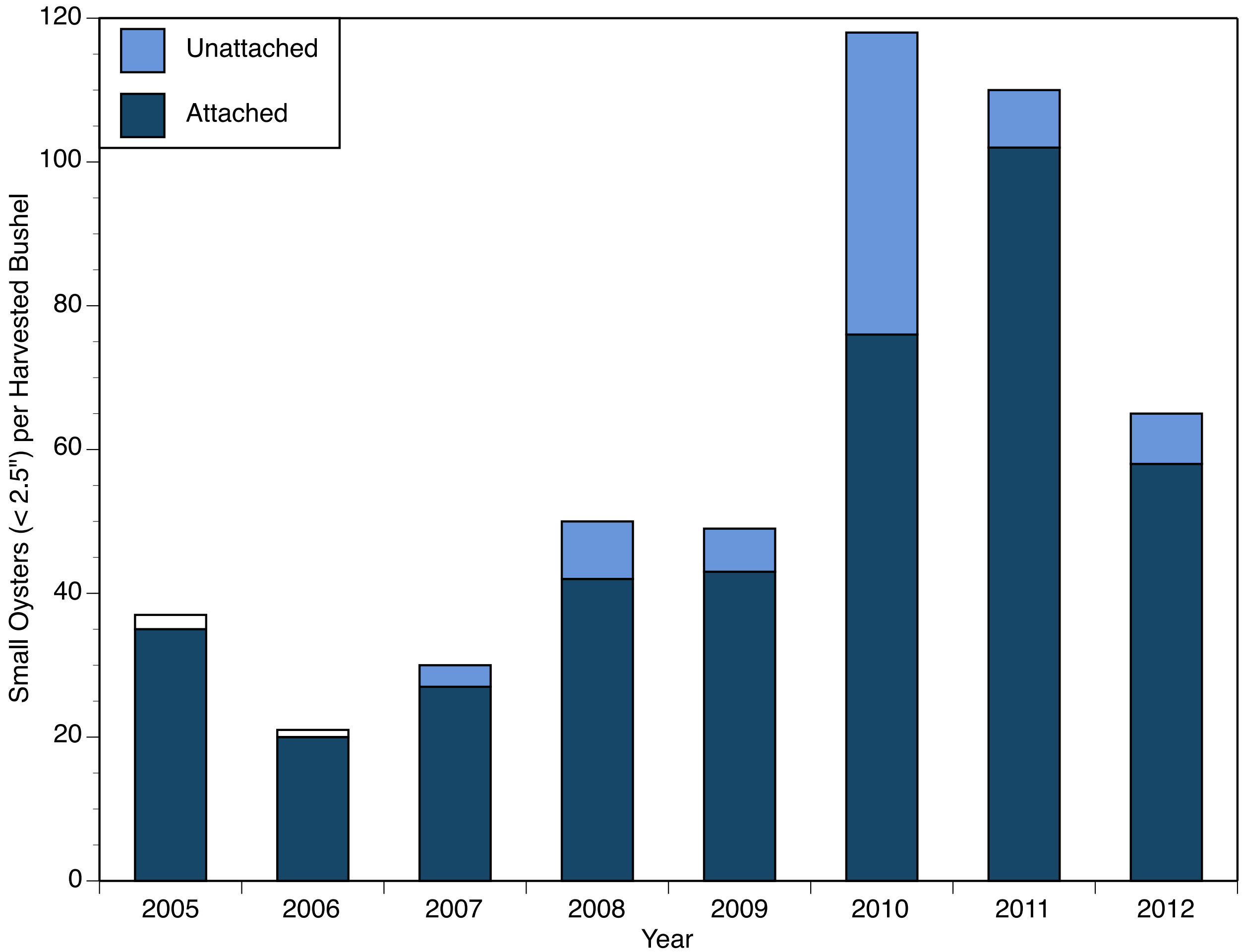


Figure 46. Size frequency of oysters landed in 2012 compared to that of 2010 and 2011. Size class values are the lower bounds of the size class.

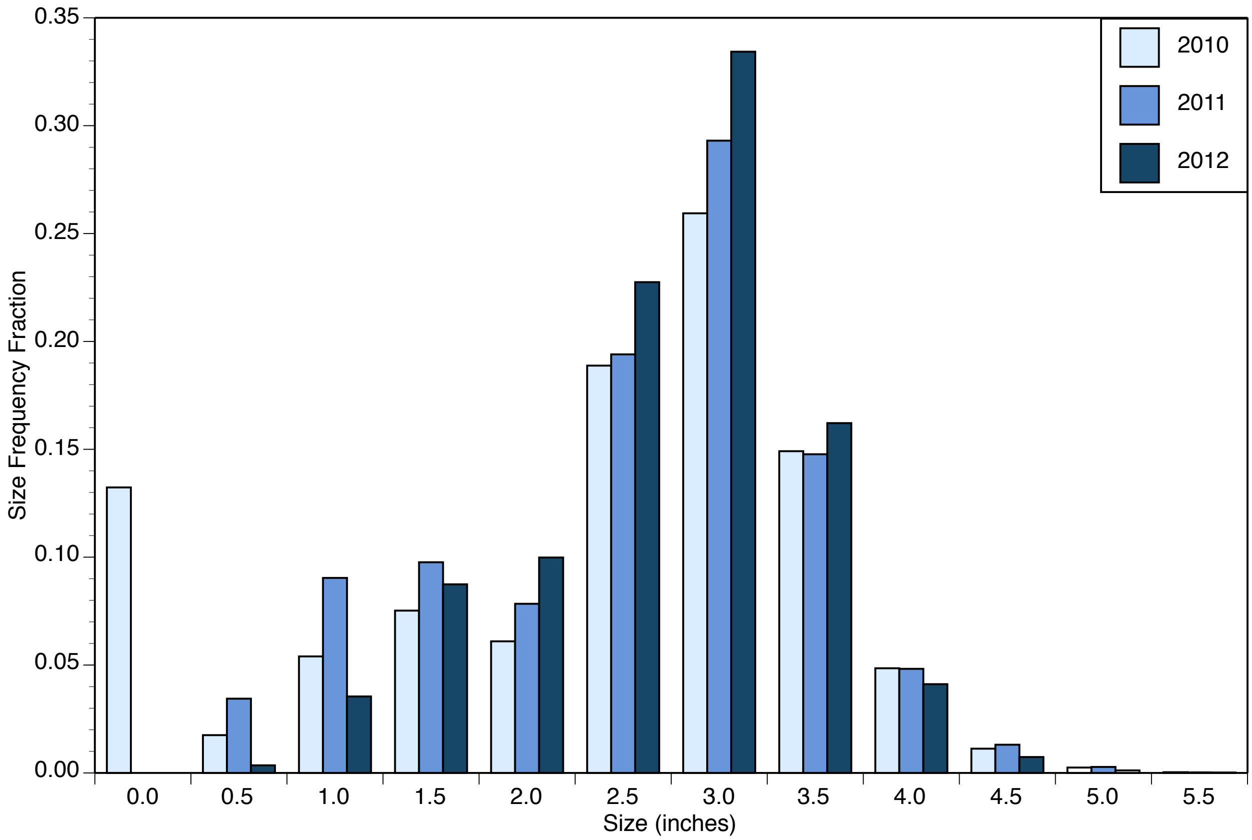


Figure 47. Recipients of 2012 intermediate transplants, Bennies Sand and Nantuxent Point, shown with large white stars.

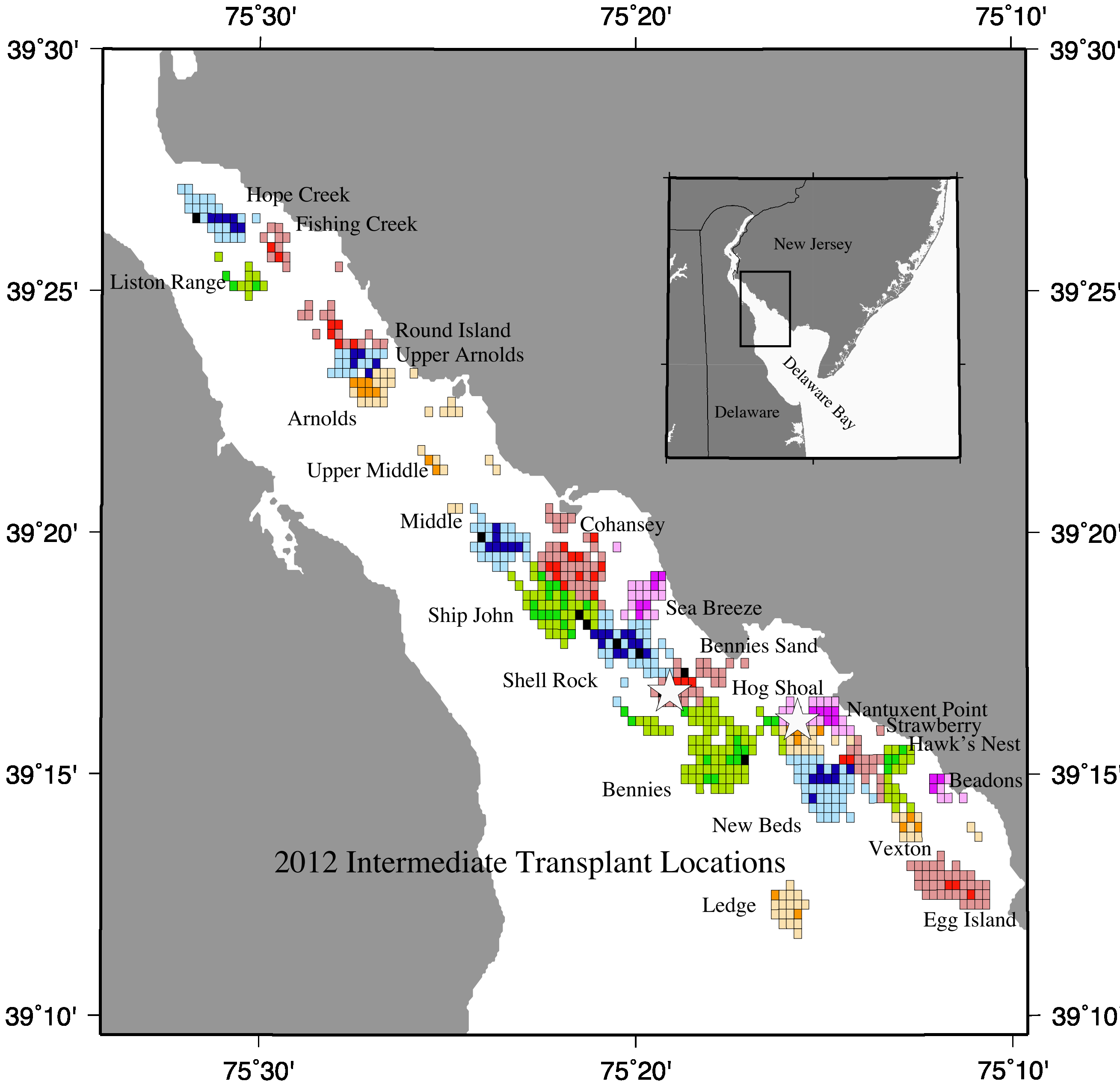


Figure 48. Real fishing mortality as a fraction of oyster abundance during the 1991 – 2012 time period excluding the Very Low Mortality region. Zeros represent years of fishery closure.

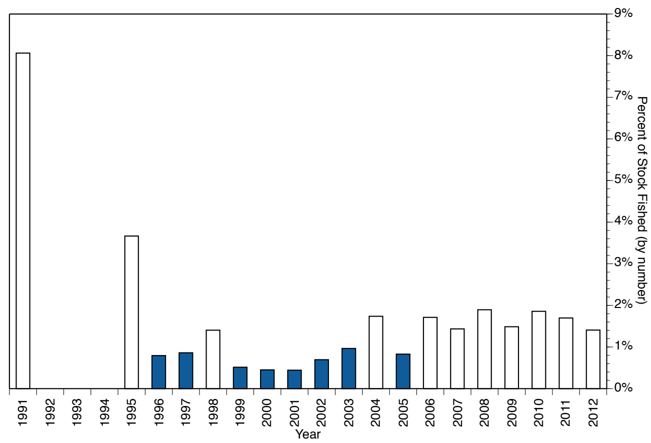


Figure 49. Fishing mortality as a fraction of the marketable abundance (oysters ≥ 2.5”) during the 1997 – 2012 time period excluding the Very Low Mortality region. Actual exploitation rates including this region fall below these values.

