Report of the
2009 Stock Assessment Workshop
(11^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

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2009 SAW

Status of Stock and Fishery

Historical Overview

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly beginning in 1953. Circa-1989, Dermo became prevalent in the bay. Nearly coincidentally, beginning in 1990, the survey protocol was updated to include the measurement of oysters, thereby permitting calculation of biomass as well as abundance. Throughout this report, except where noted, present-day conditions will be compared to these two periods of time, the 1953-2008 period encompassing the entire survey time series and the 1989-2008 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 will refer exclusively to the 1989-2008 time period, because the advent of Dermo disease as an important determinant of population dynamics occurred in 1989 and this disease has substantively controlled natural mortality rates[‡] in all succeeding years. Two exceptions exist to the dependency on the 1989-2008 time series. All size-dependent indices begin in 1990 for reasons indicated previously. Evaluation of fishery exploitation by abundance focuses on the 1996-2008 time period during which the fishery has been conducted under a direct-marketing system.

Survey Design

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly, in the fall and/or winter, since 1953. Since 1989, this period has been concentrated into about one week in the latter part of October to early November, and has been conducted using a stratified random sampling method. Each bed is divided into $0.2''$ latitude $\times$ $0.2''$ 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). Each of these grids is assigned to a specified stratum and a subset of grids, randomly selected, is chosen each year for survey from the high-quality and medium-quality strata on each bed.

Each survey sample represents a composite of three one-third bushels from three

⊙ Because the survey footprint changed in 2005, 2006, 2007, and 2008, as described in a subsequent section, the values provided in the time series plots have changed, in most cases, over the entire time series, in comparison to the values reported by SAW-7, SAW-8, SAW-9, and SAW-10. Values reported herein are considered to be improvements in accuracy and should be used in lieu of SAW-7, SAW-8, SAW-9, or SAW-10 values.

‡ Throughout, the term 'mortality rate' applies to the fraction dying per year. Values given are not true rates; rather, they are equivalent to $1 - e^{-mt}$ in the equation $N_t = N_o e^{-mt}$ with m in units of yr^{-1} and $t = 1\,yr$.

one-minute measured tows within each target grid. 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*. Sample analysis includes measurement of the total volume of material obtained in each measured dredge haul; the volume of live oysters, boxes, cultch, and debris; the number of spat, older oysters, and boxes per composite bushel; the size of live oysters and boxes >20 mm 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[⊘], 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 2004, at the behest of the 6^{th} SAW, the entire survey time series from 1953 to the present-day was retrospectively quantitated. Also in 2004, a dock-side monitoring program began. This program obtains additional fishery-dependent information on the size and number of oysters marketed, permitting, beginning in 2004, the determination of exploitation based on spawning stock biomass as well as abundance. In 2006, sufficient information was available from the dock-side monitoring program to reconstruct the 1996-2003 exploitation rates.

Through 2001, most beds were sampled yearly; however a selection of minor beds were sampled every other year. Beginning in 2005, two important changes occurred. First, all beds were sampled each year with the exception of Egg Island and Ledge that continue to alternate due to their consistent low abundance. Second, over a four-year period (2005-2008), the primary oyster beds were re-surveyed resulting in a change in stratal definition and survey design from that used historically[•]. In the new system, the strata for re-surveyed beds were based on ordering grids within beds by abundance. Grids were defined by cumulatively accounting for the first 2% of the stock as low quality, the next 48% of the stock as medium quality, and the final 50% of the stock as high quality. As of the writing of this document, only two beds remain un-surveyed: Ledge and Egg Island. Beginning in 2008, full surveys of three new beds permitted their addition to the Fall stock survey: Hope Creek, Liston Range, and Fishing Creek (Figure 1). For two of these beds, some information is also available from a preliminary survey in 2007. No earlier data are present in the survey database, however; therefore, reconstruction of the 1953-2007 time series is not possible for these three beds. In the following data presentation, some analyses will exclude these beds as a consequence.

[⊘] A 37-qt bushel is the New Jersey Standard Bushel.

[•] Details of this revision can be found in: HSRL. 2006. *Report of the 2006 Stock Assessment Workshop (8th SAW) for the New Jersey Delaware Bay Oyster Beds.* 81 pp.

The 2008 component of the re-survey effort also included a re-survey of Shell Rock to evaluate the stability of grid designation as high, medium, or low quality on a highly manipulated bed. Manipulations include extensive shell planting and significant harvest levels. Evaluation of the density of oysters among grids confirmed findings from the re-surveys of previous years that a large number of low-quality grids could be deleted from the fall survey if the survey was focused on the grids on each bed that support 98% of the stock on that bed. This designation is consistent with the definition of a low-quality grid adopted in SAW-8 after the re-survey of the Bennies Sand to Middle reach. 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 compared to the mean abundance obtained from the average of all grids. Analysis of many simulations suggested that a random survey based on two strata would suffice, remembering that a third low-quality stratum had already been split out at the cost of 2% of the stock. These two strata were defined as before by assigning grids ordered by increasing abundance that cumulatively account for the first 48% of the stock to a 'medium-quality' stratum and grids that cumulatively account for the upper 50% of the stock to a 'high-quality' stratum. These designations are also equivalent to those adopted in SAW-8 for the Bennies Sand to Middle reach and SAW-9 for the majority of beds downbay of Bennies Sand. Figure 1 shows the new bed footprint for Liston Range, Fishing Creek, and Hope Creek and the revised bed footprint for Shell Rock; Figure 2 shows the full range of grids sampled in the Hope Creek region in mapping out the three new beds.

A comparison of the Shell Rock grid system from the 2005 re-survey and the 2008 re-survey shows that the bed as a whole retained approximately the same shape; however, the distribution of high-quality and medium-quality grids was radically changed. Eight grids were promoted from medium quality to high quality (Figure 3). Twelve grids were demoted from high quality to medium quality. Three grids were upgraded from low quality to medium quality (Figure 4). Nine grids were downgraded from medium quality to low quality. These shifts suggest that survey precision degraded over the 2005 to 2008 period, potentially compromising the stratified random sampling approach for this bed.

The October 2008 survey was constructed by randomly choosing a designated number of grids from each stratum on each bed. Sampling was conducted from October 29 to November 9 using the oyster dredge boat *F/V Howard W. Sockwell* with Greg Peachey as captain. The sampling intensity is shown in Table 1 and the specific grids sampled are shown in Figure 1. Total sampling effort in 2007 was 155 grids, a value considerably above 2007. These included 22 transplant grids selectively sampled because they were sites of 2006, 2007, and 2008 shell plants or 2008 intermediate transplants.

Evaluation of 2008 Survey Bias

No additional information on dredge efficiency was available for this assessment. Dredge efficiency correction factors were obtained from Table 2[∅]. A retrospective analysis of dredge efficiency from data collected during the survey using the equations of Powell et al. (2007) estimated a value of q for total oysters for the upbay region as 13.80 in contrast to a range of 7.30-9.40 from direct measurements in Table 2. The value of q for the downbay region from this retrospective is 10.51 in contrast to a range of 2.83 to 4.87 from direct measurements. Previous estimates of this type have normally produced values of q for the upbay region consistent with direct measurement and values of q downbay somewhat above direct measurement. Values obtained for the 2008 survey are very high in comparison to previous estimates and suggest a possible decrease in dredge efficiency that, if true, would bias low the abundance estimates from the 2008 survey.

Three metrics describing survey performance were calculated from surveys in 2005, 2006, 2007, and 2008. These were average tow distance, average bushels per haul, and average bushels per meter of bottom towed. Each was compared among years using a Tukey's Studentized Range Test set at $\alpha = 0.05$. Significant variations occurred rarely in tow distance and 2008 was never a clear outlier among the four years (Table 3). The same was true for bushels per haul, with the exception of increased variability on the high-mortality beds[θ]. In this case, 2008 tended to have lower catches; however in no case was 2008 significantly different from all of the three previous years (Table 3). Normalizing bushels caught per haul to distance towed yielded essentially the same conclusion (Table 3). This analysis does not reveal any consistent bias in the 2008 survey relative to the three previous surveys.

Some grids were sampled in 2008 and also in 2007, 2006, or 2005. The difference in bushels (meter-towed)$^{-1}$ between 2008 and each of these three years was calculated. A two-tailed sign test and a two-tailed Wilcoxon signed-rank test were conducted on the differences. The expectation is that negative and positive values would occur with equivalent probability. Results indicate that 2008 catches were not significantly different from 2005 and, if anything, barely significantly

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[∅] The catchability coefficient q as used herein is defined as the inverse of dredge efficiency e: $q = \frac{1}{e}$.

[θ] Beds are distributed into six bed regions for this analysis.
High mortality: Beadons, Nantuxent Point, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Egg Island, Ledge, Bennies, Bennies Sand
Shell Rock
Medium-mortality market: Ship John, Cohansey, Sea Breeze
Medium-mortality transplant: Middle, Upper Middle
Low mortality: Arnolds, Upper Arnolds, Round Island
Very-low mortality: Hope Creek, Fishing Creek, Liston Range.

different in 2006. In both cases, the median value was slightly, but inconsequentially negative (Table 4). The differential between 2007 and 2008 was significant with 2007 biased high relative to 2008 (Table 4).

Perusal of the suite of statistical tests suggests that, if anything, the 2007 survey results provided metrics for the stock that were biased high. The statistical tests do not support a significant change in dredge efficiency in 2008 relative to most previous survey years and, in particular, do not conform to the scale of change suggested by the retrospective calculation of tow-based q values that would require a factor-of-two or more difference in the number of bushels caught per meter towed.

Oyster Abundance

Analytical Approach

Since 1998, swept areas have been measured for each dredge tow, permitting estimation of oyster density directly. Bay-region point-estimates are obtained by averaging the per-m^2 samples per stratum, expanding these averages for each bed according to the stratal area for that bed, and then summing over strata and then beds in a series of bay regions. Throughout this report, these 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. 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 belief that a $\times 2$ error is unlikely to be exceeded. Accordingly, the quantitative time-series estimates are considered the best estimates for the 1953-1997 time period.

All quantitative and post-1997 time-series estimates were corrected for dredge efficiency using the dredge efficiency measurements made in 2000 and 2003. The size-class-specific dredge efficiencies were applied whenever size-class data were analyzed. The differential in dredge efficiency between the upper and lower beds was retained in all cases (Table 2).

Throughout this report, 'oyster' refers to all animals ≥ 20 mm. Animals <20 mm are referred to as 'spat'. Adult oysters are animals ≥ 35 mm. Calculations of spawning stock biomass (SSB) are based on this 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 animals are divided into animals $\geq$76 mm and animals $\geq$63.5 mm, but $<$76 mm. These two size categories are based on the consistent knife-edge selection of oysters for market by the fisher, in which nearly all harvested animals are $\geq$63.5 mm and the historical use of the 76-mm boundary to define a market oyster. For a few analyses, size classes are variously defined depending on yearly growth increment and analytical goals as indicated. Shell planting permitted an estimate of the accuracy of the 20-mm size boundary for spat on Bennies Sand, Cohansey, and Nantuxent Point. These 2008 shell plants revealed that spat routinely exceeded 40 mm by early November, 2008 (Figure 5). This suggests that the 2008 recruitment index is biased low and probably severely so, in comparison to 2006 and 2007 when most spat fell below the 20-mm size cutoff.

A summary of the per-sampled-grid dataset providing the 2008 survey database is given in Table 5. Table 5 also provides a summary of data for each bed on a volumetric basis. Quantitative survey indices are the focus of the remainder of the analyses reported hereafter.

Abundance Trends

Since 1989, the natural oyster beds have experienced a two-fold fluctuation in the number of oysters per bushel, but, with the exception of a few years characterized by the highest and lowest values, no statistical differences exist (Table 6). High variances are to be expected because oysters are being sampled along a salinity gradient that affects spat set, predation, disease, and growth. On a volumetric basis, 2008 abundance, bay-wide, was not significantly different from any year since 1989 except for 1990, 1992, and 1996. The bay-wide average number of 145 oysters bu^{-1} in 2008 fell below the 1989-2008 average of 165 oysters bu^{-1}, but not significantly so. Quantitative estimates using the time-series analysis indicate that bay-wide oyster abundance downbay of the very-low-mortality beds declined from 2007, but remained above 2003-2005 values, at 1,175,566,464. Including these upbay beds raises the total to 1,571,853,056 (Figures 6 and 7). Abundance in 2008 fell at the 10^{th} percentile of the 1953-2008 time series and the 18^{th} percentile post-1988, so abundance remains near historical lows (Table 7).

Most (54.3%) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 8), a proportion considerably above the 38.1% recorded in 2007, due primarily to a substantive decrease in oyster abundance on the low-mortality beds, but in keeping with the distribution of oysters in most years post-1995. Of this, 68.3% were on the three market beds, Ship John, Cohansey, and Sea Breeze. Examination of the fraction of oysters on the medium-mortality beds shows that the period since 1997 is unique in the 56-year time series in continual above-median proportions of oysters on these beds (Figure 9). Abundance fell from 2006 by a large fraction, but remained consistent with values observed since 2002. Abundance on the medium-mortality beds ranked at the 26^{th} percentile (transplant beds) and 22^{nd} percentile (market beds) of the 56-yr time series and the 28^{th} percentile (transplant) and 18^{th} percentile (market) post-1988 (Table 7). The number of oysters per bushel did not deviate significantly from the remainder of the 1989-2008 time series, with the exception of three years (Table 8).

Abundance in 2008 on the low-mortality beds fell 57% from 2007 to one of the lowest levels recorded; the 3^{rd} percentile for the 1956-2008 time series and the 8^{th} percentile for the post-1988 era (Table 7). The low-mortality beds contributing 40% of the stock in 2007, account for only 21% of the stock at the end of 2008 (Figure 8). The number of oysters per bushel differed significantly only from four years in the early 1990s within the 1989-2008 time series (Table 9). The large drop in abundance between 2007 and 2008 is not fully explained by the natural mortality rate observed. The retrospective comparison of tow metrics (Table 3) suggests that the 2007 point estimate may have been biased high. Abundance fell, however, by 41% from 2006, suggesting that abundance has significantly declined on these beds.

Abundance also declined in 2008 on the high-mortality beds, 19.9% relative to 2007, the second year of decline from a local high in 2006, but remained above the low values of 2003 and 2004. The entire high-mortality bed region contributed only 10.8% to the total stock, a value, however, consistent with the post-1999 time period (Figure 8). Abundance on the high-mortality beds ranked at the 8^{th} and 13^{th} percentiles, respectively, for the 56-year time series and the time series post-1988 (Table 7). The number of oysters per bushel differed significantly only from four years in the early and middle 1990s in the 1989-2008 time series, however table 8(Table 10).

Abundance in 2008 rose on Shell Rock for the fourth consecutive year, by a factor of 1.12, principally as a result of the shell-planting program. Shell Rock contributed 14.1% of the stock in 2008 (Figure 8). Abundance on Shell Rock ranked at the 56^{th} and 73^{rd} percentiles, respectively, for the 56-year time series and the time series post-1988 (Table 7).

The very-low-mortality beds contained 25% of the stock in 2008. Including these beds reduces the proportional contribution of the medium-mortality beds to 41%, the low-mortality beds to 16%, and Shell Rock to 14%. Insufficient data are available to generate percentile comparisons to earlier years, nor can trends be evaluated at this time.

Spawning Stock Biomass (SSB)

Spawning stock biomass rose slightly in 2008 (Figure 10). This was the fifth straight year of increasing SSB from the 2003 nadir. 2008 SSB was at the 55^{th} percentile of the 1990-2008 time series (Table 7). SSB declined by 20% on the low-mortality beds and by 32.5% on the high-mortality beds. This marks the second straight year of decline on the high-mortality beds. The declines at the extremes of the stock's range were offset by significant increases in the Shell Rock to Upper Middle reach. Greatest proportional increase was on the medium-mortality transplant beds (Figure 11). For the low-mortality beds, the medium-mortality beds, transplant and market, Shell Rock, and the high-mortality beds, the percentiles were the 61^{st}, 92^{nd}, 71^{st}, 87^{th}, and 8^{th}, respectively (Table 7).

SSB is highest on the medium-mortality beds in most years. In 2008, these beds contributed 51.5% of the stock's SSB (Figure 11). The low-mortality beds contributed an additional 26.9%. SSB was more concentrated on the medium-mortality beds in 2008 than in recent years, but still less than was routinely observed during the 1998-2003 time period. Including the very-low-mortality beds, the fractions of SSB contributed by the five bay regions are 13.5% (very-low-mortality), 23.2% (low-mortality), 44.6% (medium-mortality), 9.6% (Shell Rock), and 9.2% (high-mortality).

Oyster Size Frequency

Perusal of the 1990-2008 time series (Figure 12) shows that the fraction of the population $<2.5''$ was high in the early 1990s, then declined somewhat, and rose again through 2002. In 2008, including the very-low-mortality beds, 63.8% of the animals were below $2.5''$ and 17.8% of the animals were $\geq 3''$ in size. Excluding them, animals below $2.5''$ contribute 61.4% of the stock; 21/7% of the stock exceeds $3''$.The number of animals $<2.5''$ remains well below historical highs, but above the previous few years, whereas the larger animals are at or above the long-term average (Figure 13). Thus, marketable animals account for less of the stock in 2008 than in the past five years, but the fraction is still high relative to the 1990s. Early in the time series, values of 20%-25% were more typical, about half of the proportion found in 2008. Much of the shift in size frequency at the decadal transition is due to the loss of small animals during an extended period of low recruitment after 1999.

The 2007 recruitment event was one of the better ones on record, as measured by the ratio of spat to oysters (Figure 20). However, the 2008 survey shows that the vast majority of this recruitment did not survive the winter. The 2007 recruitment occurred late in the year and spat were still very small as cold temperatures began; this may explain the increased mortality relative to most other years. Survivorship to yearling age from 2007 shell plants, discussed later, support the interpretation that 2007 spat survivorship was low.

Small oysters accounted for 57.9% of the animals on the low-mortality beds, a fraction much below the long-term trends due to persistent low recruitment and increased average size (Figure 14). More than half of all animals (transplant beds, 59.3%; market beds, 69.7%) on the medium-mortality beds were $\leq 2.5''$ in size. This proportion is distinctly above the that observed during the 2002-2005 time period. Small oysters contributed 69.6% of the stock for Shell Rock, continuing a trend of increasing proportion of smaller animals due to enhanced recruitment though shell planting, and 56.1% for the high-mortality beds, a relatively high value also associated with the results of shell planting, though lower than the typical proportion for the 1990s. Thus, on no bed area did marketable oysters contribute the majority of the stock and in all bed regions, except the low-mortality beds, the trend is towards an increasing proportion of smaller animals since the early 2000s, thus correcting an unfavorable size-frequency distribution weighted towards market-size individuals that existed at that time. The shift in size frequency between Fall 2007 and Fall 2008 towards smaller sizes is evidence that the large recruitment event of 2007, though not characterized by high survivorship, nevertheless was characterized by sufficient survivorship to substantively influence the population structure; in many bed regions, this was abetted by a higher than average adult mortality event that removed a disproportionate fraction of the larger size classes.

Of the animals $\geq 2.5''$, 50.9% were $\geq 3''$ in size (Figure 15). The proportion of small markets ($<3''$) relative to larger markets has remained relatively stable since 2002, but was much higher earlier in the time series. Small markets made up the larger percentage on the high-mortality beds: 57.7%. The proportion was almost even for Shell Rock: 49.5%. For the remaining bed regions, the reverse was true: 38.4% for the medium-mortality transplant beds, 40.1% for the medium-mortality market beds, and 30.7% for the low-mortality beds. These trends explain the continuing high biomass levels with decreasing abundance since the 1990s as an increase in the number of larger animals has counterweighed the loss of a host of smaller ones.

Oyster Condition and Growth

Condition index rose in 2008 to one of the highest values in the 1989-2008 time series (Figure 16). Condition increased or remained unchanged throughout most of the bay (Figure 17). The high stock-wide value is due to the generally high values throughout most of the bay regions. This continues a trend that has existed since 2004.

No new growth rate data was available for this assessment. Growth rates were estimated from a von-Bertalanffy relationship provided by Kraeuter et al.[†] The von-Bertalanffy parameters used, L_∞, k, and $t_\circ$ respectively, are: for the low-mortality beds (data from Arnolds), 110 mm, .175 yr^{-1}, .2 yr; for the medium-mortality beds (data from Middle and Cohansey), 125 mm, .23 yr^{-1}, .2 yr; for Shell Rock, 125 mm, .25 yr^{-1}, .2 yr; and for the high-mortality beds (data from New Beds) 140 mm, .23 yr^{-1}, .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).

Oyster Sex Ratio

A survey was conducted on each of the primary beds in June to determine the sex ratio of animals 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 2008 survey data. The population in all bed regions was about 40% female (Table 12). Females were most common on the low-mortality and high-mortality beds. Oysters less than 2.5″ were about 75% male. Market-size animals were about 60% to 67% female. Thus, the fishery is dominantly a female fishery. Trends in size frequency suggest that the proportion of females in the population is much higher now than it was in the 1990s.

Surplus Production

Surplus production is defined for this analysis as the number of animals available for harvest under the expectation of no net change in ≥76-mm oyster abundance over the year, given a specified natural mortality rate and growth rate. If fishing mortality rate is set to zero, surplus production as calculated herein is equivalent to the differential between the number of animals expected to recruit to the ≥76-mm size class in a year less the number of such animals expected to die naturally. In the absence of fishing, a positive surplus production indicates that the ≥76-mm portion of the population is expected to expand in abundance. If negative, this segment 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 observed; 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 fishery has routinely done so; thus, some component of natural mortality is compensatory. A detailed description is found in Klinck et al. (2001)[⊕]. Surplus production was estimated using the 50^{th} and 75^{th} percentiles

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

⊕ 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.

of natural mortality rate. As a probabilistic application of growth rate cannot yet be done, surplus production projections used the size range of animals expected to grow to 3″ in one growing season obtained from the von-Bertalanffy curves of Kraeuter et al. (2007) (Table 11).

Surplus production projections for 2009 are positive, but less than the previous two years. Estimates for the high-mortality beds were particularly low (Table 13). No estimates could be made for the very-low-mortality beds because no growth rate data are as yet available.

Surplus production estimates for bed regions upbay of Shell Rock continue to yield improbable catch estimates; exploitation rates would be very high, relative to other estimates of long-term sustainable yields, were they used to define fishing quotas. However, projections are in agreement with long-term trends in biomass in these bay regions. Projections for 2009 for SAW-10 were in agreement on all bed regions above the high-mortality beds as anticipated expansions of biomass were observed to occur (Figure 10). Predictions of the same for the high-mortality beds were not borne out, as SSB declined on these beds in 2009. However, harvest of 34,706 bu on these beds in 2008 accounts for about half of the SAW-10 expected surplus production on these beds, so that the error associated with the SAW-10 projection is partially explained by the 2008 fishery. Nevertheless, at present, use of these projections to determine fishing mortality rates is not recommended because the 'constant market-size abundance' assumption does not include a comparison with target or threshold goals.

Recruitment

Spat set in 2008 was one of the lowest recorded since 1999 bay-wide (Figures 18 and 19); however this value is clearly biased low due to rapid spat growth rates observed this year (Figure 5). The recruitment index does not directly influence most status-of-the-stock metrics, as all abundance and biomass metrics are based on all animals >20 mm. Moreover, uncertainty in the recruitment index is absorbed in the estimation of 'unrecorded mortality' that is a component of the analysis of N_{msy} reference points and surplus production. Nevertheless, 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.

The number of spat per bushel averaged over all survey samples fell significantly below the long-term average for the 1989-2008 time series, but all significantly higher years occurred in the 1990s. The 2008 level was consistent with all previous years in the 2000s (Table 6). The same metrics by bay region reveal that the number of spat per bushel on the high-mortality beds was not significantly different from the 1989-2008 mean, but significantly below many years in the 1990s (Table 10).

For the medium-mortality beds, the number of spat per bushel was significantly different from five years in the 1989-2008 time series, all in the 1990s (Table 8). A relatively similar trend was observed on the low-mortality beds (Table 9).

The 2008 spat settlement ranked at the 10^{th} percentile for the 1953-2007 time series and at the 13^{th} percentile post-1988 (Table 7). Recruitment estimated quantitatively for each bay region fell at the 19^{th}, 8^{th}, 1^{st}, 47^{th}, and 19^{th} percentiles of the 1953-2008 time series for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and the high-mortality beds, respectively. Percentile values were higher in each case for the 1989-2008 time series, but not by much (Table 7).

The number of spat recruiting per oyster was also low at 0.27 (Figure 20), a value at the 24^{th} percentile of the 1953-2008 time series and at the 28^{th} percentile for the 1989-2008 time series (Table 7). The ratio of spat to oyster varies from bed region to bed region with high recruitment events, defined as exceeding 1 spat per oyster, occurring simultaneously on all bed regions infrequently. Recruitment has been consistently higher downbay than upbay, per adult, for many years. 2008 is no exception, as the ratio of spat to adult was 0.50 and 0.89 on Shell Rock and the high-mortality beds, respectively, while falling no higher than 0.22 upbay, except on the very-low-mortality beds (Figure 21). The spat-to-adult ratio was unusually low on the medium-mortality beds, at 0.11. The respective percentiles for the 1953-2008 time series for the low-mortality, medium-mortality transplant, medium-mortality market, Shell Rock, and high-mortality beds are: 44^{th}, 13^{th}, 15^{th}, 40^{th}, and 49^{th}. Percentiles were similar for the 1989-2008 time series, except for the low-mortality beds, where the percentile was considerably higher. The percentiles were 68^{th}, 13^{th}, 18^{th}, 43^{rd}, and 38^{th}, respectively (Table 7).

Shell planting had a substantive impact on the spat-to-adult ratio in 2008, raising it to 0.346. This differential occurred because spat on shell plants accounted for 19.7% of the spat on the medium-mortality market beds and 40.9% on the high-mortality beds. Shell plants raised the spat-to-adult ratio significantly above 1 on the high-mortality beds (Table 14).

Recruitment trends, highlighted by the order of years in Tables 8, 9, and 10, suggest a change in recruitment rate at or near the 2000 decadal ascension. This period of time follows by a few years the initiation of an unparalleled sequence of years in which the stock was consolidated significantly upbay with high proportions on the medium-mortality beds. Thus, low recruitment in the 2000s seems to coincide with high stock consolidation; that is, a low proportion of the stock on the high-mortality beds. Evaluation of the probability of a good recruitment event relative to the fraction of stock on the high-mortality beds suggests that the present stock distribution pattern may be one factor sustaining the low-recruitment pattern (Figures 22 and 23).

Recruitment-enhancement Program

Shell-planting was carried out in June-July, 2008. Ocean quahog and surf clam shell were used. Shell was planted in 2008 as follows: Nantuxent Point 68, 48,376 bu; Nantuxent Point 17, 53,164 bu; Bennies Sand 8, 50,587 bu; Bennies Sand 9, 20,360 bu (Figure 24). Cohansey 64 received 21,898 bu of surf clam shell originally planted downbay and then moved upbay in August through September. This totals to 194,385 bushels, somewhat less than planted in 2006-2007.

Total spat were estimated based on observations that spat tend to recruit to larger particles preferentially collected by the dredge. The average of a series of comparisons between dredge and diver samples from 2005 and 2006 for the correction factor is 0.571; that is, the dredge biases the estimate high by a factor of 1.75 based on total shell planted (Table 15).

Projections of marketable bushels on the 2008 shell plants assumed a 3-year time to market size, and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality rates used were the 50^{th} percentiles of the 1989-2008 time series: for the medium-mortality beds, 0.277, 0.162, 0.162; for the high-mortality beds: 0.601, 0.257, 0.257. Bushel conversions assume 262 oysters per bushel. 2008 shell plants are expected to provide 75,231 bushels for market in 2011/2012 (Table 16).

The median survivorship for yearlings from 2007 in 2008 was 17% (Table 17). The mean was 19.6%, much lower than the bay's long-term average of 37.1%. This is direct evidence for the failure of much of the large 2007 spatfall to survive into 2008. Estimated harvest from the 2007 shell plants is updated using the 50^{th} percentile adult mortality rates in years 2 and 3 from the 1989-2008 time series: for Middle, 0.108; for Shell Rock, 0.162; for Bennies Sand: 0.257. Bushel conversions assume 262 oysters per bushel. A projected harvest of 25,853 bushels was estimated, much lower than the original estimates from 2007 spat counts (Table 17). 2007 shell continued to attract spat in 2008; however the rate of attraction was no better than native shell. Nevertheless, the net addition of shell to these beds sustained an increased recruitment rate for a second year. A minimal estimate of year-2 recruitment on this shell results in an estimated future harvest of 72,908 bushels (Table 18). Thus, total projected harvest from the 2007 shell plants is 98,761 bushels.

Shell Budget Projections

A shell budget was constructed using bed-specific half-life estimates for catch updated using the model of Powell et al.[♮] Half lives ranged generally between 3 and 7 years, with a median of 4.69 years (Table 19). Half lives for Upper Middle, Egg Island, Hope Creek, Liston Range, and Fishing Creek could not be estimated. These beds are only newly surveyed or have been surveyed every other year for all or part of the time series (Table 19). The analyses are subject to substantial yearly variations retrospectively because not all beds were sampled each year in the first two-thirds of the time series and because the addition of shell beginning in 2005 increases the difficulty of analysis as the industry dredging activities redistribute the shell beyond its original grid placement. Also, some conversions are poorly known and the time series is still relatively short, being of the same order as many of the half-life estimates. Half lives estimated in 2008 average shorter than estimates in 2007, but fall 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, as 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[⊖]. Values for the five beds with uncertain half lives were borrowed from neighboring beds. New Jersey oyster beds have been losing on the order of 250,000 to 600,000 bushels of cultch annually since 1999, with loss rates significantly higher during the period 2000-2003 (Figure 25). 1999 is the first year an estimate can be made as 1998 is the first year that full survey data are available. These estimates are somewhat modified using the 1998-2008 time series versus the 1998-2007 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 and conversions to shell volume 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 shorter half-lives estimated in this assessment and the longer half-lives estimated in 2008 (HSRL, 2008).

The shell budget shows a gradual reduction in shell loss since 2003, with greater uncertainty in 2006 and 2007, and a more certain 2008 value (Figure 25). This year, 2008, the range of estimates encompasses zero, suggesting that shell on the New

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

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

Jersey beds was relatively in equilibrium in 2008. Years 2007 and 2008 are the only years in the 1999-2008 time series when at least one estimate was near or above zero. In 2008, three of four estimates are near or above zero. This represents the coincidence of shell planting increasing total shell supply and the addition of increased carbonate from the living population due to epizootic levels of Dermo mortality.

By region, the low-mortality beds have been losing about 20,000-80,000 bushels annually, with larger losses during the 2005-2007 period (Figure 26). This low level of shell loss is due to low taphonomic loss rates, as input rates are also low. The medium-mortality beds are losing >200,000 bushels annually in many years due to higher loss rates and a larger total area. Parts of this region recorded a positive shell budget in 2007 for the first time and this continued into 2008. Shell Rock showed a net gain in 2005-2006 due to shell planting, and a slight loss in 2007 and 2008. The high-mortality beds typically have lost upwards of 200,000 bushels annually due mostly to the larger area of coverage and moderate shell half lives. A decline in 2006 is due to the substantial shell planting that occurred downbay of Shell Rock in that year. The loss in 2007 was above average. Most of the bay-wide loss of shell was contributed by the high-mortality beds in 2007. This year, 2008, represents the first year in the time series when all bed regions were within 50,000 bushels of shell balance. The decline in shell loss rates in 2008 overall is due to two factors, the purposeful addition of surf clam and ocean quahog shell and the continuing high level of natural input due to the Dermo epizootic that began in 2007 and continued into 2008.

Disease Prevalence and Intensity

MSX disease, caused by *Haplosporidium nelsoni*, and Dermo disease, caused by *Perkinsus marinus*, remain the two primary disease concerns in Delaware Bay. Following a major bay-wide MSX epizootic in the mid-1980s, most of the oyster population appears to have become resistant to MSX. Monitoring via standard histological methods showed that MSX continued to be insignificant during 2008.

In general, Dermo disease* and mortality increase downbay as salinity increases. During 2008, water temperature rose early and exceeded the long-term average for much of June and July (Figure 27). Salinity was below average in the early spring, but exceeded the long-term average by August and remained very high through the end of the monitoring season in November. The early rise in temperature

* The percent of oysters in the sample with detectable infections is termed prevalence. Infection intensity is scored along the Mackin scale from zero (= pathogen not detected) to five (= heavily infected) and then averaged among all oysters in the sample to calculate a weighted prevalence. A full analysis of the 2008 disease monitoring program is available as an HSRL report: Bushek, D. 2009. *Delaware Bay Oyster Seedbed Monitoring Program 2008 Status Report.*

followed by an extended period of higher than average salinity produced conditions conducive to the proliferation of *Perkinsus marinus* and, consequently, facilitated the continuation of epizootic conditions that began in 2007.

In 2008, the prevalence and weighted prevalence of Dermo followed somewhat atypical seasonal and spatial patterns across the oyster beds (Figure 28). Compared to levels since 1999, prevalence and weighted prevalence were at or below long-term levels during the spring, but, by July, both exceeded the long-term mean. Both measures remained above average into November. Dermo prevalence and weighted prevalence were at or below the long-term mean from Shell Rock downbay; however, the values were in general not extraordinarily low (Figure 29). In sharp contrast, prevalence averaged distinctly above the long-term mean on the middle-mortality beds and upbay to Round Island. Infection intensity was above long-term mean values in the reach from Middle to Round Island. This unusual pattern explains the inordinately high contribution of the medium-mortality beds to total stock mortality in 2008.

Since the onset of Dermo disease in 1990, two periods of epizootic mortality have occurred, each of them multi-year (Figures 30-31). The first occurred during the 1992-1994 time period and the second from 1998-2002, with an intermediate lessening in intensity in 2001. Each of these epizootics was characterized by multiyear increases and decreases in disease intensity with a tendency for disease prevalence to follow a 7 year cycle. The time series shows that 2007-2008, the third such period of higher-than-average Dermo activity, falls within expectations based on the timing of the first two. Dermo levels have increased for three years following a 2004 low and mortality reached epizootic levels in 2007. The time series suggests that the increase has ceased downbay and that infection intensities may now be on the wane. The time series suggests that infection intensity has probably built to a high point in 2008 upbay. The tendency for trends on the high-mortality beds to lead the rest of the bay is consistent with the post-1988 epizootic history of Dermo disease. Based on these trends, Dermo-induced mortality is likely to decrease in 2009 unless extreme environmental conditions facilitate further development.

HSRL transplanted Hope Creek oysters to the Capeshore region in early spring of 2008 to evaluate their susceptibility to Dermo infection, as animals this far upbay had not previously been evaluated. Comparison was made to oysters transplanted to Capeshore from Shell Rock. No evidence was found suggesting that Hope Creek oysters were unusually susceptible to Dermo disease (Figure 32).

Natural Mortality Trends

Quantitative box-count mortality rates were obtained by calculating the number of boxes per m^2 and summing over strata and beds within bay regions. Analytical details are in Powell et al.[II] Box-count mortality was 19.1% bay-wide in 2008, excluding the very-low-mortality beds and 16.9% including them. This is a minor decrease from 2007, and represents the second consecutive epizootic year (Figure 33). This is one of the highest mortality levels since 1999, and relatively high for the time series. Box-count mortality was at the 72^{nd} percentile of the 56-yr time series and at the 53^{rd} percentile post-1988 (Table 7).

Mortality rates were high in most bay regions in 2008, unlike most years when mortality rates decline upbay (Figure 34). The mortality rate was 22.1% on the high-mortality beds, 19.4% on Shell Rock, 19.4% on the medium-mortality market beds, 22.9% on the medium-mortality transplant beds, but considerably lower, 9.3% on the low-mortality beds and even lower, 2.9%, on the very-low-mortality beds. Thus epizootic conditions extended upbay to the uppermost beds of the medium-mortality region. A year this extreme upbay has not occurred since 1995, the only other time since the great MSX epizootic of 1985 (Figure 34).

The high-mortality beds contributed 43.0% of the total deaths in 2008, thus contributing substantively to the observed decline in market-size abundance, followed by 35.9% for the medium-mortality market beds, 13.6% for Shell Rock, 10.0% for the medium-mortality transplant beds, and 7.5% for the low-mortality beds. Box-count mortality on the high-mortality beds fell at the 65^{th} percentile of the 56-year time series, but only the 33^{rd} percentile of the post-1988 time series (Table 7). The lower percentile rank belies the fact that epizootic mortality levels have occurred on the high-mortality beds all but one year since 1990. That is, 2008 was a fairly average year on the high-mortality beds because epizootic mortality has become the average condition.

Mortality on Shell Rock was relatively high with percentile positions of 65^{th} and 53^{rd}, respectively (Table 7). Box-count mortality on the medium-mortality beds was unusually high. The 2008 level of mortality for the medium-mortality market beds was at the 80^{th} percentile for the 56-year time series and the 58^{th} percentile for the post-1988 time series. For the medium-mortality transplant beds, the respective percentiles are an astounding 92^{nd} and 93^{rd}. Box-count mortality fell at the 47^{th} percentile for the 56-year time series for the low-mortality beds and at the 48^{th} percentile for the post-1988 period (Table 7).

Some mortality is not recorded by box counts. Much of this is probably juvenile mortality, as most such deaths do not leave long-term surviving boxes for collection.

[II] 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.

The percentiles of this unrecorded mortality are aberrant in several bay regions in 2008. For all bay areas except Shell Rock and the medium-mortality transplant beds, the percentile fell at the 13^{th} or lower for the 1989-2008 time series (Table 7). Low percentiles represent high rates of unrecorded mortality (Powell et al., 2008). The principal source of this trend is the failure of the 2007 recruitment event to survive well. One-year survivorship was low (see also Table 17).

Population Dynamics Trends

Broodstock-recruitment, abundance-mortality, and mortality-recruitment relationships were updated.

The broodstock-recruitment diagram suggests that present-day abundance directly affects recruitment in some way (Figure 35). The shell-planting program suggests that the relationship does not involve fecundity. 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 shell-planting program strongly suggests that the bay is not larvae limited.

A large recruitment event is very unlikely. However, the long-term likelihood of a replacement event, 1 spat per oyster, is 15 of 56 and a rate half that occurs in 32 of 56 years, so that the expectation of a respectable recruitment event remains greater than 50%. The expectation, however, is lower since 1989 (Figure 35).

First passage times were used to quantify the likelihood that the population will transition from its present low abundance-low recruitment state to any other. The input data were obtained by dividing a two-dimensional dataset, such as shown in Figure 35, into quadrants by the medians of the x and y variables (Figure 36). One-year transition probabilities are compiled by examining the quadrant location for the x-y datum at consecutive years. These transition probabilities can be used to estimate first passage time, the interval of time in which the population would find itself back in a specified quadrant, given a starting point in the same or other specified quadrant. In the case of the data presented in Figure 35 relating broodstock to recruitment, the distribution of points in the four quadrants (x/y = broodstock abundance/recruitment) is: low/low = 18; low/high = 9; high/low = 9; and high/high = 19. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant ($P < 0.10$; $P < 0.10$; $P < 0.10$; $P < 0.10$, respectively (Table 20). First passage times show a high tendency for the population to remain in the low abundance-low recruitment or high abundance-high recruitment quadrants.

Since 1989, the tendency to remain in a low abundance-low recruitment state is nearly overwhelming. During this time, the chance of arriving in a high abundance-high recruitment state is very low, showing that recruitment rate, even when high, is unlikely to generate a transition to high abundance. Since 1989, the distribution of points in the four quadrants is: low/low = 9; low/high = 3; high/low = 4; high/high = 3, based on the 56-yr medians (Table 20). This distribution is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P < 0.02$, $P > 0.10$; $P > 0.10$, $P > 0.10$, respectively. That is, the relationship between broodstock and recruitment in the post-1988 era is very different from the random expectation. The 2008 relationship between broodstock and recruitment is an expected outcome. That is, the relationship between broodstock and recruitment in the post-1988 era is dominantly described by the linear portion of the broodstock-recruitment curve.

Epizootics occur primarily at abundances below 4×10^9 and their effect is further reduce abundance. However, geographic contraction of the stock as abundance declines so that the stock is increasingly concentrated in the central part of the bay tends to reduce total mortality rate and therefore decreases the chance of epizootics at some point. A relationship between broodstock abundance and mortality exists and is characterized by an 'epizootic hump' in the 1.5×10^9 to 3.5×10^9 abundance range (Figures 37-38). Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about one-third (37%) of the years since 1989 (Figure 38). Non-epizootic years tend to average around 10% mortality. The bay-wide average for 2008 was 19.1%, an epizootic mortality rate. Year 2008 falls appropriately along the epizootic hump (Figure 38), suggesting that some portion of the responsibility for the 2008 epizootic accrues from the downbay expansion of the stock over the few previous years (Figure 9). Geographic contraction of the stock, an ongoing process since 2002, has limited the scale of epizootics to levels near 20% in the 2000s. Since 2005, the proportion of the stock on the high-mortality beds and Shell Rock increased moderately, exposing an increased proportion of the stock to the potential for increased mortality. The last two years of epizootic mortality have re-established the consolidated distribution pattern by reducing abundance on the high-mortality beds (Figure 9).

The relationship between broodstock and mortality continues to clarify as low abundance values accumulate. The distribution of points in the four quadrants (x/y = broodstock abundance/mortality rate) is: low/low = 12; low/high = 15; high/low = 15; high/high = 13 (Table 21). This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. This is dominantly due to the fact that the median mortality rate falls near the 'epizootic hump'. First passage times show that transitions to quadrant 3 occur rarely, but quadrant 3 is a relatively stable state. This quadrant is characterized by high abundance and low mortality. In contrast, since 1989, the distribution of points in the four quadrants is: low/low = 4; low/high = 9; high/low = 1; high/high = 5. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.02$; $P < 0.05$, $P > 0.05$, respectively. Since 1988, the high mortality-low abundance state has occurred significantly more frequently than anticipated from the long-term time series. The first passage time for a return to this quadrant from itself is also short, confirming observation that epizootics tend to be multi-year events and that the low abundance-high mortality state is a very stable state for the Dermo era that began circa 1989.

A relationship between box-count mortality and recruitment remains unclear (Figure 39). The distribution of points in the four quadrants (x/y = recruitment/mortality rate) is: low/low = 14; low/high = 14; high/low = 14; high/high = 14 (Table 22). This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. First passage times show that return intervals to quadrant 3 are long. This quadrant is characterized by low mortality and high recruitment. Return intervals to quadrant 1, low mortality-low recruitment, are short, from all four quadrants. Since 1989, the distribution of points in the four quadrants is: low/low = 5; low/high = 8; high/low = 1; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.02$; $P < 0.10$, $P > 0.05$, retrospectively. The high recruitment-low mortality state has occurred only once since 1988. Alternatively, low recruitment has occurred relatively equally regardless of high or low mortality, suggesting that low recruitment is not a function of adult mortality rate.

Harvest Statistics

Total harvest in 2008 was 89,882 bushels[♭] (Figure 40). This is above the 1996-2008 average of 72,724 bushels and marks the second consecutive year above the mean of the time series. Figure 41 shows the time-series of oyster removal from the natural oyster beds in Delaware Bay since 1953. Since 1997, an intermediate transplant program has moved oysters among beds. In this figure, the 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. Harvest has been relatively stable during direct-marketing times and below all bay-season[△] years. Oyster production continued to be low in 2008 in comparison to pre-1986

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

[△] Prior to 1996, oysters were taken from the natural beds by deck-loading them and moving them downbay to leased grounds during a few weeks in the spring. This time period was termed 'bay season'. During this time, oysters were taken from beds for which survey bushel samples contained an average oyster volume of ≥40%. This 40% rule was the first reference point and was used for management decisions from the late 1950s until 1995.

levels; oyster production has incremented yearly since the shell-planting program began in 2005 (Figure 41).

Beds were harvested almost continually from April 7 to November 21, 2008. Eleven beds were fished. Highest catches were on Shell Rock, Ship John, Bennies Sand, Bennies, and New Beds, where catches neared or exceeded 7,000 bushels (Table 23). The recommended area management policy resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John.

Seventy-three boats participated in the fishery and worked for a total of 1,322 boat-days. These included 41 single-dredge boats working for 93 boat-days (22.7 days/boat) and 32 dual-dredge boats working for 389 boat-days (12.0 days/boat). CPUE in 2008 was about the same as in 2007 and considerably higher than observed in 2000-2005. CPUE for single-dredge boats remained near 2006 and 2007 values. The 2008 dual-dredge-boat value is also similar to 2007; both, however, are the highest values since 1998 and the single-dredge-boat value was near the historical high for this vessel type (Figure 42).

Total dredging impact was estimated to exceed bed area in five cases[⊗] (Table 23): Bennies Sand, Shell Rock, Nantuxent Point, New Beds, and Ship John. Highest value was 2.99 on Shell Rock. Two other beds exceeded 2: Ship John and Bennies Sand[@].

The number of oysters per 37-qt marketed bushel averaged 299 oysters per bushel in 2008. Of these, 252 were $\geq 2.5''$ (Table 24). Incidental capture averaged 47 oysters per bushel. These were mostly animals that could not be culled from chosen oysters. The number of oysters landed per bushel was the highest since 2004 due to the increased number of small oysters landed incidentally. This trend follows the increase in small animals in the population (Figure 14) and conforms with the high fraction male in the population (Table 12). The size of harvested individuals was very similar to previous years and nearly identical to 2007. Most animals marketed were $2.75''$ to $4.25''$ in length and there was little difference between beds. Catch approximated a knife-edge process with few oysters marketed below $2.5''$ (Figure 43).

Conversion of oysters to bushels for allocation projections used the value of 262 oysters/bu, the average of the five years 2004-2008. This value is the mean

[⊗] The method for estimation is described in: 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.

[@] This intensity of dredging is unlikely to negatively impact these beds – 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.

of the total oysters and chosen oysters. The rationale for taking the mean is that the number of attached small animals will vary widely between years depending on recruitment dynamics, so the use of the total number 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 intermediate transplant program moved 8,200 bushels of material from Middle to Bennies Sand 13 in 2008. Oysters per bushel averaged 312 in this transplant. In addition, 9,450 bushels were transplanted from Arnolds to Cohansey 43. Oysters per bushel averaged 428. Cullers were used for both transplants. The Middle transplant slightly exceeded the target 60^{th} percentile exploitation rate recommended at SAW-10. Bed-average values of 181 oysters per bushel on Middle and 258 on Arnolds (Table 5) suggest that both transplant activities concentrated oysters relative to shell by a considerable degree.

The net of all fishing and transplant activities was that most oysters taken to market ultimately were debited from Shell Rock and the high-mortality beds (Figures 44 and 45). In comparison to 2003 and 2004 and a number of other years less dramatically, the upbay beds contributed relatively little. In large measure, this is due to the lower exploitation rate levels permitted on these beds upbay beginning in 2005 .

Real fishing mortality was 1.9% of total abundance in 2008, excluding the very-low-mortality beds, and 1.8% including them, whereas apparent fishing mortality was 2.4% (Figure 46). The increment reflects the intermediate transplant program that transplanted oysters downbay in 2008. Fishing mortality has been below 2% every year since 1995. 2008 fishing mortality was at the 40^{th} percentile of the 56-yr time series excluding closure years, and at the 89^{th} percentile of years post-1995 (Table 7). This high level accrues from the decision to use primarily the 60^{th} percentile exploitation reference points in 2008 combined with unusually high natural mortality rates over much of the bay as a product of the ongoing Dermo epizootic and the increase in marketable animals through shell planting. But also, it accrues from the relatively narrow range of exploitation rates in the 1996-2008 time series, so that small changes in exploitation can result in large percentile shifts and the limited number of small animals relative to the 1990s regime. By bed region, the percentiles were 99^{th}, 99^{th}, and 38^{th} for the high-mortality beds, Shell Rock, and the medium-mortality market beds respectively (Table 7).

Fishing mortality, by SSB, was 3.0% in 2008 (Figure 47). Fishing removed 3.2% of the animals $\geq 2.5''$ in 2008 (Figure 48). This is a relatively low value relative to the 1996-2008 time series, in contrast to the earlier numerical valuation and suggests that the fishery was not unduly exploitative when referenced to the exploitable portion of the stock.

By bay section, fishing and management activities removed 1.0%, 2.6%, 1.0%, 6.0% and 5.0% of the animals for the low-mortality beds, medium-mortality beds (transplant and market), Shell Rock, and the high-mortality beds, respectively. Restricted to market-size animals (>2.5″), the respective values are 1.0%, 2.6%, 1.8%, 12.1%, and 8.8%. The values for the high-mortality and medium-mortality beds include intermediate transplant additions and direct harvest. With the exception of Shell Rock, these values are representative of the 1996-2008 time series. The Shell Rock value is the highest since 2004 and reflects the success of the shell-planting program on this bed.

Status of Stock Summary

Stock Status and Population Management Goals – Bay-area 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 ambit of oyster population dynamics in the present climate and disease regime. As a consequence, the median abundance and SSB values for the time periods 1989-2005 or 1990-2005 were set as abundance and biomass targets and values half these levels were set as threshold abundance and biomass levels (Table 25). Due to the absence of a time series, the very-low-mortality beds do not have these target and threshold reference points.

Time series data shows that the decade of the 2000s has been very different from the 1990s. Particular examples include the dramatically lower recruitment rates in the 2000s for all bay regions (e.g., Tables 8-10), the increased stock consolidation upbay (Figure 9), the change in size composition from a small-oyster dominated stock to a stock enriched in animals ≥2.5″ in size (Figures 13-14), and a lowering of the range of mortality rates produced by a lessening of the scale of epizootic mortality (Figure 33). Of particular interest is the long-term drop in abundance without an equivalent response in SSB. 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. However, an adequate replacement is also unavailable. Consequently, the SARC concludes that these "stock performance" reference points for abundance be retained with the caveat that the target and threshold values be used with caution, as their adequacy as benchmarks for comparison to 2008 abundances is unclear.

Surplus production is expected to be positive on the low-mortality beds for 2008. The low-mortality beds are well below the abundance target and just below the abundance threshold. Abundance fell relative to 2007 but is distinctly above the 2004-2006 period. The low-mortality beds are above the SSB target and SSB has been increasing (Figure 49). Recruitment was low relative to adult abundance in 2008, but the number of spat recruited per adult was high for the 1989-2008 time period.

Surplus production is expected to be significant on the medium-mortality beds for 2008. The medium-mortality beds are well below the abundance target, but above the abundance threshold, particularly the transplant beds. Abundance rose relative to the previous few years on the transplant beds and remained relatively stable on the market beds. SSB is well above the SSB target in both cases (Figure 49). The number of spat recruiting to the medium-mortality beds was very low and the number of spat per adult fell below the 20^{th} percentile in both cases.

Surplus production is expected to be positive on Shell Rock in 2008. Abundance on Shell Rock is well above the abundance target. Abundance has been rising for four years as a result of shell planting. SSB is more than double the SSB target and has been rising for four years (Figure 49). Recruitment was average in 2008 for the post-1988 era by number or spat-per-adult ratio.

Surplus production is expected to be barely positive on the high-mortality beds in 2008. The high-mortality beds remain below the abundance threshold. Abundance is lower in 2008 that in any year since 2004. SSB is at the SSB threshold for the first time in many years (Figure 49). The number of spat recruiting was low for the post-1988 era and the number of spat per adult was below average. The high-mortality beds show the effects of two epizootic years plus fishing at the 60^{th} percentile exploitation rate in terms of both abundance and biomass.

Stock Status and Population Management Goals – Surplus-production and Stock-performance Whole-stock Targets

Whereas, area management continues to be a priority, as addressed by the bay-area stock performance targets, the oyster population is a single stock and thus whole-stock reference points are important criteria upon which to judge 2008 stock status. The SARC considered two whole-stock abundance targets. The first is the sum of the area-specific abundance targets listed in Table 25. The second was derived more theoretically from an analysis of biological relationships and formulation of a surplus production model[Φ]. The surplus production model used the 1953-2008 time series to derive relationships between broodstock and recruitment and between broodstock and adult mortality, as well as values for juvenile mortality. The model identifies a multiple-stable-point system in Delaware Bay with two stable states, one at high abundance and one at low abundance. Delaware Bay has

[Φ] Working paper: Powell, E.N., J.M. Klinck, K.A. Ashton-Alcox, & J.N. Kraeuter. Multiple stable points in oyster populations: implications for reference point-based management.

been in a low-abundance state since 1986. The surplus production model permits the estimation of carrying capacity for both stable states, an N_{msy} (number-at-maximum-sustainable-yield) value, defined as a high in surplus production, for both stable states, the abundance associated with a surplus production low between the two stable states, and the abundance at a point-of-no-return between the two stable states that marks a threshold abundance leading to a collapse to the low-abundance state (Table 26)$^{\Psi}$.

Five simulations were conducted. These examined the use of the median and mean parameterization of unrecorded natural mortality, the use of a Ricker or linear/Ricker combination curve for the relationship between broodstock abundance and recruitment (Figure 35), and the use of an adult mortality curve with an 'epizootic hump' of various amplitudes (Figure 37). Surplus production modelling suggests that the abundance values are relatively stable with respect to uncertainty in the survey time series, but that surplus production values associated with these abundances are not (Figure 50); thus, N_{msy} values can be obtained, but f_{msy} estimates cannot. Of the five simulations shown in Figure 50, four fall in a narrow abundance range between 1.57 and 1.75 billion animals. The fifth simulation depicts a condition with a low disease-mortality rate that is less representative of stock population dynamics than the other four and demonstrates that the scale of the surplus production minimum is primarily influenced by the severity of disease

$^{\Psi}$ The parameters of the Ricker and linear broodstock-recruitment relationship and the broodstock-mortality relationship were updated for this analysis. The Ricker curve is expressed as:

$$\tilde{R}_t = \tilde{N}_{t-1} e^{-\alpha\left(1+\frac{\tilde{N}_{t-1}}{\beta}\right)}$$

where $\tilde{R}$ is the number of spat in millions and $\tilde{N}_{t-1}$ is oyster abundance in millions. Fitting this curve to the data for the high- and medium-quality strata yields $\alpha = 0.3897$ and $\beta = 5,226.6$. A best-fit linear regression with zero intercept yields the relationship:

$$R_t = 0.50731\, N_{t-1}.$$

The mortality relationship is expressed as:

$$\Phi_{bc_t} = \omega + \kappa\, log_e(\tilde{N}_{t-1} + \rho) - \varphi\tilde{N}_{t-1} + \chi\tilde{N}_{t-1} e^{\left(-\frac{(\tilde{N}_{t-1}-\psi)^2}{2\varrho^2}\right)}$$

where $\omega = 0.055$, $\kappa = 0.03$, $\rho = 1.$, $\varphi = 0.0025$, $\chi = 0.1$, $\psi = 2.2$, and $\varrho = .8$, with $\tilde{N}$ expressed as billions of animals. Surplus production S is calculated as the difference between additions to the population through recruitment and debits through mortality. The two processes are structurally uncoupled in time, however. First, mortality occurs differentially in time relative to recruitment. Second, the methodology of data collection results in a time-integrated value of mortality, but a year ending value for recruitment, inasmuch as the death of recruits between settlement and the time of observation is not recognized as a component of the mortality term. Consequently, in the absence of fishing,

$$S_t = N_{t-1}(e^{\Gamma_t}t - 1) - N_{t-1}(1 - e^{-(m_{bc_t}+m_{0_t})t})$$

which reduces to the familiar equation

$$S_t = N_{t-1}e^{-(m_{bc_t}+m_{0_t})t}) + R_t$$

where t increments the time elapsed between observations of recruitment, m_{0_t} is the unrecorded mortality rate, m_{bc_t} is the box-count mortality rate, and Γ_t is the recruitment rate.

epizootics. On the other hand, surplus production varies by more than a factor of 3 among the five simulations. This agrees with independent observations that small changes in growth rate substantially affect surplus production projections using the Klinck et al. model. Surplus production modelling suggests that the two stable states may be separated by a zone of negative surplus production, thereby generating a point-of-no-return; however, this inference remains uncertain.

During SAW-10, The SARC discussed the use of reference points obtained from the stable-state surplus-production model in comparison to the reference points obtained from the stock-performance model. Two whole-stock reference points come from each model. For the stable-state surplus-production model, a target can be defined as the lower maximum in surplus production. The SARC did not identify a preferred simulation. For comparison to 2008 abundance, the median of the four best estimates of the N_{msy} for the low-abundance state will be used as a representative target value and a threshold set at half that value. Two additional reference points can be derived from the area-specific stock performance data for the 1989-2005 time period by summing the area-specific target values. The target is the sum of the median stock abundances for that period and the threshold is half that value (Table 25). The four respective values are: 1.628 billion, 0.814 billion, 2.261 billion, and 1.130 billion.

Superposition of these four reference points on the set of surplus production trajectories obtained from the stable-point surplus-production model (Figure 50) led the SARC during SAW-10 to the following conclusions. The stock-performance target may be too high to be used as a rebuilding goal, because the value falls near the surplus production low between the two stable states and may, therefore, be difficult to achieve. On the other hand, the N_{msy} estimate, by falling at the surplus-production peak, assures that a Dermo epizootic will push the population to a lower state of surplus production and delay recovery. The SAW-10 recommendation was that a stock rebuilding goal might be set between these two values. This has the laudable result that a Dermo epizootic, if it occurs when the stock is near the abundance goal, while decreasing abundance, will increase surplus production, and hence recovery of the stock will be facilitated. A specific target number was not set at SAW-10, but the SARC noted that the mean of the two target values, 1.945 billion, is a factor of 1.19 above the N_{msy} estimate and this factor falls within the range of abundance changes anticipated by a Dermo epizootic. Epizootic mortality rates normally fall between 20% and 30% of the stock and have tended to fall near 20% during the decade of the 2000s.

During SAW-10, the SARC similarly evaluated the two thresholds. Both 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.

As a consequence, the stock dynamics at that abundance level are unknown. The SARC recommended during SAW-10 that an abundance threshold not be set at a level below observed abundance levels. The threshold obtained from the stock-performance model falls within known stock dynamics and is the preferred threshold[β].

The 2008 abundance is 1.176 billion animals excluding the very-low-mortality beds. These reference points can be compared to the survey point estimate by evaluating the uncertainty of the point estimate. In this case, 1,000 simulated surveys were conducted 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. The confidence-level values were obtained in two ways. First, the simulated surveys were sorted by the number of $\geq$2.5″ oysters (Table 27). Second, the simulated surveys were sorted by the total number of oysters (Table 28). Dredge efficiency is less certain for oysters $<$2.5″, so that the latter approach comes with increased uncertainty that cannot be fully evaluated. On the other hand, the smaller size class is numerically important, so that the former approach sometimes fails to order surveys in a hierarchical position by total abundance.

The point estimate of 1.176 billion animals falls between the 40^{th} and 50^{th} percentiles of abundance in one case and the 40^{th} and 70^{th} percentiles of abundance in the other. Assuming that N_{msy} is the target and the threshold is half that value, the oyster beds are below the target but distinctly above the threshold. The N_{msy} estimate falls above the 90^{th} percentile of abundance. Thus, 2008 abundance is significantly below this target value. However, the threshold value of 0.81 billion falls below the 10^{th} percentile of abundance in each case. Thus, 2008 abundance falls significantly above the threshold value. A similar comparison against the stock performance reference points yields the same conclusion for the target; however, the bay is near the abundance threshold and the uncertainty of the survey encompasses this threshold value. Mitigating facts should should also be taken into account in evaluating the stock relative to these reference points. These include the high estimates of 2009 surplus production, the likelihood of additional shell planting in 2009, the more favorable size-frequency distribution in which juveniles outnumber animals $>$2.5″ in size in many bed regions, the expectation that natural mortality rate will drop in 2009, the relatively high abundance on Shell Rock and the medium-mortality beds, and the continuing high SSB levels in most bay regions. Moreover, the SARC notes that the stock performance reference point for abundance based on the 1989-2005 time series may not be reliable for the present decade because stock performance over that time suggests a significant change in the population dynamics from previous years resulting in a lower abundance of animals $\leq$2.5″.

[β] Note that the very-low-mortality beds have been excluded from all stock-wide reference point estimates and comparisons because time series data is insufficient to include them at this time.

Summary of Stock Status and Population Management Goals

Figure 51 summarizes the condition of the oyster stock throughout the New Jersey waters of Delaware Bay and by bay region. All percentiles are based on the 1989-2008 period (Table 7). This period is chosen because the advent of Dermo as a major influence on population dynamics began in 1989/1990 and evidence indicates a substantive change in population dynamics as a consequence. 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 a single year, 1991.

In 2008, the stock presents a mixture of positive and negative indicators that approximately balance (Figure 51). Abundance is low and decreasing in two of five bay regions relative to 2007. Abundance is near historical highs on Shell Rock, however, and has increased on the medium-mortality transplant beds. Abundance continued to be below target levels in all bay regions but Shell Rock, and below threshold levels on the low-mortality and high-mortality beds. The low recruitment in 2008 limits the possibility of a natural increase in abundance on these beds in 2009. However, shell planting in 2008 should improve conditions on the high-mortality beds and the SARC recommends a relatively large, in comparison to the past few years, intermediate transplant to these beds to augment natural recruitment. The decline in abundance in 2008 is essentially completely explained by the poor survival of the 2007 recruits and a second year of epizootic mortality. The stock continues to be disproportionately consolidated on the medium-mortality and low-mortality beds. However, three newly mapped beds contain about 25% of the total stock, thus significantly increasing the estimated bay resource in 2008.

Spawning stock biomass is relatively high bay-wide and increasing on Shell Rock and the medium-mortality beds. SSB on the low-mortality beds decreased relative to 2007, but remains above the 2003-2007 5-yr median. SSB has increased steadily on Shell Rock over the last three years (Figure 49). SSB is above the biomass target in four of five bay regions. In contrast to upbay, SSB has declined on the high-mortality beds. SSB is now near the biomass threshold and has decreased relative to 2007 and the 2003-2007 5-yr median.

The 2008 recruitment was low throughout the bay, except for Shell Rock. Spat-per-adult ratios exceeded 0.5 in only two bay regions, the low-mortality beds, where recruitment was relatively good in comparison to the 2003-2007 5-yr median, and the high-mortality beds where shell planting added considerably to the paltry natural spatfall. The oyster population as a whole continues to be depauperate in the smaller size classes, but the 2008 situation is somewhat improved over recent years in all bay regions, as a consequence of the large 2007 recruitment event, despite its poor survival. Only in the low-mortality beds is the proportion of juveniles decreasing. Surplus production is expected to permit an increase in market-size abundance bay-wide and in all bay regions, though less so on the high-mortality beds. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease remained at epizootic levels in 2008 and natural mortality rates were well above average on the medium-mortality beds. A declining trend in Dermo disease weighted prevalence, particularly downbay, may presage a relaxation of epizootic conditions in 2009.

Fishery exploitation levels since 1989 have been low ($<$2% of abundance per year). Recent improvements in collection of fishery-dependent data indicate that exploitation in terms of biomass has been $\leq$3% for most of that time. Exploitation rates were relatively high in 2008, but still remained below 4% of the marketable stock by number. Low exploitation rates indicate that the fishery does not have a significant effect on the stock as a whole and that fishing mortality is not responsible for the current conditions of low abundance that exist throughout the stock..

Overall, the conditions on the medium-mortality beds and Shell Rock are distinctly more advantageous than other bay regions; the conditions on Shell Rock are exemplary, after several years of shell planting to expand abundance. Conditions remain ambiguous on the low-mortality beds as abundance is remaining stable at a relative low level relative to the abundance targets, whereas biomass is above the target. In contrast, the high-mortality beds are in poor shape after two epizootic years, regardless of the metric used for evaluation. The fact that all but one bay region fell below their abundance targets indicates that actions to enhance abundance are needed in most bay regions, however the abundance-based reference points based on the 1989-2005 time series may over-emphasize the seriousness of this situation. Nevertheless, a reduction in fishing effort will not address this need because exploitation rates are already low; however, conditions are sufficiently poor on the high-mortality beds to engender increased precaution in this regard. Substantial increases in exploitation rate on the high-mortality beds should be avoided and a reduction in exploitation is in order unless mitigating measures are taken to augment natural recruitment in this region. The importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining biomass near or above target levels. Management measures have been successful in accomplishing this goal upbay of the high-mortality beds. The SARC strongly recommends continued shell planting and a substantive intermediate transplant this year as responses to the deteriorating conditions on the high-mortality beds.

Management Advice

Cultch Management Goals

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. Most bed regions were nearly in shell balance in 2008 and the likelihood that the entire bay was in shell balance or accreted shell in 2008 is good. Thus shell planting does not need to include a consideration of the regional shell balance in 2009. On the other hand, recruitment continues to be low, as has been typical of most years since 2000. Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell. Thus, shell plants, wherever feasible, should target areas where oysters grow rapidly to marketable size, where the probability of recruitment is high, and where cultch loss exceeds the addition of shell through natural mortality. Design of the 2009 program should consider the following recommendations.

1. The area of greatest concern is the high-mortality bed region. Recruitment was low in 2008 and abundance and biomass are declining after two epizootic years. Shell planting should target beds in the upbay portion of this region, such as Bennies Sand and Nantuxent Point.

2. Shell Rock continues to perform in an exemplary manner; however, the last shell plant on Shell Rock was in 2006. Maintaining high production on Shell Rock is important. Thus, shell might also be planted on Shell Rock in 2009.

2008 Management Goals

Fishery Exploitation Reference Points

The important areas for the oyster industry are the beds in the medium-mortality and high-mortality region. Examination of the trends on the individual beds indicates that these two regions have substantially different processes controlling oyster abundance. The average number of oysters on the medium-mortality beds for the 1989 to 2008 period is much greater than on the high-mortality beds, even though the total acreage is much less. The number of spat recruiting per adult has been consistently higher on the high-mortality beds and growth rates are consistently higher. Present information suggests that the high-mortality beds are characterized by multiple cohorts moving through the population of relatively equivalent size, whereas the medium-mortality beds are characterized by aperiodically-occurring larger cohorts that can dominate the population for a time. In addition, the broodstock-mortality relationship indicates that the medium-mortality beds represent the core of the stock. Epizootic mortalities result in consolidation of the stock in this region (and upbay). Stock expansions include increased recruitment downbay. The differential in response to population dynamics processes suggests that management of the medium-mortality beds generally should be more precautionary than the high-mortality beds. However, low exploitation levels on these beds since the direct-market program began in 1996 limit our ability to evaluate the response of these beds to exploitation even at lower than average levels typical of downbay regions. Historically, management of these beds has been in a highly precautionary mode.

The low-mortality beds are characterized by slower growth rates and very sporadic recruitment events. Abundance is maintained by the coincidence of low mortality, hence longer life span, that limits the negative effect of lower recruitment potential. The exploitation record on these beds is limited; but the assumption is that exploitation rates should be kept relatively low. The very-low-mortality beds provide a particular conundrum this year as no time series record exists to judge their population dynamics relative to other bed regions. Presumably, the low-mortality beds provide the best analogy.

Because the evidence indicates that the oyster stock varies in its population dynamics within bay regions, management goals must be established separately for each region. SAW-8 established exploitation-based reference points to be used to set recommended fishing goals. Recent surplus production modeling confirms the difficulty of obtaining biologically-based (or f_{msy}-type) reference points for this purpose. Thus, the exploitation-based approach is clearly the preferred alternative. The SARC recognizes that these reference points do not permit evaluation of the full range of possible exploitation on these beds due to precautionary management since 1996. The SARC is in general agreement with this approach, but proposes that one bay region be identified this year for an experimental increase in exploitation rate to begin to evaluate applicability of the present exploitation-based reference-point system.

Implementation of the exploitation reference points recognizes that the fishery has been successfully prosecuted at relatively low exploitation levels since 1995. SAW-8 promulgated exploitation-based reference points based on the median exploitation rate, defined in terms of the fraction of abundance removed, for each bay region for the years 1996-2005. This approach was substantially revised in 2006 based on the 1996-2006 time series using new software permitting more accurate estimates of size-dependent exploitation rates. As these abundance-based exploitation reference points are derived from a period of conservative fishery management characterized by low exploitation rates, the abundance-based exploitation reference points are likely to provide conservative management goals. The exploitation reference points come with the following cautions as to their use. 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 $\geq 2.5''$ were removed proportionately. Insufficient data are available for the low-mortality beds and the very-low-mortality beds. The exploitation indices for the transplant group of medium-mortality beds (Middle+Upper Middle) were applied also to the two upbay bed groups.

Exploitation rates can be calculated based on real removals and apparent removals (Tables 29-30). Real removals are defined as the net of the market catch, increased or debited by the removals and additions by intermediate transplant. Apparent removals are defined as the market catch plus removals by intermediate transplant. The two values are identical for beds upbay of Shell Rock because transplants to these beds have never occurred. In some cases, negative real exploitation rates appear in the time series for Shell Rock and the high-mortality beds because the number added by intermediate transplant exceeds the number removed. The alternative, use of the apparent exploitation rates, overestimates the inherent productivity of these beds, however, and would permit potentially unsustainable harvest levels without careful implementation of the intermediate transplant program. The SARC retains the precedent set in 2007 that the real exploitation rate reference points be used for any analysis for direct marketing and that the reference points used should be based on the 1996-2006 values for the $\geq 2.5''$ size class. The SARC also retains the precedent that the 40^{th}, 50^{th}, and 60^{th} percentiles normally be employed.

Use of the real exploitation rates for the high-mortality beds represents a precautionary approach to managing these beds; however, the SARC cautions that the precautionary value of these reference points is retained only as long as an intermediate transplant program is incorporated into the management plan. The SARC notes that one outcome of the implementation of the exploitation reference points for beds upbay of Shell Rock has been to reduce the transplant of animals downbay in the intermediate transplant program, and this has abetted increased Dermo mortality leading to a decline of abundance and biomass on these beds. Accordingly, the SARC recommends that the intermediate transplant program be expanded in 2009. Intermediate transplant can be conducted by suction dredge or dry dredge with or without a culling device. Exploitation rates for suction dredge or dry dredge without a culling device should be estimated assuming all size classes are removed proportionately. The concentration factor for culling devices is of the order of 1.28[Υ]; a concentration factor insufficient to use the exploitation rates for $\geq 2.5''$ animals. Thus, all intermediate transplant estimates should rely on the 'all-animal' exploitation rate reference points. The SARC strongly advises, however, that intermediate transplant use culling devices as the goal of this activity is to move downbay proportionately more marketable animals while retaining upbay under a

[Υ] Powell, E.N. and K.A. Ashton-Alcox. 2004. A comparison between a suction dredge and a traditional oyster dredge in the transplantation of oysters in Delaware Bay. *J. Shellfish Res.* 23:803-823.

lower mortality regime the smaller animals that will grow into these larger size classes. In this way, most animals moved downbay will be available for harvest within 18 months, thus minimizing their loss to Dermo disease.

Abundance-based Exploitation Reference Point Projections – Direct Marketing

Shell Rock and the high-mortality beds have provided most of the fished animals since 1995 because market quality is consistently high; however in many years, a substantial fraction of these animals have originated from the medium-mortality beds through the intermediate transplant program. The high-mortality beds in particular are highly influenced by disease and therefore susceptible to rapid population declines. Juvenile mortality rates also are high. Nevertheless, these beds normally have been characterized by positive surplus production due to high growth rates and adequate recruitment rates.

In 2008, the high-mortality beds continue to be at low abundance and biomass has dropped to near threshold levels after two epizootic years. The SARC notes that the high-mortality beds are 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 shorter term. The intermediate transplant program was successful in this regard for much of the 1996-2004 time period, and the lessoning of this activity in recent years has resulted in an increased realized exploitation rate relative to that assumed using the exploitation-based reference points that have embedded in them the assumption that animals will be added to these beds as well as taken to market in each year. The SARC considers the present state of these beds to need immediate attention and recommends that a fishing level above the 40^{th} percentile not be used without implementation of a significant intermediate transplant program. Because a significant intermediate transplant program will substantially reduce realized exploitation rate on these beds, higher percentile harvests (e.g., the 50^{th} percentile) on the high-mortality beds may be implemented under that proviso.

Due to the uniqueness of medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed independently of the high-mortality beds. This year, Shell Rock is above the abundance and biomass targets. Given the high biomass and abundance on Shell Rock, the SARC recommends that any fishing level inclusive of the 40^{th} to 60^{th} percentiles can be considered for 2009.

SAW-8 recommended that management should emphasize increased direct marketing on the lower group of medium-mortality beds to reduce the exploitation rate downbay. Beginning in 2005, these beds have contributed directly and significantly to this goal. The SARC supports this recommendation that the three medium-mortality beds, Cohansey, Ship John, and Sea Breeze, continue to be managed as direct-market beds. This year, biomass is above target levels. Substantial catches in 2007 and 2008 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance, nor have two years of Dermo epizootics changed the trajectory of these beds sufficiently to bring biomass below target levels. Thus, these beds have been relatively resilient under the low exploitation rates used to date. High levels of surplus production are again anticipated for 2009. The SARC notes that the history of exploitation in this region, with the evolution of these beds from an initial contributor to intermediate transplant to a fully functional component of the direct-market program has resulted in exploitation-based reference points that may be more precautionary than required for sustainable management. For example, the highest measured exploitation rate since 1996 falls below the 10^{th} percentile of Shell Rock, the next bed immediately downbay. Unfortunately, no theoretical analysis has permitted a determination of f_{msy} for these beds. Thus, the SARC recommends an experimental fishery on these beds to evaluate their response under increased exploitation rates. The SARC emphasizes the following facts relative to this proposal.

1. No other way exists to evaluate optimal exploitation levels except through this mechanism.

2. Due to the importance of these beds for the stock, exploitation rates should be raised moderately and the effect re-evaluated at the end of the year.

3. The experimental fishery will require careful monitoring of the stock through increased sampling during the survey. This can best be accomplished by resampling certain grids already sampled in 2008 to permit direct comparisons. These grids should be in areas targeted by the fishery during 2009.

4. Metrics for evaluation should include SSB, marketable abundance, total abundance, box-count mortality, and spat counts and the evaluation should include a comparison to 2008 and also to adjacent beds in 2009.

5. The Shell Fisheries Council must recognize that the 2009 recommendation *does not set a precedent* for future years. Should the bed respond poorly, the SARC will recommend reinstitution of the earlier reference points and may recommend lower exploitation rates to aid bed recovery.

The SARC discussed at length the exploitation rate that might be used. Two options are included in the projection tables, the highest exploitation rate for the medium-mortality market beds and the 10^{th} percentile exploitation rate observed on Shell Rock. The two values are very similar and amount to approximately a doubling of the exploitation rate over the 50^{th} percentile used previously on these beds. Even at this rate, the total exploitation rate will fall below 5% of the marketable stock and thereby remain well below natural mortality rates on these beds and well below exploitation rates normally used for Shell Rock.

The SARC notes that implementation of this higher exploitation rate may require transplant of some animals from Cohansey downbay. This transplant will also move small animals downbay not covered by the use of the direct-market exploitation-based reference points. However, the percentile exploitation-based reference points for this bay region applicable to intermediate transplant are about half that for direct market. Given the percentage of marketable animals on this bed, an intermediate transplant from Cohansey could be successfully accomplished within direct market guide lines by tracking marketable animals moved downbay, such that cullers are used to approximately double the proportional contribution of $\geq 2.5''$ oysters on the deck relative to those on the bottom. This latter would be an essential component of this option; otherwise overharvesting of smaller animals may occur and the desired quota augmentation would not be achieved.

Projections are provided in Table 31 for the high-mortality beds, Shell Rock, and the market group of medium-mortality beds (Cohansey, Ship John, Sea Breeze).

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant

The SARC strongly supports the inclusion of an intermediate-transplant program and emphasizes the urgent need of this program as a vehicle to repair the damage of two years of epizootic mortality on the high-mortality beds. The medium-mortality transplant beds are above the biomass target and the abundance threshold. The SARC supports the use of either the 40^{th}, 50^{th}, or 60^{th} percentile exploitation rates.

The low-mortality beds are above the biomass target, but below abundance threshold. Growth rates are slower on these beds and recruitment has been sporadic at best. The ability of these beds to recover from a decline in abundance is, therefore limited, despite the lower rate of natural mortality. However, surplus production is projected to be positive in this bed region in 2009. The SARC, therefore, recommends that this region be included in the intermediate transplant program in 2009, but that the 60^{th} percentile exploitation rate be avoided.

No exploitation record is available for the very-low-mortality beds. However, the SARC emphasizes the need to evaluate these beds as intermediate transplant beds. Thus, an intermediate transplant is recommended, but not to exceed the 40^{th} percentile to retain precaution until a better understanding of these beds' response to fishing activities can be achieved. Due to the pristine nature of these three beds, the SARC recommends that this transplant be taken from one of the three beds, retaining the other two in a pristine state to permit comparison of bed response to the intermediate transplant.

Note that transplant options will require transplant before the allocation can be set because allocation estimates provided herein can only be confirmed after the transplant is complete. This year, the same caution pertains to the high-mortality beds unless management chooses the 40^{th} percentile option for these beds.

Given the plight of the high-mortality beds, the SARC recommends that transplants from the low-mortality and medium-mortality transplant beds be moved to the upper portion of the high-mortality beds, including, for example, inner Bennies, Bennies Sand, Hog Shoal and Nantuxent Point. Given the uncertainty of survival of transplants from the very-low-mortality beds, the SARC recommends that the lower half of Ship John be a preferred location to receive these transplants.

Projections for intermediate transplant are provided in Table 32.

Science and Management Issues

Management Issues

Abundance is at or below the abundance threshold in most bay regions. 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 dock-side monitoring program must continue. This 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.

Science Recommendations

These science recommendations are not ordered as to priority. The SARC makes special note, however, of the need to continue the Dermo monitoring program,

The Dermo monitoring program should continue. Collection of ancillary data on mortality, size-frequency distribution, and growth rate should be continued.

A spat settlement monitoring program should be continued.

A sampling program should be undertaken to evaluate the 3-tows-per-grid sampling protocol.

Given the range of surplus production values obtained by the stable-point surplus production model, and the uncertainty as to the best configuration to use for simulation of the surplus production trajectory, a probabilistic model should be developed utilizing all of the observed yearly values of abundance, recruitment, and mortality to provide an improved estimate of f_{msy}.

A program should be developed to permit yearly 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. The program should begin with the re-survey of beds that have not been highly manipulated by shell planting to determine the need for their re-survey relative to the highly manipulated beds.

Further dredge calibration information is urgently needed to determine if tow-based dredge efficiencies are sufficiently accurate to be used in survey quantification and to determine if a temporal change in dredge efficiency is occurring or has occurred. This study should use experiments occurring simultaneously with the survey to directly test the tow-based regressions.

A size-dependent model should be expanded to include box-frequencies so that size-dependent mortality can be included in the assessment. These data should be used to construct a retrospective time series of surplus production.

An observer program should be initiated too determine the usefulness of these data to assess changes in grid quality between re-surveys and also to assess reporting accuracy.

The survey data should be analyzed comprehensively to examine the factors promoting high-recruitment events.

An improved recruitment index should be investigated, using observations from the shell plants and other available data.

The relationship between condition and recruitment should be investigated.

A re-evaluation of bed regions, particularly downbay of Shell Rock, should be undertaken to optimize the area-management program.

A re-evaluation of the exploitation-based reference points is needed, particularly a determination of whether information on growth, recruitment and mortality in the population can be used to improve estimates of the range of allowable exploitation rates.

A pre-fishery-recruit index should be investigated, by applying the known growth rates to identify the proportion of the stock likely to grow to $\geq 2.5''$ in the coming year. These data should be used to expand the surplus production projections.

A video or diver transect survey should be conducted on the very-low-mortality beds prior to exploitation.

Investigation of issues related to larval transport and bay circulation should be investigated using the EID implementation of the ROMS model for Delaware Bay.

Table 2. Dredge efficiency estimates expressed as the reciprocal of the efficiency e: $q = \frac{1}{e}$. The value q is the multiplier by which swept area estimates were converted to per-meter-square values. The upper bay includes all beds upbay of Shell Rock[♯]

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

♯ 2003 and 2000 values are taken from: 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 and 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.

Table 3. Results of Tukey's Studentized Range Tests for tow distance (m), bushels haul^{-1}, and bushels (meter-towed)$^{-1}$ for four primary bed regions. Tests compared survey tows for surveys in 2005, 2006, 2007, and 2008. Different letters within variable groups of four means indicate that years are significantly different at $\alpha = 0.05$.

High-mortality Beds

Variable	Tukey Group	Mean	Year
Tow Distance (m)	A	95.86	2005
	B	88.16	2008
	B	86.33	2007
	C	69.93	2006
Bushels Haul^{-1}	A	4.182	2007
	B	2.887	2005
	CB	2.406	2006
	C	2.233	2008
Bushels (Meter-towed)$^{-1}$	A	0.0531	2007
	B	0.0387	2006
	CB	0.0324	2005
	C	0.0265	2008

Shell Rock

Variable	Tukey Group	Mean	Year
Tow Distance (m)	A	98.96	2005
	B	72.49	2006
	B	71.39	2008
	B	65.62	2007
Bushels Haul^{-1}	A	4.533	2007
	BA	3.712	2008
	BA	2.975	2006
	B	2.606	2005
Bushels (Meter-towed)$^{-1}$	A	0.0832	2007
	A	0.0578	2008
	BA	0.0434	2006
	B	0.0282	2005

Medium-mortality Beds

Variable	Tukey Group	Mean	Year
Tow Distance (m)	A	102.67	2005
	B	80.57	2007
	B	80.16	2008
	C	67.41	2006
Bushels Haul^{-1}	A	2.933	2006
	BA	2.910	2007
	BA	2.560	2008
	B	2.157	2005
Bushels (Meter-towed)$^{-1}$	A	0.0461	2006
	A	0.0376	2007
	A	0.0357	2008
	B	0.0234	2005

Low-mortality Beds

Variable	Tukey Group	Mean	Year
Tow Distance (m)	A	91.19	2008
	A	85.66	2005
	A	81.09	2007
	B	67.23	2006
Bushels Haul^{-1}	A	3.371	2005
	BA	3.191	2007
	BA	2.2179	2008
	B	1.789	2006
Bushels (Meter-towed)$^{-1}$	A	0.0440	2005
	A	0.0418	2007
	A	0.0318	2006
	A	0.0266	2008

Table 4. Percentile differences between bushels caught per meter towed between 2008 and the same grids sampled in 2005, 2006, or 2007, calculated as:

$$difference = 2008\, or\, 2007\, or\, 2006\, index - 2007\, index$$

and the results of Sign and Wilcoxon Signed-rank tests.

Difference Between	N	25^{th} Percentile	Median	75^{th} Percentile	Sign Test P-value	Wilcoxon Signed-Rank Test P-value
2008 vs 2007	84	-0.0457	-0.0231	-0.0064	<0.0001	<0.0001
2008 vs 2006	63	-0.0306	-0.0079	0.0086	0.077	0.043
2008 vs 2005	39	-0.0263	-0.0077	0.0128	0.337	0.308

Table 5. Results of the 2008 random sampling program for the Delaware Bay natural oyster beds. Included for comparison are data for 2006 and 2007. Data are displayed from the farthest upbay beds to those downbay. The second column called 'Bushels/haul' indicates the average number of bushels brought up by the three dredge hauls from each grid. For each bed the percentage of oysters for each sample is presented, with rankings from highest to lowest. Percent oyster is based on volume of oyster in the sample divided by the total volume of shell, oyster, and debris. Letters 'H', 'M', and 'T', indicate high-quality, medium-quality, and transplant or shell-plant grids, respectively. Oysters per bushel and spat per bushel are based on actual counts adjusted to a 37-quart bushel. 'Size' columns indicate the number of oysters greater than 2.5″. Condition index is a measure of the dry meat weight in an oyster relative to the hinge-to-lip (greatest) dimension. The 'Percentage Mortality' value is based on the number of boxes counted in the samples. Prevalence is the percentage of oysters with detectable infections by Dermo. Weighted Prevalence is the average infection intensity (scored from 0 to 5) of all sampled oysters. With the exception of information on Dermo, all bed-average data are weighted averages based on the relative proportion of high-quality and medium-quality grids on the bed. 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 rendered on a per-bushel basis.

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Hope Creek	3.0	75.7 H	56.0 H																									
Hope Creek	1.0	70.6 H	49.8 H																									
Hope Creek	5.2	60.7 H	44.7 H																									
Hope Creek	5.8	60.6 H	29.3 M		403	334		116	93		3	5		20	0		0.13	.00		103	41		26	12		0.008	0.009	0.000
Hope Creek	5.2	54.1 M																										
Hope Creek	2.8	49.1 M																										
Hope Creek	1.7	48.2 M																										
Hope Creek	2.6	29.2 M																										
Liston Range	2.4	78.0 M																										
Liston Range	3.4	58.3 M																										
Liston Range	2.8	53.6 H			336			91			3			25			0.48			128			38			0.010	0.017	
Liston Range	0.0	49.3 H																										
Liston Range	1.0	31.1 M																										
Liston Range	0.1	20.0 M																										
Fishing Creek	0.8	64.2 M	63.3 M																									
Fishing Creek	5.0	63.6 H			293	293		40	56		3	4		65			0.70			153	118		52	40		0.012	0.026	
Fishing Creek	0.9	56.0 H																										
Fishing Creek	1.1	55.0 M																										
Fishing Creek	0.1	49.6 M																										
Round Island	0.9	55.0 M	51.9 M	49.4 M																								
Round Island	3.7	51.1 H	46.0 H	44.4 M	191	206	217	22	67	6	6	7	6	80	25	10	1.20	.35	.20	100	93	86	52	45	40	0.014	0.010	0.007
Round Island	2.9	40.1 H	28.0 H	39.7 H																								
Round Island	0.2	24.4 M	23.9 M	27.0 M																								
Round Island	0.4	14.4 M	17.7 M	9.0 M																								
Upper Arnolds	4.3	68.9 H	55.4 M	54.0 H																								
Upper Arnolds	3.4	64.7 H	50.6 H	23.5 M	371	249	172	53	76	12	10	6	10	90	60	10	1.38	.73	.20	160	115	85	43	46	49	0.027	0.012	0.007
Upper Arnolds	3.9	59.5 M	48.9 H																									
Upper Arnolds	1.5	58.0 M	34.0 M																									
Upper Arnolds	2.5	55.8 M	8.5 M																									

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Arnolds	2.1	73.3 H	53.1 M	46.5 H																								
Arnolds	3.0	60.5 H	48.9 H	40.9 M																								
Arnolds	0.7	59.3 M	44.2 H	34.7 M	258	180	186	37	66	18	9	7	5	95	60	25	2.10	1.18	.25	130	87	67	50	48	36	0.016	0.012	0.007
Arnolds	5.6	58.2 H	41.4 H	12.8 M																								
Arnolds	0.0	56.4 M	31.3 M	0.0 M																								
Arnolds	0.2	11.9 M	16.1 M																									
Upper Middle	3.6	34.3 H	65.8 M	7.1 M																								
Upper Middle	2.7	31.4 M	42.1 M	0.0 H	115	195	21	10	85	0	26	16	6	95	75	60	2.23	1.68	1.55	49	126	8	43	65	40	0.012	0.013	0.016
Upper Middle	0.6	15.1 M	41.4 H																									
Upper Middle	0.1	6.2 M	24.9 M																									
Middle	2.1	71.6 T	49.5 T	54.2 M																								
Middle	6.4	51.9 H	33.5 M	50.3 M																								
Middle	0.9	48.0 M	22.7 M	47.9 M	181	90	203	11	47	52	25	21	14	100	89	65	2.33	2.82	1.50	72	50	101	40	55	50	0.012	0.011	0.008
Middle	3.4	42.8 H	21.6 H	40.2 H																								
Middle	3.2	25.4 M	21.2 M	25.0 H																								
Middle	2.4	7.6 M	10.1 H																									
Ship John	1.1	75.2 M	63.9 T	63.9 H																								
Ship John	1.8	71.9 M	56.5 H	49.7 H																								
Ship John	4.1	67.6 H	55.7 T	49.6 M																								
Ship John	3.1	66.5 T	54.7 H	48.5 M																								
Ship John	3.2	63.7 T	51.0 M	40.4 H	238	155	181	22	164	56	20	19	17	95	100	55	1.95	2.23	.80	85	63	89	36	41	49	0.010	0.011	0.010
Ship John	3.2	63.6 T	45.4 M	34.5 M																								
Ship John	2.2	53.7 T	44.3 T	20.9 M																								
Ship John	3.2	51.0 H	44.0 H																									
Ship John	1.7	46.2 H	33.7 T																									
Ship John	1.5	25.7 M	11.7 M																									
Ship John	0.2	22.0 M	7.6 M																									

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Cohansey	3.7	79.0 T	46.3 H	60.5 M																								
Cohansey	3.0	72.3 T	43.6 H	57.4 H																								
Cohansey	3.4	65.6 T	38.9 H	48.4 H																								
Cohansey	3.2	64.8 H	35.3 M	37.1 M	202	121	151	12	144	13	24	23	16	90	95	100	1.90	2.48	2.23	79	60	96	39	49	63	0.022	0.012	0.010
Cohansey	4.1	54.3 M	33.3 T	30.4 M																								
Cohansey	2.6	51.9 M	24.2 M	14.8 H																								
Cohansey	2.0	46.3 H	21.9 M																									
Cohansey	4.1	37.1 H																										
Cohansey	2.4	33.3 M																										
Sea Breeze	4.5	50.3 H	41.2 M	53.7 M																								
Sea Breeze	0.2	32.3 M	33.8 H	42.8 H	100	76	110	19	48	17	20	27	19	95	100	90	1.75	3.48	2.20	38	43	62	38	56	56	0.013	0.015	0.012
Sea Breeze	2.2	29.7 H	20.4 M	37.1 H																								
Sea Breeze	2.2	16.8 H	15.8 H	27.5 H																								
Sea Breeze	1.5	14.2 M	0.0 H	24.3 M																								
Shell Rock	3.0	75.7 T	60.3 H	68.8 H																								
Shell Rock	3.6	61.4 H	59.5 T	61.0 T																								
Shell Rock	4.0	60.0 M	58.8 T	57.8 T																								
Shell Rock	3.3	57.9 M	52.6 T	56.5 H																								
Shell Rock	2.5	54.3 T	51.3 T	52.9 T																								
Shell Rock	2.6	54.0 H	46.6 H	51.7 M																								
Shell Rock	3.2	49.7 M	45.6 M	48.2 T	262	139	164	77	171	29	18	24	20	95	95	100	1.93	1.93	3.28	76	59	79	29	42	48	0.015	0.012	0.011
Shell Rock	5.4	49.4 H	44.8 T	48.2 T																								
Shell Rock	3.9	48.8 T	37.3 H	47.3 T																								
Shell Rock	3.9	43.7 H	26.6 M	47.1 T																								
Shell Rock	3.7	28.1 M	8.8 M	46.8 M																								
Shell Rock				46.4 H																								
Shell Rock				44.3 T																								
Shell Rock				2.1 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Bennies Sand	2.2	87.5 T	62.2 T	52.6 T																								
Bennies Sand	2.2	57.2 T	52.7 H	49.4 H																								
Bennies Sand	1.5	54.2 T	47.3 T	41.4 T																								
Bennies Sand	3.4	46.2 H	39.9 T	40.3 M																								
Bennies Sand	2.2	40.1 T	36.9 T	37.3 T	136	91	136	33	33	34	27	21	14	100	95	90	3.0	3.30	1.80	59	42	54	44	46	40	0.014	0.013	0.011
Bennies Sand	3.7	38.7 T	21.5 M	33.4 H																								
Bennies Sand	3.6	34.9 T	20.8 H	27.9 M																								
Bennies Sand	1.8	34.8 M	20.4 M	27.8 T																								
Bennies Sand	1.9	30.7 H	20.1 H	26.1 H																								
Bennies Sand	0.4	24.4 M	12.2 M	23.0 M																								
Bennies Sand	1.3	19.2 M																										
Bennies	2.2	60.4 H	31.3 H	61.0 H																								
Bennies	3.4	40.5 H	23.8 M	39.7 M																								
Bennies	0.4	32.7 M	23.8 M	35.0 H																								
Bennies	2.1	30.4 M	23.4 H	30.3 M																								
Bennies	1.4	29.2 H	12.2 M	27.2 H																								
Bennies	1.3	24.0 M	11.3 H	14.6 M	55	32	72	9	9	10	32	32	17	55	90	100	0.93	2.15	2.55	38	25	28	70	79	39	0.018	0.019	0.015
Bennies	0.3	15.7 M	8.9 M	13.0 M																								
Bennies	0.8	14.0 M	7.9 M	10.4 M																								
Bennies	0.4	9.2 M	1.0 M	10.1 M																								
Bennies	0.4	7.0 M	0.6 M	8.1 M																								
Bennies	3.9	3.7 M	0.4 M	6.3 M																								
Bennies	2.3	3.7 M	0.3 M	2.6 M																								
Hog Shoal	3.7	50.0 H	39.0 H	28.6 H																								
Hog Shoal	3.0	36.1 H	20.0 H	26.7 H																								
Hog Shoal	2.0	35.6 M	12.0 H	24.4 H	70	40	48	13	44	11	26	37	23	100	100	95	2.70	3.28	2.97	31	21	27	45	53	56	0.018	0.015	0.014
Hog Shoal	2.6	12.8 H	10.1 M	21.3 M																								
Hog Shoal	2.4	6.5 M	8.8 M	10.0 M																								
Hog Shoal	1.0	3.6 M	6.9 M	7.3 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Nantuxent Point	3.3	59.9 T	49.7 M	47.3 T																								
Nantuxent Point	1.6	50.3 T	41.2 T	41.8 H																								
Nantuxent Point	2.2	35.8 T	39.6 T	39.7 H																								
Nantuxent Point	2.0	31.0 M	30.1 M	37.9 H																								
Nantuxent Point	4.3	25.5 H	26.1 T	32.5 M	118	96	84	54	293	13	22	30	30	40	100	95	1.73	4.08	2.60	38	47	45	32	49	53	0.009	0.013	0.014
Nantuxent Point	3.2	23.3 T	22.3 H	16.2 M																								
Nantuxent Point	3.7	21.0 H	21.3 H	1.9 M																								
Nantuxent Point	4.0	16.6 H	17.4 H																									
Nantuxent Point	1.1	14.3 M	16.1 T																									
Nantuxent Point	3.0	8.5 M	15.8 M																									
New Beds	3.2	32.3 H	35.2 H	43.9 H																								
New Beds	4.5	26.0 H	22.0 M	17.1 M																								
New Beds	6.4	13.2 M	19.1 H	16.5 M																								
New Beds	4.5	12.6 M	17.2 M	12.7 M	27	45	42	3	20	7	43	36	23	90	100	100	2.08	2.68	3.05	22	30	28	83	67	66	0.026	0.025	0.017
New Beds	1.8	6.7 M	13.7 M	8.3 M																								
New Beds	2.4	5.1 M	6.7 M	1.6 M																								
New Beds	3.7	3.4 M	5.3 M	0.9 M																								
New Beds	3.2	3.0 M	3.6 M																									
New Beds	1.0	2.4 M	0.2 M																									
Strawberry	2.6	15.1 H	4.9 H	13.8 H																								
Strawberry	0.9	11.8 M	2.1 M	2.8 M	20	6	8	3	10	2	45	44	13	50	95	88	0.58	3.13	2.13	14	4	7	68	72	79	0.020	0.014	0.046
Strawberry	2.0	6.1 M	1.3 M	1.0 M																								
Strawberry	1.9	4.4 M	0.0 M	0.0 M																								
Hawk's Nest	5.6	44.8 T	22.8 H	57.0 T																								
Hawk's Nest	3.7	40.1 H	22.7 M	35.8 H																								
Hawk's Nest	0.5	29.4 M	20.9 T	29.5 H	206	50	57	108	138	10	13	35	25	90	90	100	2.15	2.45	2.63	29	31	35	14	62	61	0.017	0.013	0.016
Hawk's Nest	2.7	27.3 M	16.8 H	17.2 M																								
Hawk's Nest	2.2	24.3 H	13.1 M	11.6 M																								
Hawk's Nest	2.6	8.3 M	2.0 M	7.0 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2008	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006	**2008**	2007	2006
Vexton	2.6	10.6 H	18.3 M	15.1 M																								
Vexton	3.4	10.2 H	13.4 H	14.8 H	10	32	11	2	42	4	39	34	26	85	100	90	1.00	3.00	2.25	5	19	9	47	61	78	0.021	0.021	0.020
Vexton	1.7	2.8 M	12.9 M	13.4 H																								
Vexton	0.2	2.7 M	6.6 H	3.0 M																								
Vexton	2.9	0.3 M	5.1 M	0.0 M																								
Beadons	1.0	36.5 H	27.6 H	26.6 H																								
Beadons	1.1	35.3 H	23.5 H	17.4 H																								
Beadons	1.5	30.7 H	16.4 H	13.3 H	67	24	26	36	47	7	26	18	15	60	70	75	1.80	1.33	2.05	16	9	12	25	36	47	0.019	0.011	0.014
Beadons	1.7	6.6 M	4.0 M	7.8 M																								
Beadons	2.6	5.9 M	1.0 M	7.1 M																								
Beadons	1.0	3.1 M	0.9 M	5.4 M																								
Beadons	1.6	3.0 M	0.0 M	0.7 M																								
Ledge	2.1	0.0 M		2.0 M																								
Ledge	2.6	0.0 M		0.4 H			1			0	100		45			67			.92			1			70			0.035
Ledge	4.5	0.0 M		0.0 M																								
Ledge	1.3	0.0 H		0.0 M																								
Ledge	0.2	0.0 M		0.0 M																								
Egg Island			2.3 M																									
Egg Island			2.1 M																									
Egg Island			0.5 M																									
Egg Island			0.5 H			2			1			52			85			1.70			1			84			0.047	
Egg Island			0.0 M																									
Egg Island			0.0 M																									
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 the 1990-2008 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean = mean of annual values for 1990-2008.

Year	1996	1990	1992	1991	1995	1997	1998	1993	2000	1994	1999	2008	2001	2002	2003	2007	2004	2006	2005	Mean
Oyster	262	242	237	211	196	187	183	178	169	155	149	145	145	134	123	123	113	101	81	**165**
	A	A	A	A	A	A														
		B	B	B	B	B	B	B	B											
				C	C	C	C	C	C	C	C	C	C	C						
					D	D	D	D	D	D	D	D	D	D	D	D				
						E	E	E	E	E	E	E	E	E	E	E	E			
								F	F	F	F	F	F	F	F	F	F	F		
										G	G	G	G	G	G	G	G	G	G	

Year	1991	1997	1999	1994	1995	1990	1998	2007	2002	1993	2000	2008	1992	1996	2004	2003	2005	2006	2001	Mean
Spat	267	209	204	175	156	154	126	81	46	45	35	31	25	24	23	20	19	19	12	**88**
	A	A	A																	
		B	B	B	B	B														
				C	C	C	C													
					D	D	D	D												
								E	E	E	E	E	E	E	E	E	E	E	E	

Table 7. Percentile positions in the indicated time series for the given bay regions and stock variables. Note that for most of the variables, a lower percentile equates with a lower value of the variable relative to the entire time series. For 'Unexplained Mortality", however, a lower value indicates a higher degree of unexplained mortality relative to the time series. Very-low-mortality beds are not included in the percentile evaluations of the time series.

	Abundance	Spawning Stock Biomass*	Recruitment	Spat to Adult Ratio	Box-count Mortality	Fishing Mortality⋆	Market Fishing Mortality	Unexplained Mortality
Bay-wide: 1953-2008	.098		.098	.241	.723	.398		
Bay-wide: 1989-2008	.175	.553	.125	.275	.525	.885	.455	
Low-mortality: 1953-2008	.027		.188	.438	.473	.755		.098
Low-mortality: 1989-2008	.075	.605	.225	.675	.475	.708	.636	.075
Medium-mortality Transplant: 1953-2008	.259		.080	.134	.920	.682		.759
Medium-mortality Transplant: 1989-2008	.275	.921	.125	.125	.925	.708	.727	.725
Medium-mortality Market: 1953-2008	.223		.009	.152	.759	.427		.098
Medium-mortality Market: 1989-2008	.175	.711	.010	.175	.575	.375	.364	.125
Shell Rock: 1953-2008	.562		.473	.402	.652	.682		.402
Shell Rock: 1989-2008	.725	.868	.525	.425	.525	.990	.636	.475
High-mortality: 1953-2008	.080		.188	.491	.652	.791		.098
High-mortality: 1989-2008	.125	.079	.125	.375	.325	.990	.909	.075

*SSB values used the 1990-2008 time series

⋆Fishing values used the 1997-2008 time series

Table 8. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality beds for the 1990-2008 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tykey's Studentized Range Test). Mean = mean of annual values for 1990-2008.

Year	**1996**	**2000**	**1990**	**1992**	**1997**	**1998**	**2003**	**1991**	**2001**	**1993**	**2002**	**1999**	**2008**	**1995**	**1994**	**2005**	**2006**	**2004**	**2007**	**Mean**
Oyster	434	364	328	304	291	270	258	255	233	227	212	208	197	197	196	191	172	157	132	**243**
	A	A	A																	
		B	B	B	B	B	B	B												
			C	C	C	C	C	C	C	C	C									
				D	D	D	D	D	D	D	D	D	D	D	D	D				
						E	E	E	E	E	E	E	E	E	E	E	E	E		
									F	F	F	F	F	F	F	F	F	F	F	

Year	**1999**	**1991**	**1995**	**1998**	**1994**	**1990**	**1997**	**2007**	**2002**	**1993**	**2000**	**1996**	**2006**	**2004**	**2008**	**2003**	**1992**	**2005**	**2001**	**Mean**
Spat	302	268	195	195	182	140	127	114	89	54	47	37	35	30	29	28	28	27	12	**102**
	A	A	A	A																
		B	B	B	B															
			C	C	C	C	C	C	C											
						D	D	D	D	D	D	D	D	D	D	D	D	D		
							E	E	E	E	E	E	E	E	E	E	E	E	E	

Table 9. Average annual oyster and spat abundance per 37-qt. bushel for the low-mortality beds for the 1990-2008 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tykey's Studentized Range Test). Mean = mean of annual values for 1990-2008.

Year	**1992**	**1991**	**1993**	**1990**	**1995**	**1994**	**2002**	**2001**	**1996**	**1999**	**2000**	**1997**	**2003**	**2008**	**2005**	**1998**	**2004**	**2006**	**2007**	**Mean**
Oyster	698	663	588	575	483	450	405	375	353	328	318	311	310	302	263	259	255	221	199	**387**
	A	A	A	A	A															
		B	B	B	B	B														
			C	C	C	C	C	C												
				D	D	D	D	D	D											
					E	E	E	E	E	E	E	E	E	E	E	E	E			
						F	F	F	F	F	F	F	F	F	F	F	F	F		
							G	G	G	G	G	G	G	G	G	G	G	G	G	

Year	**1991**	**1990**	**1999**	**1998**	**1995**	**1994**	**2007**	**2005**	**1996**	**1997**	**2008**	**2002**	**1992**	**1993**	**2000**	**2006**	**2001**	**2003**	**2004**	**Mean**
Spat	371	228	117	99	84	84	80	53	52	52	48	45	38	23	20	16	14	11	5	**76**
	A																			
		B																		
			C	C	C	C	C	C	C	C	C	C	C							
				D	D	D	D	D	D	D	D	D	D	D	D					
					E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	

Table 10. Average annual oyster and spat abundance per 37-qt. bushel for the high-mortality beds for the 1990-2008 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tykey's Studentized Range Test). Mean = mean of annual values for 1990-2008.

Year	1996	1995	1998	1990	1992	1997	1994	1991	1999	2000	2008	2001	1993	2006	2005	2004	2007	2003	2002	Mean
Oyster	230	162	159	158	152	132	114	112	106	88	84	77	75	67	63	62	50	46	29	**104**
	A	A	A																	
		B	B	B	B	B	B	B	B											
			C	C	C	C	C	C	C	C										
					D	D	D	D	D	D	D									
						E	E	E	E	E	E	E	E	E	E	E				
							F	F	F	F	F	F	F	F	F	F	F	F		
										G	G	G	G	G	G	G	G	G	G	

Year	1997	1991	1994	1999	1995	1990	1998	2007	1993	2000	2008	2002	1992	2004	2003	1996	2005	2001	2006	Mean
Spat	307	273	247	201	182	161	135	66	49	44	31	27	25	24	20	17	15	14	13	**97**
	A	A	A	A	A															
		B	B	B	B	B														
			C	C	C	C	C													
					D	D	D	D												
						E	E	E	E	E										
							F	F	F	F	F	F	F	F	F	F	F	F	F	

Table 11. Average 1-year growth increment for animals reaching market (3″) size, the average minimal size of animals reaching market size in one year, and age-to-market size for oysters from four bay regions, based on von Bertalanffy growth curves.

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. Estimated sex ratios listed as the fraction of the population that is functionally female ($\frac{F}{F+M}$), based on sex-ratio survey data from June 2008 applied to Fall 2008 size frequencies.

Bed Area	Oysters $<2.5''$	Oysters $>2.5''$	All Oysters
Bay Total	0.260	0.633	0.424
Very Low Mortality Beds	0.275	0.593	0.368
Low Mortality Beds	0.317	0.649	0.458
Medium Mortality Transplant Beds	0.237	0.643	0.389
Shell Rock	0.259	0.665	0.377
High Mortality Beds	0.250	0.628	0.446

Table 13. Surplus production as projected for 2007 and 2008 by SAW-9 and SAW-10 and as projected for 2009 for the oyster stock on the New Jersey natural oyster beds in Delaware Bay. Projections for 2009 were conducted using the 50^{th} and 75^{th} percentiles of natural mortality and a conversion of 262 oysters bu^{-1}. Also provided for 2009 is the fraction of the stock $\geq 2.5''$ equivalent to the surplus production estimate. Note that the fraction of the stock predicted to support expansion in marketable abundance in 2009 exceeds exploitation rates normally occurring in these bed regions, except for the high-mortality beds.

SAW-9 Surplus Production Estimate for 2007

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	125,691	123,193
Medium mortality	360,275	238,914
Shell Rock	31,146	18,161
High mortality	26,908	-10,949
Total	544,020	369,319

SAW-10 Surplus Production Estimate for 2008

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	171,218	165,422
Medium mortality	370,173	312,937
Shell Rock	104,795	97,688
High mortality	80,521	76,137
Total	726,707	652,184

Surplus Production Estimate for 2009

Bay Region	50^{th} Percentile Fraction $\geq 2.5''$	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Fraction $\geq 2.5''$	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	22.8	90,106	21.2	83,602
Medium mortality Transplant	28.7	90,152	22.8	71,655
Medium mortality Market	25.9	160,491	19.1	118,365
Shell Rock	36.9	70,668	31.7	60,694
High mortality	12.7	26,164	1.8	3,703
Total		437,581		338,019

Table 14. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Bay regions are defined in Figure 6. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

Year	Low Mortality	Medium Mortality Transplant	Medium Mortality Market	Shell Rock	High Mortality
1996	0.19	0.14	0.08	0.09	0.12
1997	0.20	0.26	0.73	0.92	3.06
1998	0.92	1.16	2.13	1.64	2.03
1999	0.59	2.00	2.17	4.04	4.54
2000	0.15	0.18	0.20	0.79	1.08
2001	0.05	0.04	0.09	0.22	0.44
2002	0.20	0.18	0.54	4.59	0.86
2003	0.05	0.13	0.17	0.38	1.28 (1.54)
2004	0.05	0.14	0.28	1.85	2.07
2005	0.31	0.19	0.20	0.46 (1.01)	0.54 (0.62)
2006	0.14	0.42	0.32	0.32 (0.64)	0.42 (1.00)
2007	0.18	0.71 (0.88)	1.63 (1.70)	1.53	2.54 (2.59)
2008	0.22	0.11	0.11 (0.13)	0.50	0.89 (1.50)

Table 15. Ratio of spat per bushel of cultch obtained by dredge and diver from the same shell plant sampled simultaneously (Dredge 1) or within thirty days (Dredge 2).

Location	Sampling Gear	No. Spat (bu clam cultch)$^{-1}$	Ratio Diver:Dredge
2005			
Bennies Sand 11	Average Dive	432	
	Dredge 1	721	0.60
	Dredge 2	770	0.56
Shell Rock 43A	Average Dive	281	
(Surf Clam)	Dredge 1	552	0.51
	Dredge 2	211	1.33
Shell Rock 43B	Average Dive	254	
(Quahog)	Dredge 1	434	0.59
	Dredge 2	266	0.95
2006			
Hawk's Nest 1	Average Dive	89	
	Dredge 1	171	0.52
	Dredge 2	370	0.24
Nantuxent 25	Average Dive	98	
	Dredge 1	201	0.49
	Dredge 2	132	0.74

Table 16. Summary of shell-planting activities for 2008. Shell-planting was carried out in late June-early July, 2008. Direct plants occurred on Nantuxent Point 17 and 68, and Bennies Sand 8 and 9. Replants occurred on Cohansey 64. Projections of marketable bushels assumed a 3-year time to market size and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality rate estimates used were the 50^{th} percentiles of the 1989-2008 time series: for Cohansey, 0.277, 0.162, 0.162; for the high-mortality beds: 0.601, 0.257. 0.257, for years 1, 2, and 3, respectively. Bushel conversions assume 262 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Projected Harvest
Bennies Sands	8	Surf clam mix*	50,587	12,011,230	237	8,689
Bennies Sands	9	Surf clam mix*	20,360	1,171,070	58	847
Cohansey	64	Surf clam replant	21,898	11,362,455	519	21,196
Nantuxent Point	17	Surf clam mix*	53,164	43,919,099	826	31,773
Nantuxent Point	68	Surf clam mix*	48,376	17,590,514	364	12,726
Total			194,385	86,054,368		75,231

*Surf clam mix = Ocean quahog and surf clam processed to small size

Table 17. Spat survival on shell planted in 2007 and projected harvest estimated from the 2008 re-survey of these grids. Shell-planting was carried out in late June-early July, 2007. Five 25-acre grids received direct plants: Ship John 22, 48, and 50, Nantuxent Point 28, and Middle 34. Three grids received replants of shell planted off Reeds Beach and moved upbay in late August: Middle 34, Cohansey 59, and Ship John 53. Ocean quahog shell and surf clam shell were used. Projections of marketable bushels assumed a 2-year time to market size at the adult rate. The mortality estimates used for years 2 and 3 were the 50^{th} percentiles of the 1989-2008 time series: for Middle, 0.108; for Shell Rock, 0.187; for the remainder: 0.257. Bushel conversions assume 262 oysters per bushel. One-year survivorship based on shell counts from 2007 reported by the 10^{th} SAW (HSRL, 2008).

Location		Type of Shell Planted	Bushels Planted	Yearlings Collected	Yearlings per Bu	Yearling Survival	Projected Harvest
Ship John	22	Quahog mix	39,032	998,365	26	9%	2,576
Ship John	48	Surf clam mix	53,229	2,823,090	48	42%	7,284
Ship John	50	Surf clam mix	43,967	1,203,130	27	21%	3,104
Nantuxent Point	28	Surf clam mix	43,360	772,852	18	19%	1,434
Middle	34	Surf clam mix	43,800	1,858,870	42	14%	5,562
Cohansey	59	Surf clam replant	19,881	791,206	40	17%	2,041
Ship John	53	Surf clam replant	26,414	1,493,020	57	15%	3,852
Total			275,683	9,940,533			25,853

*Quahog mix = dominantly ocean quahog with some surf clam processed to small size

*Surf clam mix = dominantly surf clam with some ocean quahog processed to small size

Table 18. Summary of 2008 recruitment on 2007 shell plants. Shell-planting was carried out in late June-early July, 2007. Details are in Table 17. Projections of marketable bushels assumed a 3-year time to market size and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality estimates used were the 50^{th} percentiles of the 1989-2008 time series: for Middle, 0.369, 0.108, 0.108; for Shell Rock, 0.461, 0.187, 0.187; for the remainder: 0.601, 0.257, 0.257 for years 1, 2, and 3, respectively. Bushel conversions assume 262 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat per Clam Bu	Clam Shell Projected Harvest
Ship John	22	Quahog mix	39,032	0	0	0
Ship John	48	Surf clam mix	59,229	1,249,140	22	2,330
Ship John	50	Surf clam mix	43,967	18,918,837	430	35,292
Nantuxent Point	28	Surf clam mix	43,360	682,435	16	494
Middle	34	Surf clam mix	43,800	17,243,430	394	32,559
Cohansey	59	Surf clam replant	19,881	517,642	26	966
Ship John	53	Surf clam replant	26,414	679,355	26	1,267
Total			275,683	39,290,839	143	72,908

*Quahog mix = dominantly ocean quahog with some surf clam processed to small size

*Surf clam mix = dominantly surf clam with some ocean quahog processed to small size

Table 19. Average half lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2008 time period.

Location	Half-life (yr)
Hope Creek	insufficient data
Fishing Creek	insufficient data
Liston Range	insufficient data
Round Island	21.95
Upper Arnolds	5.49
Arnolds	3.70
Upper Middle	insufficient data
Middle	7.02
Cohansey	4.88
Ship John	2.09
Sea Breeze	21.29
Shell Rock	4.49
Bennies Sand	3.84
Bennies	3.34
Nantuxent Point	2.75
Hog Shoal	2.78
Hawk's Nest	4.44
Strawberry	4.29
New Beds	65.71
Beadons	5.28
Vexton	6.00
Egg Island	insufficient data
Ledge	6.91

Table 20. The one-year transition probabilities for the broodstock-recruitment diagram shown as Figure 35 for each quadrant in the 56-year time series and mean first passage times. The 1989-2008 first passage times are also based on the 56-yr medians. The medians are: abundance = 2.96×10^9, recruitment = 1.80×10^9. Quadrant definitions are in Figure 36. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.65	0.06	0.12	0.18
2→	0.43	0.29	0.14	0.14
3→	0.11	0.33	0.33	0.22
4→	0.11	0.16	0.16	0.58

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	2.81	7.42	7.57	5.58
2→	3.56	5.71	7.35	5.82
3→	5.16	4.74	5.85	5.34
4→	5.65	6.01	7.02	3.35

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.355	0.175	0.171	0.299

Mean First Passage Time (years): 1989-2008

Quadrant	1	2	3	4
1→	1.75	9.00	7.50	11.00
2→	3.00	6.00	5.25	14.00
3→	3.00	6.00	5.25	14.00
4→	3.00	4.00	7.00	14.00

Table 21. The one-year transition probabilities for the broodstock-mortality diagram shown as Figure 37 for each quadrant in the 56-year time series and the mean first passage times. The 1989-2008 first passage times are also based on the 56-yr medians. The medians are: abundance = 2.96×10^9, mortality fraction= 0.13. Quadrant definitions are in Figure 36. Arrows indicate trajectory direction. Un-est, insufficient occurrences to calculate first passage times.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.17	0.42	0.17	0.25
2→	0.36	0.36	0.00	0.29
3→	0.07	0.07	0.67	0.20
4→	0.23	0.31	0.23	0.23

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.81	3.77	8.19	4.00
2→	3.66	3.59	9.46	3.78
3→	6.57	6.36	3.68	4.56
4→	4.74	4.34	7.54	4.14

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.21	0.28	0.27	0.24

Mean First Passage Time (years): 1989-2007

Quadrant	1	2	3	4
1→	4.25	1.86	Un-est	2.57
2→	3.00	2.13	Un-est	3.14
3→	4.00	1.00	Un-est	4.14
4→	3.50	1.71	Un-est	3.40

Table 22. The one-year transition probabilities for the recruitment-mortality diagram shown as Figure 39 for each quadrant in the 56-year time series and the mean first passage times. The 1989-2008 first passage times are also based on the 56-yr medians. The medians are: recruitment = 1.80×10^9, mortality fraction = 0.13. Quadrant definitions are in Figure 36. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.14	0.50	0.14	0.21
2→	0.31	0.39	0.08	0.23
3→	0.21	0.00	0.64	0.14
4→	0.29	0.14	0.14	0.43

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.18	3.72	8.39	4.93
2→	3.55	3.95	8.88	4.81
3→	4.28	7.19	3.96	5.76
4→	3.71	5.41	8.16	3.92

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.24	0.25	0.25	0.26

Mean First Passage Time (years): 1989-2008

Quadrant	1	2	3	4
1→	4.48	2.73	18.25	4.33
2→	3.38	2.33	21.63	5.22
3→	4.13	4.82	22.38	1.00
4→	3.13	3.82	21.38	3.32

Table 23. Harvest statistics for 2008. Fraction covered indicates the fraction of bed area swept by industry dredges during the fishing season. Fractions above 1 indicate a total swept area greater than the bed area.

Oyster Bed	Bed Area (m^2)	Fraction Covered	Bushels Harvested	Percent of Harvest
Hope Creek	2,970,947	0	0	0
Fishing Creek	1,273,459	0	0	0
Liston Range	1,167,525	0	0	0
Round Island	1,910,960	0	0	0
Upper Arnolds	1,911,274	0	0	0
Arnolds	2,548,739	0	0	0
Upper Middle	956,159	0	0	0
Middle	3,719,585	0.29	1,120	1.25
Cohansey	5,314,243	0.30	2,611	2.90
Sea Breeze	2,338,640	0.05	170	0.19
Ship John	4,677,614	2.58	21,469	23.89
Shell Rock	5,104,046	2.99	29,736	33.08
Bennies Sand	2,977,796	2.61	14,806	16.47
Bennies	8,404,238	0.49	7,192	8.00
Nantuxent Point	2,765,542	1.68	4,637	5.16
New Beds	4,788,189	1.32	6,956	7.74
Hawk's Nest	2,021,560	0.16	116	0.13
Hog Shoal	1,808,455	0.92	1,069	1.19
Strawberry	1,808,668	0	0	0
Beadons	2,447,474	0	0	0
Vexton	2,022,090	0	0	0
Egg Island	4,045,293	0	0	0
Ledge	1,916,423	0	0	0
Total or Mean	64,765,314	0.80	89,882	100.00

Table 24. Statistics for oysters going to market, obtained from dock-side monitoring of landings. Sizes are given in inches. Percentiles refer to the percentile sizes of the size-frequency distribution.

	Mean size	25^{th} percentile	50^{th} percentile	75^{th} percentile	Mean Number per bushel	Number $\geq 2.5''$ 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

Table 25. Area-specific stock-performance biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 (1990-2005 for biomass) time period. The threshold is taken as half these values.

	Low Mortality Beds	Medium Transplant Mortality Beds	Medium Market Mortality Beds	Shell Rock	High Mortality Beds
Abundance					
Target (50^{th} Percentile)	531,733,632	278,444,928	864,934,144	113,350,896	473,125,088
Threshold (1/2 Target)	265,866,816	139,222,464	432,467,072	56,675,448	236,562,544
Spawning Stock Biomass					
Target (50^{th} Percentile)	175,499,360	106,646,608	392,472,896	62,450,392	267,982,768
Threshold (1/2 Target)	87,749,680	53,323,304	196,236,448	31,225,196	133,991,384

Table 26. Stable-point surplus-production-based reference points derived from the modeling of process rates governing the rates of recruitment, unrecorded mortality, and box-count mortality relative to abundance. Numbers are in billions.

Reference Point Type	10% Lower Recruitment[1]	Low Recruitment[2]	High Recruitment[3]	Low Juvenile Mortality[4]	Low Dermo Mortality[5]
Carrying capacity K, high-abundance state			7.8392	9.1658	8.0201
N_{msy}, high-abundance state			5.3668	5.5477	5.0653
Point-of-no-return	3.4975				
Surplus-production low	3.1357	3.0754	3.3769	3.2563	3.2563
Carrying capacity K, low-abundance state	2.7739				
N_{msy}, low-abundance state	1.5678	1.6281	1.6281	1.7487	1.9899

[1]Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 35), predicted recruitment from each reduced by 5%, plotted adult mortality rate (Figure 37), median unrecorded mortality rate.

[2]Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 35), plotted adult mortality rate (Figure 37), median unrecorded mortality rate.

[3]Ricker recruitment curve (Figure 35), plotted adult mortality rate (Figure 37), median unrecorded mortality rate.

[4]Ricker recruitment curve (Figure 35), plotted adult mortality rate (Figure 37), mean unrecorded mortality rate.

[5]Ricker recruitment curve (Figure 35), average of background (10%) and plotted adult mortality rate (Figure 37), median unrecorded mortality rate.

Table 27. Confidence percentiles for the 2008-survey abundance point estimate with rank order based on the number of small market and large market animals. Values exclude the very-low-mortality beds.

Percentile	Oysters <2.5″	Oysters 2.5-<2.95″	Oysters >2.95″	Total Oysters
10.	647,846,400	157,311,904	183,480,544	988,638,848
20.	634,223,552	157,106,960	207,142,448	998,472,960
30.	687,657,920	185,562,544	198,335,776	1,071,556,240
40.	790,175,616	172,591,360	225,897,712	1,188,664,688
50.	737,065,728	176,375,568	237,361,616	1,150,802,912
60.	721,788,800	178,745,904	250,194,752	1,150,729,456
70.	875,066,624	210,875,040	235,188,544	1,321,130,208
80.	817,839,808	208,423,808	258,386,368	1,284,649,984
90.	826,984,576	216,367,952	286,569,984	1,329,922,512

Table 28. Confidence percentiles for the 2008-survey abundance point estimate with rank order based on the total number of animals. Values exclude the very-low-mortality beds.

Percentile	Oysters <2.5″	Oysters 2.5-<2.95″	Oysters >2.95″	Total Oysters
10.	661,678,272	138,899,584	197,564,048	998,141,904
20.	738,358,912	138,722,592	190,838,128	1,067,919,632
30.	682,592,576	174,091,216	254,919,216	1,111,603,008
40.	725,534,336	180,514,368	241,186,048	1,147,234,752
50.	780,633,920	159,228,144	242,774,592	1,182,636,656
60.	772,370,816	192,692,048	259,646,192	1,224,709,056
70.	781,171,968	205,114,912	285,477,408	1,271,764,288
80.	838,934,528	189,210,192	287,746,368	1,315,891,088
90.	954,338,176	216,395,584	220,308,048	1,391,041,808

Table 29. Percentiles of the real and apparent exploitation rates for oysters ≥2.5″ based on the fishing record for 1996-2006. The SARC recommends using the real exploitation rates for setting harvest provisions.

Percentile	Shell Rock Real		Shell Rock Apparent		High Mortality Beds Real		High Mortality Beds Apparent	
0.10	1997	0.0441	1997	0.0441	2003	-0.0999	2002	0.0690
0.25	2005	0.0531	2000	0.0880	1999	0.0095	2004	0.0927
0.40	2003	0.0870	2005	0.0912	2002	0.0122	2005	0.1048
0.50	2000	0.0880	2006	0.1029	2000	0.0652	1999	0.1053
0.60	1998	0.1140	1998	0.1140	1998	0.0782	1997	0.1282
0.75	1999	0.1586	1999	0.1859	2006	0.0827	2000	0.1421
0.90	2001	0.2362	2001	0.2362	2005	0.1048	2001	0.2040

Table 30. Percentiles of the real exploitation rates for all oysters and for one bay region for oysters ≥2.5″ based on the fishing record for 1996-2006. The medium-mortality transplant bed group is Middle and Upper Middle. The medium-mortality market bed group is Cohansey, Ship John, and Sea Breeze. The all-oyster upper medium-mortality percentiles are also used for the low-mortality beds: Arnolds, Upper Arnolds, and Round Island.

Percentile	All Oysters Medium Mortality		All Oysters Medium Mortality Transplant		All Oysters Medium Mortality Market		Oysters ≥2.5″ Medium Mortality Market	
0.10	2001	0.0066	1998	0.0000	1997	0.0000	1997	0.0001
0.25	1997	0.0078	1999	0.0102	2001	0.0059	2001	0.0154
0.40	2002	0.0081	2001	0.0103	2000	0.0065	2000	0.0178
0.50	1999	0.0162	2005	0.0127	2002	0.0090	2002	0.0214
0.60	2000	0.0162	2006	0.0233	2003	0.0148	2003	0.0267
0.75	1998	0.0223	2004	0.0570	2006	0.0190	1999	0.0328
0.90	2003	0.0245	2003	0.0799	2004	0.0242	1998	0.0358

Table 31. Allocation projections for direct marketing for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze), based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index. An upper and lower bound are taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest), with on exception. Projections use the average numbers per marketed bushel of 262 derived from the 2004-2008 dock-side monitoring program. Arrows indicate recommended options

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	652,789	2,492
	$^{\Gamma}50^{th}$	.0652	3,488,680	13,316
	$^{\Gamma}60^{th}$	.0782	4,184,270	15,971
Shell Rock	$\longrightarrow 40^{th}$	.0870	4,370,520	16,681
	$\longrightarrow 50^{th}$	.0880	4,420,750	16,873
	$\longrightarrow 60^{th}$	.1140	5,726,890	21,858
Medium Mortality Market	$\longrightarrow 40^{th}$	.0178	2,872,190	10,963
	$\longrightarrow 50^{th}$	.0214	3,453,080	13,180
	$\longrightarrow 60^{th}$	.0267	4,308,280	16,444
	$\longrightarrow 100^{th}$	.0398	6,456,990	24,634
Shell Rock	10^{th}	.0441	7,154,696	27,308
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

$^{\Gamma}$Requires intermediate transplant before marketing can occur. The SARC recommends taht at least the transplant from the medium-mortality transplant beds occur prior to implementing this level of exploitation.

Table 32. Projections for intermediate transplant assuming that intermediate transplant will be conducted on the upper medium-mortality beds (Middle, Upper Middle) and that direct-marketing will be conducted on beds downbay of these two beds. Numbers to be moved by intermediate transplant 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 by dry 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 beds obtained from the 2008 intermediate transplant program. Cullers were used for this transplant; thus, the indicated number of bushels to be moved are likely minimal values. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.5''$ and these animals are converted to bushels using the 262 animal/bu conversion. Percentiles for the very-low-mortality and low-mortality beds use the exploitation reference points for the medium-mortality transplant beds. Arrows indicate preferred alternatives.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Medium Mortality Market						NA§
Medium Mortality Transplant	$\longrightarrow 40^{th}$	.0127	2,570,560	312	8,239	3,993
	$\longrightarrow 50^{th}$	.0188	3,805,240	312	12,196	5,911
	$\longrightarrow 60^{th}$	.0233	4,716,070	312	15,115	7,326
Low Mortality	$\longrightarrow 40^{th}$	.0127	3,122,220	428	7,295	5,017
	$\longrightarrow 50^{th}$	.0188	4,621,870	428	10,798	7,427
	60^{th}	.0233	5,728,160	428	13,384	9,204
Very Low Mortality	$\longrightarrow 40^{th}$	.0127	5,032,780	428	11,759	5,609
	50^{th}	.0188	7,450,110	428	17,407	8,303
	60^{th}	.0233	9,233,380	428	21,573	10,291

§NA: not applicable to this reference point.

Table 1. 2008 sampling scheme for the November survey of the Delaware Bay oyster beds. The numbers given are the number of samples devoted to that bed stratum. Arrows indicate beds with the new configuration of strata based on the 2005, 2006, 2007, and 2008 re-surveys. For Ledge, the pre-2005 sampling scheme was used. Egg Island was not sampled.

Sampled Bed	High-quality	Medium-quality	Low-quality	Transplant
→ Hope Creek	4	4	0	0
→ Fishing Creek	2	3	0	0
→ Liston Range	2	4	0	0
→ Round Island	2	3	0	0
→ Upper Arnolds	2	3	0	0
→ Arnolds	3	3	0	0
→ Upper Middle	1	3	0	0
→ Cohansey	3	3	0	3
→ Ship John	3	3	0	4
→ Middle	2	3	0	1
→ Sea Breeze	3	2	0	0
→ Shell Rock	4	4	0	3
→ Bennies Sand	2	3	0	6
→ Bennies	3	9	0	0
→ New Beds	2	7	0	0
→ Nantuxent Point	3	3	0	4
→ Hog Shoal	3	3	0	0
→ Strawberry	1	3	0	0
→ Vexton	2	3	0	0
→ Beadons	3	4	0	0
→ Hawk's Nest	2	3	0	1
Egg Island	0	0	0	0
Ledge	1	4	0	0
Total	53	80	0	22

Grand Total: 155

Figure 1. The footprint of the Delaware Bay natural oyster beds showing the locations of the high-quality (dark shade) and medium-quality (light shade) grids. Each grid is a rectangle 0.2″ latitude × 0.2″ longitude, equivalent to approximately 25 acres. The 2008 random sampling sites are indicated by white stars. Ledge and Egg Island beds have not been re-surveyed. For the remaining beds, the depicted footprint is based on re-surveys that occurred in 2005-2008.

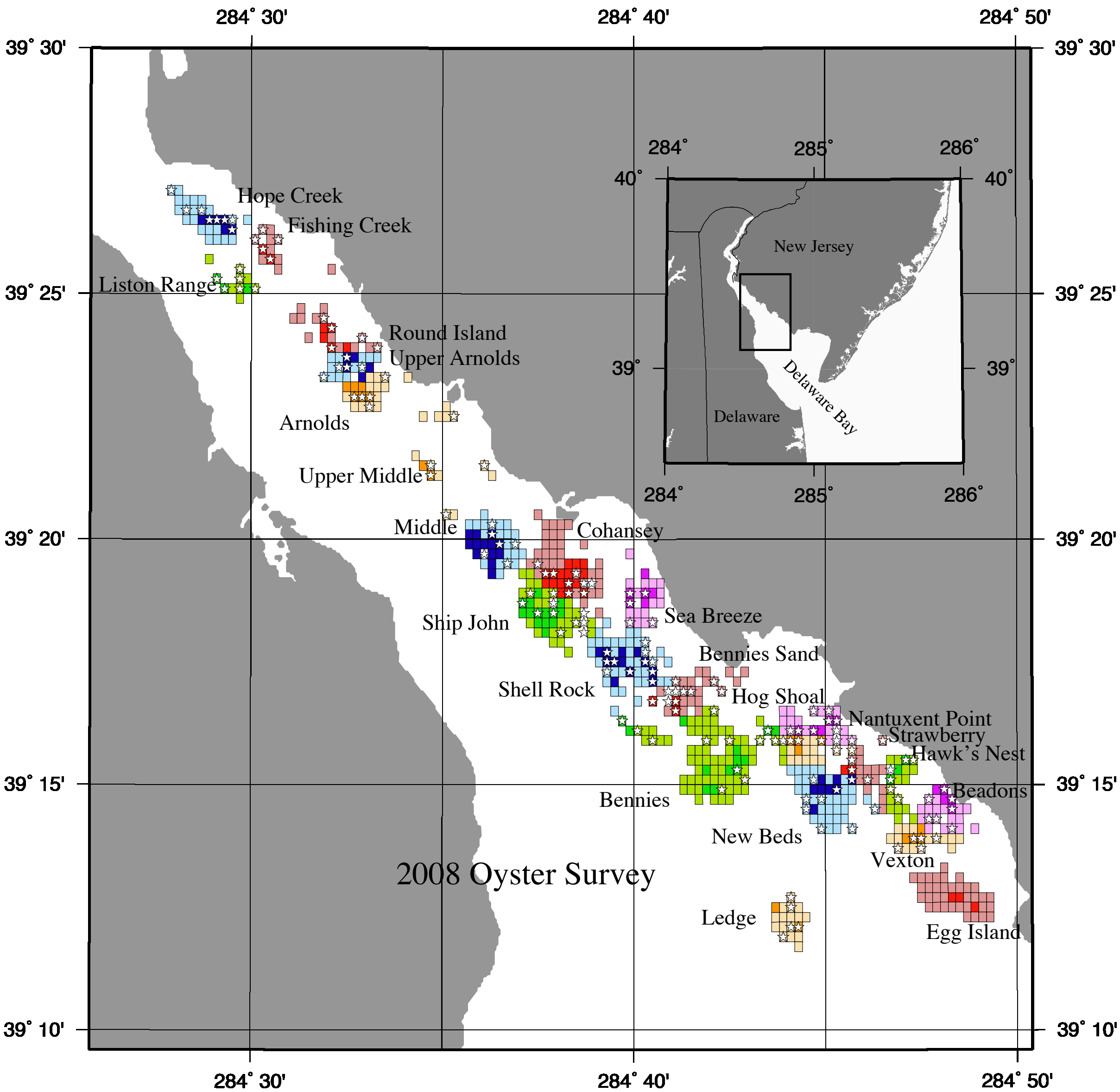


Figure 2. Distribution of grids in the Hope Creek area during the 2008 re-survey, shaded accordingly to oyster density. The 2008 survey program covered all navigable grids upbay of Round Island. High-quality grids are shaded darkly, while medium-quality grids are lightly shaded. Low-quality grids are white.

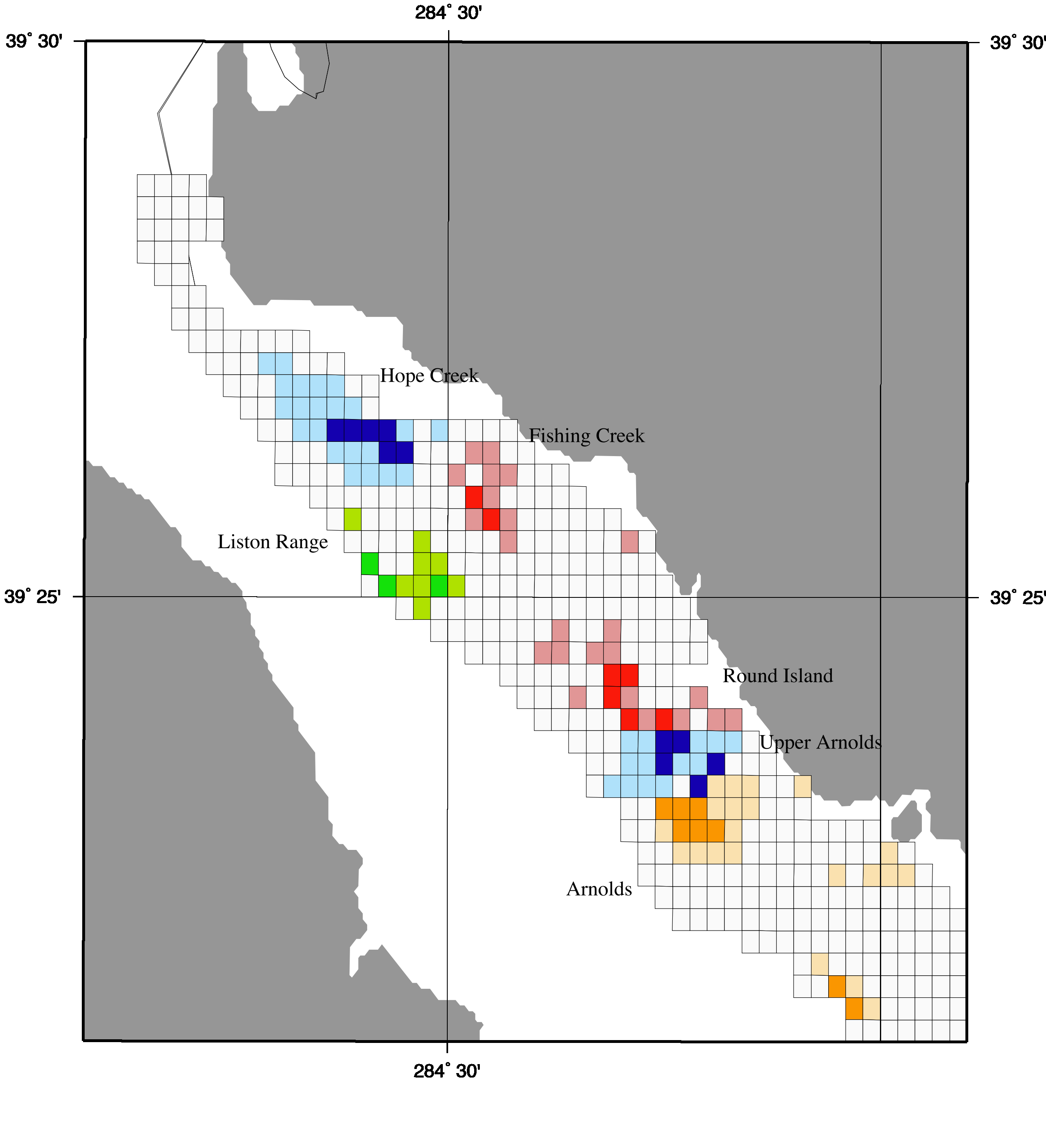


Figure 3. Shell Rock bed, showing grids that changed from high quality to medium quality and from medium quality to high quality between 2005 and 2008.

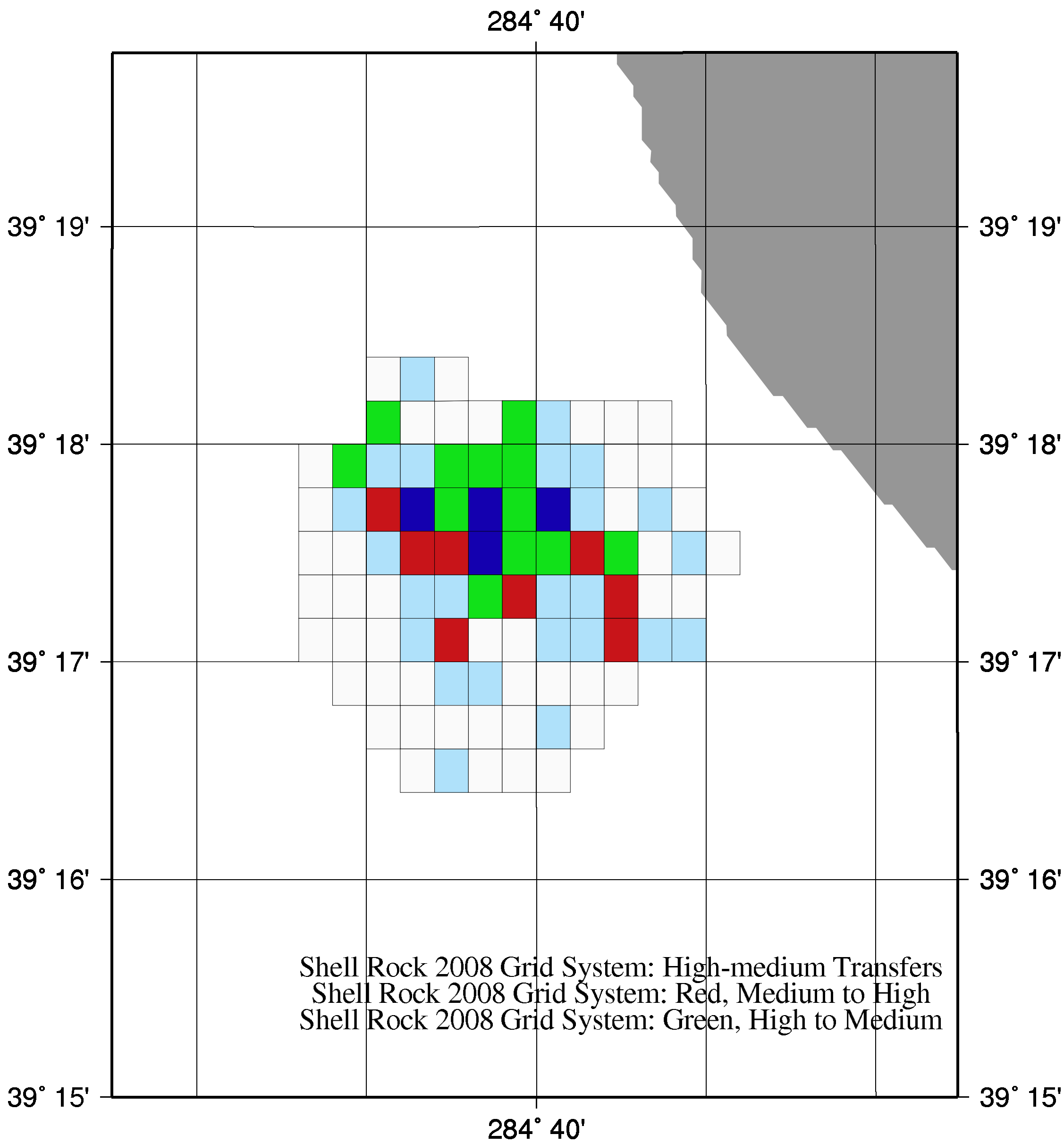


Figure 4. Shell Rock bed, showing grids that changed from medium quality to low quality and from low quality to medium quality between 2005 and 2008.

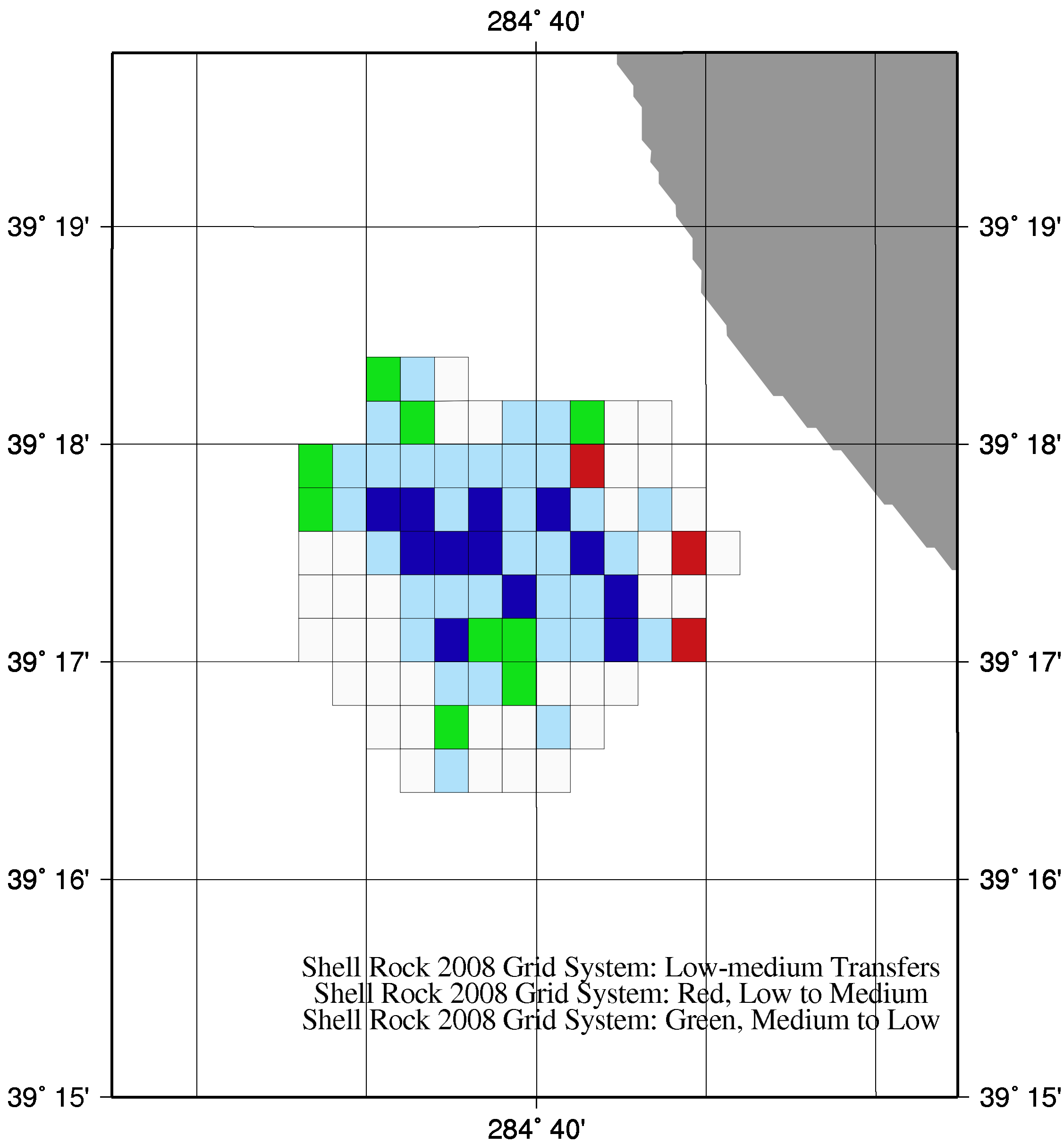


Figure 5. Example size-frequency distributions for spat recruiting in 2008 to shell planted in 2008 on Bennies Sand, Cohansey, and Nantuxent Point.

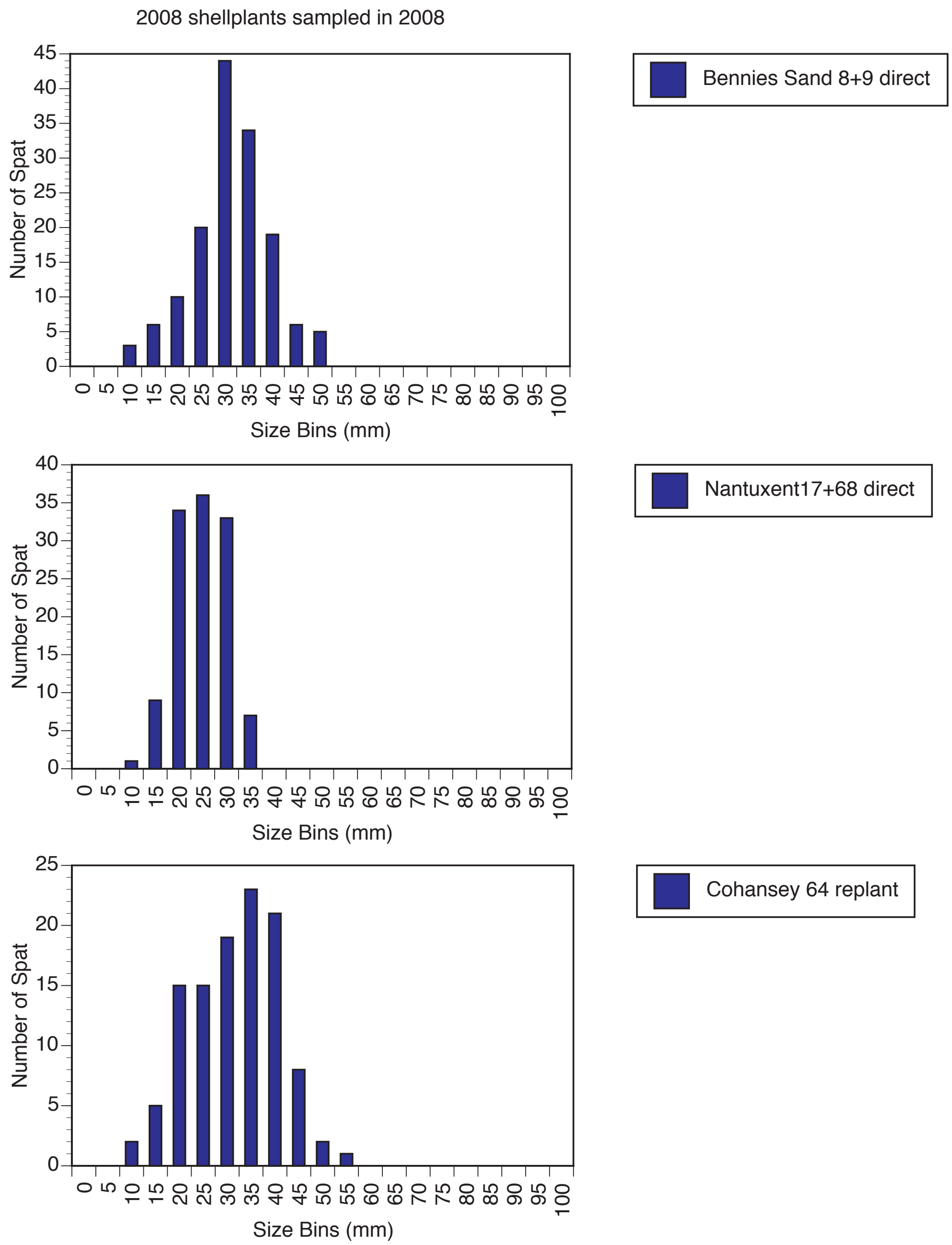


Figure 6. Time series of oyster abundance by bay region. High mortality: Beadons, Nantuxent Point, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Egg Island, Ledge, Bennies, Bennies Sand; medium mortality market (less Shell Rock): Ship John, Cohansey, Sea Breeze; medium mortality transplant: Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island; very-low mortality: Hope Creek, Fishing Creek, Liston Range. No data are available for the very-low-mortality beds prior to 2007.

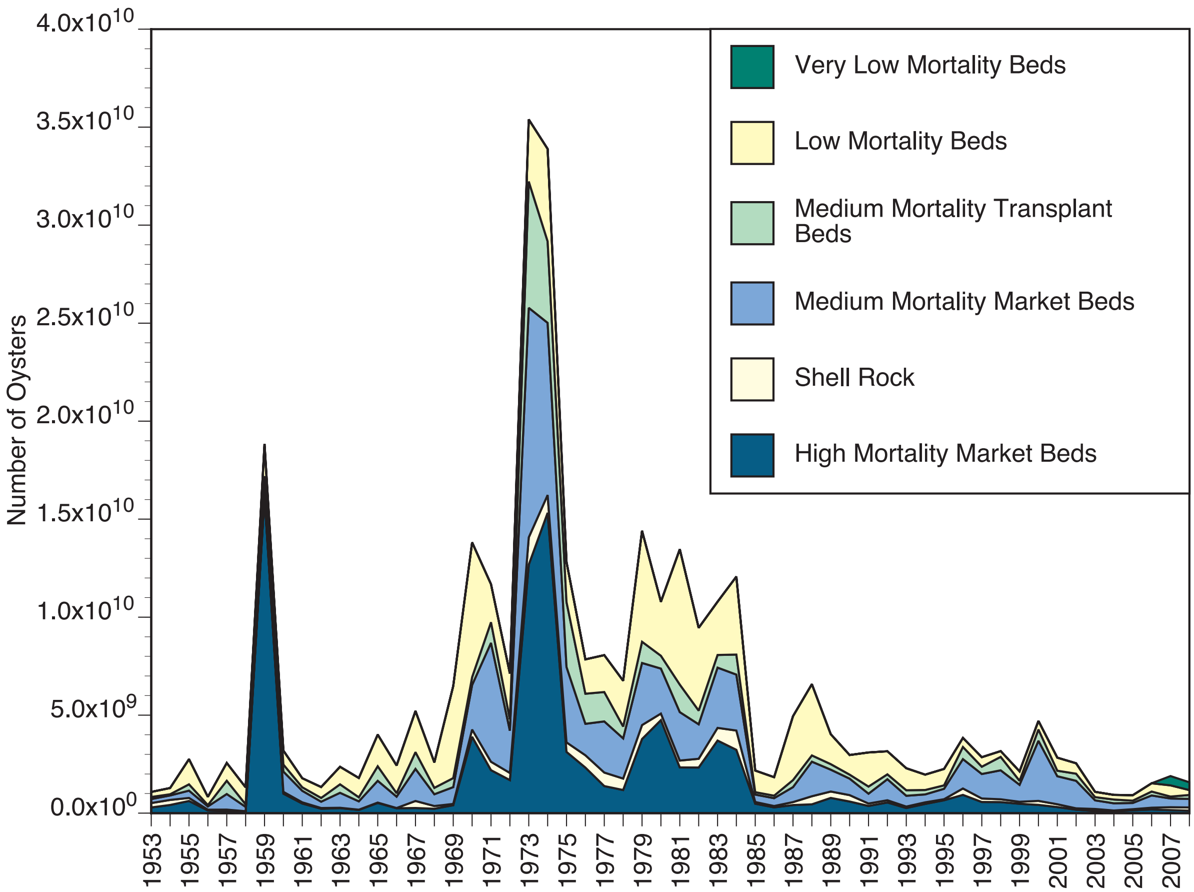


Figure 7. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2008. Bed regions are defined in Figure 6. No data are available for the very-low-mortality beds prior to 2007.

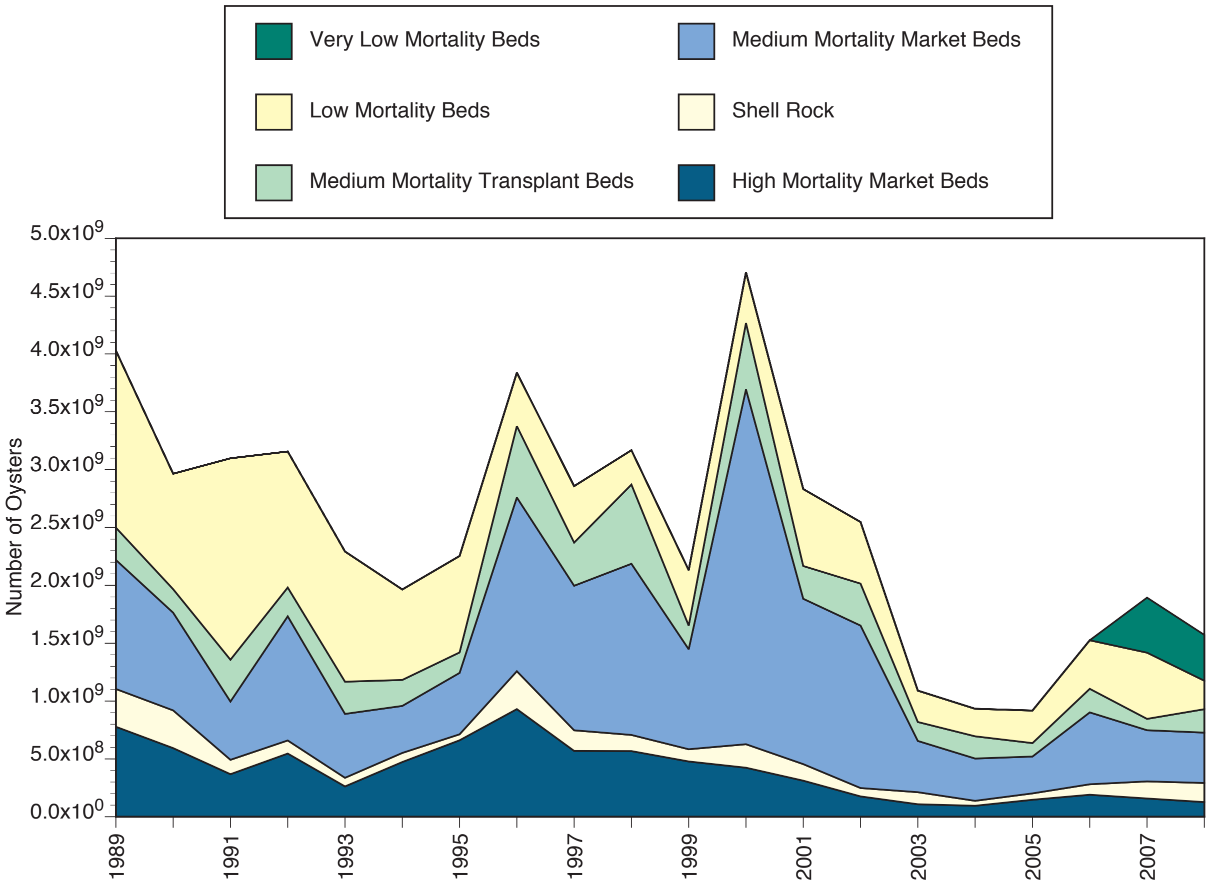


Figure 8. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 6.

