Report of the
2008 Stock Assessment Workshop
(10^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

Presenters

Eric Powell, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory
John Kraeuter, Haskin Shellfish Research Laboratory

Stock Assessment Review Committee

Russell Babb, New Jersey Department of Environmental Protection
Barney Hollinger, Delaware Bay Section of the Shell Fisheries Council
Roger Mann, Virginia Institute of Marine Science
Steve Fleetwood, Delaware Bay Section of the Shell Fisheries Council
Mike Celestino, New Jersey Department of Environmental Protection
Gef Flimlin, Rutgers University
Thomas Landry, Department of Fisheries and Oceans, Canada
Steve Jordan, U.S. Environmental Protection Agency

Editors:

Eric Powell, Haskin Shellfish Research Laboratory
John Kraeuter, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory

Distribution List

Barney Hollinger, Chair, Delaware Bay Section of the Shell Fisheries Council
Jim Joseph, New Jersey Department of Environmental Protection
Selected faculty and staff, Haskin Shellfish Research Laboratory
Oyster Industry Science Steering Committee
Stock Assessment Review Committee

February 4-5, 2008

New Jersey Agricultural Experiment Station – Rutgers University

Executive Summary of the 2008 Stock Assessment Workshop (10^{th} SAW) for the New Jersey Delaware Bay Oyster Beds

Presenters

Eric Powell, Haskin Shellfish Research Laboratory
John Kraeuter, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory

Stock Assessment Review Committee

Russell Babb, New Jersey Department of Environmental Protection
Barney Hollinger, Delaware Bay Section of the Shell Fisheries Council
Roger Mann, Virginia Institute of Marine Science
Steve Fleetwood, Delaware Bay Section of the Shell Fisheries Council
Mike Celestino, New Jersey Department of Environmental Protection
Gef Flimlin, Rutgers University
Thomas Landry, Department of Fisheries and Oceans, Canada
Steve Jordan, U.S. Environmental Protection Agency

Editors:

Eric Powell, Haskin Shellfish Research Laboratory
John Kraeuter, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory

Distribution List

Barney Hollinger, Chair, Delaware Bay Section of the Shell Fisheries Council
Jim Joseph, New Jersey Department of Environmental Protection
Selected faculty and staff, Haskin Shellfish Research Laboratory
Oyster Industry Science Steering Committee
Stock Assessment Review Committee

February 4-5, 2008

New Jersey Agricultural Experiment Station – Rutgers University

Status of the Stock

Figure 1 summarizes the condition of the oyster stock throughout the New Jersey waters of Delaware Bay at the end of 2007. In 2007, the stock presents a mixture of positive and negative indicators that approximately balance. Abundance is low and decreasing in three of four bay regions (Figure 2). Abundance is near historical highs on Shell Rock, however. Abundance continued to be below target levels in all bay regions but Shell Rock, and near or below threshold levels on the medium-mortality and high-mortality beds (Figure 3). Abundance was slightly above threshold levels on the low-mortality beds. The high recruitment in 2007 promises to increase abundance on these beds in 2008. The decline in abundance in 2007 is essentially completely explained by the poor 2006 recruitment followed by the 2007 Dermo epizootic that dropped abundance, particularly on the medium-mortality beds. The stock continues to be disproportionately consolidated on the medium-mortality and low-mortality beds, but less so than in some previous years.

Spawning stock biomass is relatively low bay-wide, but rose in 2007 on Shell Rock and the low-mortality beds, while decreasing in the remaining bay regions (Figure 4). SSB has increased steadily on Shell Rock over the last three years. SSB was well above the biomass threshold in all four bay regions and above the target in two (Figure 3).

The 2007 recruitment was extraordinary bay-wide (Figure 5) and in all four bay regions. Spat-per-adult ratios exceeded 1.0 in three and reached a relatively high level of 0.8 on the low-mortality beds. The oyster population as a whole continues to be depauperate in the smaller size classes (Figure 6), but the 2007 recruitment event promises to correct this imbalance in 2008. In 2007, surplus production is expected to permit an increase in market-size abundance bay-wide and in all bay regions. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease rose to epizootic levels in 2007 and natural mortality rates were well above average on Shell Rock and the medium-mortality beds (Figure 7). A rising trend in Dermo disease weighted prevalence may presage continued high rates of natural mortality in 2008.

Fishery exploitation levels since 1989 have been low ($<2\%$ of abundance per year). Recent improvements in collection of fishery-dependent data indicate that exploitation in terms of biomass has been $\leq 3\%$ for most of that time. Low exploitation rates indicate that the fishery does not have a significant effect on the stock and that fishing mortality is not responsible for the current conditions of low abundance.

Overall, the conditions on the medium-mortality beds are less advantageous than other bay regions, whereas the conditions on Shell Rock are exemplary, after two years of shell planting to expand abundance. However, the fact that all but one bay region fell below their abundance targets indicates that actions to enhance abundance are needed in most bay regions. A reduction in fishing effort will not address this need because exploitation rates are already low; however, conditions are sufficiently poor on the medium-mortality beds to engender increased precaution in this regard. Substantial increases in exploitation rate should be avoided, as the importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining biomass near or above target levels. Abundance has been enhanced on the high-mortality beds and Shell Rock by downbay transplant and shell planting and these programs should be continued.

2008 Management Goals

Cultch Management Goals

Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Most beds not receiving shell plants in 2006 suffered a loss of surficial shell, however the bay was nearer equilibrium than in years past and may have been in equilibrium. The high-mortality beds contributed most of the deficit in 2007 (Figure 8). Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell. Shell plants, wherever feasible, should target areas where marketable oysters grow, where the probability of recruitment is high, and where cultch loss exceeds the addition of shell through natural mortality. Design of the 2008 program should consider the following recommendations.

1. The biggest deficits this year are on the high-mortality beds and this bed region is below the abundance threshold. Over the last decade, recruitment rates per adult on the high-mortality beds have been higher and more consistent than on beds farther upbay. Such beds as Bennies Sand, Nantuxent Point, Hog Shoal, Hawk's Nest, Beadons, and Strawberry might be considered as planting locales.

2. Downbay plants and replants are expensive and have shown unpredictable results. This activity should be scaled back in 2008, but not abandoned. Given the expense, replants should target bay regions where survivorship is high such as Ship John and Cohansey. This will also enhance expansion of the stock in a region where stock abundance has dropped to disturbingly-low levels and where recruitment has been less predictable than on beds downbay. Direct plants on these beds should be given lower priority due to the lower frequency of high recruitment events in this bay region.

3. The intermediate transplant program removes animals from the upbay beds. However, these beds routinely show lower probabilities of recruitment than beds further downbay, so that direct shell planting is unlikely to be an optimal approach to bed maintenance. An option is to plant spatted shell in this region. This should be encouraged.

4. Shell Rock abundance is near historical highs and, consequently, this bed should not be planted in 2007. Planting should avoid Bennies and New Beds as evidence indicates that oysters in this region suffer proportionately higher Dermo mortality for a given disease level than the inshore beds.

Abundance-based Exploitation Reference Point Projections – Direct Marketing

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

The high-mortality beds are toward the edge of the stock range, rather than near the center, and the continuing high natural mortality rate limits the success of stock rebuilding on these beds. Thus, management that includes explicit rebuilding goals to a target level will rarely be successful, given the frequency of epizootic-level mortality in this bed region. As a consequence, the high-mortality beds should be managed under a somewhat more risk-prone manner than beds farther upbay. Abundance is below threshold levels. However, given the high biomass, the record of relatively good recruitment, the 2007 recruitment level, and the expectation of intermediate transplant to these beds, any fishing level inclusive of the 40^{th} to 60^{th} percentiles can be chosen for 2008. However, it is important to recognize that a continuing decline in abundance, should 2008 mortality levels reach epizootic levels, will very likely require a more conservative approach in 2009, as abundance begins 2008 below the threshold level on these beds.

Due to the uniqueness of medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed under a separate allocation from the high-mortality beds. This year, Shell Rock is above the abundance and biomass targets. Given the high biomass and abundance on Shell Rock, any fishing level inclusive of the 40^{th} to 60^{th} percentiles can be considered for 2008.

Management should emphasize direct marketing on the lower group of medium-mortality beds (Cohansey, Ship John, and Sea Breeze) to reduce the exploitation rate downbay. Over the 1996-2005 direct-market period, these beds contributed a substantial fraction of the animals supporting the fishery, albeit indirectly through transplant to replace animals fished from the beds farther downbay. Beginning in 2005, these beds have contributed directly and significantly to the direct-market harvest. However, these beds represent the center of the stock and, as a consequence, must be managed with more precaution than beds farther downbay.

This year, abundance is near threshold levels, and biomass, while still high, is lower than 2006, because Dermo mortality was unusually high in this region in 2007. Abundance is now at one of the lowest levels observed in the 1989-2007 time series. However, high levels of surplus production are anticipated for 2008. The SARC notes, as it did in 2007, that the high surplus production rate originates from the growth of the last large cohort, recruited in the early 2000s, into market size and that these beds do not have substantial numbers of smaller animals supporting continued stock expansion in the future. Thus, the surplus production anticipated for 2008 should be viewed as the basis for fishery yield over a number of years. The 2007 recruitment event provides optimism that this bed region will respond with expanding abundance and a more balanced size-frequency distribution over the next few years; however, a number of years will be required for these animals to grow into market size and the likelihood of continued high Dermo mortality in 2008 is sobering. Thus, the continued precautionary management of this bed region is considered the best approach.

As a consequence of the importance of this bed region for the stock as a whole, the low abundance and unbalanced size-frequency distribution present, and the number of years required to permit resolution of these negative attributes should the 2007 recruitment adequately survive, the exploitation level should not exceed the 50^{th} percentile on these beds in 2008. Furthermore, restricting exploitation to the 40^{th} percentile should be given highest consideration.

Projections are provided in Table 1 for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze).

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant

The same approach used for the lower group of medium-mortality beds should be used to manage the upper component of the medium-mortality beds (Upper Middle, Middle). That is, intermediate transplant should be limited to no higher than the 50^{th} percentile exploitation level.

The low-mortality beds are above the biomass target, but very near the abundance threshold. Growth rates are slow on these beds and recruitment has been sporadic at best. The 2007 recruitment was relatively high on these beds in comparison to previous years, but not nearly as high as observed downbay. The ability of these beds to recover from a decline in abundance is, therefore limited, despite the lower rate of natural mortality. However, surplus production is projected to be positive in this bed region in 2008. This region should be included in the intermediate transplant program in 2008, but the 60^{th} percentile exploitation rate should be avoided. Transplant should not exceed the 50^{th} percentile level.

Projections are provided in Table 2 for the low-mortality beds exclusive of Hope Creek and the upper group of medium-mortality beds (Middle, Upper Middle).

Caveats Apropos to Risk for 2008 Fishery Yield

1. The 2007 abundance estimate is 1.317 billion animals. The stock-performance threshold reference point is 1.251 billion. This threshold falls within the survey uncertainty of the 2007 point estimate. Thus, 2007 abundance is not significantly above the threshold. This suggests that the stock should be managed with precaution in 2008. However, the SARC notes several mitigating facts: (1) the high estimates of 2008 surplus production, (2) the relatively high recruitment rate in 2007, (3) the very high spat-to-adult ratio, and (4) the likelihood of additional shell planting in 2008. These facts suggest that the stock may respond robustly to the 2007 drop in abundance. On the other hand, a second epizootic year in 2008 will restrict stock recovery by reducing surplus production, as the stock is below the surplus production maximum expected in the range of 1.58 to 1.75 billion animals.

2. The Dermo epizootic is likely to continue into 2008. A continuing decline in abundance, should 2008 mortality levels reach epizootic levels, will very likely require a more conservative management approach in 2009, as abundance begins 2008 near the threshold level.

3. Proper management of the medium-mortality beds this year is critical. The SARC notes that the surplus production expected in 2008 should be harvested over a period of years to stabilize the resource. Abundance has dropped to very low levels on these beds. Consequently, management of these beds should include rebuilding of abundance as a goal.

4. Consideration was given to higher exploitation rates on Shell Rock than the 60^{th} percentile due to the high abundance and biomass levels present. However, focusing exploitation at a higher-than-the-60^{th}-percentile level in a small area of the bay may damage the stock and the bed as dredging effort will have to be high. A better approach is to consider the oyster stock on this bed as a source of harvest over a number of years. Thus, 2008 exploitation levels should not exceed the 60^{th} percentile number.

5. The intermediate transplant program should be continued. However, any transplant option requires transplant to occur before the allocation derived therefrom can be set and harvested.

6. The intermediate transplant should use culling devices as the goal of this activity is to move downbay submarket-size and market-size animals while retaining upbay under a lower mortality regime the smaller animals that will grow into these larger size classes.

7. The area-management program in which the high-mortality beds, Shell Rock, the medium-mortality beds, and the low-mortality beds are managed as separate units with separately determined allocations should be retained.

8. Hope Creek is not included in the exploitation-rate projections. That portion of Hope Creek surveyed in 2007 contributes 35% of the stock on the low-mortality beds. However, the full extent of the Hope Creek population is not yet known. Moreover, the degree of disease-resistance in this population is unclear. A management plan for the Hope Creek oysters cannot be established until more information becomes available. Hope Creek should be excluded from intermediate transplant in 2008.

Table 1. Allocation projections for direct marketing for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze), based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index. An upper and lower bound are taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest). Projections use the average numbers per marketed bushel of 259 derived from the 2004-2007 dock-side monitoring program.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	40^{th}	.0257	2,578,320	9,952*
	50^{th}	.0572	5,738,510	22,150*
	60^{th}	.0762	7,644,660	29,507*
Shell Rock	40^{th}	.0867	5,989,050	23,117*
	50^{th}	.0938	6,479,510	25,010*
	60^{th}	.1121	7,743,630	29,889*
Lower Medium Mortality	40^{th}	.0173	3,516,010	13,571*
	50^{th}	.0213	4,328,600	16,710•
	60^{th}	.0271	5,507,740	21,259
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

*This exploitation rate falls within the guidelines recommended by the SARC for 2008.

•This exploitation rate may be permissible for 2008; however, careful consideration should be given to the possible consequence that this exploitation level may lead to a decreased allocation in the 2009 fishing year.

Table 2. Projections for intermediate transplant assuming that intermediate transplant will be conducted on the upper medium-mortality beds (Middle, Upper Middle) and that direct-marketing will be conducted on beds downbay of these two beds. Numbers to be moved by intermediate transplant are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading by dry dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel for these beds obtained from the 2007 survey. If cullers are used, the number of bushels can be reduced by an estimated factor of 1.28. 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 259 animal/bu conversion. Percentiles for the low-mortality beds are taken as the average for the upper medium-mortality beds. Projections for the low-mortality beds exclude Hope Creek.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Lower Medium Mortality						NA§
Upper Medium Mortality	40^{th}	.0106	1,042,470	98	10,638	2,275*
	50^{th}	.0127	1,249,000	98	12,744	2,677•
	60^{th}	.0233	2,291,480	98	23,382	5,003
Low Mortality	40^{th}	.0106	3,058,211	164	18,647	4,583*
	50^{th}	.0127	3,664,083	164	22,342	5,492*
	60^{th}	.0233	6,722,300	164	40,990	10,076

§NA: not applicable to this reference point.

*This exploitation rate falls within the guidelines recommended by the SARC for 2008.

•This exploitation rate may be permissible for 2008; however, careful consideration should be given to the possible consequence that this exploitation level may lead to a decreased allocation in the 2009 fishing year.

Figure 1. Summary status of the stock for 2007. Green indicates variables judged to be above average relative to the 1989-2007 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2007 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 1989-2007 time period, but sometimes determined by scientific judgment. 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 1989-2007 time series. Parentheses are values that include the 2007 shell plants.

	Low Mortality Beds	Medium Mortality Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.34	0.41	0.12	0.13
Total Abundance				
2007 Percentile	0.24	0.08	0.71	0.18
2006-2007 Trend	Decreasing	Decreasing	Increasing	Decreasing
Spawning Stock Biomass				
2007 Percentile	0.66	0.22	0.91	0.34
2006-2007 Trend	Increasing	Decreasing	Increasing	Decreasing
Recruitment				
2007 Percentile	0.77	0.71	0.87	0.50
2006-2007 Trend	Increasing	Increasing	Increasing	Increasing
Spat per Adult				
2007 Ratio	0.80	1.46 (1.55)	1.97	2.33 (2.38)
2007 Percentile	0.92	0.87 (0.90)	0.87	0.82 (0.83)
2007 Juveniles **(fract.<2.5")**	0.74	0.48	0.51	0.43
2007 Percentile	0.06	0.24	0.29	0.12
Dermo Infection Status				
2006-2007 trend	increasing	increasing	increasing	increasing
2007 Mortality Rate	0.06	0.21	0.21	0.30
2007 Percentile	0.18	0.71	0.61	0.55
Abundance Position vs				
Target	Below	Below	Above	Below
Threshold	Above	Near	Above	Below
SSB Position vs				
Target	Above	Below	Above	Below
Threshold	Above	Above	Above	Above
2008 Surplus Production				
50^{th} percentile mortality	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Positive	Positive	Positive	Positive

Figure 2. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2007. High mortality: Beadons, Nantuxent Point, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Egg Island, Ledge, Bennies, Bennies Sand; medium mortality (less Shell Rock): Ship John, Cohansey, Sea Breeze, Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island, Hope Creek.

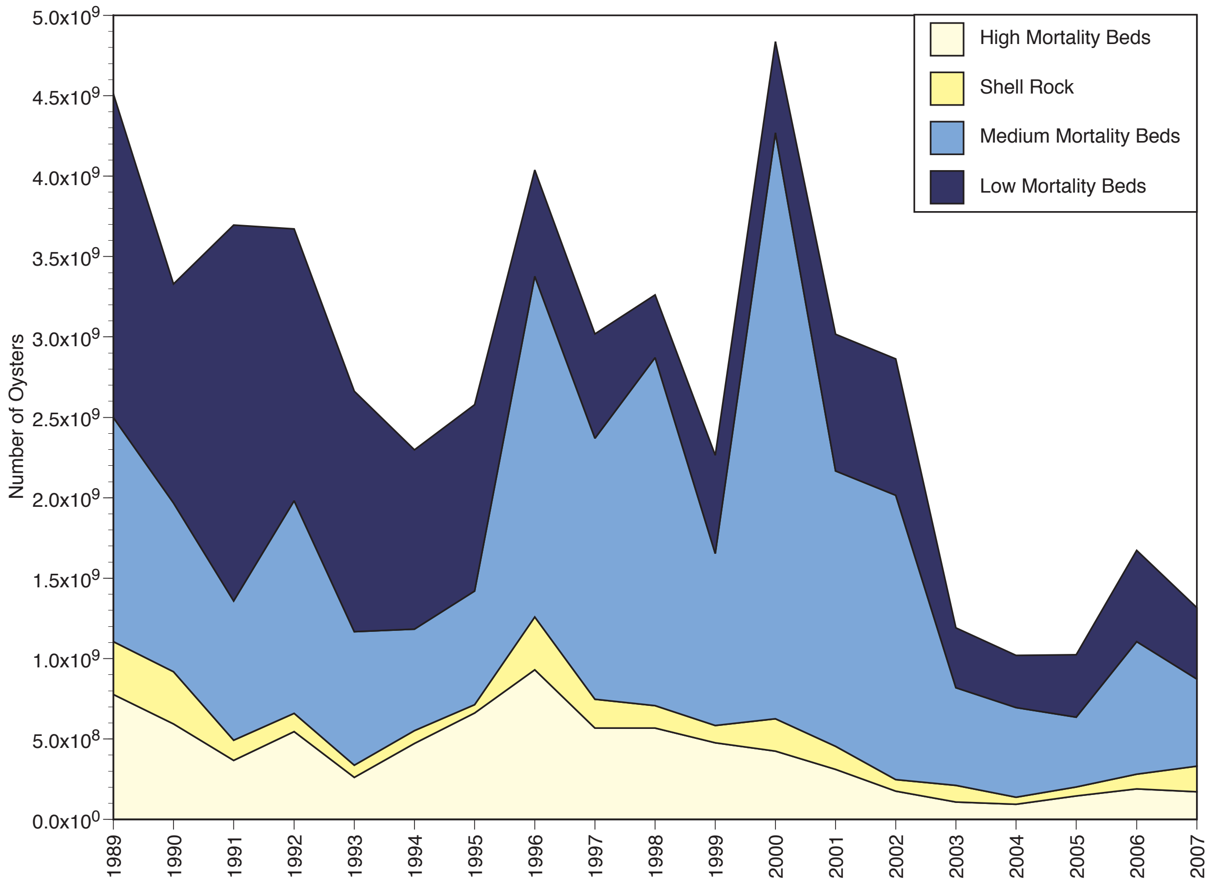

Figure 3. Position of the oyster stock in 2004-2007 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values.

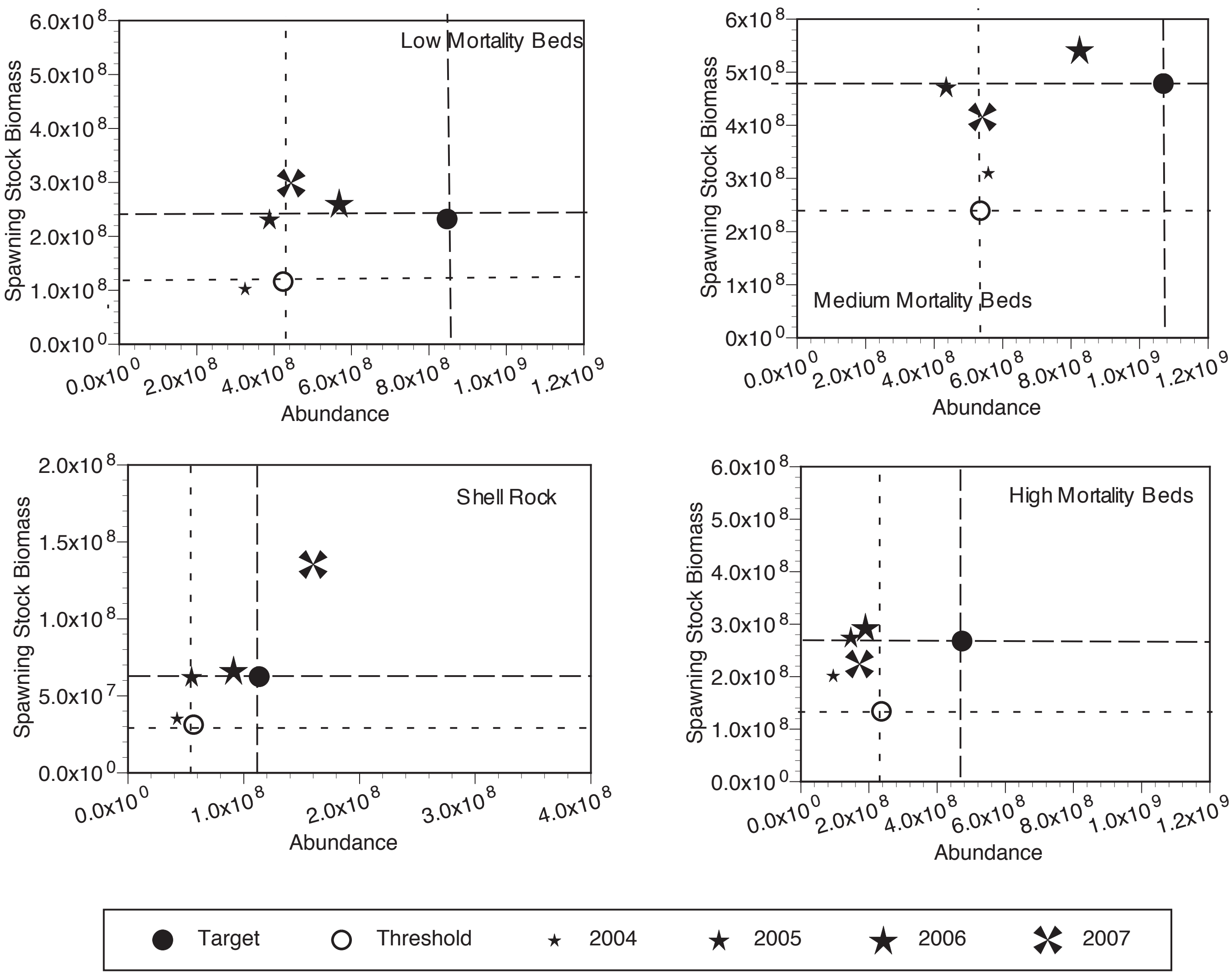

Figure 4. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 1.

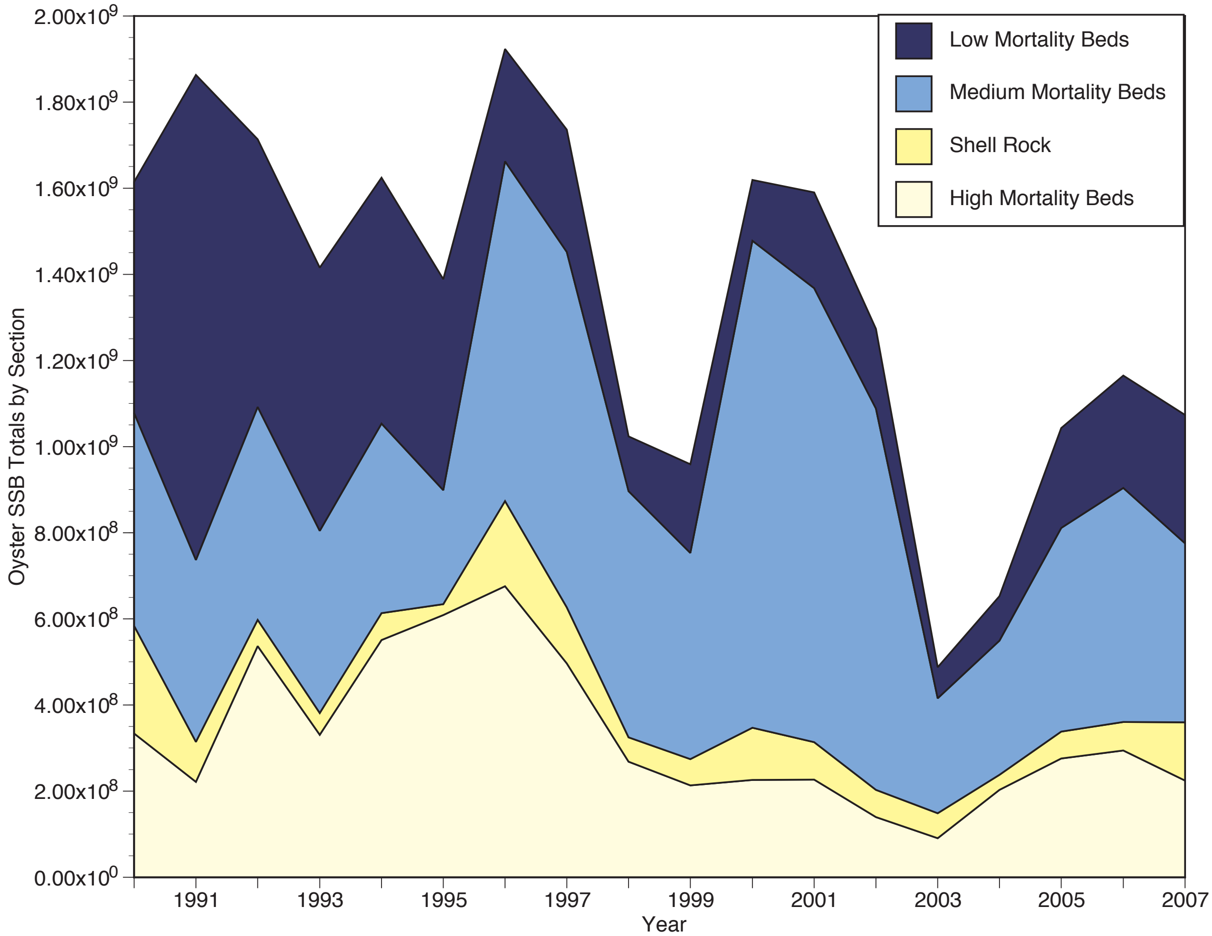

Figure 5. The number of spat recruiting per >20-mm oyster per year.

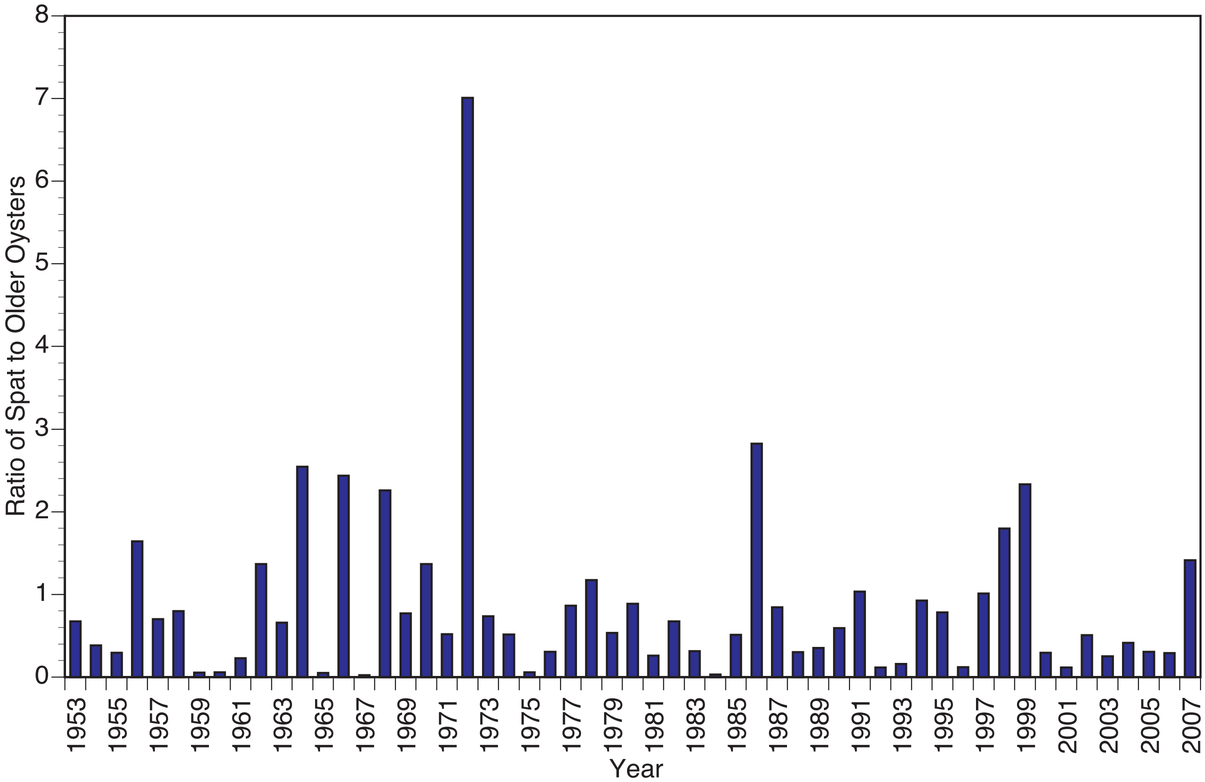

Figure 6. The abundance of small, submarket, and market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 1.

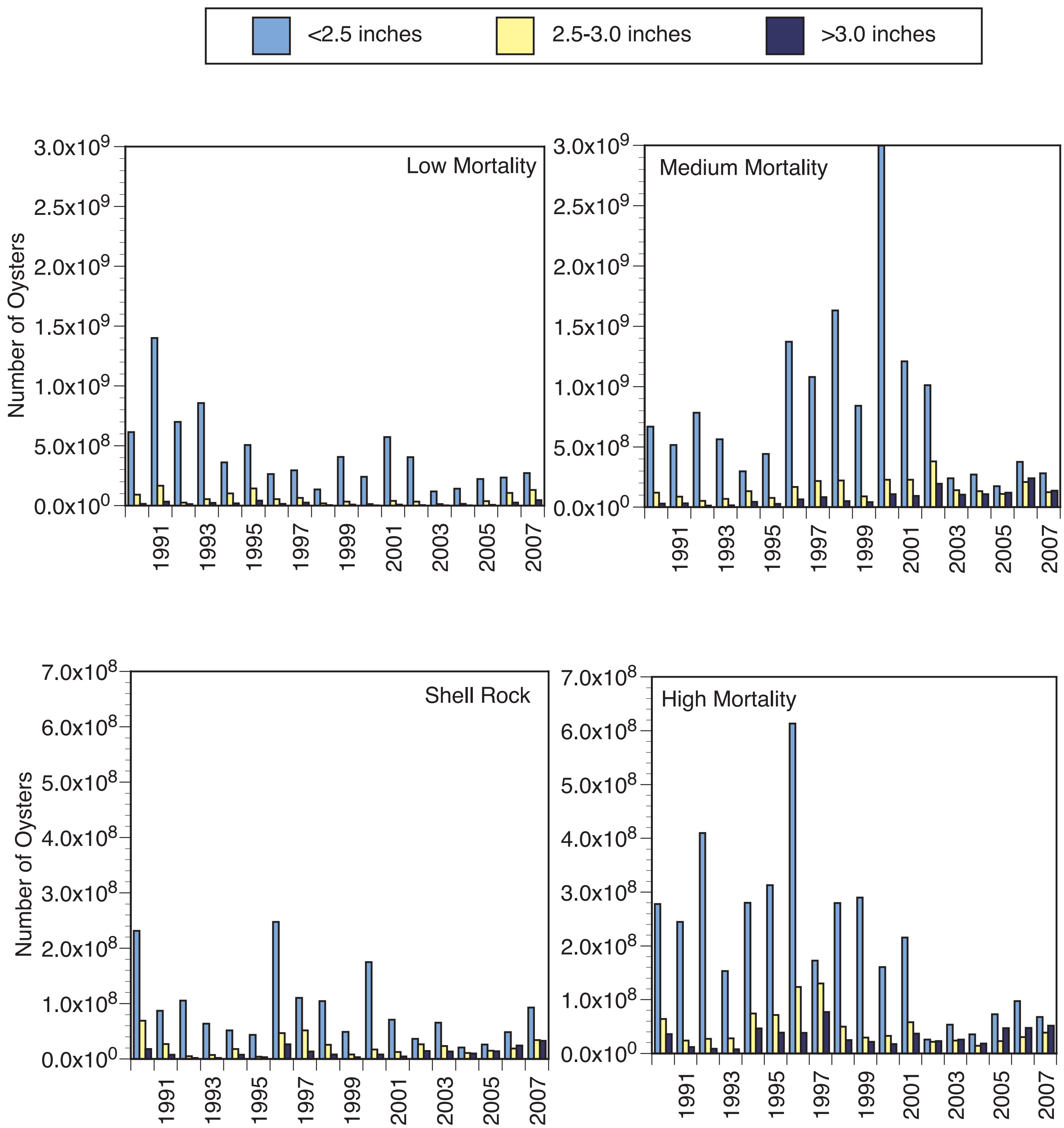

Figure 7. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region.

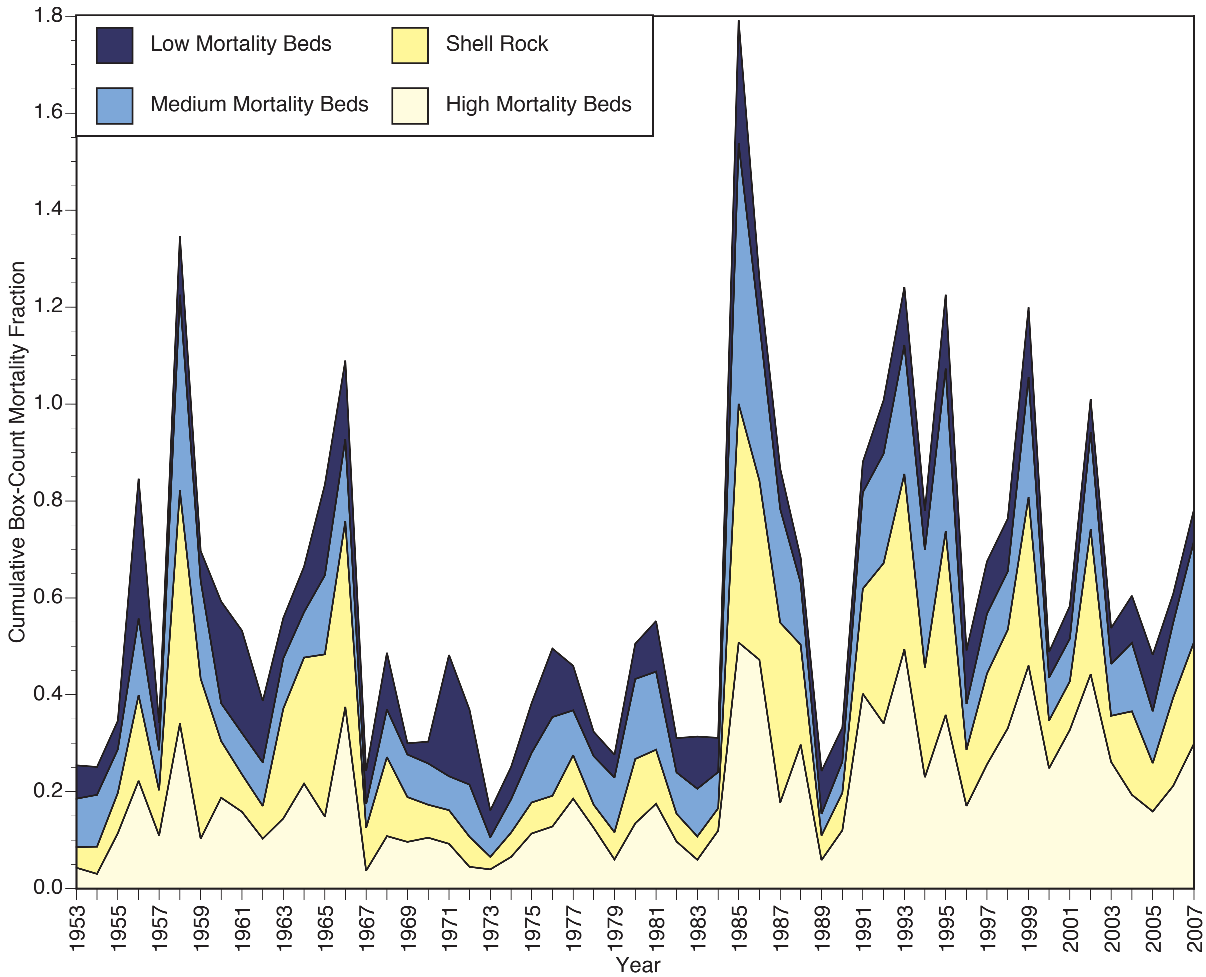

Figure 8. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2007. Positive values on Shell Rock in 2005 and 2006 and on the medium-mortality beds in 2007 reflect the addition of shell through shell planting to offset shell loss.

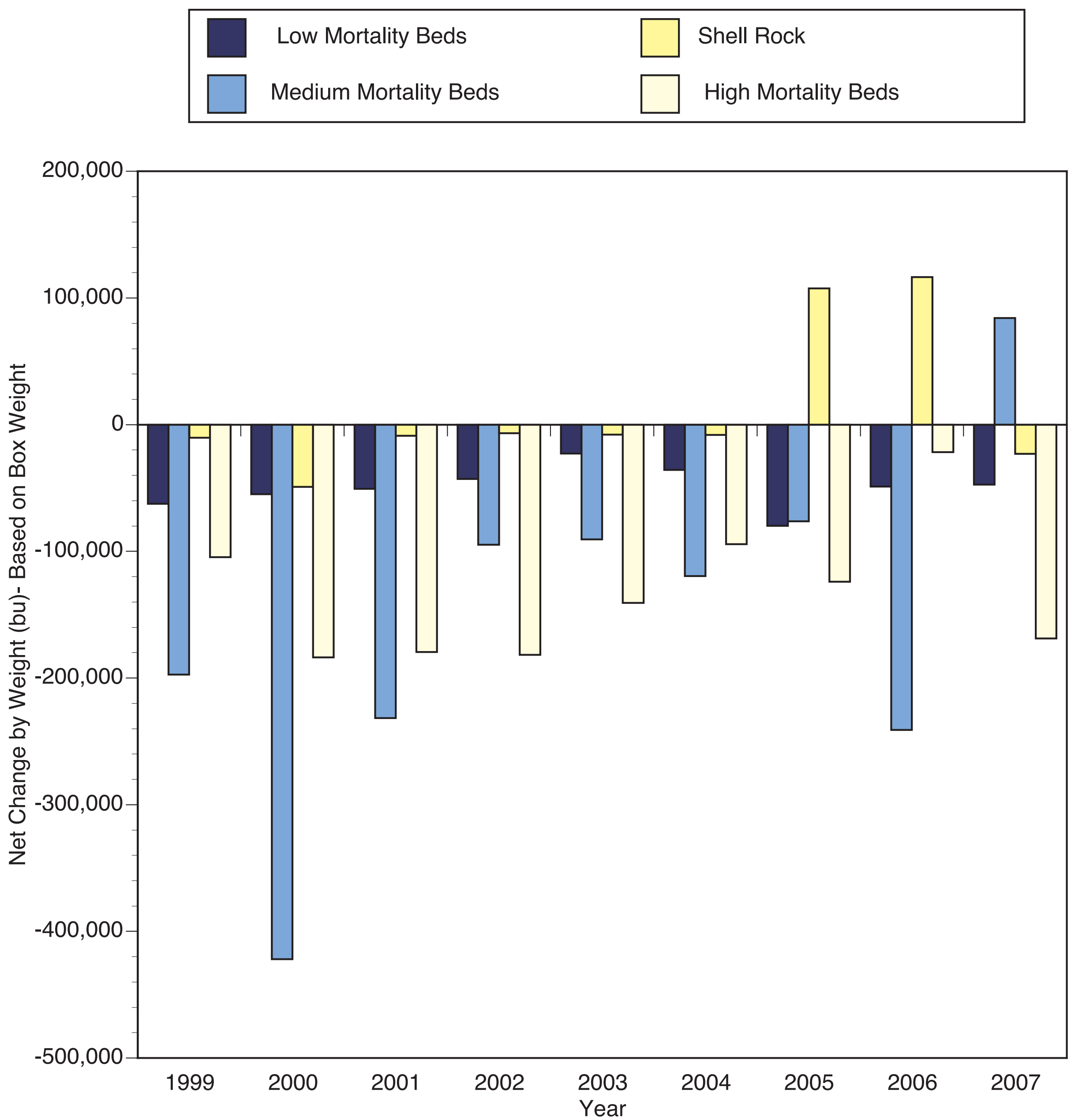

TABLE OF CONTENTS

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 1953-2007 period encompassing the entire survey time series and the 1989-2007 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 1989-2007 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 1989-2007 time series. All size-dependent indices begin in 1990 for reasons indicated previously. Evaluation of fishery exploitation by abundance focuses on the 1996-2007 time period during which the fishery has been conducted under a direct-marketing system.

Survey Design

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly, in the fall and/or winter, since 1953. Since 1989, this period has been concentrated into about one week in the latter part of October to early November, and has been conducted using a stratified random sampling method. Each bed is divided into $0.2''$ latitude $\times$ $0.2''$ longitude grids, each having an area of approximately 25 acres. Three strata are designated: the bed core (high quality), the bed proper (medium quality), and the bed margin (low quality). Each of these grids is assigned to a specified stratum and a subset of grids, randomly selected, is chosen each year for survey from each high-quality and medium-quality stratum on each bed. Through 2001, most beds were sampled yearly; the remaining mostly minor beds were sampled every other year. Beginning in 2002, sampling intensity was revised on a number of beds to better reflect their utilization by the

---

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

‡ Throughout, the term 'mortality rate' applies to the fraction dying per year. Values given are not true rates; rather, they are equivalent to $1 - e^{-mt}$ in the equation $N_t = N_0 e^{-mt}$ with m in units of yr^{-1} and $t = 1\,yr$.

fishery, and, to provide more accurate estimates of oyster abundance, fewer beds were sampled in alternate years.

Each survey sample represents a composite of 3 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 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.

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 three-year period (2005-2007), 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, three beds remain un-surveyed: Ledge, Egg Island, and a newly added bed, Hope Creek. The former two have low abundance, thus re-survey would not substantively change their minor contribution to the stock. The Hope Creek bed has been partially surveyed. Survey will be completed in the coming year.

[∅] 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 (8^{th} SAW) for the New Jersey Delaware Bay Oyster Beds. 81 pp.

The 2007 component of the re-survey effort included New Beds, Upper Middle, Arnolds, Upper Arnolds, Round Island, and a portion of Hope Creek, including all navigable 25-acre grids from the ship channel to shore or previously surveyed area in these regions. These sampled grids consisted of all previously designated grids and a number of grids not in the pre-2007 footprint. Each of the new grids were assigned to the nearest bed while maintaining simple linear boundaries between adjoining beds whenever possible, and given a unique grid number. In total, over 400 grids were sampled.

Preliminary evaluation of the density of oysters among grids confirmed findings from the re-surveys of the previous two years that a large number of 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. As before, these grids were assigned to a 'low-quality' stratum. This designation is consistent with the definition of a low-quality grid adopted in SAW-8 after the re-survey of the Bennies Sand to Middle reach. The remaining grids were input into a Monte Carlo model in which grids were subsampled repeatedly, without replacement, under a given set of rules, and the mean abundance estimated from the subsample compared to the mean abundance obtained from the average of all grids. Analysis of many simulations suggested that a random survey based on two strata would suffice, remembering that a third low-quality stratum had already been split out at the cost of 2% of the stock. These two strata were defined as before by assigning grids ordered by increasing abundance that cumulatively account for the first 48% of the stock to a 'medium-quality' stratum and grids that cumulatively account for the upper 50% of the stock to a 'high-quality' stratum. These designations are also equivalent to those adopted in SAW-8 for the Bennies Sand to Middle reach and SAW-9 for the majority of beds downbay of Bennies Sand. The new high-quality stratum generally includes most grids originally assigned to the high-quality stratum used prior to 2007 and a few of the old medium-quality grids. The medium-quality stratum generally includes some of the old medium-quality and low-quality grids plus a number of new grids. Figure 1 shows the revised bed footprint defined by the high-quality and medium-quality strata for these beds.

Dredge efficiency for grids surveyed in the 2007 spring re-survey and the previous fall (2006) and subsequent fall (2007) surveys varied by a factor of 0.66. Comparison to fall survey abundance estimates, after this correction, revealed that the 2006 survey of New Beds underestimated abundance by a factor of 2.3. The value of the underestimate of abundance on Arnolds, Upper Arnolds, and Round Island was a factor of 2.1. Evaluation of time series data identified some old (1953-1989) samples obtained from newly-designated high-quality and medium-quality grids that did not fall within the previous bed footprint. This suggests that not all of the 'new' areas are 'new' oyster bed; that is, some portion of the underestimate is due to an historical redefinition of the bed footprint used for survey design.

The October 2007 survey was constructed by randomly choosing a designated number of grids from each stratum on each bed. Sampling was conducted from October 29 to November 9 using the oyster dredge boat *F/V Howard W. Sockwell* with Greg Peachey as captain. The sampling intensity is shown in Table 1 and the specific grids sampled are shown in Figure 1. Total sampling effort in 2007 was 143 grids, a value considerably above 2006. These included 20 transplant grids selectively sampled because they were sites of 2005, 2006, and 2007 shell plants or 2007 intermediate transplants.

No additional information on dredge efficiency was available for this assessment. Dredge efficiency correction factors were obtained from Table 2[∅]. A retrospective analysis of dredge efficiency from data collected during the survey using the equations of Powell et al. (2007) estimated a value of q for total oysters for the upbay region as 8.44 in contrast to a range of 7.30-9.40 from direct measurements in Table 2. The value of q for the downbay region from this retrospective is 5.99 in contrast to a range of 2.83 to 4.87 from direct measurements. This latter retrospective value continues a trend noted over the last few years of a possible decrease in dredge efficiency on the high-mortality beds. If true, this would bias low the abundance estimates for this region provided in subsequent analyses.

Oyster Abundance

Analytical Approach

Since 1998, swept areas have been measured for each dredge tow, permitting estimation of oyster density directly. Bay-region point-estimates are obtained by averaging the per-m^2 samples per stratum, expanding these averages for each bed according to the stratal area for that bed, and then summing over strata and then beds in a series of bay regions. Throughout this report, these quantitative point estimates of abundance sum the high-quality (bed core), medium-quality (bed proper), 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 $\leq$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

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

is the most stable component of the survey sample and support the belief that a $\times 2$ error is unlikely to be exceeded. Accordingly, the quantitative time-series estimates are considered the best estimates for the 1953-1997 time period.

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

Throughout this report, 'oyster' refers to all animals $\geq$20 mm. Animals <20 mm are referred to as 'spat'. Adult oysters are animals $\geq$35 mm. Calculations of spawning stock biomass (SSB) are based on this size class and used bed-specific and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size animals are animals $\geq$75 mm. Submarket size classes are variously defined depending on growth rates and analytical goals as indicated. Shell planting permitted an estimate of the accuracy of the 20-mm size boundary for spat on Ship John, Cohansey, and Middle. These 2007 shell plants revealed that about 24.6% of the spat exceeded 20 mm in size and reached sizes as large as 41 mm (Figure 2). This error is somewhat higher than in 2006 despite the fact that most recruitment occurred in late summer/early fall and so many spat were small when the beds were surveyed. Recruitment indices may underestimate recruitment by this amount and bias high abundance indices by a small amount.

Abundance Trends

Since 1989, the natural oyster beds have experienced a two-fold fluctuation in the number of oysters per bushel, but, with the exception of a few years characterized by the highest and lowest values, no statistical differences exist (Table 3). High variances are to be expected because oysters are being sampled along a salinity gradient that reflects spat set, predation, disease, and growth. The bay-wide average number of 114 oysters bu^{-1} in 2007 fell below the 1989-2007 average of 133 oysters bu^{-1}, but not significantly so. This year (2007) differed significantly only from 1989. A summary of the 2007 survey data is provided in Table 4. Quantitative estimates using the time-series analysis indicate that oyster abundance summed across all strata and bay regions declined somewhat from 2006, but remained above 2003-2005 values, at 1,316,813,056 individuals (Figures 3 and 4). Abundance in 2007 fell to the 10th percentile of the 1953-2007 time series and the 18th percentile post-1988 (Table 5), so abundance remains near historical lows.

Most (41.7%) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 5). This is a substantive decrease in proportion for these beds over 2006, but in keeping with the distribution of oysters in most years post-1995. The reduction originates from a substantive increase in oyster abundance on Shell Rock as a result of the shell-planting program and a proportionately higher naturally mortality rate on the medium-mortality beds than normal. Abundance on these beds ranked at the 16^{th} percentile of the 55-yr time series and the 8^{th} percentile post-1988 (Table 5). The number of oysters per bushel did not deviate significantly from the remainder of the time series (Table 6).

Abundance in 2007 fell 32% from 2006 on the low-mortality beds to one of the lowest levels recorded (12^{th} percentile), but higher than many years since 2001, coming in at the 24^{th} percentile for the post-1988 era (Table 5). The low-mortality beds contributed 33.7% of the stock in 2007 (Figure 5). Abundance also declined in 2007 on the high-mortality beds (10%) from 2006, but remained consistent with values observed throughout the 2000s. The proportion of the stock on the high-mortality beds (13.1%) remained relatively high for the third straight year (Figure 5). The number of oysters per bushel did not differ significantly from any other year in the 1989-2007 time series (Table 6). Abundance on the high-mortality beds ranked at the 14^{th} and 18^{th} percentiles, respectively, for the 55-year time series and the time series post-1988 (Table 5).

Abundance in 2007 rose dramatically on Shell Rock, by a factor of 1.75, principally as a result of the shell-planting program. This is the third year of increase on this bed. Abundance on Shell Rock ranked at the 56^{th} and 71^{st} percentiles, respectively, for the 55-year time series and the time series post-1988 (Table 5). Expansions of the oyster population as a whole occur less frequently than contractions. For the 1991-2007 time period, values above 1 for the ratio of oysters in year t versus year $t-1$ occurred 23 times out of 15 years$\times$4 bay regions or 23 out of 64 possible occurrences. A value above 2 has occurred only thrice. Only Shell Rock exceeded a value of 1 in 2007.

Spawning Stock Biomass (SSB)

Spawning stock biomass decreased bay-wide by 8% in 2007 (Figure 6), falling at the 33^{rd} percentile of the 1990-2007 time series (Table 5). SSB rose slightly (a factor of 1.14) on the low-mortality beds, declined by 24% on the medium-mortality beds, though still remaining relatively high for the 1990-2007 time series, declined by 25% on the high-mortality beds, and rose dramatically, by a factor of 2.03, on Shell Rock. For the low-mortality beds, the medium-mortality beds, Shell Rock, and the high-mortality beds, the percentiles were the 66^{th}, 22^{nd}, 91^{st}, and 34^{th}, respectively (Table 5).

SSB is highest on the medium-mortality beds in most years. In 2007, these beds contributed 38.7% to bay-wide SSB. The low-mortality beds contributed an additional 27.8%, and the high-mortality beds an additional 20.9% (Figure 7). SSB was less concentrated on the medium-mortality beds in 2007 than any year since 1994 due to a continuing increase in SSB on the low-mortality beds and the dramatic rise of SSB through the shell-planting program on Shell Rock. Expansions in bay-wide SSB occur relatively frequently. From 1991 to 2005, values above 1 for the ratio of oyster biomass in year t versus year $t-1$ occurred in 30 out of 64 possible occurrences. A value above 2 has occurred six times. In 2007, SSB rose in two of four bay regions and by more than a factor of 2 on Shell Rock.

Oyster Size Frequency

Perusal of the 1990-2007 time series (Figure 8) shows that the fraction of the population $<2.5''$ was high in the early 1990s, then declined somewhat, and rose again in the late 1990s to early 2000s. In 2007, bay-wide, 54.4% of the animals were below $2.5''$ and 20.4% of the animals were $\geq 3''$ in size. Thus, marketable animals accounted for just under half of all animals. The fraction of animals of marketable size increased considerably between 2000 and 2002 and tended to level out around 50% thereafter (Figure 9). Early in the time series, values of 20%-25% were more typical. The increase in this percentage in the 2000s is primarily due to low recruitment rather than unusually low adult mortality. That is, the number of smaller oysters has declined as animals have grown to $>2.5''$ in size or have died, and few of these small oysters have been replaced by new recruits.

Small oysters accounted for 60.4% of the animals on the low-mortality beds, a fractional contribution below the long-term trend due to persistent low recruitment and increased average size (Figure 10). More than half of all animals (51.7%) on the medium-mortality beds were $\leq 2.5''$ in size. Small oysters contributed 58.1% of the stock for Shell Rock and 43.0% for the high-mortality beds. Thus, only on the high-mortality beds did marketable oysters contribute the majority of the stock (Figure 10). Nevertheless, the marketable fraction of the stock remained well above that observed in the first half to two-thirds of the 1990-2007 time series in all bay regions (Figure 9).

Of the animals $\geq 2.5''$, 44.8% were $\geq 3''$ in size (Figure 11). For two of the bay regions, the submarkets made up the larger percentage: 74.1% for the low-mortality beds and 51.2% for Shell Rock. But, for the two largest regions, the reverse was true: 47.8% for the medium-mortality beds and 42.9% for the high-mortality beds (Figure 10). The proportion of submarkets relative to markets has remained relatively stable since 2002, but was much higher earlier in the time series. A moderate increase in submarket proportions on Shell Rock and the high-mortality beds in 2007 is substantially the result of the shell-planting programs in 2005 and 2006. Nevertheless, the population continues to be over-represented by larger animals due to low recruitment. Such a populations is sensitive to epizootic decline and to overfishing under exploitation-rate reference points.

Oyster Condition and Growth

Condition index rose in 2007 to one of the highest values in the 1990-2007 time series (Figure 12). Condition increased throughout the bay, increasing in all bay regions, with a particularly large increase on the low-mortality beds. As a consequence, although the high-mortality beds continued to average highest, the differential between them and the low-mortality beds was less than a factor of two (Figure 13).

A new analysis of growth rate was performed in 2007. Growth was 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 oyster sizes expected to reach 3″ in one year 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 7). Time to market size was estimated as: high-mortality beds, 3-4 yr; medium-mortality beds, 4-5 yr; low-mortality beds, $\geq$7 yr (Table 7).

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 market-size 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 market size in a year less the number of market-size animals expected to die naturally. In the absence of fishing, a positive surplus production indicates that the market-size population is expected to expand in abundance. If negative, the market-size 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 market-size animals are removed from the population by means other than natural mortality. A detailed description is found in Klinck et al. (2001)[⊕].

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

⊕ Klinck, J.M., E.N. Powell, J.N. Kraeuter, S.E. Ford and K.A. Ashton-Alcox. 2001. A fisheries

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 submarket size range obtained from the von-Bertalanffy curves of Kraeuter et al. (2007). Additional direct observations of growth in 2007 for oysters recruited in 2005 on the 2005 shell plants further support the growth rate used, at least for the Bennies Sand region; however, insufficient information is available to judge how near the long-term average these growth rate estimates might be.

Surplus production estimates projected for 2008 were positive and in keeping with last year's estimates for 2007 on the low-mortality and medium-mortality beds. Surplus production projections were considerably higher on Shell Rock and the high-mortality beds than estimated last year (Table 8). Overall, surplus production estimates suggest that SSB should increase in all bay regions in 2008, barring unusually high mortality rates, unusually low growth rates, or overharvesting.

Recruitment

Spat set in 2007 was the highest since 1999 bay-wide (Figures 14 and 15), ending a string of seven consecutive years of relatively low recruitment and four consecutive years of very low recruitment. The number of spat per bushel averaged over all survey samples fell above the long-term average for the 1989-2007 time series, but was not significantly different from any of these years except 1991 and 1999 (Table 3). Nevertheless, 2007 spat settlement ranked at the 46^{th} percentile for the 1953-2007 time series and at the 61^{st} percentile post-1988 (Table 5). The higher ranking post-1988 indicates a long-term decline in recruitment rate relatively to the earlier portion of the time series. The number of spat recruiting per oyster was the highest since 1999 at 1.413, and one of the highest on record (Figure 16), a value at the 85^{th} percentile of the 1953-2007 time series (Table 5). Shell planting raised this ratio only slightly to 1.457. 2007 came in at the 87^{th} percentile for the 1989-2007 time series (Table 5).

The number of spat per bushel (66) averaged over the survey samples for the high-mortality beds was slightly below the 1989-2007 average of 73. The same metric (137) was well above the long-term average of 98 for the medium-mortality beds. In this latter case, only four previous years fell significantly above the 2007 value (Table 6). Recruitment estimated quantitatively for each bay region fell at the 45^{th}, 52^{nd}, 74^{th}, and 46^{th} percentiles of the 1953-2007 time series for the low-mortality beds, medium-mortality beds, Shell Rock, and the high-mortality beds, respectively. Percentile values were higher in each case for the 1989-2007 time series and particularly so for the low-mortality beds (Table 5).

model for managing the oyster fishery during times of disease. *J. Shellfish Res.* 20:977-989.

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 (Table 9). Recruitment has been consistently higher downbay than upbay, per adult, for many years. In particular, recruitment has been unusually low on the medium-mortality beds since 1999, but much more representative of the normal condition on beds downbay of this region. For 2007, the spat-to-oyster ratios were 0.80, 1.46, 1.97, and 2.33 for the low-mortality beds, the medium-mortality beds, Shell Rock, and the high-mortality beds, respectively. The respective percentiles for the 1953-2007 time series are: 77^{th}, 83^{rd}, 83^{rd}, and 81^{st}. Percentiles were even higher for the 1989-2007 time series (Table 5).

Shell planting in 2007 enhanced recruitment by a small factor bay-wide. Recruitment was increased 6% on the medium-mortality beds and 1.9% on the high-mortality beds (Table 9). These increments were relatively low due to the lateness of the largest setting event, that limited the influence of shell 'cleanliness', and because of the overwhelmingly good set generally throughout the bay.

Recruitment-enhancement Program

Shell planting was carried out in June-July, 2007. Ocean quahog and surf clam shell were used with amounts planted as follows: Ship John, 168,642 bu; Nantuxent Point, 43,360 bu; Middle, 43,800 bu; and Cohansey, 19,881 bu. This totals to 275,683 bushels, about the same quantity as planted in 2006. Of these, 26,414 bu were replanted on Ship John, 30,637 bu on Middle, and 19,881 bu on Cohansey. This shell was originally planted downbay and then moved upbay in August through September (Figure 17, Table 10). In contrast to previous years, downbay plants returned relatively few spat per bushel in comparison to direct plants (Table 10). Unlike in previous years, direct plants did not significantly out-perform native shell. Recruitment on direct plants averaged 237 spat per bushel. Native shell on the same grids averaged 222 spat per bushel. Replants did poorest of all. The similarity between direct plants and native shell originates in the timing of the set in 2007. Most of the set occurred in late September to early October and the shell, planted in June/July, by that time, had lost most of its 'cleanliness' and so performed no differently than native shell. The poor showing of the replants originated in a large recruitment of tunicates downbay that either smothered spat or prevented recruitment. Interestingly, this shell did not appear to perform adequately after replant, as shown by the low recruitment on Cohansey, relative to native shell (21 bu^{-1} vs. 375 bu^{-1}).

Projections of marketable bushels expected to accrue from the 2007 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}-percentile mortality rates for the 1989-2007 time series: for the medium-mortality beds, 0.261, 0.141, 0.141; for the high-mortality beds: 0.601, 0.262, 0.262. Bushel conversions assume 259 oysters per bushel. The 2007 shell plants are expected to provide 108,520 bushels for market in 2010/2011.

The yearly mortality rate for yearlings from the 2006 shell plants in 2007 averaged 55.7%, somewhat lower than the long-term average of 62.9%. Estimated harvest from the 2006 shell plants is updated using the mortality rates observed in year 1 and the 50^{th} percentile adult rates in years 2 and 3 from the 1989-2007 time series: for Shell Rock, 0.182; for Bennies Sand: 0.267. Bushel conversions assume 259 oysters per bushel. A projected harvest of 74,402 bushels was estimated, somewhat lower than the original estimates from 2006 spat counts (Table 11). The shell planted in 2006 continued to attract spat in 2007; however the rate of attraction was no better than native shell (Table 12). Nevertheless, the net addition of shell to these beds resulted in an increase in the number of recruits for a second year. A minimal estimate of year-2 recruitment on this shell results in an estimated future harvest of 71,211 bushels. Thus, total projected harvest from the 2006 shell plants is 145,613 bushels.

A monitoring program for setting potential was initiated in 2004. The 2007 program did not show the anticipated trend of greater spat availability downbay (Figure 18); rather, monitoring of setting potential indicated a high setting potential in 2007 throughout most of the oyster beds relative to the preceding three years, particularly on the New Jersey side of the bay (Figure 19). Setting potential was highest in August over much of the bay on both the Delaware and New Jersey sides. However, survey data suggest that the largest set occurred in early October and was missed by the spat-settlement monitoring program.

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 generally ranged between 3 and 15 years, with an overall average of 9.2 years (Table 13). Estimates could not be made for some beds: Round Island, Upper Middle, Sea Breeze, New Beds, Egg Island, Strawberry, and Hope Creek. Egg Island is surveyed every other year. Upper Middle, Round Island, and Sea Breeze were poorly surveyed from 1996-2003. Thus, the time series is inadequate. New Beds was re-stratified this year and the time series for Hope Creek is inadequate.

In addition, estimates of half life are subject to substantial yearly variations retrospectively because some conversions are poorly known. These include the

[♮] 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.

value of cultch attached to live oysters and boxes and the conversion of cultch and shell-plant volume to weight. The amount of cultch in oyster and box volume measurements, as attached shell, was evaluated during the 2007 survey. No obvious bed-dependent trends were noted. Average fractions of cultch as attached shell in oyster volume measurements was 16.2% and in box volume measurements, 21.3%. These values are distinctly lower than the crude 50% estimates used in earlier assessments.

New Jersey oyster beds have been losing on the order of 250,000 to 500,000 bushels of cultch annually since 1999. Year 1999 is the first year an estimate can be made as 1998 is the first year that full survey data are available. Shell budget estimates are somewhat modified using the 1998-2007 time series versus the 1998-2006 time series due to improved data for historically poorly-sampled beds and to survey variations. In addition, the half-life values for the seven beds previously enumerated were borrowed from adjacent beds because estimates could not be made. Two estimates of the shell budget 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.

The shell budget shows a substantial reduction in shell loss in 2005 through 2007 as a result of the shell-planting program that has reduced the yearly deficit by at least two-thirds. This year, 2007, is the first year in the time series since 1999 that the range of the two estimates encompasses zero, suggesting that shell on the New Jersey beds was relatively in equilibrium for the first time in eight years (Figure 20). The improved shell balance in 2007 is due to two factors, the purposeful addition of surfclam and ocean quahog shell and the relatively high level of natural input due to the Dermo epizootic of 2007.

By region, the low-mortality beds have been losing about 20,000-60,000 bushels annually (Figure 21). 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 100,000 to 200,000 bushels annually in most years due to higher loss rates and a larger total area. This region recorded a positive shell budget in 2007 for the first time, due to shell planting. Shell Rock showed a net gain in 2005-2006 due to shell planting, and a slight loss in 2007. The high-mortality beds are losing 100,000 to 200,000 bushels annually due mostly to the larger area of coverage. Lower loss in 2006 is due to the substantial shell planting that occurred downbay of Shell Rock in that year. The loss in 2007 was above average. Most of the bay-wide loss of shell was contributed by the high-mortality beds in 2007.

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 2007.

In general, Dermo disease* and mortality increase downbay as salinity increases. A regression between Fall Dermo disease and box-count mortality explains approximately 40% of the variation in mortality among beds since 1990 (Figure 22). The y-intercept for this regression is just below 10%, indicating that background (non-disease) box-count mortality is about 10%. The regression by bay region reveals that background mortality is about 10% for all bay regions except the high-mortality region, where it rises to 19% (Figure 22).

In 2007, the prevalence and infection intensity of Dermo followed typical seasonal and spatial patterns across the oyster beds. Compared to levels since 1999, prevalence and mean infection intensity were at or below long-term levels during the spring, but, by July, prevalence exceeded the long-term mean and this was followed by infection intensity in August. Both measures remained above average into November, as a consequence of the relatively high salinity and unusually warm Fall (Figures 23 and 24).

Since the onset of Dermo disease in 1990, two periods of epizootic mortality have occurred, each of them multi-year (Figure 25). 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 suggests that 2007 may be initiating another period of higher than average Dermo activity. Dermo levels were in their third year of increase following a 2004 low and mortality reached epizootic levels (Figure 25). History suggests that Dermo-induced mortality is likely to increase or remain near 2007 levels in 2008 unless environmental conditions inhibit further development.

Dermo prevalences were unusually high on the medium-mortality beds and

* 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 2007 disease monitoring program is available as an HSRL report: Bushek, D. 2008. Delaware Bay Oyster Seedbed Monitoring Program 2007 Status Report.

some of the low-mortality beds in 2007 (Figure 26). Of particular note is the reach from Ship John upbay to Upper Arnolds. Prevalence was high but near average downbay of Shell Rock. Infection intensities were near average over much of the high-mortality beds in 2007 (Figure 27), with unusually high values restricted to Nantuxent Point and Bennies Sand. Dermo infection intensity reached unusually high levels on the medium-mortality beds, particularly Sea Breeze, Cohansey, and Middle. This unusual pattern explains the inordinately high contribution of this bay region to total stock mortality in 2007.

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. Box-count mortality was 20.5% bay-wide in 2007 (Figure 28). This is a moderate increase from 2006, and within epizootic mortality levels. Box-count mortality rate in 2007 was at the highest level since 1999, and relatively high for the time series, coming in at the 79^{th} percentile of the 55-yr time series and at the 66^{th} percentile post-1988 (Table 5). The mortality rates were highest on the high-mortality beds, as usual (29.9%) (Figure 29). Shell Rock and the medium-mortality beds had lower, but still epizootic, mortality rates at 21.0% and 20.8%, respectively. Mortality was typically low on the low-mortality beds, 6.5% (Figure 29). Mortality rate was higher in all bed regions relative to 2006, but only slightly so on the low-mortality beds. For the remainder of the bay, natural mortality rate has been rising each year since a nadir in 2005, and was about double 2005 levels in 2007.

Box-count mortality on the high-mortality beds fell at the 77^{th} percentile of the 55-year time series, but only the 55^{th} percentile of the post-1988 time series (Table 5). That is, 2007 was a fairly average year on the high-mortality beds. Mortality on Shell Rock was relatively higher with percentile positions of 70^{th} and 61^{st}, respectively. The percentile rank indicates that mortality was somewhat above average in 2007 on Shell Rock, but not egregiously so. Box-count mortality on the medium-mortality beds was unusually high. The 2007 level of mortality was at the 83^{rd} percentile for the 55-year time series and the 71^{st} percentile for the post-1988 time series (Table 5). The high 2007 rate was likely due primarily to the high proportion of older oysters that were more sensitive to a Dermo epizootic due to their already long life spans. Box-count mortality fell at the 25^{th} percentile for the 55-year time series for the low-mortality beds and at the 18^{th} percentile for the post-1988 period. The lower percentile positions during this epizootic for the post-1988 time series relative to the longer time series indicate that natural mortality rates have averaged higher under Dermo disease than earlier under MSX disease.

The high-mortality and medium-mortality beds accounted for the bulk of the total deaths in 2007 (Figure 28). The high-mortality beds contributed 45.2% of the total deaths in 2007, followed by 31.7% for the medium-mortality beds, 16.1% for Shell Rock, and 7.0% for the low-mortality beds. The disproportionate contribution from the medium-mortality beds is partly due to the concentration of animals on the medium-mortality beds that occurred in the early 2000s. This is a consequence of the last epizootic and has persisted subsequently as a result of recruitment failure. However, the disproportionate contribution in 2007 is also due to the unusually high Dermo infection intensities in 2007 on the medium-mortality beds relative to beds upbay and downbay. Accordingly, both abundance and infection level contributed to a high number of deaths. The contribution from the high-mortality beds is primary due to the high mortality rate on these beds in 2007, as total abundance is considerably lower than on the medium-mortality beds. It is the increased mortality on the medium-mortality beds that is primarily responsible for the stock-wide epizootic mortality level in 2007.

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. 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 14 of 55 and a ratio half that occurs in 31 of 55 years, so that the expectation of a respectable recruitment event remains greater than 50%. The expectation, however, is lower since 1989 (Figure 30). The distribution of points in the four quadrants[ℜ] of the broodstock-recruitment diagram (see Figure 31 for quadrant definitions) (x/y = broodstock abundance/recruitment) is: low/low = 17; low/high = 10; high/low = 10; and high/high = 17. This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. First passage times show a high tendency for the population to remain in the low/low or high/high quadrants (Table 14).

[ℜ] To assign data points to each of the four quadrants, each x-y datum pair is assessed as to its position versus the median of the x and y values. An assignment to the 'low/low' quadrant, for example, would occur if the datum pair was below the median of the y values and below the median of the x values.

Since 1989, the distribution of points in the four quadrants is: low/low = 8; low/high = 5; high/low = 4; high/high = 1, based on the 55-yr medians. This distribution is highly significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P < 0.0001$, $P > 0.05$; $P > 0.05$, $P < 0.05$, respectively. 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. Mean first passage times, using the 1989-2007 time series only, but based on the 1953-2007 median abundance and recruitment, show the strong tendency for the stock to return to quadrants 1 and 2, low abundance-low recruitment or low-abundance high-recruitment, showing that recruitment rate, even when high, is unlikely to generate a transition to high abundance.

Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about one-third (37%) of the years since 1989 (Figure 32). Non-epizootic years tend to average around 10% mortality (Figures 22 and 32). The bay-wide average for 2007 was 20.5%, an epizootic mortality rate. Geographic contraction of the stock, an ongoing process since 2002, ceased in 2005 (Figure 5). During that time, the stock became increasingly concentrated in the central part of the bay where mortality rates tend to be moderate. Since 2005, the proportion of the stock on the high-mortality beds and Shell Rock has increased moderately, exposing an increased proportion of the stock to the potential for increased mortality.

A relationship between broodstock abundance and mortality exists and is characterized by an 'epizootic hump' in the 2×10^9 to 5×10^9 abundance range (Figure 32). Year 2007 falls appropriately within this hump (Figure 33), suggesting that some portion of the responsibility for the 2007 epizootic accrues from the downbay expansion of the distribution of the stock during a time of environmental facilitation of disease proliferation.

The relationship between broodstock and mortality continues to clarify as low abundance values accumulate. The distribution of the points in the four quadrants (x/y = broodstock abundance/mortality rate) is: low/low = 12; low/high = 15; high/low = 15; high/high = 12 (Table 15). This distribution of occurrences between quadrants is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. This is dominantly due to the fact that the median mortality rate falls near the 'epizootic hump'. First passage times show that transitions to quadrant 3 occur rarely, but quadrant 3 is a relatively stable state. This quadrant is characterized by high abundance and low mortality. Since 1989, the distribution of points in the four quadrants is: low/low = 4; low/high = 9; high/low = 1; high/high = 4. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.005$; $P < 0.05$, $P > 0.05$, respectively. Since 1989, 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 is also short, indicating that the response time of Dermo to stock expansion in increasing mortality and thereby lowering stock abundance is 1-2 years.

A relationship between box-count mortality and recruitment remains unclear (Figure 34). The distribution of points in the four quadrants (x/y = recruitment/mortality rate) is: low/low = 15; low/high = 13; high/low = 13; high/high = 14. This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. First passage times show that return intervals to quadrant 3 are long. This quadrant is characterized by low mortality and high recruitment. Return intervals to quadrant 1, low mortality-low recruitment are short, from all four quadrants (Table 16). Since 1989, the distribution of points in the four quadrants is: low/low = 6; low/high = 7; high/low = 0; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P > 0.05$; $P < 0.01$, $P > 0.05$, retrospectively. The high recruitment-low mortality state has not occurred in this time period. Alternatively, low recruitment has occurred relatively equally regardless of high or low mortality, suggesting that low recruitment is not a function of adult mortality rate.

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 2006 period was statistically greater than for the high-mortality beds (Table 6). 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 large cohorts that dominate the population for an extended period of 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.

Harvest Statistics

Total harvest in 2007 was 81,235 bushels[♭]. This is above the 1996-2007 average of 71,294 bushels (Figure 35). Figure 36 shows the time-series of oyster harvest in

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

Delaware Bay. 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 9 to November 16, 2007. Harvest was from 10 beds. Highest catches were on Cohansey, Bennies Sand, Shell Rock, and Ship John, where catches exceeded 9,000 bushes, and Nantuxent Point, New Beds, and Bennies, where catch exceeded 5,000 bushels (Table 17). The recommended area-management policy resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John and Cohansey.

Seventy-one boats participated in the fishery and worked for a total of 1,203 boat-days. These included 42 single-dredge boats working for 904 boat-days (21.5 days/boat) and 29 dual-dredge boats working for 299 boat-days (10.3 days/boat). CPUE rose considerably from 2006 on two-dredge boats, continuing a rising trend since 2003. CPUE for single-dredge boats remained near 2006 values. The 2007 dual-dredge-boat value is the highest since 1998 and the single-dredge-boat value was only exceeded in 1997 and 2006 (Figure 37).

Total dredging impact was estimated to exceed bed area in five cases (Table 17) [⊗]: Bennies Sand, Cohansey, Shell Rock, Nantuxent Point, and Ship John. Highest value was 2.23 on Nantuxent Point. Two other beds exceeded 2: Cohansey and Shell Rock[@].

The number of oysters per 37-qt marketed bushel averaged 262 in 2007. Of these, 235 were $\geq 2.5''$. Incidental capture averaged 27 per bushel. These were mostly animals that could not be culled from chosen oysters. These values are near 2006 values (Table 18). The size of harvested individuals was about that of 2005

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, hence the identification of bushel samples $\geq$40% in Table 4.

⊗ 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.

and 2006 and larger than observed in 2004. Most animals marketed were 2.75″ to 4.25″ in length and there was little difference between beds (Table 18). Catch approximated a knife-edge process with few oysters marketed below 2.5″ (Figure 38). Little difference was found in the size frequency of landings between originating beds.

Conversion of oysters to bushels for allocation projections used the value of 259 oysters/bu, the average of the four years 2004-2007 (Table 18). 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 15,182 bushels in 2007 to Nantuxent Point and a tongers bed from Middle, with 84% going to Nantuxent Point. Cullers were used, so this transplant should have been enriched in larger animals. The observed value of 252 oysters per bushel suggests that oysters were concentrated during this transplant as the average oysters per bushel in the survey, for Middle, was 68. The net of all fishing and transplant activities was that most oysters taken to market ultimately were debited from the high-mortality beds and Shell Rock (Figures 39 and 40). The low-mortality beds were closed in 2007. The 2006 management plan was to distribute landings among the major bed regions downbay of Arnolds. That goal was accomplished.

Real fishing mortality was 1.3% of total abundance in 2007, whereas apparent fishing mortality was 1.5%. Fishing mortality has been below 2% every year since 1996 (Figure 41). In 2007, fishing mortality was at the 29^{th} percentile of the 55-yr time series excluding closure years, and at the 71^{st} percentile of years post-1995 (Table 5). This high level suggests that the quota setting process in 2007 was not conservative. Fishing mortality rate, by SSB, was 2.5% in 2007 (Figure 42). Fishing removed 2.8% of the animals $\geq 2.5''$ in 2007 (Figure 43). This is the lowest value in the 1996-2007 time series. This trend occurred due to management by numbers-based exploitation rates and the relatively large fraction of the total stock in the marketable size classes in 2007.

By bay section, fishing and management activities removed 0%, 2.2%, 9.5%, and 1.1% of the animals from the low-mortality beds, medium-mortality beds, Shell Rock, and the high-mortality beds, respectively. The values for the high-mortality and medium-mortality beds include intermediate transplant removals and direct harvest. With the exception of the high-mortality beds, these values are representative of the 1996-2007 time series. The high-mortality-bed value is exceeded only thrice in that time series. The percentile position for 2007 for the medium-mortality beds, Shell Rock, and the high-mortality beds exceeded the 50^{th} percentile for the 1953-2007 time series and equaled or exceeded this percentile for the post-1995 period. The fishing rate on the high-mortality beds reached the 77^{th} percentile for the 1996-2007 time series (Table 5).

Management Advice

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. Target and threshold values for SSB and abundance were recalculated in 2007 based on updated numbers for the period 1990-2005. This was required due to re-survey of New Beds and the low-mortality beds (Table 19).

Surplus production is expected to be positive on the low-mortality beds for 2008. The low-mortality beds are well below the abundance target and just above the abundance threshold. Abundance fell relative to 2006 but is distinctly above the 2003-2005 period. The low-mortality beds are above the SSB target and SSB has been increasing for four years (Figure 44). Recruitment was high relative to adult abundance in 2007 and the number of spat was higher than in any year since 1999.

Surplus production is expected to be significant on the medium-mortality beds for 2008. The medium-mortality beds are well below the abundance target, but slightly above the abundance threshold. Abundance is similar to the 2003-2005 low abundance period, but fell significantly from 2006. SSB is well above the SSB threshold, but distinctly below the SSB target (Figure 44). SSB fell from 2006, but remains well above the nadir of 2003-2004. The number of spat recruiting to the medium-mortality beds was higher than any year since 2002. The number per adult was above 1 and the highest value since 1999.

Surplus production is expected to be considerably more positive on Shell Rock in 2008 than in 2007. Abundance on Shell Rock is well above the abundance target. Abundance has been rising for three years as a result of shell planting. SSB is nearly double the SSB target and has been rising for three years (Figure 44). Recruitment was the highest since 2002 and the number of spat per adult neared 2, a level not seen since 2002.

Surplus production is expected to be positive on the high-mortality beds in contrast to 2007. The high-mortality beds remain below the abundance threshold. Abundance is lower than in 2006, but above the 2003-2005 period. SSB is well above the SSB threshold, but distinctly below the SSB target (Figure 44). The number of spat recruiting is the highest value since 2000 and the number of spat per adult exceeded 2.

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 2007 stock status. The SARC considered two whole-stock abundance targets. The first is the sum of the area-specific abundance targets listed in Table 19. The second was derived more theoretically from an analysis of biological relationships and formulation of a surplus production model[♭]. The surplus production model used the 1953-2007 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 20)[II].

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

II 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 $\alpha = 0.4321$ and $\beta = 6,551.3$. A best-fit linear regression with zero intercept yields the relationship:

$$R_t = 0.49317\, N_{t-1}.$$

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 $\omega = 0.065$, $\kappa = 0.03$, $\rho = 0.75$, $\varphi = 0.0025$, $\chi = 0.06$, $\psi = 2.8$, and $\varrho = 1.$, with $\tilde{N}$ expressed as billions of animals. Surplus production S is calculated as the difference between additions

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 30), and the use of an adult mortality curve with an 'epizootic hump' of various amplitudes (Figure 32). Surplus production modelling suggests that the abundance values are relatively stable with respect to uncertainty in the survey time series, but that surplus production values associated with these abundances are not (Figure 45); thus, N_{msy} values can be obtained, but f_{msy} estimates cannot. Of the five simulations shown in Figure 45, 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 primary 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. Surplus production modelling suggests that the two stable states may be separated by a zone of negative surplus production, thereby generating a point-of-no-return; however, this inference remains uncertain.

The SARC discussed the use of reference points obtained from the stable-state surplus-production model in comparison to the reference points obtained from the stock-performance model. Two whole-stock reference points come from each model. For the stable-state surplus-production model, a target can be defined as the lower maximum in surplus production. The SARC did not identify a preferred simulation. For comparison to 2007 abundance, the median of the four best estimates of the N_{msy} for the low-abundance state will be used as a representative target value and a threshold set at half that value. Two additional reference points can be derived from the area-specific stock performance data for the 1989-2005 time period by summing the area-specific target values. The target is the sum of the median stock abundances for that period and the threshold is half that value (Table 19). The four respective values are: 1.628 billion, 0.814 billion, 2.503 billion, and 1.251 billion.

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.

Superposition of these four reference points on the set of surplus production trajectories obtained from the stable-point surplus-production model (Figure 45) leads to the following conclusions. The stock-performance target may be too high to be used as a rebuilding goal, because the value falls near the surplus production low between the two stable states and may, therefore, be difficult to achieve. On the other hand, the N_{msy} estimate, by falling at the surplus-production peak, assures that a Dermo epizootic will push the population to a lower state of surplus production and delay recovery. The SARC recommends that a stock rebuilding 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. The SARC did not establish a specific target number, but notes that the mean of the two target values, 2.065 billion, is a factor of 1.27 above the N_{msy} estimate and this factor falls within the range of abundance changes anticipated by a Dermo epizootic. Epizootic mortality rates normally fall between 20% and 30% of the stock.

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 1953-2007 time series. As a consequence, the stock dynamics at that abundance level are unknown. The SARC recommends 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.

Target abundances lie between 1.628 billion and 2.503 billion animals. The 2007 abundance is 1.32 billion animals. These targets can be compared to the survey point estimate by evaluating the uncertainty of the point estimate. In this case, 1,000 simulated surveys were conducted each with a selection of samples from each bed and each corrected for dredge efficiency by a randomly chosen value from all 2000-2003 efficiency estimates. The confidence-level values were obtained in two ways. First, the simulated surveys were sorted by the number of $\geq 2.5''$ oysters (Table 21). Second, the simulated surveys were sorted by the total number of oysters (Table 22). Dredge efficiency is less certain for oysters $<2.5''$, so that the latter approach comes with increased uncertainty that cannot be fully evaluated. On the other hand, the smaller size class is numerically important, so that the former approach sometimes fails to order surveys in a hierarchical position by total abundance.

The point estimate of 1.317 billion animals falls between the 50^{th} and 60^{th} percentiles of abundance regardless of the approach used. Regardless of the approach, both target values fall above the 90^{th} percentile of abundance. The favored threshold value is 1.251 billion. This threshold falls within the survey uncertainty of the 2007 point estimate. Thus, 2007 abundance is not significantly above the threshold. This suggests that the stock should be managed with precaution in 2008. However, the SARC notes several mitigating facts: (1) the high estimates of 2008 surplus production, (2) the relatively high recruitment rate in 2007, (3) the very high spat-to-adult ratio, and (4) the likelihood of additional shell planting in 2008. These facts suggest that the stock may respond robustly to the 2007 drop in abundance. On the other hand, a second epizootic year in 2008 will restrict stock recovery by reducing surplus production, as the stock is to the left of the surplus production maximum shown in Figure 45.

Summary of Stock Status and Population Management Goals

Figure 46 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 1989-2007 period (Table 5). This period is chosen because the advent of Dermo as a major influence on population dynamics began in 1989/1990 and evidence indicates a substantive change in population dynamics as a consequence. In particular, average mortality rates are up, the frequency of epizootics is up, the average abundance is down, and the average recruitment rate is down with respect to the 1953-1988 time period. These changes commenced in the first part of the 1990s when the fishery was closed in most years. Harvest was significant during the 1989-1996 period in only a single year, 1991.

In 2007, the stock presents a mixture of positive and negative indicators that approximately balance (Figure 46). Abundance is low and decreasing in three of four bay regions. Abundance is near historical highs on Shell Rock, however. Abundance continued to be below target levels in all bay regions but Shell Rock, and near or below threshold levels on the medium-mortality and high-mortality beds. Abundance was slightly above threshold levels on the low-mortality beds. The high recruitment in 2007 promises to increase abundance on these beds in 2008. The decline in abundance in 2007 is essentially completely explained by the poor 2006 recruitment followed by the 2007 Dermo epizootic that dropped abundance, particularly on the medium-mortality beds. The stock continues to be disproportionately consolidated on the medium-mortality and low-mortality beds, but less so than in some previous years.

Spawning stock biomass is relatively low bay-wide, but rose in 2007 on Shell Rock and the low-mortality beds, while decreasing in the remaining bay regions. SSB has increased steadily on Shell Rock over the last three years (Figure 44). SSB was well above the biomass threshold in all four bay regions and above the target in two.

The 2007 recruitment was extraordinary in all four bay regions. Spat-per-adult ratios exceeded 1.0 in three and reached a relatively high level of 0.8 on the low-mortality beds. The oyster population as a whole continues to be depauperate in the smaller size classes, but the 2007 recruitment event promises to correct this imbalance in 2008. In 2007, surplus production is expected to permit an increase in market-size abundance bay-wide and in all bay regions. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease rose to epizootic levels in 2007 and natural mortality rates were well above average on Shell Rock and the medium-mortality beds. A rising trend in Dermo disease weighted prevalence may presage continued high rates of natural mortality in 2008.

Fishery exploitation levels since 1989 have been low ($<2\%$ of abundance per year). Recent improvements in collection of fishery-dependent data indicate that exploitation in terms of biomass has been $\leq 3\%$ for most of that time. Low exploitation rates indicate that the fishery does not have a significant effect on the stock and that fishing mortality is not responsible for the current conditions of low abundance.

Overall, the conditions on the medium-mortality beds are less advantageous than other bay regions, whereas the conditions on Shell Rock are exemplary, after two years of shell planting to expand abundance. However, the fact that all but one bay region fell below their abundance targets indicates that actions to enhance abundance are needed in most bay regions. A reduction in fishing effort will not address this need because exploitation rates are already low; however, conditions are sufficiently poor on the medium-mortality beds to engender increased precaution in this regard. Substantial increases in exploitation rate should be avoided. The importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining biomass near or above target levels. Abundance has been enhanced on the high-mortality beds and Shell Rock by downbay transplant and this program should be continued. The preferred mechanism to address low abundance is to enhance recruitment. This program began in 2005 focused on Shell Rock and the high-mortality beds and has been successful. Additional emphasis on the high-mortality beds is desirable.

Cultch Management Goals

Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Most beds not receiving shell plants in 2006 suffered a loss of surficial shell, however the bay was nearer equilibrium than in years past and may have been in equilibrium. The high-mortality beds contributed most of the deficit in 2007. Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell. Shell plants, wherever feasible, should target areas where marketable oysters grow, where the probability of recruitment is high, and where cultch loss exceeds the addition of shell through natural mortality. Design of the 2008 program should consider the following recommendations.

1. The biggest deficits this year are on the high-mortality beds and this bed region is below the abundance threshold. Over the last decade, recruitment rates per adult on the high-mortality beds have been higher and more consistent than on beds farther upbay. Such beds as Bennies Sand, Nantuxent Point, Hog Shoal, Hawk's Nest, Beadons, and Strawberry might be considered as planting locales.

2. Downbay plants and replants are expensive and have shown unpredictable results. This activity should be scaled back in 2008, but not abandoned. Given the expense, replants should target bay regions where survivorship is high such as Ship John and Cohansey. This will also enhance expansion of the stock in a region where stock abundance has dropped to disturbingly-low levels and where recruitment has been less predictable than on beds downbay. Direct plants on these beds should be given lower priority due to the lower frequency of high recruitment events in this bay region.

3. The intermediate transplant program removes animals from the upbay beds. However, these beds routinely show lower probabilities of recruitment than beds further downbay, so that direct shell planting is unlikely to be an optimal approach to bed maintenance. An option is to plant spatted shell in this region. The SARC encourages the development of a program with community-level participation in this area, as selected grids can easily be closed for extended periods, without harm to the fishery.

4. Shell Rock abundance is near historical highs and, consequently, this bed should not be planted in 2007.

5. Planting should avoid Bennies and New Beds as evidence indicates that oysters in this region suffer proportionately higher Dermo mortality for a given disease level than the inshore beds.

2008 Management Goals

Fishery Exploitation Reference Points

Evidence indicates that the oyster stock varies in its population dynamics within bay regions and, as a consequence, 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. 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 SARC notes that these reference points, based on 1996-2006 data, should not be updated yearly, but retained until such time as a Term of Reference permits formal review based on new information.

The newly-formulated exploitation reference points are introduced 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. The exploitation indices for the upper group of medium-mortality beds (Middle+Upper Middle) were applied also to the low-mortality beds.

Exploitation rates can be calculated based on real removals and apparent removals. Real removals are defined as the net of the market catch, increased or debited by the removals and additions by intermediate transplant. Apparent removals are defined as the market catch plus removals by intermediate transplant. The two values are identical for beds upbay of Shell Rock because transplants to these beds have never occurred. In some cases, negative real exploitation rates appear in the time series for Shell Rock and the high-mortality beds because the number added by intermediate transplant exceeds the number removed. The alternative, use of the apparent exploitation rates, overestimates the inherent productivity of these beds, however, and would permit potentially unsustainable harvest levels without careful implementation of the intermediate transplant program. Use of the real exploitation rates 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.

Because the low-mortality beds and New Beds were re-surveyed this year, the values for the exploitation-based references points have been recalculated (Tables 23 and 24). The present implementation continues to be based on the 1996-2006 time series, however; a decision conforming with recommendations of the 9^{th} SAW.

The SARC recommends 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 recommends that the 40^{th}, 50^{th}, and 60^{th} percentiles normally be employed. Lower percentiles might be evaluated when abundance or SSB values are near threshold levels to enhance stock rebuilding. Higher percentiles might be employed in times of high surplus production or when abundance or biomass are over target levels; however, in this case, the SARC also notes that the employment of percentile harvests above the 60^{th} percentile reduces the likelihood of a consistent harvest over a period of years that would otherwise be permitted by the oyster's life span, particularly upbay of the high-mortality beds.

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[#]; 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 submarket-size and market-size animals while retaining upbay under a lower mortality regime the smaller animals that will grow into these larger size classes.

Abundance-based Exploitation Reference Point Projections – Direct Marketing

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

In 2007, the high-mortality beds continue to be at low abundance; however, biomass is well above threshold levels. The SARC notes that the high-mortality beds are toward the edge of the stock range, rather than near the center, and that the continuing high natural mortality rate limits the success of stock rebuilding on these beds. Thus, management that includes explicit rebuilding goals to a target level will rarely be successful, given the frequency of epizootic-level mortality in

[#] 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.

this bed region. As a consequence, the high-mortality beds should be managed under a somewhat more risk-prone manner than beds farther upbay. Given the high biomass, the record of relatively good recruitment, the 2007 recruitment level, and the expectation of intermediate transplant to these beds, the SARC considers that any fishing level inclusive of the 40^{th} to 60^{th} percentiles can be chosen for 2008. The SARC emphasizes, however, that a continuing decline in abundance, should 2008 mortality levels reach epizootic levels, will very likely require a more conservative approach in 2009, as abundance begins 2008 below the threshold level on these beds.

Due to the uniqueness of medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed independently of the high-mortality beds. This year, Shell Rock is above the abundance and biomass targets. Given the high biomass and abundance on Shell Rock, the SARC recommends that any fishing level inclusive of the 40^{th} to 60^{th} percentiles can be considered for 2008. The SARC considered higher exploitation rates on Shell Rock than the 60^{th} percentile due to the high abundance and biomass levels present. However, the SARC expressed concern about focusing exploitation at a higher-than-the-60^{th}-percentile level in a small area of the bay and notes that a better approach is to consider the oyster stock on this bed as a source of harvest over a number of years. Thus, the SARC recommends that 2008 exploitation levels not exceed the 60^{th} percentile number.

SAW-8 recommended that management should emphasize increased direct marketing on the lower group of medium-mortality beds to reduce the exploitation rate downbay. The SARC supports this recommendation that the three medium-mortality beds, Cohansey, Ship John, and Sea Breeze, continue to be managed as direct-market beds. These beds have contributed much of the stock supporting the fishery over the entire 55-year history of the survey, excepting the 1970s high-abundance period. Over the 1996-2005 direct-market period, these beds contributed a substantial fraction of the animals supporting the fishery, albeit indirectly through transplant to replace animals fished from the beds farther downbay. Beginning in 2005, these beds have contributed directly and significantly to the direct-market harvest. These beds represent the center of the stock and, as a consequence, must be managed with more precaution than beds farther downbay.

This year, abundance is near threshold levels, and biomass, while still high, is lower than 2006, because Dermo mortality was unusually high in this region in 2007. Abundance is now at one of the lowest levels observed in the 1989-2007 time series. However, high levels of surplus production are anticipated for 2008. The SARC notes, as it did in 2007, that the high surplus production rate originates from the growth of the last large cohort, recruited in the early 2000s, into market size and that these beds do not have substantial numbers of smaller animals supporting continued stock expansion in the future. Thus, the surplus production anticipated for 2008 should be viewed as the basis for fishery yield over a number of years. The 2007 recruitment event provides optimism that this bed region will respond with expanding abundance and a more balanced size-frequency distribution over the next few years; however, a number of years will be required for these animals to grow into market size and the likelihood of continued high Dermo mortality in 2008 is sobering. Thus, the continued precautionary management of this bed region is considered the best approach.

As a consequence of the importance of this bed region for the stock as a whole, the low abundance and unbalanced size-frequency distribution present, and the number of years required to permit resolution of these negative attributes should the 2007 recruitment adequately survive, the SARC recommends that the exploitation level not exceed the 50^{th} percentile on these beds in 2008. Furthermore, the SARC strongly advises that the 40^{th} percentile be given highest consideration.

Projections are provided in Table 25 for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze).

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant

The SARC strongly supports the inclusion of an intermediate-transplant program. The SARC recommends the same approach for the upper component of the medium-mortality beds (Upper Middle, Middle) as for the lower group, as previously described. That is, transplant should be limited to no higher than the 50^{th} percentile exploitation level.

The low-mortality beds are above the biomass target, but very near the abundance threshold. Growth rates are slow on these beds and recruitment has been sporadic at best. The 2007 recruitment was relatively high on these beds in comparison to previous years, but not nearly as high as observed downbay. The ability of these beds to recover from a decline in abundance is, therefore limited, despite the lower rate of natural mortality. However, surplus production is projected to be positive in this bed region in 2008. The SARC, therefore, recommends that this region be included in the intermediate transplant program in 2008, but that the 60^{th} percentile exploitation rate be avoided. Transplant should not exceed the 50^{th} percentile level.

The SARC discussed the inclusion of Hope Creek in the exploitation-rate projections. That portion of Hope Creek surveyed in 2007 contributes 35% of the stock on the low-mortality beds as reported herein. However, the full extent of the Hope Creek population is not yet known. Moreover, the degree of disease-resistance in this population is unclear. Thus, the SARC does not believe that sufficient information is available to provide guidance for management of the Hope Creek oysters in 2008. The SARC recommends that Hope Creek be excluded from intermediate transplant in 2008.

Projections are provided in Table 26 for the low-mortality beds exclusive of Hope Creek and the upper group of medium-mortality beds (Middle, Upper Middle).

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 made special note, however, of the need to conduct the remaining re-survey program, and to continue the Dermo monitoring program,

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

A spat settlement monitoring program should be continued.

A special survey of the Hope Creek region should occur in 2008 to provide improved survey design and stock estimates.

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

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

A program should be developed to permit yearly re-evaluation of grid allocation to strata to take into account changes in oyster distribution on beds as a consequence of natural population dynamics and population enhancement programs. A re-survey of Shell Rock or Bennies Sand should be used to verify the approach.

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

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

Conversions for improving the shell budget model should be obtained. These include the amount of cultch attached to live oysters and boxes and the conversion of cultch and shell-plant volume to weight.

Hope Creek oysters should be evaluated for disease resistance, particularly with regard to MSX.

Now that the beds have been re-surveyed, the distribution of old survey sites with high oyster catches should be evaluated to determine if bed configurations have changed since 1953.

A program monitoring oyster food supply should be initiated.

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

A size-dependent production model should be constructed to determine if that approach can be used to better estimate f_{msy}-style reference points.

Table 1. 2007 sampling scheme for the October survey of the Delaware Bay oyster beds. The numbers given are the number of samples devoted to that bed. Arrows indicate beds with the new configuration of strata based on the 2005, 2006, and 2007 re-surveys. For the remainder, either the pre-2005 sampling scheme was used or, for Hope Creek, an incomplete sampling was conducted.

Sampled Bed	High-quality	Medium-quality	Low-quality	Transplant
Hope Creek	3	3	0	0
→ Round Island	2	3	0	0
→ Upper Arnolds	2	3	0	0
→ Arnolds	3	3	0	0
→ Upper Middle	1	3	0	0
→ Cohansey	3	3	0	1
→ Ship John	3	4	0	4
→ Middle	2	3	0	1
→ Sea Breeze	3	2	0	0
→ Shell Rock	3	3	0	5
→ Bennies Sand	3	3	0	4
→ Bennies	3	9	0	0
→ New Beds	2	7	0	0
→ Nantuxent Point	3	3	0	4
→ Hog Shoal	3	3	0	0
→ Strawberry	1	3	0	0
→ Vexton	2	3	0	0
→ Beadons	3	4	0	0
→ Hawk's Nest	2	3	0	1
Egg Island	1	7	0	0
Ledge	0	0	0	0

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

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

[♯] 2003 and 2000 values are taken from: Powell, E.N., K.A. Ashton-Alcox, J.A. Dobarro, M. Cummings, and S.E. Banta. 2002. The inherent efficiency of oyster dredges in survey mode. *J. Shellfish Res.* 21:691-695 and Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter. 2007. Re-evaluation of eastern oyster dredge efficiency in survey mode: Application in stock assessment. *N. Am. J. Fish. Manage.* 27:492-511.

Table 3. Average annual bay-wide oyster and spat abundance per 37-qt. bushel for the 1989-2007 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean = average of annual values for 1989-2007.

Delaware Bay Seed Beds																					
Year	**1989**	**1992**	**1996**	**1991**	**2000**	**1993**	**1997**	**1990**	**1995**	**1999**	**2001**	**2003**	**2005**	**2007**	**2002**	**1998**	**1994**	**2006**	**2004**		**Mean**
Oysters	189	178	172	172	153	153	152	151	148	121	119	115	114	114	110	107	101	99	95		**133**
	a	a	a	a	a	a	a	a	a	a	a	a	a								
		b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b				
			c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c			
				d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d		
Year	**1991**	**1999**	**1997**	**1998**	**1995**	**1994**	**1990**	**2007**	**1989**	**2000**	**2002**	**1993**	**2005**	**2004**	**1992**	**1996**	**2003**	**2006**	**2001**		**Mean**
Spat	268	191	151	128	127	124	112	95	69	55	44	44	29	27	25	22	22	21	15		**80**
	a	a																			
		b	b	b	b	b	b														
			c	c	c	c	c	c	c	c											
				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		

Table 4. Results of the 2007 random sampling program for the Delaware Bay natural oyster beds. Included for comparison are data for 2005 and 2006. Data are displayed from the farthest upbay beds to those downbay. The column called 'Bushels/haul' to the left of the column headed 'Percent Oyster' indicates the average number of bushels brought up by the 3 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. Those samples that have over 40% oyster are underlined. 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. Note, for example, that the abundance changes noted for Shell Rock in this table do not include the enhanced abundance due to shell planting. Grids selected for non-random sampling, because of recent transplants or shell plants, are listed separately at the end of the table.

Table 4, page 1.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/ Haul	Percent Oyster			Oysters/Bushel			Spat/Bushel			Percent Mortality			Dermo Percent Prevalence			Dermo Weighted Prevalence			Size No./bu.>2.5 in.			Size %oysters>2.5 in.			Condition Index Dry Meat/Height		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
	--		-	-		-	-		-	-		-	-		-	-		-	-		-	-		-	--		-	-
Hope Creek	3.4	**66.8**	--	--																								
Hope Creek	8.5	**58**	--	--																								
Hope Creek	10.0	**55.4**	--	--	**346**	--	--	**122**	--	--	**5**	--	--	**0**	--	--	**0**	--	--	**86**	--	--	**25**	--	--	**0.01**	--	--
Hope Creek	9.5	**48.8**	--	--																								
Hope Creek	6.8	**31.8**	--	--																								
Hope Creek	0.1	**23.1**	--	--																								
Round Island	7.8	**55.4**	48.4	30																								
Round Island	5.0	**48.8**	44.4	22.6																								
Round Island	9.8	**30.1**	39.7	18	**213**	178	98	**86**	7	14	**7**	6	16	**25**	10	0	**0.35**	0.2	0.00	**99**	96	34	**46**	54	35	**0.011**	0.007	0.010
Round Island	0.4	**28.6**	27	16.9																								
Round Island	0.5	**18.6**	9.05	9.1																								
Round Island	--	--	0	4.2																								
Up. Arnolds	9.0	**61.1**	54	41.7																								
Up. Arnolds	4.3	**55.4**	23.5	32.5	**259**	51	300	**89**	0.2	61	**5**	15	13	**60**	10	0	**0.73**	0.2	0.00	**133**	26	57	**51**	51	19	**0.014**	0.008	0.011
Up. Arnolds	6.9	**53.5**	--	--																								
Up. Arnolds	5.6	**37.2**	--	--																								
Up. Arnolds	1.5	**9.61**	--	--																								
Arnolds	7.0	**54.6**	46.5	49.2																								
Arnolds	2.4	**54.5**	40.9	46.6																								
Arnolds	7.9	**50.4**	34.7	38.8	**216**	144	227	**113**	14	60	**6**	5	12	**60**	25	0	**1.18**	0.25	0.00	**97**	72	64	**45**	50	32	**0.014**	0.008	0.013
Arnolds	6.5	**45.7**	12.8	26.9																								
Arnolds	1.2	**32.6**	9.95	5.9																								
Arnolds	4.3	**0**	0	0																								

Table 4, page 2.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/ Haul	Percent Oyster			Oysters/Bushel			Spat/Bushel				Percent Mortality			Dermo Percent Prevalence			Dermo Weighted Prevalence			Size No./bu. >2.5 in.			Size %oysters >2.5 in.			Condition Index Dry Meat/Height		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005		**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
Up. Middle	3.2	**73**	7.14	0																									
Up. Middle	8.5	**44.9**	0	0	**197**	13	0	**92**	0	0	0	**16**	0	0	**75**	60	--	**1.68**	1.55	--	**128**	5	0	**65**	38	0	**0.014**	0.008	--
Up. Middle	3.8	**43.4**	--	--																									
Up. Middle	0.9	**26.8**	--	--																									
Middle	6.5	**38.6**	54.2	76.4																									
Middle	1.3	**25.7**	50.4	67.2																									
Middle	5.5	**24.5**	47.9	51.9	**85**	199	212	**46**	56	27		**23**	14	11	**89**	65	55	**2.82**	1.5	0.98	**43**	114	109	**50**	57	68	**0.014**	0.009	0.015
Middle	0.9	**24.3**	40.2	30.6																									
Middle	0.4	**0**	25	0																									
Cohansey	9.5	**60.9**	60.5	67.9																									
Cohansey	6.5	**56.8**	57.4	62.1																									
Cohansey	6.8	**46.1**	44.4	61.6																									
Cohansey	3.9	**44.1**	37.1	53	**139**	131	184	**237**	16	34		**22**	15	12	**95**	100	45	**2.48**	2.23	0.80	**67**	92	112	**48**	70	61	**0.014**	0.011	0.017
Cohansey	2.3	**29.8**	14.8	38.6																									
Cohansey	2.7	**24.7**	0	14.6																									
Ship John	6.0	**76.4**	63.9	79.3																									
Ship John	7.8	**66.7**	49.7	74.7																									
Ship John	6.3	**58.2**	49.6	68.1																									
Ship John	6.8	**57.3**	48.5	62.2	**161**	189	211	**202**	64	49		**19**	16	11	**100**	55	70	**2.23**	0.8	1.00	**68**	108	147	**42**	57	70	**0.015**	0.012	0.021
Ship John	8.5	**55.9**	40.4	52.5																									
Ship John	2.4	**14.9**	34.5	49.1																									
Ship John	0.8	**11.4**	20.9	37																									
Seabreeze	5.8	**50.1**	53.5	62.8																									
Seabreeze	3.6	**36.3**	42.8	50.5																									
Seabreeze	3.5	**25.4**	37.1	35.7	**62**	120	166	**47**	28	13		**28**	20	7	**100**	90	65	**3.48**	2.2	1.40	**36**	70	103	**58**	58	62	**0.017**	0.015	0.024
Seabreeze	2.8	**19.8**	27.5	33.3																									
Seabreeze	0.2	**0**	24.3	27.2																									

Table 4, page 3.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/ Haul	Percent Oyster			Oysters/Bushel			Spat/Bushel			Percent Mortality			Dermo Percent Prevalence			Dermo Weighted Prevalence			Size No./bu. >2.5 in.			Size %oysters >2.5 in.			Condition Index Dry Meat/Height		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
Shell Rock	7.8	**73.4**	68.8	69.4																								
Shell Rock	8.5	**67.8**	*59.4*	62.1																								
Shell Rock	8.0	**50.2**	*57.1*	59																								
Shell Rock	6.3	**47.1**	56.5	47.7																								
Shell Rock	3.5	**40.2**	*52.9*	47.1	**137**	213	173	**197**	52	47	**26**	19	11	**95**	100	94	**1.93**	3.28	2.09	**58**	95	86	**42**	45	62	**0.016**	0.014	0.020
Shell Rock	0.3	**9.56**	51.7	42.1																								
Shell Rock	--	--	47.3	9.93																								
Shell Rock	--	--	47.2	--																								
Shell Rock	--	--	46.8	--																								
Shell Rock	--	--	*46.6*	--																								
Shell Rock	--	--	46.4	--																								
Shell Rock	--	--	*44.1*	--																								
Bennies Sand	6.25	**47.4**	49.4	46.2																								
Bennies Sand	5.375	**24.2**	40.4	38.7																								
Bennies Sand	4	**23.7**	35.8	33.2	**87**	144	175	**20**	42	73	**28**	17	11	**95**	90	75	**3.3**	1.8	1.35	**36**	66	77	**41**	46	44	**0.021**	0.02	0.025
Bennies Sand	7.5	**22.2**	33.4	23.1																								
Bennies Sand	3.75	**21.4**	27.9	18.5																								
Bennies Sand	1.17	**13.6**	27.8	--																								
Bennies Sand	--	--	26.1	--																								
Bennies Sand	--	--	23	--																								
Bennies	4.3	**32**	61	34.5																								
Bennies	4.4	**27.7**	39.7	31																								
Bennies	1.3	**25**	35	24.8																								
Bennies	4.3	**23.6**	30.3	23																								
Bennies	1.8	**12.2**	27.2	18.5																								
Bennies	1.4	**12.1**	14.6	17.3																								
Bennies	3.4	**9.09**	13	16.8	**31**	86	46	**9**	17	17	**35**	16	15	**90**	100	67	**2.15**	2.55	1.45	**25**	37	25	**80**	43	55	**0.023**	0.02	0.031
Bennies	4.3	**8.9**	10.4	9.5																								
Bennies	6.5	**1.39**	10.1	6																								
Bennies	2.5	**1.19**	8.06	4.9																								
Bennies	10.0	**0.6**	6.3	4.8																								
Bennies	6.5	**0.26**	2.63	0																								

Table 4, page 4.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/Haul	Percent Oyster			Oysters/Bushel			Spat/Bushel			Percent Mortality			Dermo Percent Prevalence			Dermo Weighted Prevalence			Size No./bu.>2.5 in.			Size %oysters>2.5 in.			Condition Index Dry Meat/Height		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
Nantuxent Pt	4.3	**77.1**	46.4	47.1																								
Nantuxent Pt	11.0	**35.4**	41.8	32.4																								
Nantuxent Pt	8.0	**28.8**	39.7	18.9																								
Nantuxent Pt	6.6	**23.4**	37.9	7.5	**87**	122	95	**216**	26	37	**32**	31	25	**100**	95	95	**4.08**	2.6	2.75	**45**	65	39	**51**	53	47	**0.016**	0.017	0.023
Nantuxent Pt	6.5	**23.4**	32.5	4.2																								
Nantuxent Pt	4.0	**17.9**	16.2	0																								
Nantuxent Pt	--	--	1.87	--																								
HogShoal	9.5	**46.4**	28.6	34.7																								
HogShoal	10.0	**21**	26.7	27.3																								
HogShoal	7.0	**14.3**	24.4	20.1	**57**	61	66	**80**	14	22	**35**	28	28	**100**	95	90	**3.28**	2.97	2.77	**30**	34	28	**52**	56	43	**0.022**	0.018	0.022
HogShoal	8.5	**13.8**	21.3	20																								
HogShoal	8.5	**12.1**	10	10.1																								
HogShoal	5.0	**6.95**	7.25	5.3																								
New Beds	10.0	**37.1**	43.9	21.2																								
New Beds	9.5	**28**	17.1	18.3																								
New Beds	9.5	**25.4**	16.5	14.8																								
New Beds	10.0	**20.3**	12.7	12.5																								
New Beds	3.3	**15.3**	8.28	5.4	**48**	30	30	**23**	6	22	**36**	24	14	**100**	100	90	**2.68**	3.05	2.08	**31**	22	12	**65**	73	40	**0.029**	0.021	0.026
New Beds	9.5	**7.35**	1.8	4.5																								
New Beds	8.5	**5.26**	1.61	3.9																								
New Beds	5.8	**3.8**	0.86	1.9																								
New Beds	4.0	**0.24**	0	1.6																								
Strawberry	8.5	**9.88**	13.8	34.1																								
Strawberry	6.5	**3.11**	2.76	31.3																								
Strawberry	4.5	**1.41**	0.96	8.2	**7**	12	47	**14**	2	18	**53**	17	21	**95**	88	96	**3.13**	2.13	2.27	**6**	11	24	**77**	92	52	**0.023**	0.018	0.022
Strawberry	7.5	**0**	0	6.8																								
Strawberry	--	--	--	2.8																								
Strawberry	--	--	--	2.7																								

Table 4, page 5.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/Haul	Percent Oyster			Oysters/Bushel			Spat/Bushel			Percent Mortality			Dermo Percent Prevalence			Dermo Weighted Prevalence			Size No./bu. >2.5 in.			Size %oysters >2.5 in.			Condition Index Dry Meat/Height		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
Hawks Nest	6.5	**37.6**	53.9	48.3																								
Hawks Nest	10.0	**32**	35.8	14																								
Hawks Nest	9.5	**27.1**	27.5	6.8	**53**	101	59	**149**	24.4	22	**39**	26	10	**90**	100	100	**2.45**	2.63	2.53	**32**	58	17	**61**	57	39	**0.017**	0.018	0.025
Hawks Nest	7.0	**14.4**	17.2	5.2																								
Hawks Nest	8.8	**2**	11.6	1.9																								
Hawks Nest		--	6.97	0																								
Beadons	6.3	**43.8**	26.6	22.2																								
Beadons	5.0	**36.7**	17.4	20.8																								
Beadons	7.3	**21.1**	13.3	19.1																								
Beadons	3.9	**17.3**	7.79	18.4																								
Beadons	6.5	**2.55**	7.14	15.1	**43**	42	48	**97**	22	22	**18**	16	17	**70**	75	85	**1.33**	2.05	1.94	**15**	19	18	**36**	45	38	**0.016**	0.015	0.029
Beadons	3.0	**1.52**	5.41	4																								
Beadons	4.5	**0**	0.67	3.9																								
Beadons	--	--	--	3.4																								
Beadons	--	--	--	0																								
Vexton	7.3	**32.8**	15.1	29.5																								
Vexton	8.5	**15.9**	14.8	15.7																								
Vexton	5.0	**15.7**	13.4	12.8	**31**	14	24	**49**	9	9	**36**	22	30	**100**	90	80	**3**	2.25	1.05	**18**	12	17	**60**	86	70	**0.029**	0.022	0.031
Vexton	5.3	**8.52**	3.01	12.8																								
Vexton	5.8	**8.18**	0	12.3																								
Vexton	--	--	--	0.8																								
Vexton	--	--	--	0.3																								
Egg Island	6.0	**3.62**	--	60.1																								
Egg Island	7.0	**3.45**	--	8.3																								
Egg Island	9.8	**1.06**	--	2																								
Egg Island	10.0	**0.54**	--	1	**2**	--	10	**0.9**	--	0	**53**	--	17	**85**	--	75	**1.7**	--	1.65	**1**	--	8	**85**	--	79	**0.038**	--	0.030
Egg Island	6.5	**0.45**	--	0.4																								
Egg Island	7.3	**0.05**	--	0																								
Egg Island	6.2	**0**	--	0																								
Egg Island	7.3	**0**	--	0																								

Table 4, page 6.

Table 4. Delaware Bay Seed Bed data for 2007.

Bed	Bushels/ Haul	Percent Oyster			Oysters/Bushel			Spat/ Bushel			Percent Mortality		
		2007	2006	2005	**2007**	2006	2005	**2007**	2006	2005	**2007**	2006	2005
Transplants													
Middle		**50**			**189**			**426**			**21**		
Ship John		**62**			**287**			**480**			**20**		
Shell Rock		**71**	57	67	**161**	255	284	**335**	51	92	**27**	18	10
Nantxt Pt		**49**			**174**			**216**			**23**		
Nantxt Pt		**42**			**157**			**358**			**28**		
Nantxt Pt		**37**			**149**			**62**			**28**		
Nantxt Pt		**22**			**173**			**55**			**23**		
Shelling													
Cohansey		**53**			**196**			**388**			**22**		
Ship John		**55**			**211**			**182**			**20**		
Ship John		**34**			**246**			**141**			**21**		
Ship John		**29**			**169**			**63**			**22**		
Shell Rock		**79**	59	61	**232**	333	261	**653**	116	27	**25**	19	7
Shell Rock		**65**	47	59	**263**	216	276	**308**	62	147	**20**	22	11
Shell Rock		**62**	44	56	**208**	233	204	**394**	70	105	**23**	21	9
Shell Rock		**57**		37	**286**		180	**310**		80	**20**		10
Ben Sand		**66**			**211**			**29**			**21**		
Ben Sand		**58**			**154**			**412**			**18**		
Ben Sand		**49**			**111**			**36**			**21**		
Ben Sand		**37**			**195**			**36**			**21**		
Hawks Nest		**37**	54		**159**	230		**665**	61		**20**	29	

Table 5. 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.

	Abundance	Spawning Stock Biomass*	Recruitment	Spat to Adult Ratio	Box-count Mortality	Fishing Mortality⋆	Unexplained Mortality
Bay-wide: 1953-2007	.100		.464	.845	.791	.291	
Bay-wide: 1989-2007	.184	.344	.605	.868	.658	.708	
Low-mortality: 1953-2007	.118		.445	.773	.245	NA	.209
Low-mortality: 1989-2007	.237	.656	.763	.921	.184	NA	.184
Medium-mortality: 1953-2007	.155		.518	.827	.827	.546	.227
Medium-mortality: 1989-2007	.079	.219	.711	.868	.711	.500	.289
Shell Rock: 1953-2007	.555		.736	.827	.700	.602	.864
Shell Rock: 1989-2007	.711	.906	.868	.868	.605	.682	.921
High-mortality: 1953-2007	.136		.464	.809	.773	.639	.191
High-mortality: 1989-2007	.184	.344	.500	.816	.553	.773	.132

*SSB values used the 1990-2007 time series

⋆Fishing values used the 1996-2007 time series; NA, no fishing occurred in 2007.

Table 6. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality and high-mortality beds for the 1989-2007 time period. Values within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean = average of annual values for 1989-2007.

Medium Mortality Beds

Year	1997	2000	1996	1991	1989	2003	1992	1993	1990	2005	2001	1998	1999	2002	2006	2004	1995	2007	1994		Mean
Oysters	265	262	247	222	214	213	195	190	184	158	155	155	153	149	144	141	138	130	124		178*
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		

High Mortality Beds

Year	1996	1989	1995	1997	1992	1990	1991	1999	1998	2006	2000	2005	2001	1993	2007	1994	2003	2004	2002		Mean
Oysters	116	99	85	80	78	77	77	72	65	61	60	60	59	51	46	43	40	34	25		64*
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a			
		b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b		

Medium Mortality Beds

Year	1999	1991	1995	1998	1994	2007	1997	1990	2000	2002	1989	1993	2006	2004	2003	2005	1996	1992	2001		Mean
Spat	351	307	179	169	140	137	113	103	78	75	70	60	36	36	29	28	28	28	17		98
	a	a	a																		
			b	b	b																
					c	c	c	c	c	c	c	c	c	c	c	c	c	c	c		

High Mortality Beds

Year	1991	1997	1999	1994	1995	1998	1990	1989	2007	2000	1993	2004	2005	2002	2003	1992	2006	2001	1996		Mean
Spat	255	209	146	129	121	112	98	68	66	52	44	26	24	22	21	20	16	14	13		73
	a	a	a	a	a																
		b	b	b	b	b	b														
			c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c		

Table 7. Average 1-year growth increment for animals reaching market (3″) size, the average minimal size of animals reaching market size in one year, and ages-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 8. Surplus production as projected for 2007 by SAW-9 and as projected for 2008 for the oyster stock on the New Jersey natural oyster beds in Delaware Bay. Projections were conducted using the 50^{th} and 75^{th} percentiles of natural mortality and a conversion of 259 oysters bu^{-1}.

SAW-9 Surplus Production Estimate for 2007

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

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

Table 9. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Bay regions are defined in Figure 3. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

	Low Mortality	Medium Mortality	Shell Rock	High Mortality
1996	0.19	0.10	0.09	0.12
1997	0.21	0.62	0.92	3.06
1998	1.38	1.82	1.64	2.03
1999	0.65	2.14	4.04	4.54
2000	0.17	0.19	0.79	1.08
2001	0.06	0.08	0.22	0.44
2002	0.18	0.46	4.59	0.86
2003	0.07	0.16	0.38	1.28 (1.54)
2004	0.06	0.23	1.85	2.07
2005	0.32	0.20	0.46 (1.01)	0.54 (0.62)
2006	0.15	0.35	0.32 (0.64)	0.42 (1.00)
2007	0.80	1.46 (1.55)	1.97	2.33 (2.38)

Table 10. Summary of shell-planting activities for 2007. Shell-planting was carried out in late June-early July, 2007. Direct plants occurred on Ship John 48, 50, 55, Nantuxent Point 28, and Middle 34. Replants occurred on Middle 34, Ship John 53, and Cohansey 59. 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 1989-2007 time series: for the medium-mortality beds, 0.261, 0.141, 0.141, for years 1, 2, and 3, respectively; for the high-mortality beds: 0.601, 0.262. 0.262. Bushel conversions assume 259 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Projected Harvest
Ship John	48	Quahog mix*	59,229	4,086,801	69	8,402
Ship John	50	Quahog mix*	43,967	5,276,040	120	10,846
Ship John	22	Quahog mix*	39,032	17,213,112	441	35,387
Ship John	53	Quahog mix*	26,414	6,603,500	250	13,575
Nantuxent Point	28	Quahog mix*	43,360	7,848,160	181	5,775
Middle	34	Quahog mix*	43,800	16,381,200	374	33,677
Cohansey	59	Quahog mix*	19,881	417,501	21	858
Total			275,683	57,826,314		108,520

*Quahog mix = Quahog and surf clam processed to same small size

Table 11. Summary of shell-planting activities for 2006. Shell-planting was carried out in late June-early July, 2006. Six 25-acre grids received direct plants: Hawk's Nest 1, Nantuxent Point 25, Bennies Sand 7, and Shell Rock 20, 24, and 32. Two others were replants of shell planted off Reeds Beach and moved upbay in late August to Bennies Sand 6 and 12. 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 and the observed juvenile mortality rate for year 1. The mortality estimates used for years 2 and 3 were the 50^{th} percentiles of the 1989-2007 time series: for Shell Rock, 0.187; for the remainder: 0.262. Bushel conversions assume 259 oysters per bushel. Est, insufficient data; totals estimated from mean values of other grids.

Location		Type of Shell Planted	Bushels Planted	Yearlings Collected	Yearlings per Bu	Yearling Survival	Projected Harvest
Hawk's Nest	1	Surf Clam	17,850	3,194,729	179	.870	5,892
Nantuxent	25	Quahog mix*	49,488	5,813,969	118	.540	10,722
Bennies Sand	6	Surf Clam replant	14,811	5,757,345	389	.233	10,618
Bennies Sand	7	Quahog mix*	49,037	2,241,199	45	.081	3,069
Bennies Sand	12	Surf Clam replant	15,826	5,762,281	365	.132	4,133
Shell Rock	20	Quahog mix*	48,472	4,576,346	Est	Est	10,085
Shell Rock	24	Quahog mix*	53,193	3,557,297	Est	Est	8,811
Shell Rock	32	Quahog mix*	23,689	8,687,798	364	.800	21,072
Total			272,366	36,033,667			74,402

*Quahog mix = Quahog and surf clam processed to same small size

Table 12. Summary of 2007 recruitment on 2006 shell plants. Shell-planting was carried out in late June-early July, 2006. Six 25-acre grids received direct plants: Hawk's Nest 1, Nantuxent Point 25, Bennies Sand 7, and Shell Rock 20, 24, and 32. Two others were replants of shell planted off Reeds Beach and moved upbay in late August to Bennies Sand 6 and 12. Ocean quahog shell and surf-clam shell were used. Total spat estimated based on the assumption from 2007 observations that spat tend to recruit to larger particles preferentially collected by the dredge. The average of five estimates from 2007 for the correction factor is 0.625; that is, the dredge biases the estimate high by a factor of 1.6 based on total shell planted. 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 1989-2007 time series: for Shell Rock, 0.447, 0.187, 0.187 for years 1, 2, and 3, respectively; for the remainder: 0.601, 0.262, 0.262. Bushel conversions assume 259 oysters per bushel. Harvest estimates are provided for spat recruiting to clam shell only. Also provided are measures of spat per bushel on native oyster shell from the same grids on which the clam shell was planted.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat per Clam Bu	Spat per Native Oyster Bu	Clam Shell Projected Harvest
Hawk's Nest	1	Surf Clam	17,850	7,697,813	690	709	5,665
Nantuxent	25	Quahog mix*	49,488	12,650,370	409	304	9,309
Bennies Sand	6	Surf Clam replant	14,811	1,666,238	180	25	1,226
Bennies Sand	7	Quahog mix*	49,037	3,187,405	104	440	2,346
Bennies Sand	12	Surf Clam replant	15,826	2,670,638	270	23	1,966
Shell Rock	20	Quahog mix*	48,472	14,693,075	485	295	19,707
Shell Rock	24	Quahog mix*	53,193	17,586,936	529	608	23,589
Shell Rock	32	Quahog mix*	23,689	5,519,537	233	267	7,403
Total			272,366	65,672,012			71,211

*Quahog mix = Quahog and surf clam processed to same small size.

Table 13. Average half lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2007 time period.

Location	Half-life (yr)
Hope Creek	insufficient data
Round Island	insufficient data
Upper Arnolds	7.40
Arnolds	5.17
Upper Middle	insufficient data
Middle	6.26
Cohansey	12.12
Ship John	2.81
Sea Breeze	insufficient data
Shell Rock	9.49
Bennies Sand	7.90
Bennies	7.99
Nantuxent Point	3.31
Hog Shoal	6.39
Hawk's Nest	24.79
Strawberry	insufficient data
New Beds	insufficient data
Beadons	15.30
Vexton	10.04
Egg Island	insufficient data
Ledge	9.56

Table 14. The one-year transition probabilities for the broodstock-recruitment diagram shown as Figure 30 for each quadrant in the 55-year time series and mean first passage times. The medians are: abundance = 3.33×10^9, recruitment = 1.98×10^9. Quadrant definitions are in Figure 31. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.63	0.06	0.13	0.19
2→	0.40	0.30	0.10	0.20
3→	0.10	0.40	0.40	0.10
4→	0.06	0.12	0.18	0.65

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	3.31	6.87	7.13	5.72
2→	4.27	5.30	7.35	5.61
3→	5.70	3.79	5.30	6.36
4→	7.11	5.87	6.47	3.12

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.302	0.189	0.189	0.321

Mean First Passage Time (years): 1989-2007

Quadrant	1	2	3	4
1→	1.98	5.60	7.25	10.14
2→	2.71	3.88	6.50	12.86
3→	3.14	3.20	6.06	13.29
4→	3.71	1.00	7.50	13.86

Table 15. The one-year transition probabilities for the broodstock-mortality diagram shown as Figure 32 for each quadrant in the 55-year time series and the mean first passage times. The medians are: abundance = 3.33×10^9, mortality fraction= 0.13. Quadrant definitions are in Figure 31. 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→	0.43	0.36	0.00	0.21
3→	0.07	0.07	0.60	0.27
4→	0.17	0.33	0.33	0.17

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.69	3.71	7.12	4.14
2→	3.24	3.52	8.28	3.32
3→	6.42	6.02	3.61	3.91
4→	5.06	4.35	5.94	4.43

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.21	0.28	0.28	0.23

Mean First Passage Time (years): 1989-2007

Quadrant	1	2	3	4
1→	4.00	1.67	Un-est	3.00
2→	2.33	2.00	Un-est	4.00
3→	3.33	1.00	Un-est	5.00
4→	3.67	1.33	Un-est	4.00

Table 16. The one-year transition probabilities for the recruitment-mortality diagram shown as Figure 34 for each quadrant in the 55-year time series and the mean first passage times. The medians are: recruitment = 1.98×10^9, mortality fraction = 0.13. Quadrant definitions are in Figure 31. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.20	0.47	0.07	0.27
2→	0.33	0.33	0.08	0.25
3→	0.23	0.00	0.62	0.15
4→	0.29	0.14	0.21	0.36

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	3.83	3.68	8.73	4.12
2→	3.38	4.19	8.62	4.19
3→	4.07	7.02	4.15	5.07
4→	3.66	5.53	7.35	3.86

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.26	0.24	0.24	0.26

Table 17. Harvest statistics for 2007. 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	2,228,441	0	0	0
Round Island	1,910,960	0	0	0
Upper Arnolds	1,911,274	0	0	0
Arnolds	2,548,739	0	0	0
Upper Middle	956,159	0	0	0
Middle	3,719,585	0	0	0
Cohansey	5,314,243	2.16	19,947	24.55
Sea Breeze	2,338,640	0	0	0
Ship John	4,677,614	1.53	12,519	15.41
Shell Rock	5,742,042	2.15	18,042	22.21
Bennies Sand	2,977,796	1.92	10,306	12.69
Bennies	8,404,238	0.47	5,462	6.72
Nantuxent Point	2,765,542	2.23	6,289	7.74
New Beds	4,788,189	0.71	5,270	6.49
Hawk's Nest	2,021,560	0.81	2,436	3.00
Hog Shoal	1,808,455	0.38	950	1.17
Strawberry	1,808,668	0	0	0
Beadons	2,447,474	0.02	14	0.02
Vexton	2,022,090	0	0	0
Egg Island	4,045,293	0	0	0
Ledge	1,916,423	0	0	0
Total or Mean	64,765,314	0.79	81,235	100.00

Table 18. 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

Table 19. 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 time period. The threshold is taken as half these values.

	Low Mortality Beds	Medium Mortality Beds	Shell Rock	High Mortality Beds
Abundance:				
Target (50th Percentile)	846,948,736	1,069,557,440	113,350,896	473,125,088
Threshold (1/2 Target)	423,474,368	534,778,720	56,675,448	236,562,544
Spawning Stock Biomass:				
Target (50th Percentile)	232,141,616	478,714,304	62,450,392	267,982,768
Threshold (1/2 Target)	116,070,808	239,357,152	31,225,196	133,991,384

Table 20. 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	5% 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 30), predicted recruitment from each reduced by 5%, plotted adult mortality rate (Figure 32), median unrecorded mortality rate.

[2]Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 30), plotted adult mortality rate (Figure 32), median unrecorded mortality rate.

[3]Ricker recruitment curve (Figure 30), plotted adult mortality rate (Figure 32), median unrecorded mortality rate.

[4]Ricker recruitment curve (Figure 30), plotted adult mortality rate (Figure 32), mean unrecorded mortality rate.

[5]Ricker recruitment curve (Figure 30), average of background (10%) and plotted adult mortality rate (Figure 32), median unrecorded mortality rate.

Table 21. Confidence percentiles for the 2007-survey abundance point estimate with rank order based on the number of submarket and market animals.

Percentile	Oysters <2.5″	Oysters 2.5-<3″	Oysters >3″	Total Oysters
10.	705146240.	254663728.	208158064.	1167868032
20.	659574656.	243676096.	246171008.	1149421760
30.	722512064.	267775968.	242762448.	1233050480
40.	684598528.	284499520.	240546688.	1209644736
50.	712767552.	282813344.	256761680.	1252342576
60.	830309120.	308025152.	249181616.	1387515888
70.	708099968.	306563328.	269209952.	1283806648
80.	816188416.	323609568.	281218944.	1421016928
90.	909802816.	320737216.	317745184.	1548285216

Table 22. Confidence percentiles for the 2007-survey abundance point estimate with rank order based on the total number of animals.

Percentile	Oysters <2.5″	Oysters 2.5-<3″	Oysters >3″	Total Oysters
10.	694400384.	254466848.	183683552.	1132550784
20.	736971136.	268608224.	184936336.	1190515896
30.	699230272.	294856128.	233887776.	1227974176
40.	750864896.	279931072.	239934864.	1270730832
50.	794035968.	288778112.	218376816.	1301190896
60.	764795008.	298080992.	277936736.	1340812736
70.	830309120.	308025152.	249181616.	1387515888
80.	910796608.	294724320.	230656544.	1436177472
90.	879648384.	350627008.	264457968.	1494733360

Table 23. Percentiles of the real and apparent exploitation rates for oysters ≥2.5″ based on the fishing record for 1997-2006. 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	0.0433	1997	0.0433	2003	-0.1287	2002	0.0825
0.25	2005	0.0531	2005	0.0912	1999	0.0087	2004	0.0927
0.40	2000	0.0867	2003	0.0938	2002	0.0257	1999	0.1045
0.50	2003	0.0938	2006	0.1029	2000	0.0572	2005	0.1048
0.60	1998	0.1121	1998	0.1121	1998	0.0762	1997	0.1260
0.75	1999	0.1375	1999	0.1661	2005	0.1048	2000	0.1354
0.90	2001	0.2110	2001	0.2110	2001	0.1109	2003	0.1878

Table 24. 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 1997-2006. The upper medium-mortality bed group is Middle and Upper Middle. The lower medium-mortality 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 Upper Medium Mortality		All Oysters Lower Medium Mortality		Oysters $\geq 2.5''$ Lower Medium Mortality	
0.10	2001	0.0066	1998	0.0000	1997	0.0000	1997	0.0001
0.25	1997	0.0078	2001	0.0103	2001	0.0060	2001	0.0166
0.40	2002	0.0081	1999	0.0107	2000	0.0065	2000	0.0173
0.50	1999	0.0162	2005	0.0127	2002	0.0090	2002	0.0213
0.60	2000	0.0162	2006	0.0233	2003	0.0147	2003	0.0271
0.75	1998	0.0223	2004	0.0570	2006	0.0190	1999	0.0331
0.90	2003	0.0245	2003	0.0799	2004	0.0242	1998	0.0357

Table 25. Allocation projections for direct marketing for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze), based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index. An upper and lower bound are taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest). Projections use the average numbers per marketed bushel of 259 derived from the 2004-2007 dock-side monitoring program.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	40^{th}	.0257	2,578,320	9,952
	50^{th}	.0572	5,738,510	22,150
	60^{th}	.0762	7,644,660	29,507
Shell Rock	40^{th}	.0867	5,989,050	23,117
	50^{th}	.0938	6,479,510	25,010
	60^{th}	.1121	7,743,630	29,889
Lower Medium Mortality	40^{th}	.0173	3,516,010	13,571
	50^{th}	.0213	4,328,600	16,710
	60^{th}	.0271	5,507,740	21,259
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

Table 26. Projections for intermediate transplant assuming that intermediate transplant will be conducted on the upper medium-mortality beds (Middle, Upper Middle) and that direct-marketing will be conducted on beds downbay of these two beds. Numbers to be moved by intermediate transplant are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading by dry dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel for these beds obtained from the 2007 survey. If cullers are used, the number of bushels can be reduced by an estimated factor of 1.28. 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 259 animal/bu conversion. Percentiles for the low-mortality beds are taken as the average for the upper medium-mortality beds. Projections for the low-mortality beds exclude Hope Creek.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Lower Medium Mortality						NA§
Upper Medium Mortality	40^{th}	.0106	1,042,470	98	10,638	2,275
	50^{th}	.0127	1,249,000	98	12,744	2,677
	60^{th}	.0233	2,291,480	98	23,382	5,003
Low Mortality	40^{th}	.0106	3,058,211	164	18,647	4,583
	50^{th}	.0127	3,664,083	164	22,342	5,492
	60^{th}	.0233	6,722,300	164	40,990	10,076

§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 2007 random sampling sites are indicated by white stars. The survey of Hope Creek is incomplete; the depicted footprint is an underestimate of bed size and an incomplete rendition of bed shape. Ledge and Egg Island beds have not been re-surveyed. For the remaining beds, the depicted footprint is based on re-surveys that occurred in 2005-2007.

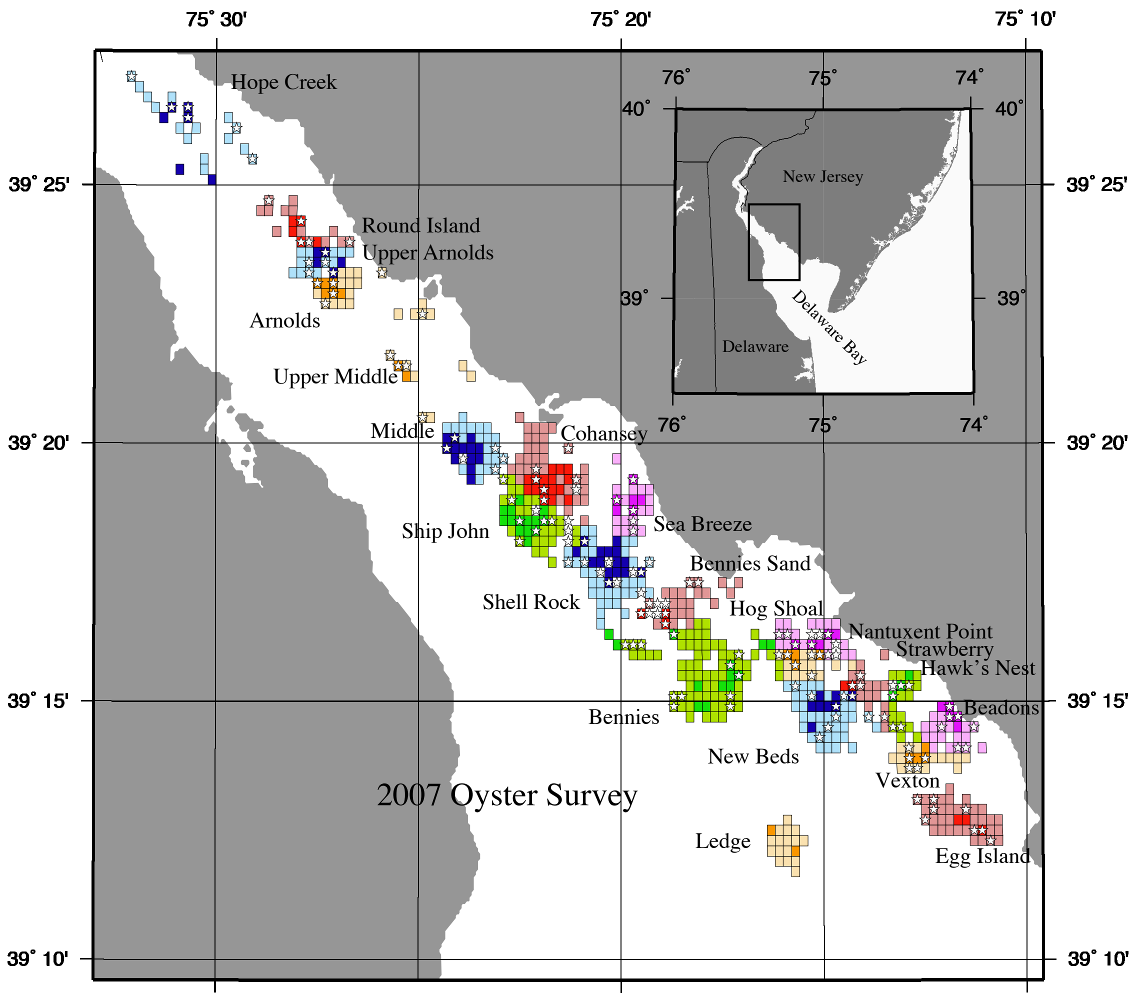

Figure 2. Example size-frequency distributions for spat recruiting to shell planted on Middle and Ship John in late June, 2007.

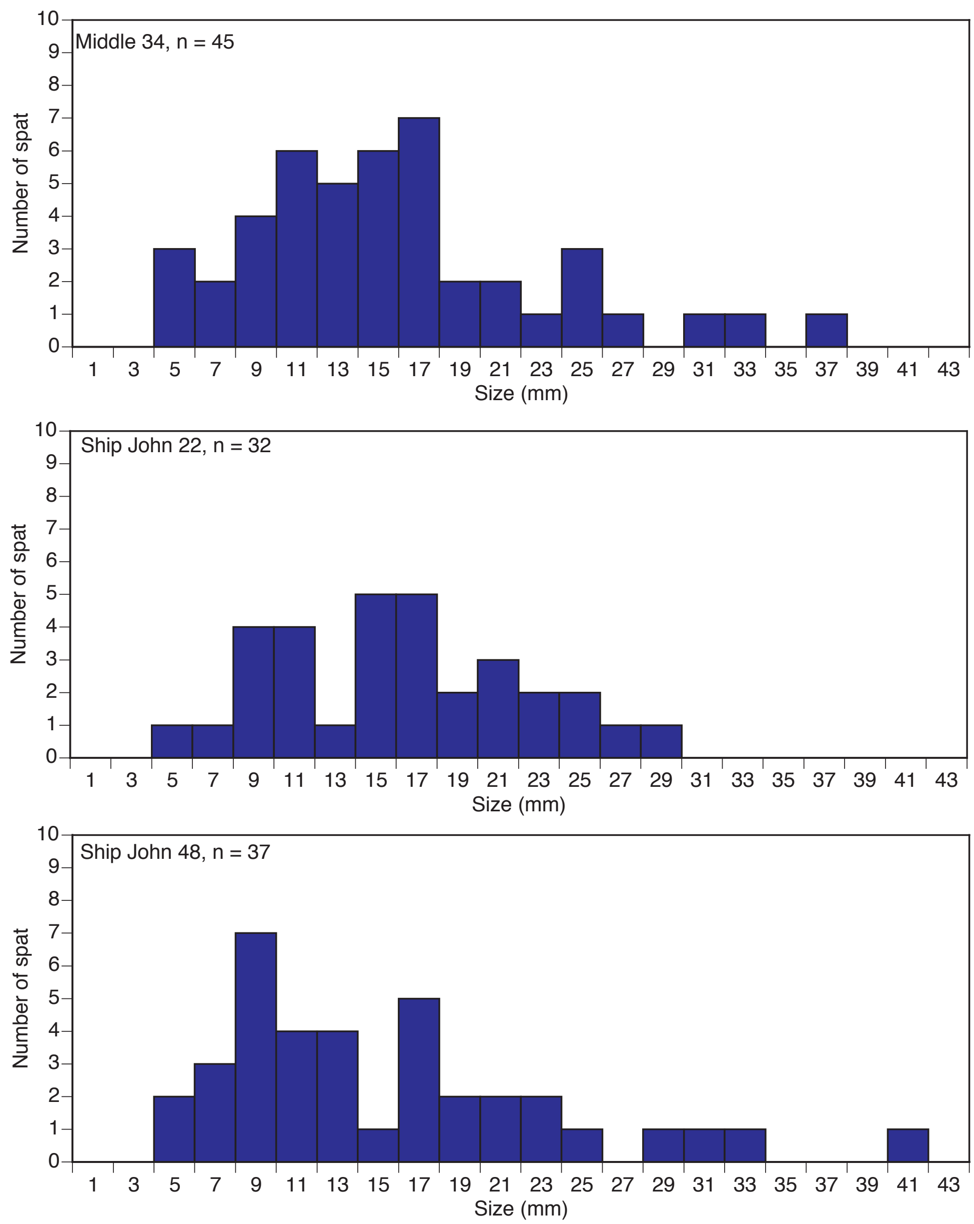

Figure 3. Time series of oyster abundance by bay region. High mortality: Beadons, Nantuxent Point, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Egg Island, Ledge, Bennies, Bennies Sand; medium mortality (less Shell Rock): Ship John, Cohansey, Sea Breeze, Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island, Hope Creek.

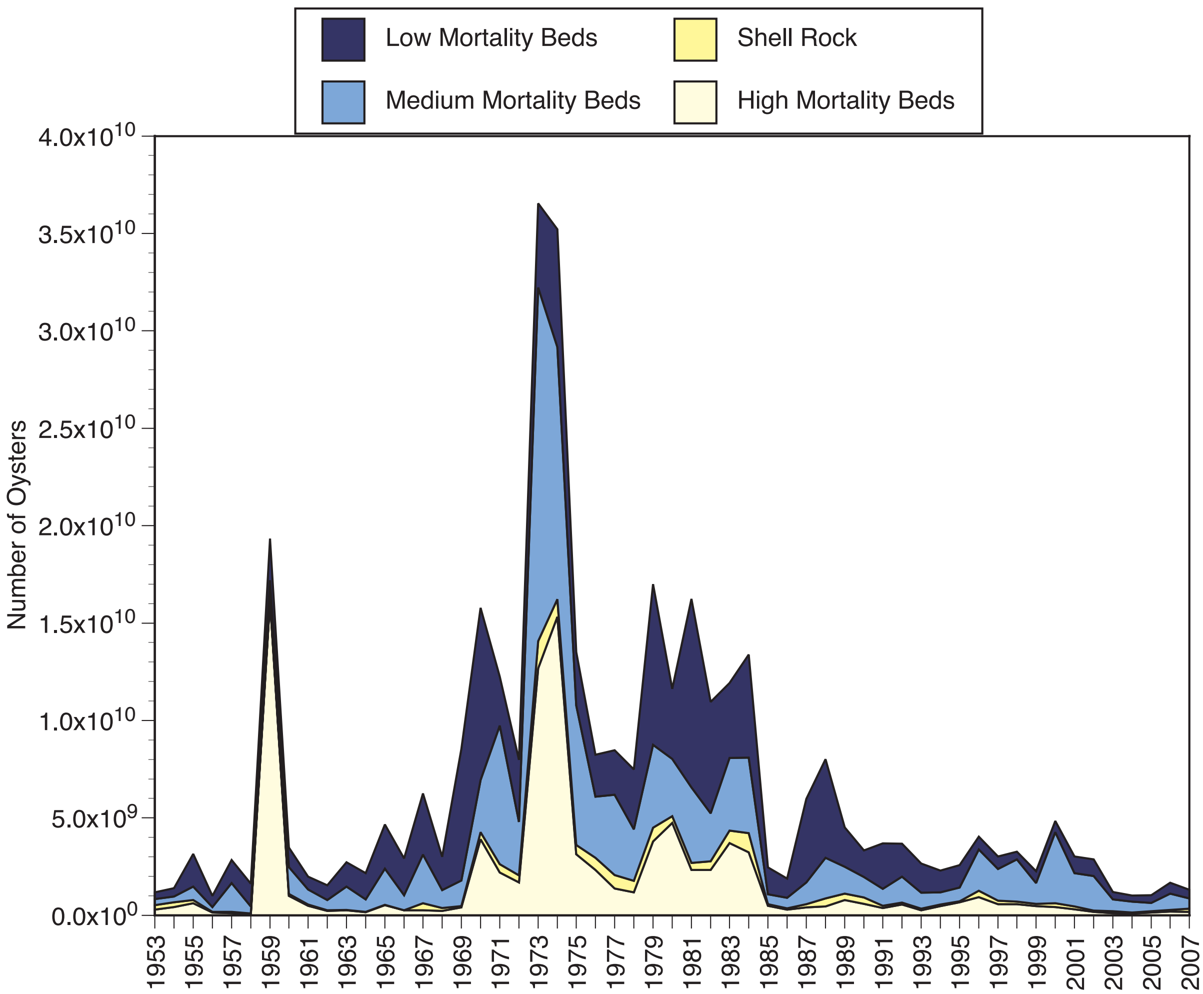

Figure 4. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2007. Bed regions are defined in Figure 3.

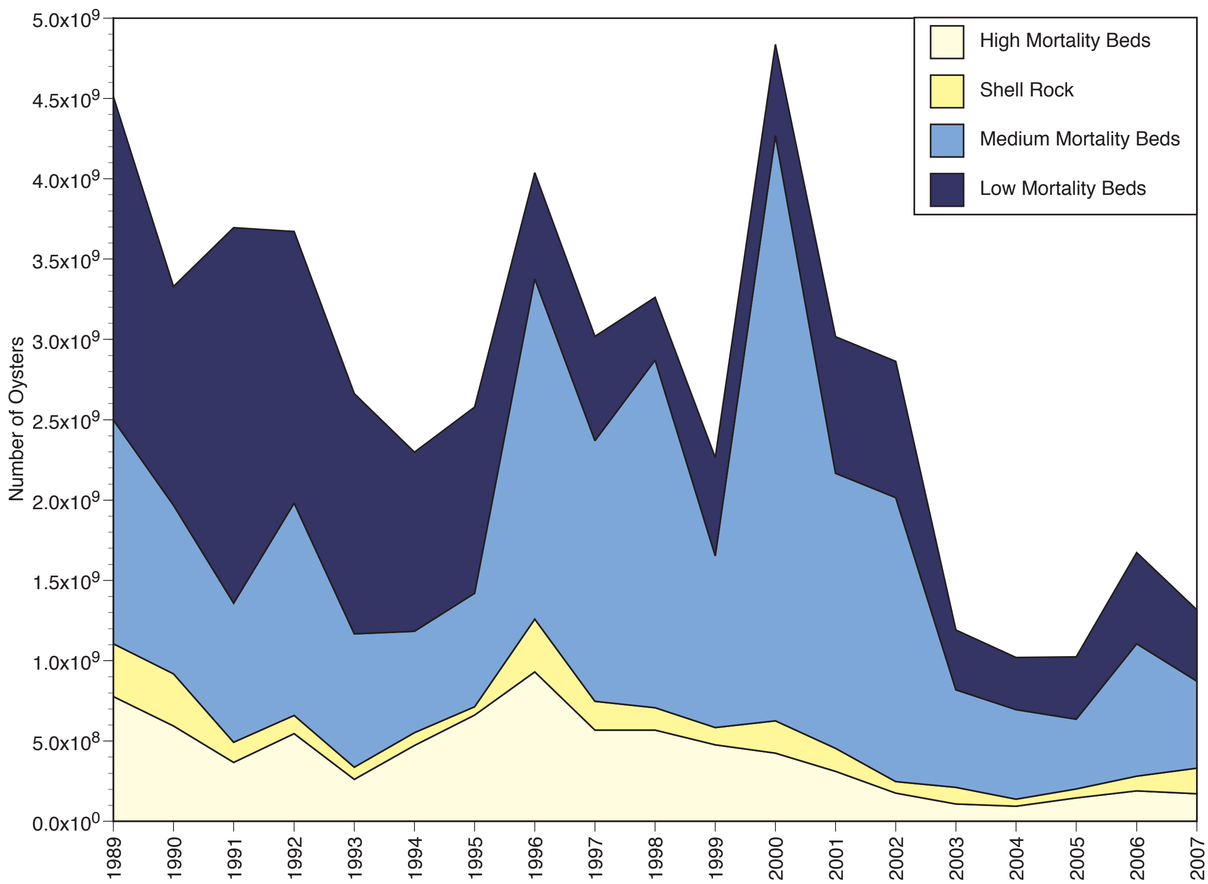

Figure 5. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 3.

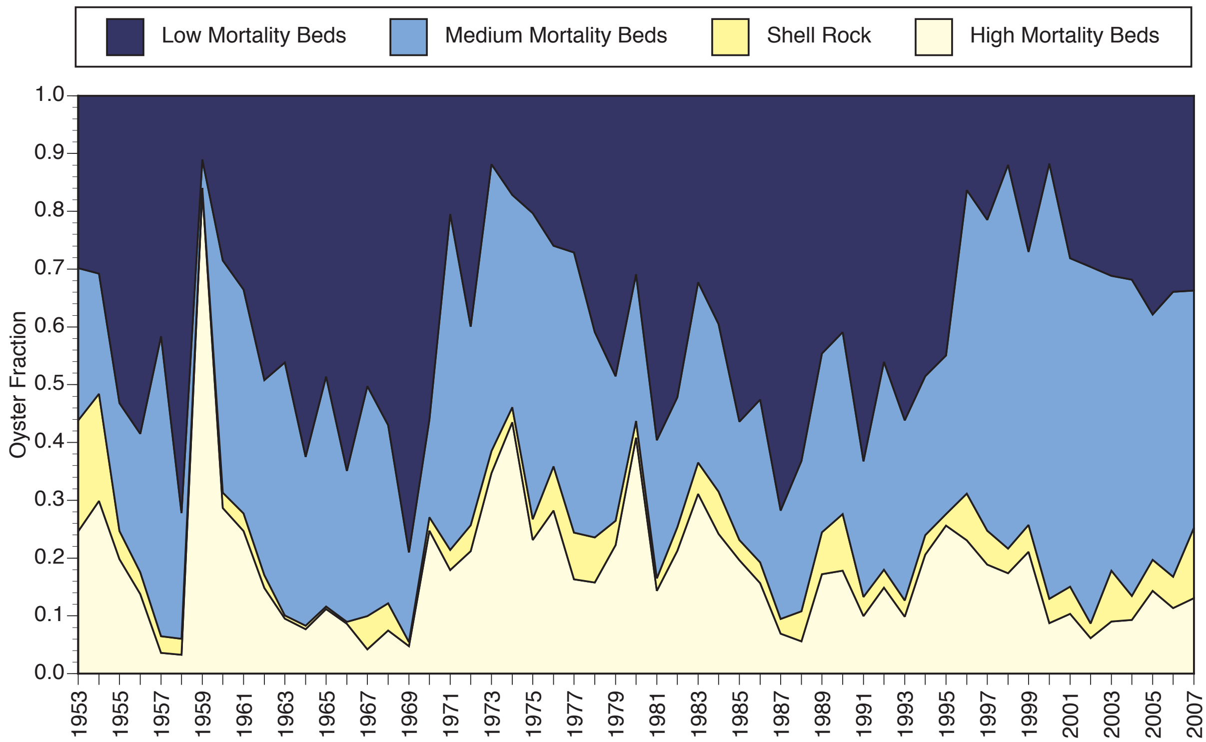

Figure 6. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 3.

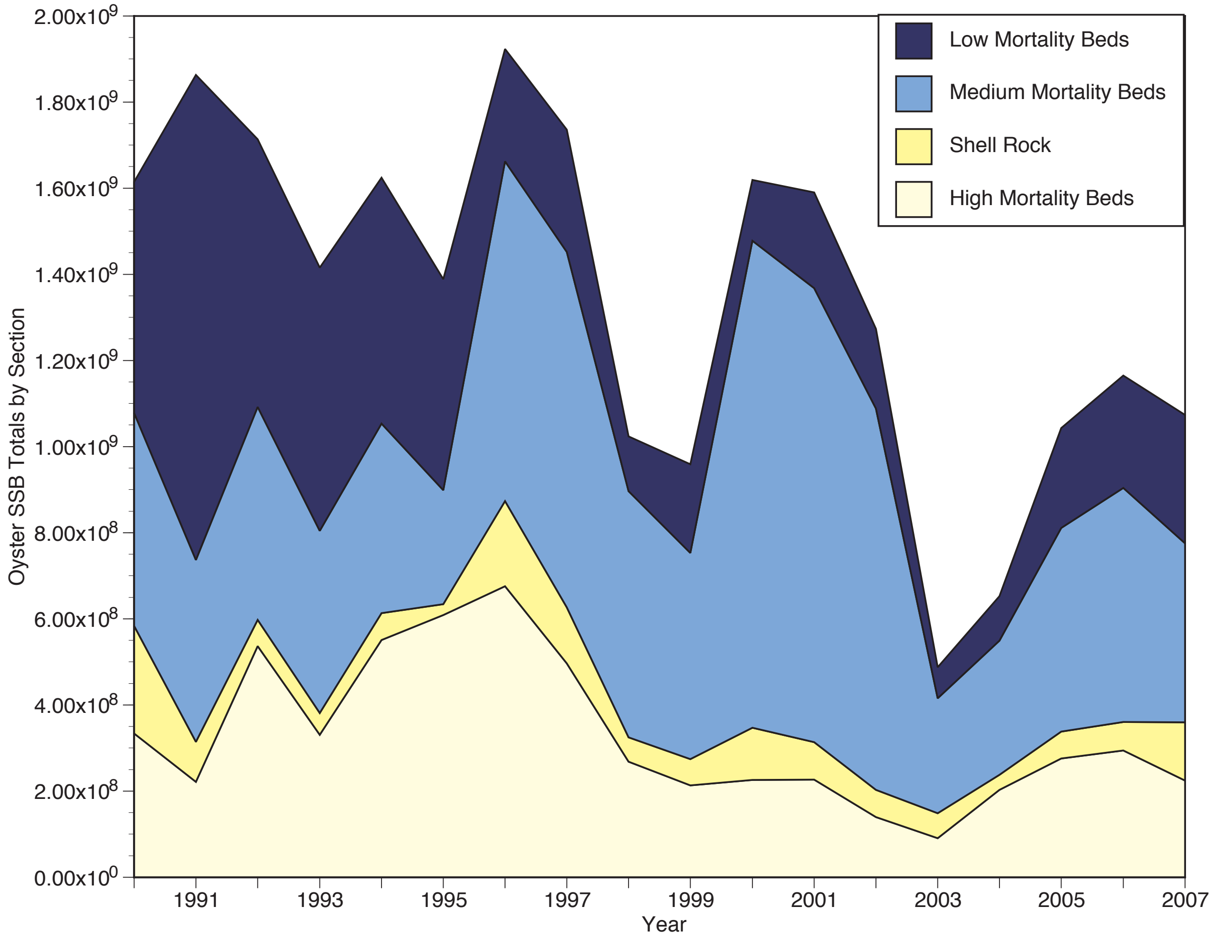

Figure 7. Time series of the fractional distribution of spawning stock biomass among the bay regions. Bed distributions by region are given in Figure 3.

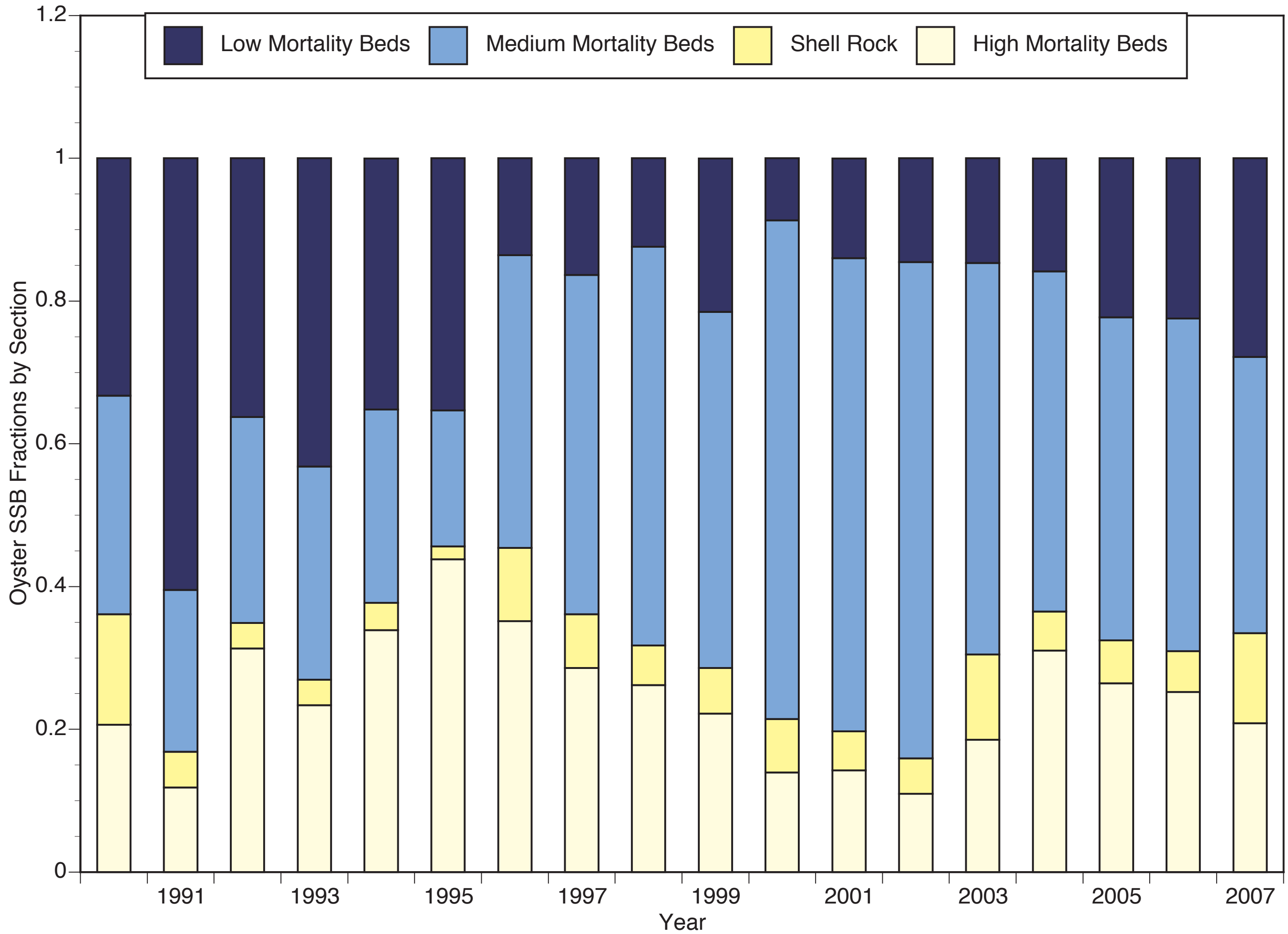

Figure 8. The abundance of small, submarket, and market-size animals since 1990.

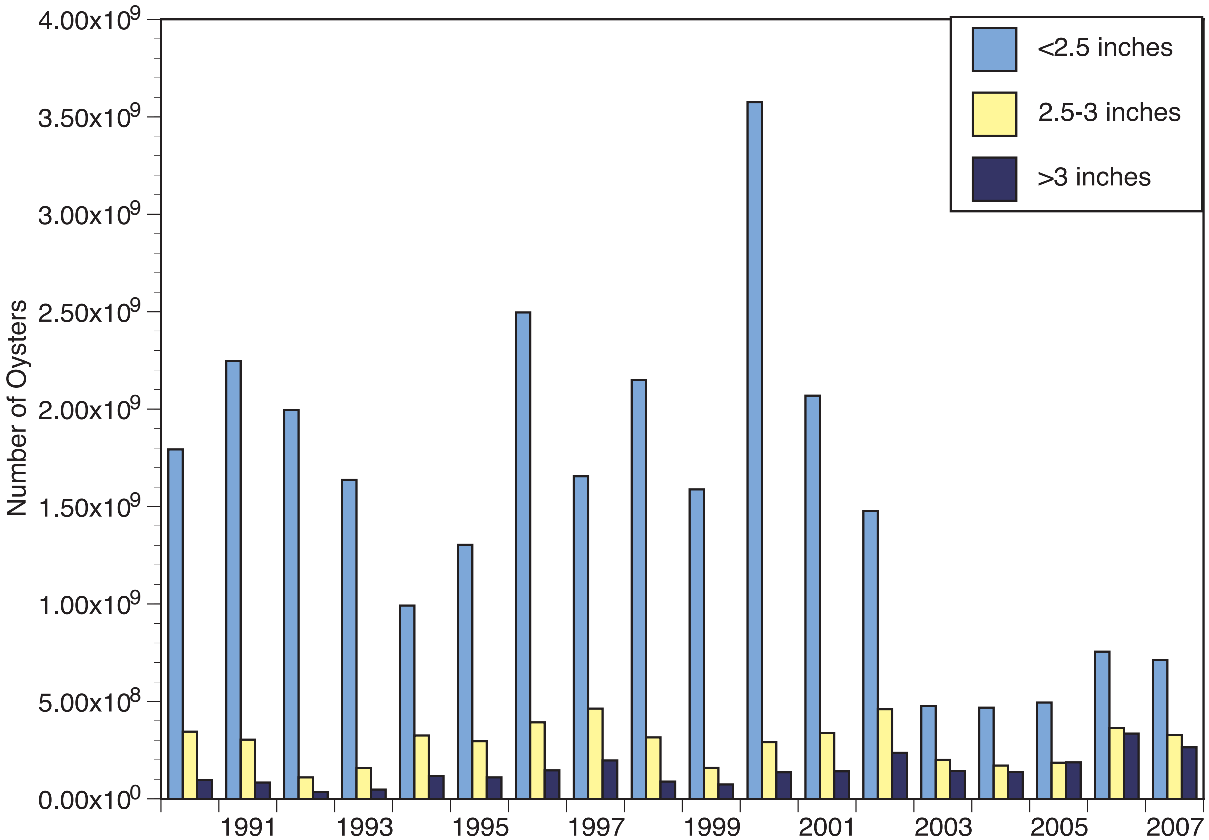

Figure 9. The fraction of small, submarket, and market-size animals since 1990.

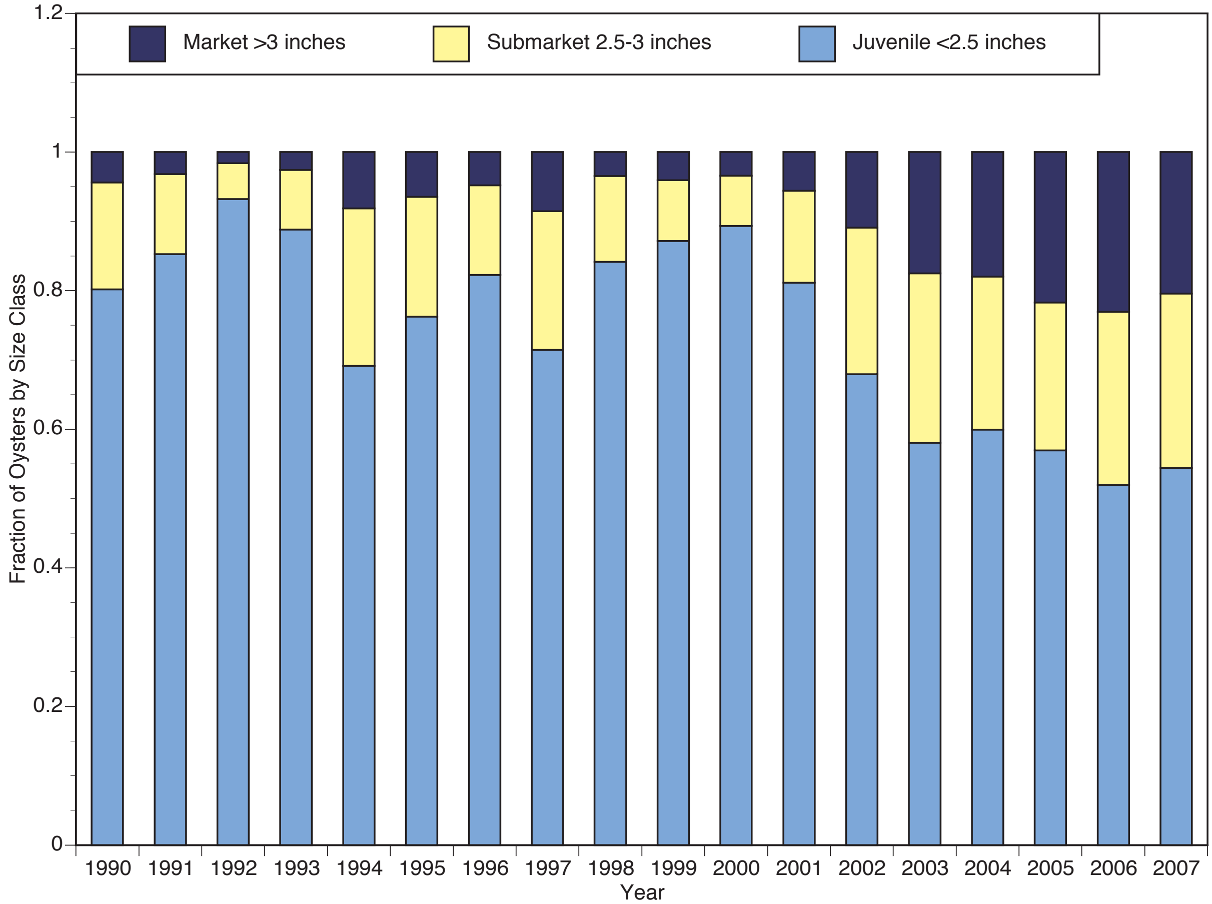

Figure 10. The abundance of small, submarket, and market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 3. Note variation in y-axis scale between graphs.

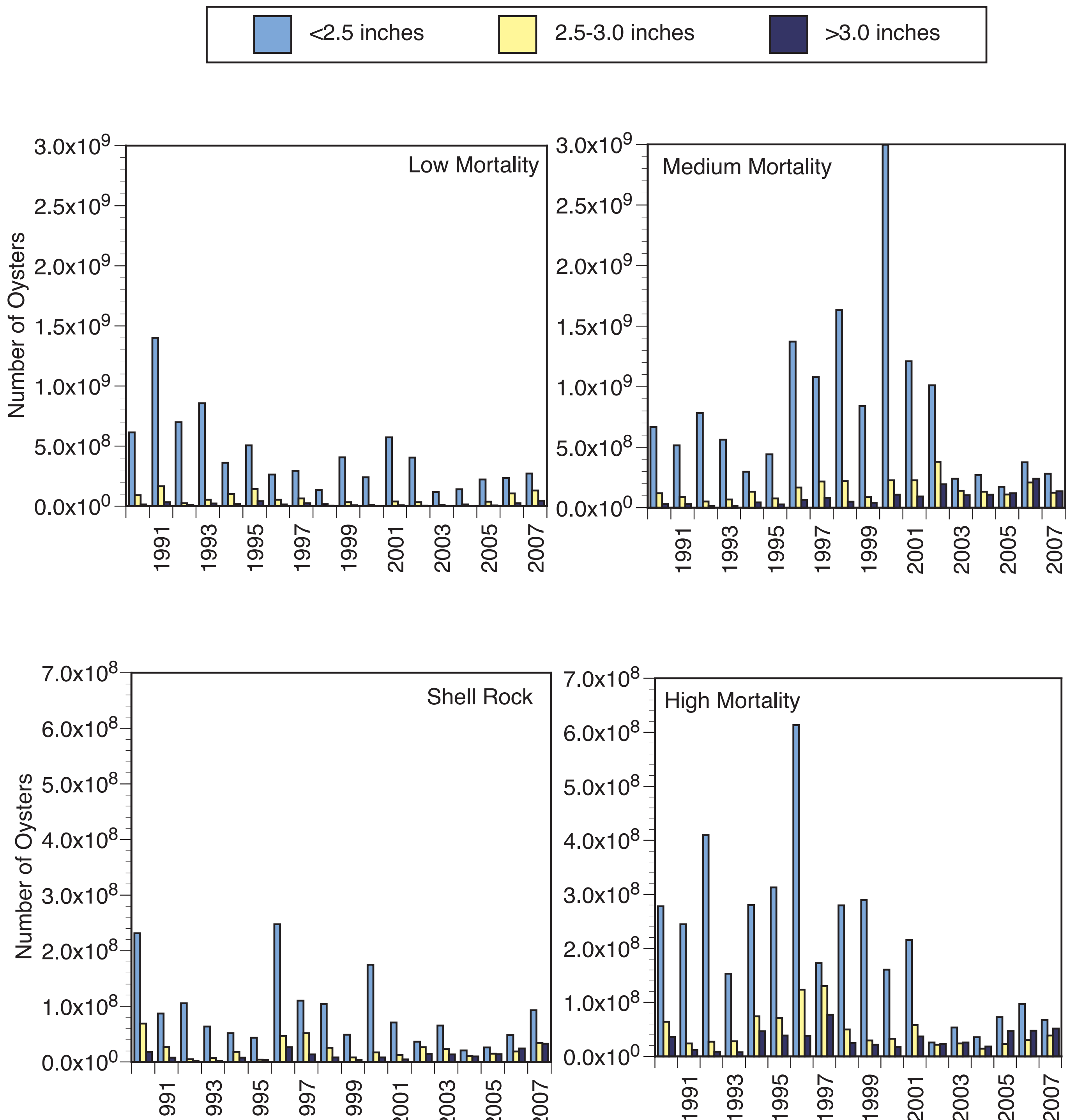

Figure 11. The fraction of marketable animals ≥2.5″ that were of market-size (≥3″).

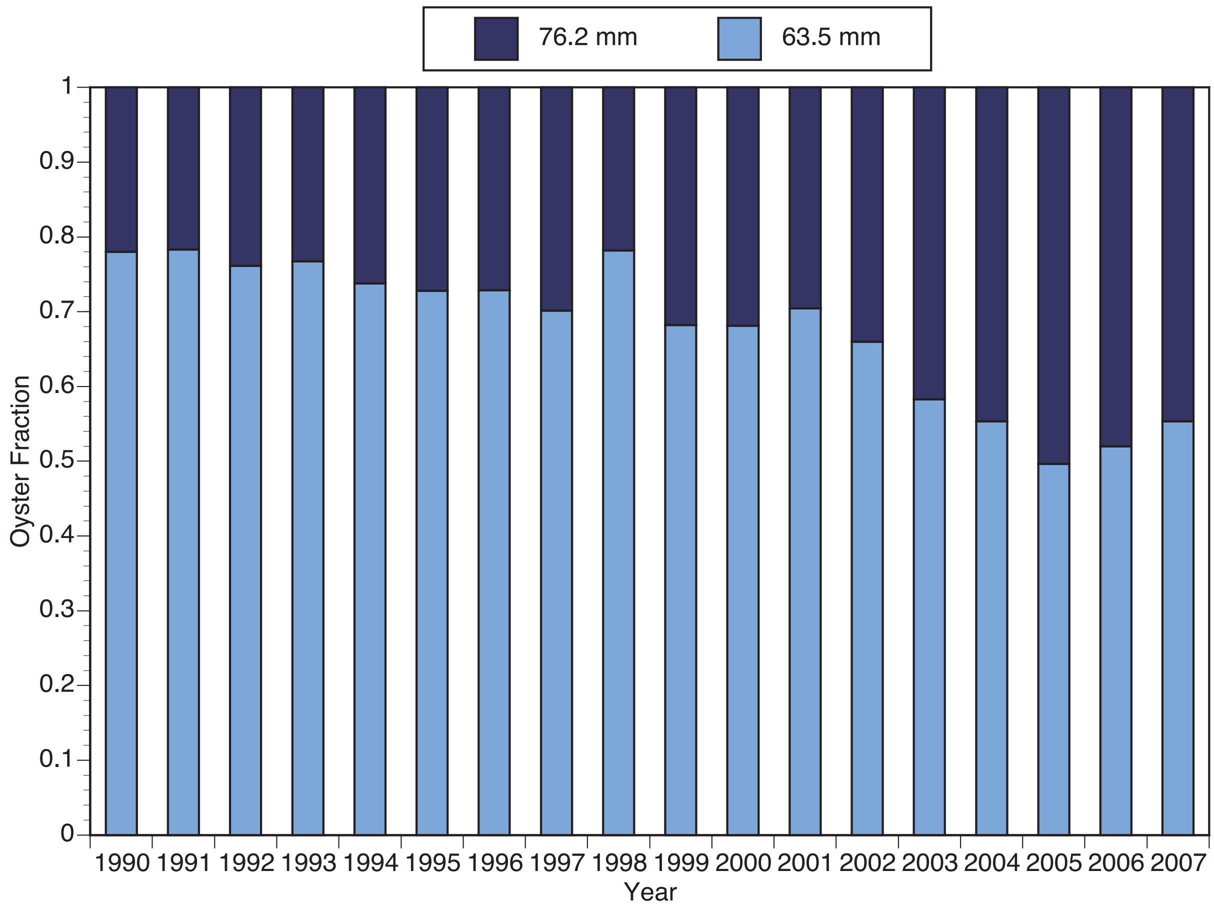

Figure 12. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)].

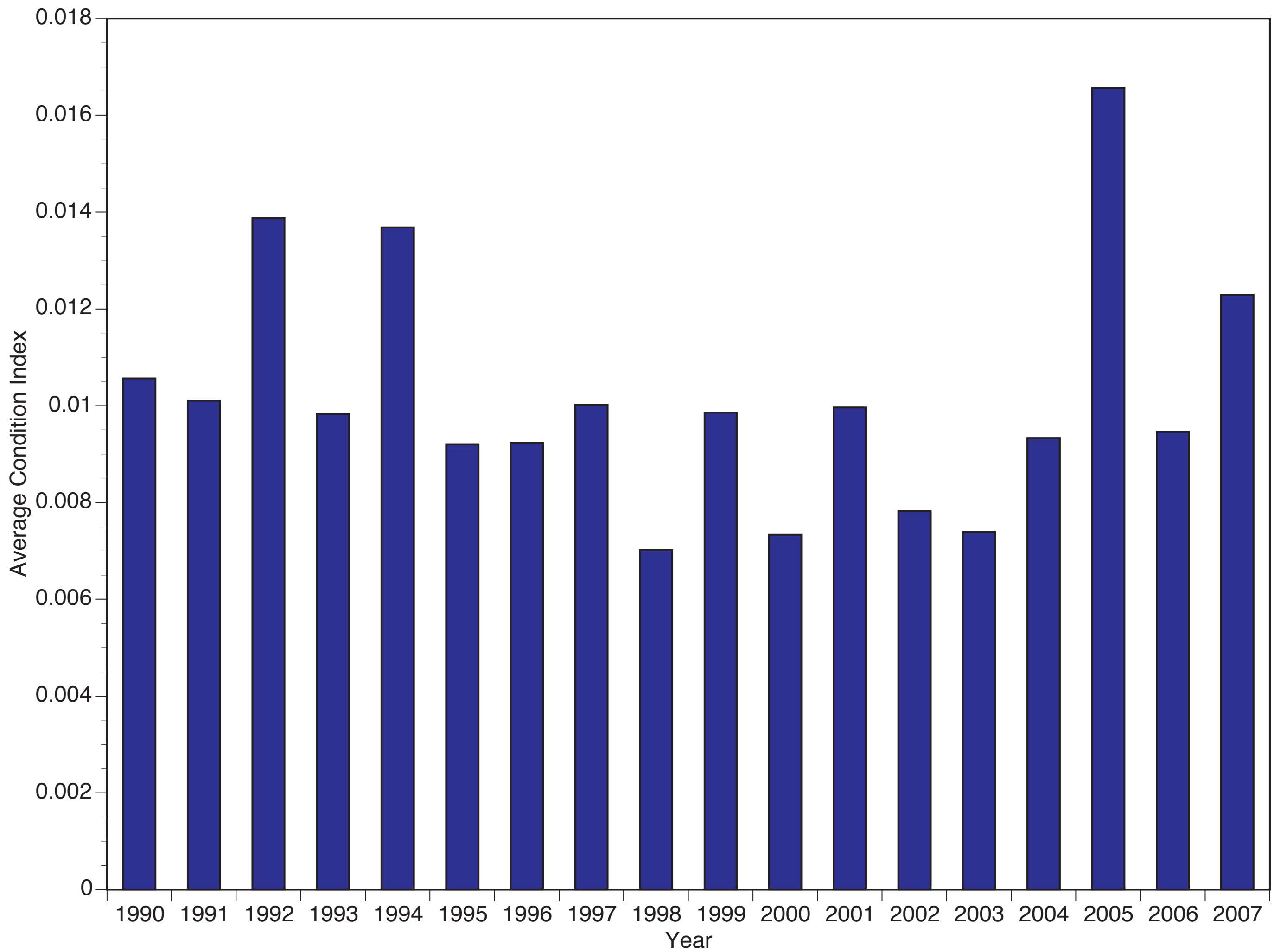

Figure 13. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)] by bay group. Bed distributions by region are given in Figure 3.

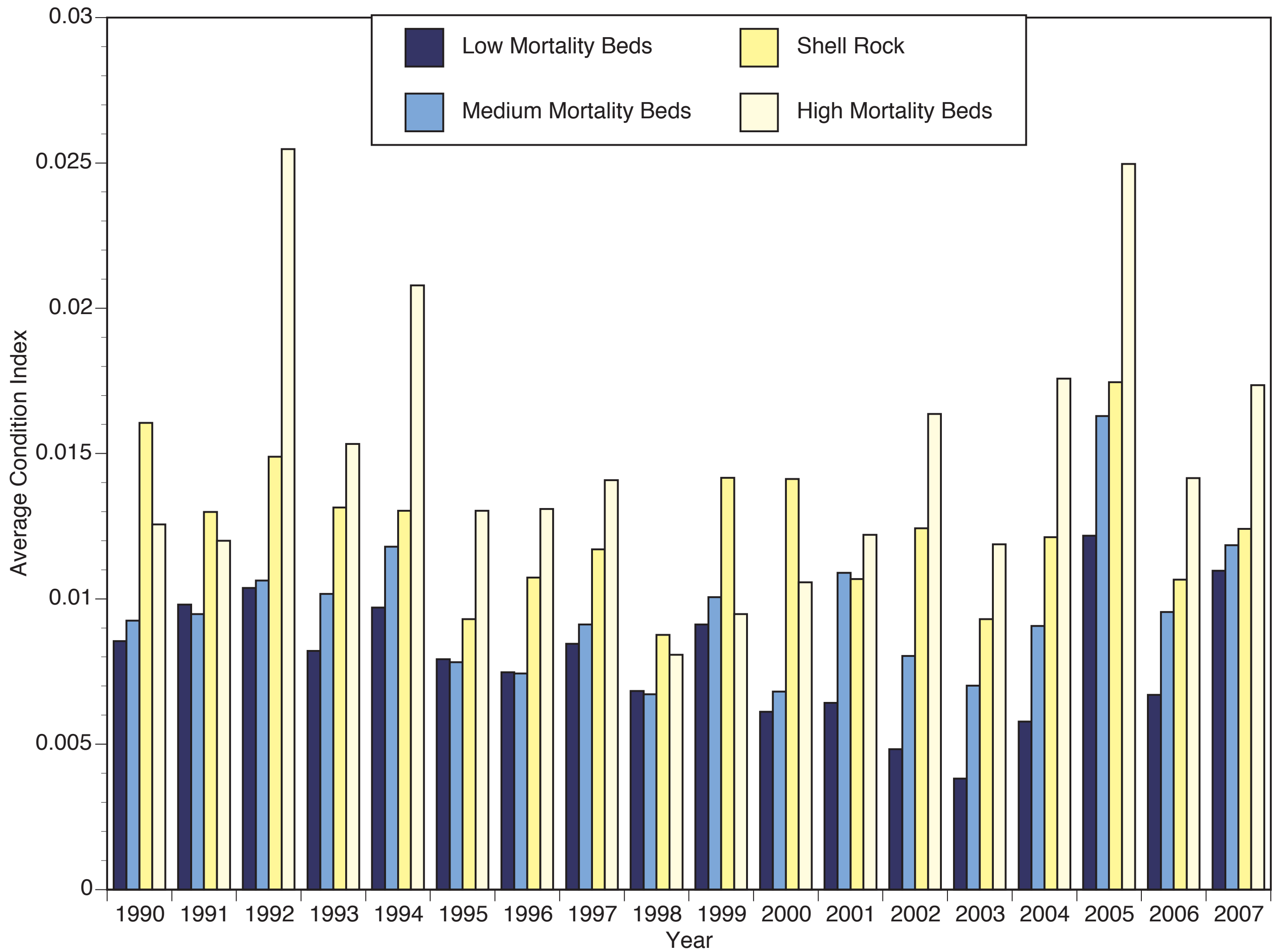

Figure 14. Number of spat recruiting per year for the 1953-2007 time series, cumulatively by bay region. Bay regions are defined in Figure 3.

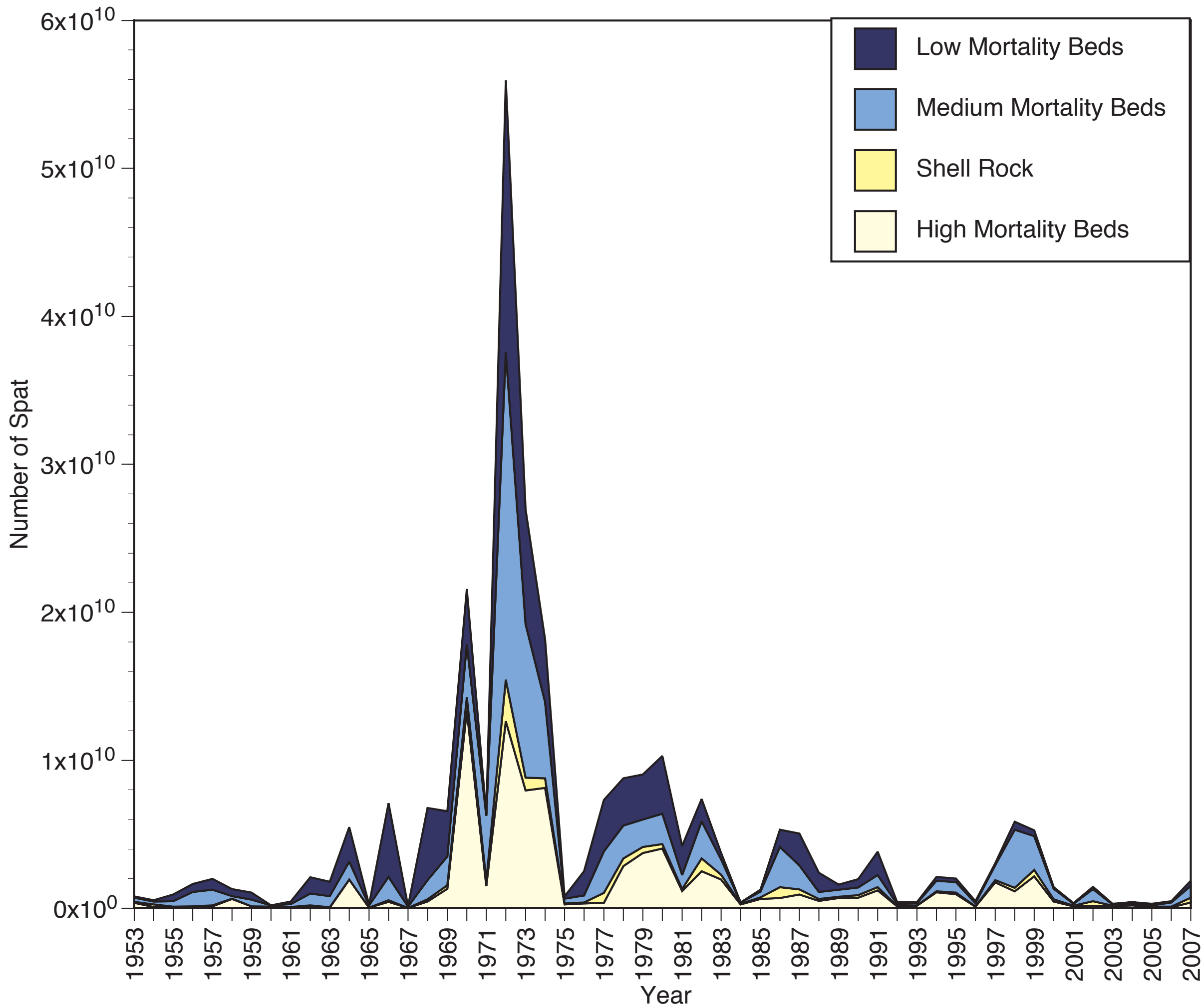

Figure 15. Number of spat recruiting per year for the 1989-2007 time series. Bay regions are defined in Figure 3.

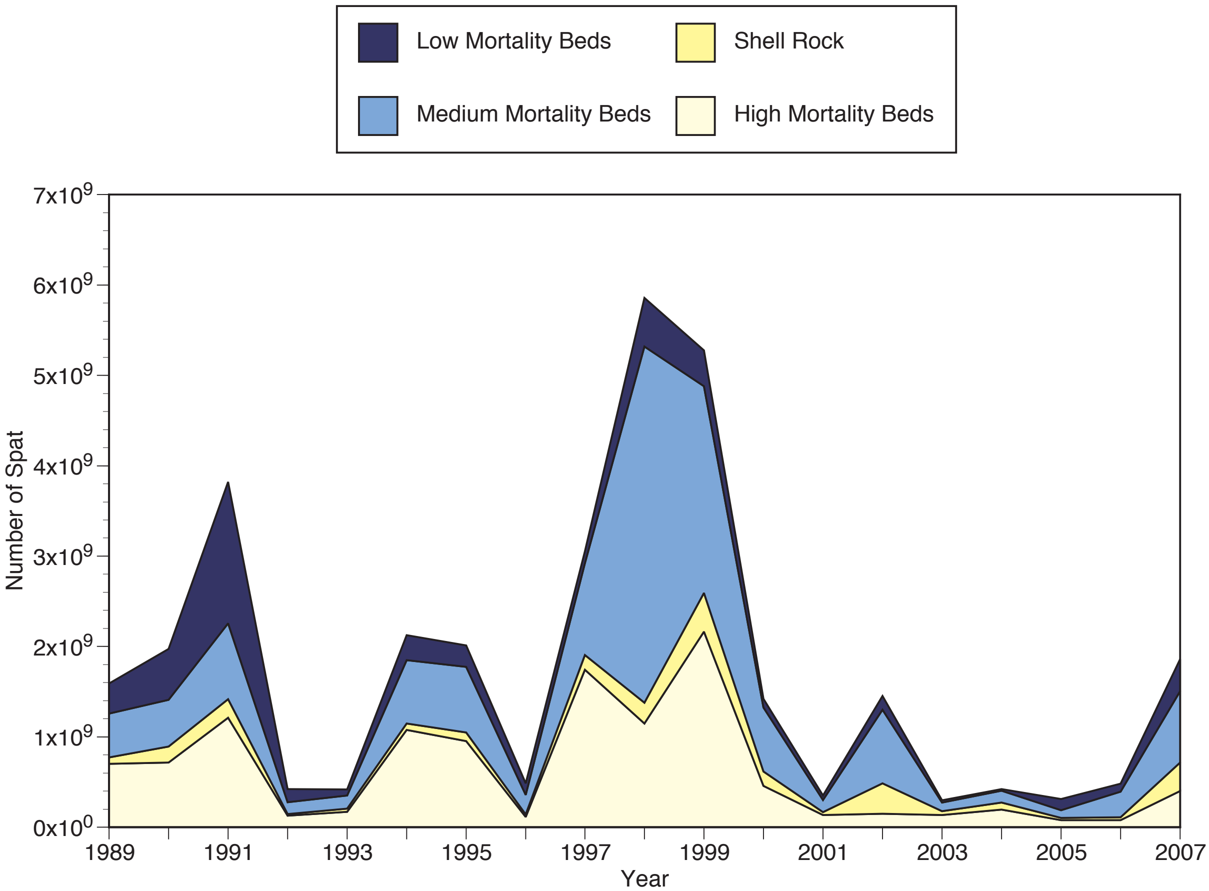

Figure 16. The number of spat recruiting per >20-mm oyster per year.

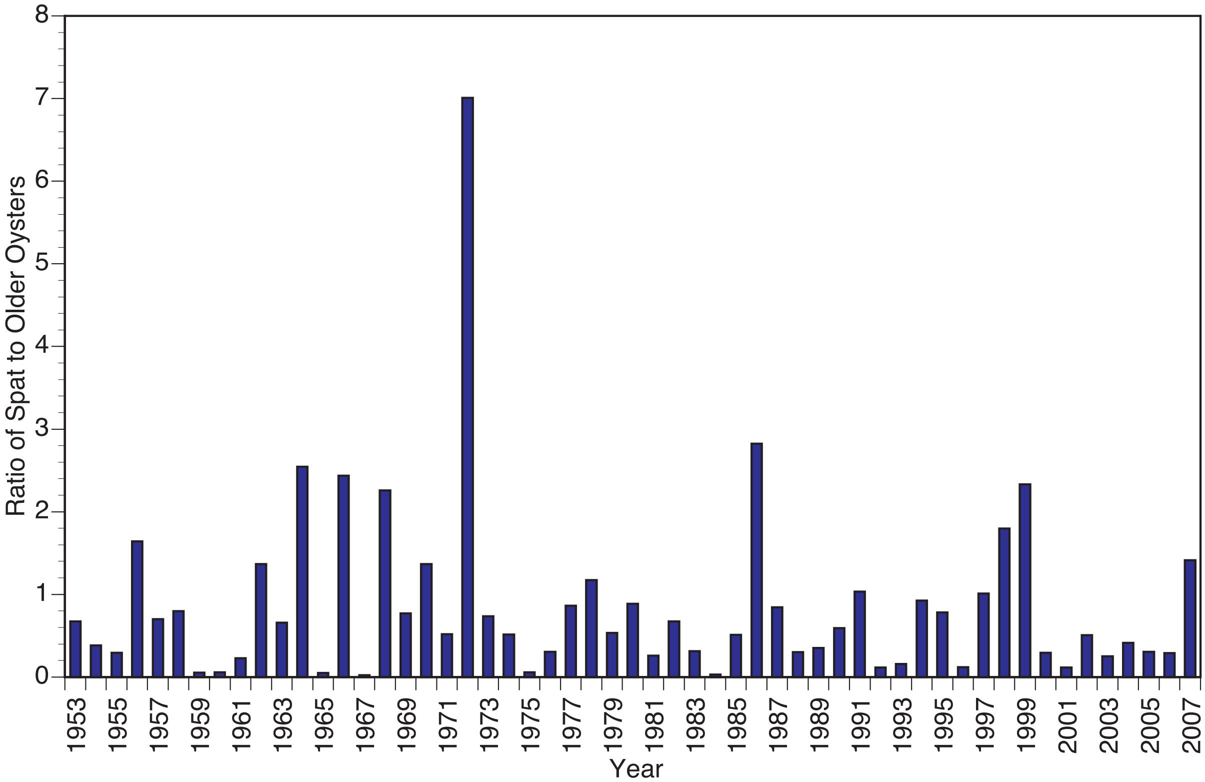

Figure 17. Location of 2007 shell plants, denoted by yellow stars. New Jersey downbay plants are on leased grounds. Transplant locations for these downbay plants are denoted as replants. Selected high-quality oyster grounds in New Jersey are denoted by shaded 25-acre grids. Red delineates State of Delaware beds.

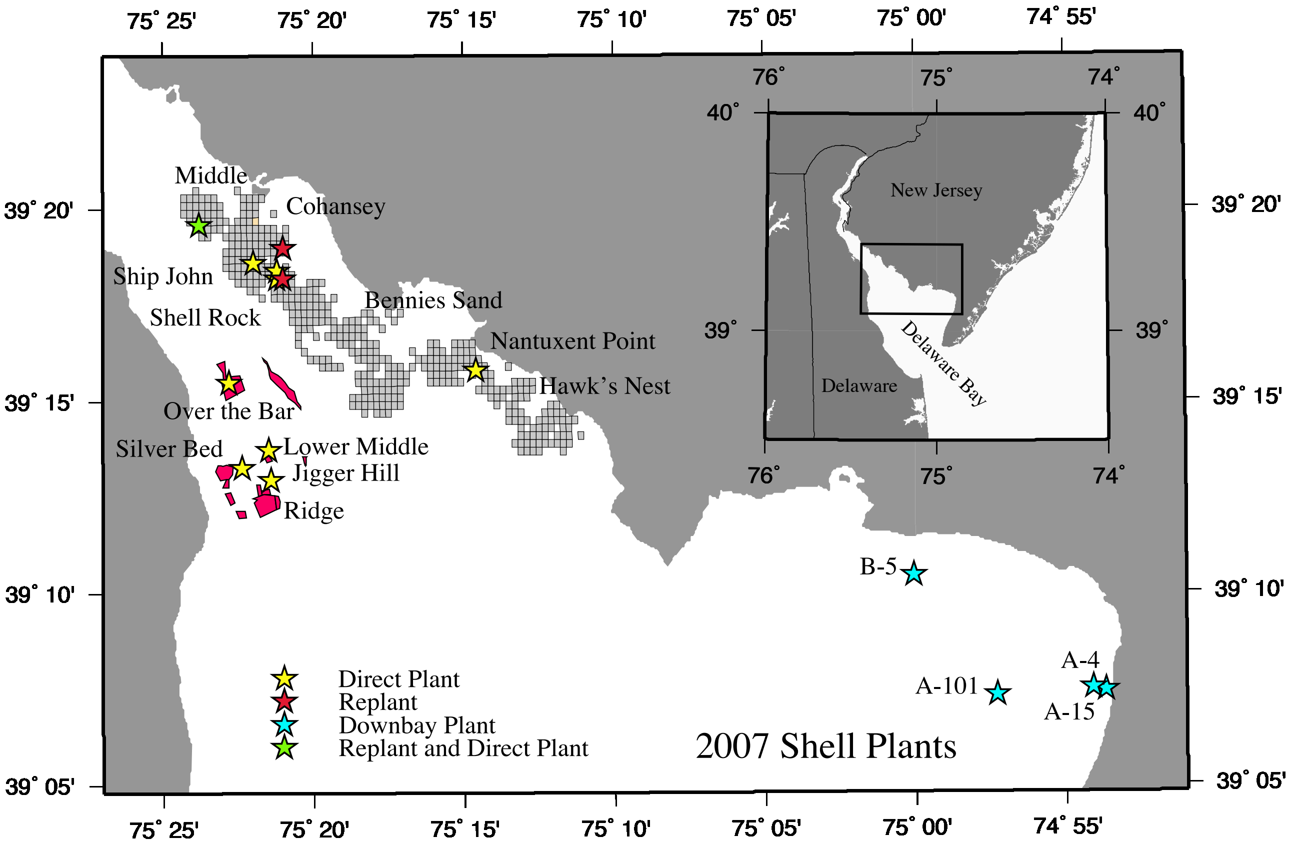

Figure 18. Cumulative number of spat recruiting to 20-oyster-shell bags deployed in the last week of June and collected bi-weekly through end-of-September. Colors identify the month of settlement. Increment in circle diameter indicates the number of spat that settled during that time period. Total diameter indicates the cumulative number of spat. Note that circle diameter bears a nonlinear relationship to total spat counts.

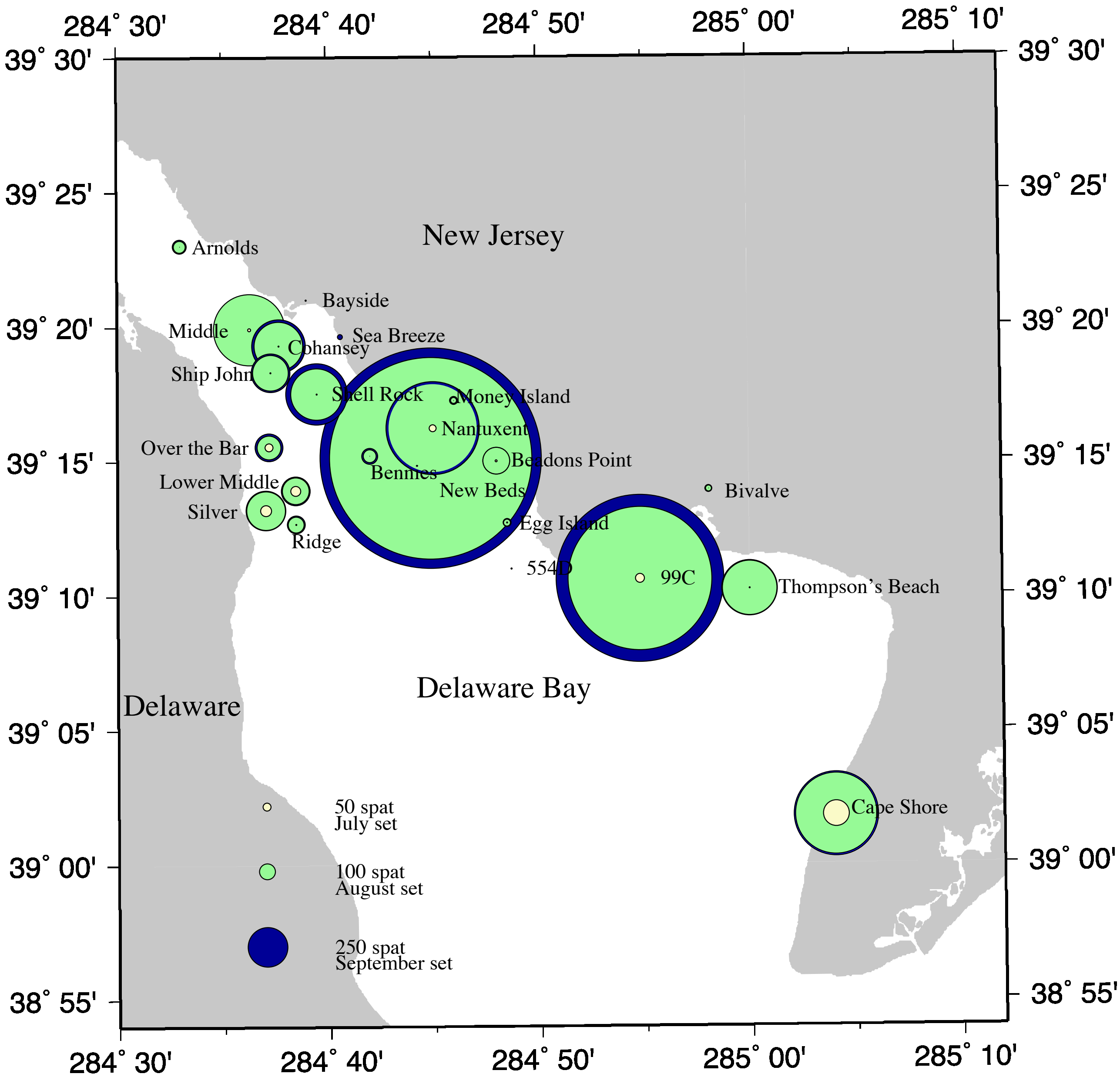

Figure 19. Cumulative number of spat recruiting to 20-oyster-shell bags deployed in the last week of June and collected bi-weekly through end-of-September since 2004. Station locations are depicted in Figure 18.

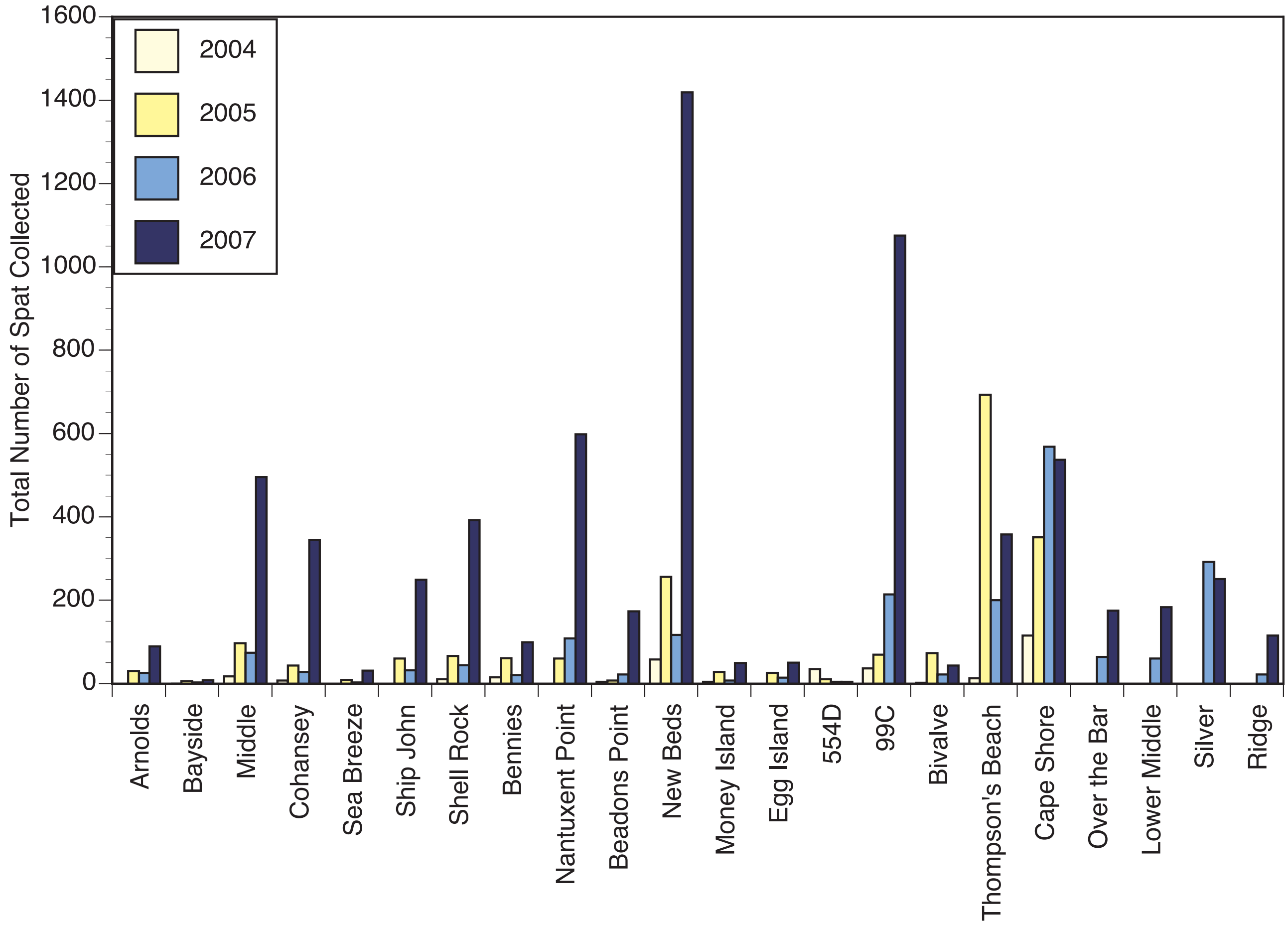

Figure 20. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2007. Lower estimates in 2005 and 2006 reflect the addition of shell through shell planting to offset the shell loss. The lesser loss estimate in 2007 reflects the addition of shell through shell planting and the natural input from the 2007 Dermo epizootic. Estimates were derived based on box volumes and box weights added (see text for further explanation).

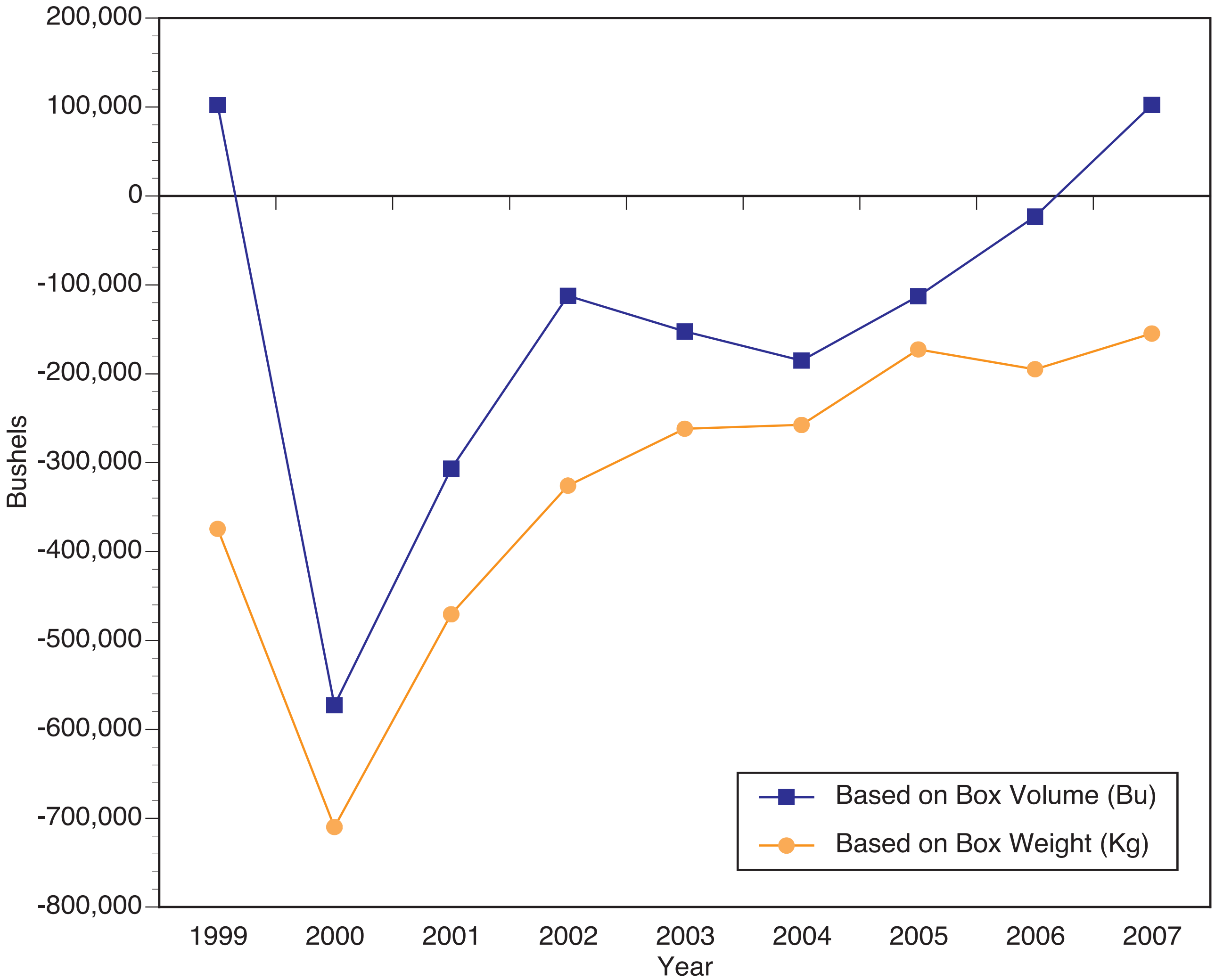

Figure 21. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2007. Positive values on Shell Rock in 2005 and 2006 and on the medium-mortality beds in 2007 reflect the addition of shell through shell planting to offset shell loss.

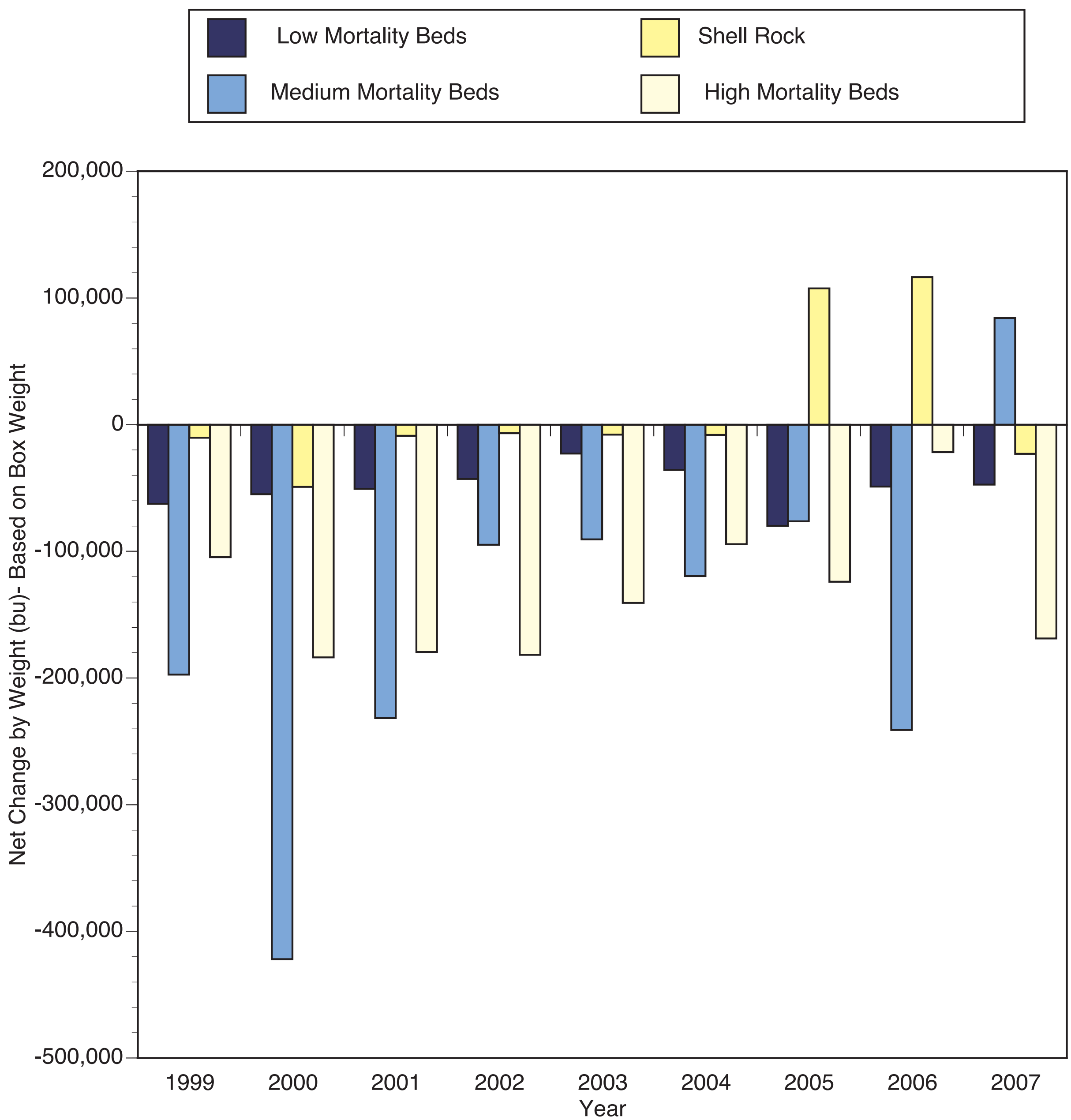

Figure 22. Relationship between Fall Dermo infection levels (WP=weighted prevalence) and Fall mortality as measured by box counts. Each point corresponds to a measurement from one bed for one year.

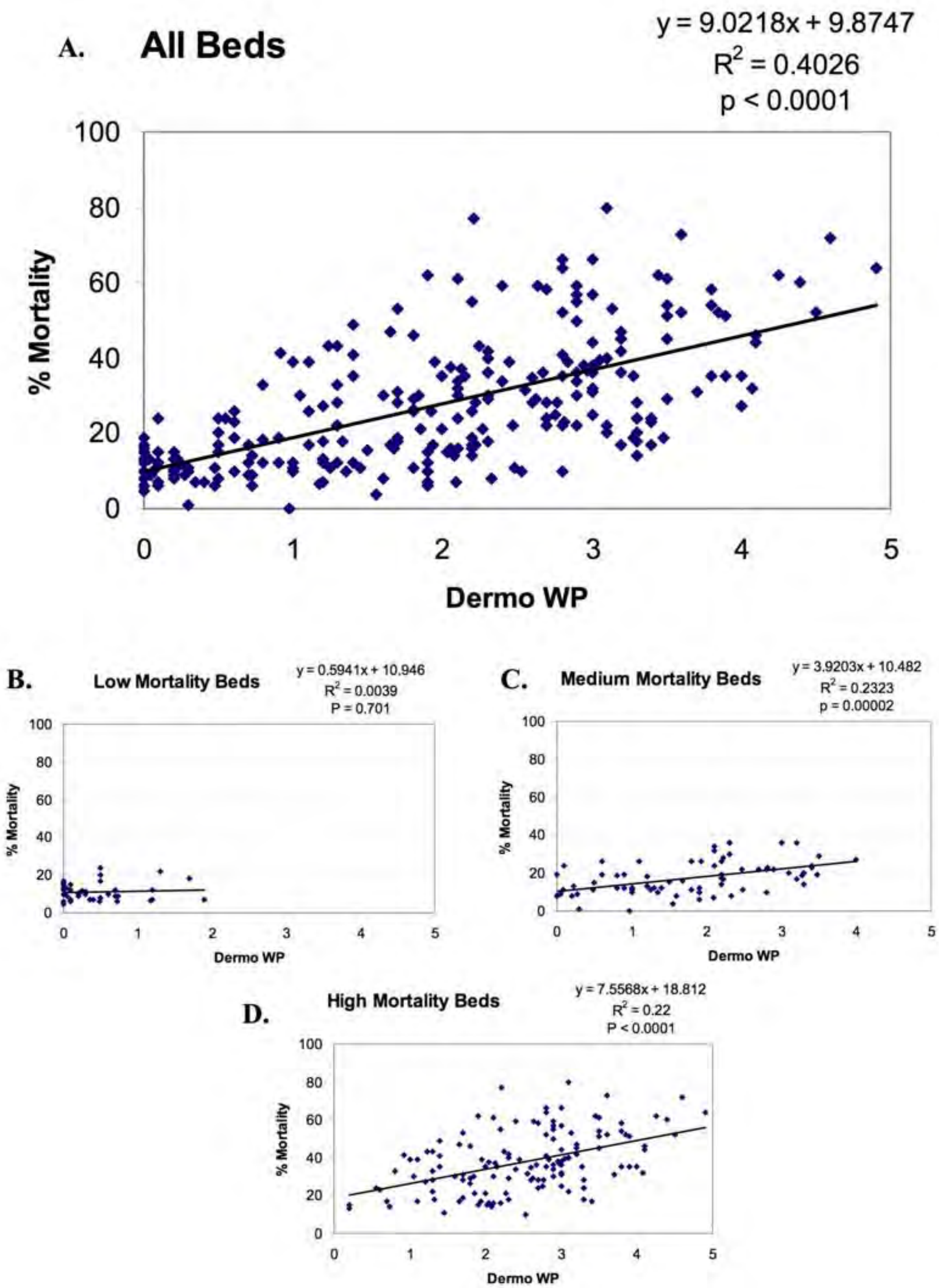

Figure 23. Mean and 2007 Dermo prevalence in oysters on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals for the 1990-2007 mean.

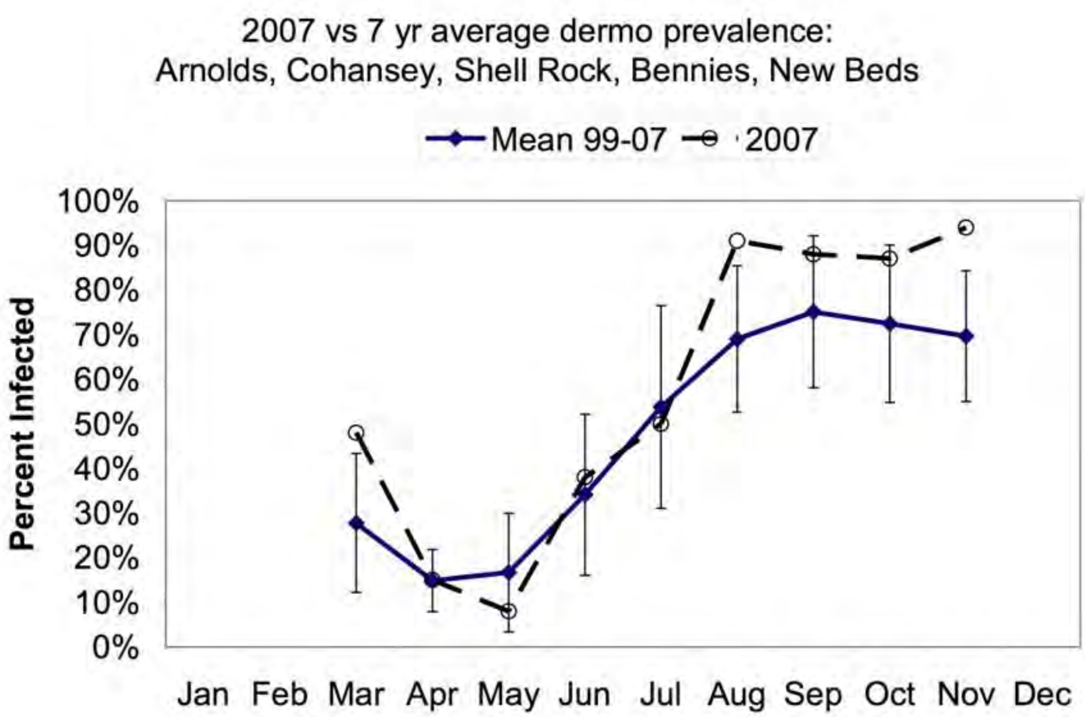

Figure 24. Mean and 2007 infection intensity of Dermo disease on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals for the 1990-2007 mean.

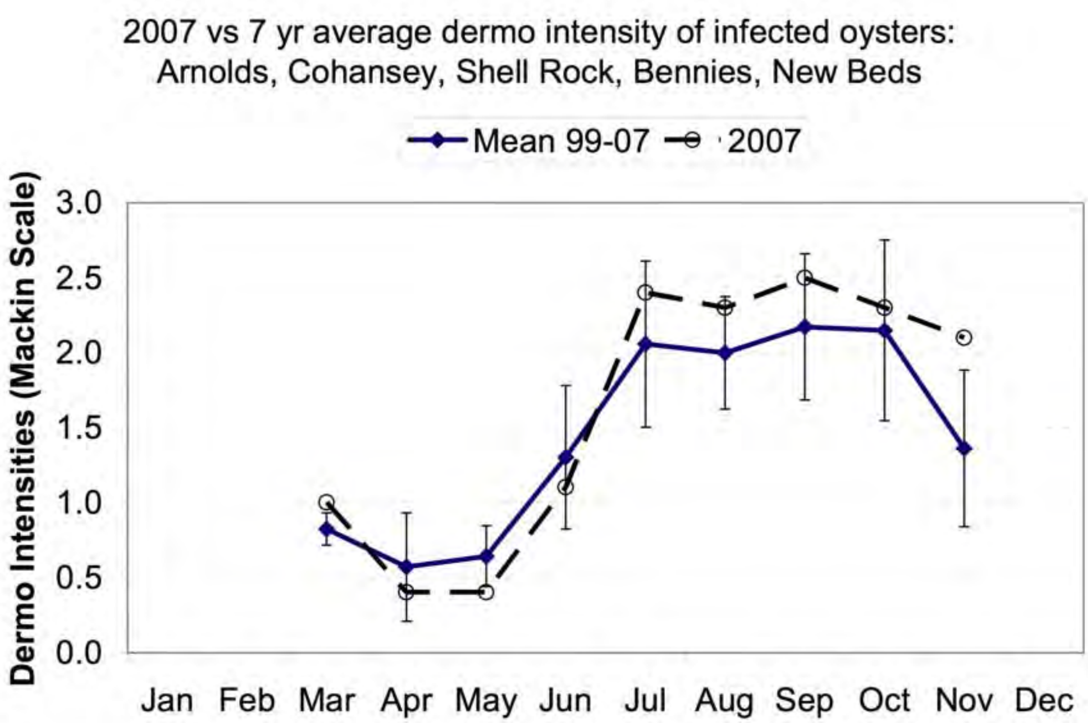

Figure 25. Time series showing the cyclic nature of Dermo disease weighted prevalence. Note the tendency for epizootics (weighted prevalences >2) to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

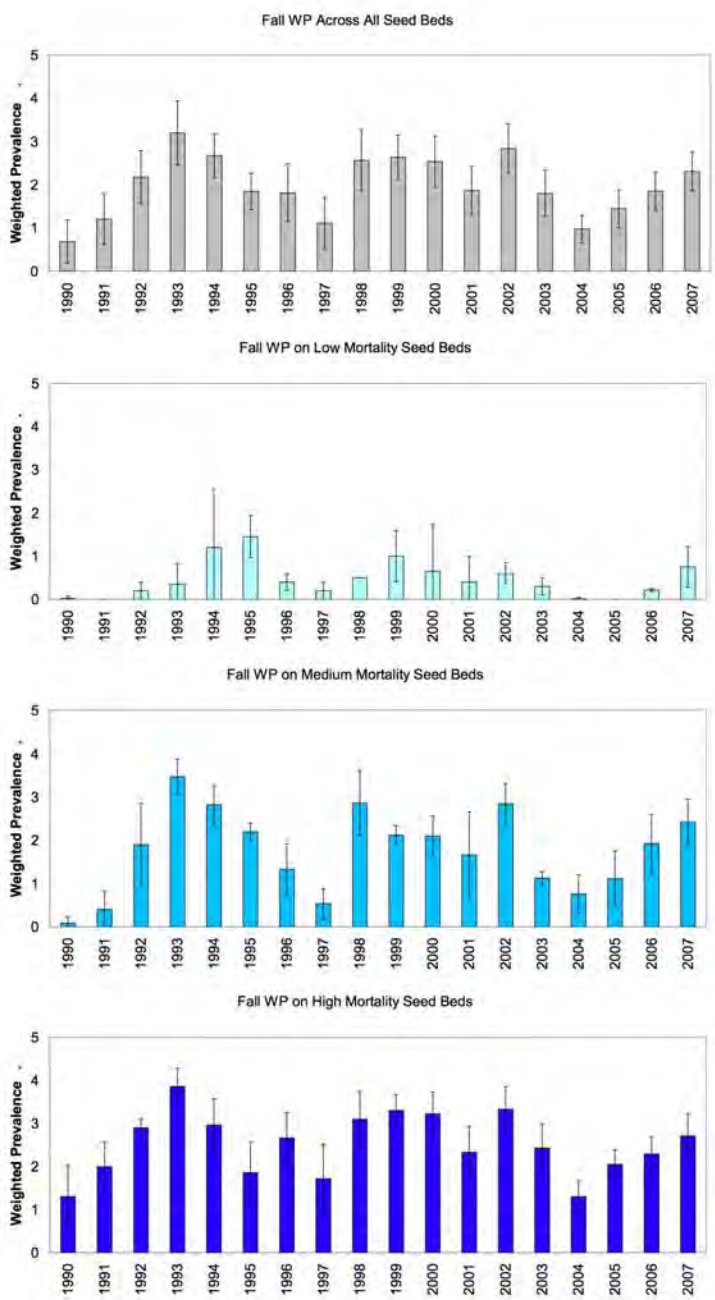

Figure 26. Comparison of average annual fall Dermo prevalence in oysters since 1990 (open bars with 95% confidence intervals) with 2007 levels (shaded area). Trend line is a 6^{th} order polynomial fit of long-term data. Ledge bed was not sampled in 2007 and 2007 was the first year of data for Hope Creek.

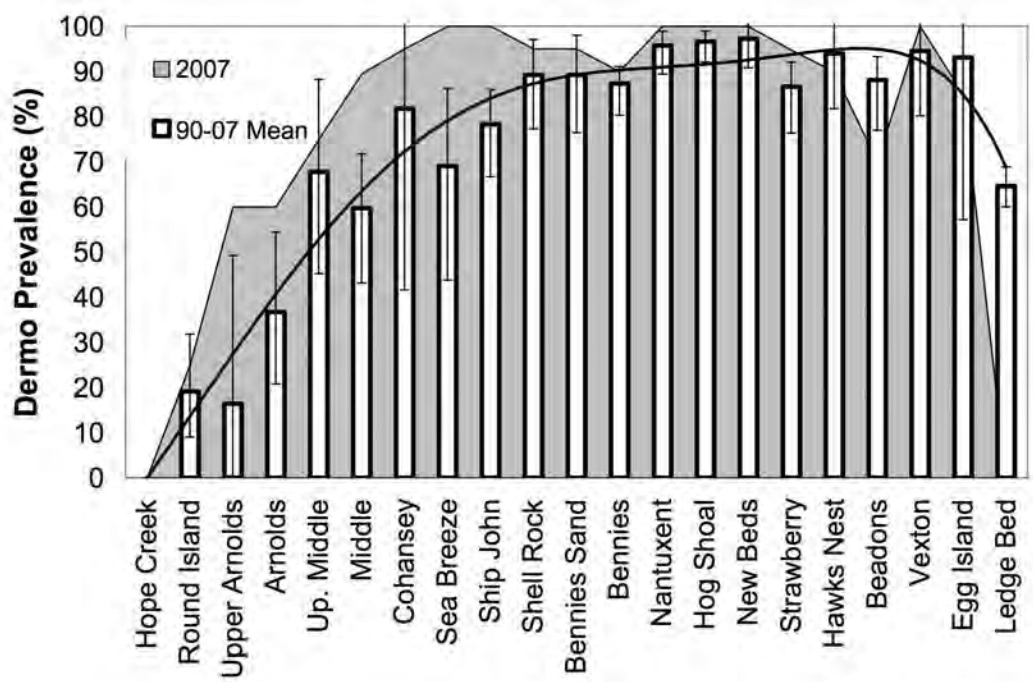

Figure 27. Comparison of average annual fall Dermo weighted prevalence in oysters since 1990 (open bars with 95% confidence intervals) with 2007 levels (shaded area). Trend line is a 6^{th} order polynomial fit of long-term data. Ledge bed was not sampled in 2007 and 2007 was the first year of data for Hope Creek.

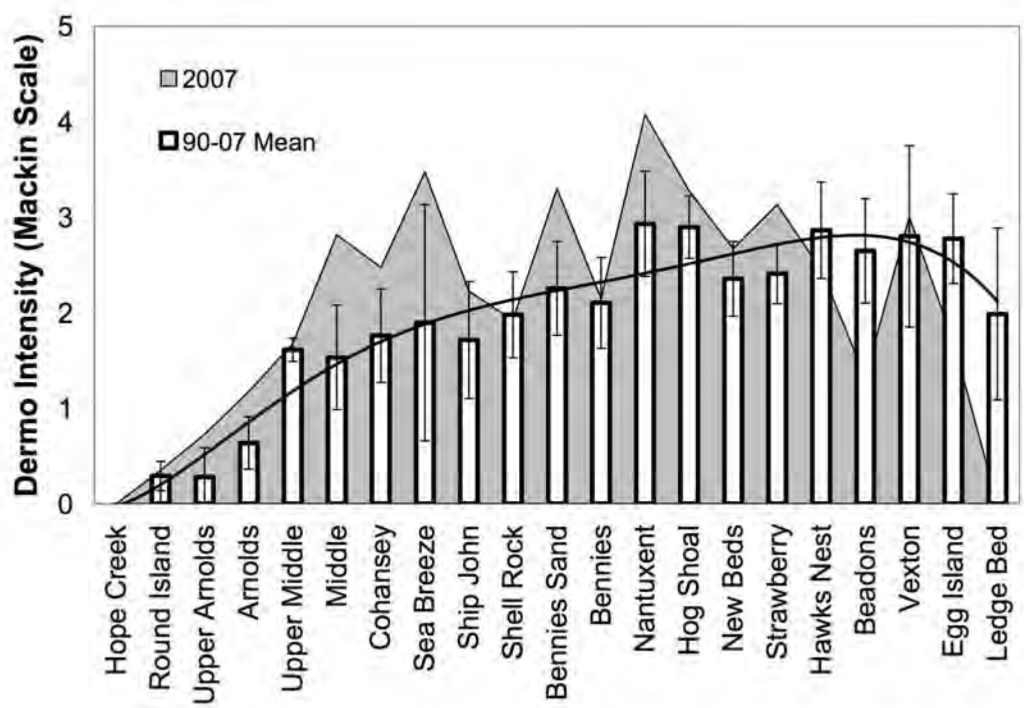

Figure 28. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the four bay regions measures the bay-wide mortality rate for that year.

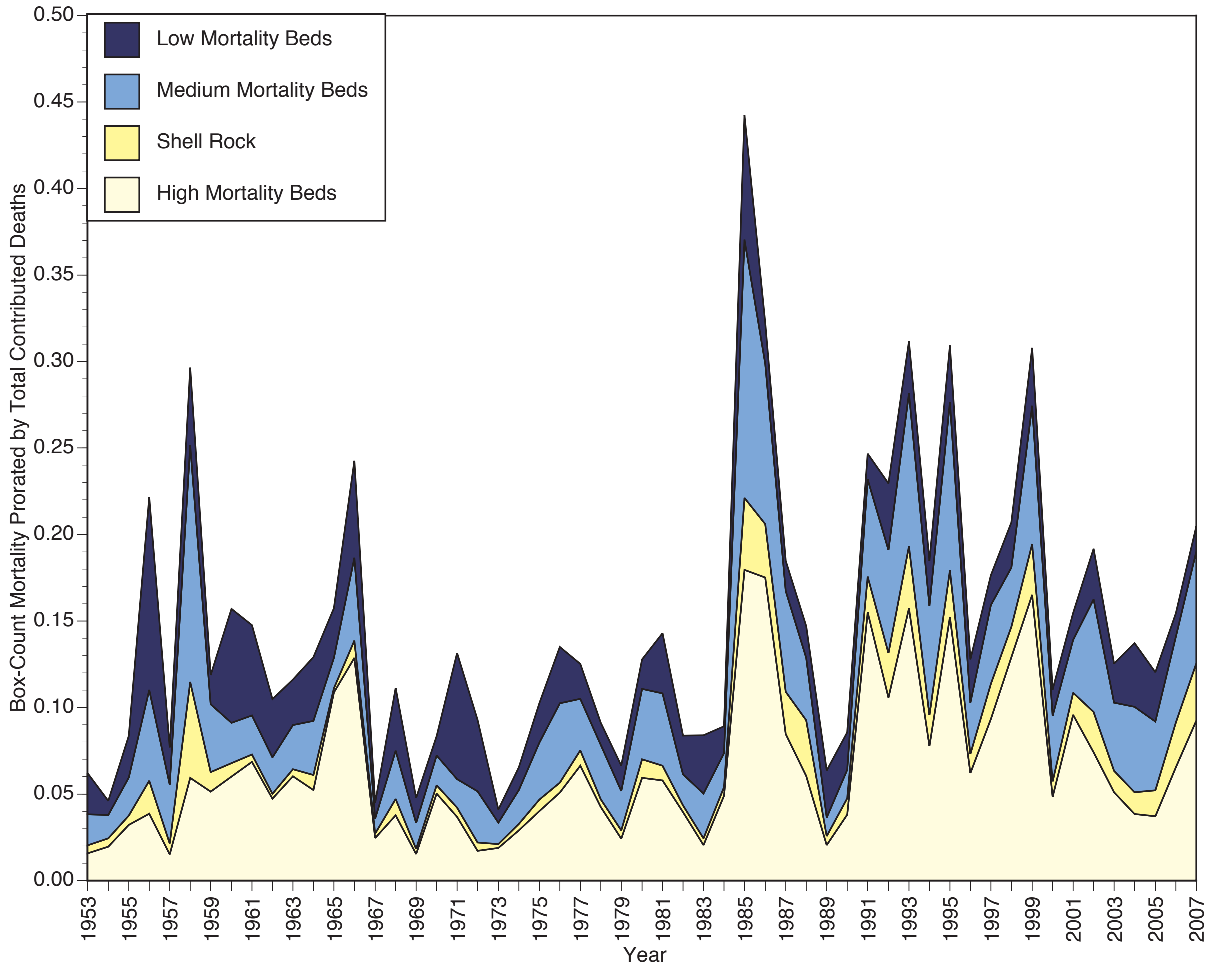

Figure 29. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region.

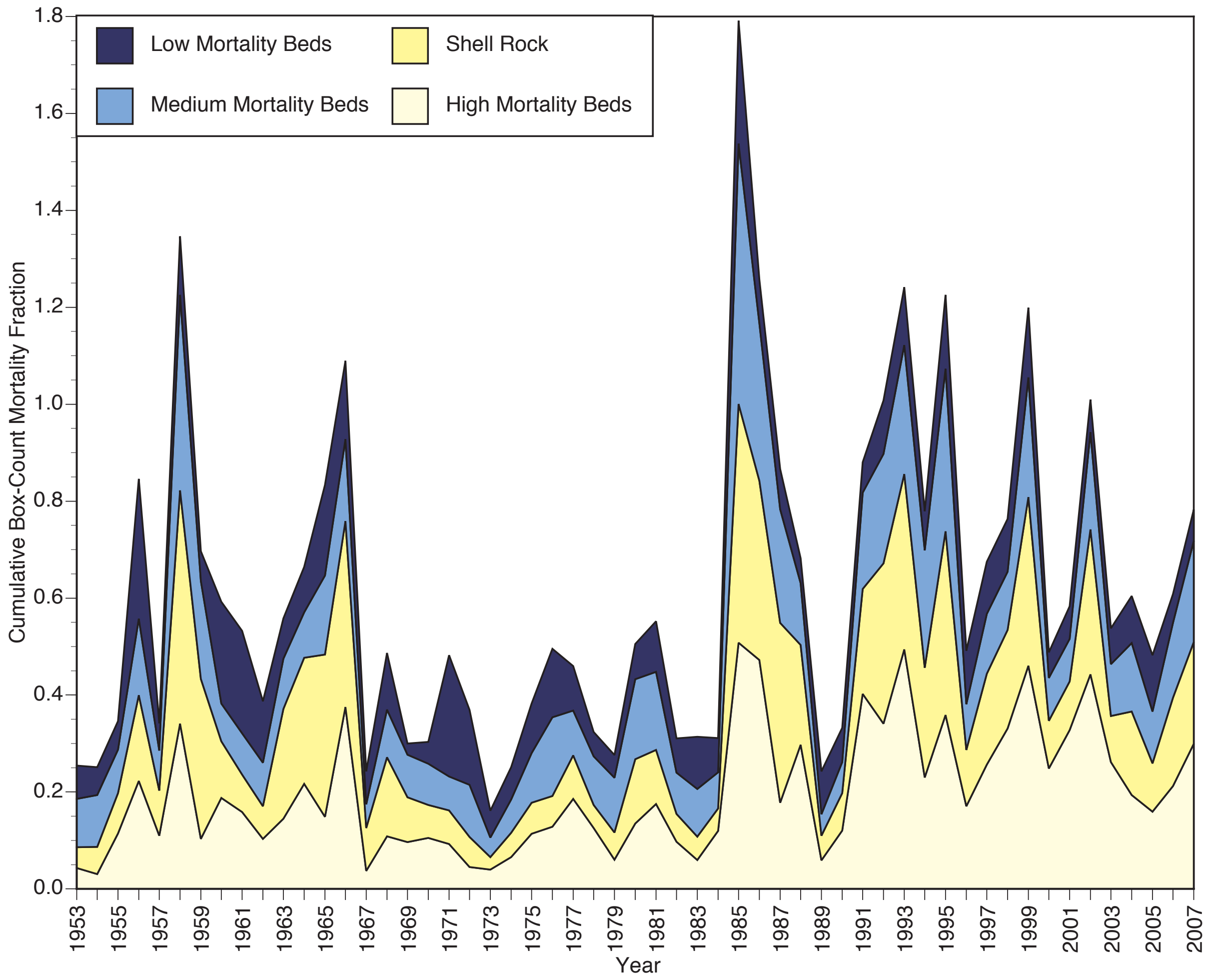

Figure 30. Broodstock-recruitment relationship for the 1953-2007 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2006 because the plot compares end-of-2006 oyster abundance with 2007 recruitment. Dotted lines identify the 55-year medians used for calculation of first passage times (Table 14).

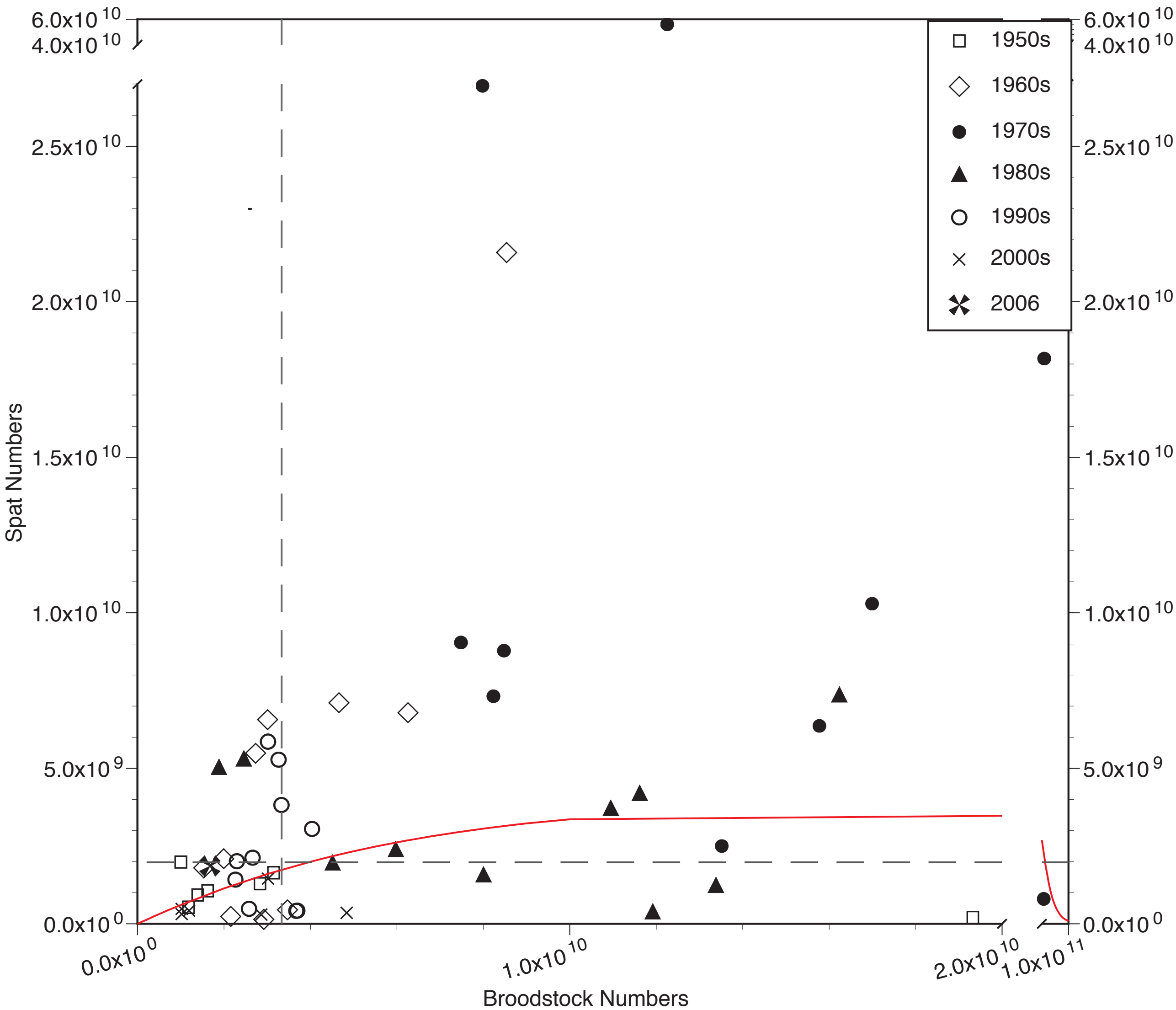

Figure 31. The quadrant numbering convention used to calculate mean first passage times. The one year transition probabilities are obtained by examining the position of consecutive x-y data pairs in quadrant space. Four transitions are possible for each starting position, the possibilities for Quadrant 1 being depicted. Sixteen total trajectories are possible.

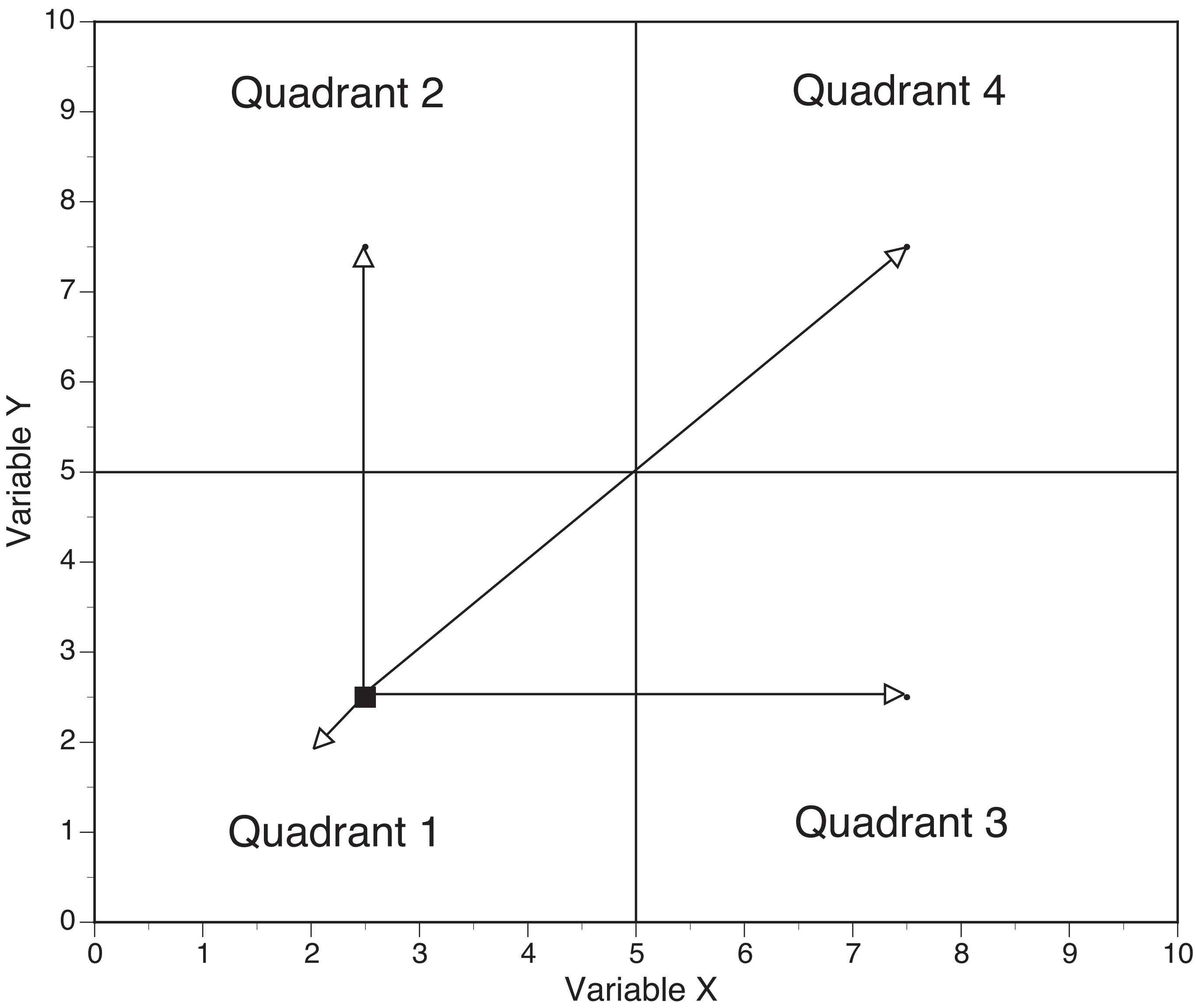

Figure 32. The relationship between oyster abundance and box-count mortality for the 1953-2007 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2006 because the plot compares end-of-2006 oyster abundance with 2007 mortality. Dotted lines identify the 55-year medians used for calculation of first passage times (Table 15).

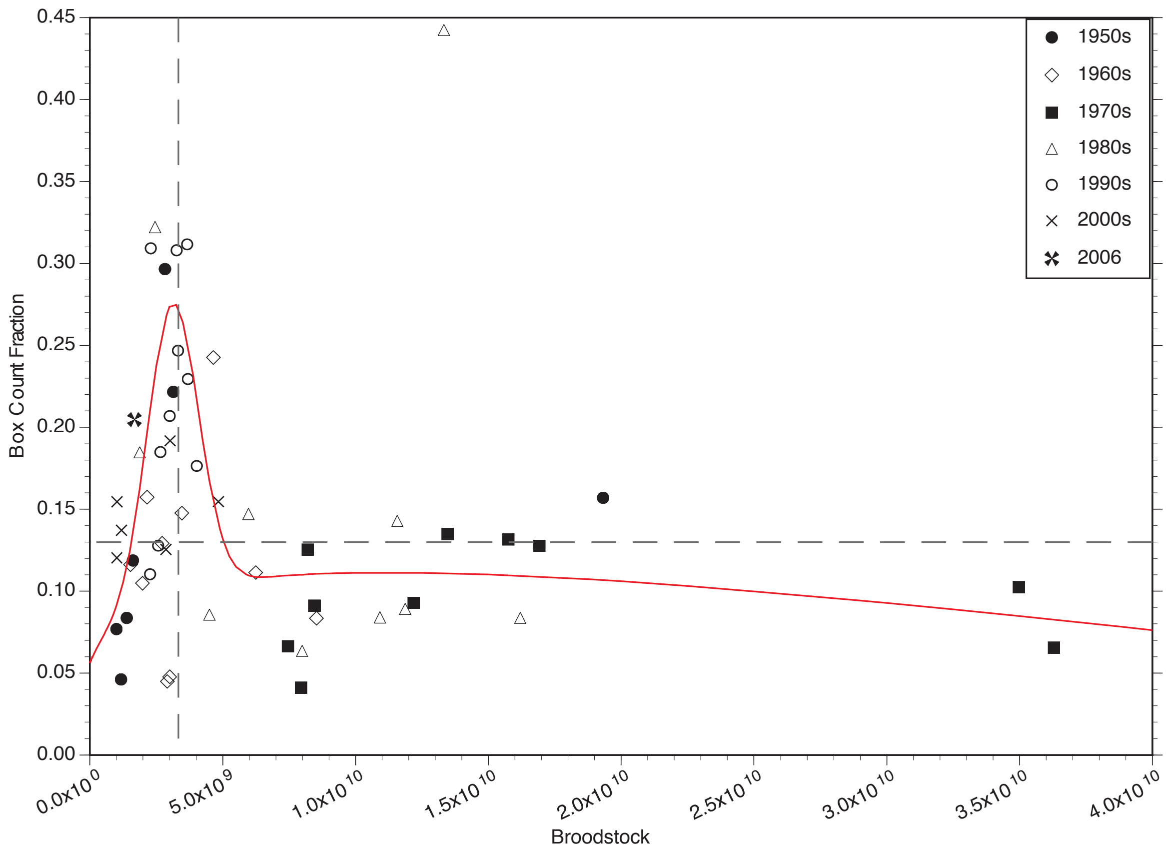

Figure 33. A closer look at the lower end of the oyster abundance and box-count mortality relationship. The entire dataset is depicted in Figure 32. Latest year listed as 2006 because the plot compares end-of-2006 oyster abundance with 2007 mortality. Dotted lines identify the 55-year medians used for calculation of first passage times (Table 15).

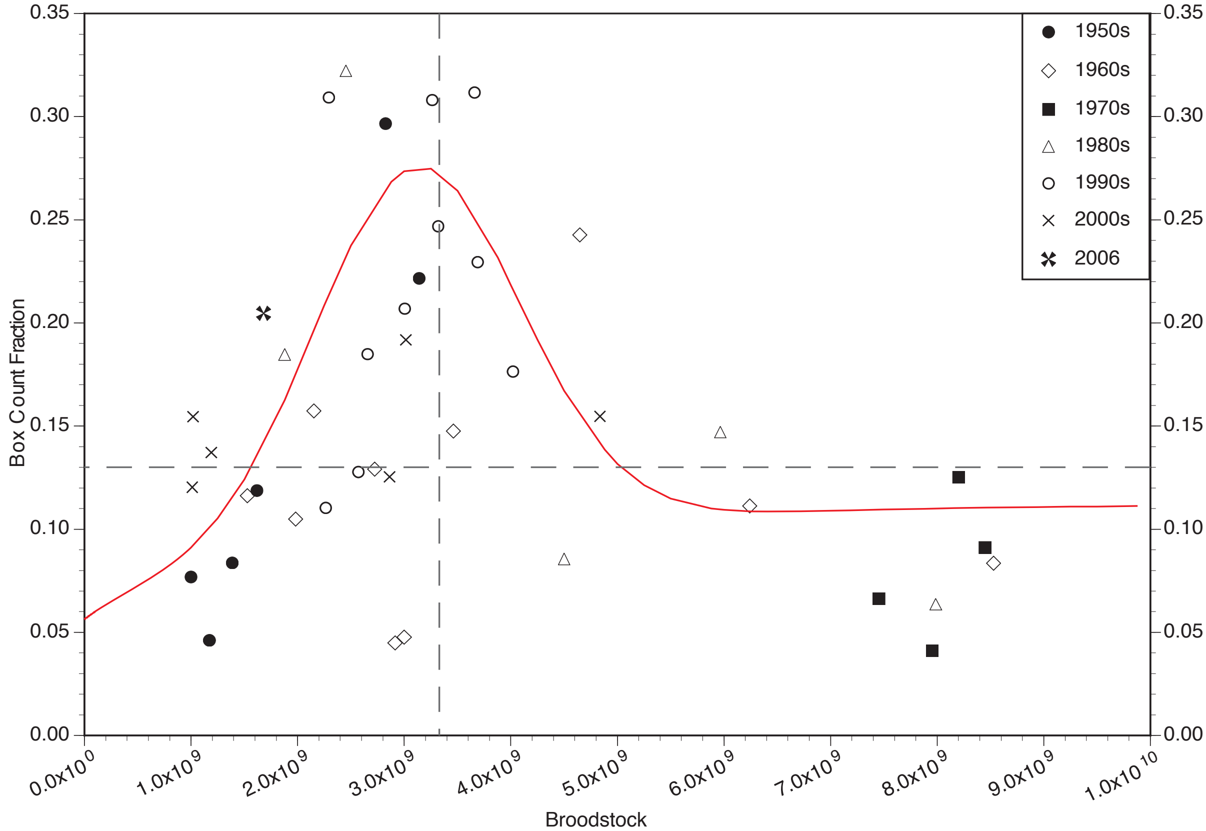

Figure 34. The relationship between recruitment and box-count mortality for the 1953-2007 time period for the natural oyster beds of Delaware Bay. Dotted lines identify the 55-year medians used for calculation of first passage times (Table 16).

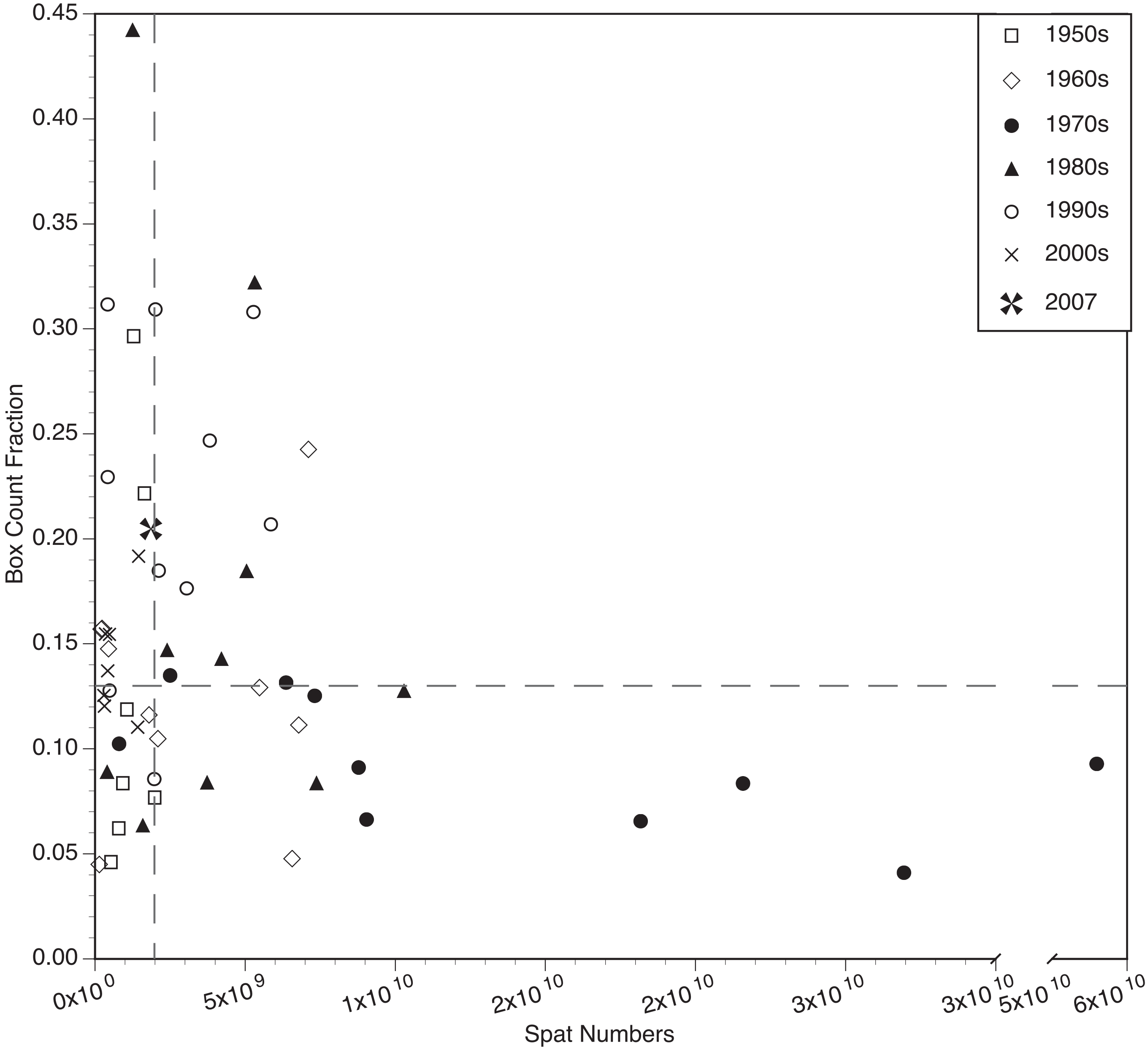

Figure 35. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

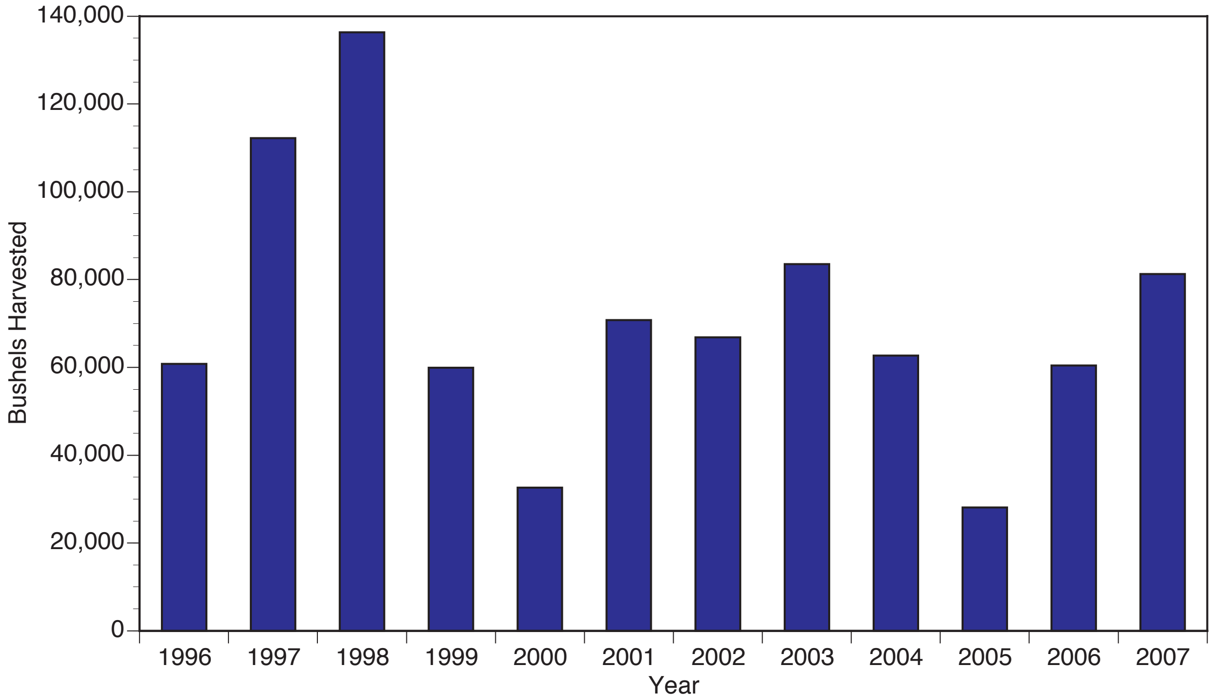

Figure 36. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

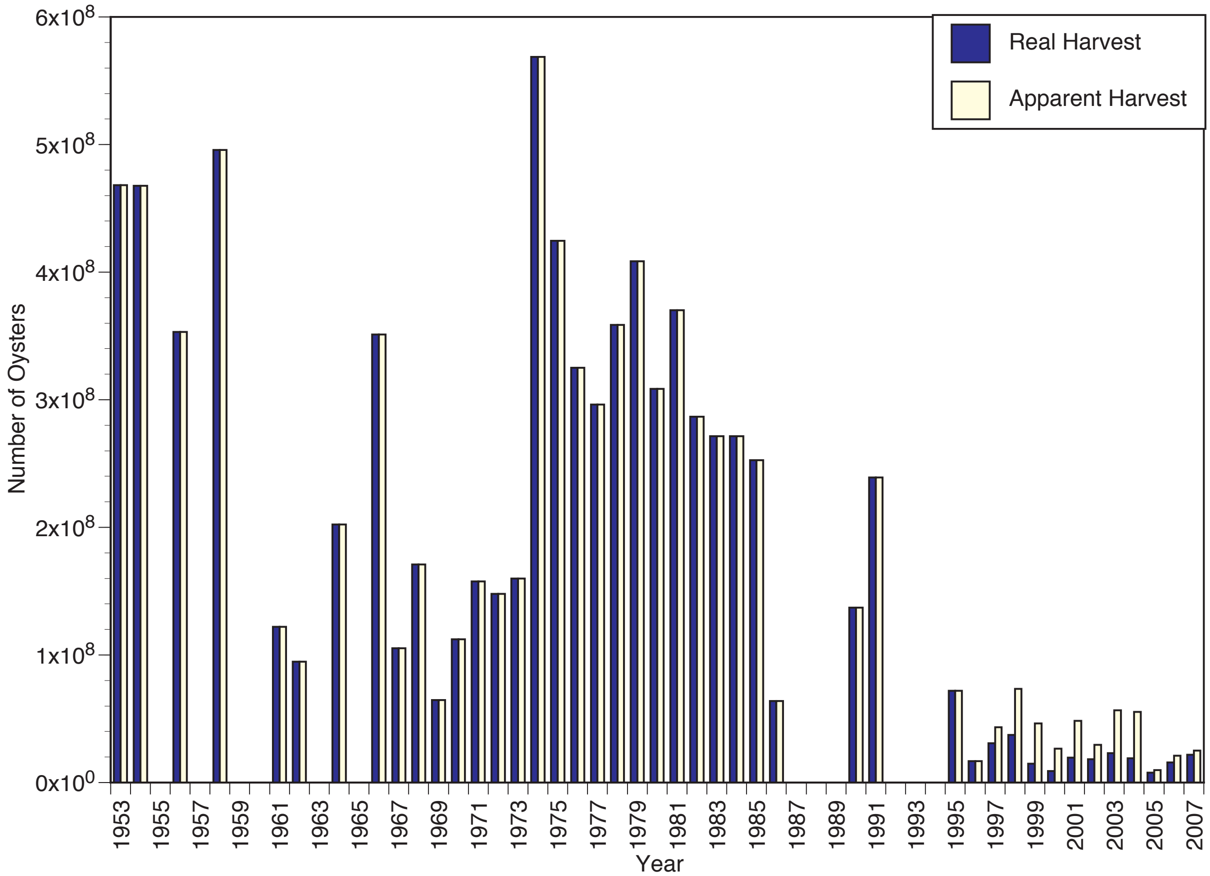

Figure 37. Catch (in bushels) per boat-day by vessel style.

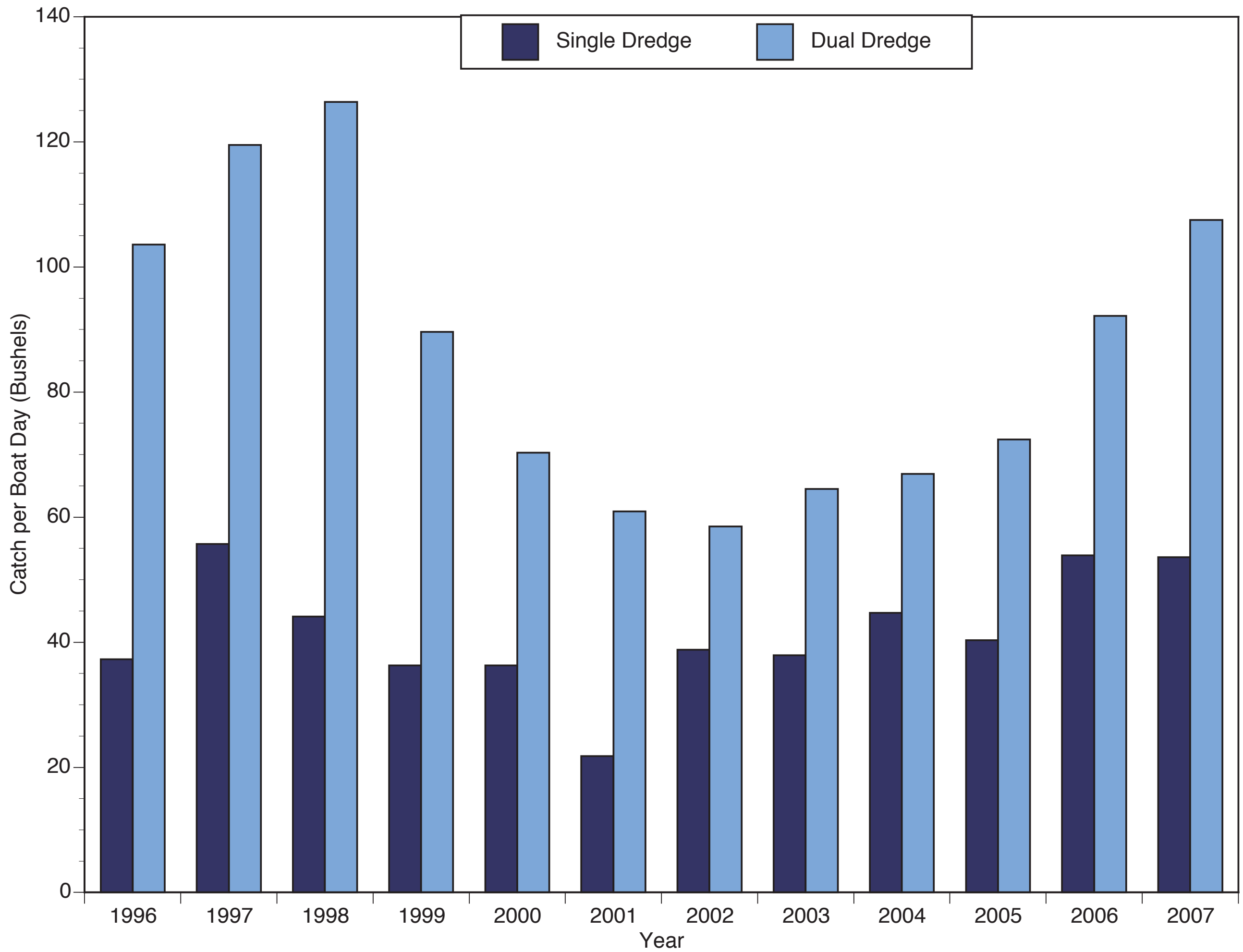

Figure 38. Size frequency of oysters landed in 2007. Size class values are the mean of the size class.

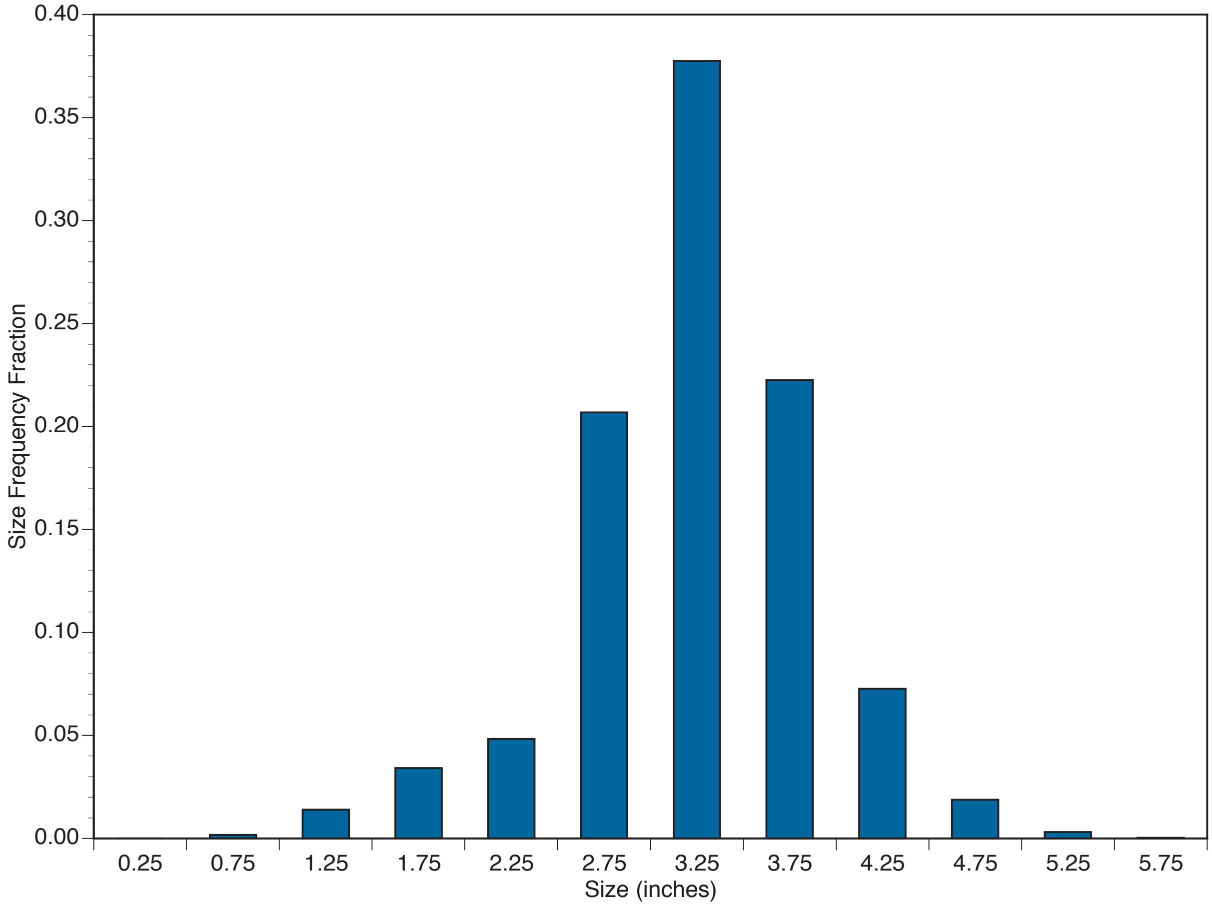

Figure 39. Fishing mortality rates by bay region during the 1953-2007 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 3. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

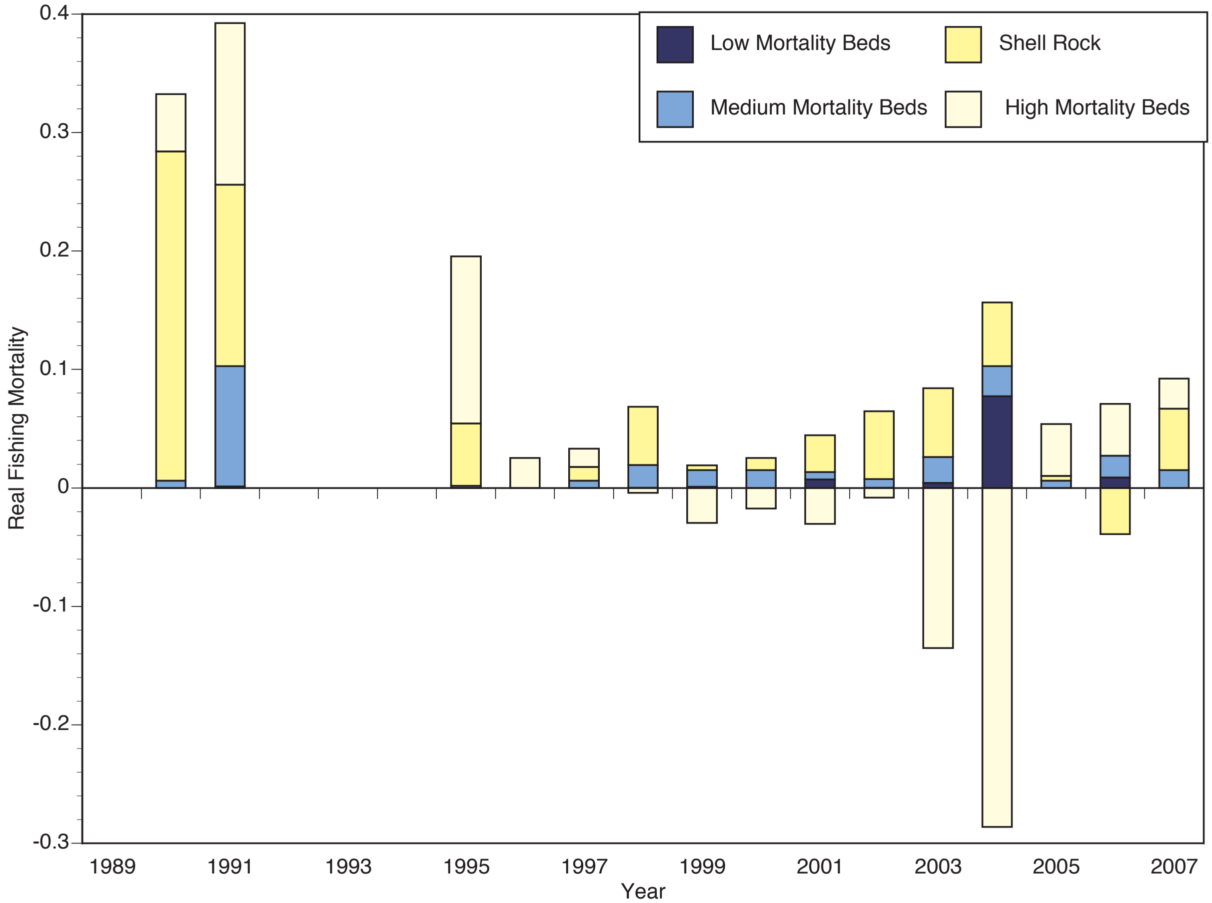

Figure 40. Fishing mortality rates by bay region during the 1996-2007 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 3. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

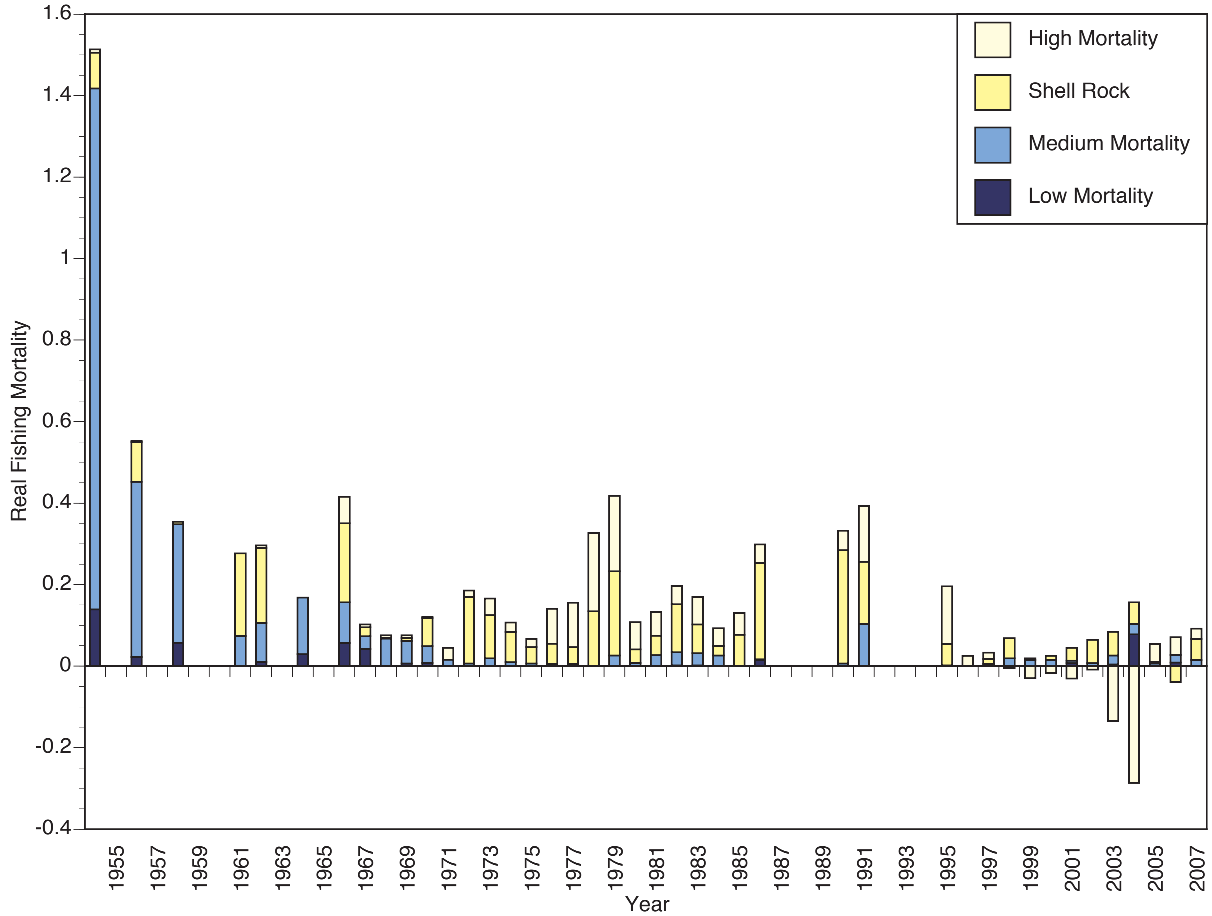

Figure 41. Real fishing mortality rate during the 1991-2007 time period. Zeros represent years of fishery closure.

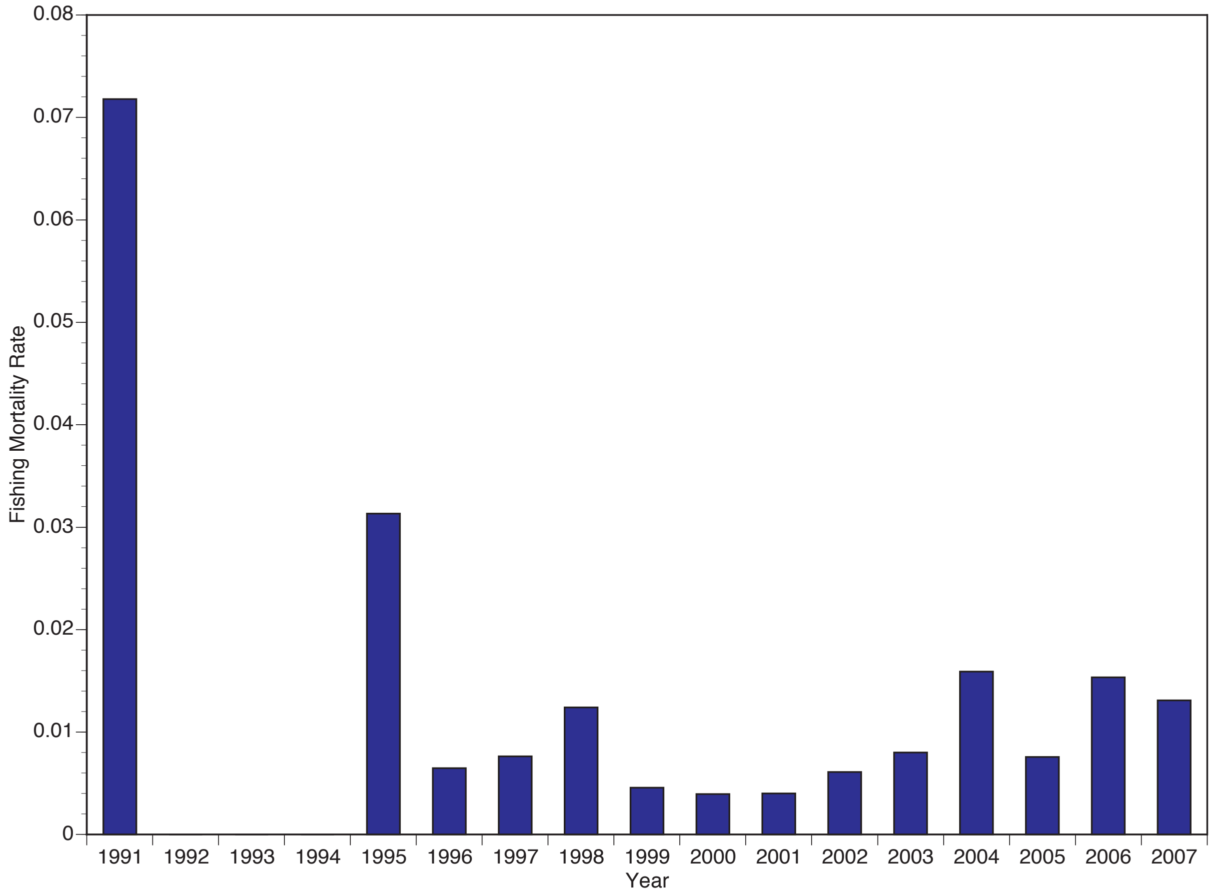

Figure 42. Fishing mortality rate during the 1997-2007 time period based on spawning stock biomass.

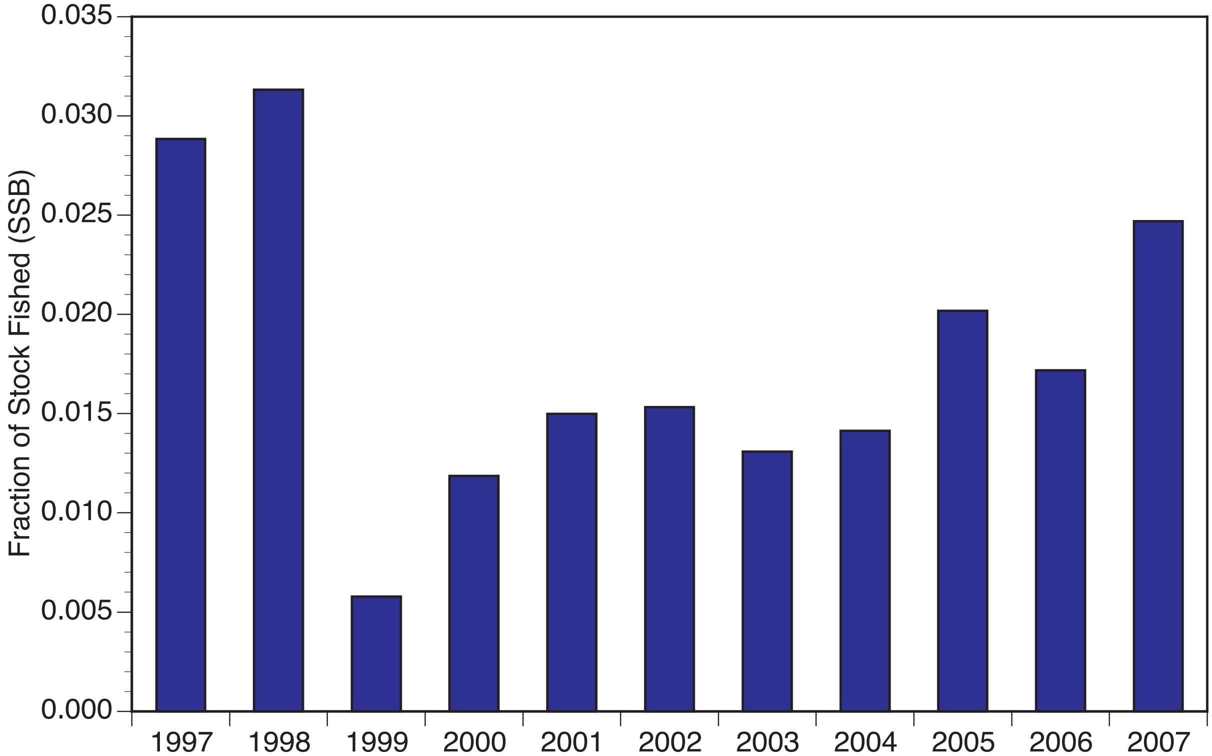

Figure 43. Fishing mortality rate during the 1997-2007 time period based on marketable abundance (animals $\geq 2.5''$).

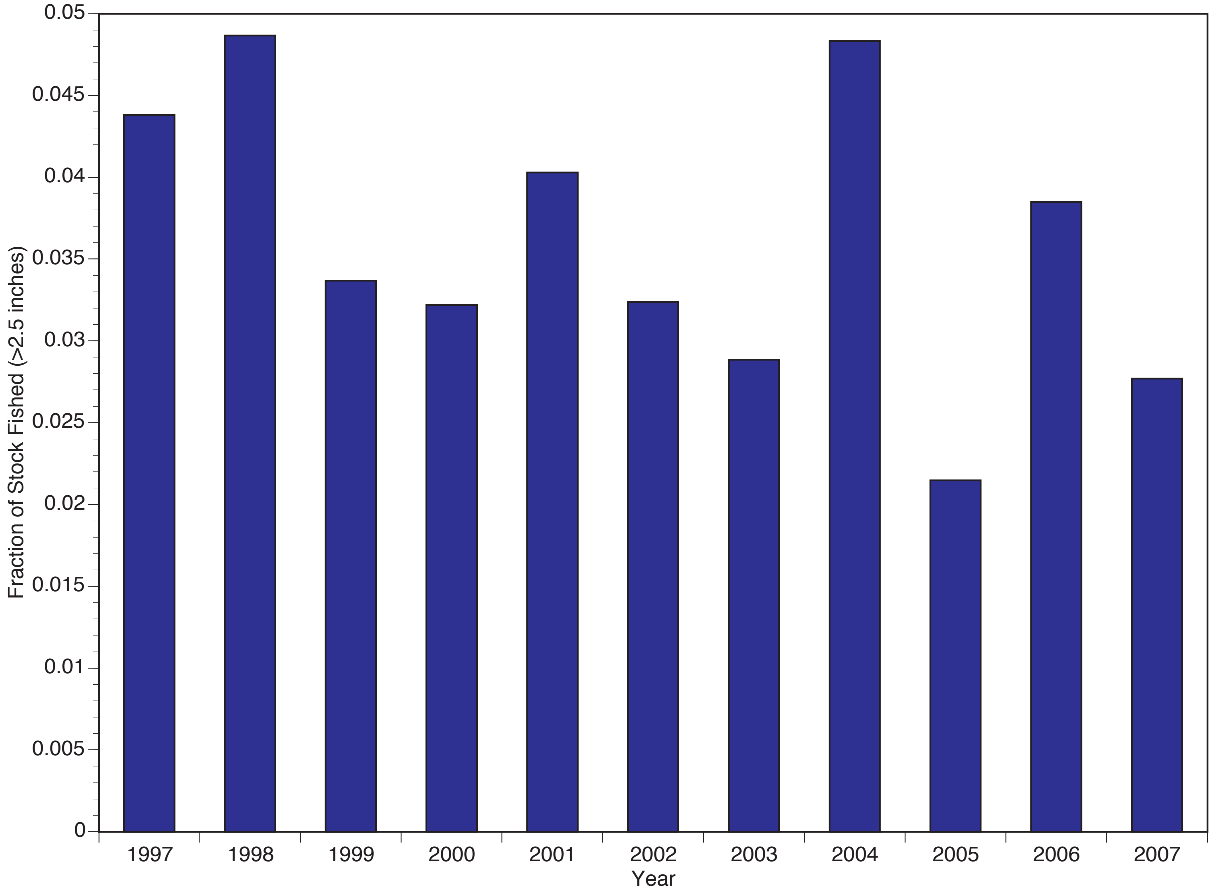

Figure 44. Position of the oyster stock in 2004-2007 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values (Table 19).

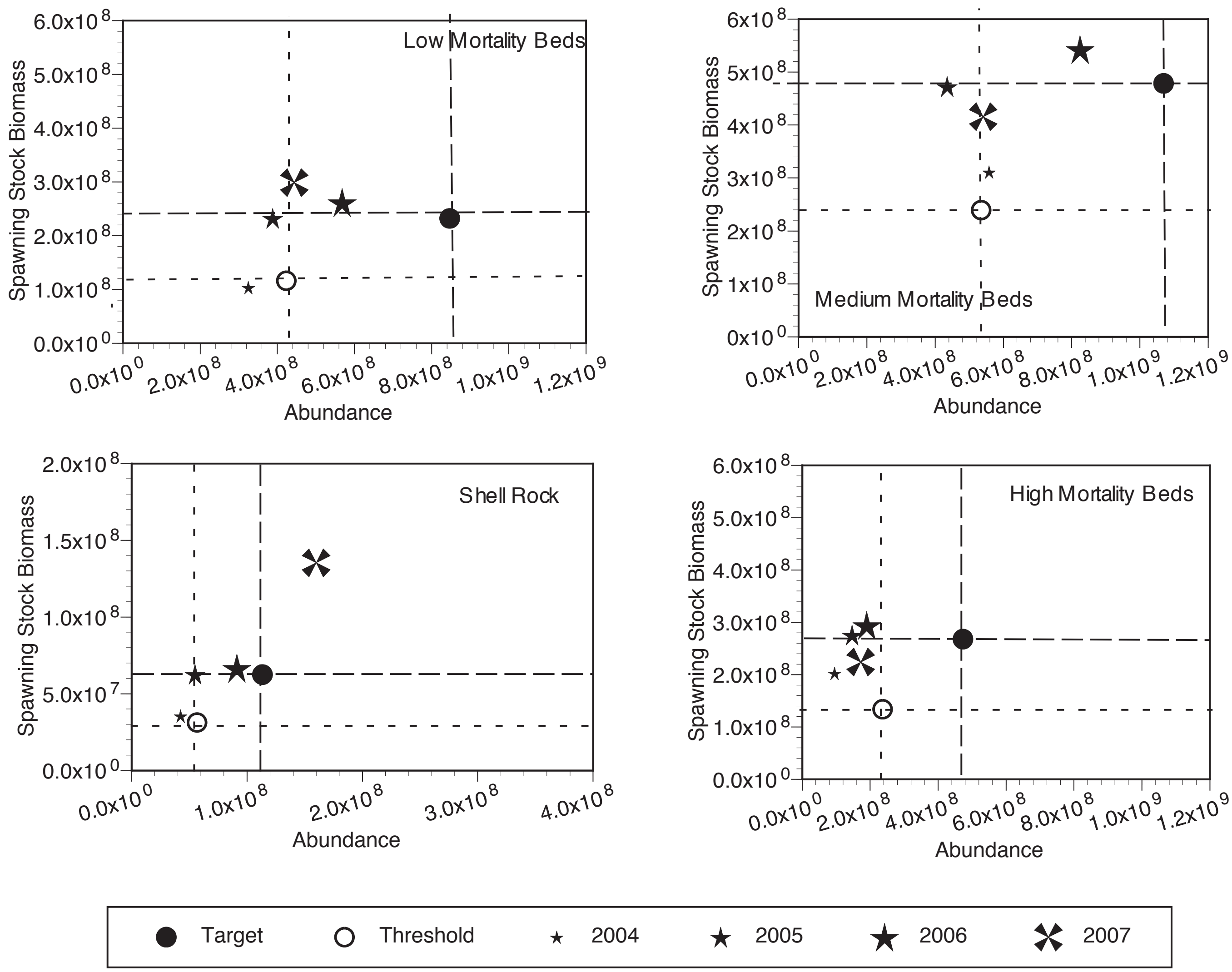

Figure 45. Plot of surplus production trajectories obtained from simulations of the stable-point surplus-production model. Descriptions of the simulations are given in Table 20 and the text. Vertical bars correspond to four whole-stock reference points. Two are derived from the surplus production model, 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 19). The four respective values are: 1.628 billion, 0.814 billion, 2.503 billion, and 1.251 billion.

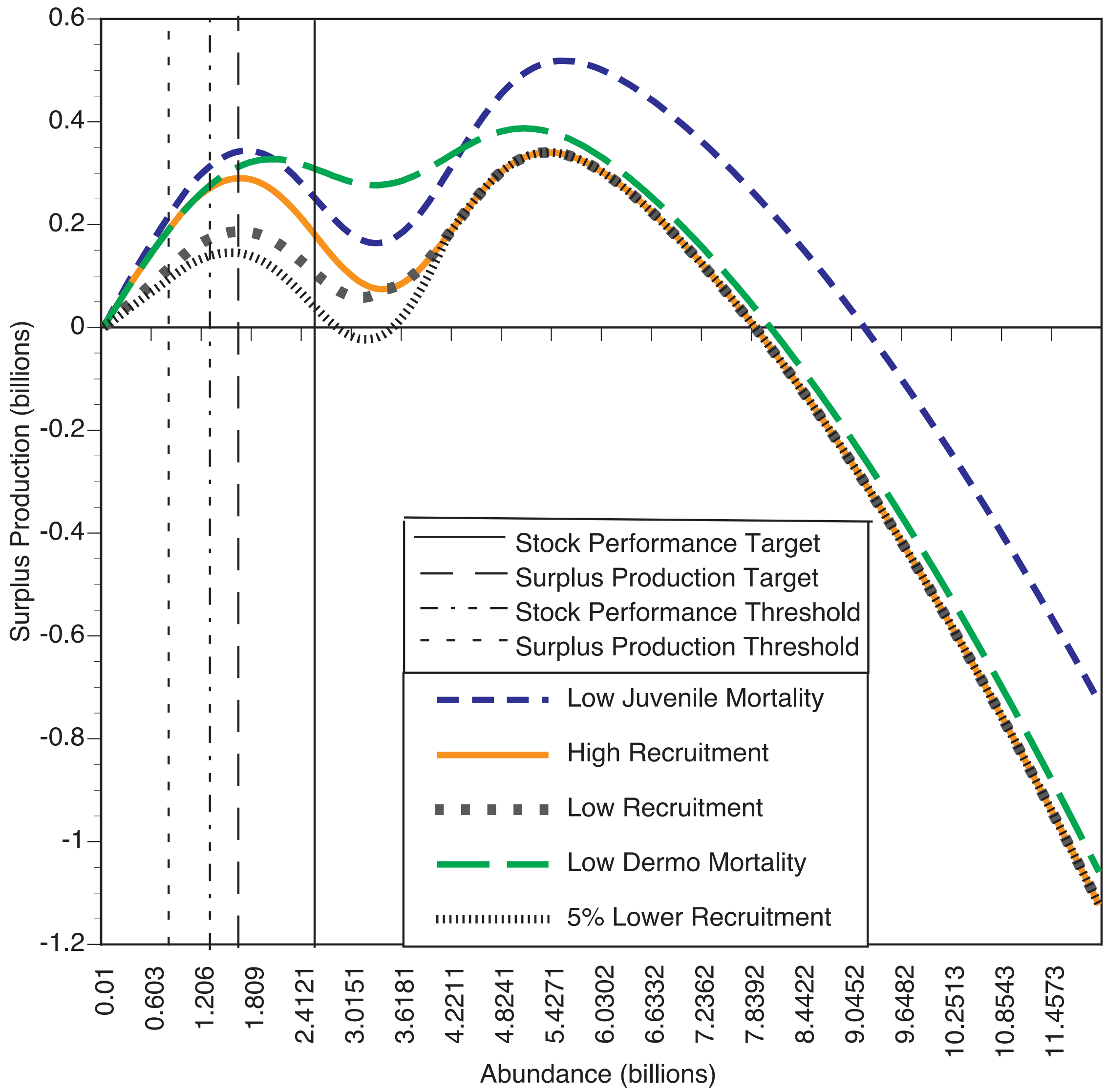

Figure 46. Summary status of the stock for 2007. Green indicates variables judged to be above average relative to the 1989-2007 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2007 time period or having 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 1989-2007 time period, but sometimes determined by scientific judgment. 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 1989-2007 time series. Parentheses are values that include the 2007 shell plants.

	Low Mortality Beds	Medium Mortality Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.34	0.41	0.12	0.13
Total Abundance				
2007 Percentile	0.24	0.08	0.71	0.18
2006-2007 Trend	Decreasing	Decreasing	Increasing	Decreasing
Spawning Stock Biomass				
2007 Percentile	0.66	0.22	0.91	0.34
2006-2007 Trend	Increasing	Decreasing	Increasing	Decreasing
Recruitment				
2007 Percentile	0.77	0.71	0.87	0.50
2006-2007 Trend	Increasing	Increasing	Increasing	Increasing
Spat per Adult				
2007 Ratio	0.80	1.46 (1.55)	1.97	2.33 (2.38)
2007 Percentile	0.92	0.87 (0.90)	0.87	0.82 (0.83)
2007 Juveniles (fract.<2.5")	0.74	0.48	0.51	0.43
2007 Percentile	0.06	0.24	0.29	0.12
Dermo Infection Status				
2006-2007 trend	increasing	increasing	increasing	increasing
2007 Mortality Rate	0.06	0.21	0.21	0.30
2007 Percentile	0.18	0.71	0.61	0.55
Abundance Position vs				
Target	Below	Below	Above	Below
Threshold	Above	Near	Above	Below
SSB Position vs				
Target	Above	Below	Above	Below
Threshold	Above	Above	Above	Above
2008 Surplus Production				
50^{th} percentile mortality	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Positive	Positive	Positive	Positive