Executive Summary of the
2011 Stock Assessment Workshop
(13^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

Presenters

Eric Powell, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory

Stock Assessment Review Committee

Russell Babb, New Jersey Department of Environmental Protection
Danielle Kreeger, Partnership for the Delaware Estuary
Barney Hollinger, Delaware Bay Section of the Shell Fisheries Council
Roger Mann, Virginia Institute of Marine Sciences
Bill Riggin, Delaware Bay Oyster Industry
Rich Wong, Delaware Department of Natural Resources
Mike Celestino, New Jersey Department of Environmental Protection
Olaf Jensen, Rutgers University
Patrick Banks, Louisiana Department of Wildlife and Fisheries

Editors:

Eric Powell, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory

Distribution List

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

February 7-9, 2011

New Jersey Agricultural Experiment Station – Rutgers University

Status of the Stock

The SARC concludes that the Delaware Bay oyster stock is not overfished and that overfishing is not occurring in 2010, nor has either condition occurred since the inception of the port-sampling program in 2004. Both are characteristic of and requirements for a sustainable stock. Evaluation was based on a series of stock characteristics, including the time series stability of market-size abundance and a retrospective evaluation of net surplus production. The 1990-2010 time series shows that the abundance of market-size animals has remained relatively stable over this period of two decades (Figure 1). This stability comes from a balance between the death of larger animals primarily caused by disease and the recruitment potential of the population, plus a fishing mortality rate such that removals by the fishery have not exceeded the replacement capacity of the population. A retrospective examination of the tendency for forgone yield to exist shows that net surplus production has been positive in every year since port-sampling began (Figure 2). Further support comes from a comparison of the natural mortality rate with the fishing mortality rate (Figure 3). In this case, the fishing mortality rate has been less than 20% of the natural mortality rate throughout this time period. As a consequence, no evidence exists that overfishing has occurred under the present management regime nor that the stock is in an overfished state.

In 2010, the stock presents a mixture of positive and negative indicators, but the positive indicators substantially outnumber the negative ones (Figure 4). Abundance remains low, but is increasing in five of six bay regions relative to 2009 and in four of five bay regions relative to the previous five years' median (Figure 5). Abundance remains below target levels in all but one bay region, but is near or above the threshold in all bay regions (Figure 6). The increase in abundance in 2010 is explained by the above-average recruitment event of 2009 plus the addition of some early recruits in 2010 that grew to a size exceeding 20 mm.

High recruitment occurred in all bay regions except the high-mortality beds in 2010, and this region, which recruits with greater predictability than other bay regions, sustained a near-median level in 2010. The 2010 recruitment was noteworthy for reaching substantive levels over all bed regions, including the low-mortality and very-low-mortality beds. Based on total recruits, the 2010 spatfall exceeded the 75^{th} percentile for the 1989-2010 time period in all but one bed region, a position not attained previously in the 2000s over such a wide bay region. On a spat-per-adult basis, the 2010 recruitment was well above average in all bed regions, and near historical highs upbay of Ship John/Cohansey (Figure 7).

Spawning stock biomass remained relatively unchanged in 2010 relative to the previous five years (Figure 8), but increased distinctly from 2009 in five of six regions (Figure 4). SSB fell below the biomass target in two regions, but near or above the threshold in all five (Figure 6). In contrast, marketable abundance fell near or above the target in all bay regions and increased substantively in five of six (Figure 9).

Dermo disease remained near epizootic levels in 2010 and natural mortality rates were well above average upbay of Ship John/Cohansey, reaching an historical high on the low-mortality beds and the 80^{th} percentile on the medium-mortality transplant beds for the 1989-2010 period (Figure 4). This marks a continuation of a pattern observed in 2009 for unusually high mortality rates upbay. In contrast, the mortality rate on the high-mortality beds and Shell Rock was relatively low by historical standards. A decreasing trend in Dermo disease weighted prevalence throughout the bay suggests a possible relaxation of epizootic conditions in 2011.

Overall, the six bed regions are in better shape in 2010 than in many previous years. Few cautionary data exist for Shell Rock or either medium-mortality section, aside from the continuing high mortality rates on the medium-mortality transplant beds. No evidence of impact from the higher exploitation rate permitted in 2010 on the medium-mortality market beds could be discerned, supporting the retention of this option for exploitation in 2011. Exploitation rates have routinely been low in all bed regions over most of the direct-market period (Figure 10). The high-mortality beds have recovered somewhat from the poor condition of 2009 after three epizootic years, regardless of the metric used for evaluation. This recovery is abetted by an above average recruitment year in 2009 and lower natural mortality in 2010, but owes more to the management advice of SAW-12 to target this area to receive intermediate transplants in 2010 and to restrict exploitation rate. A continued emphasis on intermediate transplant to this bed region in 2011 would seem prudent, as the 2010 recruitment provides an opportunity to further improve the condition of this region.

Conditions remain ambiguous on the low-mortality beds as abundance and market abundance have declined to undesirable levels, relative to the 1989-2010 historical record due to unusually high rates of natural mortality and a decadal dearth in recruitment. However, the 2010 recruitment event was near historical highs, at levels not seen since the early 1990s. Given the normally high survival rate on these beds, increasing abundance can be anticipated from the 2010 recruitment event. No indication that intermediate transplants of previous years have significantly depressed abundance on the low-mortality or very-low-mortality beds is evident in this assessment.

2010 Management Goals

Cultch Management Goals

Shell planting serves a dual purpose of enhancing recruitment and maintaining shell balance. Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Most bed regions were nearly in shell balance in 2010, although conditions have worsened since 2008 (Figure 11), due to a reduction in shell planting in 2009-2010. Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell. Thus, shell plants, wherever feasible, should target areas where oysters grow rapidly to marketable size, where the probability of recruitment is high, and where cultch loss exceeds the addition of shell through natural mortality. Design of a 2011 program should consider the following recommendations.

1. Shell Rock has demonstrated exemplary performance under shell planting. Maintaining high production on Shell Rock is important. No intermediate transplant to this bed is recommended in 2011. Thus, shell should be planted on Shell Rock in 2011.

2. The area of greatest concern is the high-mortality bed region, as total shell loss is normally highest in this region, in part due to low marketable abundance that is the outcome of persistent high mortality from Dermo disease. In addition, continued low abundance in this region can be assuaged by recruitment enhancement through this means. Shell planting should target beds in the upbay portion of this region.

3. The SARC notes that an unfortunate attendant to the movement of oysters downbay during intermediate transplant is the transplant downbay of cultch. The SARC recommends that measures be put in place to minimize the downbay transplant of cultch, unless a program replacing transplanted cultch through shell planting can be mobilized.

Abundance-based Exploitation Reference Point Projections – Direct Marketing

In 2010, the high-mortality beds continue to be at low abundance, though improving, but marketable abundance remains above target levels even after three epizootic years. The SARC notes that the high-mortality beds are toward the edge of the stock's range, rather than near the center, and that the continuing high natural mortality rate limits the success of stock rebuilding on these beds. However, these beds can be managed to augment abundance and increase fishery yield in the short term. The intermediate transplant program has been successful in this regard. The SARC considers the present state of these beds to need continuing attention and recommends that a fishing level above the 40^{th} percentile not be used without implementation of a significant intermediate transplant program. Because a significant intermediate transplant program will substantially reduce realized exploitation rate on these beds, higher percentile harvests (e.g., the 50^{th} or 60^{th} percentile) on the high-mortality beds may be implemented under that proviso.

Due to the uniqueness of medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed independently of the high-mortality beds. This year, Shell Rock is above all target levels. The SARC recommends that exploitation rates as high as the 60^{th} percentile be permitted.

An increased exploitation rate was recommended at SAW-11 for the medium-mortality market beds. Despite higher than average mortalities during the four-year epizootic of 2007-2010, substantial catches in 2007-2010 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance. Thus, these beds have been relatively resilient under the exploitation rates used to date. The SARC recommends continuation of the experimental fishery begun in 2009 on these beds to evaluate their response under increased exploitation rates.

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

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant

The SARC strongly supports the inclusion of an intermediate-transplant program and emphasizes the urgent need for this program as a vehicle to support abundance on the high-mortality beds.

The medium-mortality transplant beds are below, but within, survey error of the abundance target (Figure 4) and above the market-size abundance target. The region received a much higher than average recruitment event in 2010 and both abundance and market abundance are well above the previous five years' median. The SARC recommends that intermediate transplant be permitted at the 50^{th} percentile level and that Middle and Upper Middle be targeted.

The low-mortality beds are above the marketable-abundance target, but below the abundance target and only modestly above the threshold. Growth rates are slower on these beds and recruitment has been sporadic. The ability of these beds to recover from a decline in abundance consequently is limited, despite the lower rate of natural mortality. However, the region sustained an unusually good recruitment event in 2010 and a return to lower mortality rates in 2011 is highly likely. Nevertheless, the status of the stock in this region suggests that a precautionary approach be taken in 2011. The SARC, therefore, recommends that the intermediate transplant be no higher than the 40^{th} percentile. The SARC recommends that Round Island be preferentially targeted in 2011, and that Arnolds be included only if necessary.

No exploitation record is available for the very-low-mortality beds. However, the SARC emphasizes the need to evaluate these beds as intermediate transplant beds. Thus, an intermediate transplant is recommended, but not to exceed the

40^{th} percentile as a precaution until a better understanding of these beds' response to fishing activities can be achieved. Normally, the SARC would recommend that Hope Creek be targeted in 2011, as the other two beds were targeted in 2010. However, the SARC notes disturbing trends in SSB and market abundance on Hope Creek over the last three years. Therefore, the SARC recommends that half of the recommended transplant come from Hope Creek and that the remainder come from the other very-low-mortality beds.

Given the plight of the high-mortality beds, the SARC recommends that transplants from the low-mortality and medium-mortality transplant beds be moved to the upper portion of the high-mortality beds; for example, inner Bennies, Bennies Sand, Hog Shoal and Nantuxent Point. Given the uncertainty of survival of transplants from the very-low-mortality beds, but also the need to support abundance on Ship John/Cohansey, the SARC recommends that Ship John/Cohansey be a preferred location to receive these transplants.

Projections for intermediate transplant are provided in Table 2.

Caveats Apropos Risk for 2011 Fishery Yield

1. The Dermo epizootic may be on the wane in 2011. However, low abundance after four epizootic years will require a conservative management approach on the low-mortality beds and the high-mortality beds in 2011, as abundance begins 2011 near the threshold level.

2. The SARC notes that the recommendation for Sea Breeze, once considered a medium-mortality market bed, to managed for intermediate transplant as part of the Middle and Upper Middle group of beds be retained

3. Conditions remain ambiguous on the low-mortality beds as abundance remains stable at a relative low level relative to the abundance targets, whereas marketable abundance is above the target. No indication that intermediate transplants of previous years have significantly depressed abundance on the low-mortality or very-low-mortality beds is evident in this assessment, but the decline in stock status in this region in 2010 due to an historically high mortality rate requires conservative management of these beds in 2011.

4. The high-mortality beds are below the threshold for abundance and SSB and near the target for marketable abundance. Conditions are sufficiently poor on the high-mortality beds to engender increased precaution in managing this bed region unless a substantial intermediate transplant program accompanies a higher exploitation rate.

5. The SARC notes that any transplant option requires transplant to occur before

the allocation derived therefrom can be determined. Given the condition of the high-mortality beds this year, a significant portion of the program should be carried out prior to harvest commencing on this bed region. The SARC is sensitive, however, to the closure rules associated with the transplant program and recognizes that the Council will need to maintain some beds open for harvest at the beginning of the season. The intermediate transplant should use culling devices as the goal of this activity is to move downbay a component of the population enriched in marketable animals while retaining upbay under a lower mortality regime smaller animals that will grow into these larger size classes.

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

7. The SARC recommendations for intermediate transplant include as a basic premise that specific beds in a bed region not be targeted for intermediate transplant in consecutive years. Doing otherwise may lead to local over-exploitation within the bed region.

8. The SARC continues to support the experimentally-increased exploitation rates on the medium-mortality market beds, but emphasizes that the 2011 recommendation does not set a precedent for its continuation in 2012. Rather, the SARC expects to re-evaluate this option at SAW-14.

9. The heavy set on Beadons suggests that Beadons be included in an intermediate transplant program to increase market abundance on Bennies Sand or a neighboring high-mortality bed in 2012/2013. This will not increase the overall quota in 2011, but would support the quota in coming years. Direct marketing has rarely occurred from Beadons, so that the heavy set on this bed will be lost to the industry without a transplant program.

Table 1. Allocation projections for direct marketing for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John), based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index. An upper and lower bound are taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest), with one exception. Projections use the average numbers per marketed bushel of 261 derived from the 2004-2010 port-sampling program. Arrows indicate recommended options. Γ indicates recommendations with intermediate transplant.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	692,010	2,651
	$^{\Gamma}50^{th}$	.0652	3,698,281	14,170
	$^{\Gamma}60^{th}$	.0782	4,435,668	16,995
Shell Rock	$\longrightarrow 40^{th}$	.0870	3,725,234	14,273
	$\longrightarrow 50^{th}$	.0880	4,991,544	19,125
	$\longrightarrow 60^{th}$	.1140	6,466,319	24,775
Medium Mortality Market				
without Sea Breeze	$\longrightarrow 40^{th}$	.0178	3,682,846	14,111
	$\longrightarrow 50^{th}$	.0214	4,427,692	16,964
	$\longrightarrow 60^{th}$	.0267	5,524,270	21,166
	$\longrightarrow 100^{th}$	.0398	8,234,679	31,551
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

ΓRequires intermediate transplant before marketing can occur. The SARC recommends that at least the transplant from the medium-mortality transplant beds occur prior to implementing this level of exploitation.

Table 2. Projections for intermediate transplant assuming that intermediate transplant will be conducted on the very-low-mortality, low-mortality, and Middle-Upper Middle-Sea Breeze group of medium-mortality beds. Numbers to be moved by intermediate transplant are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading by dry dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel for these beds obtained from the 2010 intermediate transplant program. Cullers were used for this transplant; however, numbers per bushel are similar to survey numbers (Table 4) suggesting that the indicated number of bushels to be moved may overestimate the required quantity. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.5''$ and these animals are converted to bushels using the 261 animal/bu conversion. Percentiles for the very-low-mortality and low-mortality beds use the exploitation reference points for the medium-mortality transplant beds. Arrows indicate preferred alternatives.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Medium Mortality Market						NA§
Medium Mortality Transplant						
including Sea Breeze	$\longrightarrow 40^{th}$	.0127	3,550,138	196	18,113	4,013
	$\longrightarrow 50^{th}$	.0188	5,255,322	196	26,812	5,940
	60^{th}	.0233	6,513,245	196	33,231	7,362
Low Mortality	$\longrightarrow 40^{th}$	.0127	3,991,178	410	9,734	4,450
	50^{th}	.0188	5,908,201	410	14,410	6,587
	60^{th}	.0233	7,322,398	410	17,869	8,164
Very Low Mortality	$\longrightarrow 40^{th}$	.0127	5,003,664	452	11,070	4,716
	50^{th}	.0188	7,406,953	452	16,387	6,871
	60^{th}	.0233	9,179,894	452	20,310	8,652

§NA: not applicable to this reference point.

Figure 1. Abundance of market-size ($\geq 2.5''$) oysters, excluding the very-low-mortality beds.

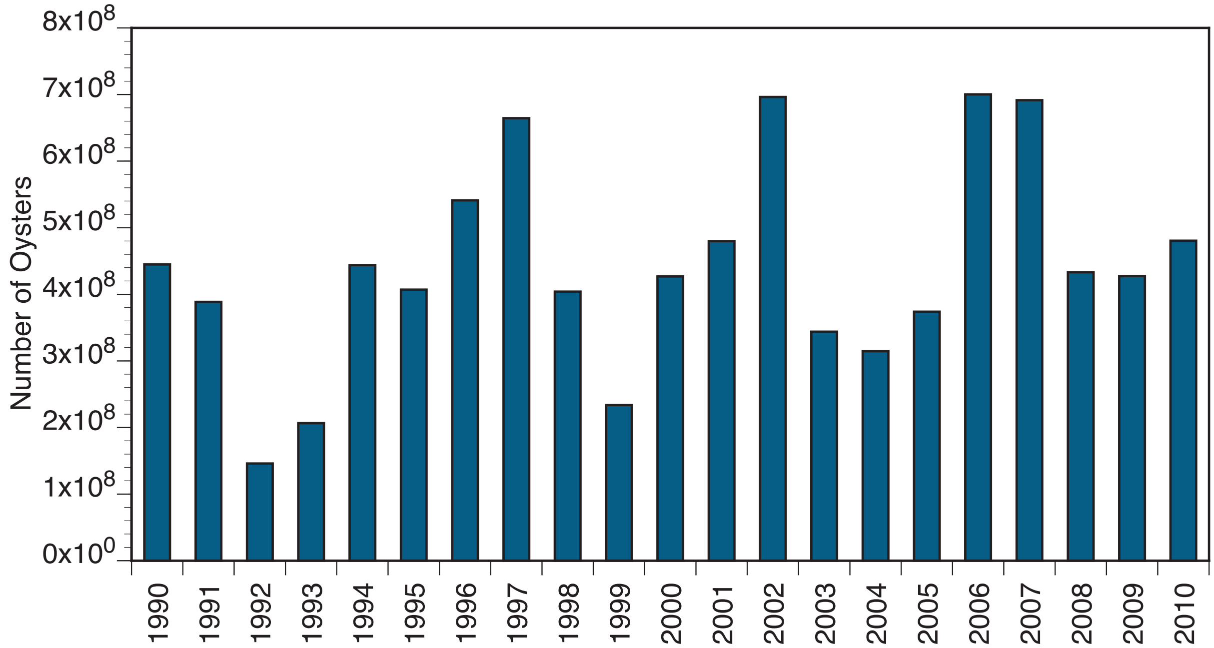


Figure 2. Net surplus production for the entire stock from a retrospective analysis of survey indices and landings. Surplus production was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous years survey. This provides high and low bounds for the estimates. Left column: green indicates that net surplus production was positive under both assumptions, indicating forgone yield; and grey, that the lower estimate was negative and the higher estimate was positive, indicating that the yield to the fishery approximated the potential yield available. Right column: green indicates conditions where the average of the two estimates was positive, indicating forgone yield.

Year	75th percentile	75th percentile
2005		5.68
2006		5.25
2007		5.71
2008		5.76
2009		5.36
2010		4.77

Figure 3. The relationship between the number of deaths per year from natural mortality and the number from fishing for animals $\geq 2.5''$ in size.

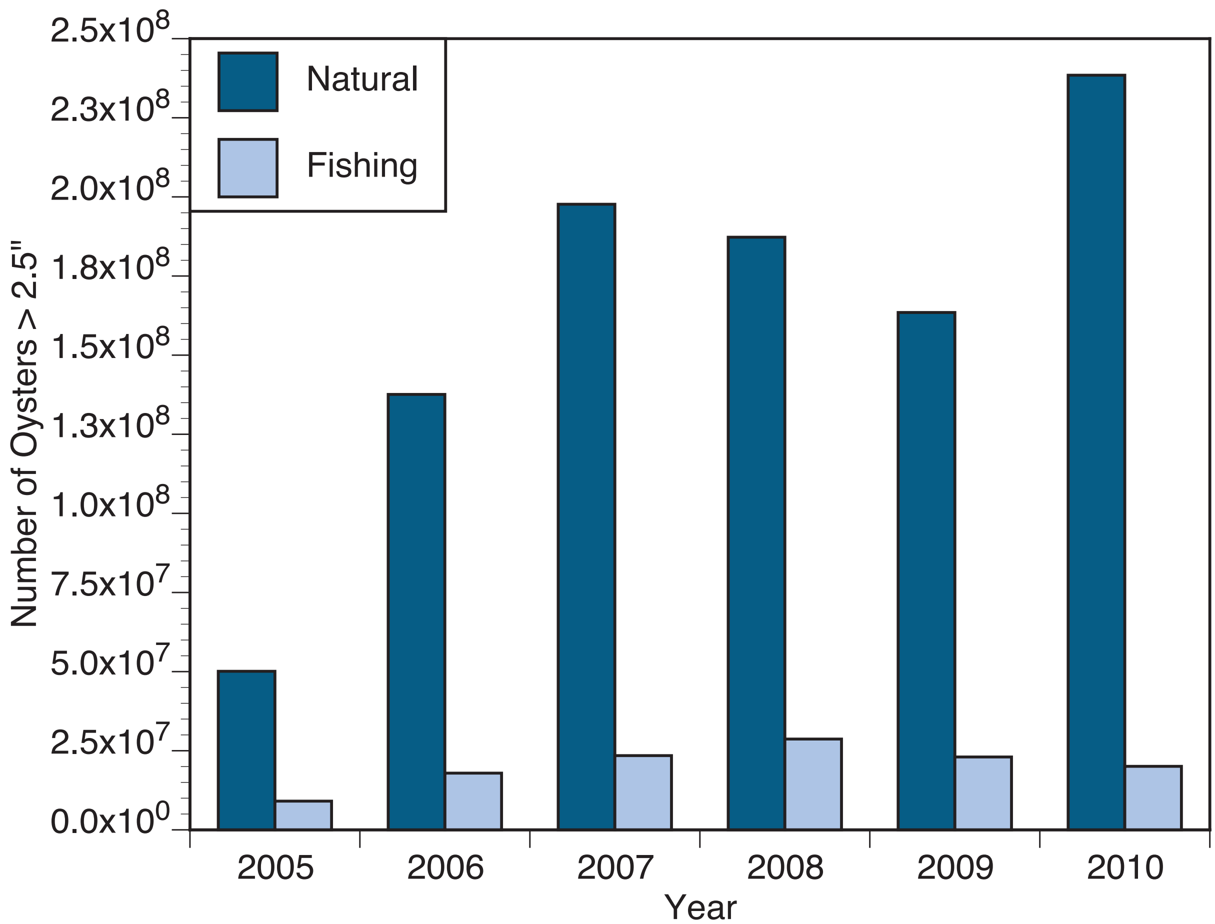


Figure 4. Summary status of the stock for 2010. Lime green indicates variables judged to be above average relative to the 1989-2010 time period or having an improving trend relative to the previous year or to the previous five years' median. Orange indicates variables judged to be below average relative to the 1989-2010 time period or having a degrading trend relative to the previous year or the previous five years' median. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2010 time period, but sometimes determined by scientific judgment. Trends in light green indicate a change $< \pm 15\%$. Fraction of stock refers to the dispersion of the stock across the salinity gradient in the six bay regions. All percentiles are relative to the 1989-2010 time series (1990-2010 for SSB). The 2005-2009 median identifies comparisons between the 2010 value and the 5-yr median value from 2005-2009.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.19	0.15	0.10	0.33	0.11	0.13
Fraction of Stock (No Very Low)	Not Incl.	0.18	0.12	0.41	0.13	0.16
Total Abundance						
2010 Percentile	Not Incl.	0.25	0.33	0.52	0.84	0.43
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Increasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Spawning Stock Biomass						
2010 Percentile	Not Incl.	0.26	0.50	0.50	0.64	0.21
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Decreasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Market Abundance						
2010 Percentile	Not Incl.	0.50	0.64	0.69	0.69	0.31
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Decreasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Recruitment						
2010 Percentile	Not Incl.	0.75	0.84	0.75	0.89	0.57
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2009-2010 Trend	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing
Spat per Adult						
2010 Ratio	0.87	0.74	1.04	0.89	1.37	1.63
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2010 Percentile	Not Incl.	0.93	0.90	0.71	0.61	0.61
Small Oys (fract.<2.5")	0.75	0.71	0.69	0.67	0.81	0.79
2010 Percentile	Not Incl.	0.25	0.45	0.50	0.75	0.70
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
Dermo Infection Status						
Weighted Prevalence	0.2	1.10	1.15	2.10	1.80	1.80
2009-2010 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Mortality Rate	0.09	0.18	0.21	0.19	0.11	0.20
2010 Percentile	Not Incl.	1.00	0.80	0.52	0.30	0.25
2005-2009 Median	Not Incl.	Increasing	Increasing	Decreasing	Decreasing	Decreasing
2009-2010 Trend	Increasing	Increasing	Decreasing	Decreasing	Decreasing	Decreasing
Abundance Position vs						
Target	Not Incl.	Below	Below	Below	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Near
SSB Position vs						
Target	Not Incl.	Below	Near	Near	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Near
Market Abundance vs						
Target	Not Incl.	Above	Above	Above	Above	Near
Threshold	Not Incl.	Above	Above	Above	Above	Above
Surplus Production						
50^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive

Figure 5. Time series of oyster abundance by bay region. High mortality: Bennies Sand, Nantuxent Point, Bennies, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Beadons, Egg Island, Ledge; medium mortality market (less Shell Rock): Ship John, Cohansey, Sea Breeze; medium mortality transplant: Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island; very-low mortality: Hope Creek, Fishing Creek, Liston Range. No data are available for the very-low-mortality beds prior to 2007.

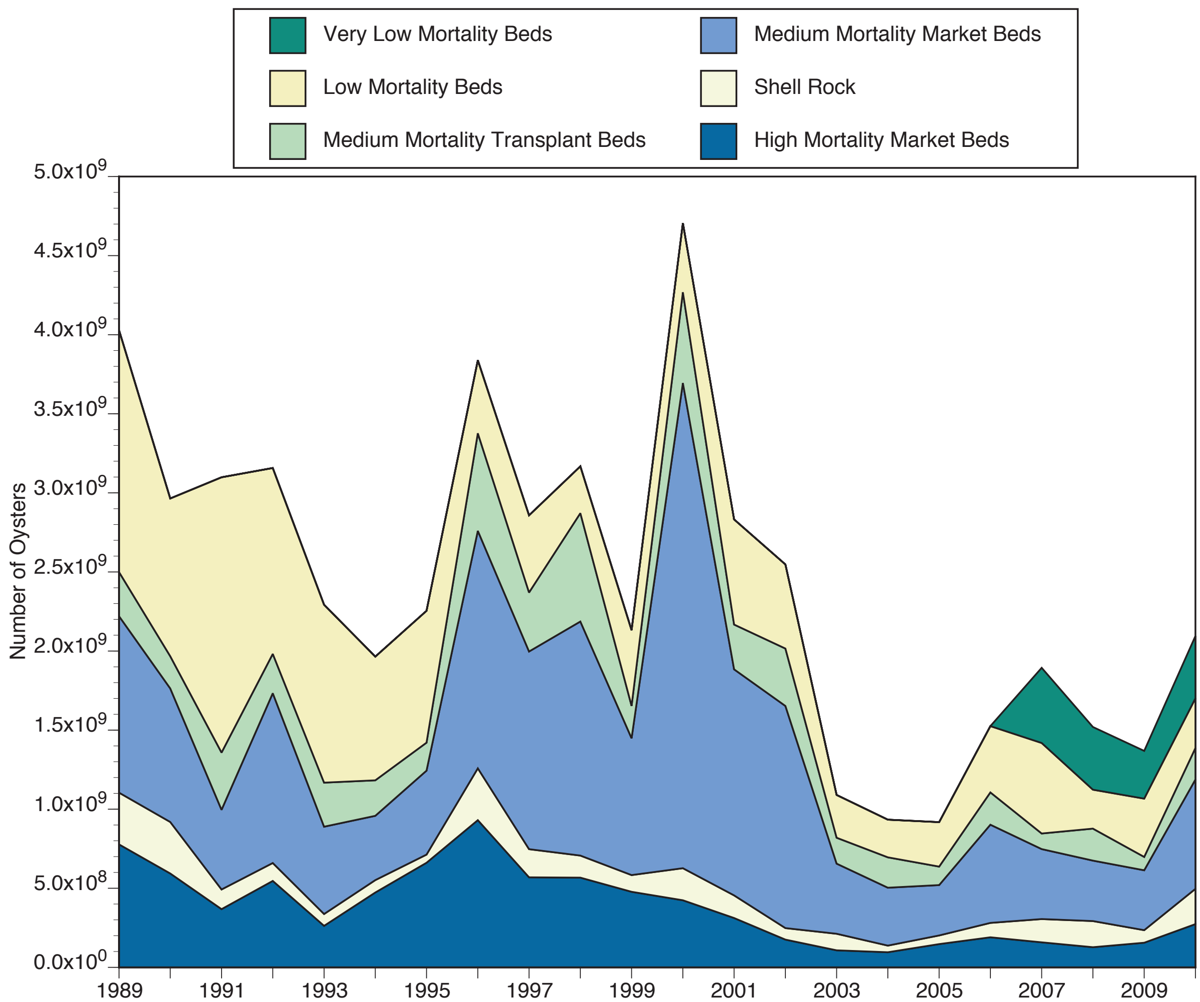


Figure 6. Position of the oyster stock in 2006-2010 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values.

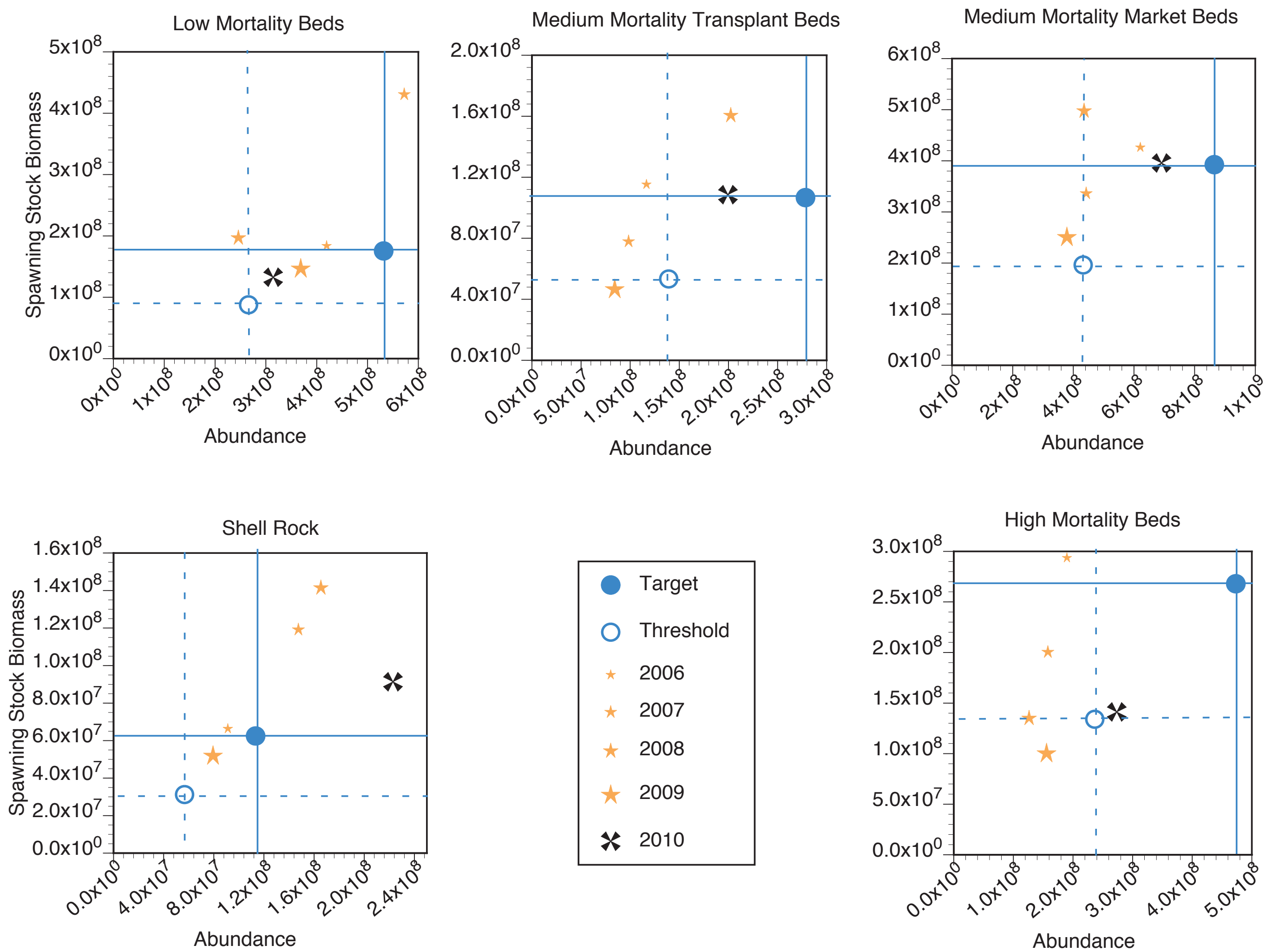


Figure 7. Number of spat recruiting for each bay region and for the stock as a whole, for the 1989-2010 time period. Bed distributions by bay region are given in Figure 5.

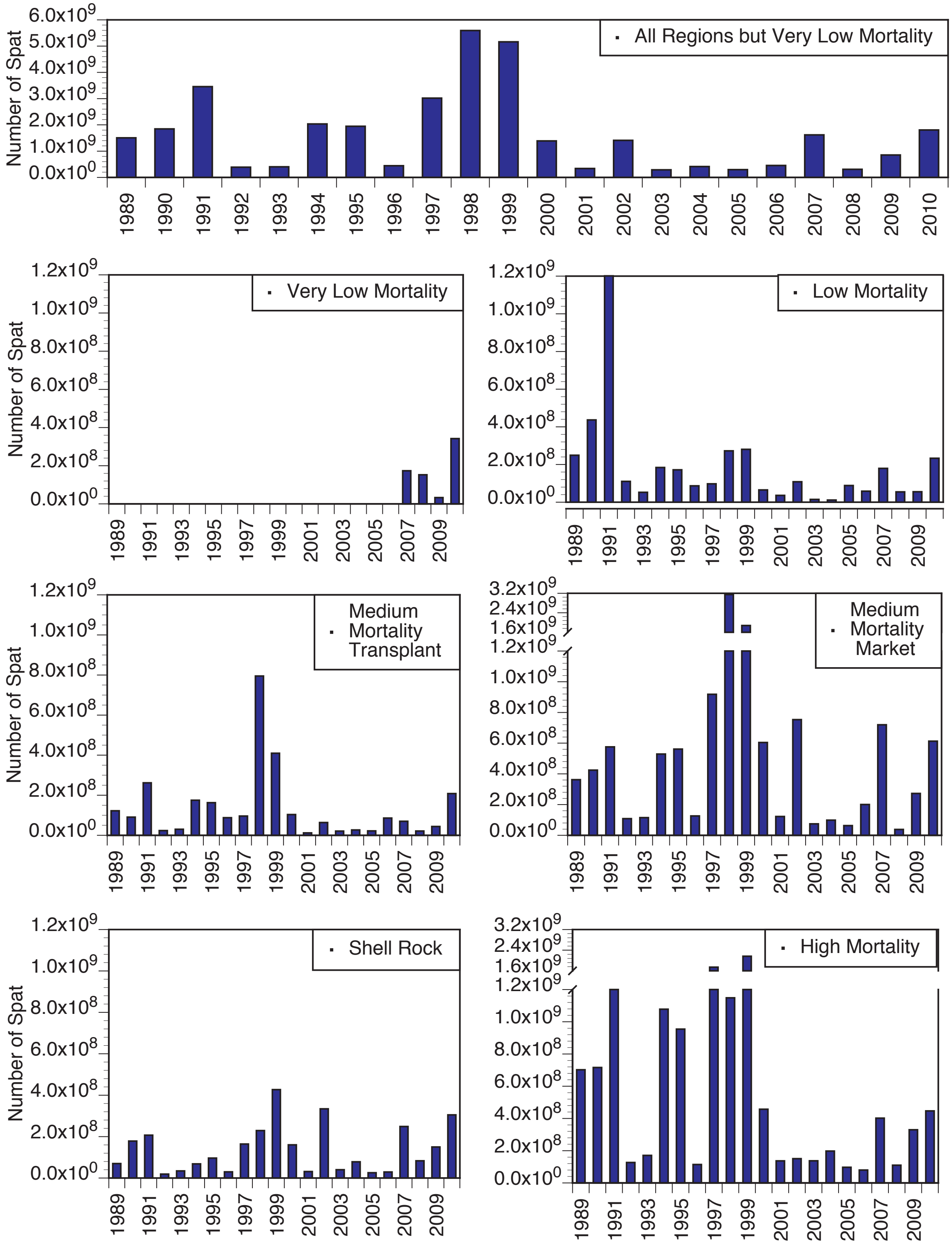


Figure 8. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 5. No data are available for the very-low-mortality beds prior to 2007.

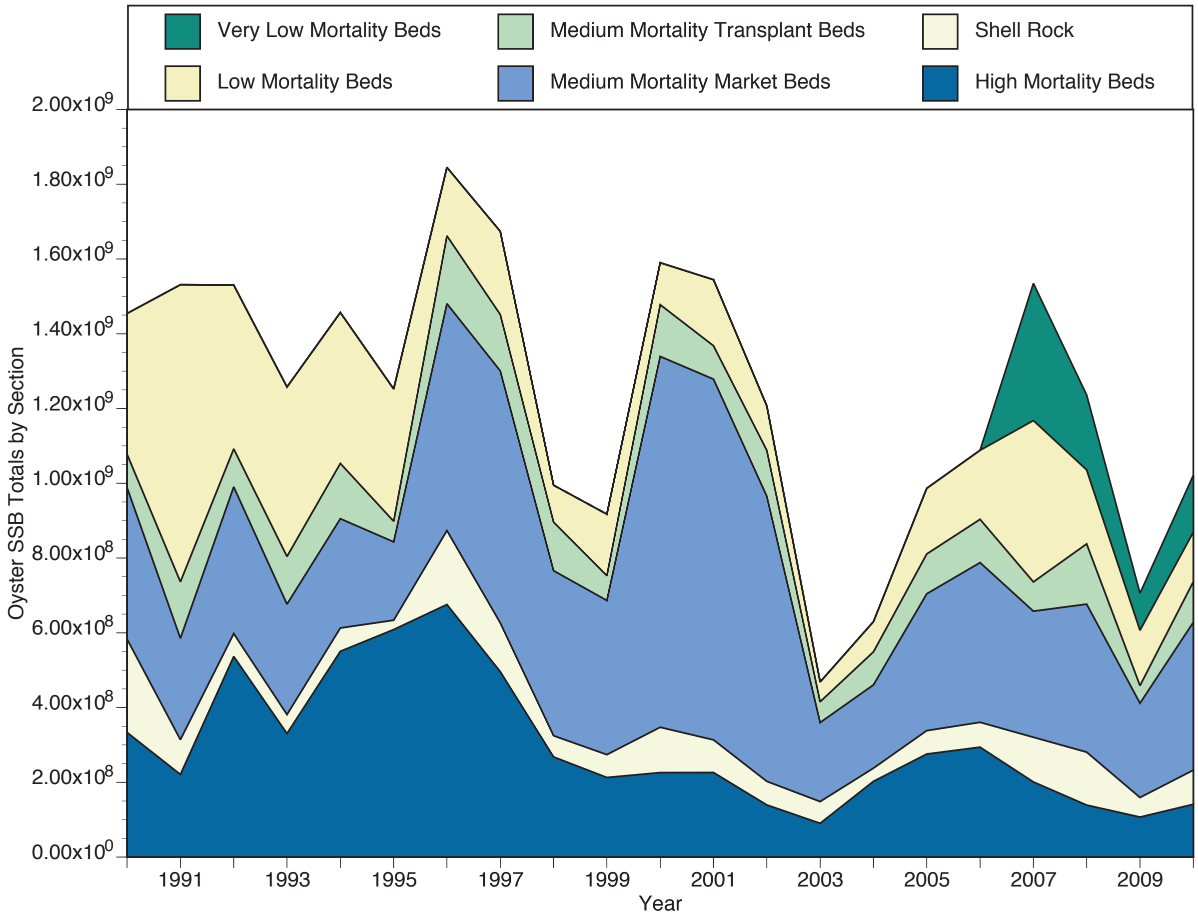


Figure 9. Position of the oyster stock in 2006-2010 with respect to market abundance ($\geq 2.5''$) and abundance targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989-2005 time period. The threshold is taken as half these values.

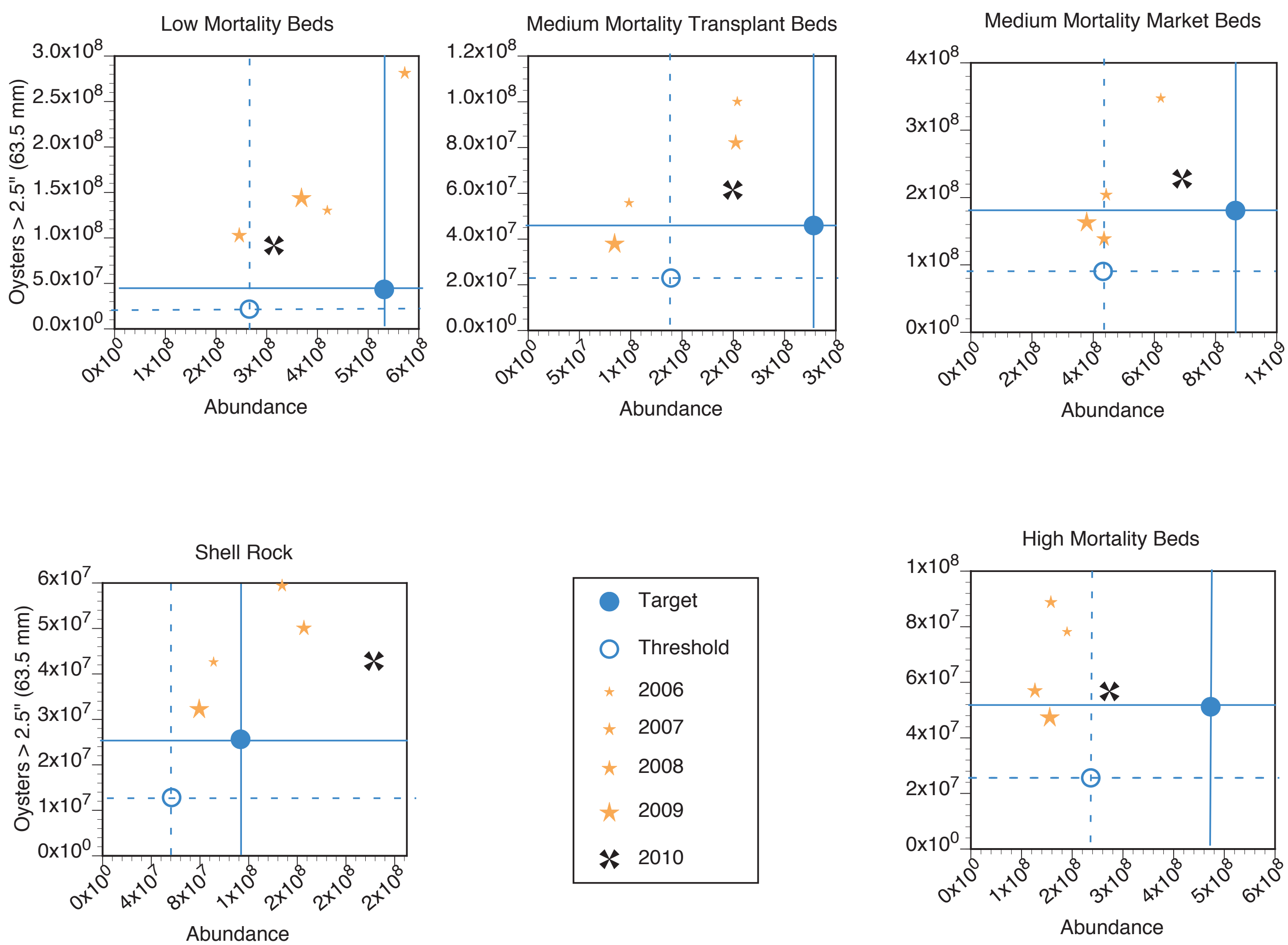


Figure 10. Exploitation rate (fraction of stock harvested) by bed region. Bed regions defined in Figure 5.

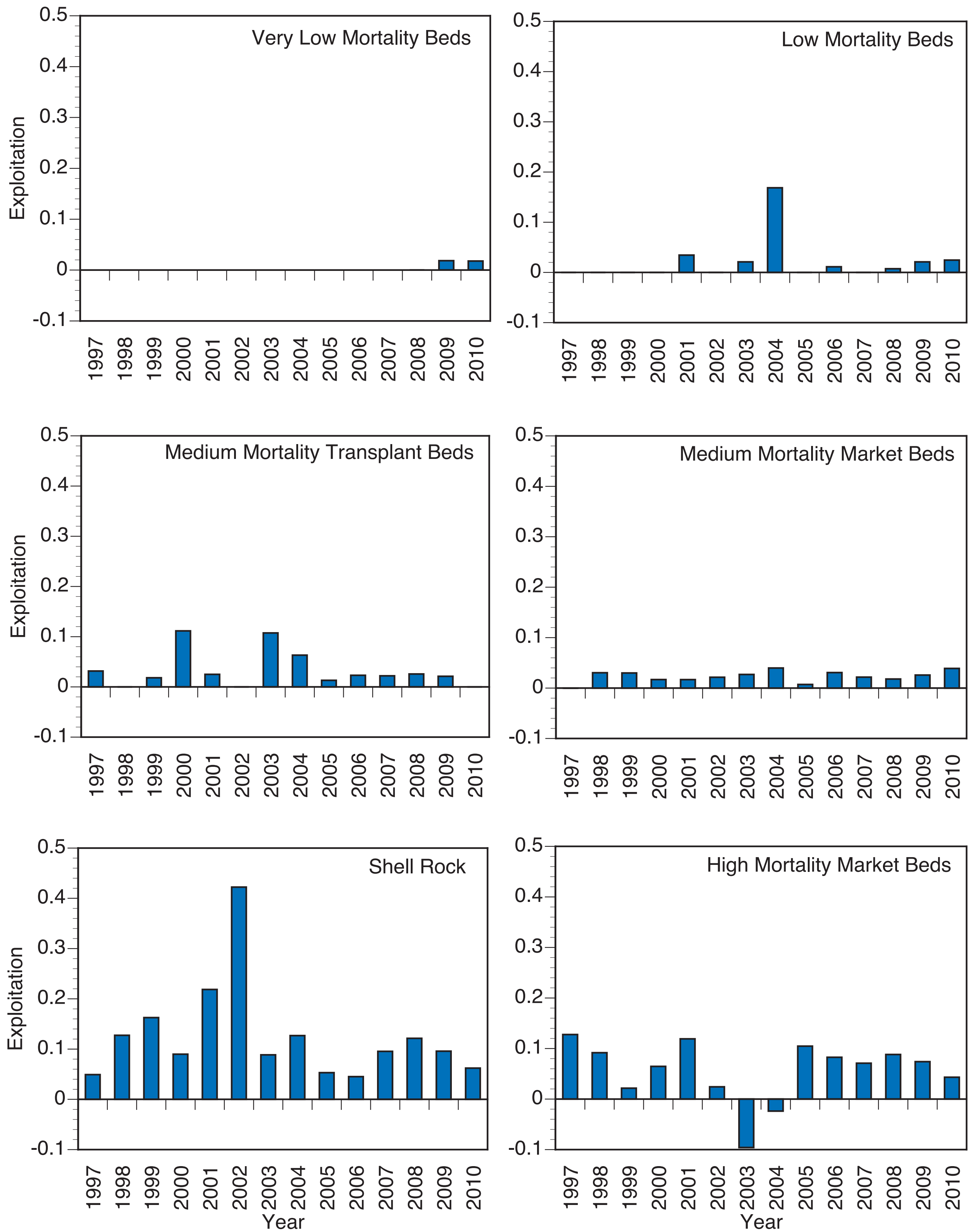
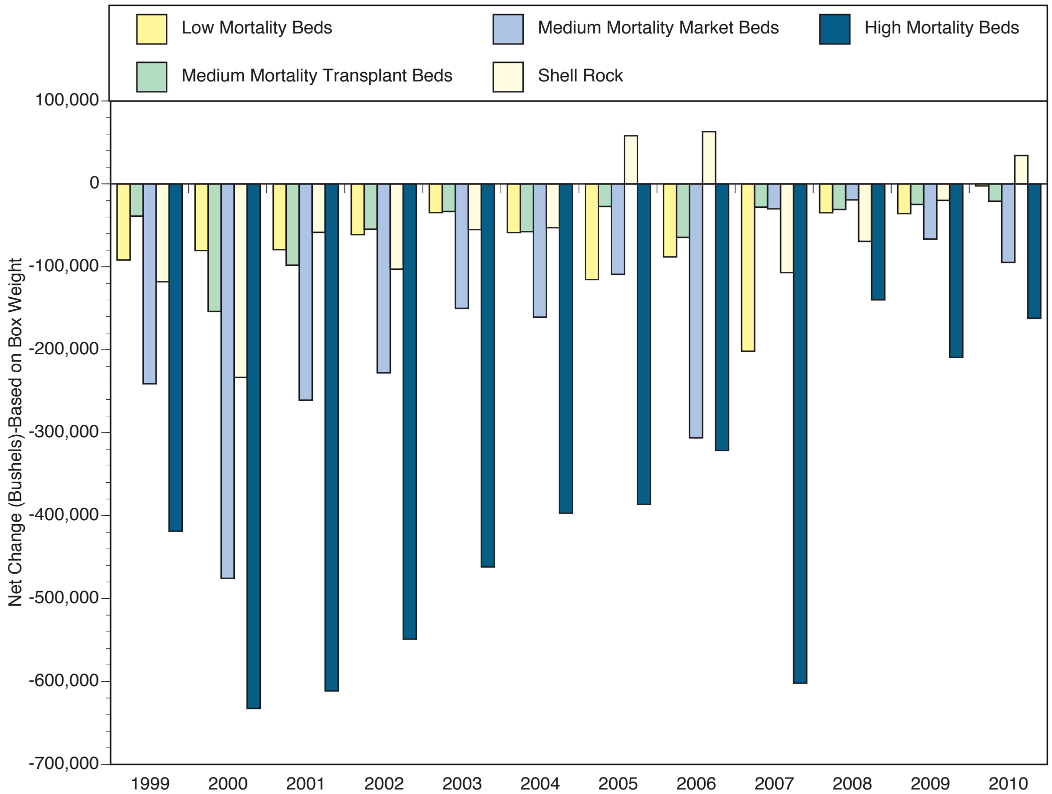


Figure 11. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2010. Positive values reflect the addition of shell through shell planting to offset shell loss.



Report of the
2011 Stock Assessment Workshop
(13^{th} SAW) for the
New Jersey Delaware Bay Oyster Beds

Presenters

Eric Powell, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory

Stock Assessment Review Committee

Russell Babb, New Jersey Department of Environmental Protection
Danielle Kreeger, Partnership for the Delaware Estuary
Barney Hollinger, Delaware Bay Section of the Shell Fisheries Council
Roger Mann, Virginia Institute of Marine Sciences
Bill Riggin, Delaware Bay Oyster Industry
Rich Wong, Delaware Department of Natural Resources
Mike Celestino, New Jersey Department of Environmental Protection
Olaf Jensen, Rutgers University
Patrick Banks, Louisiana Department of Wildlife and Fisheries

Editors:

Eric Powell, Haskin Shellfish Research Laboratory
Kathryn Ashton-Alcox, Haskin Shellfish Research Laboratory
David Bushek, Haskin Shellfish Research Laboratory

Distribution List

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

February 7-9, 2011

New Jersey Agricultural Experiment Station – Rutgers University

Table of Contents

2011 SAW
Table of Contents
Tables and Figures

2011 SAW
Table of Contents
Tables and Figures

Status of Stock and Fishery

Historical Overview

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly beginning in 1953. Circa-1989, Dermo became prevalent in the bay. Nearly coincidentally, beginning in 1990, the survey protocol was updated to include the measurement of oysters, thereby permitting calculation of biomass as well as abundance. Throughout this report, except where noted, present-day conditions will be compared to these two periods of time, the 1953-2010 period encompassing the entire survey time series and the 1989-2010 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 1989-2010 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 1989-2010 time series. All size-dependent indices begin in 1990 for reasons indicated previously. Evaluation of fishery exploitation by abundance focuses on the 1997-2010 time period during which the fishery has been conducted under a direct-marketing system. The direct-market program began in 1996, but the first full year of fishing under this program occurred in 1997.

Survey Design

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly, in the fall and/or winter, since 1953. Since 1989, this period has been concentrated into about one week in the latter part of October to early November, and has been conducted using a stratified random sampling method. Each bed is divided into 0.2-min latitude × 0.2-min longitude grids, each having an area of approximately 25 acres. Three strata are designated: the bed core (high quality), the bed proper (medium quality), and the bed margin (low quality). Each of the grids on each bed is assigned relative to the remaining grids on that bed to a specified stratum. A subset of grids, randomly selected, is chosen each year for survey from the high-quality and medium-quality strata on each bed.

Each survey sample represents a composite 37-quart bushel[⊘] obtained from three one-third bushels each taken from a separate one-minute measured tow within the target grid. A one-minute tow covers about 100-125 m^2. The current

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

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

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 2005, at the behest of the 6^{th} SAW, the entire survey time series from 1953 to the present-day was retrospectively quantitated. Also in 2004, a dock-side monitoring program began. This program obtains additional fishery-dependent information on the size and number of oysters marketed, permitting, beginning in 2004, the determination of exploitation based on spawning stock biomass as well as abundance. In 2006, sufficient information was available from the dock-side monitoring program to reconstruct the 1996-2003 exploitation rates.

Through 2004, most beds were sampled yearly; however a selection of minor beds were sampled every other year. Beginning in 2005, two important changes occurred. First, all beds were sampled each year with the exception of Egg Island and Ledge that continue to alternate due to their consistent low abundance. Second, over a four-year period (2005-2008), the primary oyster beds were re-surveyed resulting in a change in stratal definition and survey design from that used historically[•]. In the new system, the strata for re-surveyed beds were based on ordering grids within beds by abundance. Grids were defined by cumulatively accounting for the first 2% of the stock as low quality, the next 48% of the stock as medium quality, and the final 50% of the stock as high quality. As of the writing of this document, only two beds remain completely un-surveyed: Ledge and Egg Island. Beginning in 2008, full surveys of three new beds permitted their addition to the Fall stock survey: Hope Creek, Liston Range, and Fishing Creek (Figure 1). For two of these beds, some information is also available from a preliminary survey in 2007. No earlier data are present in the survey database, however; therefore, reconstruction of the 1953-2007 time series is not possible for these three beds. In the following data presentation, some analyses will exclude these beds as a consequence.

Finally, beginning in 2009, a few beds were re-surveyed each year on a 10-year

• 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.

rotating schedule (Table 1). For this assessment, the strata for Nantuxent Point and Ship John have been updated from 2009 based on the 2010 re-survey of these two beds. Evaluation of the density of oysters among grids confirmed findings from the re-surveys of previous years that a large number of low-quality grids could be deleted from the fall survey if the survey was focused on the grids on each bed that support 98% of the stock on that bed. This designation is consistent with the definition of a low-quality grid adopted in SAW-8 after the re-survey of the Bennies Sand to Middle reach. The remaining grids were input into a Monte Carlo model in which grids were subsampled repeatedly, without replacement, under a given set of rules, and the mean abundance estimated from the subsample compared to the mean abundance obtained from the average of all grids. Analysis of many simulations suggested that a random survey based on two strata would suffice, remembering that a third low-quality stratum had already been split out at the cost of 2% of the stock. These two strata were defined as before by assigning grids ordered by increasing abundance that cumulatively account for the first 48% of the stock to a 'medium-quality' stratum and grids that cumulatively account for the upper 50% of the stock to a 'high-quality' stratum (Figure 2). Figure 3 shows the new bed footprint for Nantuxent Point and Ship John.

A comparison of the Nantuxent Point and Ship John grid systems prior to the 2010 re-survey (Figure 4) with the revised grid system after the 2010 re-survey (Figure 3) shows that the beds as a whole retained approximately the same shape; however, the distribution of high-quality and medium-quality grids was substantially changed, particularly for Ship John (Figure 5). On Ship John, one low-quality grid was redesignated a high-quality grid, eight medium-quality grids were redesignated high quality, and six low-quality grids were redesignated medium quality. Eight high-quality grids were redesignated medium quality and four medium-quality grids were redesignated low quality. Thus a total of 26 of the 68 grids changed designations. Figure 5 shows that most grids increasing in quality were on the northeastern and southwestern sides of the bed. Most grids declining in quality were on the central bed region. The number of low-quality grids decreased by two. The number of high-quality grids increased by one. The number of medium-quality grids increased by one.

For Nantuxent Point, three medium-quality grids were redesignated high quality. Three high-quality grids were redesignated medium quality and two medium-quality grids were redesignated low quality. Thus, 8 of the 68 grids changed designation. The number of low-quality grids increased by two. Overall, the distribution of grids among strata and the locations of medium-quality and high-quality grids was little altered.

The October 2010 survey was constructed by randomly choosing a designated number of grids from each medium-quality and high-quality stratum on each bed.

Sampling was conducted from October 29 to November 2 using the oyster dredge boat *F/V Howard W. Sockwell* with Lemmy Robbins as captain. The sampling intensity is shown in Table 2 and the specific grids sampled are shown in Figure 1. Total sampling effort in 2010 was 158 grids, a value comparable to 2009. These included 14 transplant grids selectively sampled because they were sites of 2008, 2009, and 2010 shell plants or 2010 intermediate transplants.

Evaluation of 2010 Survey Bias

No additional information on dredge efficiency was available for this assessment. Dredge efficiency correction factors were obtained from Table 3[∅]. A retrospective analysis of dredge efficiency from data collected during the 2009 survey using the equations of Powell et al. (2007)[∇] estimated a value of q for total oysters for the upbay region as 14.30 in contrast to a range of 7.30-9.40 from direct measurements in Table 3. The value of q for the downbay region from this retrospective is 10.94 in contrast to a range of 2.83 to 4.87 from direct measurements. Previous estimates of this type have produced values of q for the upbay region varying from being consistent with direct measurements to higher than direct measurements with no apparent pattern (Figure 6). Previous estimates of this type for the downbay beds have often produced estimates of q above direct measurement, particularly since 2005. The trend for these beds has been towards increasing estimates of q relative to the directly measured values. Values obtained for the 2010 survey are high in comparison to previous estimates, but within the envelope of previous estimates for the upbay beds. For the downbay beds, 2010 survey estimates continue a slow rise since 2005, with the 2010 value being among the highest recorded. This suggests a possible decrease in dredge efficiency that, if true, would bias low the abundance estimates from the 2010 survey, particularly for the high-mortality beds and Shell Rock.

Oyster Abundance

Analytical Approach

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

---

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

∇ Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter. 2007. Re-evaluation of eastern oyster dredge efficiency in survey mode: Application in stock assessment. *N. Am. J. Fish. Manage.* 27:492-511.

timates of abundance sum the high-quality, medium-quality, and transplant strata only. Low-quality areas are excluded. The exclusion of the low-quality grids underestimates abundance by approximately 2%. In 2005, the 1953-1997 survey time series was retrospectively quantitated. These estimates were obtained by using bed-specific cultch density determined empirically from 1998-2004. This quantification assumes that cultch density is relatively stable over time. Comparison of retrospective estimates for 1998-2004, obtained using the 'stable cultch' assumption, with direct measurements for 1998-2004 suggests that yearly time-series estimates prior to 1997 may be biased by a factor of ≤ 2. Cultch varies with input rate from natural mortality and the temporal dynamics of this variation are unknown for the 1953-1997 time frame; however, recent improvements in the understanding of shell dynamics on Delaware Bay oyster beds show that shell is the most stable component of the survey sample and support the belief that a $\times 2$ error is unlikely to be exceeded. Accordingly, the quantitative time-series estimates are considered the best estimates for the 1953-1997 time period. Details of the retrospective quantification are provided by Powell et al. (2008)[ℵ].

All quantitative and post-1997 time-series estimates were corrected for dredge efficiency using the dredge efficiency measurements made in 2000 and 2003. The 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 $\geq$20 mm. Animals <20 mm are referred to as 'spat'. Adult oysters are animals $\geq$35 mm. Calculations of spawning stock biomass (SSB) are based on this size class and were derived using bed-specific and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size animals are divided into animals $\geq$76 mm and animals $\geq$63.5 mm, but <76 mm. These two size categories are based on a knife-edge selection of oysters for market by the fishery that has been routinely observed since monitoring began, in which nearly all harvested animals are $\geq$63.5 mm and the historical use of the 76-mm boundary to define a market oyster. In 2010, proportionately more smaller oysters were taken to the dock; however, analysis has retained these two size divisions for comparison to previous years. For a few analyses, size classes are variously defined depending on yearly growth increment and analytical goals as indicated. Shell planting permitted an estimate of the accuracy of the 20-mm size boundary for spat on Bennies Sand and Shell Rock. Additional information was provided by spat attached to clam shell planted in 2009. These 2010 shell plants revealed that many spat exceeded 20 mm by early November, 2010 (Figures 7-8). This suggests that the 2010 recruitment index is

ℵ Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter, S.E. Ford and D. Bushek. 2008. Long-term trends in oyster population dynamics in Delaware Bay: Regime shifts and response to disease. *J. Shellfish Res.* 27:729-755.

biased low.

A summary of the per-sampled-grid dataset providing the 2010 survey database is given in Table 4. Table 4 also provides a summary of data for each bed on a volumetric basis. Quantitative survey indices are the focus of the remainder of the analyses reported hereafter.

Abundance Trends

On a volumetric basis, 2010 abundance, bay-wide, was significantly higher than many years in the decade of the 2000s (Table 5). The bay-wide average number of 229 oysters bu^{-1} in 2010 fell well above the 1990-2010 average of 167 oysters bu^{-1}, but not significantly so. Quantitative estimates using the time-series analysis indicate that bay-wide oyster abundance exclusive of the very-low-mortality beds rose substantially from 2009, an abundance level lower than most years since 1988. In fact, the 2010 abundance of 1,700,989,952 was distinctly higher than any year since 2002. Including the verylow-mortality beds raises the total to 2,094,983,168 (Figures 9 and 10). Abundance in 2010 fell at the 21st percentile of the 1953-2010 time series and the 38th percentile post-1988, so abundance remains well below historical mean values (Table 6).

Most (52.4%) (42.5% including the very-low-mortality beds) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figure 11), a proportion somewhat above the 43.4% recorded in 2009, due primarily to a decrease in oyster abundance on the low-mortality beds, but in keeping with the distribution of oysters in most years post-1995, during which time this bed region has consistently accounted for about half of the stock (Figure 12). Of this, 77.6% were on the three market beds, Ship John, Cohansey, and Sea Breeze. Examination of the fraction of oysters on the medium-mortality beds shows that the period beginning in 1996 is unique in the 58-year time series in continual above-median proportions of oysters on these beds (Figure 12). Abundance on the medium-mortality beds rose substantially from 2009 to a level not seen since the early 2000s. Abundance on the medium-mortality beds ranked at the 27th percentile (transplant beds) and 42rd percentile (market beds) of the 58-yr time series, but at the 33nd percentile (transplant) and 52nd percentile (market) post-1988 (Table 6). The number of oysters per bushel deviated significantly from only a few of the the remainder of the years in the 1990-2010 time series (Table 7). Year 1996 was significantly higher and four years in the 2000s averaged significantly lower than the 2010 value of 289 oysters bu^{-1}.

Abundance in 2010 on the low-mortality beds dropped modestly from 2009, and remained low relative to the historical record; the 11th percentile for the 1953-

2010 time series and the 25^{th} percentile for the post-1988 era (Table 6). Abundance was comparable, however, to most other years since 2002. The low-mortality beds contributed 34.6% of the stock in 2009, but only 18.5% of the stock at the end of 2010 (15.0% including the very-low-mortality beds) (Figure 11). However, much of this change was due to increased abundance downbay, rather than a decline in abundance in this bed region. The number of oysters per bushel differed significantly only from four years in the early 1990s within the 1990-2010 time series (Table 8).

Abundance nearly doubled in 2010 on the high-mortality beds to a level not seen since 2001. The entire high-mortality bed region contributed 16.1% to the total stock (13.1% including the very-low-mortality beds), a value higher than observed since 1999, but lower than routinely observed in the 1990s (Figure 11). Abundance on the high-mortality beds ranked at the 33^{rd} and 43^{rd} percentiles, respectively, for the 58-year time series and the time series post-1988 (Table 6). The number of oysters per bushel of 176 was the second highest recorded post-1988 and differed significantly from most years in the decade of the 2000s (Table 9).

Abundance in 2010 rose by a factor of 2.8 on Shell Rock from 2009. Abundance in 2010 neared the highest values observed in the post-1988 era. The increase is consistent with increases observed in all bed regions downbay of the low-mortality beds, suggesting that survey bias is not a likely explanation for the observed abundance increase. Shell Rock contributed 13.1% of the stock in 2010 (10.6% including the very-low-mortality beds) (Figure 11). Abundance on Shell Rock ranked at the 63^{rd} and 84^{th} percentiles, respectively, for the 58-year time series and the time series post-1988 (Table 6).

The very-low-mortality beds contained 18.9% of the stock in 2010. Insufficient data are available to generate percentile comparisons to earlier years, nor can trends be evaluated at this time.

Spawning Stock Biomass (SSB)

Spawning stock biomass rose modestly in 2010, a low value relative to values typically observed post-1989, but consistent with values observed since 2002 (Figure 13). SSB in 2010 was at the 18^{th} percentile of the 1990-2010 time series (Table 6). SSB rose in all bay regions except for the low-mortality beds, with greatest increases downbay of this region, extending to a near doubling on Shell Rock (Figure 13). For the low-mortality beds, the medium-mortality beds, transplant and market, Shell Rock, and the high-mortality beds, the percentiles were the 26^{th}, 50^{th}, 50^{th}, 64^{th}, and 21^{st}, respectively (Table 6).

SSB is highest on the medium-mortality beds in most years. In 2010, these beds contributed 58.0% of the stock's SSB (Figure 14). SSB was more concentrated on the medium-mortality beds in 2010 than during the 2004-2009 period, and higher than routinely observed except for the 1999-2001 time period. The low-mortality beds contributed an additional 15.2%. Shell Rock contributed 10.5% and the high-mortality beds, 16.2%. Including the very-low-mortality beds, the fractions of SSB contributed by the five bay regions are 14.9% (very-low-mortality), 13.0% (low-mortality), 49.4% (medium-mortality), 8.9% (Shell Rock), and 13.8% (high-mortality). These regional fractions are nearly identical to those observed in 2008 and 2009, with the exception of a slight decrease in contribution from the low-mortality beds. The medium-mortality market beds contributed proportionately more to the medium-mortality fraction in 2010 than in 2008 and 2009, however.

Oyster Size Frequency

Perusal of the 1990-2010 time series exclusive of the very-low-mortality beds shows that the fraction of the population $<2.5''$ was high in the early 1990s, then declined somewhat, and rose again through 2001 (Figure 15). The fraction of animals below $2.5''$ remained low thereafter until this year, when the proportion of small individuals rose to values only slightly lower than routinely observed through most of the 1990s. In 2010, including the very-low-mortality beds, 72.3% of the animals were below $2.5''$ and 12.4% of the animals were $\geq 3''$ in size. Excluding the very-low-mortality beds, animals below $2.5''$ contributed a similar 71.6% of the stock; 13.9% of the stock exceeds $3''$ (Figure 15). The number of animals $<2.5''$ nearly doubled in 2010 from the previous few years, reaching a value only slightly below values observed in some years during the 1990s, whereas the number of larger animals remained near the decadal average and well above the average of the previous decade (Figure 16). Much of the shift in size frequency at the 2000/2001 decadal transition was originally thought due to the loss of small animals during an extended period of low recruitment after 1999, that extended through 2008. Recent information suggests that an increase in growth rate may have contributed substantially to this trend as well (see later discussion). The increase in abundance in 2010 of animals below $2.5''$, however, is accompanied by a continued high abundance of market-size ($>3''$) animals. Such an event is not elsewhere recorded in the 1990-2010 time series.

The 2009 recruitment was relatively high downbay, but declined in significance upbay of Shell Rock. This pattern of decreasing recruitment upbay has been the standard situation over the 1990-2010 time period for which data are available. The 2010 increase in abundance of small animals ($<2.5''$) was noticeably higher downbay, consistent with the 2009 recruitment trend (Figure 17). A large increase in abundance in this smallest size class was observed on Shell Rock and the high-mortality beds, a lesser increase on the medium-mortality beds, and minimal change upbay of this region (Figure 17). Small oysters accounted for 70.8% of the animals on the low-mortality beds, a fraction below the long-term trends due to persistent low recruitment and increased average size, but increased relative to the four previous years. This increase in small oysters, however, was due to a relatively high mortality for the larger size classes rather than increased abundance in this size class. The fraction of small animals on the low-mortality beds has been unusually low since 2003 until this year: historical values routinely exceeded this year's 70% value, however. More than half of all animals (transplant beds, 69.1%; market beds, 66.9%) on the medium-mortality beds were $\leq 2.5''$ in size. This proportion is also low relative to historical levels set in the 1990s through 2002 that routinely exceeded 70%, but higher than values observed since 2002. Small oysters contributed 80.7% of the stock for Shell Rock, a value exceeding most previous years including the 1990s, and 78.7% for the high-mortality beds, a value not seen since 2001, but routinely exceeded, though not by much, in the 1990s.

Thus, on no bed area did marketable oysters contribute the majority of the stock; on only one bed area, Shell Rock, did the small-oyster-dominated size frequency of the 1990s exist; but consistently across the bay, the ratio of markets to small animals was lower than over most of the 2000s and this trend was produced by an increase in the number of small animals, rather than a decline in the number of large ones. The time period since 2002, until this year, is characterized by a distinctly increased proportion of larger animals, with the low-mortality beds responding distinctly later (~2003) than the regions further downbay. Year 2010, therefore marks a dramatic change in size frequency from the previous decade. Note in Figure 17 that a trend towards increased numbers of small oysters, albeit still well below the 1990s level, during 2006-2008, observed in many bed regions, and reversed in 2009, was reinstituted in 2010. Numbers of small oysters increased in all bed regions except for the low-mortality beds.

Of the oysters $\geq 2.5''$, 48.9% were $\geq 3''$ in size (Figure 18). The proportion of small markets ($<3''$) relative to larger markets has remained relatively stable since 2002, but was much higher earlier in the time series. Large markets made up the larger percentage on the high-mortality beds: 60.8%. The proportion was almost even for Shell Rock, 49.2%, and the medium-mortality market beds, 53.7%, but much lower for the medium-mortality transplant beds, 40.0%, and the low-mortality beds, 35.5%. In all bay regions except the medium-mortality transplant beds, the fraction of marketable animals $>3''$ is near historical highs and in this last bed region, the fraction exceeds values for all years except 2005-2009.

The number of animals of market size ($\geq 2.5''$) rose modestly from 2009, a value at the 50^{th} percentile of the 1990-2010 time series (Table 6, Figure 19). The abundance of these larger animals rose in all bed regions except the low-mortality beds, where a distinct decline was observed (Figure 20). The increment in abundance of these larger animals was substantial in all downbay regions. By percentile, the number of marketable animals fell at the 50^{th}, 64^{th}, 69^{th}, 69^{th}, and 31^{st} percentiles for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and high-mortality beds, respectively, for the 1990-2010 time series (Table 6).

Oyster Condition and Growth

Condition index remained low in 2010, very near the value observed in 2009, and lower than three of the immediately prior four years. The condition index value for 2010 was typical of the late 1990s-early 2000s (Figure 21). Condition was just above or just below the 2009 value in all bay sections (Figure 22). The expected decline in condition upbay, observed in many years, did not materialize in 2010 because condition was disproportionately low downbay (or high upbay). Low condition can be expected to lower SSB; the increase in SSB noted in Figure 13 noted in nearly all bay regions is particularly significant given the dampening effect of low condition.

No new growth rate data were available for this assessment. Growth rates were estimated from von-Bertalanffy relationships provided by Kraeuter et al.[†] The von-Bertalanffy parameters used, L_∞, k, and $t_\circ$ respectively, are: for the low-mortality beds (data from Arnolds), 110 mm, .175 yr^{-1}, .2 yr; for the medium-mortality beds (data from Middle and Cohansey), 125 mm, .23 yr^{-1}, .2 yr; for Shell Rock, 125 mm, .25 yr^{-1}, .2 yr; and for the high-mortality beds (data from New Beds) 140 mm, .23 yr^{-1}, .2 yr. Minimum sizes reaching $3''$ in one season were found to be: high-mortality beds $2.34''$, Shell Rock, $2.48''$; medium-mortality beds, $2.51''$; and low-mortality beds, $2.76''$ (Table 10).

Growth data are not available for the 1990s. Trends in size frequency suggest that growth rate may have been slower in the 1990s and faster recently. We used a population dynamics model (DyPoGEn: Powell et al., 2011)[ς] to evaluate a possible shift in the von-Bertalanffy growth curve. The Kraeuter et al. (2007) data come from 2000 and so may be representative of the transition time. Simulations with DyPoGEn suggest that the change in length frequency between the mid-1990s and mid-2000s (Figure 16) would require a change of 35-45% in the von-Bertalanffy *k* parameter, assuming L_∞ remains unchanged. A similar effect comes from dropping the L_∞ about 25%. An example using the data for Bennies bed is provided in

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

[ς] Powell, E.N., J.M. Klinck and E.E. Hofmann. 2011. Generation time and the stability of sex-determining alleles in oyster populations as deduced using a gene-based population dynamics model. *J. Theor. Biol.* 271:27-43.

Figure 23.

Oyster Sex Ratio

No new information is available concerning oyster sex ratio. A survey was conducted on each of the primary beds in June 2008 to determine the sex ratio of animals as a function of size. The percent female increased with size and age as anticipated. Relationships between size and percent female by bed were applied to the size-frequency data from the Fall 2009 survey data by SAW-12. The population at that time was estimated in all bed regions to be about 40% female. Market-size animals were estimated to be about 60% to 65% female. Trends in size frequency towards an increased number of smaller oysters suggest that the proportion of males very likely increased in the population in 2010.

Surplus Production

Surplus production is defined for this analysis as the number of animals available for harvest under the expectation of no net change in ≥76-mm oyster abundance over the year, given a specified natural mortality rate and growth rate. If fishing mortality rate is set to zero, surplus production as calculated herein is equivalent to the differential between the number of animals expected to recruit to the ≥76-mm size class in a year less the number of such animals expected to die naturally. In the absence of fishing, a positive surplus production indicates that the ≥76-mm portion of the population is expected to expand in abundance. If negative, this segment of the population is expected to contract even in the absence of fishing. The model used for the calculation assumes an uneven distribution of mortality rate during the year as observed; however this assumption is only noteworthy if the fishery removes oysters before the primary season of Dermo mortality in the late summer and early fall. The fishery has routinely done so; thus, some component of natural mortality is compensatory. A detailed description is found in Klinck et al. (2001)[⊕]. Surplus production was estimated using the 50^{th} and 75^{th} percentiles of natural mortality rate. As a probabilistic application of growth rate cannot yet be done, surplus production projections used the size range of animals expected to grow to 3″ in one growing season obtained from the von-Bertalanffy curves of Kraeuter et al. (2007) (Table 10).

Bay-wide surplus production projections for 2011 are positive, and higher than the previous two years (Table 11). Surplus production was projected to be higher in all bay regions except for the low-mortality beds, where a moderate decrease was projected to occur, relative to 2010. However, the projection remains strongly positive. A projection was made for the very-low-mortality beds for the first time,

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

based on two assumptions. First, the growth rate was assumed to be similar to that observed on the low-mortality beds, as no direct observations are available. Second, a low and a high mortality rate were chosen from the 2007-2010 time series as a surrogate for the 50^{th} and 75^{th} percentile rate used for the remaining bed regions.

Surplus production projections have been high relative to exploitation rates, except for the high-mortality beds and Shell Rock. Concern over what were interpreted to be unrealistic surplus production rates upbay led to the abandonment of the original surplus production reference point used in the early SAWs and replacement with the present exploitation-based reference point system[κ]. SAW-12 initiated an examination of the accuracy of the surplus production projections through retrospective examination. Here, we expand that examination by evaluating a series of years since 2004.

The retrospective examination is in two parts. First, we compare the realized surplus production with the previous year's projection. In this case, the appropriate comparison uses the abundance and natural mortality indices from the survey, without consideration of the landings. Positive differentials between realization and prediction indicate that the projection underestimated surplus production. Negative differentials indicate that the projection overestimated surplus production. Realized surplus production is calculated as:

$$Surplus\,Production_{t+1} = N_{recruit_t} - Deaths_{\geq 76_{t+1}} - Deaths_{recruit_{t+1}}$$

where recruits are those oysters expected to recruit to the ≥76-mm size class in $t \rightarrow t+1$ and times t and $t+1$ represent consecutive October surveys.

Secondly, we include the catch in the retrospective to examine the appropriateness of previous management decisions. Thus this evaluation focuses on the possibility that catch was forgone under the original assumption of no net change in ≥76-mm abundance. Positive numbers indicate that the quota was underestimated under this assumption. Negative numbers indicate that the quota was overestimated under this assumption. Assuming that the goal is $N_{76_t} = N_{76_{t+1}}$, then

$$\begin{aligned} Net\,Surplus\,Production_{t+1} = & N_{recruit_t} - Deaths_{\geq 76_{t+1}} - Deaths_{recruit_{t+1}} \\ & - Landings_{\geq 76_{t+1}} - Landings_{recruit_{t+1}} \end{aligned}$$

where times t and $t+1$ represent consecutive October survey indices or, for landings,

[κ] The exploitation-based reference point system also stabilized year-to-year variability in the quota that was a byproduct of the more volatile surplus production projection.

the yearly tally between surveys. A negative net surplus production would indicate landings higher than a sustainable level for the stock for that year under the assumed goal. A positive net surplus production would indicate forgone yield.

In either case, a retrospective examination rests on several assumptions concerning the available data. The projections are based on the designation of a ≥76-mm oyster as a size class to be conserved yearly, so that the number of individuals neither increases nor declines. Thus, surplus production, as defined in this analysis is equivalent to the number of animals that will recruit into that size class debited by the number of animals that will die during the year in the recruit size class and the ≥76-mm size class. The data for the retrospective includes known numbers of animals in each of these size classes at the beginning and ending of the year (the previous year's and present year's surveys). In addition, survey and landings data provide the size frequencies of the deaths. Boxes and landed oysters ≥76-mm are unambiguous as they came from one of the two initial size classes. Boxes or landings of recruit size, however, are ambiguous. These animals may have been of recruit size in the previous year's survey and thus used in the original projection. However, they may have been pre-recruits that grew into recruit size during the year, prior to their death or capture. These would not be in the previous year's projections. Unfortunately, no information is available to decipher to what degree boxes or landed animals of recruit size included animals of pre-recruit size in the initial survey (time t). Thus, two retrospective calculations are required to bound the evaluation of the original projection: (a) boxes or landed animals of recruit size were of recruit size in the previous year's survey; or (b) boxes or landed animals of recruit size were smaller than recruit size in the previous year's survey. This results in a high and a low estimate of surplus production that must bound the true value.

In addition, the intermediate transplants are included in the retrospective calculation. These are not present in the projections, as no knowledge of that endeavor is available at that time. Thus, intermediate transplant introduces an assured deviation between observation and projection. However, the inclusion of these animals provides a mechanism to evaluate the adequacy of the overall quota-setting process relative to the information available at the time of quota setting, namely the exploitation rate reference points and the surplus production projections.

Results of the comparison between predicted (e.g., Table 11) and realized surplus production are found in Figure 24. Green shades in the left-hand table in Figure 24 indicate cases were the lower and upper bounds to the surplus production estimate were positive, indicating forgone yield. Red shades in the left-hand table in Figure 24 indicate cases were the lower and upper bounds to the surplus production estimate were negative, indicating a suggested fishing level exceeding a level permitting the desired goal of $N_{3''_t} = N_{3''_{t+1}}$. Grey indicates an estimate that fell between the two bounds. Arguably, this is the desired outcome as the goal of $N_{3''_t} = N_{3''_{t+1}}$ exists between the two bounds. Surplus production projections frequently overestimate the coming year's actual surplus production. Using the 75^{th} percentile of mortality rate produces estimates closer to observed outcomes routinely, suggesting that this precautionary approach, promulgated by early SAWs, was a relatively good one. Furthermore, the retrospective shows that the approach has routinely performed better on Shell Rock and the high-mortality beds than on the medium-mortality beds, in keeping as well with inferences made at previous SAWs.

To examine the outcomes of management policies, two additional sources of uncertainty are particularly important to evaluate; uncertainty in mortality rate and growth rate. Because the survey tracks the sizes of boxes and because the port-sampling program tracks the sizes of the landings, a minimal estimate of mortality rate is available. Mortality rate cannot be less than this number. Thus uncertainty in mortality rate comes from the possibility that some boxes are not observed, due to their disarticulation prior to sampling. Thus mortality rate may be higher than observed. How much higher is uncertain. We use the assumption of a 25% and a 50% underestimate to evaluate the outcome under alternative mortality rates. Growth rates may be overestimated or underestimated. Arguably, the growth rates provided by Kraeuter et al. (2007)† were obtained during a period of rapid change in growth from a slow-growth decade to a faster-growth decade. Simulations using DyPoGEn suggest a possible range of growth rate based on a 40% change in the Bertalanffy k parameter for Bennies (Figure 25). We assume a $k \pm 0.04$ for evaluation of uncertainty.

Results of this second retrospective are first provided by simply examining whether the management measures imposed resulted in forgone yield. Green shades in Figure 26a-b indicate cases where the estimate of net surplus production exceeded the lower and upper bounds, indicating forgone yield. The quota might have been set higher for that bed region and year while still achieving the goal of $N_{3''_t} = N_{3''_{t+1}}$. Red shades in Figure 26a-b indicate cases where the estimate of net surplus production fell below the upper and lower bounds, indicating that a fishing level occurred that exceeded the level permitting achievement of the desired goal of $N_{3''_t} = N_{3''_{t+1}}$. Grey indicates an estimate that fell between the two bounds. Arguably, this is the desired outcome as the goal of $N_{3''_t} = N_{3''_{t+1}}$ exists between the two bounds. The results show that in most years for most bay regions, either the outcome is as desired or that forgone yield occurred. Thus, overall, management measures imposed have been precautionary. Examination of the states of nature show that faster growth did not much change the overall

† Op. cit.

evaluation of the management strategy. Slower growth resulted in some additional years in which the ≥76-mm size class was not conserved, an undesirable outcome. This undesirable outcome was most common in the high-mortality and medium-mortality bed regions. No case occurred upbay of the medium-mortality beds and in only one case on Shell Rock. Assuming that the mortality rate was underestimated produced a pattern relatively similar to the assumption of slower growth. Year 2010 showed a somewhat less favorable outcome than preceding years.

The scale of the deviation from zero for net surplus production is included in the rendering provided in Figure 27. Interpretation is relatively similar to Figure 26a. In most cases, substantial yield has been forgone in most bay regions. However, cases otherwise typically show considerable overharvesting. This outcome was most apparent in 2010. One interesting consideration comes from comparison of market-size abundance between 2009 and 2010 as observed in the survey and the surplus production retrospective estimates. The fast-growth assumption shows a mildly negative outcome for the medium-mortality transplant beds and the high-mortality market beds, and a positive outcome for the medium-mortality market beds. These are distinctly divergent from the other states of nature in Figure 27. The 2009-2010 trends in abundance agree best with the fast-growth outcome, suggesting that this state of nature may be more appropriate for comparison than the remaining three.

Care should be given to interpreting Figures 26 and 27 based on the uncertainty of the survey indices (to be described in a subsequent section) and the uncertainty in the assumptions underlying oyster growth rate.

Recruitment

Spat set in 2009 though low by historical standards was one of the highest during the 2000s, exceeded only by 2002 and 2007. Spat set in 2010 was substantively higher in all bed regions than in 2009 and more than a factor of 5 higher upbay of the medium-mortality market beds (Figures 28 and 29). This value is biased low, at least for the Shell Rock downbay, as an estimated 40-65% of the spat observed this year were greater than 20 mm long on Shell Rock and the high-mortality beds (Figures 7-8). The recruitment index does not directly influence most status-of-the-stock metrics, as abundance and biomass metrics are based on all animals >20 mm. Moreover, uncertainty in the recruitment index is absorbed in the estimation of 'unrecorded mortality' that is a component of the analysis of N_{msy} reference points and surplus production. Nevertheless, all primary recruitment indices and indices based on spat-per-adult should be taken provisionally until further evaluation of recruitment index bias can be undertaken.

The number of spat per bushel averaged over all survey samples was above the long-term average of 92 for the 1990-2010 time series (Table 5). Only one year was significantly higher than the 2010 value of 177 spat bu^{-1}, 1991; significantly lower years include all years in the 2000s and some in the 1990s (Table 5). The same metric by bay region reveals that the number of spat per bushel on the high-mortality beds was not significantly different from the 1989-2010 mean, and significantly different from only three years (Table 9). For the medium-mortality beds, the number of spat per bushel of 227 was significantly higher than in all years in the 2000s except 2007 (Table 7). A more extreme trend was observed on the low-mortality beds (Table 8), in which the 2010 value of 179 spat bu^{-1} was significantly lower than only one year, 1991, and significantly higher than all but three of the remaining years. This year, 2010, marks the third highest recruitment year in the post-1988 time series for the low-mortality beds and the highest since 1991.

The 2010 spat settlement ranked at the 51^{st} percentile for the 1953-2010 time series and at the 66^{th} percentile post-1988 (Table 6). Recruitment estimated quantitatively for each bay region fell at the 46^{th}, 56^{th}, 58^{th}, 75^{th}, and 51^{st} percentiles of the 1953-2010 time series for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and the high-mortality beds, respectively. The percentile values for the 1989-2010 time series, in the same order, were 75^{th}, 84^{th}, 75^{th}, 89^{th}, and 57^{th} (Table 6). The upbay-downbay gradient in recruitment in which recruitment tends to increase downbay, present in most years, was muted in 2010. Recruitment was high bay-wide.

The number of spat recruiting per oyster exceeded 1.0 in 2010, an event seen only six times previously in the post-1988 era (Figure 30), a value at the 77^{th} percentile of the 1953-2010 time series and at the 80^{th} percentile for the 1989-2010 time series (Table 6). The ratio of spat to oyster varies from bed region to bed region with high recruitment events, defined as exceeding 1 spat per oyster, occurring simultaneously on all bed regions infrequently (Figure 31). Recruitment has been consistently higher downbay than upbay, per adult, for many years. In 2010, this trend was less well developed due to unusually good recruitment upbay. The ratio of spat to adult was 1.37 and 1.63 on Shell Rock and the high-mortality beds, respectively, while falling only to 0.89 on the medium-mortality market beds, 1.04 on the medium-mortality transplant beds, 0.74 on the low-mortality beds, and 0.87 on the very-low-mortality beds (Figure 31). The respective percentiles for the 1953-2010 time series for the low-mortality, medium-mortality transplant, medium-mortality market, Shell Rock, and high-mortality beds are: 77^{th}, 80^{th}, 66^{th}, 72^{nd}, and 68^{th}. Percentiles were similar for the 1989-2010 time series at 93^{rd}, 90^{th}, 71^{st}, 61^{st}, and 61^{st}, respectively (Table 6).

Shell planting had an impact on the spat-to-adult ratio in 2010, similar to previous years, raising it from 1.06 to 1.22. Shell plants raised the spat-to-adult ratio significantly above 2 (2.18) on the high-mortality beds and up to 1.94 on Shell Rock (Table 12).

Recruitment-enhancement Program

Shell-planting was carried out in June-July, 2010. Ocean quahog and surf clam shell were used. Shell was planted in 2010 as follows: Bennies Sand 4, 49,645 bu; Shell Rock 23, 40,199 bu (Figure 32).

Total spat were estimated from dry dredge samples, using a correction factor 1.75 as estimated in SAW-11. The survey dry dredge oversamples spat on planted shell because smaller shell particles which larvae tend to eschew are captured with less efficiency. Projections of marketable bushels on the 2010 shell plants assumed a 3-year time to market size, and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality rates used were the 50^{th} percentiles of the 1989-2010 time series. Bushel conversions assume 261 oysters bu-1. 2010 shell plants are expected to provide 258,633 bushels for market in 2013/2014 (Table 13), assuming stock status permits allocation of all animals to harvest rather than maintenance of abundance. For this reason, the terms 'harvest potential' or 'potential yield' are used hereafter. 2009 shell continued to attract spat in 2010. A minimal estimate of year-2 recruitment on this shell results in an estimated future harvest of 160,131 bushels (Table 14). Adventitious sampling of previous years' shell plants reveals that shell continues to attract spat over multiple years (Table 15).

Shell Budget Projections

A shell budget was constructed using bed-specific half-life estimates for cultch updated using the model of Powell et al.[♮] Half-lives ranged generally between 3 and 7 years, with a median of 4.69 years (Table 16). Half lives for Upper Middle, Hope Creek, Liston Range, and Fishing Creek could not be estimated. These beds are only newly surveyed or have been surveyed every other year for some part of the time series. The analyses are subject to substantial yearly variations retrospectively due to limited sampling of some beds in some years prior to 2005 and because the addition of shell beginning in 2005 increases the difficulty of analysis as the industry dredging activities redistribute the shell beyond its original grid placement. Also, some conversions are poorly known and the time series is still relatively short, being of the same order as many of the half-life estimates. Half-lives estimated in 2010 are in the same range as estimates in 2009, and remain within the range originally estimated by Powell et al. (2006). Continued experience with this database confirms the original conclusions of Powell et al. (2006) that half lives routinely fall well below 10 years; however, uncertainties of a factor of about two are present and this uncertainty will affect shell budget estimates, as the accuracy of the half-life

[♮] 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.

estimate is the principal source of uncertainty in that calculation.

A shell budget was constructed using bed-specific half-life estimates for cultch following Powell and Klinck[⊖]. Values for the four beds with uncertain half lives (Table 16) were borrowed from neighboring beds. New Jersey oyster beds have been losing on the order of 500,000 bushels of cultch annually since 1999, with loss rates significantly higher during the period 2000-2003 (Figure 33). 1999 is the first year an estimate can be made as 1998 is the first year that full survey data are available. These estimates are somewhat modified using the 1998-2010 time series versus the 1998-2009 time series due to improved data for historically poorly-sampled beds and to survey variations. Two estimates are provided, one based on box volume and one based on box weight. The box-weight estimate is considered the better estimate, as box weights are more precisely known and conversions to shell volume less speculative; however, the two estimates probably fairly represent the range of uncertainty. For comparison, estimates are made from the same datasets for mortality and cultch quantity using the updated half-lives estimated in this assessment and the those estimated in 2009 and 2010 (SAW-11, SAW-12).

The shell budget shows a gradual reduction in shell loss since 2003, with greater uncertainty in 2006 and 2007, and a more certain and definitive trend towards lower shell loss in 2008-2010 (Figure 33). Years 2008-2010 are the only years in the 1999-2010 time series when at least one estimate was near zero, with 2008 being the only year in which estimates suggest that shell balance may have been achieved. For 2010, the estimates fall between about 150,000 and 350,000 bushels of shell lost, with the best estimate of a loss near 200,000 bushels.

By region, the low-mortality beds have been losing about 20,000-80,000 bushels annually, with larger losses during the 2005-2007 period (Figure 34). This low level of shell loss is due to low taphonomic loss rates, as input rates are also low. The medium-mortality beds lost >200,000 bushels annually in many years prior to 2007, with lesser but still comparatively large losses relative to other bed regions in the last few years, due to higher loss rates and a larger total area. Shell Rock showed a net gain in 2005, 2006, and 2010 due to shell planting, and a slight loss in 2008 and 2009. The high-mortality beds typically have lost upwards of 200,000 bushels annually due mostly to the larger area and moderate shell half lives. With the exception of 2007, which was an aberrant year over much of the bay, shell loss has declined steadily over the 2000s, with lowest levels in the last three years, at least in part due to the substantial shell planting that occurred downbay of Shell Rock since 2004. This year, 2010, represents the third year in succession when all bed regions were within (or very near) 200,000 bushels of shell balance. The decline in

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

shell loss rates in 2008-2010 overall is due to two factors, the purposeful addition of surf clam and ocean quahog shell and the continuing high level of natural input due to the Dermo epizootic that began in 2007 and continued into 2010. However it is noteworthy that the earlier epizootic in the 2000-2002 time frame did not substantively ameliorate the imbalance in the shell budget.

Disease Prevalence and Intensity

MSX disease, caused by *Haplosporidium nelsoni*, and Dermo disease, caused by *Perkinsus marinus*, remain the two primary disease concerns for oysters 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[Λ]. Disease monitoring during 2010 showed that MSX continued to be present but insignificant in terms of influencing oyster population dynamics whereas Dermo disease continued to exert significant influence. A full analysis of the 2010 disease monitoring program is available as an HSRL report[Θ].

Temperature and salinity are the dominant environmental factors influencing Dermo disease dynamics. Seasonal temperature cycling drives a seasonal cycle of Dermo intensification and remission. Spatial patterns in salinity correlate to spatial patterns of disease intensity and resulting oyster mortality. During 2010, water temperatures were warmer than average from May to August (Figure 35) which accelerates the seasonal intensification of the disease. Salinity followed the normal spatial pattern increasing from upper to lower bay sites. Salinity levels were lower than normal at the beginning of the year, but increased steadily to levels higher than normal with a peak in September (Figure 35). These conditions favor the development of Dermo disease and facilitated the continuation of an epizootic that began in 2007.

Both Dermo prevalence and weighted prevalence exceeded long-term mean levels during summer and fall of 2010 before declining to average levels in November (Figure 36). Dermo begins to cause noticeable increases in mortality once weighted prevalence reaches 1.5; levels above 2.0 are often associated with epizootic mortality. Weighted prevalence exceeded 1.5 by July and was well above 2.0 during August to October. Spatially, Dermo was more prevalent and more intense than normal on the low-mortality beds, near mean levels across the medium-mortality beds, but tended to be at or below average across the high-mortality beds (Figure 37). This pattern belies the typical increase in prevalence and intensity from the low-mortality to the

---

[Λ] Ford, S. and D. Bushek. 2006. Additional evidence of high resistance to *Haplosporidium nelsoni* (MSX) in the native oyster population of Delaware Bay. *J. Shellfish Res.* 25:726-727.

[Θ] Bushek D. 2011. *Delaware Bay New Jersey oyster seedbed monitoring program 2010 status report*, Haskin Shellfish Research Laboratory, Port Norris, NJ.

high-mortality regions of the bay and may be a result of high recruitment downbay in 2009, as younger animals typically have lower infection levels.

Since establishing itself over the seedbeds in 1990, Dermo levels have fluctuated in a cyclical pattern of about 7 years (Figure 38). The pattern is more evident in weighted prevalence than prevalence with lows occurring in 1997 and 2004 since 1990. Reasons for this pattern remain unclear, but if the pattern holds, 2011 should mark the end of the third epizootic cycle. Possibly supporting this prediction is the observation of depressed Dermo levels on the high-mortality beds in 2010. The high-mortality beds often lead disease and mortality trends across the reef tract.

A meta-analysis of the entire Dermo monitoring dataset compared with mortality data over the same period supports the division of the bay into low-mortality, medium-mortality and high-mortality regions driven significantly by Dermo-induced mortality (Figure 39). Previous indications that the high-mortality beds could be sub-divided into inshore and offshore groups are, however, no longer evident. Of particular note is the precarious position of Shell Rock, which indicates that less than one doubling of parasite densities could push this valuable bed into the high-mortality category.

Natural Mortality Trends

Quantitative box-count mortality rates were obtained by calculating the number of boxes per m^2 and summing over strata and beds within bay regions. Analytical details are in Powell et al.[ℵ] Box-count mortality was 17.8% bay-wide in 2010, excluding the very-low-mortality beds, and 16.8% including them. This is a distinct decrease from the previous three years, and potentially represents a modest relaxation of epizootic mortality rates that have been present since 2005 (Figure 40). The mortality rate for 2010 was moderate for the 1989-2010 era. but still relatively high for the 58-year time series. Box-count mortality was at the 68^{th} percentile of the 58-yr time series, but only at the 43^{rd} percentile post-1988 (Table 6).

Mortality rates were relatively low on the high-mortality beds and Shell Rock, but unusually high upbay (Figure 41). The medium-mortality beds suffered unusually high mortality for the fourth consecutive year. The current epizootic has sustained a period of high mortality in this region not seen since the early 1990s. The mortality rate was unusually high on the low-mortality beds, which sustained the fourth year of increased mortality. The rate observed in 2010 was the highest observed in the 1989-2010 time series and one of the highest on record. The decline in SSB in this bed region in 2010 is likely explained by this mortality event. The mortality rate was 19.7% on the high-mortality beds, 10.7% on Shell Rock, 19.3%

[ℵ] Op. cit.

on the medium-mortality market beds, 21.2% on the medium-mortality transplant beds, 17.6%, on the low-mortality beds, but distinctly lower, 9.3%, on the very-low-mortality beds.

The high-mortality beds contributed 17.5% of the total deaths in 2010, excluding the very-low-mortality beds, thus contributing substantively to stock mortality despite the lower abundance, due to the high mortality rate. Most deaths were contributed by the medium-morality market beds, 43.2%, due to a combination of high abundance and unusually high mortality. The low-mortality beds contributed 17.9%, 7.7% for Shell Rock, and 13.7% for the medium-mortality transplant beds. The third-place ranking for the low-mortality beds is unusual and reflects the extraordinary mortality rate observed in this bed region in 2010.

Box-count mortality on the high-mortality beds fell at the 60^{th} percentile of the 58-year time series, but only the 25^{th} percentile of the post-1988 time series, emphasizing the relatively low mortality rate in this bed region in 2010 (Table 6). The lower percentile rank belies the fact that epizootic mortality levels have occurred on the high-mortality beds all but one year since 1990. That is, 2010 mortality remained high in comparison to most years prior to the onset of Dermo disease circa 1989. Mortality on Shell Rock was relatively low with percentile positions of 47^{th} and 30^{th}, respectively (Table 6). Box-count mortality on the medium-mortality beds was unusually high. The 2010 level of mortality for the medium-mortality market beds was at the 73^{rd} percentile for the 58-year time series and the 52^{nd} percentile for the post-1988 time series. For the medium-mortality transplant beds, the respective percentiles are an astounding 87^{th} and 80^{th} and for the low-mortality beds, an equally astounding 91^{st} percentile for the 58-year time series and the highest level recorded for the post-1988 period (Table 6).

Population Dynamics Trends

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

The broodstock-recruitment diagram suggests that present-day abundance directly affects recruitment in some way (Figure 42). The shell-planting program suggests that the relationship does not involve fecundity. Setting potential far exceeds set. Oyster larvae tend to set preferentially on live oysters and boxes, so that one cannot exclude the possibility that broodstock abundance modulates settlement success by being a principal source of clean shell. The shell-planting program strongly suggests that the bay is not larvae limited.

A large recruitment event is very unlikely. However, the long-term likelihood of a replacement event, 1 spat per oyster, is 16 of 58 and a rate half that occurs in

34 of 58 years, so that the expectation of a respectable recruitment event remains greater than 50%. The expectation, however, is lower since 1989 (Figure 42).

First passage times were used to quantify the likelihood that the population will transition from its present low abundance-low recruitment state to any other. The input data were obtained by dividing a two-dimensional dataset, such as shown in Figure 42, into quadrants by the medians of the x and y variables (Figure 43). One-year transition probabilities are compiled by examining the quadrant location for the x-y datum at consecutive years. These transition probabilities can be used to estimate first passage time, the interval of time in which the population would find itself back in a specified quadrant, given a starting point in the same or other specified quadrant. In the case of the data presented in Figure 42 relating broodstock to recruitment, the distribution of points in the four quadrants (x/y = broodstock abundance/recruitment) is: low/low = 19; low/high = 9; high/low = 9; and high/high = 20. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant ($P > 0.10$; $P < 0.05$; $P < 0.05$; $P < 0.05$, respectively (Table 17). First passage times show a high tendency for the population to remain in the low abundance-low recruitment or high abundance-high recruitment quadrants.

Since 1989, the tendency to remain in a low abundance-low recruitment state is nearly overwhelming. During this time, the chance of arriving in a high abundance-high recruitment state is very low, showing that recruitment rate, even when high, is unlikely to generate a transition to high abundance (Table 17). Since 1989, the distribution of points in the four quadrants is: low/low = 10; low/high = 4; high/low = 3; high/high = 4, based on the 58-yr medians (Figure 42). This distribution is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P = 0.024$, $P > 0.10$; $P > 0.10$, $P > 0.10$, respectively. That is, the relationship between broodstock and recruitment in the post-1988 era is very different from the random expectation. The 2010 relationship between broodstock and recruitment just falls into the category of a high-recruitment low-abundance year (Figure 42). This is a relatively unusual outcome (Table 17). That is, the relationship between broodstock and recruitment in the post-1988 era is dominantly described by the linear portion of the broodstock-recruitment curve described by the lower half of the observed abundances and recruitments over the 58-yr time series. Year 2010 fell slightly outside of that envelope.

Epizootics occur primarily at abundances below 4×10^9 and their effect is to further reduce abundance. However, abundance has declined so that the stock is increasingly concentrated in the central part of the bay and this tends to reduce total mortality rate and therefore decreases the chance of epizootics at some point. A relationship between broodstock abundance and mortality exists and is characterized by an 'epizootic hump' in the 1.5×10^9 to 3.5×10^9 abundance range (Figures 44-45). Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about one-third (41%) of the years since 1989 (Figure 45). Non-epizootic years tend to average around 10% mortality. The bay-wide average for 2010 was 17.8%, a lower, but still high, mortality rate than 2009. Year 2010 falls appropriately along the epizootic hump, well within the other points at the same approximate abundance (Figure 45). The last three years of epizootic mortality have continued the consolidated distribution pattern of reduced abundance on the high-mortality beds (Figure 11). However, the 2008-2010 epizootic includes an uncharacteristically high mortality upbay of Shell Rock that, in this instance, contributes significantly to the high bay-wide mortality rate.

The relationship between broodstock and mortality continues to clarify as low abundance values accumulate. The distribution of points in the four quadrants (x/y = broodstock abundance/mortality rate) is: low/low = 12; low/high = 16; high/low = 16; high/high = 13 (Figure 45). This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. This is dominantly due to the fact that the median mortality rate falls near the 'epizootic hump'. First passage times show that transitions to quadrant 3 occur rarely, but quadrant 3 is a relatively stable state (Table 18). This quadrant is characterized by high abundance and low mortality. In contrast, since 1989, the distribution of points in the four quadrants is: low/low = 4; low/high = 10; high/low = 1; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P = 0.021$; $P = 0.019$, $P > 0.10$, respectively. Since 1988, the high mortality-low abundance state has occurred significantly more frequently than anticipated from the long-term time series. The first passage time for a return to this quadrant from itself is also short, confirming observation that epizootics tend to be multi-year events and that the low abundance-high mortality state is a very stable state for the Dermo era that began circa 1989.

A relationship between box-count mortality and recruitment remains unclear (Figure 46). The distribution of points in the four quadrants (x/y = recruitment/mortality rate) is: low/low = 14; low/high = 15; high/low = 15; high/high = 14 (Table 19). This is not significantly different from the expectation that one-quarter of the years should fall into each quadrant. First passage times show that return intervals to quadrant 3 are long. This quadrant is characterized by low mortality and high recruitment. Return intervals to quadrant 2, high mortality-low recruitment, are short, from all four quadrants. Since 1989, the distribution of points in the four quadrants is (recruitment/mortality): low/low = 5; low/high = 9; high/low = 1; high/high = 7. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P = 0.075$;

$P = 0.015$, $P > 0.10$, respectively. The high recruitment-low mortality state has occurred only once since 1988. The high-mortality low-recruitment state has occurred relatively frequently, suggesting that low recruitment is more likely to occur when mortality is high, although low recruitment rates are also relatively common when mortality rate is low. Nevertheless, this tendency is consistent with the trajectory of the broodstock-recruitment curve at low abundance and suggests that the abundance decline associated with Dermo disease may also result in low recruitment rates.

Potential Food Limitation

An estimate of the within-bed reduction in food supply due to overfiltration is provided in Figure 47. The model is based on Wilson-Ormond et al.[⊙]. The model assumes simple upestuary/downestuary flow with or without vertical mixing with recovery of food supply between beds. Model estimates indicate reductions in food supply due to population density effects of no more than 12%, assuming vigorous vertical mixing and up to 44% assuming a more laminar flow. The former estimate is more likely to be correct based on the tidal current speed and homogeneous vertical structure typical of Delaware Bay waters over the oyster beds.

Harvest Statistics

Direct-market Harvest

Total harvest in 2010 was 74,375 bushels[♭] (Table 20, Figure 48). This is just above the 1996-2010 average of 73,365 bushels. Figure 49 shows the oyster removals from the natural oyster beds in Delaware Bay since 1953. Since 1997, an intermediate transplant program has moved oysters among beds. In this figure, the total stock manipulation, including transplant and direct-market, is identified as the apparent harvest; those oysters taken to market are identified as the real harvest. Harvest has been relatively stable during direct-marketing times and below all bay-season[△] years.

Beds were harvested almost continually from April 6 to November 20, 2010.

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

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

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

Thirteen beds were fished. Highest catches were on Shell Rock, Ship John, Bennies Sand, Hog Shoal, Nantuxent Point, and Bennies, where catches exceeded 5,000 bushels (Table 20). The recommended area management policy resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John, but a significant catch also occurred on Cohansey.

Fifty-eight boats participated in the fishery and worked for a total of 1,009 boat-days. These included 35 single-dredge boats working for 678 boat-days (19.4 days/boat) and 23 dual-dredge boats working for 331 boat-days (14.4 days/boat). CPUE in 2010 was about the same as in 2006-2009 time frame and considerably higher than observed in 2000-2005. CPUE for single-dredge boats remained near 2006-2009 values. The 2010 dual-dredge-boat value was modestly less than 2009, but nearly identical to 2007-2008 (Figure 50).

Total dredging impact was estimated to exceed bed area in five cases[⊗] and nearly so for a sixth (Table 20): Bennies Sand, Hawk's Nest, Hog Shoal, Nantuxent Point, Shell Rock, and Ship John. Highest value was 2.57 on Hog Shoal. Three other beds exceeded 2: Ship John, Bennies Sand, and Nantuxent Point[@]. Shell Rock fell barely under 2.

The number of oysters per 37-qt marketed bushel averaged 318 oysters per bushel in 2010. Of these, 204 were $\geq 2.5''$ (Table 21). Landings included many more small oysters than in the previous six years. Of the 114 oysters per bushel differential, 85 were judged to be incidental, in that they were small oysters not culled from larger oysters chosen for market. The proportion of such oysters far exceeded previous years, likely a byproduct of the relatively good 2009 recruitment event and the even better 2010 event (Figure 51). The number of oysters landed per bushel was much above average for the time series, as a consequence. The average and median size of harvested individuals consequently was much smaller than previous years (Table 21, Figure 52).

Conversion of oysters to bushels for allocation projections used the value of 261 oysters bu^{-1}, the average of the seven years 2004-2010 (median=261). This value is the mean of the total oysters and chosen oysters. The rationale for taking the mean is that the number of attached small animals will vary widely between years depending on recruitment dynamics, so the use of the total number risks underestimating the allocation. On the other hand, the smaller number does not

---

[⊗] 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.

account for all of the oyster removals and this undervalues the fishing mortality rate.

2010 Intermediate Transplant

The intermediate transplant program moved 1,200 bushels of material from Hope Creek, 200 bushels from Fishing Creek, 2,250 from Upper Arnolds, 1,500 from Cohansey, and 8,200 from Sea Breeze to Bennies 86, 1,800 bushels from Fishing Creek, 1,200 bushels from Upper Arnolds, and 4,750 bushels from Liston Range to Shell Rock 22, and 14,800 from Upper Arnolds and 2,850 from Sea Breeze to Bennies 87. Oysters per bushel averaged 416, 407, 534, 410, 167, and 224, respectively, for transplants from Hope Creek, Fishing Creek, Liston Range, Upper Arnolds, Cohansey, and Sea Breeze. Cullers were used for all transplants. The movement of oysters to Shell Rock and Bennies followed recommendations from SAW-12. Bed-average values of 453 oysters per bushel for Hope Creek, 350 for Fishing Creek, 316 for Liston Range, 288 for Upper Arnolds, and 250 for Sea Breeze (Table 4) suggest that these transplant activities concentrated oysters relative to shell to only a moderate degree on most beds.

Table 22 summarizes the fraction of each intermediate transplant contributed by cultch: shell with no live oysters attached. Culling is clearly effective in reducing shell content, often by half or more, relative to the suction dredge or the use of a dry dredge without automatic culling machines engaged. Trends are not obvious between the three primary transplant regions. The records suggest that shell contents of $\leq$30% are achievable.

Fishing Mortality

The net of all fishing and transplant activities was that most oysters taken to market ultimately were debited from the very-low-mortality beds, the low-mortality beds, and the medium-mortality market beds (Figures 53 and 54). In comparison to the 2005-2008 period, the upbay beds contributed a relatively high fraction, as they had in 2009. This is in keeping with the SAW-11 recommendation to expand the intermediate transplant program to a scale routinely employed in the 1997-2003 time frame. For Figures 53 and 54, Sea Breeze was considered a medium-mortality market bed. However, it was used primarily as a transplant bed in 2010; moving this bed to that category would have increased the contribution from the medium-mortality transplant beds in Figures 53 and 54.

Real fishing mortality was 1.9% of total abundance in 2010, excluding the very-low-mortality beds, and 1.7% including them, whereas apparent fishing mortality was 3.2% (2.8% including the very-low-mortality beds) (Figure 55). The increment reflects the intermediate transplant program that transplanted oysters downbay in 2010. Fishing mortality has been below 2% every year since 1995. 2010 fishing mortality was at the 40^{th} percentile of the 58-yr time series excluding closure years, and at the 71^{st} percentile of years post-1995 (Table 6). By bed region, the percentiles were 55^{th}, 45^{th}, and 93^{rd} for the high-mortality beds, Shell Rock, and the medium-mortality market beds respectively (Table 6). The high exploitation rate on the medium-mortality beds was a product of the recommendation of the 100^{th} percentile exploitation rate by SAW-12 and the inclusion of the Sea Breeze intermediate transplant in this calculation.

Fishing mortality, by SSB, was 3.1% in 2010 (Figure 56). Fishing removed 3.3% of the animals $\geq 2.5''$ in 2010 (Figure 57). This is a relatively low value relative to the 1996-2010 time series, falling at the 39^{th} percentile, and suggests that the fishery was not unduly exploitative when referenced to the exploitable portion of the stock. Percentiles by bay section are tabulated in Table 6.

By bay section, fishing and transplant activities removed 1.3%, 2.0%, 0.%, 2.7%, 7.0%, and 6.8% of the animals from the very-low-mortality beds, low-mortality beds, medium-mortality beds (transplant and market), Shell Rock, and the high-mortality beds, respectively. Restricted to market-size animals ($>2.5''$), the respective values are 1.8%, 2.5%, 0.%, 3.9%, 6.2%, and 4.3%. The values for the high-mortality and medium-mortality beds include intermediate transplant additions and direct harvest. These values are relatively high upbay of the medium-mortality transplant beds relative to the preceding years, and as well for the medium-mortality market beds. The values are distinctly lower than preceding years from Shell Rock downbay, in keeping with the conservative harvest allocations for these beds as recommended by SAW-12. The 2010 value of zero listed for the medium-mortality transplant beds is due to the use of Sea Breeze as a transplant bed in 2010. In this document, all statistics, unless otherwise noted, include Sea Breeze in the medium-mortality market bed group.

Results of 2010 Experimental Fishery

SAW-11 proposed two experimental fisheries for 2009 and these were continued pursuant to SAW-12 into 2010. The first of these was an intermediate transplant from the very-low-mortality beds. These beds have not been previously exploited, so that no exploitation record exists on which to base management decisions. The recommendation was set at the 40^{th} percentile exploitation rate for the medium-mortality transplant beds, 0.0127. Intermediate transplant focused on Hope Creek in 2009. In 2010, most animals came from Fishing Creek and Liston Range, although a small number were taken from Hope Creek. Figure 58 shows the abundance trends for the three very-low-mortality beds. Little change was observed on Hope Creek, a rise in abundance on Fishing Creek and a decline on Liston Range, however, the decline on Liston Range is within survey uncertainty and inconsequential from 2009. SSB and Market abundance dropped on Hope Creek, but not significantly (the 2010 decline from 2009 was within the 90% confidence intervals – see later discussion on survey confidence intervals for a description of the methodology for calculation), and remained unchanged or rose on Fishing Creek and Liston Range despite the fact that the majority of the intermediate transplant came from Fishing Creek and Liston Range. Recruitment rose spectacularly on all three beds. Thus, the experimental fishery with an exploitation rate of 0.0127 would appear to have been inconsequential in its impact on the stock.

The second experimental fishery was an increased exploitation rate on the medium-mortality market beds. In this case, the exploitation rate was set at the 100^{th} percentile of the time series. Figure 59 suggests that this exploitation rate did not materially influence the stock. Total abundance increased in 2010, as did market abundance. The survey production retrospective is consistent with this interpretation (Figure 26a-b), however quantitative trends depicted in Figure 27 suggest that continuing vigilence to identify long-term trends in stock performance is necessary.

Status of Stock Summary

Stock Status and Population Management Goals – Bay-area Stock Performance Targets

In 2006, the SARC set specific target and threshold abundances and spawning stock biomasses based on the 1989-2005 and 1990-2005 time periods, respectively, under the assumption that this time period likely represents the ambit of oyster population dynamics in the present climate and disease regime. As a consequence, the median abundance and SSB values for the time periods 1989-2005 or 1990-2005 were set as abundance and biomass targets and values half these levels were set as threshold abundance and biomass levels (Table 23). Due to the absence of a time series, the very-low-mortality beds do not have these target and threshold reference points.

Time series data shows that the decade of the 2000s has been very different from the 1990s. Particular examples include the dramatically lower recruitment rates in the 2000s for all bay regions (e.g., Tables 7-9), the increased stock consolidation upbay (Figure 12), the change in size composition from a small-oyster dominated stock to a stock enriched in animals $\geq 2.5''$ in size (Figures 16-17), and the tendency towards the end of the 2000s for epizootics to be characterized by a higher fraction of mortality upbay of the high-mortality beds (Figure 41). Of particular interest is the long-term drop in abundance without an equivalent response in SSB. These changes suggest that target and threshold values, particularly for abundance, based on a times series significantly influenced by 1990s abundances and biomasses may not be appropriate for the 2000s. Simulations with DyPoGEn strongly imply that growth rates have risen between the 1990s and 2000s. Increased growth rate may be the primary reason for a relative decline in the number of submarket-size animals in the size-frequency diagram. 2010 is unique in the last decade in showing a partial return to 1990s-style size-frequency distributions; however, this is due to consecutive good recruiting years and may not be sustained, if growth rate remains high and recruitment rate drops to decadal norms. Thus, applications of reference points based on 1990s data to 2010 conditions must be done with caution. However, an adequate replacement is also unavailable. Consequently, the SARC concludes that these "stock-performance" reference points for abundance be retained with the caveat that the target and threshold values be used with caution, as their adequacy as benchmarks for comparison to 2010 abundances is unclear.

The volatility in condition can result in a large change in SSB relative to marketable abundance (animals $\geq 2.5''$) as was seen in 2009. This suggests that a less volatile analogue to the comparison between abundance and biomass might be a comparison between abundance and marketable abundance. Regional reference points for this third axis are provided in Table 23.

Surplus production is expected to be significant on the low-mortality beds for 2011 (Table 11). Values in Table 11 are likely an overestimate, however (Figure 24). The low-mortality beds are below the abundance and biomass targets, but above the thresholds (Figure 60). Abundance declined modestly relative to 2009, but remained near the median for the the 2006-2009 period. SSB is distinctly below SSB levels observed during the 2006-2009 period, excepting 2009 (Figure 60). Lower SSB and a modest decline in abundance is the product of an unusually high mortality rate in this bed region in 2010. Nevertheless, market abundance remains well above the target, as it has been since 2004, with values representative of the 2006-2009 period (Figure 61). Recruitment was the highest recorded since 1991.

Surplus production is expected to be significant on the medium-mortality beds for 2010 (Table 11, with previous caveat). The medium-mortality beds are below the abundance target but well above the abundance threshold. Abundance rose substantially relative to 2009 on both the transplant beds and market beds and was near or above all values observed for the 2006-2009 period. The unusually low value of abundance observed in 2009 is almost assuredly a survey artifact as was postulated at SAW-12. SSB was above, but near, the SSB target in both cases (Figure 60) and near the median observed in the 2006-2009 period in both cases. Market abundance fell above the target in 2010 in both regions (Figure 61). The number of spat recruiting to the medium-mortality beds per adult fell above the 70^{th} percentile in both regions.

Surplus production is expected to be positive on Shell Rock in 2010 (Table 11). Abundance on Shell Rock is well above the abundance target. The same superior position is true for SSB and market abundance (Figures 60-61). Recruitment was well above average in 2010 for the post-1988 era by number or spat-per-adult ratio and the shell-planting program resulted in an additional increment over this already high value.

Surplus production is expected to be positive on the high-mortality beds in 2010. The high-mortality beds remain below the abundance target, but modestly above the threshold. Abundance is higher than in 2009 and, in fact, higher than any year since 2001. SSB is below the SSB target, but also modestly above the threshold (Figure 60). Market abundance fell above the target in 2010, after falling briefly below it in 2009 (Figure 61). Until 2009, market abundance has not been below the target since 2004. Thus, the high-mortality beds improved in 2010 by all three metrics, abundance, market abundance, and SSB. Recruitment was near average for the post-1988 era by total number or the number of spat per adult. The value, however, was still 1.63 spat per adult. Shell planting modestly increased this total.

These reference points can be compared further to the survey point estimate by evaluating the uncertainty of the point estimate. In this case, 1,000 simulated surveys were conducted each with a selection of samples from each bed and each corrected for dredge efficiency by a randomly chosen value from all 2000-2005 efficiency estimates. The confidence-level values were obtained in two ways. First, the simulated surveys were sorted by the number of $\geq 2.5''$ oysters (Table 24). Second, the simulated surveys were sorted by the total number of oysters (Table 25). Dredge efficiency is less certain for oysters $<2.5''$, so that the latter approach comes with increased uncertainty that cannot be fully evaluated. On the other hand, the smaller size class is numerically important, so that the former approach sometimes fails to order surveys in a hierarchical position by total abundance. The relationship of the abundance and market-abundance reference points provided in Table 23 and figured in Figures 60-61 are compared to the uncertainty surrounding the 2010 point estimate for each bay region in Figures 62 and 63. These generally confirm the significance of the position of the 2010 point estimate relative to the Table-23 stock-performance reference points. Of particular note is that four of five bay regions fall distinctly above the abundance threshold, taking into account survey uncertainty and the abundance target for three of five fall within or above the survey envelope (Figure 62). The market-abundance reference point falls beneath the survey uncertainty envelope for two regions and well within the envelope for the other three (Figure 63). Thus, the bed regions meet all market abundance goals in 2010 and are positioned above the abundance threshold in most cases. This latter occurrence has been uncommon during the decade of the last half of the 2000s.

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

Whereas, area management continues to be a priority, as addressed by the bay-area stock performance targets, the oyster population is a single stock and thus whole-stock reference points are important criteria upon which to judge 2010 stock status. The SARC considered three whole-stock abundance targets. The first two are the sum of the area-specific abundance and marketable-abundance targets listed in Table 23. The third was derived more theoretically from an analysis of biological relationships and formulation of a surplus production model[Φ]. The surplus production model used the 1953-2010 time series to derive relationships between broodstock and recruitment and between broodstock and adult mortality, as well as values for juvenile mortality. The model identifies a multiple-stable-point system in Delaware Bay with two stable states, one at high abundance and one at low abundance. Delaware Bay has been in a low-abundance state since 1986. The surplus production model permits the estimation of carrying capacity for both stable states, an N_{msy} (number-at-maximum-sustainable-yield) value, defined as a high in surplus production, for both stable states, the abundance associated with a surplus production low between the two stable states, and the abundance at a point-of-no-return between the two stable states that marks a threshold abundance leading to a collapse to the low-abundance state (Table 26)[Ψ].

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

[Ψ] The parameters of the Ricker and linear broodstock-recruitment relationship and the broodstock-mortality relationship were updated for this analysis. The Ricker curve is expressed as:

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

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

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

The mortality relationship is expressed as:

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

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

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

Five simulations were conducted. These examined the use of the median and mean parameterization of unrecorded natural mortality, the use of a Ricker or linear/Ricker combination curve for the relationship between broodstock abundance and recruitment (Figure 42), and the use of an adult mortality curve with an 'epizootic hump' of various amplitudes (Figure 44). Surplus production modelling suggests that the abundance values are relatively stable with respect to uncertainty in the survey time series, but that surplus production values associated with these abundances are not (Figure 64); thus, N_{msy} values can be obtained, but f_{msy} estimates cannot. The SARC notes that the greatest uncertainty may be the position and height of the epizootic hump in the abundance-mortality relationship (Figure 44) and that further simulations to evaluate this uncertainty are desirable. As a consequence, the SARC recommends greater reliance on alternative reference points not dependent upon this relationship until further sensitivity studies can be conducted.

Of the five simulations shown in Figure 64, four fall in a narrow abundance range between 1.57 and 1.75 billion animals. The fifth simulation depicts a condition with a low disease-mortality rate that is less representative of stock population dynamics than the other four and demonstrates that the scale of the surplus production minimum is primarily influenced by the severity of disease epizootics. On the other hand, surplus production varies by more than a factor of 3 among the five simulations. This agrees with independent observations that small changes in growth rate substantially affect surplus production projections using the Klinck et al.[⊕] model.

During SAW-10, the SARC discussed the use of reference points obtained from the stable-state surplus-production model in comparison to the reference points obtained from the stock-performance model. For the stable-state surplus-production model, an abundance target can be defined as the lower maximum in surplus production (Figure 64). The SARC did not identify a preferred simulation. For comparison to 2010 abundance, the median of the four best estimates of the N_{msy} for the low-abundance state is used as a representative target value and a threshold set at half that value. The two respective values are: 1.628 billion and 0.814 billion. Stock-performance reference points can be derived from the area-specific stock performance data for the 1989-2005 time period by summing the area-specific target values (Table 23). These are based on total abundance and total marketable abundance. For total abundance, the target is the sum of the median stock abundances for that period and the threshold is half that value (Table

---

which reduces to the familiar equation

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

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

⊕ Op. Cit.

23). The two respective values are 2.261 billion and 1.130 billion. The equivalent reference points based on marketable ($\geq 2.5''$) numbers from Table 23 are 346.8 million and 173.4 million.

The SARC during SAW-10 opined that the stock-performance target for the whole stock (2.261 billion) may be too high to be used as an abundance goal, because the value falls near the surplus production minimum between the two stable states in Figure 64 and may, therefore, be difficult to achieve. On the other hand, the N_{msy} estimate from the surplus production model, by falling at the surplus-production peak, assures that a Dermo epizootic will push the population to a lower state of surplus production and delay recovery. The SAW-10 recommendation was that an abundance goal be set between these two values. This has the laudable result that a Dermo epizootic, if it occurs when the stock is near the abundance goal, while decreasing abundance, will increase surplus production, and hence recovery of the stock will be facilitated. However, a specific target number was not set at SAW-10 and the two alternative abundance goals are carried forward here.

During SAW-10, the SARC similarly evaluated the two thresholds. Both are taken as half the targets in keeping with the precedent established in the management of federal fisheries. The threshold for the stable-point surplus-production model is at an abundance level lower than observed in the time series. As a consequence, the stock dynamics at that abundance level are unknown. The SARC recommended during SAW-10 that an abundance threshold not be set at a level below observed abundance levels. The threshold obtained from the stock-performance model falls within known stock dynamics and is the preferred threshold[β].

The 2010 abundance is 1.701 billion animals excluding the very-low-mortality beds, of which 480 million are $\geq 2.5''$ in size. The point estimate of 1.701 billion animals falls above the N_{msy} target, but significantly below the stock performance target (Figure 65). Eighty-percent confidence limits are 1.631 and 2.031 billion animals (Figure 65, Table 25), suggesting that the 2010 point estimate may be low relative to expectation from the variability in survey samples and dredge efficiencies. This is consistent with earlier comments concerning the likelihood that the downbay beds are underestimated due to a time-dependent change in dredge efficiency since 2003. The marketable abundance of 480 million falls near the 70^{th} percentile of abundance with the 80% confidence limits being 397 and 502 million animals (Figure 66, Table 24), suggesting that the survey index for marketable animals may be high.

The N_{msy} reference point falls just below the 20^{th} percentile of the survey

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

index, suggesting that 2010 abundance is very likely to be above this reference point (Figure 65). A similar comparison against the stock-performance reference points for total abundance shows that the 2011 point estimate falls significantly below the target, but significantly above the threshold value (Figure 65). Application of the marketable abundance reference point to an equivalent set of percentiles (Figure 66) reveals that the 2010 point estimate is significantly above the stock-performance target.

Summary of Stock Status and Population Management Goals

Figure 67 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 1989-2010 period (Table 6). This period is chosen because the advent of Dermo as a major influence on population dynamics began in 1989/1990 and evidence indicates a substantive change in population dynamics as a consequence. In particular, average mortality rates are up, the frequency of epizootics is up, the average abundance is down, and the average recruitment rate is down with respect to the 1953-1988 time period. These changes commenced in the first part of the 1990s when the fishery was closed in most years. Harvest was significant during the 1989-1996 period in only two years, 1990 and 1991 (Figure 49).

In 2010, the stock presents a mixture of positive and negative indicators, but the positive indicators substantially outnumber the negative ones (Figure 67). Abundance remains low, but is increasing in five of six bay regions relative to 2009 and in four of five bay regions relative to the previous five years' median. Abundance remains below target levels in all but one bay region, but is near or above the threshold in all bay regions. Near-historically high recruitment occurred in all bay regions except the high-mortality beds in 2010, and this region, which recruits with greater predictability than other bay regions, sustained a near-median level in 2010. However, the SARC continues to recommend augmentation of natural recruitment with a vigorous shell-planting program as the long-term trend in recruitment since 1999 does not augur favorably for above-average recruitment events in the coming years. The increase in abundance in 2010 is explained by the above-average recruitment event of 2009 plus the addition of some early recruits in 2010 that grew to a size exceeding 20 mm. The stock continues to be disproportionately consolidated on the medium-mortality beds; however, the very-low-mortality beds contain about 19% of the total stock.

Spawning stock biomass remained relatively unchanged in 2010 relative to the previous five years, but increased distinctly from 2009 in five of six regions (Figure 67). Much of this increase originates in a lower natural mortality rate than in 2009 accompanied by good growth. The decline on the low-mortality beds is the product of an unusually high mortality rate in this region in 2010. SSB fell below the biomass target in two regions, but near or above the threshold in all five. In contrast, marketable abundance fell near or above the target in all bay regions and increased substantively in five of six. Marketable abundance fell only on the low-mortality beds, but remained at the 50^{th} percentile of the time series.

The 2010 recruitment was well above average following an above average event in 2009. The 2010 recruitment was noteworthy for reaching substantive levels over all bed regions, including the low-mortality and very-low-mortality beds. Based on total recruits, the 2010 spatfall exceeded the 75^{th} percentile for the 1989-2010 time period in all but one bed region, a position not attained previously in the 2000s over such a wide bay region. On a spat-per-adult basis, the 2010 recruitment was well above average in all bed regions, and near historical highs upbay of Ship John/Cohansey. Thus, 2010 was a good recruitment year by any measure. The oyster population as a whole continues to be depauperate in the smaller size classes; however, much less so than in previous years. Moreover, new information suggests that the change in size frequency since the 1990s is a function of increased growth rate rather than, for example, high juvenile mortality. Surplus production, though likely overestimated, is expected to permit an increase in marketable abundance bay-wide and in all bay regions, though less so on the high-mortality beds. This continues the trend of positive surplus production in most bay regions observed over the last few years.

Dermo disease remained near epizootic levels in 2010 and natural mortality rates were well above average upbay of Ship John/Cohansey, reaching an historical high on the low-mortality beds and the 80^{th} percentile on the medium-mortality transplant beds. This marks a continuation of a pattern observed in 2009 for unusually high mortality rates upbay. In contrast, the mortality rate on the high-mortality beds and Shell Rock was relatively low by historical standards. A decreasing trend in Dermo disease weighted prevalence throughout the bay suggests a possible relaxation of epizootic conditions in 2011. The present epizootic is in its fourth year, a stretch of time rarely exceeded for this disease.

Fishery exploitation levels since 1989 have been low ($<2\%$ of abundance per year). Exploitation in terms of biomass and market abundance have been $\leq 3\%$ for most of that time. Exploitation rates were near average in 2010 on Shell Rock and the high-mortality beds, but at near historical highs on the low-mortality beds and the medium-mortality market beds. The latter was consistent with SAW-12 that supported a higher percentile exploitation rate on these beds coupled with the inclusion of the Sea Breeze intermediate transplant in the percentile calculation for the medium-mortality market beds. However, these exploitation rates were still below 5% of the marketable stock by number in all bed regions except Shell Rock, for which exploitation just exceeded 6%. Overall, due to the intermediate transplant program, the landings were supported relatively evenly by all bed regions in 2010.

In summary, the fact that all but one bay region fell below its abundance target indicates that actions to enhance abundance continue to be important; however the abundance-based reference points based on the 1989-2005 time series may over-emphasize the seriousness of this situation. Moreover, whole-stock abundance falls near the N_{msy} reference point, a distinct improvement from 2009. The importance of adults as sites for larval settlement and the continued need to minimize shell loss reinforces the importance of maintaining marketable abundance near or above target levels in each region, however. All bay regions are near or above target levels for market abundance at the present time. Thus, management measures have been successful at maintaining market abundance during a period of unprecedentedly low recruitment in the mid-2000s. This accomplishment accrues from a relatively accurate quota setting process, a conclusion supported this year by results of a surplus production retrospective, and proactive measures to enhance recruitment through shell planting. This suggests that the present approach to setting exploitation rates, the area management program, and the intermediate transplant program have been implemented in a sufficiently precautionary way to maintain sustainable marketable abundance and guard against overfishing of the stock.

Overall, the six bed regions are in better shape in 2010 than in many previous years. Few cautionary data exist for Shell Rock or either medium-mortality section, aside from continuing high mortality rates on the medium-mortality transplant beds. No evidence of impact from the higher exploitation rate permitted in 2010 on the medium-mortality market beds could be discerned, supporting the retention of this option for exploitation in 2011. The high-mortality beds have recovered somewhat from the poor condition of 2009 after three epizootic years, regardless of the metric used for evaluation. This recovery is abetted by an above average recruitment year in 2009 and lower natural mortality in 2010, but owes more to the management advice of SAW-12 to target this area to receive intermediate transplants in 2010 and to restrict exploitation rate. A continued emphasis on intermediate transplant to this bed region in 2011 would seem prudent, as the 2010 recruitment provides an opportunity to further improve the condition of this region. This includes consideration of a transplant of seed from Beadons to the Bennies Sand region, continued targeting of this region for intermediate transplant, and increased precaution in exploitation unless a substantial intermediate transplant program accompanies a higher exploitation rate.

Conditions remain ambiguous on the low-mortality beds as abundance and market abundance have declined to undesirable levels, relative to the 1989-2010 historical record due to unusually high rates of natural mortality and a decadal dearth in recruitment. However, the 2010 recruitment event was near historical highs and at levels not seen since the early 1990s. Given the normally high survival rate on these beds, increasing abundance can be anticipated from the 2010 recruitment event. No indication that intermediate transplants of previous years have significantly depressed abundance on the low-mortality or very-low-mortality beds is evident in this assessment. Thus, previous exploitation levels appear appropriate.

Definition of Sustainability

The concept of a sustainable stock, under federal guidelines articulated by the Magnuson-Stevens Fishery Conservation and Management Act, is expressed in the concepts of 'overfishing' and an 'overfished' stock. The term 'overfishing' represents a comparison of the current fishing mortality rate relative to the rate permitted at maximum sustainable yield, f_{msy}. The term 'overfished' refers to the biomass of the stock relative to the biomass at maximum sustainable yield, B_{msy}. These concepts do not depend on the history of the stock or the fishery prior to the year of the assessment; rather, the concepts are yearly designations that express the conditions that exist in the assessment year (or the year of most recent survey data).

The concepts of B_{msy} and f_{msy} have not been applied to populations strongly influenced by disease. Thus, the SARC considered a number of metrics to judge sustainability that provide analogies to the federal criteria. The federal concept of B_{msy} is a whole-stock characteristic that relates the biomass B that supports maximal surplus production to carrying capacity K; typically $B_{msy} = \frac{K}{2}$. The application of B_{msy} to the Delaware Bay oyster stock is impeded by a minimal range in biomass observed over the time span that biomass estimates can be made: 1990-2010 (Figure 13). Furthermore, until very recently, mortality could not be expressed on a biomass basis. Thus, the dataset does not permit a ready estimate of K on a biomass basis. However, the 58-yr time series provides a wide range of abundance values (easily a factor of 5) permitting the analogous parameter, N_{msy}, to be calculated[ℵ]. In 2010, the survey point estimate of whole-stock abundance is not significantly different from the N_{msy} reference point (Figure 65). Thus, by this measure, the stock is not overfished.

The SARC considered the efficacy of relying on this measure and noted the uncertainty posed by the uncertain shape of the epizootic hump in the abundance-mortality relationship (Figure 44). As a consequence, the SARC recommends greater reliance on alternative metrics until further sensitivity studies can be conducted.

The SARC considered characteristics of a well-managed stock that would not be expected to be present in an overfished stock. Of most importance is the trend in market-size abundance. Market-size abundance is the least volatile of the stock metrics (abundance, SSB, market abundance), and so is the one most likely to

ℵ Powell et al. (2008), Op. cit.

provide unambiguous evidence of over-exploitation, were it to occur. The premise that an important management goal is the conservation of market-size abundance has underpinned management of the resource since SAW-1. This premise is based on the recognition that natural mortality rate has risen by minimally a factor of two during the Dermo era (Figure 40) and that most of this mortality is concentrated on the larger size classes. Thus, the first evidence of an overfished stock would be a decline in market-size abundance from one epizootic cycle to the next, as recovery of abundance during cycle nadir would be limited by fishery removals. The Delaware Bay stock has traversed three epizootic cycles since 1990 (Figure 38). The 1990-2010 time series shows that the abundance of market-size animals has remained relatively stable over this period of two decades (Figure 19). This stability comes from two sources. First, a balance exists between the death of larger animals primarily caused by disease and the recruitment potential of the population. Second, the fishing mortality rate has been constrained such that removals by the fishery have not exceeded the replacement capacity of the population. As a consequence, the population has been able to recover from epizootic events during disease cycle nadirs. The SARC considers this characteristic indicative of a stock that is not in an overfished state.

A second metric of importance permits a determination of overfishing. A characteristic of overfishing is a negative surplus production in a stock. In populations controlled by epizootic disease, surplus production potential will cycle transiently between negative and positive states during the epizootic cycle, lending a degree of uncertainty to the potential of the stock from one year to the next. The Delaware Bay stock has been managed since SAW-1 under the expectation that natural mortality will be at epizootic levels (the 75^{th} percentile). This is a distinctly precautionary approach that should minimize the number of years in which the population cannot achieve positive surplus production. A retrospective examination of the tendency for forgone yield to exist under this management approach shows that net surplus production has been positive in every year since port-sampling began[II] (Figure 68). This retrospective was based on observed stock dyanamics as measured in the survey, including observed abundance, size frequency, and mortality, rather than being based on any theoretical stock relationships. Thus, the retrospective focuses on actual stock performance under the 2005-2010 management program. Further support comes from a comparison of the natural mortality rate with the fishing mortality rate (Figure 69). In this case, the fishing mortality rate has been less than 20% of the natural mortality rate throughout this time period. As a consequence, no evidence exists that overfishing has occurred under the present management regime.

Thus, the SARC concludes that the Delaware Bay oyster stock is not overfished

[II] The calculation of net surplus production requires information on the size frequency of landings. A port-sampling program to collect these data was initiated in 2004.

and that overfishing is not occurring in 2010, nor has either condition occurred since the inception of the port-sampling program in 2004. Both are characteristic of and requirements for a sustainable stock.

Management Advice

Cultch Management Goals

Shell planting serves a dual purpose of enhancing recruitment and maintaining shell balance. In the past, shell-planting goals have attempted to respond simultaneously to both needs. Continued shell planting is essential to maintain habitat quality as well as provide substrate to enhance recruitment. Most bed regions were nearly in shell balance in 2010, although conditions have worsened since 2008. Thus, a reduction in shell planting in 2009-2010 has resulted in a deterioration in shell balance that will continue, unless redressed. Shell plants have routinely equaled and usually far exceeded the recruitment rate of native shell. Thus, shell plants, wherever feasible, should target areas where oysters grow rapidly to marketable size, where the probability of recruitment is high, and where cultch loss exceeds the addition of shell through natural mortality. Design of a 2011 program, funds permitting, should consider the following recommendations.

1. Shell Rock has demonstrated exemplary performance under shell planting. Maintaining high production on Shell Rock is important. No intermediate transplant to this bed is recommended in 2011. Thus, shell should be planted on Shell Rock in 2011.

2. The area of greatest concern is the high-mortality bed region, as total shell loss is normally highest in this region, in part due to low marketable abundance that is the outcome of persistent high mortality from Dermo disease. In addition, continued low abundance in this region can be assuaged by recruitment enhancement through this means. Shell planting should target beds in the upbay portion of this region.

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

4. The SARC notes that an unfortunate attendant to the movement of oysters downbay during intermediate transplant is the transplant downbay of cultch. The SARC recommends that measures be put in place to minimize the downbay transplant of cultch, unless a program replacing transplanted cultch through

shell planting can be mobilized.

2010 Management Goals

Fishery Exploitation Reference Points

The important areas for the oyster industry are the beds in the medium-mortality and high-mortality region. Examination of the trends on the individual beds indicates that these two regions have substantially different processes controlling oyster abundance. The average number of oysters on the medium-mortality beds for the 1989 to 2010 period is much greater than on the high-mortality beds, even though the total acreage is much less. The number of spat recruiting per adult has been consistently higher on the high-mortality beds and growth rates are consistently higher. Present information suggests that the high-mortality beds are characterized by multiple cohorts moving through the population of relatively equivalent size, whereas the medium-mortality beds are characterized by aperiodically-occurring larger cohorts that can dominate the population for a time. In addition, analysis of proportional abundance indicates that the medium-mortality beds represent the core of the stock. Epizootic mortalities downbay and low recruitment upbay result in consolidation of the stock in this region. Stock expansions include increased recruitment downbay. The differential in response to population dynamics processes suggests that management of the medium-mortality beds generally should be more precautionary than the high-mortality beds. However, low exploitation levels on these beds since the direct-market program began in 1996 limit our ability to evaluate the response of these beds to exploitation even at lower levels than typical of downbay regions. The primary reason for this was the use of all of the medium-mortality beds for intermediate transplant through 2003, when the region was first divided into market and transplant beds. Prior to then, a tendency to target Ship John and Cohansey for intermediate transplant kept exploitation of beds farther upbay artificially low. As a consequence, historically, management of these beds has been in a highly precautionary mode.

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

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

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

In addition, SAW-11 evaluated the exploitation rates for the medium-mortality transplant beds. These are weighted in the early years by low values due to the tendency to transplant from Ship John and Cohansey pre-2003, as the area-management program implemented at that time included all medium-mortality beds in one management region. As a consequence, the exploitation rates for the transplant beds apportion themselves into two groups, a very-low group and a high group that is temporally biased, and dichotomized at the 50^{th} percentile. To provide more range of outcomes for management, an intermediate value, 0.188, was added as the 50^{th} percentile by SAW-11, this being the average between the original 50^{th} and 60^{th} percentile values (Table 27). That value is carried forward in the projection tables that follow.

Exploitation rates can be calculated based on real removals and apparent removals (Tables 27-28). Real removals are defined as the net of the market catch, increased or debited by the removals and additions by intermediate transplant.

Apparent removals are defined as the market catch plus removals by intermediate transplant. The two values are identical for beds upbay of Shell Rock because transplants to these beds did not occur during the time frame used for establishing the exploitation rates. In some cases, negative real exploitation rates appear in the time series for Shell Rock and the high-mortality beds because the number added by intermediate transplant exceeds the number removed. The alternative, use of the apparent exploitation rates, overestimates the inherent productivity of these beds, however, and would permit potentially unsustainable harvest levels without careful implementation of the intermediate transplant program. The SARC retains the precedent set in 2007 that the real exploitation rate reference points be used for any analysis for direct marketing and that the reference points used should be based on the 1996-2006 values for the $\geq 2.5''$ size class. The SARC also retains the precedent that the 40^{th}, 50^{th}, and 60^{th} percentiles normally be employed. In keeping with the precedent set at SAW-11, the 100^{th} percentile is provided for the medium-mortality market beds. This level of fishing was recommended by SAW-11 as an experimental fishery based on the continuing large inequity between the historical exploitation values and the surplus production projections which routinely exceed the historical values by a significant margin. It is the SARC's recommendation that this experimental fishery continue in 2011.

Use of the real exploitation rates for the high-mortality beds represents a precautionary approach to managing these beds; however, the SARC advises that the precautionary value of these reference points is retained only as long as an intermediate transplant program is incorporated into the management plan. Intermediate transplant can be conducted by suction dredge or dry dredge with or without a culling device. Exploitation rates for suction dredge or dry dredge without a culling device should be estimated assuming all size classes are removed proportionately. The concentration factor for culling devices is of the order of 1.28[ϒ]; a concentration factor insufficient to use the exploitation rates for $\geq 2.5''$ animals. Thus, all intermediate transplant estimates should rely on the 'all-animal' exploitation rate reference points. The SARC strongly advises, however, that intermediate transplant use culling devices as the goal of this activity is to move downbay proportionately more marketable animals while retaining upbay under a lower mortality regime the smaller animals that will grow into these larger size classes. In this way, most animals moved downbay will be available for harvest within 18 months, thus minimizing their loss to Dermo disease.

In 2010, at SAW-12, the SARC recommended that Sea Breeze be reassigned from the medium-mortality market beds to the medium-mortality transplant beds. This was due to the long-term trend of minimal direct-market exploitation on

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

this bed and the desire to limit intermediate transplant from Middle to alternate years. The SARC recommends continuation of this practice in 2011. Hence, all direct-market exploitation recommendations for the medium-mortality market beds apply to Ship John and Cohansey exclusively and all intermediate transplant recommendations for the medium-mortality transplant beds apply to Middle, Upper Middle, and Sea Breeze. The SARC further recommends that the 2012 assessment retain this bed region configuration for all analyses.

Abundance-based Exploitation Reference Point Projections – Direct Marketing (Table 29)

In 2010, the high-mortality beds continue to be at low abundance, though improving, but marketable abundance remains above target levels even after three epizootic years. The SARC notes that the high-mortality beds are toward the edge of the stock's range, rather than near the center, and that the continuing high natural mortality rate limits the success of stock rebuilding on these beds. However, these beds can be managed to augment abundance and increase fishery yield in the short term. The intermediate transplant program has been successful in this regard. The SARC considers the present state of these beds to need continuing attention and recommends that a fishing level above the 40^{th} percentile not be used without implementation of a significant intermediate transplant program. Because a significant intermediate transplant program will substantially reduce realized exploitation rate on these beds, higher percentile harvests (e.g., the 50^{th} or 60^{th} percentile) on the high-mortality beds may be implemented under that proviso.

Due to the uniqueness of medium mortality and high production, and given its importance to the fishery, Shell Rock must be managed independently of the high-mortality beds. This year, Shell Rock is above all target levels. The SARC recommends that exploitation rates as high as the 60^{th} percentile be permitted.

SAW-8 recommended that management should emphasize increased direct marketing on the lower group of medium-mortality beds to reduce the exploitation rate downbay. Beginning in 2005, these beds have contributed directly and significantly to this goal. The SARC supports this recommendation that two of the three medium-mortality beds, Cohansey and, Ship John continue to be managed as direct-market beds. The SARC noted previously the desirability of managing Sea Breeze as a transplant bed. Despite higher than average mortalities during the four-year epizootic of 2007-2010, substantial catches in 2007-2010 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance. Thus, these beds have been relatively resilient under the low exploitation rates used to date. High levels of surplus production are again anticipated for 2011. The SARC notes that the history of exploitation in this region, with the evolution of these beds from an initial contributor to intermediate transplant to a fully functional component of the direct-market program has resulted in exploitation-based reference points that may be more precautionary than required for sustainable management. For example, the highest measured exploitation rate since 1996 falls below the 10^{th} percentile of Shell Rock, the next bed immediately downbay. Unfortunately, no theoretical analysis has permitted a determination of f_{msy} for these beds. Thus, the SARC recommends continuation of the experimental fishery begun in 2009 on these beds to evaluate their response under increased exploitation rates.

Projections are provided in Table 29 for the high-mortality beds, Shell Rock, and the market group of medium-mortality beds (Cohansey, Ship John).

Abundance-based Exploitation Reference Point Projections – Intermediate Transplant (Table 30)

The SARC strongly supports the inclusion of an intermediate-transplant program and emphasizes the urgent need for this program as a vehicle to support abundance on the high-mortality beds. SARC recommendations include as a basic premise that specific beds in a bed region not be targeted for intermediate transplant in consecutive years. Doing otherwise may lead to local over-exploitation within the bed region, to the detriment of the targeted bed.

The medium-mortality transplant beds are within survey error of the abundance target (Figure 62) and above the market-size abundance target (Figure 63). The region received a much higher than average recruitment event in 2010 and both abundance and market abundance are well above the previous five years' median. The SARC notes that Middle will be a site for planting of spatted shell in 2011 as part of the *Athos* remediation project. The SARC recommends that intermediate transplant be permitted at the 50^{th} percentile level and that Middle and Upper Middle be targeted.

The low-mortality beds are above the marketable-abundance target, but below the abundance target and only modestly above the threshold. Growth rates are slower on these beds and recruitment has been sporadic at best. The ability of these beds to recover from a decline in abundance consequently is limited, despite the lower rate of natural mortality. However, the region sustained an unusually good recruitment event in 2010 and a return to lower mortality rates in 2011 is highly likely. Nevertheless, the status of the stock in this region suggests that a precautionary approach be taken in 2011. The SARC, therefore, recommends that the intermediate transplant be no higher than the 40^{th} percentile. Upper Arnolds was utilized for intermediate transplant in 2010. The SARC recommends that Round Island be preferentially targeted in 2011 and that Arnolds be included only if necessary.

No exploitation record is available for the very-low-mortality beds. However, the SARC emphasizes the need to evaluate these beds as intermediate transplant beds. Thus, an intermediate transplant is recommended, but not to exceed the 40^{th} percentile as a precaution until a better understanding of these beds' response to fishing activities can be achieved. Fishing Creek and Liston Range were targeted in 2010. Normally, the SARC would recommend that Hope Creek be targeted in 2011. However, the SARC notes disturbing trends in SSB and market abundance on Hope Creek over the last three years. Therefore, the SARC recommends that half of the recommended transplant come from Hope Creek and that the remainder come from the other very-low-mortality beds.

Note that transplant options will require transplant before the allocation can be set because allocation estimates provided herein can only be confirmed after the transplant is complete. This year, the same caution pertains to the high-mortality beds unless management chooses the 40^{th} percentile option for these beds. A significant portion of the program should be carried out prior to harvest commencing on these bed regions. The SARC is sensitive, however, to the closure rules associated with the transplant program and recognizes that the Council will need to maintain some beds open for harvest at the beginning of the season.

Given the plight of the high-mortality beds, the SARC recommends that transplants from the low-mortality and medium-mortality transplant beds be moved to the upper portion of the high-mortality beds; for example, upper Bennies, Bennies Sand, Hog Shoal and Nantuxent Point. Given the uncertainty of survival of transplants from the very-low-mortality beds, but also the need to support abundance on Ship John/Cohansey, the SARC recommends that Ship John/Cohansey be a preferred location to receive these transplants.

Projections for intermediate transplant are provided in Table 30.

Science and Management Issues

Management Issues

Abundance is at or near the abundance threshold in most bay regions. A shell-planting program aimed at enhancing abundance by enhancing recruitment must continue with the aim of planting not less than 250,000 bushels annually.

The port sampling 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.

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

The heavy set on Beadons suggests that Beadons be included in an intermediate transplant program to increase market abundance on Bennies Sand or a neighboring high-mortality bed in 2012/2013. This will not increase the overall quota in 2011, but would support the quota in coming years. Direct marketing has rarely occurred from Beadons, so that the heavy set on this bed will be lost to the industry without a transplant program. Exploitation on Beadons is summarized in Table 31.

A program moving spatted shell upbay should be implemented to return cultch to these beds where it was removed during intermediate transplant operations. The SARC notes that the *Athos* shell planting in 2011 is a useful precedent.

Science Recommendations

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

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

Given the range of surplus production values obtained by the stable-point surplus production model, and the uncertainty as to the best configuration to use for simulation of the surplus production trajectory, further sensitivity analyses should be conducted and alternate modeling approaches, including probabilistic approaches, should be evaluated.

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

The tow-based regression equations for dredge efficiency should be internally tested using presently available data. This includes experiments conducted in 2004-2006, as well as comparisons between the two major experimental programs in 2001 and 2003.

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

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

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

The relationship between condition and other population and disease variables should be investigated and contrasted amongdifferent management areas.

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

Re-evaluation of the stock-performance reference points should be undertaken consistent with the change in population dynamics observed between the decades of the 1990s and 2000s.

A shell budget reference point should be developed.

Given the apparent change in growth rates over the past 20 years, additional length-at-age data should be acquired to update the growth models used.

A yield-per-recruit analysis should be undertaken.

An independent estimate of carrying capacity for each bed region should be undertaken using the ROMS bottom velocity data now available. This estimate can be based on the Wilson et al. model[⊙].

Evaluate the proportion of shell loss on the transplant beds contributed by the intermediate transplant program either as movement of cultch or the relocation of live oysters that no longer would die on the donor bed.

A long-range plan for reef management taking into account sea level rise, salinity shifts and other factors related to climate change, should be developed.

[⊙] Op. cit.

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

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

Table 2. 2010 sampling scheme for the November survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of samples devoted to that bed stratum. Egg Island was not sampled.

Sampled Bed	High-quality	Medium-quality	Low-quality	Transplant
Hope Creek	4	4	0	0
Fishing Creek	2	3	0	0
Liston Range	2	4	0	0
Round Island	2	3	0	0
Upper Arnolds	2	3	0	0
Arnolds	3	3	0	0
Upper Middle	1	3	0	0
Cohansey	5	5	0	1
Ship John	6	5	0	0
Middle	2	3	0	0
Sea Breeze	3	2	0	0
Shell Rock	4	4	0	3
Bennies Sand	2	6	0	4
Bennies	3	9	0	2
New Beds	2	7	0	0
Nantuxent Point	3	3	0	3
Hog Shoal	3	3	0	0
Strawberry	1	3	0	0
Vexton	2	3	0	0
Beadons	3	4	0	0
Hawk's Nest	2	3	0	0
Egg Island	0	0	0	0
Ledge	1	4	0	0
Total	58	87	0	13

Grand Total: 158

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

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

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

Table 4. Results of the 2010 random sampling program for the Delaware Bay natural oyster beds of New Jersey. Included for comparison are data for 2008 and 2009. Data are displayed from the farthest upbay beds to those downbay. The second column called 'Bushels/haul' indicates the average number of bushels brought up by the three dredge hauls from each grid. For each bed the percentage of oysters for each sample is presented, with rankings from highest to lowest. Percent oyster is based on volume of oyster in the sample divided by the total volume of shell, oyster, and debris. Letters 'H', 'M', and 'T', indicate high-quality, medium-quality, and transplant or shell-plant grids, respectively. Oysters per bushel and spat per bushel are based on actual counts adjusted to a 37-quart bushel. 'Size' columns indicate the number of oysters per 37-qt bushel greater than $2.5''$. Condition index is a measure of the dry meat weight in an oyster relative to the hinge-to-lip (greatest) dimension. The 'Percent Mortality' value is based on the number of boxes counted in the samples. Prevalence is the percentage of oysters with detectable infections by Dermo. Weighted Prevalence is the average infection intensity (scored from 0 to 5) of all sampled oysters. With the exception of information on Dermo, all bed-average data are weighted averages based on the relative proportion of high-quality and medium-quality grids on the bed. Transplant grids are not included in bed-average estimates. In no case are samples normalized to swept area, nor are dredge efficiency corrections included; all analyses are rendered on a per-bushel basis[ℑ].

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

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Hope Creek	4.3	64.2 H	59.6 H	75.7 H																								
Hope Creek	2.6	58.8 H	54.3 M	70.6 H																								
Hope Creek	3.5	58.3 H	52.8 H	60.7 H																								
Hope Creek	2.6	57.2 M	52.4 M	60.6 H	453	399	403	290	32	116	8	6	3	20	05	20	0.20	0.25	0.13	87	110	103	19	27	26	0.007	0.006	0.008
Hope Creek	5.2	52.4 H	47.8 H	54.1 M																								
Hope Creek	2.2	41.0 M	42.8 H	49.1 M																								
Hope Creek	2.2	34.1 M	37.7 M	48.2 M																								
Hope Creek	2.2	32.9 M	37.3 M	29.2 M																								
Liston Range	5.0	75.2 H	73.5 M	78.0 M																								
Liston Range	1.1	42.7 H	59.6 H	58.3 M																								
Liston Range	0.6	39.7 M	57.8 H	53.6 H	316	428	336	164	29	91	4	4	3	10	10	25	0.50	0.05	0.48	83	139	128	26	32	38	0.008	0.006	0.010
Liston Range	0.7	35.2 M	57.3 M	49.3 H																								
Liston Range	2.2	34.7 M	46.9 M	31.1 M																								
Liston Range	0.5	12.3 M	40.2 M	20.0 M																								
Fishing Creek	4.5	62.8 M	64.3 H	64.2 M																								
Fishing Creek	4.8	54.6 H	63.0 M	63.6 H	350	331	293	190	28	40	12	7	3	50	20	65	0.10	0.50	0.70	113	164	153	32	49	52	0.007	0.007	0.012
Fishing Creek	1.7	51.3 H	60.2 M	56.0 H																								
Fishing Creek	0.9	36.3 M	44.0 M	55.0 M																								
Fishing Creek	2.0	31.2 M	37.6 H	49.6 M																								
Round Island	2.6	64.5 H	56.2 H	55.0 M																								
Round Island	0.6	54.3 M	46.8 M	51.1 H	348	260	191	203	23	22	19	10	6	70	50	80	1.10	0.90	1.20	130	118	100	37	45	52	0.007	0.007	0.014
Round Island	0.0	50.6 M	45.9 H	40.1 H																								
Round Island	2.1	47.5 M	35.2 M	24.4 M																								
Round Island	1.9	40.4 H	17.7 M	14.4 M																								
Upper Arnolds	2.2	58.5 H	65.3 H	68.9 H																								
Upper Arnolds	4.5	58.3 H	64.2 H	64.7 H	288	343	371	141	29	53	21	15	10	90	65	90	1.10	1.40	1.38	85	149	160	29	43	43	0.007	0.007	0.013
Upper Arnolds	2.2	45.0 M	61.3 M	59.5 M																								
Upper Arnolds	2.8	32.6 M	46.9 M	58.0 M																								
Upper Arnolds	0.8	18.5 M	46.5 M	55.8 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Arnolds	2.3	72.1 H	64.3 H	73.3 H																								
Arnolds	4.1	66.7 H	54.7 H	60.5 H																								
Arnolds	2.6	61.4 H	53.4 M	59.3 M	302	335	258	126	42	37	17	16	9	75	55	95	1.20	1.48	2.10	87	121	130	29	36	50	0.009	0.006	0.011
Arnolds	2.2	57.8 M	52.5 H	58.2 H																								
Arnolds	3.7	25.9 M	49.5 M	56.4 M																								
Arnolds	1.4	18.3 M	41.1 M	11.9 M																								
Upper Middle	4.2	57.4 M	34.6 M	34.3 H																								
Upper Middle	3.1	50.2 H	19.7 M	31.4 M	212	80	115	109	30	10	20	28	26	65	85	95	0.90	2.48	2.23	67	37	49	32	47	43	0.010	0.007	0.012
Upper Middle	2.4	27.2 M	19.5 H	15.1 M																								
Upper Middle	0.1	0.0 M	0.0 M	6.2 M																								
Middle	5.6	57.3 H	75.4 T	71.6 T																								
Middle	2.5	48.2 M	49.5 H	51.9 H																								
Middle	0.7	34.9 M	38.7 H	48.0 M	187	124	181	118	40	11	22	27	25	65	75	100	1.40	1.78	2.33	62	59	72	33	47	40	0.011	0.009	0.012
Middle	0.1	33.1 H	37.9 M	42.8 H																								
Middle	0.9	5.6 M	8.4 M	25.4 M																								
Middle			2.0 M	7.6 M																								
Ship John	1.6	72.0 H	63.0 T	75.2 M																								
Ship John	5.0	69.8 M	63.0 H	71.9 M																								
Ship John	2.8	69.1 H	55.9 T	67.6 H																								
Ship John	4.7	60.6 M	52.5 T	66.5 T																								
Ship John	3.6	59.1 M	52.4 T	63.7 T																								
Ship John	3.9	58.6 H	43.7 H	63.6 T	255	153	238	167	86	22	22	27	20	95	100	95	2.40	2.33	1.95	91	70	85	36	46	36	0.011	0.009	0.010
Ship John	3.0	57.6 H	43.3 T	53.7 T																								
Ship John	6.7	56.9 H	41.5 M	51.0 H																								
Ship John	3.6	52.0 H	40.4 H	46.2 H																								
Ship John	2.2	44.2 M	37.0 M	25.7 M																								
Ship John	2.8	23.8 M	21.6 M	22.0 M																								
Ship John			11.0 M																									

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Cohansey	3.7	74.6 T	70.6 M	79.0 T																								
Cohansey	4.5	63.7 M	63.0 H	66.8 T																								
Cohansey	3.9	59.2 H	57.0 H	65.6 T																								
Cohansey	2.6	57.6 M	56.6 M	64.8 H																								
Cohansey	1.7	53.1 H	54.7 T	54.3 M																								
Cohansey	4.0	46.5 H	47.5 H	51.9 M	228	173	202	131	96	12	19	24	24	95	80	90	2.10	2.38	1.90	67	84	79	29	48	39	0.010	0.011	0.021
Cohansey	2.8	41.2 H	44.4 T	46.3 H																								
Cohansey	2.1	36.0 M	40.3 H	37.1 H																								
Cohansey	3.9	30.4 H	33.8 M	33.3 M																								
Cohansey	4.9	27.9 M	33.3 M																									
Cohansey	1.0	27.7 M	31.2 H																									
Cohansey			26.1 M																									
Sea Breeze	1.6	74.3 H	49.2 M	50.3 H																								
Sea Breeze	2.1	64.9 M	44.3 M	32.3 M	250	221	100	277	141	19	13	12	20	95	90	95	1.60	1.93	1.75	68	60	38	27	27	38	0.010	0.012	0.013
Sea Breeze	1.8	64.0 H	40.1 H	29.7 H																								
Sea Breeze	0.4	18.4 M	34.1 H	16.8 H																								
Sea Breeze	3.6	18.0 H	29.1 H	14.2 M																								
Shell Rock	2.2	85.2 T	61.6 T	75.7 T																								
Shell Rock	2.8	82.1 T	57.7 H	61.4 H																								
Shell Rock	4.1	82.0 M	54.4 M	60.0 M																								
Shell Rock	3.9	80.0 T	52.2 H	57.9 M																								
Shell Rock	2.0	76.8 H	50.3 H	54.3 T	482	157	262	481	190	77	11	24	18	85	100	95	1.80	2.90	1.93	97	69	76	20	44	29	0.008	0.010	0.015
Shell Rock	3.7	76.5 H	45.0 H	54.0 H																								
Shell Rock	3.7	75.4 H	42.2 M	49.7 M																								
Shell Rock	2.4	72.5 H	23.5 M	49.4 H																								
Shell Rock	2.6	64.8 M	9.2 M	48.8 T																								
Shell Rock	2.0	55.1 M		43.7 H																								
Shell Rock	1.7	39.4 M		28.1 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Bennies Sand	2.9	81.0 T	61.7 T	70.6 T																								
Bennies Sand	2.6	54.4 T	56.7 H	57.2 T																								
Bennies Sand	4.3	50.2 T	45.0 H	54.2 T																								
Bennies Sand	1.4	45.6 M	43.7 T	46.2 H																								
Bennies Sand	2.6	43.1 T	35.0 T	38.7 T																								
Bennies Sand	2.1	39.8 H	24.9 M	37.9 T	233	99	136	146	121	33	20	26	27	90	95	100	2.30	2.70	3.0	59	41	59	25	42	44	0.010	0.012	0.015
Bennies Sand	3.2	27.8 M	24.0 M	34.9 T																								
Bennies Sand	2.4	25.8 M	20.3 M	34.8 M																								
Bennies Sand	1.5	25.8 M	18.2 H	30.7 H																								
Bennies Sand	0.5	23.0 M	12.7 M	24.4 M																								
Bennies Sand	1.9	21.6 H	8.3 M	19.2 M																								
Bennies Sand	1.2	14.3 M	3.9 M																									
Bennies	2.1	43.8 T	31.3 T	60.4 H																								
Bennies	1.2	39.4 M	24.3 H	40.5 H																								
Bennies	3.4	35.0 H	17.1 H	32.7 M																								
Bennies	2.1	24.4 T	15.8 T	30.4 M																								
Bennies	1.0	16.6 M	11.6 M	29.2 H																								
Bennies	0.6	13.4 H	11.1 H	24.0 M																								
Bennies	0.2	11.9 M	5.0 M	15.7 M	44	17	55	20	18	9	34	39	32	100	100	55	3.60	3.10	0.93	19	12	38	43	72	70	0.015	0.018	0.018
Bennies	3.7	11.6 M	3.3 M	14.0 M																								
Bennies	3.4	10.4 M	2.2 M	9.2 M																								
Bennies	3.7	5.7 H	2.2 M	7.0 M																								
Bennies	0.6	4.0 M	0.9 M	3.7 M																								
Bennies	3.2	1.3 M	0.7 M	3.7 M																								
Bennies	1.5	0.3 M	0.0 M																									
Bennies	4.1	0.2 M	0.0 M																									
Hog Shoal	4.5	48.2 H	52.2 H	50.0 H																								
Hog Shoal	3.6	44.1 M	42.9 M	36.1 H																								
Hog Shoal	3.2	33.2 H	42.2 H	35.6 M	119	116	70	103	279	13	24	31	26	85	100	100	1.50	3.40	2.70	29	46	31	24	40	45	0.010	0.013	0.018
Hog Shoal	2.1	6.7 H	21.0 H	12.8 H																								
Hog Shoal	1.7	2.8 M	17.2 M	6.5 M																								
Hog Shoal	0.3	0.7 M	13.4 M	3.6 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Nantuxent Point	2.4	72.5 H	60.0 T	59.2 T																								
Nantuxent Point	2.2	67.2 T	53.5 H	45.8 T																								
Nantuxent Point	4.5	60.8 T	50.5 T	35.8 T																								
Nantuxent Point	4.5	58.4 M	48.6 T	31.0 M																								
Nantuxent Point	2.6	57.9 H	46.8 M	25.5 H	329	172	118	340	288	54	22	24	22	100	85	40	1.80	2.93	1.73	58	45	38	18	26	32	0.012	0.009	0.009
Nantuxent Point	5.0	50.4 T	44.0 H	23.3 T																								
Nantuxent Point	4.3	45.4 H	35.7 H	21.0 H																								
Nantuxent Point	2.1	31.3 M	18.6 M	16.6 H																								
Nantuxent Point	5.8	23.8 M	11.1 T	14.3 M																								
Nantuxent Point			10.8 M	8.5 M																								
New Beds	3.6	27.8 H	25.5 H	32.3 H																								
New Beds	2.4	22.7 M	16.9 M	26.0 H																								
New Beds	1.3	17.8 M	16.0 H	13.2 M																								
New Beds	2.4	17.2 H	7.0 M	12.6 M	43	24	27	17	29	3	38	41	43	100	100	90	2.60	2.50	2.08	22	14	22	51	60	83	0.018	0.016	0.026
New Beds	1.7	15.0 M	6.5 M	6.7 M																								
New Beds	1.9	6.1 M	4.4 M	5.1 M																								
New Beds	4.3	5.5 M	3.0 M	3.4 M																								
New Beds	1.8	2.2 M	2.3 M	3.0 M																								
New Beds	0.4	0.5 M	0.0 M	2.4 M																								
Strawberry	3.4	4.6 M	10.3 H	15.1 H																								
Strawberry	3.6	3.4 H	4.0 M	11.8 M	7	6	20	4	2	3	51	57	45	90	100	50	2.40	3.23	0.58	3	4	14	44	78	68	0.011	0.019	0.020
Strawberry	1.1	0.4 M	0.4 M	6.1 M																								
Strawberry	2.2	0.0 M	0.3 M	4.4 M																								
Hawk's Nest	1.7	85.6 M	69.7 M	44.8 T																								
Hawk's Nest	3.3	32.7 H	45.3 H	40.1 H																								
Hawk's Nest	2.0	14.0 H	23.6 H	29.4 M	278	208	206	252	195	108	23	17	13	90	100	90	1.70	2.95	2.15	60	36	29	21	17	14	0.010	0.011	0.017
Hawk's Nest	3.5	12.0 M	8.3 M	27.3 M																								
Hawk's Nest	2.0	1.7 M	6.0 M	24.3 H																								
Hawk's Nest				8.3 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2010	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008	**2010**	2009	2008
Vexton	1.7	15.5 H	4.0 M	10.6 H																								
Vexton	1.1	4.4 H	1.7 H	10.2 H	31	6	10	46	5	2	16	60	39	80	95	85	1.30	3.77	1.00	5	2	5	15	28	47	0.008	0.010	0.021
Vexton	0.6	2.0 M	1.2 H	2.8 M																								
Vexton	0.7	0.7 M	0.3 M	2.7 M																								
Vexton	1.2	0.0 M	0.0 M	0.3 M																								
Beadons	0.8	78.4 H	25.6 H	36.5 H																								
Beadons	2.3	67.1 H	20.9 M	35.3 H																								
Beadons	0.6	19.0 H	19.6 H	30.7 H	315	72	67	300	101	36	9	34	26	70	80	60	1.50	2.80	1.80	10	18	16	3	25	25	0.006	0.013	0.019
Beadons	0.7	2.5 M	14.5 M	6.6 M																								
Beadons	0.5	2.5 M	10.0 M	5.9 M																								
Beadons	1.6	2.3 M	9.6 H	3.1 M																								
Beadons	0.6	1.5 M	4.1 M	3.0 M																								
Ledge	2.4	0.5 M		0.0 M																								
Ledge	0.4	0.3 M		0.0 M	1			0			63		100	Ledge	1.8	0.2 H		0.0 M										
Ledge	3.2	0.0 M		0.0 H																								
Ledge	2.2	0.0 M		0.0 M																								
Egg Island			0.7 M																									
Egg Island			0.6 M																									
Egg Island			0.6 H																									
Egg Island			0.5 M			1			0			62		Egg Island			0.0 M											
Egg Island			0.0 M																									
Egg Island			0.0 M																									
Egg Island			0.0 M																									

Table 5. Average annual bay-wide oyster and spat abundance per 37-qt. bushel for the 1990-2010 time period. Statistical comparisons are based on the per-bushel values for each survey sample for that year. Years within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$. Mean of the annual values for 1990-2010: oyster abundance = 167; spat abundance = 92.

Oyster Abundance			Spat Abundance		
Tukey's Rankings	Mean	Year	Tukey's Rankings	Mean	Year
A	262.18	1996	A	266.61	1991
A B	242.10	1990	A B	209.11	1997
A B	236.95	1992	A B C	204.37	1999
A B C	**229.11**	**2010**	**B C**	**177.43**	**2010**
A B C D	210.55	1991	B C	174.72	1994
A B C D E	195.80	1995	B C D	156.34	1995
A B C D E F	186.57	1997	B C D	154.05	1990
A B C D E F G	182.63	1998	C D E	125.80	1998
B C D E F G	178.10	1993	D E F	87.71	2009
B C D E F G	168.92	2000	D E F	81.24	2007
C D E F G H	154.69	1994	E F	46.13	2002
C D E F G H	153.01	2009	E F	44.73	1993
C D E F G H	148.80	1999	F	35.12	2000
D E F G H	144.89	2001	F	29.12	2008
D E F G H	143.64	2008	F	25.00	1992
D E F G H	133.92	2002	F	24.17	1996
E F G H	122.98	2003	F	22.62	2004
E F G H	122.59	2007	F	20.37	2003
F G H	113.30	2004	F	19.18	2005
G H	101.08	2006	F	18.75	2006
H	81.46	2005	F	12.18	2001

Table 6. Percentile positions in the indicated time series for the given bay regions and stock variables. Note that for most of the variables, a lower percentile equates with a lower value of the variable relative to the entire time series. For 'Unexplained Mortality", however, a lower value indicates a higher degree of unexplained mortality relative to the time series. Very-low-mortality beds are not included in the percentile evaluations of the time series. Recruitment values do not include the enhancements from shell planting.

	Abundance	Spawning Stock Biomass*	Market >2.5″ Abundance*	Recruitment	Spat to Adult Ratio	Box-count Mortality	Fishing Mortality	Market Fishing Mortality⋆	Unexplained Mortality
Bay-wide: 1953-2010	.216			.509	.767	.681	.402		
Bay-wide: 1989-2010	.375	.175	.500	.659	.795	.432	.711	.385	
Low-mortality: 1953-2010	.112			.457	.767	.905	.868		.526
Low-mortality: 1989-2010	.250	.262	.500	.750	.932	.999	.929	.846	.477
Medium-mortality Transplant: 1953-2010	.267			.560	.802	.871	.307		.910
Medium-mortality Transplant: 1989-2010	.333	.500	.643	.841	.900	.795	.310	.231	.932
Medium-mortality Market: 1953-2010	.422			.578	.664	.733	.728		.905
Medium-mortality Market: 1989-2010	.523	.500	.690	.750	.705	.523	.929	.923	.886
Shell Rock: 1953-2010	.625			.750	.716	.474	.430		.664
Shell Rock: 1989-2010	.841	.643	.690	.886	.614	.295	.452	.231	.705
High-mortality: 1953-2010	.333			.509	.681	.595	.412		.405
High-mortality: 1989-2010	.432	.214	.310	.568	.614	.250	.548	.385	.477

*SSB and market abundance values used the 1990-2010 time series

⋆Market fishing values used the 1997-2010 time series

Table 7. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality beds for the 1990-2010 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Years within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean of the annual values for 1990-2010: oyster abundance = 241; spat abundance = 107.

Oyster Abundance			Spat Abundance		
Tukey's Rankings	Mean	Year	Tukey's Rankings	Mean	Year
A	433.61	1996	A	302.38	1999
A B	363.77	2000	A	268.28	1991
A B C	328.04	1990	**A B**	**227.00**	**2010**
B C D	304.43	1992	A B C	195.48	1995
B C D E	290.91	1997	A B C	194.59	1998
B C D E	**289.45**	**2010**	A B C	181.78	1994
B C D E F	270.36	1998	B C D	140.16	1990
B C D E F	257.91	2003	B C D E	127.47	1997
B C D E F	254.75	1991	B C D E	114.47	2007
C D E F G	232.99	2001	C D E	88.92	2002
C D E F G	226.94	1993	C D E	84.23	2009
D E F G	211.90	2002	D E	53.89	1993
D E F G	207.60	1999	D E	47.43	2000
D E F G	197.28	1995	D E	37.42	1996
D E F G	195.53	1994	D E	34.86	2006
D E F G	191.16	2005	D E	29.97	2004
E F G	179.59	2008	D E	28.33	2003
F G	171.88	2006	D E	27.77	1992
F G	168.45	2009	D E	27.27	2005
F G	157.24	2004	D E	25.39	2008
G	132.04	2007	E	11.65	2001

Table 8. Average annual oyster and spat abundance per 37-qt. bushel for the low-mortality beds for the 1990-2010 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Years within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean of the annual values for 1990-2010: oyster abundance = 383; spat abundance = 79.

Oyster Abundance			Spat Abundance		
Tukey's Rankings	Mean	Year	Tukey's Rankings	Mean	Year
A	698.22	1992	A	370.54	1991
A B	662.89	1991	B	227.59	1990
A B C	587.68	1993	**B C**	**179.47**	**2010**
A B C D	574.69	1990	C D	116.91	1999
A B C D E	482.69	1995	C D E	98.58	1998
B C D E F	450.44	1994	D E F	84.06	1995
C D E F G	405.47	2002	D E F	83.54	1994
C D E F G	375.39	2001	D E F	80.09	2007
D E F G	353.05	1996	D E F	52.81	2005
E F G	**345.84**	**2010**	D E F	51.88	1996
E F G	336.80	2009	D E F	51.83	1997
E F G	327.77	1999	D E F	47.50	2008
E F G	318.13	2000	D E F	44.67	2002
E F G	310.92	1997	D E F	38.29	1992
E F G	309.79	2003	D E F	35.93	2009
E F G	302.39	2008	E F	23.00	1993
E F G	262.81	2005	E F	20.15	2000
E F G	258.54	1998	E F	15.72	2006
F G	254.58	2004	E F	13.96	2001
G	220.83	2006	E F	10.63	2003
G	199.00	2007	F	4.95	2004

Table 9. Average annual oyster and spat abundance per 37-qt. bushel for the high-mortality beds for the 1990-2010 time period. Statistical comparisons are based on the per-bushel values for each survey sample for the bay region for that year. Years within category with the same underlying letter designation are not significantly different at $\alpha = 0.05$ (Tukey's Studentized Range Test). Mean of the annual values for 1990-2010: oyster abundance = 108; spat abundance = 101.

Oyster Abundance			Spat Abundance		
Tukey's Rankings	Mean	Year	Tukey's Rankings	Mean	Year
A	230.33	1996	A	306.63	1997
A B	**175.55**	**2010**	A B	272.61	1991
A B C	161.61	1995	A B C	247.31	1994
A B C D	159.26	1998	A B C D	201.29	1999
A B C D	157.79	1990	A B C D E	182.36	1995
A B C D	152.35	1992	B C D E F	160.97	1990
B C D E	132.09	1997	**B C D E F G**	**156.81**	**2010**
B C D E F	117.31	2009	B C D E F G H	135.27	1998
B C D E F	114.23	1994	C D E F G H	110.18	2009
B C D E F	112.27	1991	D E F G H	66.20	2007
B C D E F	106.20	1999	E F G H	48.98	1993
B C D E F	87.58	2000	E F G H	43.96	2000
B C D E F	83.71	2008	F G H	29.25	2008
C D E F	77.42	2001	F G H	26.61	2002
C D E F	74.96	1993	F G H	24.77	1992
C D E F	67.03	2006	F G H	24.00	2004
D E F	62.90	2005	F G H	20.13	2003
D E F	61.87	2004	G H	17.35	1996
E F	50.32	2007	G H	15.20	2005
E F	45.74	2003	H	13.83	2001
F	29.03	2002	H	13.49	2006

Table 10. Average 1-year growth increment for animals reaching market (3″) size, the average minimal size of animals reaching market size in one year, and age-to-market size for oysters from four bay regions, based on von Bertalanffy growth curves of Kraeuter et al. (2007)†.

Bed Group	Data Source	Average Growth Increment	Average Minimal Size Reaching Market	Age to Market
Low mortality	Arnolds	0.24″	2.76″	7.0 yr
Medium mortality	Middle, Cohansey	0.49″	2.51″	4.3 yr
Shell Rock	Shell Rock	0.52″	2.48″	4.0 yr
High mortality	Bennies Sand, New Beds	0.66″	2.34″	3.6 yr

† Op. cit.

Table 11. Surplus production as projected for 2009 and 2010 by SAW-11 and SAW-12 and as projected for 2011. Projections for 2011 were conducted using the 50^{th} and 75^{th} percentiles of natural mortality and a conversion of 261 oysters bu^{-1}. Mortality rate for the very-low-mortality beds was chosen to represent a high and a low value from the 2007-2010 time series. Growth rate on the very-low-mortality beds was assumed to be similar to that on the low-mortality beds.

SAW-11 Surplus Production Estimate for 2009

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	90,106	83,602
Medium mortality Transplant	90,152	71,655
Medium mortality Market	160,491	118,365
Shell Rock	70,668	60,694
High mortality	26,164	3,703
Total	437,581	338,019

SAW-12 Surplus Production Estimate for 2010

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Low mortality	130,077	120,519
Medium mortality Transplant	54,726	46,295
Medium mortality Market	250,344	206,116
Shell Rock	53,874	48,519
High mortality	49,030	26,553
Total	538,051	448,002

SAW-13 Surplus Production Estimate for 2011

Bay Region	50^{th} Percentile Estimate Surplus Production (market-equivalent bushels)	75^{th} Percentile Estimate Surplus Production (market-equivalent bushels)
Very-low mortality	88,330	85,072
Low mortality	81,672	75,492
Medium mortality Transplant	121,813	108,432
Medium mortality Market	277,391	221,042
Shell Rock	61,744	52,777
High mortality	64,793	35,344
Total	695,743	578,159

Table 12. The ratio of spat to oysters by bay region since the beginning of the direct-market program. Bay regions are defined in Figure 9. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

Year	Low Mortality	Medium Mortality Transplant	Medium Mortality Market	Shell Rock	High Mortality
1996	0.19	0.14	0.08	0.09	0.12
1997	0.20	0.26	0.73	0.92	3.06
1998	0.92	1.16	2.13	1.64	2.03
1999	0.59	2.00	2.17	4.04	4.54
2000	0.15	0.18	0.20	0.79	1.08
2001	0.05	0.04	0.09	0.22	0.44
2002	0.20	0.18	0.54	4.59	0.86
2003	0.05	0.13	0.17	0.38	1.28 (1.54)
2004	0.05	0.14	0.28	1.85	2.07
2005	0.31	0.19	0.20	0.46 (1.01)	0.54 (0.62)
2006	0.14	0.42	0.32	0.32 (0.64)	0.42 (1.00)
2007	0.18	0.71 (0.88)	1.63 (1.70)	1.53	2.54 (2.59)
2008	0.22	0.11	0.10 (0.11)	0.50	0.86 (1.64)
2009	0.15	0.52	0.72	1.89 (2.75)	2.12 (2.56)
2010	0.74	1.04	0.89	1.37 (1.94)	1.63 (2.18)

Table 13. Summary of shell-planting activities for 2010. Shell-planting was carried out in late June-early July, 2010. Direct plants occurred on Shell Rock 23 and Bennies Sand 4. Projections of marketable bushels assumed a 3-year time to market size and natural mortality at the juvenile rate in year 1 and at the adult rate in years 2 and 3. The mortality rate estimates used were the 50^{th} percentiles of the 1989-2010 time series: for Shell Rock, 0.460, 0.187, 0.187; for the high-mortality beds: 0.451, 0.257. 0.257, for years 1, 2, and 3, respectively. Bushel conversions assume 261 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat/Bu	Potential Yield (bushels)
Shell Rock	23	Surf clam mix*	40,199	91,472,825	2,276	118,473
Bennies Sand	4	Surf clam mix*	49,645	137,106,305	2,762	140,160
Total			89,844	328,579,130		258,633

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

Table 14. Summary of 2010 recruitment on 2009 shell plants. Shell-planting was carried out in late June-early July, 2009. 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 1989-2010 time series: for Shell Rock, 0.460, 0.187, 0.187; for the high-mortality beds: 0.451, 0.257. 0.257, for years 1, 2, and 3, respectively. Bushel conversions assume 261 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat per Clam Bu	Clam Shell Potential Yield (bushels)
Shell Rock	21	Surf clam mix*	58,233	103,628,524	1,780	134,217
Bennies Sand	15	Surf clam mix*	51,366	3,092,897	60	3,162
Nantuxent Point	24	Surf clam mix*	34,686	22,248,738	641	22,744
Total			194,385	128,970,159		160,123

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

Table 15. Summary of 2010 recruitment on earlier shell plants, where data were available. Shell-planting was carried out in late June-early July in each of these years. 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. Bushel conversions assume 261 oysters per bushel.

Location		Type of Shell Planted	Bushels Planted	Spat Collected	Spat per Clam Bu	Clam Shell Potential Yield (bushels)
2008						
Bennies Sand	8	Surf clam mix*	50,587	17,122,763	338	17,504
Bennies Sand	9	Surf clam mix*	20,360	1,052,432	52	1,076
Nantuxent Point	17	Surf clam mix*	53,164	25,482,472	479	26,050
Cohansey	64	Surf clam mix*	21,898	10,657,588	487	21,098
2007						
Ship John	48	Surf clam mix*	59,229	5,918,340	100	11,716
Ship John	53	Surf clam mix*	26,414	2,722,529	103	5,389
2006						
Hawk's Nest	1	Surf clam mix*	17,850	7,577,239	424	7,746
Bennies Sand	7	Surf clam mix*	49,037	5,349,260	109	5,468

*Surf clam mix = surf clam and ocean quahog in various proportions processed to small size

Table 16. Average half-lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2010 time period.

Location	Half-life (yr)
Hope Creek	insufficient data
Fishing Creek	insufficient data
Liston Range	insufficient data
Round Island	17.94
Upper Arnolds	4.81
Arnolds	5.31
Upper Middle	insufficient data
Middle	4.18
Cohansey	5.85
Ship John	3.08
Sea Breeze	6.64
Shell Rock	2.95
Bennies Sand	4.65
Bennies	5.97
Nantuxent Point	3.10
Hog Shoal	3.12
Hawk's Nest	4.55
Strawberry	15.56
New Beds	9.67
Beadons	4.63
Vexton	3.83
Egg Island	5.60
Ledge	5.34

Table 17. The one-year transition probabilities for the broodstock-recruitment diagram shown as Figure 42 for each quadrant in the 58-year time series and mean first passage times. The 1989-2010 first passage times are also based on the 58-yr medians. The medians are: abundance = 2.86×10^9, recruitment = 1.80×10^9. Quadrant definitions are in Figure 43. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.63	0.11	0.11	0.16
2→	0.38	0.25	0.00	0.38
3→	0.11	0.33	0.33	0.22
4→	0.10	0.15	0.20	0.55

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	3.09	6.39	8.33	5.03
2→	4.50	5.50	9.05	3.85
3→	5.86	4.44	6.52	4.26
4→	6.32	5.61	7.09	2.93

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.324	0.182	0.153	0.341

Mean First Passage Time (years): 1989-2010

Quadrant	1	2	3	4
1→	1.98	6.67	9.25	7.86
2→	3.22	4.94	10.00	5.43
3→	3.11	4.83	7.42	8.14
4→	3.44	5.17	7.75	6.36

Table 18. The one-year transition probabilities for the broodstock-mortality diagram shown as Figure 44 for each quadrant in the 58-year time series and the mean first passage times. The 1989-2010 first passage times are also based on the 58-yr medians. The medians are: abundance = 2.86×10^9, mortality fraction= 0.13. Quadrant definitions are in Figure 43. Arrows indicate trajectory direction. Un-est, insufficient occurrences to calculate first passage times.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.17	0.42	0.17	0.25
2→	0.33	0.47	0.00	0.20
3→	0.06	0.06	0.65	0.24
4→	0.23	0.31	0.23	0.23

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.81	3.77	8.91	4.37
2→	3.65	3.13	10.51	4.61
3→	6.60	6.35	4.07	4.33
4→	4.74	4.34	8.17	4.42

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.21	0.32	0.25	0.23

Mean First Passage Time (years): 1989-2009

Quadrant	1	2	3	4
1→	4.58	2.00	Un-est	3.40
2→	3.23	1.89	Un-est	4.80
3→	4.92	3.00	Un-est	1.00
4→	3.92	2.00	Un-est	3.97

Table 19. The one-year transition probabilities for the recruitment-mortality diagram shown as Figure 46 for each quadrant in the 58-year time series and the mean first passage times. The 1989-2010 first passage times are also based on the 58-yr medians. The medians are: recruitment = 1.80×10^9, mortality fraction = 0.13. Quadrant definitions are in Figure 43. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.14	0.50	0.14	0.21
2→	0.27	0.40	0.07	0.27
3→	0.20	0.00	0.67	0.13
4→	0.31	0.15	0.15	0.39

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.34	3.73	8.47	4.71
2→	3.81	3.91	9.04	4.41
3→	4.48	7.37	3.78	5.83
4→	3.70	5.33	8.12	4.02

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.23	0.26	0.27	0.25

Mean First Passage Time (years): 1989-2009

Quadrant	1	2	3	4
1→	4.86	2.73	20.00	3.64
2→	3.90	2.46	23.90	4.07
3→	4.30	4.82	24.30	1.00
4→	3.30	3.82	23.30	2.89

Table 20. Harvest statistics for 2010. Fraction covered indicates the estimated 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. Bed areas are for the medium-quality and high-quality grids only.

Oyster Bed	Bed Area (m^2)	Fraction Covered	Bushels Harvested	Fraction of Harvest
Hope Creek	2,970,947			
Fishing Creek	1,273,459			
Liston Range	1,167,525			
Round Island	1,910,960			
Upper Arnolds	1,911,274			
Arnolds	2,548,739			
Upper Middle	956,159			
Middle	3,719,585	.02	56	
Cohansey	4,995,452	.28	2,806	.04
Sea Breeze	2,338,640	.06	220	
Ship John	4,890,278	2.20	20,409	.27
Shell Rock	5,104,046	1.90	17,493	.24
Bennies Sand	3,190,495	2.16	10,147	.14
Bennies	8,404,238	.38	5,526	.07
Nantuxent Point	2,552,807	2.35	6,572	.09
New Beds	4,788,189	.17	1,075	.01
Hawk's Nest	2,021,560	.98	2,693	.04
Hog Shoal	1,808,455	2.57	7,281	.10
Strawberry	1,808,668	.02	25	
Beadons	2,447,474	.03	72	
Vexton	2,022,090			
Egg Island	4,045,293			
Ledge	1,916,423			
Total or Mean	68,792,753	0.67	74,375	1.00

Table 21. Statistics for oysters going to market, obtained from dock-side monitoring of landings. Sizes are given in inches. Percentiles refer to the percentile sizes of the size-frequency distribution.

	Mean size	25^{th} percentile	50^{th} percentile	75^{th} percentile	Mean Number per bushel	Number $\geq 2.5''$ per bushel
2004	3.04	2.79	3.08	3.37	302	265
2005	3.05	2.73	3.13	3.42	275	235
2006	3.22	2.95	3.24	3.54	260	238
2007	3.23	2.94	3.26	3.59	262	235
2008	3.12	2.77	3.17	3.50	299	252
2009	3.14	2.74	3.21	3.58	277	230
2010	2.52	1.67	2.87	3.40	318	204

Table 22. Proportion of cultch moved downbay during intermediate transplant from the various bed regions targeted between 2003 and 2010. Three gear types were used: a suction dredge, a dry dredge without the automatic culler engaged, and a dry dredge with the automatic culler engaged. Percentages are based on bushel volume.

	Region	Oys/Bu	Oys	Cultch	Box
Culled Transplants (2003-2009)	Very Low Mortality	621	75%	24%	1%
	Low Mortality	461	66%	30%	4%
	Medium Mortality Transplant	347	65%	29%	6%
	Medium Mortality Market	338	78%	18%	4%
Culled Transplants (2010)	Very Low Mortality	453	57%	40%	3%
	Low Mortality	410	67%	25%	8%
	Medium Mortality Market	192	44%	39%	17%
Unculled Transplants (2004-2006)	Low Mortality	407	39%	57%	4%
	Medium Mortality Transplant	388	68%	30%	2%
	High Mortality	111	22%	74%	4%
Suction Dredge Transplants (2004)	Low Mortality	465	36%	58%	5%
	Overall Culled	442	71%	25%	4%
	Overall Unculled	302	43%	53%	3%
	Overall Suction	465	36%	58%	5%

Table 23. Area-specific stock-performance biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 (1990-2005 for biomass) time period. The threshold is taken as half these values.

	Low Mortality Beds	Medium Transplant Mortality Beds	Medium Market Mortality Beds	Shell Rock	High Mortality Beds
Abundance					
Target (50^{th} Percentile)	531,733,632	278,444,928	864,934,144	113,350,896	473,125,088
Threshold (1/2 Target)	265,866,816	139,222,464	432,467,072	56,675,448	236,562,544
Spawning Stock Biomass					
Target (50^{th} Percentile)	175,499,360	106,646,608	392,472,896	62,450,392	267,982,768
Threshold (1/2 Target)	87,749,680	53,323,304	196,236,448	31,225,196	133,991,384
Market ($\geq 2.5''$) Abundance					
Target (50^{th} Percentile)	43,388,077	45,934,727	180,658,285	25,622,244	51,205,771
Threshold (1/2 Target)	21,694,039	22,967,364	90,329.143	12,811,122	25,602,886

Table 24. Confidence percentiles for the 2010-survey abundance point estimate with rank order based on the number of small market and large market animals.

Percentile	Oysters <2.5″	Oysters 2.5-<2.95″	Oysters >2.95″	Total Oysters > 2.5″
10.	1,287,097,984	184,089,168	185,492,608	369,581,760
20.	1,200,795,776	200,447,936	196,067,696	396,515,648
30.	1,222,783,360	212,157,456	202,731,920	414,889,376
40.	1,578,844,544	224,771,344	205,580,464	430,351,808
50.	1,241,171,200	224,064,736	222,993,248	447,057,984
60.	1,588,593,280	232,882,288	229,155,424	462,037,696
70.	1,575,353,472	252,575,872	229,056,000	481,631,872
80.	1,463,629,824	253,038,160	249,164,272	502,202,432
90.	1,407,085,824	260,636,160	279,007,200	539,643,392

Table 25. Confidence percentiles for the 2010-survey abundance point estimate with rank order based on the total number of animals.

Percentile	Oysters <2.5″	Oysters 2.5-<2.95″	Oysters >2.95″	Total Oysters
10.	1,122,523,008	208,193,824	206,184,624	1,536,901,376
20.	1,253,932,416	168,446,896	208,967,120	1,631,346,432
30.	1,312,662,272	180,016,448	197,373,968	1,690,052,608
40.	1,322,932,608	218,204,592	215,757,344	1,756,894,464
50.	1,356,539,648	231,948,192	225,585,696	1,814,073,472
60.	1,318,023,040	261,542,768	301,990,112	1,881,555,968
70.	1,484,689,920	236,240,496	224,988,080	1,945,918,464
80.	1,506,264,320	266,197,184	258,856,560	2,031,318,144
90.	1,633,437,440	249,125,360	275,827,104	2,158,390,016

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

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

[1] Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 42), predicted recruitment from each reduced by 5%, plotted adult mortality rate (Figure 44), median unrecorded mortality rate.

[2] Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 42), plotted adult mortality rate (Figure 44), median unrecorded mortality rate.

[3] Ricker recruitment curve (Figure 42), plotted adult mortality rate (Figure 44), median unrecorded mortality rate.

[4] Ricker recruitment curve (Figure 42), plotted adult mortality rate (Figure 44), mean unrecorded mortality rate.

[5] Ricker recruitment curve (Figure 42), average of background (10%) and plotted adult mortality rate (Figure 44), median unrecorded mortality rate.

Table 27. Percentiles of the real exploitation rates for all oysters and for one bay region for oysters $\geq 2.5''$ based on the fishing record for 1996-2006. The medium-mortality transplant bed group is Middle and Upper Middle. The medium-mortality market bed group is Cohansey, Ship John, and Sea Breeze. The all-oyster upper medium-mortality percentiles are also used for the low-mortality beds: Arnolds, Upper Arnolds, and Round Island.

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

Table 28. Percentiles of the real and apparent exploitation rates for oysters $\geq 2.5''$ based on the fishing record for 1996-2006. The SARC recommends using the real exploitation rates for setting harvest provisions.

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

Table 29. Allocation projections for direct marketing for the high-mortality beds, Shell Rock, and the lower group of medium-mortality beds (Cohansey, Ship John), based on the exploitation record from 1996-2006, using the abundance of $\geq 2.5''$ animals in each bay region as the basis to estimate an exploitation index. An upper and lower bound are taken as the 40^{th} and 60^{th} percentiles of the 1996-2006 time series using data on the total removals from each bay region (transplant or harvest), with one exception. Projections use the average numbers per marketed bushel of 261 derived from the 2004-2010 port-sampling program. Arrows indicate recommended options. Γ indicates recommendations with intermediate transplant.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	692,010	2,651
	$^{\Gamma}50^{th}$	.0652	3,698,281	14,170
	$^{\Gamma}60^{th}$	.0782	4,435,668	16,995
Shell Rock	$\longrightarrow 40^{th}$	.0870	3,725,234	14,273
	$\longrightarrow 50^{th}$	.0880	4,991,544	19,125
	$\longrightarrow 60^{th}$	.1140	6,466,319	24,775
Medium Mortality Market without Sea Breeze	$\longrightarrow 40^{th}$	.0178	3,682,846	14,111
	$\longrightarrow 50^{th}$	.0214	4,427,692	16,964
	$\longrightarrow 60^{th}$	.0267	5,524,270	21,166
	$\longrightarrow 100^{th}$	.0398	8,234,679	31,551
Upper Medium Mortality				NA§
Low Mortality				NA§

§NA: not applicable to this reference point.

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

Table 30. Projections for intermediate transplant assuming that intermediate transplant will be conducted on the very-low-mortality, low-mortality, and Middle-Upper Middle-Sea Breeze group of medium-mortality beds. Numbers to be moved by intermediate transplant are based on the assumption that transplant involves the removal of all size classes approximately in proportion to their representation in the population as would occur by suction dredge, deck loading by dry dredge, or inefficient culling. The estimated number of bushels to be moved is derived from the mean of the number of oysters per bushel for these beds obtained from the 2010 intermediate transplant program. Cullers were used for this transplant; however, numbers per bushel are similar to survey numbers (Table 4) suggesting that the indicated number of bushels to be moved may overestimate the required quantity. The proportion of animals available for market is estimated based on the fraction of animals $\geq 2.5''$ and these animals are converted to bushels using the 261 animal/bu conversion. Percentiles for the very-low-mortality and low-mortality beds use the exploitation reference points for the medium-mortality transplant beds. Arrows indicate preferred alternatives. The 50^{th} percentile exploitation rate of 0.0188 is the average of the 50^{th} and 60^{th} percentiles from Table 27, consistent with the decision made in earlier SAWs that the original gap between these two percentiles was too large for effective management.

Bay Region	Percentile	Exploitation Rate	Animals Removed	Deck-load Oysters/Bu	Transplant Bushels	Marketable Bushel Equivalents
High Mortality						NA§
Shell Rock						NA§
Medium Mortality Market						NA§
Medium Mortality Transplant						
including Sea Breeze	$\longrightarrow 40^{th}$	.0127	3,550,138	196	18,113	4,013
	$\longrightarrow 50^{th}$	.0188	5,255,322	196	26,812	5,940
	60^{th}	.0233	6,513,245	196	33,231	7,362
Low Mortality	$\longrightarrow 40^{th}$	.0127	3,991,178	410	9,734	4,450
	50^{th}	.0188	5,908,201	410	14,410	6,587
	60^{th}	.0233	7,322,398	410	17,869	8,164
Very Low Mortality	$\longrightarrow 40^{th}$	.0127	5,003,664	452	11,070	4,716
	50^{th}	.0188	7,406,953	452	16,387	6,871
	60^{th}	.0233	9,179,894	452	20,310	8,652

§NA: not applicable to this reference point.

Table 31. Exploitation history for Beadons.

Year	Bushels Harvested or Transplanted	Comments
Direct Market		
1999	20	
2000	508	
2001	110	
2002	821	
2003	652	
2004	26	
2005	0	
2006	0	
2007	14	
2008	0	
2009	82	
2010	72	
Transplant		
2000	4,900	culled to New Beds
2004	1,200	un-culled to Bennies

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-min latitude × 0.2-min longitude, equivalent to approximately 25 acres. The 2010 random sampling sites are indicated by white stars. Ledge and Egg Island beds have not been re-surveyed. For the remaining beds, the depicted footprint is based on re-surveys that began in 2005. Ship John and Nantuxent Point were re-surveyed in 2010 and their footprints updated on this map.

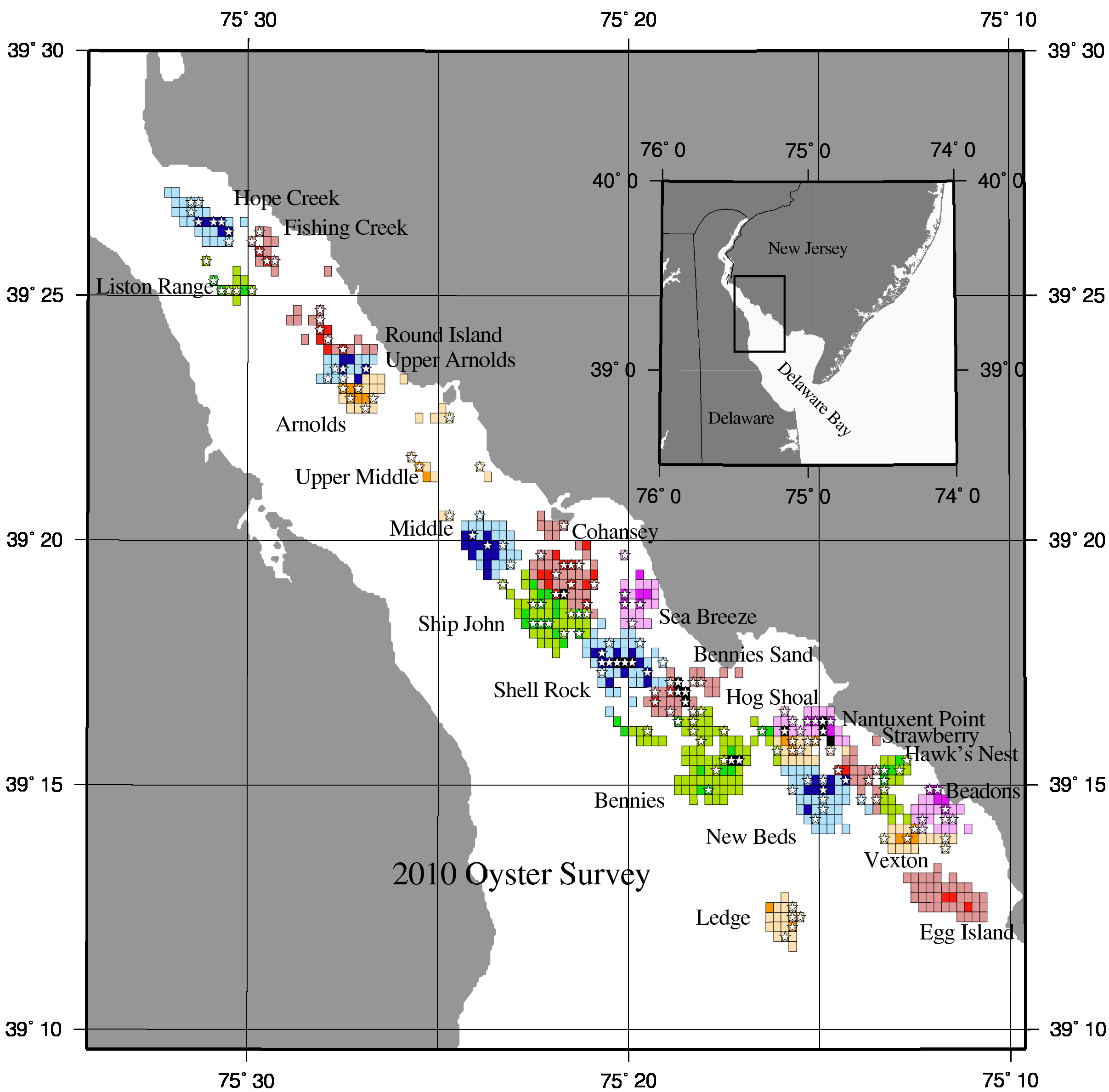
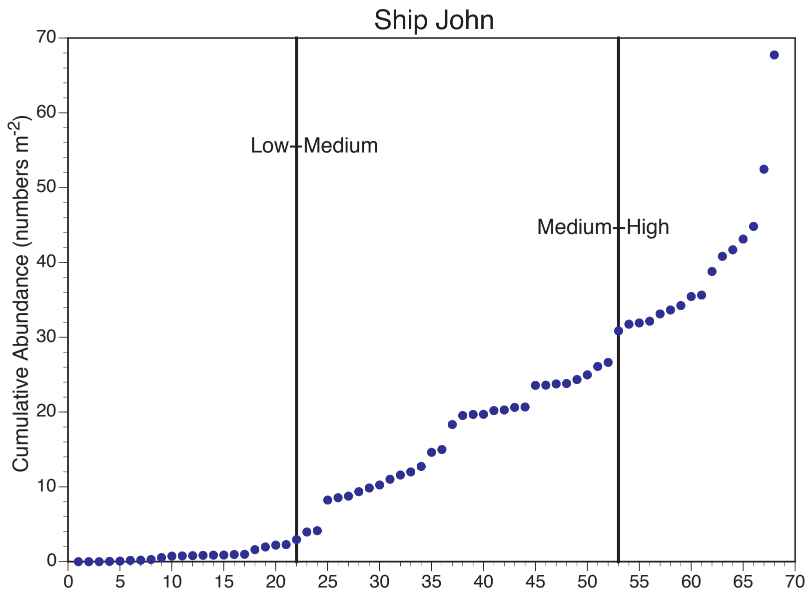


Figure 2. Relationship of cumulative abundance versus sample number for grids ordered by increasing abundance for all grids sampled on Nantuxent Point and Ship John during the 2010 re-survey. The 2010 re-survey program covered all navigable grids associated with these two bed regions. The vertical lines mark the boundary between the low-, medium-, and high-quality strata



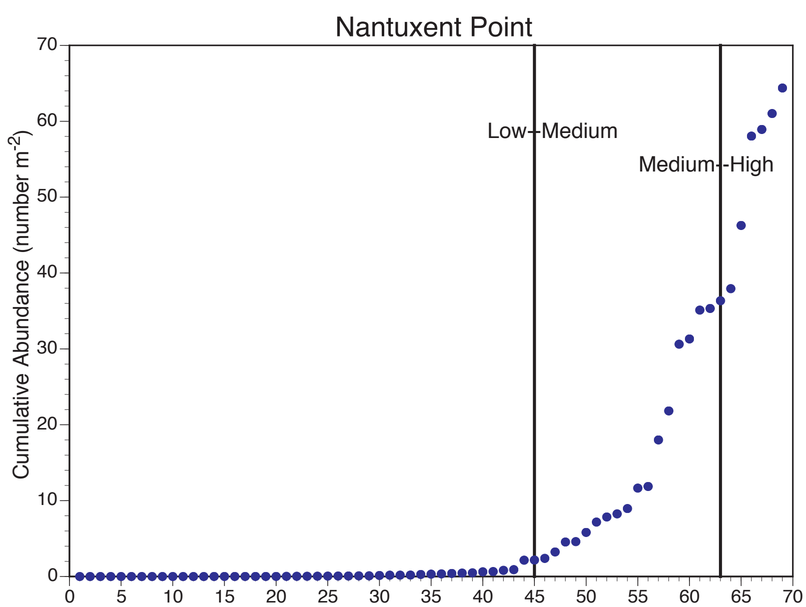


Figure 3. Distribution of grids for Nantuxent Point and Ship John after the 2010 re-survey, shaded accordingly to oyster density. The 2010 re-survey program covered all navigable grids associated with these two bed regions. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded a light color.

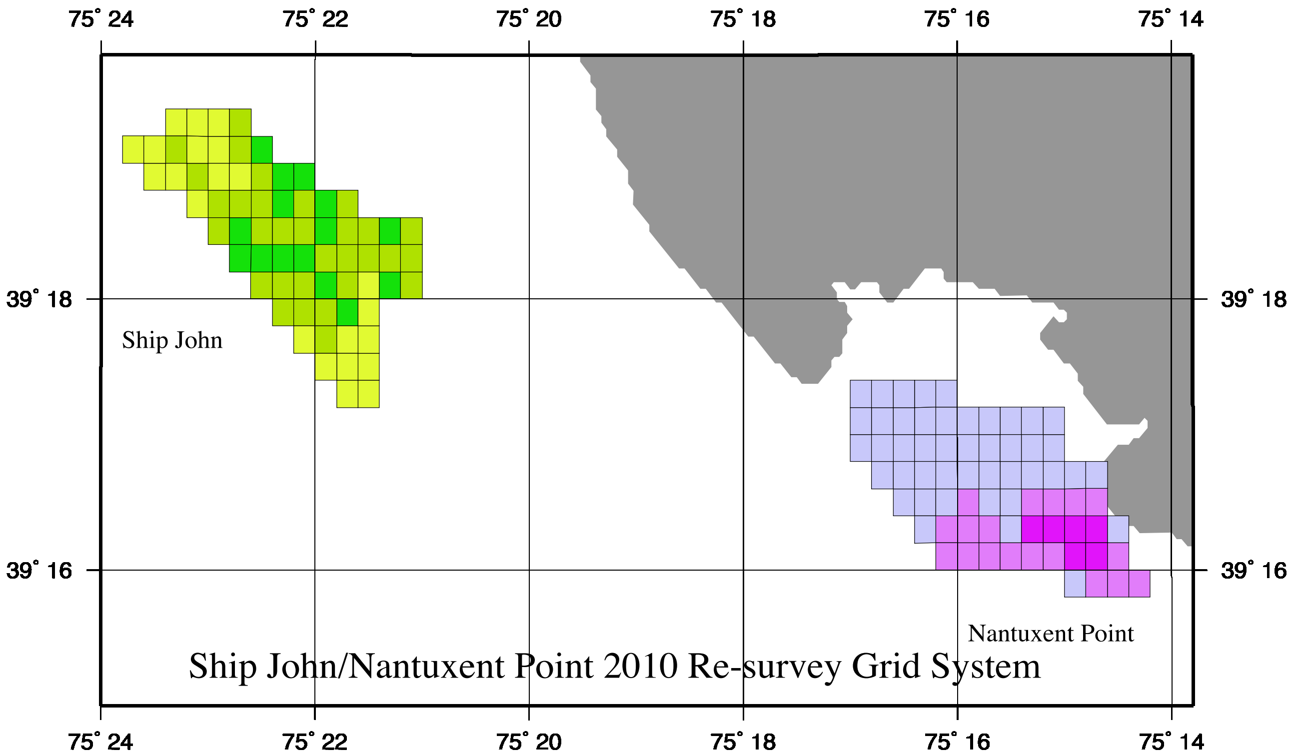


Figure 4. Distribution of grids for Nantuxent Point and Ship John prior to the 2010 re-survey, shaded accordingly to oyster density. The 2010 survey program covered all navigable grids associated with these two bed regions. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded a light color.

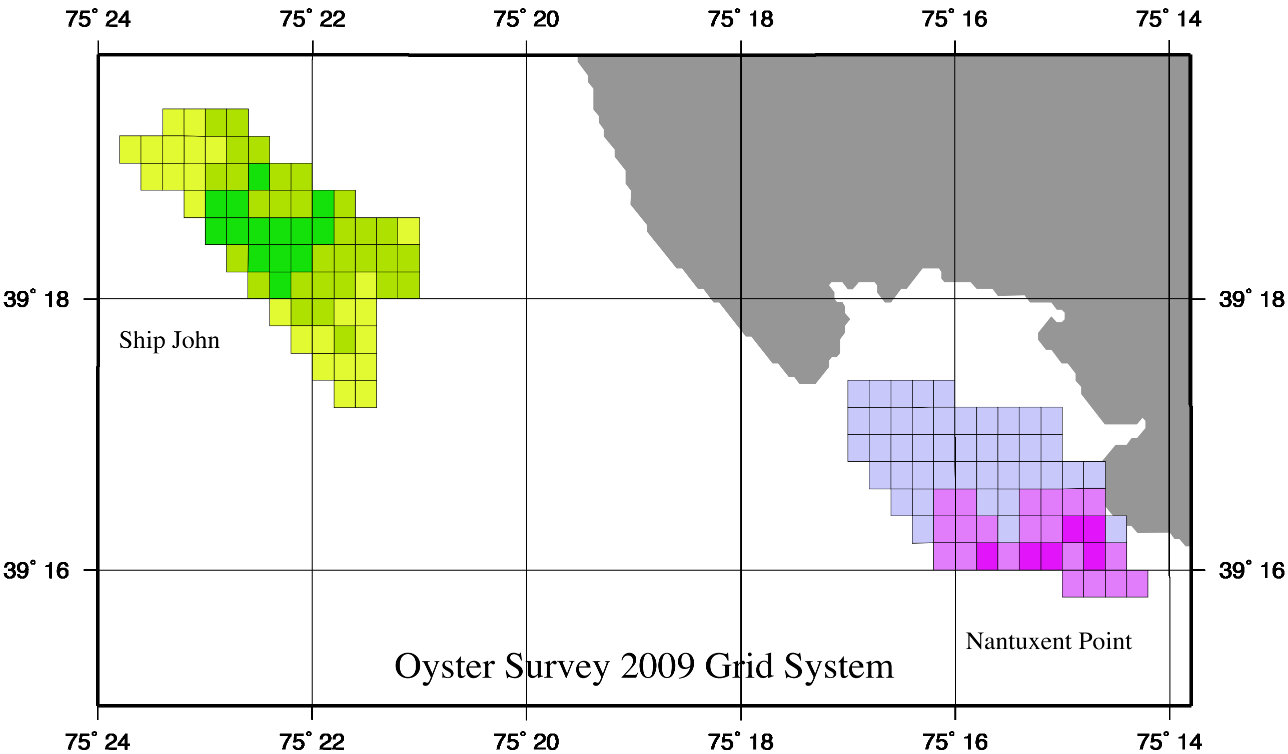


Figure 5. Ship John and Nantuxent Point beds, showing grids that changed in quality designation between the 2009 and 2010 assessments based on the 2010 re-survey of these beds. For those grids not changing quality, high-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded lightly consistent with Figures 2 and 3.

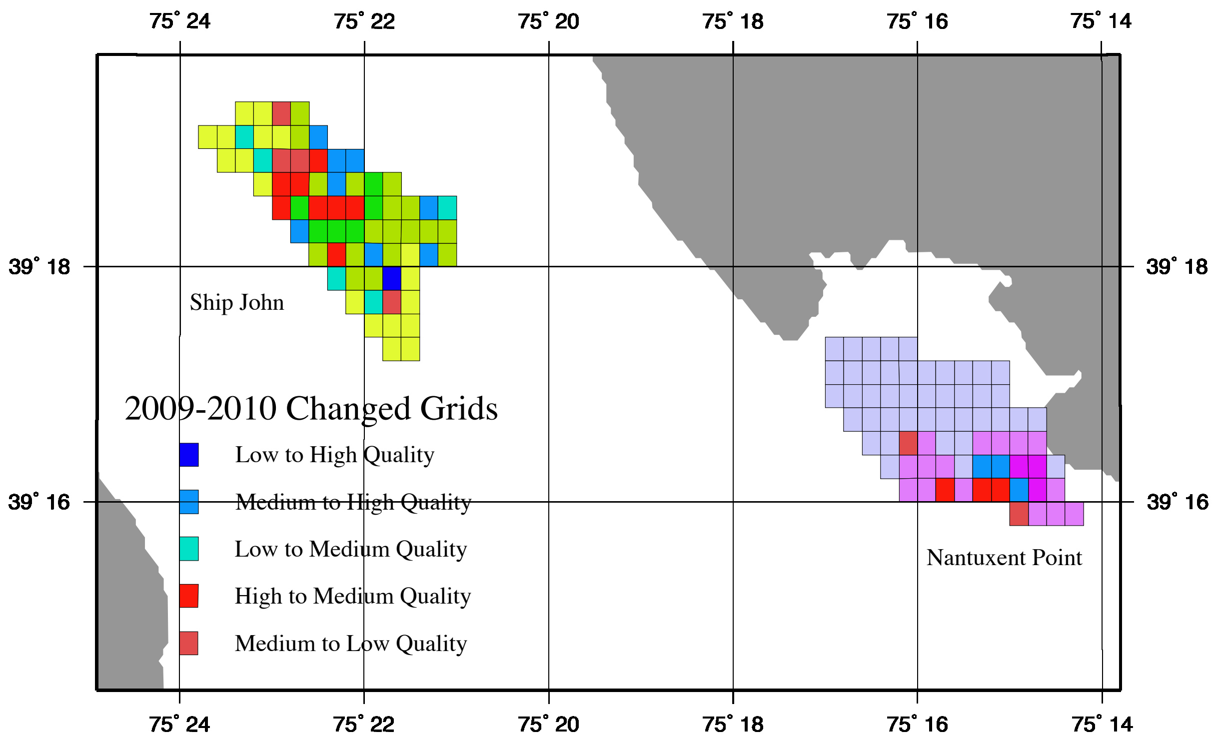
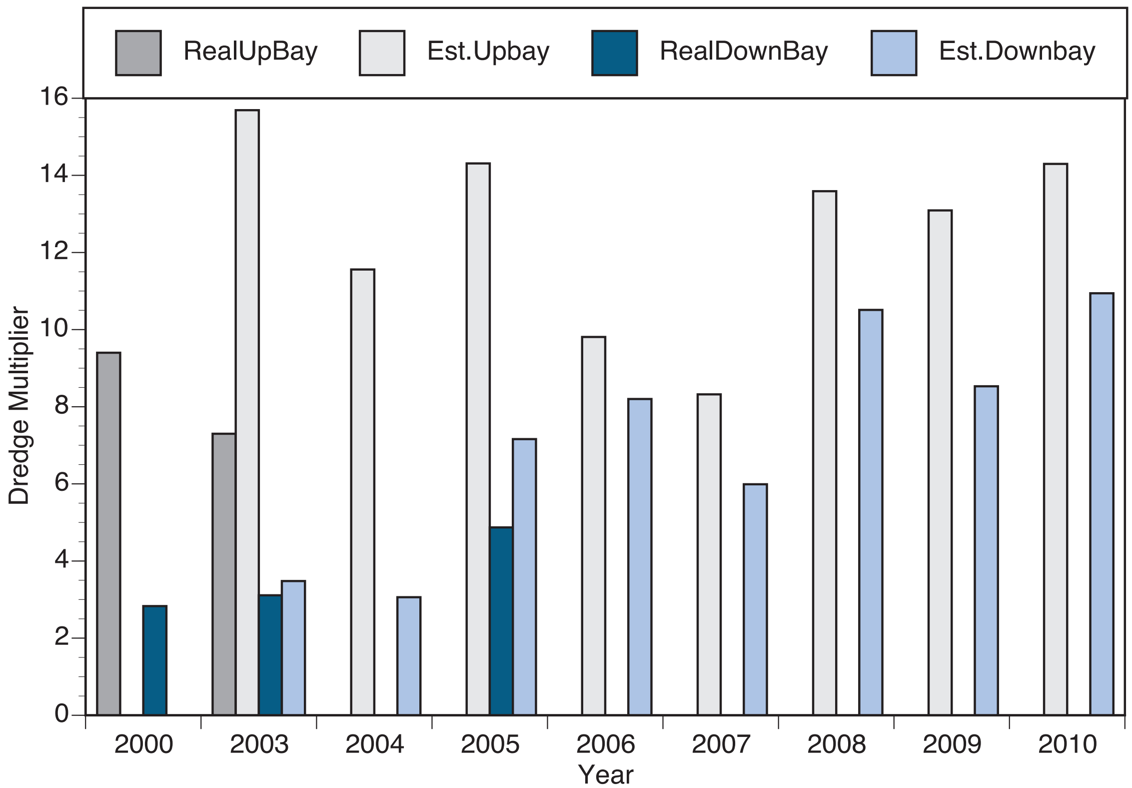


Figure 6. Estimates of q from retrospective analyses described in Powell et al. (2007)[∇] compared with directly measured values. The upbay estimates do not include the very-low-mortality beds, as no direct measurements are available for these beds.



∇ Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter. 2007. Re-evaluation of eastern oyster dredge efficiency in survey mode: Application in stock assessment. *N. Am. J. Fish. Manage.* 27:492-511.

Figure 7. Example size-frequency distributions for spat recruiting in 2010 to shell planted in 2010 on Bennies Sand and Shell Rock. X-axis class intervals mark the upper bound of the size class. Occasional larger oysters are animals attached to previously planted clam shell on nearby grids likely redistributed by fishing activities.

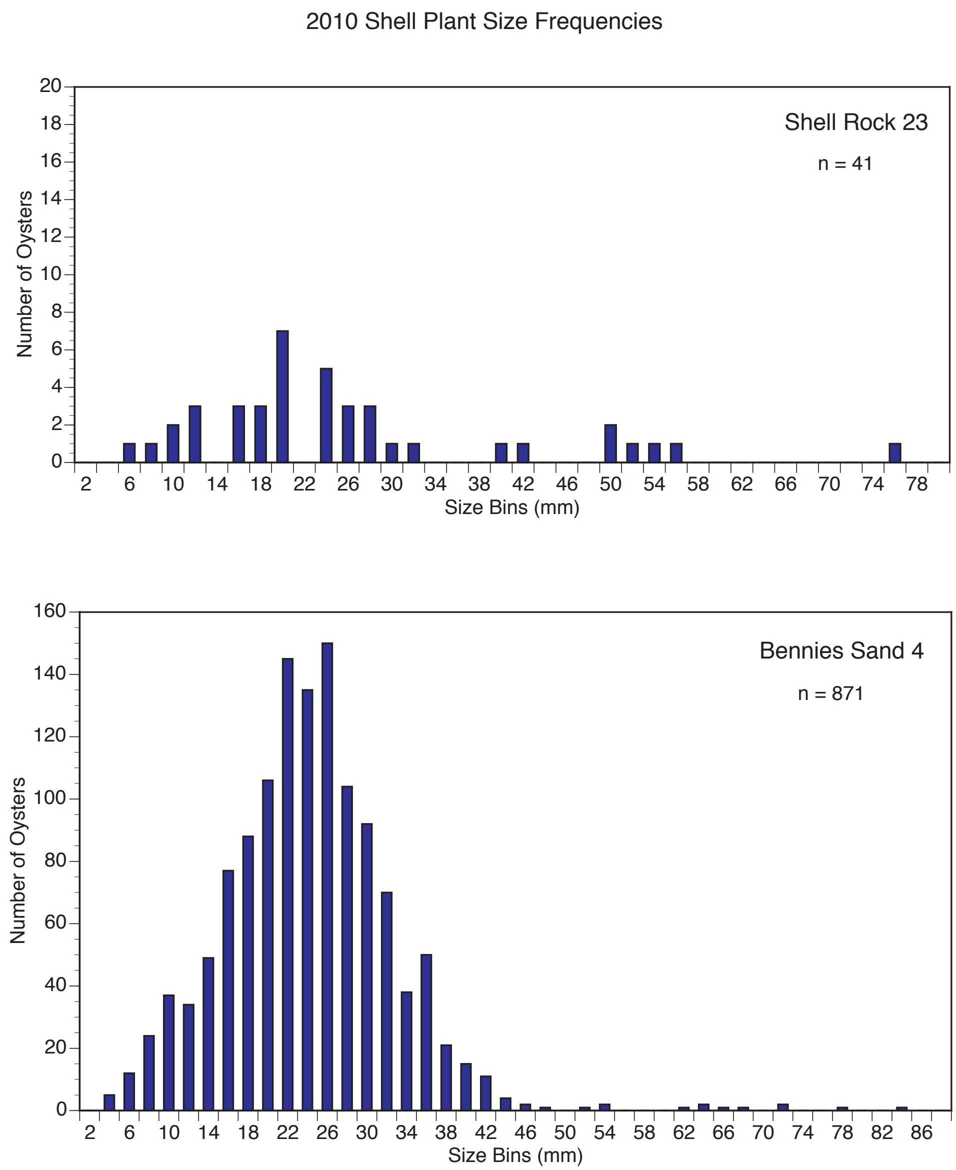


Figure 8. The size frequency of spat and yearlings on shell planted in 2009. X-axis class intervals mark the upper bound of the size class. Occasional larger oysters are animals attached to previously planted clam shell on nearby grids likely redistributed by fishing activities.

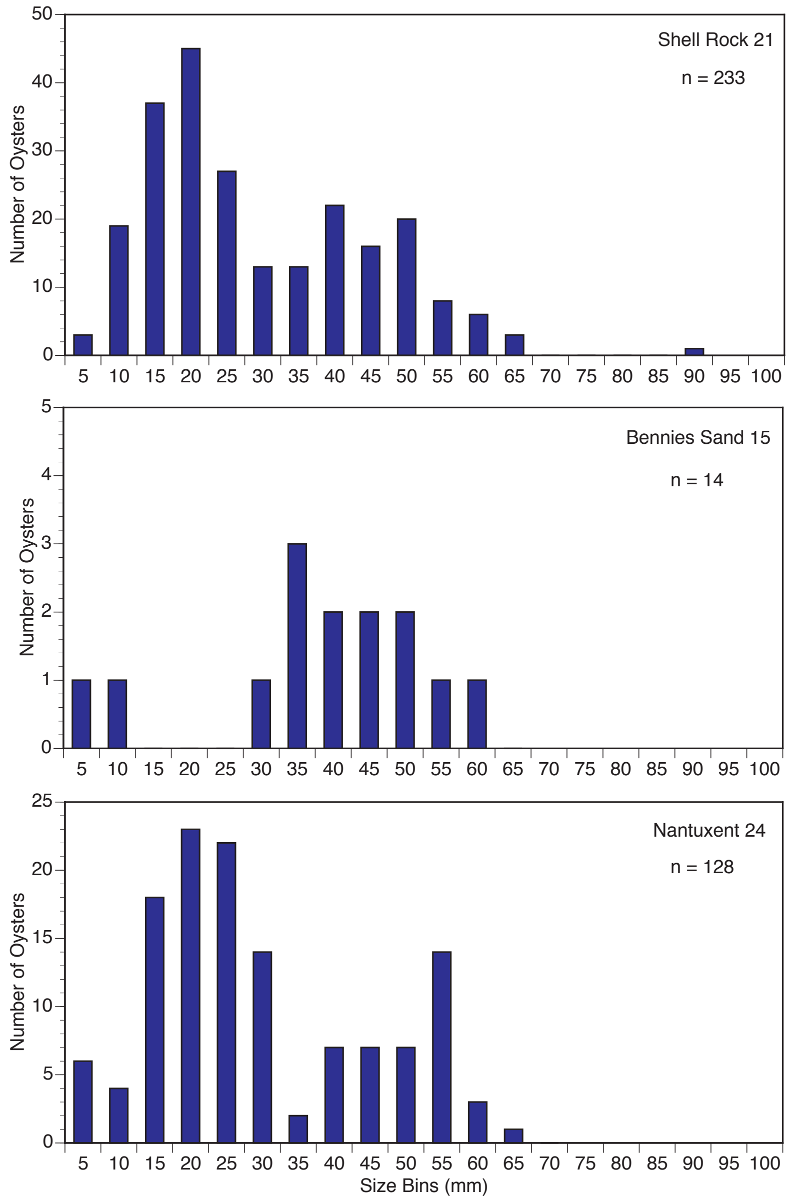


Figure 9. Time series of oyster abundance by bay region. High mortality: Bennies Sand, Nantuxent Point, Bennies, Strawberry, Hog Shoal, Vexton, Hawk's Nest, New Beds, Beadons, Egg Island, Ledge; medium mortality market (less Shell Rock): Ship John, Cohansey, Sea Breeze; medium mortality transplant: Middle, Upper Middle; low mortality: Arnolds, Upper Arnolds, Round Island; very-low mortality: Hope Creek, Fishing Creek, Liston Range. No data are available for the very-low-mortality beds prior to 2007.

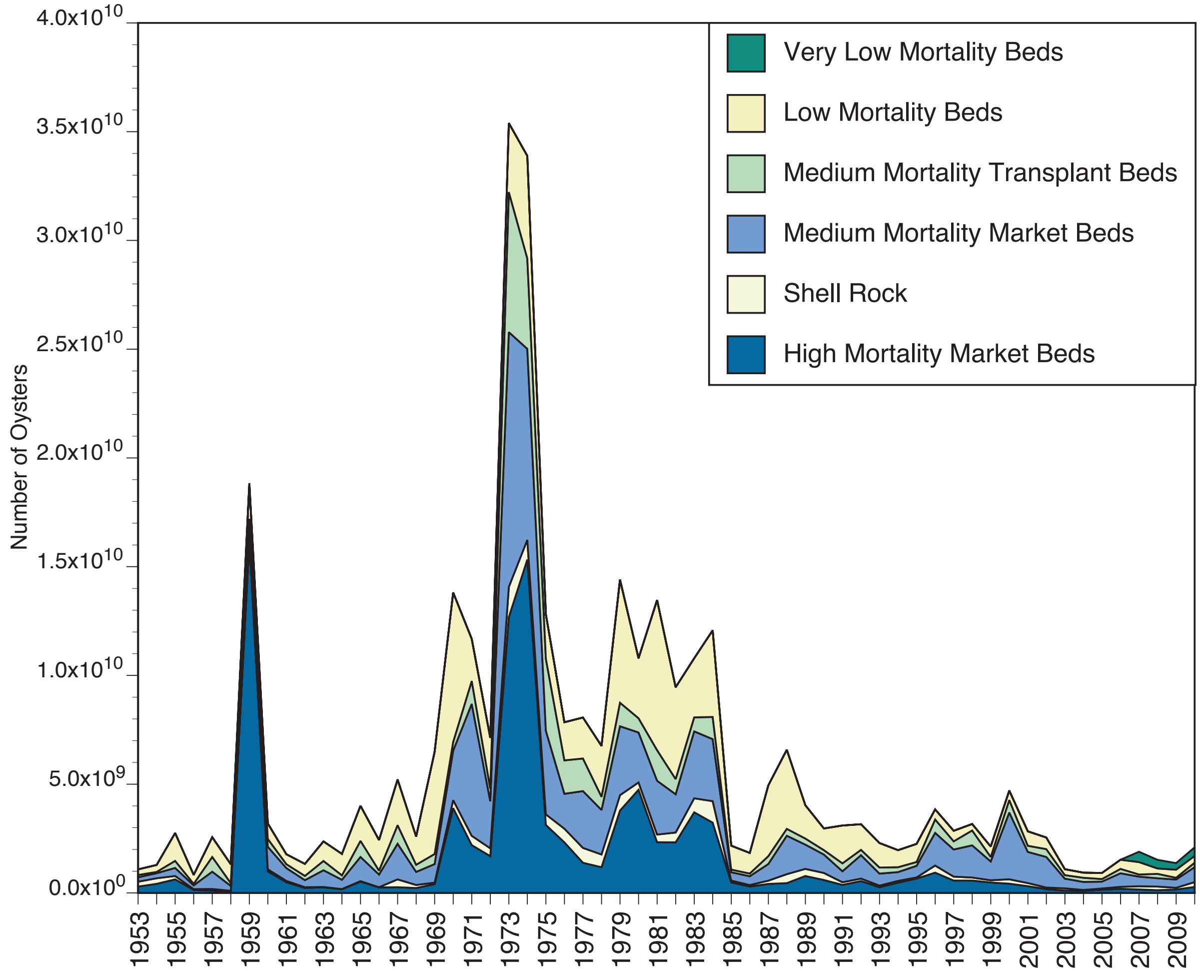


Figure 10. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2010. Bed regions are defined in Figure 9. No data are available for the very-low-mortality beds prior to 2007.

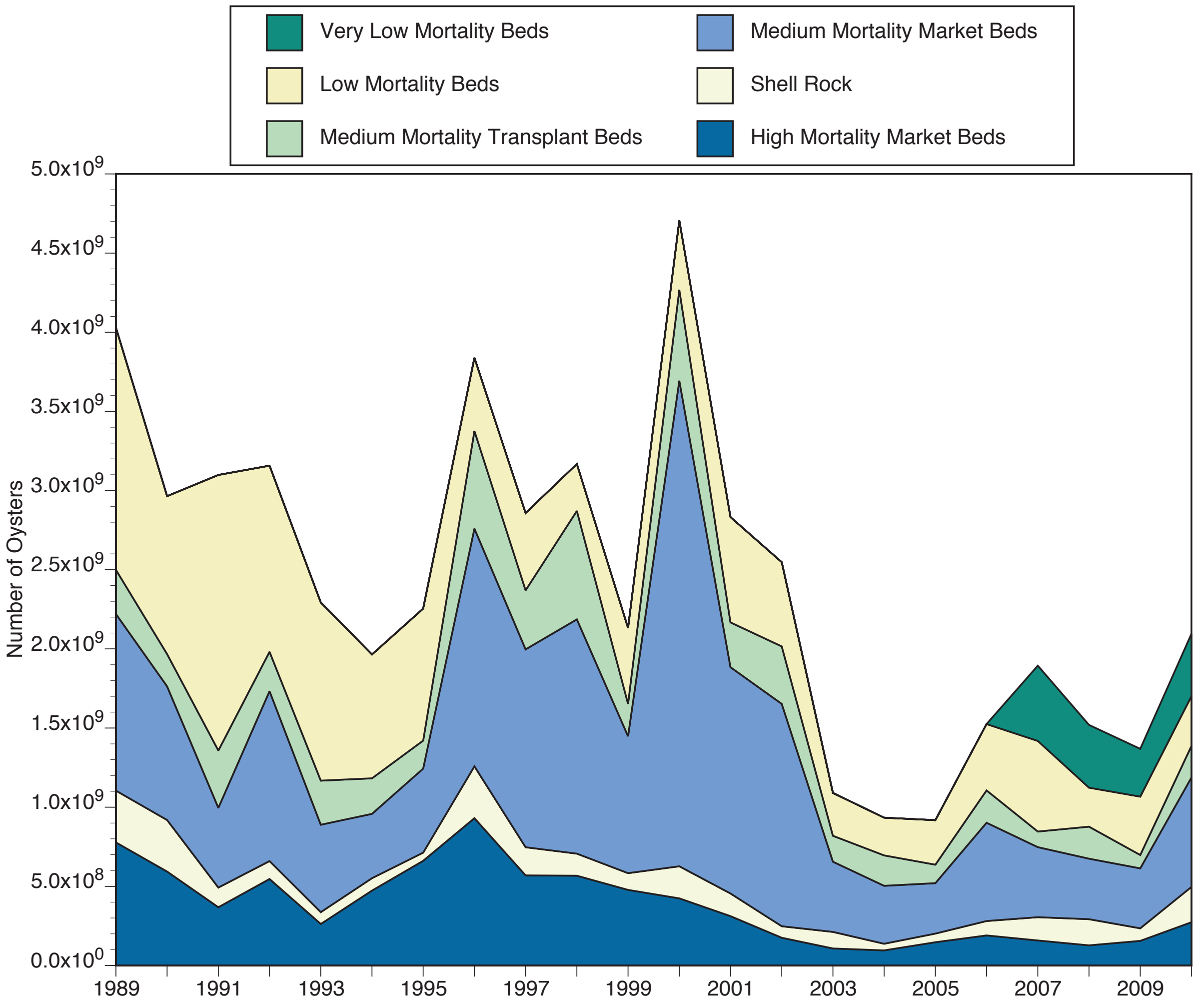


Figure 11. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 9.

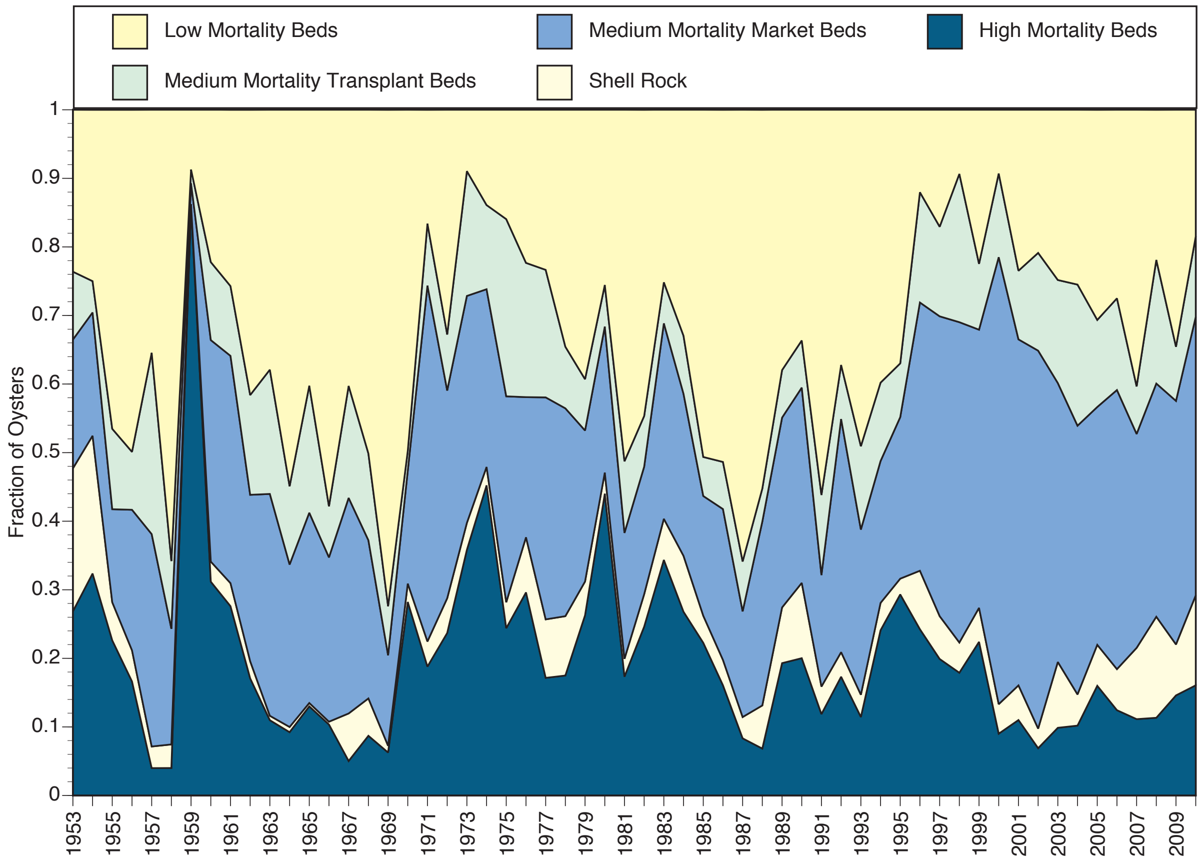


Figure 12. Fraction of animals on the medium-mortality beds, 1953-2010. The horizontal line identifies the median value of 0.384.

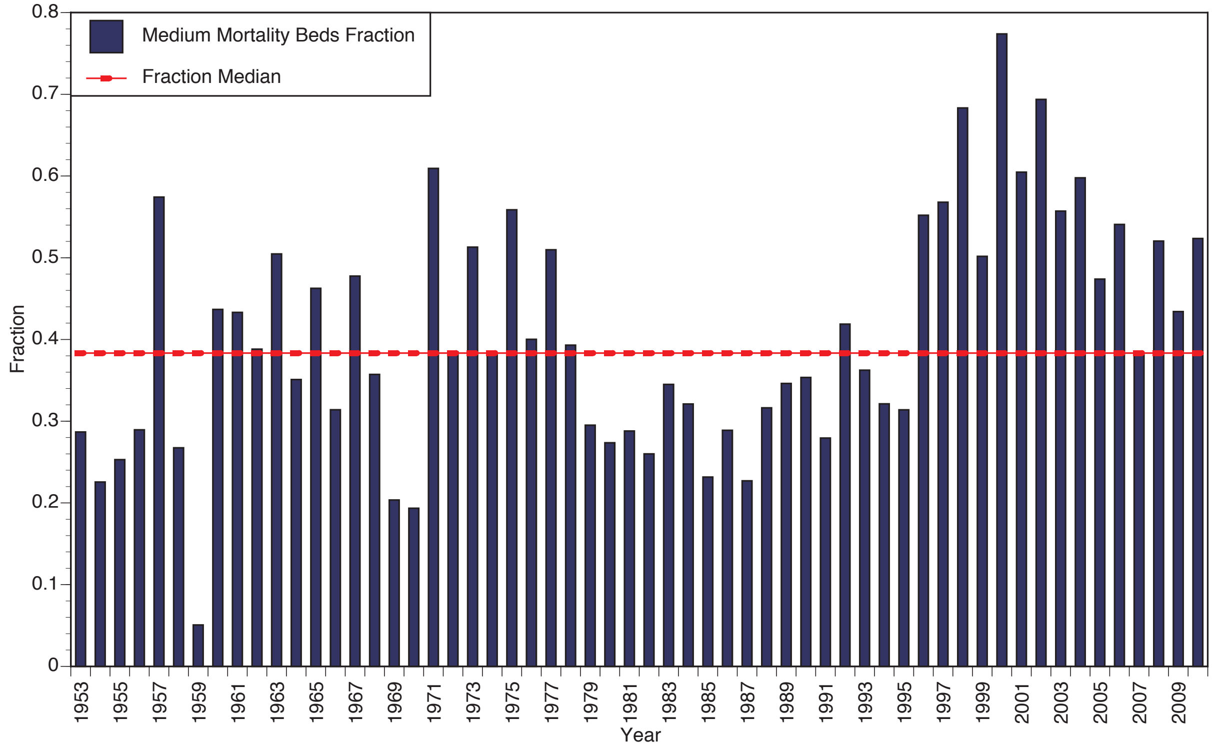


Figure 13. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 9. No data are available for the very-low-mortality beds prior to 2007.

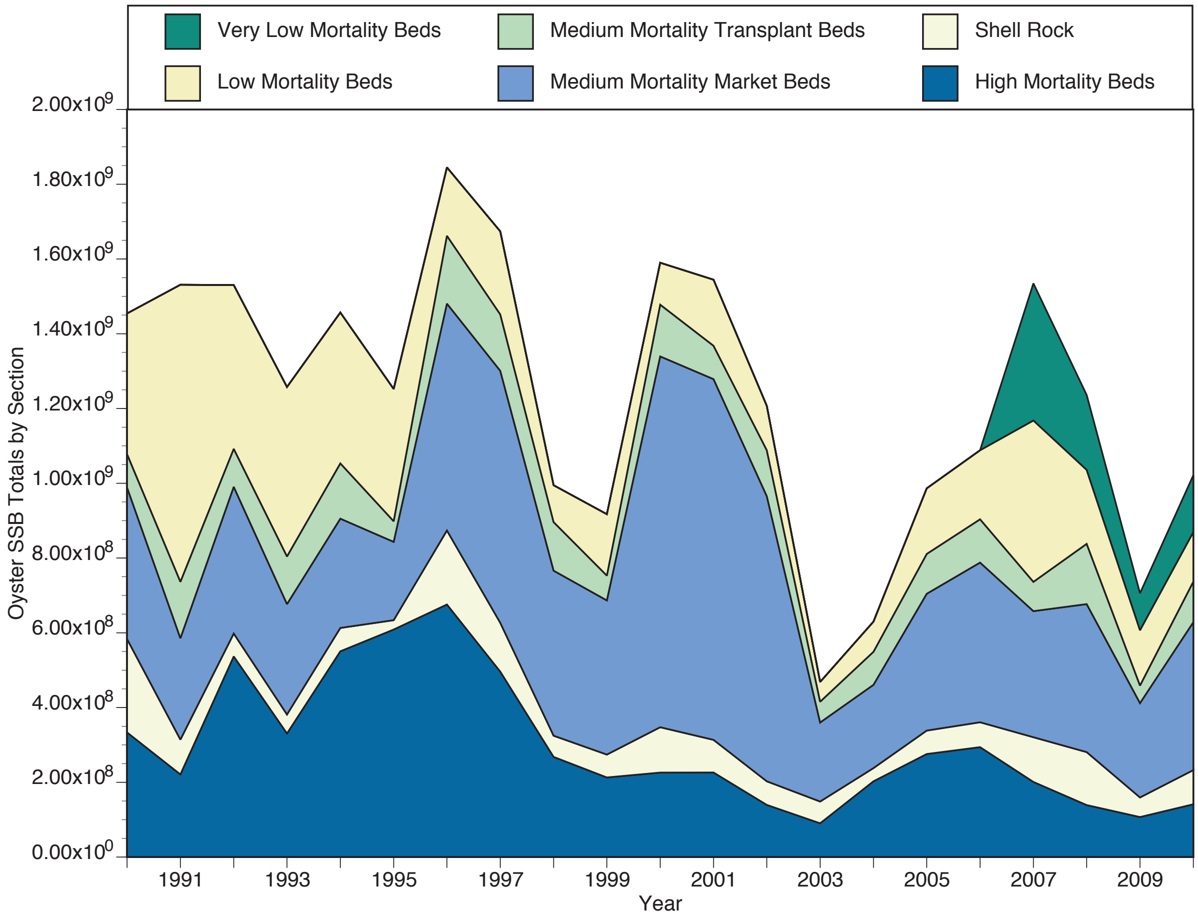


Figure 14. Time series of the fractional distribution of spawning stock biomass among the bay regions, excluding the very-low-mortality beds. Bed distributions by region are given in Figure 9.

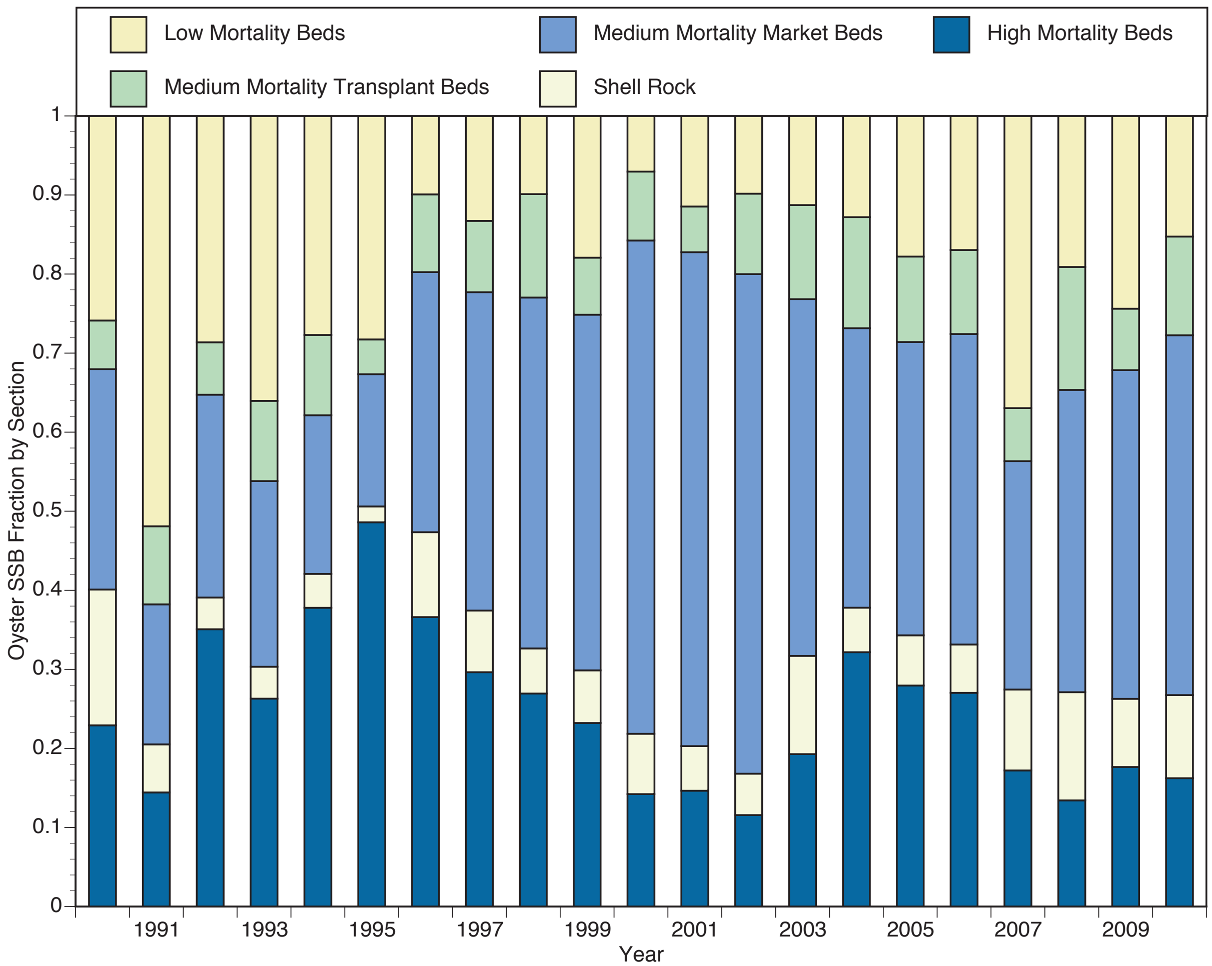


Figure 15. The fraction of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

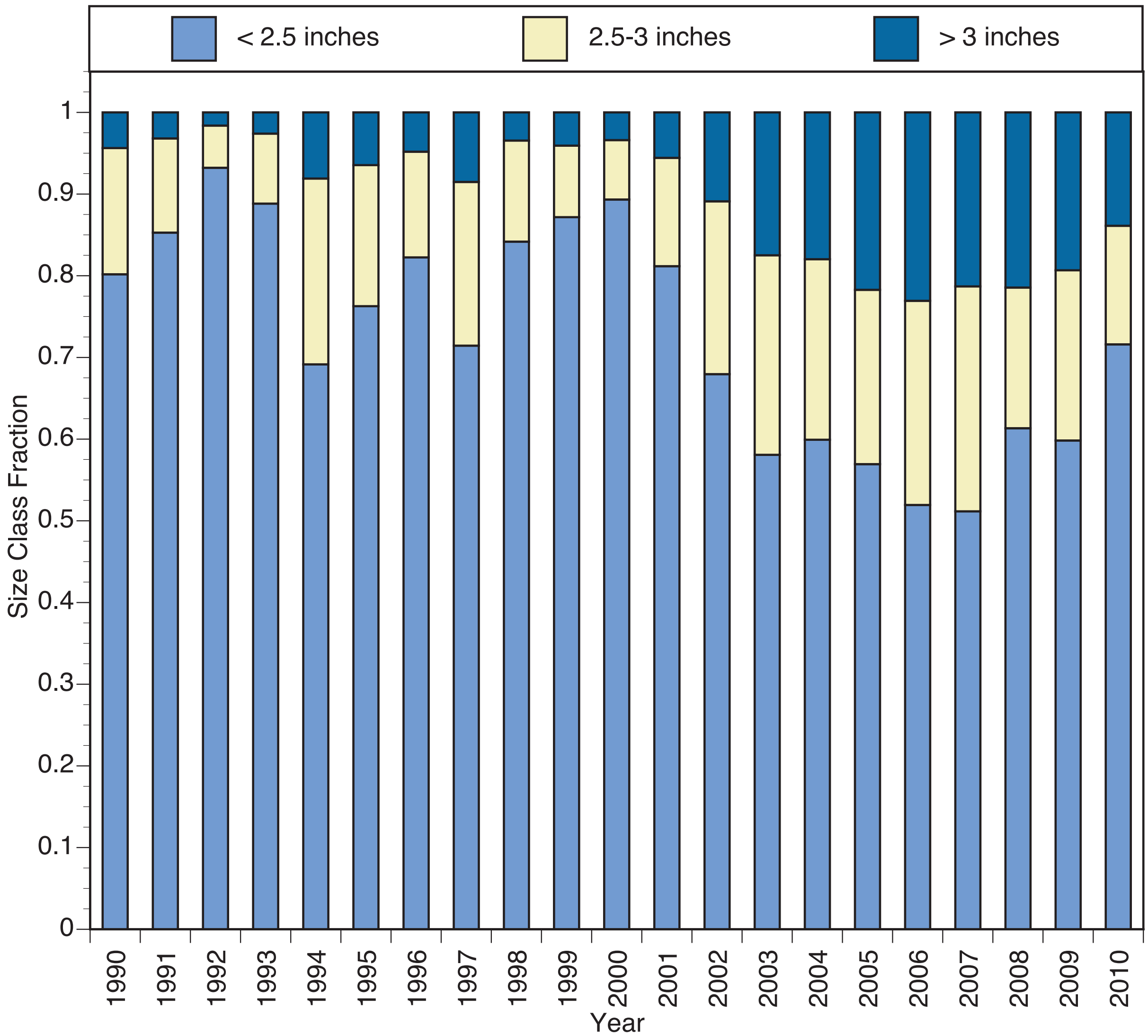


Figure 16. The abundance of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

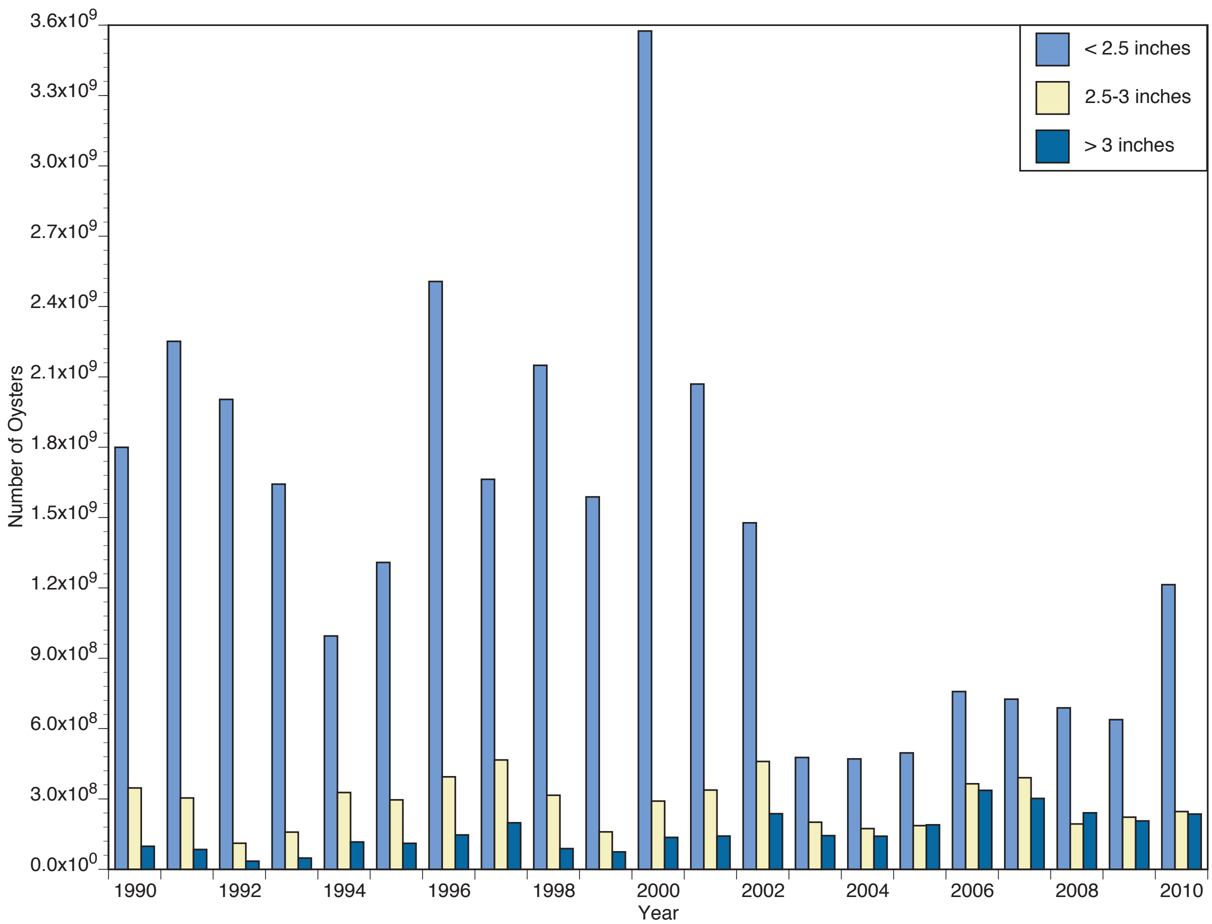


Figure 17. The abundance of small, small market, and large market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 9. Note variation in y-axis scale between graphs.

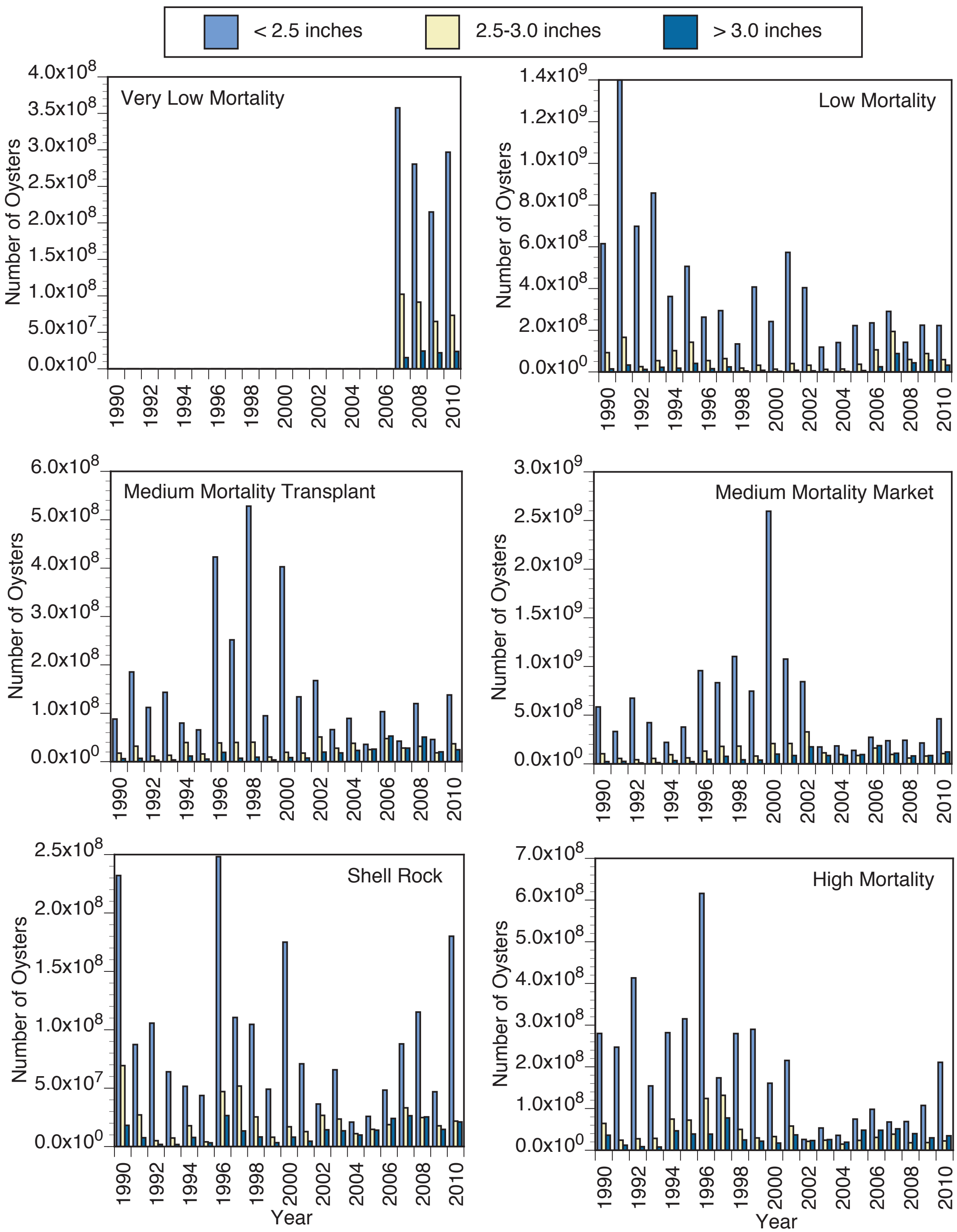


Figure 18. The fraction of marketable animals that were $\geq 2.5''$-$<3''$ and $\geq 3''$, excluding the very-low-mortality beds.

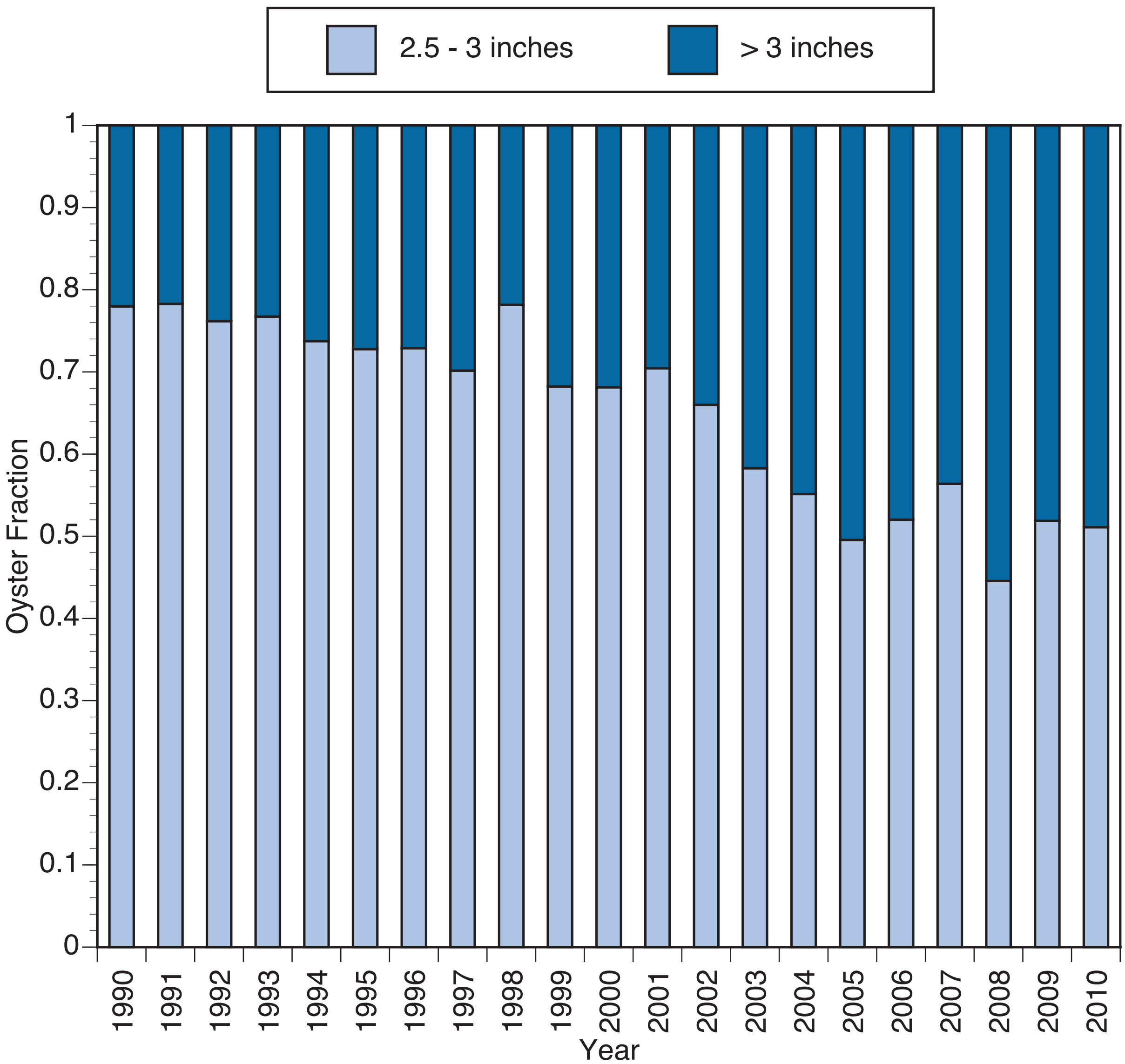


Figure 19. Abundance of market-size ($\geq 2.5''$) oysters, excluding the very-low-mortality beds.

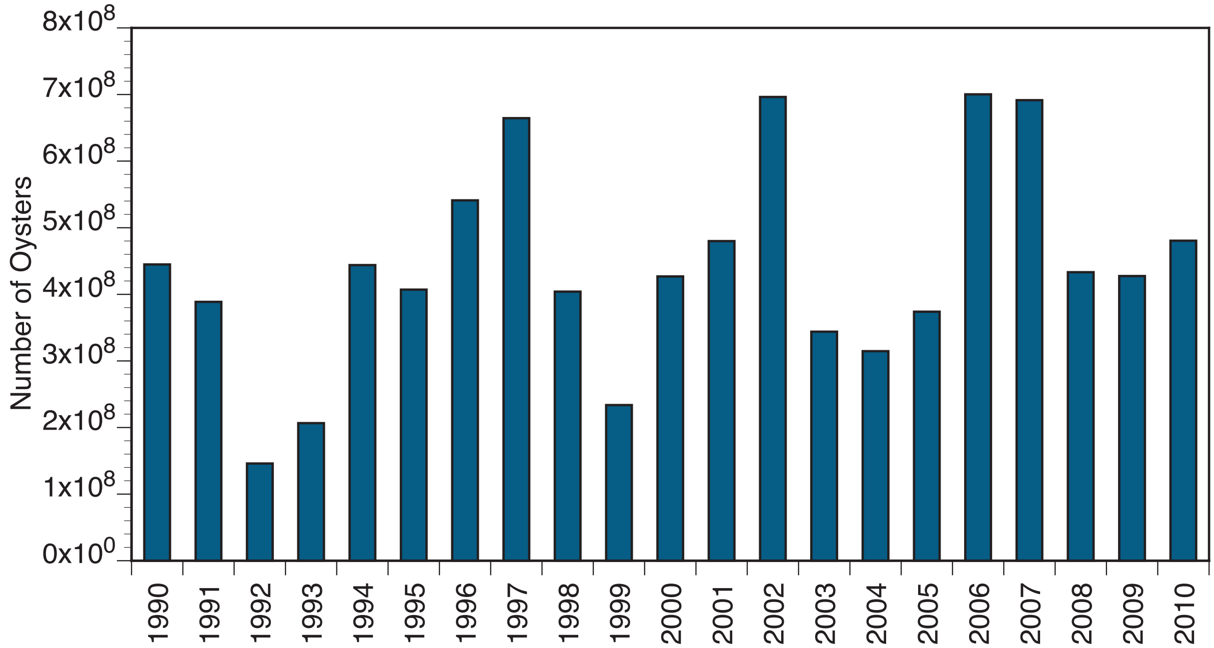


Figure 20. Abundance of market-size ($\geq 2.5''$) oysters by bay region, excluding the very-low-mortality beds. Bed regions are defined in Figure 9.

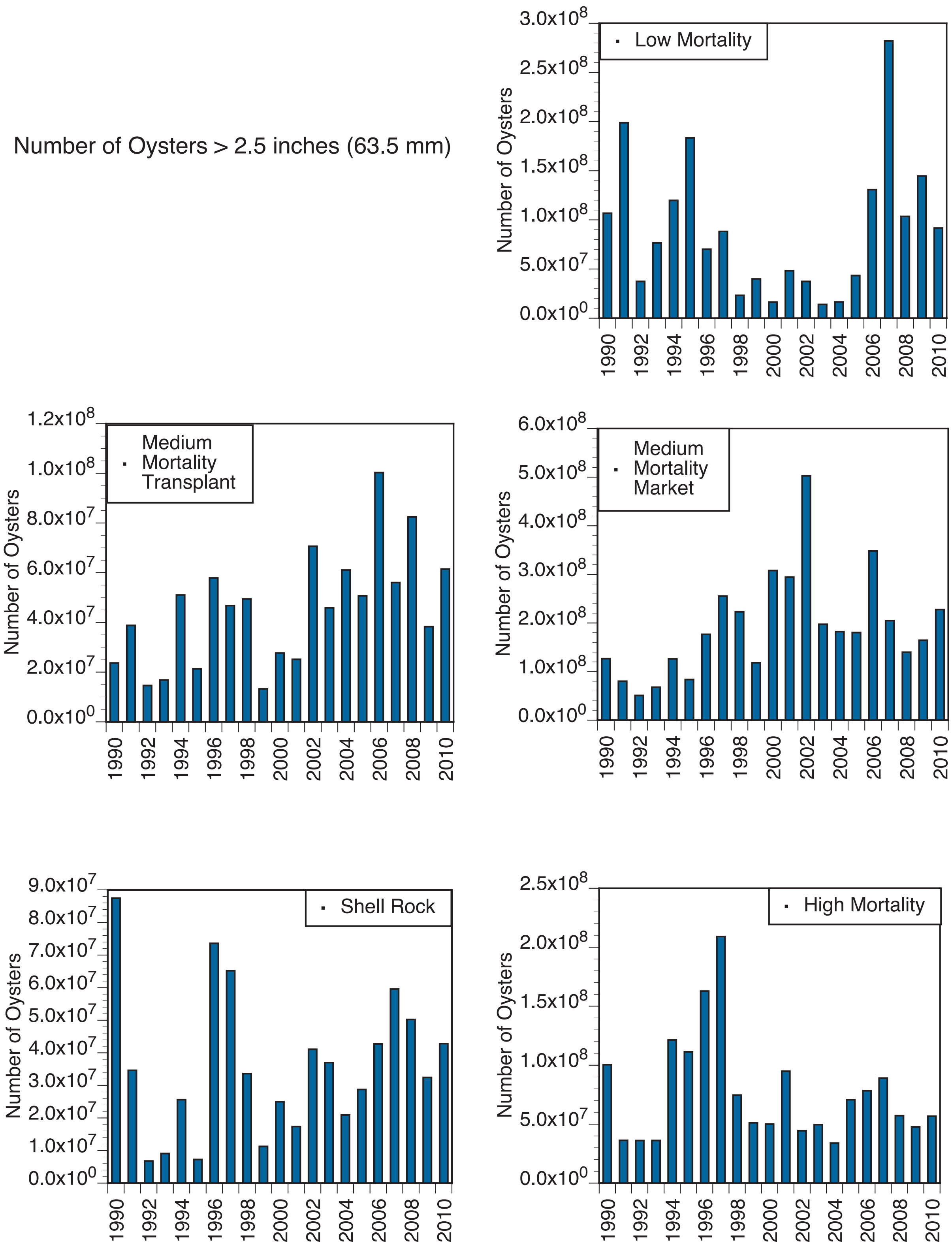


Figure 21. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)], excluding the very-low-mortality beds.

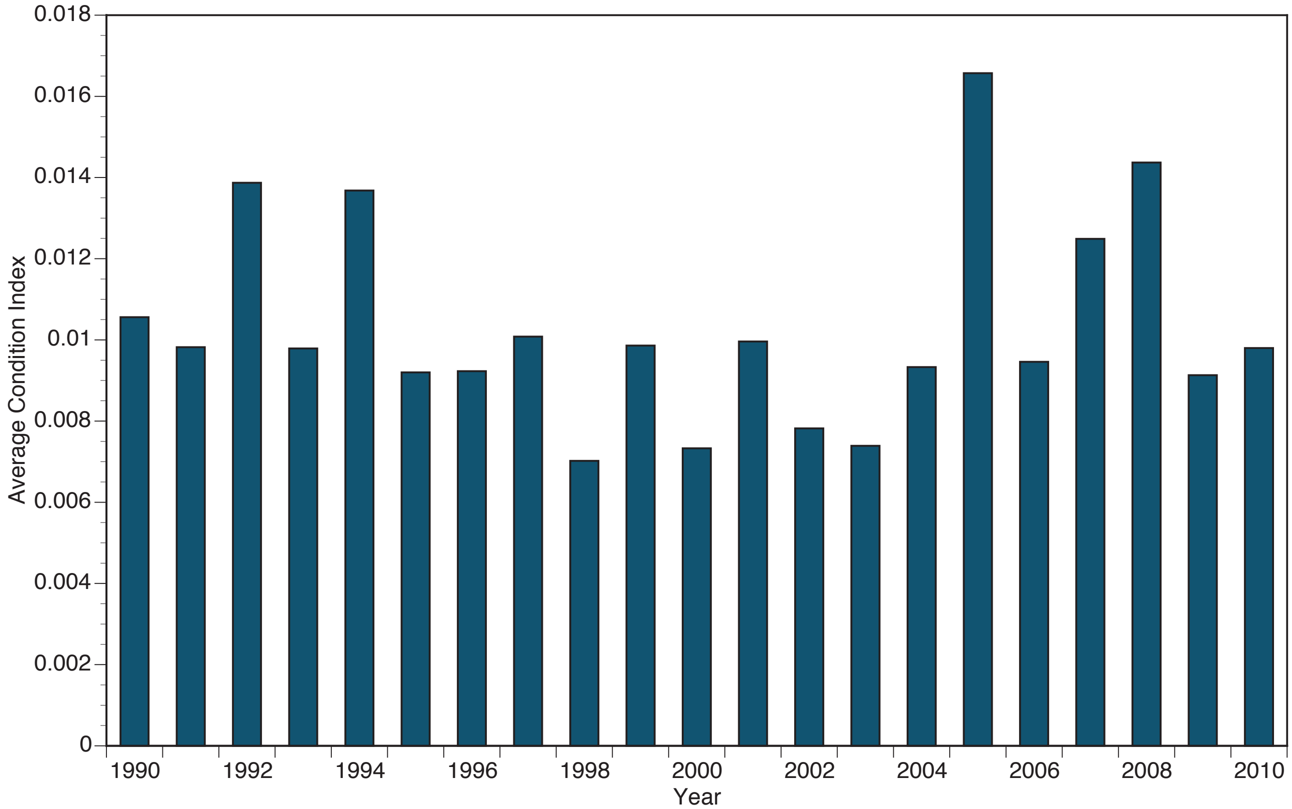


Figure 22. Annual average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)] by bay group. Bed distributions by region are given in Figure 9.

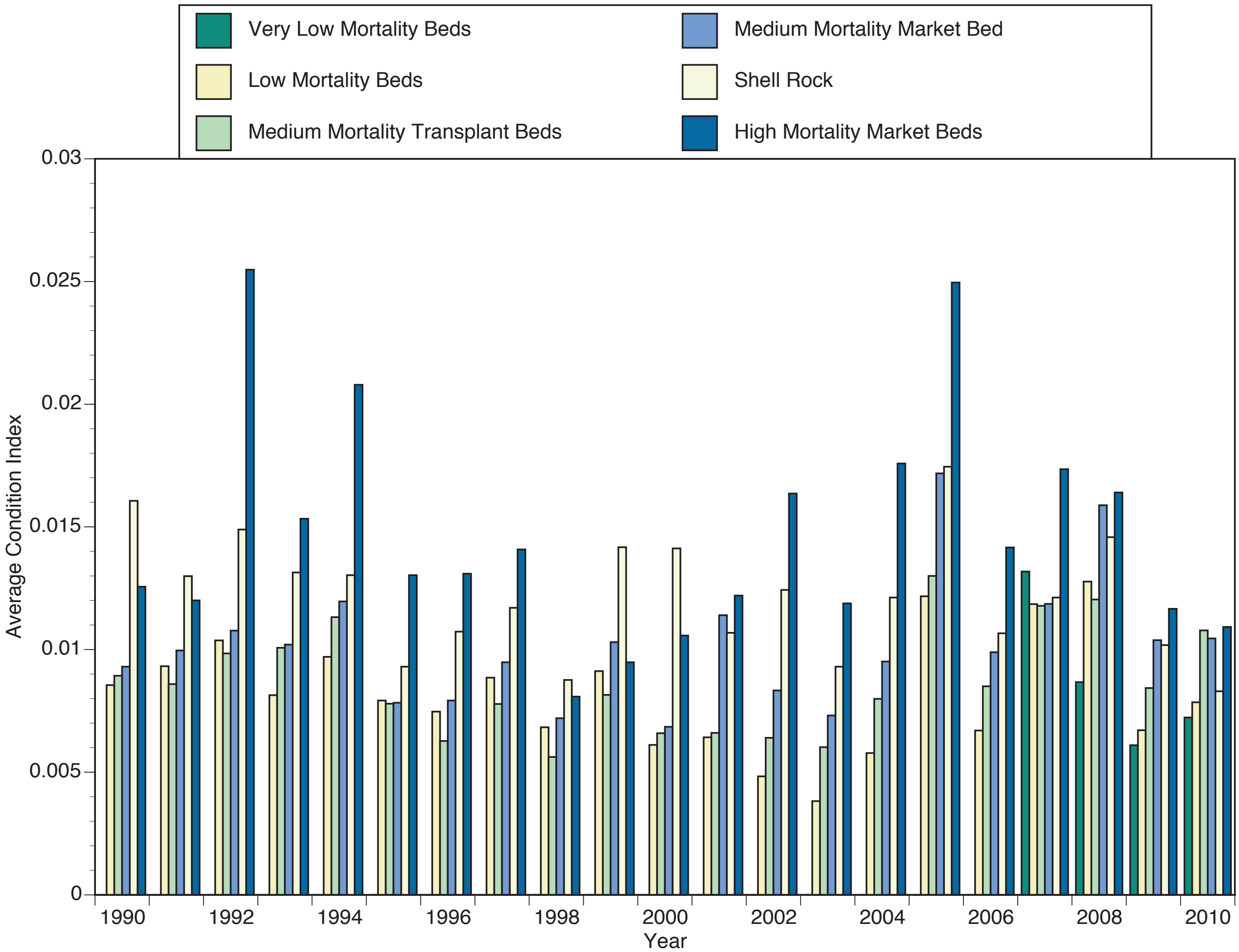


Figure 23. Bar plot showing oyster length frequencies for Bennies from 1990-2009. Overlaid black lines show the mean length frequency for each decade with the average from 1990's shown in triangles with black solid line and the average from 2000's shown in diamonds with dotted line. Overlaid orange lines show the simulated length frequency for each decade with 1990's shown in triangles with orange solid line and 2000's shown in diamonds with a dotted line. Note: size class 0-20 mm is not included in this plot. Results show that the change in size frequency can be achieved by a change in growth rate described by change in k.

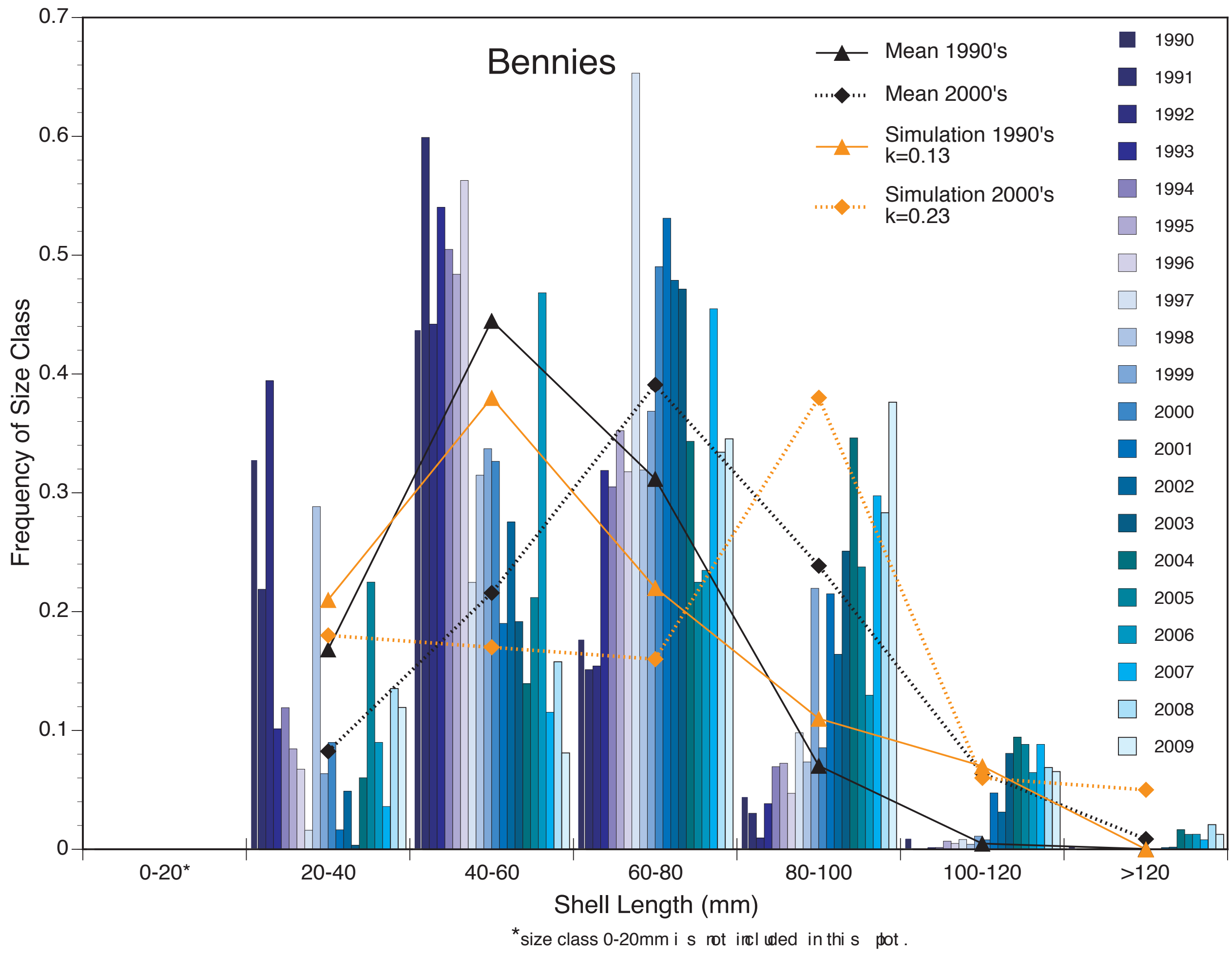
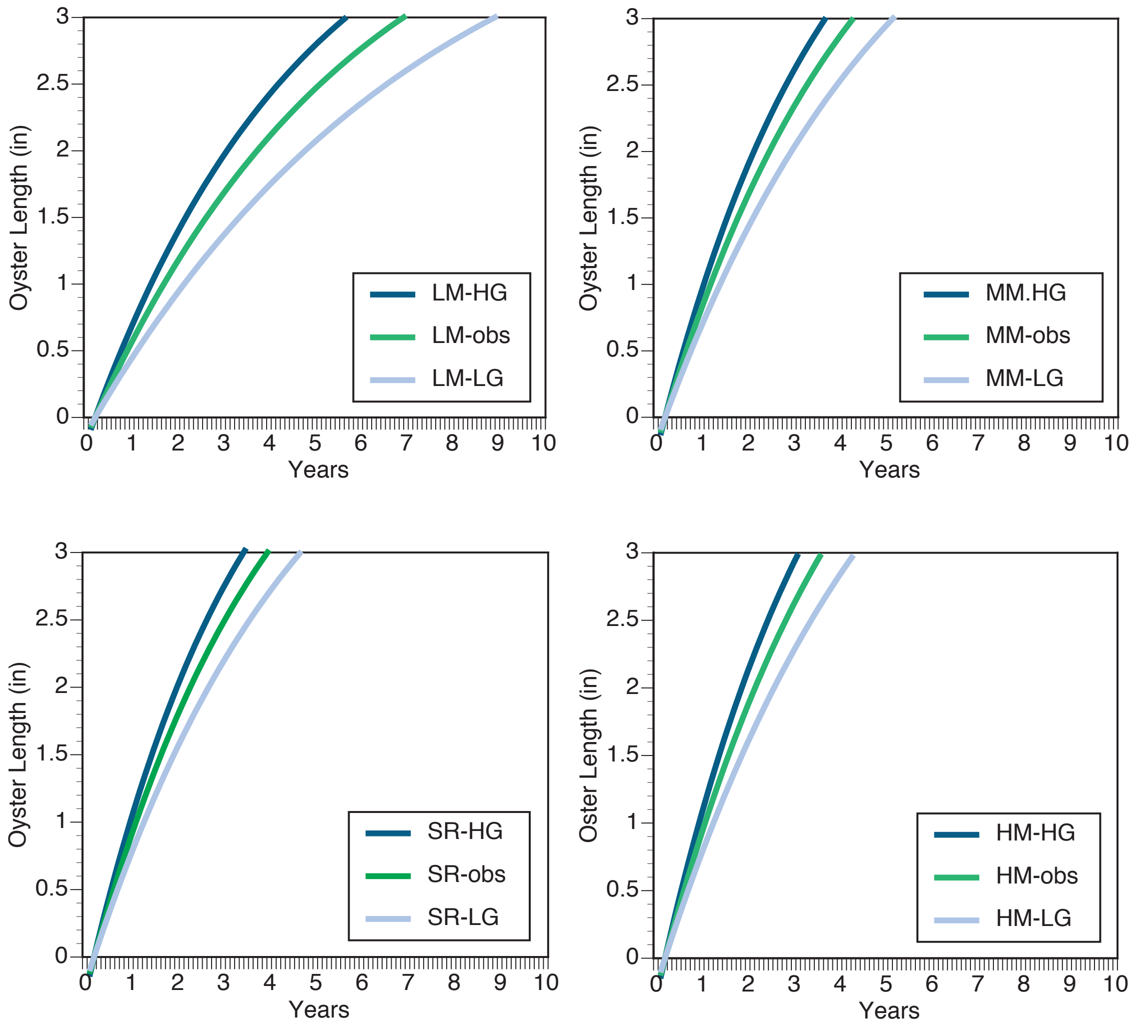


Figure 24. The differential between predicted and observed surplus production from a retrospective analysis of survey indices under a series of assumptions. Predictions assumed a 50^{th} and a 75^{th} percentile mortality rate (e.g., Table 11). Surplus production was calculated based on the assumption that all deaths of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous year's survey. This provides high and low bounds for the estimates. Left figure evaluates the by comparing the predicted value to the lower and upper bounds. Green indicates that the predicted value was lower than the observed value under both assumptions; red, that the predicted value was higher than the observed value for both estimates; and grey, that the predicted value fell between the lower and upper estimate of observed surplus production. Right figure is based on the average differential between the upper and lower bounds value and the prediction [numbers are log10(bushels)]. In this case, red shades indicate cases where the average of the upper and lower bounds fell below the predicted value; green shades indicate cases where the average of the upper and lower bounds fell above the predicted value.