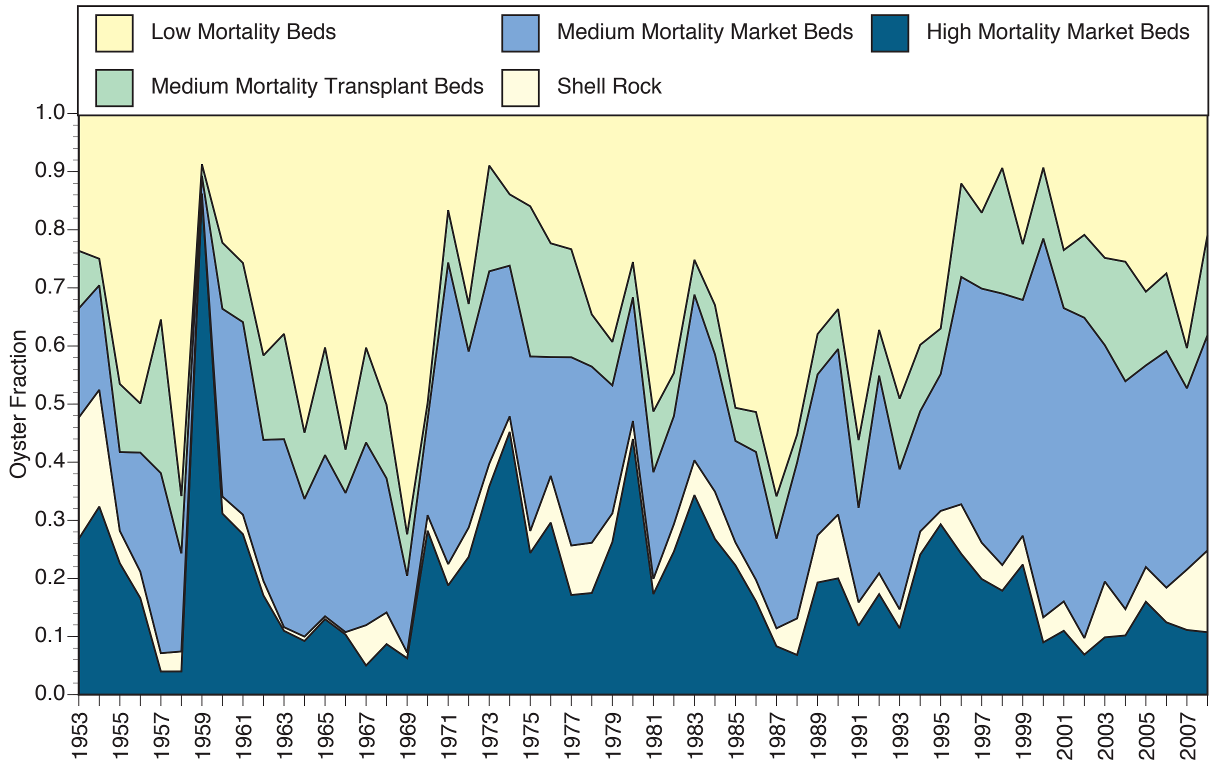


Figure 9. Fraction of animals on the medium-mortality beds, 1953-2008. The horizontal value identifies the median value of 0.382.

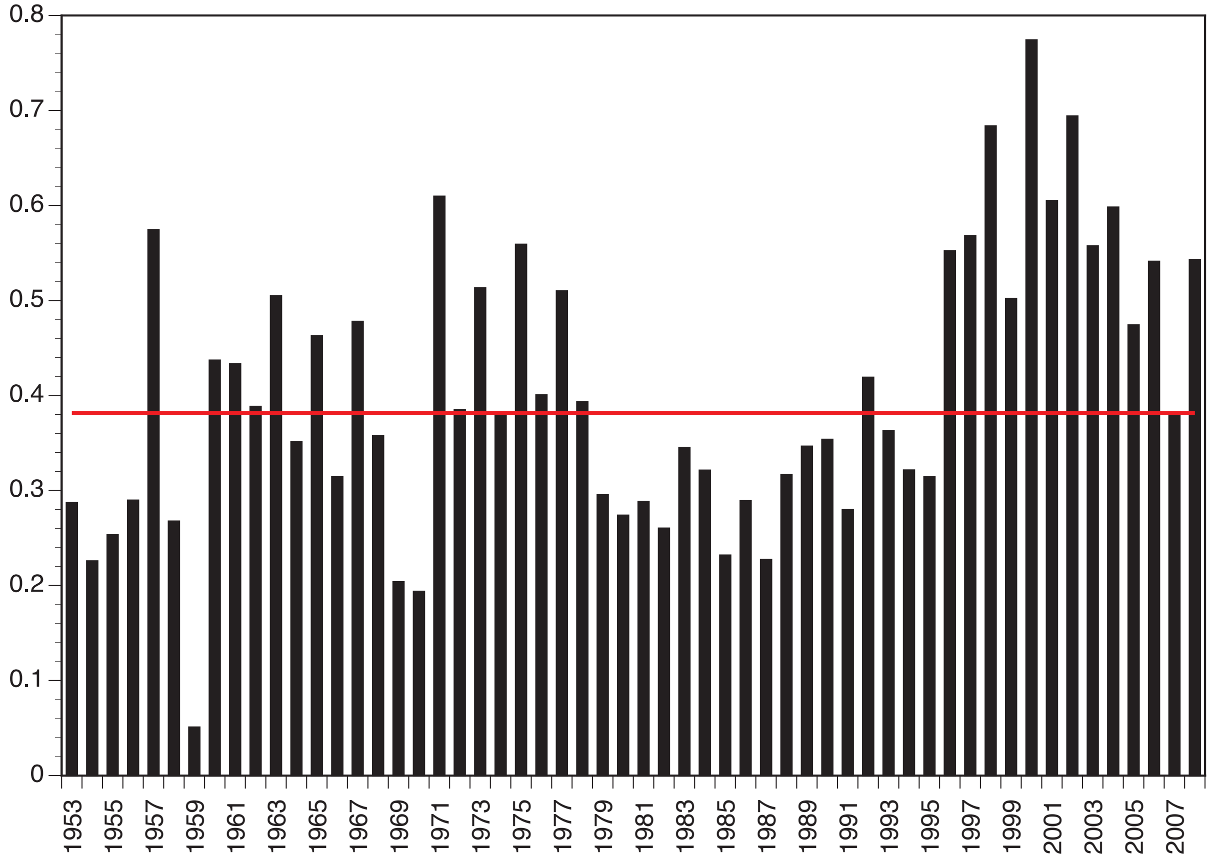


Figure 10. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 6. No data are available for the very-low-mortality beds prior to 2007.

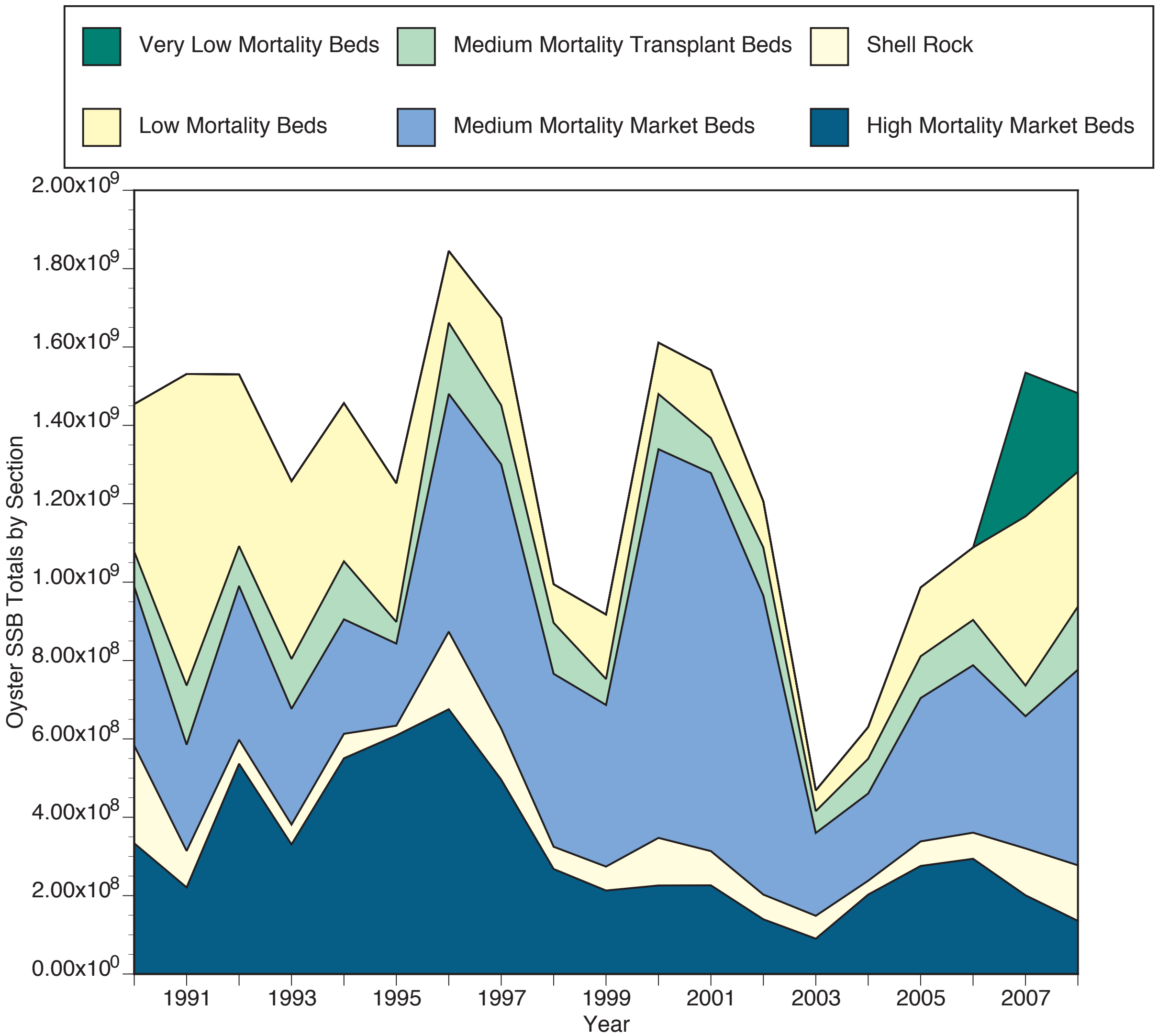


Figure 11. Time series of the fractional distribution of spawning stock biomass among the bay regions. Bed distributions by region are given in Figure 6.

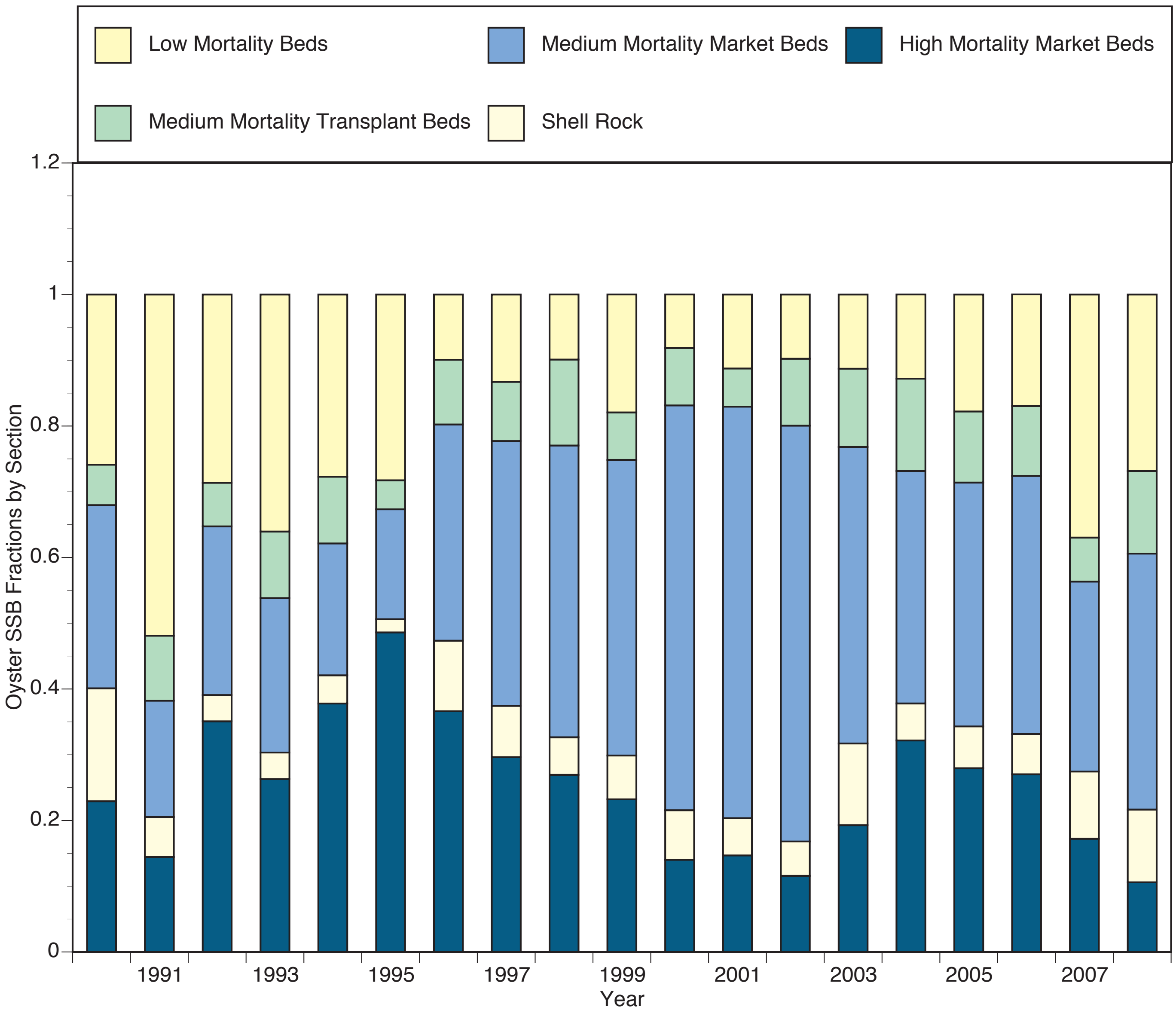


Figure 12. The abundance of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

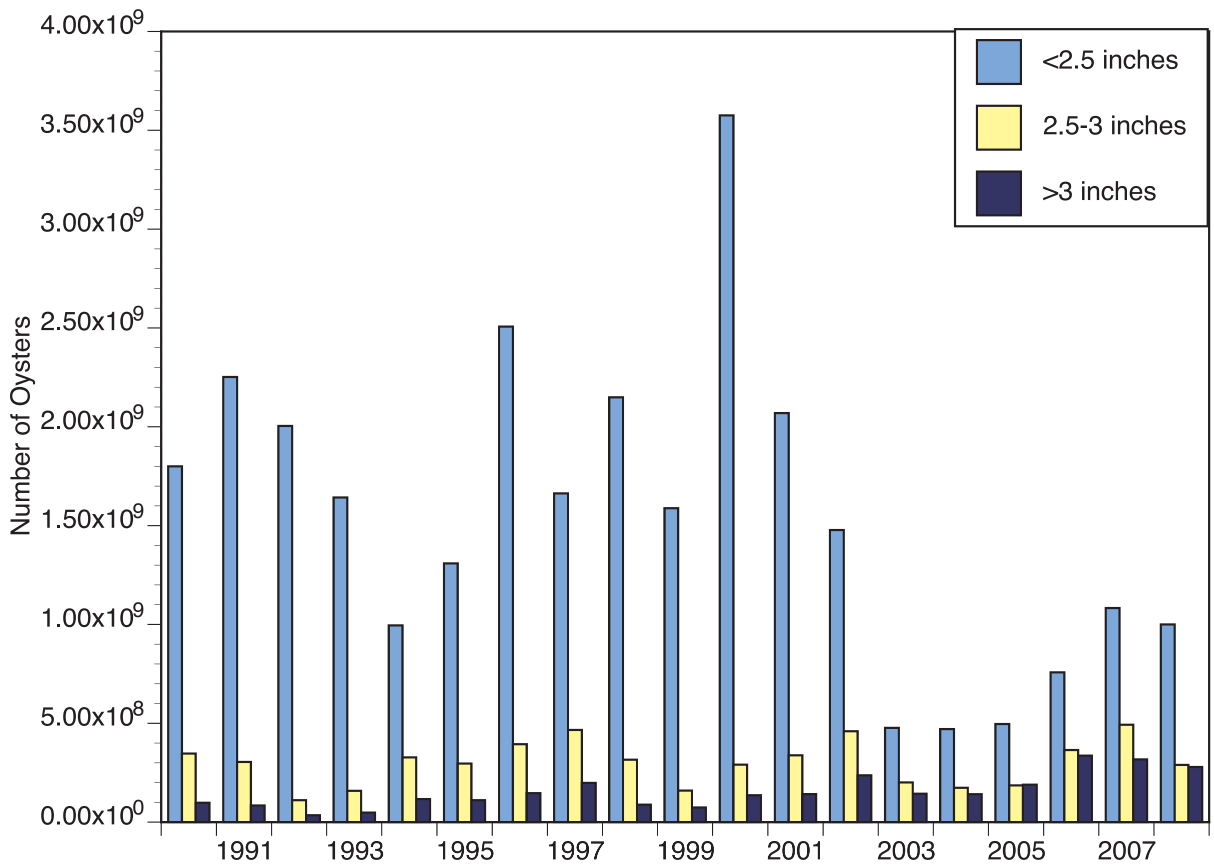


Figure 13. The fraction of small, small market, and large market-size animals since 1990.

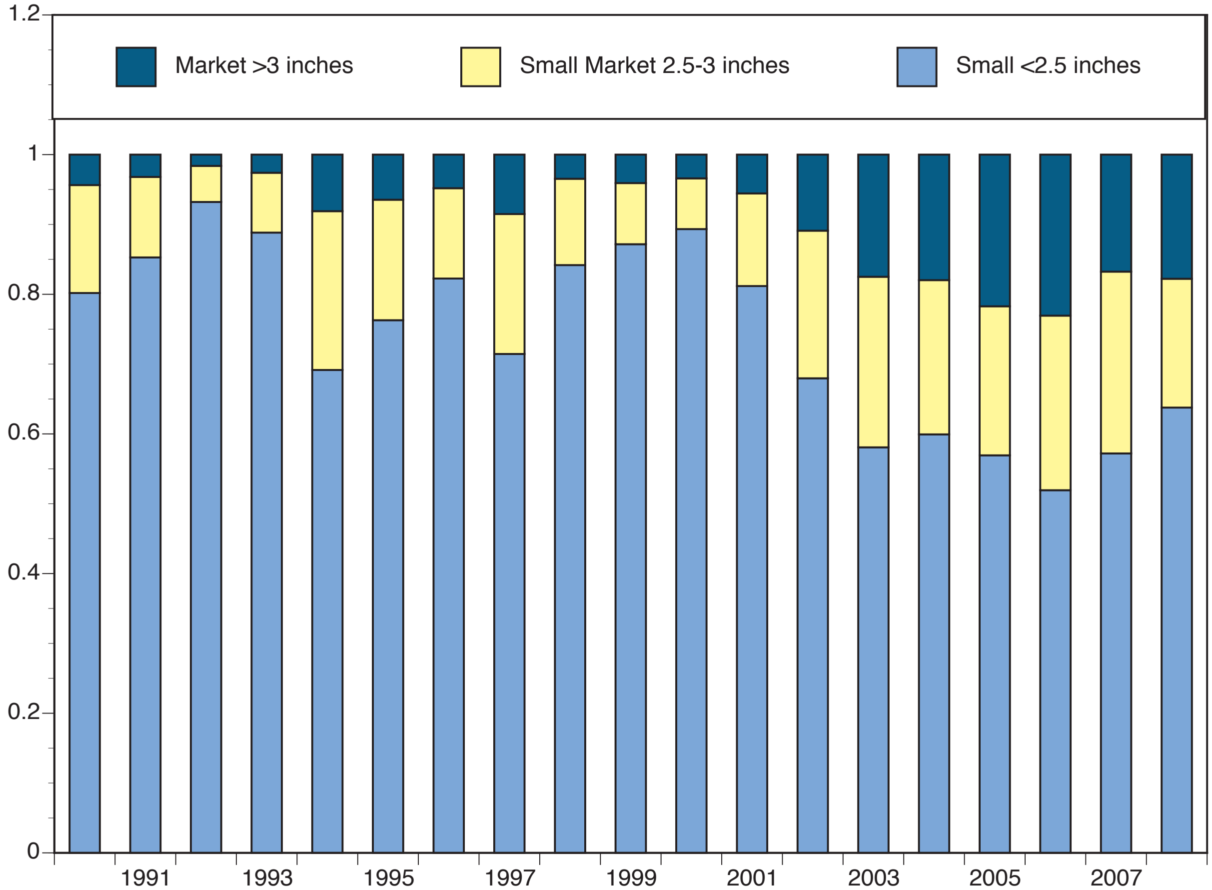


Figure 14. The abundance of small, small market, and large market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 6. Note variation in y-axis scale between graphs.

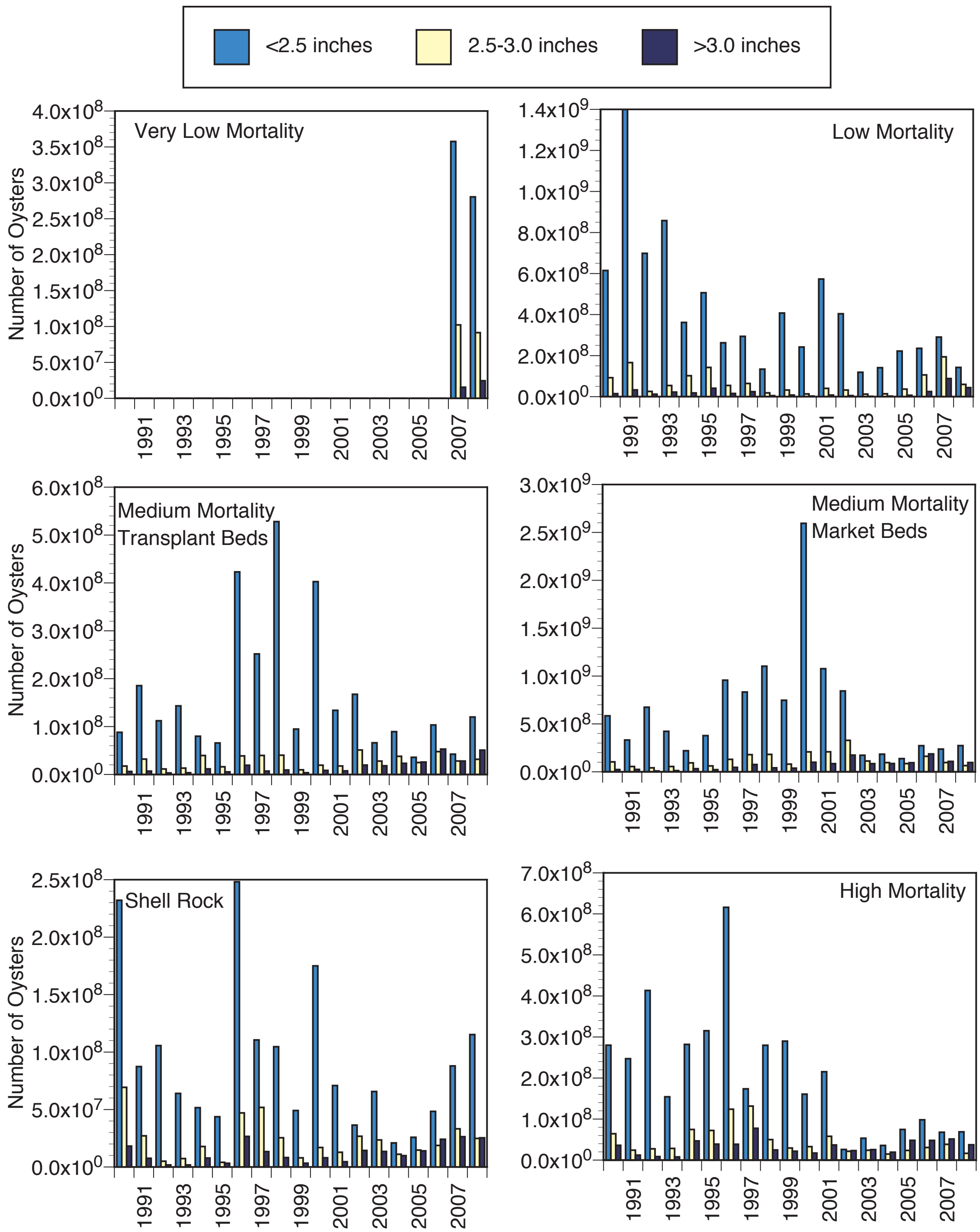


Figure 15. The fraction of marketable animals $\geq 2.5''$ that were $\geq 2.5''$-$<3''$ and $\geq 3''$, excluding the very-low-mortality beds.

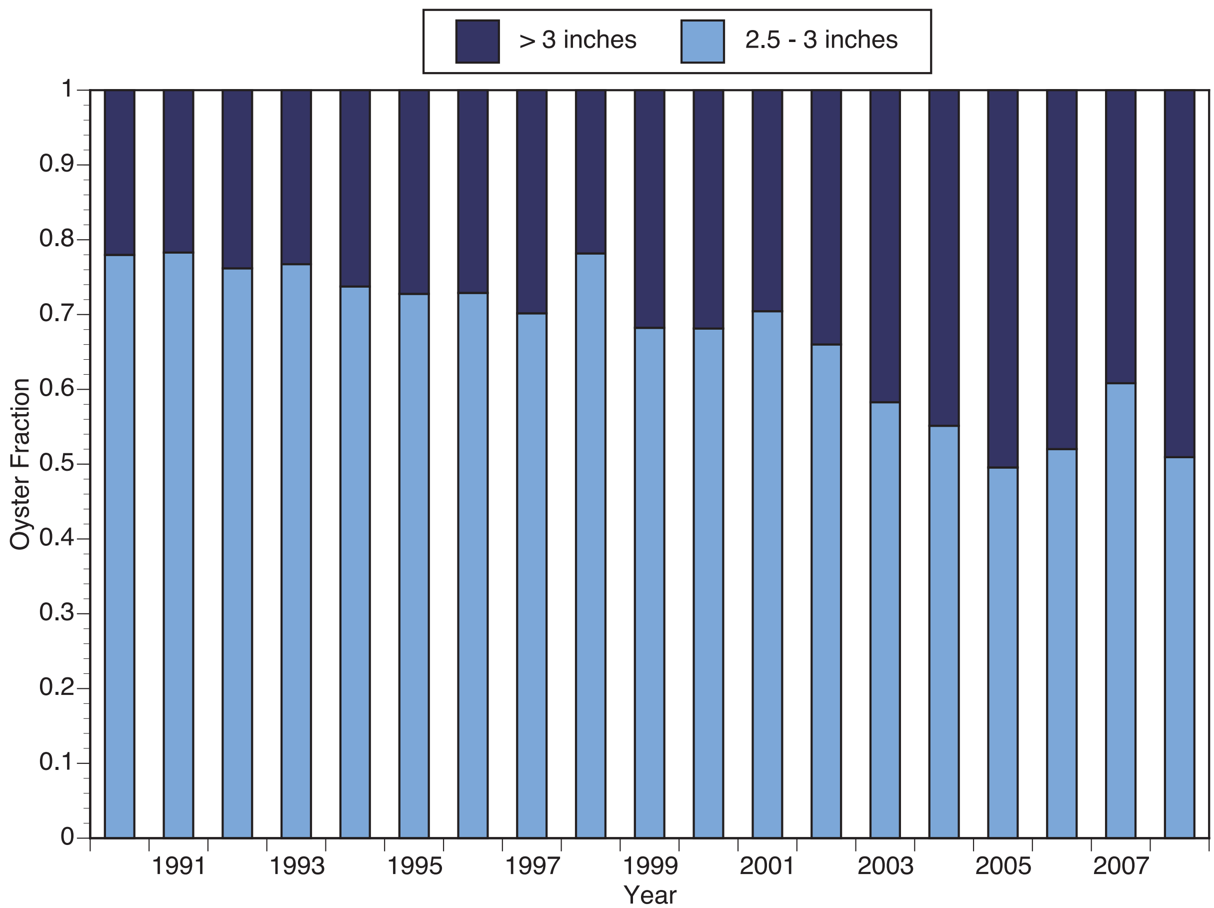


Figure 16. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)], excluding the very-low-mortality beds.

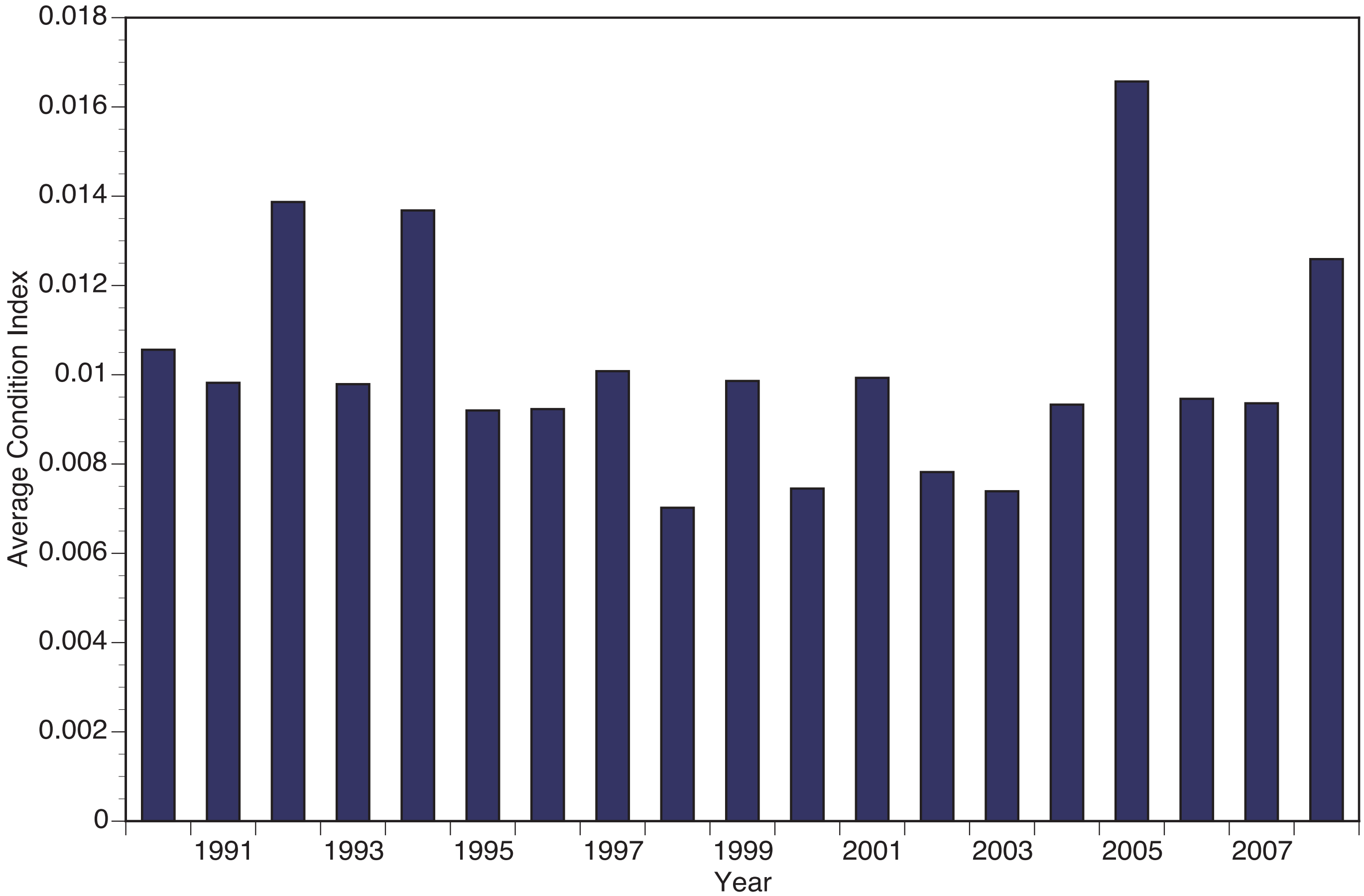


Figure 17. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)] by bay group. Bed distributions by region are given in Figure 6.

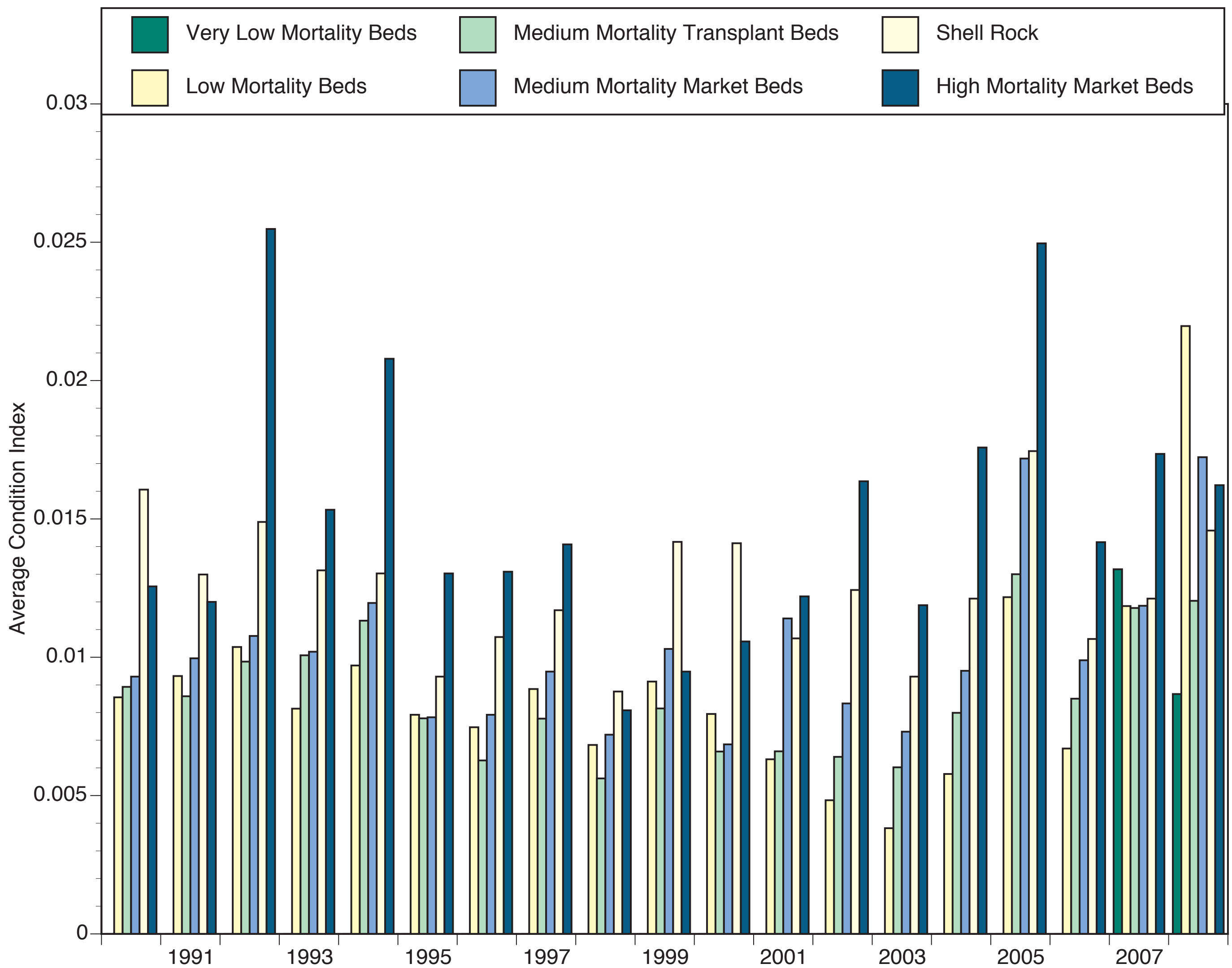


Figure 18. Number of spat recruiting per year for the 1953-2008 time series, cumulatively by bay region. Bay regions are defined in Figure 6.No data are available for the very-low-mortality beds prior to 2007.

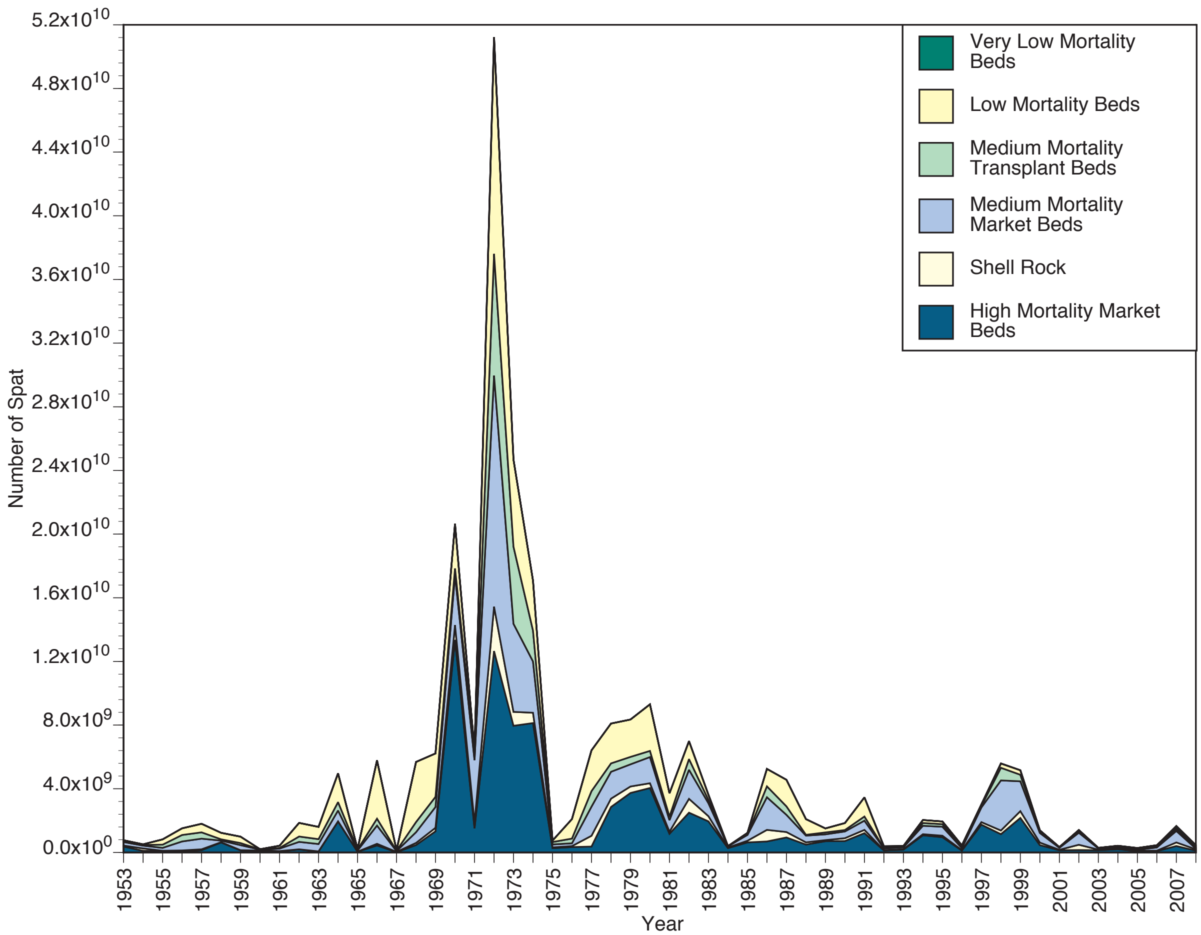


Figure 19. Number of spat recruiting per year for the 1989-2008 time series. Bay regions are defined in Figure 6.No data are available for the very-low-mortality beds prior to 2007.

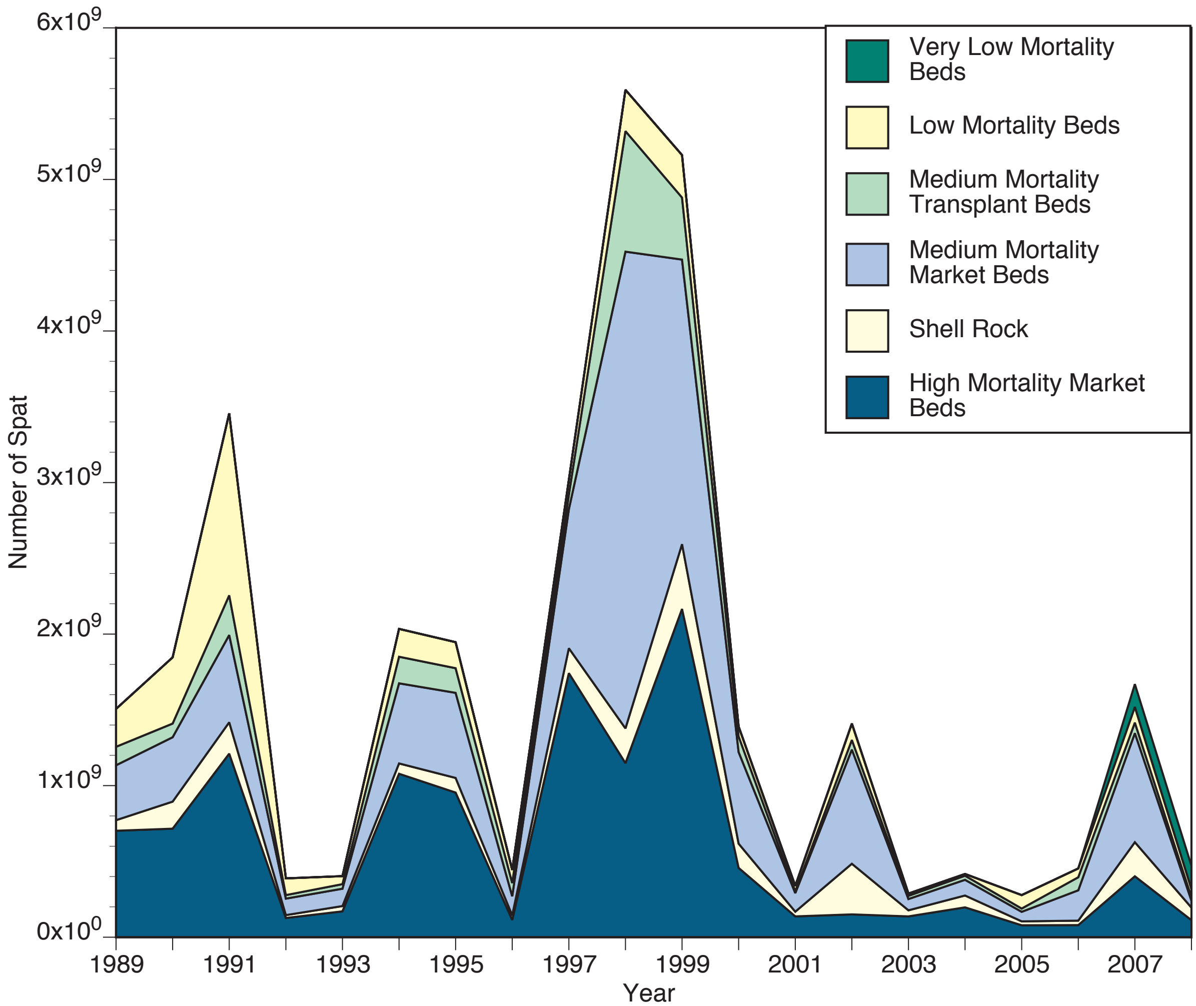


Figure 20. The number of spat recruiting per >20-mm oyster per year, excluding the very-low-mortality beds.

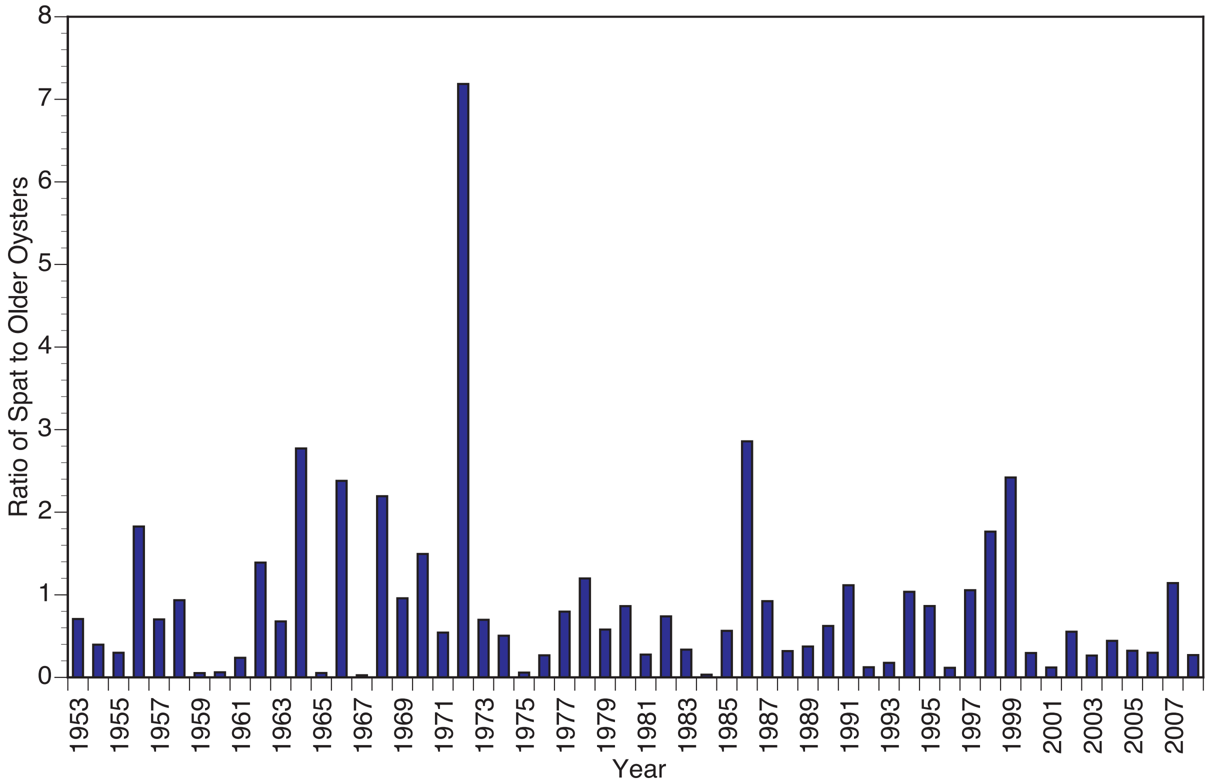


Figure 21. Spat-to-adult oyster ratio for each bay region.

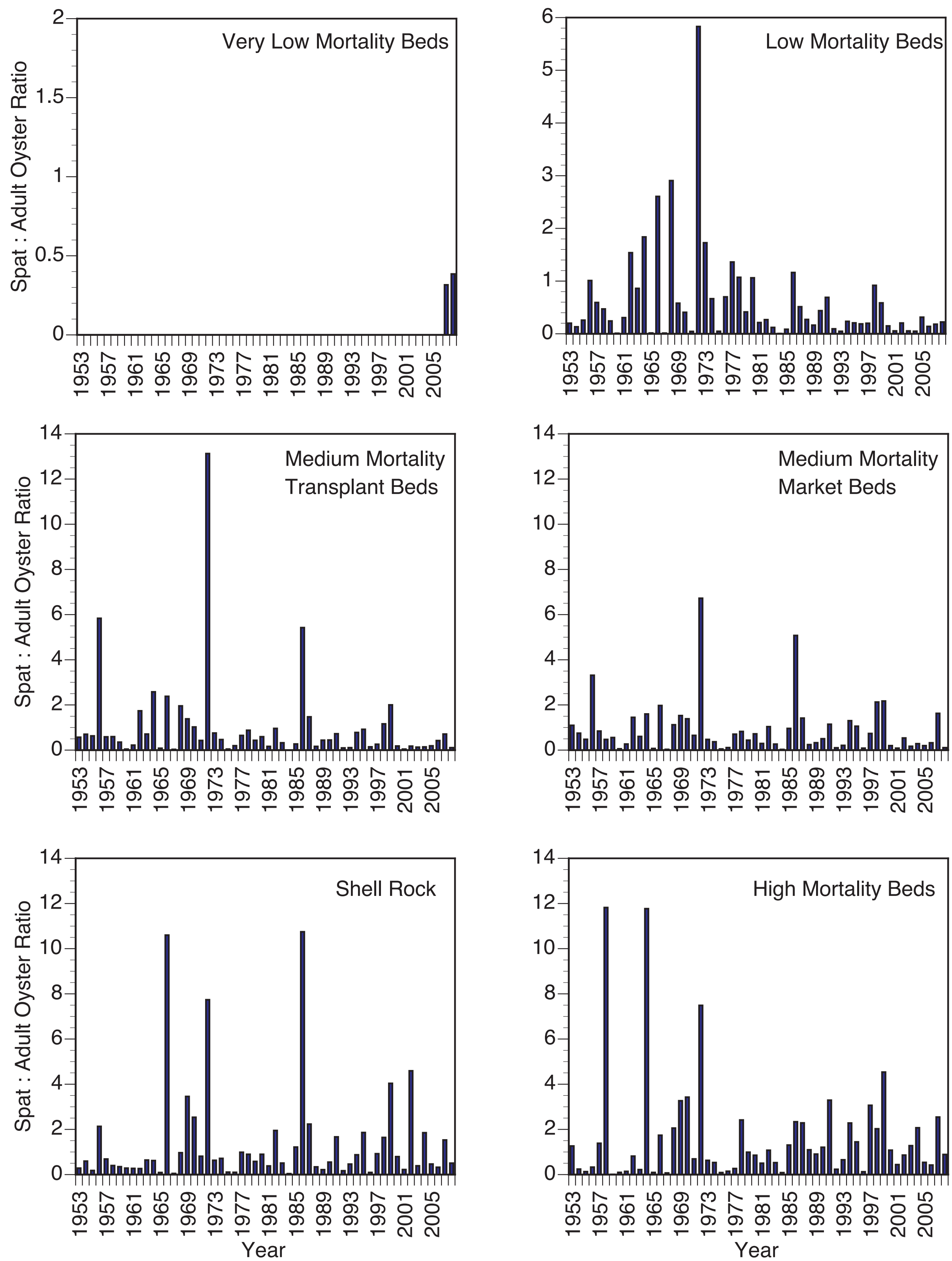


Figure 22. Occurrences of a spat-to-adult ratio above the median for the 56-year time series relative to occurrences of a proportion of the stock on the medium-mortality beds above that 56-year median. The probability of a coincidence of the two occurrences is 0.11.

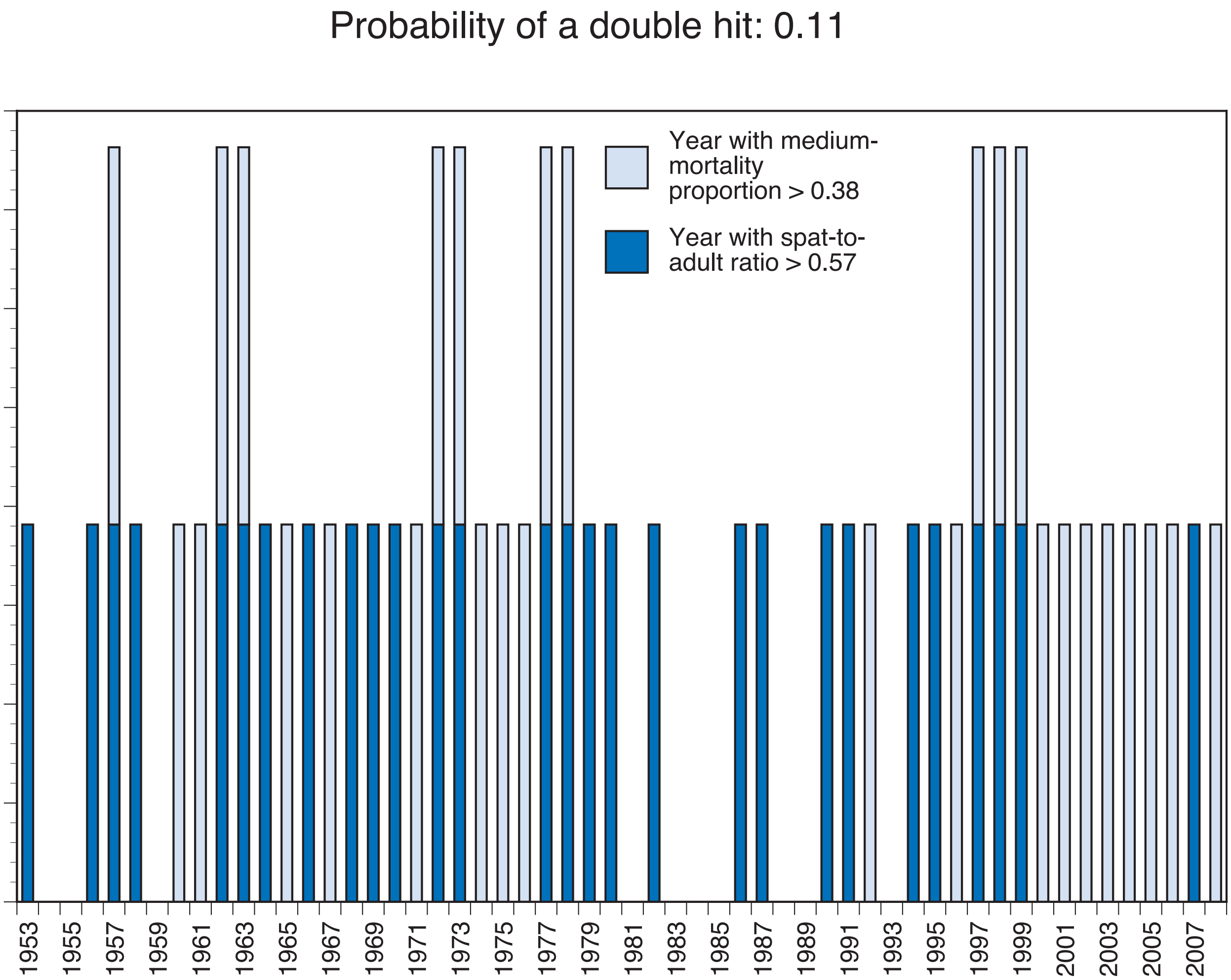


Figure 23. Occurrences of a spat-to-adult ratio above the median for the 56-year time series relative to occurrences of a proportion of the stock upbay of the high-mortality beds above that 56-year median. The probability of a coincidence of the two occurrences is 0.17.

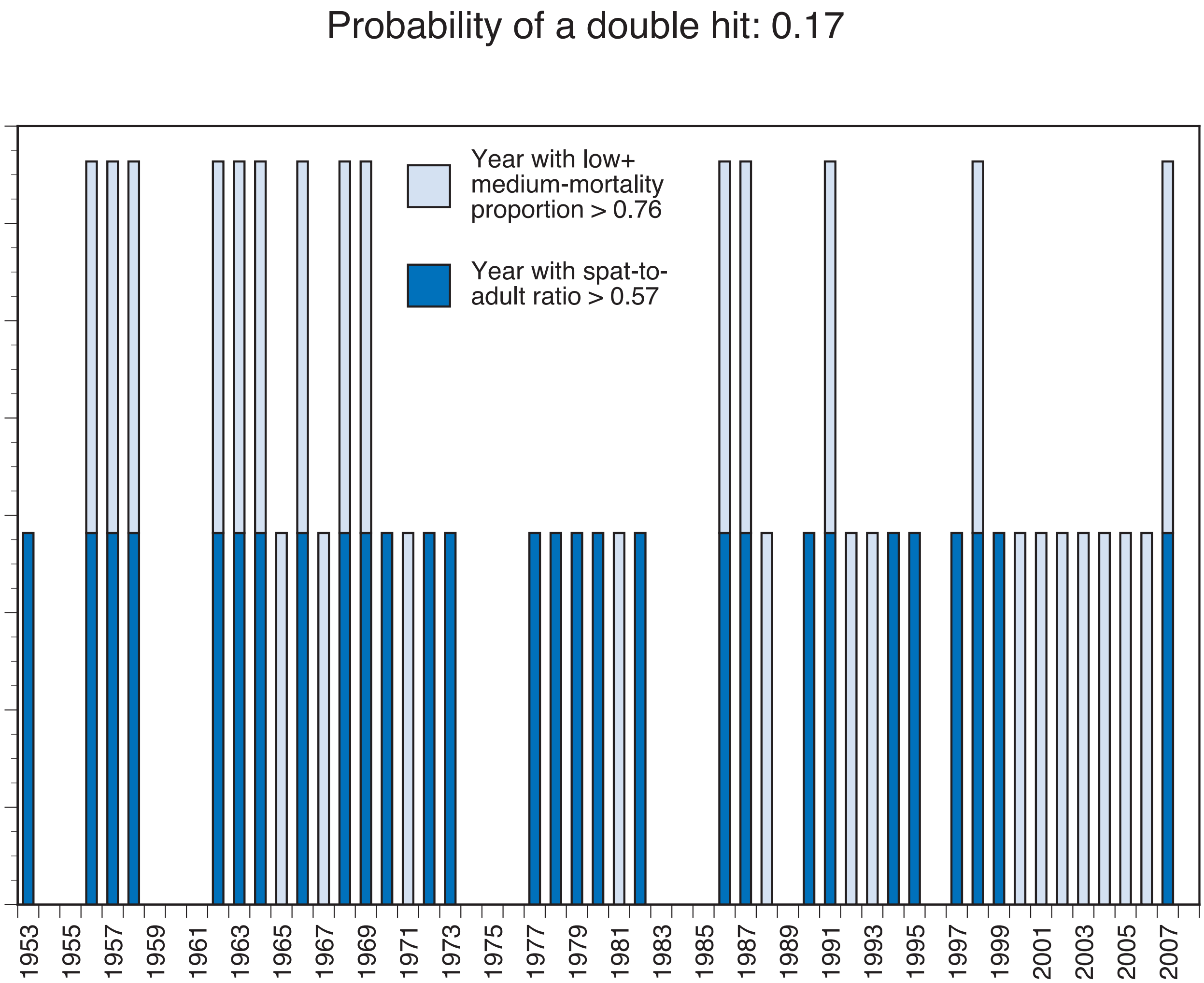


Figure 24. Location of 2008 shell plants, denoted by yellow stars. New Jersey downbay plants are on leased grounds. Transplant locations for these downbay plants are denoted as replants. Selected high-quality oyster grounds in New Jersey are denoted by shaded 25-acre grids. Red delineates State of Delaware beds.

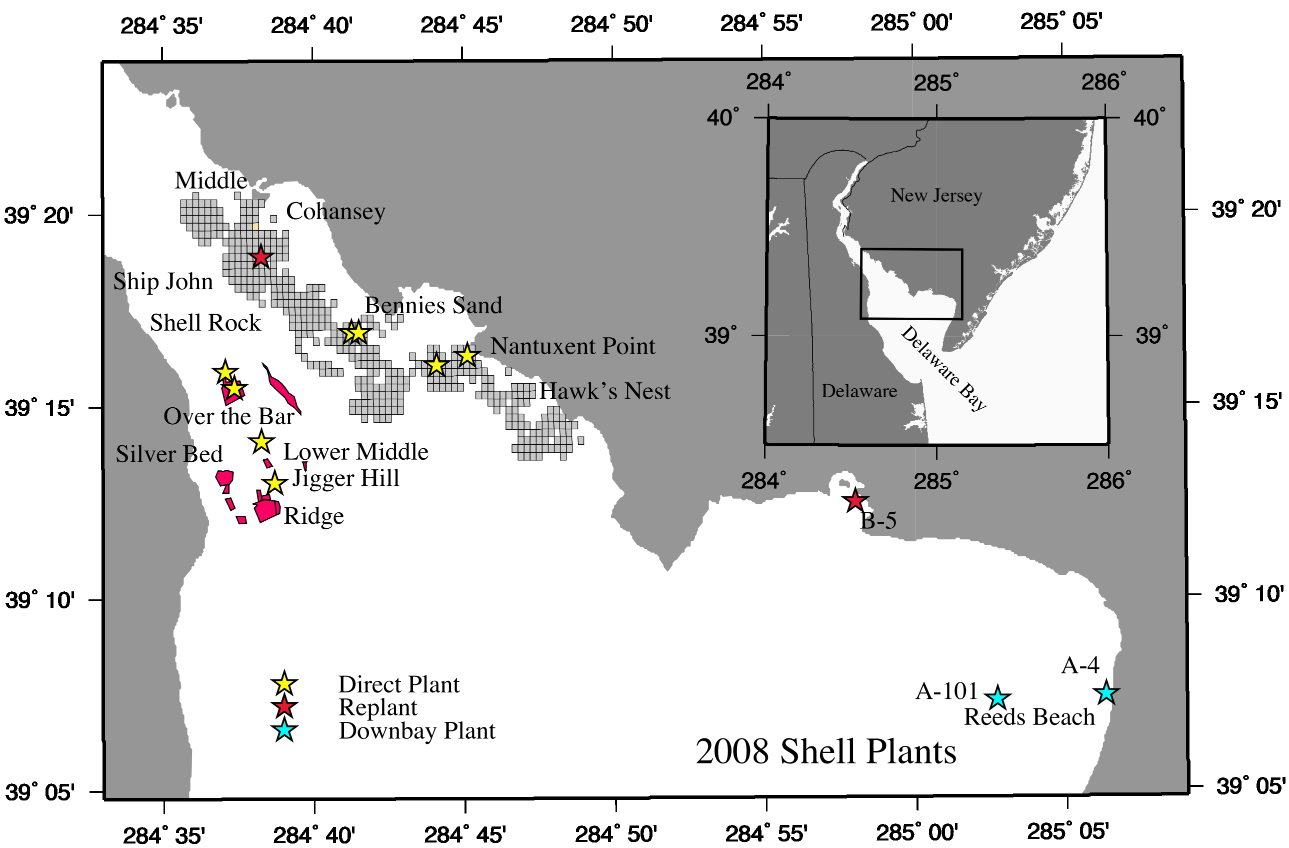


Figure 25. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2008. Shell planting began in 2005 and increased in 2006-2008. Shell budgets are calculated using the shorter half-lives estimated in this assessment and using the longer half-lives estimated in 2008 (HSRL, 2008) for comparison.

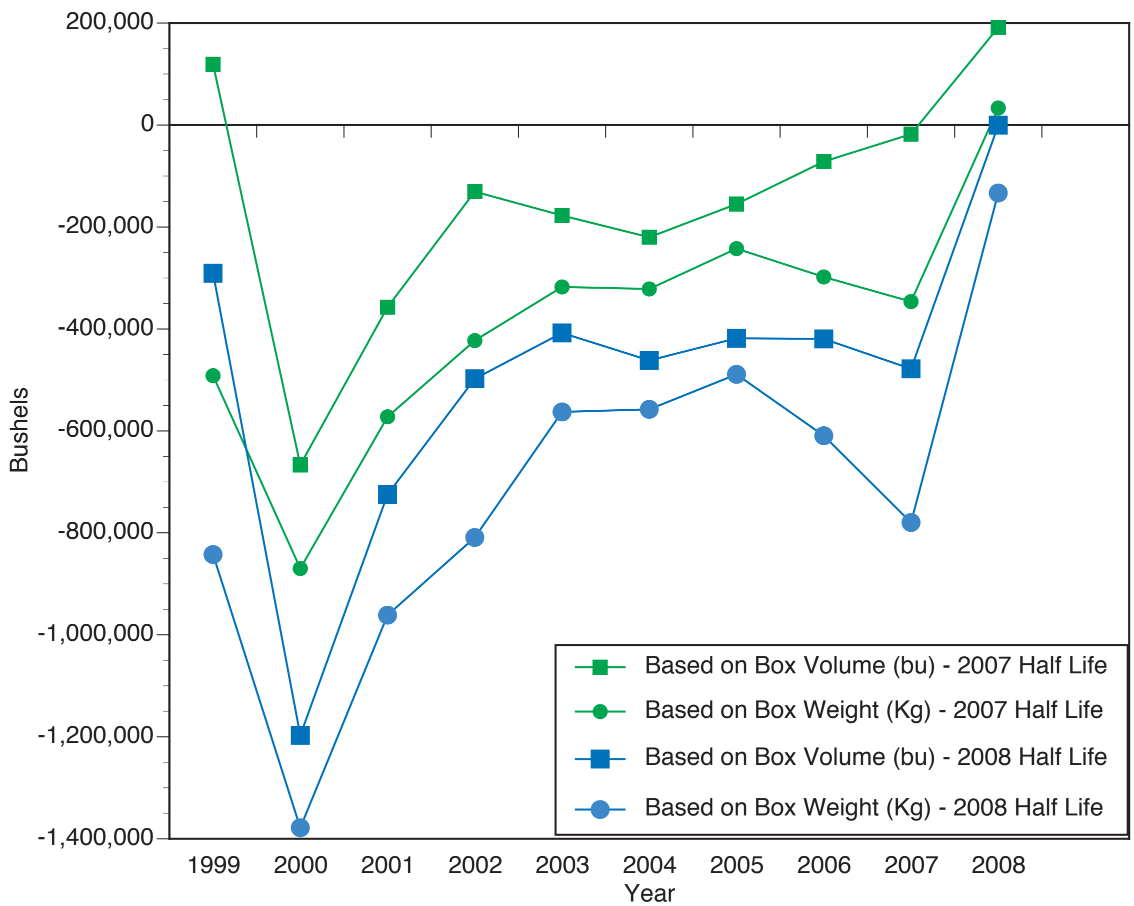


Figure 26. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2008. Positive values on Shell Rock in 2005 and 2006 and on the medium-mortality beds in 2007 and 2008 reflect the addition of shell through shell planting to offset shell loss.

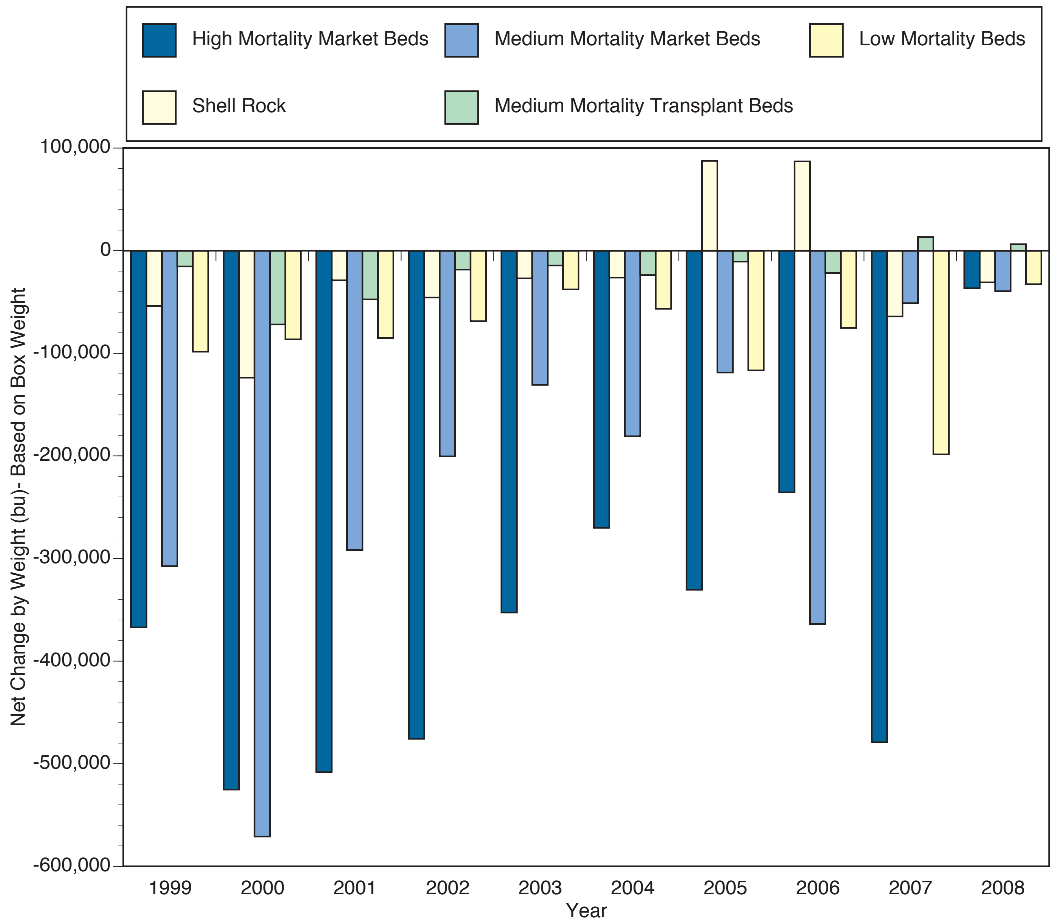
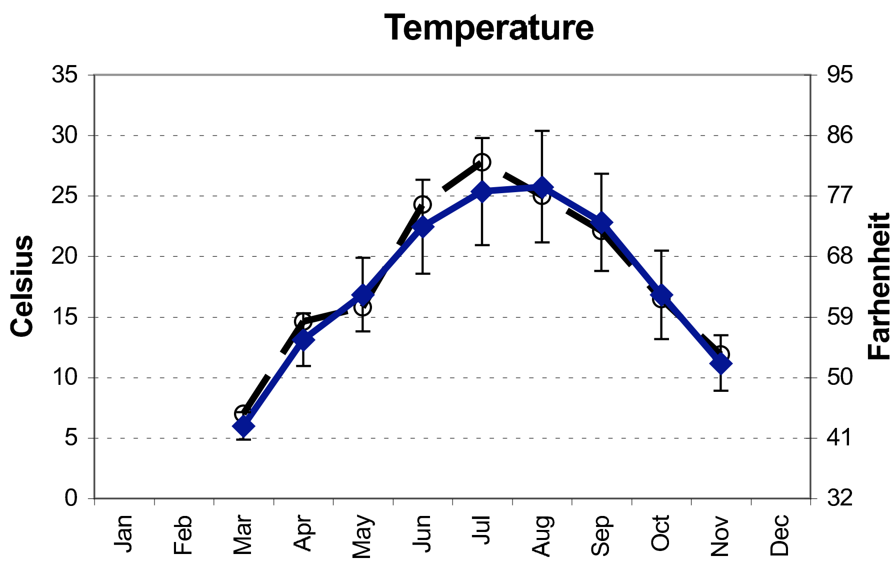


Figure 27. Trends in water temperature and salinity during 2008. Dashed line is the mean of data collected during the Dermo monitoring program. Solid line represents the long-term mean values.



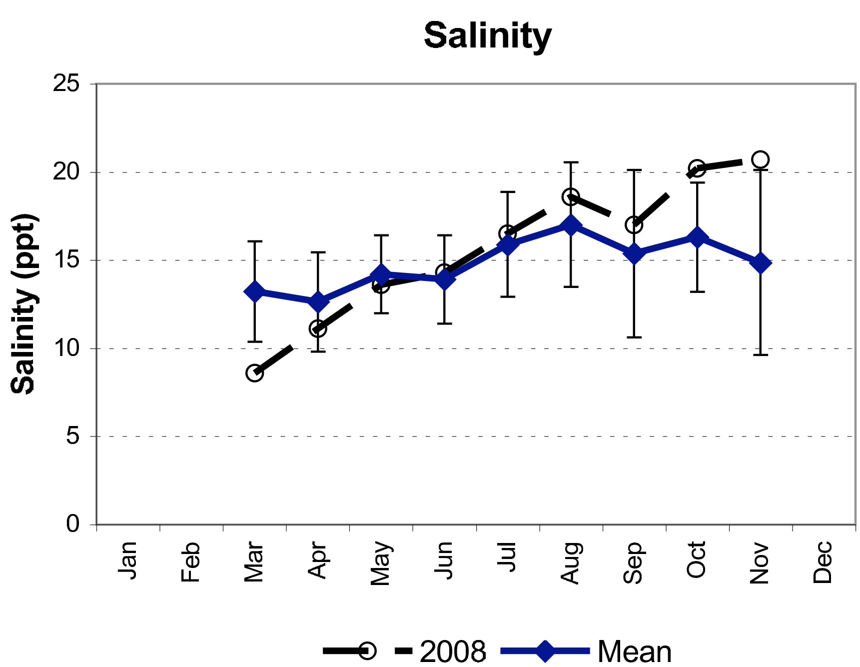


Figure 28. Mean and 2008 Dermo prevalence and weighted prevalence in oysters on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals for the 1990-2008 mean.

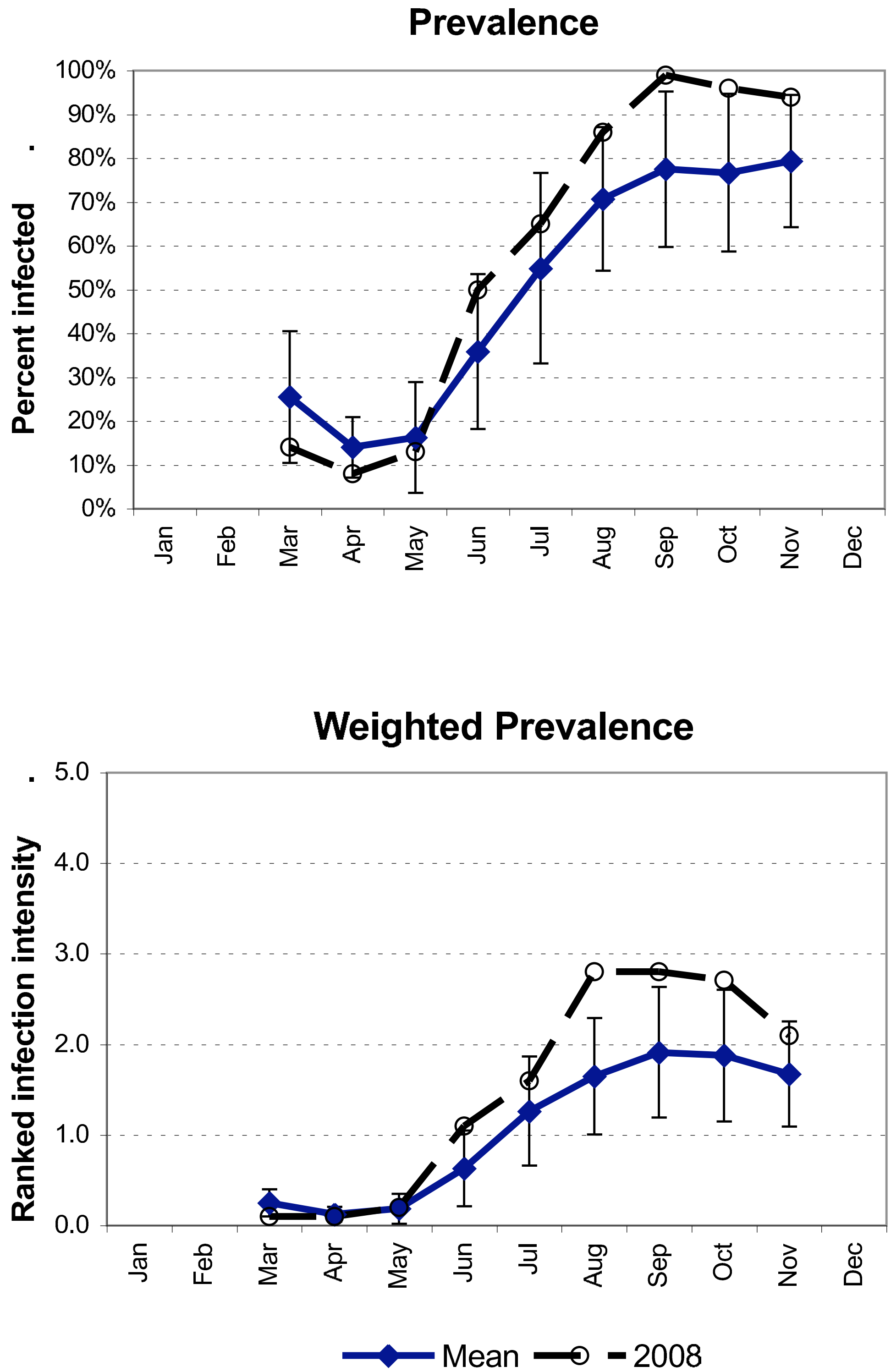


Figure 29. Comparison of average annual fall Dermo prevalence and weighted prevalence in oysters since 1990 (open bars with 95% confidence intervals) with 2008 levels (shaded area). Egg Island bed was not sampled in 2008.

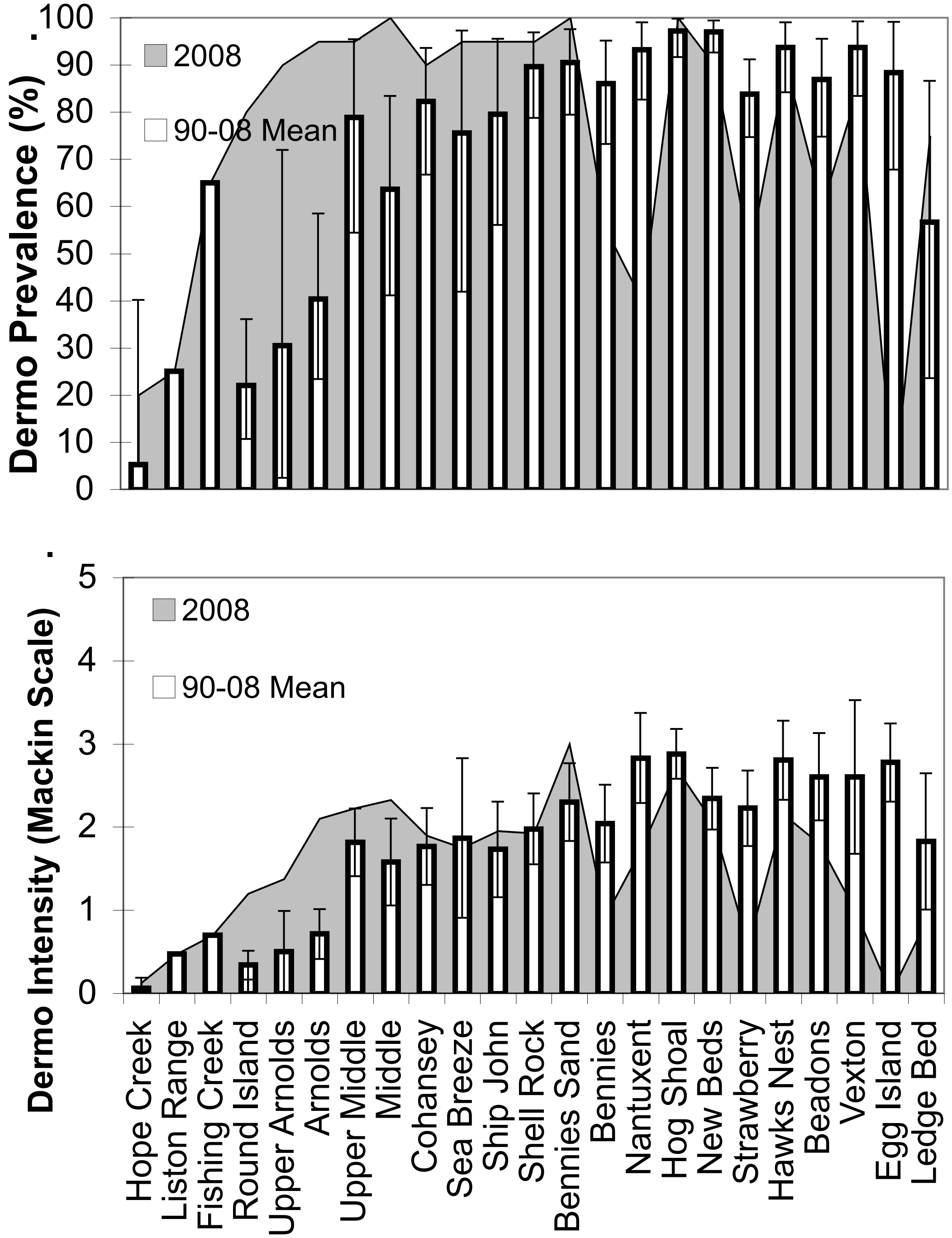


Figure 30. Time series showing the cyclic nature of Dermo prevalence. Note the tendency for epizootics to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

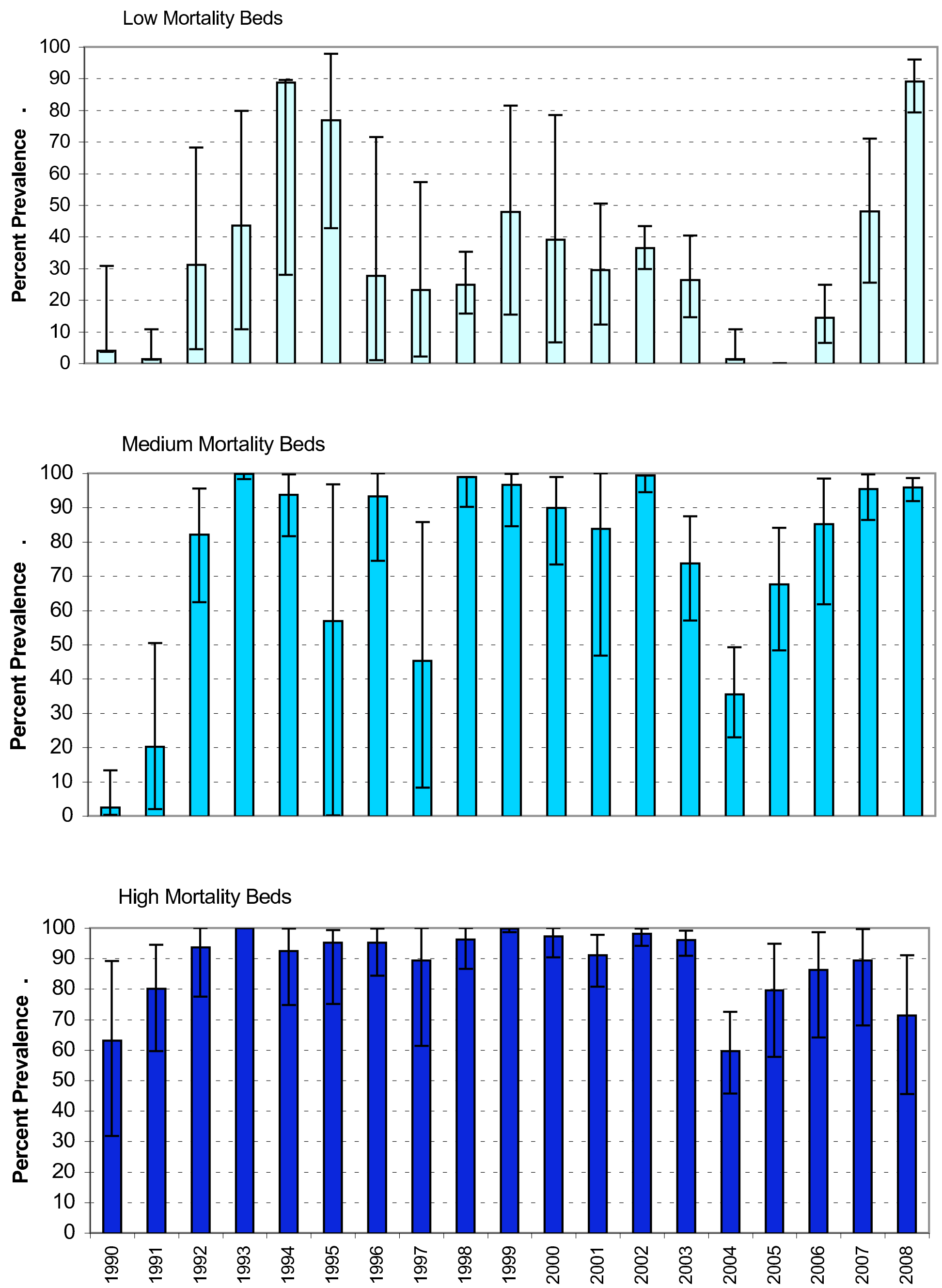


Figure 31. Time series showing the cyclic nature of Dermo disease weighted prevalence. Note the tendency for epizootics (weighted prevalences >2) to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

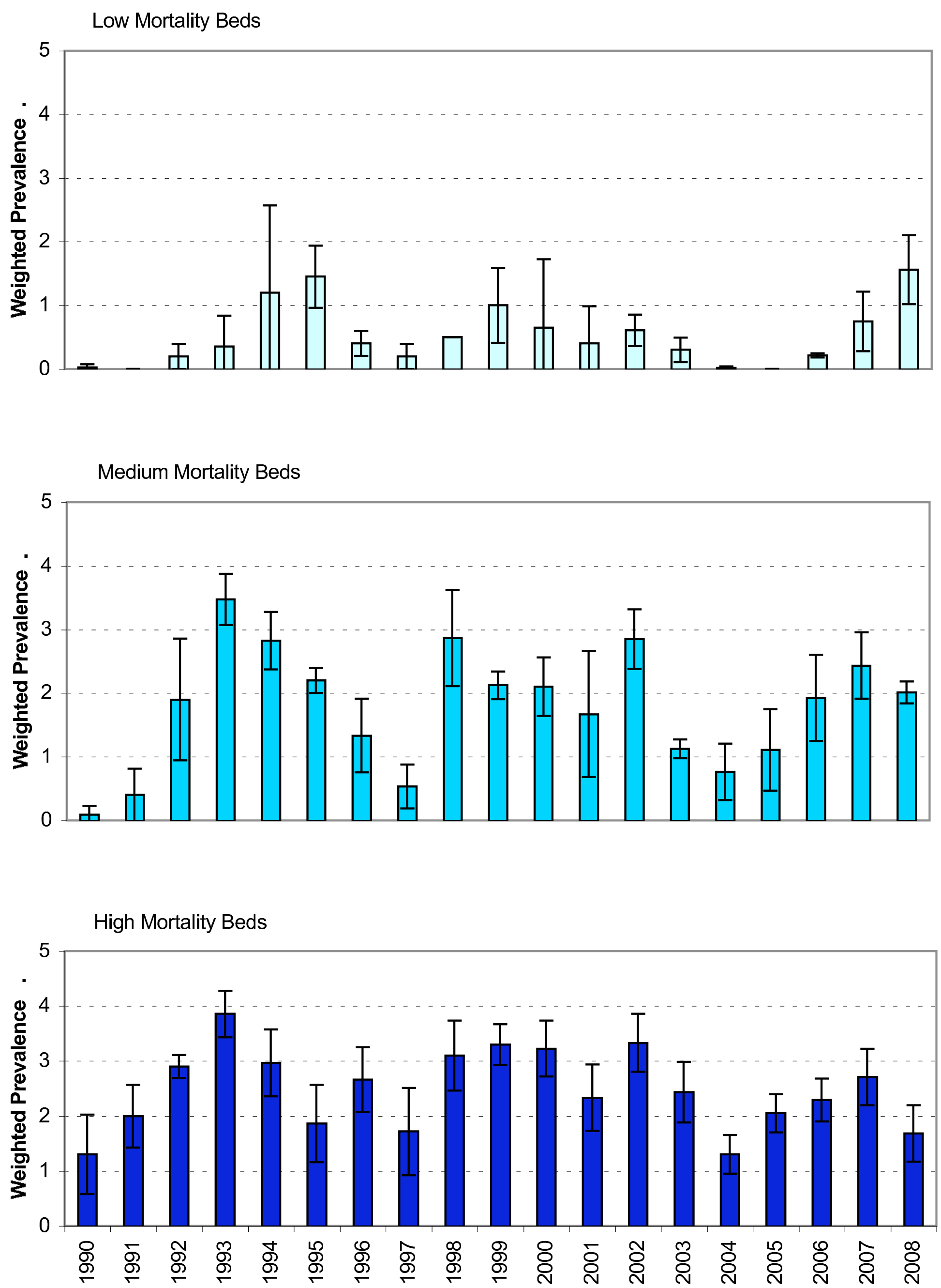


Figure 32. Comparison of mortality from Dermo infection between Hope Creek oysters and Shell Rock oysters, both transplanted to the Capeshore region of Delaware Bay in early spring.

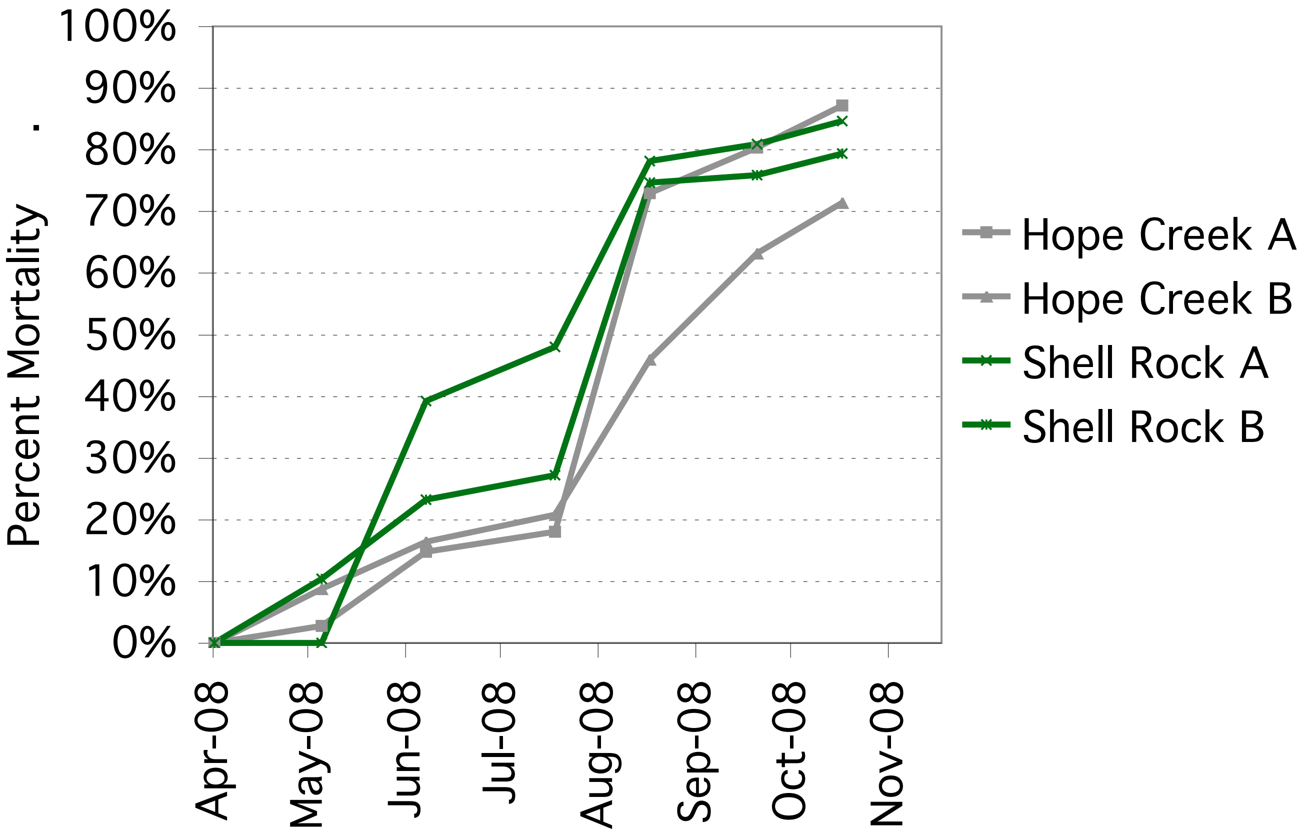


Figure 33. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the four bay regions measures the bay-wide mortality rate for that year.

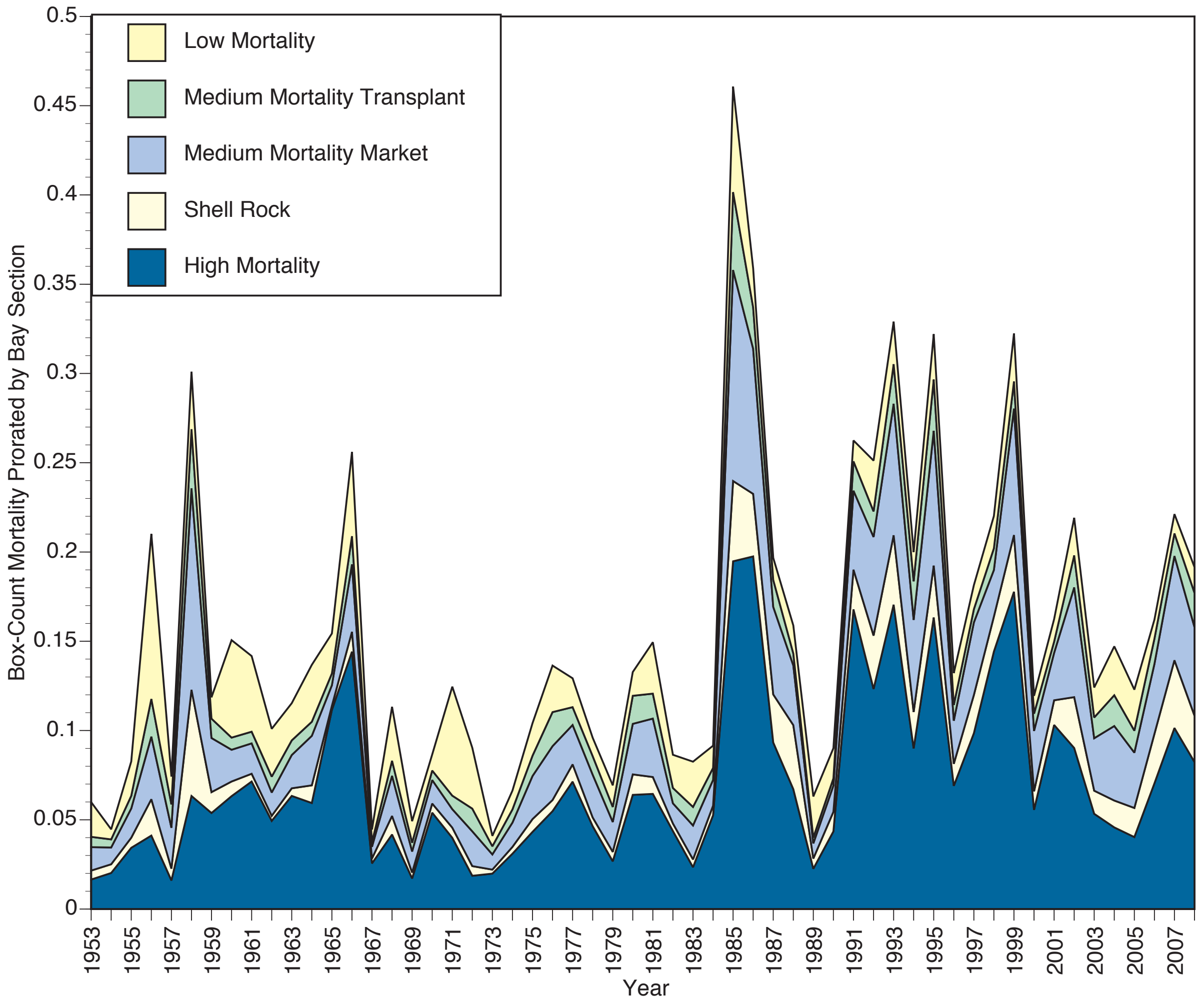


Figure 34. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region.No data are available for the very-low-mortality beds prior to 2007.

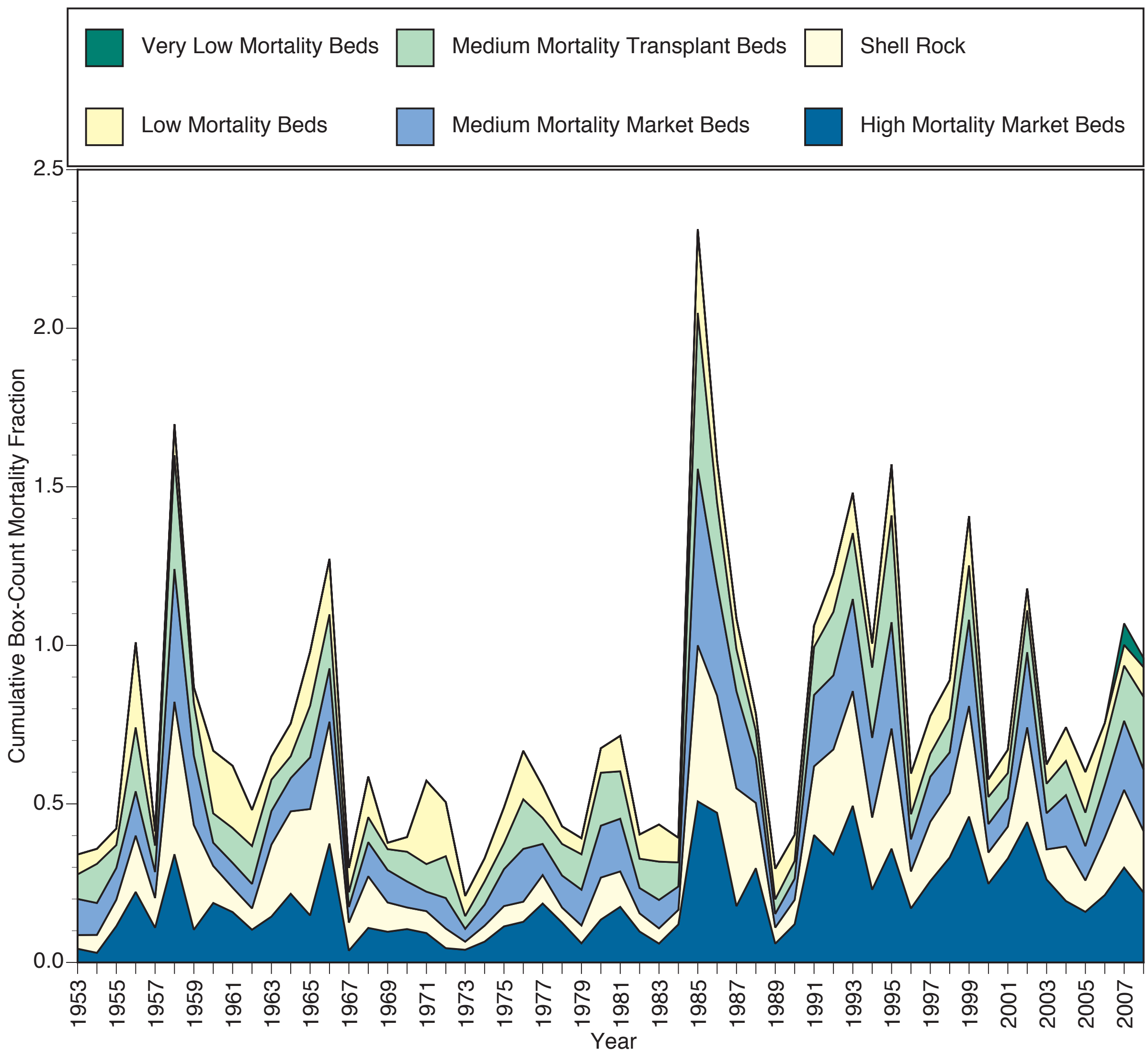


Figure 35. Broodstock-recruitment relationship for the 1953-2008 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2007 because the plot compares end-of-2007 oyster abundance with 2008 recruitment. Dotted lines identify the 56-year medians used for calculation of first passage times (Table 20).

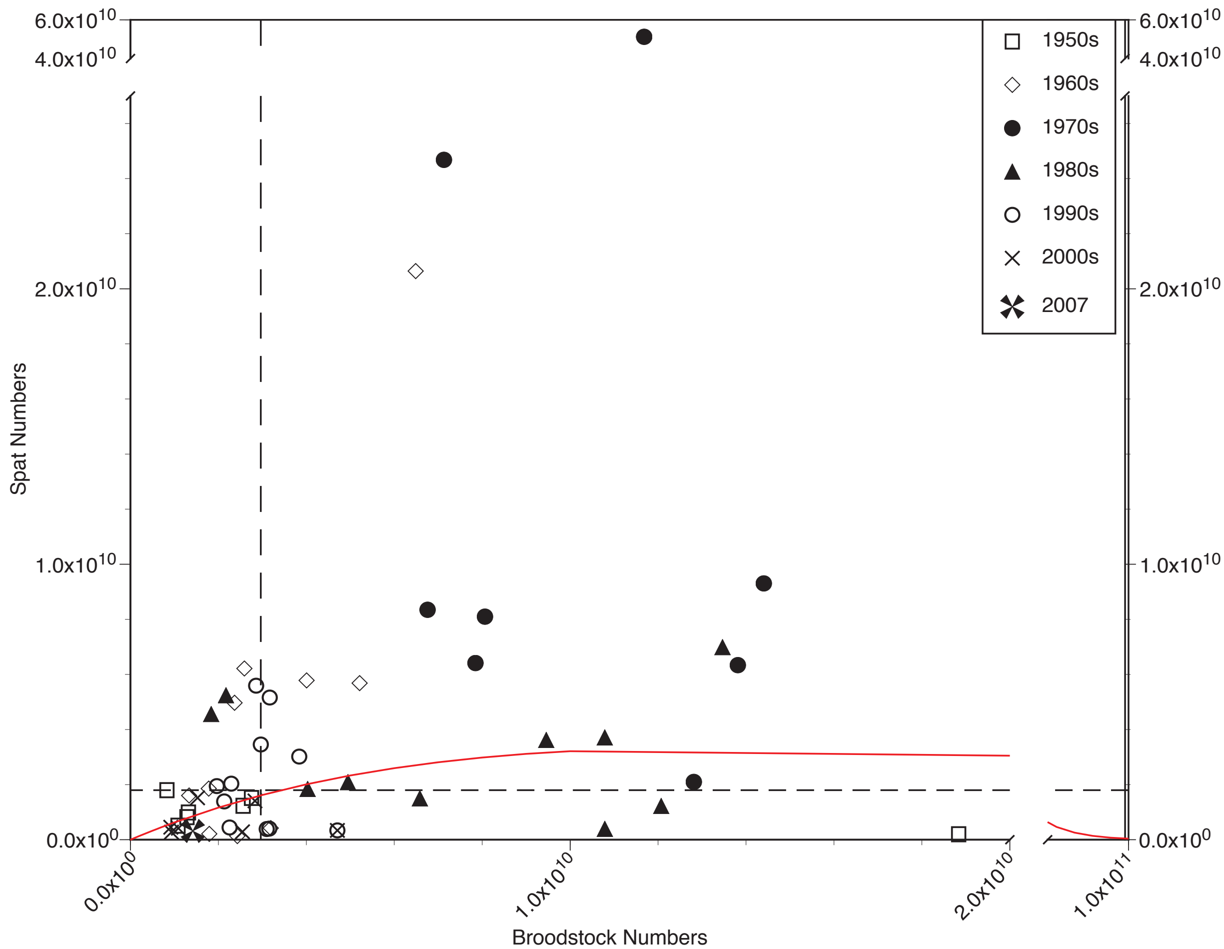


Figure 36. The quadrant numbering convention used to calculate mean first passage times. The one year transition probabilities are obtained by examining the position of consecutive x-y data pairs in quadrant space. Four transitions are possible for each starting position, the possibilities for Quadrant 1 being depicted. Sixteen total trajectories are possible.

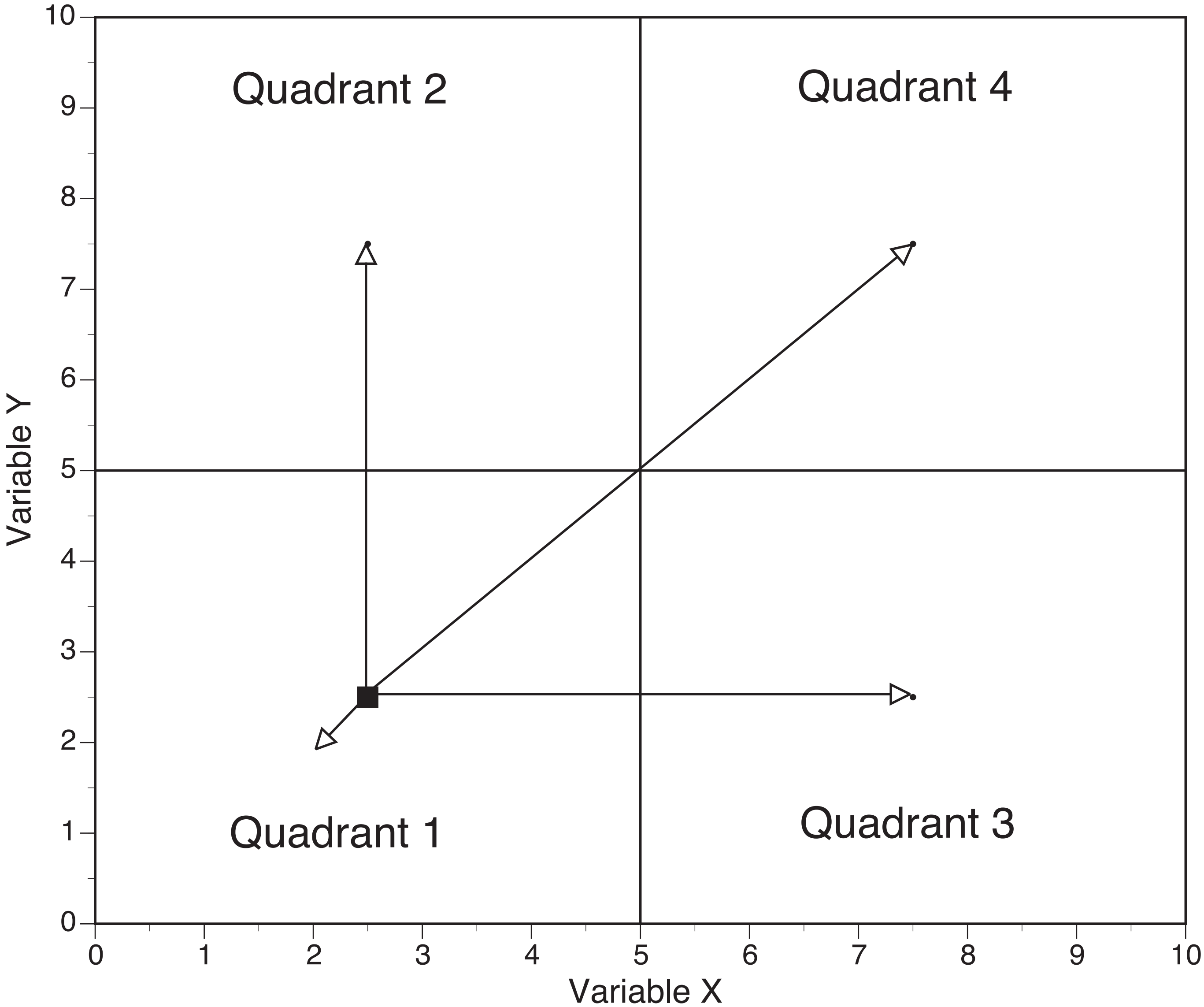


Figure 37. The relationship between oyster abundance and box-count mortality for the 1953-2008 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2007 because the plot compares end-of-2007 oyster abundance with 2008 mortality. Dotted lines identify the 56-year medians used for calculation of first passage times (Table 21).

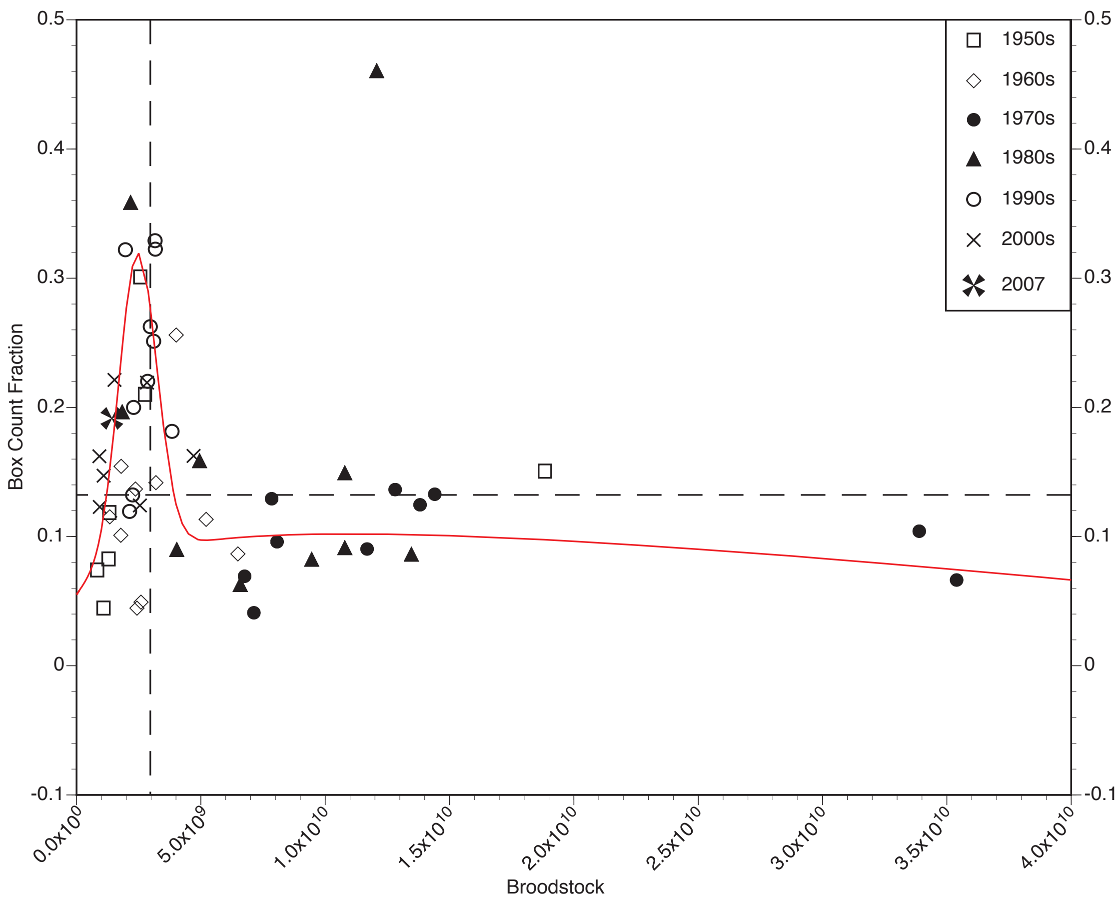


Figure 38. A closer look at the lower end of the oyster abundance and box-count mortality relationship. The entire dataset is depicted in Figure 37. Latest year listed as 2007 because the plot compares end-of-2007 oyster abundance with 2008 mortality. Dotted lines identify the 56-year medians used for calculation of first passage times (Table 21).

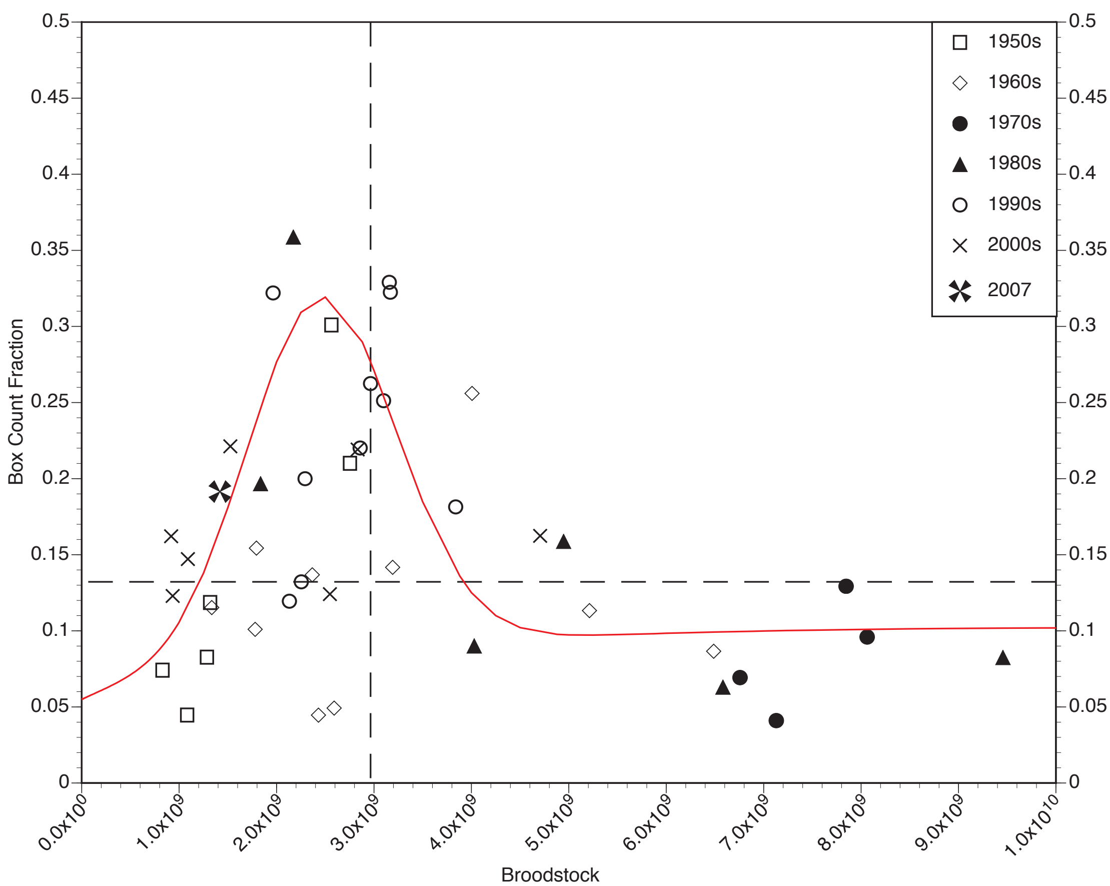


Figure 39. The relationship between recruitment and box-count mortality for the 1953-2008 time period for the natural oyster beds of Delaware Bay. Dotted lines identify the 56-year medians used for calculation of first passage times (Table 22).

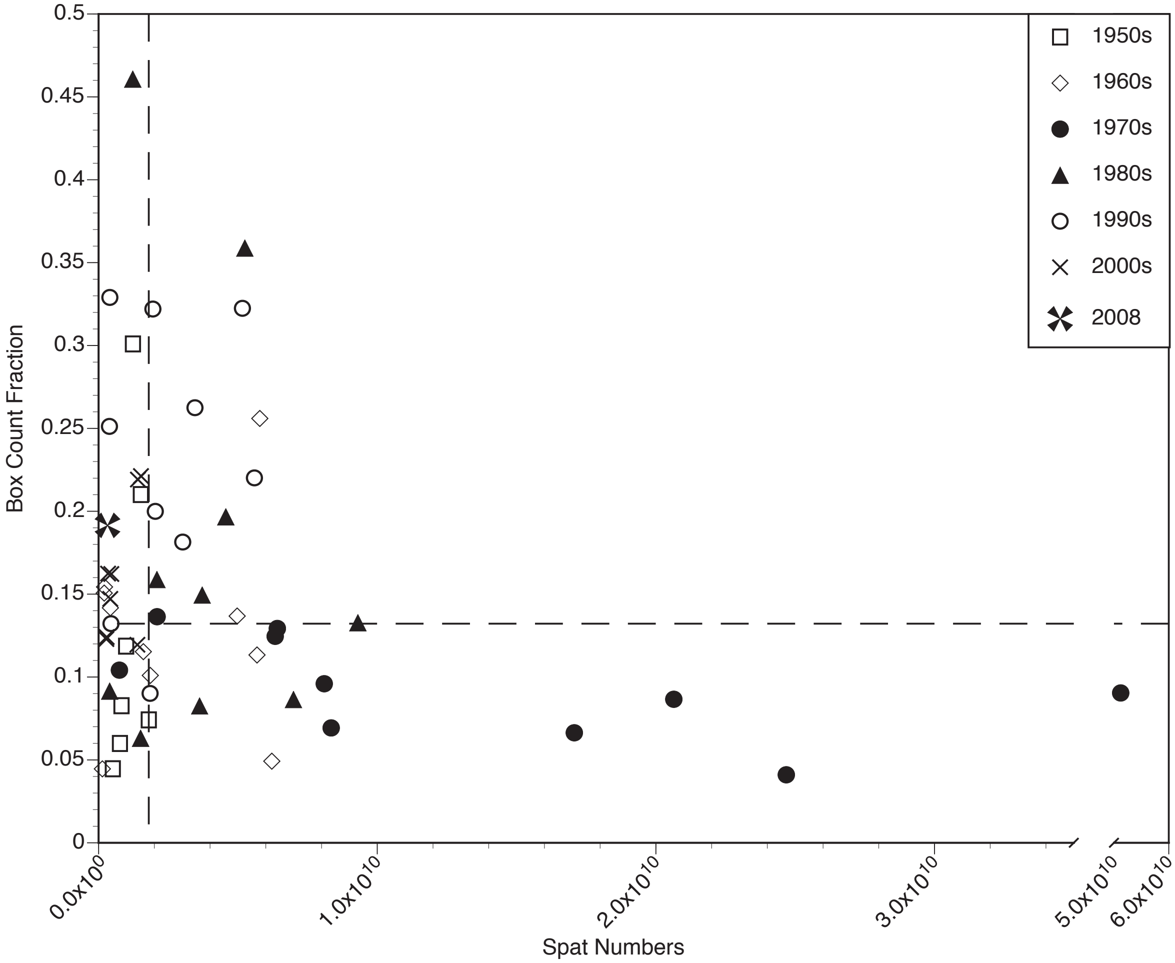


Figure 40. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

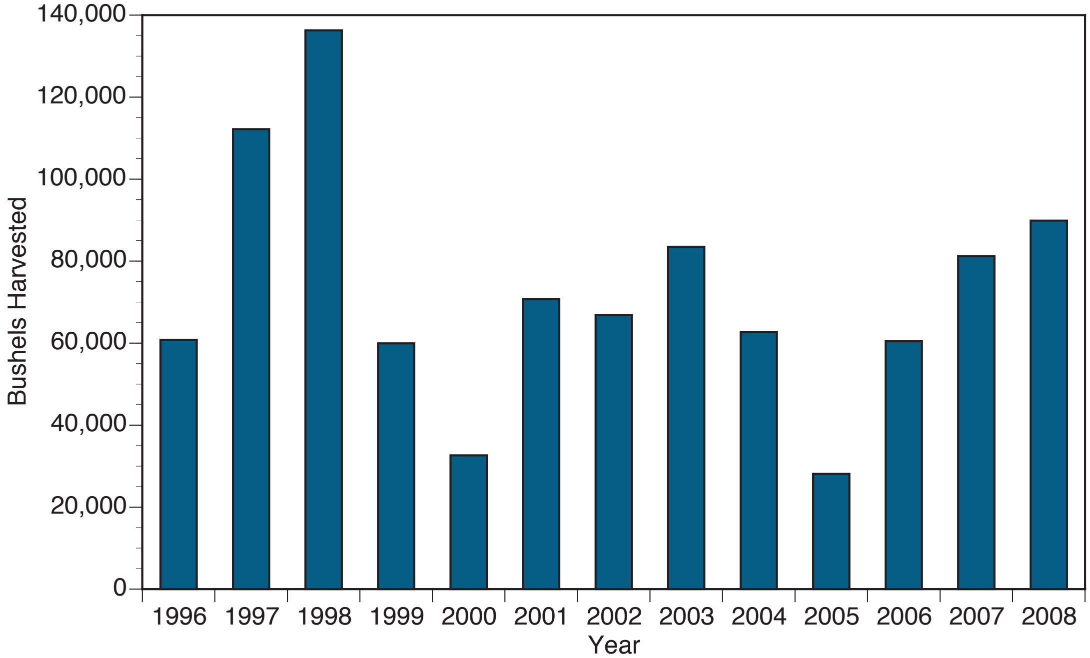


Figure 41. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this figure, 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.

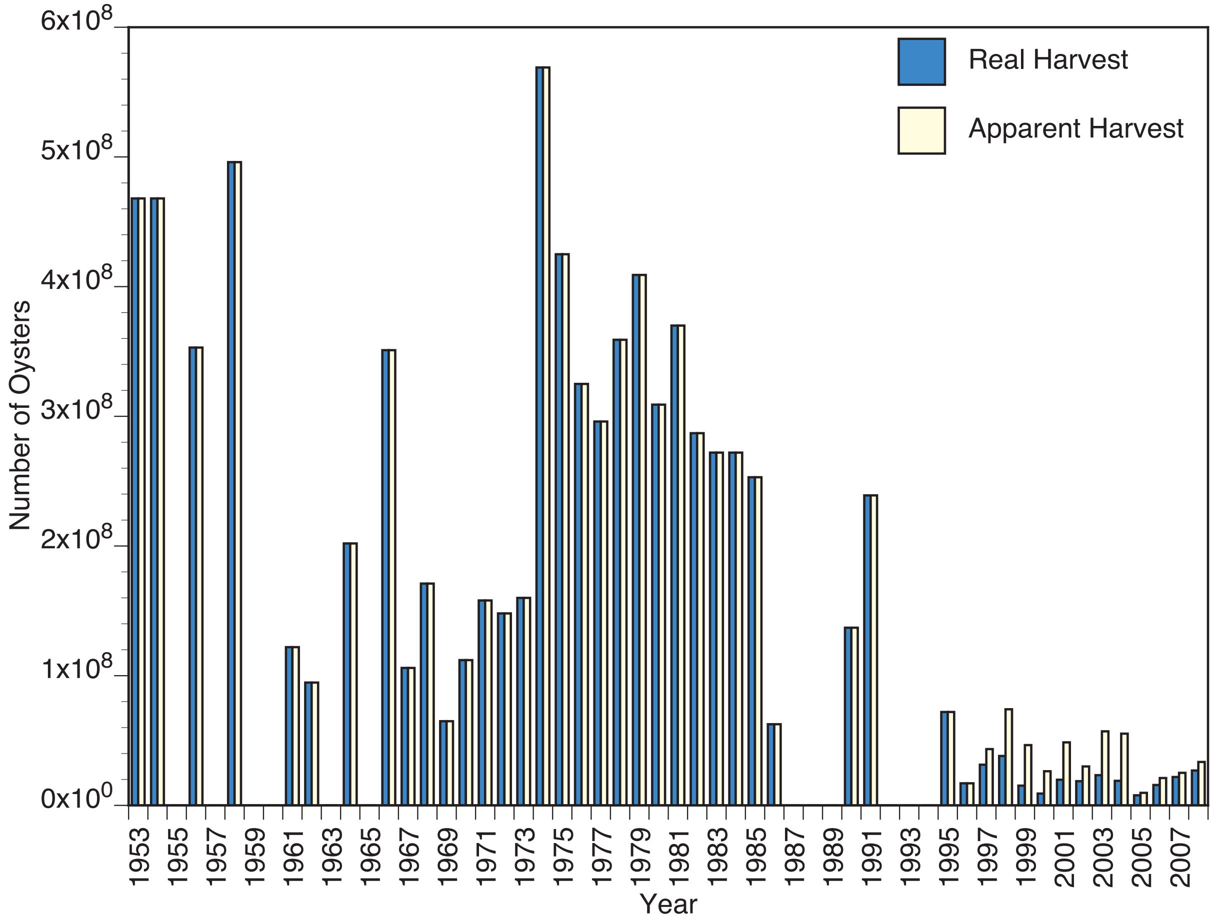


Figure 42. Catch (in bushels) per boat-day by vessel style.

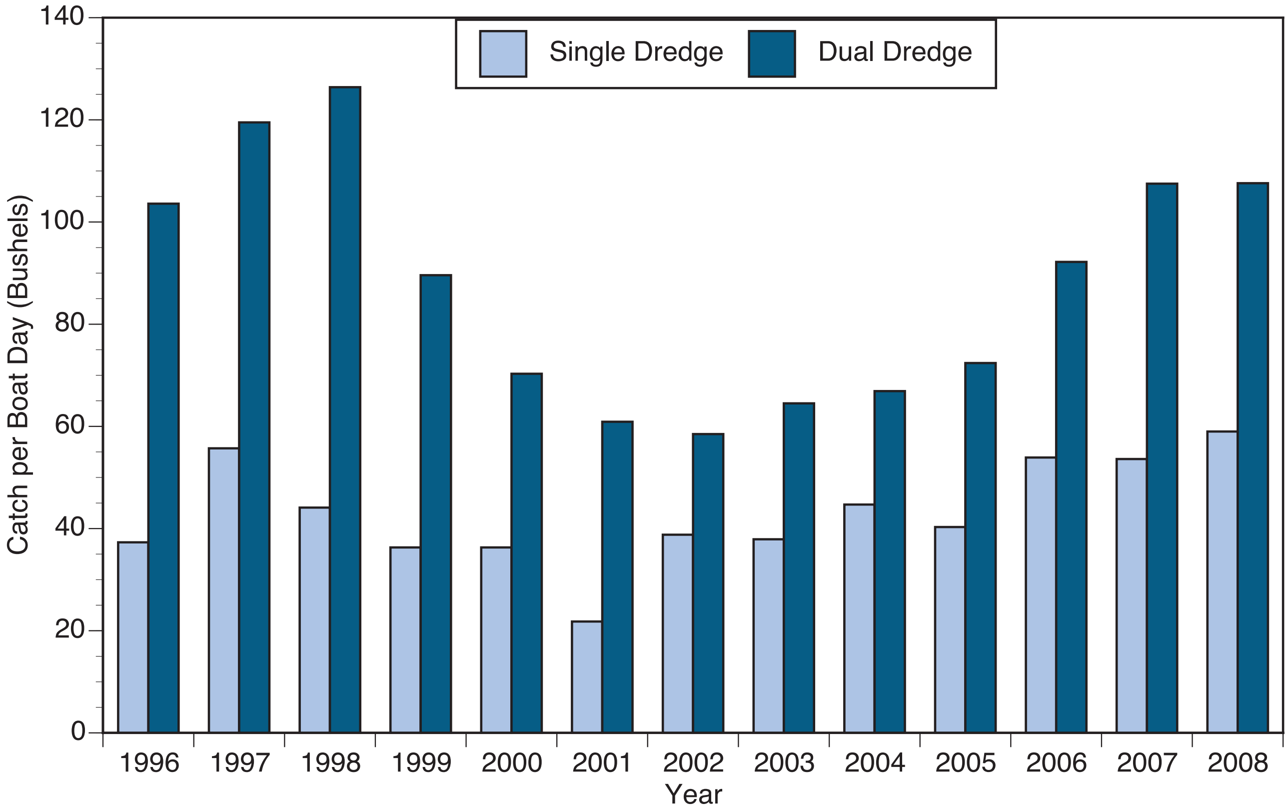


Figure 43. Size frequency of oysters landed in 2008. Size class values are the mean of the size class.

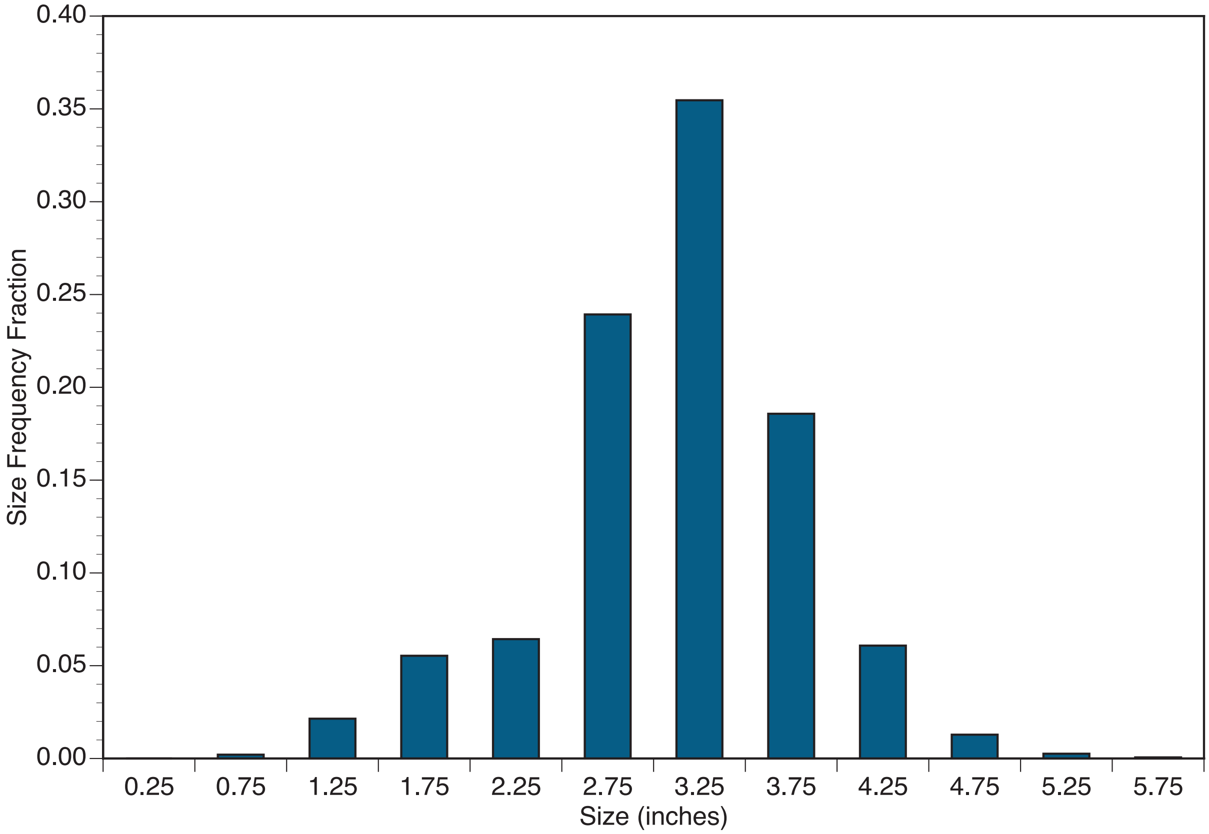


Figure 44. Fishing mortality rates by bay region during the 1954-2008 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 6. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

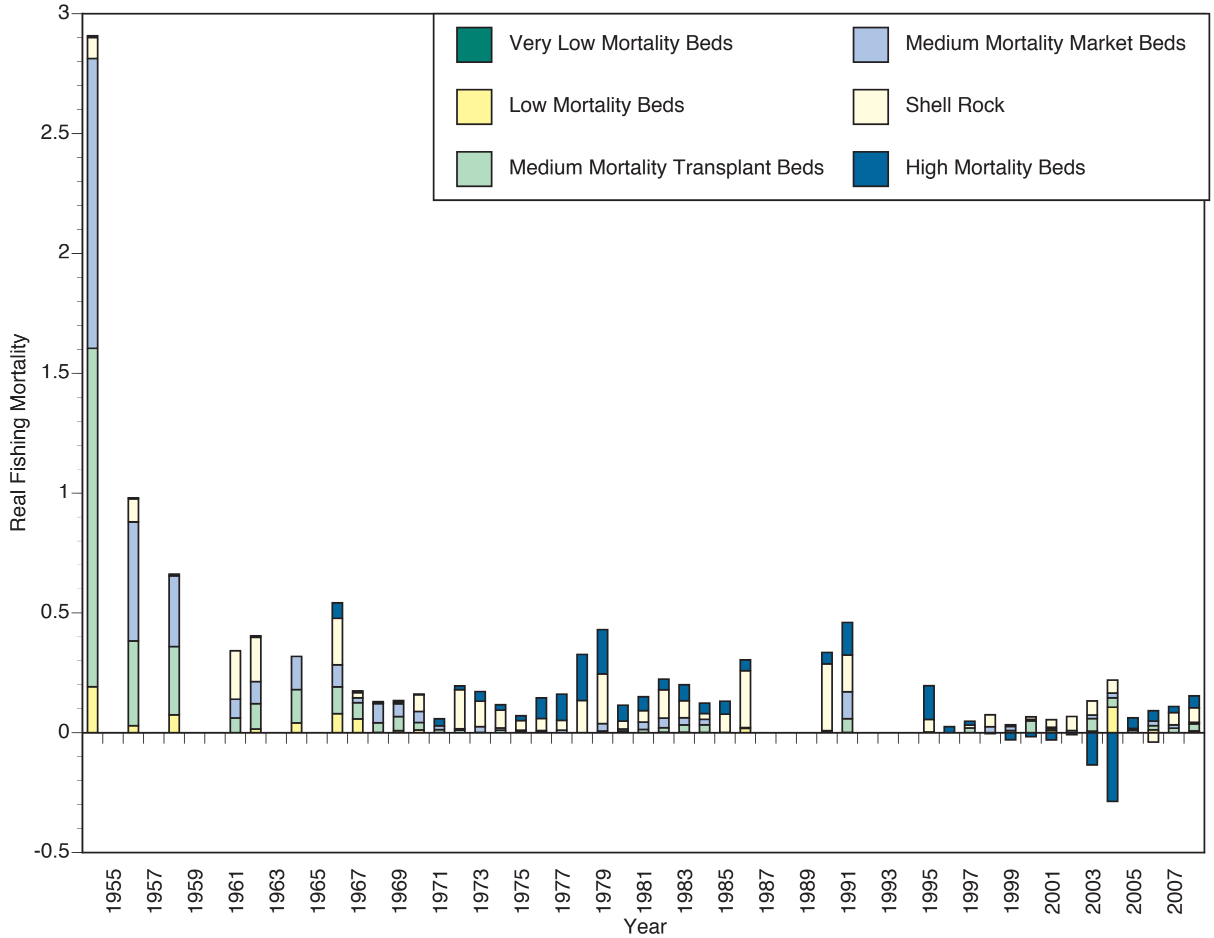


Figure 45. Fishing mortality rates by bay region during the 1989-2008 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 6. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

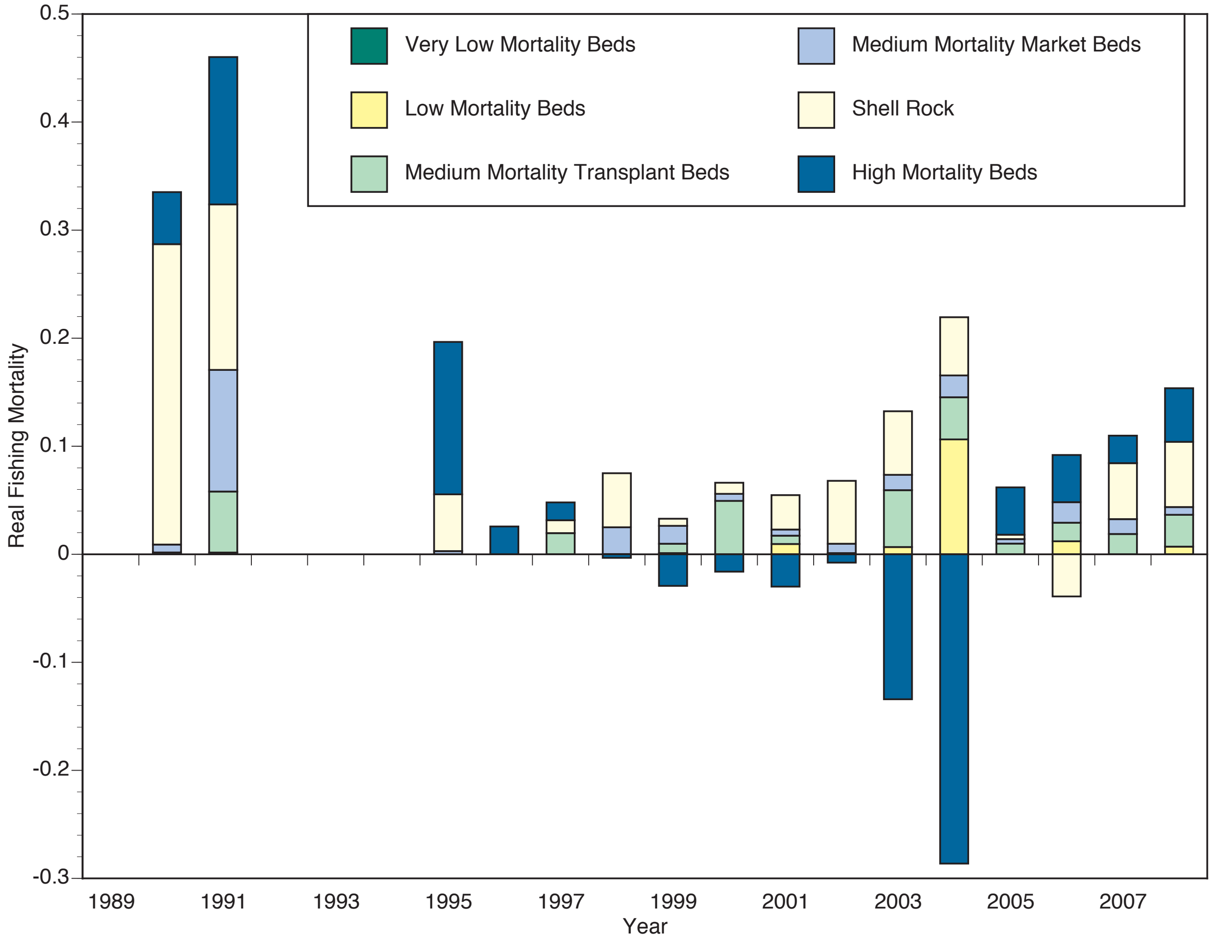


Figure 46. Real fishing mortality rate during the 1991-2008 time period. Zeros represent years of fishery closure.

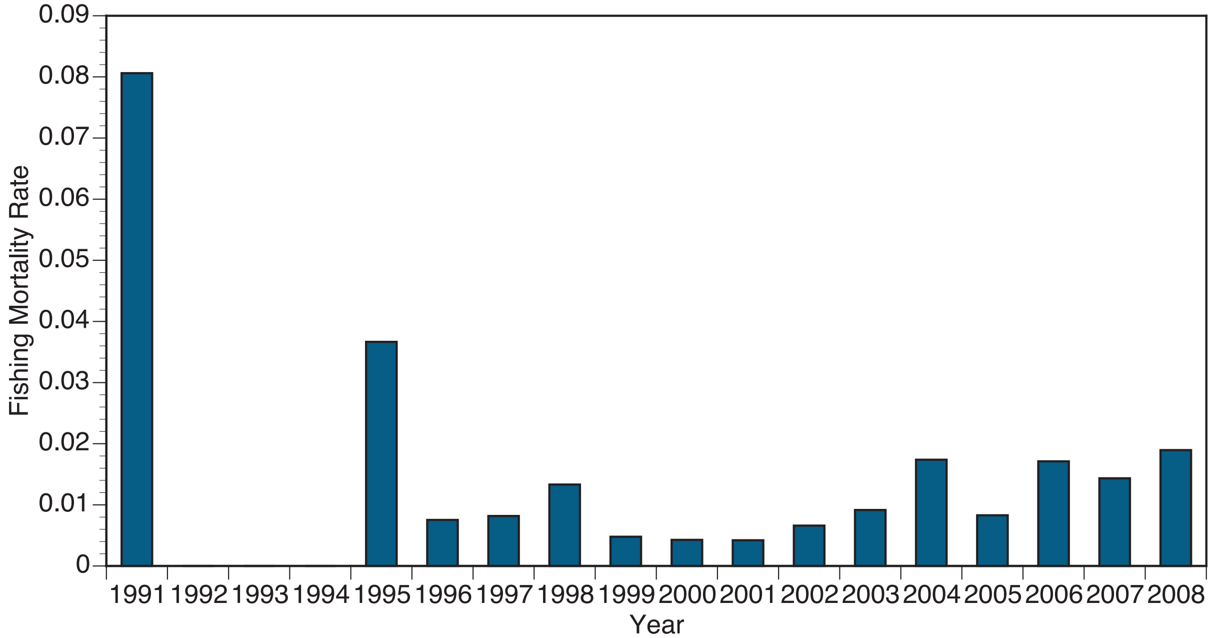


Figure 47. Fishing mortality rate during the 1997-2008 time period based on spawning stock biomass.

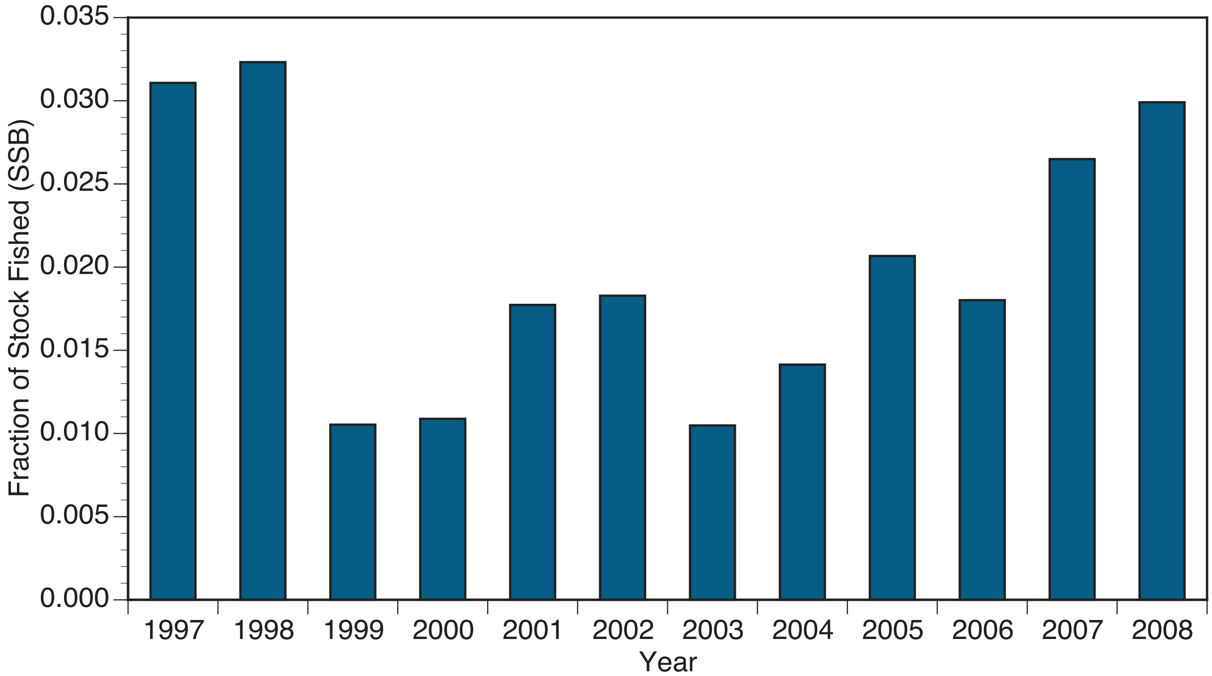


Figure 48. Fishing mortality rate during the 1997-2008 time period based on marketable abundance (animals $\geq 2.5''$).

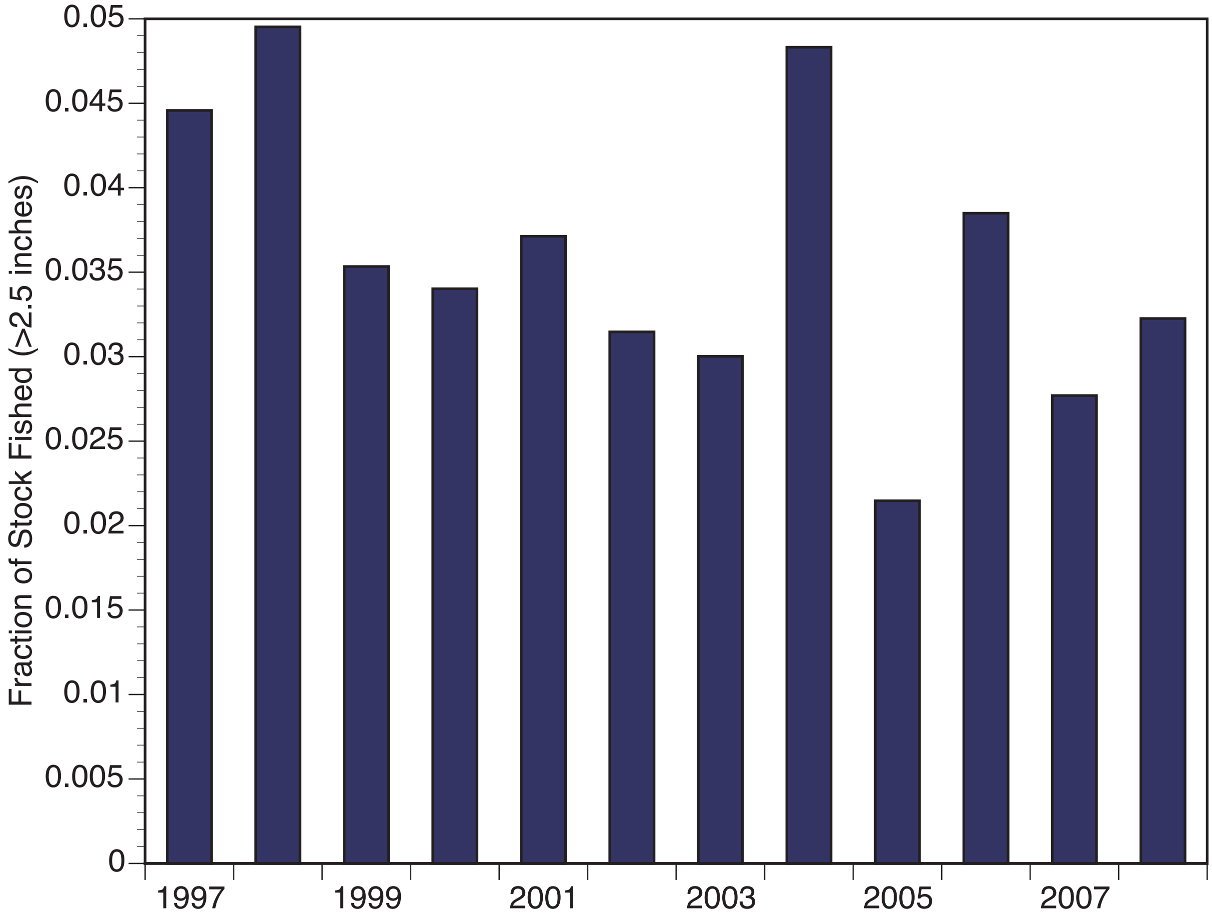


Figure 49. Position of the oyster stock in 2005-2008 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values (Table 25).

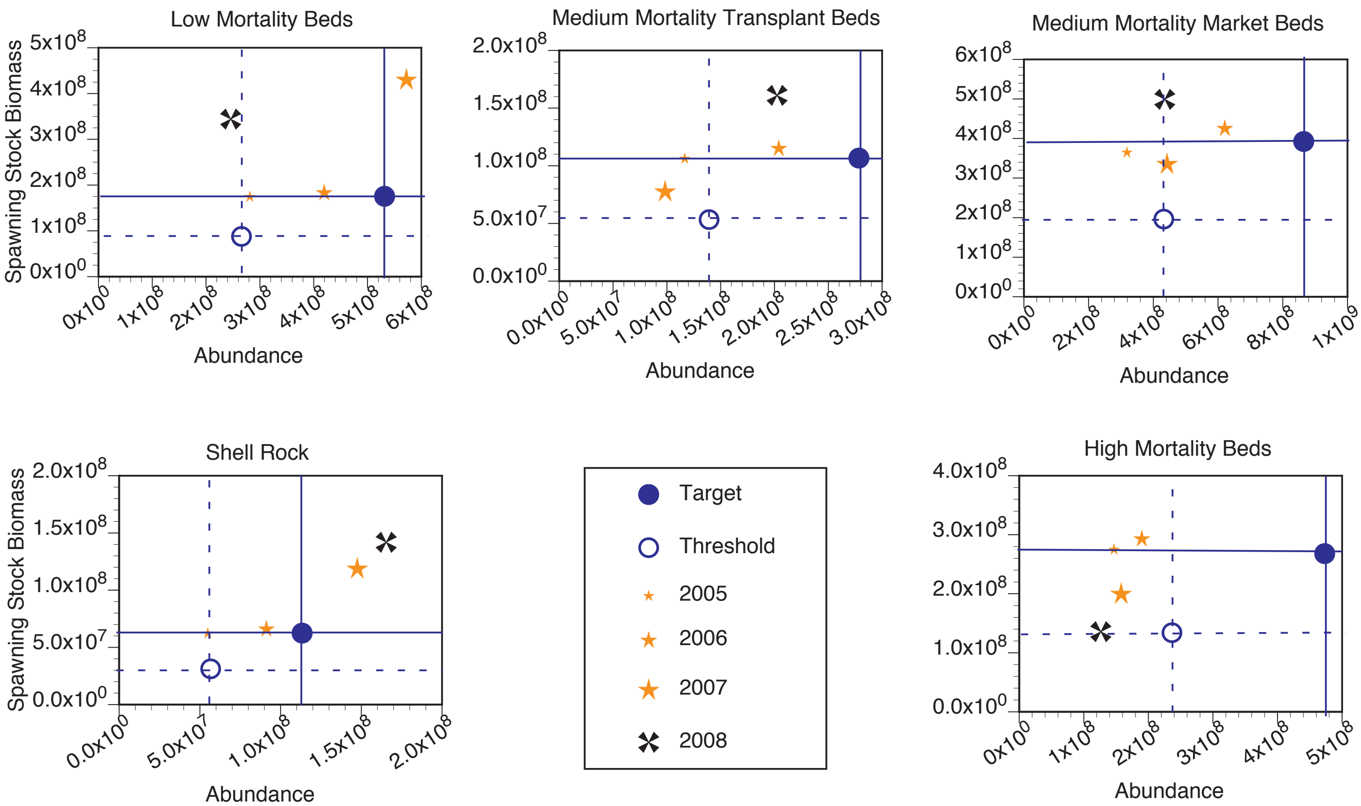


Figure 50. Plot of surplus production trajectories obtained from simulations of the stable-point surplus-production model. Descriptions of the simulations are given in Table 26 and the text. Vertical bars correspond to four whole-stock reference points. Two are derived from the surplus production model, a target defined as the median of five estimates of the N_{msy} for the low-abundance state and a threshold set at half that value. Two are derived from stock performance data for the 1989-2005 time period. The target is the median stock abundance for that period and the threshold is half that value (Table 25). The four respective values are: 1.628 billion, 0.814 billion, 2.262 billion, and 1.130 billion.

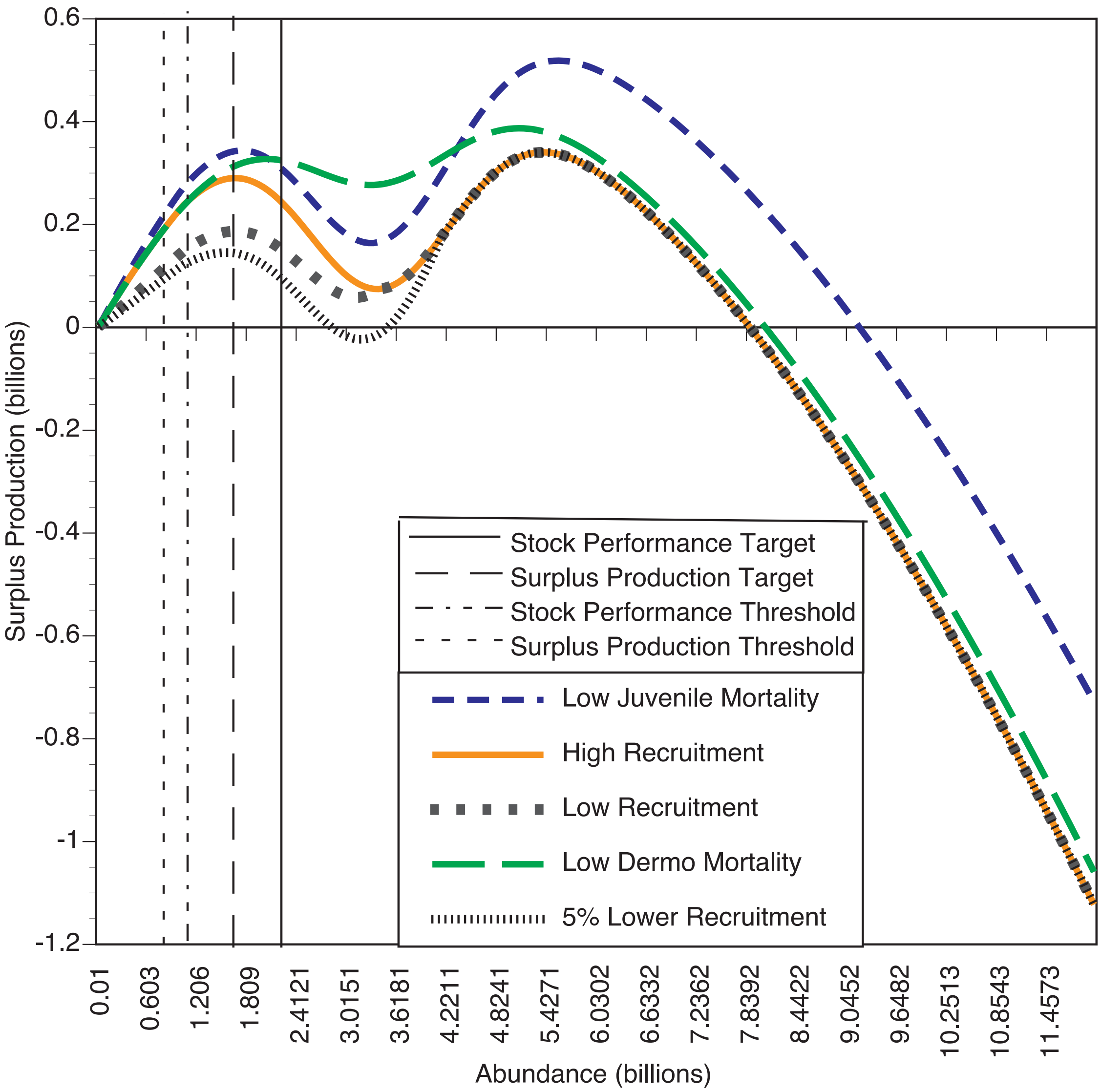


Figure 51. Summary status of the stock for 2008. Lime green indicates variables judged to be above average relative to the 1989-2008 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2008 time period or having a degrading trend relative to the previous year. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2008 time period, but sometimes determined by scientific judgment. Trends in light green indicate a change $< \pm 15\%$. Fraction of stock refers to the dispersion of the stock across the salinity gradient in the four bay regions. All percentiles are relative to the 1989-2008 time series. Parentheses are values that include the 2008 shell plants. The 2003-2007 median identifies comparisons between the 2008 value and the 5-yr median value from 2003-2007.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.25	0.16	0.13	0.28	0.11	0.08
Fraction of Stock (No Very Low)	Not Incl.	0.21	0.17	0.37	0.14	0.11
Total Abundance						
2008 Percentile	Not Incl.	0.08	0.28	0.18	0.73	0.13
2007-2008 Trend	Decreasing	Decreasing	Increasing	Decreasing	Increasing	Decreasing
Spawning Stock Biomass						
2008 Percentile	Not Incl.	0.61	0.92	0.71	0.87	0.08
2007-2008 Trend	Decreasing	Decreasing	Increasing	Increasing	Increasing	Decreasing
Recruitment						
2008 Percentile	Not Incl.	0.23	0.13	0.01	0.53	0.13
2007-2008 Trend	Increasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Spat per Adult						
2008 Ratio	0.39	0.22	0.11	0.11 (0.13)	0.50	0.89 (1.50)
2008 Percentile	Not Incl.	0.68	0.13	0.18 (0.26)	0.13	0.38 (0.69)
2008 Juveniles (fract.<2.5")	0.71	0.58	0.59	0.63	0.70	0.56
2007-2008 Trend	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing
2008 Percentile	Not Incl.	0.11	0.28	0.39	0.50	0.44
Dermo Infection Status						
2007-2008 Trend	Not Incl.	Increasing	Unchanged	Decreasing	Unchanged	Decreasing
2008 Mortality Rate	0.03	0.09	0.23	0.19	0.19	0.22
2007-2008 Trend	Decreasing	Increasing	Increasing	Decreasing	Decreasing	Decreasing
2008 Percentile	Not Incl.	0.48	0.93	0.58	0.53	0.33
Abundance Position vs						
Target	Not Incl.	Below	Below	Below	Above	Below
Threshold	Not Incl.	Below	Above	Near	Above	Below
SSB Position vs						
Target	Not Incl.	Above	Above	Above	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Near
2008 Surplus Production						
50^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive