Executive Summary of the
2007 Stock Assessment Workshop
(9^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

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February 5-6, 2007

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 at the end of 2006. The stock presents a mixture of positive and negative indicators that approximately balance. Abundance is low, but abundance increased in three of four bay regions. Abundance continued to be below target levels in all bay regions (Figures 2 and 3), but above threshold levels on the medium-mortality beds and Shell Rock and near, but below, threshold levels on the high-mortality beds. The shell-planting program promises to increase abundance on these downbay beds in 2007. Abundance has increased each year on the high-mortality beds since reaching a post-1988 low in 2004 (Figures 2 and 3) and abundance has moved in a positive direction for several years on Shell Rock. The stock continues to be disproportionately consolidated on the medium-mortality beds, a process that began in the early 2000s with persistent recruitment failure and the influence of Dermo disease downbay.

Spawning stock biomass rose slightly in 2006. Increases were noted in all bay regions except upbay on the low-mortality beds. SSB has increased steadily on the high-mortality and medium-mortality beds over the last three years and has risen for the last two years on Shell Rock (Figures 3 and 4). SSB was above the biomass target in three of 4 bay regions and near the threshold for the low-mortality beds.

Recruitment remains low bay-wide (Figure 5) and was particularly low on the low-mortality beds, high-mortality beds, and Shell Rock in 2006. A near-average recruitment event occurred on the medium-mortality beds. However, in no case did recruitment reach the value of 0.5 spat per adult. The ratio of spat to oysters has been lower than 0.5 over six of the last 7 years. Shell planting increased recruitment on Shell Rock and the high-mortality beds and this increase brought the spat-per-adult ratio above 0.5 on Shell Rock and up to 1.0 on the high-mortality beds. Both ratios are normally associated with increasing abundance in the following year. Evidence exists that low spat abundance is associated with low adult abundance, and suggests that the explanation involves the contribution of live oyster shell to the cultch resource preferred for settlement. This implies that high recruitment may be less likely under current conditions of low abundance.

The oyster population as a whole continues to be depauperate in the smaller size classes (Figure 6), with the proportion of animals $\leq 2.5''$ being below the 40^{th} percentile in all bay regions and no higher than the 25^{th} percentile in three. If this trend continues, a decline in abundance and SSB is highly likely to occur over the coming few years and this will restrict fishery yield. In contrast, surplus production projected for 2007 is expected to permit an increase in market-size abundance bay-wide and in all bay regions, given average mortality rates, barring a higher than average rate of natural mortality, and not counting removals by the fishery. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease rose to moderate levels in 2006 and natural mortality rates were somewhat above average (Figure 7). A rising trend in Dermo disease weighted prevalence may presage epizootic rates of natural mortality in 2007.

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

The beds continued to suffer a net loss of shell in 2007. However, the shell-planting program reduced this net loss to the lowest value during the 1999-2006 time period when data are sufficient to estimate the trend (Figure 8).

Overall, the conditions on the low-mortality beds are distinctly disadvantageous, whereas the remaining bay regions appear to have improved since 2004. However, the fact that all bay regions fall below their abundance targets indicates that actions to enhance abundance are needed in all bay regions. A reduction in fishing effort will not significantly address this need because exploitation rates are already low; however, substantial increases in exploitation rate should be avoided as the importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining biomass at or above target levels. Abundance has been enhanced on the high-mortality beds and Shell Rock by downbay transplant and this program should be continued. The preferred mechanism to address low abundance overall is to enhance recruitment through shell planting.

2007 Management Goals

Cultch Management Goals

Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Shell plants should target areas where marketable oysters grow but where cultch loss exceeds the addition of shell through natural mortality. The Ship John region is such a case. Due to the enhanced survival of juveniles in this region, replants from downbay plants should be moved to selected areas of Ship John in 2007. The same region, and Cohansey as well, should be considered for direct shell plants. In addition, Nantuxent Point, Hawk's Nest, Hog Shoal, Vexton, and Strawberry should be considered as planting locales for direct shell plants. Downbay plants and replants should be expanded to the extent funds permit to enhance recruitment. Shell Rock and Bennies Sand should not be receive shell plants in 2007.

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 have been successfully managed using a constant-abundance reference point since 1998 with a precautionary component to guard against epizootic losses. Harvest levels derived from exploitation-based reference points that vary considerably from the range suggested by surplus production projections should be considered non-precautionary. This year, exploitation-based reference points using the 40^{th} to 60^{th} percentiles fall within the range established by surplus production calculations using the 50^{th} to 75^{th} percentile of natural mortality rate and the average of the 2005 and 2006 updated growth rates. Thus the two approaches provide relatively equivalent allowable harvest levels.

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.

Bay Region Considerations–Low-mortality Beds

This bay region is below threshold abundance levels and at threshold SSB levels. The SARC recommends that this bay region be closed in 2007.

Bay Region Considerations–Medium-mortality Beds

These beds have contributed the bulk of the stock supporting the fishery over the entire 54-year history of the survey, excepting the 1970s high-abundance period. SAW-8 recommended that management should emphasize increased direct marketing on these beds to reduce the exploitation rate downbay while stock rebuilding continues. Biomass continues to be high on these beds and continued focus on directing effort to these beds is important. The SARC recommends that the upper bed group (Middle and Upper Middle) be used for intermediate transplant and encourages that intermediate transplant to Shell Rock or Bennies Sand be a component of the 2007 program. The SARC recommends that Sea Breeze, Cohansey, and Ship John be managed as direct-market beds in 2007 as in 2006.

The high levels of surplus production anticipated for 2007 should not permit dramatically expanded exploitation of these beds. The SARC strongly recommends continued use of the exploitation reference points on these beds. The SARC notes that the high surplus production expected in 2007 originates from the growth of the last large cohort, recruited in the early 2000s, into market size and that these beds do not have substantial numbers of smaller animals supporting continued stock expansion in the future. Given the likely average age of animals growing into market size (5 to 6 years), management of these beds should consider that a 2007 recruitment event will not benefit the fishery for minimally 5 years. Thus, the surplus production anticipated in 2007 should be viewed as minimally a 5-year allotment. The five-year time period has implications for the evaluation of exploitation reference points in the context of minimizing yearly variations in the allocation. A yearly harvest level above 15,800 to 34,000 bushels risks a reduction in allocation from this bed region in future years that may be long-term in duration, even with a substantive recruitment event in 2007. The SARC strongly recommends that exploitation rate percentiles permitting harvest above this level be viewed as inhibitory to the long-term health of the fishery.

Allocation Projections – Constant-abundance Reference Point

The surplus-production option assumes direct-marketing. Consequently, estimates are provided only for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze). The SARC notes that surplus production estimates for these beds covered a wide range because of uncertainty in growth rates and strongly recommends use of the exploitation based reference points rather than the constant-abundance reference point for all bed regions except Shell Rock. Accordingly, the SARC recommends that exploitation rate reference points be used for allocation decisions for the high-mortality beds in 2007 with a harvest value chosen that does not stray substantively from the range delineated in the following table, so that rebuilding of abundance can be achieved during times of shell planting. The SARC recommends that the 75^{th} percentile constant-abundance projection be used for allocation decisions for Shell Rock. A range of options exists this year for the medium-mortality beds. The SARC recommends that exploitation reference points be used for these beds with allocation estimates in accordance with a 5-year distribution of 2007 surplus production as shown in the following table.

Bay Region	Natural Mortality Percentile	Allocation (market-equivalent bushels)
High mortality	50^{th}-75^{th}	3,963-31,264$^{\amalg}$
Shell Rock	75^{th}	17,822
Lower medium mortality	75^{th}	15,800 to 34,000*
Upper medium mortality		NA§
Low mortality		NA§

§NA: not applicable to this reference point.
‖The range given provides guidance for the implementation of an allocation plan using the exploitation reference points in the next table.
*The range given provides guidance for the implementation of an allocation plan using the exploitation reference points in the next table. The range is based on a 5-year distribution of 2007 surplus production.

Allocation Projections – Exploitation Reference Point – Direct Marketing

Projections are provided for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze). The SARC recommends that the high-mortality and medium-mortality beds be managed using this reference point in 2007, cognizant of the restrictions imposed by surplus production on the high-mortality beds and the likely reduction in SSB over the next five years on the medium-mortality beds. The SARC notes than an upper and lower bound for this reference point normally should be taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series; however, the SARC recognizes that lower or higher percentiles may be investigated after consideration of surplus production projections and the position of abundance and SSB relative to threshold and target levels. This year, these bay regions are above their SSB targets, but below their abundance targets and, below the abundance threshold for the high-mortality bed group; thus stock rebuilding should be included in the management goal.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High mortality	40^{th}	.0201	1,586,910	6,034
	50^{th}	.0573	4,523,870	⊖17,201
	60^{th}	.0781	6,166,040	23,445
	80^{th}	.0836	6,600,260	Γ25,096
Shell Rock	40^{th}	.0800	3,425,970	13,027
	50^{th}	.0868	3,717,180	14,134
	60^{th}	.1142	4,890,580	*18,595
Lower medium mortality	40^{th}	.0176	6,120,010	23,270
	50^{th}	.0215	7,485,430	28,462
	60^{th}	.0267	9,293,210	35,335
Upper medium mortality				NA§
Low mortality				NA§

§NA: not applicable to this reference point.

[Γ]The inclusion of this percentile recommendation was not uniformly supported by the SARC. The SARC notes the following. (1.) This value falls within the range of values estimated using the constant-abundance approach. (2.) The high-mortality beds are above the biomass target; however a higher than anticipated mortality event is anticipated to occur on these beds in 2007. (3.) The high-mortality beds are below the threshold in abundance, requiring the rebuilding of abundance; however, shell planting has targeted this area and initial estimates show a promising increase in abundance that might bring abundance above the threshold in 2007. The SARC was about evenly divided on the issue of whether the concern about rebuilding abundance should outweigh the high-biomass level present, considering that the volatility of the resource in this bay region caused by the wide range of mortalites from Dermo disease may limit the long-term success of stock rebuilding programs. The SARC has chosen to include this option with the caveat that it is unlikely to be a precautionary option and with the further caveat that its inclusion should not be considered precedent setting for application to management advise by future SARCs.
[Θ]The SARC notes that this value approximates the value obtained using the constant-abundance method with a 67^{th} percentile natural mortality rate and average growth. It is, therefore, a precautionary option given the prediction that natural mortality rates will exceed the 50^{th} percentile in 2007.
[*]The SARC notes that this value is consistent with the 75^{th} percentile surplus production recommendation.

Allocation Projections – Exploitation Reference Point – Intermediate Transplant

The estimates assume that intermediate transplant will be conducted on the upper medium-mortality beds (Middle, Upper Middle) and that direct-marketing will be conducted on beds downbay of these two beds. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel obtained from the 2006 survey. If cullers are used, the number of bushels can be reduced by an estimated factor of 1.28. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.5''$. Note that allocation values are estimates and can only be specified after the transplant is complete. Moreover, if cullers are used, the marketable-bushel estimate may be low.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Deck-load Population Oysters/Bu	Transplant Bushels	Deck-load Marketable Bushel Equivalents
High mortality						NA§
Shell Rock						NA§
Lower medium mortality						NA§
Upper medium mortality	40^{th}	.0117	2,174,440	133	18,427	3,969
	50^{th}	.0127	2,363,680	133	20,031	4,314
	60^{th}	.0233	4,313,620	133	36,556	7,873
Low mortality						CLOSED[θ]

§NA: not applicable to this reference point.

[θ]The SARC recommends closure of the low-mortality beds in 2007.

Caveats Apropos to Risk for 2007 Fishery Yield

Management options for 2007 provided in the preceding tables permit a relatively wide range of possible 2007 fishery allocations. Mortality in 2006 was above that in 2005, but not yet at epizootic levels. Dermo levels are increasing, however, and Dermo-induced mortality is likely to increase unless environmental conditions inhibit further development. The corollary is the natural mortality rates are expected to be above average in 2007. Increasing Dermo disease and continued uncertainty in recruitment suggests that moderation in setting 2007 allocation goals may be desirable. Specific observations include the following.

1. The SARC recognizes the need to manage Shell Rock and the high-mortality beds conservatively. Present-day abundance on the high-mortality beds is below threshold levels (Figure 3), requiring that rebuilding be included as a management goal. 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.

2. The SARC notes that the low-mortality beds will be re-surveyed in 2007 and that the updated abundance and biomass estimates thus derived should be used to re-evaluate the closure recommendation.

3. Proper management of the medium-mortality beds this year is critical. The SARC notes that the surplus production expected in 2007 should be harvested over a 5-year period to stabilize the fishery. Population demographics suggest that harvesting in excess of this level will reduce SSB rapidly and result in lower allocations from this bed region and a possible closure in future years. Abundance remains below target levels (Figure 3). Consequently, management of these beds should include rebuilding of abundance as a goal.

4. Evidence exists that low spat abundance is associated with low adult abundance, and suggests that the explanation involves the contribution of live oyster shell to the cultch resource preferred for settlement. This implies that high recruitment may be less likely under current conditions of low abundance. Coupled with the observation that all bay regions are below the abundance target, this trend emphasizes the essential need to include abundance enhancement in any management plan for 2007.

5. The SARC strongly encourages continuation of the intermediate transplant program and notes that any transplant option requires transplant to occur before the allocation derived therefrom can be set.

6. The SARC strongly encourages retention of the area-management program in

which the high-mortality beds, Shell Rock, the medium-mortality beds, and the low-mortality beds are managed as separate units with separately determined allocations.

Figure 1. Summary status of the stock for 2006. Green indicates variables judged to be above average relative to the 1989-2006 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2006 time period or having a degrading trend relative to the previous year. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2006 time period, but sometimes determined by scientific judgment. Fraction of stock refers to the dispersion of the stock across the salinity gradient in the four bay regions. All percentiles are relative to the 1989-2006 time series. Parentheses are values that include the 2006 shell plants.

	Low Mortality Beds	Medium Mortality Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.14	0.64	0.07	0.15
Total Abundance				
2006 Percentile	0.08	0.42	0.40	0.25
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Spawning Stock Biomass				
2006 Percentile	0.27	0.67	0.67	0.67
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Recruitment				
2006 Percentile	0.18	0.42	0.18 (0.45)	0.08 (0.55)
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Spat per Adult				
2006 Ratio	0.16	0.34	0.32 (0.64)	0.42 (1.00)
2006 Percentile	0.36	0.47	0.25 (0.50)	0.18 (0.60)
2006 Juveniles (fract.<2.5")	0.63	0.46	0.53	0.55
2006 Percentile	0.06	0.13	0.25	0.38
Dermo Infection Status				
2005-2006 trend	increasing	increasing	increasing	increasing
2006 Mortality Rate	0.06	0.16	0.18	0.21
2006 Percentile	0.08	0.58	0.47	0.31
Abundance Position vs				
Target	Below	Below	Below	Below
Threshold	Below	Above	Above	Below
SSB Position vs				
Target	Below	Above	Above	Above
Threshold	Near	Above	Above	Above
2007 Surplus Production				
50^{th} percentile mortality	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Positive	Positive	Positive	Positive

Figure 2. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2006. 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.

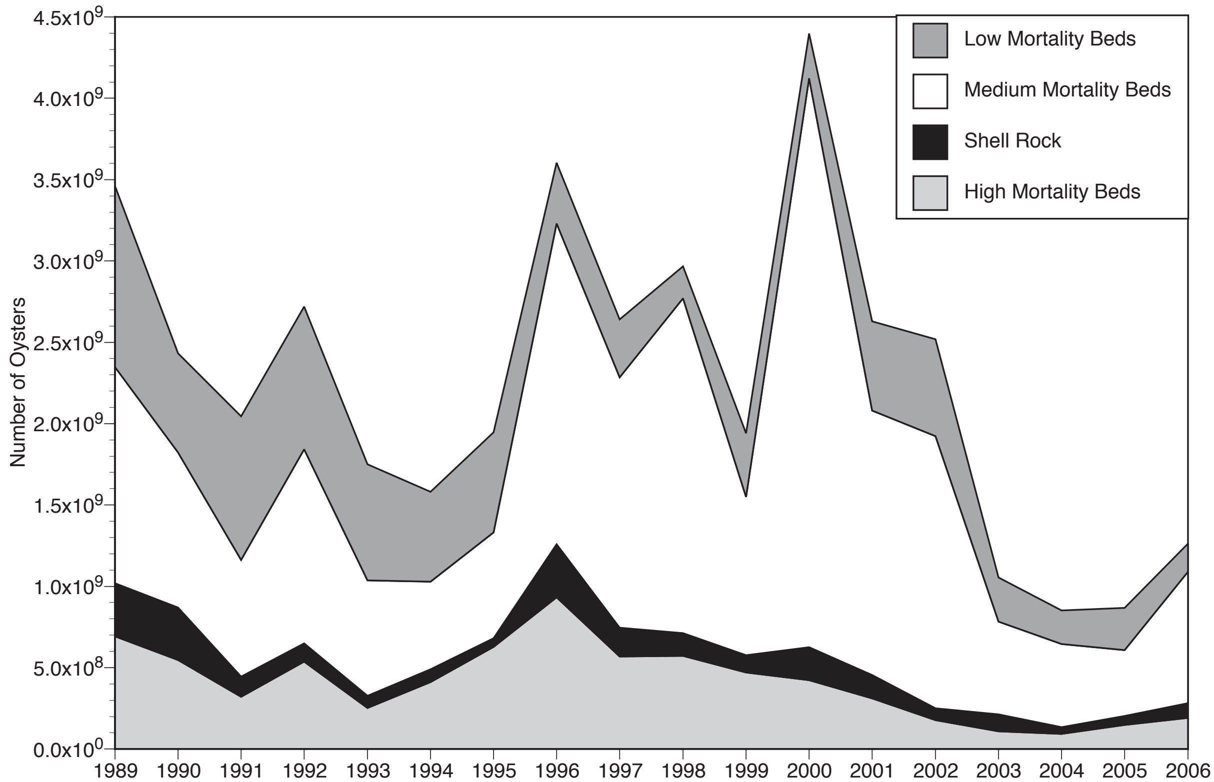


Figure 3. Position of the oyster stock in 2003-2006 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values.

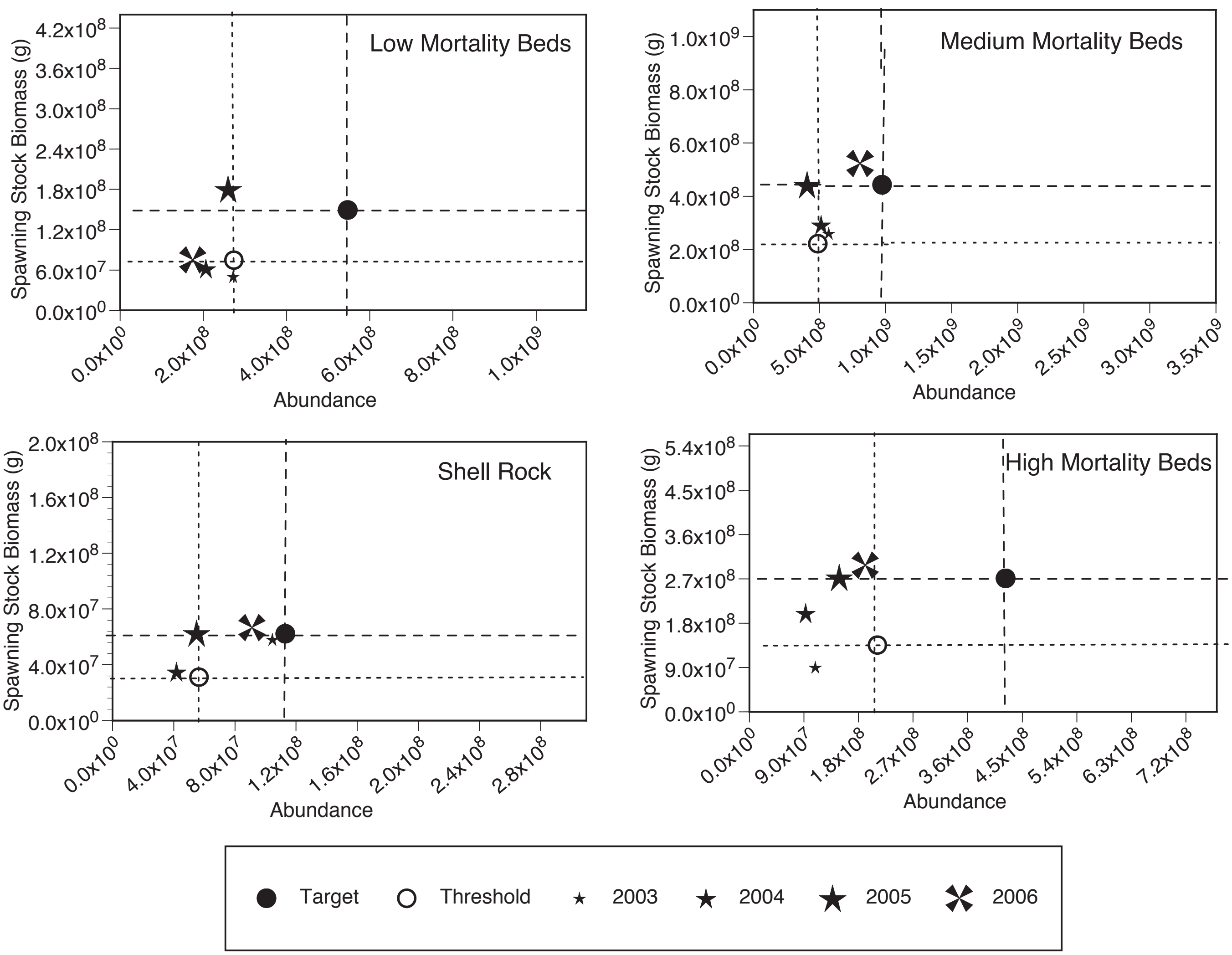


Figure 4. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 2.

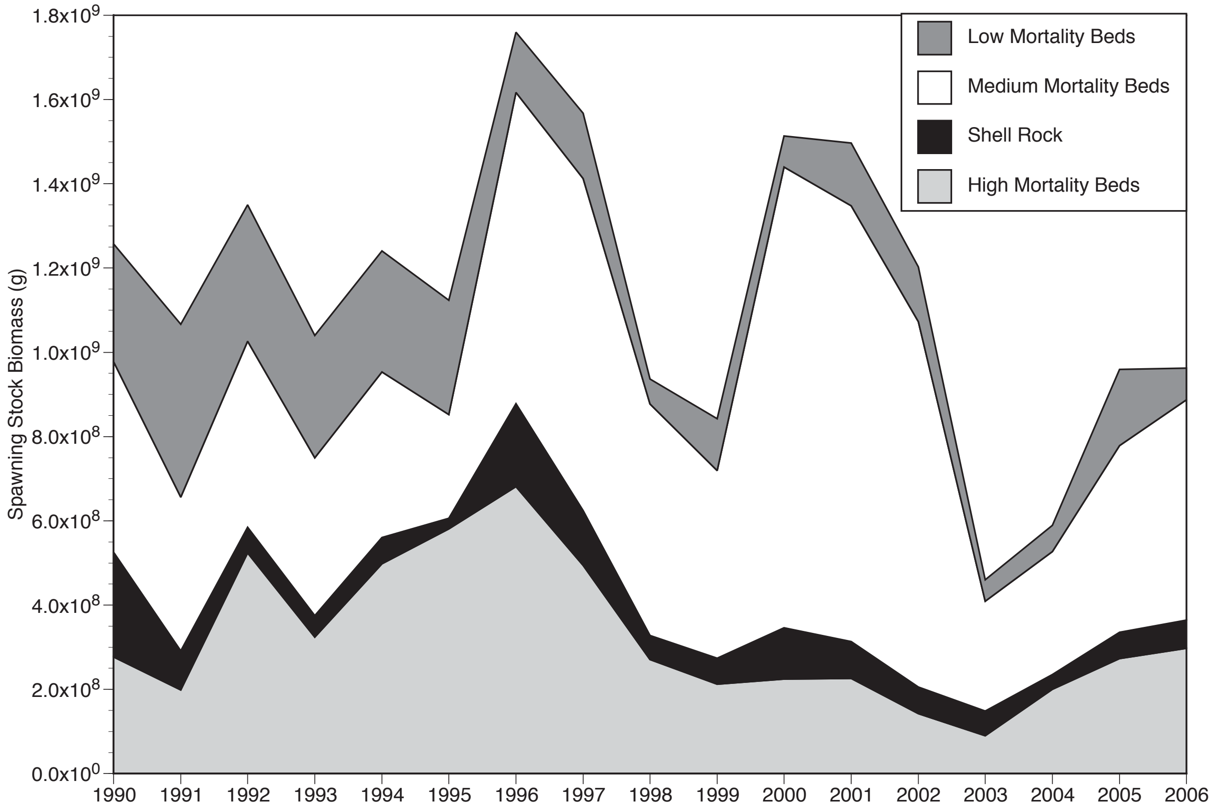


Figure 5. Number of spat recruiting per year for the 1989-2006 time series.

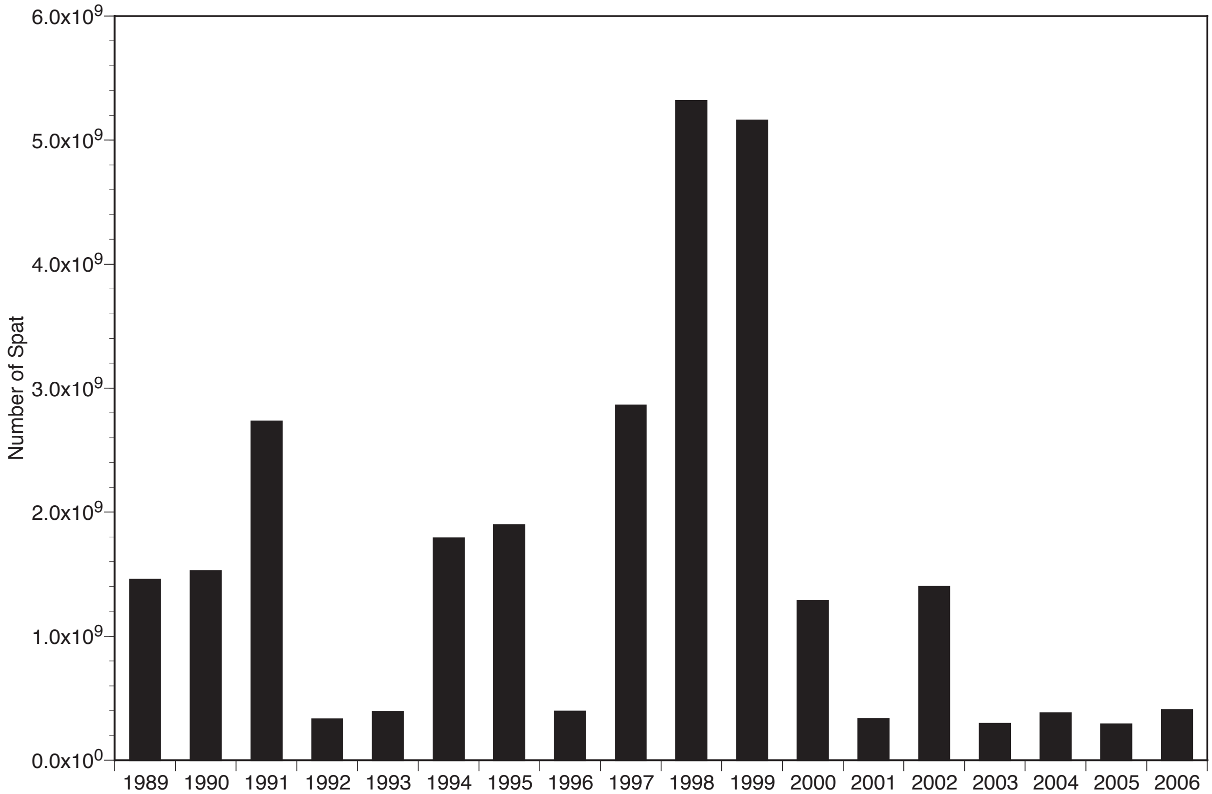


Figure 6. The abundance of small, submarket and market-size animals since 1989.

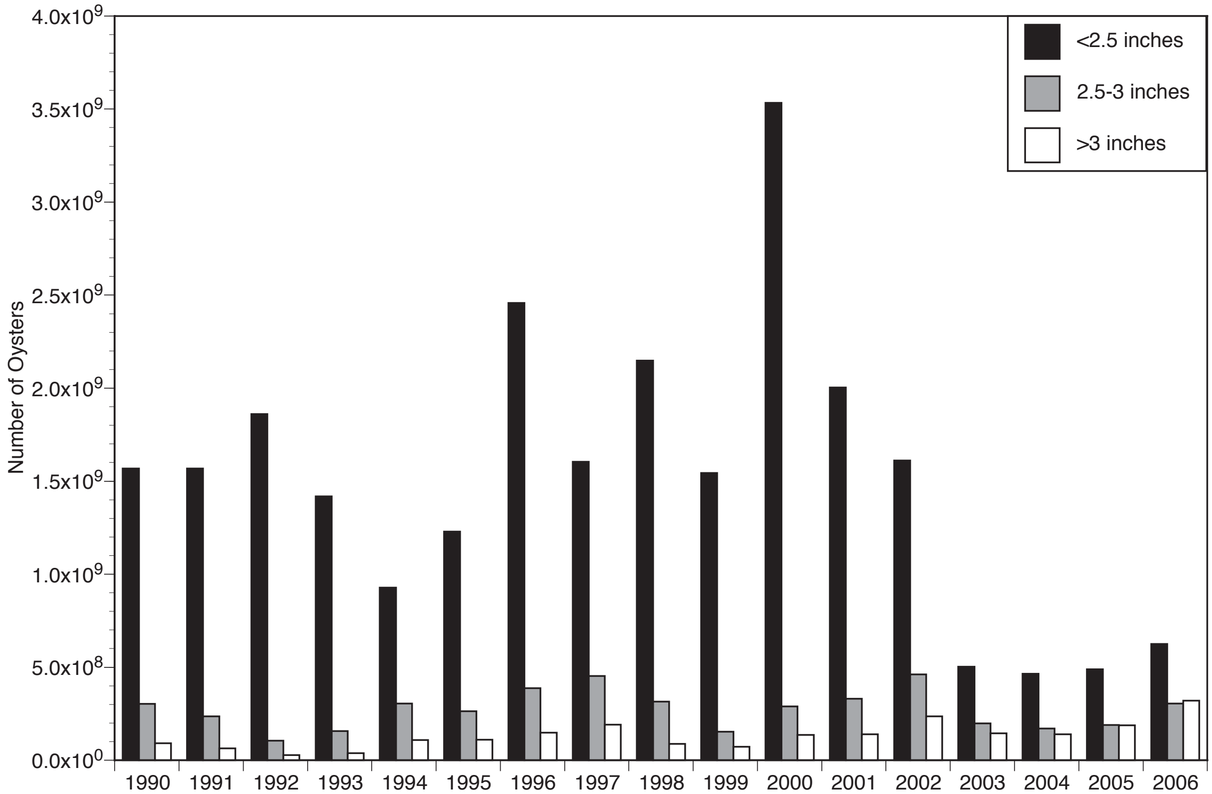


Figure 7. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the four bay regions measures the bay-wide mortality rate for that year.

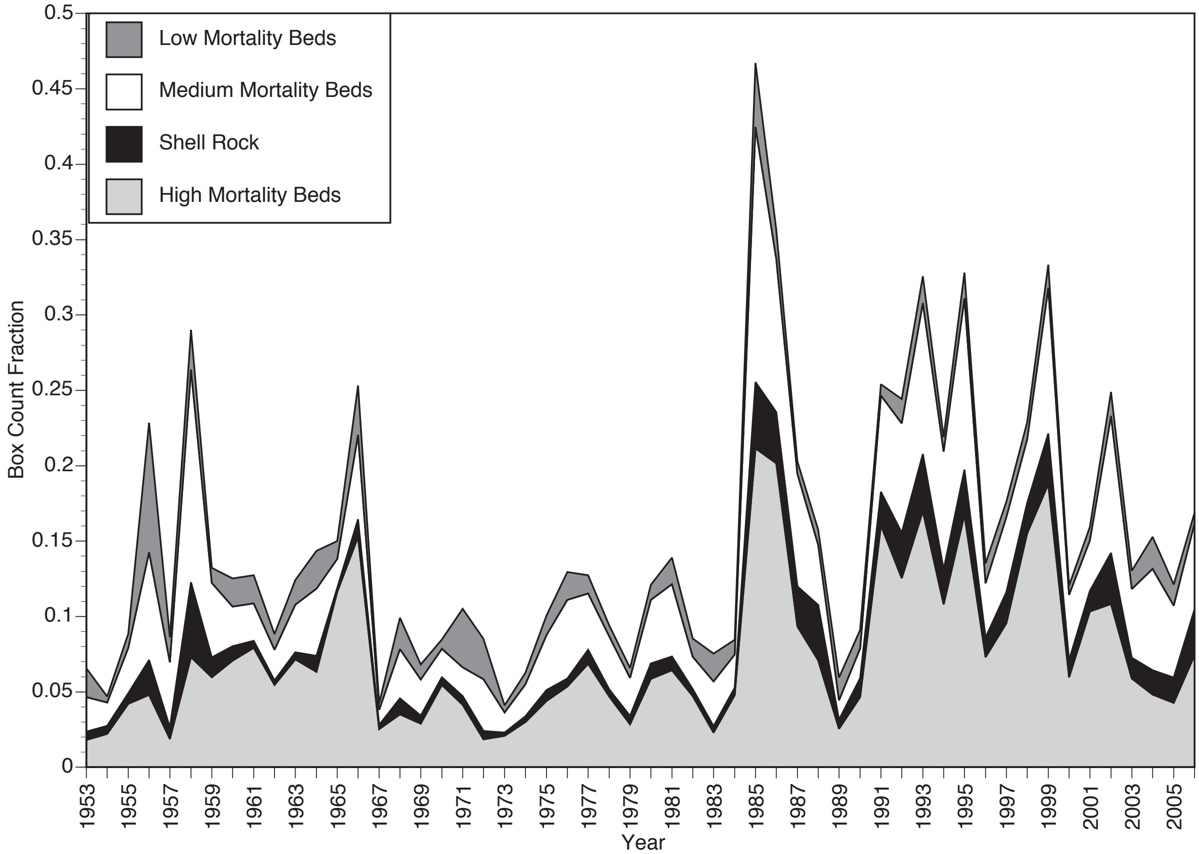
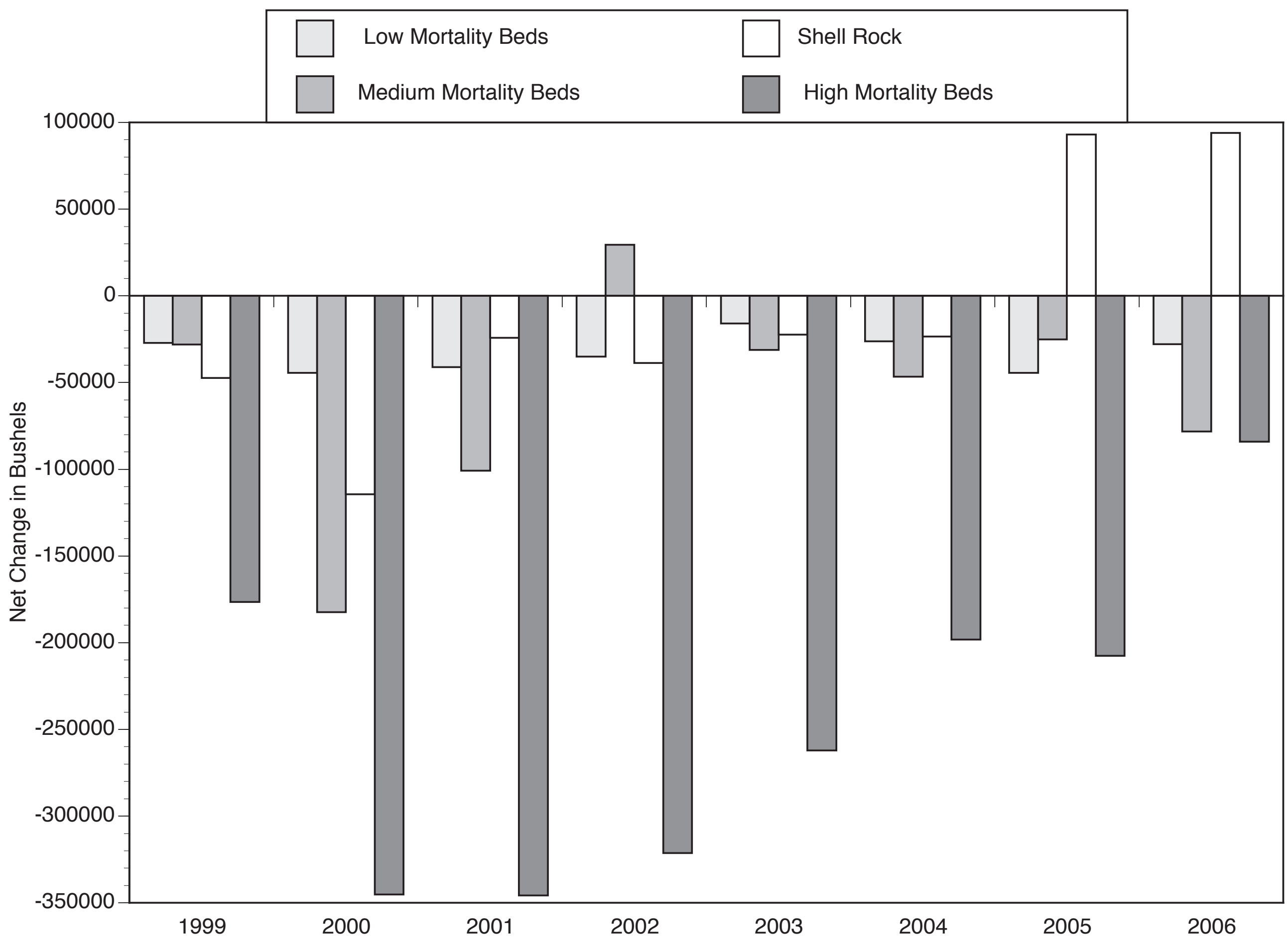


Figure 8. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2006. Positive values on Shell Rock in 2005 and 2006 reflect the addition of shell through shell planting to offset the shell loss.



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February 5-6, 2007

New Jersey Agricultural Experiment Station – Rutgers University

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 $0.2''$ latitude $\times$ $0.2''$ longitude grids, each having an area of approximately 25 acres. These grids fall into one of three strata: the bed core (high quality), the bed proper (medium quality), or the bed margin (low quality). 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 and boxes >20 mm from the composite bushel, condition index, and the intensity of Dermo and MSX infections. Until 1999, the principal data used in management were based on the proportion of live oysters, excluding spat, in a composite 37-quart bushel[⊘], although spat set also entered the decision-making process. Beginning in 1998, dredge tow lengths were measured and recorded every 5 seconds by GPS navigation during the survey and, in 2000, 2003, 2005, and 2006 separate dredge calibration studies were undertaken to determine dredge efficiency. These data integrated into the regular sampling permit quantitative estimation of the number of oysters per square meter beginning in 1998. In 2004, at the behest of the 6^{th} SAW, the entire survey time series from 1953 to the present-day was retrospectively quantitated. Also in 2004, a dock-side monitoring program began. This program obtains additional fishery-dependent information on the size and number of oysters marketed, permitting, beginning in 2004, the determination of exploitation based on spawning stock biomass as well as abundance. In 2006, sufficient information was available from the dock-side monitoring program to reconstruct the 1996-2003 exploitation rates.

Status of Stock and Fishery

Historical Overview

From 1953 to 2006, the bay-wide mean number of >20-mm oysters per bushel was about 276 (Table 1). 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

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

Island and Ledge (Table 1). Since 1989 when Dermo became prevalent in the bay, the bay-wide overall mean of 135 oysters/bu, about half the long-term average, has varied little, and the changes, with the exception of the extremes (1989, 1992, 2004, and 2006), have not been statistically significant from any other year (Figure 2). Throughout this report, except where noted, present-day conditions will be compared to these two periods of time, the 1953-2006 period encompassing the entire survey time series and the 1989-2006 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 1989-2006 time period, because the advent of Dermo disease as an important determinant of population dynamics occurred in 1989 and this disease has substantively controlled natural mortality rates[‡] in all succeeding years. Two exceptions exist to the dependency on the 1989-2006 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 1996-2006 time period during which the fishery has been conducted under a direct-marketing system.

The 1953-2006 bay-wide mean number of spat/bu was 177 (Table 1), with the greatest set of 1700+ spat/bu. occurring in 1972. Since 1988, the bay-wide average has been 79 spat/bu, slightly less than half the long-term mean (Figure 2). The long-term (1953-2006) average box-count mortality is approximately 15% (Table 1). The appearance of Dermo in the bay has increased the average mortality since 1989 to 21%, 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. 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 70,390 bu.

Survey Design

The survey has been conducted as a random survey of the twenty primary oyster beds (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

[⊙] Because the survey footprint changed in 2005 and 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 values reported by SAW-7 and SAW-8. Values reported herein are considered to be improvements in accuracy and should be used in lieu of SAW-7 or SAW-8 values.

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

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, most beds were sampled yearly; the remaining mostly minor beds were sampled every other year. Beginning in 2002, sampling intensity was revised on a number of beds to better reflect their utilization by the fishery, and, to provide more accurate estimates of oyster abundance, fewer beds were sampled in alternate years.

Beginning in 2005, two important changes occurred. First, all beds were sampled each year with the exception of Egg Island and Ledge that continue to alternate due to their consistent low abundance. Second, the area from Middle to Bennies Sand was re-surveyed resulting in a change in stratal definition and survey design•. In the new system, the strata for re-surveyed beds were based on ordering grids within beds by abundance. Grids were defined by cumulatively accounting for the first 2% of the stock as low quality, the next 48% of the stock as medium quality, and the final 50% of the stock as high quality. In 2006, the area downbay of Bennies Sand, except Egg Island, Ledge, and New Beds was similarly re-surveyed and this re-survey resulted in an equivalent change in stratal definition and survey design.

The spring 2006 re-survey of the area from Bennies Sand to Vexton exclusive of Egg Island, Ledge, and New Beds, included all navigable 25-acre grids. These sampled grids consisted of all previously designated grids and a number of grids not in the pre-2006 footprint. Each of the new grids were assigned to the nearest bed while maintaining simple linear boundaries between adjoining beds whenever possible, and given a unique grid number. In total, over 300 grids were sampled over a two-week period.

Preliminary evaluation of the density of oysters among grids revealed that a large number of grids could be deleted from the fall survey if the survey was focused on the grids on each bed that support 98% of the stock on that bed. These grids were assigned to a 'low-quality' stratum. This designation is consistent with the definition of a low-quality grid adopted in SAW-8 after the re-survey of the Bennies Sand to Middle reach. The remaining grids were input into a Monte Carlo model in which grids were subsampled repeatedly, without replacement, under a given set of rules, and the mean abundance estimated from the subsample compared to the mean abundance obtained from the average of all grids. Analysis of many simulations suggested that a random survey based on two strata would suffice,

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

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' stratum. These designations are also equivalent to those adopted in SAW-8 for the Bennies Sand to Middle reach. The new high-quality stratum generally includes most grids originally assigned to the high-quality stratum used prior to 2006 and a few of the old medium-quality grids. The medium-quality stratum generally includes some of the old medium-quality and low-quality grids plus a number of new grids. Figure 3 shows the revised bed footprint defined by the high-quality and medium-quality strata for these beds.

Dredge efficiency for grids surveyed in the 2006 spring re-survey and the previous fall (2005) survey varied by a factor of 1.04. Comparison to fall survey abundance estimates, after this correction, revealed that the 2006 assessment of the re-surveyed beds underestimated abundance by about 25%. Evaluation of time series data identified some old (1953-1989) samples obtained from newly-designated high-quality and medium-quality grids that did not fall within the previous bed footprint. This suggests that not all of the 'new' areas are 'new' oyster bed; that is, some portion of the 25% underestimate is due to an historical redefinition of the bed footprint used for survey design.

The October 2006 survey was constructed by randomly choosing a designated number of grids from each stratum on each bed. Sampling was conducted from October 30 to November 15 using the oyster dredge boat *F/V Howard W. Sockwell* with Greg Peachey as Captain. The sampling intensity is shown in Table 2 and the specific grids sampled are shown in Figure 3. Total sampling effort in 2006 was 124 grids, a value about the same as 2005. These included 14 transplant grids selectively sampled because they were sites of 2005 and 2006 shell plants or 2006 intermediate transplants. The 2005 shell-plant grids were Bennies Sand 11 and Shell Rock 12 and 43. The 2006 shell-plant grids were: Bennies Sand 6, 7, and 12, Hawk's Nest 1, Nantuxent Point 25, and Shell Rock 20, 24, and 32. The intermediate transplant grids were Shell Rock 90 and 44.

In 2006, a few additional dredge efficiency measurements were made for grids involved in the 2006 shell-planting program. Dredge efficiency experiments were conducted on Hawk's Nest and Nantuxent Point. Values were representative of previous experiments. Live oyster $q^{\emptyset}$ averaged 3.93 versus the 3.11 value obtained in 2003 and used in this assessment. Boxes averaged 6.01 versus 4.64. Cultch averaged 9.05 versus 8.14. These additional measurements suggest that dredge efficiency has

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

changed little since 2003 (Table 3).

Oyster Abundance

Analytical Approach

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 each 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 stratal 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 excluded. For much of the bay, exclusion of the low-quality grids underestimates abundance by approximately 2%. Judging from the targeted spring re-survey of the Middle to Vexton reach, 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. Cultch varies with input rate from natural mortality and the temporal dynamics of this variation are unknown for the 1953-1997 time frame; however, recent improvements in the understanding of shell dynamics on Delaware Bay oyster beds show that shell is the most stable component of the survey sample and support the belief that a $\times 2$ error is unlikely to be exceeded. Accordingly, the quantitative time-series estimates are considered the best estimates for the 1953-1997 time period.

All quantitative and post-1997 time-series estimates were corrected for dredge efficiency using the dredge efficiency measurements made in 2000 and 2003. The size-class-specific dredge efficiencies were applied whenever size-class data were analyzed. The differential in dredge efficiency between the upper and lower beds was retained in all cases (Table 3).

Throughout this report, 'oyster' refers to all animals ≥ 20 mm. Animals <20 mm are referred to as 'spat'. Adult oysters are animals ≥ 35 mm. Calculations of spawning stock biomass (SSB) are based on this size class and used bed- and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size animals are animals $\geq$75 mm. Submarket size classes are variously defined depending on growth rates and analytical goals as indicated. Shell planting permitted an estimate of the accuracy of the 20-mm size boundary for spat on the beds downbay of Ship John and Cohansey. 2006 shell plants revealed that about 19% of the spat exceeded 20 mm in size and reached sizes as large as 30 mm. Thus recruitment on the downbay beds may be underestimated by this amount. Spat growth rates are unknown upbay of Shell Rock; however, the error upbay is unlikely to exceed the 19% value.

Abundance Trends

Since 1989, the natural oyster beds have experienced a two-fold fluctuation in the number of oysters per bushel, but, with the exception of the two highest and lowest values, no statistical differences exist (Figure 2). High variances are to be expected because oysters are being sampled along a salinity gradient that reflects spat set, predation, disease, and growth. The bay-wide average number of 99 oysters/bu in 2006 was statistically the same as for most of the 1989-2006 period, but 36% of the long-term average of 276 oysters/bu (Table 1).

Quantitative estimates using the time-series analysis indicate that oyster abundance summed across all strata and bay regions increased in 2006 after four years of decline to 1,263,495,680 from the 2005 estimate of 867,735,936 (Figure 4). In 2006, abundance was at the 16^{th} percentile of the 1953-2006 time series and the 19^{th} percentile for the post-1988 era.

Beds in the low-mortality and medium-mortality segments of the bay (see Figure 4 for bed groupings) continue to support relatively high oyster abundance (Table 4), but many beds declined somewhat this year. Only Round Island, Middle, Ship John, and Shell Rock have >150 oysters/bu. In 2006, oyster abundance on beds in the medium-mortality segment of the bay did not deviate statistically from the remaining years of the 1989-2006 time series (Figure 5), but all beds except Shell Rock experienced a slight decline on a per-bushel basis. Average oyster abundance in the high-mortality region was the same as last year and in the mid-range of abundances of the 1989-2006 time series (Table 4, Figure 5).

Quantitative estimates confirm that most (64%) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 6). This is a substantive increase in proportion for these beds over 2005, but in keeping with the distribution of oysters in most years post-1995. Abundance on these beds ranked at the 33^{rd} percentile of the 54-yr time series and the

42^{nd} percentile post-1988. Abundances also rose on the high-mortality beds and on Shell Rock in 2006. The high-mortality beds and Shell Rock ranked at the 18^{th} and 37^{th} percentiles, respectively, for the 54-year time series and at the 25^{th} and 40^{th} percentiles post-1988. Abundance in 2006 on the high-mortality beds rose from 2005, by a factor of 1.29 (Figure 7). This is the second consecutive year abundance has increased on these beds. Abundance rose substantially as well on Shell Rock (by 1.67) and for the second consecutive year. The large increase on Shell Rock was partly due to the 2005 shell-planting program. In contrast, abundance declined by 33% on the low-mortality beds to one of the lowest levels ever recorded (3^{rd} percentile) and the lowest level in the post-1988 era.

The dramatic decline in abundance on the low-mortality beds in 2006 is unsupported by mortality data reported subsequently and, so, may be, in part, a survey artifact. This section of the bay has, as yet, not been re-surveyed and the original stratum footprint is unlikely to permit a stable assessment of abundance on these beds.

SAW-8 projected an eventual harvest of 53,490 bushels from the shell-planting program of 2005. The yearly mortality rate for yearlings from the 2005 shell plants in 2006 was 20.3% on Bennies Sand and 9.3% on Shell Rock. These rates are much below the rate used for harvest projections by SAW-8. Assuming marketable size is reached in year 3 and that the mortality rate will average at the 50^{th} percentile of the 1989-2006 time series in years 2 and 3 permits a revision of the projected harvest from the 2005 program as 21,507 bushels on Bennies Sand and 65,867 on Shell Rock, totaling 87,374 bushels. The yearlings from these shell plants represent an important source of the abundance increase observed in these bay regions in 2006.

Spawning Stock Biomass (SSB)

Spawning stock biomass rose slightly bay-wide in 2006 (Figure 8). 2006 SSB was at the 33^{rd} percentile of the 1990-2006 time series. SSB declined markedly on the low-mortality beds, rose on the medium-mortality beds, and remained essentially unchanged on Shell Rock and on the high-mortality beds, in keeping with the management goals established by SAW-8 that sought to stabilize market-size abundance on Shell Rock and beds downbay. For the low-mortality beds, the medium-mortality beds, Shell Rock, and the high-mortality beds, the percentiles were the 27^{th}, 63^{rd}, 63^{rd}, and 63^{rd}, respectively.

SSB is highest on the medium-mortality beds in most years (Figure 9). In 2006, these beds contributed 54% to bay-wide SSB. The high-mortality beds contributed an additional 31%. SSB was more concentrated on the medium-mortality beds in 2006 than in 2005 because of the decline in SSB on the low-mortality beds.

Oyster Size Frequency

Size-frequency trends were calculated for the first time in 2006 based on the contribution of each sample to total bay-wide abundance. Perusal of the 1990-2006 time series (Figure 10) shows that the fraction of the population $<2.5''$ was high in the early 1990s, then declined somewhat, and rose again in the late 1990s to early 2000s. In 2006, bay-wide, 50% of the animals were below $2.5''$ and 26% of the animals were $\geq 3''$ in size (Tables 4 and 5). Thus, marketable animals ($\geq 2.5''$) accounted for half of all animals. This size-frequency distribution is not representative of the long-term trend (Figure 10). In fact, the proportion of small animals in 2006, 50%, is the lowest in the 1990-2006 time series. Over the time series, values of 75%-80% are more typical. The recent decrease in this percentage is primarily due to low recruitment rather than unusually low adult mortality. That is, the number of smaller oysters has declined as animals have grown to $>2.5''$ in size or have died, and these small oysters have not been replaced by new recruits.

The fraction of the population $<2.5''$ began a dramatic decline in 2002 downbay and 2003 above Shell Rock, and this size-frequency structure depauperate in juveniles has been retained since then. Small oysters accounted for 63% of the animals on the low-mortality beds in 2006, a fraction much below long-term trends, due to persistent very low recruitment (Figure 11). More than half of all animals (64%) on the medium-mortality beds were $\geq 2.5''$ in size. Population percentage for $\geq 2.5''$ animals for Shell Rock was 47% and for the high-mortality beds, 44%. These latter two values are above average for the 1990-2006 time series. Bay-wide, of the animals $\geq 2.5''$, 51% were $\geq 3''$ in size (Figure 12). This unbalanced size-frequency distribution occurred in all bay areas except the low-mortality region and was most extreme on the medium-mortality beds (Figure 11). The moderate increase in juvenile proportions on Shell Rock and the high-mortality beds is substantially the result of the shell-planting program. Nevertheless, the population remains overly weighted towards older adult animals. Such populations are sensitive to processes increasing adult mortality, namely disease epizootics and overfishing.

Oyster Condition and Growth

Condition bay-wide was calculated for the first time in 2006 based on the contribution of each sample to total bay-wide abundance. Condition index declined from an unusually high value in 2005 to a value representative of the 1990-2006 time series (Figure 13) and the decrease was similar in all areas of the bay. Condition rose downbay, averaging on the high-mortality beds more than double the low-mortality-bed value (Figure 14).

Growth rates were updated from 2005 for each of the bay regions. Growth of submarket individuals to market size was evaluated by three separate methods:

size-at-age, repeated measures of known individuals throughout the growth season, and annual shifts of population size-frequency peaks from one fall sampling to the next. These measures were supplemented using information on the size changes of cohorts of animals on clam-shell plants and in hatchery-produced cohorts held in trays in the lower bay. These latter individuals also provide a means to check the size-at-age estimates.

All methods indicated that the differential in size at age for oysters across the salinity gradient is established by differential growth in the first two to three years of life, and, after that initial growth, the year-to-year growth increment is remarkably similar throughout the bay. Data were obtained for representative beds for the low (Arnolds), medium (Cohansey, Middle) and high-mortality (New Beds, Bennies Sand) bay sections (Table 6). New data were obtained for Shell Rock, but heavy exploitation of this resource and recent additions by intermediate transplant have modified the size-frequency distribution enough to reduce confidence in those determinations. Thus Shell Rock growth rates were not updated in 2006. The minimum-sized animal reaching 3″ in one growth year was found to be: high-mortality beds and Shell Rock, 2.59″; medium-mortality beds, 2.69″; low-mortality beds, 2.64″ (Table 6). These compare to values used in 2005: high-mortality beds, 2.45″; Shell Rock, 2.59″; medium-mortality beds, 2.85″; low-mortality beds, 2.85″.

While the minimum submarket sizes yielding animals of market size with one year's growth are only separated by a few millimeters, the age of the animals reaching this size is appreciably different in the various parts of the bay. Time to market size was estimated from growth rings as: high-mortality beds, 3-4 yr; medium-mortality beds, 5-6 yr; low-mortality beds, 6-7 yr (Table 6).

Surplus Production

Surplus production is defined in this assessment as the number of animals available for harvest under the expectation of no net change in market-size abundance over the year, given a specified natural mortality rate and growth rate. If fishing mortality rate is set to zero, surplus production as calculated herein is equivalent to the differential between the number of animals expected to recruit to market size in a year less the number of market-size animals expected to die naturally. In the absence of fishing, a positive surplus production indicates that the market-size population is expected to expand in abundance. If negative, the market-size population is expected to contract even in the absence of fishing. The model used for the calculation assumes an uneven distribution of mortality rate during the year as observed; however this assumption is only noteworthy if market-size animals are removed from the population by means other than natural mortality. A detailed description is found in Klinck et al. (2001)[⊕].

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

Surplus production was estimated using the 50^{th} and 75^{th} percentiles of natural mortality rate. Growth rates were updated for this assessment. As a probabilistic application of growth rate cannot yet be done, surplus production estimates were made using the 2005 growth rates from SAW-8, the updated 2006 growth rates (Table 6), and the average of the two. 2006 updated growth rates produced substantively higher surplus production estimates in comparison to the growth rates used in 2006 by SAW-8 upbay of Shell Rock, despite the relatively small increment in the estimate: ~4 mm. On the high-mortality beds, the change in growth rates reduced surplus production from the estimate using the growth rates from SAW-8 (Table 7).

Surplus production estimates were generally positive and in keeping with previous estimates on the high-mortality beds and Shell Rock (Table 7). Surplus production estimates were very high on the medium-mortality and low-mortality beds using the 2006 updated growth rates, as a consequence of a large cohort of individuals of about 2.5-2.75″ in size on these beds, and low natural mortality rates. This is likely the 2000 or 2002 cohort. Negative surplus production estimates occur only twice, both using the 75^{th} percentile of natural mortality. These are both associated with low growth and high natural mortality. Overall, surplus production estimates suggest that SSB should increase in all bay regions in 2007, barring unusually high mortality rates, unusually low growth rates, or overharvesting.

Recruitment

Recruitment was low for the seventh year in a row, bay-wide, and very low for the fourth year in a row (Figures 15 and 16). Seven consecutive years of low recruitment is unprecedented in the 1953-2006 time series. The bay-wide 2006 spat count (mean = 21/bu) was far below the long-term mean of 177 spat/bu (Table 1), and well below the post-1988 long-term mean of 79 spat/bu (Figure 2). 2006 recruitment (spat/bu) was significantly below six other years in the 1989-2006 time series, all in the 1990s (Figure 2). No bed achieved a spat set of 100 spat/bu and spat set was 50 spat/bu or higher on only three beds: Middle, Ship John, and Shell Rock (Table 4). 2006 spat settlement ranked at the 23^{rd} percentile for the 1953-2006 time series and at the 42^{nd} percentile post-1988. The higher ranking post-1988 indicates a long-term decline in recruitment rate relative to the earlier portion of the time series (Figure 15).

The number of spat recruiting per oyster was similar to 2005; however, it continued to be very low, 0.32 (Figure 17). The 2006 value is at the 33^{rd} percentile of the 1953-2006 time series. Shell planting raised this ratio to 0.43, a factor of 1.34

model for managing the oyster fishery during times of disease. *J. Shellfish Res.* 20:977-989 above the 2005 ratio for the entire bay region, and a value near the 40^{th} percentile. The ratio has been above 0.5 only one year since 1999 (2002).

The ratio varies from bay region to bay region with high recruitment events, defined as exceeding 1 spat per oyster, occurring simultaneously on all bay regions infrequently. In particular, the low-mortality and high-mortality beds often show distinctive patterns (Table 8). Viewed in this way, recruitment has been unusually low on the medium-mortality beds since 1999, but much more representative of the normal condition on beds downbay of this region. For 2006, the spat-to-adult ratios were 0.12, 0.34, 0.32, and 0.42 for the low-mortality beds, the medium-mortality beds, Shell Rock, and the high-mortality beds, respectively. Recruitment has been consistently higher downbay than upbay, per adult, for many years. The respective percentiles for the 1953-2006 time period are: 25^{th}, 34^{th}, 27^{th}, and 27^{th}; and for the post-1988 era: 36^{th}, 47^{th}, 25^{th}, and 14^{th}.

Recruitment enhancement programs were successful in 2006. Shell-planting was carried out in June-July, 2006. Ocean quahog and/or surf-clam shell was planted on Hawk's Nest, 17,850 bu; Nantuxent Point, 49,488 bu; Bennies Sand, 79,674 bu; and Shell Rock, 125,354 bu (Figure 18, Table 9). This totals 272,366 bushels. Of these, 30,637 were replants from downbay shell plants (Figure 18). These latter were replanted on Bennies Sand (Table 9). Shell planting in 2006 enhanced recruitment by a factor of 1.34 bay-wide, providing 26% of total bay-wide recruitment. On Shell Rock, shell plants accounted for 50% of total recruitment. On the high-mortality beds, shell plants accounted for 58% of total recruitment. Spat-per-adult ratios, after including the shell plants, rose to 0.64 on Shell Rock and 1.00 on the high-mortality beds (Table 8), with percentile positions, respectively, of 50^{th} and 60^{th} for the post-1988 period. Values ≥ 1 are desirable because they are always associated with stock expansion. An increase in abundance can be anticipated on Shell Rock and beds downbay in 2007, barring an unusual mortality event or overharvesting.

Projections of marketable bushels from the 2006 shell plants were obtained by assuming a 3-year time to market size and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality rates used were the 50^{th} percentiles of the 1989-2006 time series: for Shell Rock, 0.451, 0.180, 0.180, for years 1, 2, and 3, respectively; for Bennies Sand: 0.559, 0.252, 0.252. 2006 shell plants are expected to provide 130,915 bushels for market in 2009 (Table 9).

Shell was planted directly on the oyster beds and downbay off Cape Shore (Figure 18). These latter plants were replanted upbay. As in 2005, even direct plants significantly out-performed native shell, with an average of 302 spat per bushel. Native shell on Bennies Sand attracted 54 spat per bushel and on Shell Rock, 48 spat per bushel in comparison; thus, the increase was about a factor of

5.9. Downbay plants average 2,213 spat per bushel (Table 9). Thus, in contrast to 2005, downbay plants returned more than double the spat per bushel of direct plants (Table 9).

Shell planted in 2005 continued to attract spat in 2006; however the rate of attraction (67/bu) was little better than native shell in the same grids (47/bu). Nevertheless, the net addition of shell to these beds sustained an increased recruitment rate for a second year. Year 2 recruitment will contribute minimally an additional 4,659 marketable bushels in 2009.

A monitoring program for settlement potential was initiated in 2004. The 2006 program showed the anticipated trend of greater spat availability downbay (Figure 19), but a lower setting potential overall than in 2005 (Figure 20). The monitoring program suggested that two recruitment waves occurred in 2006, one early, in July, and downbay and another later, in August, and upbay (Figure 19). High settlement potential in the Cape Shore region conforms to the observed higher settlement rates on shell planted in this area and subsequently replanted upbay (Figure 18, Table 9). The higher settlement potential on Middle was realized by the higher recruitment on this bed. The higher settlement potential on Nantuxent Point and New Beds, however, was not.

Shell Budget Projections

A shell budget was constructed using bed-specific half-life estimates for catch[♮]. Half lives ranged generally between 3 and 10 years (Table 10). The analyses are subject to substantial yearly variations when analyzed retrospectively because not all beds were sampled each year in the first two-thirds of the time series and because the addition of shell beginning in 2004 increases the difficulty of analysis as industry dredging redistributes the shell beyond its original grid placement and the half-lives for surf clam and ocean quahog shell may diverge substantively from that for oyster shell. Outlier half-life values occurred on beds poorly sampled in the first two-thirds of the survey or beds heavily impacted by shell planting in 2005-2006. Three beds have negative half-life estimates: Round Island, Upper Middle, and Sea Breeze. All three were surveyed in alternate years from 1996-2003; thus the time series is inadequate.

New Jersey oyster beds have been losing on the order of 250,000 to 500,000 bushels of shell annually since 1999 (Figure 21). 1999 is the first year an estimate can be made as 1998 is the first year that full survey data are available. The shell budget shows a substantial reduction in shell loss in 2005 and 2006 as a result of the

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

shell-planting program that has reduced by at least two-thirds the yearly deficit.

By region, the low-mortality beds have been losing about 20,000-40,000 bushels annually (Figure 22). This low level of shell loss is due to low taphonomic loss rates. The medium-mortality beds are losing 30,000 to 100,000 bushels annually due to higher loss rates and larger total area. Shell Rock has shown a net gain since 2005 due to shell planting. The high-mortality beds are losing 175,000 to 350,000 bushels annually due mostly to the larger area of coverage. A reduction in the rate of decline in 2006 is due to the substantial shell planting that occurred downbay of Shell Rock.

By bed, Ship John and Bennies have the largest negative numbers, Bennies due to its large size and Ship John due to its high loss rate (Table 11). Other beds exceeding a loss of 1 million kg per year include Arnolds, New Beds, Hog Shoal, Vexton, and Egg Island. Four of these beds are high-mortality beds with low abundance and thus low rates of natural shell addition. Five beds had positive balances in 2006; four of these were the beds on which shell planting occurred. The fifth is Beadons.

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 2006.

In general, Dermo disease* and mortality increase downbay as salinity increases. A regression between Fall Dermo disease and box-count mortality explains approximately 41% 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%. The regression by bay region reveals that background mortality is about 10% for all bay regions except the high-mortality region, where it rises to 18% (Figure 23).

In 2006, the prevalence and infection intensity of Dermo increased from 2005 and approached or exceeded long-term means on most beds (Figures 24 and 25). In 2003 and 2004, summer water temperatures were cooler than normal

* The percent of oysters in the sample with detectable infections is termed prevalence. Infection intensity is scored along the Mackin scale from zero (= pathogen not detected) to five (= heavily infected) and then averaged among all oysters in the sample to calculate a weighted prevalence. A full analysis of the 2006 disease monitoring program is available as an HSRL report: Bushek, D. 2007. Delaware Bay Oyster Seedbed Monitoring Program 2006 Status Report.

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. Higher salinities and temperatures during 2005 encouraged proliferation of Dermo and weighted prevalence rose (Figure 26). In 2006, temperature and salinity showed normal seasonal fluctuations, but both tended to be higher than average and Dermo weighted prevalences rose again relative to 2005 (Figure 26.

Since the onset of Dermo disease in 1990, three epizootics, most of them multi-year, have occurred (Figure 26) with peaks in 1993, 1999, and 2002. Each of these epizootics was characterized by multiyear increases and decreases in disease intensity with a tendency for disease prevalence to follow a 7 year cycle. Since Fall 1990, prevalence greater than 80% or weighted prevalence approaching 2.0 has corresponded to mortalities exceeding 25%. In 2006, Dermo levels were in their second year of increase following a 2004 low and near these prevalence and weighted prevalence thresholds (Figure 26). Mortality in 2006 was above that in 2005, but not yet at epizootic levels. Dermo levels are increasing, however, and Dermo-induced mortality is likely to increase unless environmental conditions inhibit further development. The corollary is the natural mortality rates are expected to be above average in 2007.

Quantitative box-count mortality rates were obtained by calculating the number of boxes per m^2 and summing over strata and beds within bay regions. Box-count mortality was 16.9% bay-wide in 2006. This is a slight increase from 2005, but still below epizootic mortality levels (Figure 27). This is the fourth year in a row with mortality below 20%. This trend is partly due to the concentration of animals on the medium-mortality beds that occurred in the early 2000s as a consequence of the last epizootic and persisted subsequently as a result of recruitment failure. Despite a relatively low mortality rate in 2006, box-count mortality was at the 71^{st} percentile of the 54-yr time series and at the 50^{th} percentile post-1988.

The high- mortality and medium-mortality beds accounted for the bulk of total mortality in 2006 (Figure 27). Although mortality rates are lower on the medium-mortality beds (Figure 28), the total number of adults is much higher, so that cumulative deaths nearly equaled those in the high-mortality region. The high-mortality beds suffer a much higher mortality rate (Figure 28) so that total deaths are high despite lower abundance on these beds (Figure 27). Box-count mortality rose on the high-mortality market beds to 21% in 2006, falling at the 64^{th} percentile of the 54-year time series, but only the 33^{rd} percentile of the post-1988 time series. Mortality on Shell Rock was somewhat lower at 18%, with percentile positions of 64^{th} and 50^{th}, respectively. The percentile rank indicates that mortality was unusually high on Shell Rock in 2006, in comparison to other bay areas. Shell Rock accounts for part of the higher bay-wide mortality rate in 2006.

Box-count mortality on the medium-mortality beds was 16%, a value distinctly higher than observed in 2005 and in keeping with the increasing proportion of large animals in the population. The 2006 level of mortality was at the 71^{st} percentile for the 54-year time series and the 60^{th} percentile for the post-1988 time series. The 2006 rate, due primarily to the high proportion of older adult animals, accounts for the remainder of the explanation for the higher bay-wide mortality rate in 2006 (Figure 27).

Box-count mortality fell to 6% on the low-mortality beds in comparison to 2005. The 2006 level of mortality is at the 14^{th} percentile for the 54-year time series and at the 10^{th} percentile for the post-1988 time series. Nothing in the mortality data explains the large decline in total abundance in 2006 on these beds (Figure 7). Possibly, this variation is, in part, due to a survey artifact.

Population Dynamics Trends

Broodstock-recruitment, abundance-mortality, and mortality-recruitment relationships were updated. The broodstock-recruitment diagram (Figure 29) suggests that present-day abundance limits recruitment in some way. Oyster larvae tend to set preferentially on live oysters and boxes, so that one cannot exclude the possibility that broodstock abundance modulates settlement success by being a principal source of clean shell. The shell-planting program strongly suggests that the bay is not larvae limited. The distribution of points in the four quadrants[ℜ] of the broodstock-recruitment diagram (y/x = recruitment/broodstock abundance) is: low/low = 11; high/low = 7; low/high = 9; and high/high = 26. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.025$; $P > 0.05$; $P < 0.0001$, respectively. High recruitment events are much more likely with high abundances. However, low recruitment events are as likely at any abundance. The 54-year average recruitment rate expressed as the number of spat per >20-mm oyster per year is 0.959. Since 1988, the same long-term average has been somewhat lower: 0.713. The long-term likelihood of a one-year population replacement event, 1 spat per >20-mm oyster, is 17 of 54 and a recruitment rate half that high occurred in 27 of 54 years. Since 1988, the same two probabilities, 6 of 18 and 8 of 18, are not significantly different, so that the expectation of a respectable recruitment event remains approximately 50%.

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

Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about half of the years since 1989 (Figure 30). Non-epizootic years tend to average around 10% mortality (Figures 23 and 30). The bay-wide average for 2006 was 16.9%, a non-epizootic mortality rate. Geographic contraction of the stock, an ongoing process since 2002, ceased in 2005 (Figure 6). Over the previous few years, the stock became increasingly concentrated in the central part of the bay where mortality rates tend to be moderate. 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 2006, a somewhat higher fraction, 63.8%, was present on the medium-mortality beds. In 2006, 13.8% of the stock was on the low-mortality beds, 7.2% on Shell Rock, and 15.1% on the high-mortality beds. Most of the increased proportion on the medium-mortality beds was due to declining abundance on the low-mortality beds.

This stock contraction should reduce total mortality rate and therefore decrease the chance of epizootics at low abundance (Figure 30). The relationship between broodstock and mortality continues to clarify as low abundance values accumulate. The distribution of points in the four quadrants (y/x = mortality rate/broodstock abundance) is: low/low = 13; high/low = 5; low/high = 26; high/high = 9 (Figure 30). This distribution is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.001$; $P < 0.0001$; $P > 0.05$. Low-mortality events are much more likely with high abundance than with low abundance. However, epizootics are less likely to occur as well at lowest abundance levels. This is because stock contraction occurs at low abundance. Thus, epizootics are most likely to occur in a narrow window of abundance as the stock expands from its place of refuge on the medium-mortality beds.

A relationship between box-count mortality and recruitment continues to be present (Figure 31). The distribution of points in the four quadrants (y/x = mortality rate/recruitment) is: low/low = 17; high/low = 4; low/high = 23; high/high = 10. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.05$, $P < 0.005$; $P < 0.005$; $P > 0.05$, respectively. Cases of high recruitment-low mortality occur more often than expected by chance. Cases of high mortality and low recruitment occur less often than expected by chance. Possibly, the increased number of boxes increases recruitment in these latter cases.

The important areas for the oyster industry are the beds in the medium-mortality and high-mortality region. Examination of the trends on the individual beds indicates that these two regions have substantially different processes controlling oyster abundance (Figure 5). The average number of oysters on the medium-mortality beds for the 1989 to 2006 period was statistically greater than for the high-mortality beds (Figure 5). The spat set was not statistically different over the same period (Figure 5). Surplus production generally has been positive on the high-mortality beds and commonly negative on the medium-mortality beds upbay of Shell Rock, although modeling suggests a strongly positive surplus production in 2007 as a large cohort matures (Table 7). The number of spat recruiting per adult has been consistently higher on the high-mortality beds and growth rates are consistently higher. Present information suggests that the high-mortality beds are characterized by multiple cohorts moving through the population of relatively equivalent size, whereas the medium-mortality beds are characterized by aperiodically-occurring large cohorts that dominate the population for an extended period of time. The differential explains the tendency for surplus-production based reference points to work well downbay and the tendency for exploitation-based reference points to work more consistently upbay.

Harvest

In 2006, 60,450 bushels were landed, somewhat less than the 1996-2006 direct-market average of 70,390 bushels[♭] (Figure 32). Figure 33 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[Δ] years.

Beds were harvested almost continually from April 1 to November 15, 2006. Harvest was from 10 beds. Five beds accounted for nearly 90% of the harvest: Cohansey (21.4%), Shell Rock (20.6%), Nantuxent Point (20.4%), Ship John (17.2%), and Hawk's Nest (10.4%) (Table 12). The recommended area-management policy formulated at SAW-8 resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John and Cohansey.

Seventy-two boats participated in the fishery and worked for a total of 837 boat-days. These included 34 single-dredge boats working for 512 boat-days (15.1 days/boat) and 38 dual-dredge boats working for 325 boat-days (8.6 days/boat).

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

[Δ] Prior to 1996, oysters were taken from the natural beds by deck-loading them and moving them downbay to leased grounds during a few weeks in the spring. This time period was termed 'bay season'. During this time, oysters were taken from beds for which survey bushel samples contained an average oyster volume of $\geq$40%. This 40% rule was the first reference point and was used for management decisions from the late 1950s until 1995, hence the identification of bushel samples $\geq$40% in Table 4.

The catch per boat-day for dual-dredge boats increased for the fourth year in a row (Figure 34). The catch-per-boat-day for single-dredge boats also increased this year, rising to the highest value since 1997 (Figure 34). This stabilization or increase in catch per boat-day may reflect the high percentage of marketable or nearly marketable oysters on most of the exploited beds.

Total dredging impact was estimated[⊗]. Five beds were covered by industry dredges more than once during 2006: Cohansey, Ship John, Shell Rock, Nantuxent Point, and Hawk's Nest (Table 12). Highest coverage was 3.63 on Nantuxent Point. No other bed exceeded 1.74[@].

The number of oysters per 37-qt marketed bushel averaged 260 in 2006, a drop from 302 in 2004 (Table 13). Of these, 238 were $\geq 2.5''$ in size. Incidental capture averaged 22 per bushel, fewer than in 2005. These were mostly animals that could not be culled from chosen oysters. Size of harvested individuals was about that of 2005 and larger than observed in 2004 (Table 13). Most animals marketed were $2.75''$ to $4.25''$ in length. Catch approximated a knife-edge process with few oysters marketed below $2.5''$ (Figure 35).

In 2006, the intermediate transplant program moved animals exclusively to Shell Rock. 12,350 bushels were moved from Arnolds and 5,550 bushels were moved from Middle. Cullers were used for the Middle transplant, so this transplant was enriched in larger animals. Oysters per bushel in the Arnolds transplant averaged 273 and in the Middle transplant, 362. 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 (Figures 36 and 37). 2006 continues a program begun in 2005 to reduce net removals from Shell Rock. This was accomplished in 2005 by transplant downbay from Middle that nearly balanced removals. A similar result occurred in 2006 with transplants from Arnolds and Middle. This was a goal of the 2006 management plan.

Apparent fishing mortality was 2.4% of the stock; that is, 2.4% of the stock was manipulated whether through transplant or harvest. True fishing mortality was 1.8% of the stock (Figure 38); that is, the direct-market harvest in 2006 removed about 1.8% of the stock by number. This equates to 1.8% of the spawning stock biomass (Figure 39). Fishing mortality measured by abundance has been below

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

[@] This intensity of dredging is unlikely to negatively impact these beds – Powell, E.N., K.A. Ashton-Alcox, S.E. Banta and A.J. Bonner. 2001. Impact of repeated dredging on a Delaware Bay oyster reef. *J. Shellfish Res.* 20:961-975.

2% every year except one since 1995. 2006 fishing mortality so measured was at the 34^{th} percentile of the 54-yr time series excluding closure years, and at the 75^{th} percentile of years post-1988. For the first time, in 2006, the fishing mortality of the larger size classes could be calculated. Fishing removed 3.8% of the animals $\geq$2.5$''$ in 2006 (Figure 40). This is a value representative of the time series.

By bay section, fishing and management activities removed 1%, 2.9%, 4.5% and 8.4% of the animals for the low-mortality beds, medium-mortality beds, Shell Rock, and the high-mortality beds. Values for the first two include intermediate transplant removals. The value for the third takes into account intermediate transplant plantings that took place, in 2006, exclusively on Shell Rock. Apparent exploitation rates for Shell Rock and the high-mortality beds were 10.3% and 8.4%, respectively. As a consequence, the majority of animals taken to market originated about evenly from the medium-mortality and high-mortality beds (Figure 37).

Management Advice

Summary of Stock Status and Population Management Goals

Target and threshold values for SSB and abundance were recalculated based on updated numbers for the period 1990-2005. This update incorporates revised information on abundance on the high-mortality beds obtained during the spring 2006 re-survey. Year 2006 was not included in determining target and threshold values.

Figure 41 summarizes the condition of the oyster stock throughout the New Jersey waters of Delaware Bay and by bay region. All percentiles are based on the 1989-2006 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 three of four bay regions. Abundance continued to be below target levels in all bay regions (Figure 42), but above threshold levels on the medium-mortality beds and Shell Rock and near, but still below, threshold levels on the high-mortality beds. Abundance was well below threshold levels on the low-mortality beds, however. The shell-planting program promises to increase abundance on these downbay beds in 2007. Abundance has increased each year on the high-mortality beds since reaching a post-1988 low in 2004 (Figure 42) and abundance has moved in a positive direction for several years on Shell Rock. The stock continues to be disproportionately consolidated on the medium-mortality beds, a process that began in the early 2000s with persistent recruitment failure and the influence of Dermo disease downbay.

Spawning stock biomass is relatively low bay-wide, but rose in 2006. Increases were noted in all bay regions except upbay on the low-mortality beds. SSB has increased steadily on the high-mortality and medium-mortality beds over the last three years and has risen for the last two years on Shell Rock (Figure 42). SSB was above the biomass target in three of 4 bay regions and near the threshold for the low-mortality beds.

Recruitment remains low bay-wide and particularly low on the low-mortality beds, high-mortality beds, and Shell Rock. A near-average recruitment event occurred on the medium-mortality beds. However, in no case did recruitment reach the value of 0.5 spat per adult. Shell planting increased recruitment on Shell Rock and the high-mortality beds and this increase brought the spat-per-adult ratio above 0.5 on Shell Rock and up to 1.0 on the high-mortality beds. Both ratios are normally associated with increasing abundance in the following year. Evidence exists that low spat abundance is associated with low adult abundance, and suggests that the explanation involves the contribution of live oyster shell to the cultch resource preferred for settlement. This implies that high recruitment may be less likely under current conditions of low abundance.

The oyster population as a whole continues to be depauperate in the smaller size classes, with the proportion of animals $<2.5''$ being below the 40^{th} percentile in all bay regions and no higher than the 25^{th} percentile in three. In contrast, this year, surplus production is expected to permit an increase in market-size abundance bay-wide and in all bay regions, given average growth rates, barring a higher than average rate of natural mortality, and not counting removals by the fishery. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease rose to moderate levels in 2006 and natural mortality rates were somewhat above average. A rising trend in Dermo disease weighted prevalence may presage increased rates of natural mortality in 2007.

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

Overall, the conditions on the low-mortality beds are distinctly disadvantageous, whereas the remaining bay regions appear to have improved since 2004. However, the fact that all bay regions fall below their abundance targets indicates that actions to enhance abundance are needed in all bay regions. A reduction in fishing effort will not address this need because exploitation rates are already low; however, substantial increases in exploitation rate should be avoided as the importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining biomass at or above target levels. Abundance has been enhanced on the high-mortality beds and Shell Rock by downbay transplant and this program should be continued. The preferred mechanism to address low abundance is to enhance recruitment and this program began in 2005 focused on Shell Rock and the high-mortality beds. Additional emphasis on the medium-mortality beds is desirable.

Cultch Management Goals

Most beds not receiving shell plants in 2006 suffered a loss of surficial shell. Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Shell plants should target areas where marketable oysters grow but where cultch loss exceeds the addition of shell through natural mortality. The Ship John region is such a case. Due to the enhanced survival of juveniles in this region, replants from downbay plants should be moved to selected areas of Ship John in 2007. This will maximize the return from this more costly endeavor. The same region, and Cohansey as well, have the lowest fraction of small oysters in the size-frequency distribution of any bay region. Hence, these beds also should be considered for direct shell plants in 2007. Downbay plants and replants should be expanded to the extent funds permit to enhance recruitment.

Shell Rock and Bennies Sand should not be planted in 2007.

The high-mortality beds have the fastest growth rates and best oysters for marketing, but increasing abundance in this region increases the risk of epizootics. The shell-planting program should not exclusively target this area; however, Nantuxent Point, Hawk's Nest, Hog Shoal, Vexton, and Strawberry should be considered as planting locales for direct shell plants. Planting should not occur on Bennies and New Beds as evidence indicates that oysters in this region suffer proportionately higher Dermo mortality for a given disease level than the inshore beds (Figure 43).

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 incorporates into this reference point a rebuilding plan that can be expected to increase market-size abundance. Use of the 75^{th} percentile 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 an 18-year time series and is therefore substantive. The latter is represented by relatively few measurements, but the dataset was updated in 2006. Nevertheless, data on growth continue to be inadequate to estimate probabilities. In contrast, application of the constant-abundance reference point has been difficult upbay of Shell Rock where less consistent recruitment results in population expansions and contractions driven by the dynamics of aperiodic large cohorts. During times when these cohorts reach market size, overharvesting is a likely outcome, if long-term stability of the fishery is a desired goal.

As a consequence, an alternate, exploitation-based reference point was proposed by SAW-8 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. SAW-8 promulgated 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. This approach has been substantially revised this year based on the 1996-2006 time series and new software permitting more accurate estimates of size-dependent exploitation rates has been implemented. As these abundance-based exploitation reference points are derived from a period of conservative fishery management characterized by low exploitation rates, the abundance-based exploitation reference points are likely to provide conservative management goals. The SARC notes that these newly-formulated reference points, based on 1996-2006 data, should not be updated yearly, but retained until such time as a Term of Reference permits formal review based on new information.

The newly-formulated exploitation reference points are introduced with the following cautions as to their use. Two sets of exploitation percentiles were calculated: one using the assumption that all size classes were removed proportionately and one using a knife-edge assumption that all size classes $\geq 2.5''$ were removed proportionately. Insufficient data are available for the low-mortality beds. The exploitation indices for the upper group of medium-mortality beds (Middle+Upper Middle) were applied also to the low-mortality beds.

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

The SARC recommends that the real exploitation rate reference points be used for any analysis for direct marketing and that the reference points used should be based on the 1996-2006 values for the $\geq 2.5''$ size class (Table 14). The SARC recommends that the 40^{th}, 50^{th}, and 60^{th} percentiles normally be employed. Lower percentiles might be evaluated when abundance or SSB values are near threshold levels to enhance stock rebuilding. Higher percentiles might be employed in times of high surplus production or when abundance or biomass are over target levels; however, in this case, the SARC also notes that the employment of percentile harvests above the 60^{th} percentile reduces the likelihood of a consistent harvest over a period of years that would otherwise be permitted by the oyster's life span, particularly upbay of the high-mortality beds.

Intermediate transplant can be conducted by suction dredge or dry dredge with or without a culling device. Exploitation rates for suction dredge or dry dredge without a culling device should be estimated assuming all size classes are removed proportionately. The concentration factor for culling devices is of the order of 1.28[#]; a concentration factor insufficient to use the exploitation rates for $\geq 2.5''$ animals. Thus, all intermediate transplant estimates should rely on the 'all-animal' exploitation rate reference points (Table 15).

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; however a substantial fraction of these animals have originated from the medium-mortality beds through the intermediate transplant program (Figure 37). The high-mortality beds in particular are highly influenced by disease and therefore susceptible to rapid population

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

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. Present-day abundance is near threshold levels (Figure 42), requiring that rebuilding be included as a management goal. 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. 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. However, the SARC also notes that surplus production estimates covered a wide range due to uncertainty in growth rates. Thus, the SARC considers the use of exploitation reference points for this bay region to be the best management option. The SARC notes that, this year, exploitation-based reference points using the 40^{th} to 60^{th} percentiles fall within a range of the central 50% of the values established by surplus production calculations derived from a 3×3 matrix defined by the 50^{th} to 75^{th} percentile of natural mortality rate and the 2005, 2006 updated, and their average growth rates (Table 7). Thus the two approaches provide relatively equivalent allowable harvest levels.

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.

Bay Region Considerations–Low-mortality Beds

These beds have rarely contributed much to the fishery and none in most years since 1995. This bay region is below threshold abundance levels and at threshold SSB levels (Figure 42). The SARC recommends that this bay region be closed in 2007. However, the SARC also notes that this bay region will be re-surveyed in 2007 and that the updated abundance and biomass estimates thus derived should be used to re-evaluate this recommendation.

Bay Region Considerations–Medium-mortality Beds

These beds are susceptible to negative surplus production. Positive surplus production has occurred in less than half of the years since 1996. In contrast, high levels of surplus production are expected to occur in 2007 (Table 7). These beds have contributed the bulk of the stock supporting the fishery over the entire 54-year history of the survey, excepting the 1970s high-abundance period (Figure 36). Over the 1996-2006 direct-market period, these beds contributed a substantial fraction of the animals supporting the fishery, albeit indirectly through transplant to replace animals fished from the beds farther downbay (Figure 37). Abundance and SSB are highest here (Figures 7 and 8) and the animals are moderately protected from disease (Figure 23). These beds must be included in the fishery; otherwise the pressure on the beds downbay of Shell Rock will be too high.

However, the high levels of surplus production anticipated for 2007 should not permit dramatically expanded exploitation of these beds. The SARC notes that the high surplus production rate originates from the growth of the last large cohort, recruited in the early 2000s, into market size and that these beds do not have substantial numbers of smaller animals supporting continued stock expansion in the future (Figure 11). Thus, the surplus production anticipated for 2007 should be viewed as the basis for fishery yield over a number of years. Given the likely average age of animals growing into market size of 5 to 6 years (Table 6), management of these beds should consider that a 2007 recruitment event will not benefit the fishery for minimally 5 years. Thus, the projected surplus production for 2007 should be viewed as minimally a 5-year allotment. As an example, the surplus production estimates for 2007 for Cohansey, Sea Breeze, and Ship John range from 79,063 to 169,963 bushels for the 50^{th} percentile to the 75^{th} percentile of natural mortality rate and average growth (Table 7). A yearly harvest level above 15,800 to 34,000 bushels risks a reduction in allocation from this bed region in future years that may be long-term in duration, even with a substantive recruitment event in 2007. The five-year time period has implications for the evaluation of exploitation reference points in the context of minimizing yearly variations in the allocation. The SARC strongly recommends that exploitation rate percentiles permitting harvest outside of the 15,800 to 34,000 bushel range be viewed as inhibitory to the long-term health of the fishery.

SAW-8 recommended that management should emphasize increased direct marketing on these beds to reduce the exploitation rate downbay while stock rebuilding continues. Biomass continues to be high on these beds and continued focus on directing effort to these beds is important. The SARC assumes that the upper bed group (Middle and Upper Middle) will be used for intermediate transplant exclusively and encourages intermediate transplant to Shell Rock or Bennies Sand be a component of the 2007 program. The SARC recommends that Sea Breeze, Cohansey and Ship John be managed as direct-market beds in 2007.

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. Projections were run using natural mortality rates for each bay region, with percentiles calculated from the 1989-2006 time series. An average growth rate was assumed, based on the average of the 2005 and 2006 updated 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, 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 263 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 2004-2006 seasons (Table 13)[†]. Note that the surplus-production option assumes direct-marketing. Consequently, estimates are provided only for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze).

Bay Region	Natural Mortality Percentile	Allocation (market-equivalent bushels)
High Mortality	50^{th}-75^{th}	3,963-31,264[II]
Shell Rock	75^{th}	17,822
Lower Medium Mortality	75^{th}	15,800 to 34,000[⋆]
Upper Medium Mortality		NA§
Low Mortality		NA§

[†] This is an average of the three years (2004-2006) and the mean of the total oysters and chosen oysters. The rationale for taking the mean is that the number of attached small animals will vary widely between years depending on recruitment dynamics, so the use of the total number risks underestimating the allocation. On the other hand, the smaller number does not account for all of the oyster removals and this undervalues the fishing mortality rate.

§NA: not applicable to this reference point.

[Π]The SARC recommends that exploitation rate reference points be used for these beds with a harvest value chosen that does not stray substantively from this range, so that rebuilding of abundance can be achieved during times of shell planting. The SARC notes that surplus production estimates for these beds covered a wide range. The range provided represents the central 50% of a 3×3 matrix of estimates using the 50^{th}, 67^{th}, and 75^{th} percentiles of mortality and the 2005, updated 2006, and average 2005-2006 growth rates.

[*]Allocation estimates based on a 5-year distribution of 2007 surplus production. The SARC recommends that exploitation rate reference points be used for these beds with a harvest value chosen that does not stray substantively from this range, if long-term harvest stability is desired.

Abundance-based Exploitation Reference Point – Direct Marketing

Projections are provided for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John, Sea Breeze). The SARC recommends that this reference point be defined based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index (Tables 14 and 15). An upper and lower bound normally should be taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest). The SARC recognizes that lower or higher percentiles may be investigated given consideration of surplus production and position of abundance and SSB relative to threshold and target levels. This year, these bay regions are above their SSB targets, but below their abundance targets and, below the abundance threshold for the high-mortality bed group; thus stock rebuilding should be included in the management goal. This projection uses the average numbers per marketed bushel of 263 derived from the 2004-2006 dock-side monitoring program.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	40^{th}	.0201	1,586,910	6,034
	50^{th}	.0573	4,523,870	[⊖]17,201
	60^{th}	.0781	6,166,040	23,445
	80^{th}	.0836	6,600,260	[Γ]25,096
Shell Rock	40^{th}	.0800	3,425,970	13,027
	50^{th}	.0868	3,717,180	14,134
	60^{th}	.1142	4,890,580	[δ]18,595
Lower Medium Mortality	40^{th}	.0176	6,120,010	23,270
	50^{th}	.0215	7,485,430	28,462
	60^{th}	.0267	9,293,210	35,335
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

Γ The inclusion of this percentile recommendation was not uniformly supported by the SARC. The SARC notes the following. (1.) This value falls within the range of values estimated using the constant-abundance approach. (2.) The high-mortality beds are above the biomass target; however a higher than anticipated mortality event is anticipated to occur on these beds in 2007. (3.) The high-mortality beds are below the threshold in abundance, requiring the rebuilding of abundance; however, shell planting has targeted this area and initial estimates show a promising increase in abundance that might bring abundance above the threshold in 2007. The SARC was about evenly divided on the issue of whether the concern about rebuilding abundance should outweigh the high-biomass level present, considering that the volatility of the resource in this bay region caused by the wide range of mortalites from Dermo disease may limit the long-term success of stock rebuilding programs. The SARC has chosen to include this option with the caveat that it is unlikely to be a precautionary option and with the further caveat that its inclusion should not be considered precedent setting for application to management advise by future SARCs.

Θ The SARC notes that this value approximates the value obtained using the constant-abundance method with a 67^{th} percentile natural mortality rate and average growth. It is, therefore, a precautionary option given the prediction that natural mortality rates will exceed the 50^{th} percentile in 2007.

δ The SARC notes that this value is consistent with the 75^{th} percentile surplus production recommendation.

Abundance-based Exploitation Reference Point – Intermediate Transplant

The estimates assume that intermediate transplant will be conducted on the upper medium-mortality beds (Middle, Upper Middle) and that direct-marketing will be conducted on beds downbay of these two beds. Numbers to be moved by intermediate transplant are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading by dry dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel obtained from the 2006 survey. If cullers are used, the number of bushels can be reduced by an estimated factor of 1.28. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.5''$ and these animals are converted to bushels using the 263 animal/bu conversion. Note that transplant options will require transplant before the allocation can be set because allocation estimates provided herein can only be confirmed after the transplant is complete. Moreover, if cullers are used, the marketable-bushel estimate may be low.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Lower Medium Mortality						NA§
Upper Medium Mortality	40^{th}	.0117	2,174,440	133	18,427	3,969
	50^{th}	.0127	2,363,680	133	20,031	4,314
	60^{th}	.0233	4,313,620	133	36,556	7,873
Low Mortality						CLOSED$^{\theta}$

§NA: not applicable to this reference point.

$^{\theta}$The SARC recommends closure of the low-mortality beds in 2007.

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.

The continuing decline in the low-mortality beds requires a plan of redress including evaluation of the reasons for the decline.

The dock-side monitoring program must continue. This program is required for SSB estimates of landings, improved abundance-to-bushel conversions, estimation of the shell budget, and evaluation of exploitation rates, as well as any development of size- or age-based models incorporating mortality.

Science Recommendations

These science recommendations are not ordered as to priority. The SARC made special note, however, of the need to improve growth data, conduct the remaining re-survey program, develop new recruitment indices for animals recruiting into the fishery, and the development of a 'clean cultch' index to compare to recruitment.

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

A spat settlement monitoring program should be continued.

A special survey of the low-mortality bed region should occur in 2007 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 expanded with emphasis on determining size at age.

A model should be formulated to provide an estimate of the amount of clean shell and a clean-shell versus recruitment relationship investigated.

Recruitment-into-the fishery indices should be formulated.

A geostatistical model for estimating abundance and SSB should be investigated and compared to the standard estimated based on the sum of stratal averages.

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

A size-dependent model should be expanded to include box-frequencies so that size-dependent mortality can be included in the assessment. Retrospective analysis should be used to better estimate mortality rates with the goal of developing a demographic model for the population.

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

An improved estimate of the numbers per bushel in catch projections might be obtained by investigating the relationship between the size-frequency of catch and population size frequency at the bed level of resolution.

The use of the 20-mm cut-off for defining spat should be re-examined.

Table 1. Long-term (1953-2006) average numbers of oyster and spat per bushel, 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	276	177	15
Low-mortality Beds	572	277	13
Medium-mortality Beds	303	179	15
High-mortality Beds - Group 1	182	160	19
High-mortality Beds - Group 2	64	64	20

Table 2. 2006 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 and 2006 Spring re-surveys. 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	8
→ Bennies Sand	3	3	0	4
→ Bennies	3	9	0	0
New Beds	1	6	2	0
→ Nantuxent Point	3	3	0	1
→ Hog Shoal	3	3	0	0
→ Strawberry	1	3	0	0
→ Vexton	2	3	0	0
→ Beadons	3	4	0	0
→ Hawk's Nest	2	3	0	1
Egg Island	0	0	0	0
Ledge	1	4	0	0

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

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

[♯] 2003 and 2000 values are taken from: Powell, E.N., K.A. Ashton-Alcox, J.A. Dobarro, M. Cummings, and S.E. Banta. 2002. The inherent efficiency of oyster dredges in survey mode. *J. Shellfish Res.* 21:691-695 and Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter. 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 2006 random sampling program for the Delaware Bay natural oyster beds. Included for comparison are data for 2004 and 2005. Data are displayed from the farthest upbay beds to those downbay. The column called 'Bushels/haul' to the left of the column headed 'Percent Oyster' indicates the average number of bushels brought up by the 3 dredge hauls from each grid. For each bed the percentage of oysters for each sample is presented, with rankings from highest to lowest. Percent oyster is based on volume of oyster in the sample divided by the total volume of shell, oyster, and debris. Those samples that have over 40% oyster are underlined. Oysters per bushel and spat per bushel are based on actual counts adjusted to a 37-quart bushel. 'Size' columns indicate the number of oysters greater than 2.5″ and their percentage based on measured size frequencies (Table 5). Condition index is a measure of the dry meat weight in an oyster relative to the hinge-to-lip (greatest) dimension. The 'Percentage Mortality' value is based on the number of boxes counted in the samples. Prevalence is the percentage of oysters with detectable infections by Dermo. Weighted Prevalence is the average infection intensity (scored from 0 to 5) of all sampled oysters. 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 2006 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2006.

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		
		2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004		**2006**	2005	2004	2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004
	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Round Island	2.2	**48.4**	30	35.3																									
Round Island	1.8	**44.4**	22.6	27																									
Round Island	1.7	**39.7**	18	25.2	**178**	98	161	**7**	14	3		**6**	16	17	**10**	0	0	**0.2**	0.00	0.00	**96**	34	23	**54**	35	14	**0.007**	0.010	0.006
Round Island	2.5	**27**	16.9	7.69																									
Round Island	0.2	**9.05**	9.1	1.96																									
Round Island	0.0	**0**	4.2	0.71																									
Up. Arnolds	3.5	**54**	41.7	--																									
Up. Arnolds	0.3	**23.5**	32.5	--	**51**	300	--	**0.2**	61	--		**15**	13	--	**10**	0	--	**0.2**	0.00	--	**26**	57	--	**51**	19	--	**0.008**	0.011	--
Up. Arnolds			--	--																									
Arnolds	2.7	**46.5**	49.2	53.1																									
Arnolds	1.8	**40.9**	46.6	50.9																									
Arnolds	0.8	**34.7**	38.8	39.9	**144**	227	222	**14**	60	5		**4.7**	12	13	**25**	0	5	**0.25**	0.00	0.03	**72**	64	50	**50**	32	22.7	**0.008**	0.013	0.006
Arnolds	0.7	**12.8**	26.9	27.8																									
Arnolds	1.1	**9.95**	5.9	24.7																									
Arnolds	0.0	**0**	0	0																									
Up. Middle	0.4	**7.14**	0	0																									
Up. Middle	0.0	**0**	0	25	**13**	0	19	**0**	0	0	0	**0**	0	0	**60**	--	0	**1.55**	--	0.00	**5**	0	0	**38**	0	--	**0.008**	--	0.010
Middle	3.8	**54.2**	76.4	62.3																									
Middle	3.3	**50.4**	67.2	52.7																									
Middle	4.3	**47.9**	51.9	51.9																									
Middle	1.6	**40.2**	30.6	51.5																									
Middle	1.9	**25**	0	46.8	**199**	212	210	**56**	27	35		**14**	11	10	**65**	55	40	**1.5**	0.98	1.35	**114**	109	98	**57**	68	46.9	**0.009**	0.015	0.010
Middle			--	31.8																									
Middle			--	29																									
Middle			--	23.5																									
Middle			--	6.19																									
Cohansey	5.0	**60.5**	67.9	68.4																									
Cohansey	4.7	**57.4**	62.1	61.5																									
Cohansey	2.5	**44.4**	61.6	48.2																									
Cohansey	2.2	**37.1**	53	47.7	**131**	184	161	**16**	34	18		**15**	12	13	**100**	45	20	**2.23**	0.80	0.23	**92**	112	102	**70**	61	63.1	**0.011**	0.017	0.012
Cohansey	1.4	**14.8**	38.6	8.8																									
Cohansey	0.5	**0**	14.6	0																									
Cohansey			--	--																									
Cohansey			--	--																									

Table 4, page 2.

Summary of the 2006 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2006.

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		
		2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--	--	--	**--**
Ship John	4.7	**63.9**	79.3	62.9																								
Ship John	3.8	**49.7**	74.7	60.9																								
Ship John	4.3	**49.6**	68.1	53.5																								
Ship John	4.2	**48.5**	62.2	50.3	**189**	211	245	**64**	49	58	**16**	11	11	**55**	70	--	**0.8**	1.00	--	**108**	147	129	**57**	70	52.6	**0.012**	0.021	0.012
Ship John	5.0	**40.4**	52.5	11.8																								
Ship John	2.0	**34.5**	49.1	--																								
Ship John	2.7	**20.9**	37	--																								
Seabreeze	2.1	**53.5**	62.8	31.9																								
Seabreeze	1.8	**42.8**	50.5	12.6																								
Seabreeze	2.2	**37.1**	35.7	0.34	**120**	166	108	**28**	13	20	**20**	7	15	**90**	65	30	**2.2**	1.40	0.48	**70**	103	31	**58**	62	28.8	**0.015**	0.024	0.012
Seabreeze	2.5	**27.5**	33.3	--																								
Seabreeze	1.3	**24.3**	27.2	--																								
Shell Rock	2.4	**68.8**	69.4	57.9																								
Shell Rock	*1.4*	***59.4***	62.1	43.2																								
Shell Rock	*4.3*	***57.1***	59	37.9																								
Shell Rock	3.3	**56.5**	47.7	37.6																								
Shell Rock	*1.5*	***52.9***	47.1	35.7	**213**	173	175	**52**	47	82	**19**	11	11	**100**	94	60	**3.28**	2.09	1.25	**95**	86	104	**45**	62	59.5	**0.014**	0.020	0.018
Shell Rock	3.3	**51.7**	42.1	34	***197***			***42***			***18***																	
Shell Rock	2.3	**47.3**	9.93	27.2																								
Shell Rock	4.0	**47.2**																										
Shell Rock	1.8	**46.8**																										
Shell Rock	*5.6*	***46.6***																										
Shell Rock	4.3	**46.4**																										
Shell Rock	*3.9*	***44.1***																										
Bennies Sand	2.7	**49.4**	46.2	33.2																								
Bennies Sand	3.3	**40.4**	38.7	31.8																								
Bennies Sand	*3.8*	***35.8***	*33.2*	*29.1*	**144**	175	142	**42**	73	71	**17**	11	14	**90**	75	40	**1.8**	1.35	0.73	**66**	77	77	**46**	44	53.9	**0.02**	0.025	0.019
Bennies Sand	3.3	**33.4**	23.1	*28.6*	***148***			***43***			***17***																	
Bennies Sand	2.4	**27.9**	18.5	28.3																								
Bennies Sand	7.0	**27.8**	--	25.8																								
Bennies Sand	3.3	**26.1**																										
Bennies Sand	1.1	**23**																										

Table 4, page 3.

Summary of the 2006 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2006.

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		
		2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--	--	--	**--**
Bennies	1.5	**61**	34.5	*34*																								
Bennies	2.7	**39.7**	31	21.5																								
Bennies	3.0	**35**	24.8	19.7																								
Bennies	2.1	**30.3**	23	18																								
Bennies	3.3	**27.2**	18.5	13.8																								
Bennies	0.5	**14.6**	17.3	11.9																								
Bennies	0.3	**13**	16.8	4.04	**86**	46	16	**17**	17	15	**16**	15	24	**100**	67	30	**2.55**	1.45	0.55	**37**	25	11	**43**	55	69.2	**0.02**	0.031	0.022
Bennies	3.7	**10.4**	9.5	3.64																								
Bennies	3.2	**10.1**	6	2.66																								
Bennies	0.2	**8.06**	4.9	1.74																								
Bennies	2.5	**6.3**	4.8	1.36																								
Bennies	3.0	**2.63**	0	0.12																								
Bennies			--	0																								
Bennies			--	0																								
Nantuxent Pt	*3.5*	***46***	*47*	--																								
Nantuxent Pt	3.3	**41.8**	32.4	--																								
Nantuxent Pt	4.0	**39.7**	18.9	--																								
Nantuxent Pt	4.0	**37.9**	7.5	--	**122**	95	--	**26**	37	--	**31**	25	--	**95**	95	--	**2.6**	2.75	--	**65**	39	--	**53**	47	--	**0.017**	0.023	--
Nantuxent Pt	3.3	**32.5**	4.2	--	***108***			***22***			***31***																	
Nantuxent Pt	0.7	**16.2**	0	--																								
Nantuxent Pt	0.5	**1.87**																										
Hog Shoal	4.0	**28.6**	34.7	20.7																								
Hog Shoal	2.7	**26.7**	27.3	18.5																								
Hog Shoal	2.7	**24.4**	20.1	5.16	**61**	66	33	**14**	22	23	**28**	28	39	**95**	90	85.0	**2.97**	2.77	1.95	**34**	28	22	**56**	43	66.4	**0.018**	0.022	0.020
Hog Shoal	3.7	**21.3**	20	4.41																								
Hog Shoal	3.0	**10**	10.1	3.02																								
Hog Shoal	1.8	**7.25**	5.3	--																								
New Beds	2.7	**43.9**	21.2	32.8																								
New Beds	0.7	**17.1**	18.3	*22*																								
New Beds	0.1	**16.5**	14.8	17.9																								
New Beds	4.3	**12.7**	12.5	6.9																								
New Beds	4.0	**8.28**	5.4	5.66	**30**	30	28	**6**	22	31	**24**	14	33	**100**	90	65	**3.05**	2.08	1.30	**22**	12	14	**73**	40	51.7	**0.021**	0.026	0.025
New Beds	0.3	**1.8**	4.5	5.44																								
New Beds	0.2	**1.61**	3.9	4.98																								
New Beds	2.0	**0.86**	1.9	3.17																								
New Beds	0.0	**0**	1.6	2.04																								
New Beds			--	0																								

Table 4, page 4.

Summary of the 2006 Random Sampling of the Seed Beds																												
Table 4. Delaware Bay Seed Bed data for 2006.																												
															Dermo			Dermo			Size			Size			Condition Index		
Bed	Bushels/ Haul	Percent Oyster			Oysters/Bushel			Spat/ Bushel			Percent Mortality			Percent Prevalence			Weighted Prevalence			No./bu. >2.5 in.			%oysters >2.5 in.			Dry Meat/Height		
		2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Strawberry	3.7	**13.8**	34.1	23.5																								
Strawberry	0.2	**2.76**	31.3	8.55																								
Strawberry	2.0	**0.96**	8.2	3.68	**12**	47	32	**2**	18	37	**17**	21	21	**88**	96	70	**2.13**	2.27	1.85	**11**	24	20	**92**	52	63.4	**0.018**	0.022	0.017
Strawberry	0.8	**0**	6.8	2.72																								
Strawberry			2.8	1.88																								
Strawberry			2.7	--																								
Hawks Nest	*4.0*	***53.9***	48.3	14.7																								
Hawks Nest	3.0	**35.8**	14	7.05																								
Hawks Nest	0.9	**27.5**	6.8	4.25	**101**	59	19	**24.4**	22	13	**26**	10	26	**100**	100	50	**2.63**	2.53	1.20	**58**	17	14	**57**	39	72.5	**0.018**	0.025	0.019
Hawks Nest	3.0	**17.2**	5.2	2.4	**75.7**			**17.1**			**24**																	
Hawks Nest	2.6	**11.6**	1.9	2.05																								
Hawks Nest	1.6	**6.97**	0	--																								
Beadons	2.3	**26.6**	22.2	17.9																								
Beadons	3.3	**17.4**	20.8	8.62																								
Beadons	1.3	**13.3**	19.1	6.9																								
Beadons	1.0	**7.79**	18.4	6.02																								
Beadons	3.3	**7.14**	15.1	5.23																								
Beadons	4.0	**5.41**	4	3.97	**42**	48	23	**22**	22	33	**16**	17	30	**75**	85	84	**2.05**	1.94	1.84	**19**	18	12	**45**	38	53.4	**0.015**	0.029	0.022
Beadons	2.7	**0.67**	3.9	3.43																								
Beadons			3.4	3.29																								
Beadons			0	1.8																								
Beadons			--	1.13																								
Vexton	3.3	**15.1**	29.5	10.6																								
Vexton	2.5	**14.8**	15.7	9.06																								
Vexton	2.8	**13.4**	12.8	6.39	**14**	24	13	**9**	9	4	**22**	30	30	**90**	80	65	**2.25**	1.05	1.60	**12**	17	11	**86**	70	83.9	**0.022**	0.031	0.025
Vexton	4.8	**3.01**	12.8	3.69																								
Vexton	1.7	**0**	12.3	1																								
Vexton			0.8	0																								
Vexton			0.3	--																								
Egg Island	--	--	60.1	--																								
Egg Island	--	--	8.3	--																								
Egg Island	--	--	2	--																								
Egg Island	--	--	1	--																								
Egg Island	--	--	0.4	--	--	10	--	--	0	--	--	17	--	--	75	--	--	1.65	--	--	8	--	--	79	--	--	0.030	--
Egg Island	--	--	0	--																								
Egg Island	--	--	0	--																								
Egg Island	--	--	0	--																								
Egg Island	--	--	0	--																								
Egg Island	--	--	0	--																								

Table 4, page 5.

Summary of the 2006 Random Sampling of the Seed Beds

Table 4. Delaware Bay Seed Bed data for 2006.

																Dermo			Dermo			Size			Size				Condition Index	
Bed	Bushels/	Percent Oyster			Oysters/Bushel			Spat/ Bushel			Percent Mortality			Percent Prevalence			Weighted Prevalence			No./bu. >2.5 in.			%oysters >2.5 in.				Dry Meat/Height		
	Haul																												
		2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004	2006	2005	2004	**2006**	2005	2004	**2006**	2005	2004	**2006**	2005	2004		**2006**	2005	2004
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--		--	--	**--**
Ledge	4.0	**1.95**	--	1.96																									
Ledge	0.9	**0.35**	--	1.57																									
Ledge	1.3	**0**	--	1.09	**1.17**	--	1.31	**0.2**	--	3	**40**	--	17	**67**	--	40	**0.92**	--	0.70	**1**	--	1	**99**	--	83.3	--	--	--	--
Ledge	0.4	**0**	--	0.28																									
Ledge	0.7	**0**	--	0																									
Ledge			--	0																									
Transplants																													
Ben Sand	3.55	**50.2**	22.2		**297**	412		**40**	187		**10**	2.9																	
Ben Sand	3.68	**28**	35.4		**190**	200		**85**	46		**15**	33.6																	
Shell Rock	4.3	**57.1**	67		**255**	284		**51**	92		**18**	9.73																	
Shell Rock	1.5	**52.9**	37.3		**264**	143		**13**	26		**7**	12.8																	
Shell Rock			20.3			52			1			10.4																	
Shelling																													
Shell Rock	1.43	**59.4**	60.6		**333**	261		**116**	27		**19**	7.2																	
Shell Rock	5.58	**46.6**	58.7		**216**	276		**62**	147		**22**	10.7																	
Shell Rock	3.92	**44.1**	56.3		**233**	204		**70**	105		**21**	9.36																	
Shell Rock			37.1			180			80			9.88																	
Hawks Nest	4.02	**53.9**			**230**			**61**			**29**																		
Nantuxent	3.54	**46.4**			**209**			**49**			**29**																		

Table 5. Oyster size frequency on the natural oyster beds in 2006. Frequencies are expressed as the number in each size class per 37-qt bushel.

Table 5. Oyster size frequency on the natural oyster beds in 2006. Frequencies are expressed as the number in each size class per bushel

Size (mm)	RI	U Arn	Arn	Up Mid	Mid	Coh	Ship J	Seab	Shell R	BenSn	Ben	Nant	Hog	New	Straw	HawN	Bead	Vext	Ledge
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	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	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	0.1	0.0	0.1	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	0.1	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	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.6	0.7	2.8	0.0	2.9	1.5	3.5	3.5	6.5	4.0	0.4	3.0	0.4	0.1	0.0	3.2	3.6	0.2	0.0
30	2.6	1.5	6.3	0.0	5.9	3.6	7.2	1.9	5.6	1.9	0.7	3.5	1.2	0.0	0.0	2.0	2.7	0.0	0.0
35	7.8	2.4	9.5	0.0	12.4	3.3	11.1	4.0	12.8	2.7	1.8	3.8	2.1	0.1	0.0	3.9	1.9	0.0	0.0
40	8.2	4.6	11.3	0.9	15.3	6.5	12.6	8.3	20.6	9.6	4.2	8.3	2.3	0.3	0.4	5.9	3.1	0.0	0.0
45	8.7	1.9	8.0	0.9	11.7	4.5	13.0	8.0	22.4	14.5	9.6	8.7	3.9	1.1	0.0	5.7	3.6	0.4	0.0
50	10.4	2.8	5.6	0.0	8.1	4.5	9.7	10.8	20.5	16.6	10.1	10.7	5.5	1.8	0.4	6.5	2.9	0.6	0.0
55	17.3	5.0	11.0	1.7	11.5	6.7	11.0	9.4	15.1	16.8	10.5	9.9	5.7	2.1	0.0	6.9	2.9	0.8	0.2
60	26.8	6.2	18.0	4.3	17.1	8.0	12.7	4.2	13.5	11.8	11.6	9.3	5.7	2.8	0.7	9.3	1.9	0.2	0.0
65	32.4	6.3	20.6	0.0	18.7	11.8	17.5	6.8	15.4	10.6	7.6	11.4	4.1	2.4	0.7	8.9	2.4	0.8	0.2
70	27.7	7.8	18.0	1.7	16.9	14.2	20.0	8.3	17.1	10.2	6.0	8.9	4.1	2.9	1.1	9.6	1.9	0.6	0.0
75	**19.2**	**5.3**	**15.1**	**0.9**	**18.5**	**15.6**	**17.6**	**8.7**	**15.2**	**10.0**	**3.8**	**12.5**	**5.7**	**2.2**	**0.7**	**8.0**	**2.9**	**0.0**	**0.3**
80	**10.8**	**3.1**	**9.7**	**0.9**	**14.9**	**11.8**	**15.6**	**9.2**	**14.6**	**10.1**	**4.4**	**9.2**	**4.1**	**2.8**	**2.5**	**7.6**	**0.5**	**0.2**	**0.0**
85	**2.8**	**2.6**	**4.3**	**0.9**	**14.0**	**12.2**	**11.6**	**10.1**	**10.8**	**8.3**	**2.8**	**6.9**	**2.8**	**1.1**	**0.7**	**6.3**	**1.9**	**0.4**	**0.2**
90	**2.4**	**0.5**	**2.4**	**0.0**	**12.2**	**10.5**	**10.8**	**9.7**	**9.4**	**4.9**	**2.8**	**5.0**	**3.9**	**1.6**	**1.1**	**4.1**	**2.4**	**1.1**	**0.0**
95	**0.2**	**0.0**	**0.7**	**0.0**	**8.6**	**7.3**	**6.4**	**5.4**	**6.2**	**5.4**	**2.5**	**3.3**	**1.8**	**1.8**	**0.4**	**3.7**	**1.5**	**1.5**	**0.0**
100	**0.0**	**0.3**	**0.7**	**0.9**	**4.5**	**4.5**	**3.7**	**4.2**	**3.1**	**3.1**	**1.6**	**3.5**	**3.4**	**2.1**	**1.1**	**3.5**	**1.7**	**1.5**	**0.2**
105	**0.0**	**0.0**	**0.0**	**0.0**	**2.9**	**1.8**	**3.2**	**4.2**	**2.4**	**1.8**	**1.4**	**2.3**	**1.9**	**1.7**	**1.1**	**3.2**	**1.5**	**0.9**	**0.0**
110	**0.0**	**0.0**	**0.0**	**0.0**	**1.1**	**1.3**	**1.4**	**0.5**	**0.5**	**0.8**	**0.8**	**0.8**	**1.4**	**0.8**	**0.0**	**0.7**	**0.9**	**2.5**	**0.0**
115	**0.0**	**0.0**	**0.0**	**0.0**	**0.9**	**1.3**	**0.5**	**1.4**	**0.5**	**0.4**	**1.7**	**0.8**	**0.9**	**0.9**	**0.4**	**1.3**	**0.9**	**0.6**	**0.0**
120	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.5**	**0.1**	**0.4**	**0.6**	**0.6**	**0.2**	**0.5**	**0.4**	**0.6**	**0.7**	**0.8**	**0.0**
125	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.5**	**0.0**	**0.0**	**0.3**	**0.2**	**0.2**	**0.5**	**0.0**	**0.2**	**0.2**	**0.0**	**0.0**
130	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.4**	**0.0**
135	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.8**	**0.0**
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**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**
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**	**0.0**	**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**	**0.1**	**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**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Total/Bu.	178	51	144	13	199	131	189	120	213	144	86	122	61	30	12	101	42	14	1
No. Measured	823	378	775	15	882	721	1189	509	2335	1112	848	813	345	228	33	545	245	74	6
Greater than 3"	**35**	**12**	**33**	**3**	**78**	**66**	**71**	**55**	**63**	**45**	**23**	**45**	**26**	**16**	**9**	**39**	**15**	**11**	**1**
> 3" 2005	9	10	21	0	96	70	104	75	71	50	22	27	21	10	20	15	16	16	-
> 3" 2004	5	-	13	0	49	68	74	63	16	47	9	-	16	11	14	9	9	9	1
Greater than 2.5"	**96**	**26**	**72**	**5**	**114**	**92**	**108**	**70**	**95**	**66**	**37**	**65**	**34**	**22**	**11**	**58**	**19**	**12**	**1**
> 2.5" 2005	34	57	72	0	144	112	147	103	107	77	25	44	28	12	24	23	18	17	-
> 2.5" 2004	23	-	50	0	98	102	129	31	104	77	11	-	22	14	20	14	12	11	1

Table 6. Average 1-year growth increment for animals reaching market (3″) size, the average minimal size of animals reaching market size in one year, and ages-to-market size for oysters from three bay regions.

Bed Group	Data Source	Average Growth Increment	Average Minimal Size Reaching Market	Age to Market
Low mortality	Arnolds	7.9 mm	67.1 mm	6 to 7 yr
Medium mortality	Middle, Cohansey	6.6 mm	68.4 mm	5 to 6 yr
*Shell Rock	Shell Rock	9.2 mm	65.8 mm	4 to 5 yr
High mortality	Bennies Sand, New Beds	9.1 mm	65.9 mm	3 to 4 yr

*Shell Rock numbers are less certain because of relatively heavy fishing on this bed and the transplant of relatively large numbers of animals to this bed from upbay.

Table 7. Surplus production estimates for 2007 for the oyster stock on the New Jersey natural oyster beds in Delaware Bay. Projections were conducted using the 50^{th} and 75^{th} percentiles of natural mortality, SAW-8 and 2006-updated growth estimates and their average, and a conversion from numbers to market-equivalent-bushels using the 2004-2006 average of 263 oysters/bushel from dock-side monitoring of landings.

2005 Growth Estimate

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	34,449	32,585
Medium mortality	87,168	-22,626
Shell Rock	30,565	17,822
High mortality	58,012	18,762
Total	210,194	46,543

Average Growth (2005 and Updated 2006)

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	69,272	67,149
Medium mortality	212,432	98,109
Shell Rock	30,565	17,822
High mortality	42,394	3,963
Total	354,663	187,043

Updated 2006 Growth Estimate

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	123,347	120,896
Medium mortality	353,557	234,459
Shell Rock	30,565	17,822
High mortality	26,406	-11,157
Total	533,875	362,020

Table 8. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Bay regions are defined in Figure 4. 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)
2006	0.116	0.342	0.322 (0.643)	0.421 (0.999)

Table 9. Summary of shell-planting activities for 2006. Shell-planting was carried out in late June-early July, 2006. Six 25-acre grids received direct plants, Hawk's Nest 1, Nantuxent Point 25, Bennies Sand 7, and Shell Rock 20, 24, and 32. Two others were replants of shell planted off Reeds Beach and moved upbay in late August to Bennies Sand 6 and 12. Ocean quahog shell and surf-clam shell were used. Projections of marketable bushels assumed a 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 1989-2006 time series: for Shell Rock, 0.451, 0.180, 0.180 for years 1, 2, and 3, respectively; for the remainder: 0.559, 0.252. 0.252. Bushel conversions assume 263 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Projected Harvest
Hawk's Nest	1	Surf Clam	17,850	3,672,102	206	3,054
Nantuxent	25	Quahog mix*	49,488	10,766,609	218	8,954
Bennies Sand	6	Surf Clam replant	14,811	24,709,636	1668	20,551
Bennies Sand	7	Quahog mix*	49,037	27,669,127	564	23,012
Bennies Sand	12	Surf Clam replant	15,826	43,653,647	2758	36,307
Shell Rock	20	Quahog mix*	48,472	10,330,353	213	13,801
Shell Rock	24	Quahog mix*	53,193	8,030,015	151	10,728
Shell Rock	32	Quahog mix*	23,689	10,859,748	458	14,508
Total			272,366	139,691,237		130,915

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

Table 10. Average half-lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2006 time period.

Location	Half-life (yr)
Round Island	-5.36
Upper Arnolds	8.28
Arnolds	4.24
Upper Middle	-1.64
Middle	7.95
Cohansey	13.91
Ship John	5.52
Sea Breeze	-78.01
Shell Rock	4.61
Bennies Sand	55.03
Bennies	5.32
Nantuxent Point	3.31
Hog Shoal	4.64
Hawk's Nest	6.20
Strawberry	4.28
New Beds	15.63
Beadons	570.81
Vexton	6.99
Egg Island	8.78
Ledge	9.15

Table 11. 2006 shell balance (net change from 2005) for Delaware Bay oyster beds (in kg per bed).

Location	Net Change Shell
Upper Arnolds	-424,397
Arnolds	-1,616,357
Middle	-908,253
Cohansey	-151,022
Ship John	-4,670,979
Shell Rock	6,881,596
Bennies Sand	6,002,242
Bennies	-5,638,249
Nantuxent Point	963,856
New Beds	-1,154,274
Hawk's Nest	210,086
Hog Shoal	-1,863,915
Strawberry	-858,048
Beadons	21,264
Vexton	-1,388,771
Egg Island	-1,722,509
Ledge	-733,859

Table 12. Harvest statistics for 2006. Fraction covered indicates the fraction of bed area swept by industry dredges during the fishing season. Fractions above 1 indicate a total swept area greater than the bed area.

Oyster Bed	Bed Area (m^2)	Fraction Covered	Bushels Harvested	Percent of Harvest
Round Island	1,698,615	0	0	0
Upper Arnolds	955,652	0	0	0
Arnolds	2,017,741	0	0	0
Upper Middle	2,124,917	0	0	0
Middle	3,719,585	0	0	0
Cohansey	5,314,243	1.49	12,925	21.38
Sea Breeze	2,338,640	0	0	0
Ship John	4,677,614	1.35	10,405	17.21
Shell Rock	5,742,000	1.32	12,447	20.59
Bennies Sand	2,977,800	0.51	2,323	3.84
Bennies	8,404,200	0.13	1,326	2.19
Nantuxent Point	2,765,500	3.63	12,324	20.39
New Beds	5,958,621	0.05	525	0.87
Hawk's Nest	2,021,670	1.74	6,291	10.41
Hog Shoal	1,808,500	0.65	1,838	3.04
Strawberry	1,808,700	0.06	46	0.08
Beadons	2,447,500	0	0	0
Vexton	2,022,100	0	0	0
Egg Island	4,045,293	0	0	0
Ledge	1,916,423	0	0	0
Total	64,765,314	0.61	60,450	100.00

Table 13. Statistics for oysters going to market, obtained from dock-side monitoring of landings. Sizes are given in inches. Percentiles refer to the percentile sizes of the size-frequency distribution.

	Mean size	25^{th} percentile	50^{th} percentile	75^{th} percentile	Mean Number per bushel	Number $\geq 2.5''$ per bushel
2004	3.04	2.79	3.08	3.37	302	265
2005	3.05	2.73	3.13	3.42	275	235
2006	3.22	2.95	3.24	3.54	260	238

Table 14. Percentiles of the real and apparent exploitation rates for oysters ≥2.5″ based on the fishing record for 1997-2006. The SARC recommends using the real exploitation rates for setting harvest provisions.

	Shell Rock		Shell Rock		High Mortality Beds		High Mortality Beds	
Percentile	Real		Apparent		Real		Apparent	
0.1	1997	0.0441	1997	0.0441	2003	-0.0970	2002	0.0771
0.2	2006	0.0452	2000	0.0800	2004	-0.0230	2006	0.0836
0.4	2000	0.0800	2005	0.0926	2002	0.0201	1999	0.1032
0.5	2003	0.0868	2006	0.1029	2000	0.0573	2005	0.1082
0.6	1998	0.1142	1998	0.1142	2001	0.0781	1997	0.1252
0.8	1999	0.1373	1999	0.1686	2006	0.0836	2000	0.1344
0.9	2001	0.2357	2001	0.2357	2005	0.1082	2001	0.2016

Table 15. Percentiles of the real exploitation rates for all oysters and for one bay region for oysters $\geq 2.5''$ based on the fishing record for 1997-2006. The upper medium-mortality bed group is Middle and Upper Middle. The lower medium-mortality bed group is Cohansey, Ship John, and Sea Breeze. The all-oyster upper medium-mortality percentiles are also used for the low-mortality beds: Arnolds, Upper Arnolds, and Round Island.

	All Oysters		All Oysters		All Oysters		Oysters $\geq 2.5''$	
Percentile	Medium Mortality		Upper Medium Mortality		Lower Medium Mortality		Lower Medium Mortality	
0.1	2001	0.0064	1998	0.0000	1997	0.0000	1997	0.0001
0.2	2005	0.0067	2002	0.0000	2005	0.0041	2005	0.0072
0.4	1997	0.0086	1999	0.0117	2000	0.0065	2000	0.0176
0.5	1999	0.0165	2005	0.0127	2002	0.0090	2002	0.0215
0.6	2000	0.0173	2006	0.0233	2003	0.0148	2003	0.0267
0.8	1998	0.0225	2004	0.0570	2006	0.0190	1999	0.0331
0.9	2003	0.0243	2003	0.0743	2004	0.0242	1998	0.0360

Figure 1. The footprint of the Delaware Bay natural oyster beds showing the locations of the high-quality (dark shade) and medium-quality (light shade) grids. Each grid is a rectangle 0.2″ latitude × 0.2″ longitude, equivalent to approximately 25 acres.

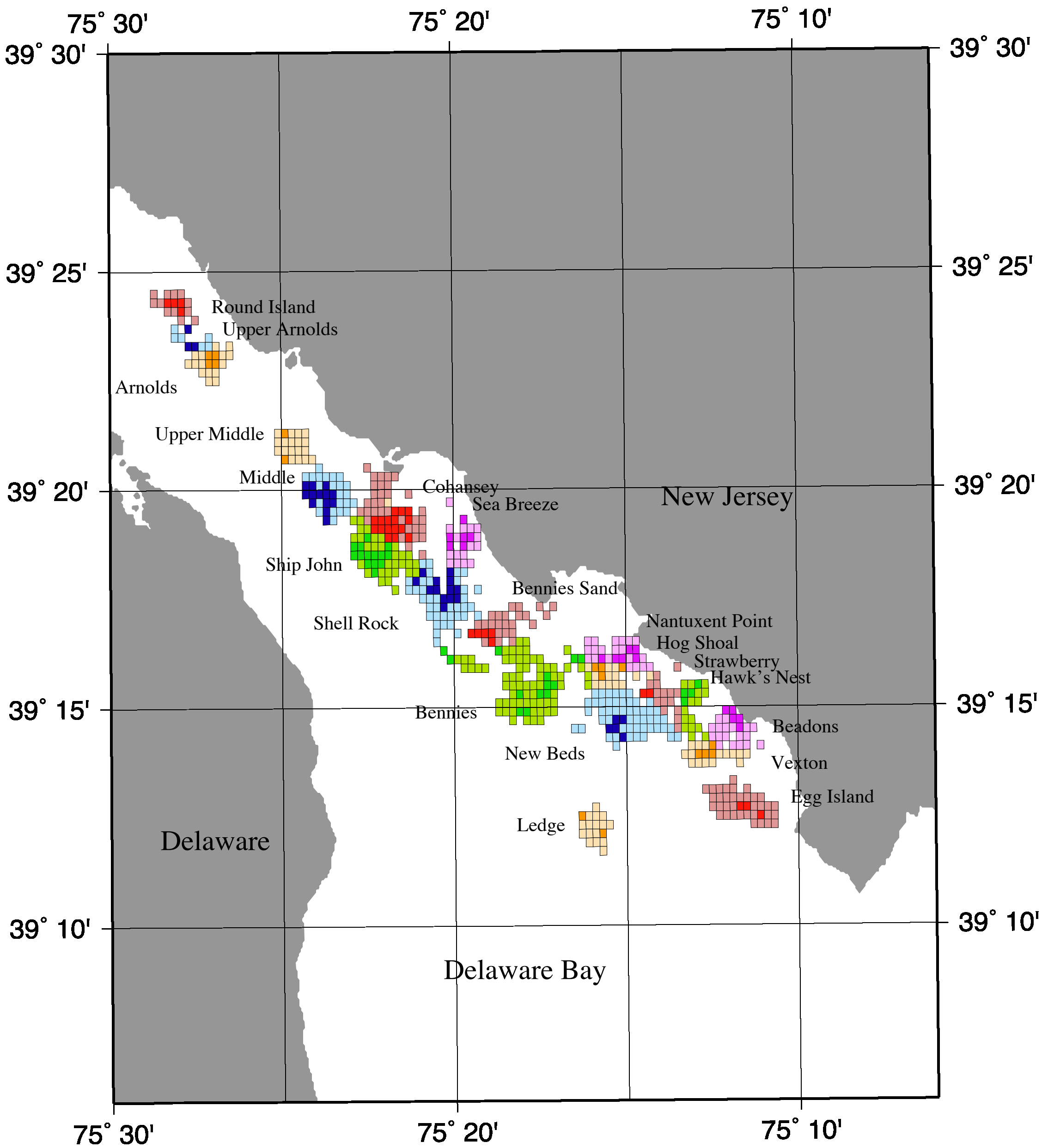

Figure 2. Average annual bay-wide oyster and spat abundance per 37-qt. bushel, with 95% Least Significant Difference confidence intervals. Underlined values are not significantly different. Mean = average of annual values for 1989-2006.

Delaware Bay Seed Beds

Year	1989	1992	1996	1991	2000	1993	1997	1990	1995	1999	2001	2003	2005	2002	1998	1994	2006	2004	Mean
Oyster	189	178	172	172	153	153	152	151	148	121	119	115	114	110	107	101	99	95	135

Year	1991	1999	1997	1998	1995	1994	1990	1989	2000	2002	1993	2005	2004	1992	1996	2003	2006	2001	Mean
Spat	268	191	151	128	127	124	112	69	55	44	44	29	27	25	22	22	21	15	79

Figure 3. Delaware Bay natural oyster beds showing the locations of the 2006 random sampling sites (white stars) and the revised bed footprint defined by the high-quality (dark shade) and medium-quality grids (light shade). The updated footprints are shown for Middle, Ship John, Sea Breeze, Cohansey, Shell Rock, Bennies Sand, Nantuxent Point, Hawk's Nest, Hog Shoal, Vexton, Beadons, and Strawberry. The original footprints are shown for the remaining beds. Low-quality grids are shown in white.

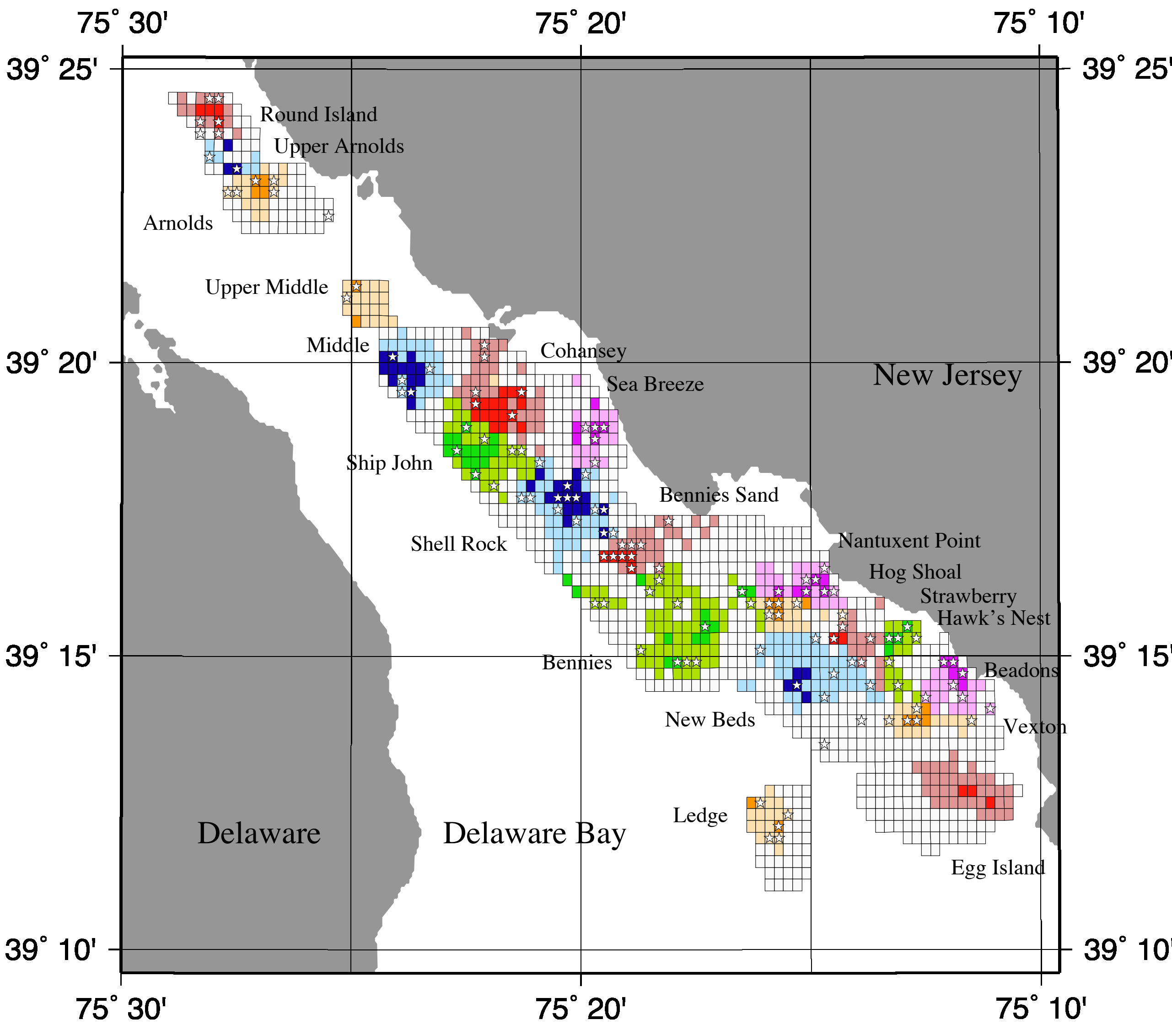

Figure 4. Time series of oyster abundance, by bay region. High mortality: Beadons, Nantuxent Point, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Egg Island, Ledge, Bennies, Bennies Sand; medium mortality (less Shell Rock): Ship John, Cohansey, Sea Breeze, Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island.

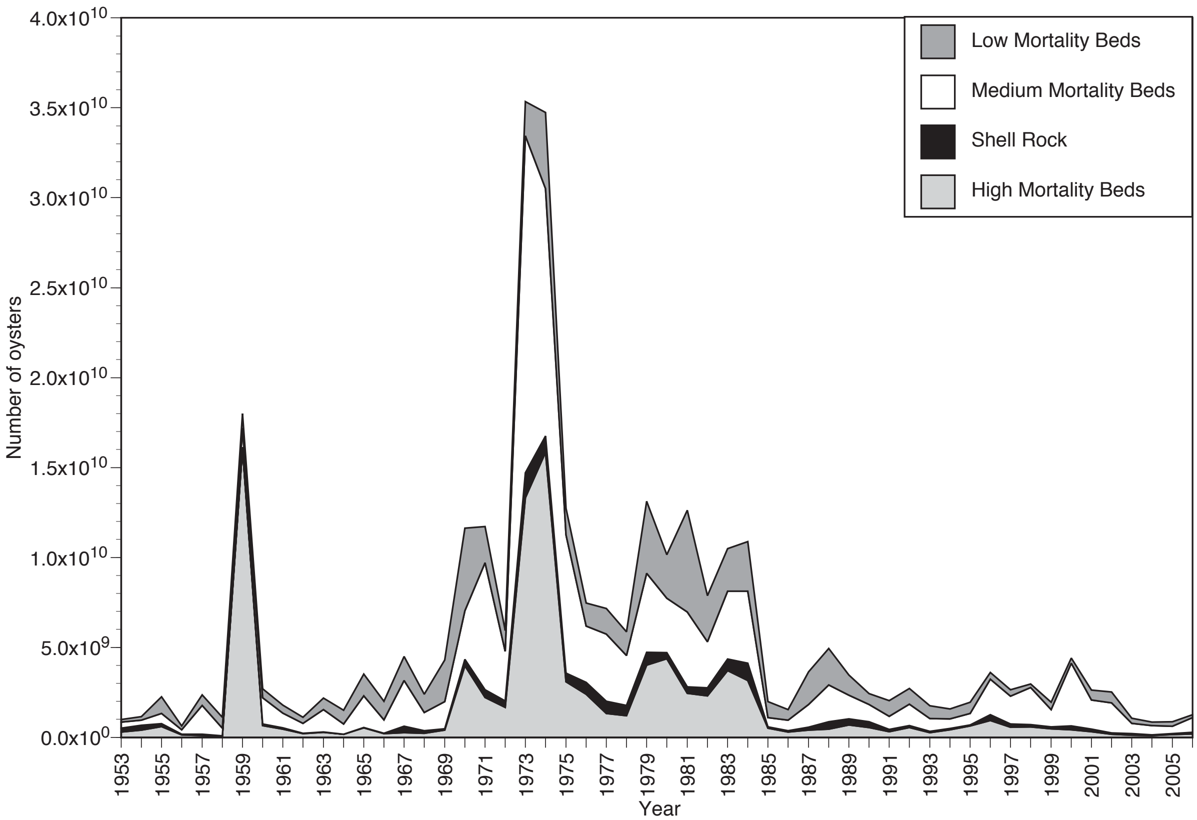

Figure 5. Average annual oyster and spat abundance per 37-qt bushel for the medium-mortality and high-mortality region for the 1989-2006 time period. Medium mortality = Upper Middle, Middle, Ship John, Cohansey, Shell Rock. High-mortality = Bennies, Bennies Sand, Nantuxent Point, Hog Shoal, New Beds, 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	**1997**	**2000**	**1996**	**1991**	**1989**	**2003**	**1992**	**1993**	**1990**	**2005**	**2001**	**1998**	**1999**	**2002**	**2006**	**2004**	**1995**	**1994**	**Mean**
Oysters	265	262	247	222	214	213	195	190	184	158	155	155	153	149	144	141	138	124	181*

High Mortality Beds

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

Medium Mortality Beds

Year	**1999**	**1991**	**1995**	**1998**	**1994**	**1997**	**1990**	**2000**	**2002**	**1989**	**1993**	**2006**	**2004**	**2003**	**2005**	**1996**	**1992**	**2001**	**Mean**
Spat	351	307	179	169	140	113	103	78	75	70	60	36	36	29	28	28	28	17	95

High Mortality Beds

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

Figure 6. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 4.

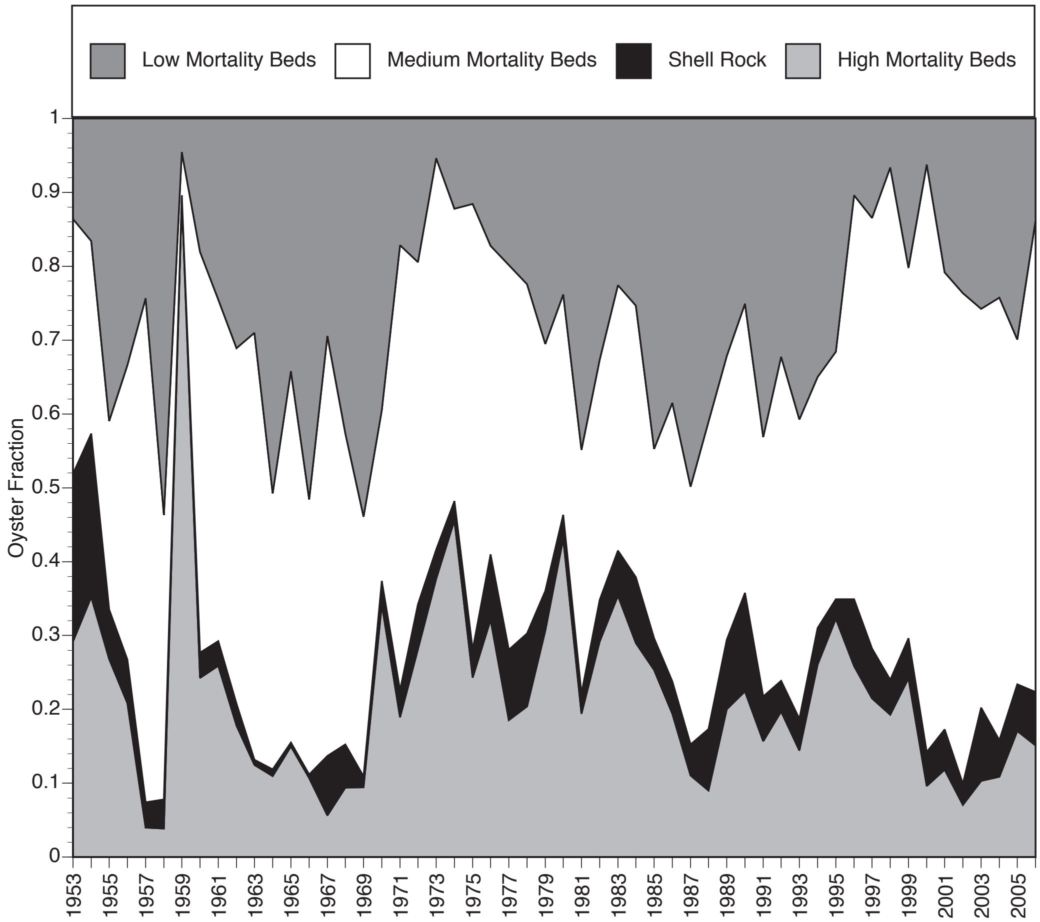

Figure 7. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2006. Bed regions are defined in Figure 4.

Figure 8. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 4.

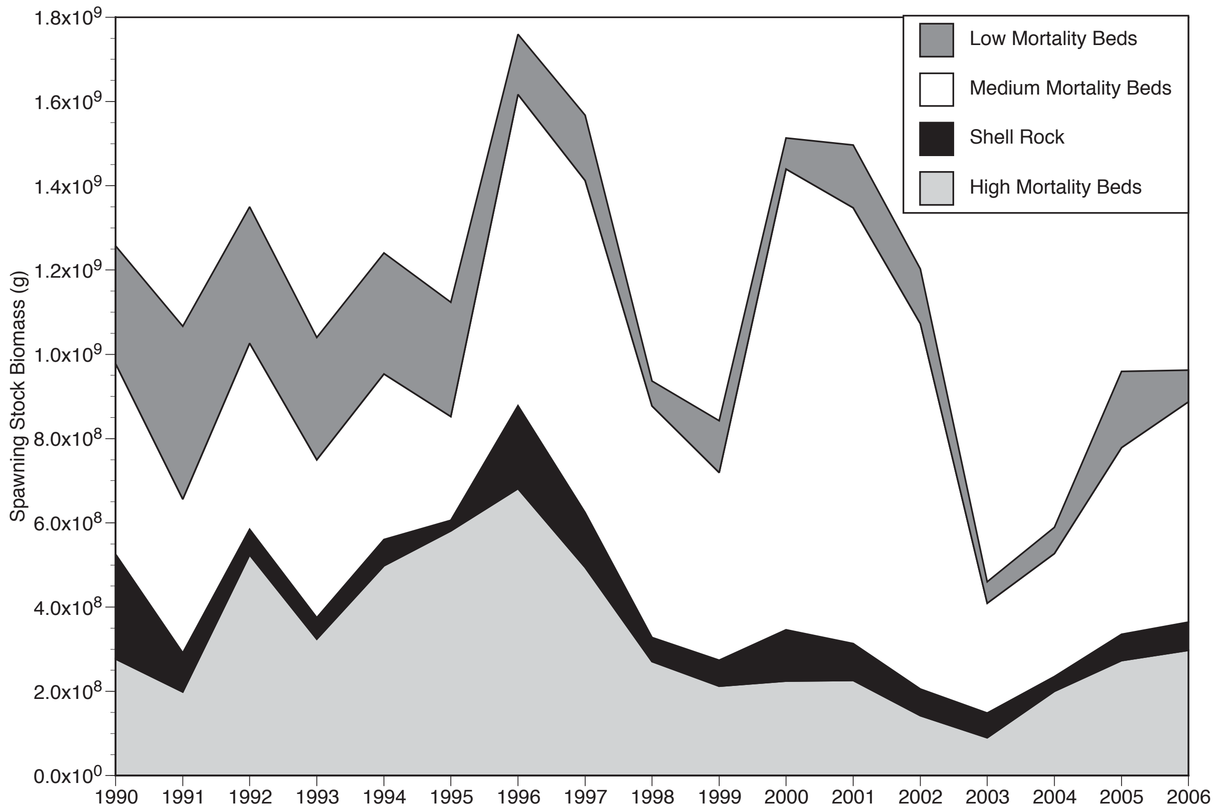

Figure 9. Time series of the fractional distribution of spawning stock biomass among the bay regions. Bed distributions by region are given in Figure 4.

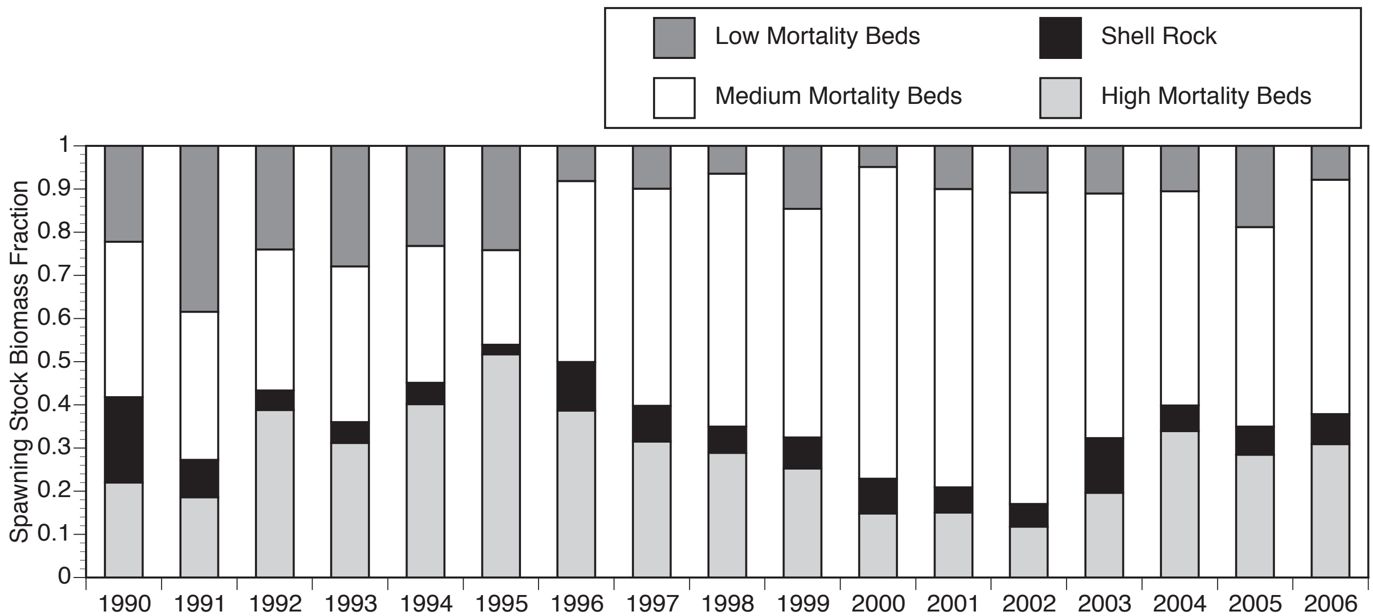

Figure 10. The abundance of small, submarket and market-size animals since 1990.

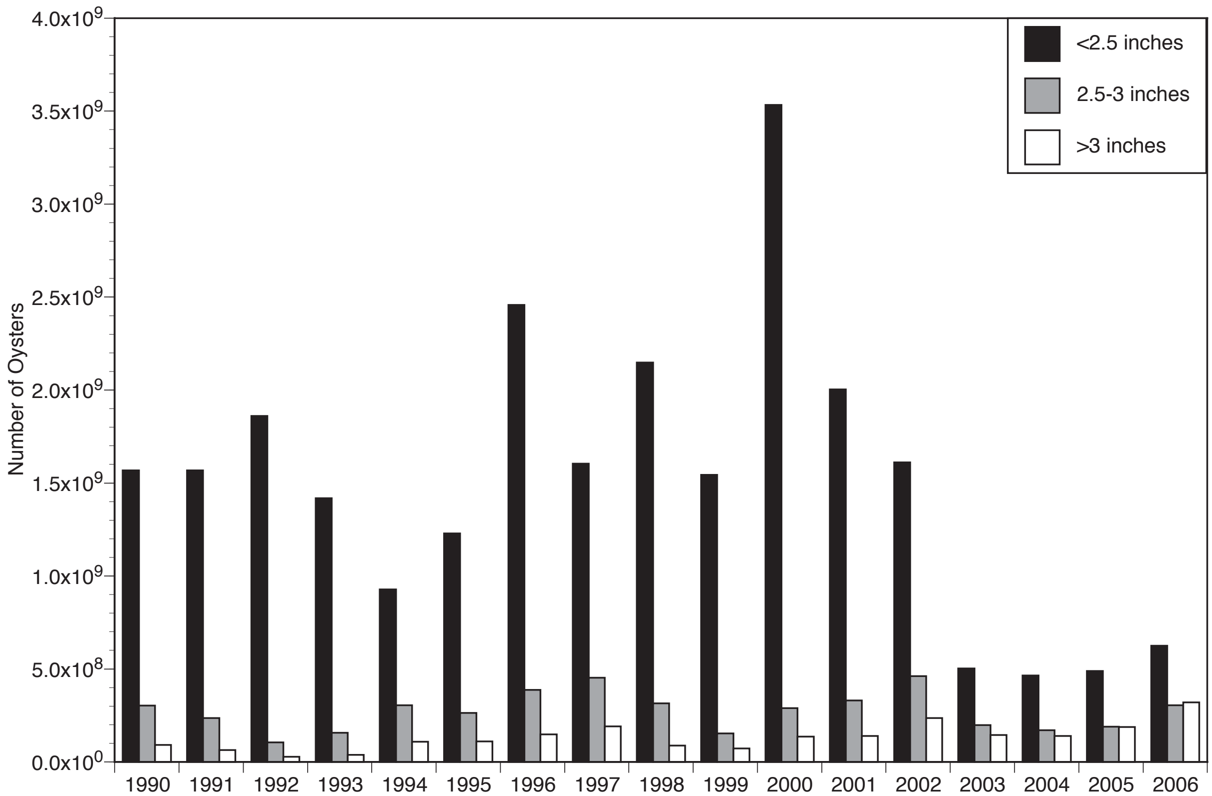

Figure 11. The abundance of small, submarket and market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 4.

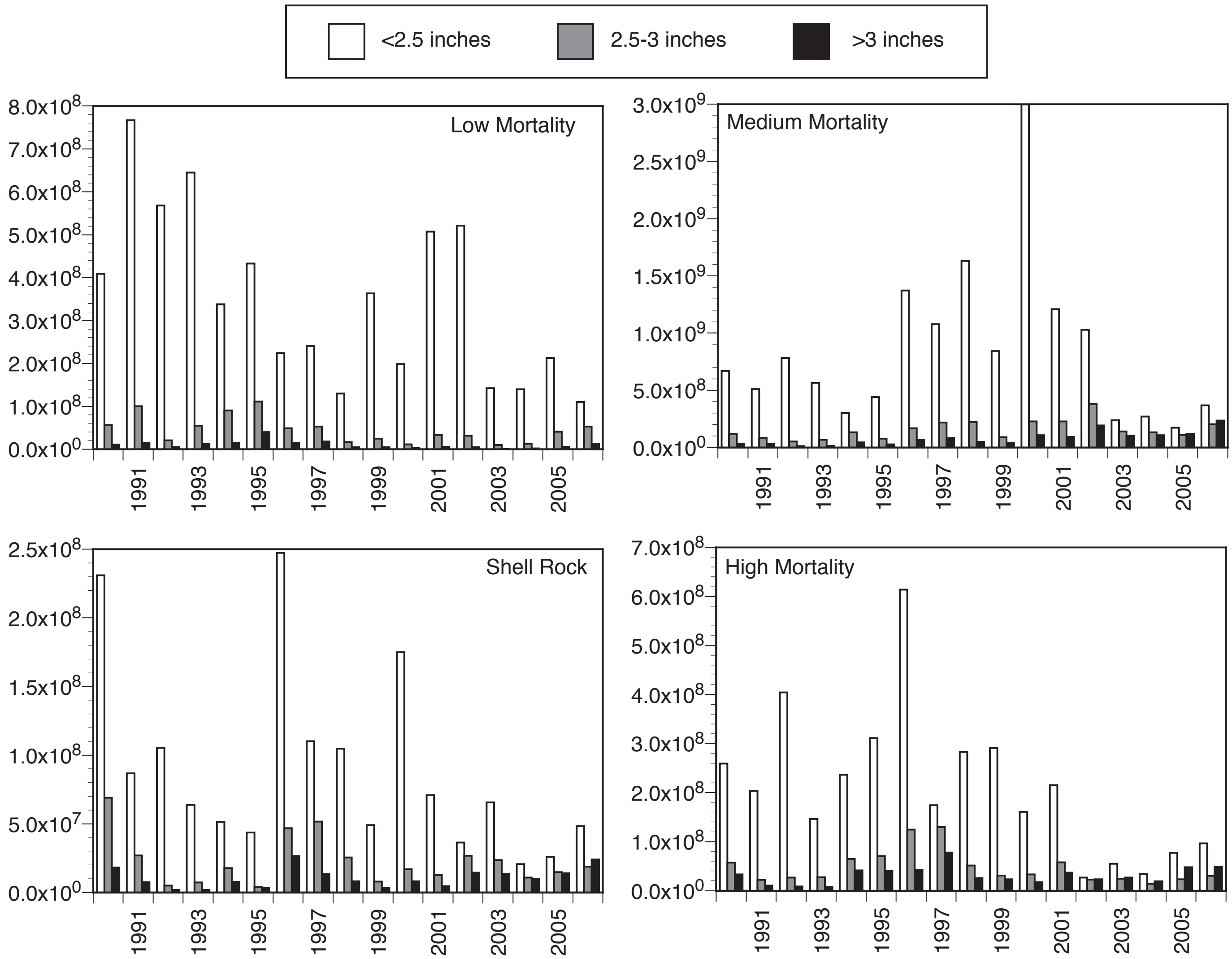

Figure 12. The fraction of marketable animals $\geq 2.5''$ that are of market-size ($\geq 3''$).

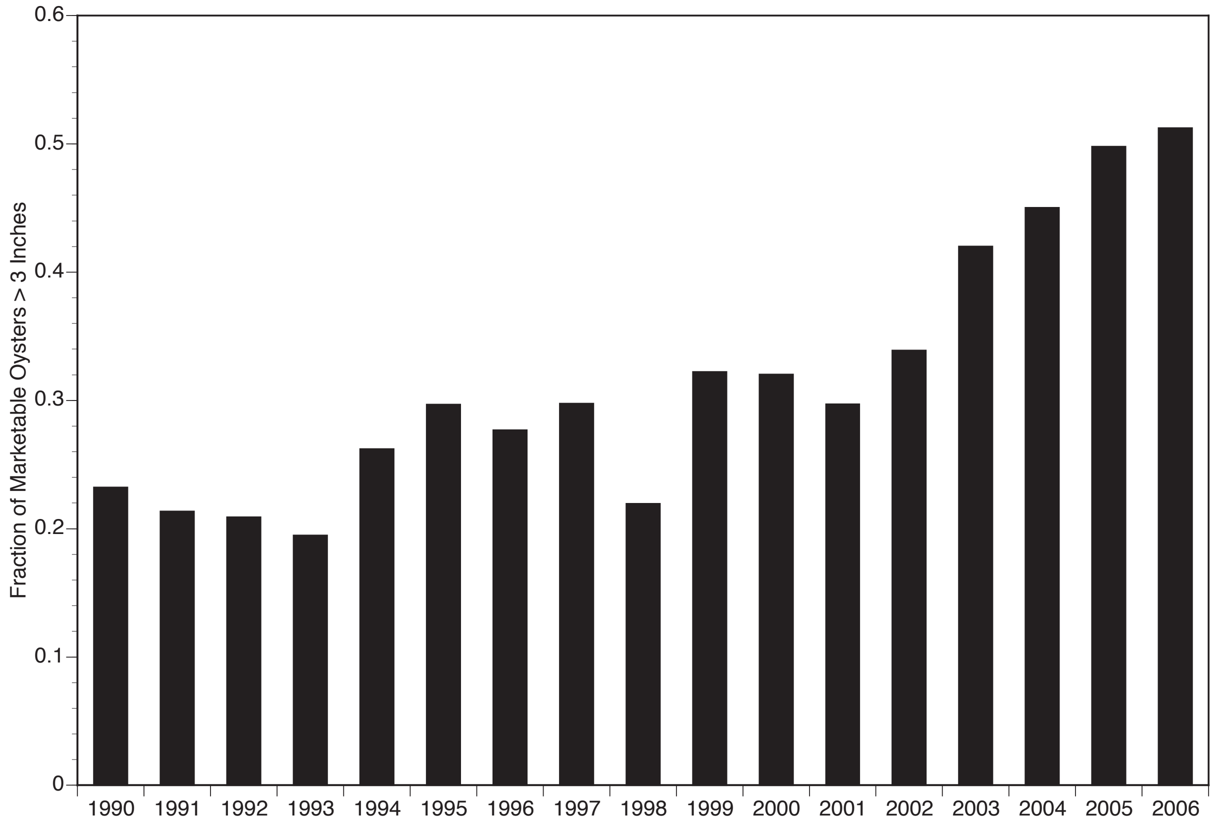

Figure 13. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)].

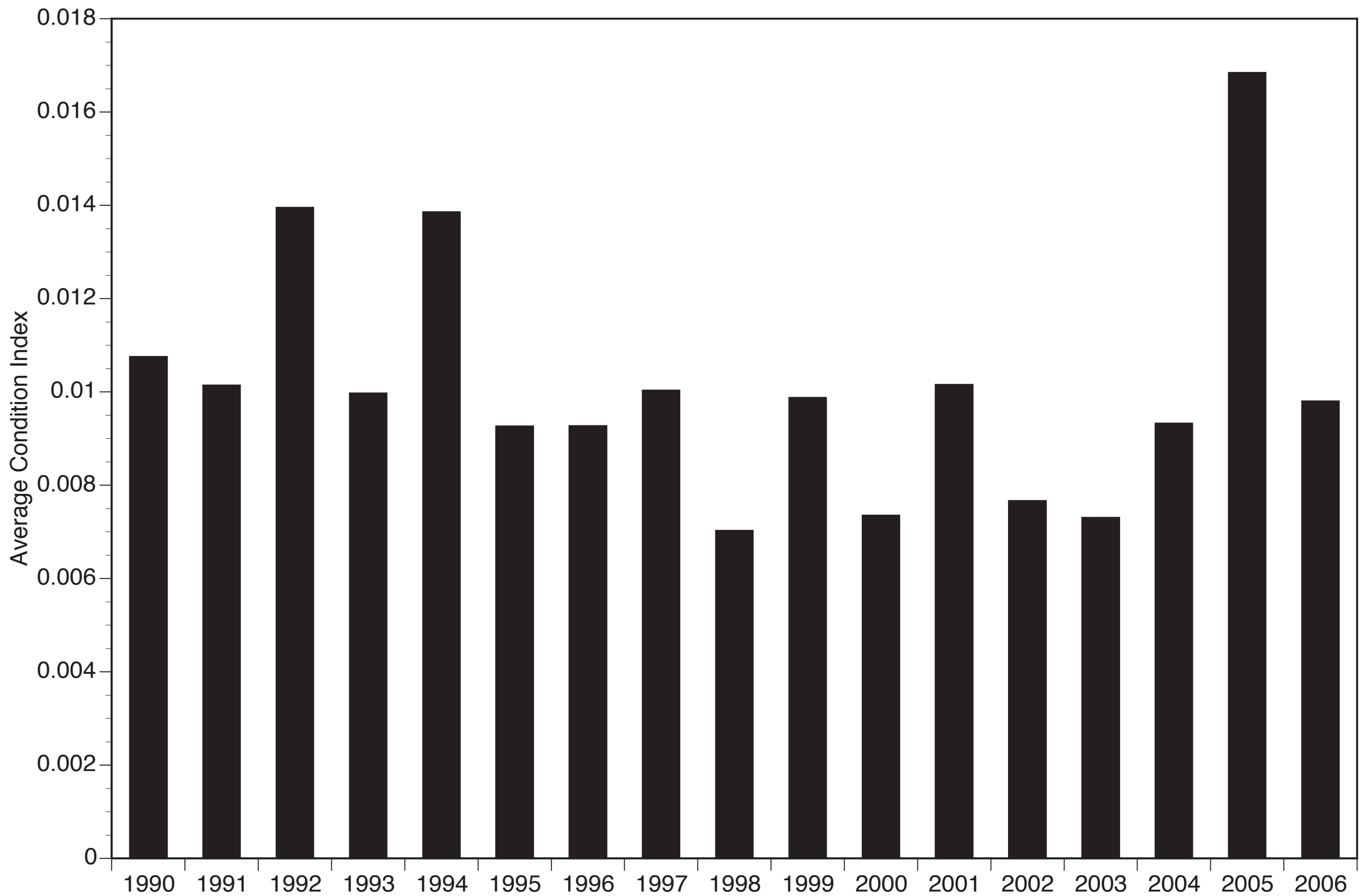

Figure 14. Annual average condition index [dry meat weight (g)/hinge-to-lip dimension (mm)] by bay group. Bed distributions by region are given in Figure 4.

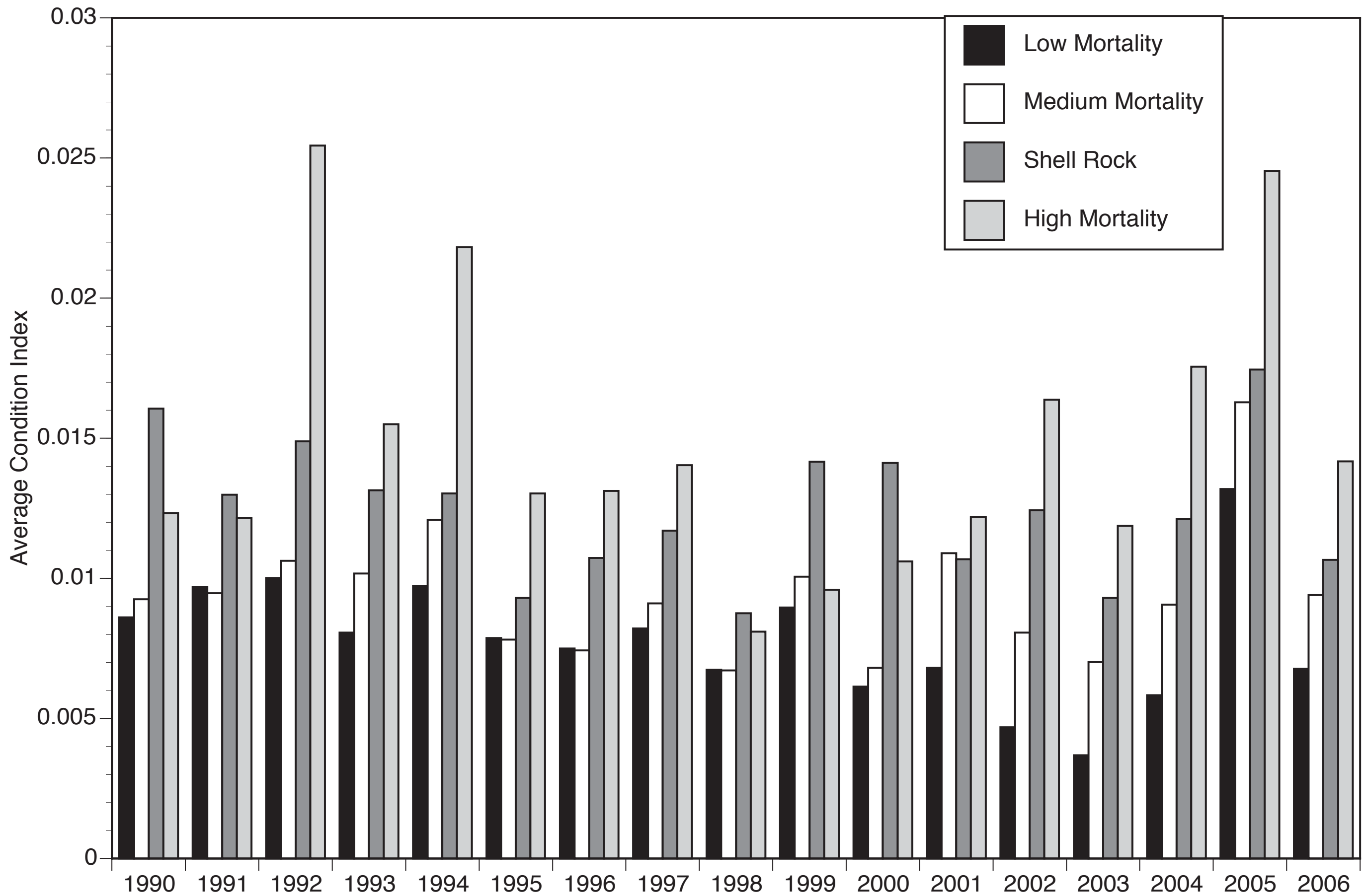

Figure 15. Number of spat recruiting per year for the 1953-2006 time series, cumulatively by bay region. Bay regions are defined in Figure 4.

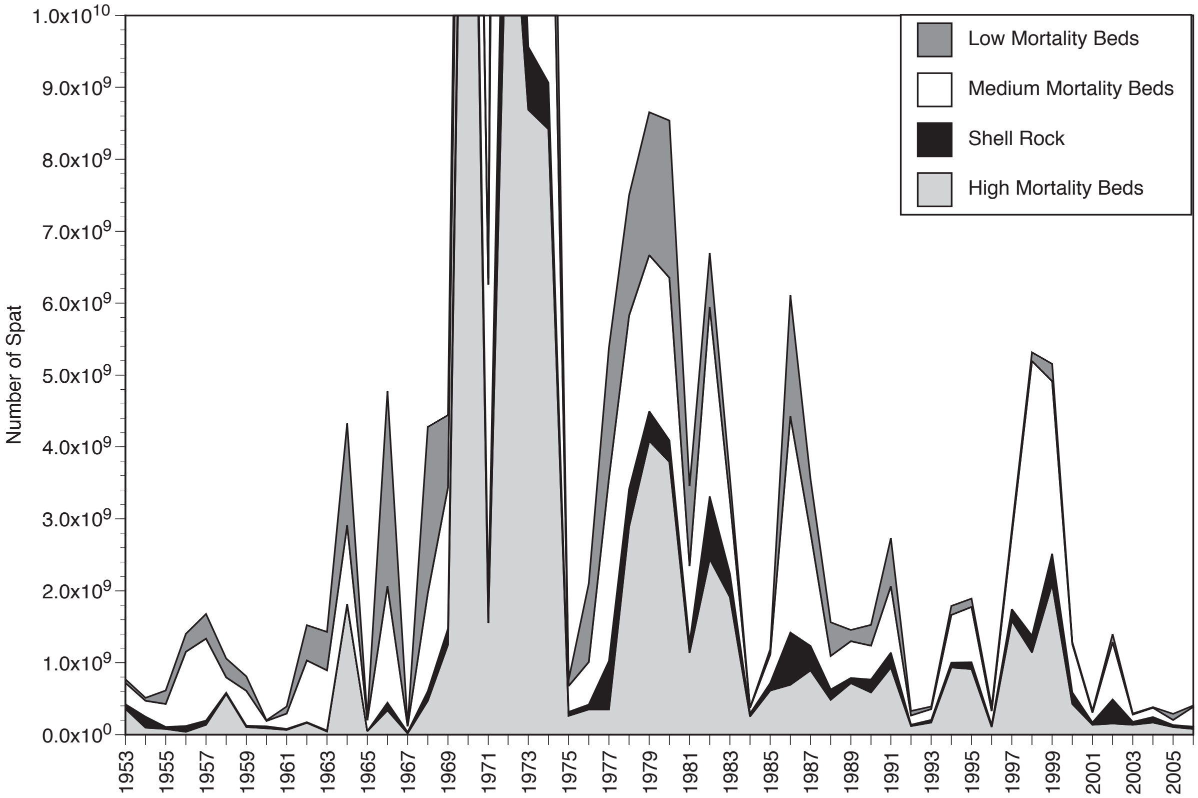

Figure 16. Number of spat recruiting per year for the 1989-2006 time series.

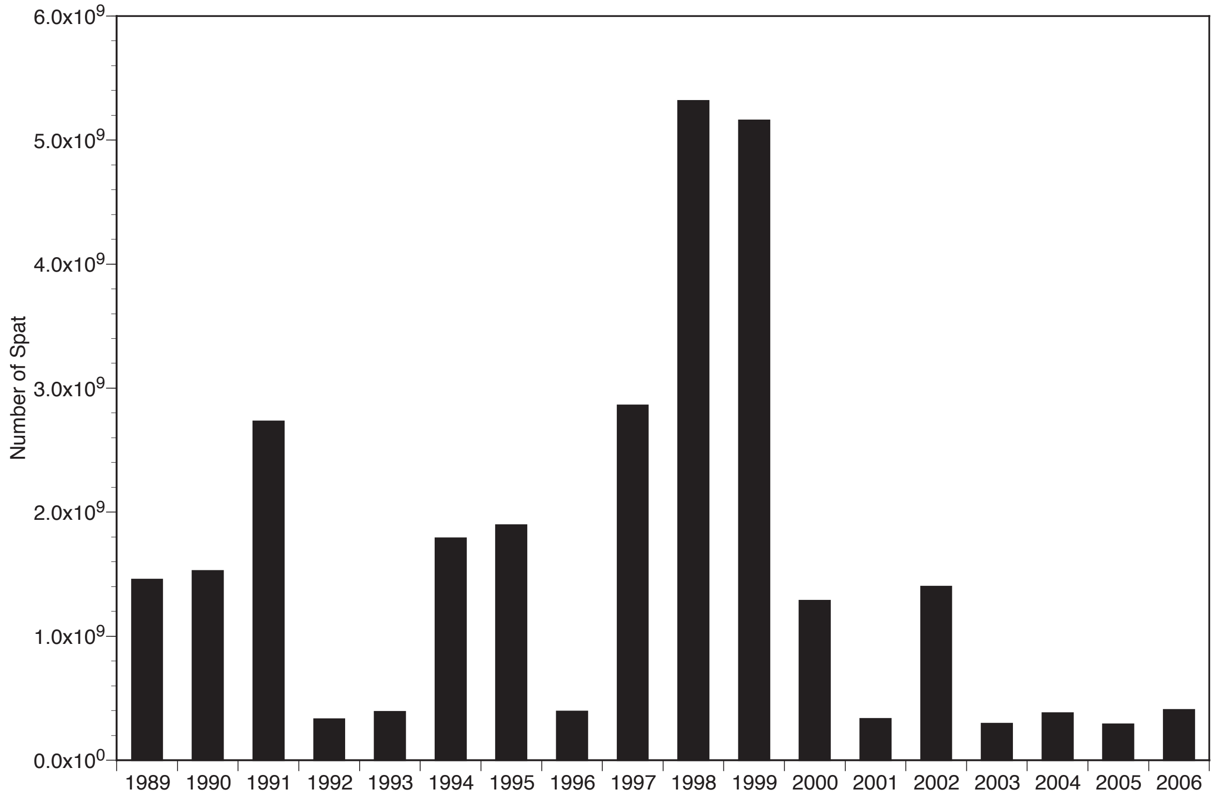

Figure 17. The number of spat recruiting per >20-mm oyster per year.

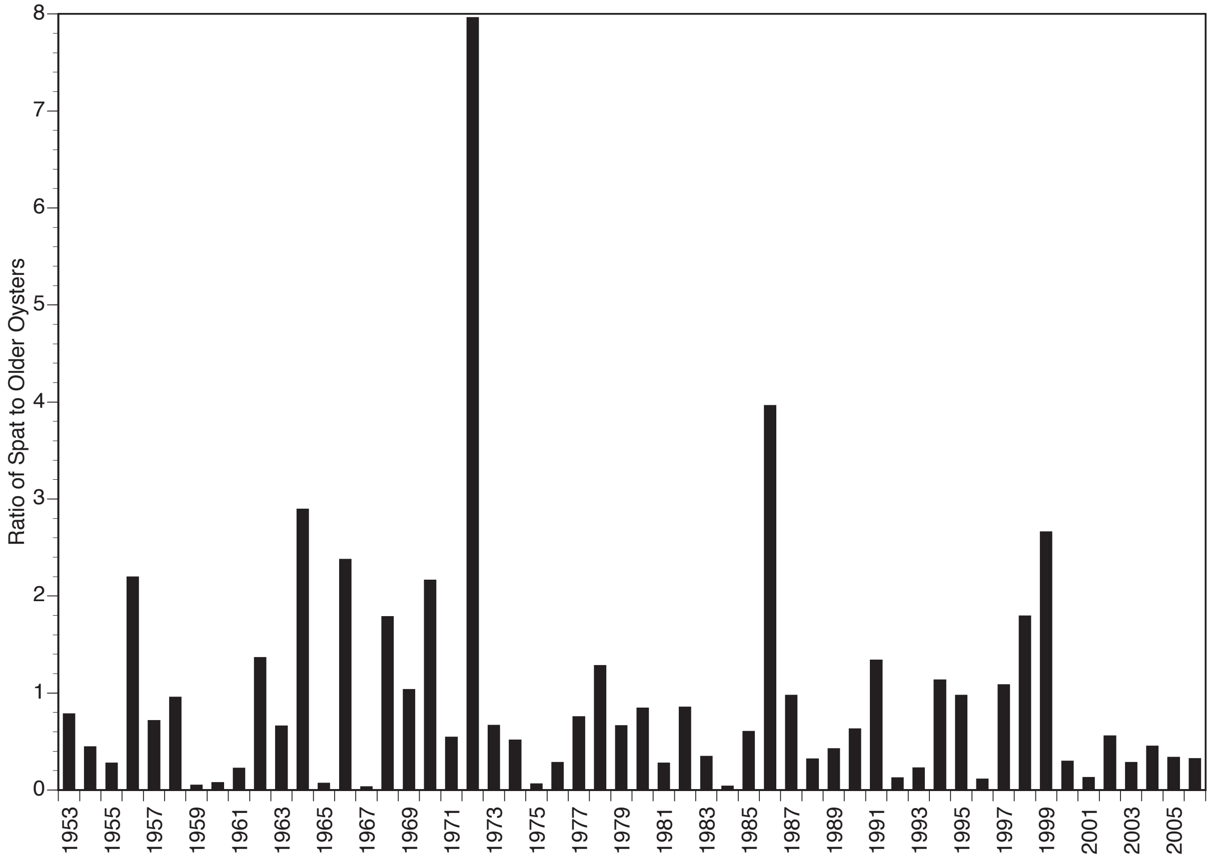

Figure 18. Location of 2006 shell plants, denoted by yellow stars. New Jersey downbay plants are on leased grounds (5-B, 101-A). Transplant locations for these downbay plants are denoted by purple stars. Selected high-quality oyster grounds in New Jersey are denoted by shaded 25-acre grids. Red delineates State of Delaware beds.

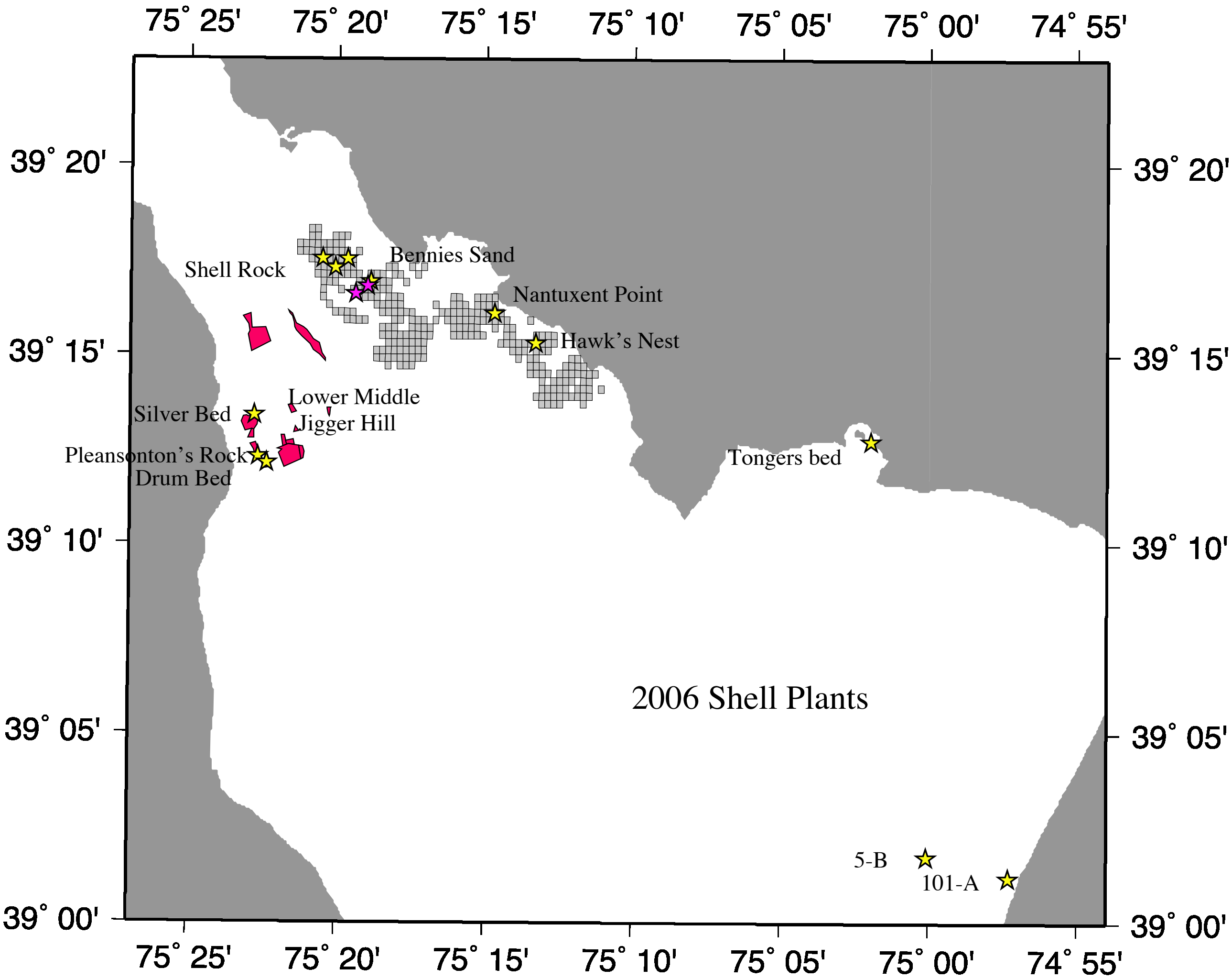

Figure 19. Cumulative number of spat recruiting to 20-oyster-shell bags deployed in the last week of June and collected bi-weekly through September. Colors identify the month of settlement. Increment in circle diameter indicates the number of spat that settled during that time period. Total diameter indicates the cumulative number of spat. Note that circle diameter bears a nonlinear relationship to total spat counts.

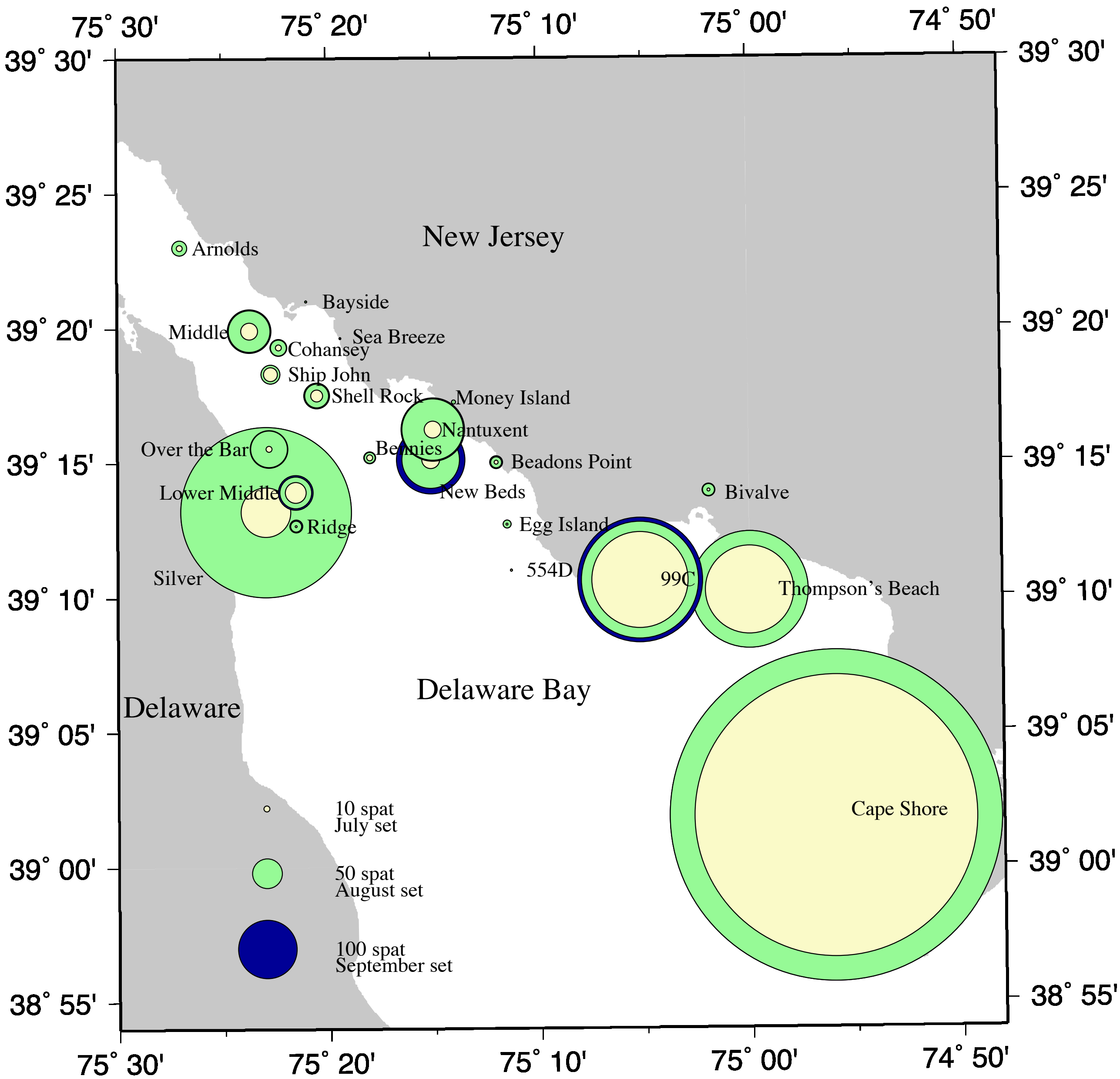

Figure 20. Cumulative number of spat recruiting to 20-oyster-shell bags deployed in the last week of June and collected bi-weekly through September since 2004. Station locations are depicted in Figure 19.

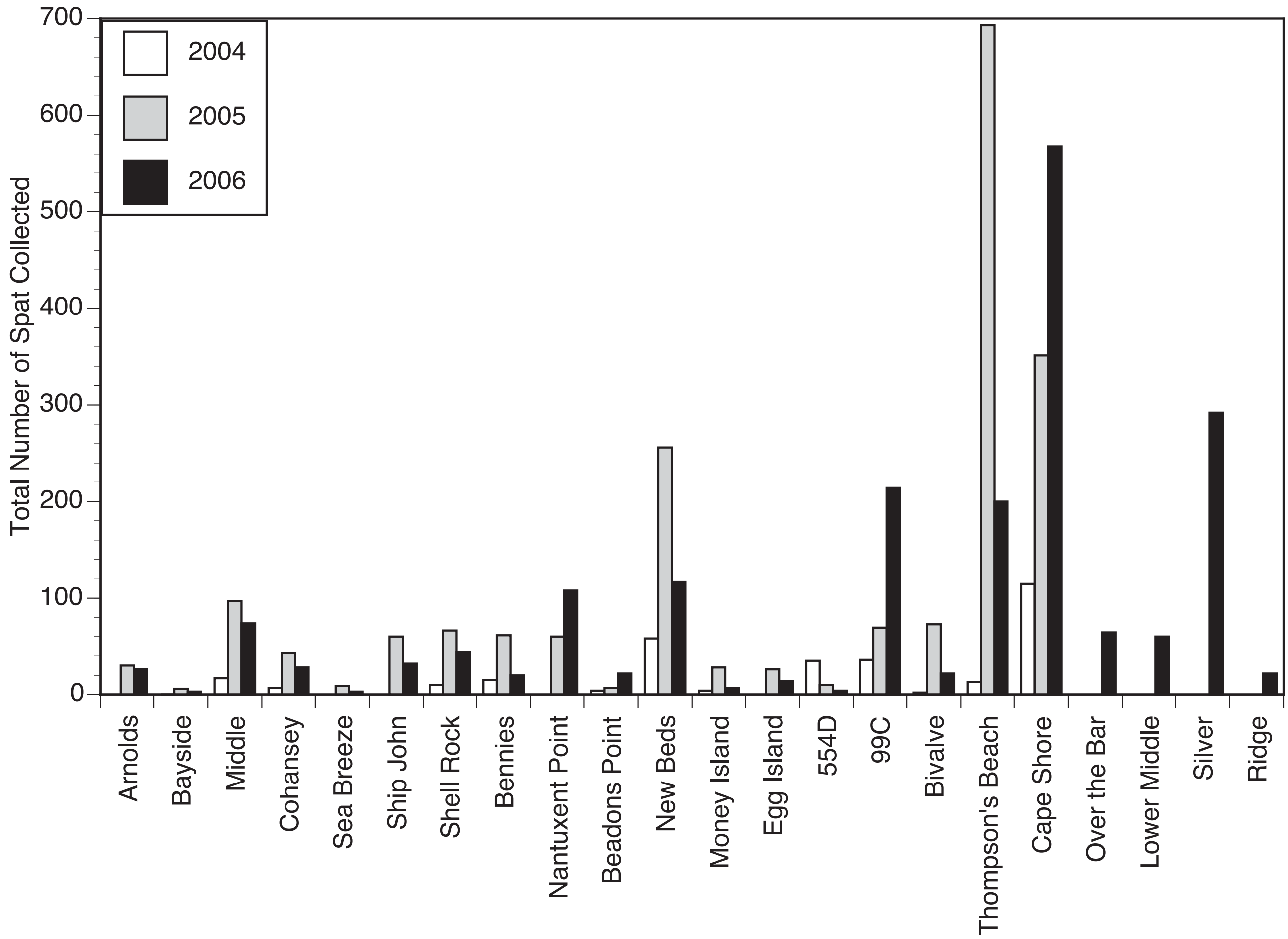

Figure 21. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2006. Lower estimates in 2005 and 2006 reflect the addition of shell through shell planting to offset the shell loss.

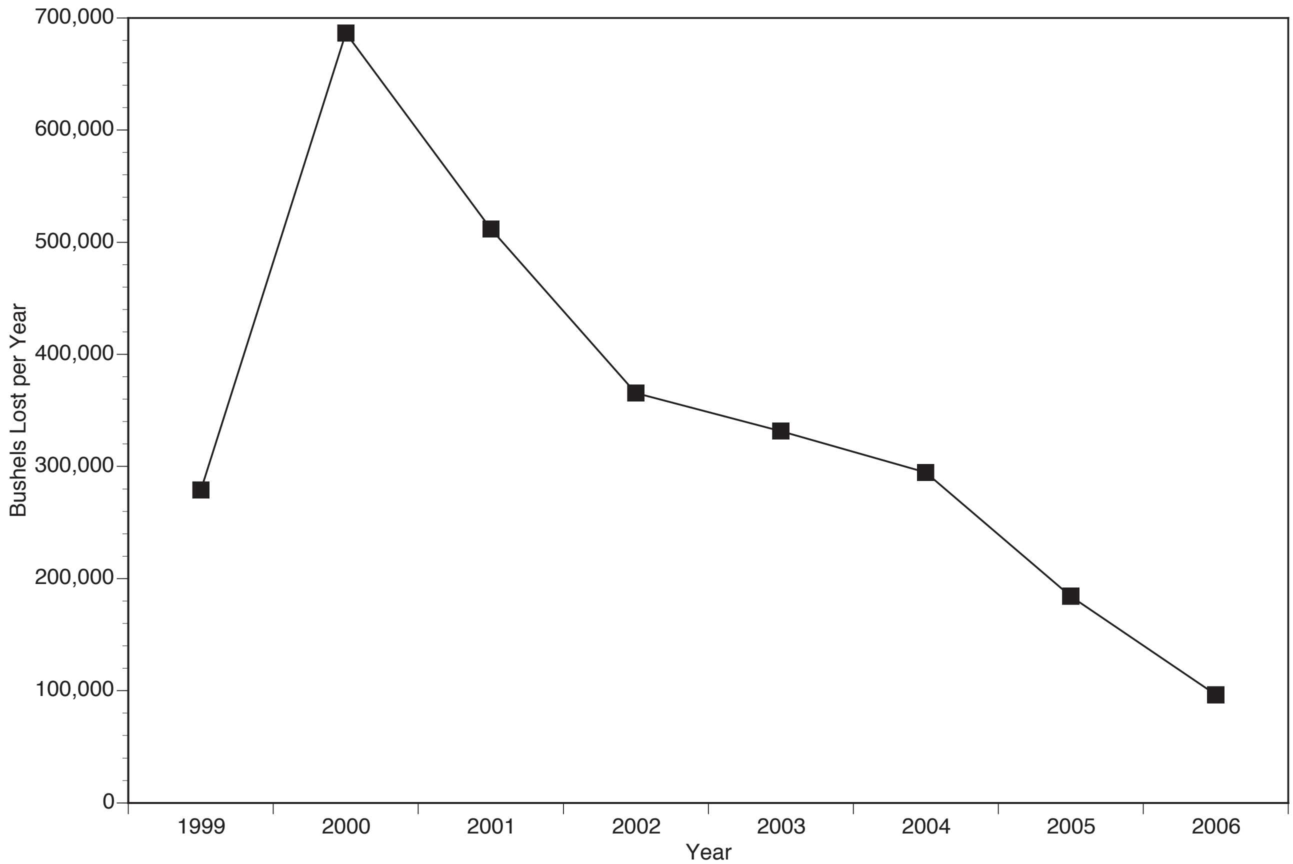

Figure 22. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2006. Positive values on Shell Rock in 2005 and 2006 reflect the addition of shell through shell planting to offset the shell loss.

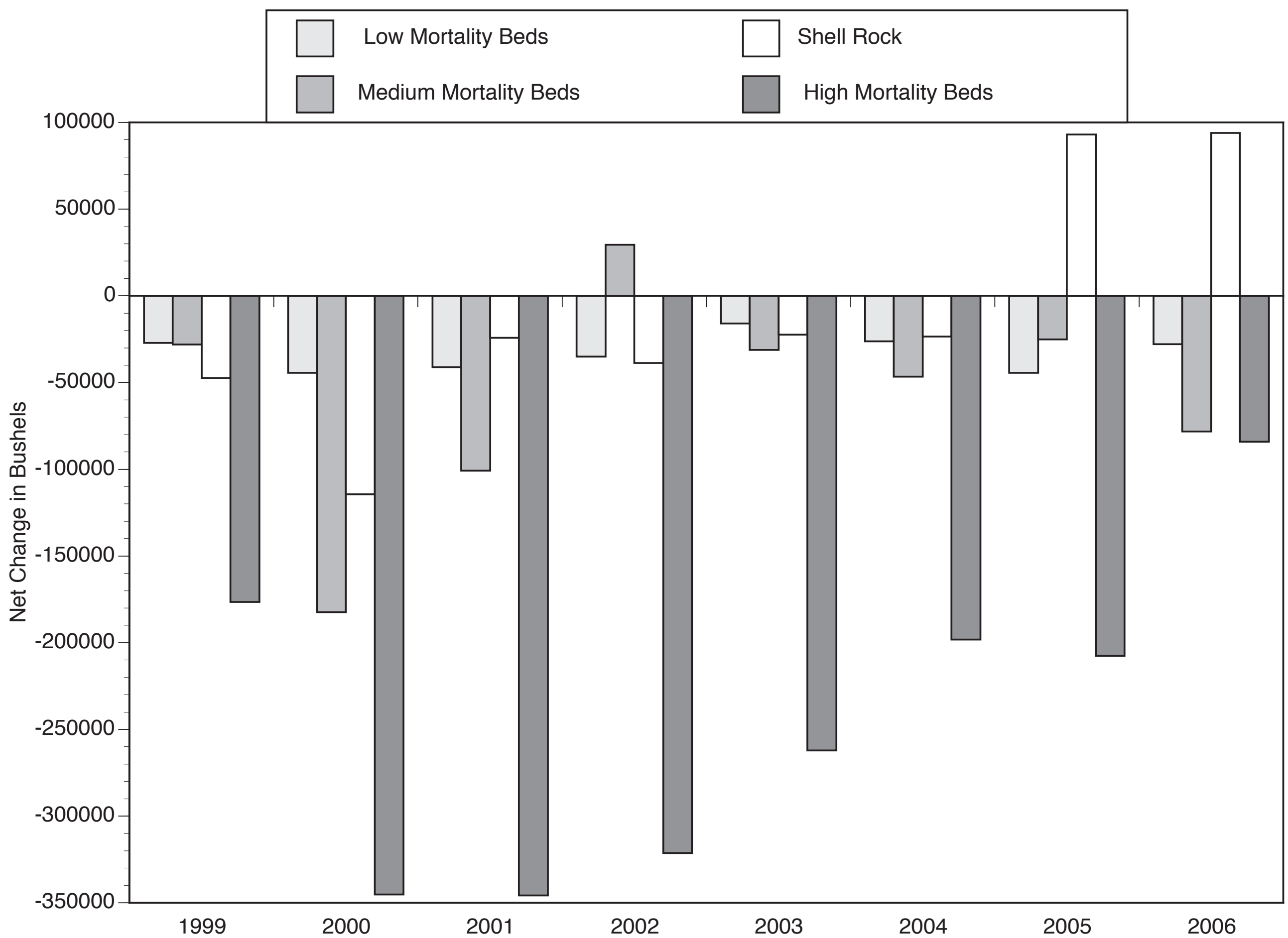

Figure 23. Relationship between Fall Dermo infection levels (WP=weighted prevalence) and Fall mortality as measured by box counts. Each point corresponds to a measurement from one bed for one year.

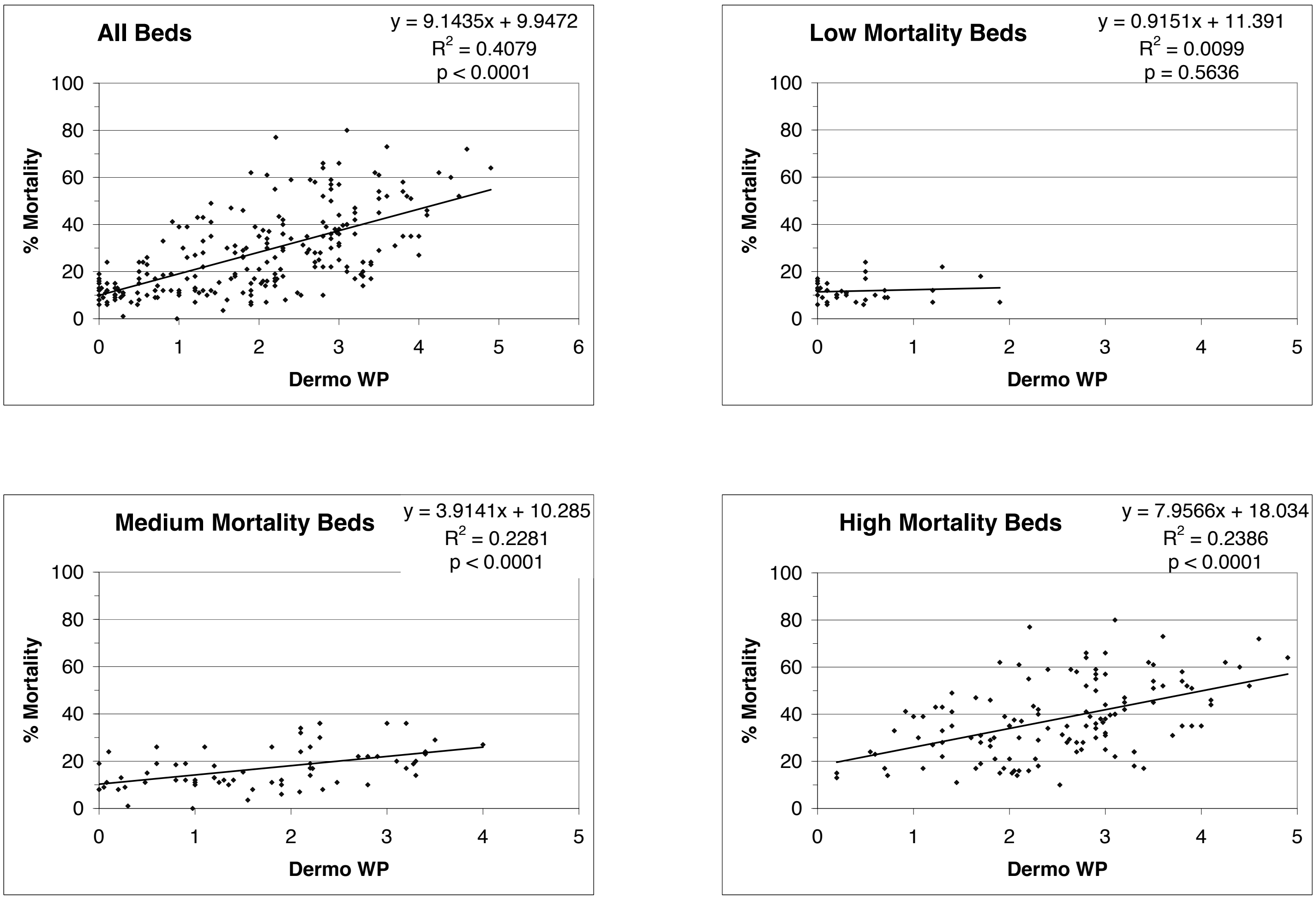

Figure 24. Mean and 2006 Dermo prevalence in oysters on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals. Upper bar in each pair represents the 1990-2006 mean. Lower bar is the 2006 value. Abscissa is prevalence in percent. ND, no data.

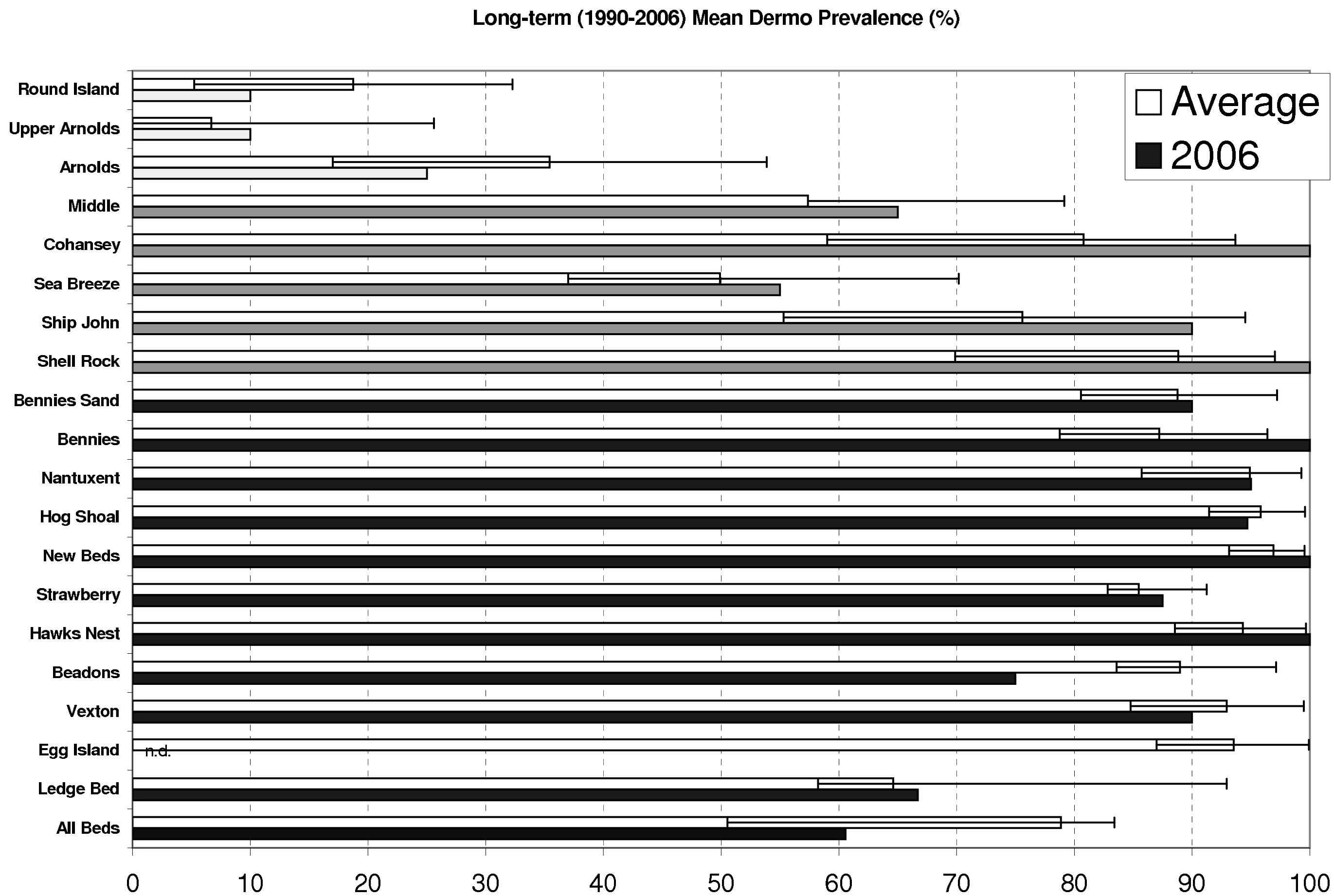

Figure 25. Mean and 2006 weighted prevalence of Dermo disease on New Jersey Delaware Bay oyster beds. Error bars are 95% confidence intervals. Upper bar in each pair represents the 1990-2006 mean. Lower bar is the 2006 value. Abscissa is weighted prevalence in Mackin's units. ND, no data.

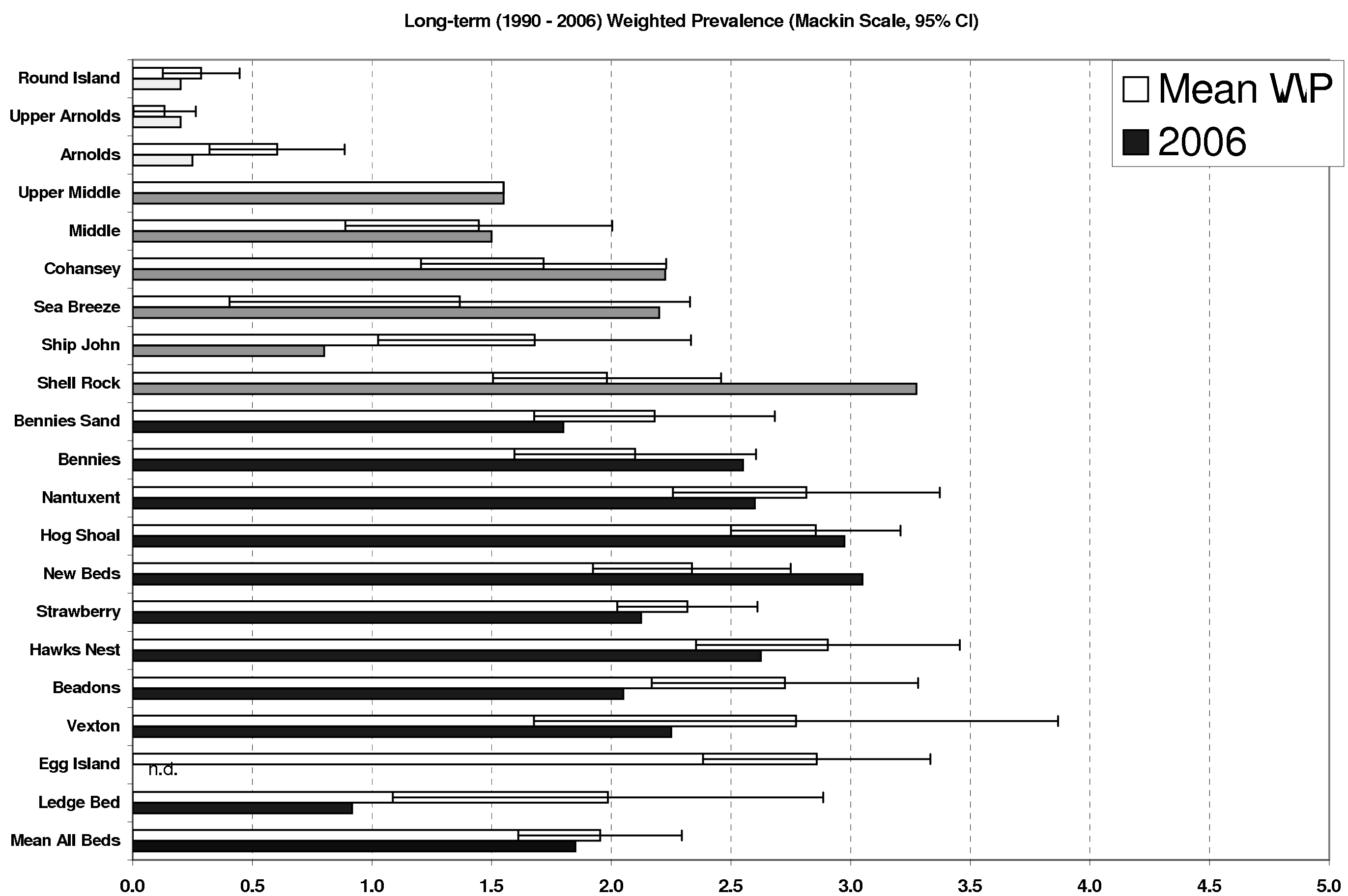

Figure 26. Time series showing the cyclic nature of Dermo disease weighted prevalence. Note the tendency for epizootics (weighted prevalences >2) to be of a number of years in duration and to occur about every 7 years. Error bars are 95% confidence intervals.

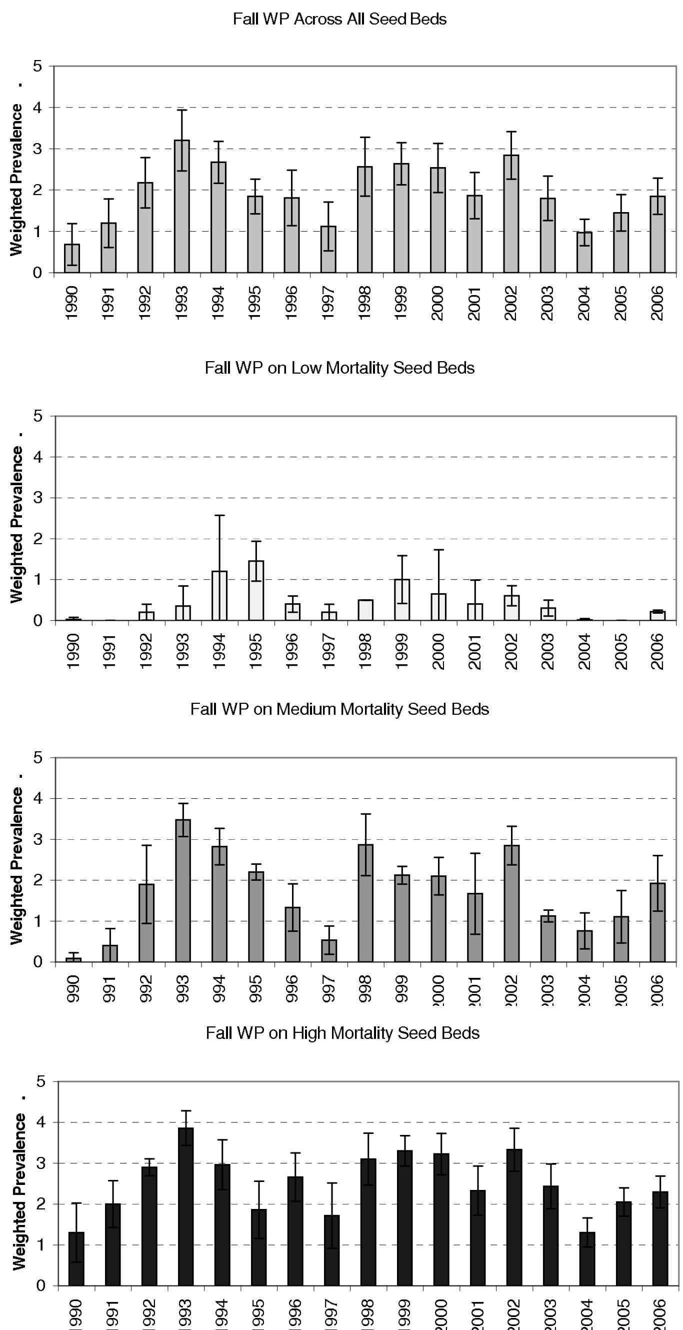

Figure 27. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the four bay regions measures the bay-wide mortality rate for that year.

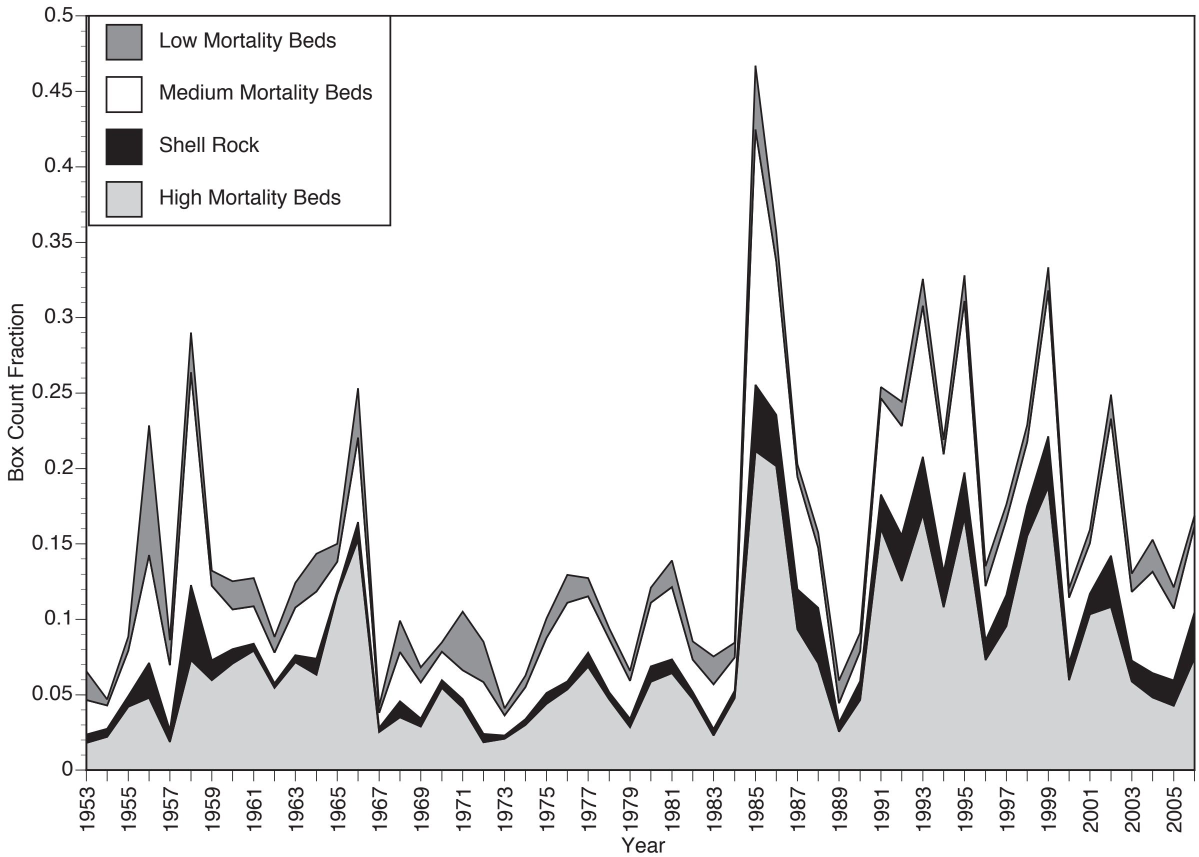

Figure 28. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region.

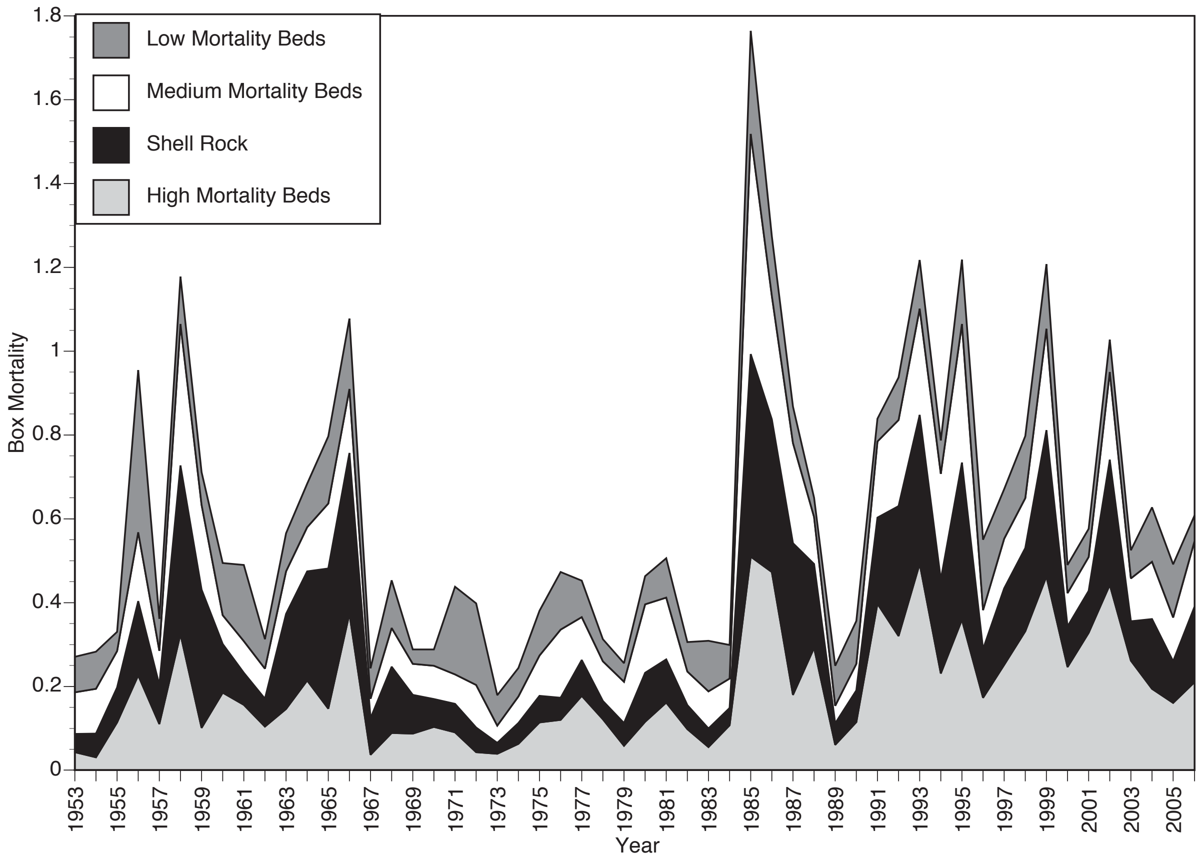

Figure 29. Broodstock-recruitment relationship for the 1953-2006 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2005 because the plot compares end-of-2005 oyster abundance with 2006 recruitment.

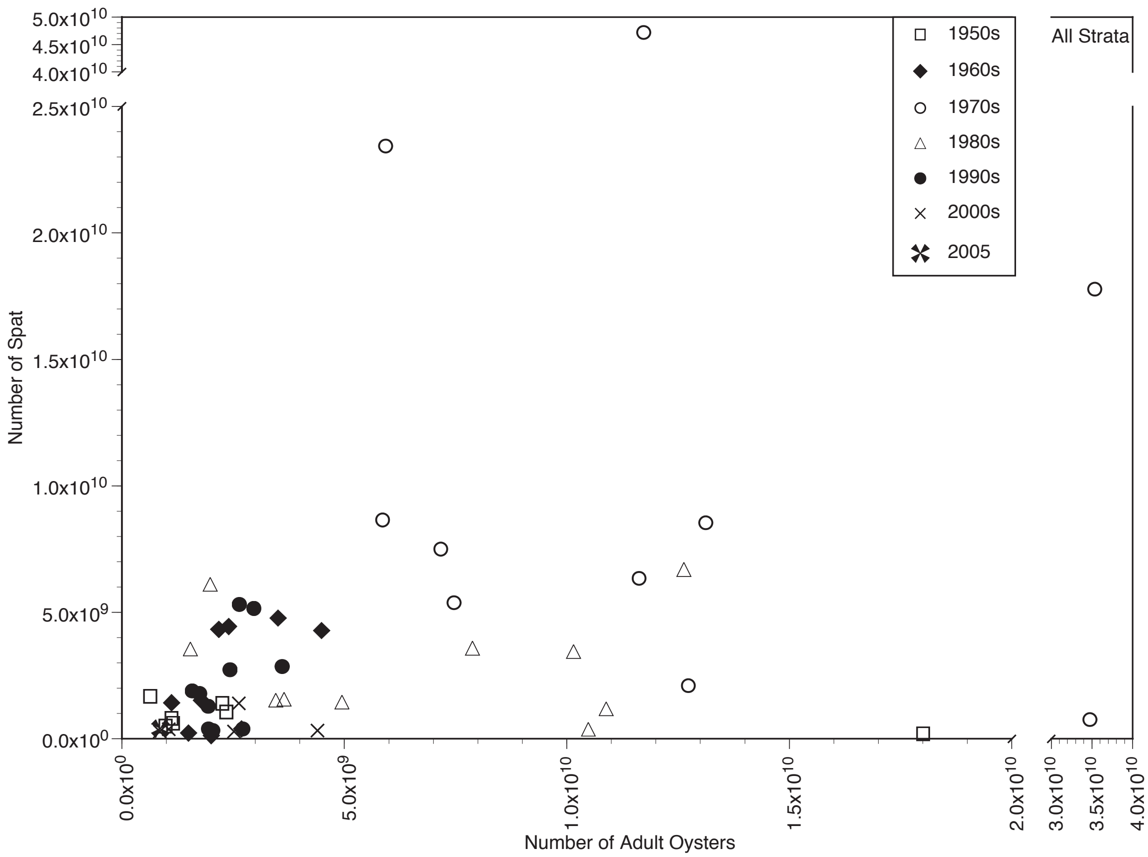

Figure 30. The relationship between oyster abundance and box-count mortality for the 1953-2006 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2005 because the plot compares end-of-2005 oyster abundance with 2006 mortality.

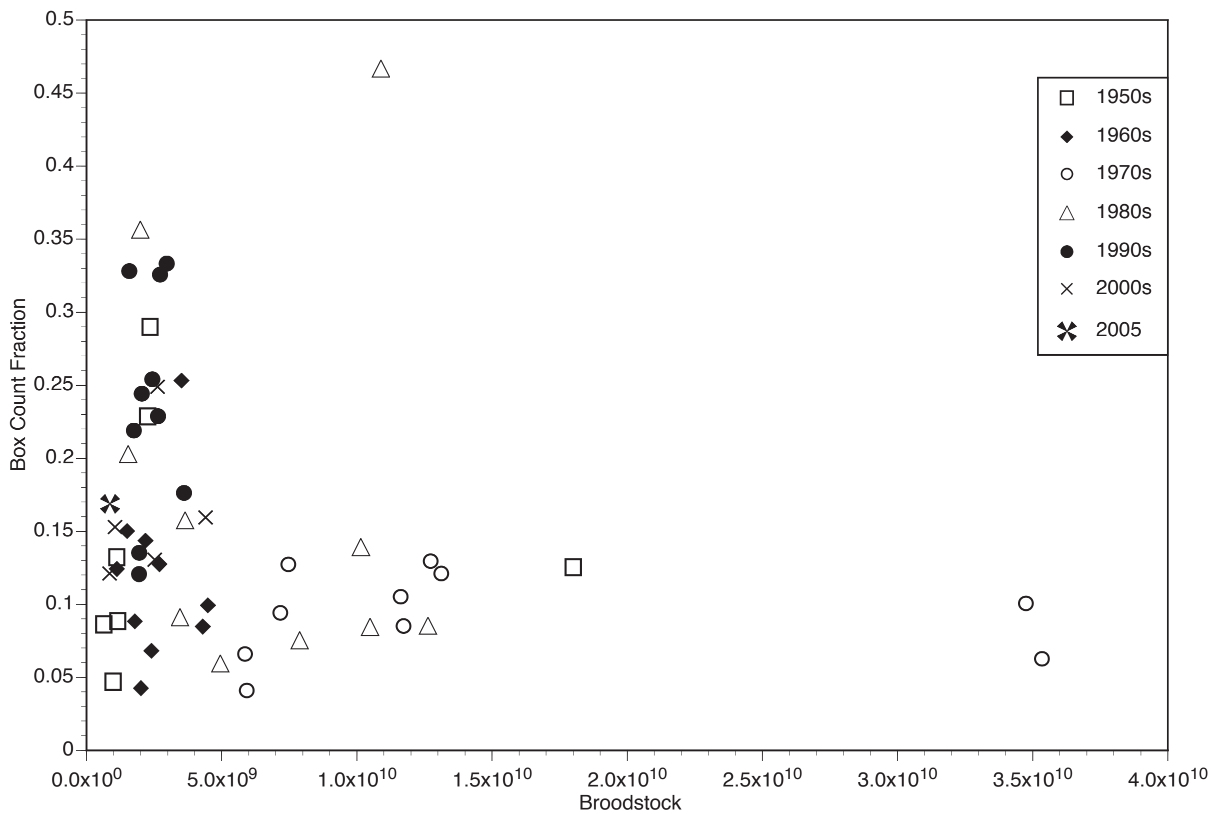

Figure 31. The relationship between recruitment and box-count mortality for the 1953-2005 time period for the natural oyster beds of Delaware Bay.

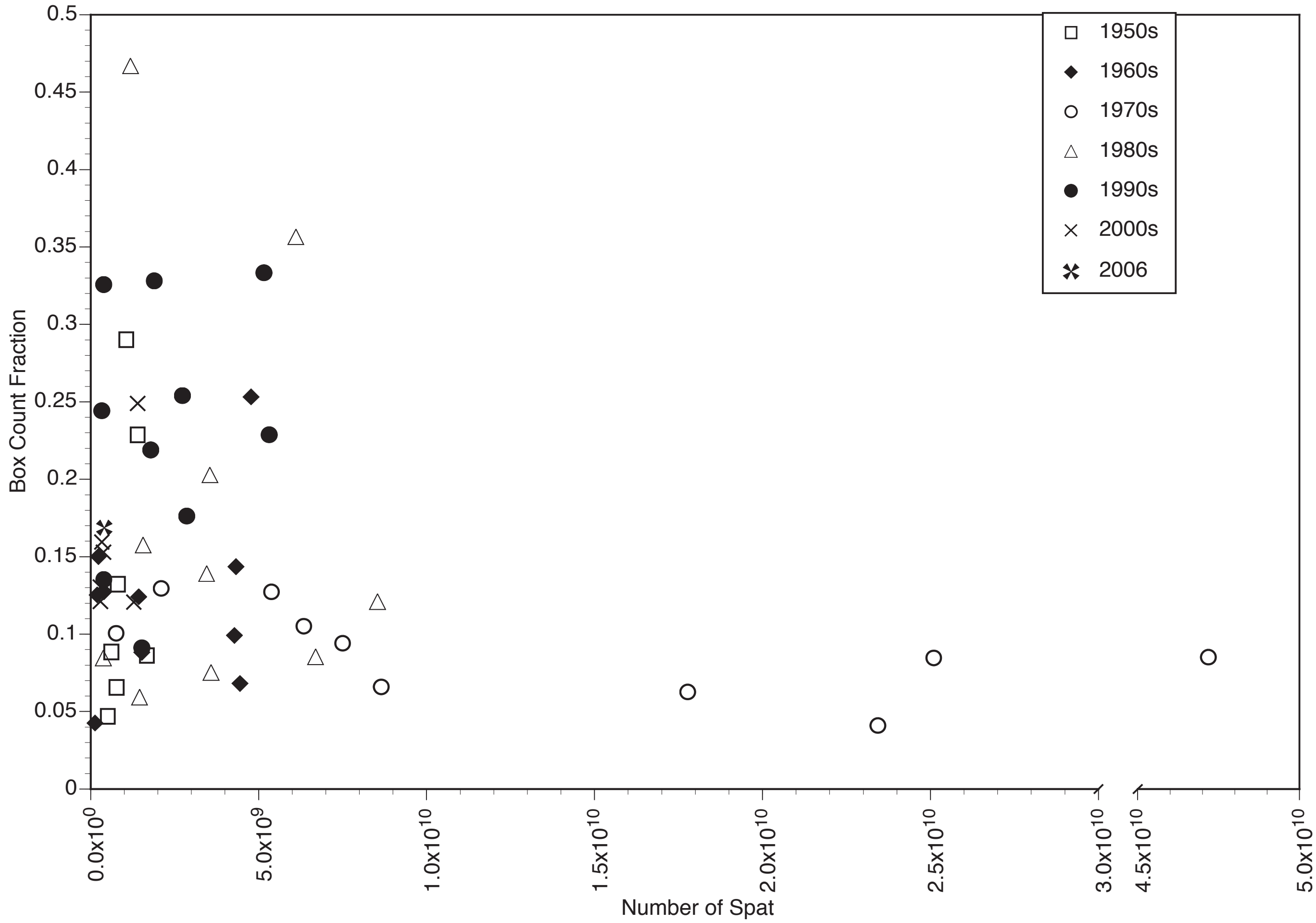

Figure 32. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

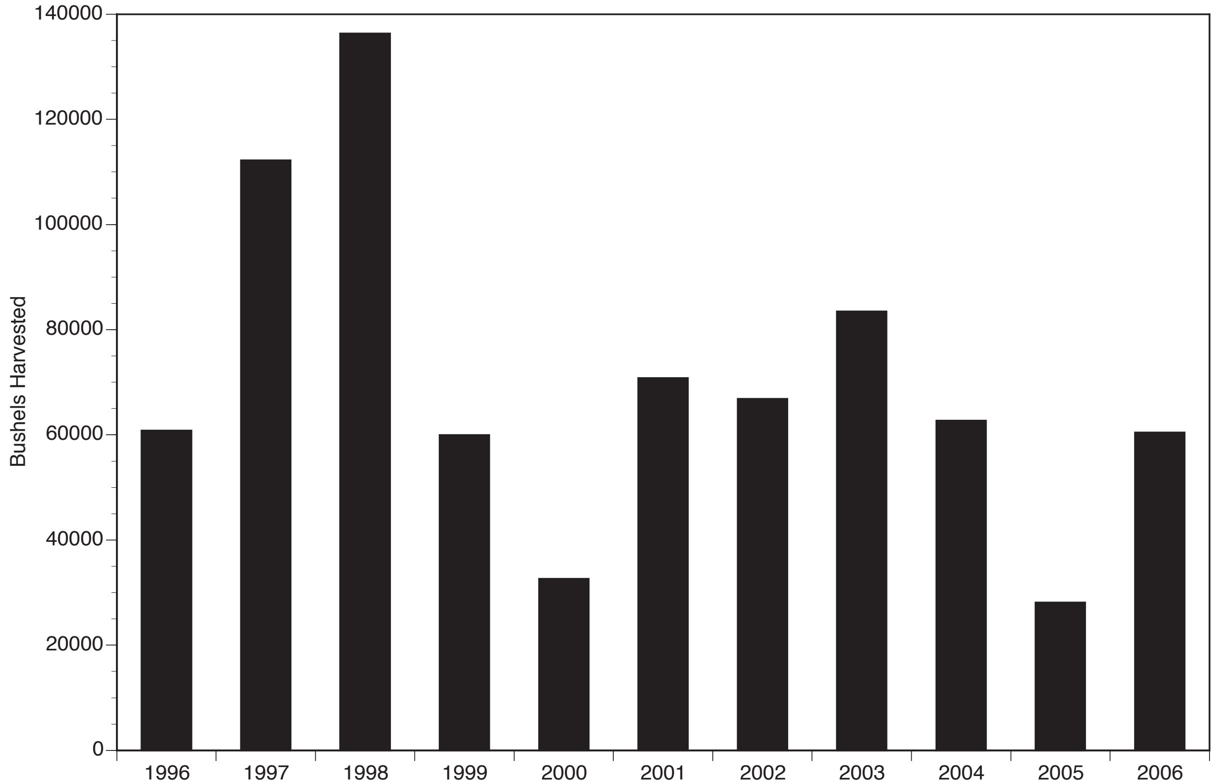

Figure 33. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

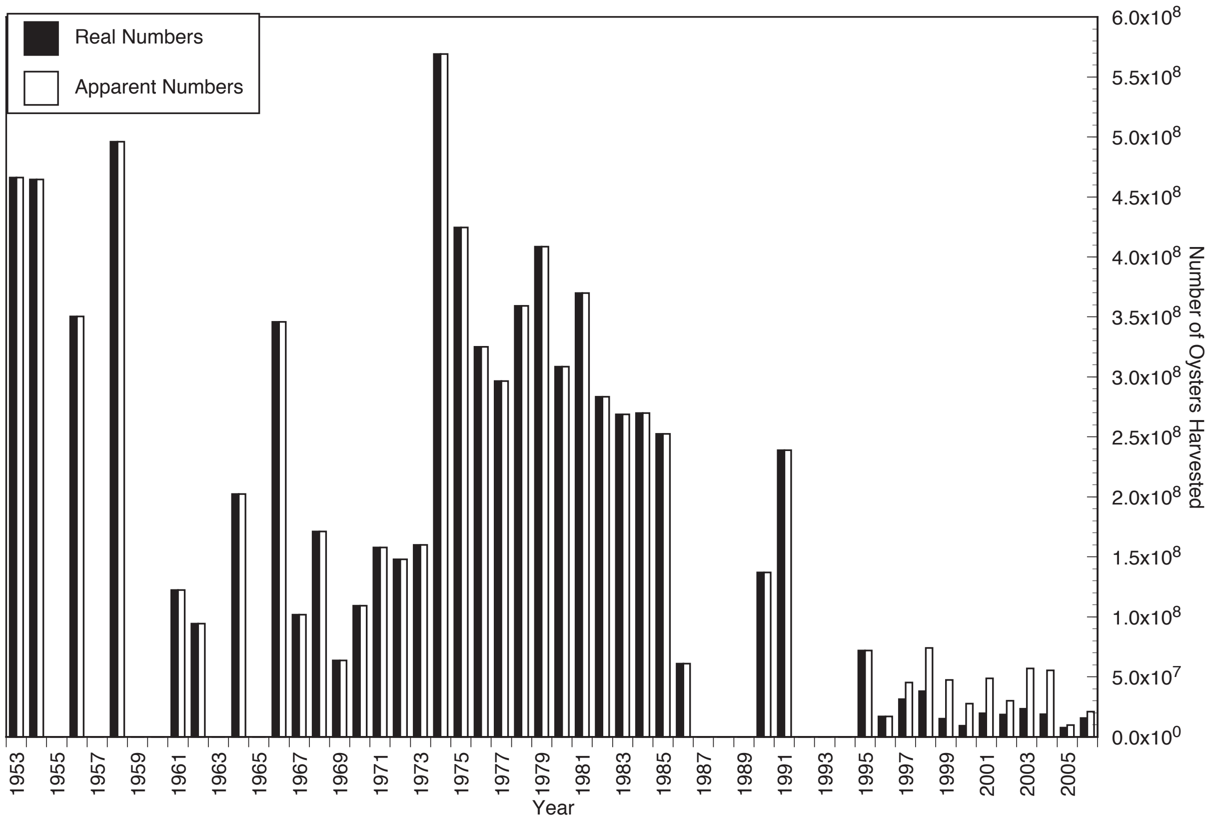

Figure 34. Catch (in bushels) per boat-day.

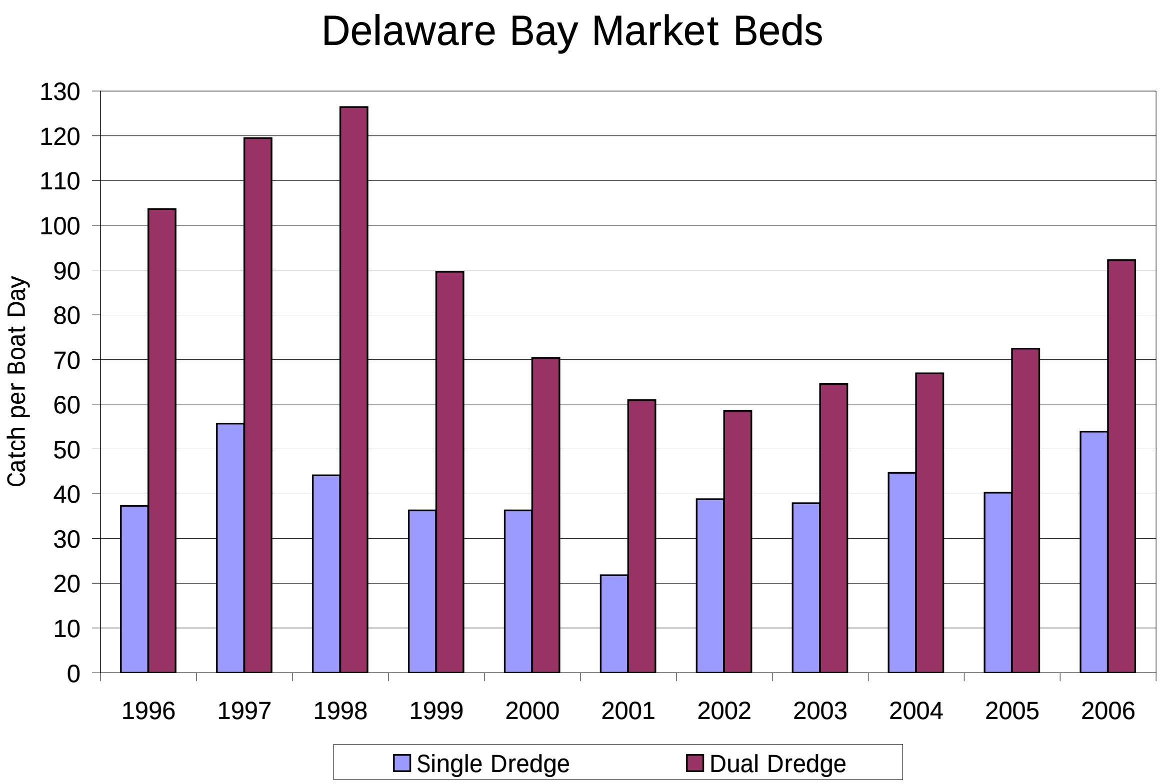

Figure 35. Size frequency of oysters landed in 2006. Size class values are the mean of the size class.

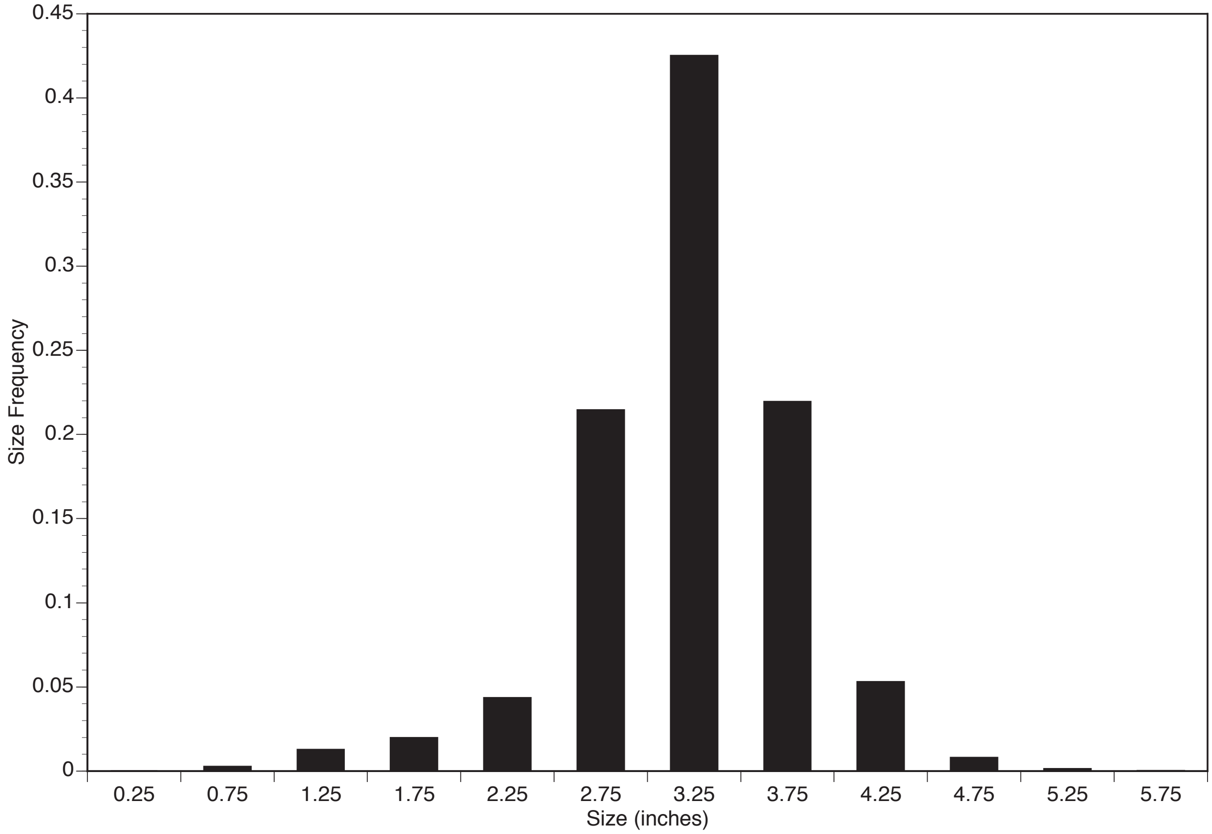

Figure 36. Fishing mortality rates by bay region during the 1953-2006 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 4. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

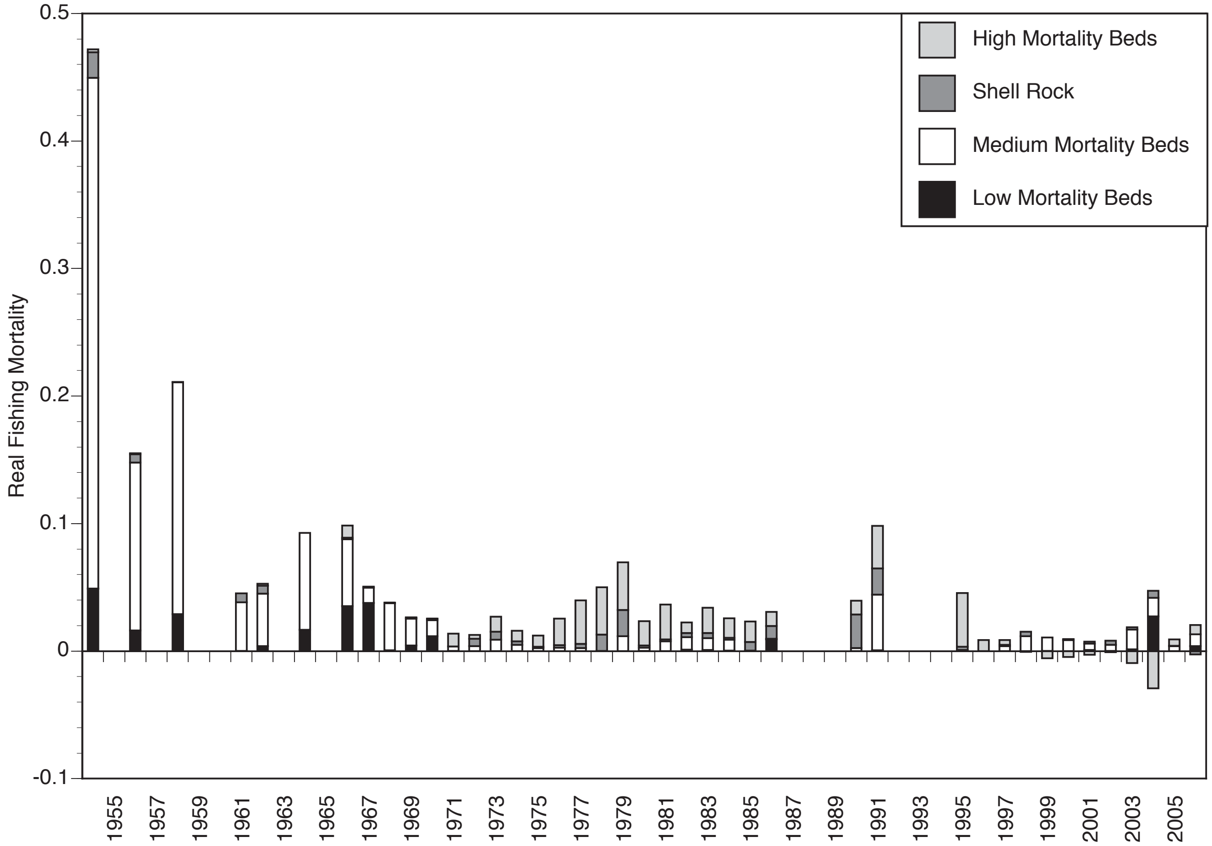

Figure 37. Fishing mortality rates by bay region during the 1996-2006 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 4. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing.

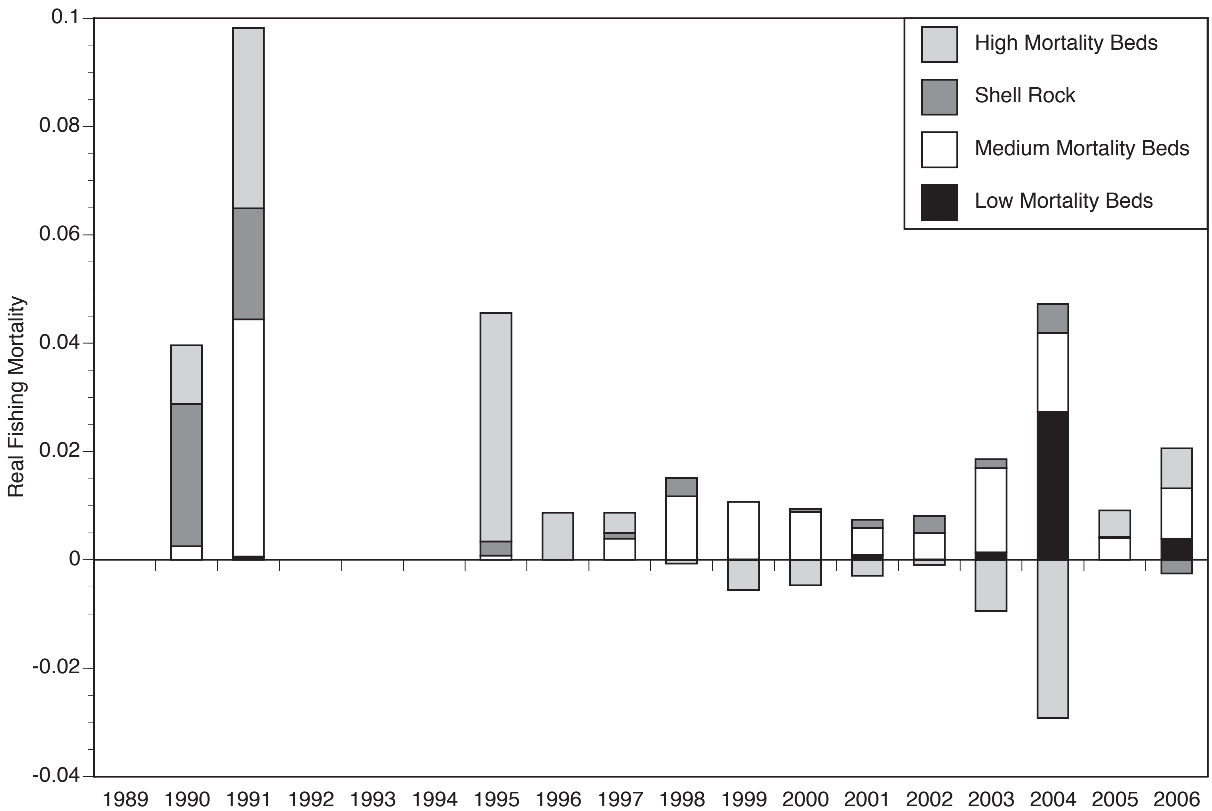

Figure 38. Fishing mortality rates during the 1953-2006 time period. In this figure, since 1996, the total stock manipulation, including transplant and direct-market is identified as the apparent rate; those oysters landed are identified as the real rate. Zeros represent years of fishery closure.

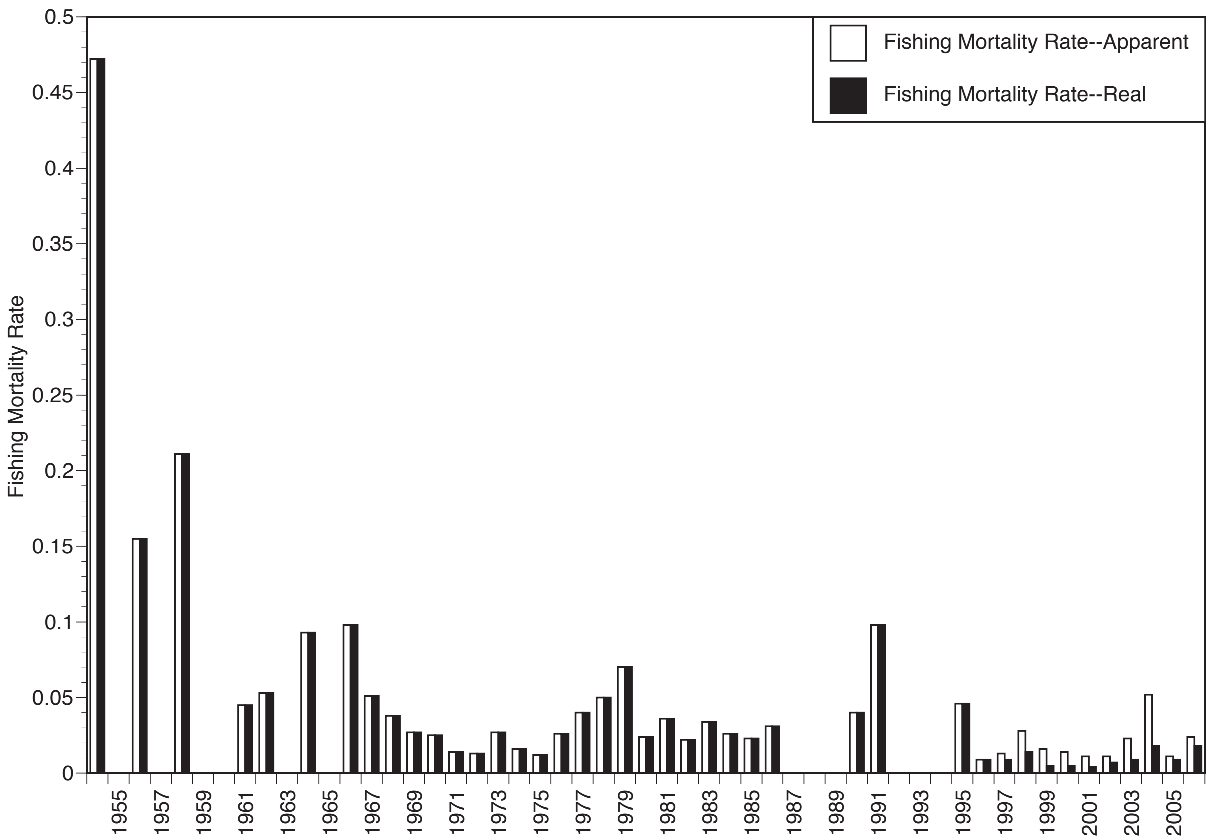

Figure 39. Fishing mortality rate during the 1997-2006 time period based on SSB.

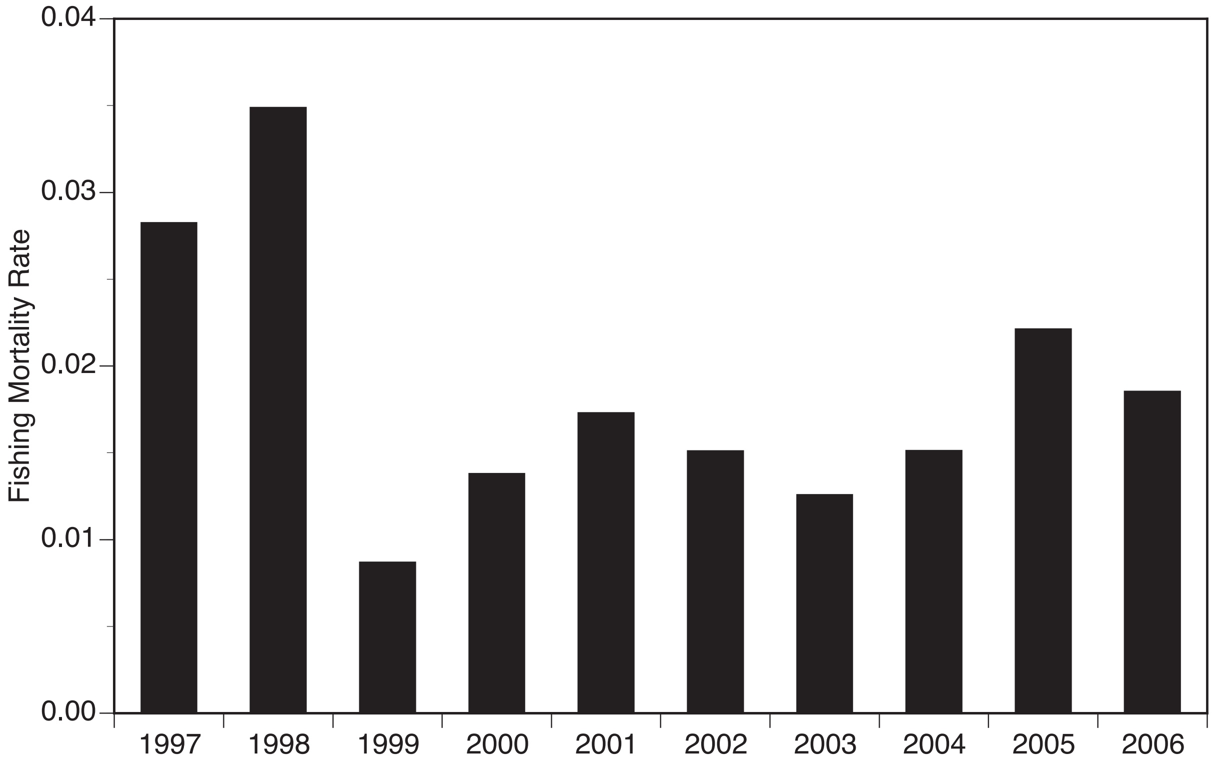

Figure 40. Fishing mortality rate during the 1997-2006 time period based on marketable abundance (animals $\geq 2.5''$).

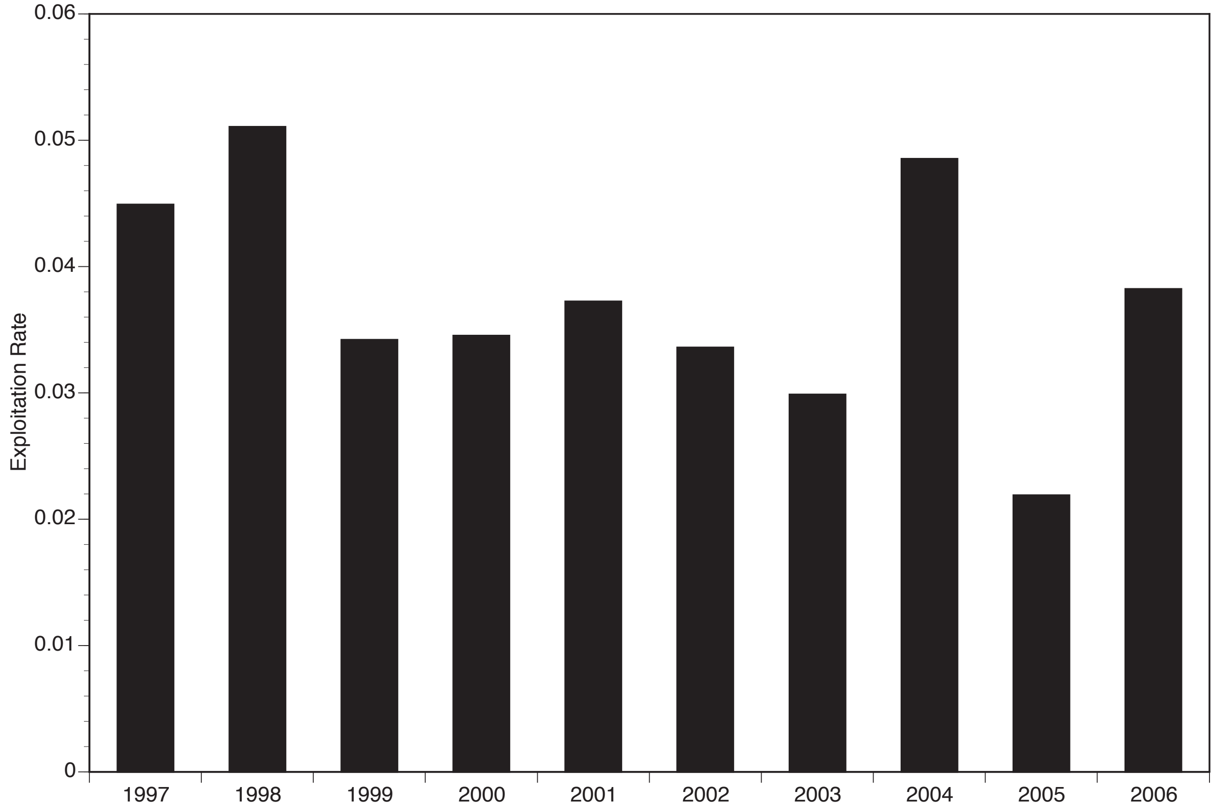

Figure 41. Summary status of the stock for 2006. Green indicates variables judged to be above average relative to the 1989-2006 time period or having an improving trend relative to the previous year. Orange indicates variables judged to be below average relative to the 1989-2006 time period or having a degrading trend relative to the previous year. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2006 time period, but sometimes determined by scientific judgment. Fraction of stock refers to the dispersion of the stock across the salinity gradient in the four bay regions. All percentiles are relative to the 1989-2006 time series. Parentheses are values that include the 2006 shell plants.

	Low Mortality Beds	Medium Mortality Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.14	0.64	0.07	0.15
Total Abundance				
2006 Percentile	0.08	0.42	0.40	0.25
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Spawning Stock Biomass				
2006 Percentile	0.27	0.67	0.67	0.67
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Recruitment				
2006 Percentile	0.18	0.42	0.18 (0.45)	0.08 (0.55)
2005-2006 Trend	Decreasing	Increasing	Increasing	Increasing
Spat per Adult				
2006 Ratio	0.16	0.34	0.32 (0.64)	0.42 (1.00)
2006 Percentile	0.36	0.47	0.25 (0.50)	0.18 (0.60)
2006 Juveniles (fract.<2.5")	0.63	0.46	0.53	0.55
2006 Percentile	0.06	0.13	0.25	0.38
Dermo Infection Status				
2005-2006 trend	increasing	increasing	increasing	increasing
2006 Mortality Rate	0.06	0.16	0.18	0.21
2006 Percentile	0.08	0.58	0.47	0.31
Abundance Position vs				
Target	Below	Below	Below	Below
Threshold	Below	Above	Above	Below
SSB Position vs				
Target	Below	Above	Above	Above
Threshold	Near	Above	Above	Above
2007 Surplus Production				
50^{th} percentile mortality	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Positive	Positive	Positive	Positive

Figure 42. Position of the oyster stock in 2003-2006 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.

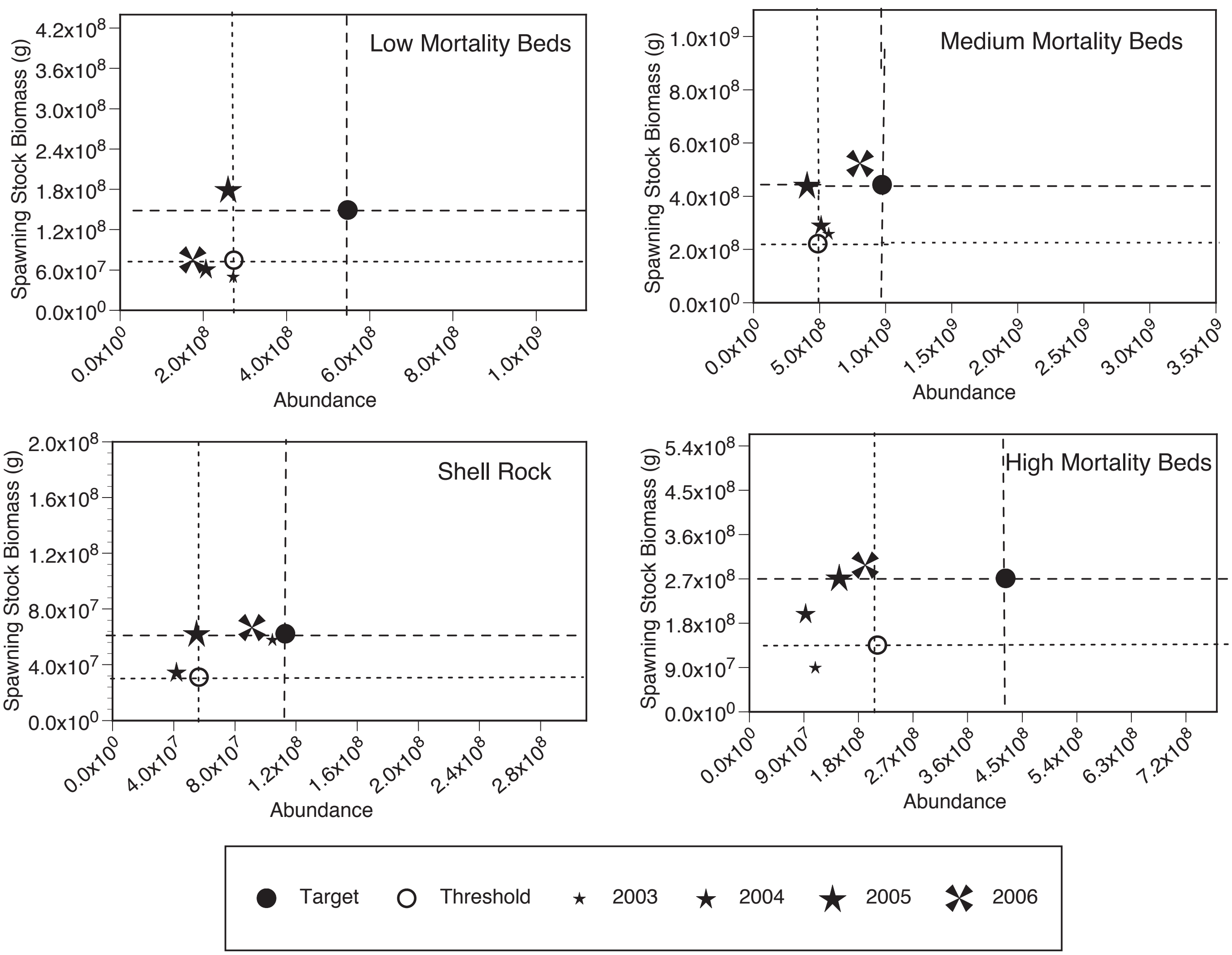

Figure 43. Relationship between the long-term mean of natural mortality estimated from Fall box counts and the long-term mean intensity of Dermo infections since 1990. Data are individual bed estimates. Note that the increase in mortality appears to be a step function with thresholds at weighted prevalences of about 1 and 2 on the Mackin scale. Note that the inshore high-mortality beds tend to withstand higher infection intensities for a given degree of mortality.