Report of the
2010 Stock Assessment Workshop
(12^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

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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 1953-2009 period encompassing the entire survey time series and the 1989-2009 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 1989-2009 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 1989-2009 time series. All size-dependent indices begin in 1990 for reasons indicated previously. Evaluation of fishery exploitation by abundance focuses on the 1997-2009 time period during which the fishery has been conducted under a direct-marketing system. The direct-market program began in 1996, but the first full year of fishing under this program occurred in 1997.

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 the grids on each bed is assigned relative to the remaining grids on that bed 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 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

[‡] 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 $N_t = N_0 e^{-mt}$ with m in units of yr^{-1} and $t = 1\,yr$.

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 completely 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.

Finally, beginning in 2009, a few beds were resurveyed each year on a 10-year rotating schedule (Table 1). For this assessment, the strata for Bennies Sand and

[∅] 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.

Cohansey have been updated from 2008 based on the 2009 resurvey of these two beds. 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. Figure 1 shows the new bed footprint for Bennies Sand and Cohansey; Figure 2 shows the full range of grids sampled in resurveying Bennies Sand and Cohansey.

A comparison of the Bennies Sand and Cohansey grid systems prior to the 2009 resurvey (Figure 3) with the revised grid system after the 2009 resurvey (Figure 2) shows that the bed as a whole retained approximately the same shape; however, the distribution of high-quality and medium-quality grids was substantially changed, particularly for Cohansey (Figure 4). On Cohansey, two low-quality grids were redesignated high-quality grids, three medium-quality grids were redesignated high quality, and three low-quality grids were redesignated medium quality. Nine high-quality grids were redesignated medium quality and eight medium-quality grids were redesignated low quality. Thus a total of 25 of the 83 grids changed designations. Figure 4 shows that most grids increasing in quality were on the southeastern side of the bed. Most grids declining in quality were on the central bed region and to the northwest. The number of low-quality grids increased by four. The number of high-quality grids also decreased by four. The number of medium-quality grids increased by one.

For Bennies Sand, five medium-quality grids were redesignated high quality and five low-quality grids were redesignated medium quality. Four high-quality grids were redesignated medium quality and three medium-quality grids were redesignated low quality. Thus, 17 of the 49 grids changed designation. The number of low-quality grids declined by two. The number of high-quality grids increased by one and the number of medium-quality grids increased by one.

The October 2009 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 2 using the oyster dredge boat *F/V Howard W. Sockwell* with Greg Peachey as captain. The sampling intensity is shown in Table 2 and the specific grids sampled are shown in Figure 1. Total sampling effort in 2009 was 163 grids, a value considerably above 2008. These included 18 transplant grids selectively sampled because they were sites of 2007, 2008, and 2009 shell plants or 2009 intermediate transplants.

Evaluation of 2009 Survey Bias

No additional information on dredge efficiency was available for this assessment. Dredge efficiency correction factors were obtained from Table 3[∅]. A retrospective analysis of dredge efficiency from data collected during the 2009 survey using the equations of Powell et al. (2007)[∇] estimated a value of q for total oysters for the upbay region as 13.09 in contrast to a range of 7.30-9.40 from direct measurements in Table 3. The value of q for the downbay region from this retrospective is 8.53 in contrast to a range of 2.83 to 4.87 from direct measurements. Previous estimates of this type have produced values of q for the upbay region varying from being consistent with direct measurements to higher than direct measurements with no apparent pattern (Figure 5). Previous estimates of this type for the downbay beds have often produced estimates of q above direct measurement, particularly since 2005. The trend for these beds has been towards increasing estimates of q relative to the directly measured values. Values obtained for the 2009 survey are high in comparison to previous estimates, but within the envelope of previous estimates for the upbay beds. For the downbay beds, 2009 survey estimates are consistent with years since 2005, but distinctly higher than all but two other years (2008 and 2006). This suggests a possible decrease in dredge efficiency that, if true, would bias low the abundance estimates from the 2009 survey, particularly for the high-mortality beds and Shell Rock.

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 es-

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

∇ 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.

timates 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. Details of the retrospective quantification are provided by Powell et al. (2008)[ℵ].

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 3).

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 ≥ 76 mm and animals ≥ 63.5 mm, but <76 mm. These two size categories are based on the consistent knife-edge selection of oysters for market by the fishery, in which nearly all harvested animals are ≥ 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 2009 shell plants revealed that spat routinely exceeded 20 mm by early November, 2009 (Figure 6). This suggests that the 2009 recruitment index is biased low.

A summary of the per-sampled-grid dataset providing the 2009 survey database is given in Table 4. Table 4 also provides a summary of data for each bed on a

[ℵ] 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.

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 (Table 5). On a volumetric basis, 2009 abundance, bay-wide, was not significantly different from any year since 1989 except for 1990, 1991, 1992, and 1996. The bay-wide average number of 132 oysters bu^{-1} in 2009 fell below the 1990-2009 average of 163 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 remained unchanged from 2008, an abundance level lower than most years since 1988, but above the 2003-2005 time period, at 1,110,938,624. Including these upbay beds raises the total to 1,412,804,224 (Figures 7 and 8). Abundance in 2009 fell at the 10^{th} percentile of the 1953-2009 time series and the 18^{th} percentile post-1988, so abundance remains near historical lows (Table 6).

Most (47.2%) (37.1% including the very-low-mortality beds) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 9), a proportion somewhat below the 54.3% recorded in 2008, due primarily to a substantive decrease in oyster abundance on Middle and Upper Middle beds, but in keeping with the distribution of oysters in most years post-1995. Of this, 83.9% 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 57-year time series in continual above-median proportions of oysters on these beds (Figure 10). Abundance fell moderately from 2008, but remained consistent with values observed since 2002. Abundance on the medium-mortality beds ranked at the 4^{th} percentile (transplant beds) and 24^{th} percentile (market beds) of the 57-yr time series and the 1^{st} percentile (transplant) and 21^{st} percentile (market) post-1988 (Table 6). The number of oysters per bushel did not deviate significantly from the remainder of the 1990-2009 time series, with the exception of five years, all prior to 2001 (Table 7).

Abundance in 2009 on the low-mortality beds rose from 2008, but remained low relative to the historical record; the 13^{th} percentile for the 1953-2009 time series and the 26^{th} percentile for the post-1988 era (Table 6). Abundance was comparable, however, to most other years since 2002. The low-mortality beds contributing 21% of the stock in 2008, account for 33.2% of the stock at the end of 2009 (26.1% including the very-low-mortality beds) (Figure 9). The number of oysters per bushel differed significantly only from four years in the early 1990s within the 1990-2009 time series (Table 8). The increase in abundance between 2008 and 2009 is not fully explained by the balance between natural mortality and recruitment observed. A retrospective comparison of tow metrics (Table 3 – SAW-11) suggests that the 2008 point estimate may have been biased low. Abundance fell, however, from 2006-2007, while remaining higher than 2003-2005, suggesting that abundance has not changed materially on these beds since 2002.

Abundance also rose moderately in 2009 on the high-mortality beds, but remained below the 2006-2007 values. The entire high-mortality bed region contributed only 12.5% to the total stock (9.8% including the very-low-mortality beds), a value, however, consistent with the post-1999 time period (Figure 9). Abundance on the high-mortality beds ranked at the 11^{th} and 17^{th} percentiles, respectively, for the 57-year time series and the time series post-1988 (Table 6). The number of oysters per bushel differed significantly only from five years in the early and middle 1990s in the 1989-2009 time series, however (Table 9).

Abundance in 2008 declined dramatically, by 52%, on Shell Rock, from 2008 ending a four-year period of increasing abundance, principally as a result of the shell-planting program in 2005 and 2006. Shell planting did not occur on Shell Rock in 2007 and 2008. Shell Rock contributed 7.1% of the stock in 2009 (5.6% including the very-low-mortality beds) (Figure 9). Abundance on Shell Rock ranked at the 31^{st} and 31^{st} percentiles, respectively, for the 57-year time series and the time series post-1988 (Table 6).

The very-low-mortality beds contained 21.4% of the stock in 2009. 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 declined precipitously in 2009 (Figure 11). This ended four years of high SSB. As will be discussed subsequently, the observed decline is primarily a function of low condition indices in 2009, particularly on the upbay beds, rather than a decline in the spawning stock by number. 2009 SSB was at the 13^{th} percentile of the 1990-2009 time series (Table 6). SSB declined in all bay regions, with greatest declines upbay of the high-mortality beds. Greatest proportional declines occurred on Shell Rock, the upper group of medium-mortality beds, and the very-low-mortality beds (Figure 12). For the low-mortality beds, the medium-mortality beds, transplant and market, Shell Rock, and the high-mortality beds, the percentiles were the 28^{th}, 1^{st}, 23^{rd}, 18^{th}, and 8^{th}, respectively (Table 6).

SSB is highest on the medium-mortality beds in most years. In 2009, these beds contributed 52.4% of the stock's SSB (Figure 12). The low-mortality beds contributed an additional 23.1%. SSB was more concentrated on the medium-mortality beds in 2009 than during the 2004-2008 period, but still less than was routinely observed during the 1998-2003 time period. Shell Rock contributed 8.2% and the high-mortality beds, 16.4%. Including the very-low-mortality beds, the fractions of SSB contributed by the five bay regions are 13.4% (very-low-mortality), 20.0% (low-mortality), 45.4% (medium-mortality), 7.1% (Shell Rock), and 14.2% (high-mortality). These regional fractions are nearly identical to those observed in 2008, with the exception of a slight increase in contribution from the high-mortality beds, reinforcing the conclusion reached later that the drop in SSB was dominantly due to a decline in condition across most bay regions. The medium-mortality market beds contributed proportionately more to the medium-mortality fraction in 2009 than in 2008, however.

Oyster Size Frequency

Perusal of the 1990-2009 time series (Figure 13) shows that the fraction of the population $<2.5''$ was high in the early 1990s, then declined somewhat, and rose again through 2002. The fraction of animals below $2.5''$ has been low since then, varying only a little through 2009. In 2009, including the very-low-mortality beds, 61.6% of the animals were below $2.5''$ and 17.2% of the animals were $\geq 3''$ in size (Figure 14). Excluding them, animals below $2.5''$ contribute 58.9% of the stock; 20.0% of the stock exceeds $3''$. The number of animals $<2.5''$ remains well below historical highs, whereas the larger animals are near the decadal average and well above the average of the previous decade (Figure 14). Much of the shift in size frequency at the decadal transition is due ostensibly to the loss of small animals during an extended period of low recruitment after 1999, that extended through 2008. An apparent large recruitment event in 2007 failed to survive in significant numbers, probably due to the lateness of the set (October) in that year.

Small oysters accounted for 60.8% 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 15). The fraction of small animals on these beds has been unusually low since 2003: historical values routinely exceeded 70%. More than half of all animals (transplant beds, 54.4%; market beds, 56.1%) on the medium-mortality beds were $\leq 2.5''$ in size. This proportion is also low relative to historical levels set in the 1990s through 2002 that routinely exceeded 70%. Small oysters contributed 59.1% of the stock for Shell Rock, a level consistent with most of the 2000s, but distinctly below the proportions routinely observed in the 1990s, and 65.8% for the high-mortality beds, a relatively high value relative to much of the 2000s, probably the result of shell planting in this region, though lower than the typical proportion for the 1990s.

Thus, on no bed area did marketable oysters contribute the majority of the stock; however, on no bed did the small-oyster dominated size frequency of the 1990s exist. The time period since 2002 is characterized by a distinctly increased proportion of larger animals, with the low-mortality beds responding distinctly later (~2003) than the regions further downbay. Note in Figure 15 that a trend towards increased numbers of small oysters, albeit still well below the 1990s level, during 2006-2008, observed in many bed regions, reversed in 2009. The shift in size frequency between Fall 2007 and Fall 2008 towards smaller sizes was 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. The poor recruitment event of 2008 is reflected in the return to conditions earlier in the 2000s of a size frequency relatively enriched in animals of marketable size. Further discussion of the interpretation and importance of the transition to a lower fraction of animals $< 2.5''$ in size that occurred circa 2000 is provided in a later section.

Of the animals $\geq 2.5''$, 48.6% were $\geq 3''$ in size (Figure 16). 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. Large markets made up the larger percentage on the high-mortality beds: 62.2%. The proportion was almost even for Shell Rock: 45.2%, the medium-mortality transplant beds, 52.7%, and the medium-mortality market beds, 52.2%, but much lower for the low-mortality beds, 39.1%. In all bay regions, the fraction of marketable animals $> 3''$ is near historical highs.

The number of animals of market size ($\geq 2.5''$) remained relatively unchanged in 2009, a value at the 43^{rd} percentile of the 1990-2009 time series (Figure 17). The abundance of these larger animals increased on the low-mortality beds and the medium-mortality market beds, declined moderately on the high-mortality beds and declined more severely on Shell Rock and the medium-mortality transplant beds (Figure 18). By percentile, the number of marketable animals fell at the 78^{th}, 38^{th}, 53^{rd}, 53^{rd}, and 10^{th} percentiles for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and high-mortality beds, respectively, for the 1990-2009 times series. The trends in abundance of marketable animals are demonstrably insufficient to account for the strong decline in SSB noted in Figure 11.

Oyster Condition and Growth

Condition index fell in 2009 in comparison to three of the last four years to levels typical of the late 1990s-early 2000s (Figure 19). Condition declined throughout the bay, although marginally less strongly on the high-mortality beds (Figure 20); nevertheless, condition has not been this low bay-wide since 2003. Low condition accounts for much of the trend in SSB noted in Figure 11 and Table 6.

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 10).

Oyster Sex Ratio

A survey was conducted on each of the primary beds in June 2008 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 2009 survey data. The stability of the relationship of sex ratio relative to oyster size across years is not established, so that the estimates provided in Table 11 should be considered cautiously. The population in all bed regions is estimated to be about 40% female (Table 11). Oysters less than 2.5″ were about 75% male. Market-size animals were about 60% to 65% 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

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

al. (2001)[⊕]. Surplus production was estimated using the 50^{th} and 75^{th} percentiles 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 10).

Bay-wide surplus production projections for 2010 are positive, more than projected for 2009, but less than for 2008. Estimates for the high-mortality beds are low relative to other bed regions, but higher than projected for 2009 (Table 12). The reverse is true for Shell Rock, where 2010 projections are distinctly below those for 2009. Projections for 2010 are distinctly higher than for 2009 for the medium-mortality market beds, distinctly lower for the medium-mortality transplant beds, and distinctly higher for the low-mortality beds. 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. Table 13 reports an effort to more carefully compare the change in abundance of $> 3''$ oysters observed between 2008 and 2009 with surplus production projections of 2008 (SAW-11) under the 75^{th} percentile mortality-rate assumption and after adjustment for the observed 2009 natural mortality rate. The comparisons are approximate as no effort has been made to differentiate the fishery removals by size class, nor has the mortality adjustment taken into account the timing of intermediate transplant in 2009. Nevertheless, projections for 2009 from SAW-11 agree relatively well for the three largest bay regions; low-mortality, medium-mortality market, and high-mortality. For the low-mortality beds, projections overestimated observed values, but by less than a factor of two. For the medium-mortality market beds, observed increases in $>3''$ oysters fell below projections by about 20%. The projected and observed change for the high-mortality beds in which the 2009 projection was for little surplus production, was also an overestimate, however both indicated either a small increase or a modest decline in $>3''$ abundance after harvest. These three regions suggest that the projections can be accurate within a factor of about two, with a consistent bias towards overestimating outcomes.

Projections in 2009 for Shell Rock and the medium-mortality transplant beds failed to materialize in 2009, however. Both projections were positive, but abundance of marketable animals dropped precipitously. This differential remained

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[⊕] 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.

even after adjustment for the high rate of natural mortality in 2009 on the medium-mortality transplant beds. For both of these beds, the observed decline cannot be fully explained by the natural mortality rate observed or the fishery removals reported. For the medium-mortality transplant beds, a survey index biased low is likely the best explanation. For Shell Rock, one cannot discount errors in landings reports that would result in an underestimate of fishery removals. In all five cases, the tendency to overestimate surplus production suggests that either the growth rates used were higher than realized in 2009, that the relative timing of natural mortality and fishery removals was mis-specified such that the degree of compensatory mortality was poorly estimated, and/or that the estimates of natural mortality from box counts are biased low in 2009.

Recruitment

Spat set in 2009 though low by historical standards was one of the highest during the 2000s, exceeded only by 2007 and 2002. (Figures 21 and 22). This value is biased low, as 32-33% of the spat observed this year were greater than 20 mm long (Figure 6). 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 was above the long-term average for the 1990-2009 time series (Table 5). All significantly higher years occurred in the 1990s and all significantly lower years occurred in the 2000s. The 2009 level of 95 spat bu^{-1} fell above the 57-yr mean of 88 spat bu^{-1}, but not significantly so (Table 5). 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 1989-2009 mean, and significantly below only three years, all in the 1990s (Table 9). For the medium-mortality beds, the number of spat per bushel was significantly different from only two years in the 1990-2009 time series, both in the 1990s (Table 7). A relatively similar trend was observed on the low-mortality beds (Table 8).

The 2009 spat settlement ranked at the 33^{rd} percentile for the 1953-2009 time series and at the 45^{th} percentile post-1988 (Table 6). Recruitment estimated quantitatively for each bay region fell at the 20^{th}, 24^{th}, 40^{th}, 59^{th}, and 43^{rd} percentiles of the 1953-2009 time series for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and the high-mortality beds, respectively. The percentile values for the 1989-2009 time series, in the same order, were 26^{th}, 40^{th}, 50^{th}, 60^{th}, and 50^{th} (Table 6). The upbay-downbay gradient in recruitment in which recruitment tends to increase downbay, present in most years, was dramatically apparent in 2009.

The number of spat recruiting per oyster was the second highest since 1999, coming in at 0.87 (Figure 23), a value at the 67^{th} percentile of the 1953-2009 time series and at the 69^{th} percentile for the 1989-2009 time series (Table 6). 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. 2009 is no exception, as the ratio of spat to adult was 1.89 and 2.53 on Shell Rock and the high-mortality beds, respectively, while falling to 0.82 on the medium-mortality market beds, 0.52 on the medium-mortality transplant beds, 0.15 on the low-mortality beds, and 0.11 on the very-low-mortality beds (Figure 24). The respective percentiles for the 1953-2009 time series for the low-mortality, medium-mortality transplant, medium-mortality market, Shell Rock, and high-mortality beds are: 29^{th}, 52^{nd}, 62^{nd}, 82^{nd}, and 83^{rd}. Percentiles were similar for the 1989-2009 time series, through trending higher in most bay regions. The percentiles were 38^{th}, 69^{th}, 69^{th}, 93^{rd}, and 79^{th}, respectively (Table 6).

Shell planting had a substantive impact on the spat-to-adult ratio in 2009, raising it from 0.867 to 0.990. This differential occurred because spat on shell plants accounted for 31.1% of the spat on the Shell Rock and 16.4% on the high-mortality beds. Shell plants raised the spat-to-adult ratio significantly above 2 on Shell Rock and above 3 on the high-mortality beds (Table 14).

Recruitment-enhancement Program

Shell-planting was carried out in June-July, 2009. Ocean quahog and surf clam shell were used. Shell was planted in 2009 as follows: Nantuxent Point 24, 34,686 bu; Bennies Sand 15, 51,366 bu; Shell Rock 21, 58,233 bu (Figure 25).

Total spat were estimated from suction dredge samples, because the survey dry dredge biases the estimate high by a factor of 1.75, estimated in SAW-11. Projections of marketable bushels on the 2009 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 1989-2009 time series: for Shell Rock beds, 0.460, 0.194, 0.194; for the high-mortality beds: 0.475, 0.262, 0.262. Bushel conversions assume 261 oysters per bushel. 2009 shell plants are expected to provide 151,753 bushels for market in 2012/2013 (Table 15), assuming stock status permits allocation of all animals to harvest rather than maintenance of abundance. For this reason, the terms 'harvest potential' or 'potential yield' is used hereafter.

Yearlings on the shell planted in 2008 ranged from about 35 mm to 60 mm (Figure 26). The median survivorship for yearlings from 2008 in 2009 was 40%, but the estimates ranged from 16% to 82% (Table 16). The mean was 57.4%, higher than the bay's long-term average of 37%. Estimated harvest from the 2008 shell plants is updated using the 50^{th} percentile adult mortality rates in years 2 and 3 from the 1989-2009 time series: for Cohansey, 0.165; for the remaining beds: 0.262. Bushel conversions assume 261 oysters per bushel. A harvest potential of 88,389 bushels was estimated (Table 16). 2008 shell continued to attract spat in 2009; 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 63,579 bushels (Table 17). Thus, total potential yield from the 2008 shell plants is 151,968 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 18). 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. 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 2009 average shorter than estimates in 2008, 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 four beds with uncertain half lives (Table 18) were borrowed from neighboring beds. New Jersey oyster beds have

♮ 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.

been losing on the order of 500,000 bushels of cultch annually since 1999, with loss rates significantly higher during the period 2000-2003 (Figure 27). 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 1998-2009 time series versus the 1998-2008 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 updated half-lives estimated in this assessment and the those estimated in 2008 and 2009 (SAW-10, SAW-11).

The shell budget shows a gradual reduction in shell loss since 2003, with greater uncertainty in 2006 and 2007, and a more certain 2008 and 2009 value (Figure 27). Years 2007-2009 are the only years in the 1999-2008 time series when at least one estimate was near or above zero. In 2008, three of six estimates were 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. Thus, 2008 marked the first year where evidence suggested that the bay as a whole was in carbonate balance. For 2009, the estimates fall from near 0 to a loss of 500,000 bushels, with the best estimate of a loss near 300,000 bushels.

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 28). 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. Shell Rock showed a net gain in 2005, 2006, and 2009 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. Declines in 2008 and 2009 also reflect shell planting. This year, 2009, represents the second year in succession when all bed regions were within 200,000 bushels of shell balance. The decline in shell loss rates in 2008 and 2009 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 2009.

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 2009.

In general, Dermo disease* and mortality increase downbay as salinity increases. During 2009, water temperature approximated the long-term mean (Figure 29). Salinity was below average in the spring and early summer, but then exceeded the long-term average in September and October. The early average temperature followed by a late summer 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 2009, the prevalence and weighted prevalence of Dermo exceeded the long-term mean prevalence and weighted prevalence throughout the summer and fall (Figure 30). Values of weighted prevalence approached 3 on the Mackin scale; values above 2 are typically associated with epizootic conditions. Dermo prevalence and weighted prevalence were at or above the long-term mean over much of the bay (Figure 31), indicating that the Dermo epizootic in 2009 extended well up the bay and that conditions conducive to proliferation reached the low-mortality beds.

Since the onset of Dermo disease in 1990, two periods of epizootic mortality have occurred, each of them multi-year (Figures 32-33). 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 2007-2009, 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 of mortality suggests that the epizootic has peaked downbay and maybe receding. The time series suggests, however, that infection intensity continues to build in the medium-mortality region of the bay. 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 2010 unless extreme environmental conditions facilitate further development.

The long-term tends in weighted prevalence support the divisions of the bay into low-mortality, medium-mortality, and high-mortality regions (Figure 34).

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* 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 2009 disease monitoring program is available as an HSRL report: Bushek, D. 2010. *Delaware Bay New Jersey Oyster Seedbed Monitoring Program 2009 Status Report.*

The indication is that the high-mortality region can be divided into an inshore and offshore group of beds, the latter showing highest mortalities at a weighted prevalence somewhat above the former. Reasons for this dichotomy remain unclear.

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 22.8% bay-wide in 2009, excluding the very-low-mortality beds and 20.4% including them. This is a minor increase from 2008, and represents the third consecutive epizootic year (Figure 35). This is one of the highest mortality levels since 1999, and relatively high for the time series. Box-count mortality was at the 83^{rd} percentile of the 57-yr time series and at the 74^{th} percentile post-1988 (Table 6).

Mortality rates were high in most bay regions in 2009, unlike most years when mortality rates decline upbay (Figure 36). The mortality rate was 28.3% on the high-mortality beds, 22.5% on Shell Rock, 22.5% on the medium-mortality market beds, 26.7% on the medium-mortality transplant beds, considerably lower but still relatively high, 13.4%, on the low-mortality beds, and distinctly lower, 6.9%, on the very-low-mortality beds. Thus epizootic conditions extended upbay to the uppermost beds of the medium-mortality region and mortality rates were high for the region on the low-mortality beds. This marks the third year of historically high mortality rates upbay of Shell Rock (Figure 36).

The high-mortality beds contributed 41.4% of the total deaths in 2009, excluding the very-low-mortality beds, thus contributing substantively to the observed decline in market-size abundance, followed by 24.6% for the medium-mortality market beds, 13.0% for the low-mortality beds. 10.9% for Shell Rock, and 10.1% for the medium-mortality transplant beds. The third-place ranking for the low-mortality beds is unusual and reflects the extraordinary mortality rate observed in this bed region in 2009. Box-count mortality on the high-mortality beds fell at the 75^{th} percentile of the 57-year time series, but only the 55^{th} percentile of the post-1988 time series (Table 6). 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, 2009 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 71^{st} and

[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.

64^{th}, respectively (Table 6). Box-count mortality on the medium-mortality beds was unusually high. The 2009 level of mortality for the medium-mortality market beds was at the 80^{th} percentile for the 57-year time series and the 64^{th} percentile for the post-1988 time series. For the medium-mortality transplant beds, the respective percentiles are an astounding 94^{th} and 93^{rd} and for the low-mortality beds, an equally astounding 87^{th} percentile for the 57-year time series and 90^{th} percentile for the post-1988 period (Table 6). The rankings identify an unusual aspect of the 2007-2009 epizootic, namely that the medium-mortality beds have contributed an unusual share of the deaths (Figure 35) relative to other epizootics in the post-1988 period.

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 37). 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 57 and a rate half that occurs in 33 of 57 years, so that the expectation of a respectable recruitment event remains greater than 50%. The expectation, however, is lower since 1989 (Figure 37).

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 37, into quadrants by the medians of the x and y variables (Figure 38). 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 37 relating broodstock to recruitment, the distribution of points in the four quadrants (x/y = broodstock abundance/recruitment) is: low/low = 19; 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 19). 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 (Table 19). Since 1989, the distribution of points in the four quadrants is: low/low = 10; low/high = 4; high/low = 3; high/high = 3, based on the 57-yr medians (Figure 37). This distribution is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P = 0.014$, $P > 0.10$; $P > 0.10$, $P > 0.10$, respectively. That is, the relationship between broodstock and recruitment in the post-1988 era is very different from the random expectation. The 2009 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 to 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 39-40). Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about one-third (37%) of the years since 1989 (Figure 39). Non-epizootic years tend to average around 10% mortality. The bay-wide average for 2008 was 22.8%, an epizootic mortality rate. Year 2009 falls appropriately along the epizootic hump, although higher than other points at the same approximate abundance (Figure 40). The last two years of epizootic mortality have re-established the consolidated distribution pattern by reducing abundance on the high-mortality beds (Figure 10). However, the 2009 epizootic includes an uncharacteristically high mortality upbay of Shell Rock that, in this instance, contributes significantly to the high bay-wide mortality rate.

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 = 16; high/low = 16; high/high = 12 (Figure 39). 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 (Table 20). 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 = 10; high/low = 1; high/high = 5. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P = 0.014$; $P = 0.024$, $P > 0.10$, 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 41). The distribution of points in the four quadrants (x/y = recruitment/mortality rate) is: low/low = 14; 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. 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 2, high 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 = 9; high/low = 1; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P = 0.056$; $P = 0.019$, $P > 0.10$, retrospectively. The high recruitment-low mortality state has occurred only once since 1988. The high-mortality low-recruitment state has occurred relatively frequently, suggesting that low recruitment is more likely to occur when mortality is high, although low recruitment rates are also relatively common when mortality rate is low. Nevertheless, this tendency is consistent with the trajectory of the broodstock-recruitment curve at low abundance and suggests that the abundance decline associated with Dermo disease may also result in low recruitment rates.

Potential Food Limitation

An estimate of the within-bed reduction in food supply due to overfiltration is provided in Figure 42. The model is based on Wilson-Ormond et al.[⊙]. The model assumes simple upestuary/downestuary flow with or without vertical mixing with recovery of food supply between beds. Model estimates indicate reductions in food supply due to population density effects of no more than 10%, assuming vigorous vertical mixing and up to 34% assuming a more laminar flow. The former estimate is more likely to be correct based on the tidal current speed and homogeneous vertical structure typical of Delaware Bay waters over the oyster beds.

[⊙] Wilson-Ormond, E.A., E.N. Powell, and S.M. Ray, 1997: Short-term and small-scale variation in food availability to natural oyster populations: food, flow and flux. *P.S.Z.N.I. Mar. Ecol.* 18:1-34.

Harvest Statistics

Total harvest in 2009 was 80,690 bushels[♭] (Figure 43). This is above the 1996-2009 average of 73,293 bushels and marks the third consecutive year above the mean of the time series. Figure 44 shows the oyster removals 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.

Beds were harvested almost continually from April 6 to November 20, 2009. A closure occurred from June 15-28 for the Hope Creek intermediate transplant. Thirteen beds were fished. Highest catches were on Shell Rock, Ship John, Bennies Sand, and Bennies, where catches exceeded 9,000 bushels (Table 22). The recommended area management policy resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John, but a significant catch also occurred on Cohansey.

Seventy-three boats participated in the fishery and worked for a total of 1,072 boat-days. These included 43 single-dredge boats working for 806 boat-days (18.7 days/boat) and 31 dual-dredge boats working for 266 boat-days (8.6 days/boat). CPUE in 2009 was about the same as in 2008 and considerably higher than observed in 2000-2005. CPUE for single-dredge boats remained near 2006-2008 values. The 2009 dual-dredge-boat value rose from 2008, nearing the highest value on record; both, however, are the highest values since 1997-1998 (Figure 45).

Total dredging impact was estimated to exceed bed area in four cases[⊗] (Table 22): Bennies Sand, Shell Rock, Ship John, and Hog Shoal. Highest value was 2.67 on Shell Rock. Two other beds exceeded 2: Ship John and Bennies Sand[@].

♭ 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 $\geq$40%. This 40% rule was the first reference point and was used for management decisions from the late 1950s until 1995.

⊗ 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.

The number of oysters per 37-qt marketed bushel averaged 277 oysters per bushel in 2009. Of these, 230 were $\geq 2.5''$ (Table 23). 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 near average for the time series. The size of harvested individuals was very similar to previous years and nearly identical to 2008. 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 46).

Conversion of oysters to bushels for allocation projections used the value of 261 oysters/bu, the average of the five years 2004-2009 (median=260). This value is the mean 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 12,000 bushels of material from Middle to Bennies 110 in 2009. Oysters per bushel averaged 331 in this transplant. In addition, 2,000 bushels were transplanted from Upper Middle to Bennies 110, 10,400 bushels were transplanted from Arnolds to Bennies 101, and 9,100 bushels were transplanted from Hope Creek to Ship John 27. Oysters per bushel averaged 263, 475, and 621, respectively, for these transplants. Cullers were used for all transplants. The movement of oysters to the high-mortality beds from Arnolds and Middle, and to the medium-mortality beds from Hope Creek followed recommendations from SAW-11. Bed-average values of 399 oysters per bushel for Hope Creek, 124 oysters per bushel on Middle, and 335 oysters per bushel on Arnolds (Table 4) suggest that these 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 transplant beds (medium-, low-, and very-low-mortality) (Figures 47 and 48). In comparison to the 2005-2008 period, the upbay beds contributed a relatively high fraction. This is in keeping with the SAW-11 recommendation to expand the intermediate transplant program to a scale routinely employed in the 1997-2003 time frame.

Real fishing mortality was 1.5% of total abundance in 2009, excluding the very-low-mortality beds, and 1.5% including them, whereas apparent fishing mortality was 2.8% (2.5% including the very-low-mortality beds) (Figure 49). The increment reflects the intermediate transplant program that transplanted oysters downbay in 2009. Fishing mortality has been below 2% every year since 1995. 2009 fishing mortality was at the 30^{th} percentile of the 57-yr time series excluding closure years, and at the 58^{th} percentile of years post-1995 (Table 6). By bed region, the percentiles were 63^{rd}, 46^{th}, and 8^{th} for the high-mortality beds, Shell Rock, and the medium-mortality market beds respectively (Table 6). The low exploitation rate on the medium-mortality beds, relative to the recommendation of the 100^{th} percentile exploitation rate by SAW-11 and its implementation for 2009 is due to the transplant of animals to this bed region from the very-low-mortality beds that offset much of the removal (Figure 48).

Fishing mortality, by SSB, was 2.2% in 2009 (Figure 50). Fishing removed 3.8% of the animals $\geq 2.5''$ in 2009 (Figure 51). This is a relatively high value relative to the 1996-2009 time series, falling at the 65^{th} percentile, but still low, and suggests that the fishery was not unduly exploitative when referenced to the exploitable portion of the stock. Percentiles by bay section are tabulated in Table 6.

By bay section, fishing and management activities removed 1.0%, 2.6%, 1.0%, 6.0% and 5.0% of the animals from 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 and the absence of intermediate transplant to this bed in 2009.

Results of 2009 Experimental Fishery

SAW-11 proposed two experimental fisheries for 2009. The first of these was a trial removal of oysters from the very-low-mortality beds. These beds have not been previously exploited, so that no exploitation record exists on which to base management decisions. The recommendation was set at the 40^{th} percentile exploitation rate for the medium-mortality transplant beds, 0.0127, or 5,032,780 oysters. Figure 52 shows the abundance trends for the three very-low-mortality beds. A decline was observed on Hope Creek. However, declines were observed on the other two beds. Box-count mortality was estimated at 6.9% for this region in 2009, however no time series exists to judge the severity of this outcome. We note that the mortality rate on the low-mortality beds fell at the 90^{th} percentile of the 1989-2009 time series, so that the value of 6.9% is likely to be high. Regardless, similar declines in abundance occurred on all three beds. Similar comparisons for SSB, marketable abundance, recruitment, and mortality provided equivalent conclusions. Stock status on Hope Creek did not deviate in any obvious way from that observed on the other two very-low-mortality beds. Thus, the experimental fishery with an exploitation rate of 0.0127 would appear to have been inconsequential in its impact on the stock.

The second experimental fishery was an increased exploitation rate on the medium-mortality beds. In this case, the exploitation rate was set at the 100^{th} percentile of the time series, 0.0398 or 24,634 bushels. Figure 53 and other information presented earlier suggests that this exploitation rate did not materially influence the stock; however, the Hope Creek intermediate transplant to Ship John resulted in total exploitation rate for the bed region falling well below the target 0.0398 (Figure 48). Market-size abundance increased in 2009 and the increase was realistic relative to 2009 surplus production projections debited by the reported removals by the fishery (Table 13), so that no information from the 2009 survey of this region suggests that the increased exploitation rate resulted in overharvesting in this bed region; however, the intermediate transplant that occurred made any other outcome unlikely.

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 24). 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 7-9), the increased stock consolidation upbay (Figure 10), the change in size composition from a small-oyster dominated stock to a stock enriched in animals $\geq 2.5''$ in size (Figures 13-14), and the tendency towards the end of the 2000s for epizootics to be characterized by a higher fraction of mortality upbay of the high-mortality beds (Figure 35). 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 2009 abundances is unclear.

The volatility in condition resulted in a large change in SSB in 2009 relative to marketable abundance (animals $\geq 2.5''$). This suggests that a less volatile analogue to the comparison between abundance and biomass in Table 5 might be a comparison between abundance and marketable abundance. Regional reference points for this third axis are provided in Table 24.

Surplus production is expected to be significant on the low-mortality beds for 2009 (Table 12). The low-mortality beds are below the abundance target, but above the abundance threshold (Figure 54). Abundance rose relative to 2008 and is near the median for the the 2005-2008 period. The low-mortality beds are below the SSB target, but above the threshold. SSB is distinctly below SSB levels observed during the 2005-2008 period (Figure 54). Market abundance remains well above the target, as it has been since 2004, with values representative of the 2005-2008 period (Figure 55). Recruitment was low relative to adult abundance in 2009.

Surplus production is expected to be significant on the medium-mortality beds for 2009 (Table 12). The medium-mortality beds are at or below the abundance threshold, with a distinctly lower status apparent for the transplant beds. Abundance declined relative to 2008 on the transplant beds and remained relatively stable on the market beds. Abundance fell below the values observed for the 2005-2008 period for the transplant beds and near the median value for the market beds. The decline on the transplant beds exceeds what can be explained by observed fishery removals and the box-count mortality rate, suggesting that some fraction of the decline may be due to a survey index that is biased low. However, the 2007 abundance was also relatively low suggesting, rather, that the 2008 survey index may have been biased high. Independent information is not available to comment further on these possibilities. SSB is below the SSB target in both cases, and below the threshold for the transplant beds (Figure 54). SSB levels were well below those observed in the 2005-2008 period in both cases. Market abundance on the transplant beds fell below the target in 2009, but remains well above the threshold, though distinctly lower than during the 2005-2008 time period (Figure 55). Market abundance remains above the target on the market beds and at a level consistent with levels observed in the 2005-2008 period. The number of spat recruiting to the medium-mortality beds per adult fell above the 67^{th} percentile in both regions.

Surplus production is expected to be positive on Shell Rock in 2009 (Table 12). Abundance on Shell Rock is below the abundance target, but above the threshold. Abundance is below values seen since 2005. SSB is below the target and above the threshold. SSB fell at its lowest level for the 2005-2009 period (Figure 54). Market abundance fell above the target in 2009, while falling at a level relatively low relative to most years of the 2005-2008 period (Figure 55). Recruitment was well above average in 2009 for the post-1988 era by number or spat-per-adult ratio and the shell-planting program resulted in a substantial increment over this already high value.

Surplus production is expected to be modestly positive on the high-mortality beds in 2009. The high-mortality beds remain below the abundance threshold. Abundance is higher than in 2008, but lower in 2009 than in any other year since 2004. SSB is below the SSB threshold for the first time in many years (Figure 54). Market abundance fell below the target in 2009 while remaining well above the threshold (Figure 55). Until 2009, market abundance has not been below the target since 2004. The number of spat recruiting was high for the post-1988 era and the number of spat per adult was above the 75^{th} percentile. Shell planting increased this already high number resulting in a spat-per-adult ratio exceeding 3.

These reference points can be compared further 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 2000-2005 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. Second, the simulated surveys were sorted by the total number of oysters. 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 relationship of the abundance and market-abundance reference points provided in Table 24 and figured in Figures 54-55 are compared to the uncertainty surrounding the 2009 point estimate for each bay region in Figures 56 and 57. These generally confirm the significance of the position of the 2009 point estimate relative to the Table-24 stock-performance reference points; however, exceptions exist.

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 2009 stock status. The SARC considered three whole-stock abundance targets. The first two are the sum of the area-specific abundance and marketable-abundance targets listed in Table 24. The third was derived more theoretically from an analysis of biological relationships and formulation of a surplus production model[Φ]. The surplus production model used the 1953-2009 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 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 25)[Ψ].

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 37), and the use of an adult mortality curve with an 'epizootic hump' of various amplitudes (Figure 39). Surplus production modelling

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

[Ψ] 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.

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 58); thus, N_{msy} values can be obtained, but f_{msy} estimates cannot. Of the five simulations shown in Figure 58, 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 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 and focuses attention on growth rate as a primary reason for that model's overestimation of surplus production in 2009 (Table 13).

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. For the stable-state surplus-production model, an abundance target can be defined as the lower maximum in surplus production (Figure 58). The SARC did not identify a preferred simulation. For comparison to 2009 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. The two respective values are: 1.628 billion and 0.814 billion. Stock-performance 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 (Table 24). These are based on total abundance and total marketable abundance. For total abundance, the target is the sum of the median stock abundances for that period and the threshold is half that value (Table 24). The two respective values are 2.261 billion and 1.130 billion. The equivalent reference points based on marketable ($\geq 2.5''$) numbers from Table 24 are 346.8 million and 173.4 million.

The SARC during SAW-10 opined that the stock-performance target for the whole stock (2.261 billion) may be too high to be used as an abundance goal, because the value falls near the surplus production low between the two stable states in Figure 58 and may, therefore, be difficult to achieve. On the other hand, the N_{msy} estimate from the surplus production model, by falling at the surplus-production peak, 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 an abundance goal 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. However, a specific target number was not set at SAW-10 and the two alternative abundance goals are carried forward here.

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 2009 abundance is 1.111 billion animals excluding the very-low-mortality beds, of which 455 million are $\geq 2.5''$ in size. The point estimate of 1.111 billion animals falls near the 40^{th} percentile of abundance with the 80% confidence limits being 1.031 and 1.277 billion animals (Figure 59, Table 26), suggesting that the 2009 point estimate may be low relative to expectation from the variability in survey samples and dredge efficiencies. This is consistent with earlier comments concerning the likelihood that the downbay beds are underestimated due to a time-dependent change in dredge efficiency since 2003. The marketable abundance of 455 million falls near the 70^{th} percentile of abundance with the 80% confidence limits being 369 and 478 million animals (Figure 60, Table 27), suggesting that the survey index for marketable animals may be high.

Assuming that N_{msy} is the target and the threshold is half that value, the oyster beds are below the target and at or above the threshold based on the surplus production and stock performance values. The N_{msy} estimate falls above the 90^{th} percentile of abundance (Figure 59). Thus, 2009 abundance is significantly below the target value. However, the threshold value of 0.81 billion falls below the 10^{th} percentile of abundance. Thus, 2009 abundance falls well above the threshold value. A similar comparison against the stock-performance reference points for total abundance 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 (Figure 59). Application of the marketable abundance reference point to an equivalent set of percentiles (Figure 60) reveals that the stock-performance threshold is well below the 10^{th} percentile; the stock-performance target, however falls near the 10^{th} percentile. The survey index for this measure, therefore, falls distinctly above the threshold and the target falls barely within the 80% confidence limits of the 2009 survey estimates.

Mitigating facts should also be taken into account in evaluating the stock relative to these reference points. These include the high estimates of 2009 surplus

[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.

production, the significant recruitment event of 2009, the expectation that natural mortality rate will drop in 2010, the continuing proportionately high numbers of marketable oysters in most bay regions, and the caution raised at SAW-10 that the whole-stock 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 $\leq 2.5''$.

Summary of Stock Status and Population Management Goals

Figure 61 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 1989-2009 period (Table 6). 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 (Figure 49).

In 2009, the stock presents a mixture of positive and negative indicators that approximately balance (Figure 61). Abundance is low and decreasing in three of six bay regions relative to 2008. Abundance is near historical lows in several bay regions. Abundance is below target levels in all bay regions and below threshold levels on the medium-mortality transplant beds and the high-mortality beds. Near-historically high recruitment downbay of the low-mortality beds in 2009 provides an opportunity for a significant increase in abundance on these beds in 2010. However, the SARC continues to recommend augmentation of natural recruitment with a vigorous shell-planting program as the long-term trend in recruitment since 1999 does not augur favorably for above-average recruitment events in the coming years. The decline in abundance in 2009 is essentially completely explained by a third year of epizootic mortality. The stock continues to be disproportionately consolidated on the medium-mortality and low-mortality beds. However, the very-low-mortality beds contain about 20% of the total stock.

Spawning stock biomass fell to low levels bay-wide and in all bay regions (Figure 61). Much of this decline is due to a decline in condition rather than market abundance. SSB fell below the biomass target in all bay regions, but above the threshold in three of five, falling below the threshold for the high-mortality beds and just below the threshold for the medium-mortality transplant beds. In contrast, marketable abundance fell above the target in two bay regions and near or just below the target in the other three. Marketable abundance fell well above the threshold in all bay regions.

The 2009 recruitment was well above average or near historical highs on a spat-per-adult basis downbay of the low-mortality beds. Based on total recruits, the 2009 spatfall was near average for the 1989-2009 time period, a position not attained previously over such a wide bay region in the 2000s. Thus, 2009 was a good recruitment year by any measure. Recruitment declined upbay, as is normally the case, but the decline in 2009 was pronounced with low recruitment rates on the low-mortality and very-low-mortality beds. Spat-per-adult ratios exceeded 0.5 in four of six bay regions and exceeded 1.0 in two bay regions, Shell Rock and the high-mortality beds. Shell planting added considerably to the natural spatfall on Shell Rock and nontrivially on the high-mortality beds. The oyster population as a whole continues to be depauperate in the smaller size classes; however, it is unclear whether this condition should generate concern as marketable abundance has been relatively stable over time while small-animal abundance has declined[ħ]. Surplus production is expected to permit an increase in marketable 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 2009 and natural mortality rates were well above average on Shell Rock, the medium-mortality beds, and the low-mortality beds, reaching near historical highs on the low-mortality beds and the medium-mortality transplant beds. An increasing trend in Dermo disease weighted prevalence throughout the medium-mortality region of the bay gives little confidence in any relaxation of epizootic conditions in 2010. However, the present epizootic is in its third year, a stretch of time rarely exceeded for this disease.

Fishery exploitation levels since 1989 have been low ($<2\%$ of abundance per year). Exploitation in terms of biomass and market abundance has been $\leq 3\%$ for most of that time. Exploitation rates were near average in 2009 in most bay regions, but at near historical highs on the low-mortality beds. However, these exploitation rates were still below 2.5% of the marketable stock by number above Shell Rock and 7%-10% of the marketable stock on the high-mortality beds and Shell Rock, respectively. The realized exploitation rate on the high-mortality beds, however, was low due to an abundance subsidy by intermediate transplant. Overall, Shell Rock and the transplant beds supported the bulk of the 2009 fishery. Low

[ħ] The SARC discussed at length the interpretation of the relative abundance of animals $<2.5''$ prior to 2000 relative to the 2000s in comparison to the stable trends in marketable abundance. Possibilities given credence include a significant increase in growth rate post-1999 and a significant change in the dynamics of juvenile mortality in the same time frame. Insufficient information is available to provide a substantive explanation for the change in proportional small-animal abundance, however.

exploitation rates indicate that the fishery does not have a significant effect on the stock as a whole, and this is also supported by stable market abundance in all bay regions (Figure 17). Stock-wide, fishing mortality is not responsible for the current conditions of low abundance that exist throughout the stock, although it has contributed to the depressed levels downbay of the medium-mortality beds.

In summary, the fact that all bay regions fell below their abundance targets indicates that actions to enhance abundance are needed; however the abundance-based reference points based on the 1989-2005 time series may over-emphasize the seriousness of this situation. Nevertheless, whole-stock abundance also falls well below the N_{msy} reference point, indicating that measures to enhance abundance are desirable. The SARC recognizes the difficulty of achieving this goal under epizootic conditions, but anticipates a relaxation of the present epizootic based on the historically cyclic nature of Dermo disease. A reduction in fishing effort will not address this need because exploitation rates are already low. Thus, other approaches are needed. In addition, the importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining marketable abundance near or above target levels. All bay regions are near or above target levels at the present time. Thus, management measures have been successful in accomplishing this goal. This suggests that the present approach to setting exploitation rates, the area management program, and the intermediate transplant program have been implemented in a sufficiently precautionary way to maintain sustainable marketable abundance.

The high-mortality beds are in poor shape after three epizootic years, regardless of the metric used for evaluation, however the 2009 intermediate transplant and a relatively higher and more predictable recruitment potential have minimized the drop in abundance relative to the three-year trend in natural mortality, so that conditions have not deteriorated to the degree that might otherwise have been expected. The SARC recommends that the intermediate transplant program continue to subsidize these beds until the present epizootic ceases, permitting natural recovery of abundance on these beds. Nevertheless, conditions are sufficiently poor on the high-mortality beds to engender increased precaution in managing them unless a substantial intermediate transplant program accompanies a higher exploitation rate. That is, 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 or intermediate transplant is used to import submarket-size animals. The SARC is particularly concerned with Shell Rock which saw a significant decline in abundance in 2009 and recommends precaution in management of this bed in 2010. Here, the SARC recommends a reduction in exploitation rate along with augmentation of abundance by intermediate transplant. The SARC strongly recommends continued shell planting this year as responses to the deteriorating conditions on the high-mortality beds and Shell Rock.

Conditions remain ambiguous on the low-mortality beds as abundance remains stable at a relatively low level relative to the abundance targets, whereas marketable abundance is above the target, while recruitment continues at a low level, a condition, however, that has existed since the late 1980s. No indication that intermediate transplants of previous years have significantly depressed abundance on the low-mortality or very-low-mortality beds is evident in this assessment. Thus, previous exploitation levels appear appropriate. The SARC continues to advise that the exploitation level on the very-low-mortality bed be kept low until a longer time series of performance can be obtained.

Overall, the conditions on the medium-mortality market beds are distinctly more advantageous than other bay regions. Surplus production projections remain very high and total abundance and marketable abundance are increasing with marketable abundance near target levels. The SARC notes that last year's increased exploitation rate was mitigated by intermediate transplant, preventing the desired evaluation of the degree to which these beds could withstand a greater harvest and recommends that the experimental fishery initiated in 2009 be retained in 2010, with commensurate re-evaluation of its effects at SAW-13.

The SARC expressed particular concern over the drop in abundance in 2009 on the medium-mortality transplant beds. However, the SARC also noted that Sea Breeze, now considered a medium-mortality market bed, is rarely fished and recommends that this bed be considered for intermediate transplant rather than Middle and Upper Middle in 2010. This will permit a one-year recovery and re-evaluation of stock trends on these latter two beds, while retaining an intermediate transplant from the medium-mortality region downbay.

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 2009, although conditions have worsened since 2008. Thus, a reduction in shell planting in 2009 has resulted in a deterioration in shell balance that will continue, unless redressed. Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell and this was dramatically apparent in 2009. 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. The SARC recognizes that inadequate funding may result in minimal shell planting in 2010 and warns that such an outcome may result in reduced quotas in 2011 if natural sources of production do not fortuitously counterweigh a consequent expected decline in marketable abundance. Design of a 2010 program, funds permitting, should consider the following recommendations.

1. The area of greatest concern is the high-mortality bed region, as total shell loss is normally highest in this region, in part due to low marketable abundance that is the outcome of persistent high mortality rates from Dermo disease. Shell planting should target beds in the upbay portion of this region, such as Bennies Sand and Nantuxent Point.

2. Shell Rock has demonstrated exemplary performance under shell planting. Shell was planted on Shell Rock in 2009 following a two-year hiatus, the results of which are evident in the declining conditions on this bed. Declining abundance on this bed is in part a result of this hiatus. Maintaining high production on Shell Rock is important. Thus, shell should also be planted on Shell Rock in 2010.

3. The SARC notes that the low-mortality beds, because of their continuing closure to direct harvest, would be a location for shell plants with funding that requires some time period of closure thereafter. Such plants should be conducted with spatted shell obtained from a downbay plant-replant program as recruitment performance is too uncertain on these beds to make direct shell planting a viable alternative.

2009 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 2009 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 levels than typical of down-bay regions. The primary reason for this was the use of all of the medium-mortality beds for intermediate transplant through 2003, when the region was first divided into market and transplant beds. Prior to then, a tendency to target Ship John and Cohansey for intermediate transplant kept exploitation of beds farther upbay artificially low. As a consequence, 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 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 continues to recommend that the medium-mortality market beds be identified 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.

In addition, SAW-10 evaluated the exploitation rates for the medium-mortality transplant beds. These are weighted in the early years by low values due to the tendency to transplant from Ship John and Cohansey pre-2003, as the area-management program implemented at that time included all medium-mortality beds in one management region. As a consequence, the exploitation rates for the transplant beds apportion themselves into two groups, a very-low group and a high group that is temporally biased, and dichotomized at the 50^{th} percentile. To provide more range of outcomes for management, an intermediate value, 0.188, was added as the 50^{th} percentile, this being the average between the original 50^{th} and 60^{th} percentile values (Table 29). That value is carried forward in the projection tables that follow.

Exploitation rates can be calculated based on real removals and apparent removals (Tables 28-29). 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 did not occur during the time frame used for establishing the exploitation rates. 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. In keeping with the precedent set at SAW-11, the 100^{th} percentile is provided for the medium-mortality market beds. This level of fishing was recommended by SAW-11 as an experimental fishery based on the continuing large inequity between the historical exploitation values and the surplus production projections which routinely exceed the historical values by a significant margin. It is the SARC's recommendation that this experimental fishery continue in 2010.

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. 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 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 (Table 30)

In 2009, the high-mortality beds continue to be at low abundance, but marketable abundance remains above threshold levels even after three 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 short term. The intermediate transplant program has been successful in this regard. 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} or 60^{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 near the abundance threshold and near the marketable-abundance target, a position distinctly poorer than in recent years. The SARC recommends that the fishing level be limited to the 40^{th} percentile and that this be accompanied by an intermediate transplant. A 25^{th} percentile exploitation rate is provided if intermediate transplant is not included in the management

[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.

program.

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 two of the three medium-mortality beds, Cohansey and, Ship John continue to be managed as direct-market beds. The SARC notes subsequently the desirability of managing Sea Breeze as a transplant bed. Despite higher than average mortalities during the three-year epizootic of 2007-2009, substantial catches in 2007-2009 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance. Thus, these beds have been relatively resilient under the low exploitation rates used to date. High levels of surplus production are again anticipated for 2010. 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 continuation of the experimental fishery begun in 2009 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 during the survey.

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 2009 and also to adjacent beds in 2010.

5. The Shell Fisheries Council must recognize that the 2010 recommendation *does not set a precedent* for future years. Should the bed respond poorly, the SARC will recommend a more conservative approach which could mean reinstitution of the earlier reference points and may recommend lower exploitation rates to aid bed recovery. Shell planting would also be an important factor in this restoration effort.

Projections are provided in Table 30 for the high-mortality beds, Shell Rock, and the market group of medium-mortality beds (Cohansey, Ship John, Sea Breeze). Projections are provided also for the medium-mortality beds restricted to Cohansey and Ship John, in case the Council determines that use of Sea Breeze as a transplant bed is advantageous. This option is discussed in the following section.

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant (Table 31)

The SARC strongly supports the inclusion of an intermediate-transplant program and emphasizes the urgent need for this program as a vehicle to repair the damage of three years of epizootic mortality on the high-mortality beds and Shell Rock. The medium-mortality transplant beds (Middle and Upper Middle), however are below the abundance and marketable-abundance targets and the abundance threshold. Thus, the SARC supports inclusion of Sea Breeze as a transplant bed in 2010 with the intermediate transplant program targeting this bed for this bay region. The SARC discourages the use of a high exploitation rate if Middle and Upper Middle are the primary transplant beds in 2010. The use of either the 40^{th}, 50^{th}, or 60^{th} percentile exploitation rates may be considered otherwise as none of these exploitation rates is high and Sea Breeze has been little fished during the direct-market time period (1996-2009).

The low-mortality beds are above the marketable-abundance target, but below the abundance target. 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 consequently is limited, despite the lower rate of natural mortality. However, surplus production is projected to be substantial in this bed region in 2010 and the region contains an usually large number of large oysters relative to the 1989-2009 time series (84^{th} percentile). This may not be a stable situation over the long term for these beds. The SARC, therefore, recommends that this region be included in the intermediate transplant program in 2009, and that the 60^{th} percentile exploitation rate be included as an option with cullers used to target the larger animals. However, the SARC recommends that Arnolds, which sustained the 2009 program, not be included, if possible, as a major contributer to the 2010 program. Otherwise, a lower exploitation rate would be recommended.

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. The SARC further recommends that Hope Creek not be the target bed in 2010, as it sustained the 2009 program.

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 and Shell Rock. A significant portion of the program should be carried out prior to harvest commencing on these bed regions. The SARC is sensitive, however, to the closure rules associated with the transplant program and recognizes that the Council will need to maintain some beds open for harvest at the beginning of the season.

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, but also the need to support abundance on Shell Rock, the SARC recommends that Shell Rock be a preferred location to receive these transplants.

Projections for intermediate transplant are provided in Table 31.

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. Hope Creek should be added to the program.

A spat settlement monitoring program should be carried out.

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, examination of a biomass- or volume-based calculation should be carried out to determine if B_{msy}-based reference points can be used to establish improved Schaeffer-style reference points.

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

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

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. Given the results of the initial retrospective in Table 13, developing this retrospective model is strongly encouraged.

Spat growth rates upbay of Shell Rock are needed to reconfigure the recruitment index and retire the 20-mm rule.

The Cohansey Point and Channel Beds should be erected as discrete beds in the survey database.

An observer program should be initiated to determine the usefulness of these data to assess changes in grid quality between re-surveys and also to assess reporting accuracy. This might include a Boatracs ssytem.

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

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

The relationship between condition and other population and disease variables should be investigated.

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 1. Ten-year re-survey schedule for the Delaware oyster beds. 2009 is Year 1.

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

Table 2. 2009 sampling scheme for the November survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of samples devoted to that bed stratum. Ledge 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	5	5	0	2
Ship John	3	4	0	5
Middle	2	3	0	1
Sea Breeze	3	2	0	0
Shell Rock	4	4	0	1
Bennies Sand	3	6	0	3
Bennies	3	9	0	2
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	0
Egg Island	1	7	0	0
Ledge	0	0	0	0
Total	56	89	0	18

Grand Total: 163

Table 3. 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 4. Results of the 2009 random sampling program for the Delaware Bay natural oyster beds of New Jersey. Included for comparison are data for 2007 and 2008. 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[ℑ].

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

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Hope Creek	2.0	59.6 H	75.7 H	56.0 H																								
Hope Creek	2.2	54.3 M	70.6 H	49.8 H																								
Hope Creek	3.2	52.8 H	60.7 H	44.7 H																								
Hope Creek	2.0	52.4 M	60.6 H	29.3 M	399	403	334	32	116	93	6	3	5	05	20	0	0.25	0.13	.00	110	103	41	27	26	12	0.006	0.008	0.009
Hope Creek	4.3	47.8 H	54.1 M																									
Hope Creek	3.9	42.8 H	49.1 M																									
Hope Creek	2.1	37.7 M	48.2 M																									
Hope Creek	0.9	37.3 M	29.2 M																									
Liston Range	2.8	73.5 M	78.0 M																									
Liston Range	2.4	59.6 H	58.3 M																									
Liston Range	0.6	57.8 H	53.6 H		428	336		29	91		4	3		10	25		0.05	0.48		139	128		32	38		0.006	0.010	0.017
Liston Range	0.1	57.3 M	49.3 H																									
Liston Range	2.2	46.9 M	31.1 M																									
Liston Range	0.6	40.2 M	20.0 M																									
Fishing Creek	1.7	64.3 H	64.2 M	63.3 M																								
Fishing Creek	1.3	63.0 M	63.6 H		331	293	293	28	40	56	7	3	4	20	65		0.50	0.70		164	153	118	49	52	40	0.007	0.012	0.026
Fishing Creek	0.0	60.2 M	56.0 H																									
Fishing Creek	0.4	44.0 M	55.0 M																									
Fishing Creek	1.5	37.6 H	49.6 M																									
Round Island	4.5	56.2 H	55.0 M	51.9 M																								
Round Island	1.5	46.8 M	51.1 H	46.0 H	260	191	206	23	22	67	10	6	7	50	80	25	0.90	1.20	.35	118	100	93	45	52	45	0.007	0.014	0.010
Round Island	2.4	45.9 H	40.1 H	28.0 H																								
Round Island	0.4	35.2 M	24.4 M	23.9 M																								
Round Island	0.7	17.7 M	14.4 M	17.7 M																								
Upper Arnolds	4.5	65.3 H	68.9 H	55.4 M																								
Upper Arnolds	3.2	64.2 H	64.7 H	50.6 H	343	371	249	29	53	76	15	10	6	65	90	60	1.40	1.38	.73	149	160	115	43	43	46	0.007	0.015	0.012
Upper Arnolds	0.6	61.3 M	59.5 M	48.9 H																								
Upper Arnolds	5.2	46.9 M	58.0 M	34.0 M																								
Upper Arnolds	3.0	46.5 M	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		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Arnolds	3.7	64.3 H	73.3 H	53.1 M																								
Arnolds	3.9	54.7 H	60.5 H	48.9 H																								
Arnolds	1.5	53.4 M	59.3 M	44.2 H	335	258	180	42	37	66	16	9	7	55	95	60	1.48	2.10	1.18	121	130	87	36	50	48	0.006	0.016	0.012
Arnolds	2.2	52.5 H	58.2 H	41.4 H																								
Arnolds	4.9	49.5 M	56.4 M	31.3 M																								
Arnolds	1.0	41.1 M	11.9 M	16.1 M																								
Upper Middle	1.9	34.6 M	34.3 H	65.8 M																								
Upper Middle	1.4	19.7 M	31.4 M	42.1 M	80	115	195	30	10	85	28	26	16	85	95	75	2.48	2.23	1.68	37	49	126	47	43	65	0.007	0.012	0.013
Upper Middle	1.4	19.5 H	15.1 M	41.4 H																								
Upper Middle	0.0	0.0 M	6.2 M	24.9 M																								
Middle	2.8	75.4 T	71.6 T	49.5 T																								
Middle	3.7	49.5 H	51.9 H	33.5 M																								
Middle	2.8	38.7 H	48.0 M	22.7 M	124	181	90	40	11	47	27	25	21	75	100	89	1.78	2.33	2.82	59	72	50	47	40	55	0.009	0.012	0.011
Middle	2.2	37.9 M	42.8 H	21.6 H																								
Middle	0.5	8.4 M	25.4 M	21.2 M																								
Middle	1.1	2.0 M	7.6 M	10.1 H																								
Ship John	5.6	63.0 T	75.2 M	63.9 T																								
Ship John	3.4	63.0 H	71.9 M	56.5 H																								
Ship John	3.4	55.9 T	67.6 H	55.7 T																								
Ship John	4.3	52.5 T	66.5 T	54.7 H																								
Ship John	4.9	52.4 T	63.7 T	51.0 M																								
Ship John	3.0	43.7 H	63.6 T	45.4 M	153	238	155	86	22	164	27	20	19	100	95	100	2.33	1.95	2.23	70	85	63	46	36	41	0.009	0.010	0.011
Ship John	2.6	43.3 T	53.7 T	44.3 T																								
Ship John	3.7	41.5 M	51.0 H	44.0 H																								
Ship John	3.9	40.4 H	46.2 H	33.7 T																								
Ship John	4.3	37.0 M	25.7 M	11.7 M																								
Ship John	1.1	21.6 M	22.0 M	7.6 M																								
Ship John	5.2	11.0 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		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Cohansey	4.1	70.6 M	79.0 T	46.3 H																								
Cohansey	1.7	63.0 H	72.3 T	43.6 H																								
Cohansey	2.6	57.0 H	65.6 T	38.9 H																								
Cohansey	2.1	56.6 M	64.8 H	35.3 M																								
Cohansey	1.9	54.7 T	54.3 M	33.3 T																								
Cohansey	1.9	47.5 H	51.9 M	24.2 M	173	202	121	96	12	144	24	24	23	80	90	95	2.38	1.90	2.48	84	79	60	48	39	49	0.011	0.021	0.012
Cohansey	3.7	44.4 T	46.3 H	21.9 M																								
Cohansey	1.9	40.3 H	37.1 H																									
Cohansey	1.5	33.8 M	33.3 M																									
Cohansey	1.3	33.3 M																										
Cohansey	2.4	31.2 H																										
Cohansey	1.9	26.1 M																										
Sea Breeze	5.2	49.2 M	50.3 H	41.2 M																								
Sea Breeze	3.0	44.3 M	32.3 M	33.8 H	221	100	76	141	19	48	12	20	27	90	95	100	1.93	1.75	3.48	60	38	43	27	38	56	0.012	0.013	0.015
Sea Breeze	4.5	40.1 H	29.7 H	20.4 M																								
Sea Breeze	1.4	34.1 H	16.8 H	15.8 H																								
Sea Breeze	2.8	29.1 H	14.2 M	0.0 H																								
Shell Rock	1.9	61.6 T	75.7 T	60.3 H																								
Shell Rock	3.7	57.7 H	61.4 H	59.5 T																								
Shell Rock	2.2	54.4 M	60.0 M	58.8 T																								
Shell Rock	4.5	52.2 H	57.9 M	52.6 T																								
Shell Rock	3.0	50.3 H	54.3 T	51.3 T	157	262	139	190	77	171	24	18	24	100	95	95	2.90	1.93	1.93	69	76	59	44	29	42	0.010	0.015	0.012
Shell Rock	4.9	45.0 H	54.0 H	46.6 H																								
Shell Rock	4.9	42.2 M	49.7 M	45.6 M																								
Shell Rock	3.7	23.5 M	49.4 H	44.8 T																								
Shell Rock	1.7	9.2 M	48.8 T	37.3 H																								
Shell Rock			43.7 H	26.6 M																								
Shell Rock			28.1 M	8.8 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		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Bennies Sand	5.2	61.7 T	87.5 T	62.2 T																								
Bennies Sand	4.1	56.7 H	57.2 T	52.7 H																								
Bennies Sand	2.0	51.2 T	54.2 T	47.3 T																								
Bennies Sand	3.4	45.0 H	46.2 H	39.9 T																								
Bennies Sand	3.0	35.0 T	40.1 T	36.9 T																								
Bennies Sand	1.4	24.9 M	38.7 T	21.5 M	99	136	91	121	33	33	26	27	21	95	100	95	2.70	3.0	3.30	41	59	42	42	44	46	0.012	0.015	0.013
Bennies Sand	1.9	24.0 M	34.9 T	20.8 H																								
Bennies Sand	3.0	20.3 M	34.8 M	20.4 M																								
Bennies Sand	2.6	18.2 H	30.7 H	20.1 H																								
Bennies Sand	0.6	12.7 M	24.4 M	12.2 M																								
Bennies Sand	1.3	8.3 M	19.2 M																									
Bennies Sand	2.4	3.9 M																										
Bennies	3.7	31.3 T	60.4 H	31.3 H																								
Bennies	2.6	24.3 H	40.5 H	23.8 M																								
Bennies	1.9	17.1 H	32.7 M	23.8 M																								
Bennies	2.4	15.8 T	30.4 M	23.4 H																								
Bennies	1.5	11.6 M	29.2 H	12.2 M																								
Bennies	5.6	11.1 H	24.0 M	11.3 H																								
Bennies	4.5	5.0 M	15.7 M	8.9 M	17	55	32	18	9	9	39	32	32	100	55	90	3.10	0.93	2.15	12	38	25	72	70	79	0.018	0.018	0.019
Bennies	1.9	3.3 M	14.0 M	7.9 M																								
Bennies	2.8	2.2 M	9.2 M	1.0 M																								
Bennies	3.0	2.2 M	7.0 M	0.6 M																								
Bennies	3.4	0.9 M	3.7 M	0.4 M																								
Bennies	4.1	0.7 M	3.7 M	0.3 M																								
Bennies	2.2	0.0 M																										
Bennies	4.9	0.0 M																										
Hog Shoal	3.0	52.2 H	50.0 H	39.0 H																								
Hog Shoal	3.2	42.9 M	36.1 H	20.0 H																								
Hog Shoal	2.3	42.2 H	35.6 M	12.0 H	116	70	40	279	13	44	31	26	37	100	100	100	3.40	2.70	3.28	46	31	21	40	45	53	0.013	0.018	0.015
Hog Shoal	3.2	21.0 H	12.8 H	10.1 M																								
Hog Shoal	0.7	17.2 M	6.5 M	8.8 M																								
Hog Shoal	4.9	13.4 M	3.6 M	6.9 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		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Nantuxent Point	4.5	60.0 T	59.9 T	49.7 M																								
Nantuxent Point	4.9	53.5 H	50.3 T	41.2 T																								
Nantuxent Point	3.3	51.0 T	35.8 T	39.6 T																								
Nantuxent Point	2.6	48.6 T	31.0 M	30.1 M																								
Nantuxent Point	2.4	46.8 M	25.5 H	26.1 T	172	118	96	288	54	293	24	22	30	85	40	100	2.93	1.73	4.08	45	38	47	26	32	49	0.010	0.009	0.013
Nantuxent Point	1.9	44.0 H	23.3 T	22.3 H																								
Nantuxent Point	2.6	35.7 H	21.0 H	21.3 H																								
Nantuxent Point	1.3	18.6 M	16.6 H	17.4 H																								
Nantuxent Point	2.2	11.1 T	14.3 M	16.1 T																								
Nantuxent Point	1.9	10.8 M	8.5 M	15.8 M																								
New Beds	1.5	25.5 H	32.3 H	35.2 H																								
New Beds	3.4	16.9 M	26.0 H	22.0 M																								
New Beds	2.8	16.0 H	13.2 M	19.1 H																								
New Beds	4.1	7.0 M	12.6 M	17.2 M	24	27	45	29	3	20	41	43	36	100	90	100	2.50	2.08	2.68	14	22	30	60	83	67	0.016	0.026	0.025
New Beds	2.4	6.5 M	6.7 M	13.7 M																								
New Beds	2.4	4.4 M	5.1 M	6.7 M																								
New Beds	1.3	3.0 M	3.4 M	5.3 M																								
New Beds	3.2	2.3 M	3.0 M	3.6 M																								
New Beds	3.9	0.0 M	2.4 M	0.2 M																								
Strawberry	1.9	10.3 H	15.1 H	4.9 H																								
Strawberry	0.3	4.0 M	11.8 M	2.1 M	6	20	6	2	3	10	57	45	44	100	50	95	3.23	0.58	3.13	4	14	4	78	68	72	0.019	0.020	0.014
Strawberry	2.5	0.4 M	6.1 M	1.3 M																								
Strawberry	0.6	0.3 M	4.4 M	0.0 M																								
Hawk's Nest	3.2	69.7 M	44.8 T	22.8 H																								
Hawk's Nest	5.2	45.3 H	40.1 H	22.7 M																								
Hawk's Nest	4.1	23.6 H	29.4 M	20.9 T	208	206	50	195	108	138	17	13	35	100	90	90	2.95	2.15	2.45	36	29	31	17	14	62	0.011	0.017	0.013
Hawk's Nest	6.7	8.3 M	27.3 M	16.8 H																								
Hawk's Nest	3.6	6.0 M	24.3 H	13.1 M																								
Hawk's Nest			8.3 M	2.0 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		
		2009	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007	**2009**	2008	2007
Vexton	0.1	4.0 M	10.6 H	18.3 M																								
Vexton	1.3	1.7 H	10.2 H	13.4 H	6	10	32	5	2	42	60	39	34	95	85	100	3.77	1.00	3.00	2	5	19	28	47	61	0.010	0.021	0.021
Vexton	2.4	1.2 H	2.8 M	12.9 M																								
Vexton	0.8	0.3 M	2.7 M	6.6 H																								
Vexton	0.1	0.0 M	0.3 M	5.1 M																								
Beadons	0.6	25.6 H	36.5 H	27.6 H																								
Beadons	0.6	20.9 M	35.3 H	23.5 H																								
Beadons	0.6	19.6 H	30.7 H	16.4 H	72	67	24	101	36	47	34	26	18	80	60	70	2.80	1.80	1.33	18	16	9	25	25	36	0.013	0.019	0.011
Beadons	0.6	14.5 M	6.6 M	4.0 M																								
Beadons	3.2	10.0 M	5.9 M	1.0 M																								
Beadons	2.8	9.6 H	3.1 M	0.9 M																								
Beadons	2.3	4.1 M	3.0 M	0.0 M																								
Ledge			0.0 M																									
Ledge			0.0 M																									
Ledge			0.0 M																									
Ledge			0.0 H																									
Ledge			0.0 M																									
Egg Island	0.1	0.7 M		2.3 M																								
Egg Island	2.1	0.6 M		2.1 M																								
Egg Island	3.0	0.6 H		0.5 M																								
Egg Island	0.2	0.5 M		0.5 H	1		2	0		1	62		52	90		85	3.07		1.70	1		1	84		84	0.031		0.047
Egg Island	0.1	0.0 M		0.0 M																								
Egg Island	0.5	0.0 M		0.0 M																								
Egg Island	2.6	0.0 M		0.0 M																								
Egg Island	2.4	0.0 M		0.0 M																								

Table 5. Average annual bay-wide oyster and spat abundance per 37-qt. bushel for the 1990-2009 time period. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean = mean of annual values for 1990-2009.

Year	**1996**	**1990**	**1992**	**1991**	**1995**	**1997**	**1998**	**1993**	**2000**	**1994**	**1999**	**2001**	**2008**	**2002**	**2009**	**2003**	**2007**	**2004**	**2006**	**2005**	**Mean**
Oyster	262	242	237	211	196	187	183	178	169	155	149	145	144	134	132	123	123	113	101	81	**163.25**
	A	A	A	A	A	A															
		B	B	B	B	B	B	B	B												
				C	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		
										G	G	G	G	G	G	G	G	G	G	G	

Year	**1991**	**1997**	**1999**	**1994**	**1995**	**1990**	**1998**	**2009**	**2007**	**2002**	**1993**	**2000**	**2008**	**1992**	**1996**	**2004**	**2003**	**2005**	**2006**	**2001**	**Mean**
Spat	267	209	204	175	156	154	126	95	81	46	45	35	29	25	24	23	20	19	19	12	**88.2**
	A	A	A																		
		B	B	B	B	B															
				C	C	C	C														
					D	D	D	D	D												
								E	E	E	E	E	E	E	E	E	E				
									F	F	F	F	F	F	F	F	F	F	F	F	

Table 6. 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. Recruitment values do not include the enhancements from shell planting.

	Abundance	Spawning Stock Biomass*	Recruitment	Spat to Adult Ratio	Box-count Mortality	Fishing Mortality⋆	Market Fishing Mortality	Unexplained Mortality
Bay-wide: 1953-2009	.096		.325	.675	.833	.300		
Bay-wide: 1989-2009	.175	.125	.452	.690	.738	.583	.654	
Low-mortality: 1953-2009	.132		.202	.289	.798	.866		.925
Low-mortality: 1989-2009	.262	.275	.262	.375	.900	.900	.917	.929
Medium-mortality Transplant: 1953-2009	.044		.237	.518	.939	.670		.482
Medium-mortality Transplant: 1989-2009	.010	.010	.400	.690	.929	.625	.583	.452
Medium-mortality Market: 1953-2009	.237		.395	.623	.798	.330		.921
Medium-mortality Market: 1989-2009	.214	.225	.500	.690	.643	.075	.083	.900
Shell Rock: 1953-2009	.307		.588	.816	.711	.491		.307
Shell Rock: 1989-2009	.310	.175	.600	.925	.643	.458	.500	.405
High-mortality: 1953-2009	.114		.430	.833	.746	.134		.395
High-mortality: 1989-2009	.167	.075	.500	.786	.548	.625	.667	.452

*SSB values used the 1990-2009 time series

⋆Fishing values used the 1997-2009 time series

Table 7. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality beds for the 1990-2009 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean = mean of annual values for 1990-2009.

Year	1996	2000	1990	1992	1997	1998	2003	1991	2001	1993	2002	1999	1995	1994	2005	2008	2006	2009	2004	2007	Mean
Oyster	434	364	328	304	291	270	258	255	233	227	212	207	197	196	191	180	172	160	157	132	**238.4**
	A	A	A																		
		B	B	B	B	B	B	B													
			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	F	F	F		
									G	G	G	G	G	G	G	G	G	G	G	G	

Year	1999	1991	1995	1998	1994	1990	1997	2007	2009	2002	1993	2000	1996	2006	2004	2003	1992	2005	2008	2001	Mean
Spat	302	268	195	195	182	140	127	114	109	89	54	47	37	35	30	28	28	27	25	12	**102.2**
	A	A	A	A																	
		B	B	B	B																
			C	C	C	C	C	C	C	C											
						D	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	E	

Table 8. Average annual oyster and spat abundance per 37-qt. bushel for the low-mortality beds for the 1990-2009 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean = mean of annual values for 1990-2009.

Year	1992	1991	1993	1990	1995	1994	2002	2001	1996	2009	1999	2000	1997	2003	2008	2005	1998	2004	2006	2007	Mean
Oyster	698	663	588	575	483	450	405	375	353	337	328	318	311	310	302	263	259	255	221	199	384.65
	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	G	

Year	1991	1990	1999	1998	1995	1994	2007	2005	1996	1997	2008	2002	1992	2009	1993	2000	2006	2001	2003	2004	Mean
Spat	371	228	117	99	84	84	80	53	52	52	48	45	38	36	23	20	16	14	11	5	73.8
	A																				
		B																			
			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		
							F	F	F	F	F	F	F	F	F	F	F	F	F	F	

Table 9. Average annual oyster and spat abundance per 37-qt. bushel for the high-mortality beds for the 1990-2009 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean = mean of annual values for 1990-2009.

Year	**1996**	**1995**	**1998**	**1990**	**1992**	**1997**	**1994**	**1991**	**1999**	**2000**	**2008**	**2009**	**2001**	**1993**	**2006**	**2005**	**2004**	**2007**	**2003**	**2002**	**Mean**
Oyster	230	162	159	158	152	132	114	112	106	88	84	79	77	75	67	63	62	50	46	29	**102.25**
	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	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	

Year	**1997**	**1991**	**1994**	**1999**	**1995**	**1990**	**1998**	**2009**	**2007**	**1993**	**2000**	**2008**	**2002**	**1992**	**2004**	**2003**	**1996**	**2005**	**2001**	**2006**	**Mean**
Spat	307	273	247	201	182	161	135	114	66	49	44	29	27	25	24	20	17	15	14	13	**98.15**
	A	A	A	A	A																
		B	B	B	B	B															
			C	C	C	C	C														
				D	D	D	D	D													
					E	E	E	E	E												
						F	F	F	F	F	F										
							G	G	G	G	G	G	G	G	G	G	G	G	G	G	

Table 10. 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 11. 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 2009 size frequencies.

Bed Area	Oysters <2.5″	Oysters >2.5″	All Oysters
Bay Total	0.258	0.635	0.423
Very Low Mortality	0.349	0.582	0.407
Low Mortality	0.317	0.651	0.449
Medium Mortality	0.241	0.643	0.416
Shell Rock	0.259	0.665	0.419
High Mortality	0.236	0.628	0.421

Table 12. Surplus production as projected for 2008 and 2009 by SAW-10 and SAW-11 and as projected for 2010 for the oyster stock on the New Jersey natural oyster beds in Delaware Bay. Projections for 2010 were conducted using the 50^{th} and 75^{th} percentiles of natural mortality and a conversion of 261 oysters bu^{-1}. Also provided for 2009 and 2010 are the fractions of the stock $\geq 2.5''$ equivalent to the surplus production estimate. Note that the fractions of the stock equivalent to the increase in marketable abundance expected in 2009 and 2010 exceed exploitation rates normally occurring in these bed regions, except in some cases for the high-mortality beds.

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

SAW-11 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	0.228	90,106	0.212	83,602
Medium mortality Transplant	0.287	90,152	0.228	71,655
Medium mortality Market	0.259	160,491	0.191	118,365
Shell Rock	0.369	70,668	0.317	60,694
High mortality	0.127	26,164	0.018	3,703
Total		437,581		338,019

Surplus Production Estimate for 2010

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	0.348	130,077	0.322	120,519
Medium mortality Transplant	0.374	54,726	0.316	46,295
Medium mortality Market	0.345	250,344	0.284	206,116
Shell Rock	0.424	53,874	0.382	48,519
High mortality	0.240	49,030	0.130	26,553
Total		538,051		448,002

Table 13. Comparison of observed 2009 surplus production with projections from SAW-11. Projections for the transplant beds are debited by the removal of market-size animals, as listed under '2009 Fishery Removals'. The fishery removals for the high-mortality beds are adjusted for the addition of these animals by intermediate transplant. Comparisons should be made between the 2008-2009 differential and the surplus production expected assuming a 75^{th} percentile mortality rate, but taking into account fishing (column 7) and after adjustment to the observed 2009 natural mortality rate (column 9). Note that these estimates are approximate as the fishery removals have not been adjusted for the proportion of animals $> 3''$ in the catch, nor has the mortality-rate adjustment (column 9) been adjusted for the time of intermediate transplant.

Bay Region	2008 $\geq 3''$ Abundance	2009 $\geq 3''$ Abundance	2008-2009 Abundance Differential	2009 Surplus Production Projection	2009 Fishery Removals	2009 Net Surplus Production Expected	Mortality Rate vs. 75^{th} Percentile Expectation	Mortality Adjusted 2009 Surplus Production Expected
Low mortality	43,772,474	56,571,393	12,798,919	21,903,724	2,535,093	19,368,631	above	18,535,437
Medium-mortality transplant	50,756,500	20,247,023	-30,509,477	18,773,610	2,052,765	16,720,845	above	10,683,252
Medium-mortality market	81,027,260	100,766,013	19,738,753	31,011,630	6,401,025	24,610,605	near	25,797,501
Shell Rock	25,384,976	14,675,062	-10,709,914	15,901,828	5,981,598	9,920,230	near	10,786,608
High mortality	37,418,326	28,928,915	-8,489,411	970,186	4,059,594	-3,089,408	below	1,052,874

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 7. 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)
2009	0.15	0.52	0.82	1.89 (2.75)	2.53 (3.03)

Table 15. Summary of shell-planting activities for 2009. Shell-planting was carried out in late June-early July, 2009. Direct plants occurred on Nantuxent Point 24, Shell Rock 21, and Bennies Sand 15. 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 1989-2009 time series: for Shell Rock, 0.460, 0.194, 0.194; for the high-mortality beds: 0.475, 0.262. 0.262, for years 1, 2, and 3, respectively. Bushel conversions assume 261 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Potential Yield (bushels)
Shell Rock	21	Surf clam mix*	58,233	67,844,908	1,166	85,906
Bennies Sand	15	Surf clam mix*	51,366	20,362,195	396	19,496
Nantuxent Point	24	Surf clam mix*	34,686	48,409,827	1,396	46,351
Total			144,285	136,616,930		151,753

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

Table 16. Spat survival to yearling on shell planted in 2008 and projected harvest estimated from the 2009 re-survey of these grids. Shell-planting was carried out in late June-early July, 2008. Four 25-acre grids received direct plants: Bennies Sand 8 and 9 and Nantuxent Point 17 and 68. One grid received a replant of shell planted off Reeds Beach and moved upbay in late August: Cohansey 64. 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 1989-2009 time series: for Cohansey, 0.165; for the remainder: 0.262. Bushel conversions assume 261 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Yearlings Collected	Yearlings per Bu	Yearling Survival	Potential Yield (bushels)
Bennies Sand	8	Surf clam mix*	50,587	27,506,100	544	65.1%	30,164
Bennies Sand	9	Surf clam mix*	20,360	7,343,810	361	15.7%	13,393
Cohansey	64	Surf clam replant	21,898	3,041,990	139	66.5%	7,809
Nantuxent Point	17	Surf clam mix*	53,164	2,030,070	382	82.3%	37,023
Nantuxent Point	68	Surf clam mix*	48,376	unest.			
Total (of four)			146,009	39,922,970			88,389

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

Table 17. Summary of 2009 recruitment on 2008 shell plants. Shell-planting was carried out in late June-early July, 2008. Details are in Table 16. 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 1989-2009 time series: for Cohansey, 0.229, 0.165, 0.165; for the remainder: 0.475, 0.262, 0.262. Bushel conversions assume 261 oysters per bushel.

Location	Type of Shell Planted	Bushels Planted	Spat Collected	Spat per Clam Bu	Clam Shell Potential Yield (bushels)
Bennies Sand 8	Surf clam mix*	50,587	1,841,920	694	33,592
Bennies Sand 9	Surf clam mix*	20,360	1,032,380	966	18,826
Cohansey 64	Surf clam replant	21,898	1,172,690	69	3,010
Nantuxent Point 17	Surf clam mix*	53,164	4,469,420	160	8,151
Nantuxent Point 68	Surf clam mix*	48,376	Unest.		
Total		194,385	8,516,410		63,579

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

Table 18. Average half lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2009 time period.

Location	Half-life (yr)
Hope Creek	insufficient data
Fishing Creek	insufficient data
Liston Range	insufficient data
Round Island	47.45
Upper Arnolds	7.43
Arnolds	6.12
Upper Middle	insufficient data
Middle	4.09
Cohansey	3.79
Ship John	3.20
Sea Breeze	37.39
Shell Rock	4.44
Bennies Sand	5.08
Bennies	7.95
Nantuxent Point	2.56
Hog Shoal	3.39
Hawk's Nest	11.87
Strawberry	5.82
New Beds	20.70
Beadons	6.28
Vexton	3.34
Egg Island	5.40
Ledge	7.71

Table 19. The one-year transition probabilities for the broodstock-recruitment diagram shown as Figure 37 for each quadrant in the 57-year time series and mean first passage times. The 1989-2009 first passage times are also based on the 57-yr medians. The medians are: abundance = 2.96×10^9, recruitment = 1.80×10^9. Quadrant definitions are in Figure 38. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.67	0.06	0.11	0.17
2→	0.33	0.22	0.11	0.33
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→	3.06	7.65	7.95	5.16
2→	4.98	6.11	7.82	4.13
3→	6.18	4.80	6.11	4.43
4→	6.56	6.09	7.30	2.90

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.327	0.164	0.164	0.345

Mean First Passage Time (years): 1989-2009

Quadrant	1	2	3	4
1→	1.74	9.86	8.89	9.67
2→	3.55	6.14	7.22	8.00
3→	3.27	6.43	6.37	10.33
4→	3.36	4.29	8.79	9.56

Table 20. The one-year transition probabilities for the broodstock-mortality diagram shown as Figure 39 for each quadrant in the 57-year time series and the mean first passage times. The 1989-2009 first passage times are also based on the 57-yr medians. The medians are: abundance = 2.96×10^9, mortality fraction= 0.13. Quadrant definitions are in Figure 38. 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→	0.33	0.40	0.00	0.27
3→	0.07	0.06	0.69	0.19
4→	0.25	0.33	0.25	0.17

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.90	3.80	8.24	4.15
2→	3.78	3.41	9.58	3.97
3→	6.81	6.54	3.52	4.83
4→	4.76	4.30	7.51	4.56

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.20	0.29	0.28	0.22

Mean First Passage Time (years): 1989-2009

Quadrant	1	2	3	4
1→	4.50	1.86	Un-est	2.71
2→	3.29	2.00	Un-est	3.43
3→	4.24	1.00	Un-est	4.43
4→	3.71	1.71	Un-est	3.60

Table 21. The one-year transition probabilities for the recruitment-mortality diagram shown as Figure 41 for each quadrant in the 57-year time series and the mean first passage times. The 1989-2009 first passage times are also based on the 57-yr medians. The medians are: recruitment = 1.80×10^9, mortality fraction = 0.13. Quadrant definitions are in Figure 38. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.14	0.50	0.14	0.21
2→	0.29	0.43	0.07	0.21
3→	0.20	0.00	0.67	0.13
4→	0.31	0.15	0.15	0.38

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.26	3.73	8.45	5.15
2→	3.68	3.73	9.02	5.09
3→	4.47	7.37	3.77	6.09
4→	3.67	5.33	8.10	4.30

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.24	0.27	0.27	0.23

Mean First Passage Time (years): 1989-2009

Quadrant	1	2	3	4
1→	4.75	2.73	19.50	4.67
2→	3.75	2.17	23.25	5.78
3→	4.25	4.82	24.75	1.00
4→	3.25	3.82	22.75	3.52

Table 22. Harvest statistics for 2009. 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			
Fishing Creek	1,273,459			
Liston Range	1,167,525			
Round Island	1,910,960			
Upper Arnolds	1,911,274			
Arnolds	2,548,739			
Upper Middle	956,159			
Middle	3,719,585	.01	33	
Cohansey	4,995,452	.69	5,909	.07
Sea Breeze	2,338,640	.17	627	.01
Ship John	4,677,614	2.27	17,989	.22
Shell Rock	5,104,046	2.67	22,918	.28
Bennies Sand	3,190,495	2.26	13,529	.17
Bennies	8,404,238	.55	9,599	.12
Nantuxent Point	2,765,542	.75	2,631	.03
New Beds	4,788,189	.34	2,778	.03
Hawk's Nest	2,021,560	.09	173	
Hog Shoal	1,808,455	1.31	3,804	.05
Strawberry	1,808,668	.29	618	.01
Beadons	2,447,474	.03	82	
Vexton	2,022,090			
Egg Island	4,045,293			
Ledge	1,916,423			
Total or Mean	68,792,824	0.88	80,690	1.00

Table 23. 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
2009	3.14	2.74	3.21	3.58	277	230

Table 24. 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
Market ($\geq 2.5''$) Abundance					
Target (50^{th} Percentile)	43,388,077	45,934,727	180,658,285	25,622,244	51,205,771
Threshold (1/2 Target)	21,694,039	22,967,364	90,329.143	12,811,122	25,602,886

Table 25. 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 37), predicted recruitment from each reduced by 5%, plotted adult mortality rate (Figure 39), median unrecorded mortality rate.

[2]Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 37), plotted adult mortality rate (Figure 39), median unrecorded mortality rate.

[3]Ricker recruitment curve (Figure 37), plotted adult mortality rate (Figure 39), median unrecorded mortality rate.

[4]Ricker recruitment curve (Figure 37), plotted adult mortality rate (Figure 39), mean unrecorded mortality rate.

[5]Ricker recruitment curve (Figure 37), average of background (10%) and plotted adult mortality rate (Figure 39), median unrecorded mortality rate.

Table 26. Confidence percentiles for the 2009-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 > 2.5″
10.	656,376,448	166,518,576	178,334,672	344,853,248
20.	534,213,664	183,049,600	185,625,952	368,675,552
30.	686,503,936	186,543,232	202,639,264	389,182,496
40.	753,836,864	209,819,824	194,566,704	404,386,528
50.	727,037,440	204,072,928	213,556,784	417,629,696
60.	703,557,952	210,081,280	223,258,000	433,339,264
70.	812,334,848	221,766,128	232,370,896	454,137,024
80.	681,349,952	229,250,512	249,120,304	478,370,816
90.	673,013,312	239,966,368	270,879,296	510,845,664

Table 27. Confidence percentiles for the 2009-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.	633,532,416	177,913,024	162,057,232	973,502,656
20.	674,891,904	186,102,656	170,362,304	1,031,356,864
30.	638,259,776	197,707,408	238,286,288	1,074,253,440
40.	696,489,856	200,060,256	216,106,272	1,112,656,384
50.	659,293,056	224,118,016	267,888,768	1,151,299,840
60.	745,673,152	213,817,616	227,424,400	1,186,915,200
70.	790,488,192	202,899,344	236,144,176	1,229,531,648
80.	799,362,944	251,587,216	226,431,200	1,277,381,376
90.	853,513,216	243,777,712	265,350,256	1,362,641,152

Table 28. Percentiles of the real and apparent exploitation rates for oysters $\geq 2.5''$ 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 29. Percentiles of the real exploitation rates for all oysters and for one bay region for oysters $\geq 2.5''$ 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 $\geq 2.5''$ 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 30. 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 ≥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 one exception. Projections use the average numbers per marketed bushel of 261 derived from the 2004-2009 dock-side monitoring program. Arrows indicate recommended options. Γ indicates recommendations with intermediate transplant. No indication indicates exploitation rates not recommended by the SARC.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	561,636	2,152
	$^{\Gamma}50^{th}$	.0652	3,001,532	11,500
	$^{\Gamma}60^{th}$	.0782	3,599,996	13,793
Shell Rock	$\longrightarrow 25^{th}$	.0531	1,722,654	6,600
	$^{\Gamma}40^{th}$	.0870	2,822,428	10,814
	50^{th}	.0880	2,854,869	10,938
	60^{th}	.1140	3,698,353	14,170
Medium Mortality Market	40^{th}	.0178	3,433,019	13,153
	50^{th}	.0214	4,127,338	15,814
	60^{th}	.0267	5,149,528	19,730
	$\longrightarrow 100^{th}$	.0398	7,676,076	29,410
Medium Mortality Market without Sea Breeze$^{\Upsilon}$	40^{th}	.0178	2,739,825	10,497
	50^{th}	.0214	3,293,947	12,621
	60^{th}	.0267	4,109,738	15,746
	$\longrightarrow 100^{th}$	.0398	6,126,126	23,472
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 that at least the transplant from the medium-mortality transplant beds occur prior to implementing this level of exploitation.

$^{\Upsilon}$The SARC strongly recommends this approach, relegating Sea Beeze to the transplant bed group, for 2010.

Table 31. 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. However, an alternative strongly recommended by the SARC that reallocates Sea Breeze from the market to the transplant category is also provided. 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 2009 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 261 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	40^{th}	.0127	1,069,905	331	3,232	1,869
	50^{th}	.0188	1,583,797	331	4,785	2,767
	60^{th}	.0233	1,962,898	331	5,930	3,429
Medium Mortality Transplant targeting Sea Breeze	$\longrightarrow 40^{th}$	.0127	2,780,199	331	8,400	3,760
	$\longrightarrow 50^{th}$	.0188	4,155,570	331	12,434	5,566
	$\longrightarrow 60^{th}$	.0233	5,100,680	331	15,409	6,899
Low Mortality	$\longrightarrow 40^{th}$	.0127	4,680,747	475	9,854	7,012
	$\longrightarrow 50^{th}$	.0188	6,928,979	475	14,587	10,380
	$\longrightarrow 60^{th}$	.0233	8,587,511	475	18,079	12,864
Very Low Mortality	$\longrightarrow 40^{th}$	.0127	3,833,693	621	6,173	5,992
	50^{th}	.0188	5,675,073	621	9,139	8,871
	60^{th}	.0233	7,033,468	621	11,326	10,995

§NA: not applicable to this reference point.

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 2009 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 began in 2005. Cohansey and Bennies Sand were resurveyed in 2009 and their footprints updated on this map.

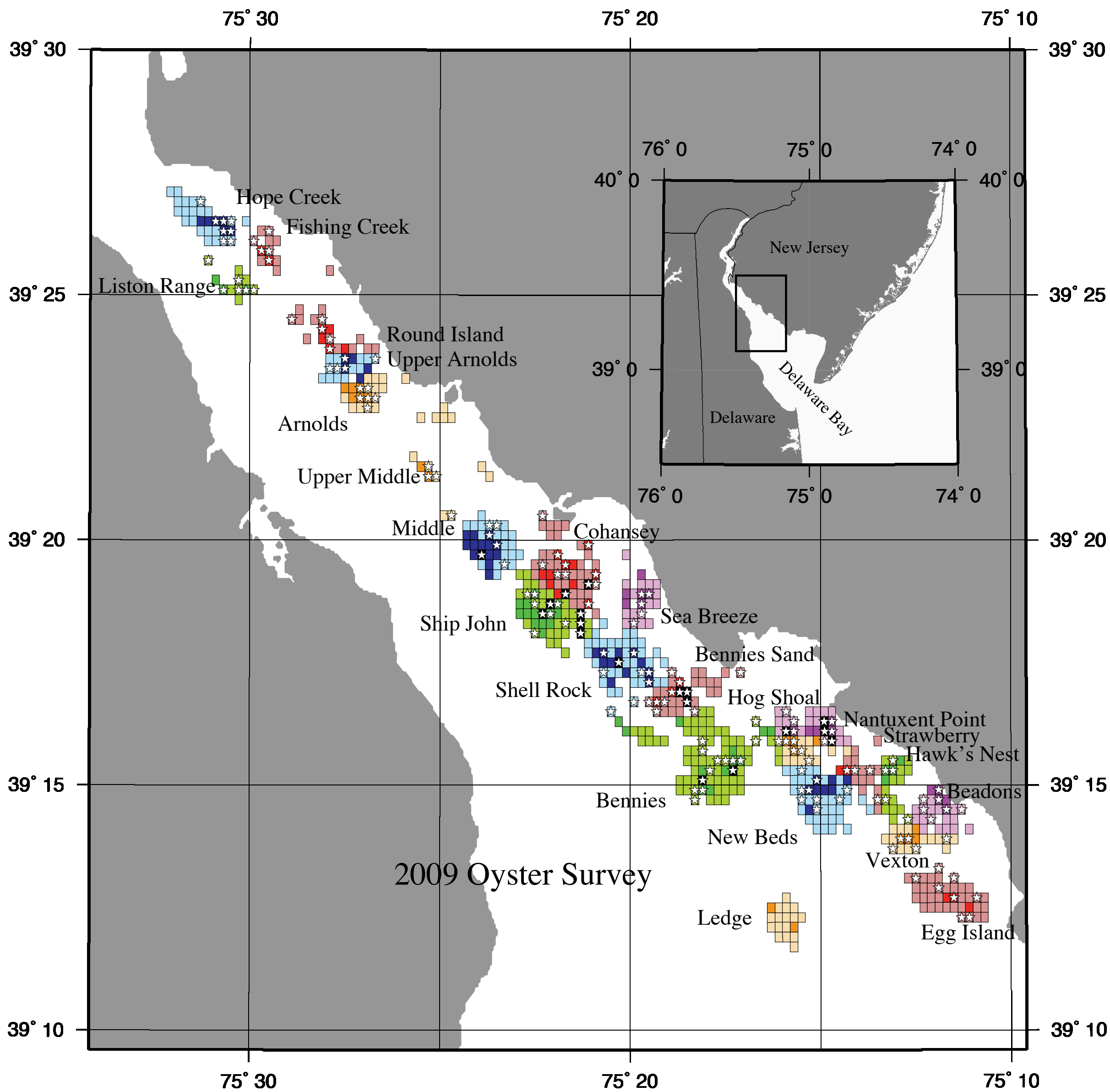


Figure 2. Distribution of grids for Bennies Sand and Cohansey after the 2009 resurvey, shaded accordingly to oyster density. The 2009 survey program covered all navigable grids associated with these two bed regions. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded grey. Black squares identify grids allocated to the transplant stratum in 2009.

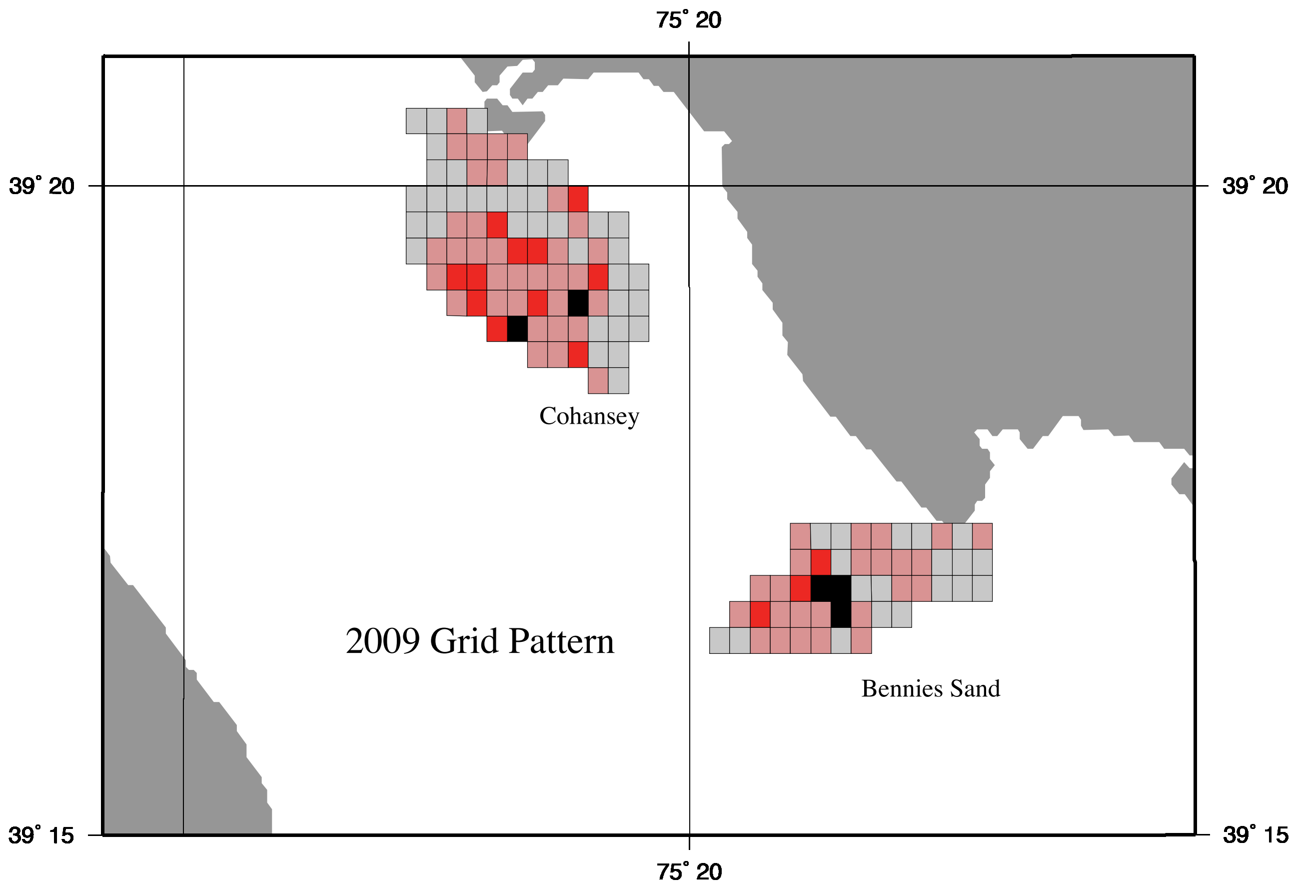


Figure 3. Distribution of grids for Bennies Sand and Cohansey prior to the 2009 resurvey, shaded accordingly to oyster density. The 2009 survey program covered all navigable grids associated with these two bed regions. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded grey. Black squares identify grids allocated to the transplant stratum in 2008.

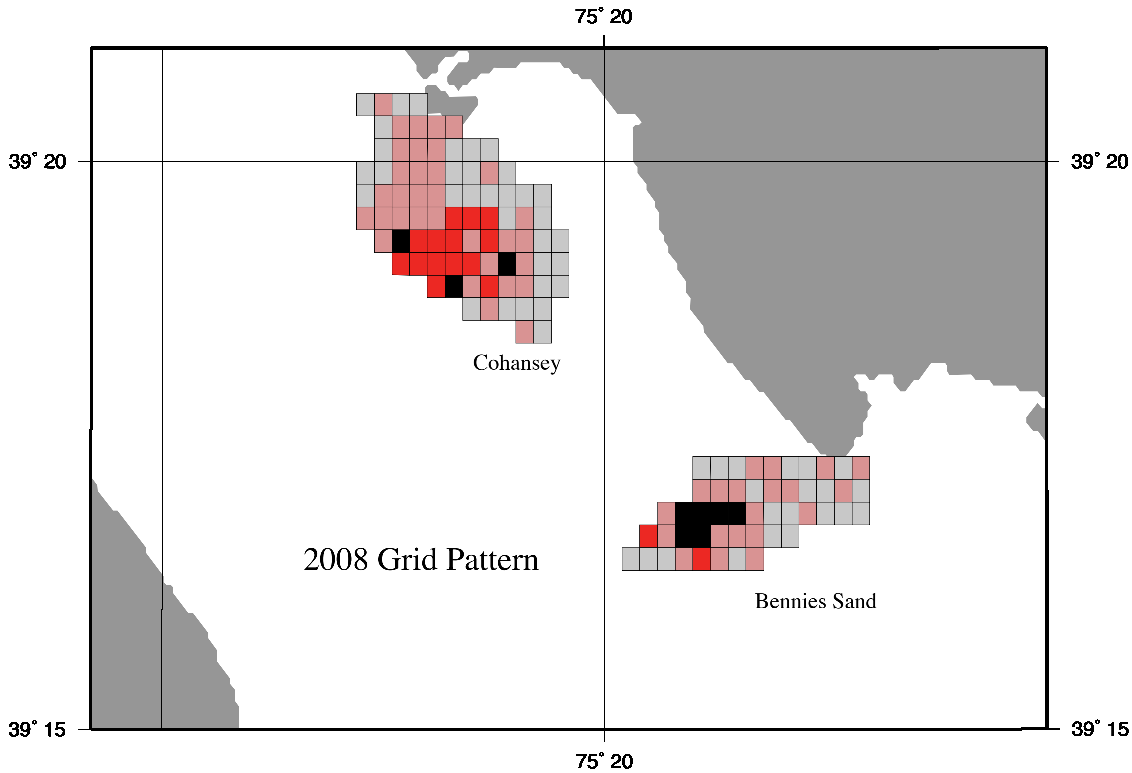


Figure 4. Cohansey and Bennies Sand beds, showing grids that changed in quality designation between the 2008 and 2009 assessments based on the 2009 resurvey of these beds. For those grids not changing quality, high-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded lightly consistent with Figures 2 and 3.

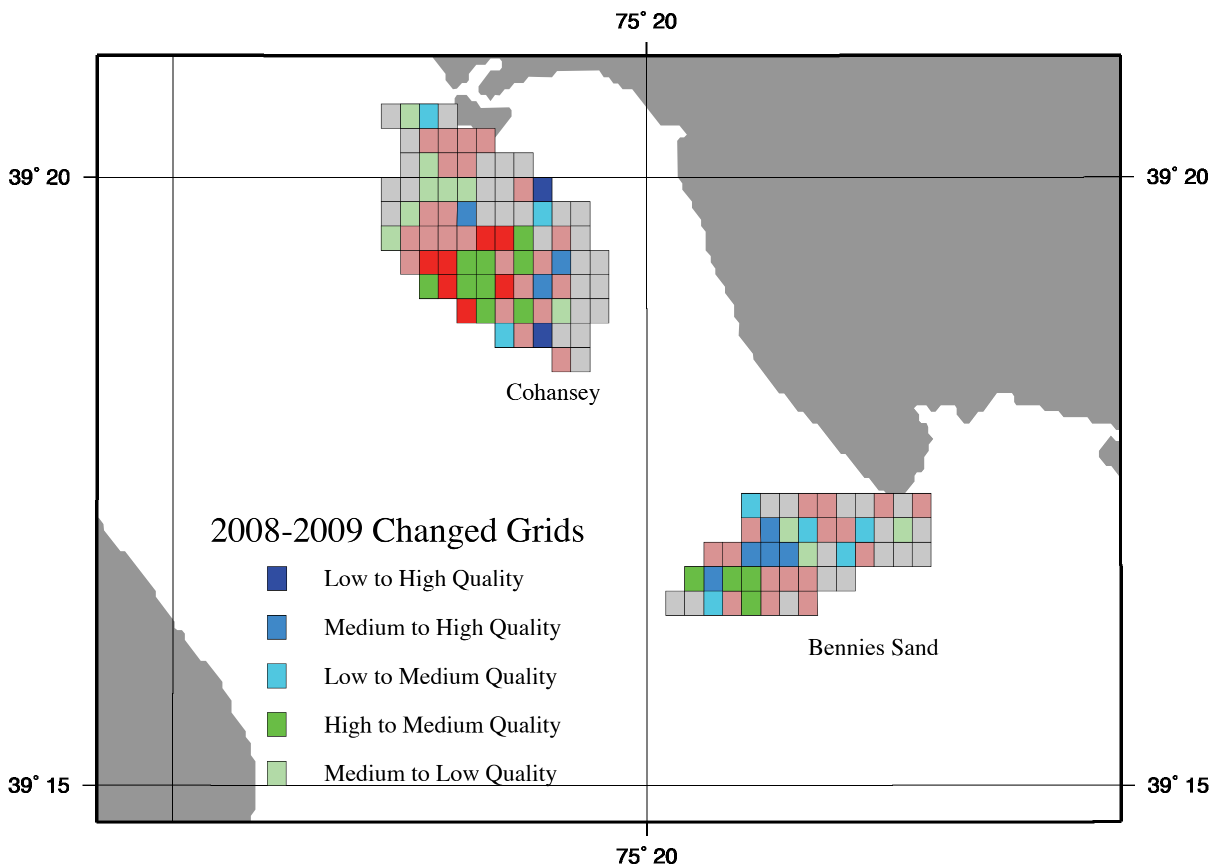
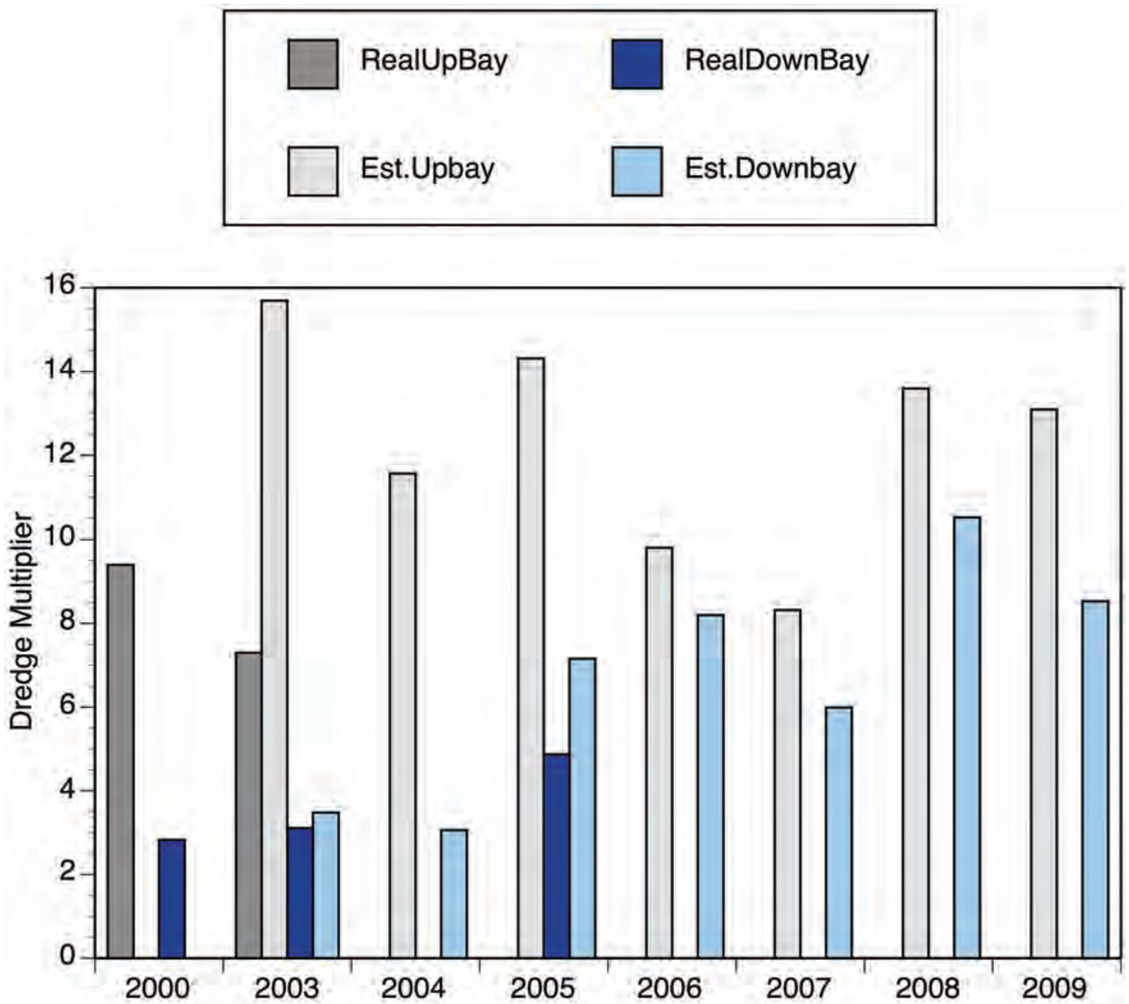


Figure 5 Estimates of q from retrospective analyses described in Powell et al. (2007) compared with directly measured values. The upbay estimates do not include the very-low-mortality beds, as no direct measurements are available for these beds[∇].



[∇] 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.

Figure 6. Example size-frequency distributions for spat recruiting in 2009 to shell planted in 2009 on Bennies Sand, Shell Rock, and Nantuxent Point. X-axis class intervals mark the lower bound of the size class.

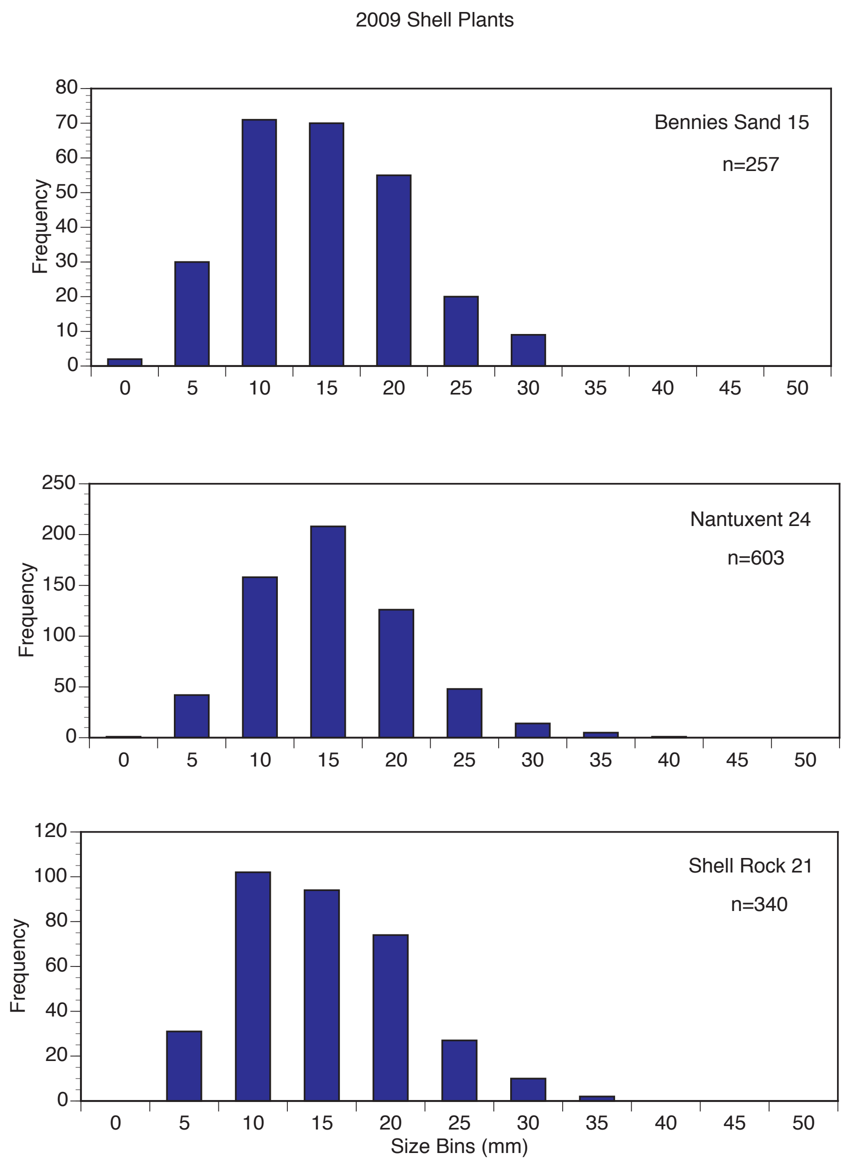


Figure 7. Time series of oyster abundance by bay region. High mortality: Bennies Sand, Nantuxent Point, Bennies, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Beadons, Egg Island, Ledge; medium mortality market (less Shell Rock): Ship John, Cohansey, Sea Breeze; medium mortality transplant: Middle, 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.

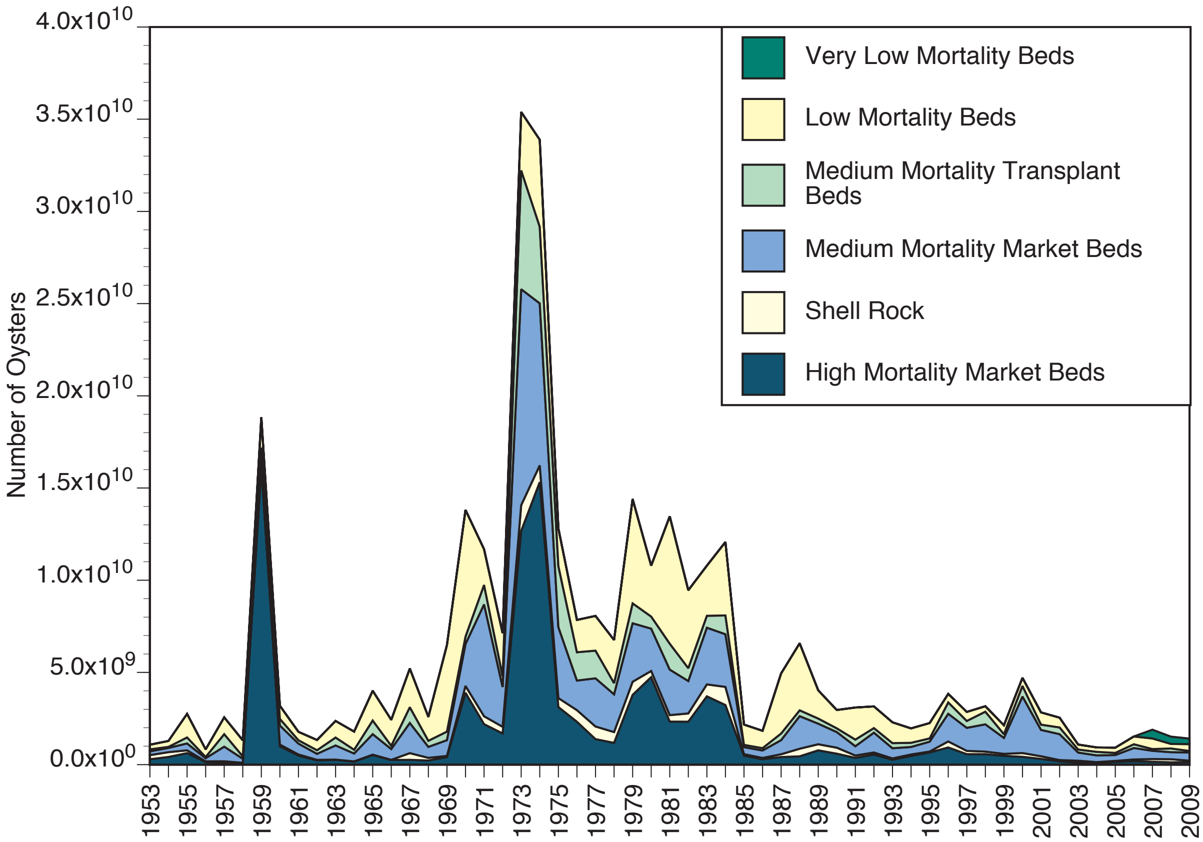


Figure 8. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2009. Bed regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

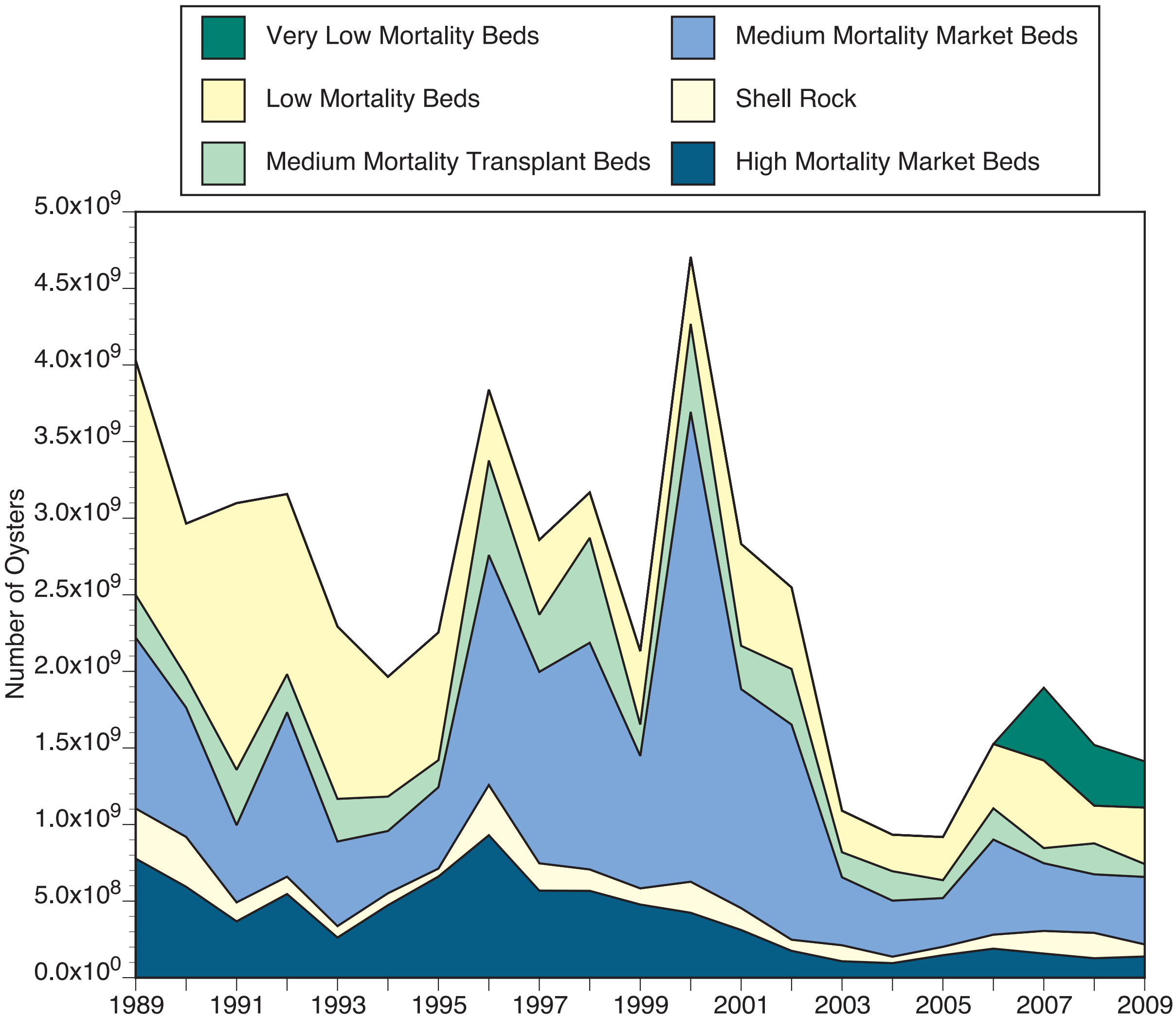


Figure 9. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 7.

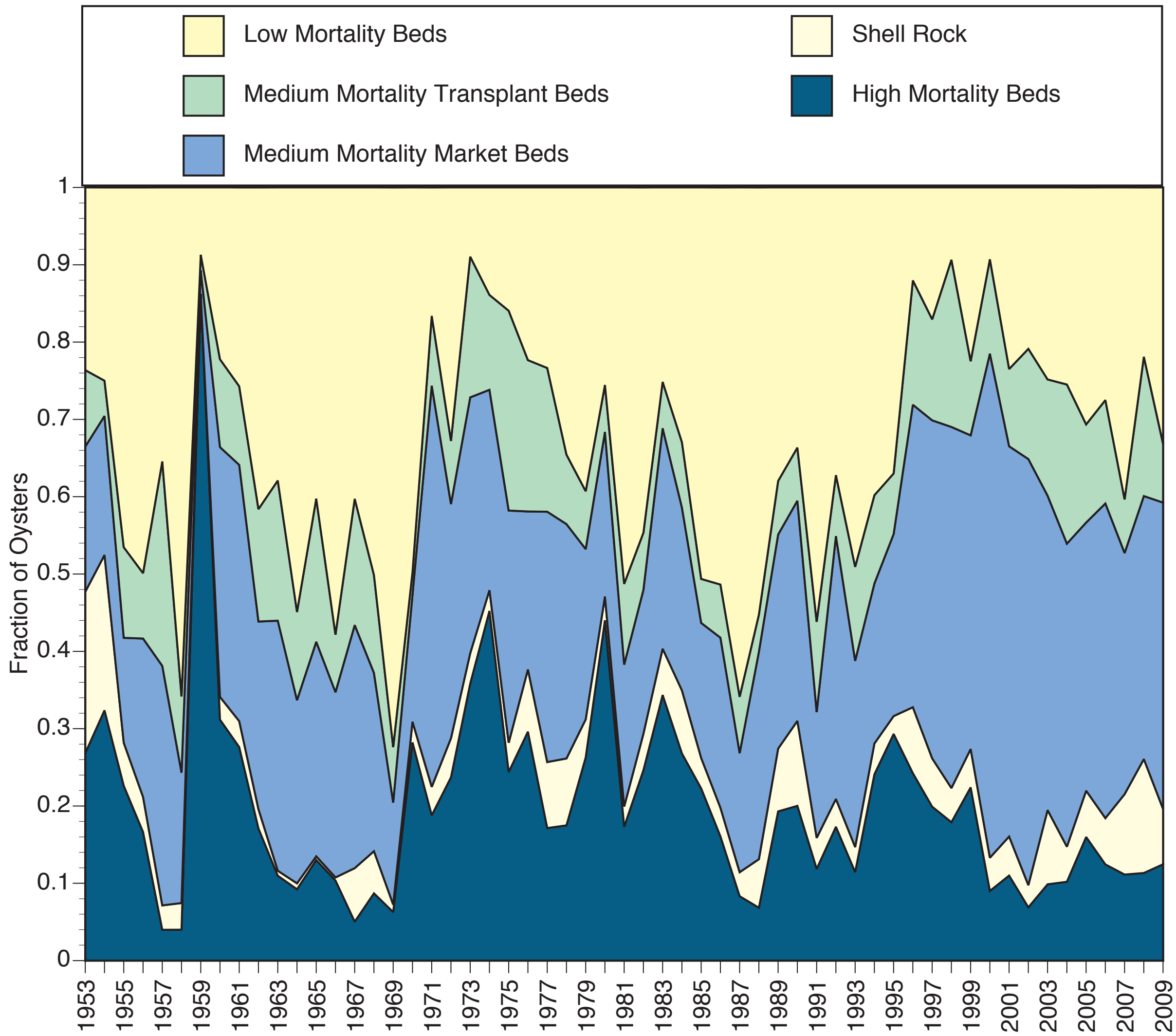


Figure 10. Fraction of animals on the medium-mortality beds, 1953-2009. The horizontal value identifies the median value of 0.382.

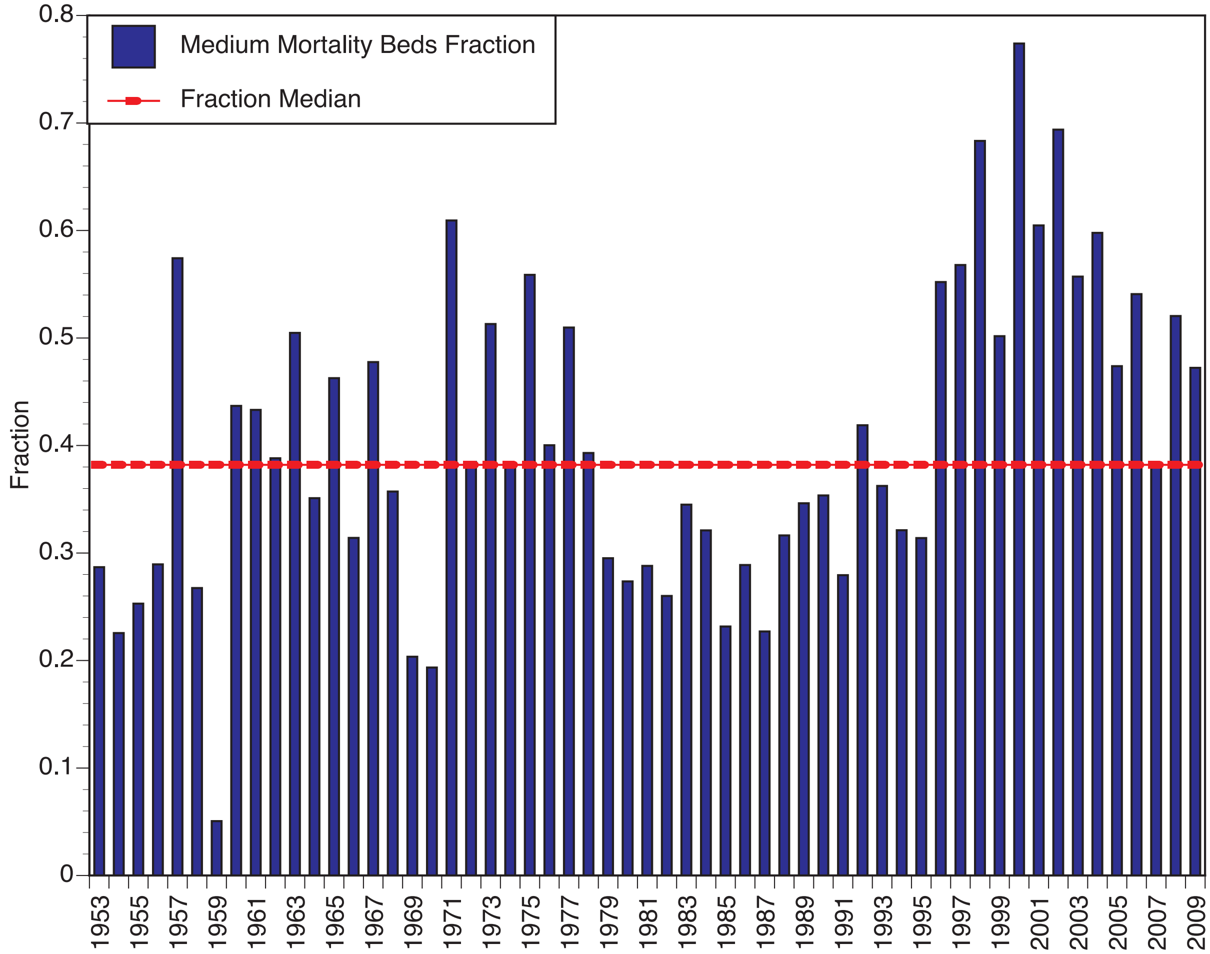


Figure 11. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

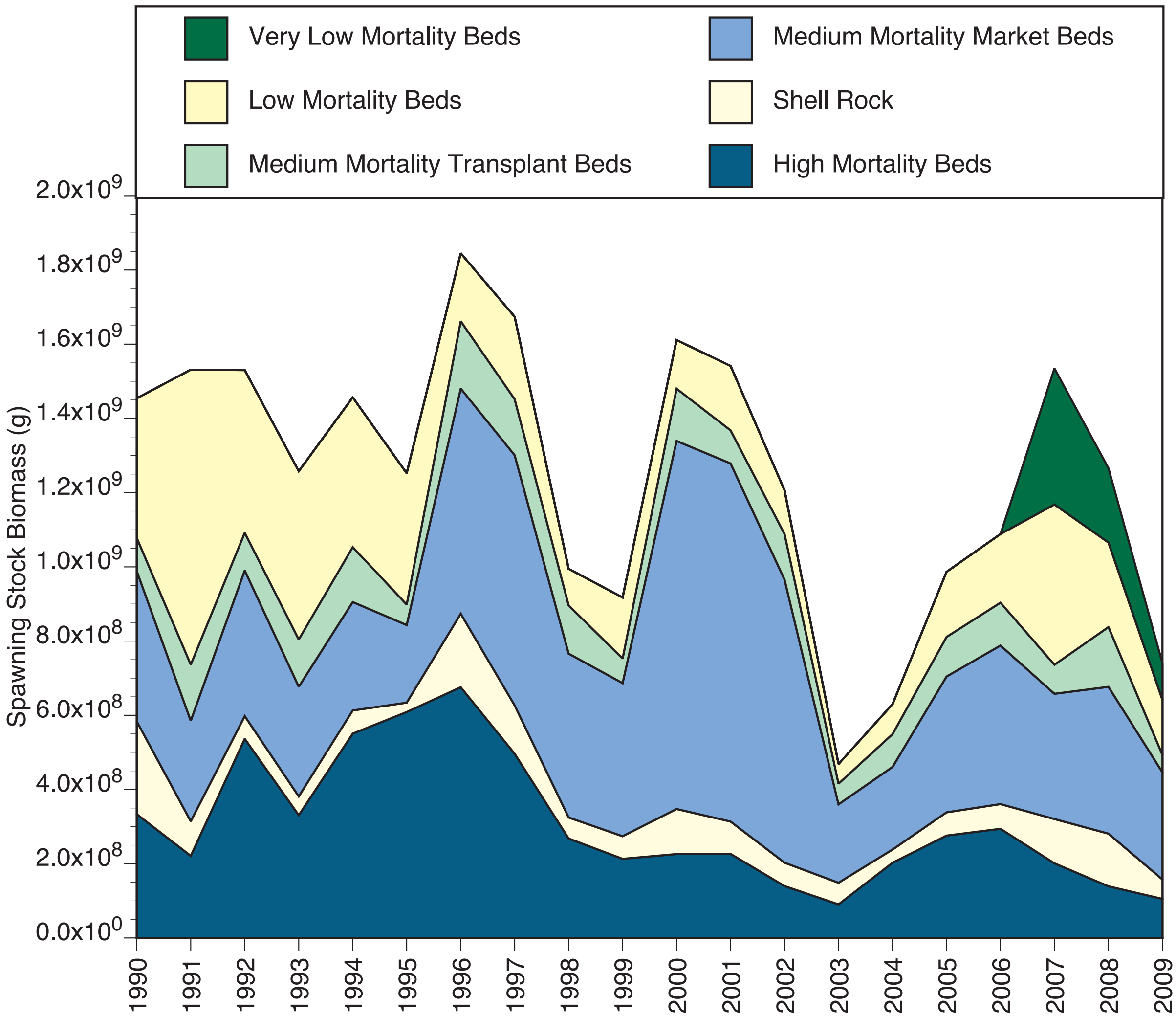


Figure 12. Time series of the fractional distribution of spawning stock biomass among the bay regions. Bed distributions by region are given in Figure 7.

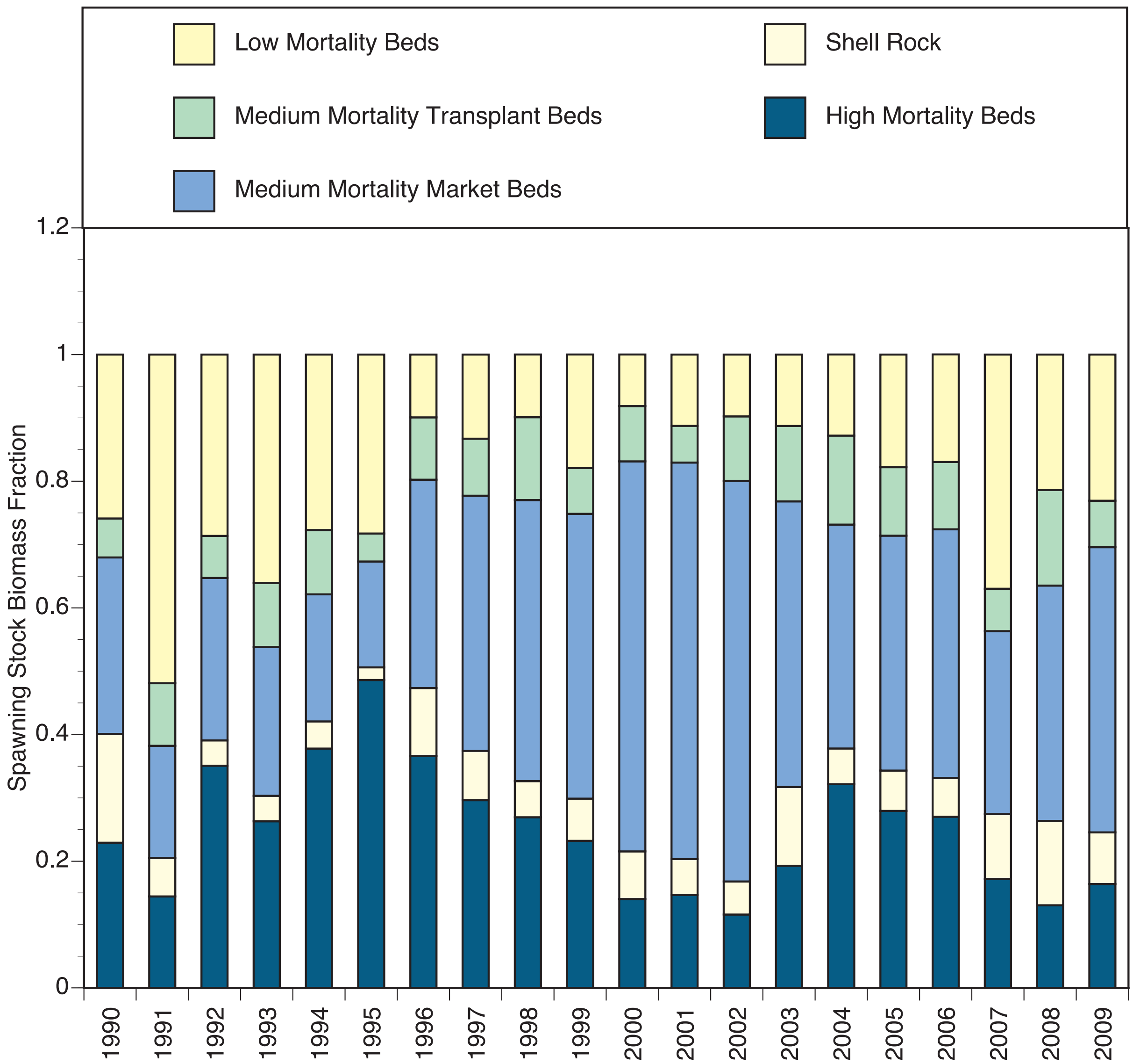


Figure 13. The abundance of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

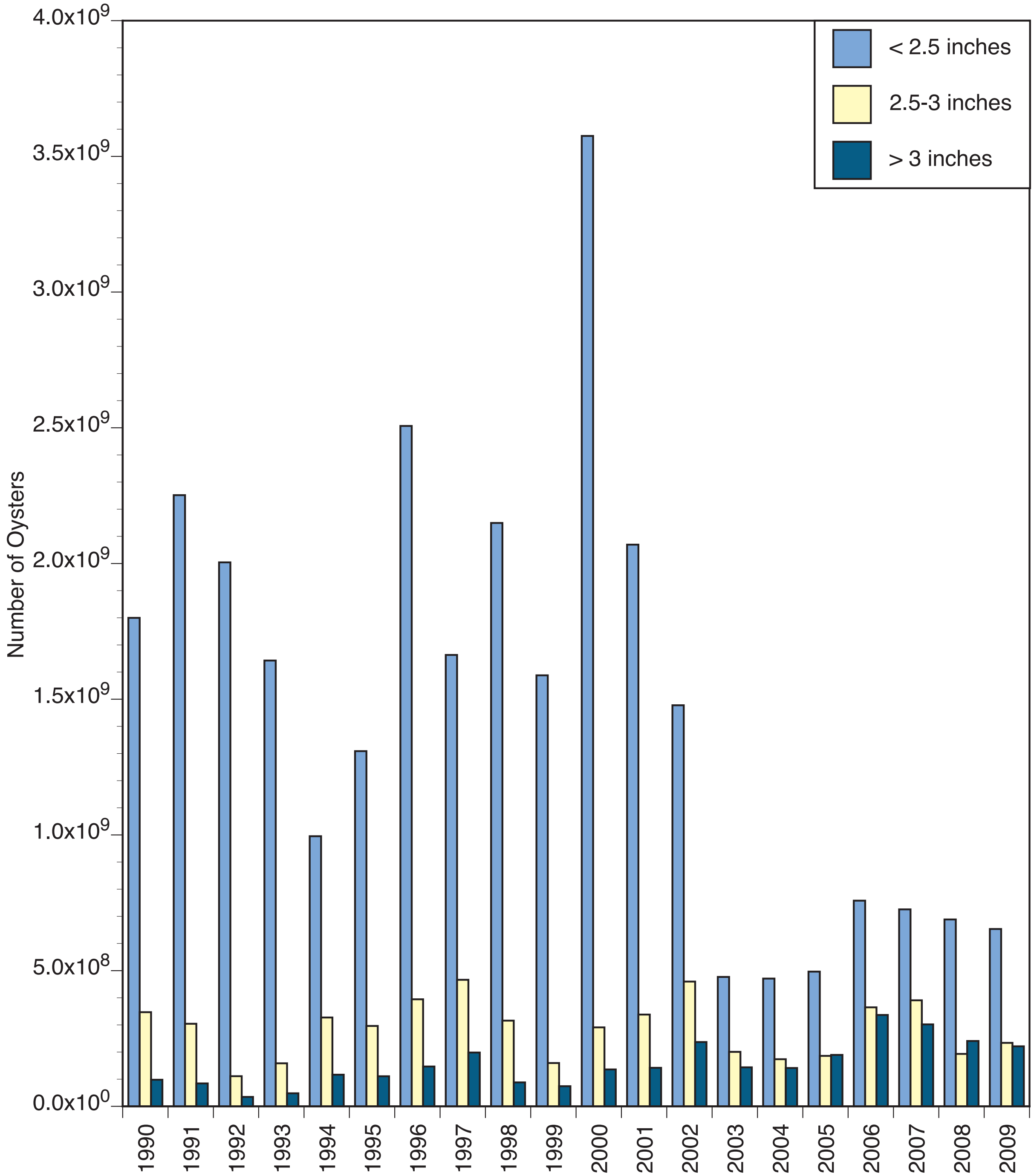


Figure 14. The fraction of small, small market, and large market-size animals since 1990.

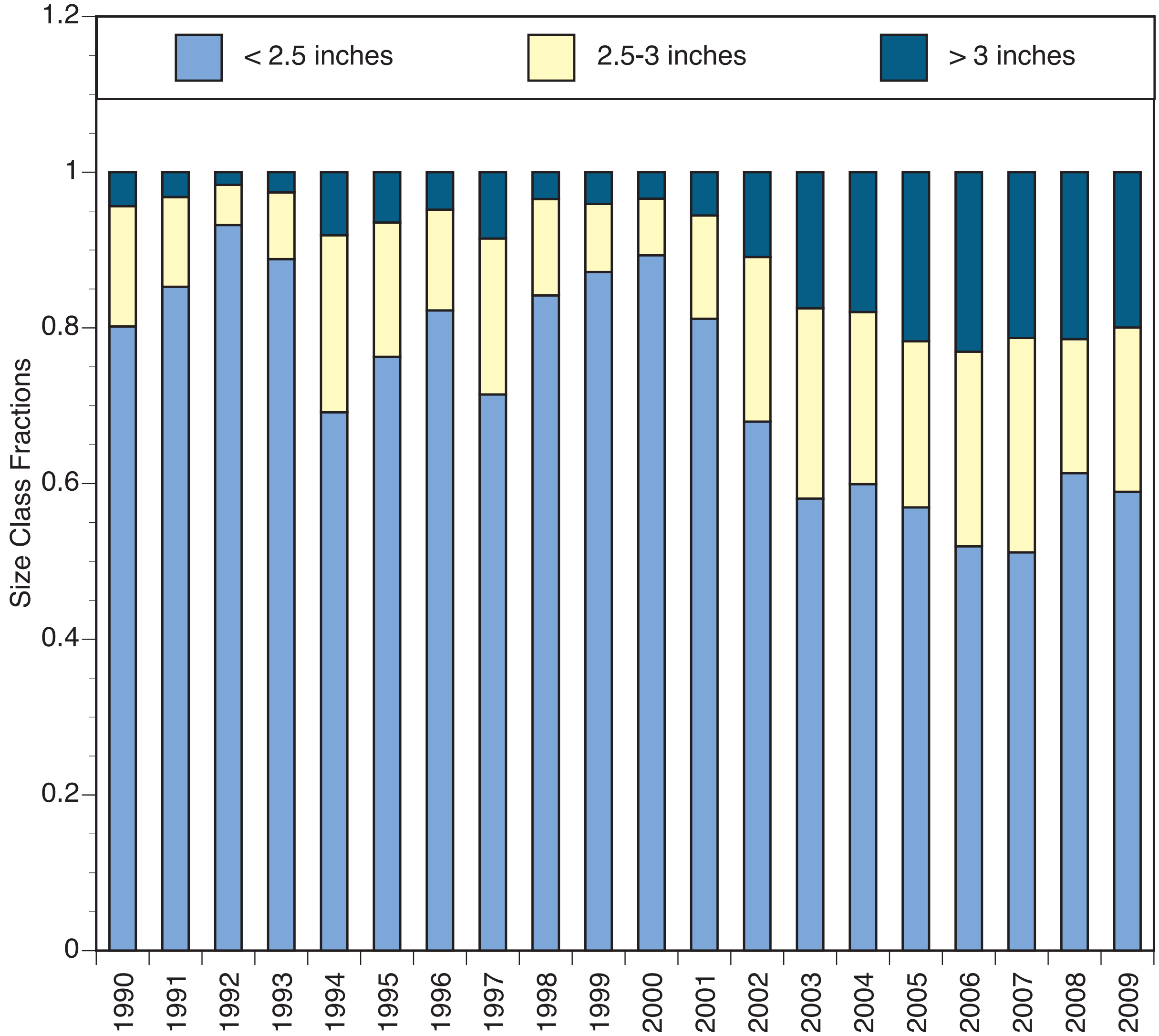


Figure 15. The abundance of small, small market, and large market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 7. Note variation in y-axis scale between graphs.

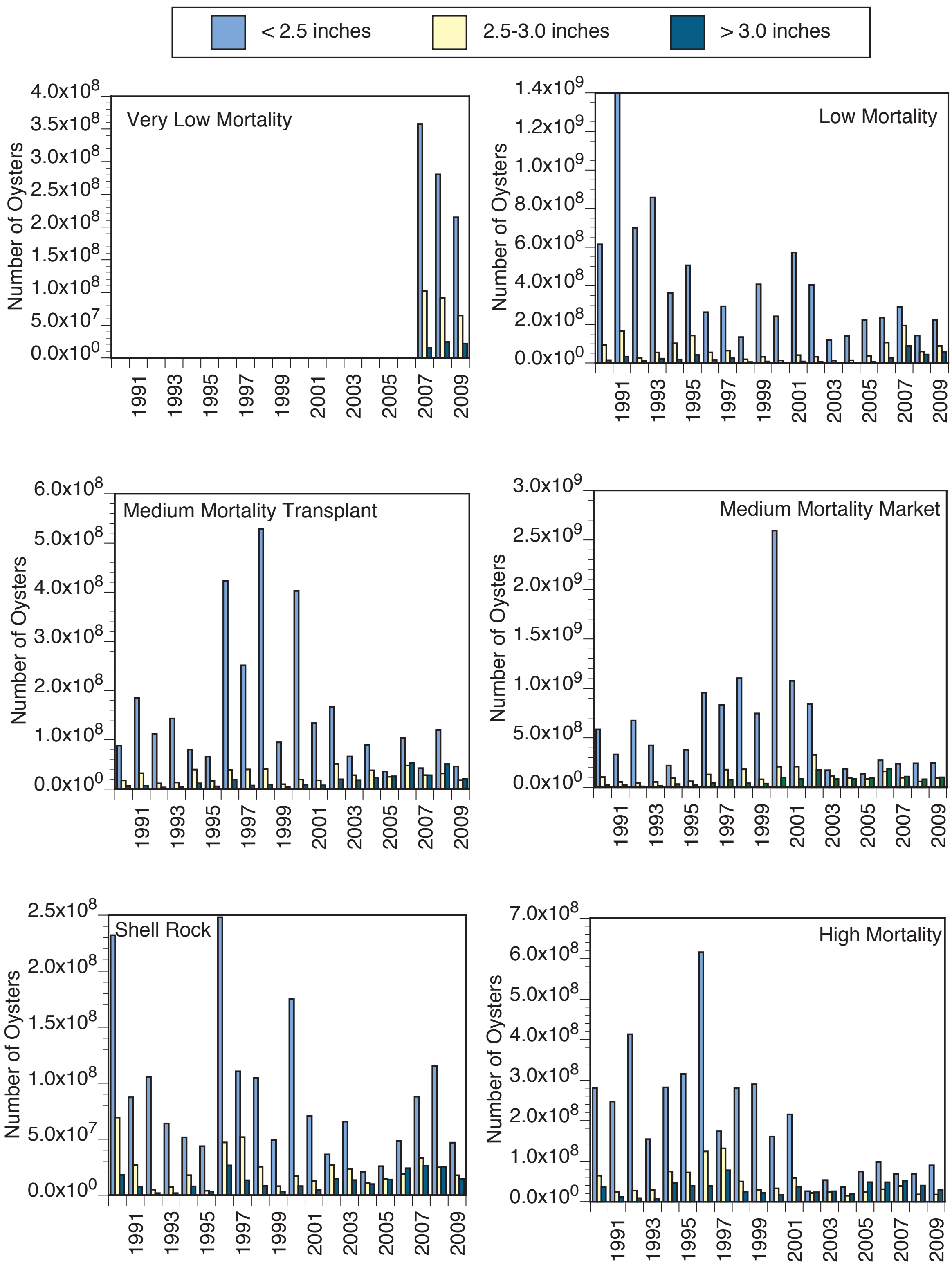


Figure 16. The fraction of marketable animals that were $\geq 2.5''$-$<3''$ and $\geq 3''$, excluding the very-low-mortality beds.

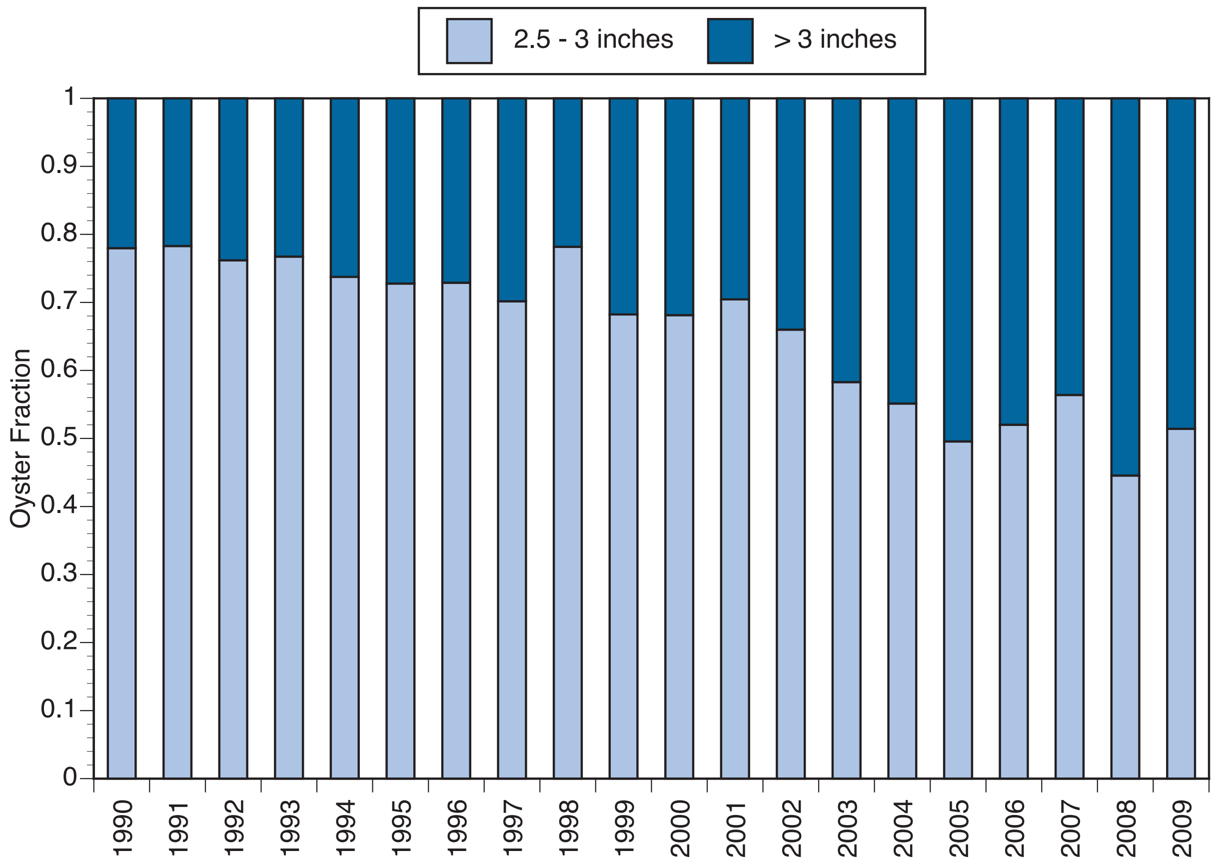


Figure 17. The number of animals $\geq$2.5″, excluding the very-low-mortality beds.

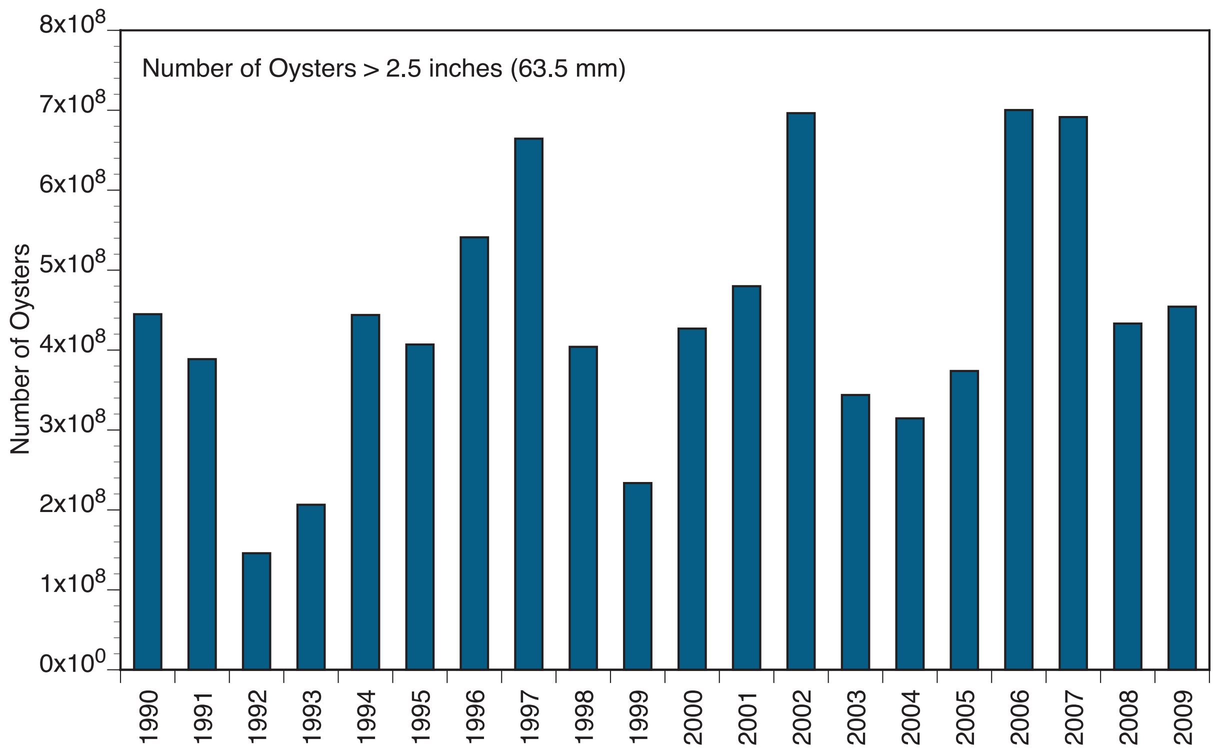


Figure 18. The number of animals $\geq 2.5''$ by bay region, excluding the very-low-mortality beds. Bed regions are defined in Figure 7.

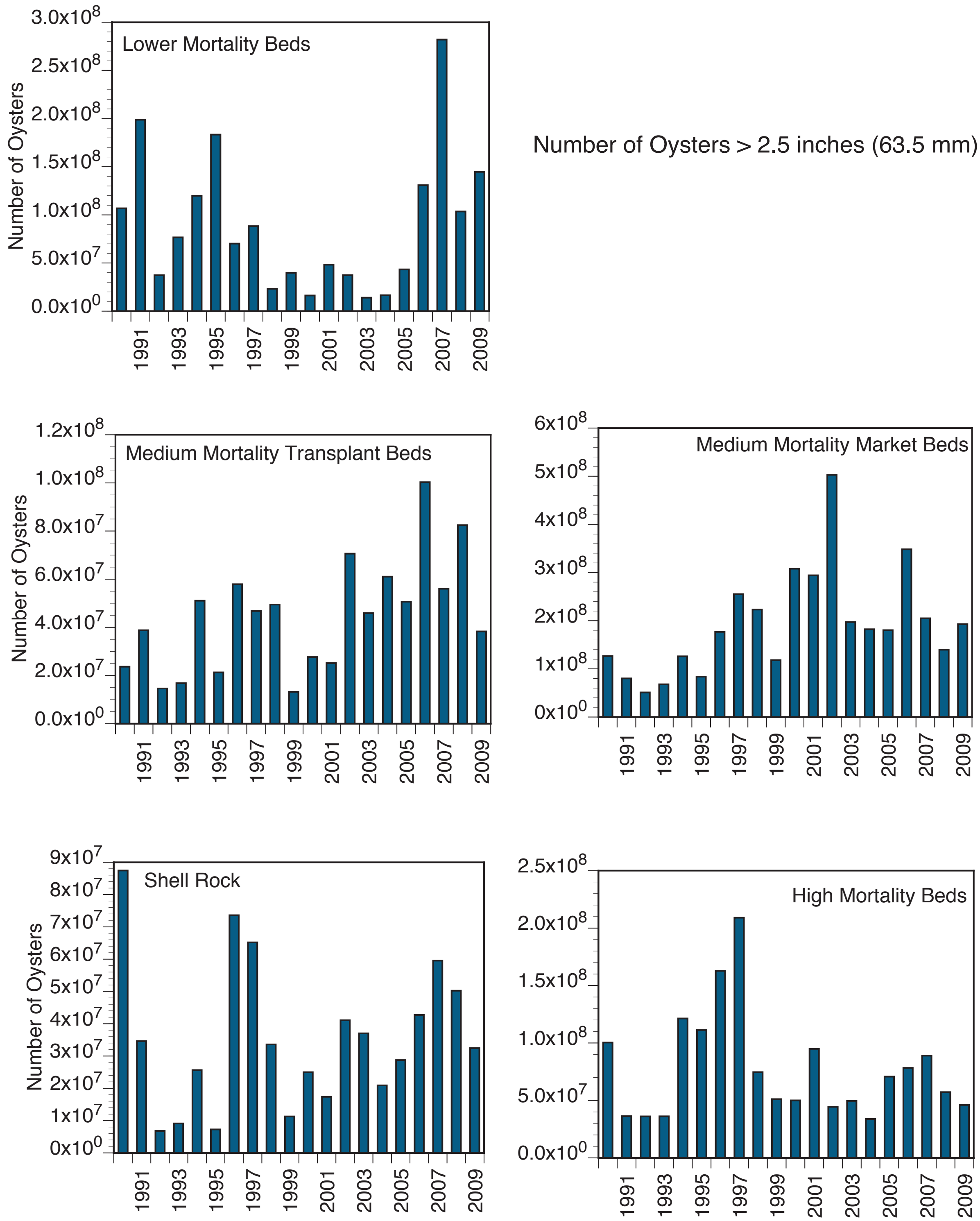


Figure 19. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)], excluding the very-low-mortality beds.

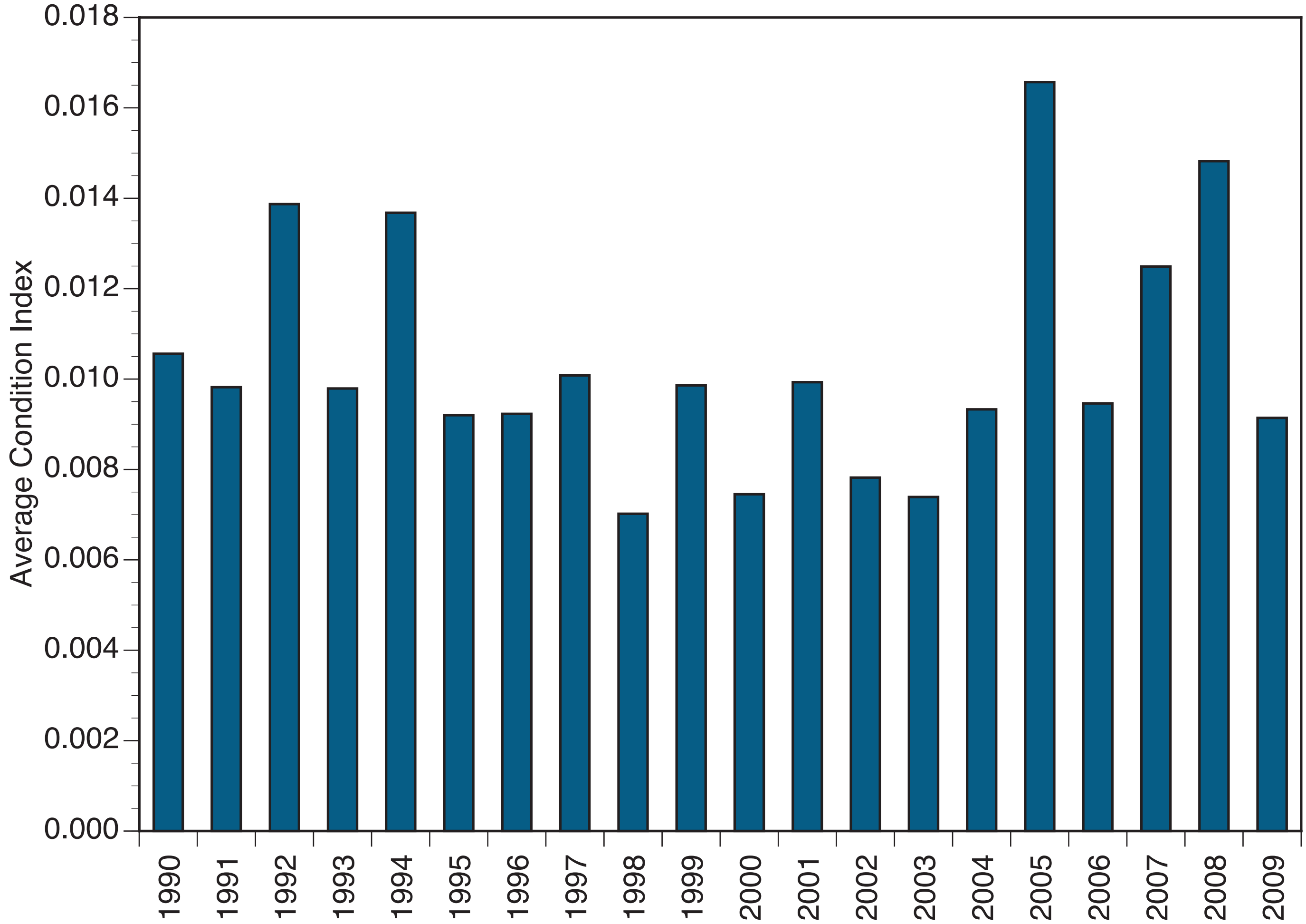


Figure 20. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)] by bay group. Bed distributions by region are given in Figure 7.

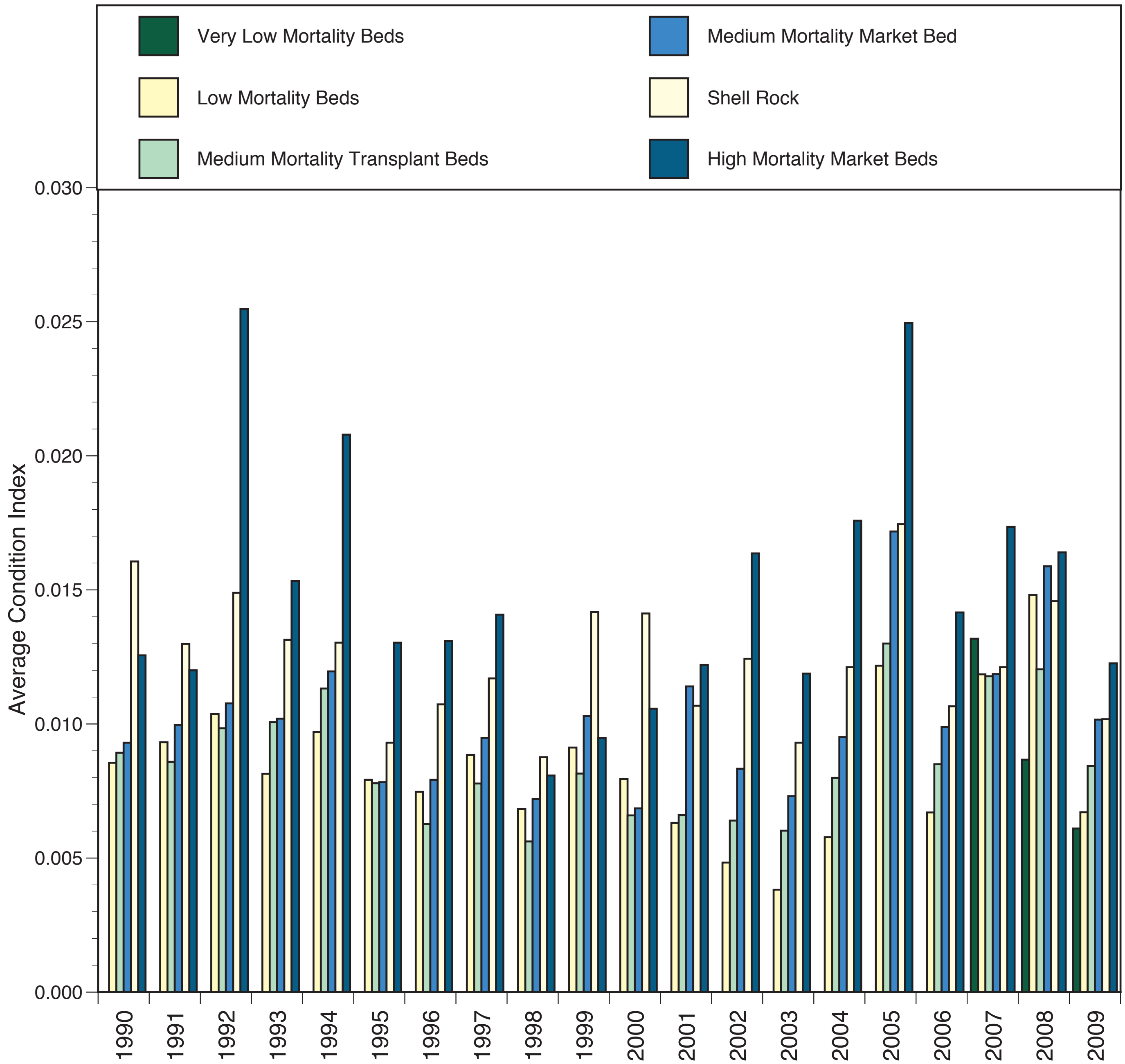


Figure 21. Number of spat recruiting per year for the 1953-2009 time series, cumulatively by bay region. Bay regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

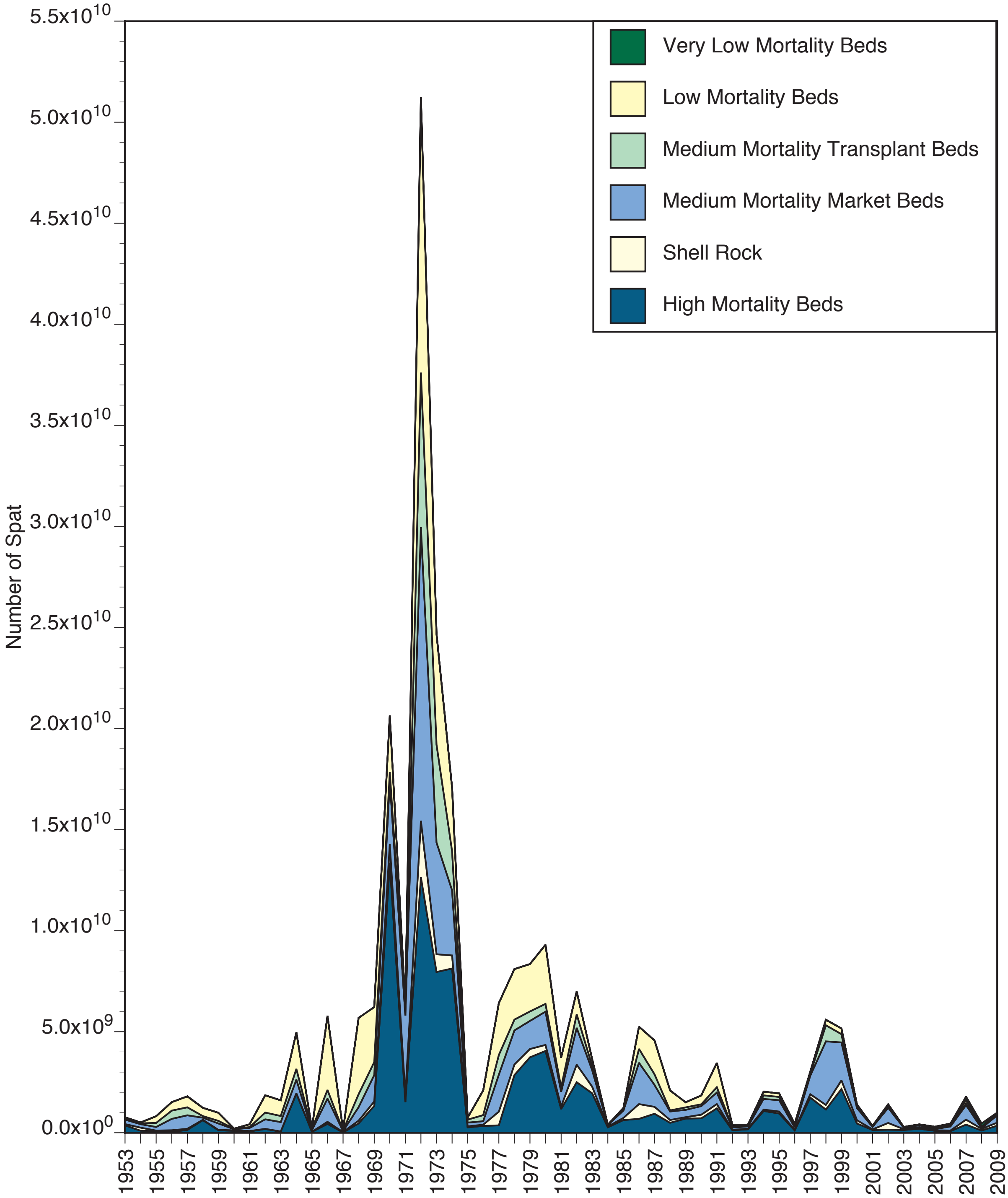


Figure 22. Number of spat recruiting per year for the 1989-2009 time series. Bay regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

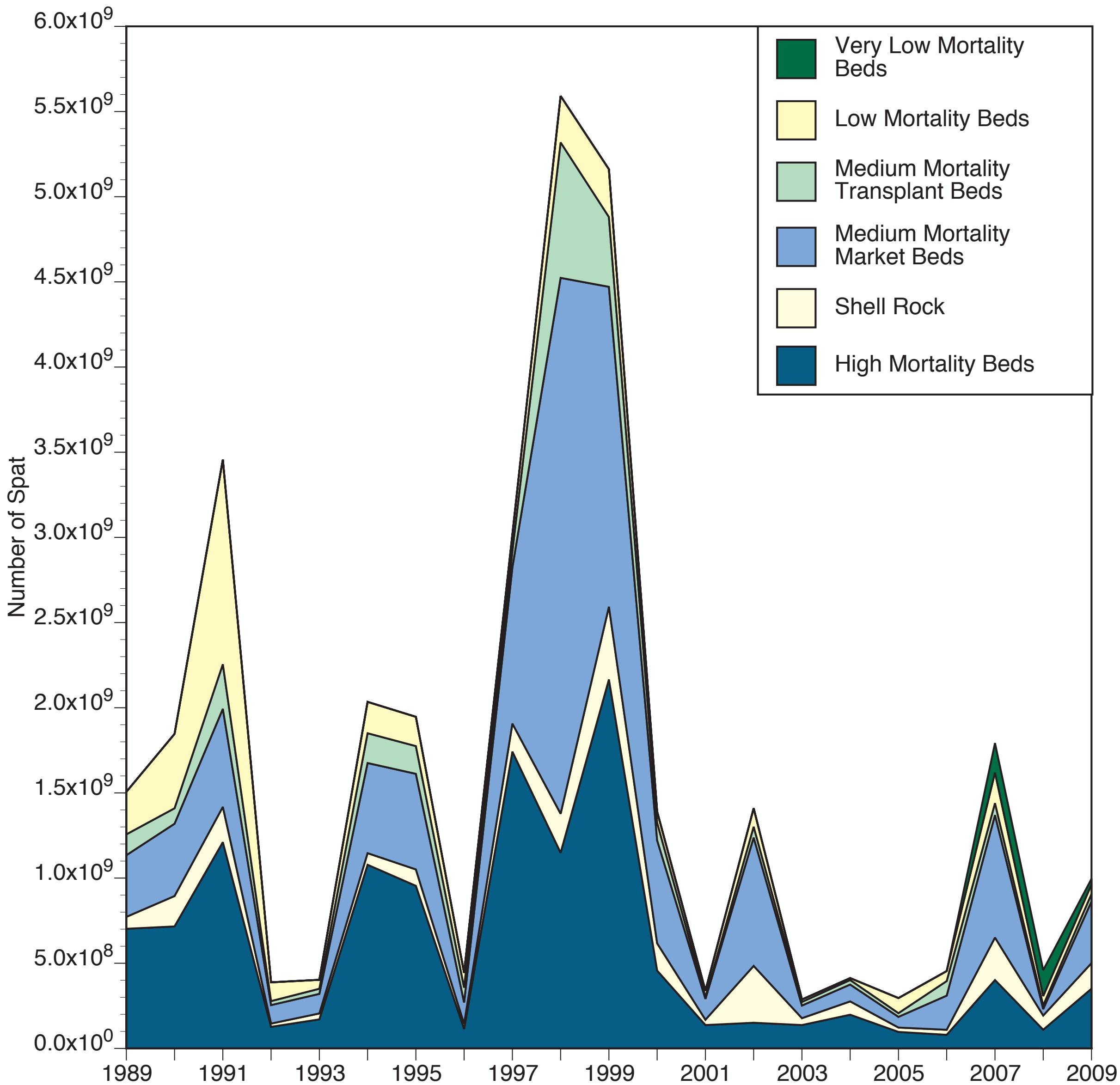


Figure 23. The number of spat recruiting per >20-mm oyster per year, excluding the very-low-mortality beds.

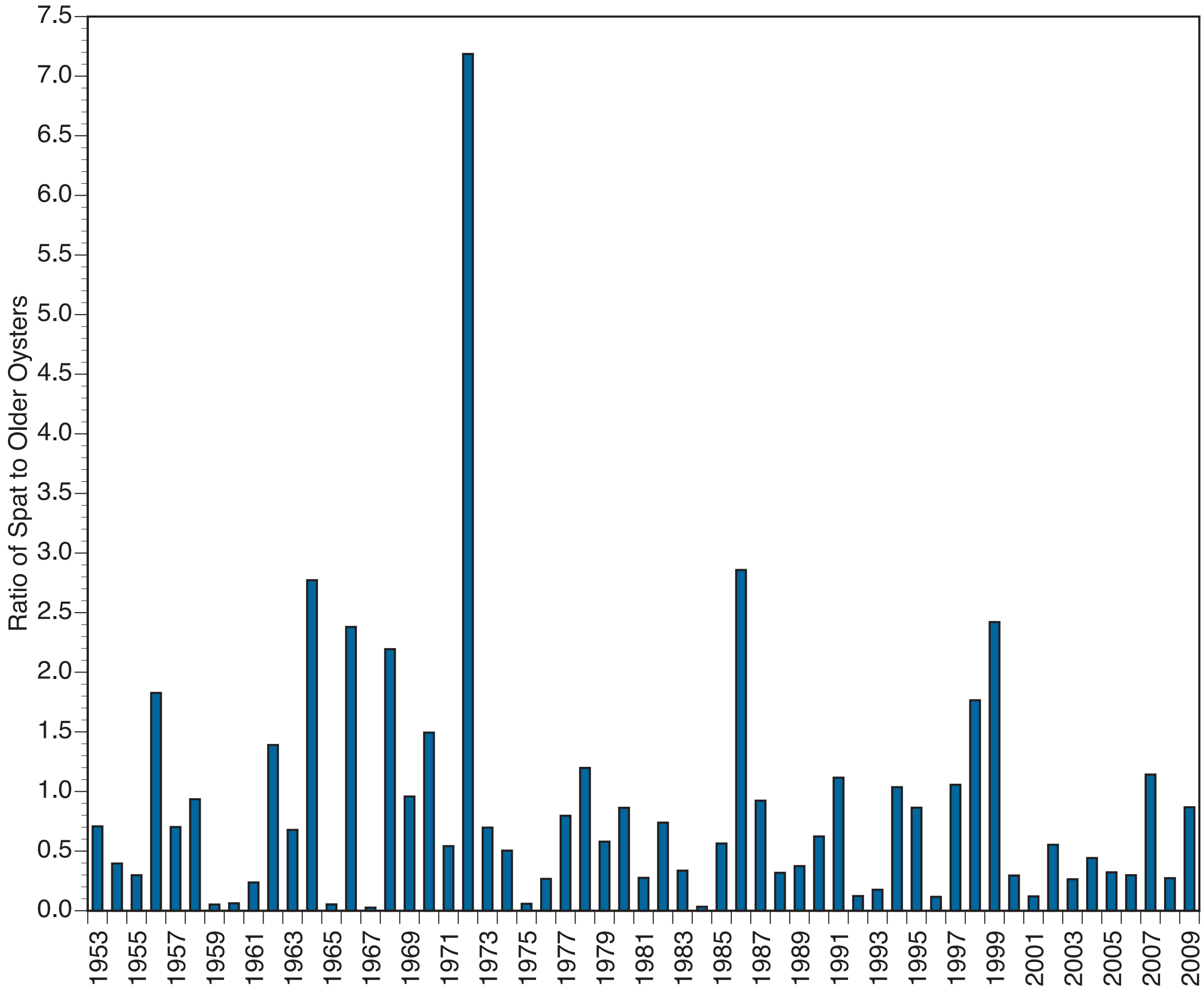


Figure 24. Spat-to-adult oyster ratio for each bay region. Bed distributions by bay region are given in Figure 7.

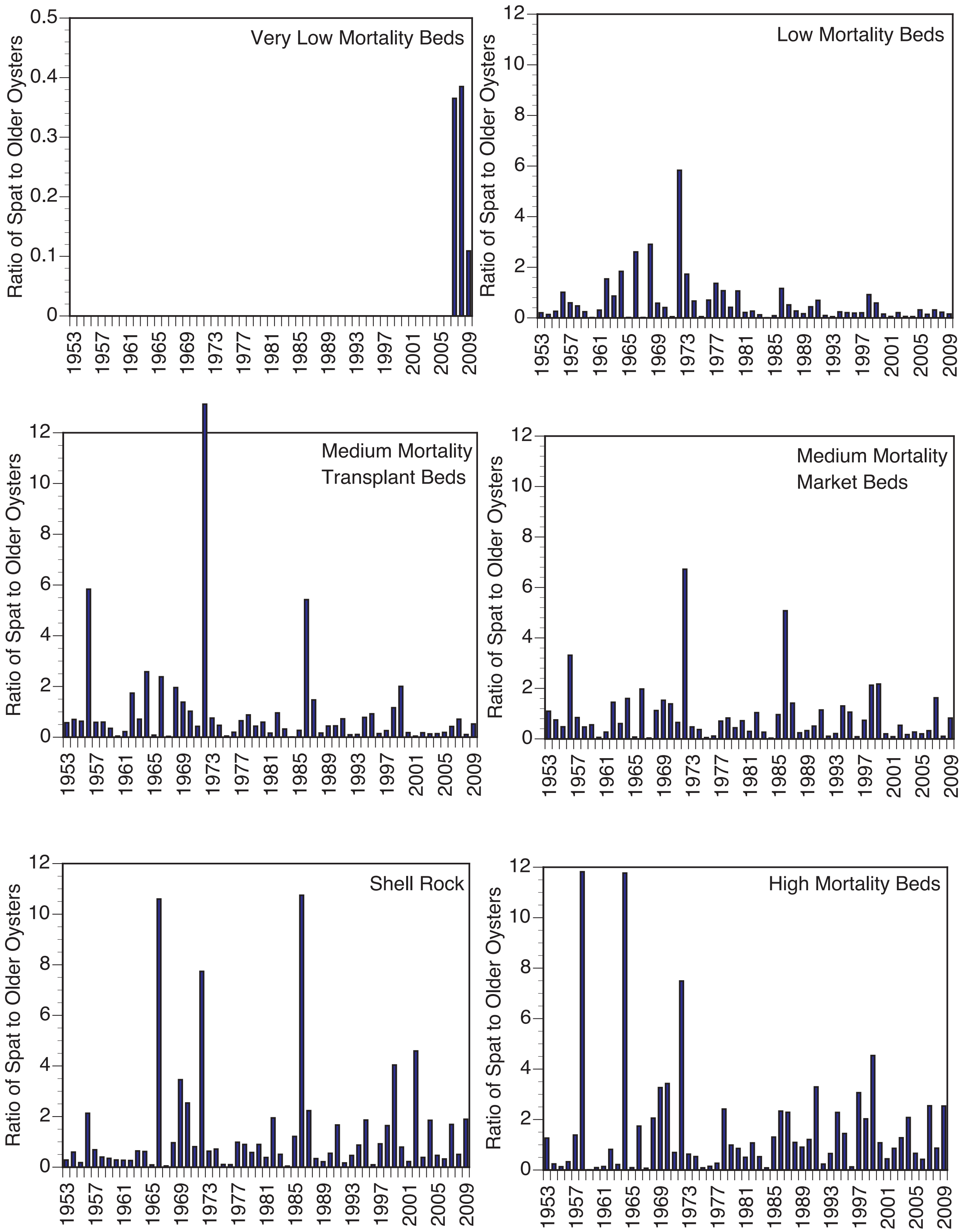


Figure 25. Location of 2009 shell plants, denoted by yellow stars. Selected high-quality and medium-quality oyster grounds in New Jersey are denoted by shaded 25-acre grids. Red delineates State of Delaware beds.

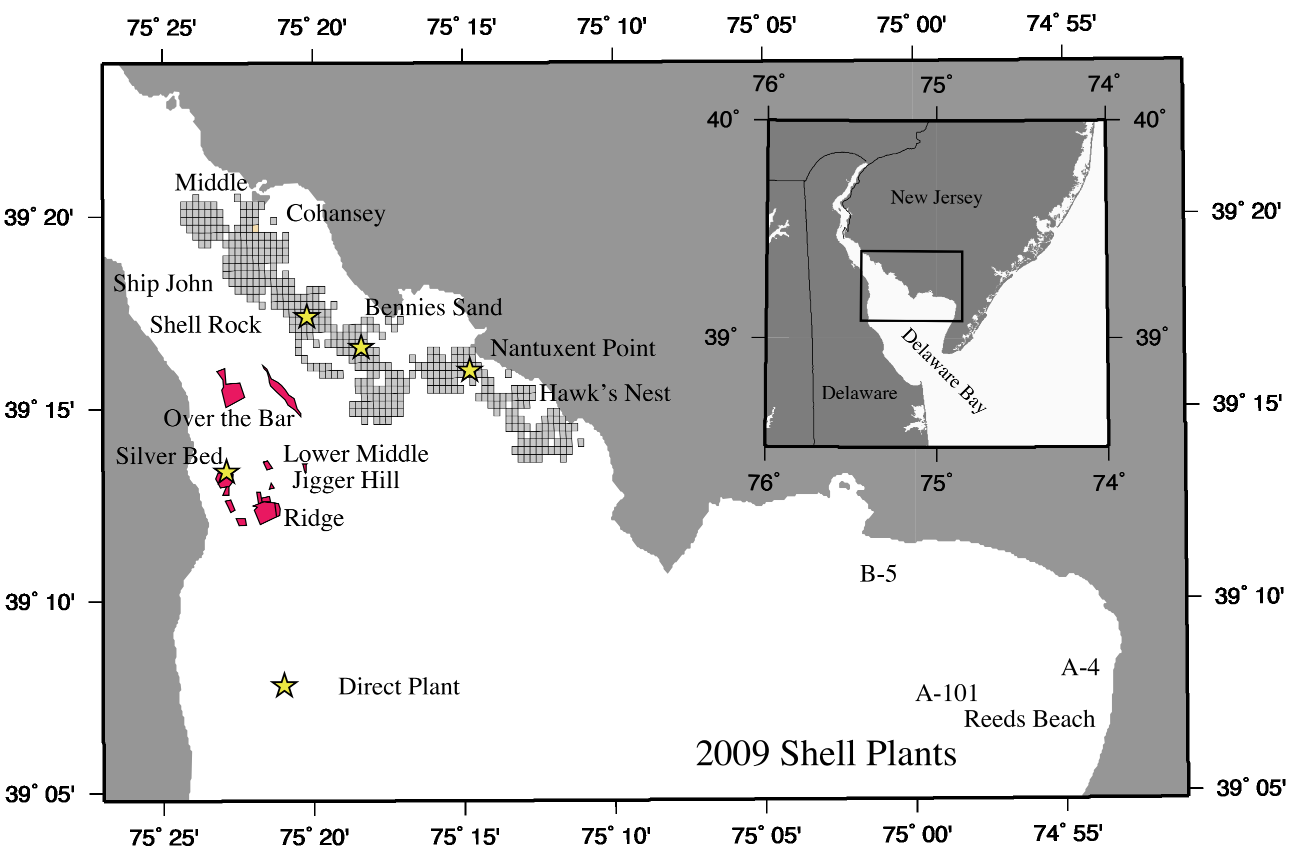


Figure 26. The size frequency of spat and yearlings on shell planted in 2008. Details of the shell plants are provided in Table 16. X-axis class intervals mark the lower bound of the size class.

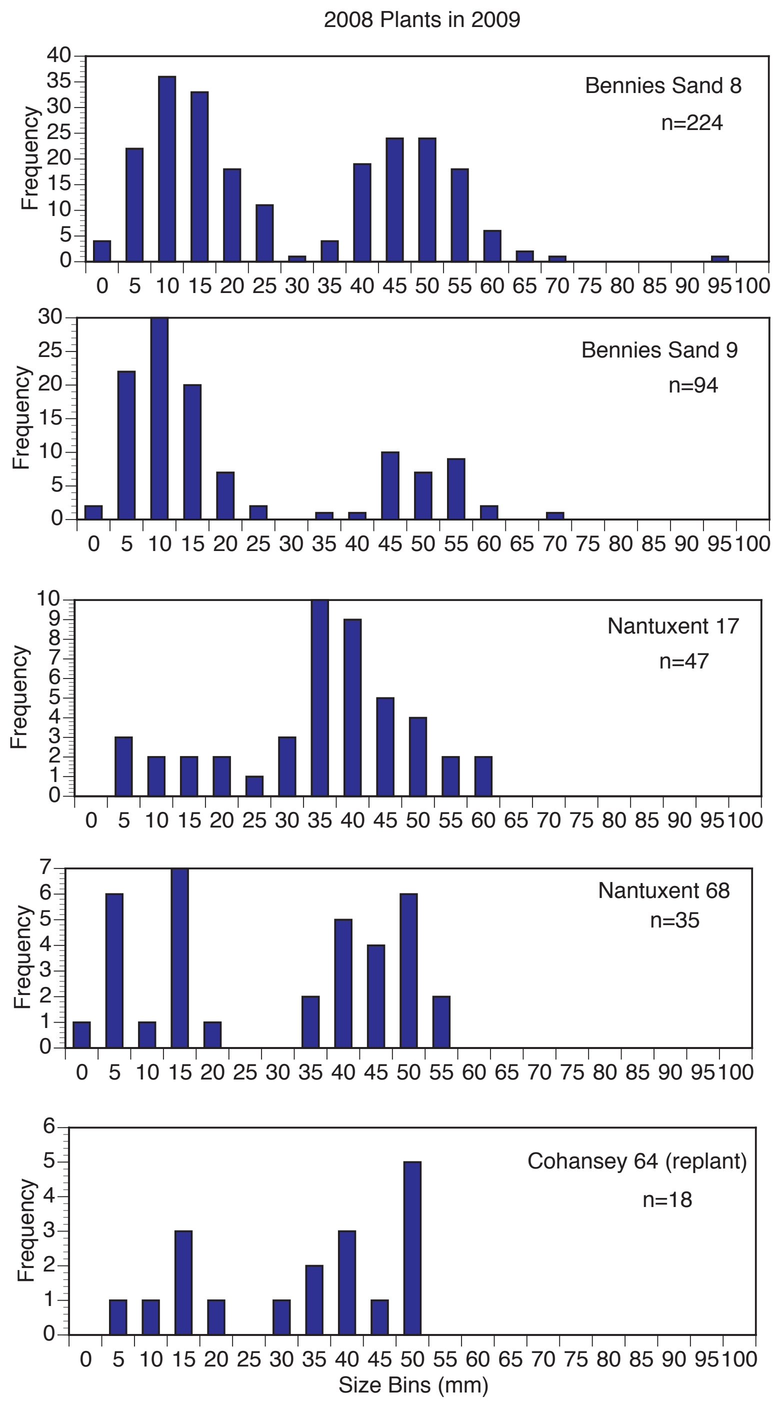


Figure 27. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2009. Shell planting began in 2005 and increased in 2006-2008, but declined again in 2009. Shell budgets are calculated using the updated half-lives estimated in this assessment and using the half-lives estimated in 2008 and 2009 (SAW-10, SAW-11) for comparison.

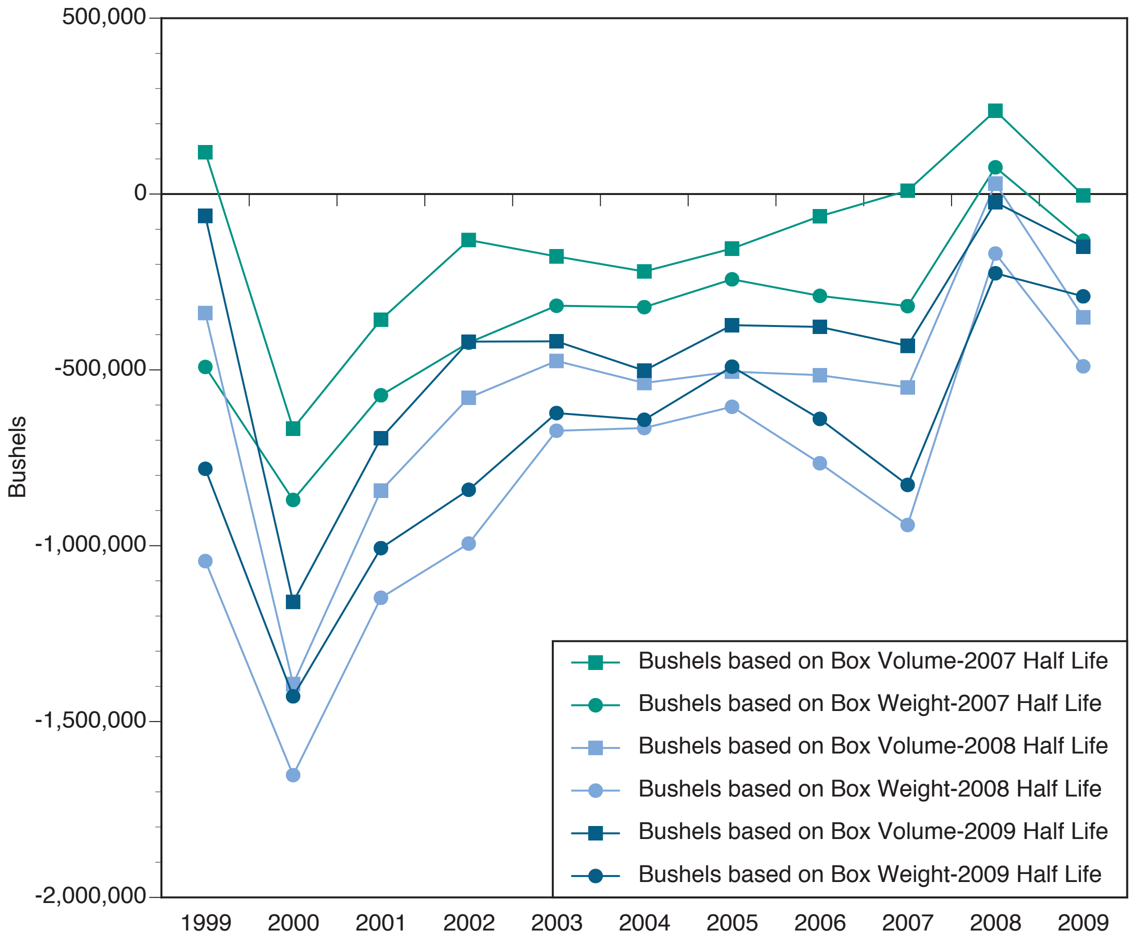


Figure 28. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2009.

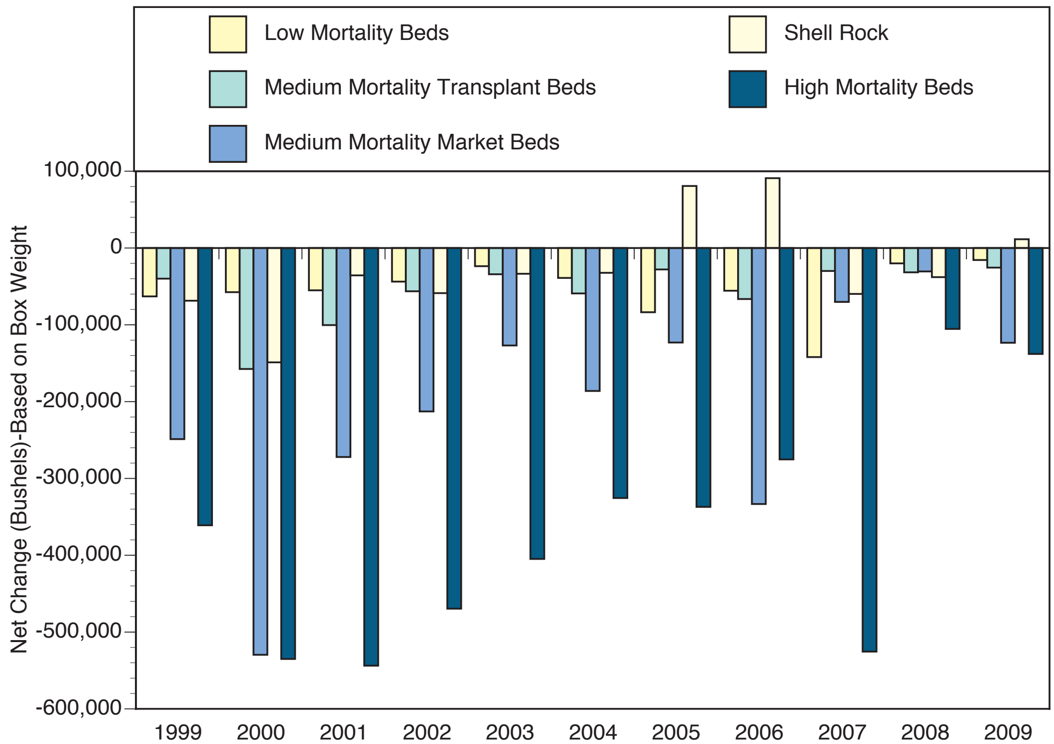
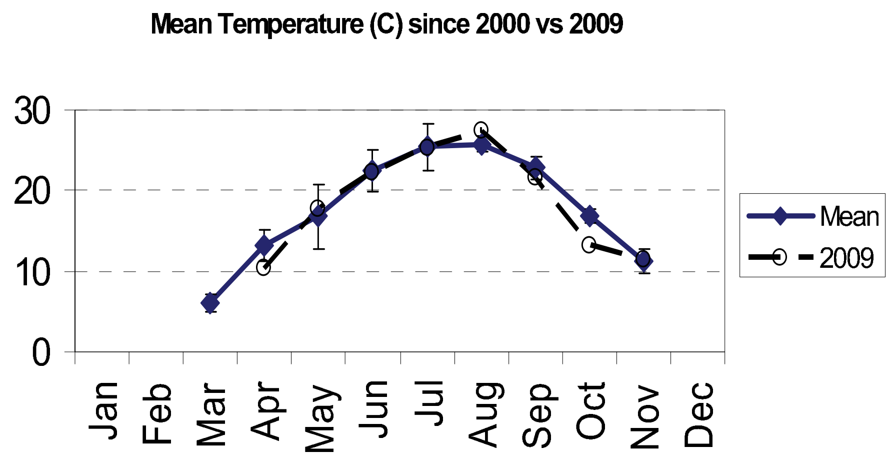


Figure 29. Trends in water temperature and salinity during 2009. Dashed line is the mean of data collected during the 2009 Dermo monitoring program. Solid line represents the long-term mean value.



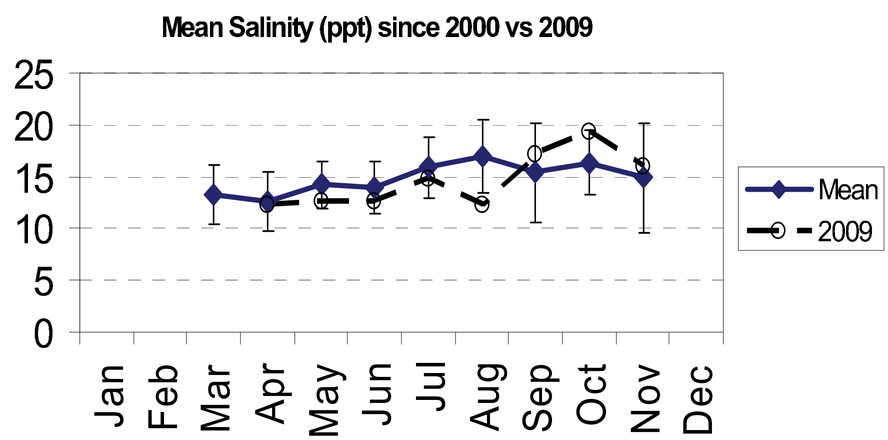
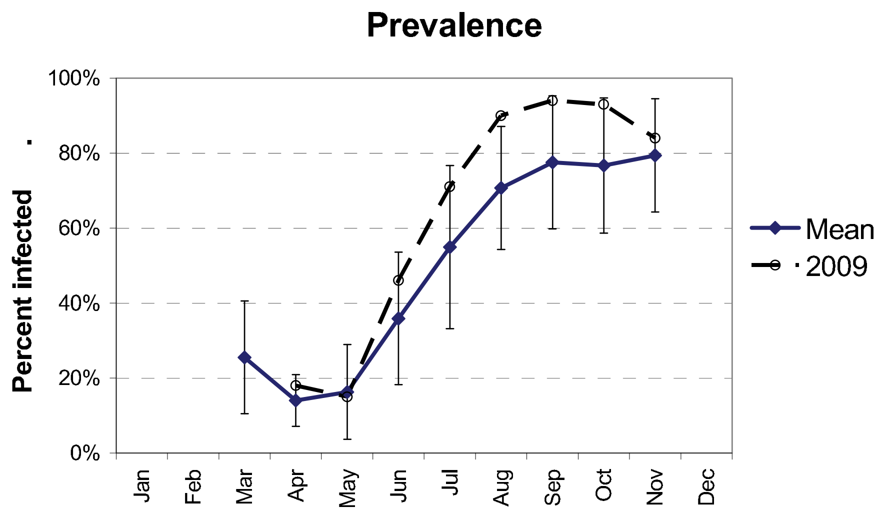


Figure 30. Mean and 2009 Dermo prevalence and weighted prevalence in oysters on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals for the 1990-2009 mean.



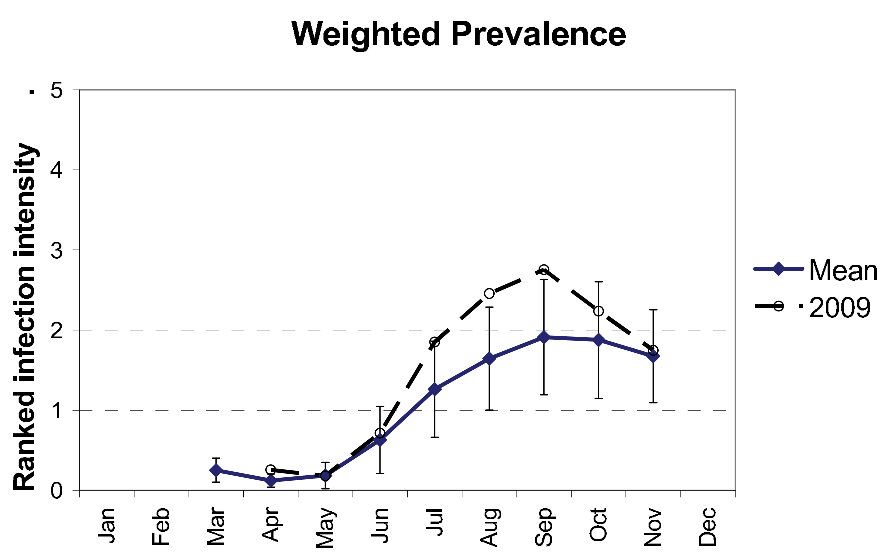
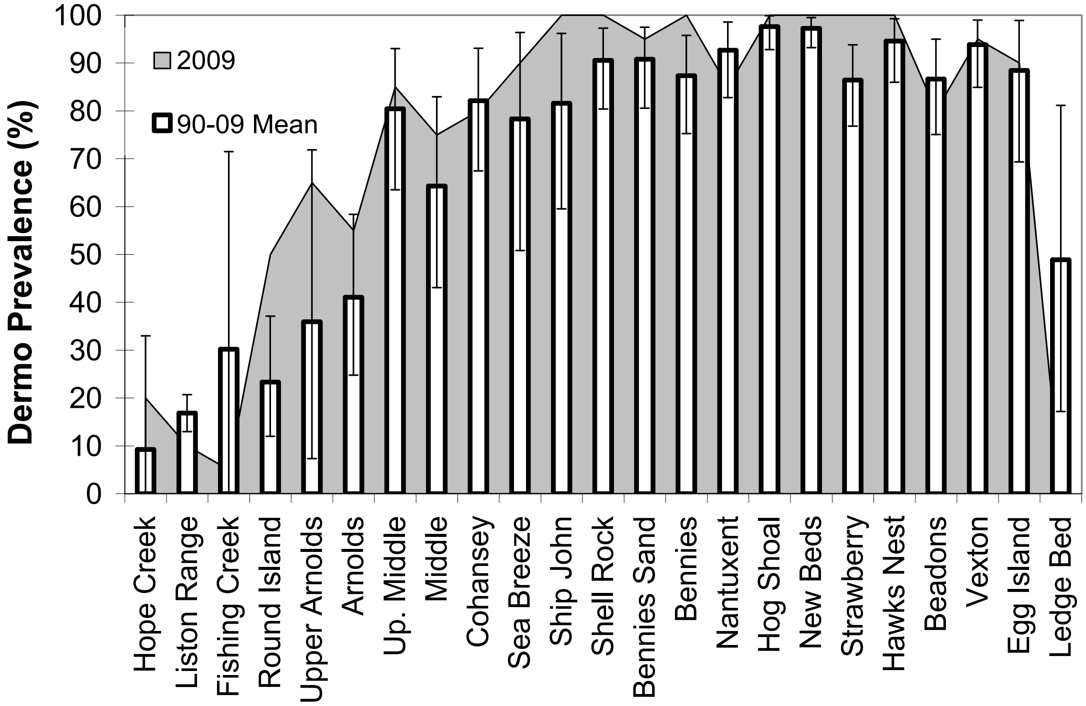


Figure 31. Comparison of average annual fall Dermo prevalence and weighted prevalence in oysters since 1990 (open bars with 95% confidence intervals) with 2009 levels (shaded area). Ledge bed was not sampled in 2009.



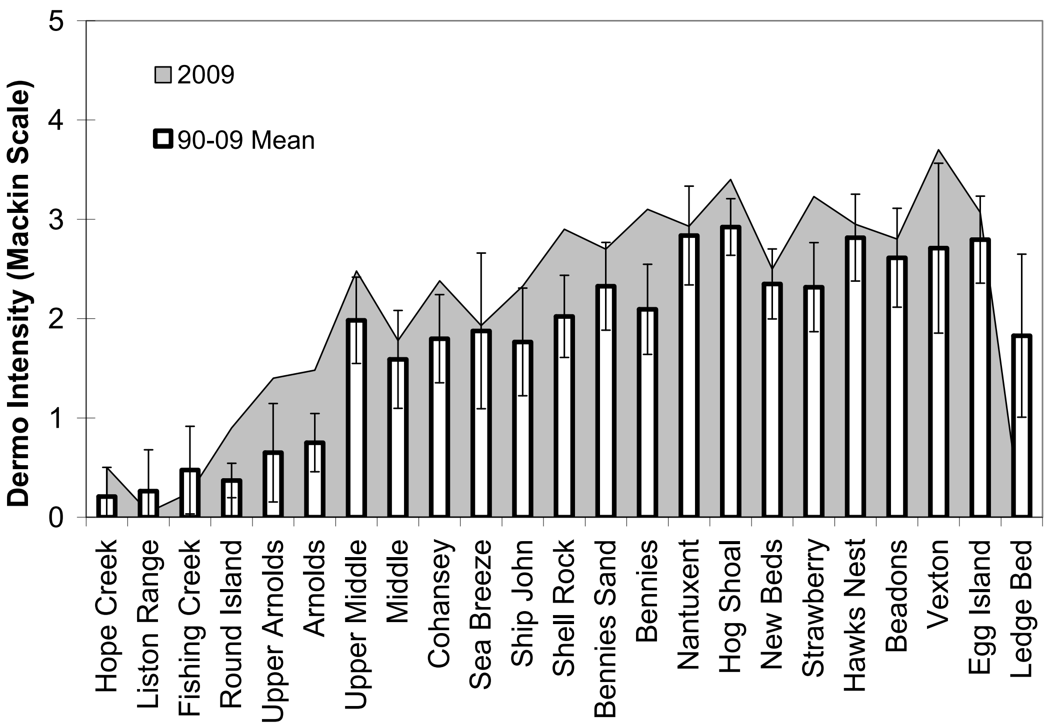


Figure 32. Time series showing the cyclic nature of Dermo prevalence. Note the tendency for epizootics to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

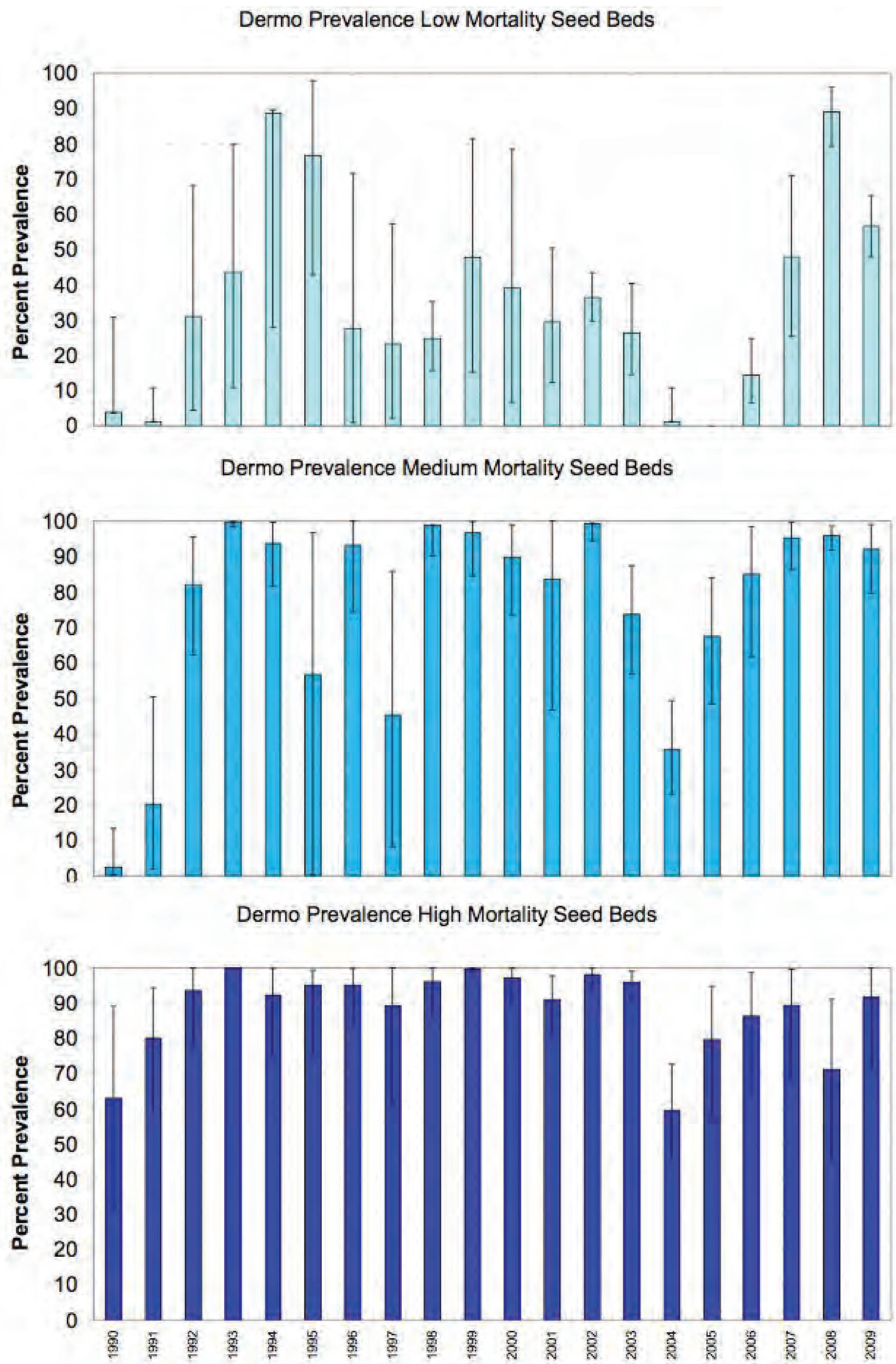


Figure 33. Time series showing the cyclic nature of Dermo disease weighted prevalence. Note the tendency for epizootics (weighted prevalences >2) to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

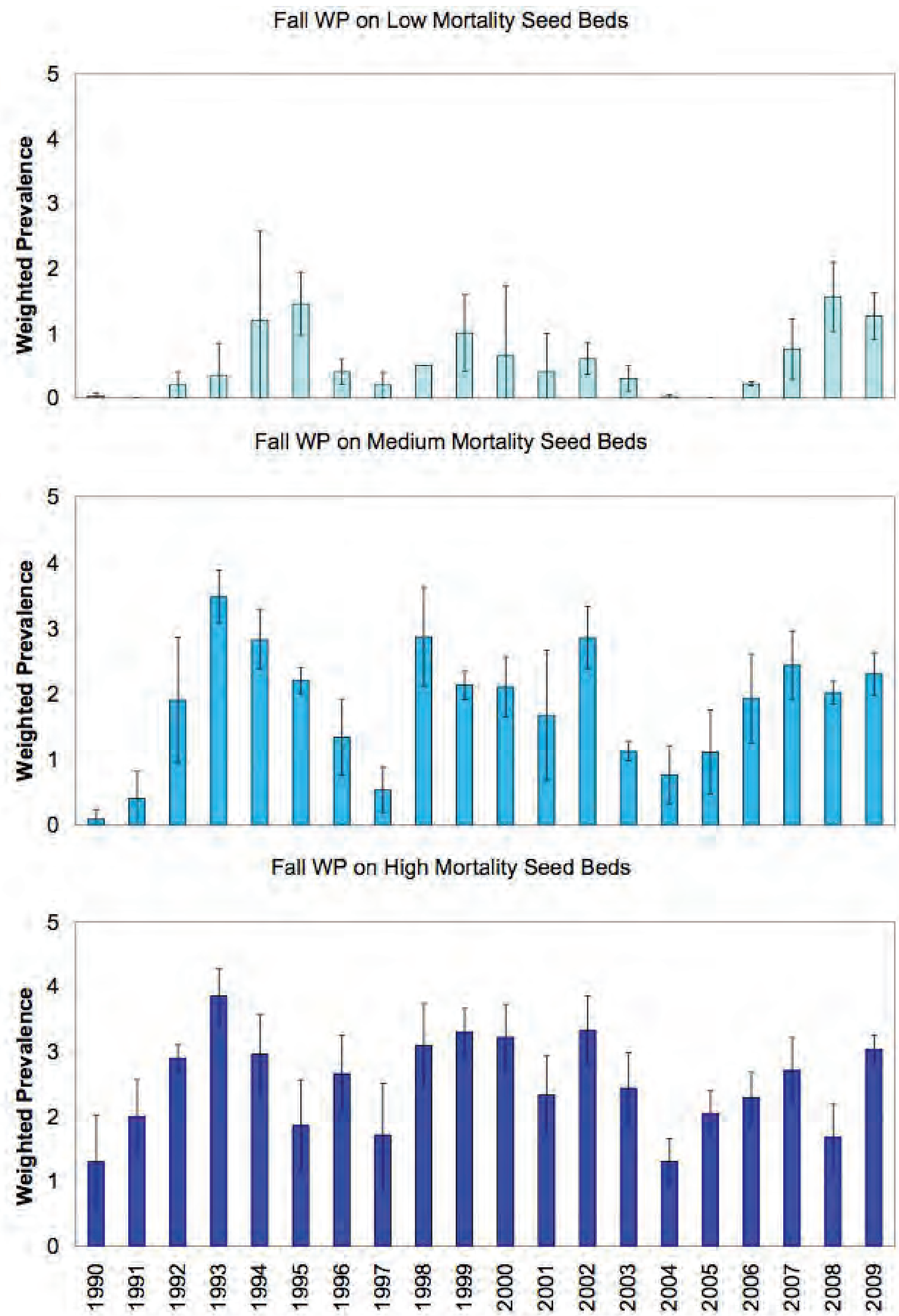
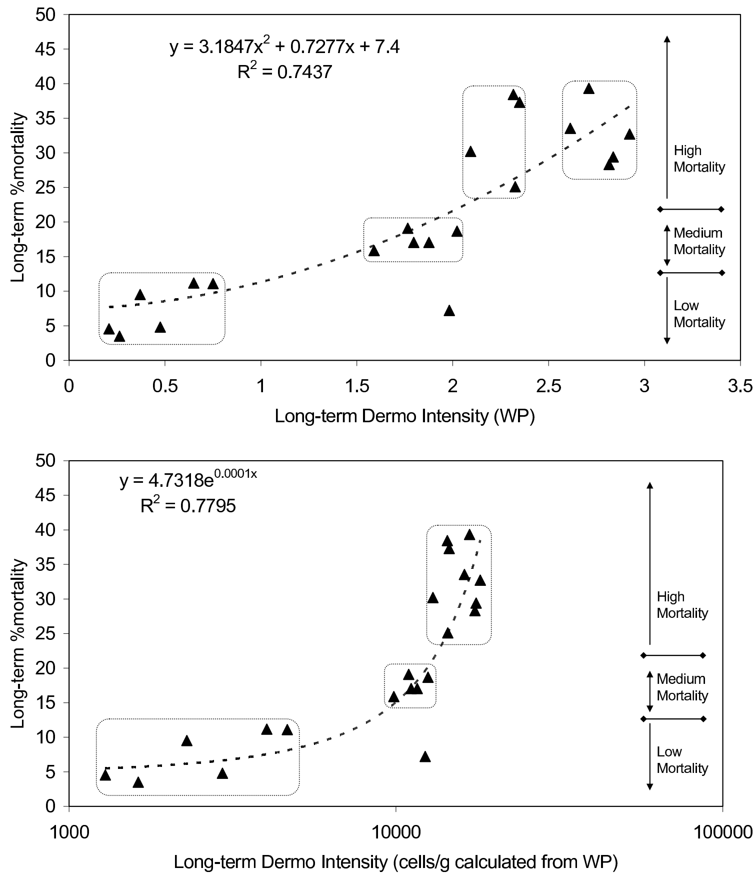


Figure 34. Relationship between the long-term mean box-count mortality estimate and the long-term mean intensity of Dermo infections since 1990. Data are individual bed estimates. The relationship is approximately linear and indicates thresholds for Dermo-caused mortality at a weighted prevalence of about 1.5 and 2 relative to the mortality incurred. Boxes represent clusters of beds in distinct regions and fall along the x-axis as follows: Hope Creek, Round Island, Liston Range, Upper Arnolds, Fishing Creek, Arnolds, Middle, Ship John, Cohansey, Sea Breeze, Shell Rock, Bennies, Strawberry, Bennies Sand, New Beds, Vexton, Beadons, Hawk's Nest, Nantuxent and Hog Shoal. Upper Middle (5% mortality), Ledge (50% mortality) and Egg Island (48% mortality) represent outliers largely resulting from inconsistent sampling over the time series.



The trend line is a third order polynomial forced through a 5% mortality representing the average mortality on the upper seed beds encompassed by the left most box. The lower panel converts weighted prevalence values in the upper panel to densities of the parasite per gram of wet tissue after Choi et al. (1989)[℘].

[℘] Choi, K-S., E.A. Wilson, D.H. Lewis, E.N. Powell and S.M. Ray, 1989: The energetic cost of *Perkinsus marinus* parasitism in oysters: quantification of the thioglycollate method. *J. Shellfish Res.* 8:125-131.

Figure 35. 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.

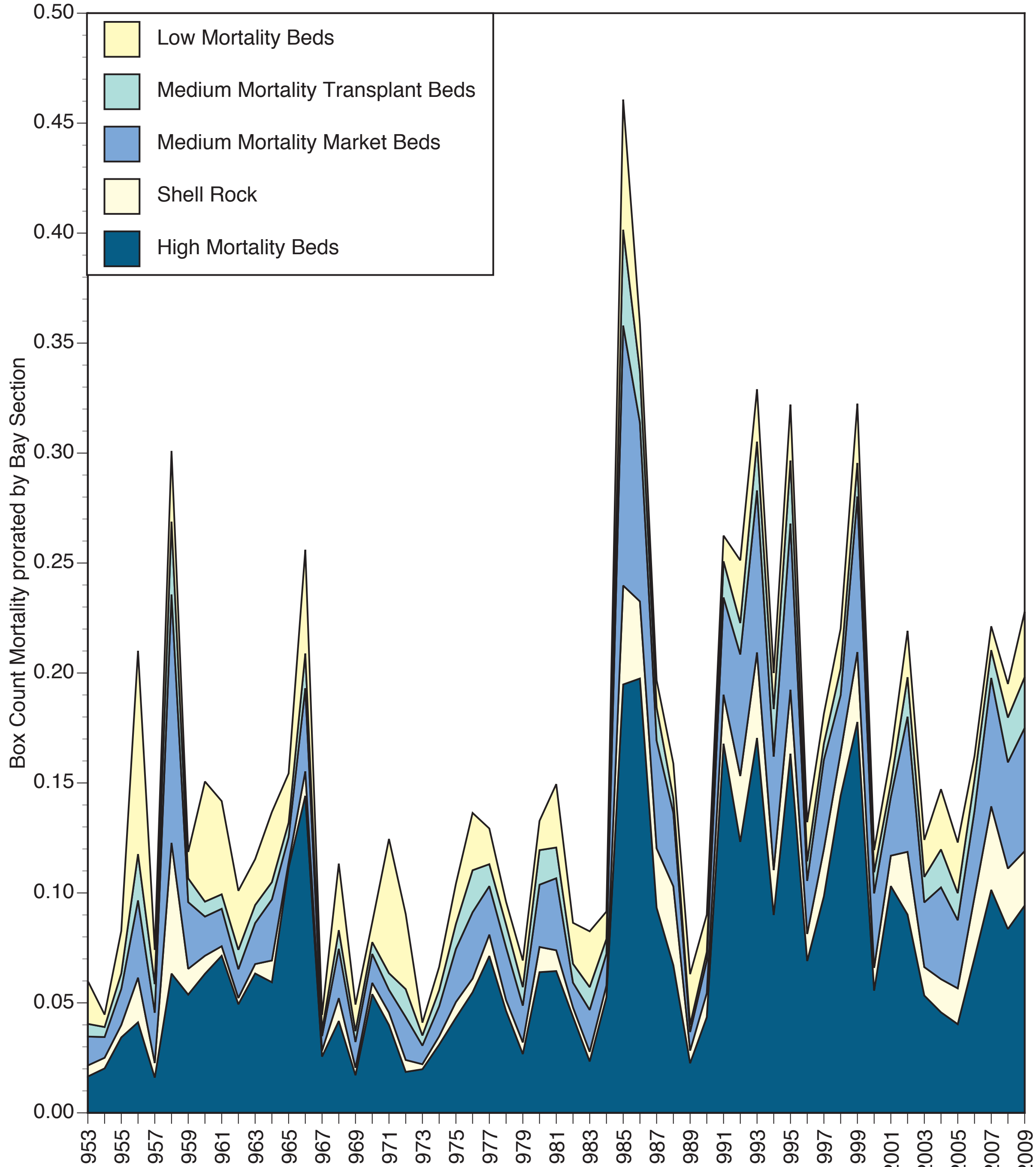


Figure 36. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region. No data are available for the very-low-mortality beds prior to 2007.

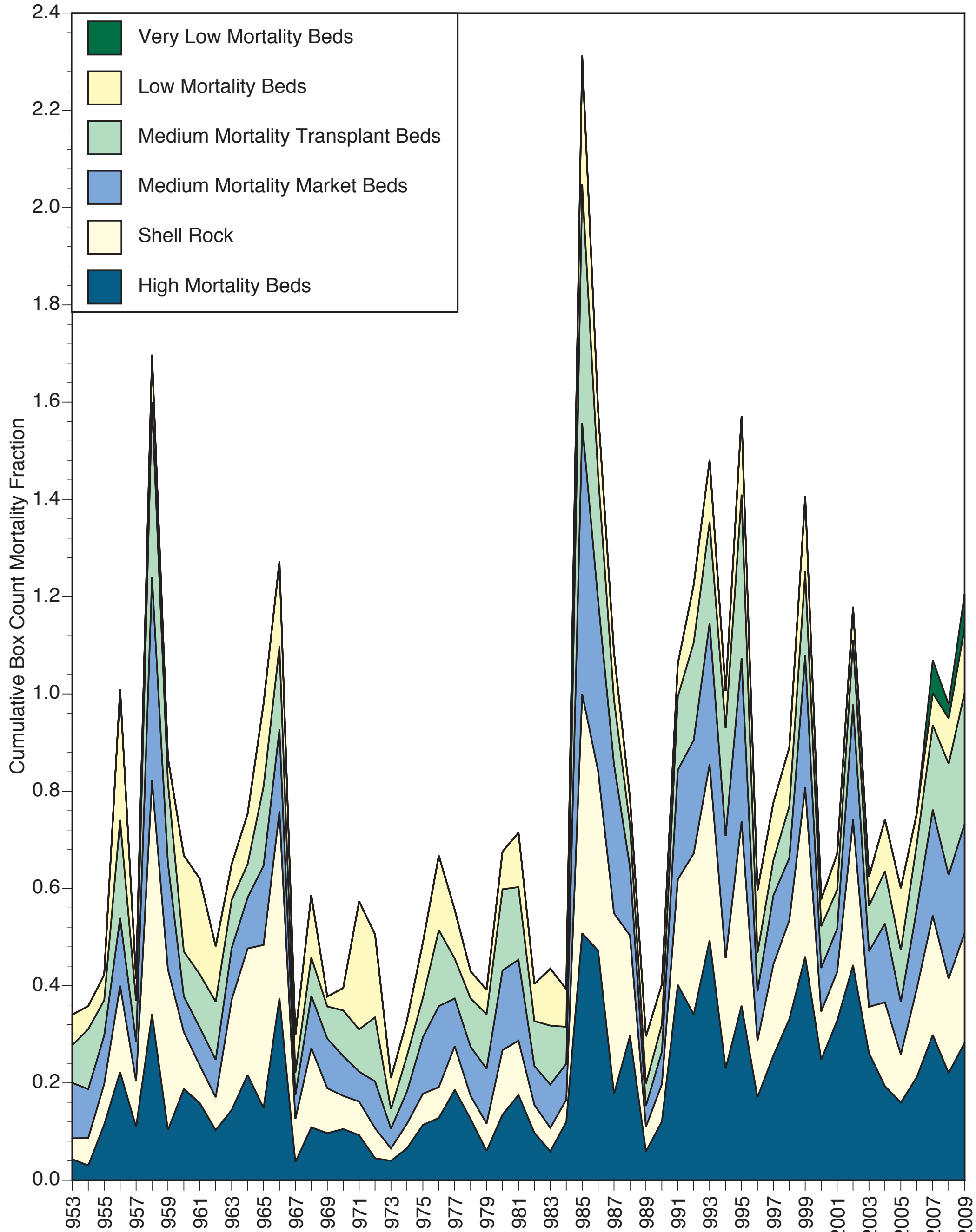


Figure 37. Broodstock-recruitment relationship for the 1953-2009 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2008 because the plot compares end-of-2008 oyster abundance with 2009 recruitment. Dotted lines identify the 57-year medians used for calculation of first passage times (Table 19).

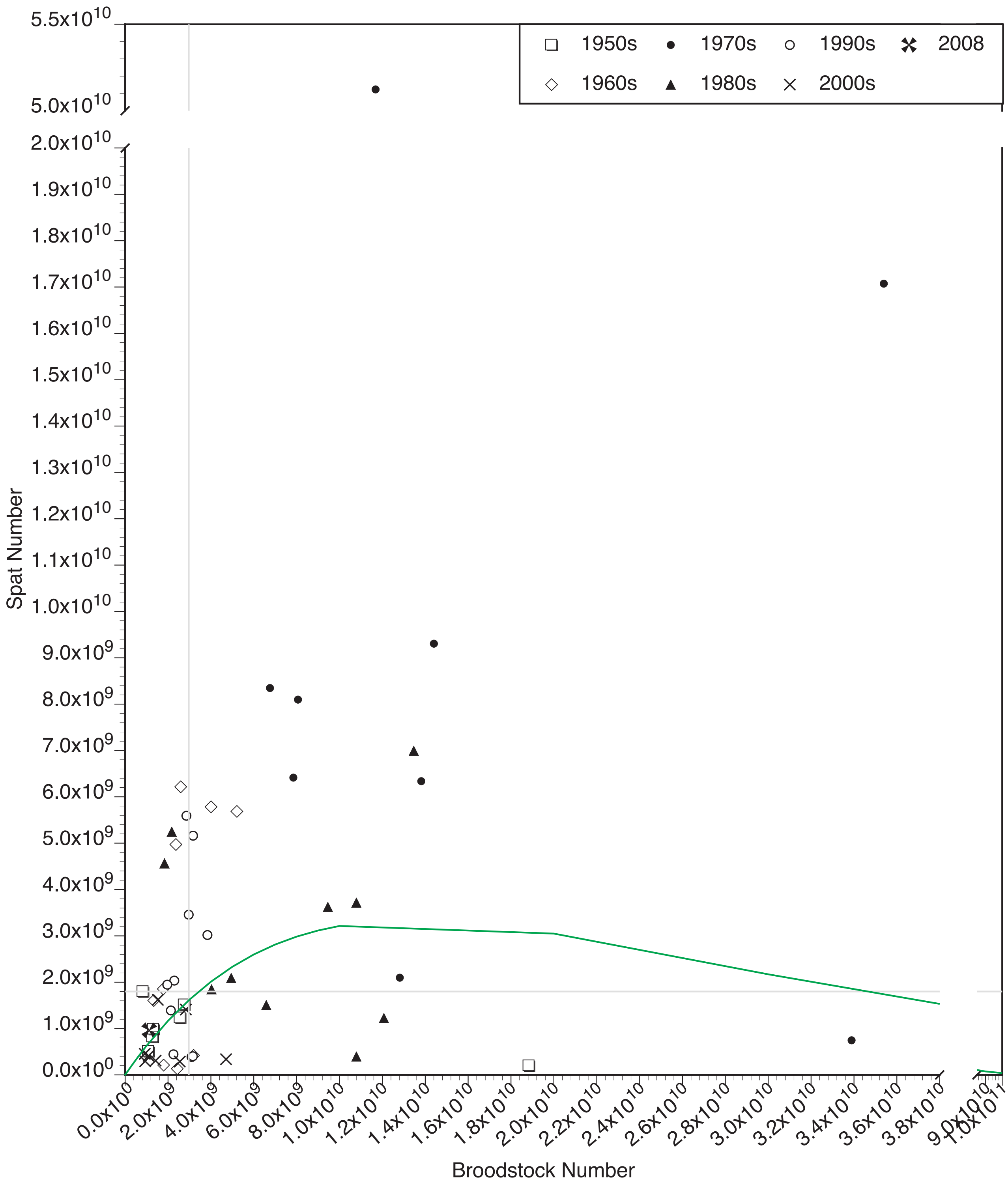


Figure 38. The quadrant numbering convention used to calculate mean first passage times. The one year transition probabilities are obtained by examining the position of consecutive x-y data pairs in quadrant space. Four transitions are possible for each starting position, the possibilities for Quadrant 1 being depicted. Sixteen total trajectories are possible.

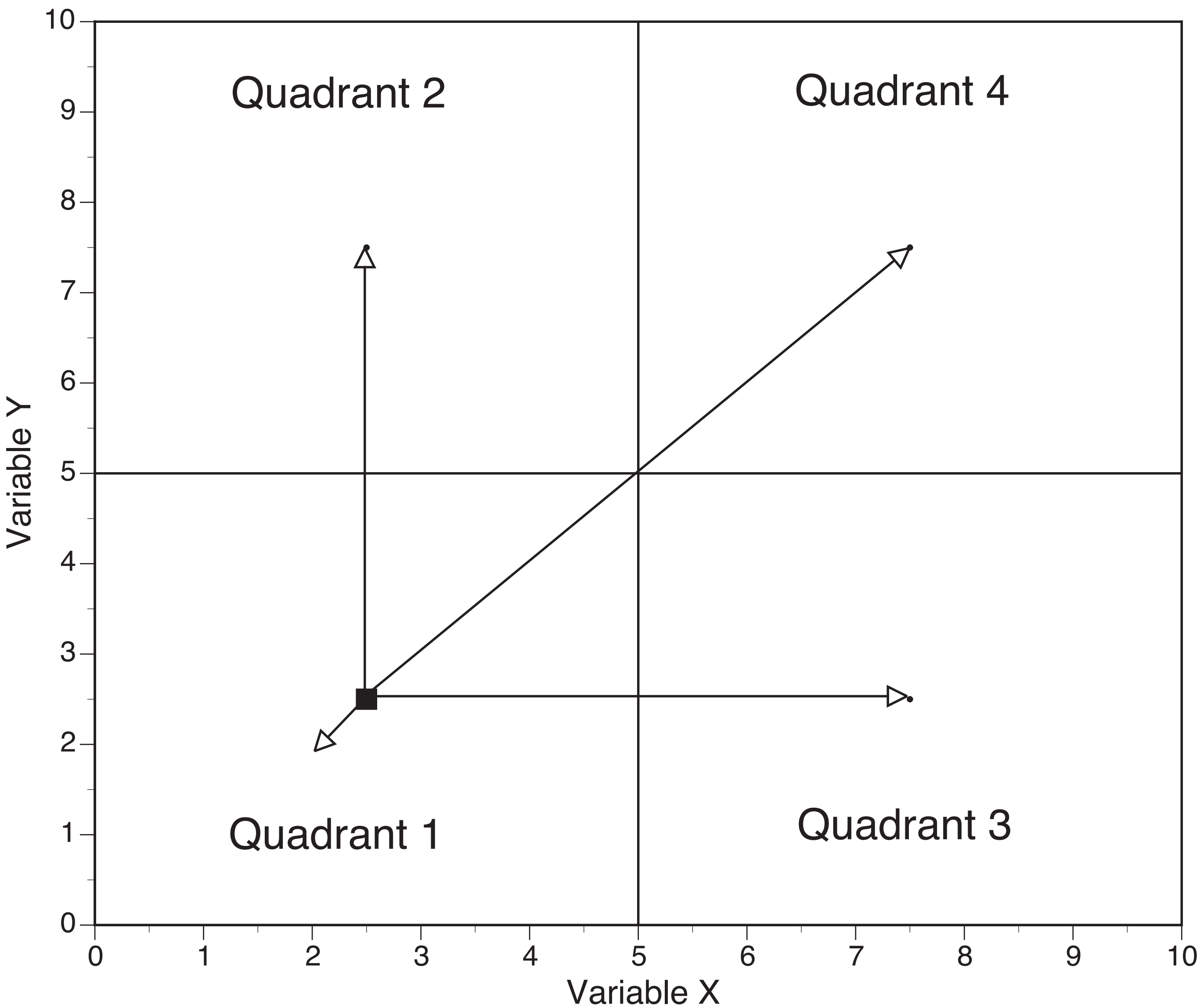


Figure 39. The relationship between oyster abundance and box-count mortality for the 1953-2009 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2008 because the plot compares end-of-2008 oyster abundance with 2009 mortality. Dotted lines identify the 57-year medians used for calculation of first passage times (Table 20).

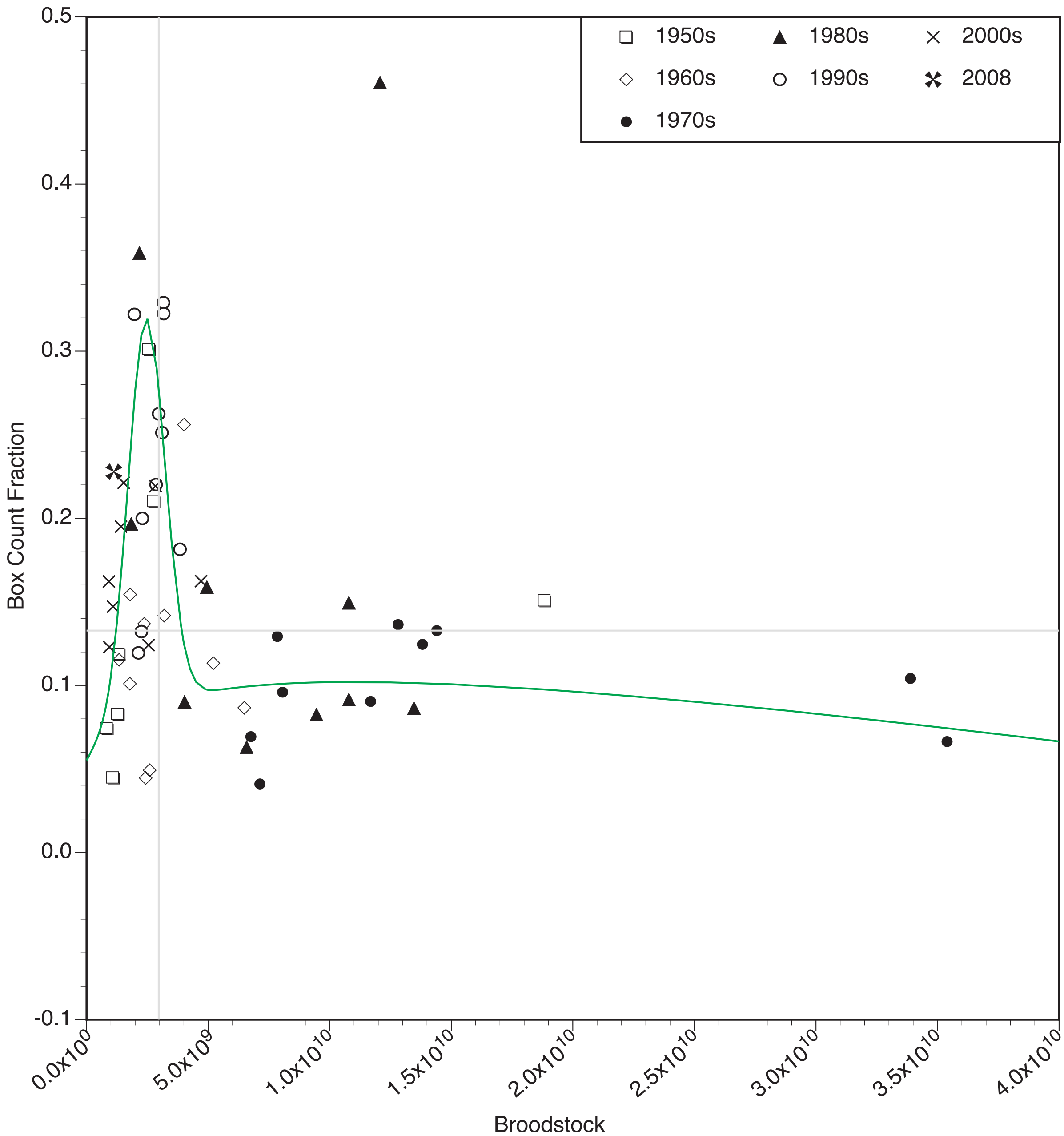


Figure 40. A closer look at the lower end of the oyster abundance and box-count mortality relationship. The entire dataset is depicted in Figure 37. Latest year listed as 2008 because the plot compares end-of-2008 oyster abundance with 2009 mortality. Dotted lines identify the 57-year medians used for calculation of first passage times (Table 20).

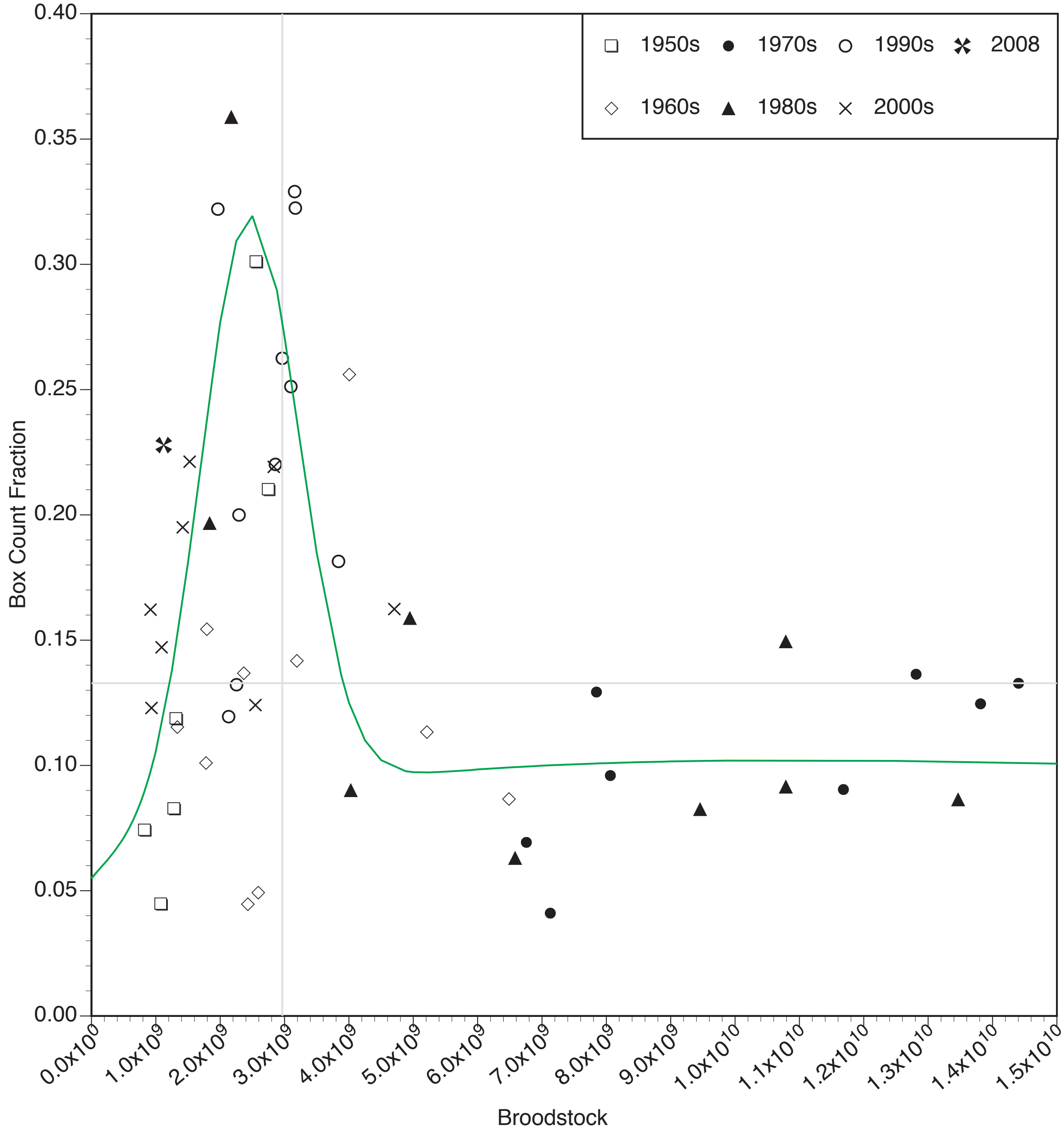


Figure 41. The relationship between recruitment and box-count mortality for the 1953-2009 time period for the natural oyster beds of Delaware Bay. Dotted lines identify the 57-year medians used for calculation of first passage times (Table 21).

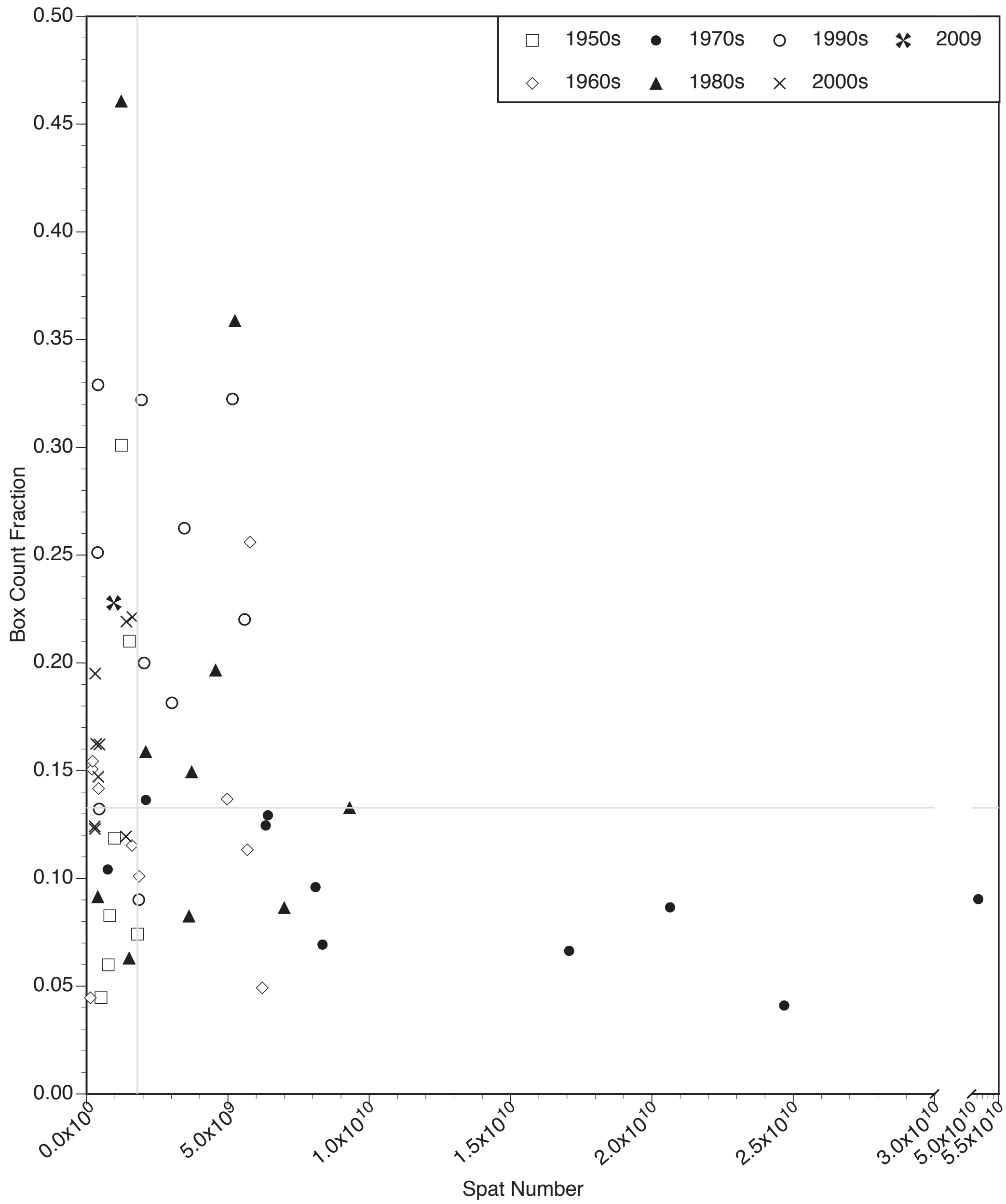


Figure 42 Estimated fractional reduction in food from within-bed density (upstream-downstream) effects. Light bars assume no vertical mixing over the oyster beds. Dark bars assume vigorous vertical mixing.

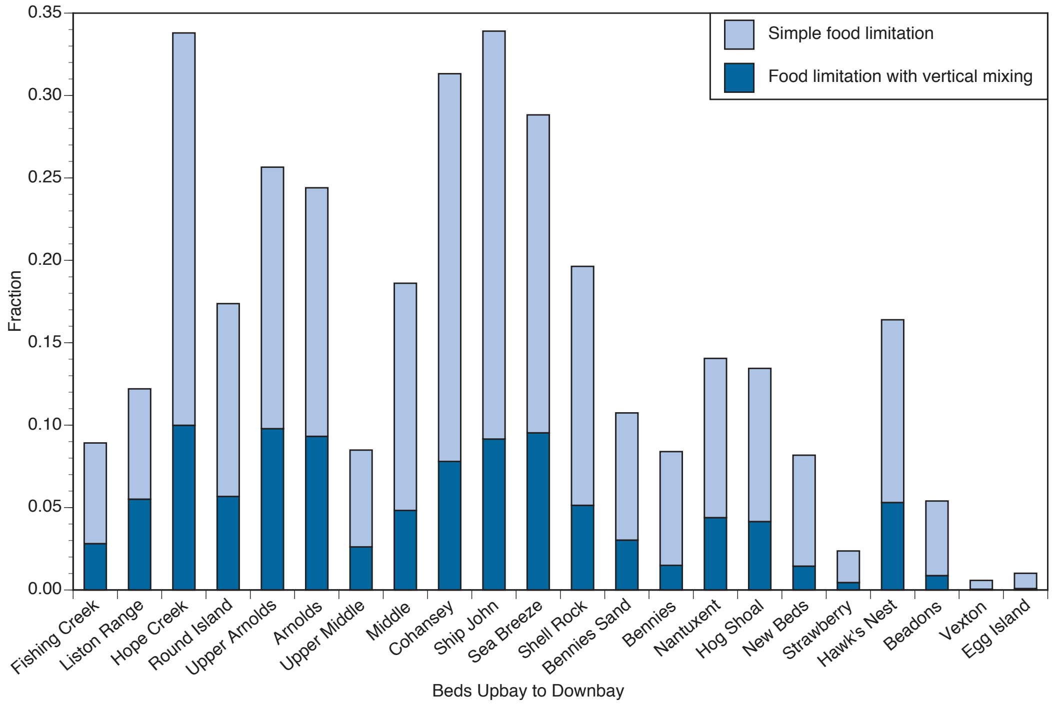


Figure 43. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

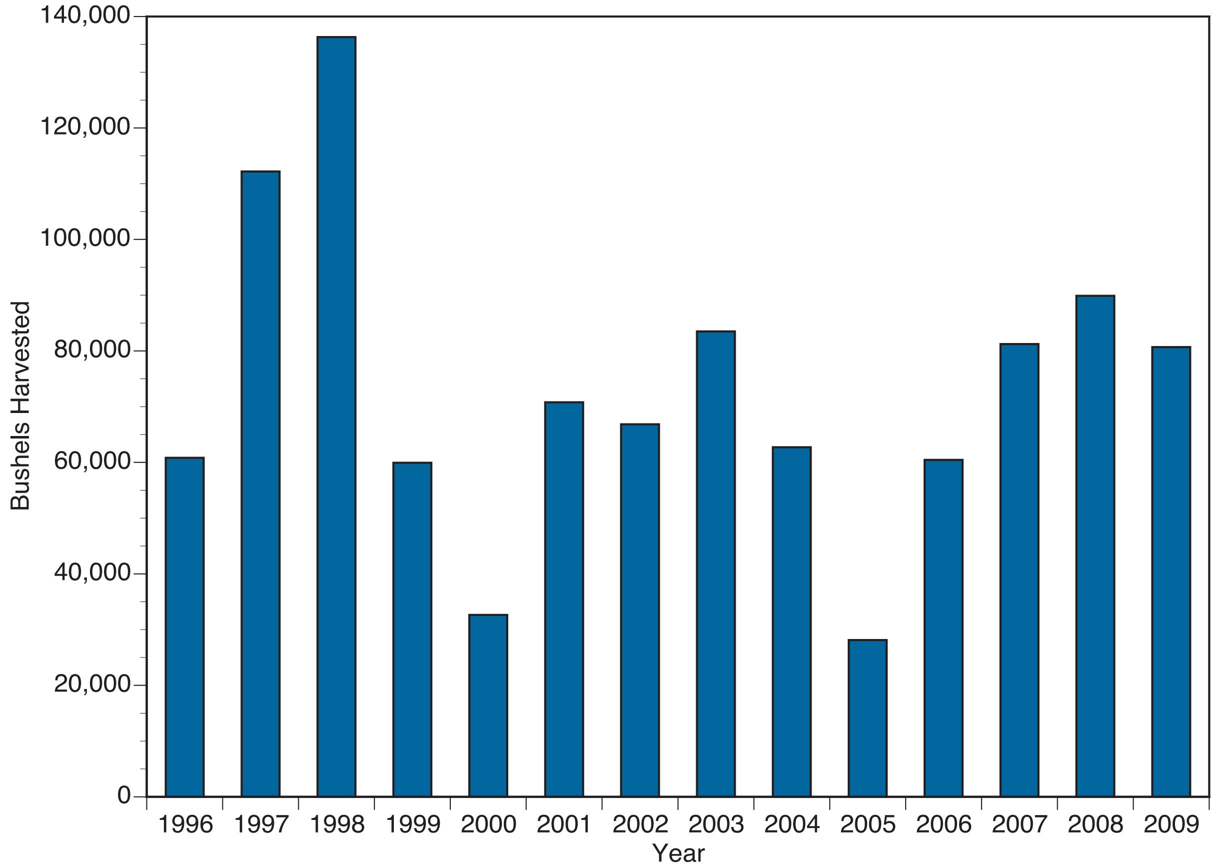


Figure 44. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

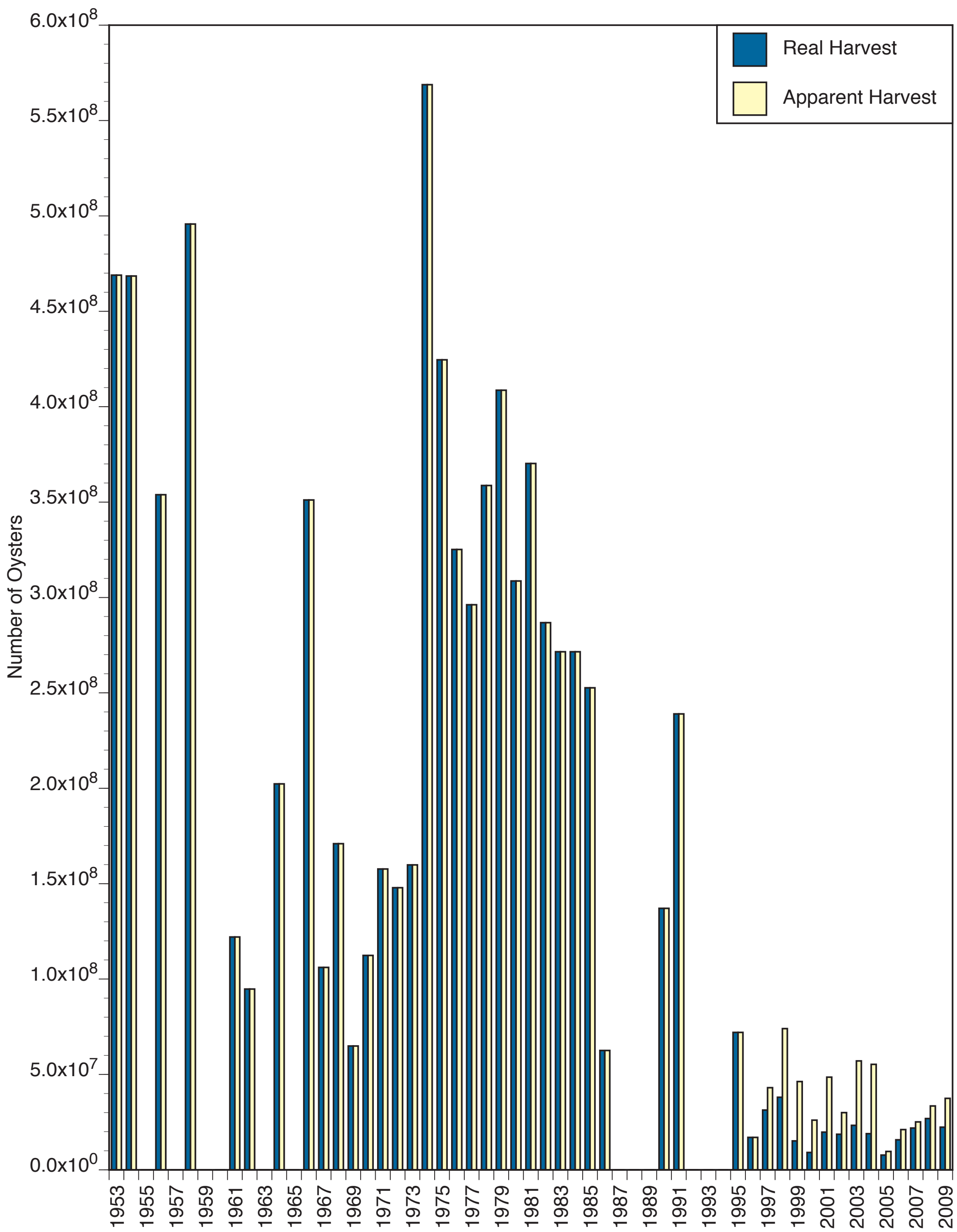


Figure 45. Catch (in bushels) per boat-day by vessel style.

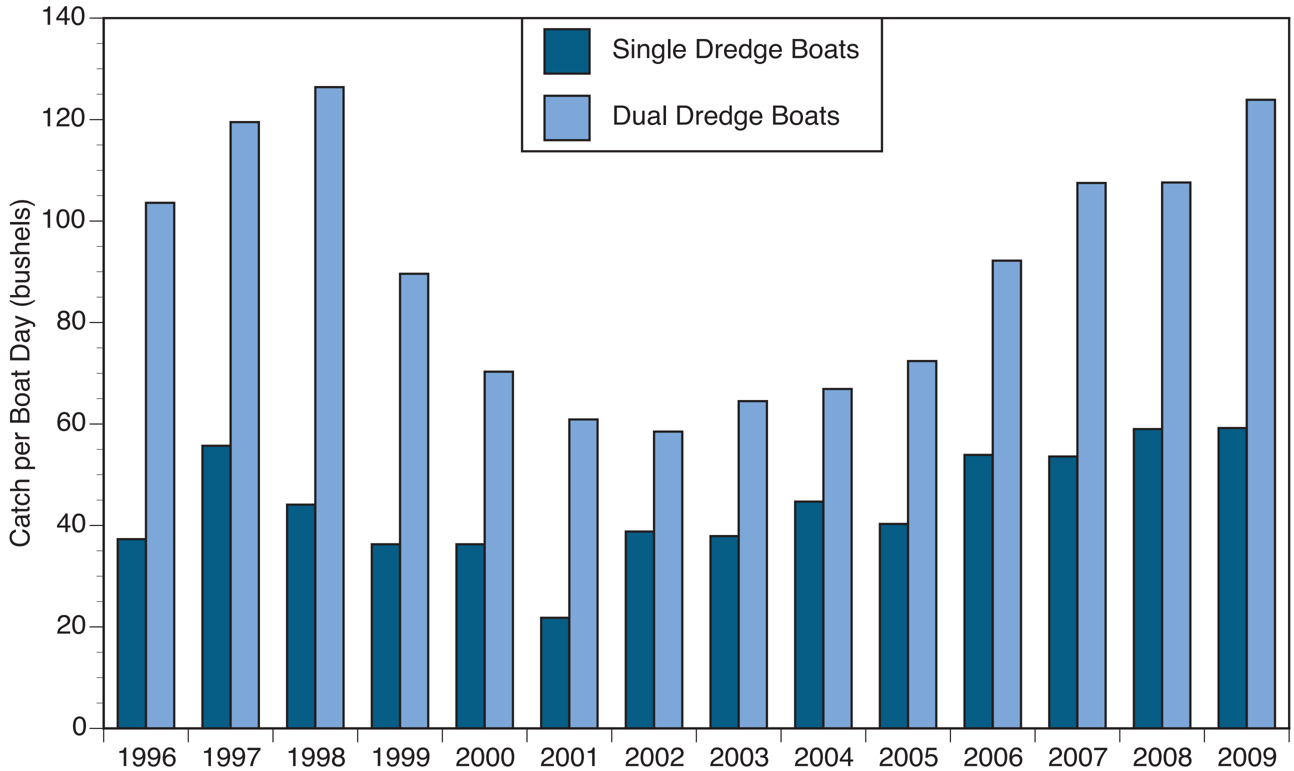


Figure 46. Size frequency of oysters landed in 2009. Size class values are the lower bounds of the size class.

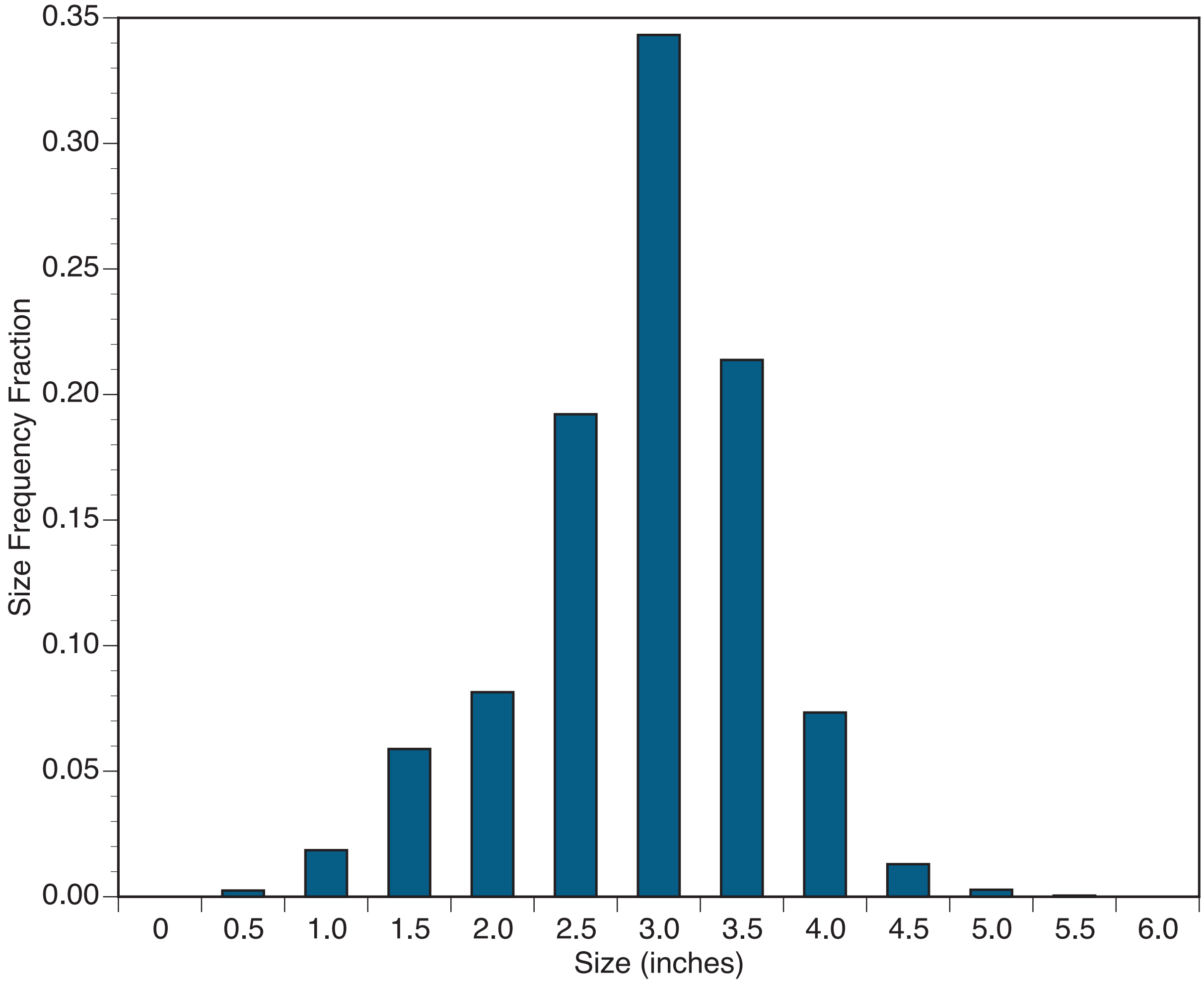


Figure 47. Fishing mortality rates by bay region during the 1954-2009 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 7. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the fishing mortality rate on that bay region. The total column height has no meaning.

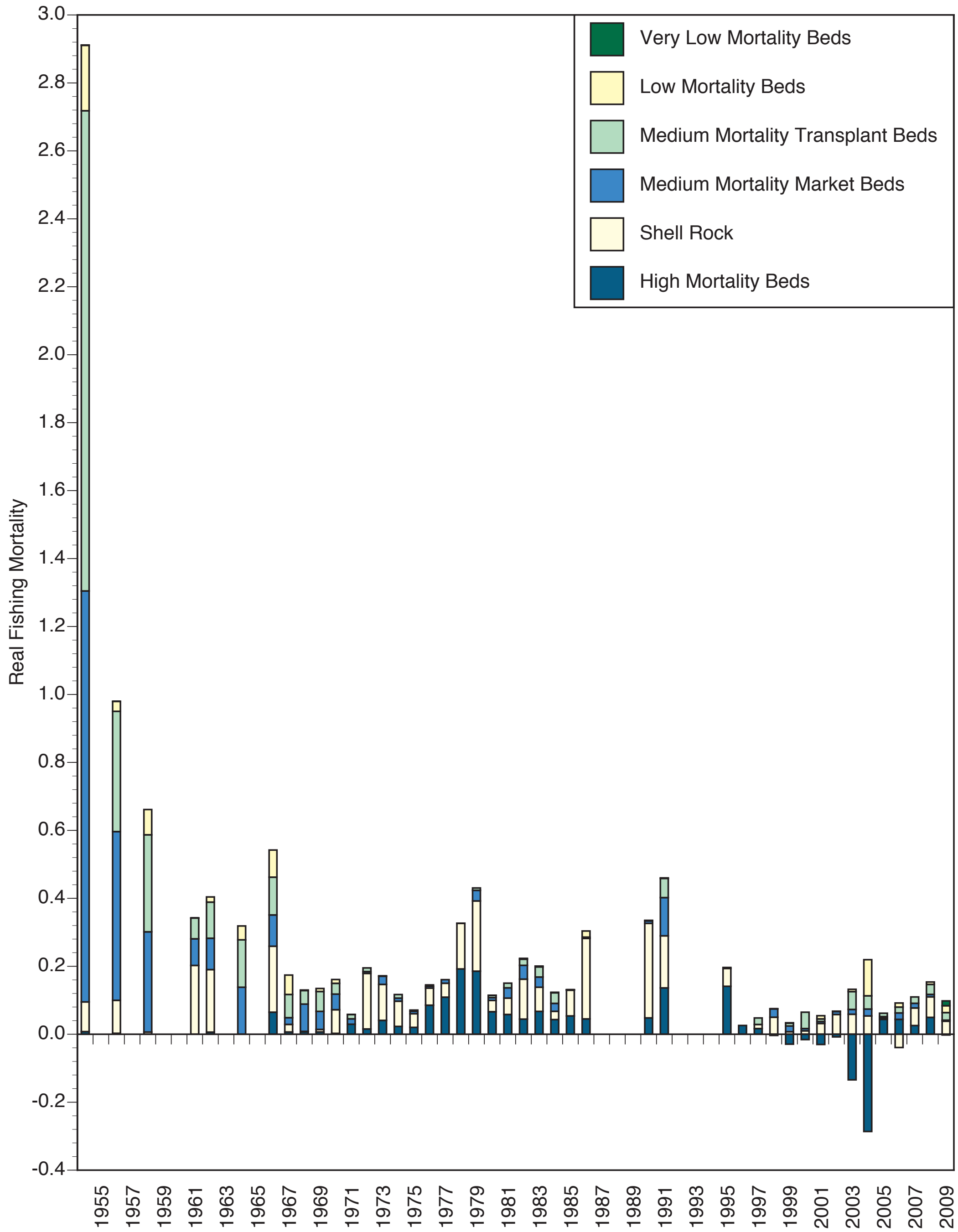


Figure 48. Fishing mortality rates by bay region during the 1989-2009 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 7. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the fishing mortality rate on that bay region. The total column height has no meaning.

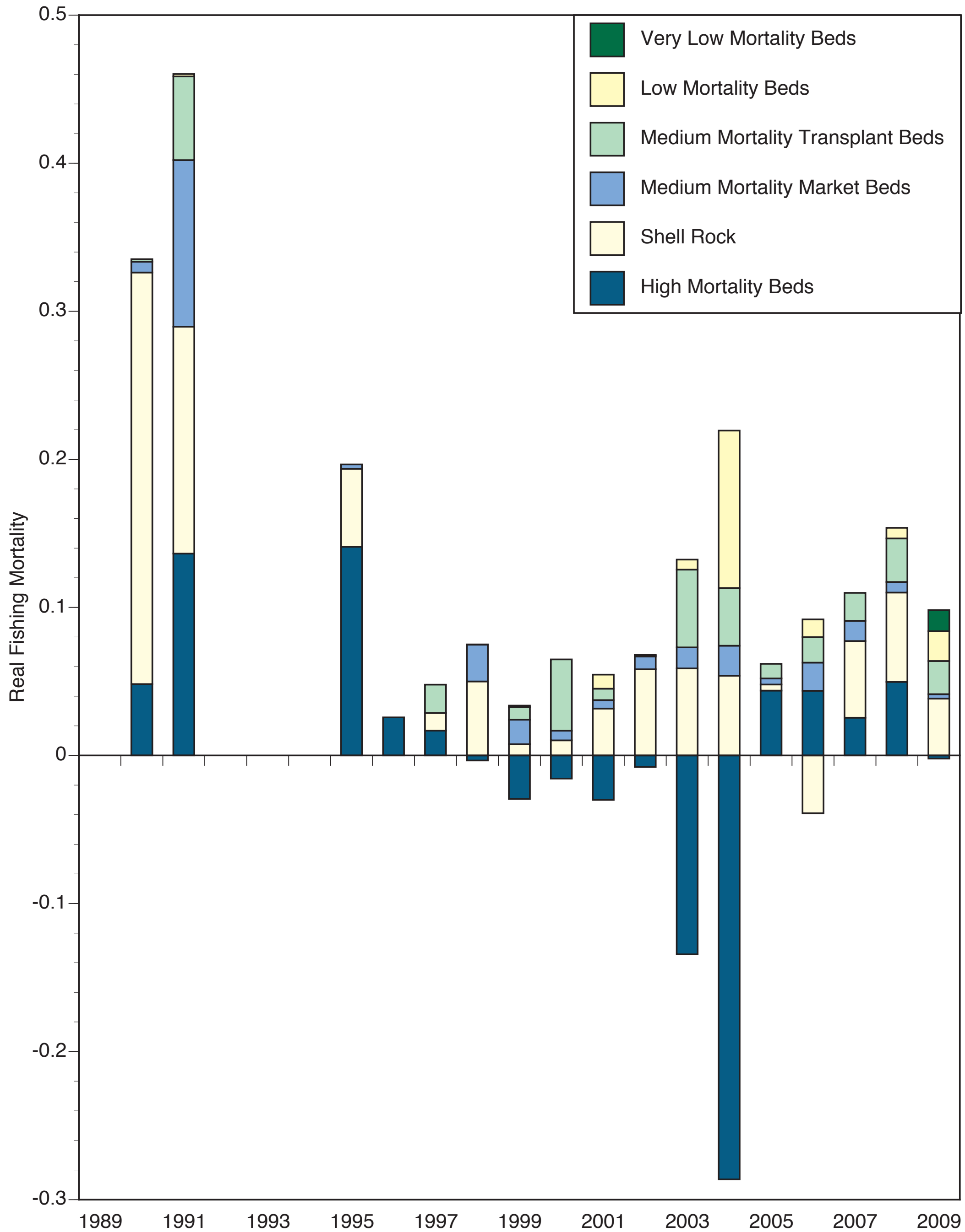


Figure 49. Real fishing mortality rate during the 1991-2009 time period. Zeros represent years of fishery closure.

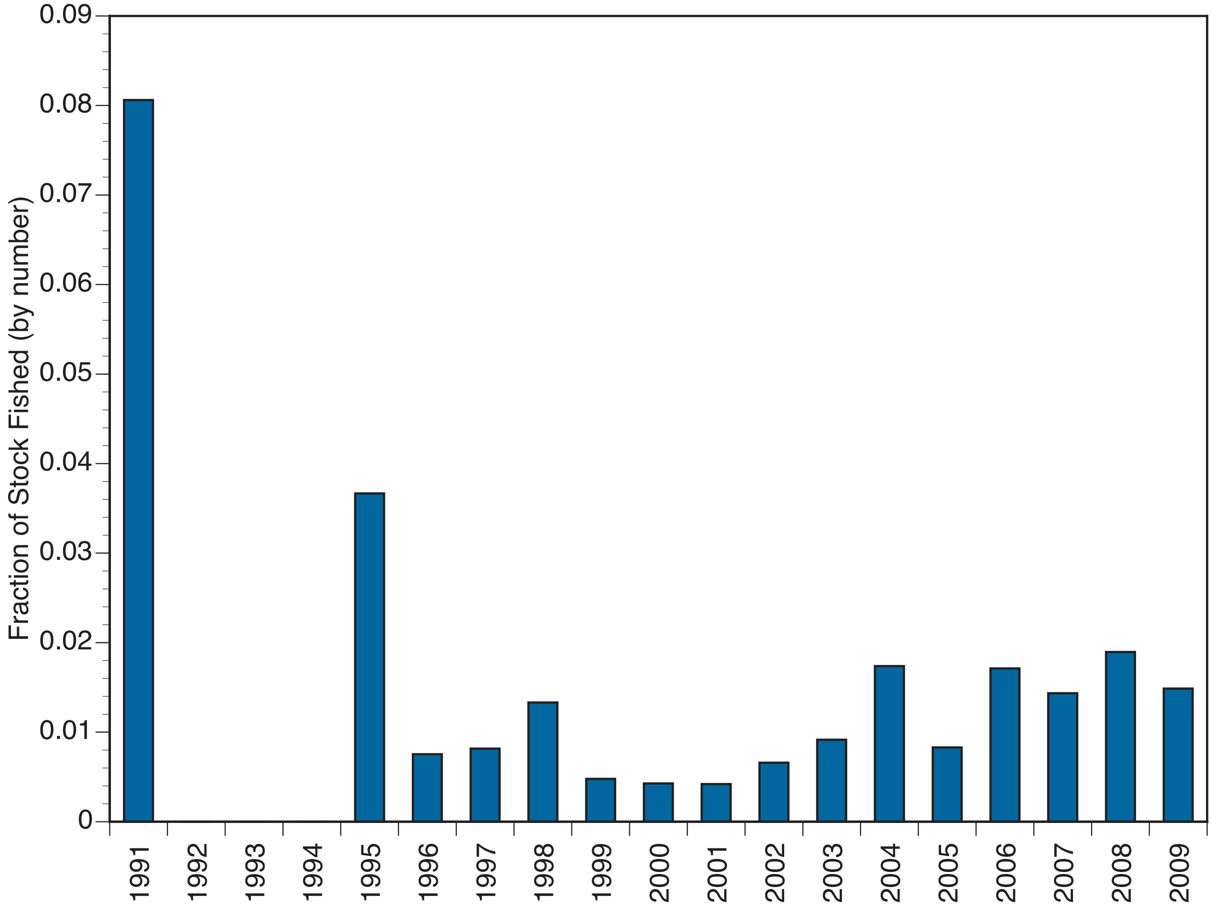


Figure 50. Fishing mortality rate during the 1997-2009 time period based on spawning stock biomass.

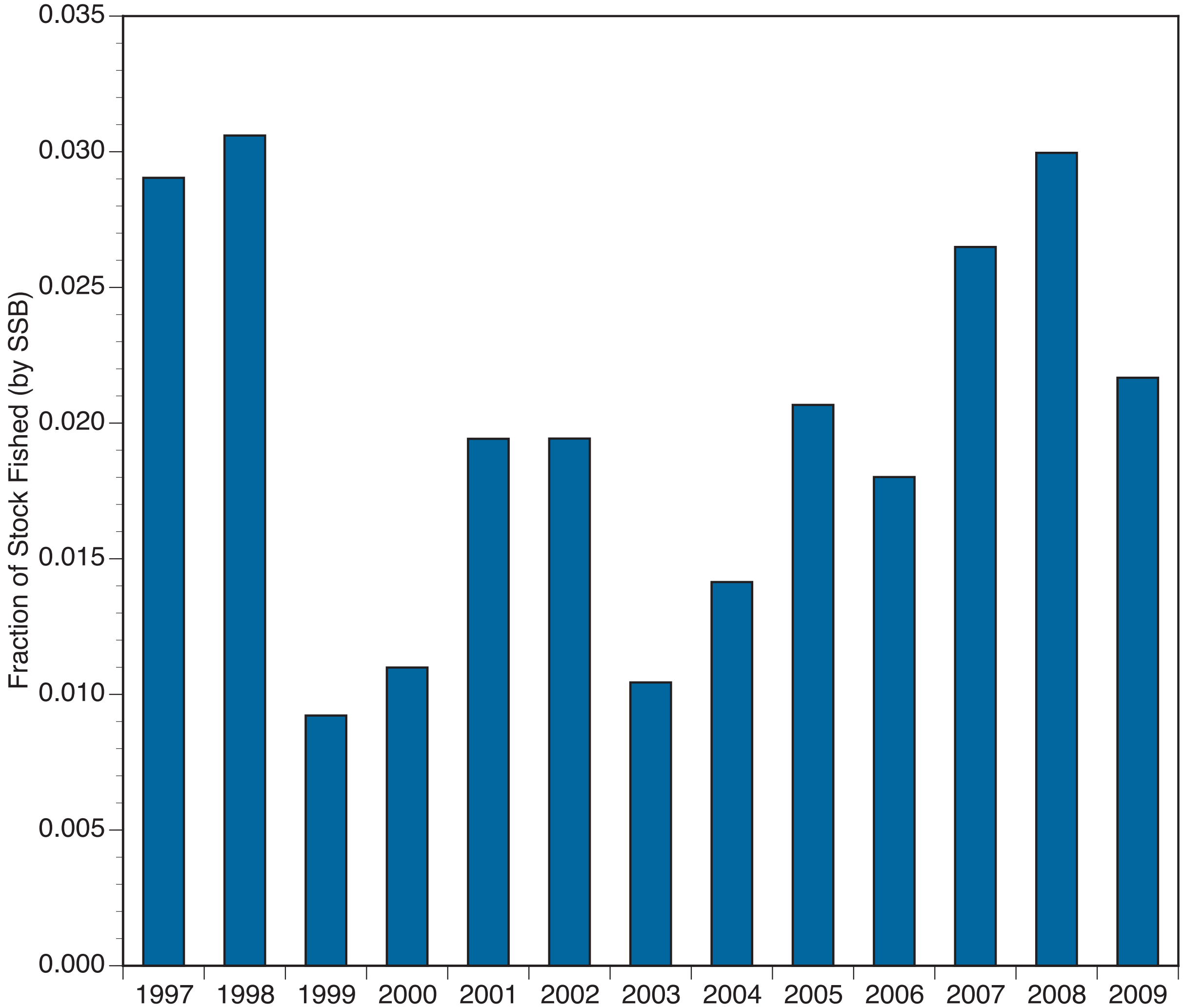


Figure 51. Fishing mortality rate during the 1997-2009 time period based on marketable abundance (animals $\geq 2.5''$).

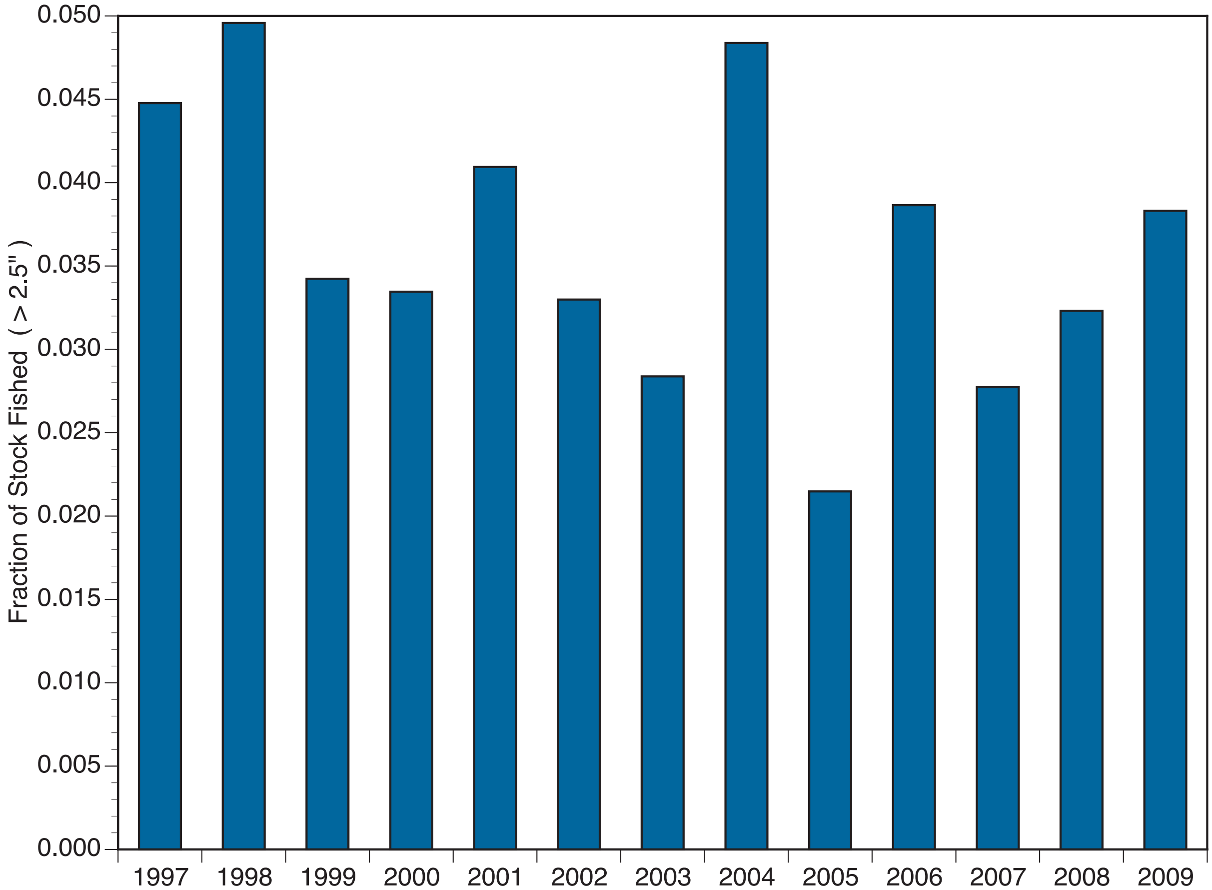


Figure 52. Abundance, SSB, marketable abundance, recruitment, and mortality trends on the very-low-mortality beds from 2008 to 2009.

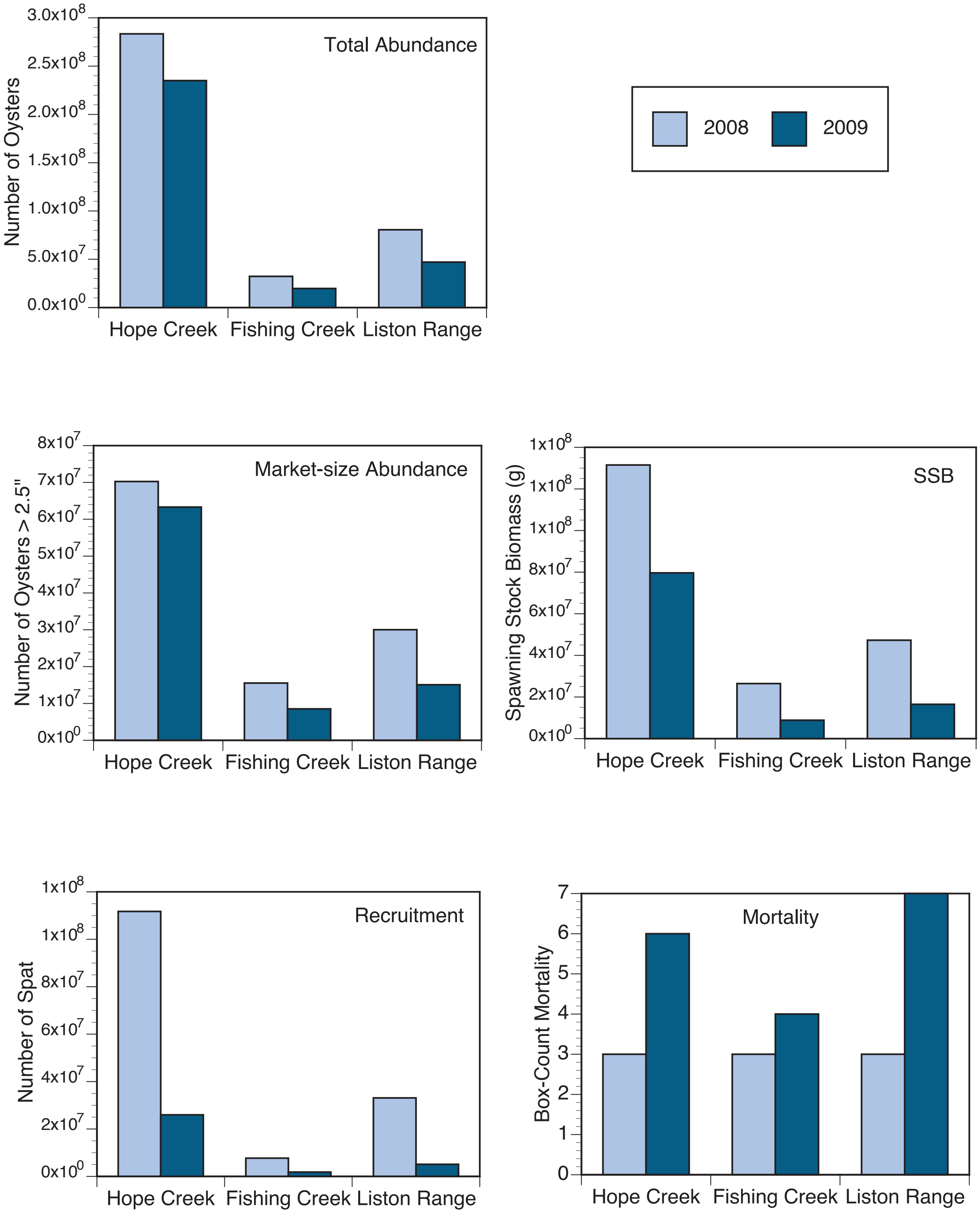


Figure 53. Abundance trends for oysters $\geq 2.5''$ for the medium-mortality market beds.

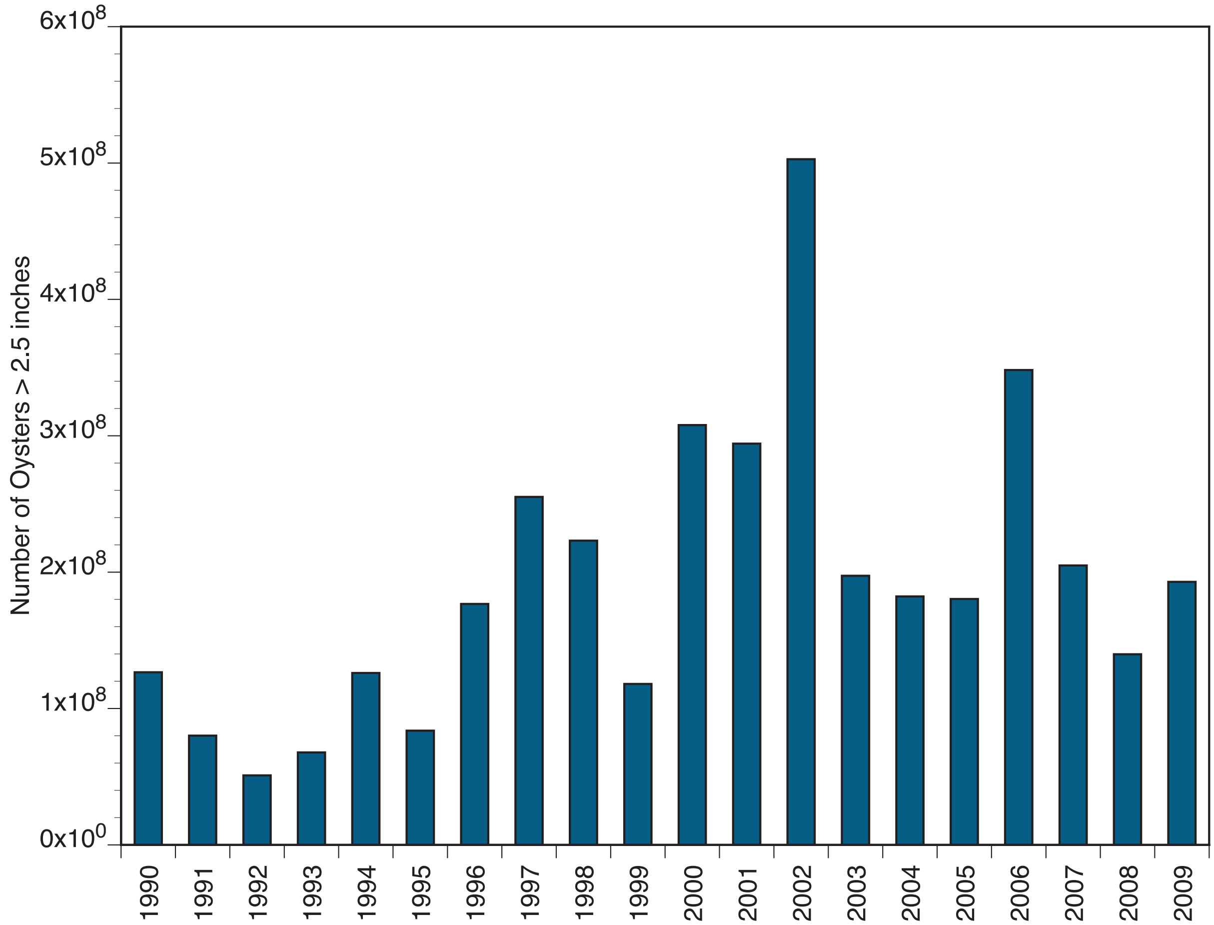


Figure 54. Position of the oyster stock in 2005-2009 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values (Table 24).

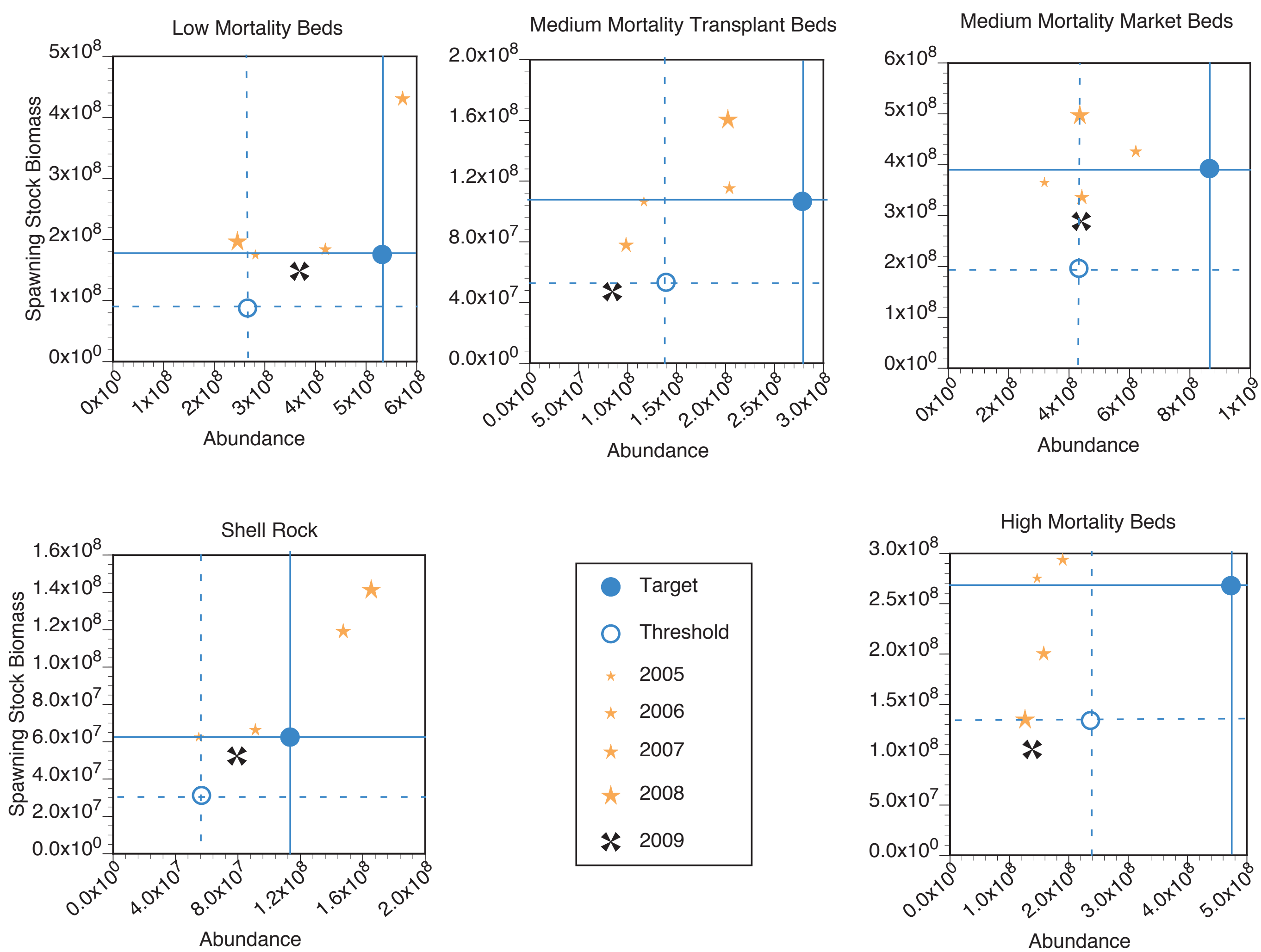


Figure 55. Position of the oyster stock in 2005-2009 with respect to market abundance ($\geq 2.5''$) and abundance targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989-2005 time period. The threshold is taken as half these values (Table 24).

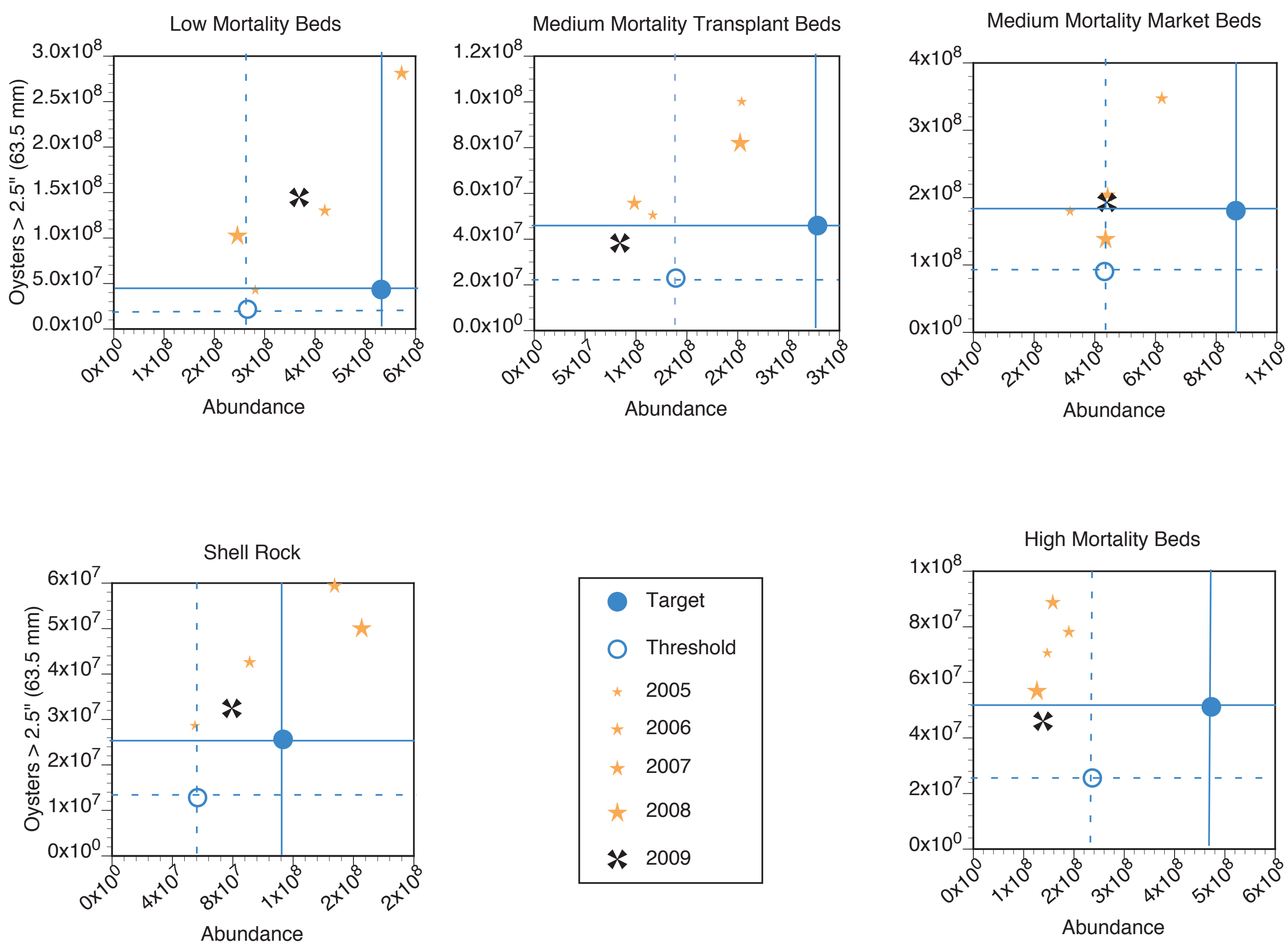


Figure 56. Relationship of the stock-performance reference points for total abundance from Table 24 to the 2009-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

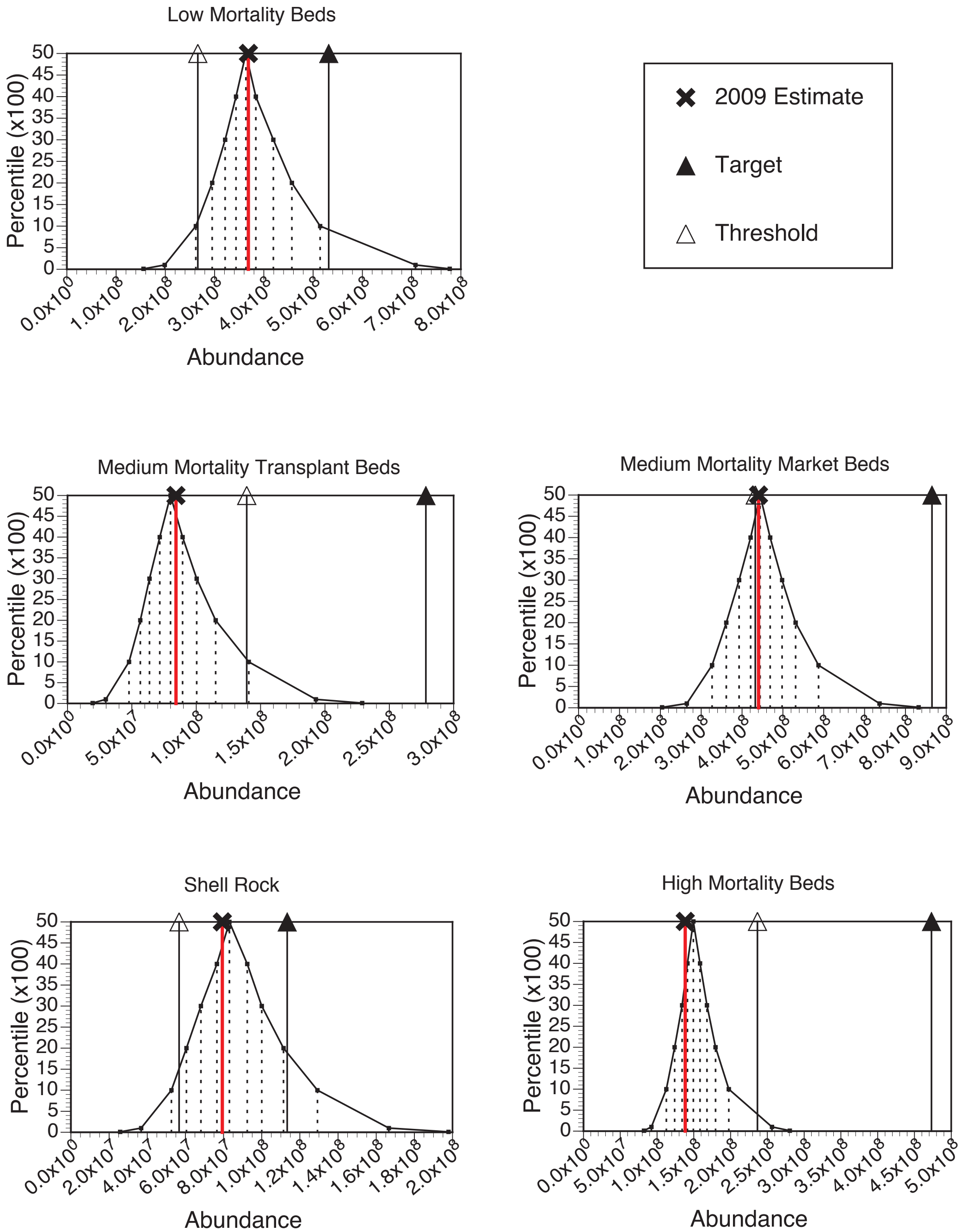


Figure 57. Relationship of the stock-performance reference points for marketable abundance (animals $\geq 2.5''$) from Table 24 to the 2009-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

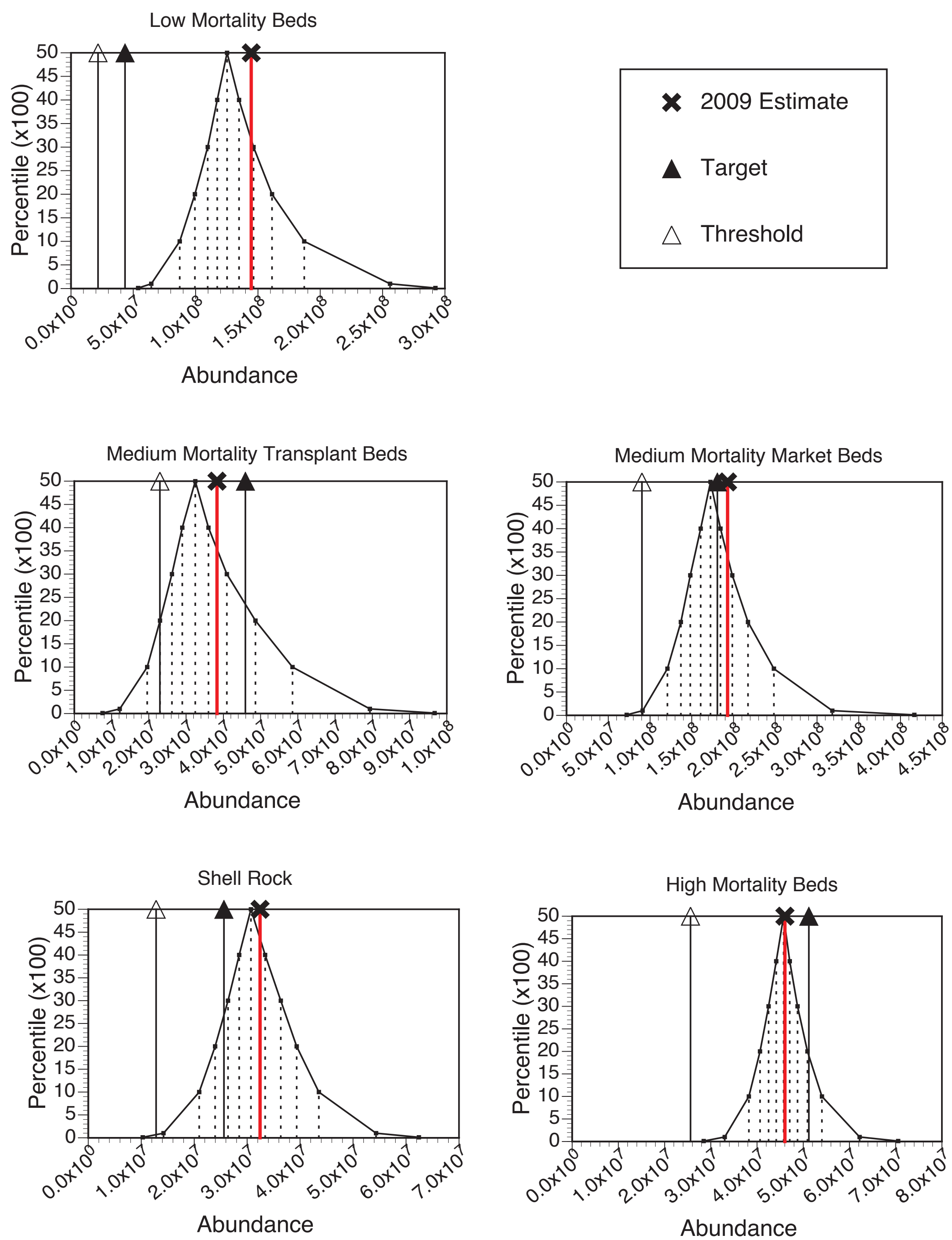


Figure 58. Plot of surplus production trajectories obtained from simulations of the stable-point surplus-production model. Descriptions of the simulations are given in Table 25 and the text. Vertical bars correspond to four whole-stock reference points. Two are derived from the surplus production model, 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 24). The four respective values are: 1.628 billion, 0.814 billion, 2.262 billion, and 1.130 billion.

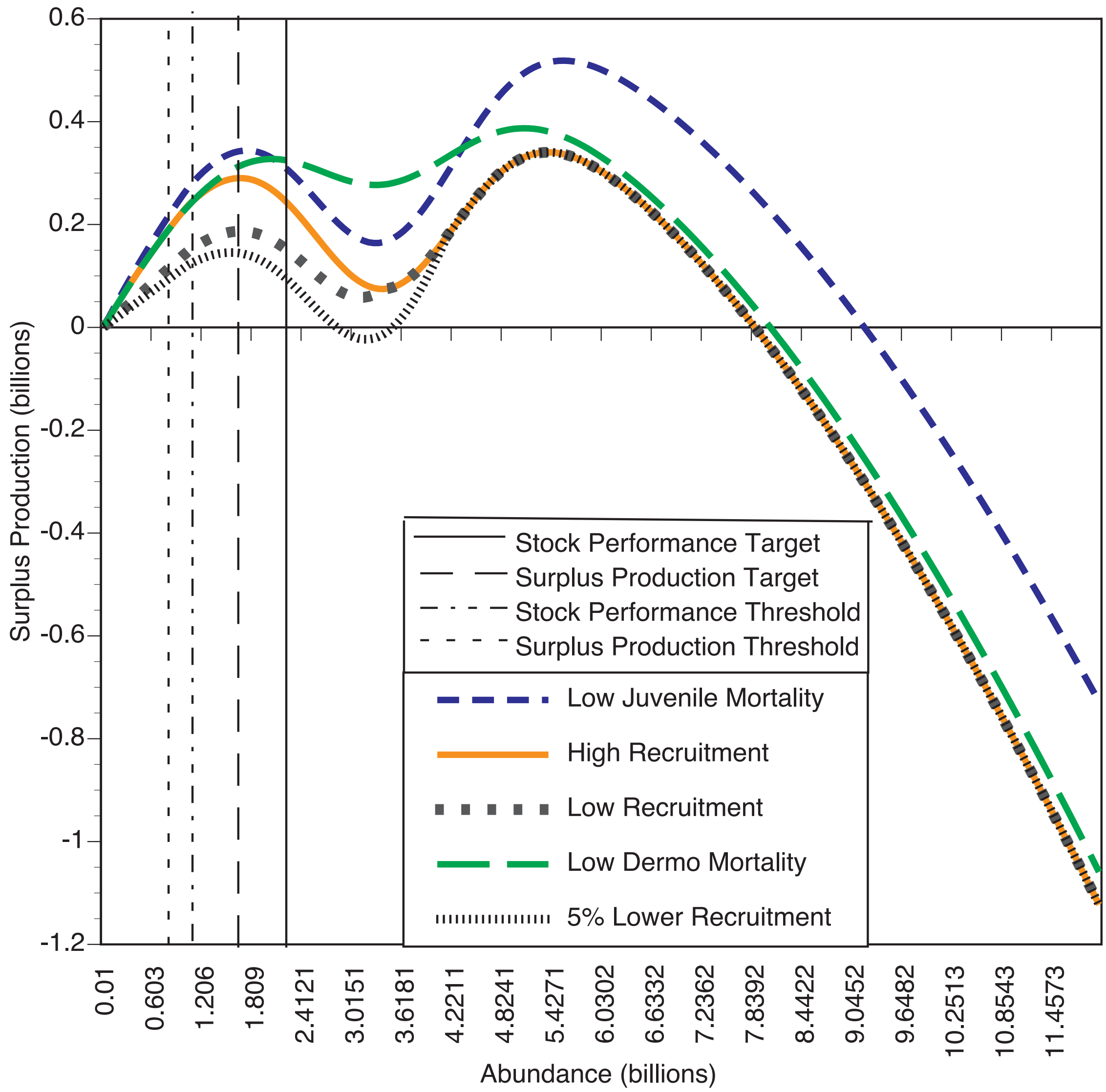


Figure 59. Position of the 2009 whole-stock abundance estimate within confidence percentiles for the 2009-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. Also indicated are the positions of the whole-stock stock-performance reference points from Table 24 and the N_{msy} reference points from Figure 58. All values exclude the very-low-mortality beds. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

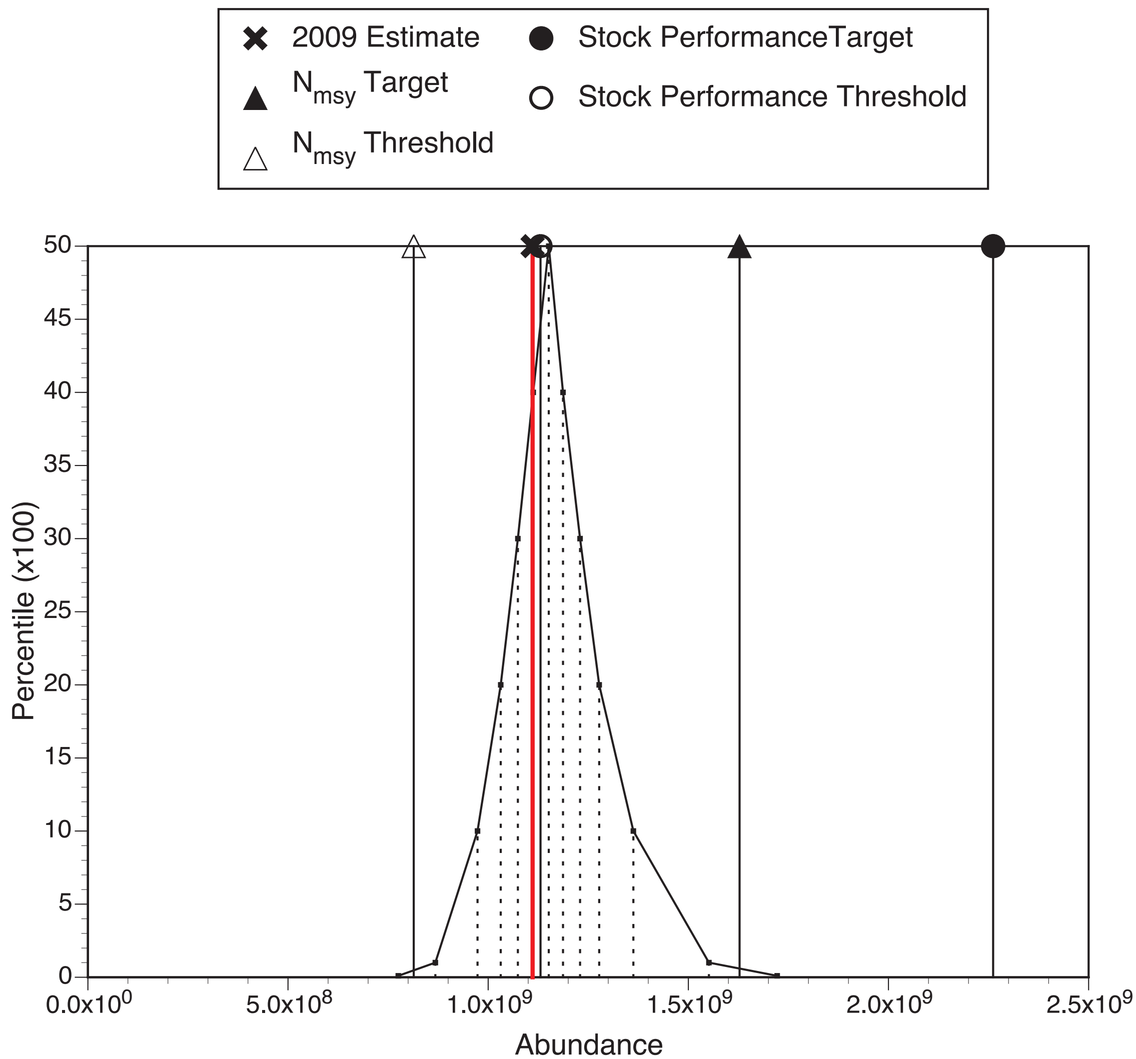


Figure 60. Position of the 2009 whole-stock marketable-abundance ($\geq$ 2.5$''$) estimate within confidence percentiles for the 2009-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. Also indicated are the positions of the whole-stock stock-performance reference points from Table 24. All values exclude the very-low-mortality beds. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

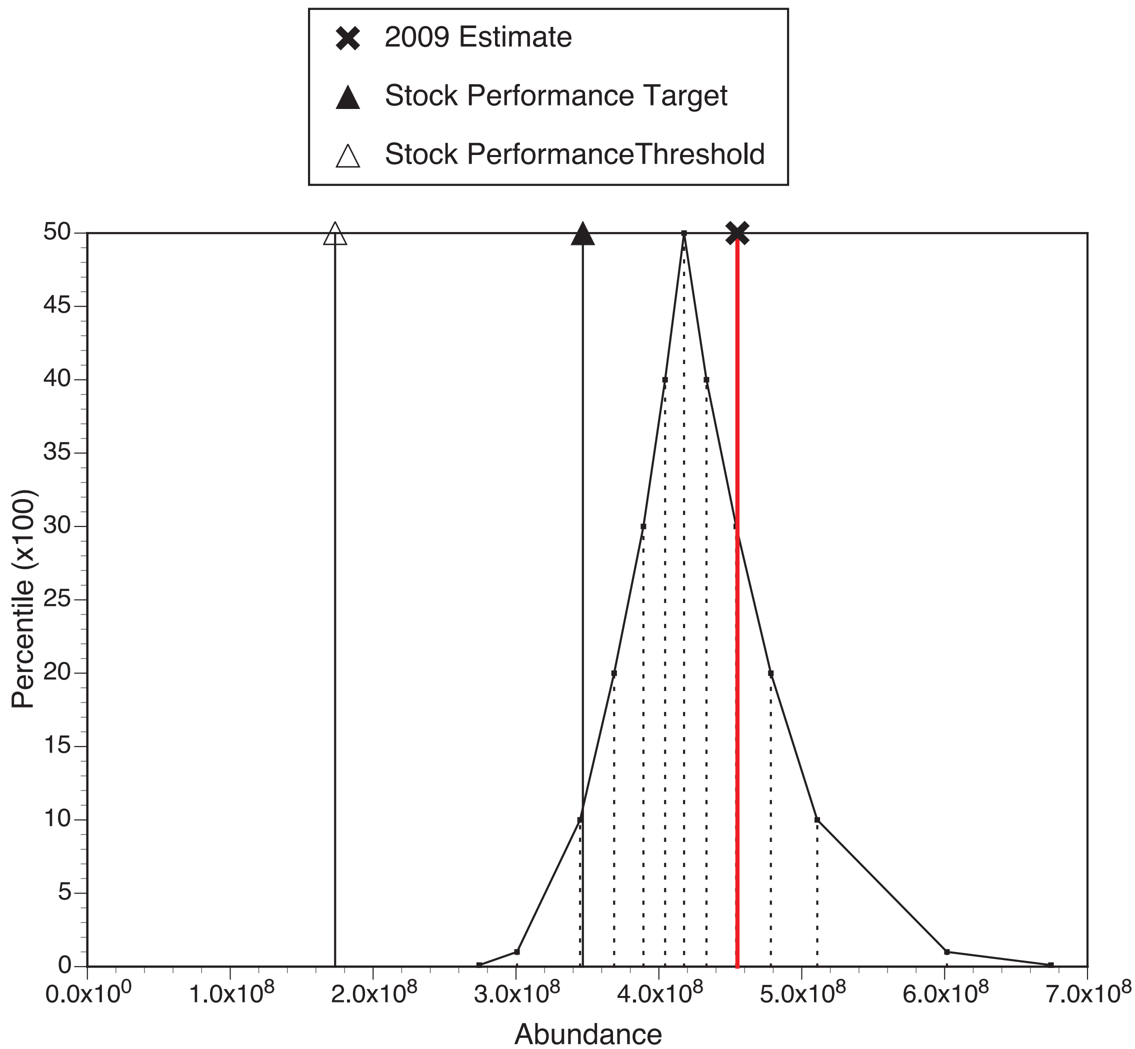


Figure 61. Summary status of the stock for 2009. Lime green indicates variables judged to be above average relative to the 1989-2009 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2009 time period or having 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 1989-2009 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 1989-2009 time series (1990-2009 for SSB). Parentheses are values that include the 2009 shell plants. The 2004-2008 median identifies comparisons between the 2009 value and the 5-yr median value from 2004-2008.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.21	0.26	0.06	0.31	0.06	0.10
Fraction of Stock (No Very Low)	Not Incl.	0.33	0.08	0.40	0.07	0.12
Total Abundance						
2009 Percentile	Not Incl.	0.26	0.01	0.21	0.31	0.17
2004-2008 Median	Not Incl.	Increasing	Decreasing	Increasing	Decreasing	Decreasing
2008-2009 Trend	Decreasing	Increasing	Decreasing	Increasing	Decreasing	Increasing
Spawning Stock Biomass						
2009 Percentile	Not Incl.	0.28	0.01	0.23	0.18	0.08
2004-2008 Median	Not Incl.	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
2008-2009 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Market Abundance						
2009 Percentile	Not Incl.	0.84	0.37	0.58	0.53	0.32
2004-2008 Median	Not Incl.	Increasing	Decreasing	Increasing	Decreasing	Decreasing
2008-2009 Trend	Decreasing	Increasing	Decreasing	Increasing	Decreasing	Decreasing
Recruitment						
2009 Percentile	Not Incl.	0.26	0.40	0.50	0.60	0.50
2004-2008 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2008-2009 Trend	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing
Spat per Adult						
2009 Ratio	0.11	0.15	0.52	0.82	1.89 (2.75)	2.53 (3.03)
2004-2008 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Increasing
2009 Percentile	Not Incl.	0.38	0.69	0.69	.93 (0.94)	0.79 (0.87)
Small Oys (fract.<2.5")	0.71	0.61	0.54	0.56	0.59	0.66
2009 Percentile	Not Incl.	0.16	0.21	0.32	0.26	0.47
2004-2008 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Increasing
Dermo Infection Status						
Weighted Prevalence	0.25	1.40	2.13	2.33	2.90	2.95
2008-2009 Trend	Decreasing	Increasing	Decreasing	Increasing	Increasing	Increasing
Mortality Rate	0.07	0.13	0.27	0.22	0.23	0.28
2009 Percentile	Not Incl.	0.90	0.93	0.64	0.64	0.55
2004-2008 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2008-2009 Trend	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing
Abundance Position vs						
Target	Not Incl.	Below	Below	Below	Below	Below
Threshold	Not Incl.	Above	Below	Near	Above	Below
SSB Position vs						
Target	Not Incl.	Below	Below	Below	Below	Below
Threshold	Not Incl.	Above	Near	Above	Above	Below
Market Abundance vs						
Target	Not Incl.	Above	Below	Near	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Above
Surplus Production						
50^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive