Executive Summary of the 2006 Stock Assessment Workshop (8^{th} SAW) for the New Jersey Delaware Bay Oyster Beds

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Haskin Shellfish Research Laboratory – Rutgers, The State University of New Jersey

Status of the Stock

Figure 1 summarizes the condition of the oyster stock throughout the New Jersey waters of Delaware Bay and by bay region in comparison to the 1989-2005 period. 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.

The stock at the end of 2005 presents a mixture of positive and negative indicators that approximately balance. Oyster abundance declined slightly in 2005 to the lowest level since the onset of Dermo disease circa 1989 and to one of the lowest levels in the 1953 to 2005 record (Figure 2). Declines were concentrated on the medium-mortality beds upbay of Shell Rock. Elsewhere, abundance increased and this increase approximately balanced the reduction in abundance on the medium-mortality beds that was anticipated at SAW-7. The expansion of the stock from its consolidation on the medium-mortality beds that has occurred over the last few years through range contraction is a positive sign, although it exposes the stock to a higher level of natural mortality if Dermo disease intensity rises.

Spawning stock biomass is still low bay-wide, but rose in 2005. Increases were noted in all bay regions upbay of and including Shell Rock, reaching or exceeding median levels for the 1990-2005 time period (Figure 3). SSB remained stable on the high-mortality beds. Increases in SSB coincided with increases in condition index, that reached historical highs bay-wide in 2005.

Recruitment remains low bay-wide and particularly low on the medium-mortality beds (Figure 4). Recruitment rose above 50 spat per bushel only on Upper Arnolds, Arnolds, and Bennies Sand. As a consequence of the former two, an above-average recruitment event occurred on the low-mortality beds in comparison to most years since 1991. Evidence exists that low spat abundance is associated with low adult abundance, although the explanation for this trend is controversial. The trend implies, however, that high recruitment may be less likely under current conditions of low abundance. The number of spat per >20-mm oyster was 0.340; insufficient to sustain the present population. The ratio of spat to oysters has been lower than the 2-year replacement level over five of the last 6 years and below that anticipated from the broodstock-recruitment relationship, suggesting that low adult abundance is not a sufficient explanation for the low recruitment of the last few years. The origin of this trend is lower recruitment in comparison to standing stock upbay of Shell Rock. Shell Rock and the high-mortality beds have been recruiting at a level at or exceeding the 2-year replacement level for most of the decade.

Inadequate recruitment upbay of Shell Rock has resulted in a population size frequency deficient in the smaller oyster size classes, particularly on the medium-mortality beds. This year, however, surplus production is expected to permit an increase in market-size abundance bay-wide, given average mortality rates, in the absence of fishing. Surplus production is anticipated to be negative on the medium-mortality beds in 2006, but the reduction in abundance of market-size individuals anticipated should be much smaller than observed in 2005. Positive surplus production will occur in all other bay regions, with a substantial increase in market-size abundance on Shell Rock and downbay, barring a higher than average rate of natural mortality and not counting removals by the fishery. This continues the trend of positive surplus production on these downbay beds, due to high growth rates and relatively good recruitment in an otherwise low-recruitment time period.

Dermo disease continued to be low in 2005 and natural mortality rates were well below average. Natural mortality, bay-wide, was 12% of the stock in 2005, a relatively typical non-epizootic mortality rate (Figure 5). Natural mortality was unusually high on the low-mortality beds. A rising trend in Dermo disease prevalence may presage increased rates of natural mortality in 2006, given facilitative environmental conditions.

The 2005 harvest removed 0.9% of the stock and 1.9% of the spawning stock biomass, with most of the harvest coming from Shell Rock, Nantuxent Point, Hawk's Nest, Bennies, and Cohansey. Fishery exploitation levels since 1989 appear to be very low ($<2\%$ of abundance per year). Recent improvements in collection of fishery-dependent data indicate that exploitation in terms of biomass has been $\leq 4\%$ in the last few years. 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 upbay of Shell Rock continue to be disadvantageous, whereas the remaining bay regions appear to have improved since 2004. Specific target and threshold abundances and spawning stock biomasses were defined for the first time in this SAW. In 2005, for the low-mortality beds, abundance fell below the abundance target set at the median abundance for that bay region during the 1989-2005 time period, and just below the threshold value of abundance, set at half that value (Figure 6). SSB fell above the equivalently-derived SSB target value (Figure 6). For the medium-mortality beds, 2005 abundance values fell below the threshold value; however, SSB fell above the target (Figure 6). Shell Rock abundance fell below the threshold value for this bed and SSB fell near target. Abundance on the high-mortality beds also fell below the abundance threshold, while SSB fell near the target (Figure 6). The fact that all bay regions fell at or below their abundance thresholds indicates that actions to enhance abundance are needed. These are ongoing. A recruitment enhancement program begun in 2005 increased recruitment on Shell Rock and Bennies Sand by about 50%. A pilot program in 2003 has about doubled market-size abundance on Bennies Sand.

2006 Management Goals

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. Two alternatives are provided for setting management goals in each bay region. Since 1998, a constant-abundance reference point has been used successfully for Shell Rock and the high-mortality beds. Under this reference point, fishing allocation is determined by the surplus production of the population in each region. The use of a natural mortality rate above the 50^{th} percentile, such as the 75^{th} percentile, incorporates into this reference point a rebuilding plan than can be expected to increase market-size abundance in most years and which guards against a high level of overfishing in epizootic years. An alternate, exploitation-based reference point also is provided. The exploitation reference point recognizes that the fishery has been successfully prosecuted at relatively low exploitation levels since 1995 and that this record permits the promulgation of an exploitation-based reference point based on the median exploitation rate, defined in terms of the fraction of abundance removed, for each bay region for the years 1996-2005. The exploitation reference point, in particular, provides alternatives for bay regions where transplant options are more likely to be chosen.

Shell Rock and the high-mortality beds have provided most of the fished animals since 1995 because market quality is consistently high. The SARC recognizes the need to manage these beds conservatively. The constant-abundance approach using a projection of surplus production has proven itself in this area and contains adequate precaution. Harvest levels at variance to those suggested by surplus production projections should be considered carefully. Given the importance of Shell Rock in maintaining both the industry and oyster population, the SARC recommends that Shell Rock be independently and more conservatively managed than the high-mortality beds.

The low-mortality beds are best used to replace abundance downbay in support of fishery removals when low recruitment downbay makes transplantation of this upbay resource useful. The present low-abundance period represents such a time. Transplanting options and an exploitation reference point are needed to manage these beds under this circumstance. Transplantation scenarios should be devised to minimize the distance downbay that the animals are moved to permit increased survival of the many juvenile-size animals.

The medium-mortality beds contributed the bulk of the stock supporting the fishery over the 1996-2005 direct-market period, albeit indirectly through transplant to replace animals fished from the beds farther downbay. These beds must be included in the fishery; otherwise the pressure on the downbay beds will be too high. A complex array of options exists to manage these beds. Direct-marketing has proven effective in some years and it is inherently a preferred option as it retains juveniles on these beds where survival is high. Direct-marketing should be encouraged as the management option of choice. Alternatively, market-size animals transplanted downbay might be marketed after a 6-week period to increase market quality. Culling machines can successfully concentrate the larger animals when properly operated, making this a viable option.

Allocation projections based on the constant-abundance reference point

Bay Region	Natural Mortality Percentile	Allocation (market-equivalent bushels)
High-Mortality	75^{th}	1,461
	67^{th}	13,476
	50^{th}	21,880
Shell Rock	75^{th}	13,606
Medium-Mortality	75^{th}	0
Low-Mortality	75^{th}	9,227

Note that the surplus-production option assumes efficient culling of market-size individuals or direct-marketing. Inefficient culling for transplant requires the use of the exploitation reference point presented subsequently, as the constant-abundance reference point assumes removals of market-size animals only. The SARC recommends consideration of a range of harvest levels for the high-mortality beds based on projections using a range of natural mortality probabilities.

Allocation projections based on the abundance-based exploitation reference point

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Efficient Cull or Direct-market Bushels	Population Oysters/Bu	Deck-load Transplant Bushels	Deck-load Marketable Bushel Equivalents
High-Mortality	40^{th}	.03675	4,216,860	15,735			
	50^{th}	.03964	4,548,470	16,972			
	60^{th}	.04396	5,044,170	18,822			
Shell Rock	40^{th}	.05391	2,657,810	9,917			
	50^{th}	.05556	2,739,150	10,221			
	60^{th}	.05600	2,760,850	10,301			
Medium -Mortality	40^{th}	.00806	3,536,180	13,195	179	19,755	6,757
	50^{th}	.01551	6,804,740	25,391	179	38,015	13,003
	60^{th}	.01855	8,138,480	30,368	179	45,466	15,551
Low-Mortality	50^{th}	.00034	84,013	313	182	461	28
	60^{th}	.00176	434,888	1,623	182	2,389	147
	75^{th}	.01507	3,723,730	13,895	182	20,460	1,258

Note that transplanting options are not provided for Shell Rock and the high-mortality beds assuming that these regions will be used exclusively for direct marketing. Note that transplant options will require transplant before the allocation derived therefrom can be set. Note that allocation values obtained from downbay transplants of oysters from the medium-mortality and low-mortality beds will likely fall in between the 'Efficient Cull' column and the 'Deck-load' column for the medium-mortality and low-mortality beds, depending on culling efficiency.

The following chart splits the medium-mortality beds into two groups based on the expectation that direct-marketing is most feasible on Cohansey, Ship John and Sea Breeze.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Efficient Cull or Direct-market Bushels	Population Oysters/Bu	Deck-load Transplant Bushels	Deck-load Marketable Bushel Equivalents
Cohansey, Ship	40^{th}	.00806	2,713,006	10,123	179	15,156	5,679
John, Sea	50^{th}	.01551	5,220,550	19,480	179	29,165	10,929
Breeze	60^{th}	.01855	6,243,950	23,299	179	34,882	13,070
Middle, Upper	40^{th}	.00806	823,174	3,072	179	4,599	1,078
Middle	50^{th}	.01551	1,584,190	5,911	179	8,850	2,074
	60^{th}	.01855	1,894,530	7,069	179	10,584	2,481

Caveats Apropos to Risk for 2007 Fishery Yield

Management options for 2006 provided in the preceding tables permit a relatively wide range of possible 2006 fishery allocations. Increasing Dermo disease and continued uncertainty in recruitment, plus the fact that the shell-planting program will not provide an increase in harvestable resource for 2007 suggests that moderation in setting 2006 allocation goals may be desirable. Specific observations include the following.

1. Consideration should be given to managing the high-mortality beds under the constant abundance reference point with a percentile no lower than the 67^{th} to protect this area against an epizootic. Coincidence of a higher fishing rate with an epizootic would likely result in a significant reduction in the 2007 quota and epizootic mortality rates are possible in 2006.

2. Since 1998, the fishery has rarely exceeded 1.5% of the stock and this has lent stability to the resource and minimized year-to-year variations in allocation. A 1.5% exploitation in 2006 equates to an allocation of 47,793 bu. The surplus production value assuming a median mortality rate (the 50^{th} percentile) for the bay equates to a harvestable quota of 45,640 bushels, very near the 1.5% value. Given anticipated above average mortality in 2006, a quota significantly exceeding the range of 45,000 to 47,000 substantially increases the risk of a quota reduction in 2007.

3. Although the exploitation rate for the low-mortality beds does not realize a significant addition to the 2006 quota, it is important to move animals downbay

from Arnolds/Upper Arnolds to the Shell Rock area to mitigate the effect of the 2006 fishery in this area of the bay. This should be done prior to the season opening and will provide animals necessary to support the fishery in 2007.

4. A drop of SSB below SSB threshold levels while abundance remains at the levels expected to be present at the end of 2006 will likely result in a bay-wide closure. A quota set at 1.5% of the stock will likely remove 3-4% of SSB. That is, the fishery can move SSB closer to the SSB threshold value much more rapidly than it can modify abundance. The tenuous status of abundance in all four bay regions at the end of 2005 argues for conservative management in 2006 to minimize the chance of a decline in SSB and a concomitant bay closure in coming years.

Figure 1. Summary status of the stock for 2005. Green (+) indicates variables judged to be above average. Red (-) indicates variables judged to be below average. Average, indicated by a '0', is defined as within the central 40% of the range of conditions. Judgments concerning trend, e.g., improving, are relative to the previous one or two years. Spatial extent refers to the dispersion of the stock across the salinity gradient.

	Whole Stock		Low Mortality		Medium Mortality		High Mortality	
Spawning stock biomass	-	improving	0	improving	0	improving	0	stable
Abundance	-	stable	-	improving	-	degrading	-	improving
Recruit abundance (spat)	-	stable	+	improving	-	stable	0	stable
Juvenile Abundance (1-2.5 in)	-	degrading	0	improving	-	degrading	0	degrading
CPUE	0	stable						
Growth	+	?						
Dermo infection intensity	+	degrading	+	stable	+	degrading	+	degrading
Condition index	+	improving	+	improving	+	improving		improving
Spat / adult	0	stable	+	improving	-	stable	-	stable
Spatial extent	-	improving						
Natural mortality	+	stable	-	stable	+	degrading	+	degrading
Surplus production @ median mortality	+	improving	+	improving	-	stable	0	stable
Surplus production @ 75-percentile of mortality	-	degrading	+	improving	-	degrading	0	stable

Figure 2. Time series of abundance by bed 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.

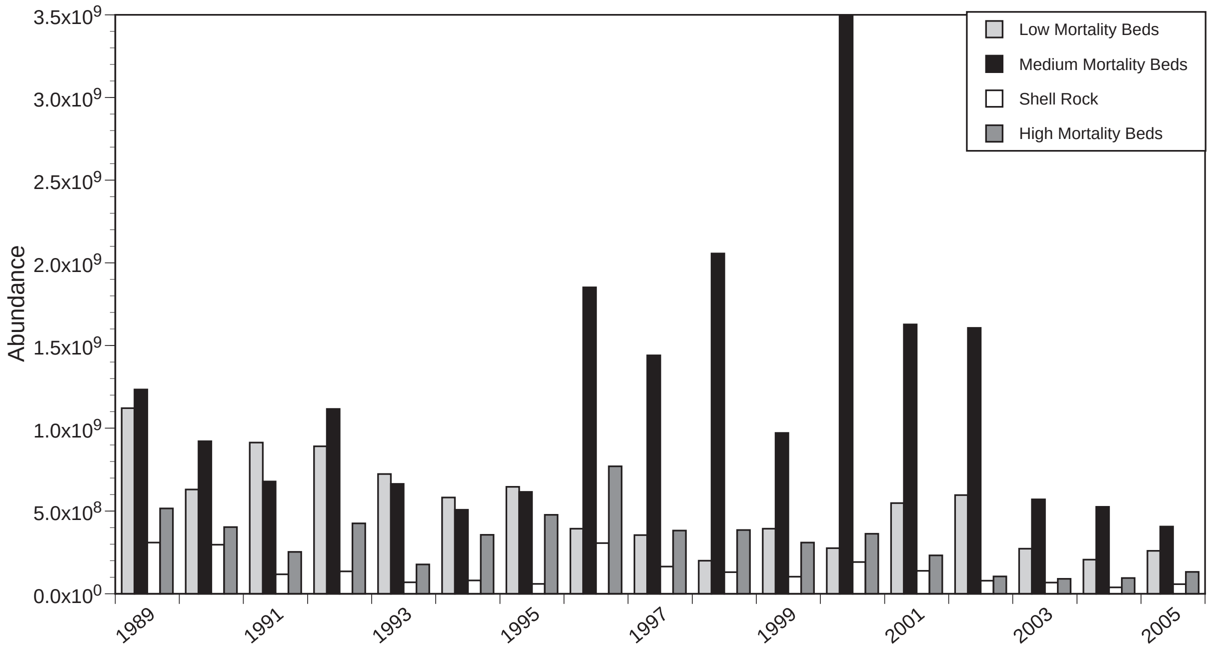


Figure 3. Time series of spawning stock biomass by bed region. Bed distributions by region are given in Figure 1.

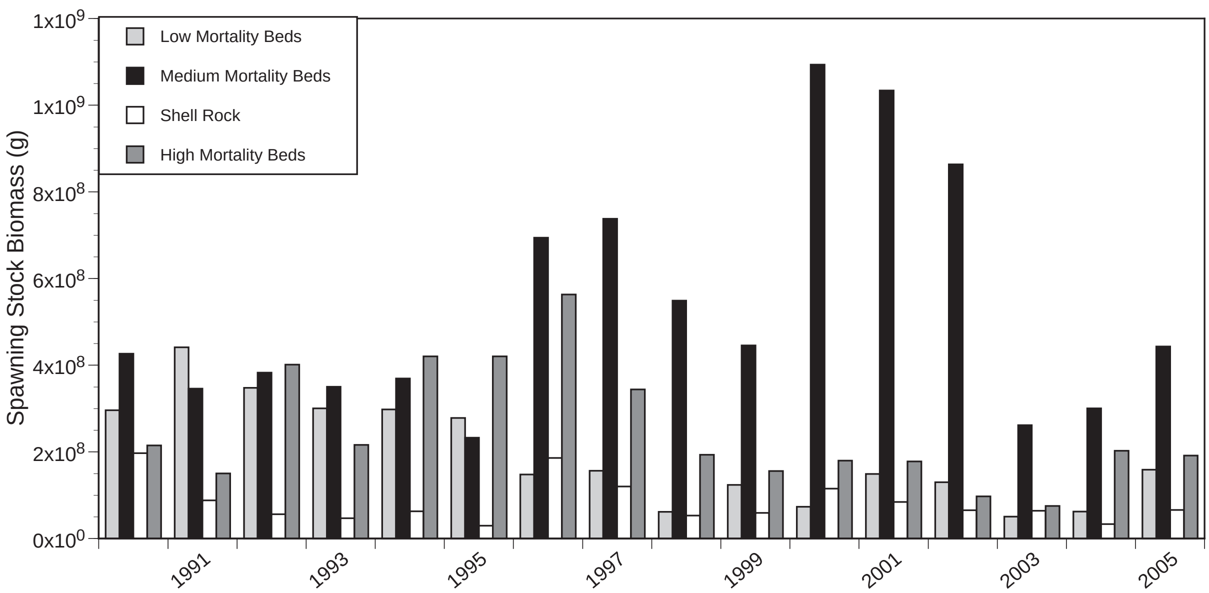


Figure 4. The number of spat recruiting per >20-mm oyster per year on the high- and medium-quality strata. Solid line marks a ratio of 1 spat per adult oyster.

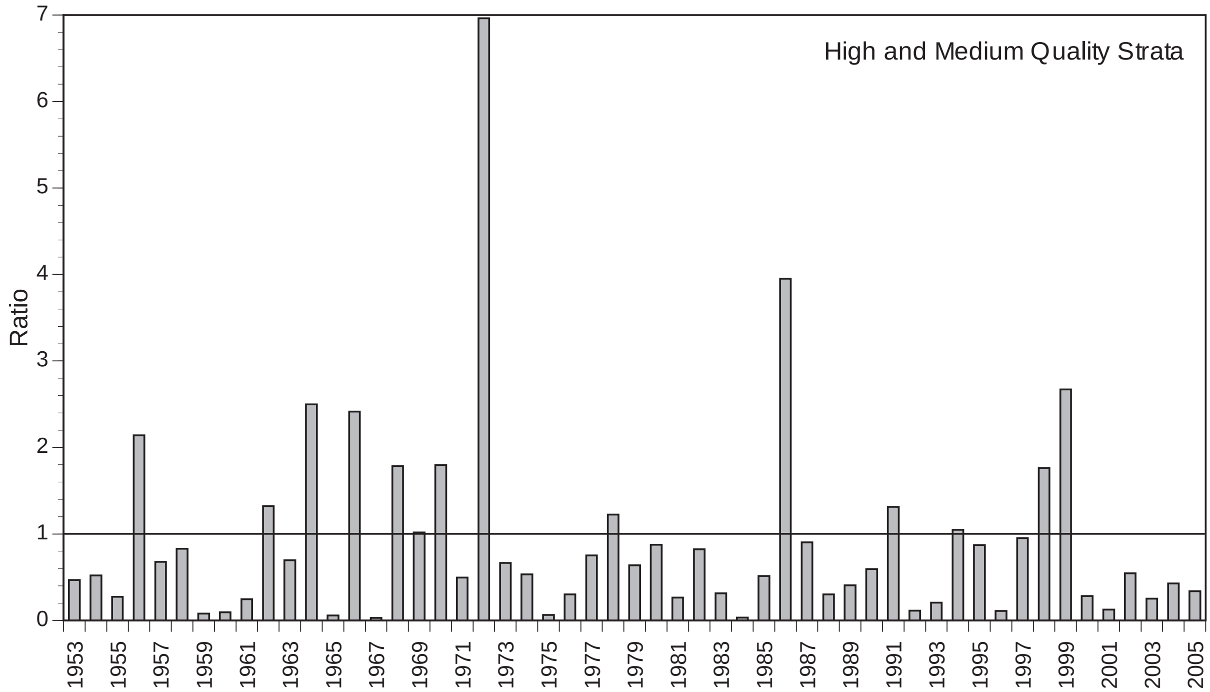


Figure 5. Mean and 2005 box-count mortality on New Jersey Delaware Bay oyster beds, rendered as the percent of beginning year abundance that died. Error bars are 95% confidence intervals.

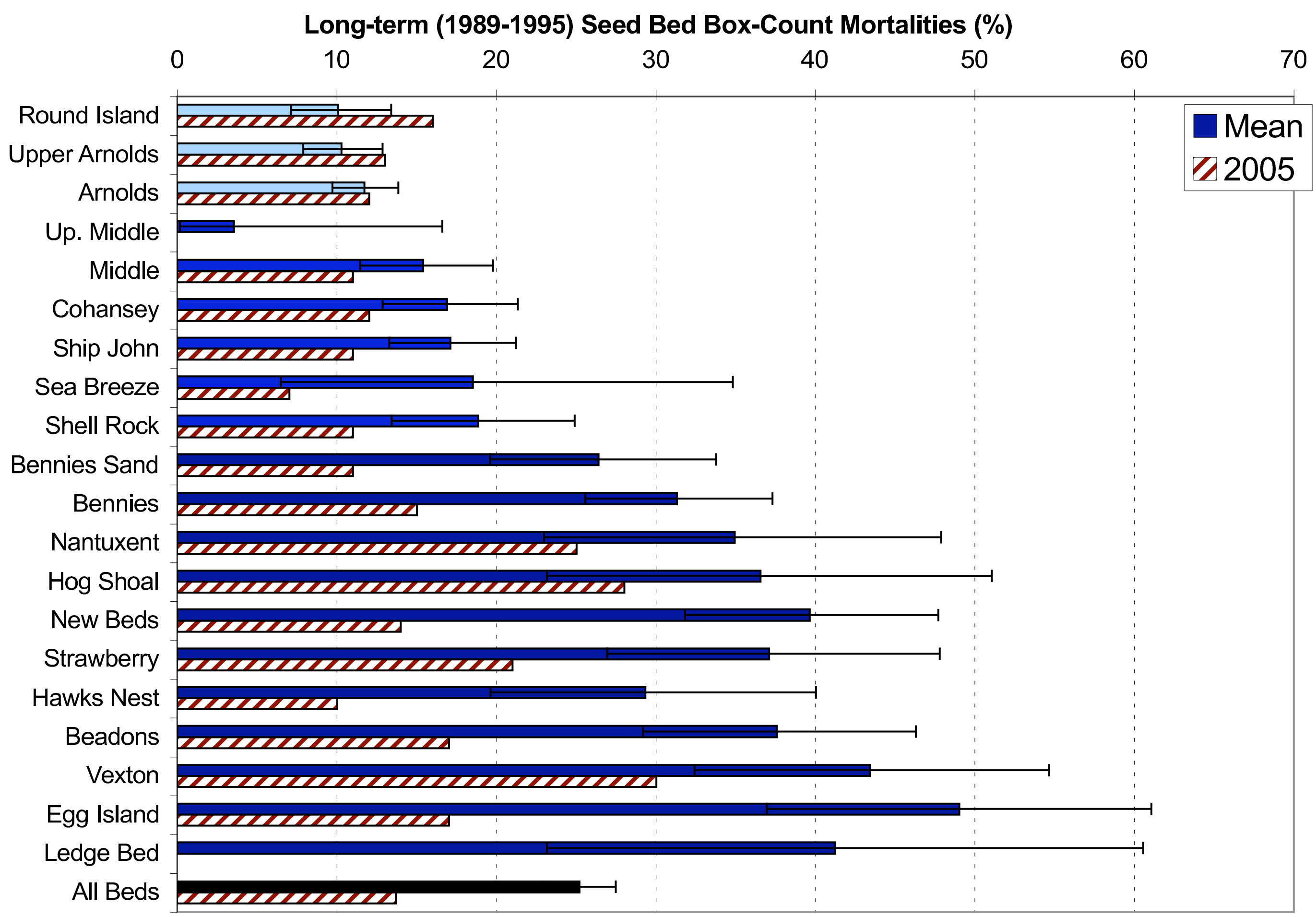
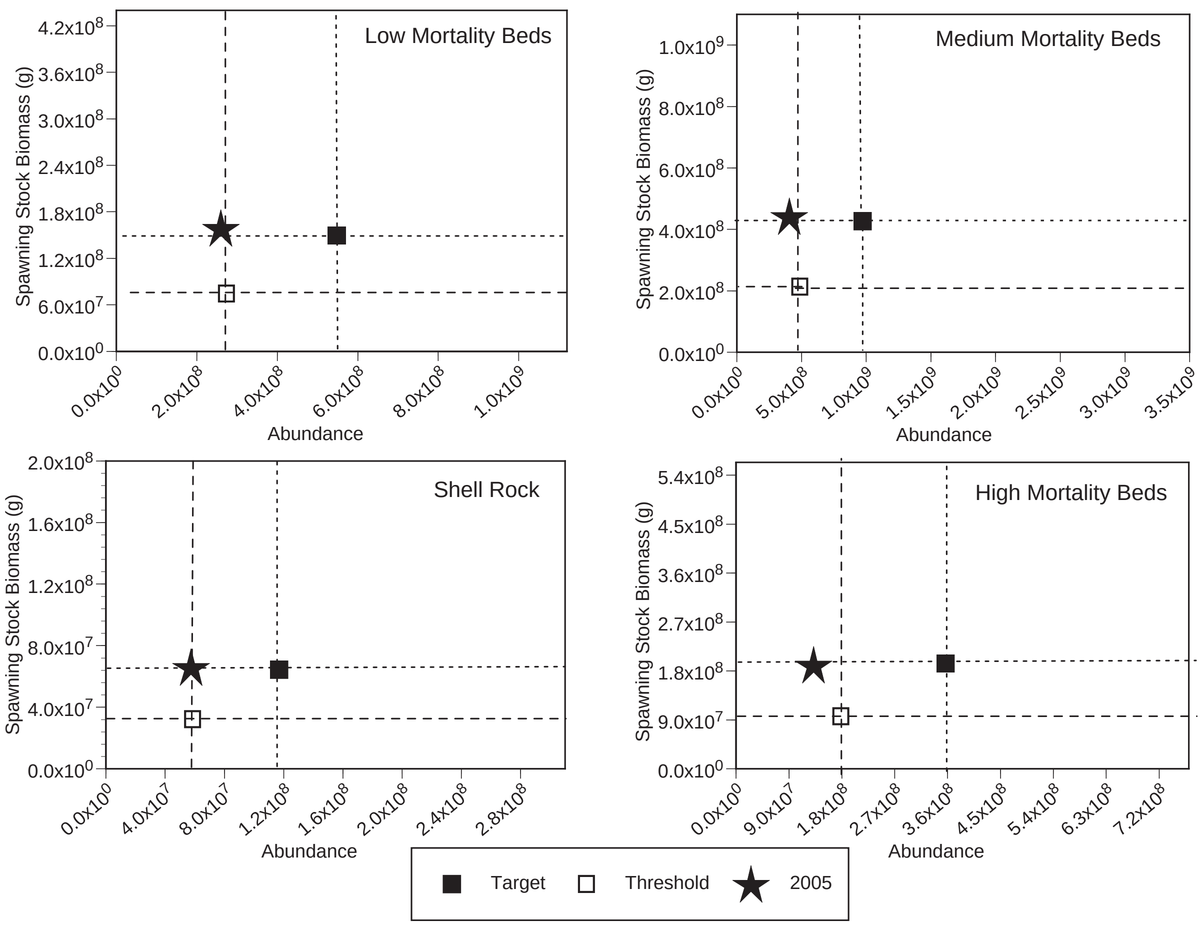


Figure 6. Position of the oyster stock in 2005 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values.



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Introduction

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 a series of 25-acre grids. These grids fall into one of three strata. The strata consist of the bed core (high quality), the bed proper (medium quality), and the bed margin (low quality). For many years, the high-quality areas were considered areas of the bed with a high abundance of oysters 75% or more of the time and the medium-quality areas were considered areas where oysters were abundant 25-75% of the time. In 2005, a re-survey of the beds from Bennies Sand to Middle revealed the necessity to restructure these stratum devisions. In this assessment, 2005 survey data were based on the old stratum system upbay of Middle and downbay of Bennies Sand. In between, the divisions were based on ordering grids within beds by abundance and defining grids cumulatively accounting for the first 2% of the stock as low quality, grids cumulatively accounting for the next 48% of the stock as medium quality, and grids cumulatively accounting for the final 50% of the stock as high quality. The survey consists of about 130 samples covering the primary and most of the minor beds. Each sample represents a composite of 3 one-third bushels from three one-minute tows within each 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 >20 mm from the composite bushel, condition index, and the intensity of Dermo and MSX infections. The data are normalized to a 37-quart bushel, the New Jersey Standard Bushel. Until 1999, the principal data used in management were based on the proportion of live oysters, excluding spat, in the composite bushel, although spat set also entered the decision-making process. Samples continue to be collected and analyzed in the same way; however beginning in 1998, dredge tow lengths were measured and recorded every 5 seconds by GPS navigation during the survey and, in 2000, 2003, and 2005, separate dredge calibration studies were undertaken to determine dredge efficiency. These new data are integrated into the regular sampling results to estimate the total numbers of oysters per square meter and the numbers of oysters in different size classes present on each bed. This improvement was added to the survey, at the recommendation of the Oyster Industry Science Steering Committee, because of concerns about management of the direct-market program that was initiated in 1996. Prior to that time, the beds had been used principally as a source of seed for transplanting to leased grounds and the semi-quantitative survey worked well.

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.

Status of Stock and Fishery

Historical Overview

From 1953 to 2005, the bay-wide mean number of >20-mm oysters per bushel was about 263. The highest numbers of oysters were on the beds upbay of Shell Rock and the lowest numbers were on the two most downbay beds, Egg Island and Ledge (Table 1). During the past 1.5 decades since Dermo became prevalent in the bay (1989 to 2005), the bay-wide overall mean of 137 oysters/bu., about half the long-term average, has varied little, and the changes, with the exception of the extremes (1989, 1992, 1994, and 2004), have not been statistically significant (Figure 2). Throughout this report, except where noted, present-day conditions will be compared to these two periods of time, the 1953-2005 period encompassing the entire survey time series and the 1989-2005 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 1989-2005 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. Three exceptions exist to the dependency on the 1989-2005 time series. All size-dependent indices begin in 1990 when size frequencies were first measured in survey samples. Evaluation of fishery exploitation by abundance is focused on the 1996-2005 time period during which the fishery has been conducted under a direct-marketing system. Biomass-dependent fishery time series begin in 2004 at the beginning of the dock-side monitoring program[⊙].

The 1953-2005 bay-wide mean number of spat/bu. was 176, with the greatest set of 1700+ spat/bu. occurring in 1972 (Table 1). Since 1988, the bay-wide average has been 83 spat/bu., slightly less than half the long-term mean. The long-term (1953-2005) average box-count mortality is approximately 15% (Table 1). The

[⊙] Because of the change in survey footprint in 2006, 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 report of SAW-7. Values reported herein are considered to be improvements in accuracy and should be used in lieu of the SAW-7 values.

appearance of Dermo in the bay has increased the average mortality for the last decade and a half to 18%, and in some years the mortality has exceeded 30%. Thus, both abundance and recruitment have averaged significantly lower since the onset of Dermo, while natural mortality rate has averaged higher.

The maximum seed volume removed from the beds by the industry since the onset of Dermo occurred in 1991 when nearly 300,000 bushels were transplanted to leased grounds. This is typical of the MSX period from the 1970's to the mid 1980's, when 300,000 to 450,000 bu. per year were transplanted to the lower bay leased grounds (Figure 3). Since the direct landing of market-size oysters from the beds was instituted in 1996, the greatest landing occurred in 1998 (136,000 bu.). The average yearly landing since 1996 has been 71,715 bu.

Survey Design

The survey has been conducted as a random survey of the primary oyster beds, of which there are 20 (Figure 1), since 1953, with embedded strata defined by differences in abundance in the random design for much of that time. Each bed is divided into $0.2''$ latitude $\times$ $0.2''$ longitude grids, approximating 25 acres in area. Each of these grids is assigned to a specified stratum and a subset of grids, randomly selected, is chosen each year for survey. Prior to 2005, these strata were based on an historical evaluation of relative abundance: the high-quality areas were considered areas of the bed with a high abundance of oysters 75% or more of the time; medium-quality areas were considered areas where oysters were abundant 25-75% of the time; and low-quality areas were considered areas where oysters were abundant less than 25% of the time. Through 2001, a selection of beds was sampled yearly, and the remainder mostly minor beds were sampled every other year. Beginning in 2002, sampling intensity was revised within the same stratum system on a number of beds to better reflect their utilization by the fishery, and, to provide more accurate estimates of oyster abundance, fewer important beds were sampled in alternate years.

Beginning in 2005, two important changes occurred. First, beginning in 2005, all beds were sampled each year with the exception of Egg Island and Ledge that will continue to alternate due to their consistent low abundance. Second, the area between Middle and Bennies Sand was re-surveyed in 2005 and this re-survey resulted in a change in stratum definition and survey design.

The spring 2005 re-survey of the area from Bennies Sand to Middle included all 25-acre grids sampled that were navigable except for a suite of high- and medium-quality grids that had been routinely included in previous surveys. For these latter, a selection were re-sampled for comparison to the Fall 2004 survey. Excluding these, the remainder of the sampled grids consisted of all previously designated low-quality grids and a number of grids not in the pre-2005 footprint depicted in Figure 1. Each of the new grids, those not in the grid system as defined prior to 2005, 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 300 grids were sampled over a two-week period.

Preliminary evaluation of the distribution of catches among grids revealed that a large number of grids could be deleted if the survey was focused on the grids that support 98% of the stock.

Middle exemplifies the fact that 2% of the stock is scattered across a relatively large number of depauperate grids (Figure 4). These grids were assigned to a 'low-quality' stratum. 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. For this comparison, samples from recent fall surveys were included by correcting spring samples for a fall-to-spring change in dredge efficiency using: $corrected\,abundance = 1.85 * spring\ abundance$. 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 are defined 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' grid stratum (Figure 4). The new high-quality stratum generally includes most grids originally assigned to the high-quality stratum used prior to 2005 and a few of the old medium-quality grids. The medium-quality stratum generally includes some of the old medium- and low-quality grids plus a number of new grids. Figure 5 shows the revised bed footprint defined by the high- and medium-quality strata for these beds.

Sampling density for the fall survey for the six beds included in the spring survey was also determined through the Monte Carlo simulation (Table 2). The October 2005 survey was then constructed by randomly choosing a designated number of grids from each stratum on each bed. For the beds surveyed in Spring 2005, all samples were allocated to the new high-quality and medium-quality strata. For the remaining beds, the old three-stratum sampling design was retained.

Total sampling effort in 2005 was 130, a value about 20 samples larger than most previous surveys (Figure 5). These included 6 transplant grids selectively sampled because they were sites of shell plants: Bennies Sand 10 and 11 and Shell Rock 4, 12, 25, and 43.

In 2005, a few additional dredge efficiency measurements were made for grids involved in the 2005 shell-planting program. These additional measurements conformed to the suite of measurements used in 2003. As a consequence, the 2000/2003 average dredge efficiencies were used in the quantitative determination of abundance, as has been done since 2003 (Table 3).

Oyster Abundance

Analytical Approach

Sampling in 2005 was conducted from October 24 to October 31, 2005 using donated time on the oyster dredge boat *F/V Howard W. Sockwell* with Larry Hickman as Captain. Samples were collected from the standard random stratified grid system on each of the major seedbeds and all minor beds except Ledge (Figure 5). An additional stratum "transplant" was added to assure that oysters recruiting to 2005 and 2003 shell plants were explicitly accounted for in the estimation of recruitment and abundance.

The data that follow are presented in three ways. (1) Data are presented in terms of numbers per 37-qt bushel. This is the datum used historically since the inception of the formal stock survey in 1953. Bay-region averages are obtained by the averaging of survey samples per bed, summed over the beds in any bay-region group. (2) Since 1998, swept areas have been directly measured, permitting estimation of oyster density. Bay-region point-estimates are obtained by averaging the per-m^2 samples per stratum, expanding these averages for each bed according to the stratum area for that bed, and then summing over the beds in any bay-region group. 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 included only in some time-series analyses where indicated as restricted sampling in this stratum limits the accuracy of single-year abundance estimates. For the Bennies Sand-to-Middle reach, exclusion of the low-quality grids underestimates abundance by approximately 2%. Judging from the targeted spring survey of this bay region, the underestimate of abundance elsewhere in the bay is likely to be considerably larger. (3) In 2005, the 1953-1997 survey time series was retrospectively quantitated. Data including this retrospective analysis will be termed 'time-series estimates' throughout this report. These estimates were obtained by using bed-specific cultch density determined empirically from 1998-2005. This quantification assumes that cultch density is relatively stable over time. Comparison of retrospective estimates for 1998-2004, obtained using the 'stable cultch' assumption, with direct measurements for 1998-2004 suggests that yearly time-series estimates prior to 1997 may be biased by a factor of ≤ 2 because cultch can vary with input rate from natural mortality and the temporal dynamics of this variation are unknown. While this is not a trivial error, it is much less than the error that would occur if the time series were not reconstructed to account for dredge efficiency and area-weighting for the dispersion of survey samples. 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 average of dredge efficiency measurements made in 2000 and 2003. The size-class-specific dredge efficiencies were applied whenever size-class data were analyzed. The differential in dredge efficiency between the upper and lower beds was retained in all cases (Table 3).

Throughout this report, oyster refers to all animals >20 mm. Animals $\leq$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 bed- and year-specific regressions between dry weight (g) and shell length (mm). Market-size animals are animals $\geq$75 mm. Submarket size classes are variously defined depending on growth rates and analytical goals as indicated.

Abundance Trends

Because oysters are being sampled along a salinity gradient that reflects spat set, predation, disease, and growth, combining the data into bay-wide averages results in high variances. Since 1989, the natural oyster beds have experienced a two-fold fluctuation in the number of oysters per bushel, but, with the exception of the two highest and lowest values, no statistical differences (Figure 6). The bay-wide average number of 114 oysters/bu. in 2005 was statistically the same as for most of the 1989-2005 period, but 43% lower than the long-term average of 263 oysters/bu.

Quantitative estimates using the time-series analysis indicate that oyster abundance summed across all strata and bay regions declined slightly in 2005 to 907,326,400 from the 2004 estimate of 917,046,464. About 94% of the oysters, 853,916,000, were found on the medium- and high-quality strata. The 2005 point estimate obtained directly from the quantitated survey using size-specific dredge efficiencies was somewhat higher, 895,386,408. In 2005, abundance was at the 3^{rd} percentile of the 1953-2005 time series and was the lowest value observed post-1988 (Figure 7).

Beds in the low-mortality and medium-mortality segments of the bay (see Figure 7 for bed groupings) continue to support relatively high oyster abundance (Table 4). Most of these beds (except Upper Middle) have > 150 oysters/bu. In 2005, oyster abundance on beds in the medium-mortality and high-mortality segments of the bay remained about the same as the prior year with Shell Rock and Bennies Sand having >150 oysters/bu. All beds sampled in the high-mortality region have increased numbers of oysters (Figure 8, Table 4), although abundance by this measure was not significantly different from most other years in the 1989-2005 period (Figure 9).

Quantitative estimates confirm that most oysters were on the medium-mortality transplant beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 7). Abundance on these beds ranked at the 8^{th} percentile of the 53-yr time series and the lowest value post-1988. In comparison, abundances on the low- and high-mortality beds and Shell Rock rose in 2005. These ranked at the 10^{th}, 20^{th}, and 18^{th} percentiles, respectively, for the 53-year time series and at the 18^{th}, 10^{th}, and 25^{th} percentiles post-1988. Abundance in 2005 on the high-mortality beds rose from 2004, by a factor of 1.39 (Figure 10). This is the second consecutive year abundance has increased on these beds. Abundance rose substantially as well on Shell Rock (by 1.53) and on the low-mortality beds (by 1.26). Abundance declined by 23% on the medium-mortality transplant beds. This decline was expected based on 2004 surplus production projections by SAW-7.

Round Island deteriorated markedly (>60%) this year with fewer grids supporting high oyster abundance (Table 4). Unlike the remainder of the beds, this bed has not received a significant recruitment event since 1990; as a consequence, abundance has declined more or less continuously for the last 14 years. In contrast, abundances on the two beds immediately downbay rose and recruitment was relatively high in 2005 for the 1989-2005 time period. Low salinities over the last few years may be partially responsible for declining abundance on Round Island.

Elsewhere, changes in abundance between 2004 and 2005 per bed were as anticipated by regional trends, with one exception. A 2003 surf-clam shell plant on Bennies Sand 10 has produced an estimated 13,393 marketable bushels of oysters for 2006. These animals were obtained from an initial shell plant at Reed's Beach and subsequent replant on Bennies 10 of 16,000 bu. of surf-clam shells in 2003. About 58% of marketable oysters on Bennies Sand in 2006 originated from this 2003 shell plant.

Spawning Stock Biomass (SSB)

Spawning stock biomass increased in 2005, continuing a trend begun in 2003 (Figure 11). SSB remained essentially unchanged on the high-mortality beds, but increased by a factor of 1.99 on Shell Rock, by 1.47 on the medium-mortality (less Shell Rock) beds, and by 2.56 on the low-mortality beds. SSB was above average bay-wide and at the 67^{th}, 56^{th}, 67^{th}, and 44^{th} percentiles for the low-, medium- (less Shell Rock), Shell Rock, and high-mortality beds, respectively.

Oyster Size Frequency

The percentage of $>2.5''$ oysters exceeded 50% on all high-mortality beds, except Bennies Sand, New Beds, and the inshore regions comprising Nantuxent Point, Hog Shoal, Hawk's Nest, and Beadons. All medium-mortality beds had $>60\%$ of the oysters $>2.5''$ (Table 4). The general trend for a proportional increase in large oysters continued upbay of Bennies Sand. Since 1988, the percentage of oysters $>2.5''$ has been in the 15% to 20% range on all of these beds. The recent increase in this percentage is primarily due to low recruitment rather than unusually high mortality. That is, the number of smaller oysters has declined as these animals have grown to $>2.5''$ in size or have died, and these small oysters have not been replaced by new recruits.

In 2004, all inshore beds had low oyster abundance and a high percentage of oysters $> 2.5''$ (Tables 4 and 5). Low abundance continued in 2005, although abundance was generally higher, but the percentage of large oysters has declined from last year. Because the number of large oysters per bushel increased slightly on these beds and the percentage of small oysters also increased, either survivorship has been high for the modest sets of the past few years or some of this year's set has been counted as oysters rather than spat. Numbers of submarket oysters ($2.5''$-$3''$) remained about the same in the medium-mortality and high-mortality beds in the past year, but there is a slight but non-significant trend downward (Figure 12). Conversely, the 5-year upward trend in number of oysters $>3''$ continued in these areas. The percentage of oysters $\geq 3''$ also continued its 5-year increase on the medium-mortality beds (Figure 13). The $2.5''$-to-$3''$ size category as a percentage of the total has remained static in the medium-mortality region and continued its 4-year downward trend in the high-mortality region. This reflects the poor spat set of the last six years.

The medium-mortality region, viz., Cohansey, Middle, Ship John, Sea Breeze, and Upper Middle, supplied a majority of the market oysters in 2004, but only 18% of the product in 2005. The numbers of $\geq 3''$ oysters on the beds supplying the bulk of the 2005 fishery, Shell Rock, Nantuxent Point, Hawk's Nest, Bennies, Cohansey, and Ship John, increased from last year (Table 4). Focusing on the high-mortality beds plus Shell Rock, in 2004 the percentage of total oysters in the $>2.5''$ size class was 50% or greater on all beds below Cohansey except for Sea Breeze. In 2005, this pattern changed by including Middle as a bed with $>50\%$ oysters above $2.5''$, but below Bennies Sand there was a general drop in the dominance of large oysters and only Bennies, Strawberry, Vexton, and Egg Island retained the dominance of large oysters. Even on these beds, the percentages were reduced.

The early spat set and the good growth this past year resulted in at least some spat exceeding 20 mm. Figure 14 shows representative size-frequency distributions for a shell plant on Shell Rock 43. At least some of these larger spat on native shell were probably measured and classified as oysters. Since growth rates are generally higher downbay of Shell Rock, this effect would be more pronounced in this region. Recalculation of the numbers of oysters and spat, classifying all 20-35-mm oysters as spat, resulted in a 44% increase in the bay-wide mean spat abundance from 29 to 42 spat/bu. and a 22% reduction in oyster abundance from 114 to 101/bu.; however, the relative positions of 2005 within the spat and oyster time series (Figure 6) remained virtually unchanged.

Oyster Condition and Growth

On a bay-wide basis, condition index increased markedly in 2005 (Figure 15, Table 4) to the highest level recorded since 1990 when the measurement of condition index was added to the survey, and the increase was similar in all areas of the bay. The gradient in condition from greater condition in the more saline areas to poorer condition in the less saline areas remained (Figure 16).

A shell plant on Bennies Sand 10 in 2003 provided an opportunity to evaluate growth in this bay region (Figure 17). Growth rate was much higher in 2005 than in 2000. Animals of 2.33″ are expected to reach market size by the 2005 measure versus 2.56″ for the earlier determination. Growth data provided by the Bayshore Discovery Project for animals held in the water column near Bayside suggests that growth rates were also higher upbay than observed in 2000.

Surplus Production

Surplus production is defined in this treatment 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 a comparison 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)[⊕].

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

Assuming a 50^{th} percentile of natural mortality rate, market-size abundance is expected to increase in 2005 bay-wide by 45,640 bushels (Table 6). Surplus production is positive; that is the number of market-size animals is expected to increase in three of four bay regions, the low-mortality and high-mortality beds and Shell Rock, by 55,734 bushels *in toto*. Market-size animals on the medium-mortality beds are anticipated to decline in abundance by 10,094 bushels, a change only of 1.6%.

A Dermo epizootic, simulated using the 75^{th} percentile of natural mortality, would reduce abundance bay-wide in 2006. Nevertheless, even at the 75^{th} percentile of natural mortality, abundance would increase in three of four bay regions, not counting removals by the fishery. However, as the medium-mortality beds upbay of Shell Rock dominate bay abundance, a bay-wide decline still would occur due to declining abundance on the medium-mortality beds upbay of Shell Rock.

An unbalanced size-frequency distribution has been present on the medium-mortality beds for a number of years, sustained by six years of low recruitment. That is, an insufficient number of smaller animals have been present during this period to replace the larger animals dying from natural causes. The 2005 size-frequency distribution is not sustainable under normal natural mortality rates either. Too few small animals will be present on these beds in 2005 to replace, through growth, those larger animals that are expected to die. Calculation of surplus production over a wide range of mortality rates indicates that abundance can be expected to decline on these beds in 2006 without fishing.

Spat Set

Spat set in 2005 was nearly identical to that of 2004 and was still poor (Table 4, Figure 18). 2005 continues a sequence of poor setting years for an unprecedented sixth consecutive year (a similar, but not as severe trend occurred from 1959 to 1963) (Figure 19). The bay-wide 2005 spat count (mean = 29/bu.) was far below the long-term mean of 180 spat/bu., and well below the 83 spat/bu. post-1988 long-term mean.

No bed achieved a spat set of 100/bu. and spat set was 50/bu. or higher on only three beds: Upper Arnolds, Arnolds, and Bennies Sand. Spat set on the low-mortality beds (Arnolds, Upper Arnolds, and Round Island) was 14 to 61/bu., terminating, with the exception of Round Island, an unprecedented period of set failure that commenced in 1991 on these beds. Typically, some of the inshore beds of the high-mortality region (Nantuxent, Hog Shoal, Strawberry, Hawk's Nest, Beadons and Vexton) receive a good set, but this did not materialize in 2005.

Quantitative estimates of spat set confirm that the 2005 set was low bay-wide, making the sixth year in a row of poor settlement (Figure 19). Total recruitment was highest on the high-mortality beds, in part due to the areal contribution of this bay region to total bed area. The 2005 spat settlement ranked at the 10^{th} percentile for the 1953-2005 time series and at the 10^{th} percentile post-1988.

The number of spat recruiting per oyster dropped somewhat from 2005 and continued to be very low, 0.340 spat per oyster. The ratio has been below 0.50 since 2002 and below 1.0[♮] since 1999 (Figure 20). A breakdown by bay region reveals that the ratio was particularly low for the medium-mortality beds, 0.184 (Table 7). The ratio for Shell Rock was 0.471 and the ratio downbay of Shell Rock was 0.808. The ratio has been above 0.80 on the high-mortality beds and on Shell Rock in all but three years since the direct-market program began. The ratio has been below 0.50 on the medium- and low-mortality beds since 1999. Thus, the low recruitment rate bay-wide is due primarily to low recruitment in the areas of the bay receiving the least amount of fishing pressure, as measured by dredged swept area, over that time period.

Recruitment enhancement programs were successful in 2005, raising the ratio of spat to oyster on Shell Rock from 0.471 to 0.991 and on the high-mortality beds from 0.808 to 0.905. Shell was planted on Shell Rock and Bennies Sand using oyster, ocean quahog, and surf-clam cultch. Three-year harvest projections, highly uncertain, suggest that about 52,000 bushels of oysters may be produced by the 2005 enhancement program (Table 8).

A spat monitoring program was initiated in 2004 and continued in 2005. The 2005 program showed the anticipated trend of greater spat availability downbay (Figure 21) and a much higher setting potential than in 2004. The spat monitoring program suggested two recruitment waves occurred in 2005, one early, in July, and another later, in August/September (Figure 21). This two-wave hypothesis was confirmed from size-frequency distributions of spat on shell plants that typically showed bimodal distributions (Figure 14).

Cultch Trends

Time series of cultch shows a downward trend on most beds, particularly after 2001 (Figure 22). This trend coincides with a declining trend in abundance and recruitment. This trend is not followed by the time series of the ratio of oysters to cultch, even after taking into account the varying dredge efficiencies of the two particle types. That is, a decline in oyster abundance is followed reasonably closely by a decline in cultch abundance. An inference is that the 'life span' of cultch is

[♮] A ratio of 0.5 assumes a mean generation time of 2 years; that is, the population must replace itself every two years to sustain abundance. The mean generation time for Delaware Bay oysters is unknown, but is likely in the range of 2-4 years for most of the bay region.

limited, and cultch stores require persistent renewal through death of live animals. At times of low abundance, cultch will also decline. Cultch half-life estimates for these beds vary, in most cases, from 2 to 6 years⋆.

Mortality and Disease

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 2005.

A targeted experiment in 2005 to verify MSX disease resistance on low-salinity beds where susceptible animals might find refuge revealed that most animals, even at this extreme of the range, were MSX resistant (Table 9)⊖. Concerns raised at the 7^{th} SAW about transplanting animals downbay from the low-mortality beds are alleviated by these results.

In general, Dermo disease* and mortality increase downbay as salinity increases. A regression between Fall Dermo disease and mortality explains approximately 42% of the variation in mortality among beds since 1990 (Figure 23). The y-intercept for this regression is just below 10%, indicating that background (non-disease) box-count mortality is about 10%.

⋆ Half-life estimates were derived by solving the equation $\frac{dC}{dt} = (addition - loss)C$, where additions are estimated by box volumes, C is the concentration of cultch, and t is time. With the loss term known, the fate of cultch for any given year C_o can be estimated from $\frac{dC_o}{dt} = -loss$ and this time series provides the solution to the half-life equation: $log(f) = \frac{-.301t}{T}$, where f is the fraction remaining after T half-lives.

⊖ Samples of 400 oysters each were collected from Arnolds, Shell Rock, the Cape Shore flats, and Maine. These oysters respectively represent three stocks that historically experienced increasingly greater selection by MSX (maximum MSX infection prevalence in most of Delaware Bay has been 30% since 1989, and <10% on the upbay beds, e.g., Cohansey and Arnolds, since 1992) and a naive stock that has never been exposed to MSX. Each sample was divided equally between two replicate plastic mesh bags and deployed on the Rutgers lease in Cape May Harbor in May 2005 where oysters have been regularly exposed to MSX infections in recent years, but where Dermo infections have been very light. Mortality was monitored throughout the summer and oysters were sampled (n = 20 per stock) in July, September, and October 2005 for MSX infection.

* The percent of oysters in the sample with detectable infections is termed the 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 2005 disease monitoring program is available as an HSRL report: Bushek, D. 2005. Delaware Bay Oyster Seedbed Disease Monitoring Program 2005 Status Report.

In 2005, the prevalence and infection intensity of Dermo increased from 2004 and approached or exceeded long-term means on most beds (Figures 24 and 25). The low-mortality beds (Round Island to Arnolds), where Dermo was not detected, were a striking exception verifying that disease and mortality processes in this region are distinct from other beds.

In 2003 and 2004, summer water temperatures were cooler than normal and watershed runoff was higher than normal. The increased flow of freshwater probably decreased disease transmission while cooler temperatures likely reduced proliferation rates within infected oysters. These conditions reduced Dermo below detectable levels on the upbay beds during 2005 (Figure 24). Residual infections remained on beds below Arnolds and higher salinities and temperatures during 2005 encouraged proliferation of Dermo on those beds. Fortunately, Dermo did not reach levels sufficient to increase mortality during 2005 and mortality levels remained well below long-term means. Unless current Dermo levels are considerably reduced or inhibited from proliferating by favorable environmental conditions (i.e., low temperature and low salinity), Dermo-related mortalities are likely to increase in 2006.

Since the onset of Dermo disease in 1990, three epizootics, most of them multi-year, have occurred (Figure 26). Prevalence provides the clearest signal with peaks in 1993, 1999, and 2002. Since Fall 1990, prevalence greater than 80% or weighted prevalence approaching 2.0 has corresponded to mortalities exceeding 25%. In 2005, Dermo levels were below these thresholds and mortality was near the lowest levels recorded for this period (Figure 27). Dermo levels are increasing, however, and Dermo-induced mortality is likely to increase next year unless environmental conditions inhibit further development.

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. Quantitative areal estimates of box-count mortality were 12% bay-wide in 2005. This is a slight drop from 2004 and well below epizootic mortality levels. In 2005, box-count mortality was at the 50^{th} percentile of the 53-yr time series and the 32^{nd} percentile post-1988. Quantitative estimates confirmed that box-count mortality dropped for the third consecutive year on the high-mortality market beds, coming in at a third of the rate observed in 2002. Box-count mortality was 23.1% on the direct-market beds, a value at the 17^{th} percentile of the 53-year time series and at the 25^{th} percentile of the post-1988 time series. Mortality declined upbay. Box-count mortality on the medium-mortality beds was 10.5%, a value slightly lower than observed in 2004. The 2005 level of mortality was at the 54^{th} percentile for the 53-year time series and the 38^{th} percentile for the post-1988 time series. Quantitative estimates of box-count mortality confirmed a slight increase in mortality on the low-mortality beds in comparison to the 1999-2003 time period, but about the same level as in

2004. The 2005 level of mortality, 12.6%, is at the 75^{th} percentile for the 53-year time series and at the 74^{th} percentile for the post-1988 time series. An explanation for this high rate of mortality is not available; Dermo disease was not responsible.

Quantitative estimates of abundance, recruitment, and box-count mortality expressed numerically permit an estimate of unrecorded mortality. The equation

$$\begin{aligned} &Beginning\,Year\,Abundance + Recruitment \\ &\qquad - Box\text{-}Count\,Mortality - Fishing\,Mortality \\ &\qquad = End\text{-}of\text{-}Year\,Abundance \end{aligned}$$

should be in balance. Typically, the left-hand side overestimates end-of-year abundance because a certain fraction of mortality is unaccounted for by box counts. Much of this unrecorded mortality is likely juvenile mortality•. In 2005, the amount of unrecorded mortality increased downbay (Table 10), presumably indicating the increased survivorship of juveniles at lower salinity. As well, the trend may in part accrue from a shorter half-life of boxes at higher salinity. Most of the bay regions had unrecorded mortalities near the 50^{th} percentile.

Population Dynamics Trends

Broodstock-recruitment, abundance-mortality, and mortality-recruitment relationships were updated. The broodstock-recruitment diagram (Figure 28) suggests that present-day abundance may limit reproductive potential. However, oyster larvae tend to set preferentially on live oysters, so that one cannot exclude the possibility that broodstock abundance modulates settlement success. Nevertheless, neither possibility offers a likely explanation for six consecutive years of very low recruitment, as other years with abundances in the 2000-2005 range have provided a much higher number of spat per >20-mm oyster (Figure 20, also compare Figures 7 and 18). The 53-year average recruitment rate expressed as the number of spat per >20-mm oyster per year is 0.965. Since 1988, the same long-term average has been somewhat lower: 0.712. The long-term likelihood of a one-year population replacement event, 1 spat per >20-mm oyster, is 17 of 53 and a recruitment rate half that high occurred in 27 of 55 years. Since 1988, the same two probabilities, 6 of 17 and 8 of 17, are not significantly different, so that the expectation of a respectable recruitment event remains approximately 50%. In contrast to these longer-term trends, a recruitment event reaching 1 spat/oyster has not occurred since 1999 and a level of 0.5 has occurred only once, in 2002. Thus, spatfall since 1999 has been well below the level anticipated from broodstock abundance.

• The calculation subsumes all sources of error into this variable, including survey errors for all measured variables such as abundance and box counts. Accordingly, the estimate of unrecorded mortality should be considered of low accuracy.

Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about half of the years since 1989 (Figure 29). Non-epizootic years tend to average around 10% mortality. The bay-wide average for 2005 was 12%, a non-epizootic mortality rate. Geographic contraction of the stock, an ongoing process since 2002, ceased in 2005. Over the previous few years, the stock had become increasingly concentrated in the central part of the bay where mortality rates tend to be moderate. This should reduce total mortality rate and therefore decrease the chance of epizootics at low abundance (Figure 29). In 2004, 63.6% of the stock was on the medium-mortality beds above Shell Rock (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle), 21.7% on the low-mortality beds (Arnolds, Upper Arnolds, Round Island), 5.7% on Shell Rock, and 9.1% on the high-mortality beds. In 2005, 30.4% of the stock was on the low-mortality beds, 6.7% on Shell Rock, and 15.4% on the high-mortality beds, all substantial increases over 2004. A lower fraction, 47.5%, was present on the medium-mortality beds upbay of Shell Rock. Some portion of this shift was due to declining abundance on these medium-mortality beds, but much of the change was due to increased abundance at the low- and high-salinity edges of the stock's range.

A relationship between box-count mortality and recruitment continues to be poor (Figure 30). Little evidence exists that disease routinely limits population reproductive potential beyond its effect on stock abundance; however, the four largest recruitment events since 1953 all occurred in years with below-average mortality rates and none have occurred since the advent of Dermo as a significant determinant of oyster population dynamics.

The important areas for the oyster industry are the beds in the medium-mortality and high-mortality region. Examination of the trends on these individual beds indicates that these two regions have substantially different processes controlling oyster abundance (Figure 9). The average numbers of oysters on the medium-mortality beds for the 1989 to 2005 period was statistically greater than for the high-mortality beds (Figure 9). The spat set was not statistically different over the same period (Figure 9). Surplus production has been consistently positive on the high-mortality beds and commonly negative on the medium-mortality beds upbay of Shell Rock. Thus, some factor or factors affect post-set survival differentially. Unrecorded mortality was higher on the downbay beds, commensurate with the abundance trend (Table 10). Growth is more rapid downbay commensurate with the surplus production trend.

Harvest

The 2005 harvest limit was set at 32,000 bu: 28,128 bushels were landed[♭].

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

Figure 31 shows the time-series of oyster harvest in Delaware Bay. Since 1996, 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 1 to November 15, 2005. The weeks fished this year is the same as last year. Harvest was from 10 beds. Five beds accounted for slightly over 75% of harvest: Shell Rock (29.9%), Nantuxent Point (18.9%), Hawk's Nest (10.5%), Bennies (10.5%), and Cohansey (9.7%) (Table 11). When Ship John (9.6%) and New Beds (5.7%) harvests are added, these 7 beds comprise over 90% of the total. Sixty-six boats participated in the fishery and worked for a total of 544 boat days. These included 32 single-dredge boats working for 346 (10.8 days/boat) and 34 dual-dredge boats working for 198 days (5.8 days/boat). The catch-per-boat-day for dual-dredge boats increased slightly for the third year in a row (Figure 32). The catch-per-boat-day for single-dredge boats decreased slightly this year (Figure 32). This stabilization or increase in catch-per-boat may reflect the high percentage of marketable or nearly marketable oysters on most of the exploited beds.

Total dredging impact was estimated[⊗]. Three beds were covered by dredging more than once during 2005: Shell Rock, Nantuxent Point, and Hawk's Nest (Table 11). This distribution of effort was vastly different from 2004 when four beds were covered by dredging more than once: Cohansey (2.25), Ship John (4.64), Shell Rock (4.37), Bennies Sand (6.37).

The number of oysters per 37-qt marketed bushel averaged 275 in 2006, a drop from 302 in 2004 (Table 12). Of these, 253 were $\geq 2.75''$ in size (Figure 33).

In 2005, 5,000 bu of oysters were transplanted from Middle to Shell Rock. Culling devices were used, so that the transplants were biased in favor of the larger size classes. Oysters per bushel in the transplant averaged 382. The net of all fishing and transplant activities was that most oysters taken to market ultimately were debited from the high-mortality and medium-mortality beds (Figure 34). 2005 was the first year since direct-marketing began in 1996 that Shell Rock did not contribute disproportionately to total fishing mortality. This occurred because the transplant downbay from Middle nearly balanced the removals. This was the desire

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Protection.

⊗ 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.

of the 2005 management plan.

Apparent fishing mortality was 1.1% of the stock; that is, 1.1% of the stock was manipulated whether through transplant or harvest. True fishing mortality was 0.9% of the stock; that is, the direct-market harvest in 2005 removed about 0.9% of the stock by number. This equates to 1.9% of the spawning stock biomass. Fishing mortality in 2005 was at the 11^{th} percentile of the 53-yr time series excluding closure years, and at the 33^{rd} percentile of open years post-1988.

Summary of Stock Status

Figure 35 summarizes the condition of the oyster stock throughout the New Jersey waters of Delaware Bay and by bay region in comparison to the 1989-2005 period. 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.

The stock presents a mixture of positive and negative indicators that approximately balance. Abundance is low, but abundance increased in both the downbay and upbay portions of the stock's range and this increase approximately balanced the reduction in abundance on the medium-mortality beds anticipated at SAW-7. The expansion of the stock from its consolidation on the medium-mortality beds that has occurred over the last few years through range contraction is a positive sign, although it exposes the stock to a higher level of natural mortality if Dermo disease intensity rises.

Spawning stock biomass is still low bay-wide, but rose in 2005. Increases were noted in all bay regions upbay of Shell Rock. SSB remained stable on the high-mortality beds. Increases in SSB coincided with increases in condition index, that reached historical highs bay-wide in 2005. New growth data suggest that 2005 was also a good growth year for oysters in Delaware Bay.

Recruitment remains low bay-wide and particularly low on the medium-mortality beds. An above-average recruitment event occurred on the low-mortality beds in comparison to most years since 1991, however. Evidence exists that low spat abundance is associated with low adult abundance, although the explanation for this trend is controversial. This implies that high recruitment may be less likely under current conditions of low abundance. However, the ratio of spat to oysters has been lower than the 2-year replacement level over five of the last 6 years and below that anticipated from the broodstock-recruitment relationship, suggesting that low adult abundance is not a sufficient explanation for the low recruitment of the last few years. The origin of this trend is lower recruitment in comparison to standing stock upbay of Shell Rock. Shell Rock and the high-mortality beds have been recruiting at a level at or exceeding the 2-year replacement level for most of the decade.

The oyster population as a whole continues to be depauperate in the smaller size classes; however, this year, surplus production is expected to permit an increase in market-size abundance bay-wide, given average mortality rates. Surplus production is anticipated to be negative in the medium-mortality beds in 2006, but the reduction in abundance of market-size individuals anticipated should be much smaller than observed in 2005. Positive surplus production will occur in all other bay regions, with a substantial increase in market-size abundance on Shell Rock and downbay, barring a higher than average rate of natural mortality and not counting removals by the fishery. This continues the trend of positive surplus production on these downbay beds, due to high growth rates and relatively good recruitment in an otherwise low-recruitment time period.

Dermo disease continued to be low in 2005 and natural mortality rates were well below average. A rising trend in Dermo disease prevalence may presage increased rates of natural mortality in 2006, given facilitative environmental conditions.

Fishery exploitation levels since 1989 appear to be very low ($<2\%$ of abundance per year). Recent improvements in collection of fishery-dependent data indicate that exploitation in terms of biomass has been $\leq 4\%$ in the last few years. 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 upbay of Shell Rock continue to be disadvantageous, whereas the remaining bay regions appear to have improved since 2004.

Management Advice

Long-term Abundance Goals

Exploitation rates by bay section indicate that the fishery has not influenced the stock since the inception of the direct-marketing program and only in one year, 1991, since Dermo became a significant determinant of oyster population dynamics. During the 1996-2005 time period, stock abundance has translated through a range of abundances typical of the entire 1989 to 2005 time period. The 1989 to 2005 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 period 1989-2005 represent good targets for a abundance and biomass goals and values half these levels represent good threshold levels, at which concerns should be raised about long-term stock sustainability.

In 2005, for the low-mortality beds, abundance fell below the abundance target, and below the threshold value of abundance (Figure 36). SSB fell above the SSB target (Figure 36). For the medium-mortality beds, 2005 abundance values fell below the abundance threshold value; however, SSB fell above the SSB target (Figure 36). Shell Rock abundance fell below the threshold value for this bed and SSB fell near the target value. Abundance on the high-mortality beds, like on the medium-mortality beds, fell below the threshold, while SSB fell near the biomass target (Figure 36).

The fact that all bay regions fall at or below their abundance thresholds indicates that actions to enhance abundance are needed for the medium-mortality and high-mortality beds. A reduction in fishing effort will not significantly address this need because exploitation rates are already low. Within bay-section exploitation rates have been below 2.7% of abundance on the medium-mortality beds since direct-marketing began and values have been below 1% in most years; however, substantial increases in exploitation rate should be avoided. Abundance has been enhanced on the high-mortality beds by downbay transplant in all years since direct-marketing began except for 1996, 1997, and 2005 and on Shell Rock in recent years, and this program should be continued. The preferred mechanism to address low abundance overall is to enhance recruitment and this program began in 2005 focused on Shell Rock and the high-mortality beds. Additional emphasis on the medium-mortality beds is desirable.

2006 Management Goals

Fishery 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. Since 1998, a constant-abundance reference point has been used. Under this reference point, fishing allocation is determined by the surplus production of the population in each region. The use of a natural mortality rate above the 50^{th} percentile, the 75^{th} percentile, incorporates into this reference point a rebuilding plan than can be expected to increase market-size abundance in most years and which guards against a high level of overfishing in epizootic years. This reference point has been successfully applied to Shell Rock and the high-mortality beds. These beds have consistently attained a productivity level permitting the expansion of market-size abundance in most years. The reference point is dependent upon good information on the past record of natural mortality and growth. The former is represented by a 17-year time series and is therefore substantive. The latter is represented by a few measurements in two years, 2000 and 2005, and is therefore inadequate. In contrast, application of this reference point has been difficult upbay of Shell Rock where less consistent recruitment results in population contractions through natural processes in many years, even when natural mortality rates are low.

As a consequence, an alternate, exploitation-based reference point is proposed with the recommendation that both reference points be considered as management options. The exploitation reference point recognizes that the fishery has been successfully prosecuted at relatively low exploitation levels since 1995. This record permits the promulgation of an exploitation-based reference point based on the median exploitation rate, defined in terms of the fraction of abundance removed, for each bay region for the years 1996-2005. SSB cannot yet be used for this purpose, as a time series of SSB landings extends back only to 2004. However, several more years of monitoring of catch length-frequency distributions may permit retrospective reconstruction of an SSB landings times series based on yearly survey-derived length-weight relationships. As the abundance-based exploitation reference point is derived from a period of conservative fishery management characterized by low exploitation rates, the abundance-based exploitation reference point is likely to provide conservative management goals. The SARC notes that this reference point, established this year based on 1996-2005 data, should not be updated yearly, but retained until such time as a Term of Reference permits formal review based on new information.

Bay Region Considerations–Shell Rock Downbay

Shell Rock and the high-mortality beds have provided most of the fished animals since 1995 because market quality is consistently high. These beds 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. These beds have been successfully managed using a constant-abundance reference point since 1998 with a precautionary component to guard against epizootic losses. That is, the beds have been managed in what is inherently a rebuilding mode.

The SARC recognizes the need to manage these beds conservatively. The constant-abundance approach using a projection of surplus production has proven itself in this area and contains adequate precaution. Harvest levels at variance to those suggested by surplus production projections, derived for example from exploitation-based reference points, should be considered carefully, particularly if abundance based. These beds have responded positively to abundance enhancement programs by shell planting to increase recruitment, and transplanting to increase adult abundance. Retention of these mechanisms within yearly management plans is essential while abundance is low.

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 and under more conservative guidelines. For surplus production projections, the 75^{th} percentile assumption should be retained. A wider range of options between the 50^{th} and 75^{th} percentiles can be considered for the high-mortality beds. The SARC assumes that these beds will continue to be used exclusively for direct marketing.

Bay Region Considerations–Low-mortality Beds

These beds have rarely contributed much to the fishery and none in most years since 1995. They cannot be used as direct-market beds due to market quality concerns and are sufficiently far upbay as to minimize routine access by fishing vessels. However, these beds are typified by large numbers of small animals that might be a source of stock maintenance and fishery support downbay in times of low recruitment when surplus production is low.

Due to the large number of small animals usually present, surplus production values are normally positive. However the premise of the constant-abundance reference point is the selective removal of market-size animals and, consequently, this approach presumes direct marketing. Direct marketing is unlikely to be effective on these beds. Best use of these beds is to replace abundance downbay in support of fishery removals when low recruitment downbay makes exploitation of this upbay resource useful.

The present low-abundance period represents such a time. Transplanting options should be considered. An exploitation reference point should be considered to manage these beds under this circumstance. A critical issue is the conversion of downbay transplant numbers into same-year marketable bushels under a transplant program. Even with culling, the larger size fractions are essentially impossible to remove selectively. Removals as defined under the exploitation reference point include all size classes. Accordingly, the SARC recommends allocating to the fishery the fraction of animals moved downbay of market size or that would reach market-size over a 12-month time period. The remaining smaller individuals will increase abundance and provide harvestable resource in future years.

Transplants, should they be considered, should minimize the downbay movement to permit increased survival of the many juvenile-size animals. Options include Shell Rock, Bennies Sand, and the new grid areas on the northern side of Shell Rock identified by the 2005 Spring survey.

Bay Region Considerations–Medium-mortality Beds

These beds are susceptible to negative surplus production (although part of this is likely inadequately known growth rates). Positive surplus production has occurred in less than half of the years since 1996. Nevertheless, these beds contribute the bulk of the stock supporting the fishery over the entire 53-year history of the survey, excepting the 1970s high-abundance period (Figure 34). Over the 1996-2005 direct-market period, these beds contributed most of the animals supporting the fishery, albeit indirectly through transplant to replace animals fished from the beds farther downbay. Abundance is highest here and the animals are moderately protected from disease. These beds must be included in the fishery; otherwise the pressure on the beds downbay of Shell Rock will be too high.

A complex array of options exists to manage these beds. Direct-marketing has proven effective in some years and is a preferred option as it retains juveniles on these beds where survival is high. Direct-marketing should be encouraged as the management option of choice, provided market quality is adequate. Alternatively, market-size animals transplanted downbay might be marketed after a 6-week period to increase market quality. Culling machines can successfully concentrate the larger animals when properly operated, making this a viable option. Accordingly, the use of culling machines should accompany any transplant option. A conversion of transplanted animals into marketable bushels should rely on the number of marketable animals transplanted. Thus, increased culling efficiency will increase harvest while protecting smaller animals in an area of inherently higher survivorship.

The constant-abundance reference point has proven very ineffective for these beds, although it should be considered as an option. In years of negative surplus production, an exploitation reference point will allow these beds to continue to support the fishery to relieve pressure on the beds further downbay and this should be encouraged unless stock status issues indicate the necessity of area closure.

Surplus Production Projections – Constant-abundance Reference Point

Surplus production projections were run under the proviso that the number of market-size oysters at the end of the year would equal the number at the beginning of the year. In essence, this allocates to the fishery a number of oysters equivalent to the number expected to grow into market size during the year after accounting for replacement of those lost to natural mortality. This is the 'constant market-size abundance' reference point. Projections were run using natural mortality rates for each bay region, with percentiles calculated from the 1989-2005 time series. An average growth rate was assumed, based on the average of 2000 and 2005 data. Submarket-size oysters were defined using the smallest individual that could attain 75 mm during the year. Natural mortality rates were taken from box counts because unrecorded mortality is assumed to be mostly juvenile. The 2^{nd} SAW recommended a precautionary approach of managing at the 75^{th} percentile of the box-count mortality rate. The 7^{th} SAW recommended relaxation of this assumption to the 50^{th} percentile for the high-mortality beds. The SARC recommends that the 75^{th} percentile continue to be used for Shell Rock and beds upbay, but that the remainder of the direct-market beds be managed within the 50^{th}-to-75^{th} percentile range. Projections assumed a continuous fishing season from April 1 to November 15 as has been typical of the last few years. This approach permits some harvest to be compensatory, as a certain proportion of the animals taken would otherwise die from disease. Allocation estimates used an updated value of 268 to convert market-size and submarket-size abundance to market-bushel equivalents. The updated values were obtained by direct measurement of selected bushels landed throughout the 2004 and 2005 seasons (Table 12).

Bay Region	Natural Mortality Percentile	Allocation (market-equivalent bushels)
High-Mortality	75^{th}	1,461
	67^{th}	13,476
	50^{th}	21,880
Shell Rock	75^{th}	13,606
Medium-Mortality	75^{th}	0
Low-Mortality	75^{th}	9,227

Note that the surplus-production option assumes efficient culling of market-size individuals or direct-marketing. Inefficient culling for transplant requires the use of the exploitation reference point discussed subsequently, as the constant-abundance reference point assumes removals of market-size animals only. The SARC recommends consideration of a range of harvest levels for the high-mortality beds based on projections using a range of natural mortality probabilities.

Abundance-based Exploitation Reference Point

The SARC recommends that this reference point be defined based on the exploitation record from 1996-2005, using the abundance in each bay region as the basis to estimate an exploitation index. An upper and lower bound should be taken as the 40^{th} and 60^{th} percentiles of the 1996-2005 time series using data on the total removals from each bay region (transplant or harvest). This time series is rendered in Figure 37. In case of ties, the next value in the ranked series has been used.

Because of rare use of the low-mortality beds early in the time series, the period considered begins with the first non-zero exploitation year after 1995. These years are: high-mortality, 1996; Shell Rock, 1997; medium-mortality, 1997; low-mortality, 1998. The exploitation of the low-mortality beds has been very inconsistent, so that the time series is inadequate to characterize the exploitation reference point for these beds. As a consequence the first value exceeded 0.01 yr^{-1} has also been added to the percentile range.

Projections are based on the abundance of >20-mm animals and given in terms of numbers of individuals based on the following abundances: low-mortality beds, 247,095,575; medium-mortality beds, 438,732,083; Shell Rock, 49,300,808; high-mortality beds, 114,744,440. Two options are then provided. First, the number of individuals is converted to bushels harvested assuming direct-marketing or transplant with efficient culling so that animals removed are of market size. This projection uses the average numbers per marketed bushel of 268 derived from the 2004-2005 dock-side monitoring program. Second, the assumption is made 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 obtained from the 2005 survey. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.75''$ and these animals are converted to bushels using the 268 animal/bu conversion. The abundance of market-size animals in the four bay regions providing these proportions are: low-mortality beds, 22,383,220; medium-mortality, 224,690,718; Shell Rock, 19,083,200; high-mortality beds, 33,564,943. The knife-edge value of $2.75''$ was obtained from the size-frequency distribution of animals marketed in 2005 as determined by the dock-size monitoring program (Figure 33).

The chart itemizing the exploitation options by bay region is followed by a second chart that splits the medium-mortality beds into two groups based on the expectation that direct-marketing is most feasible on Cohansey, Ship John and Sea Breeze.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Efficient Cull or Direct-market Bushels	Population Oysters/Bu	Deck-load Transplant Bushels	Deck-load Marketable Bushel Equivalents
High-Mortality	40^{th}	.03675	4,216,860	15,735			
	50^{th}	.03964	4,548,470	16,972			
	60^{th}	.04396	5,044,170	18,822			
Shell Rock	40^{th}	.05391	2,657,810	9,917			
	50^{th}	.05556	2,739,150	10,221			
	60^{th}	.05600	2,760,850	10,301			
Medium -Mortality	40^{th}	.00806	3,536,180	13,195	179	19,755	6,757
	50^{th}	.01551	6,804,740	25,391	179	38,015	13,003
	60^{th}	.01855	8,138,480	30,368	179	45,466	15,551
Low-Mortality	50^{th}	.00034	84,013	313	182	461	28
	60^{th}	.00176	434,888	1,623	182	2,389	147
	75^{th}	.01507	3,723,730	13,895	182	20,460	1,258

Note that transplanting options are not provided for Shell Rock and the high-mortality beds assuming that these regions will be used exclusively for direct marketing. Note that transplant options will require transplant before the allocation derived therefrom can be set. Note that allocation values obtained for the medium-mortality and low-mortality beds managed by transplant will likely fall in between the 'Efficient Cull' column and the 'Deck-load' column for the medium-mortality and low-mortality bed, depending on culling efficiency.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Efficient Cull or Direct-market Bushels	Population Oysters/Bu	Deck-load Transplant Bushels	Deck-load Marketable Bushel Equivalents
Cohansey, Ship John, Sea Breeze	40^{th}	.00806	2,713,006	10,123	179	15,156	5,679
	50^{th}	.01551	5,220,550	19,480	179	29,165	10,929
	60^{th}	.01855	6,243,950	23,299	179	34,882	13,070
Middle, Upper Middle	40^{th}	.00806	823,174	3,072	179	4,599	1,078
	50^{th}	.01551	1,584,190	5,911	179	8,850	2,074
	60^{th}	.01855	1,894,530	7,069	179	10,584	2,481

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 500,000 bushels annually.

Additional harvest policies should be considered at the next SAW; particularly emphasizing modifications to the exploitation indices for the low-mortality beds.

Science Recommendations

The Dermo monitoring program should continue. Collection of ancillary data on mortality, size-frequency distribution, and growth rate should be continued. The 1989-2005 time series should be analyzed to provide improved probabilities for coming year mortality rates taking into account the autocorrelation of yearly values.

The dock-side monitoring program should be continued. This program is required for SSB estimates of landings and improved abundance-to-bushel conversions.

A spat settlement monitoring program should be continued.

A special survey of the high-mortality bed region should occur in 2006 to provide improved survey design and stock estimates.

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

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 growth monitoring program should be established either by direct observation of marked animals, intensive size-frequency sampling, or aging.

Additional analysis of the 53-year time series should be undertaken to evaluate the significance of cultch trends observed since 2000 and to develop a shell budget for the natural oyster beds.

Recruitment data suggest a relationship between fishing intensity and settlement success; however coincidence alone may be responsible. An experiment should be conducted to determine if increased harvesting/transplanting on a bed like Ship John or New Beds will improve recruitment.

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.

The surplus production time series for 1989-2005 should be reconstructed on a bay area basis to determine how frequently periods of negative surplus production occur.

A size-dependent model should be constructed capable of evaluating, by retrospective analysis, the adequacy of the growth estimates used for calculation of surplus production.

Table 1. Long-term average numbers of oyster and spat per bushel (1953-2005), and percent mortality (total box count). Low Mortality = Round Island, Arnolds, and Upper Arnolds. Medium Mortality = Upper Middle, Middle, Cohansey, Ship John, Sea Breeze, and Shell Rock. High Mortality Group 1 = Bennies Sand, Bennies, New Beds, Nantuxent Point, Hog Shoal, Strawberry, Hawk's Nest, Beadons, and Vexton. High Mortality Group 2 = Ledge and Egg Island.

	Oyster	Spat	% Mortality
Bay Average	263	176	15
Low Mortality Beds	531	260	13
Medium Mortality Beds	309	189	14
High Mortality Beds - Group 1	184	162	19
High Mortality Beds - Group 2	65	65	20

Table 2. 2005 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 Spring survey. For these beds, no low-quality grids were sampled. For the remainder, the pre-2005 three-stratum sampling scheme was used.

Sampled Bed	High-quality	Medium-quality	Low-quality	Transplant
Round Island	1	4	1	0
Upper Arnolds	1	1	0	0
Arnolds	1	4	1	0
Upper Middle	1	1	0	0
→ Cohansey	3	3	0	0
→ Ship John	3	4	0	0
→ Middle	2	3	0	0
→ Sea Breeze	3	2	0	0
→ Shell Rock	3	3	0	4
→ Bennies Sand	2	2	0	2
Bennies	1	9	2	0
New Beds	1	6	2	0
Nantuxent Point	1	4	1	0
Hog Shoal	1	4	1	0
Strawberry	1	4	1	0
Vexton	1	5	1	0
Beadons	1	7	2	0
Hawk's Nest	1	4	1	0
Egg Island	1	7	2	0
Ledge	0	0	0	0

Table 3. Dredge efficiency estimates expressed as the reciprocal of the efficiency e: $q = \frac{1}{e}$. The value q is the multiplier by which swept area estimates were converted to per-meter-square values. The upper bay includes all beds upbay of Shell Rock[♯]

	Live Juvenile	Live Sub-market	Live Market	Live Total	Box Juvenile	Box Sub-market	Box Market	Box Total	Cultch
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. in press, Re-evaluation of Eastern oyster dredge efficiency in survey mode: Application in stock assessment. *N. Am. J. Fish. Manage.*

Table 4. Results of the 2005 random sampling program for the Delaware Bay natural oyster beds. Included for comparison are data for 2003 and 2004. All data were adjusted to a 37-quart bushel. Data are displayed from the farthest upbay beds to those downbay. The test area is a small area of high-quality grids that has been sampled consistently as representative of the better areas of the bed. The test area sample is indicated by an $*$. The column called 'Bushels/haul' to the left of the column headed 'Percent Oyster 2004' 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. Percentage of oyster is based on volume of oyster in the sample divided by the total volume of shell, oyster, and debris in the sample. Those samples that have over 40% oyster are underlined. Oysters per bushel and spat per bushel are based on actual counts adjusted to 37 quarts. 'Size' columns indicate the number of oysters greater than 2.5″ and the percentage of oysters that are greater than 3″, based on the measurements of oysters (Table 5). Condition index is a measure of the amount of dry meat weight in an oyster relative to the hinge-to-lip (greatest) dimension. Condition is generally greater in oysters farther downbay. The 'Percentage Mortality' value is based on the number of boxes that were 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. 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.

Summary of the 2005 Random Sampling of the Seed Beds

Table 3. Delaware Bay Seed Bed data for 2005.

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		
			2005	2004	2003	**2005**	2004	2003	**2005**	2004	2003		**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003
		--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Round Island	*	1.3	**30**	35.31	--																									
Round Island		1.1	**22.6**	26.98	--																									
Round Island		1.0	**18**	25.23	--	**98**	161	--	**14**	3	--		**16**	17	--	**0**	0	--	**0.00**	0.00	--	**34**	23	--	**35**	14	--	**0.010**	0.006	--
Round Island		0.8	**16.9**	7.69	--																									
Round Island		0.4	**9.1**	1.96	--																									
Round Island		0.1	**4.2**	0.71	--																									
Up. Arnolds		5.0	**41.7**	--	58.0																									
Up. Arnolds	*	3.7	**32.5**	--	27.7	**300**	--	311	**61**	--	12		**13**	--	9	**0**	--	20	**0.00**	--	0.15	**57**	--	32	**19**	--	10	**0.011**	--	0.005
Up. Arnolds			--	--	--																									
Arnolds		5.3	**49.2**	53.12	68.3																									
Arnolds		4.3	**46.6**	50.94	62.6																									
Arnolds	*	5.0	**38.8**	39.93	48.2	**227**	222	272	**60**	5	13		**12**	13	7	**0**	5	33	**0.00**	0.03	0.38	**64**	50	23	**32**	22.7	8	**0.013**	0.006	0.005
Arnolds		1.2	**26.9**	27.83	28.7																									
Arnolds		0.1	**5.9**	24.73	6.8																									
Arnolds		0.1	**0**	0	0.0																									
Up. Middle	*	0.1	**0**	0	--																									
Up. Middle		0.1	**0**	25	--	**0**	19	--	**0**	0	--	0	**0**	0	--	**--**	0	--	**--**	0.00	--	**0**	0	--	**0**	--	--	**--**	0.010	**--**
Middle		0.5	**76.4**	62.31	78.1																									
Middle	*	4.0	**67.2**	52.72	63.1																									
Middle		1.1	**51.9**	51.94	62.2																									
Middle		1.2	**30.6**	51.52	59.7																									
Middle		1.4	**0**	46.8	59.4	**212**	210	223	**27**	35	19		**11**	10	10	**55**	40	63	**0.98**	1.35	0.98	**109**	98	91	**68**	46.9	41	**0.015**	0.010	0.008
Middle			--	31.77	54.6																									
Middle			--	28.99	50.3																									
Middle			--	23.5	0.0																									
Middle			--	6.19	0.0																									
Cohansey		3.4	**67.9**	68.41	70.5																									
Cohansey	*	0.7	**62.1**	61.47	70.0																									
Cohansey	*	6.0	**61.6**	48.24	64.6																									
Cohansey		0.7	**53**	47.68	64.1	**184**	161	218	**34**	18	19		**12**	13	12	**45**	20	57	**0.80**	0.23	0.95	**112**	102	99	**61**	63.1	45	**0.017**	0.012	0.009
Cohansey		3.7	**38.6**	8.8	50.0																									
Cohansey		0.4	**14.6**	0	48.5																									
Cohansey			--	--	37.0																									
Cohansey			--	--	3.3																									

Summary of the 2005 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2005.

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		
			2005	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003
		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ship John	*	4.3	**79.3**	62.92	68.2																								
Ship John		4.2	**74.7**	60.92	66.0																								
Ship John		1.5	**68.1**	53.53	61.5																								
Ship John	*	3.5	**62.2**	50.3	48.4	**211**	245	226	**49**	58	24	**11**	11	13	**70**	--	90	**1.00**	--	1.18	**147**	129	105	**70**	52.6	47	**0.021**	0.012	0.009
Ship John		2.5	**52.5**	11.83	28.4																								
Ship John		1.6	**49.1**	--	--																								
Ship John		0.4	**37**	--	--																								
Seabreeze		2.2	**62.8**	31.86	--																								
Seabreeze	*	2.5	**50.5**	12.58	--																								
Seabreeze		3.0	**35.7**	0.34	--	**166**	108	--	**13**	20	--	**7**	15	--	**65**	30	--	**1.40**	0.48	--	**103**	31	--	**62**	28.8	--	**0.024**	0.012	--
Seabreeze		0.0	**33.3**	--	--																								
Seabreeze		0.9	**27.2**	--	--																								
Shell Rock		2.1	**69.4**	57.89	69.4																								
Shell Rock	*	2.7	**62.14**	43.24	67.7																								
Shell Rock		5.5	**58.96**	37.92	59.0																								
Shell Rock		3.0	**47.74**	37.63	55.9	**173**	175	186	**47**	82	54	**11**	11	12	**94**	60	80	**2.09**	1.25	1.25	**86**	104	68	**62**	59.5	36	**0.020**	0.018	0.013
Shell Rock		1.5	**47.14**	35.69	52.7																								
Shell Rock		1.3	**42.13**	34	46.6																								
Shell Rock		0.6	**9.93**	27.16	22.3																								
Bennies Sand		3.7	**46.2**	33.15	40.9																								
Bennies Sand		1.0	**38.7**	31.75	33.7																								
Bennies Sand		2.8	**33.2**	29.09	32.7	**175**	142	140	**73**	71	47	**11**	14	14	**75**	40	--	**1.35**	0.73	--	**77**	77	70	**44**	53.9	50	**0.025**	0.019	0.014
Bennies Sand		4.7	**23.1**	*28.6*	32.7																								
Bennies Sand		3.2	**18.5**	28.32	--																								
Bennies Sand			--	25.81	--																								
Bennies		4.0	**34.5**	*33.9*	26.9																								
Bennies		0.7	**31**	21.54	21.0																								
Bennies		0.2	**24.8**	19.66	17.2																								
Bennies		1.8	**23**	18.02	15.5																								
Bennies		0.7	**18.5**	13.75	15.0																								
Bennies		0.4	**17.3**	11.91	8.6																								
Bennies	*	3.0	**16.8**	4.04	8.1	**46**	16	19	**17**	15	4	**15**	24	29	**67**	30	85	**1.45**	0.55	1.80	**25**	11	13	**55**	69.2	68	**0.031**	0.022	0.017
Bennies		1.1	**9.5**	3.64	6.3																								
Bennies		3.0	**6**	2.66	3.4																								
Bennies		0.2	**4.9**	1.74	0.7																								
Bennies		3.1	**4.8**	1.36	0.6																								
Bennies		1.4	**0**	0.12	0.6																								
Bennies			--	0	--																								
Bennies			--	0	--																								

Summary of the 2005 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2005.

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		
			2005	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003
		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nantuxent Pt	*	5.7	**47.1**	--	53.2																								
Nantuxent Pt		6.0	**32.4**	--	13.2																								
Nantuxent Pt		2.8	**18.9**	--	7.9																								
Nantuxent Pt		5.0	**7.5**	--	7.4	**95**	--	74	**37**	--	46	**25**	--	16	**95**	--	95	**2.75**	--	2.10	**39**	--	21	**47**	--	28	**0.023**	--	0.015
Nantuxent Pt		2.7	**4.2**	--	1.7																								
Nantuxent Pt		6.0	**0**	--	0.0																								
Hog Shoal		3.3	**34.7**	20.7	23.3																								
Hog Shoal		2.5	**27.3**	18.46	10.8																								
Hog Shoal		5.0	**20.1**	5.16	10.0	**66**	33	31	**22**	23	18	**28**	39	44	**90**	85.0	90	**2.77**	1.95	3.00	**28**	22	14	**43**	66.4	45	**0.022**	0.020	0.017
Hog Shoal		2.2	**20**	4.41	9.0																								
Hog Shoal	*	1.1	**10.1**	3.02	--																								
Hog Shoal		3.0	**5.3**	--	--																								
New Beds		2.9	**21.2**	32.79	24.1																								
New Beds		2.7	**18.3**	*21.5*	23.2																								
New Beds		0.4	**14.8**	17.92	10.1																								
New Beds	*	2.1	**12.5**	6.9	9.4																								
New Beds		3.0	**5.4**	5.66	4.5	**30**	28	20	**22**	31	16	**14**	33	35	**90**	65	95	**2.08**	1.30	1.38	**12**	14	11	**40**	51.7	56	**0.026**	0.025	0.020
New Beds		1.6	**4.5**	5.44	3.0																								
New Beds		0.5	**3.9**	4.98	2.4																								
New Beds		0.2	**1.9**	3.17	2.0																								
New Beds		3.8	**1.6**	2.04	1.4																								
New Beds			**--**	0	--																								
Strawberry		0.1	**34.1**	23.53	9.6																								
Strawberry	*	3.3	**31.3**	8.55	7.2																								
Strawberry		0.5	**8.2**	3.68	3.9	**47**	32	20	**18**	37	13	**21**	21	35	**96**	70	90	**2.27**	1.85	2.00	**24**	20	14	**52**	63.4	69	**0.022**	0.017	0.017
Strawberry		1.4	**6.8**	2.72	3.0																								
Strawberry		1.2	**2.8**	1.88	--																								
Strawberry		1.5	**2.7**	--	--																								
Hawks Nest		4.3	**48.3**	14.71	18.7																								
Hawks Nest		4.7	**14**	7.05	14.9																								
Hawks Nest	*	4.0	**6.8**	4.25	11.3	**59**	19	53	**22**	13	33	**10**	26	35	**100**	50	90	**2.53**	1.20	1.95	**17**	14	35	**39**	72.5	65	**0.025**	0.019	0.015
Hawks Nest		0.4	**5.2**	2.4	8.0																								
Hawks Nest		0.5	**1.9**	2.05	--																								
Hawks Nest		0.1	**0**	--	--																								

Summary of the 2005 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2005.

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		
			2005	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003	**2005**	2004	2003
		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Beadons		1.9	**22.2**	17.9	19.7																								
Beadons	*	3.0	**20.8**	8.62	16.7																								
Beadons		4.2	**19.1**	6.9	6.0																								
Beadons		2.7	**18.4**	6.02	4.5																								
Beadons		1.3	**15.1**	5.23	2.9																								
Beadons		2.5	**4**	3.97	2.5	**48**	23	19	**22**	33	14	**17**	30	42	**85**	84	100	**1.94**	1.84	3.20	**18**	12	11	**38**	53.4	58	**0.029**	0.022	0.018
Beadons		0.2	**3.9**	3.43	2.2																								
Beadons		2.8	**3.4**	3.29	1.6																								
Beadons		0.1	**0**	1.8	0.0																								
Beadons			--	1.13	0.0																								
Vexton		2.3	**29.5**	10.6	24.6																								
Vexton		4.0	**15.7**	9.06	11.0																								
Vexton		2.5	**12.8**	6.39	10.1	**24**	13	21	**9**	4	15	**30**	30	44	**80**	65	100	**1.05**	1.60	4.10	**17**	11	16	**70**	83.9	76	**0.031**	0.025	0.023
Vexton	*	5.7	**12.8**	3.69	7.1																								
Vexton		3.6	**12.3**	1	0.0																								
Vexton		1.7	**0.8**	0	--																								
Vexton		2.5	**0.3**	--	--																								
Egg Island	*	5.3	**60.1**	--	5.9																								
Egg Island		3.7	**8.3**	--	4.9																								
Egg Island		4.7	**2**	--	3.1																								
Egg Island		0.2	**1**	--	0.7																								
Egg Island		5.3	**0.4**	--	0.5	**10**	--	4	**0**	--	0	**17**	--	29	**75**	--	100	**1.65**	--	2.30	**8**	--	3	**79**	--	84	**0.030**	--	0.009
Egg Island		3.8	**0**	--	0.5																								
Egg Island		3.3	**0**	--	0.3																								
Egg Island		1.7	**0**	--	0.0																								
Egg Island		0.8	**0**	--	--																								
Egg Island		0.2	**0**	--	--																								
Ledge			--	1.96	--																								
Ledge			--	1.57	--																								
Ledge			--	1.09	--																								
Ledge			--	0.28	--	--	1.31	--	--	3	--	--	17	--	--	40	--	--	0.70	--	--	1	--	--	83.3	--	--	--	--
Ledge			--	0	--																								
Ledge			--	0	--																								
Transplants																													
Ben Sand		4	**22.2**			**412**			**187**			**2.9**																	
Ben Sand		4	**35.4**			**200**			**46**			**33.6**																	
Shell Rock		4.5	**67**			**284**			**92**			**9.73**																	
Shell Rock		0.53	**37.3**			**143**			**26**			**12.8**																	
Shell Rock		2.67	**20.3**			**52**			**1**			**10.4**																	
Shelling																													
Shell Rock		2.33	**60.6**			**261**			**27**			**7.2**																	
Shell Rock		4.67	**58.7**			**276**			**147**			**10.7**																	
Shell Rock		4	**56.3**			**204**			**105**			**9.36**																	
Shell Rock		4	**37.1**			**180**			**80**			**9.88**																	

Table 4, page 4.

Table 5. Oyster size frequency on the natural oyster beds in 2005. Frequencies are expressed as the number in each size class per bushel.

Table 5. Oyster Seed Beds Size Frequency 2005																			
	Round Is	**Up Arn**	**Arnold**	**Up Mid**	**Middle**	**Cohan**	**Ship Jn**	**Seabrz**	**Shell Rk**	**Ben Snd**	**Bennie**	**Nant Pt**	**Hog Shl**	**New Beds**	**Straw**	**Hawks N**	**Beadon**	**Vexton**	**Egg Is**
0	0	0	0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0	0	0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0	0	0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0	0	0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0	0	0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	2	7	6		4	4	5	6	6	13	3.4	5.0	2.8	1.2	1.9	5.0	3.9	0.7	0.0
30	2	5	6		3	5	4	12	9	15	3.5	3.4	4.1	3.7	4.1	4.9	5.8	1.4	0.0
35	0	9	7		4	3	3	8	5	11	3.0	5.1	2.7	3.9	1.6	3.2	5.0	1.6	0.0
40	5	24	11		5	5	5	8	5	6	2.3	6.7	3.7	2.7	0.9	5.0	2.9	1.0	0.0
45	7	34	21		11	9	5	6	7	8	2.8	7.1	4.6	1.5	2.2	4.0	3.5	0.7	0.4
50	13	55	30		9	12	13	6	9	12	2.3	9.2	5.7	1.6	5.3	5.9	3.1	1.0	0.0
55	18	60	34		16	15	14	6	12	15	1.6	6.4	7.1	1.0	2.8	5.9	3.1	0.3	1.5
60	17	49	39		16	19	15	11	14	17	1.7	7.6	6.7	1.9	3.8	1.8	2.2	0.4	0.4
65	14	33	29		22	22	22	18	15	14	1.4	8.2	3.9	0.4	2.2	4.1	1.4	0.4	0.4
70	11	14	21		27	21	21	14	17	13	2.2	8.9	3.9	1.0	1.6	3.4	0.8	0.5	0.4
75	**4**	**7**	**9**		**24**	**21**	**23**	**18**	**20**	**13**	**2.8**	**7.3**	**3.0**	**1.0**	**3.4**	**4.5**	**1.7**	**1.0**	**0.0**
80	**4**	**2**	**6**		**24**	**17**	**25**	**15**	**17**	**13**	**2.3**	**6.9**	**3.2**	**0.6**	**2.5**	**2.7**	**2.1**	**1.0**	**0.0**
85	**1**	**1**	**4**		**15**	**11**	**23**	**11**	**15**	**8**	**3.6**	**4.4**	**1.8**	**0.9**	**3.1**	**2.5**	**2.6**	**1.7**	**0.0**
90	**1**	**0**	**1**		**12**	**8**	**14**	**6**	**11**	**5**	**3.6**	**2.7**	**2.8**	**2.1**	**1.9**	**1.1**	**1.8**	**2.0**	**0.0**
95	**0**	**0**	**0**		**9**	**6**	**9**	**6**	**4**	**4**	**2.3**	**2.7**	**3.7**	**1.0**	**3.1**	**0.9**	**2.5**	**2.7**	**0.0**
100	**0**	**0**	**0**		**4**	**4**	**5**	**6**	**3**	**2**	**1.7**	**1.4**	**1.1**	**1.5**	**2.5**	**1.1**	**2.4**	**1.0**	**1.1**
105	**0**	**0**	**0**		**4**	**1**	**3**	**5**	**3**	**1**	**2.1**	**1.1**	**2.1**	**0.9**	**0.9**	**1.1**	**0.9**	**1.8**	**1.1**
110	**0**	**0**	**0**		**2**	**1**	**1**	**1**	**1**	**2**	**0.8**	**0.4**	**1.6**	**0.3**	**0.6**	**0.9**	**0.8**	**1.3**	**1.1**
115	**0**	**0**	**0**		**1**	**0**	**1**	**1**	**1**	**1**	**1.3**	**0.2**	**0.5**	**0.7**	**0.9**	**0.2**	**0.7**	**1.0**	**1.1**
120	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.7**	**0.0**	**0.4**	**0.7**	**1.3**	**0.0**	**0.4**	**1.2**	**0.7**
125	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.2**	**0.3**	**0.0**	**0.0**	**0.0**	**0.8**	**0.4**
130	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.3**	**0.0**	**0.0**	**0.1**	**0.0**	**0.4**	**0.0**	**0.1**	**1.1**
135	**0**	**0**	**0**		**0**	**0**	**0**	**1**	**0**	**0**	**0.1**	**0.0**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.4**
140	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**
145	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
150	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
155	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Total/Bu.	98	300	227	0	212	184	211	166	173	175	46	95	66	30	47	59	48	24	10
No. Measured	324	530	1014	0	812	1118	1413	435	1428	858	445	533	317	198	149	326	364	183	28
Greater than 3"	**9**	**10**	**21**	**0**	**96**	**70**	**104**	**71**	**75**	**50**	**22**	**27**	**21**	**10**	**20**	**15**	**16**	**16**	**7**
> 3" 2004	5	-	13	0	49	68	74	16	63	47	9	-	16	11	14	9	9	9	-
> 3" 2003	-	4	4	-	41	51	55	-	34	35	9	9	9	7	9	24	7	11	11
Greater than 2.5"	**34**	**57**	**72**	**0**	**144**	**112**	**147**	**103**	**107**	**77**	**25**	**44**	**28**	**12**	**24**	**23**	**18**	**17**	**8**
> 2.5" 2004	23	-	50	0	98	102	129	31	104	77	11	-	22	14	20	14	12	11	-
> 2.5" 2003	-	23	23	-	91	99	105	-	68	70	13	13	14	11	14	35	11	16	16

Table 6. Surplus production estimate of the 2005 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, the average of 2000 and 2005 growth estimates, and an average of the 2004 and 2005 conversions between numbers and bushels. 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.

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low-Mortality	10,317	9,227
Medium-Mortality	-10,094	-60,738
Shell Rock	24,157	13,606
High-Mortality	21,880	1,461
Total	45,640	-36,444

Table 7. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Bay regions are defined in Table 6. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

	Low-mortality	Medium-mortality	Shell Rock	High-mortality
1996	0.156	0.103	0.092	0.107
1997	0.214	0.668	0.935	2.729
1998	0.599	1.857	1.637	1.906
1999	0.613	2.468	5.125	5.109
2000	0.094	0.193	0.806	1.032
2001	0.050	0.085	0.218	0.545
2002	0.188	0.480	4.228	0.786
2003	0.052	0.177	0.585	1.092 (1.412)
2004	0.035	0.235	1.741	1.844
2005	0.317	0.184	0.471 (0.991)	0.808 (0.905)

Table 8. Summary of shell-planting activities for 2005. Shell-planting was carried out in July, 2005. Three 25-acre grids received direct plants, Shell Rock 4, 12, and 43. A fourth plant off Reeds Beach was moved upbay in September to Bennies Sand 11. Maryland oyster shell, ocean quahog shell, and surf-clam shell were used. 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 1989-2005 time series: for Shell Rock, 0.443, 0.182, 0.182; for Bennies Sand: 0.529, 0.267. 0.267. Bushel conversions assume 268 oysters per bushel.

Location	Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Projected Harvest
Benny Sand 11	Replant of surf clam	22,500	12,713,461	565	12,000
Shell Rock 4	Maryland oyster	36,752	8,051,590	219	11,197
Shell Rock 12	Ocean quahog	18,248	13,503,520	740	18,769
Shell Rock 12	Maryland oyster	18,737	2,678,540	143	3,723
Shell Rock 43	Surf clam	8,000	2,492,214	312	3,464
Shell Rock 43	Ocean quahog	7,600	3,116,607	410	4,332

Table 9. MSX prevalence / percent advanced / and weighted prevalence (scale of 0 to 4) in oysters undergoing natural challenge at Cape May Harbor in 2005. N = 20 for each sample.

Source of Oysters	Time 0 May 3-12	July 7	August 8	October 13
Maine (Susceptible)	0% / 0% / 0.0	0% / 0% / 0.0	30% / 20% / 1.0	90% / 80% / 3.3
Arnolds	0% / 0% / 0.0	0% / 0% / 0.0	5% / 0% / 0.1	20% / 5% / 0.5
Shell Rock	0% / 0% / 0.0	0% / 0% / 0.0	5% / 0% / 0.1	10% / 5% / 0.3
Cape Shore	0% / 0% / 0.0	5% / 0% / 0.1	0% / 0% / 0.0	0% / 0% / 0.0

Table 10. An estimate of the unrecorded mortality in 2004 as a fraction of the stock. Bed regions are defined in Table 6. Note that higher unrecorded mortality is indicated by more negative numbers; hence a lower percentile rank indicates a higher mortality rate. A positive number indicates that recruitment was overestimated or box-count mortality underestimated. Positive values occur rarely in the time series. The data indicate uncertainty in the survey estimates for the low-mortality beds either in 2004 or 2005. However, positive values occur more commonly on the low-mortality beds than elsewhere throughout the 53-year time series, suggesting that recruitment may be overestimated by slow growth or that boxes of these smaller animals disarticulate more rapidly than the larger boxes that are more common downbay.

	2005 Unrecorded Mortality	53-year Percentile	Post-1988 Percentile
Low-mortality	.325	95	95
Medium-mortality	-.370	33	33
Shell Rock	-.533	33	27
High-mortality	-.479	52	67

Table 11. Harvest statistics for 2005. Fraction covered indicates the fraction of bed area swept by the dredge during fishing. 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
Round Island	1,698,741	0	0	0%
Upper Arnolds	955,651	0	0	0%
Arnolds	2,017,740	0	0	0%
Upper Middle	2,124,916	0	0	0%
Middle	3,719,584	0	0	0%
Cohansey	5,314,243	0.36	2,723	9.68%
Sea Breeze	2,338,639	0	0	0%
Ship John	4,677,614	0.41	2,691	9.57%
Shell Rock	5,866,284	1.06	7,571	26.92%
Bennies Sand	1,963,210	0.75	1,315	4.68%
Bennies	5,744,726	0.41	2,939	10.45%
Nantuxent Point	1,914,582	3.00	5,302	18.85%
New Beds	5,958,621	0.25	1,613	5.73%
Hawk's Nest	2,021,670	1.12	2,954	10.50%
Hog Shoal	957,410	0.57	477	1.70%
Beadons	2,553,848	0	0	0%
Strawberry	1,595,928	0.51	543	1.93%
Vexton	1,489,937	0	0	0%
Egg Island	4,045,292	0	0	0%
Ledge	1,916,422	0	0	0%
Total	36,014,288		28,128	100%

Table 12. Statistics for oysters going to market, obtained from dock-side monitoring of landings. Sizes are given in inches.

	Mean size	25^{th} percentile	50^{th} percentile	75^{th} percentile	Mean Number per bushel	Number $\geq 2.75''$ per bushel
2004	3.04	2.79	3.08	3.37	302	283
2005	3.05	2.73	3.13	3.42	275	253

Figure 1. The footprint of the Delaware Bay natural oyster beds as defined prior to 2005 showing the grid system used. Each grid is a rectangle 0.2″ latitude × 0.2″ longitude, equivalent to approximately 25 acres.

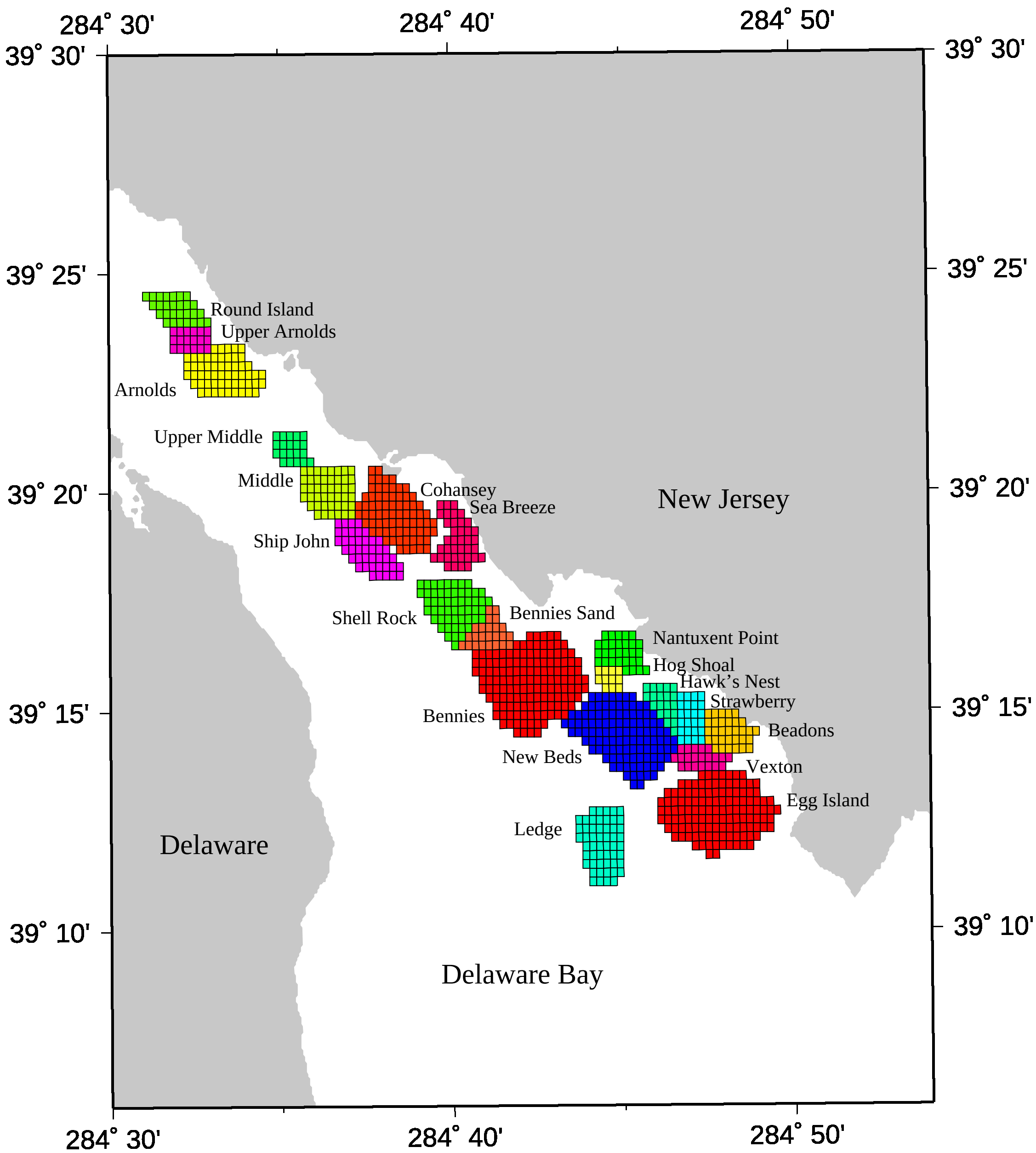

Figure 2. Annual bay-wide average number of oysters per 37-quart bushel. Error bars are the 95% confidence intervals.

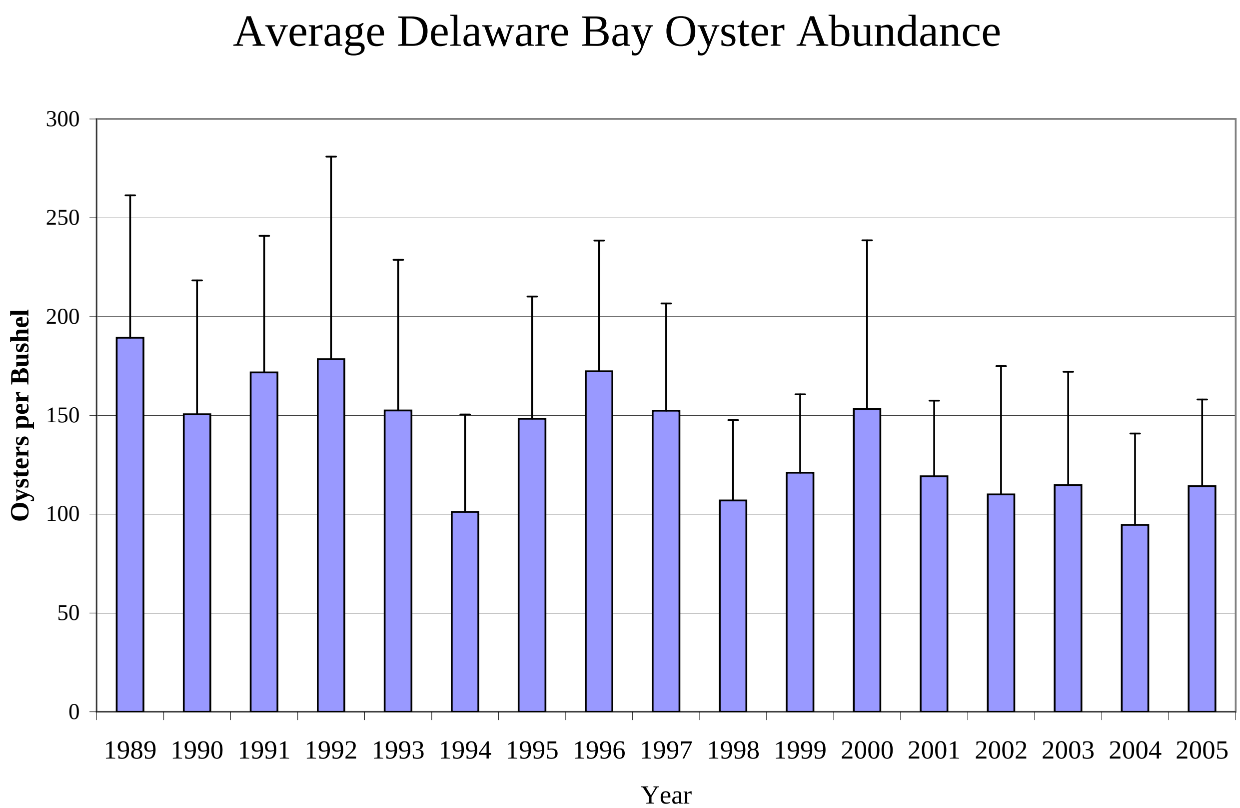

Figure 3. Annual oyster harvest from the natural oyster beds, in bushels.

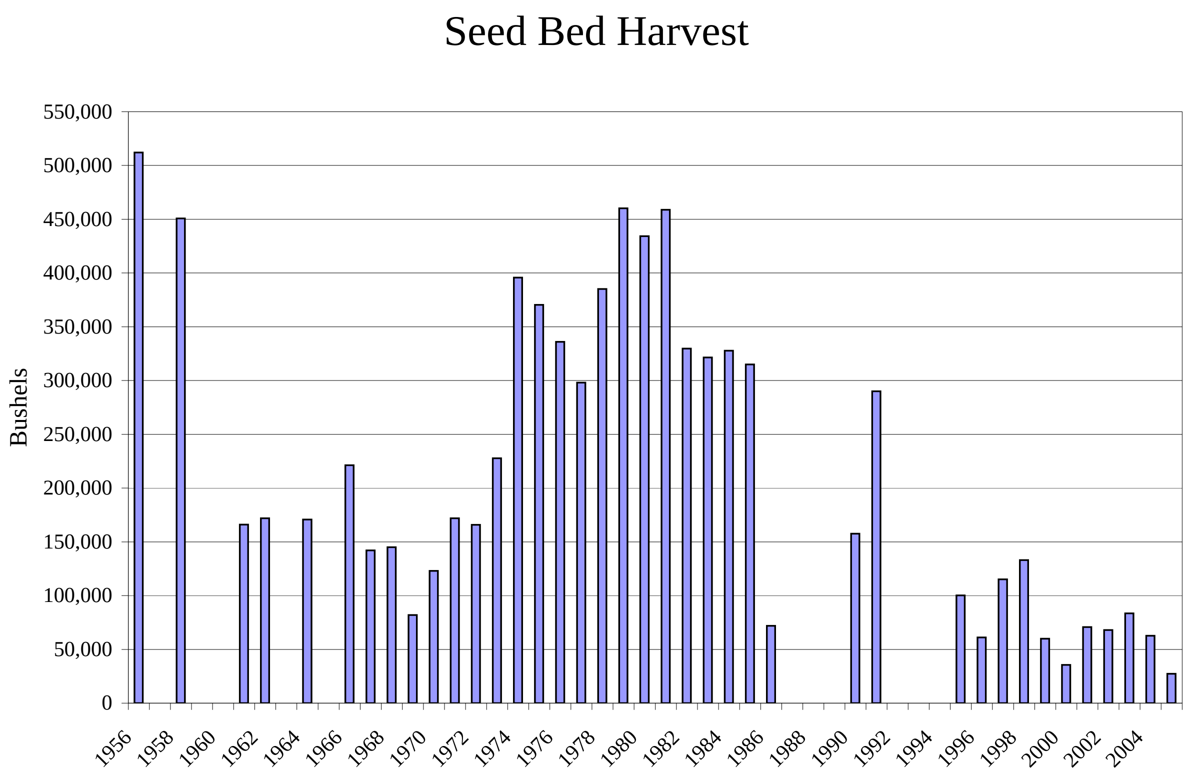

Figure 4. An example of the distribution of oysters on all grids assigned to Middle in the Spring of 2005 including neighboring grids not previously assigned to any bed. The upper plot shows the cumulative abundance with grids organized sequentially by increasing abundance, with the 2% and 50% boundaries indicated. The lower plot shows the 2% and 50% boundaries with respect to the actual abundance estimates, with grids equivalently ordered.

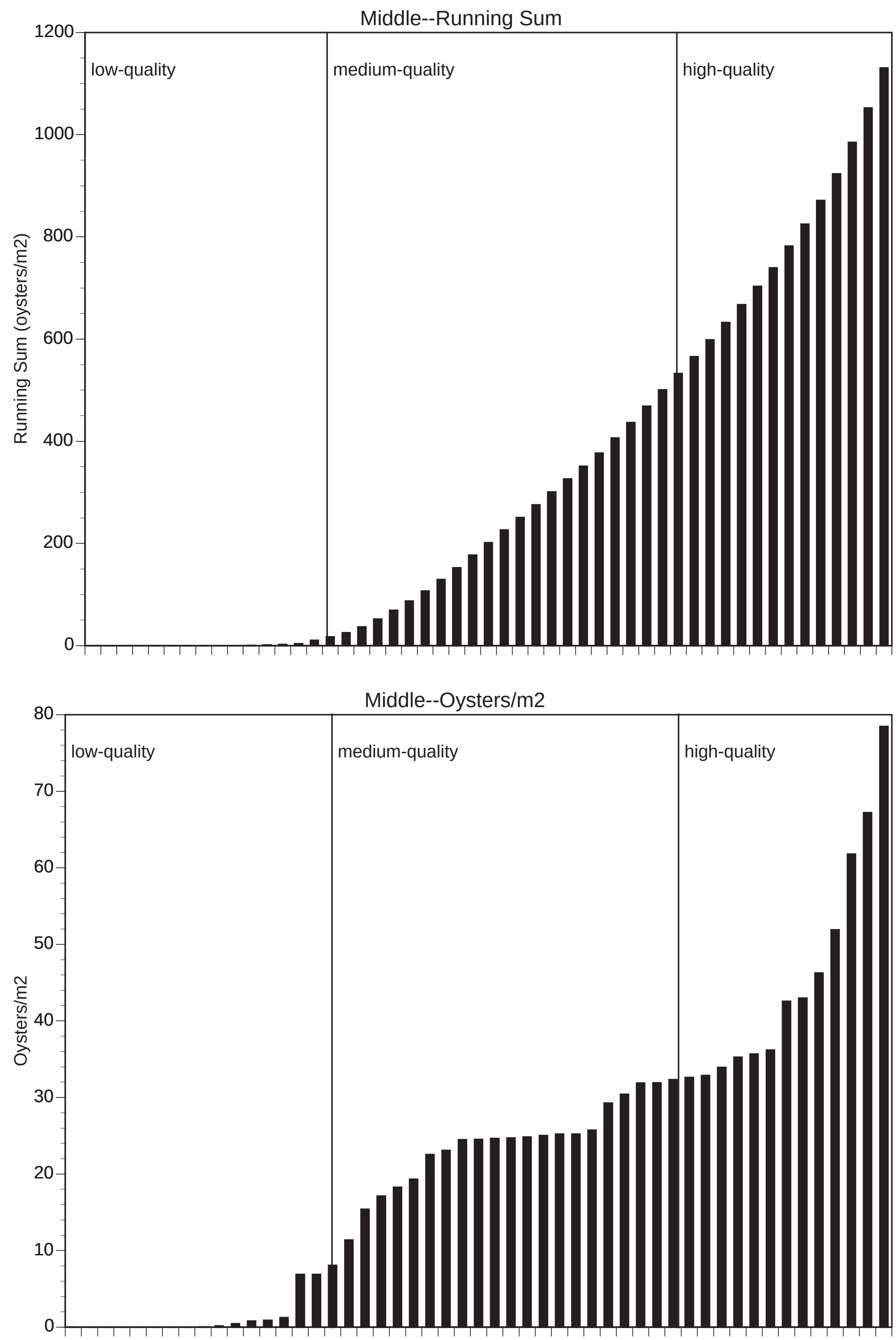

Figure 5. Delaware Bay natural oyster beds showing the locations of the 2005 random sampling sites (white dots) and the revised bed footprint defined by the high- and medium-mortality grids for Middle, Ship John, Sea Breeze, Cohansey, Shell Rock, and Bennies Sand.

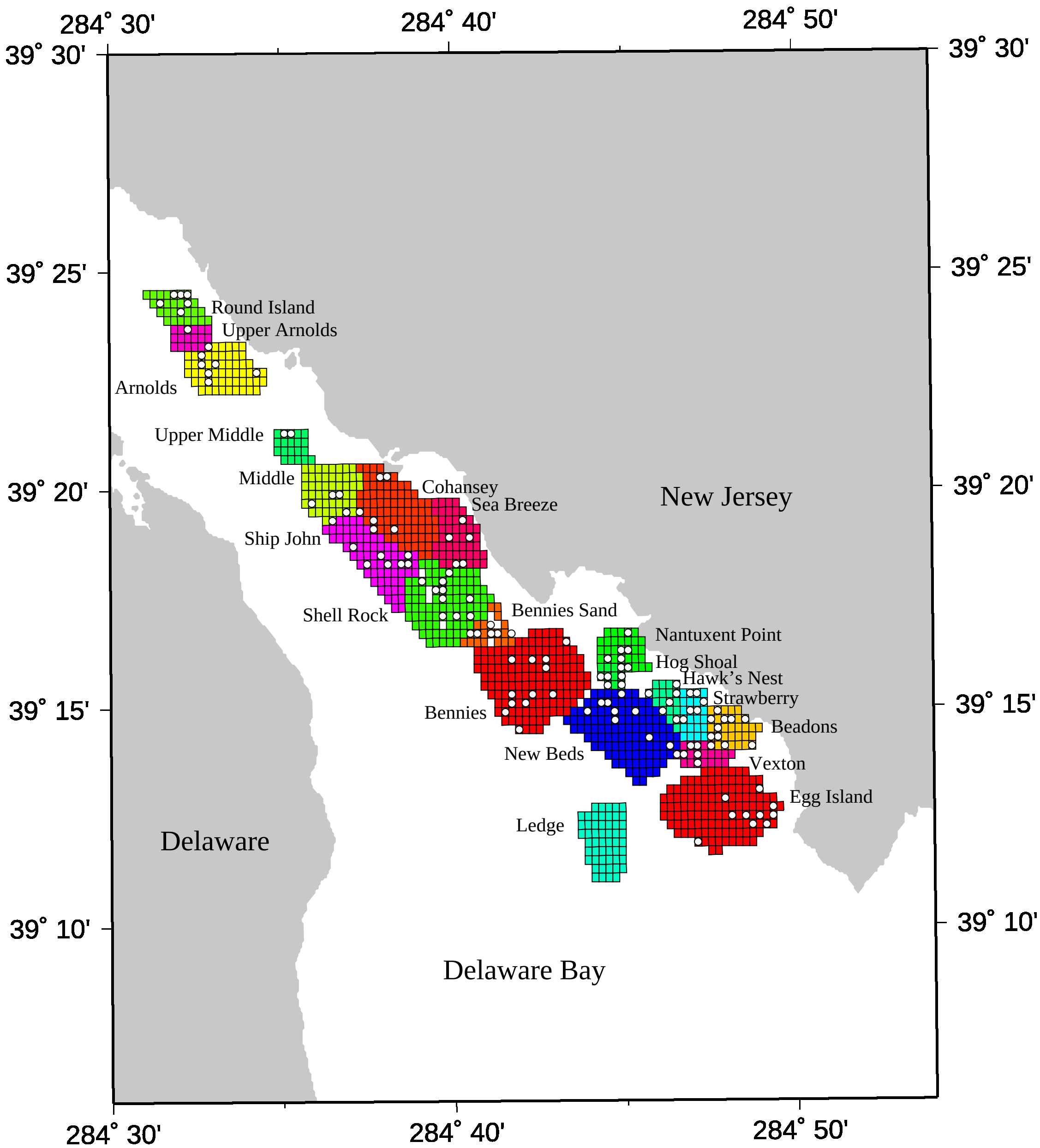

Figure 6. Average annual bay-wide oyster and spat abundance per 37-qt. bushel, with 95% Least Significant Difference confidence intervals. Underlined values are not significantly different. Mean = average of annual values. Years are arrayed across the top.

Delaware Bay Seed Beds

Year	**1989**	**1992**	**1996**	**1991**	**2000**	**1993**	**1997**	**1990**	**1995**	**1999**	**2001**	**2003**	**2005**	**2002**	**1998**	**1994**	**2004**	**Mean**
Oyster	189	178	172	172	153	153	152	151	148	121	119	115	114	110	107	101	95	**137**

Year	**1991**	**1999**	**1997**	**1998**	**1995**	**1994**	**1990**	**1989**	**2000**	**2002**	**1993**	**2005**	**2004**	**1992**	**1996**	**2003**	**2001**	**Mean**
Spat	268	191	151	128	127	124	112	69	55	44	44	29	27	25	22	22	15	**83**

Figure 7. Time series of oyster abundance, cumulatively 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.

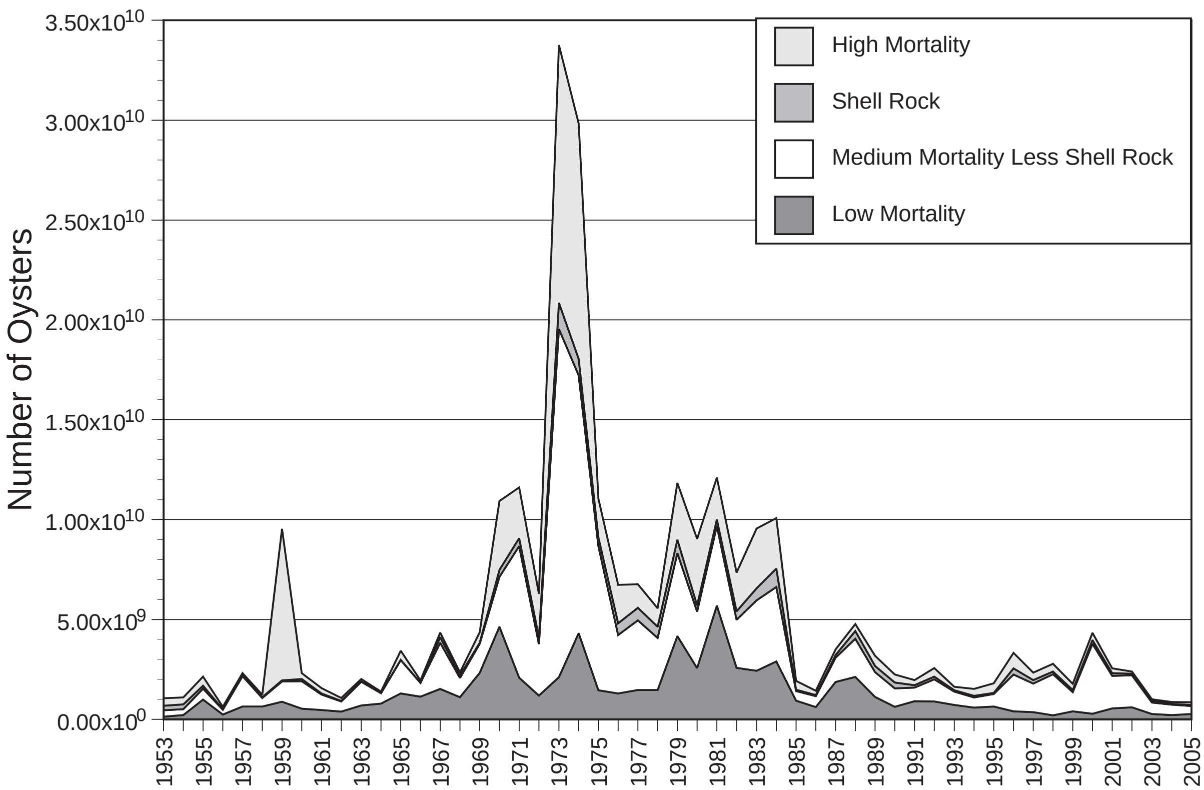

Figure 8. Total oysters per 37-qt. bushel from the medium-mortality less Shell Rock (Cohansey, Middle, Upper Middle, Ship John, Sea Breeze) and and a selection of high-mortality beds plus Shell Rock (Shell Rock, Bennies, Bennies Sand, New Beds, Hog Shoal, Strawberry, Hawk's Nest, Vexton, Egg Island, and New Beds). Error bars are the 95% confidence intervals.

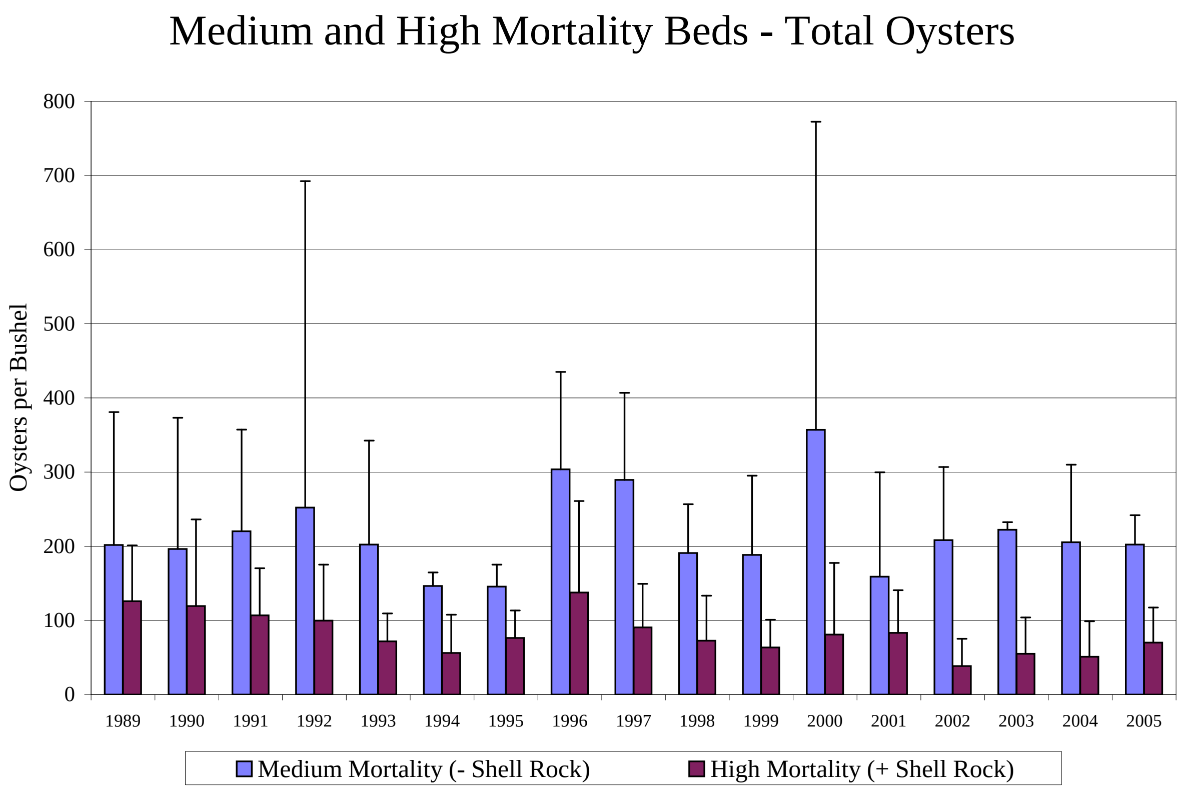

Figure 9. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality and high-mortality region for the 1989-2005 time period. Medium mortality = Upper Middle, Middle, Ship John, Cohansey, Shell Rock. High-mortality = Bennies, Bennies Sand, Nantuxent, Hog Shoal, New Beds, Strawberry, Hawk's Nest, Beadons, Vexton. Underlined values are not significantly different according to 95% Least Significant Difference confidence intervals. Mean = average of annual values. * = means that are significantly different.

Medium Mortality Beds

Year	**2000**	**1996**	**1997**	**1992**	**1990**	**1991**	**1989**	**2003**	**1998**	**1993**	**2005**	**2002**	**2004**	**2001**	**1999**	**1994**	**1995**	**Mean**
Oysters	321	309	265	244	225	222	214	213	193	190	189	167	165	155	153	143	138	203*
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High Mortality Beds

Year	**1996**	**1989**	**1995**	**1990**	**1997**	**1992**	**1991**	**1998**	**2000**	**1999**	**2001**	**2005**	**1993**	**1994**	**2003**	**2004**	**2002**	**Mean**
Oysters	153	105	95	91	91	91	84	80	80	79	67	65	55	52	44	38	28	74*
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Medium Mortality Beds

Year	**1999**	**1991**	**1998**	**1995**	**1994**	**1990**	**1997**	**2000**	**2002**	**1989**	**1993**	**2004**	**1996**	**2005**	**1992**	**2003**	**2001**	**Mean**
Spat	351	307	209	179	164	126	113	97	89	70	60	43	36	34	31	29	17	111
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High Mortality Beds

Year	**1991**	**1997**	**1999**	**1994**	**1998**	**1995**	**1990**	**1989**	**2000**	**1993**	**2004**	**2005**	**2002**	**2003**	**1992**	**1996**	**2001**	**Mean**
Spat	273	221	166	166	146	137	107	70	69	46	29	26	25	23	21	16	15	87
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Figure 10. Time series of abundance by bed region. Bed distributions by region are given in Figure 7.

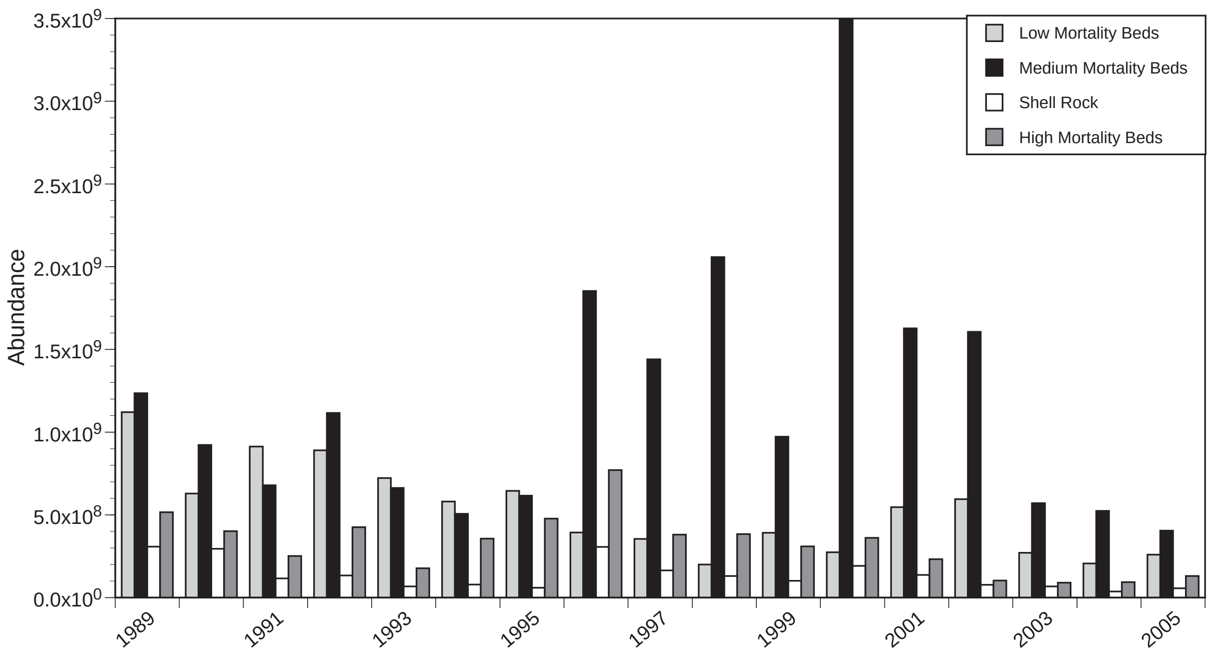

Figure 11. Time series of spawning stock biomass by bed region. Bed distributions by region are given in Figure 7.

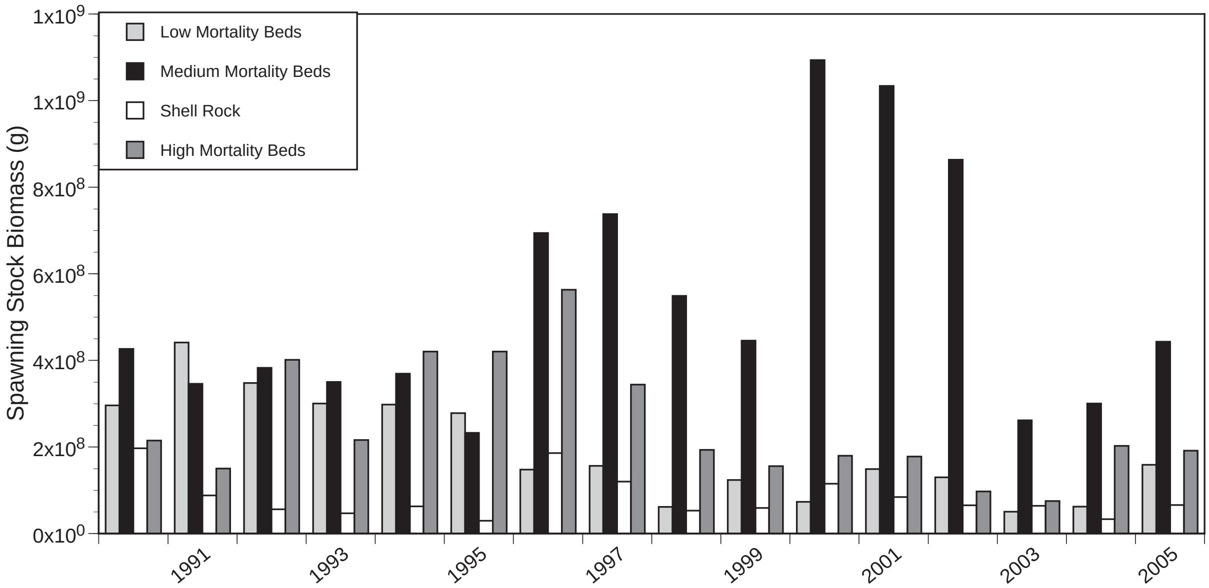

Figure 12. Oyster per 37-qt. bushel by market ($\geq 3''$) and submarket (2.5 to $2.99''$) size classes from medium-mortality (less Shell Rock) and high-mortality (plus Shell Rock) beds. Bed groups defined in Figure 8. Error bars are the 95% confidence intervals.

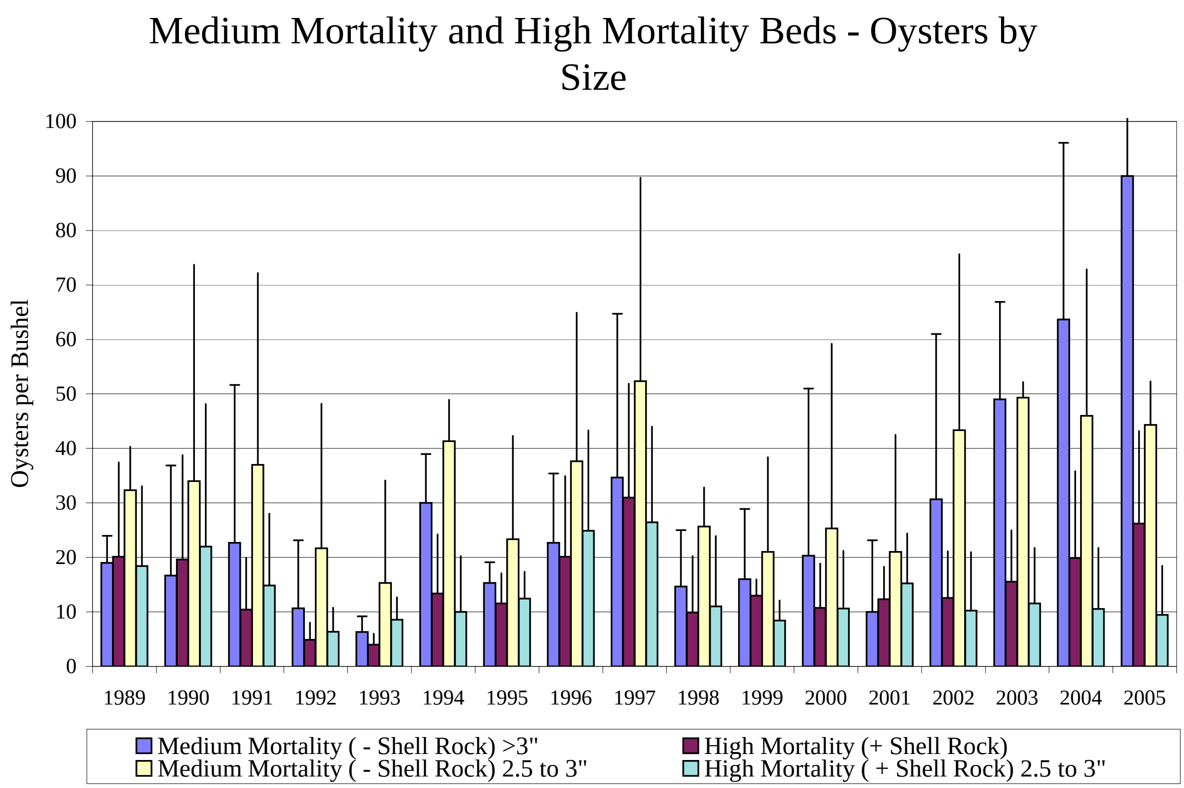

Figure 13. Percent of total oysters in the 2.5″ to 3″ (submarket) and > 3″ (market) categories for the medium-mortality (less Shell Rock) and high-mortality + Shell Rock beds. Bed groups are defined in Figure 8.

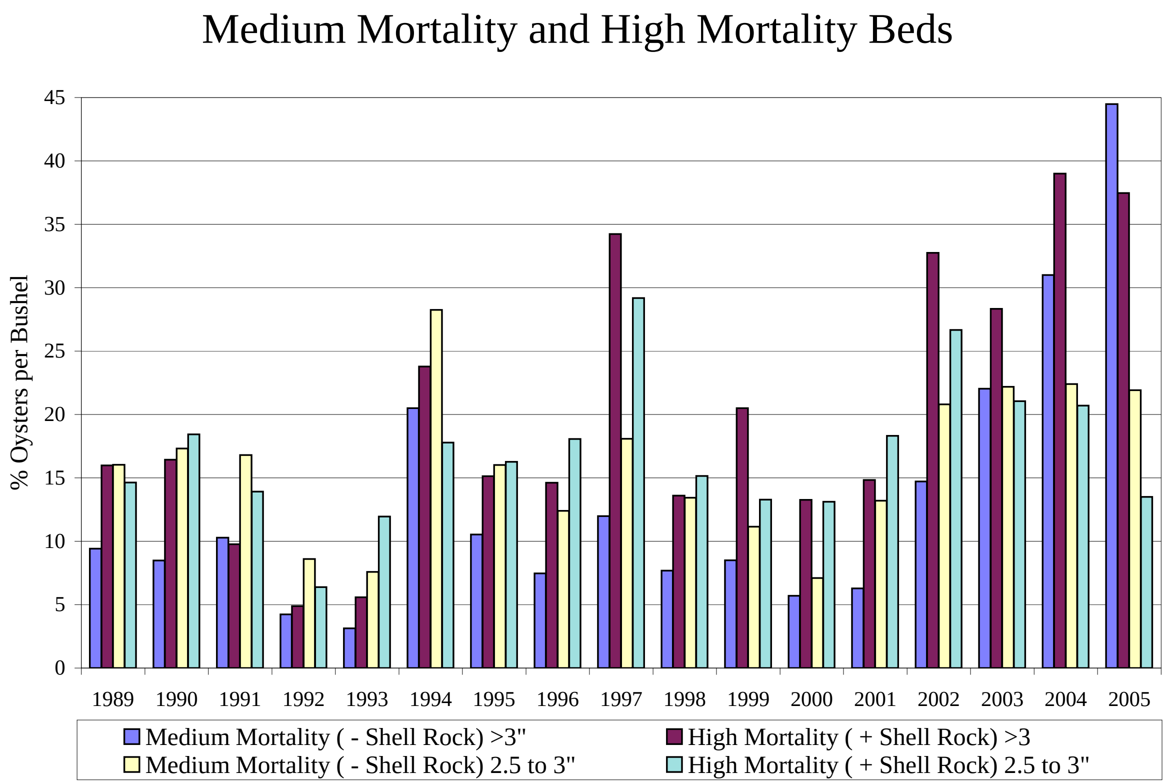

Figure 14. Size-frequency distribution of spat recruiting on planted surf clam and ocean quahog shell on Shell Rock 43 in 2005.

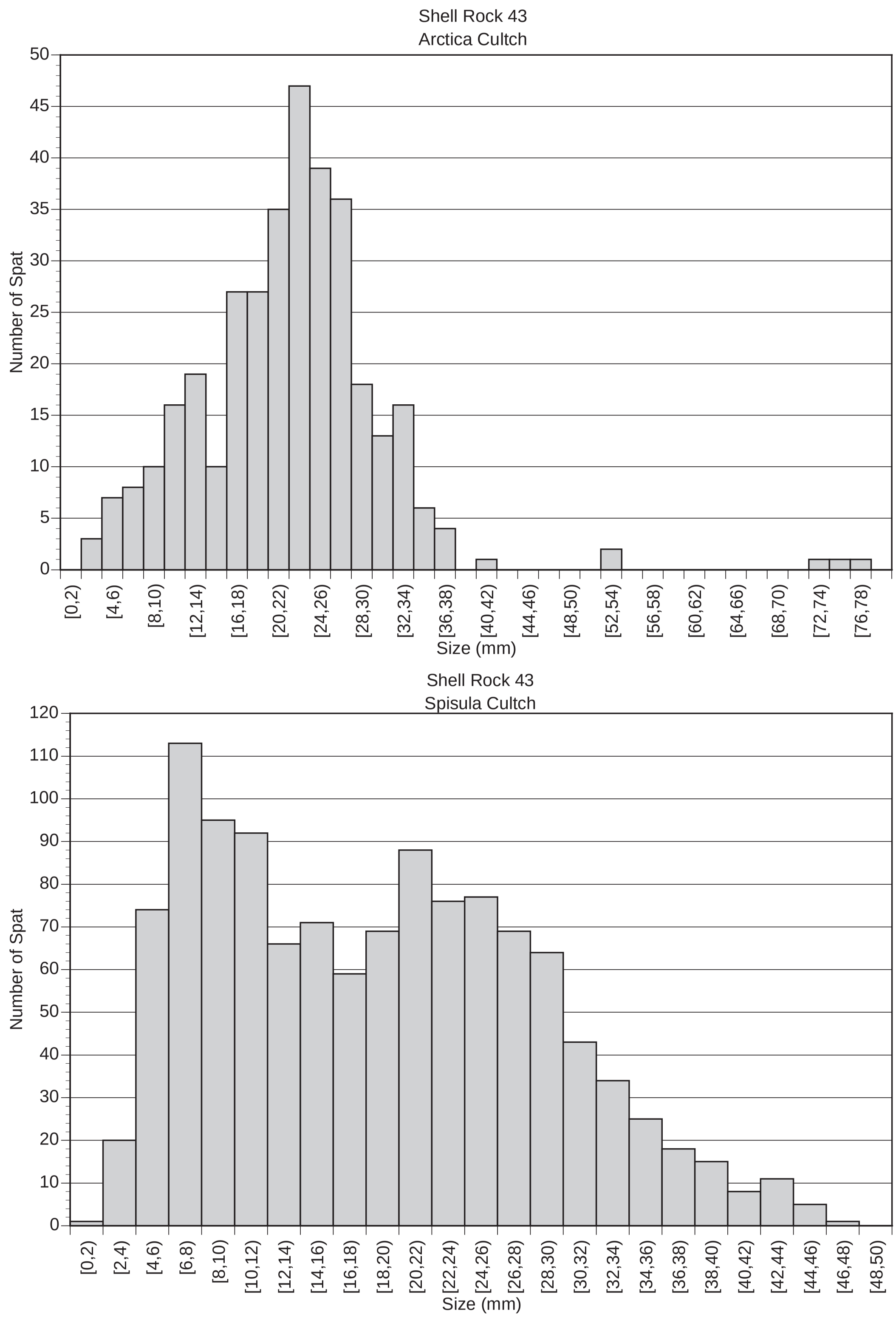

Figure 15. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)]. Error bars are the 95% confidence intervals.

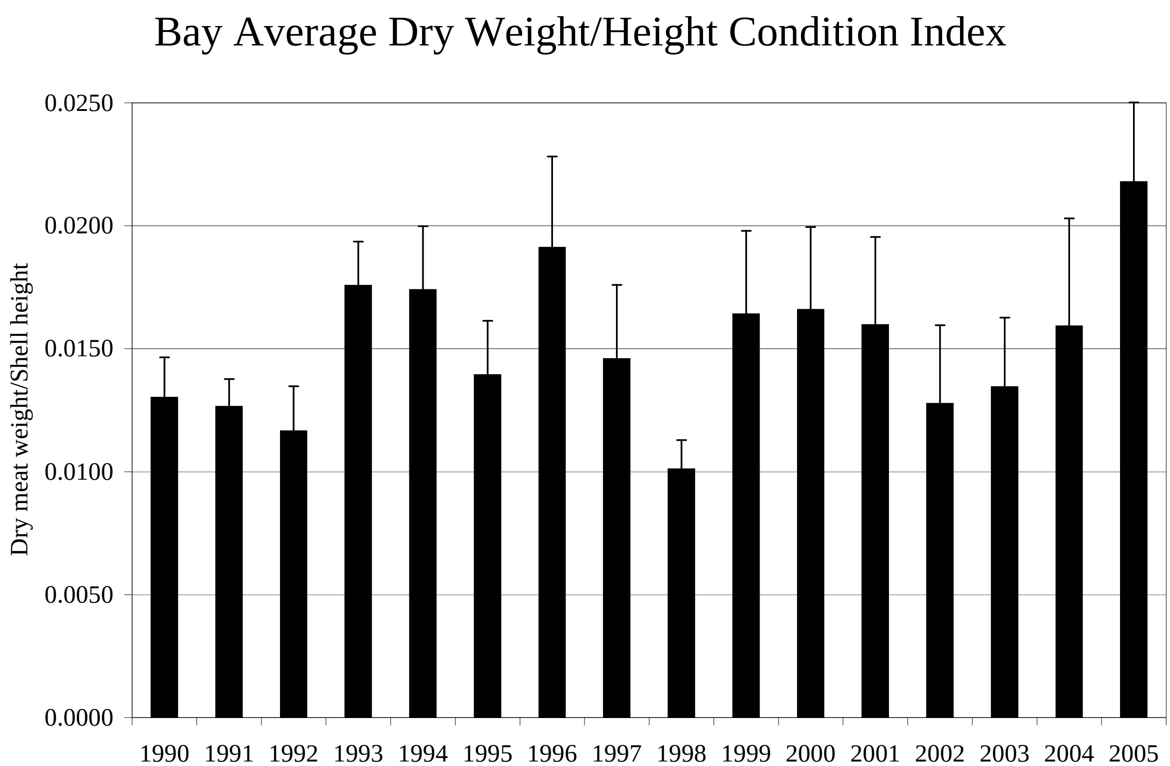

Figure 16. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)] by bed group. Low mortality = Round Island, Arnolds, Upper Arnolds. Medium mortality = Upper Middle, Middle, Ship John, Cohansey, Shell Rock. High mortality = Bennies, Bennies Sand, Nantuxent, Hog Shoal, New Beds, Strawberry, Hawk's Nest, Beadons, Vexton, Egg Island, Ledge. Error bars are the 95% confidence intervals.

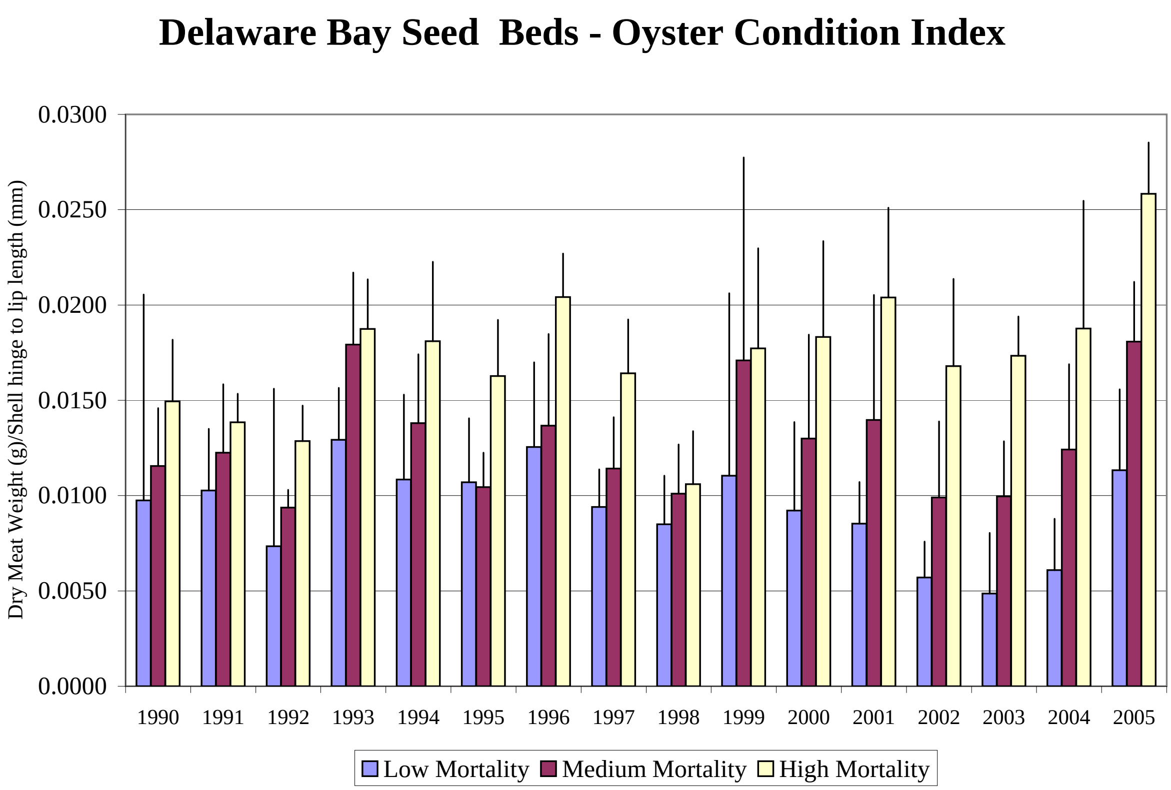

Figure 17. Oyster growth of spat caught on surf-clam shells planted near Reed's Beach in summer 2003 and transplanted to Bennies Sand 10 in early Fall 2003. Regression equations show rates of 0.17 mm d^{-1} and 0.11 mm d^{-1} for the growing seasons of 2004 and 2005, respectively.

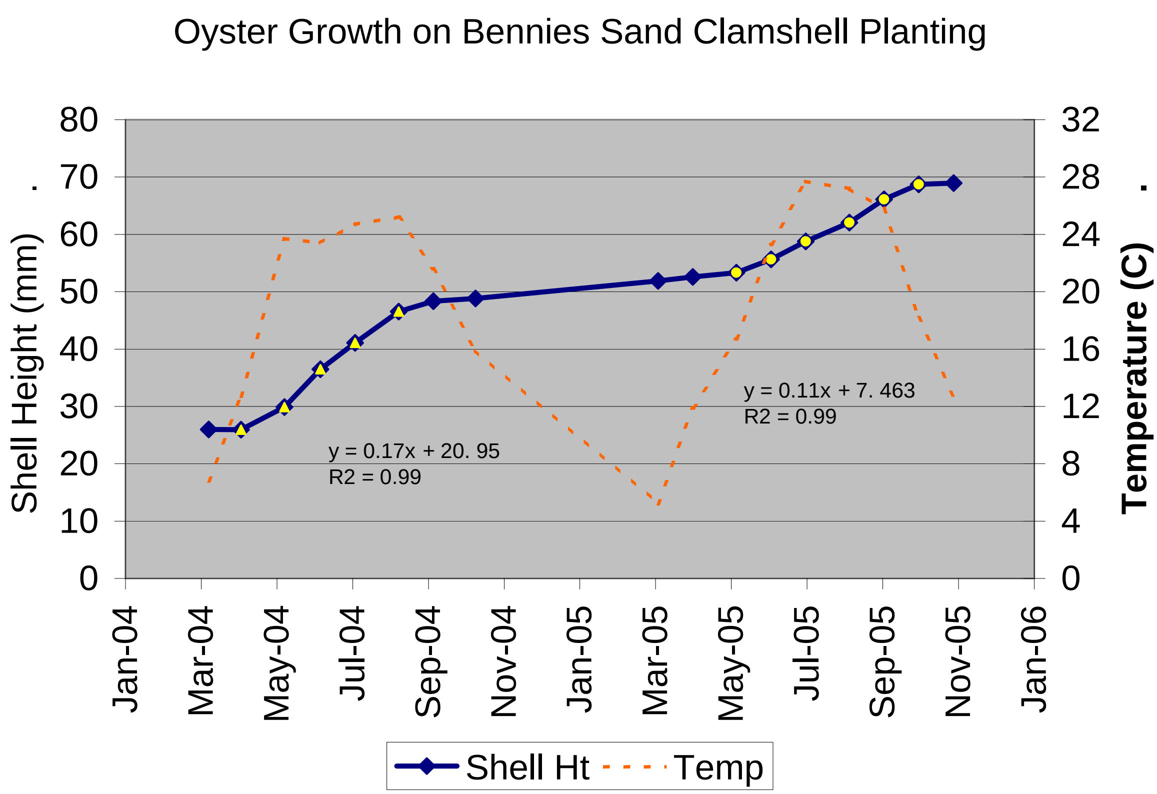

Figure 18. Annual bay-wide average spat counts per 37-quart bushel. Error bars are the 95% confidence intervals.

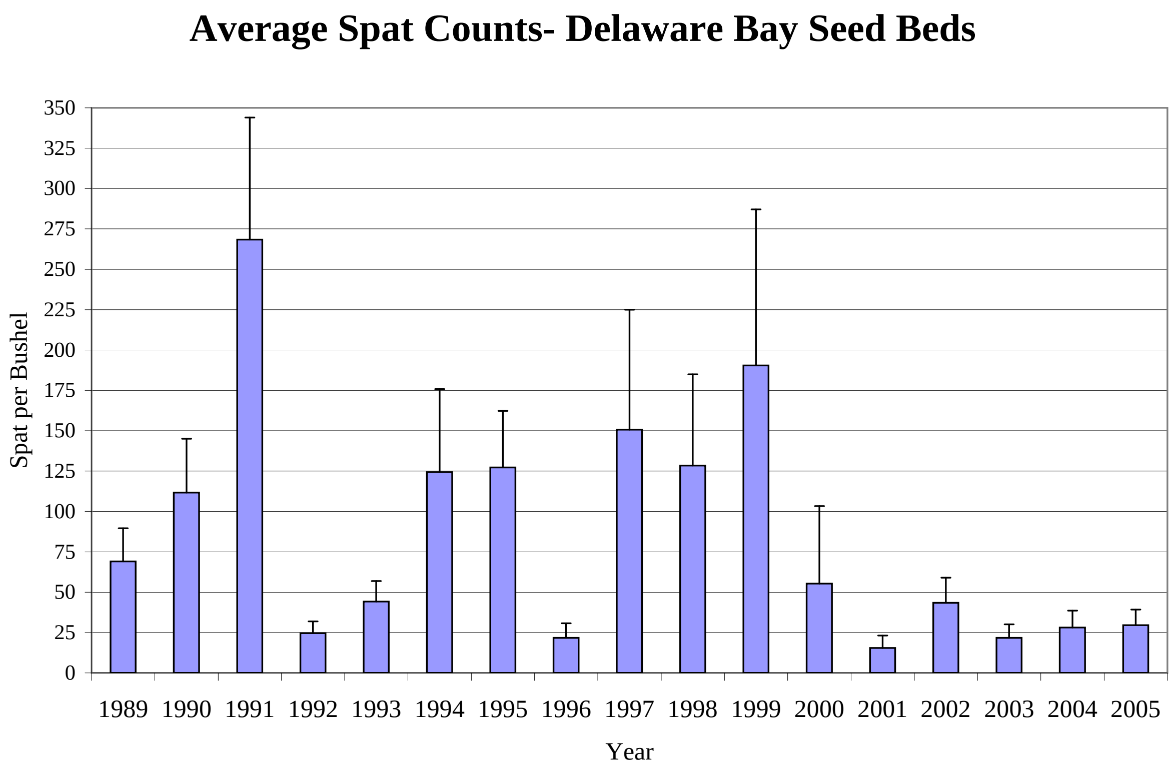

Figure 19. Number of spat recruiting per year for the 1953-2005 time series, cumulatively by bay region. Bay regions are defined in Figure 7, with Shell Rock split out from the remaining medium-mortality beds.

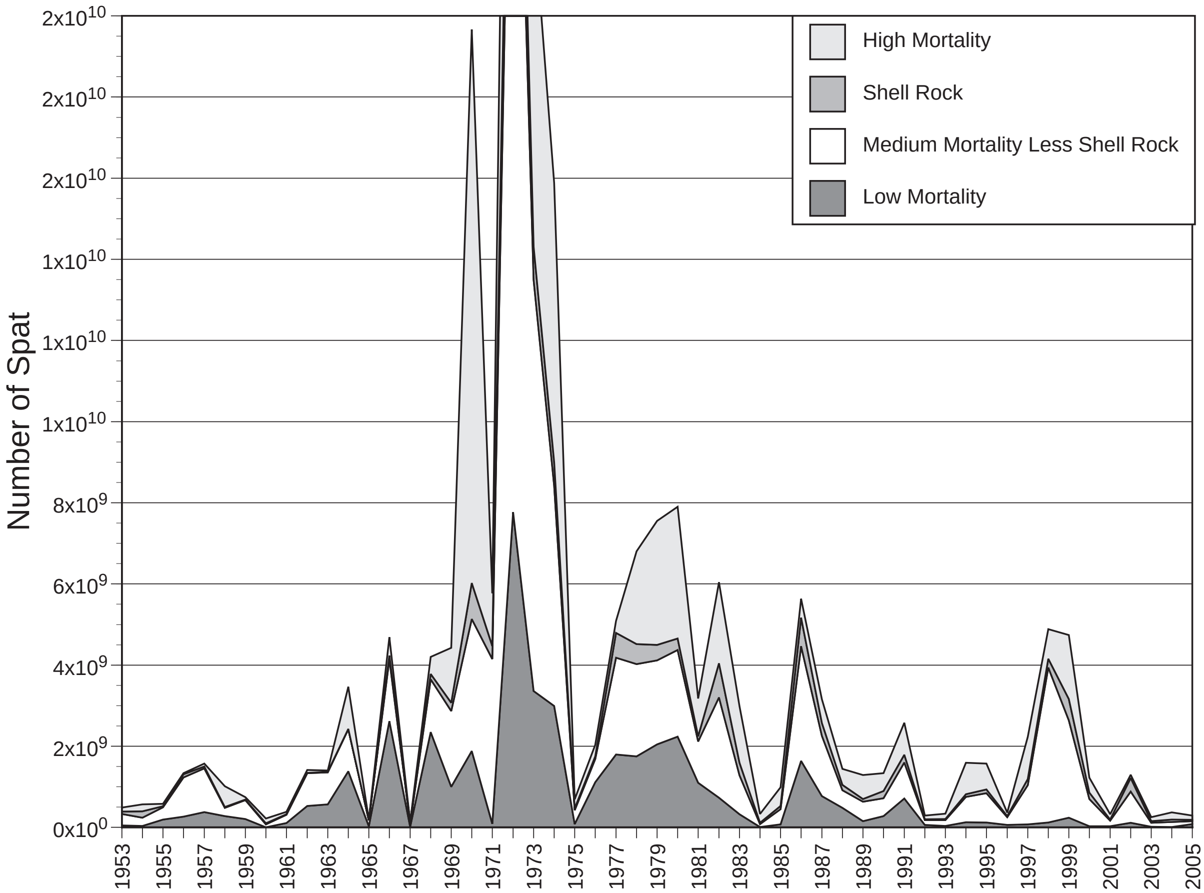

Figure 20. The number of spat recruiting per >20-mm oyster per year on the high- and medium-quality strata.

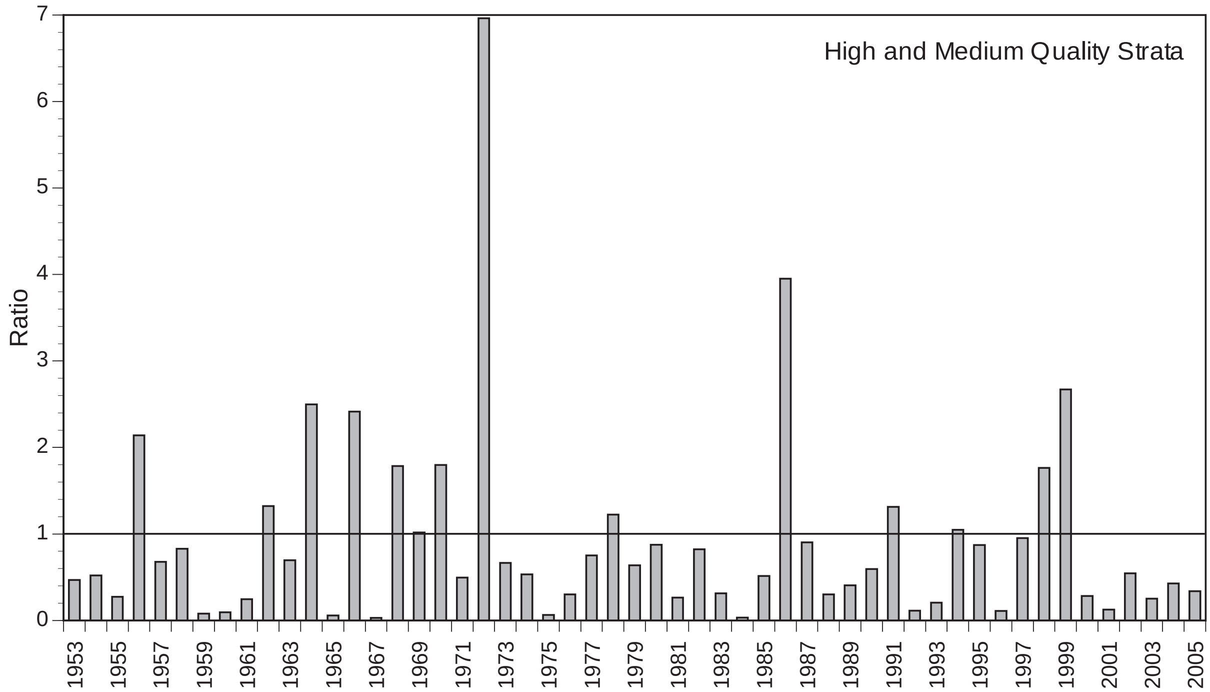

Figure 21. Cumulative number of spat recruiting to 20-oyster-shell bags deployed in the last week of June and collected bi-weekly through September. Colors identify the month of settlement. Circle diameter indicates the number of spat that settled during that time period. Total diameter indicates the cumulative number of spat. Note that circle diameter bears a nonlinear relationship to total spat counts.

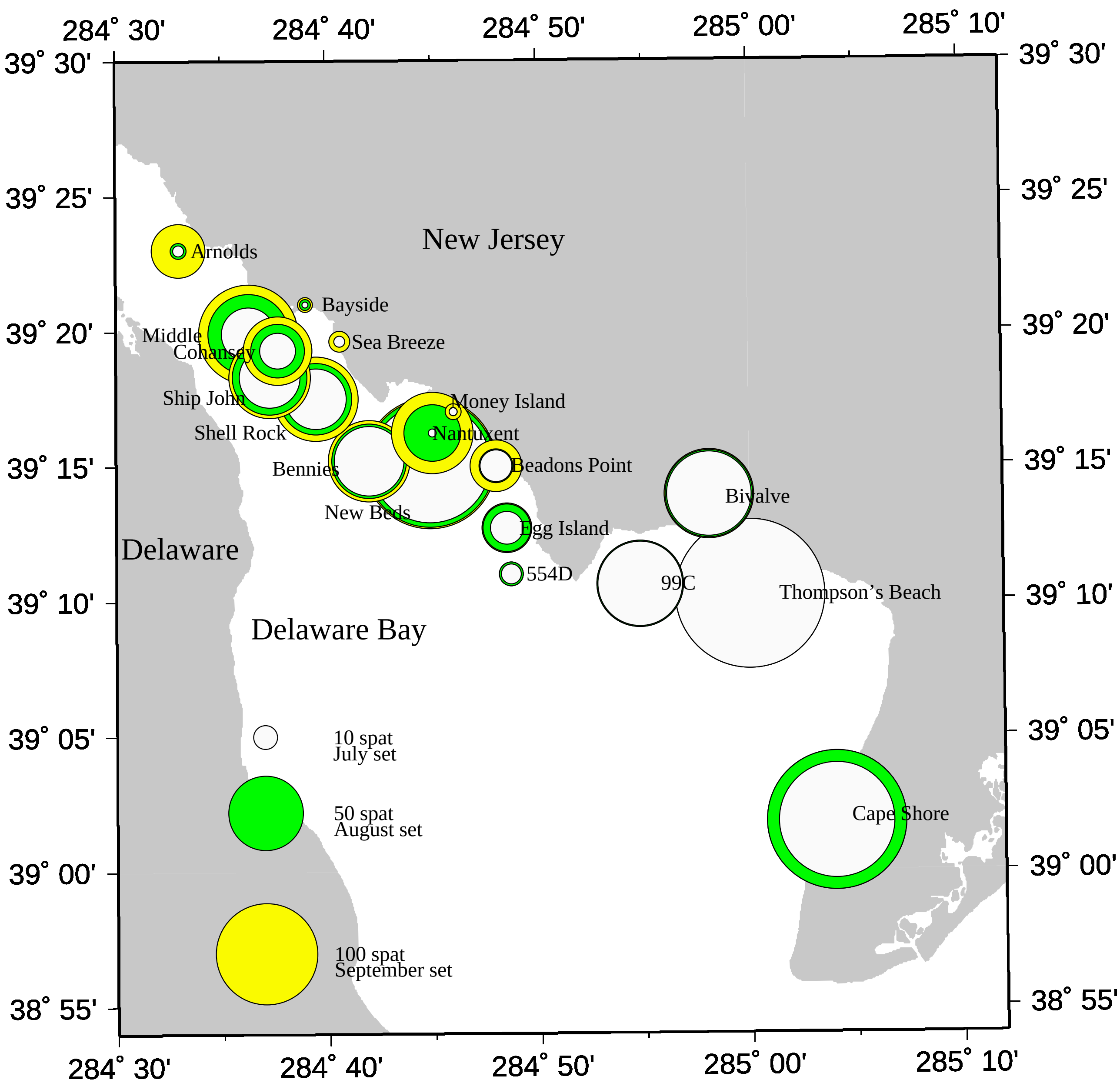

Figure 22. Trends in cultch, expressed as quarts m^{-2}, for the time period 1998-2005 for oyster beds sampled consistently in all years.

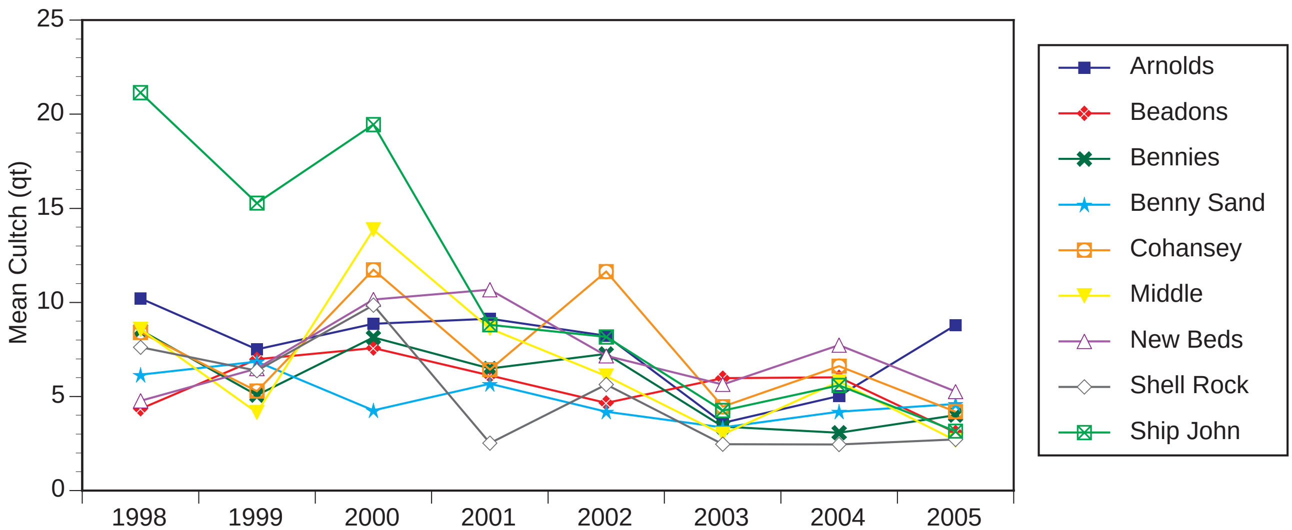

Figure 23. Relationship between Fall Dermo infection intensities and Fall mortality as measured by box counts. Each point corresponds to a measurement from one bed for one year. The regression is significant at $P < 0.05$.

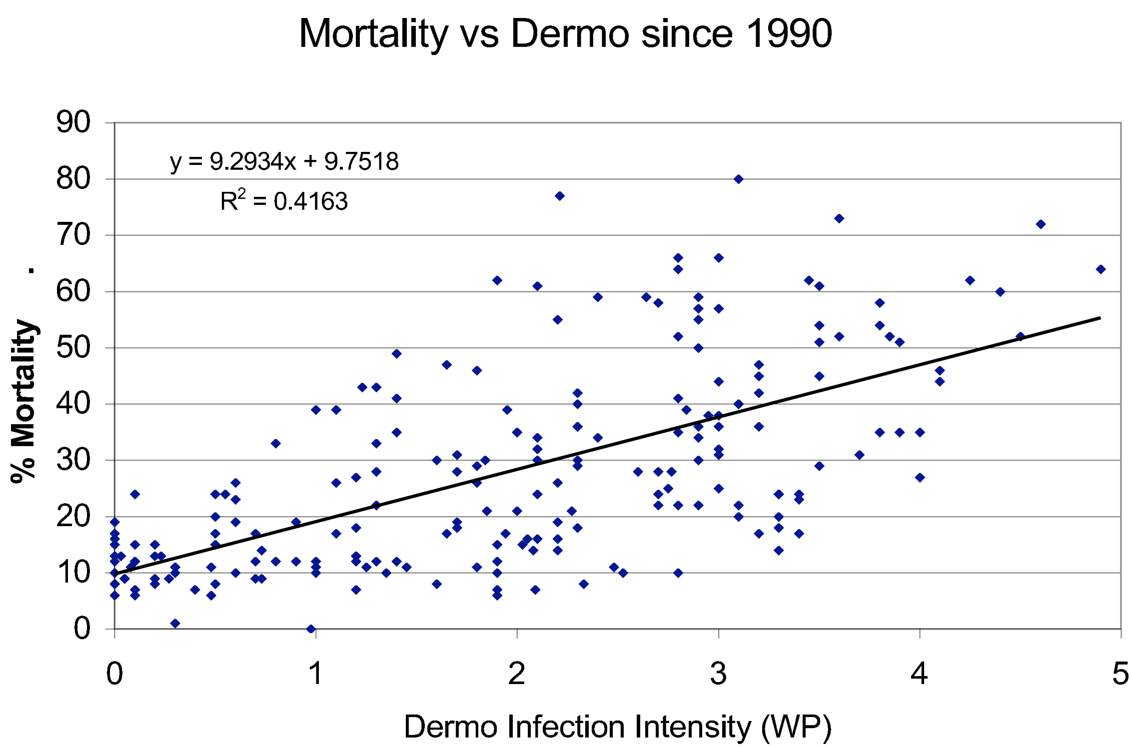

Figure 24. Mean and 2005 Dermo prevalence in oysters on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals.

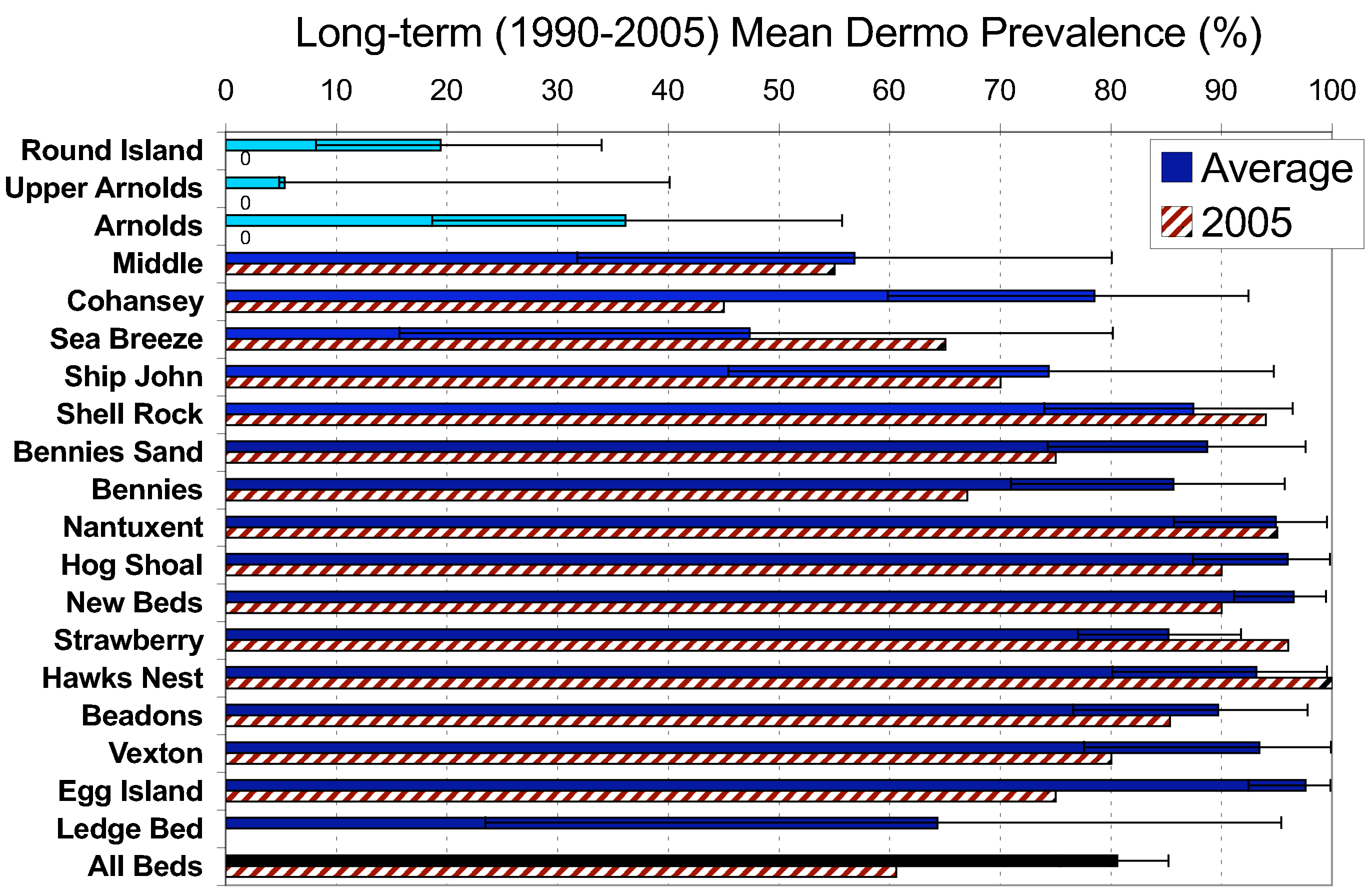

Figure 25. Mean and 2005 weighted prevalence of Dermo disease on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals.

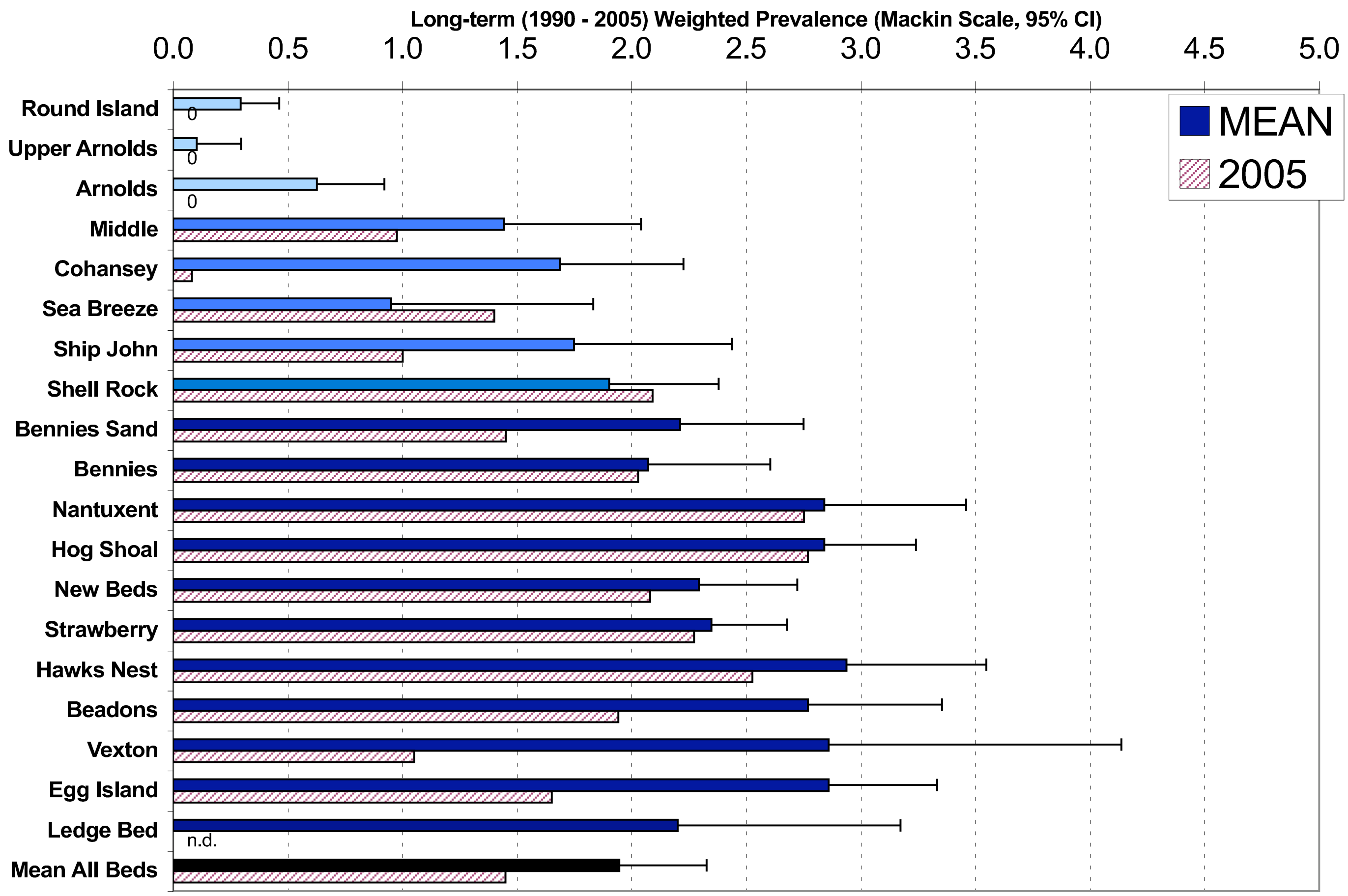

Figure 26. Time series showing the relationship of Dermo disease prevalence to periods of increased natural mortality in Delaware Bay oyster populations. Horizontal line represents the time series mean. WP = weighted prevalence.

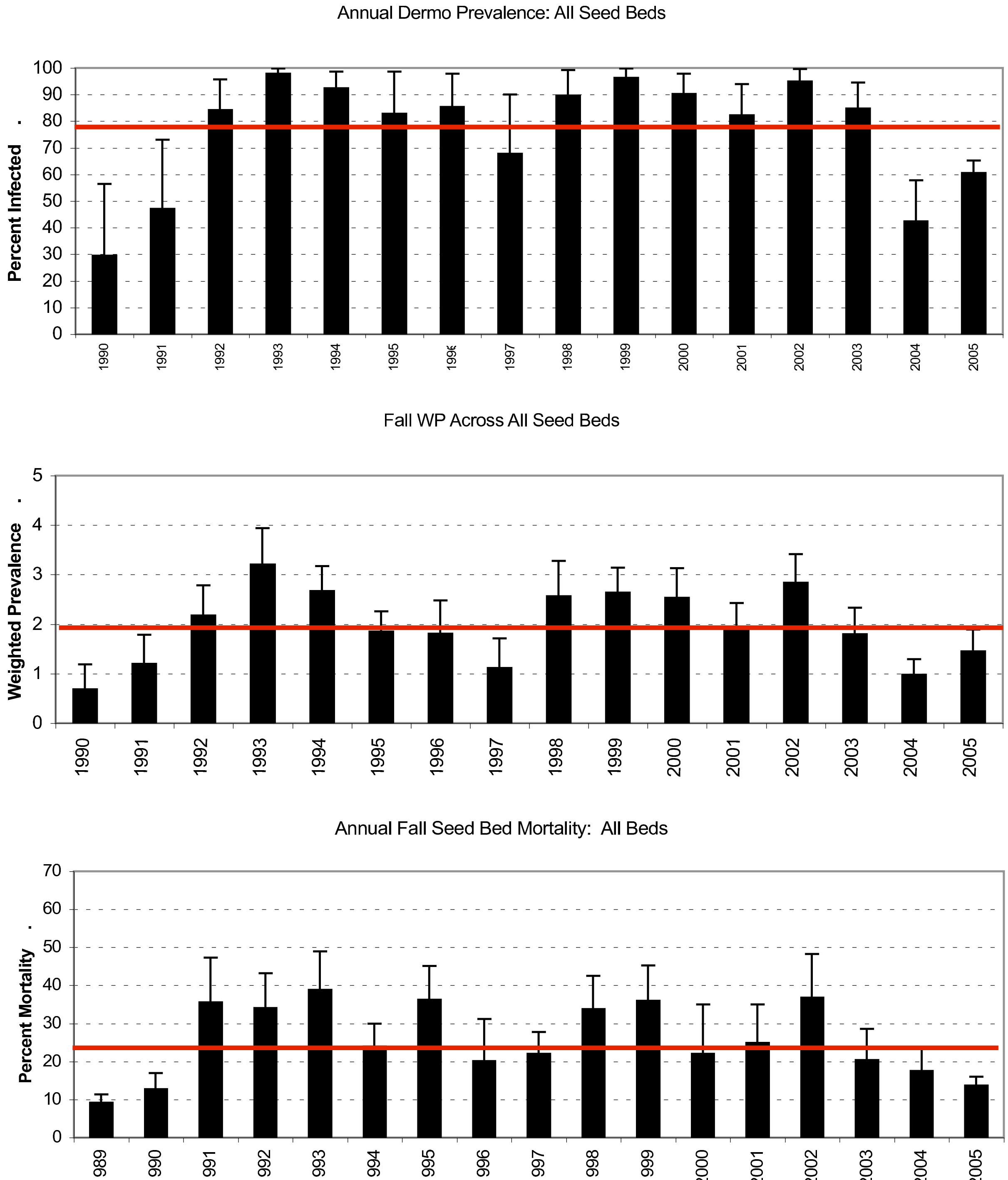

Figure 27. Mean and 2005 box-count mortality on New Jersey Delaware Bay oyster beds, rendered as the percent of beginning year abundance that died. Error bars are 95% confidence intervals.

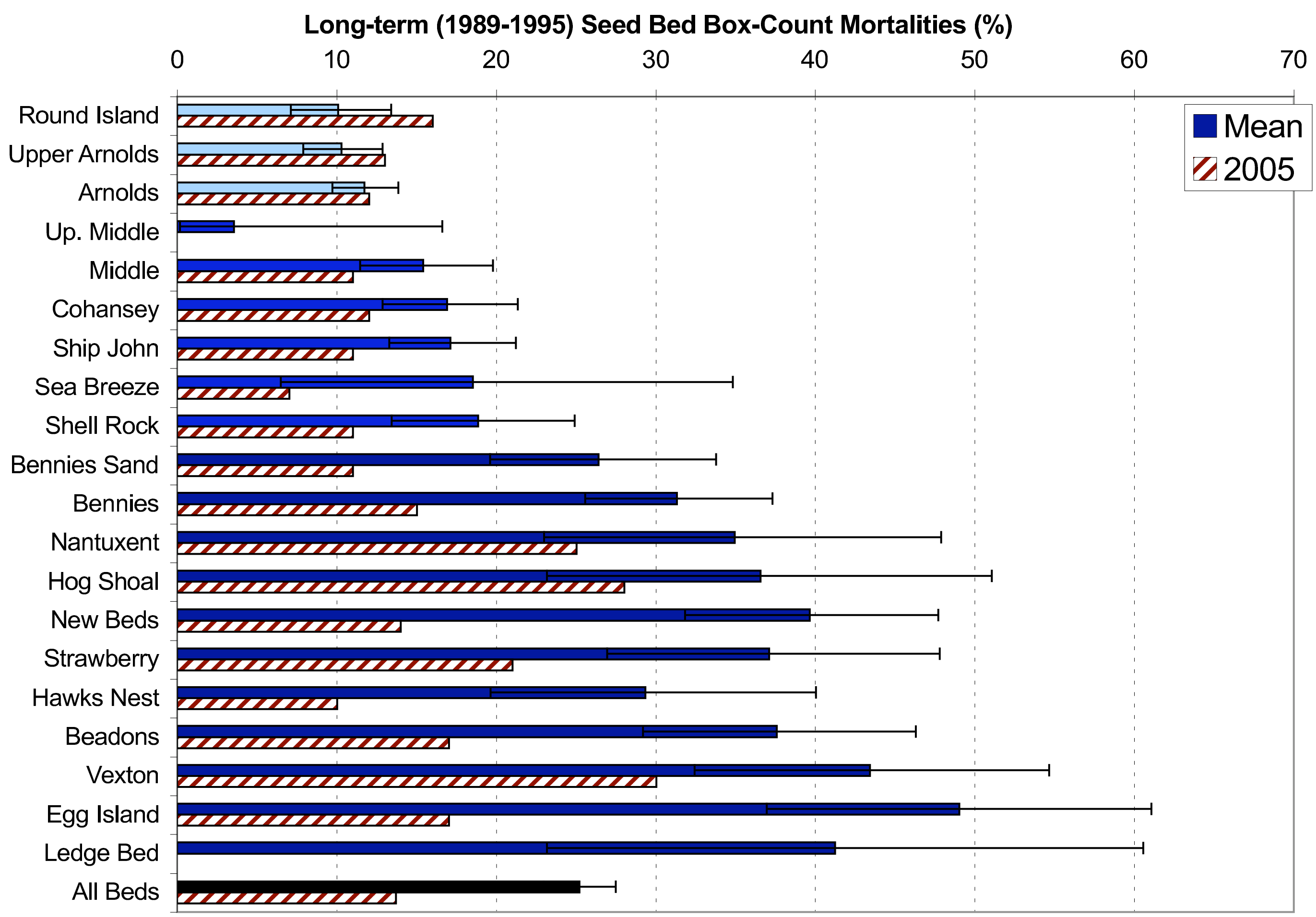

Figure 28. Broodstock-recruitment relationship for the 1953-2005 time period for the natural oyster beds of Delaware Bay.

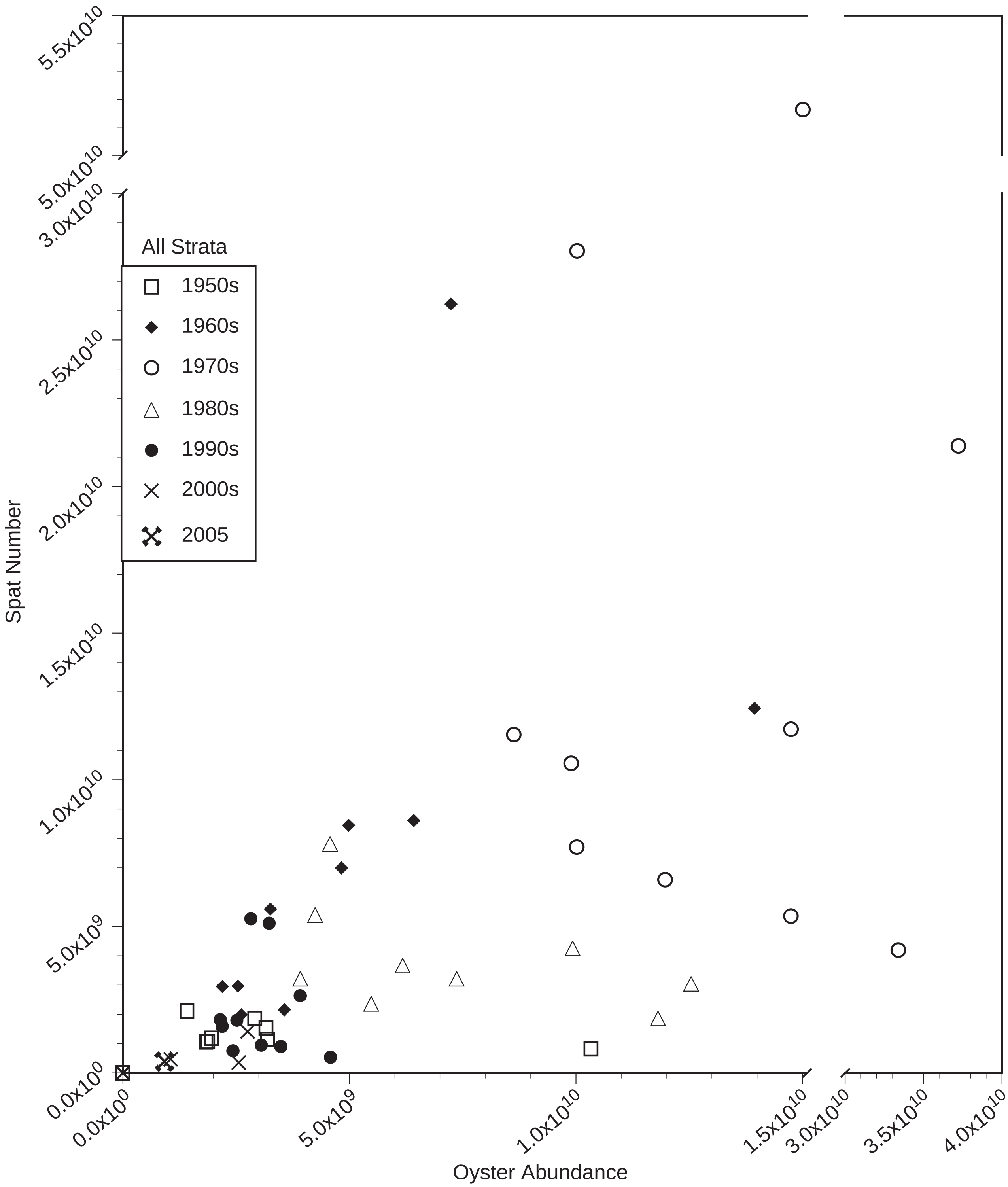

Figure 29. The relationship between oyster abundance and box-count mortality for the 1953-2005 time period for the natural oyster beds of Delaware Bay.

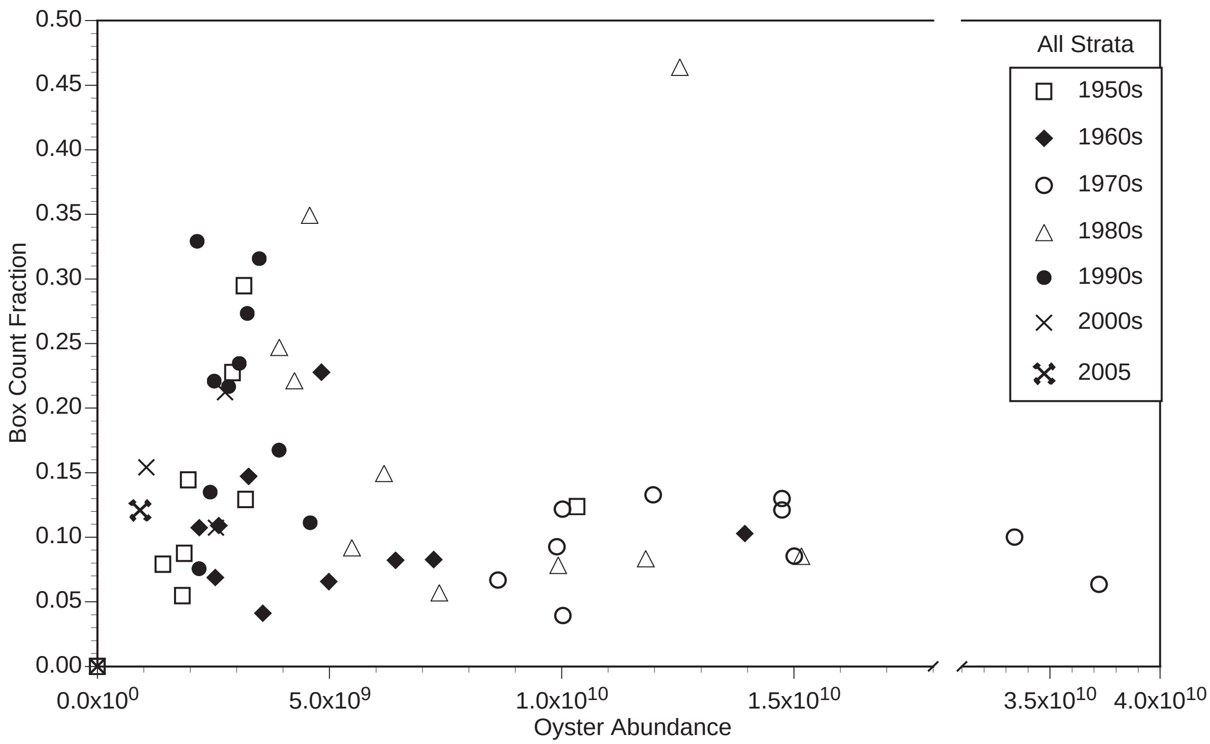

Figure 30. The relationship between recruitment and box-count mortality for the 1953-2005 time period for the natural oyster beds of Delaware Bay.

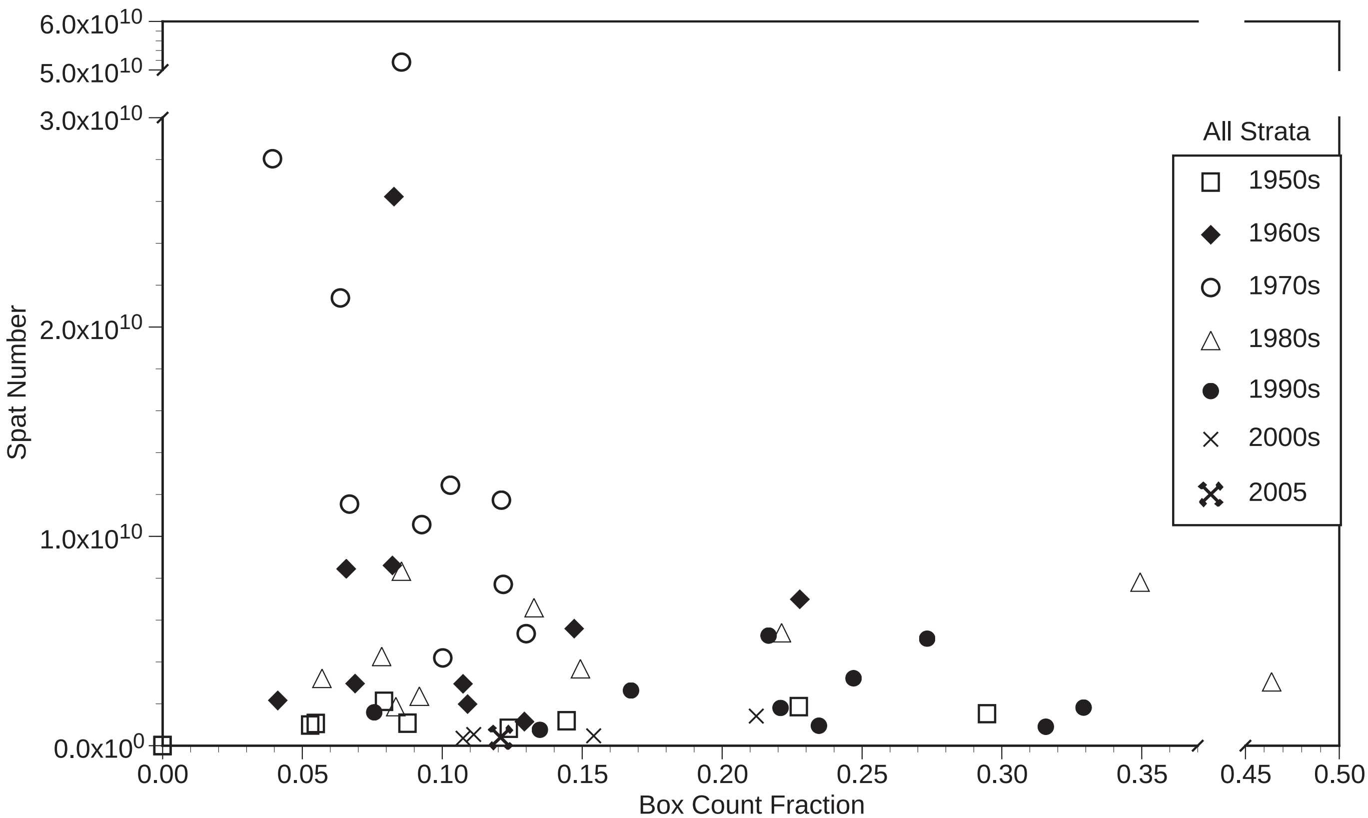

Figure 31. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

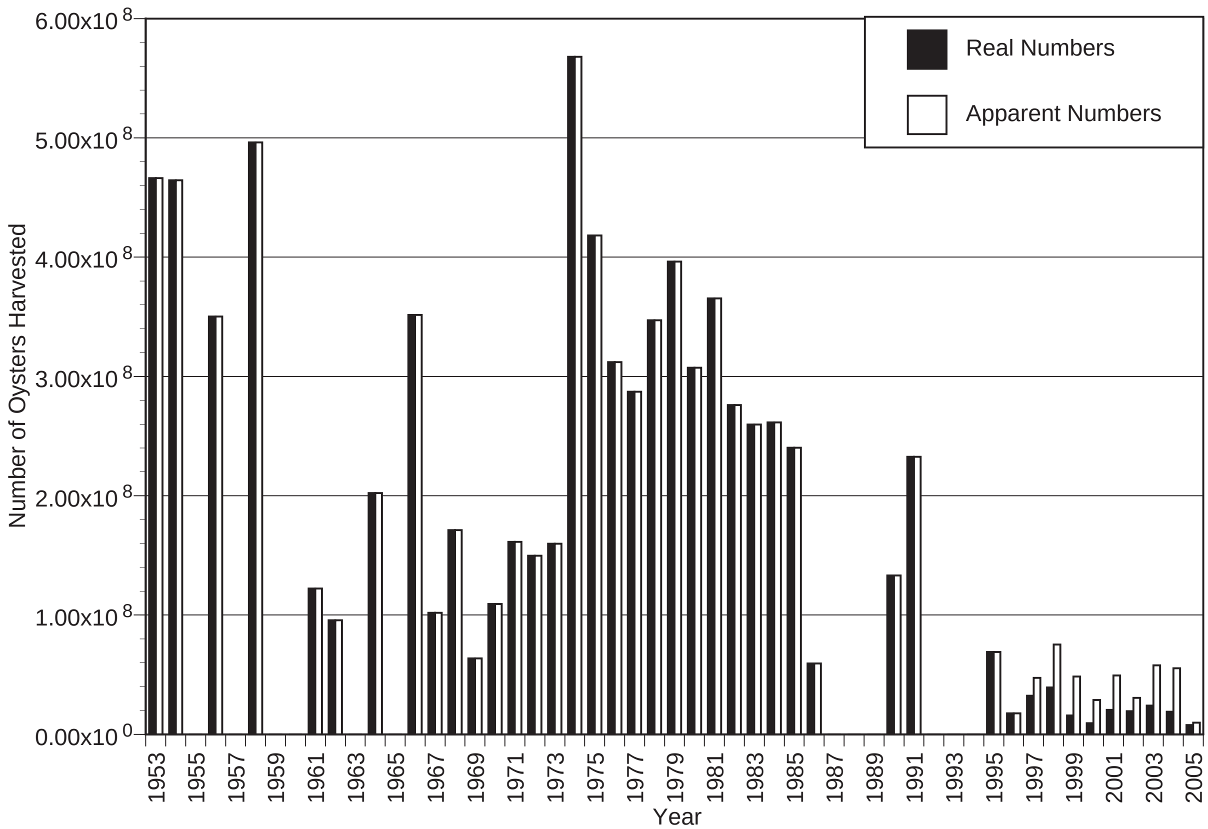

Figure 32. Catch (in bushels) per boat day.

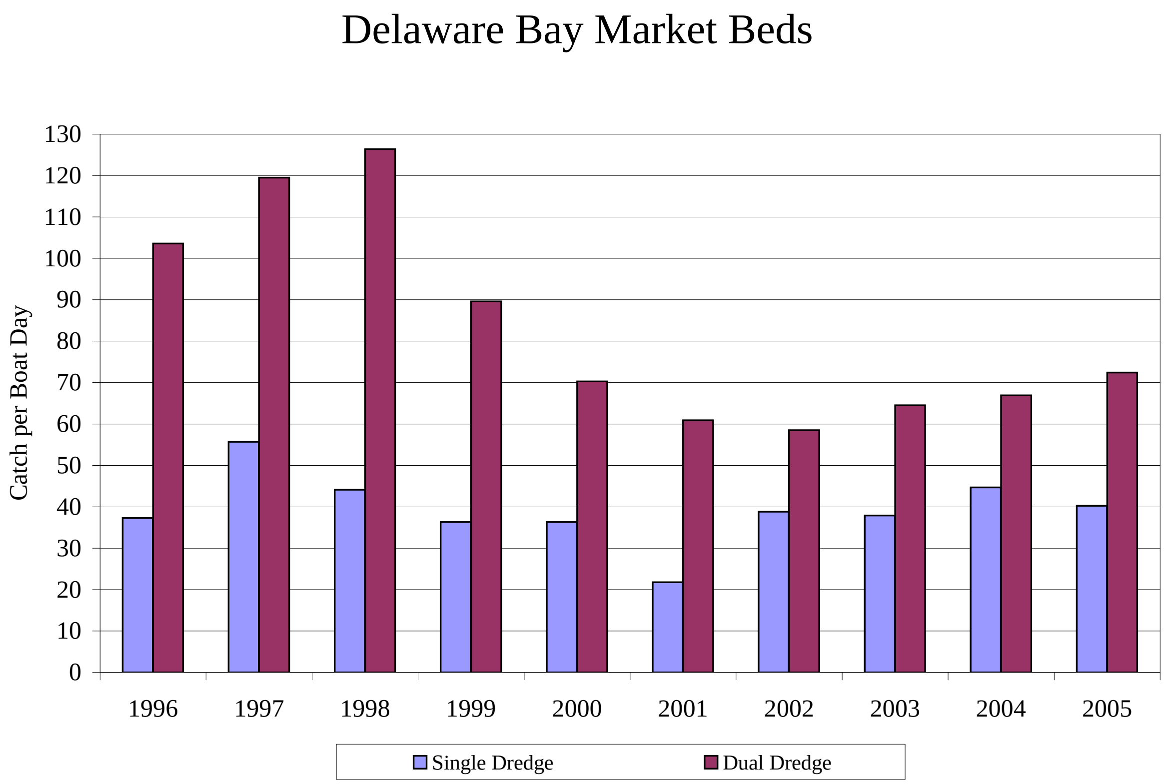

Figure 33. Size frequency of oysters landed in 2005.

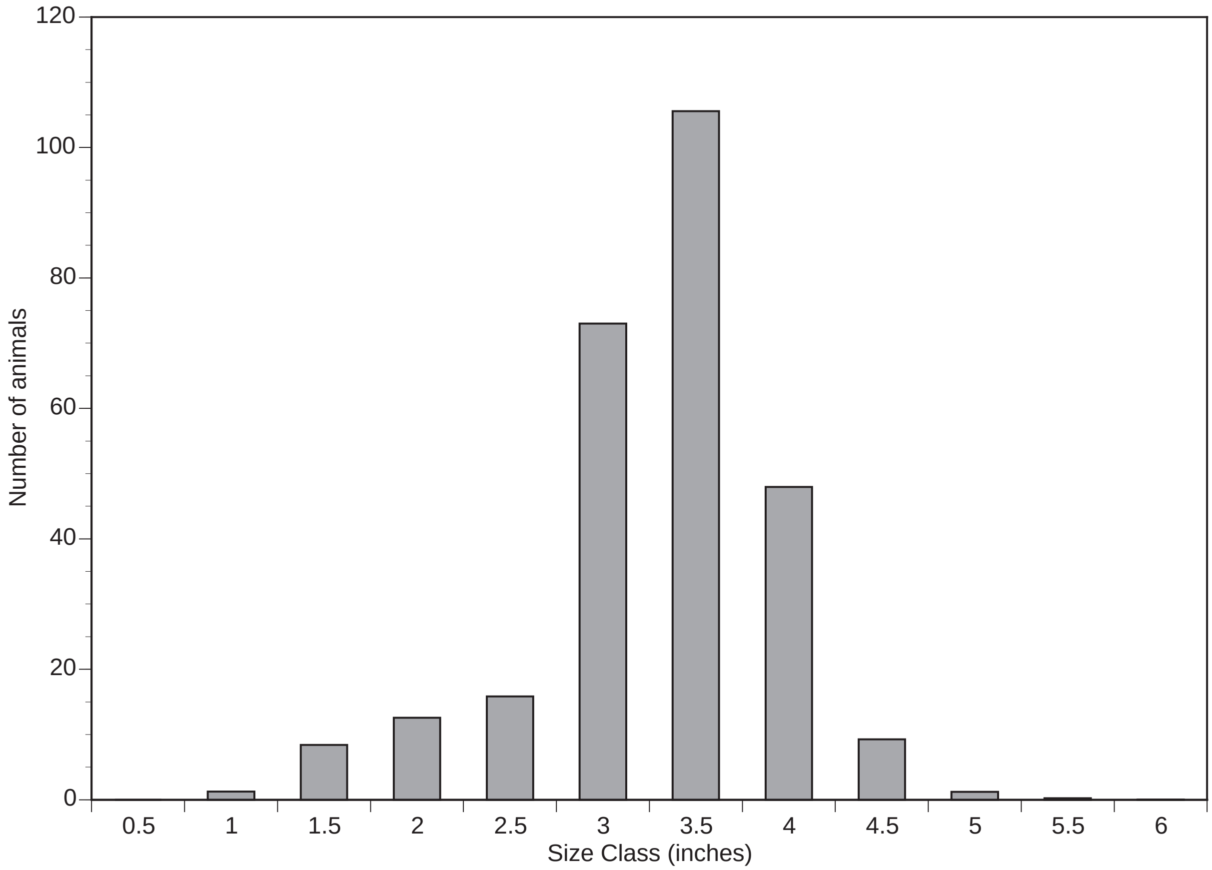

Figure 34. Oyster removals by bay region during the 1953-2005 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 16. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

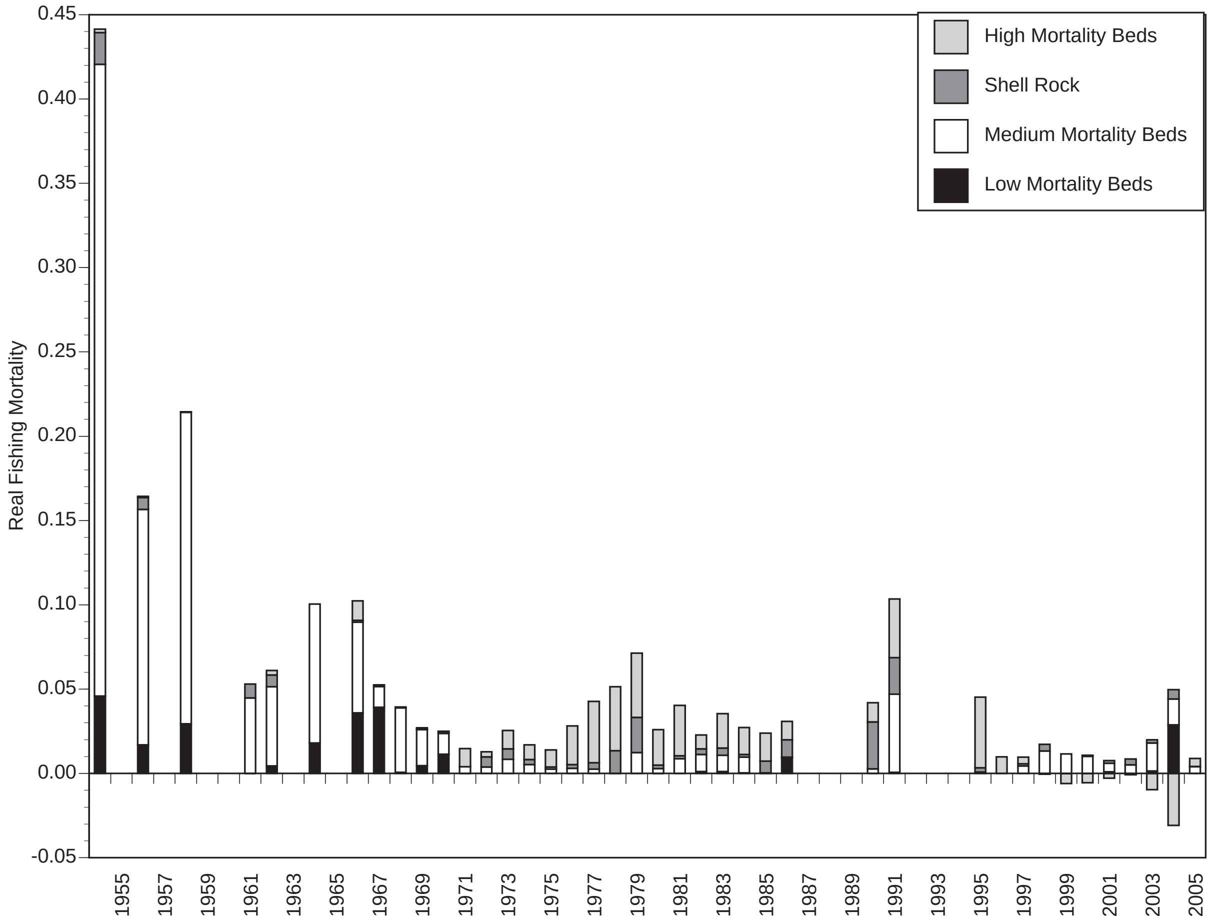

Figure 35. Summary status of the stock for 2005. Green (+) indicates variables judged to be above average. Red (-) indicates variables judged to be below average. Average, indicated by a '0', is defined as within the central 40% of the range of conditions. Judgements concerning trend, e.g., improving, are relative to the previous one or two years. Spatial extent refers to the disperison of the stock across the salinity gradient.

	Whole Stock		Low Mortality		Medium Mortality		High Mortality	
Spawning stock biomass	-	improving	0	improving	0	improving	0	stable
Abundance	-	stable	-	improving	-	degrading	-	improving
Recruit abundance (spat)	-	stable	+	improving	-	stable	0	stable
Juvenile Abundance (1-2.5 in)	-	degrading	0	improving	-	degrading	0	degrading
CPUE	0	stable						
Growth	+	?						
Dermo infection intensity	+	degrading	+	stable	+	degrading	+	degrading
Condition index	+	improving	+	improving	+	improving		improving
Spat / adult	0	stable	+	improving	-	stable	-	stable
Spatial extent	-	improving						
Natural mortality	+	stable	-	stable	+	degrading	+	degrading
Surplus production @ median mortality	+	improving	+	improving	-	stable	0	stable
Surplus production @ 75-percentile of mortality	-	degrading	+	improving	-	degrading	0	stable

Figure 36. Position of the oyster stock in 2005 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.

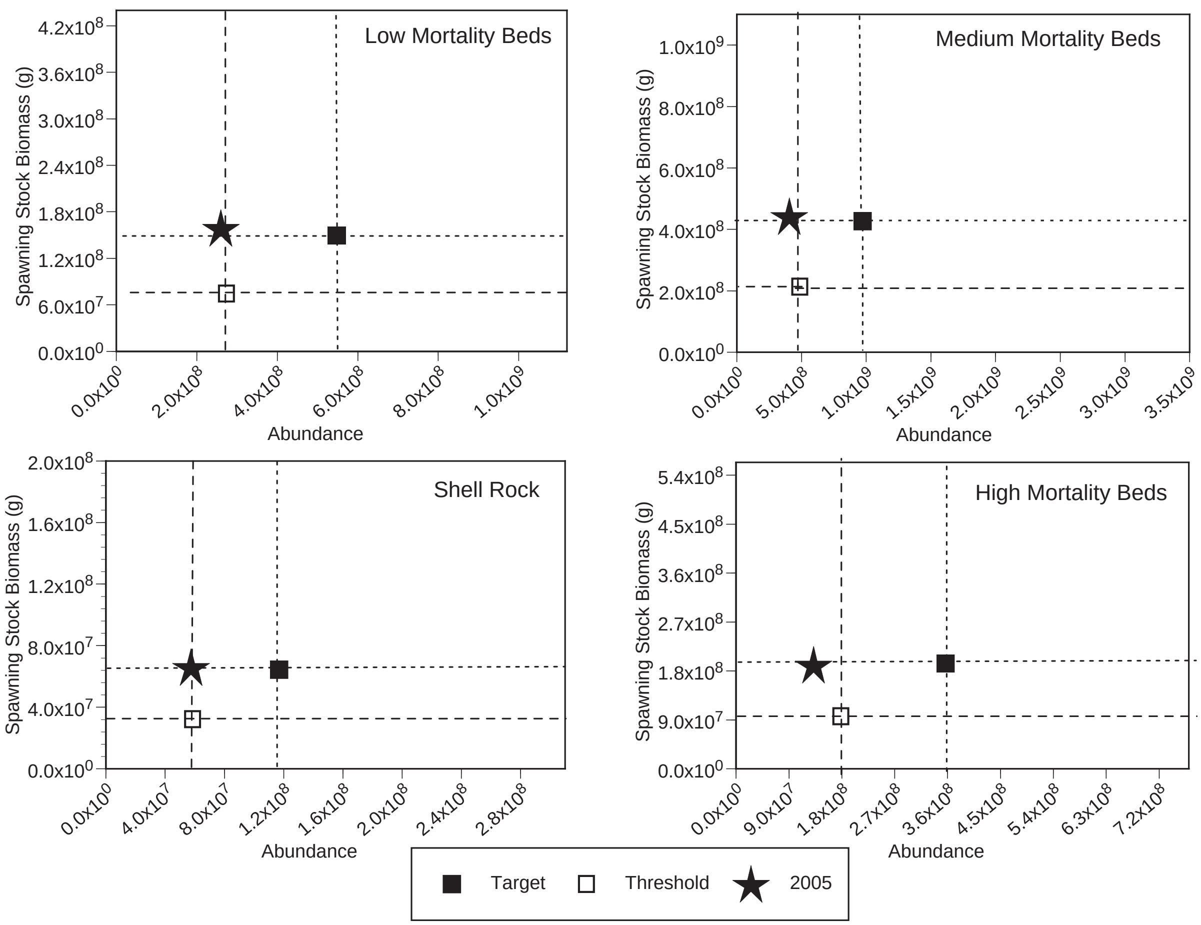

Figure 37. Exploitation rates, based on the numbers of individuals present in the four bay regions and the number removed, either by transplant or harvest, from each for the 1989-2005 time period. Elsewhere, this is termed the apparent fishing rate (e.g., Figure 31). Zeros represent years of fishery closure.