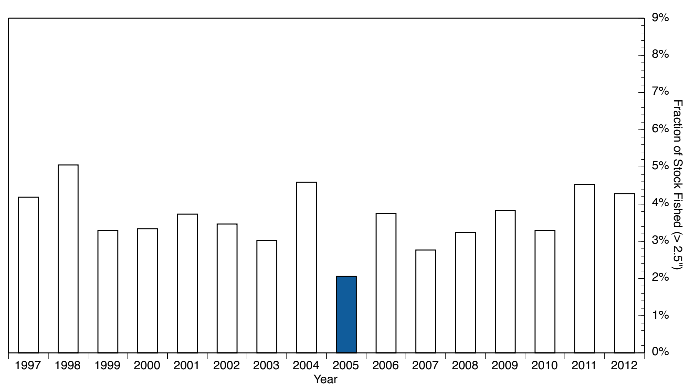


Figure 50. Fishing mortality as a fraction of the spawning stock biomass during the 1997 – 2012 time period excluding the Very Low Mortality region. Actual exploitation rates including this region fall below these values.

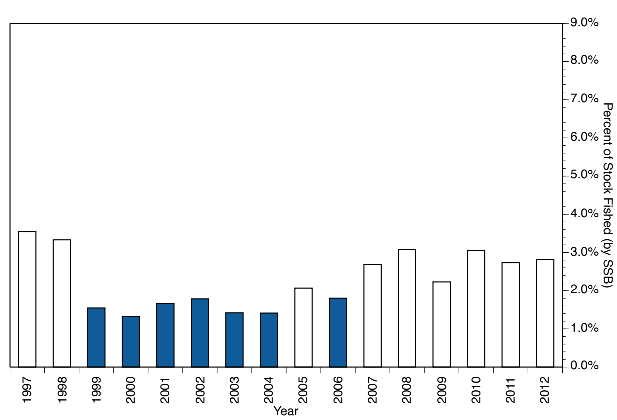
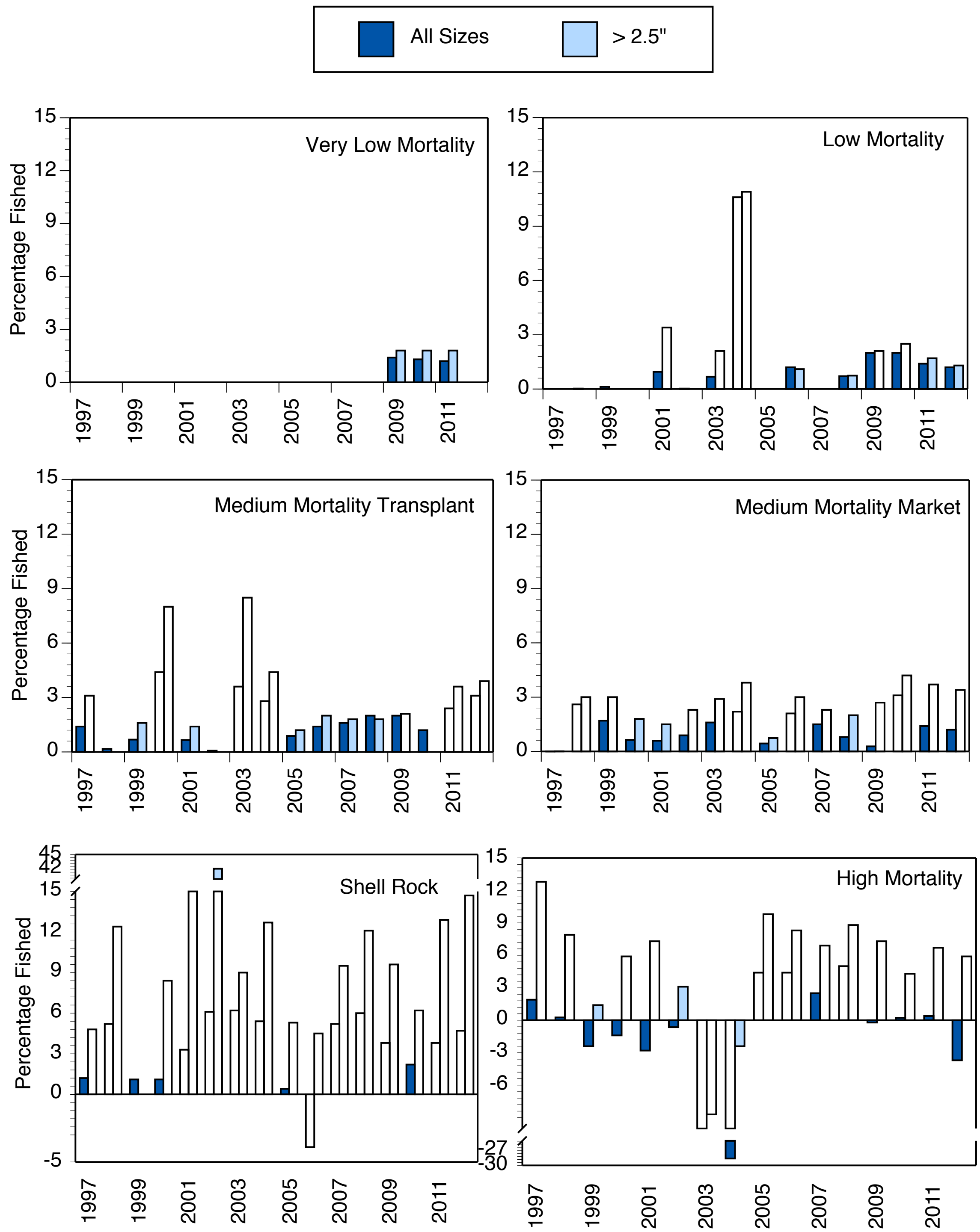
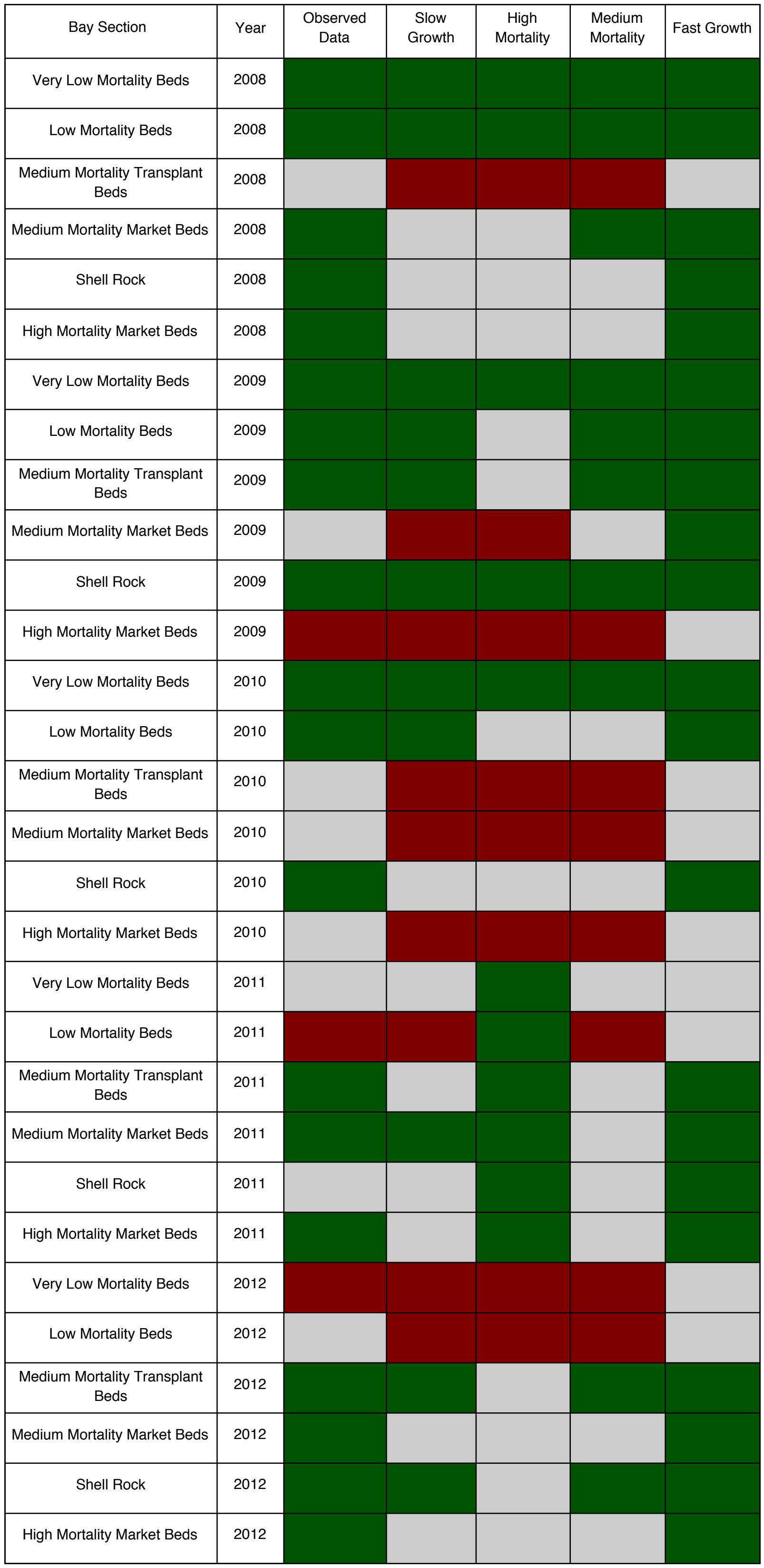


Figure 51. Real fishing mortality percentages by region during the Direct Market time series (1997-2012). Percentages reflect transplant removals from the Very Low Mortality, Low Mortality, and Medium Mortality Transplant regions and transplant additions plus direct market harvest from the Medium Mortality Market, Shell Rock, and High Mortality regions. If more oysters are transplanted to a region than are directly harvested, negative percentages will result. Bars depict the percentage fished of all oysters in each region and the percentage fished of the market (>2.5") oysters. There was no exploitation of the Very Low Mortality region prior to 2009; otherwise, no bars indicate no oysters removed from the region in that year.



Figures 52 (a and b). Net submarket surplus from a retrospective analysis of survey indices and landings under a series of assumptions. Submarket surplus was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous year's survey. This provides high and low bounds for the estimates. Green indicates that net submarket surplus was positive under both assumptions; grey, that the lower estimate was negative and the higher estimate was positive, indicating that the yield to the fishery approximated the potential yield available; and red, that both estimates of net submarket surplus were negative indicating that landings exceeded the level desired under the goal of no net reduction of ≥ 3” oysters. States of nature included a 0.04 reduction in the von-Bertalanffy-k value (slow growth), a 0.04 increase (fast growth), an increase in mortality by a factor of 1.25 (moderate mortality), and an increase in mortality by a factor of 1.5 (high mortality). Figure 52a is sorted by year and Figure 52b is sorted by bay region.

Figure 52a.



Bay Section
Year
Observed Data
Slow Growth
High Mortality
Medium Mortality
Fast Growth
Very Low Mortality Beds 2008
Low Mortality Beds 2008
Medium Mortality Transplant Beds 2008
Medium Mortality Market Beds 2008
Shell Rock 2008
High Mortality Market Beds 2008
Very Low Mortality Beds 2009
Low Mortality Beds 2009
Medium Mortality Transplant Beds 2009
Medium Mortality Market Beds 2009
Shell Rock 2009
High Mortality Market Beds 2009
Very Low Mortality Beds 2010
Low Mortality Beds 2010
Medium Mortality Transplant Beds 2010
Medium Mortality Market Beds 2010
Shell Rock 2010
High Mortality Market Beds 2010
Very Low Mortality Beds 2011
Low Mortality Beds 2011
Medium Mortality Transplant Beds 2011
Medium Mortality Market Beds 2011
Shell Rock 2011
High Mortality Market Beds 2011
Very Low Mortality Beds 2012
Low Mortality Beds 2012
Medium Mortality Transplant Beds 2012
Medium Mortality Market Beds 2012
Shell Rock 2012
High Mortality Market Beds 2012

Figure 52b.

Bay Section	Year	Observed Data	Slow Growth	High Mortality	Medium Mortality	Fast Growth
Very Low Mortality Beds	2008					
Very Low Mortality Beds	2009					
Very Low Mortality Beds	2010					
Very Low Mortality Beds	2011					
Very Low Mortality Beds	2012					
Low Mortality Beds	2008					
Low Mortality Beds	2009					
Low Mortality Beds	2010					
Low Mortality Beds	2011					
Low Mortality Beds	2012					
Medium Mortality Transplant Beds	2008					
Medium Mortality Transplant Beds	2009					
Medium Mortality Transplant Beds	2010					
Medium Mortality Transplant Beds	2011					
Medium Mortality Transplant Beds	2012					
Medium Mortality Market Beds	2008					
Medium Mortality Market Beds	2009					
Medium Mortality Market Beds	2010					
Medium Mortality Market Beds	2011					
Medium Mortality Market Beds	2012					
Shell Rock	2008					
Shell Rock	2009					
Shell Rock	2010					
Shell Rock	2011					
Shell Rock	2012					
High Mortality Market Beds	2008					
High Mortality Market Beds	2009					
High Mortality Market Beds	2010					
High Mortality Market Beds	2011					
High Mortality Market Beds	2012					

Figure 53. Position of the oyster stock in 2008-2012 with respect to abundance and biomass targets and thresholds. The target is taken as the median of abundance or biomass during the 1989 – 2005 (1990-2005) time period. The threshold is taken as half these values (Table 21). Reference points for the Very Low Mortality beds were derived as described in the text and Table 21.

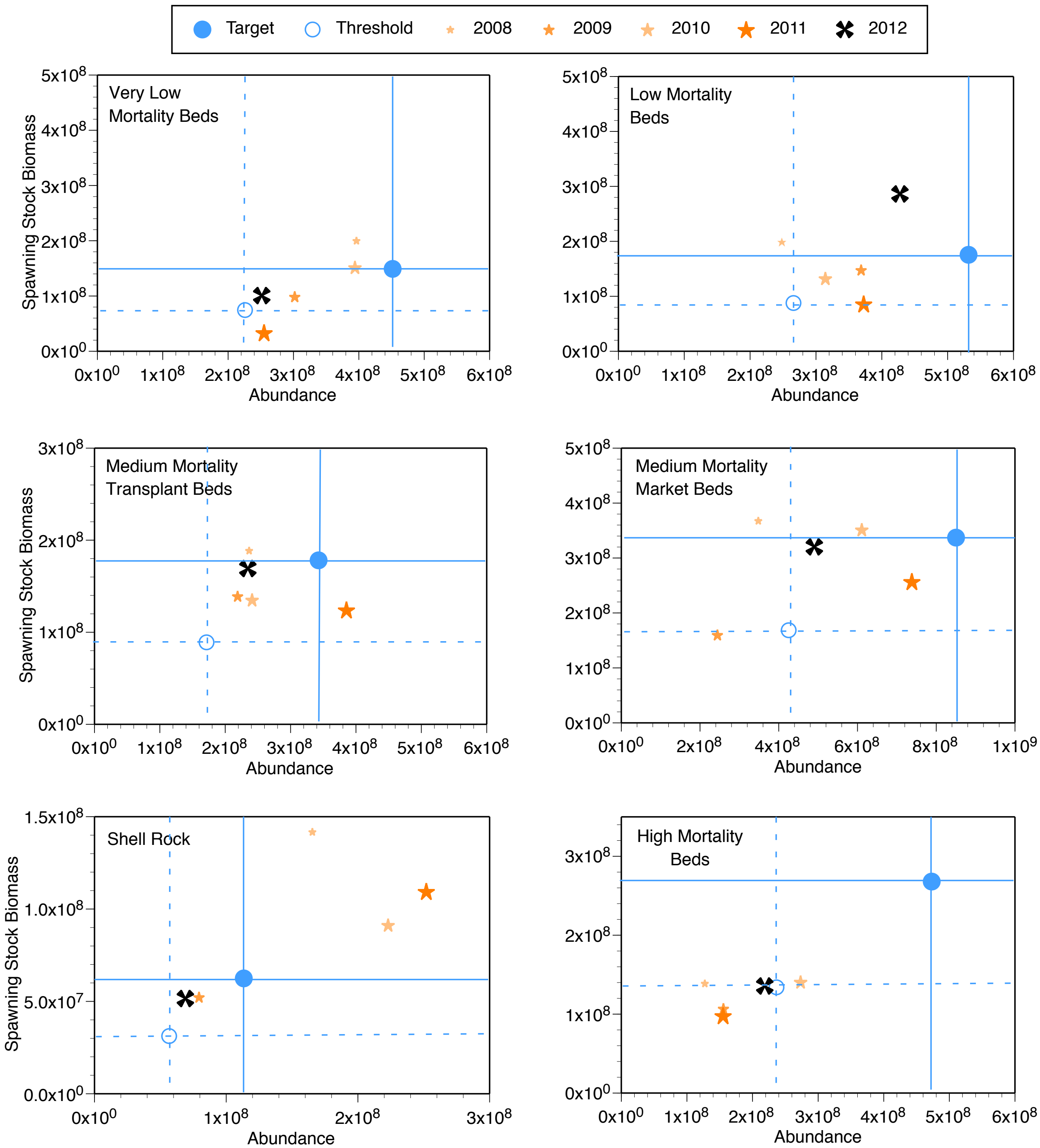


Figure 54. Position of the oyster stock in 2008 – 2012 with respect to abundance and market abundance (≥ 2.5') targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989 – 2005 (1990-2005) time period. The threshold is taken as half these values (Table 21). Reference points for the Very Low Mortality beds were derived as described in the text and Table 21.

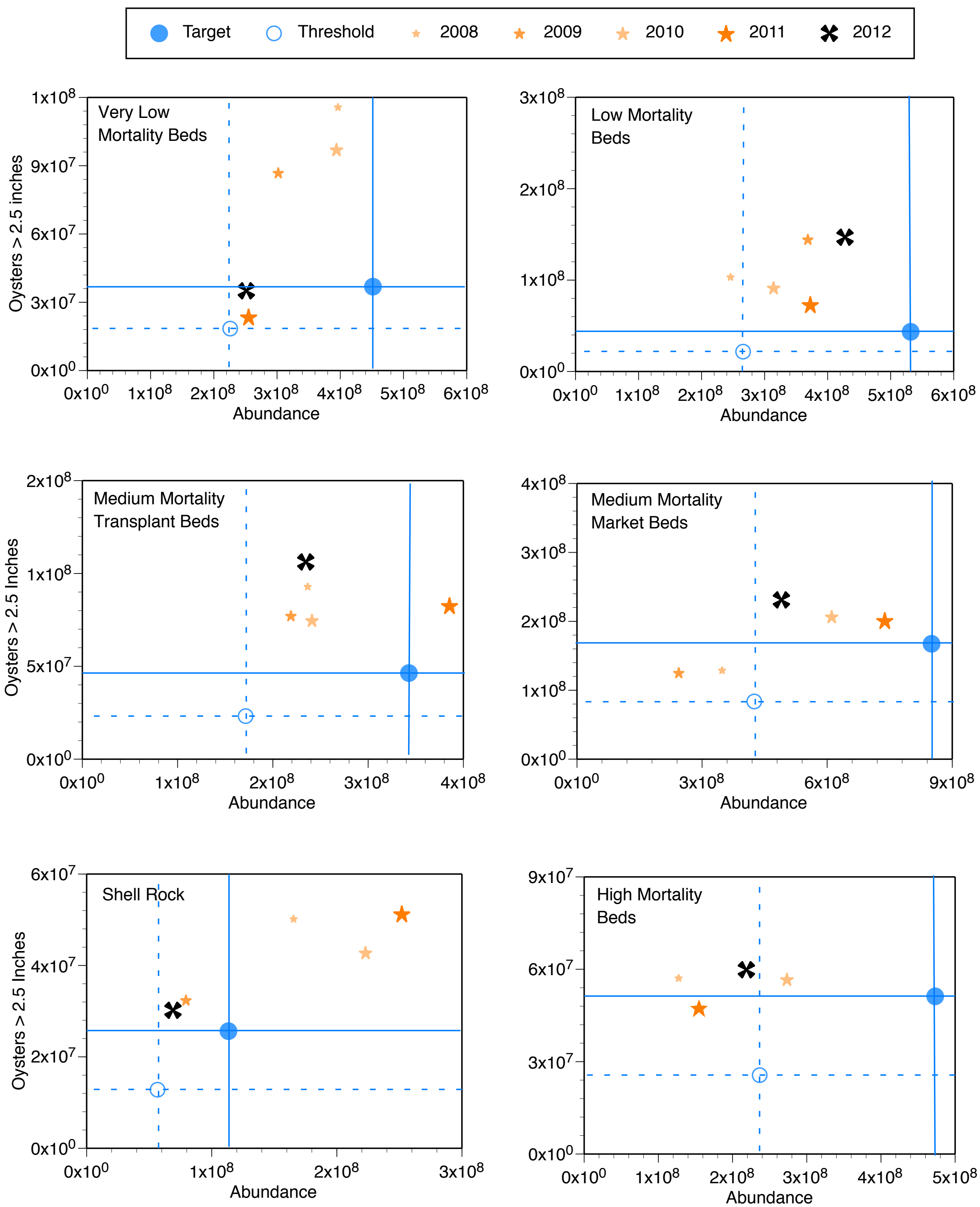


Figure 55. Relationship of the stock-performance reference points for total abundance from Table 21 to the 2012-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1 - P$ so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

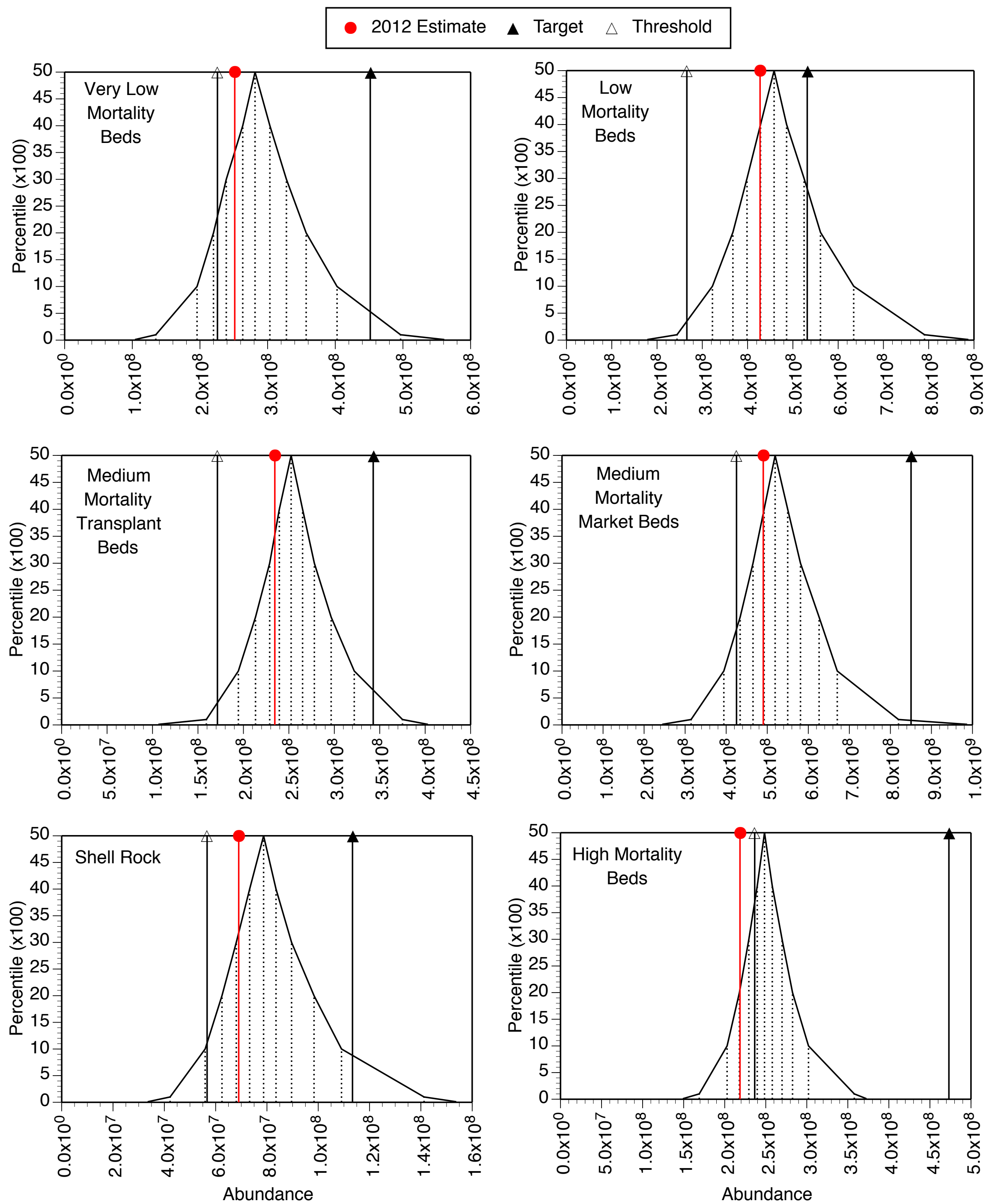


Figure 56. Relationship of the stock-performance reference points for marketable abundance (animals ≥ 2.5") from Table 21 to the 2012-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1 - P$ so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

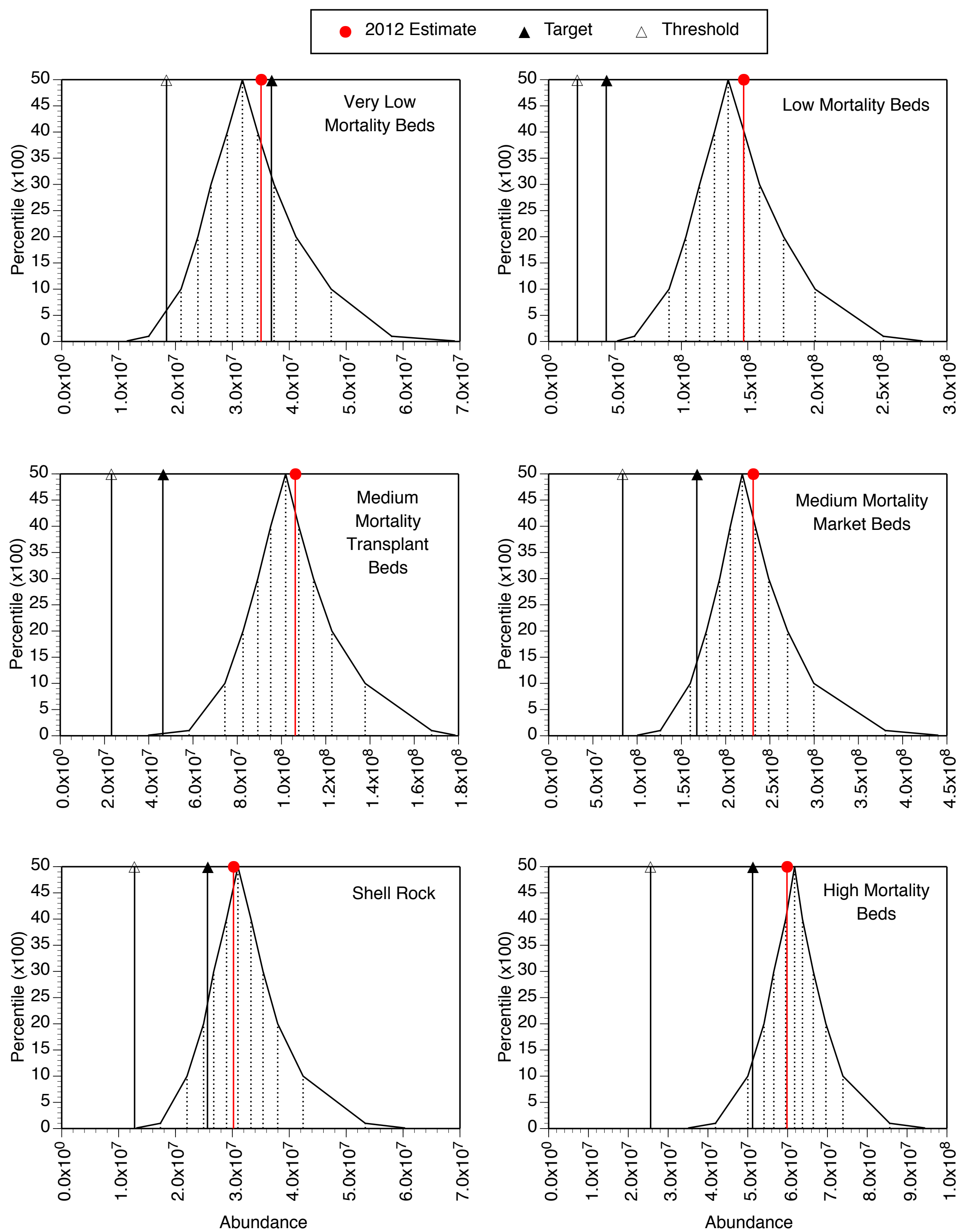


Figure 57. Position of the 2012 whole-stock abundance estimate within confidence percentiles for the 2012-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. The Very Low Mortality region is excluded. Also indicated are the positions of the whole-stock stock-performance reference points from Table 20 and the N_{msy} reference points. All values exclude the Very Low Mortality region. Note that the percentiles above the 50^{th} are rendered as $1 - P$ so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

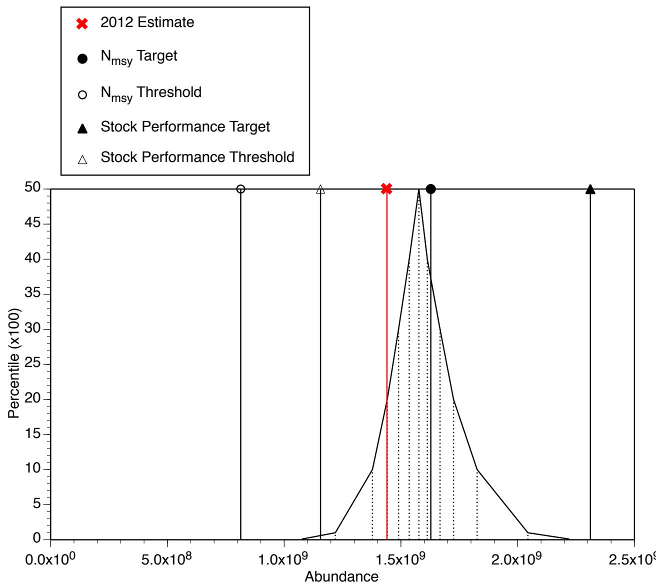


Figure 58. Position of the 2012 whole-stock marketable-abundance (≥ 2.5") estimate within confidence percentiles for the 2012-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. The Very Low Mortality region is excluded. Also indicated are the positions of the whole-stock stock-performance reference points from Table 20. Note that the percentiles above the 50^{th} are rendered as $1 - P$ so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

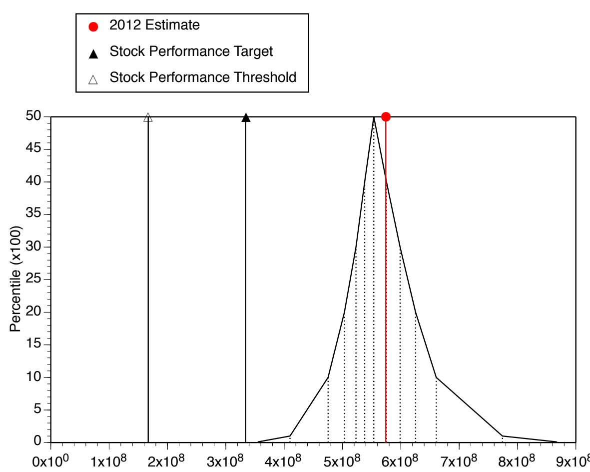


Figure 59. Summary status of the stock for 2012. Green indicates variables judged to be improved relative to the 1989 (or 1990) – 2012 time period or improving relative to 2011 or the 2007-2011 median. Orange indicates variables judged to be degraded or degrading for the same comparisons. A neutral color is used for near-average conditions falling within the 40th to 60th percentiles of the 1989 (or 1990) – 2012 time period and also for trend changes less than ± 15%.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.15	0.25	0.14	0.29	0.04	0.13
Fraction of Stock (No Very Low)	Not Incl.	0.29	0.16	0.34	0.05	0.15
Total Abundance						
2012 Percentile	Not Incl.					
2007-2011 Median						
2011-2012 Trend						
Spawning Stock Biomass						
2012 Percentile	Not Incl.					
2007-2011 Median						
2011-2012 Trend						
Market Abundance						
2012 Percentile	Not Incl.					
2007-2011 Median						
2011-2012 Trend						
Recruitment						
2012 Percentile	Not Incl.					
2007-2011 Median						
2011-2012 Trend						
Spat per Adult						
2012 Percentile	Not Incl.					
2007-2011 Median						
Small Oys (fract.<2.5")	0.86	0.66	0.55	0.53	0.56	0.72
2012 Percentile	Not Incl.					
2007-2011 Median						
Dermo Weighted Prevalence						
2012 Percentile	Not Incl.					
Weighted Prev. Median						
2011-2012 Trend						
Mortality Rate						
2012 Percentile	Not Incl.					
2007-2011 Median						
2011-2012 Trend						
Abundance Position vs						
Target	Below	Below	Below	Below	Below	Below
Threshold			Above			
SSB Position vs						
Target	Below	Above	Below	Below	Below	Below
Threshold	Above	Above	Above	Above	Above	
Market Abundance vs						
Target	Below	Above	Above	Above	Above	Above
Threshold	Above	Above	Above	Above	Above	Above
Surplus Production						
50th Percentile Mortality	Positive	Positive	Positive	Positive	Positive	Positive
75th Percentile Mortality	Positive	Positive	Positive	Positive	Positive	Positive

Figure 60. The percentages of mortality attributable to fishing as opposed to natural mortality for oysters ≥ 2.5” in size.

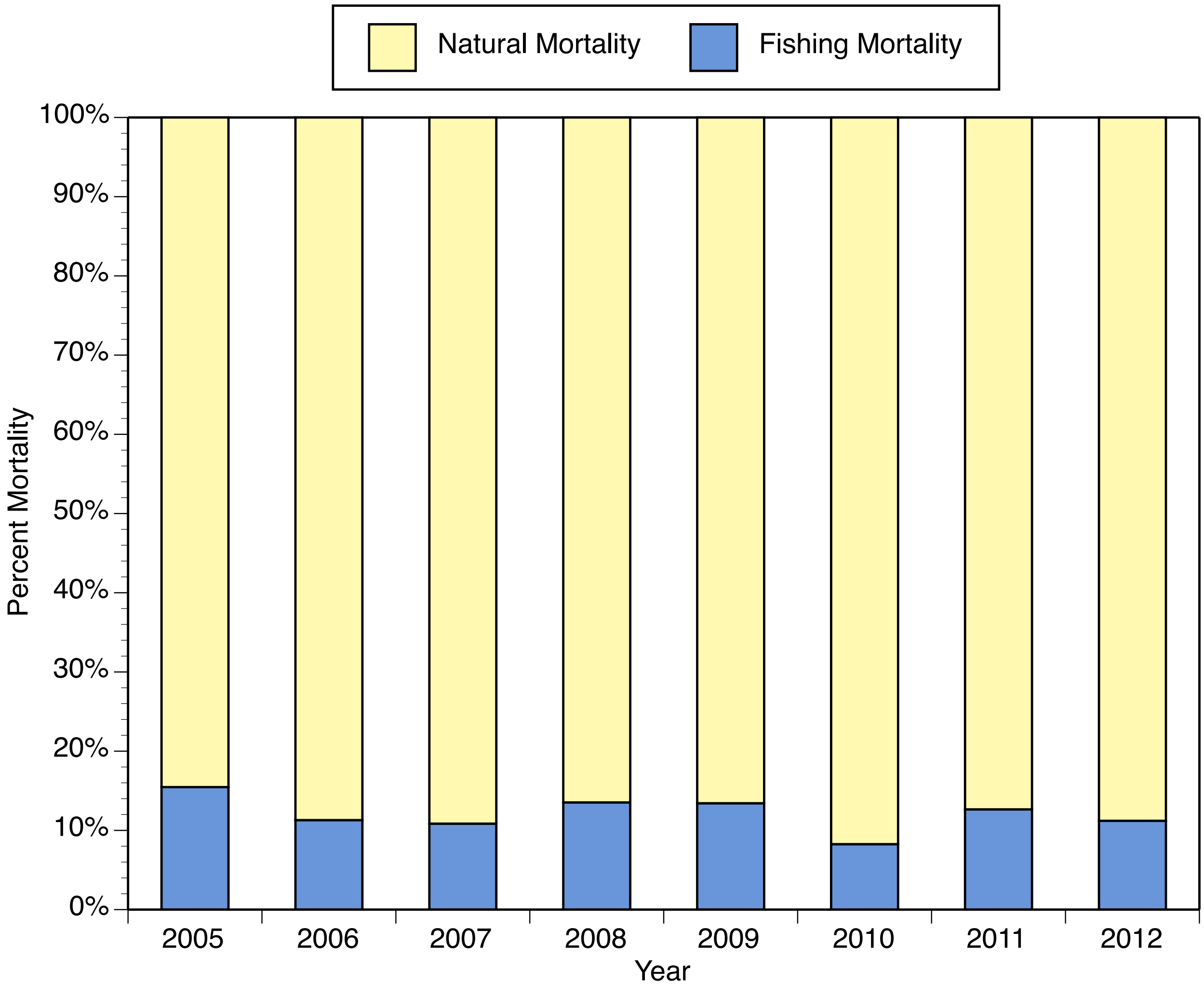


Figure 61. Net submarket surplus for the entire stock from a retrospective analysis of survey indices and landings. Submarket surplus was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous years survey. This provides high and low bounds for the estimates. Left column: green indicates that net submarket surplus was positive under both assumptions; grey, that the lower estimate was negative and the higher estimate was positive, indicating that the yield to the fishery approximated the potential yield available. Right column: green indicates conditions where the average of the two estimates was positive.

Year	Pos-Neg Method	Average Method
2005		5.7
2006		5.2
2007		5.7
2008		5.7
2009		5.4
2010		4.7
2011		5.2
2012		5.3