Bay Section	Year	50th Percentile	75th Percentile
Low Mortality Beds	2005		
Medium Mortality Transplant Beds	2005		
Medium Mortality Market Beds	2005		
Shell Rock	2005		
High Mortality Market Beds	2005		
Low Mortality Beds	2006		
Medium Mortality Transplant Beds	2006		
Medium Mortality Market Beds	2006		
Shell Rock	2006		
High Mortality Market Beds	2006		
Low Mortality Beds	2007		
Medium Mortality Transplant Beds	2007		
Medium Mortality Market Beds	2007		
Shell Rock	2007		
High Mortality Market Beds	2007		
Very Low Mortality Beds	2008		
Low Mortality Beds	2008		
Medium Mortality Transplant Beds	2008		
Medium Mortality Market Beds	2008		
Shell Rock	2008		
High Mortality Market Beds	2008		
Very Low Mortality Beds	2009		
Low Mortality Beds	2009		
Medium Mortality Transplant Beds	2009		
Medium Mortality Market Beds	2009		
Shell Rock	2009		
High Mortality Market Beds	2009		
Very Low Mortality Beds	2010		
Low Mortality Beds	2010		
Medium Mortality Transplant Beds	2010		
Medium Mortality Market Beds	2010		
Shell Rock	2010		
High Mortality Market Beds	2010		

Bay Section	Year	50th Percentile	75th Percentile
Low Mortality Beds	2005	-3.4	-3.2
Medium Mortality Transplant Beds	2005	3.9	4.3
Medium Mortality Market Beds	2005	4.5	4.9
Shell Rock	2005	-0.7	3.6
High Mortality Market Beds	2005	-4.3	-3.5
Low Mortality Beds	2006	-3.2	-2.1
Medium Mortality Transplant Beds	2006	-4.6	-4.4
Medium Mortality Market Beds	2006	-5.1	-4.9
Shell Rock	2006	-4.4	-4.2
High Mortality Market Beds	2006	-3.7	4.5
Low Mortality Beds	2007	-3.9	-3.4
Medium Mortality Transplant Beds	2007	-3.9	4.3
Medium Mortality Market Beds	2007	-5.0	-3.9
Shell Rock	2007	-4.7	-4.6
High Mortality Market Beds	2007	-4.9	-4.5
Very Low Mortality Beds	2008	3.5	3.8
Low Mortality Beds	2008	4.2	4.5
Medium Mortality Transplant Beds	2008	-5.0	-5.0
Medium Mortality Market Beds	2008	-5.1	-4.8
Shell Rock	2008	-4.5	-4.3
High Mortality Market Beds	2008	-4.3	4.4
Very Low Mortality Beds	2009	3.2	3.7
Low Mortality Beds	2009	-4.6	-4.5
Medium Mortality Transplant Beds	2009	-4.3	3.4
Medium Mortality Market Beds	2009	-5.1	-4.9
Shell Rock	2009	-3.2	3.9
High Mortality Market Beds	2009	-4.6	-3.9
Very Low Mortality Beds	2010	-3.9	-3.7
Low Mortality Beds	2010	-4.9	-4.8
Medium Mortality Transplant Beds	2010	-4.8	-4.7
Medium Mortality Market Beds	2010	-5.4	-5.3
Shell Rock	2010	-4.4	-4.3
High Mortality Market Beds	2010	-4.8	-4.6

Figure 25. Von-Bertalanffy growth curves for the low-mortality (LM) beds, medium-mortality (MM) beds, Shell Rock (SR), and high-mortality beds (HM) for the von-Bertalanffy parameters provided by Kraeuter et al. (2007)[ℵ] (obs) and two states of nature derived from simulations of DyPoGEn in which the k value was increased or decreased by .04 yielding a high growth (HG) and low growth (LG) scenario.



ℵ Op. cit.

Figure 26a. Net surplus production from a retrospective analysis of survey indices and landings, under a series of assumptions. Surplus production was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous year's survey. This provides high and low bounds for the estimates. Green indicates that net surplus production was positive under both assumptions, indicating forgone yield; grey, that the lower estimate was negative and the higher estimate was positive, indicating that the yield to the fishery approximated the potential yield available; and red, that both estimates of net surplus production were negative, indicating that landings exceeded the level desired under the goal of no-net-reduction of $\geq 3''$ oysters. States of nature included an 0.04 reduction in the von-Bertalanffy-k value (slow growth), an 0.04 increase (fast growth), an increase in mortality by a factor of 1.25 (moderate mortality), and an increase in mortality by a factor of 1.5 (high mortality).

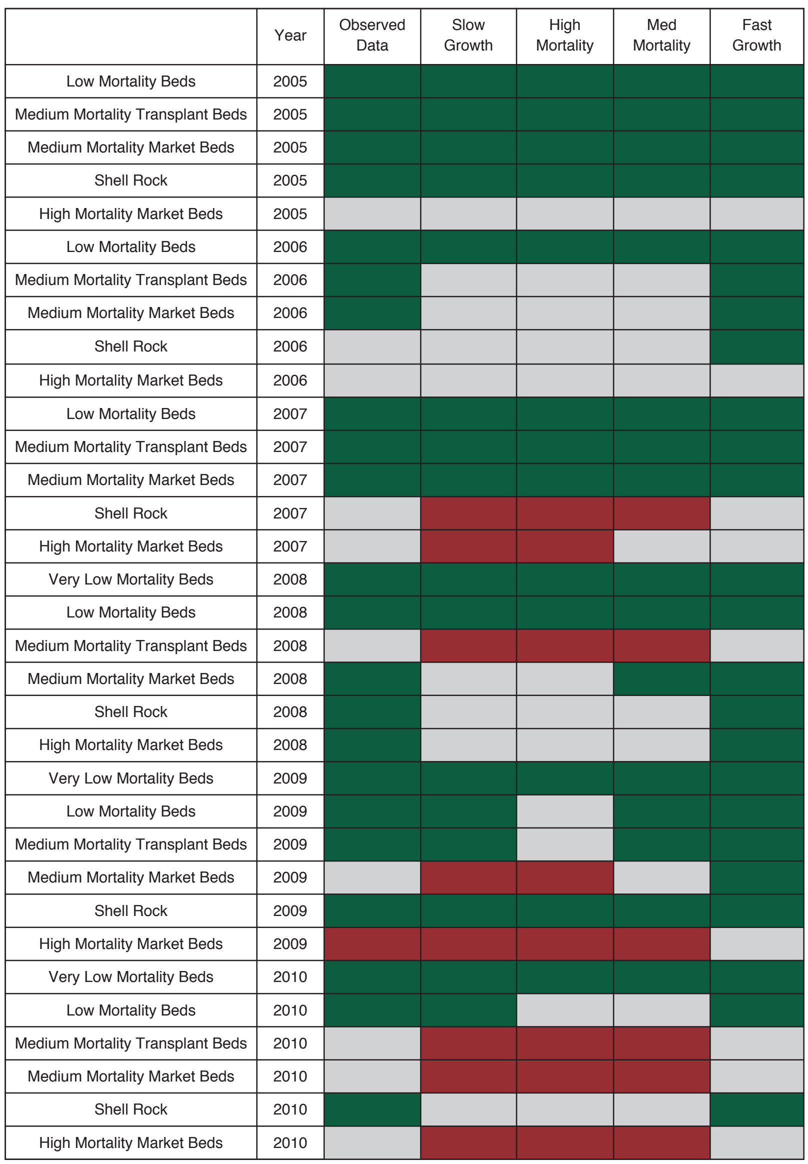


Figure 26b. Figure 26a sorted by bed region rather than by year. See Figure 26a for further explanation.

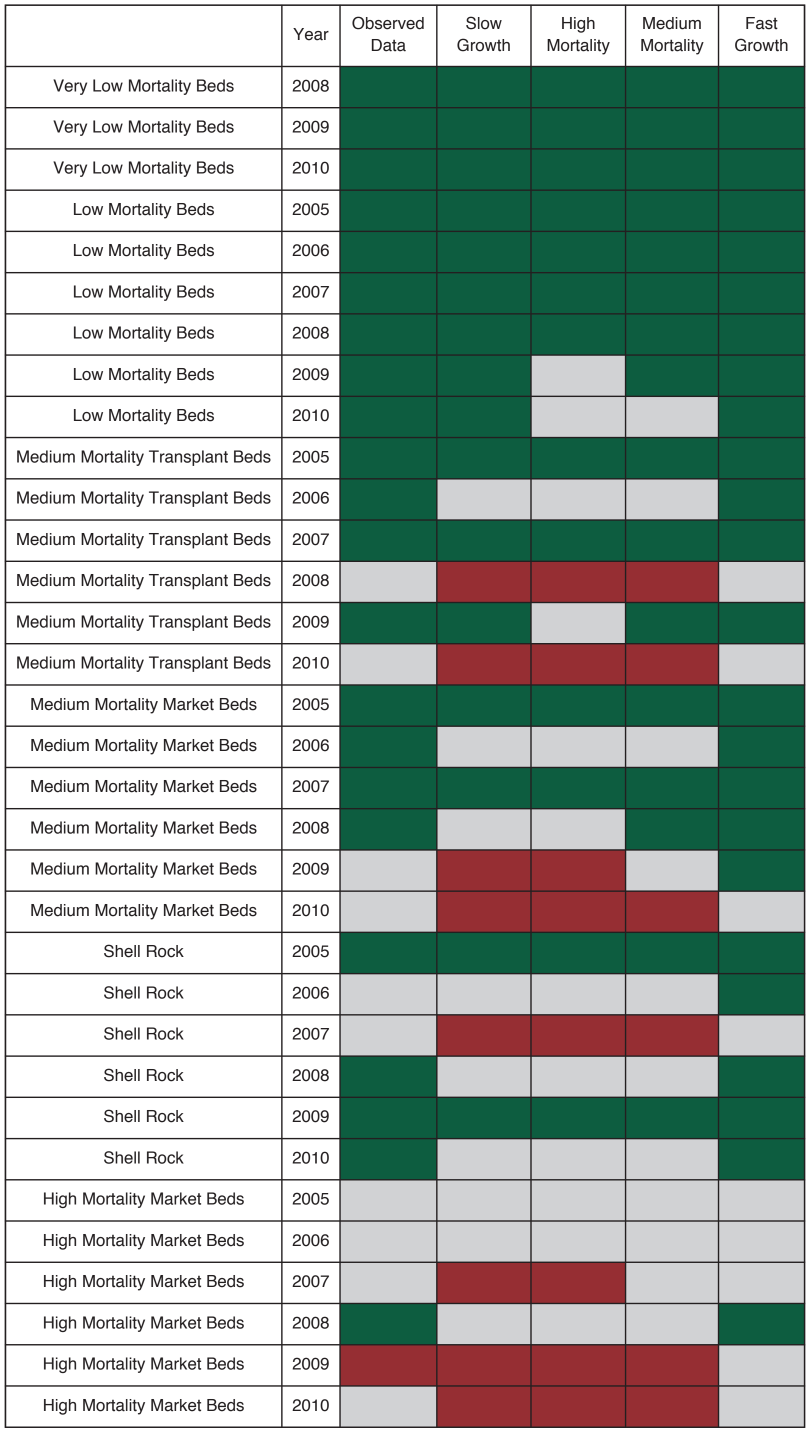


Figure 27. Net surplus production from a retrospective analysis of survey indices and landings, under a series of assumptions. Surplus production was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous year's survey. This provides high and low bounds for the estimates. Green shades indicate conditions where the average of the two estimates was positive, indicating forgone yield, with darker shades indicating an increasingly positive estimate. Reds indicate conditions where the average of the two estimates was negative, indicating overharvesting under the goal of no-net-reduction of $\geq 3''$ oysters, with darker shades indicating an increasingly negative estimate. Numbers are log10(bushels). States of nature included an 0.04 reduction in the von-Bertalanffy-k value (slow growth), an 0.04 increase (fast growth), an increase in mortality by a factor of 1.25 (moderate mortality), and an increase in mortality by a factor of 1.5 (high mortality).

	Year	Observed Data	Slow Growth	High Mortality	Med Mortality	Fast Growth
Low Mortality Beds	2005	4.1	3.9	4.1	4.1	4.3
Medium Mortality Transplant Beds	2005	5.1	5.0	5.1	5.1	5.2
Medium Mortality Market Beds	2005	5.5	5.4	5.5	5.5	5.6
Shell Rock	2005	4.4	4.3	4.4	4.4	4.6
High Mortality Market Beds	2005	3.9	-3.8	3.9	3.9	4.3
Low Mortality Beds	2006	4.4	4.3	4.4	4.4	4.7
Medium Mortality Transplant Beds	2006	4.5	4.2	4.5	4.5	4.6
Medium Mortality Market Beds	2006	4.9	4.6	4.9	4.9	5.2
Shell Rock	2006	4.1	3.9	4.1	4.1	4.4
High Mortality Market Beds	2006	4.2	-3.6	4.2	4.2	4.6
Low Mortality Beds	2007	5.1	4.9	5.1	5.1	5.3
Medium Mortality Transplant Beds	2007	5.1	4.9	5.1	5.1	5.2
Medium Mortality Market Beds	2007	5.5	5.3	5.5	5.5	5.6
Shell Rock	2007	-4.2	-4.4	-4.2	-4.2	-3.7
High Mortality Market Beds	2007	-4.1	-4.7	-4.1	-4.1	4.3
Very Low Mortality Beds	2008	5.0	4.9	5.0	5.0	5.2
Low Mortality Beds	2008	5.4	5.3	5.4	5.4	5.6
Medium Mortality Transplant Beds	2008	-4.5	-4.6	-4.5	-4.5	-4.1
Medium Mortality Market Beds	2008	5.1	4.5	5.1	5.1	5.3
Shell Rock	2008	4.6	4.3	4.6	4.6	4.9
High Mortality Market Beds	2008	4.7	4.2	4.7	4.7	4.9
Very Low Mortality Beds	2009	5.0	4.9	5.0	5.0	5.2
Low Mortality Beds	2009	4.6	4.4	4.6	4.6	4.8
Medium Mortality Transplant Beds	2009	4.7	4.6	4.7	4.7	4.9
Medium Mortality Market Beds	2009	4.0	-4.5	4.0	4.0	4.8
Shell Rock	2009	4.7	4.4	4.7	4.7	4.9
High Mortality Market Beds	2009	-4.5	-4.6	-4.5	-4.5	-4.3
Very Low Mortality Beds	2010	4.9	4.8	4.9	4.9	5.1
Low Mortality Beds	2010	4.6	4.3	4.6	4.6	4.9
Medium Mortality Transplant Beds	2010	-4.0	-4.4	-4.0	-4.0	-3.0
Medium Mortality Market Beds	2010	-4.7	-5.0	-4.7	-4.7	4.1
Shell Rock	2010	4.3	3.9	4.3	4.3	4.6
High Mortality Market Beds	2010	-4.3	-4.6	-4.3	-4.3	-2.8

Figure 28. Number of spat recruiting per year for the 1953-2010 time series, cumulatively by bay region. Bay regions are defined in Figure 9. No data are available for the very-low-mortality beds prior to 2007.

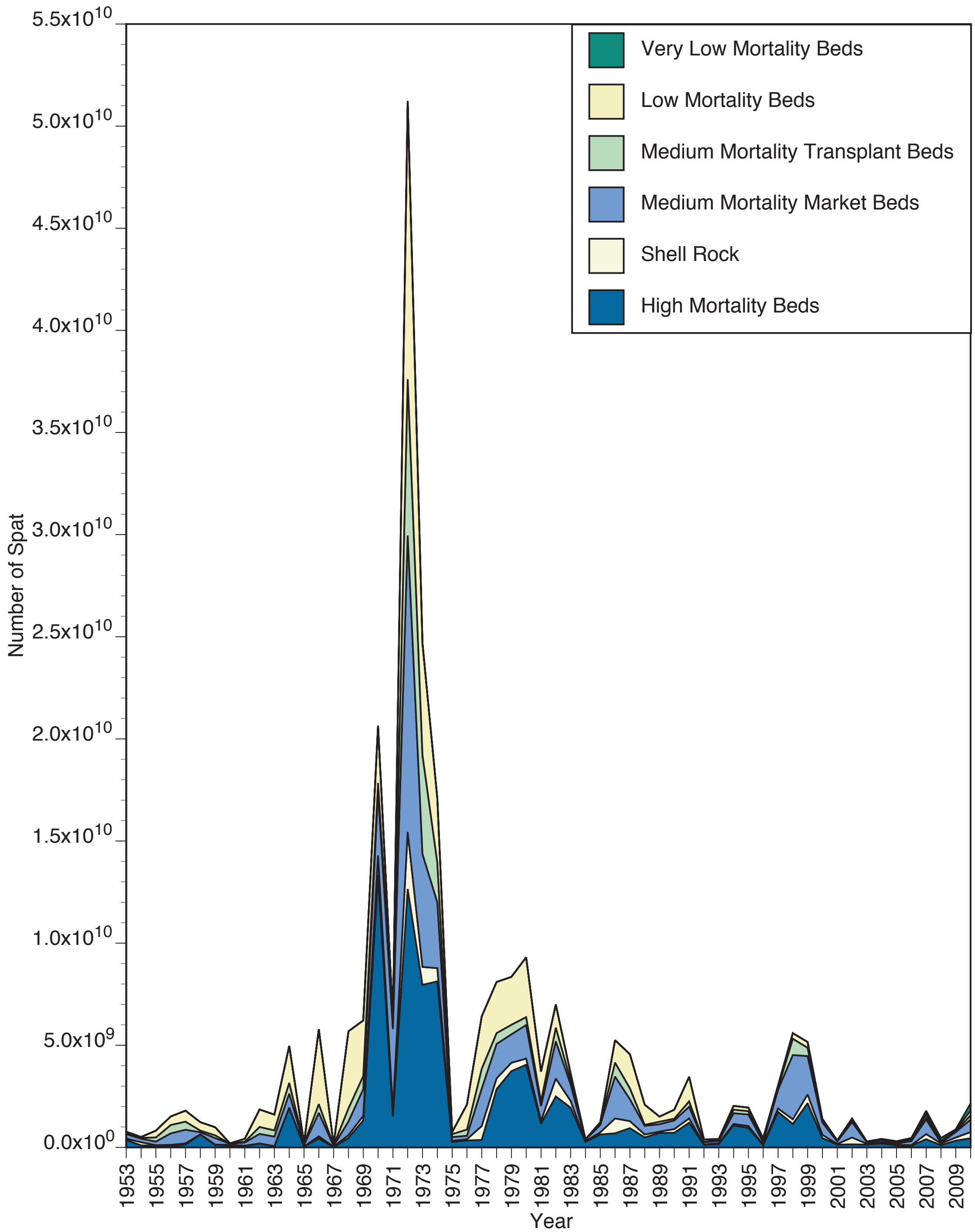


Figure 29. Number of spat recruiting per year for the 1989-2010 time series. Bay regions are defined in Figure 9. No data are available for the very-low-mortality beds prior to 2007.

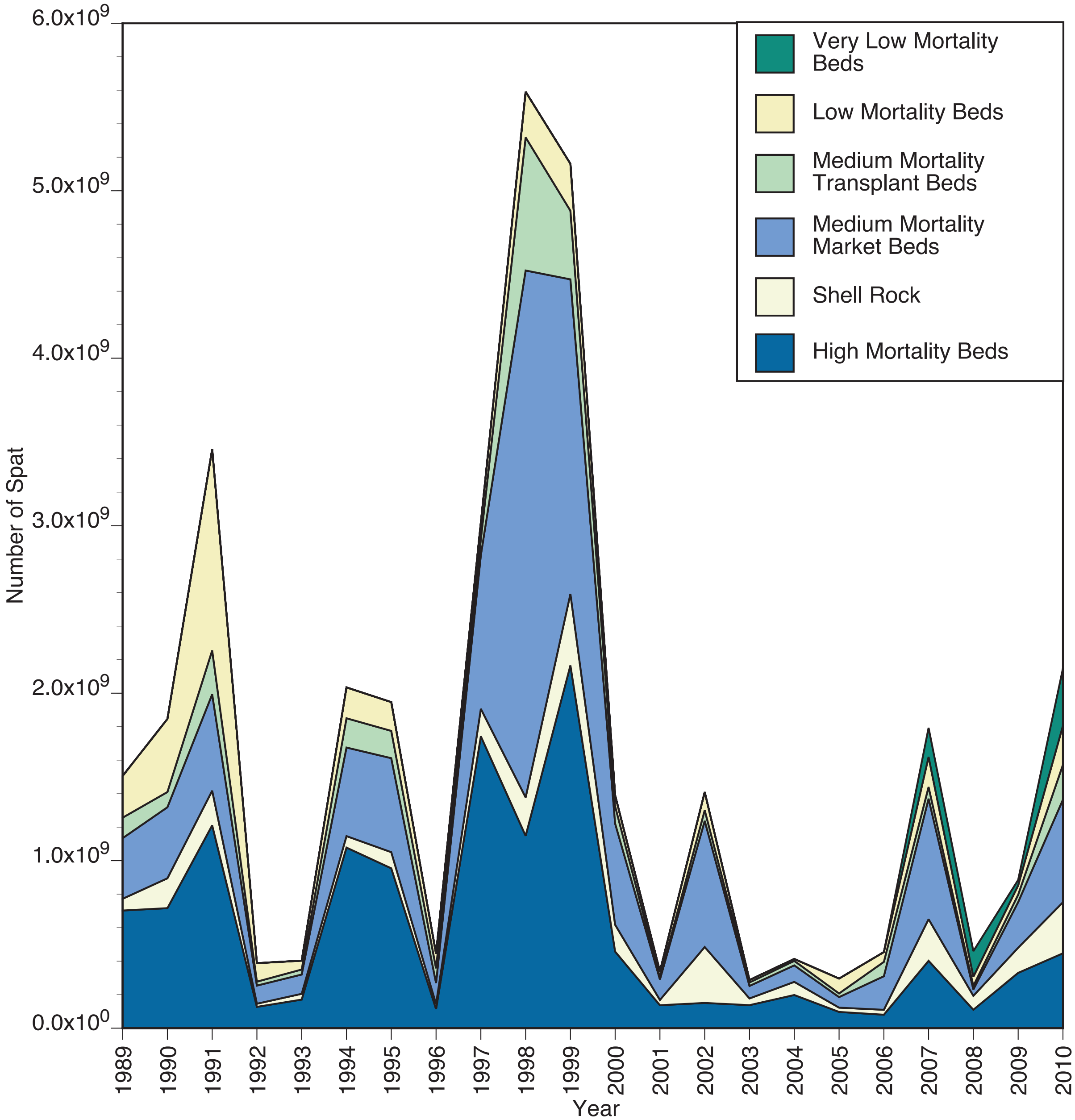


Figure 30. The number of spat recruiting per >20-mm oyster per year, excluding the very-low-mortality beds.

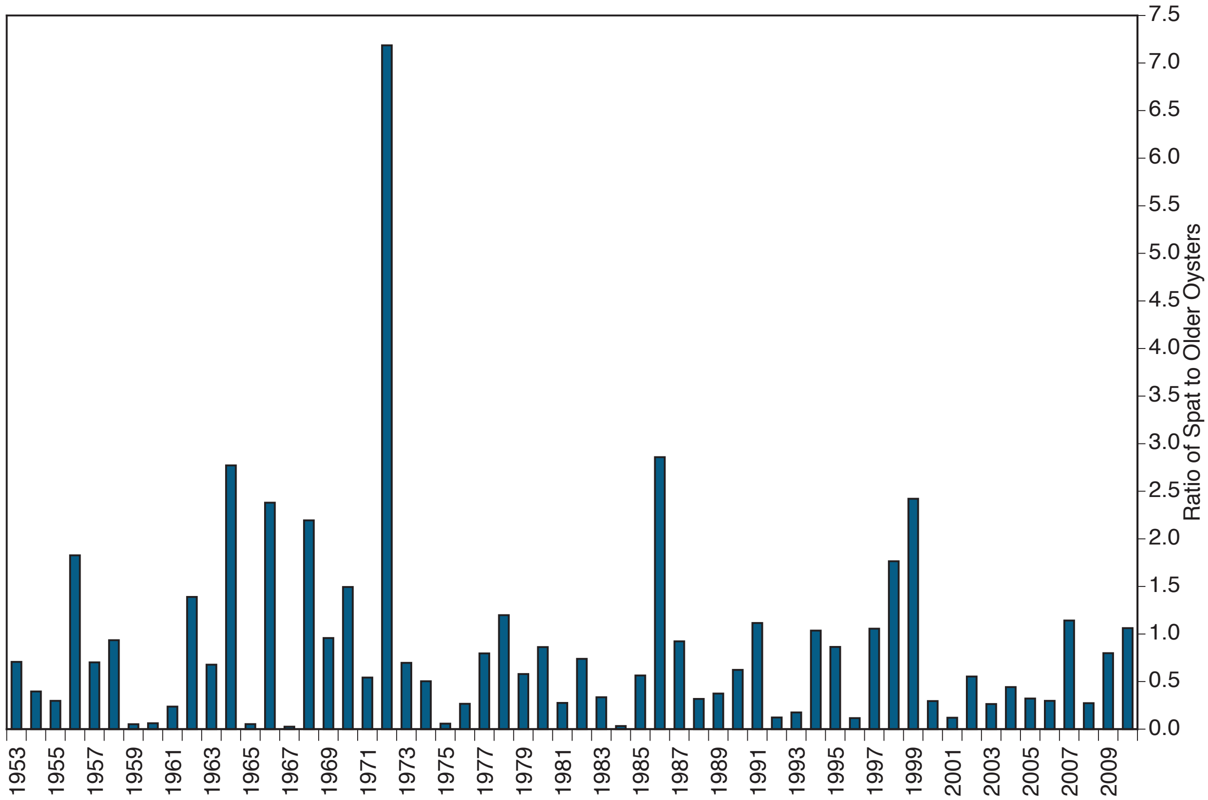


Figure 31. Spat-to-adult oyster ratio for each bay region. Bed distributions by bay region are given in Figure 9.

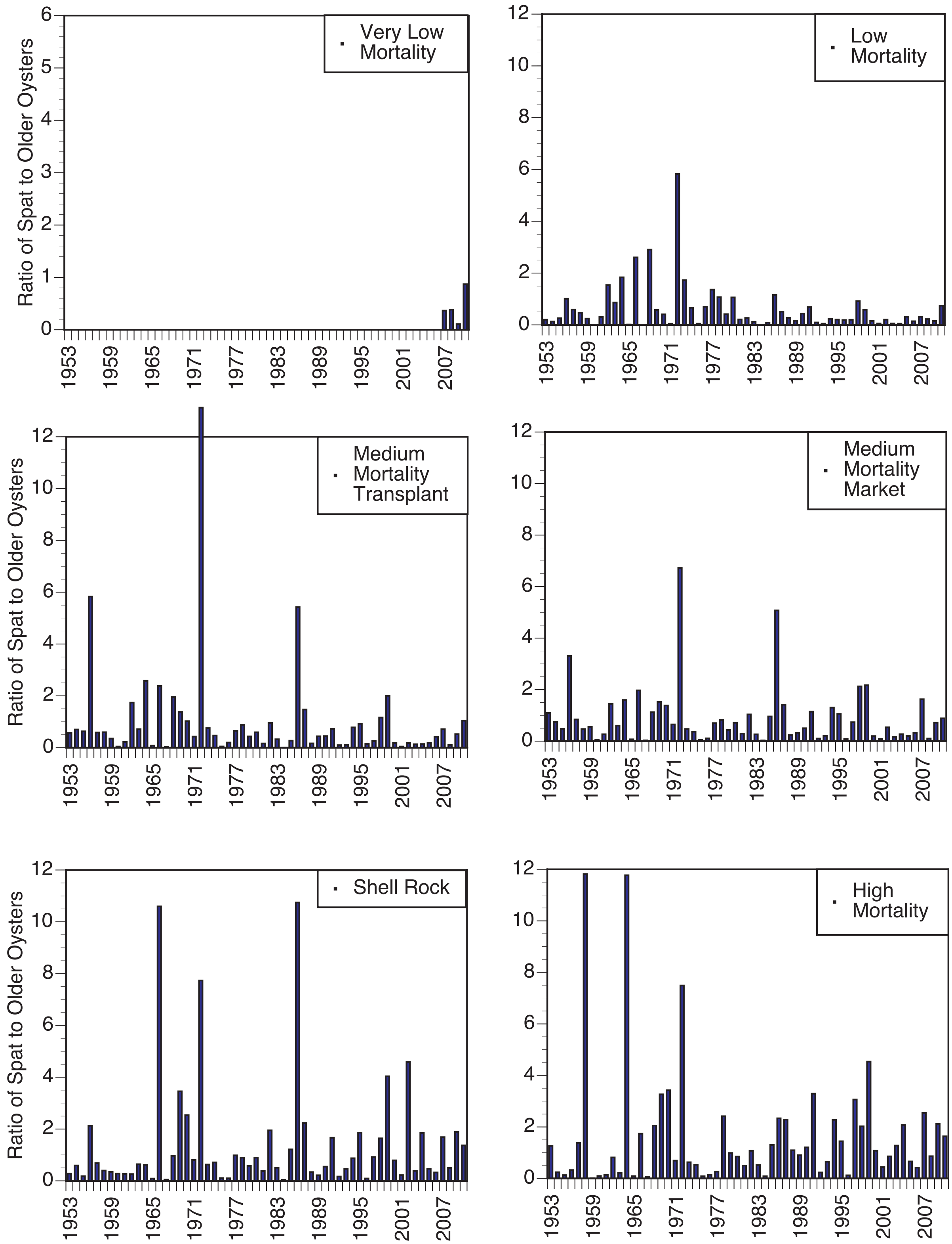


Figure 32. Location of 2010 shell plants, denoted by white stars.

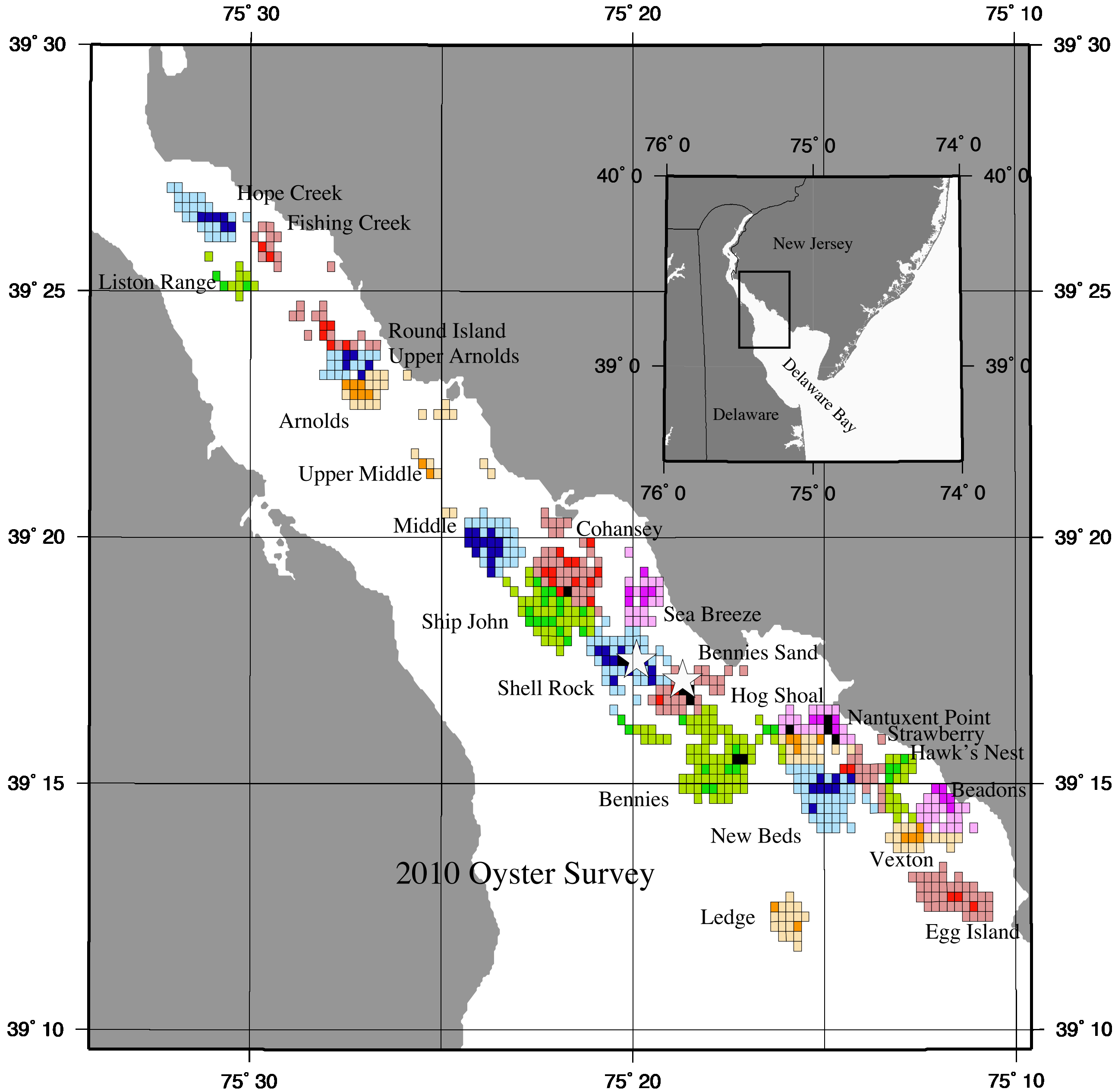


Figure 33. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2010. Shell planting began in 2005 and increased in 2006-2008, but declined again in 2009-2010. Shell budgets are calculated using the updated half-lives estimated in this assessment and using the half-lives estimated in 2009 and 2010 (SAW-11, SAW-12) for comparison.

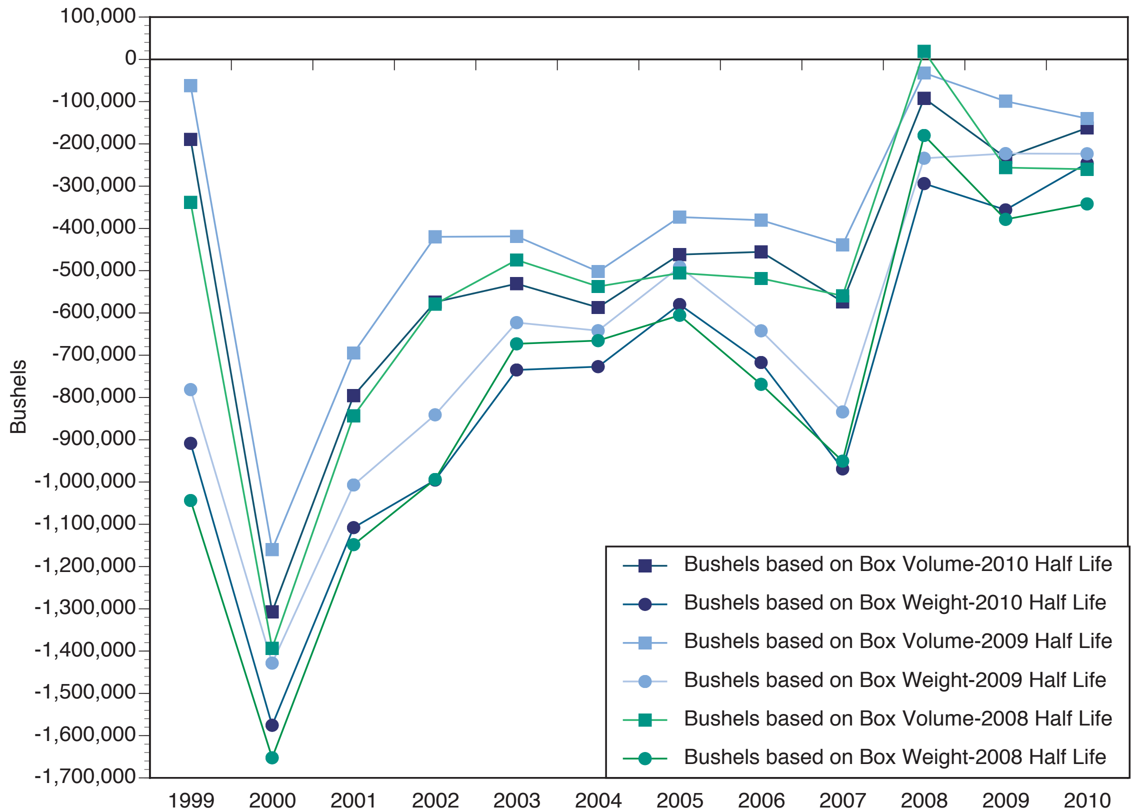


Figure 34. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2010.

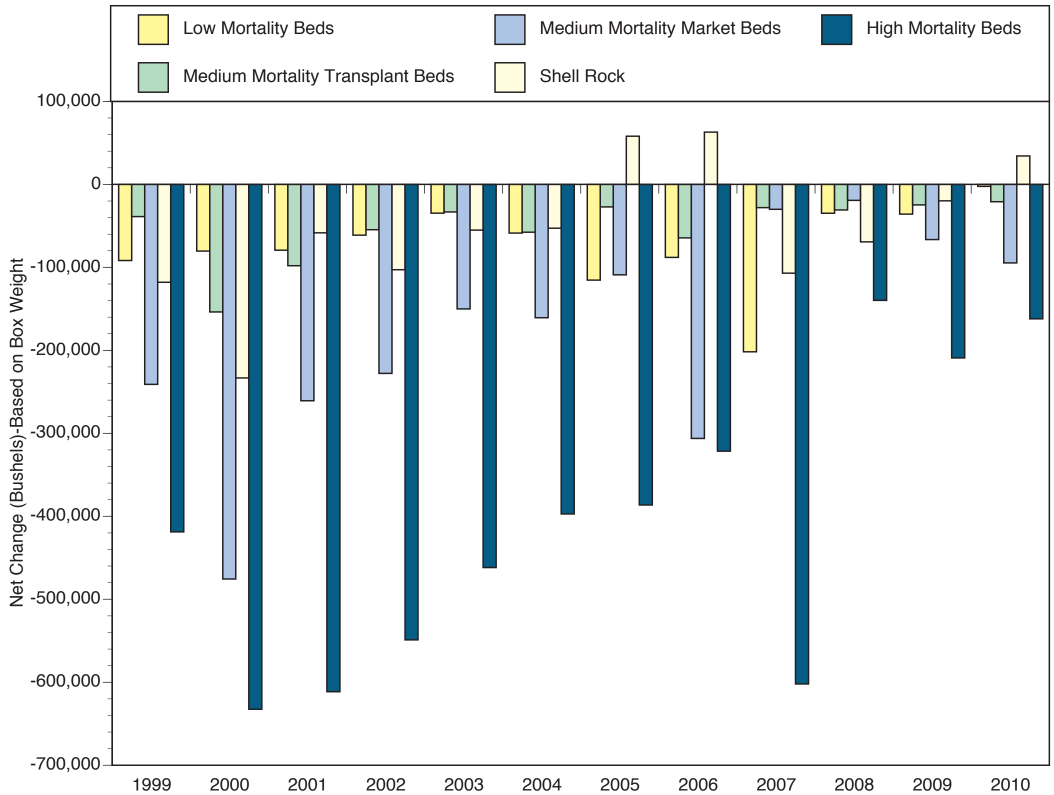
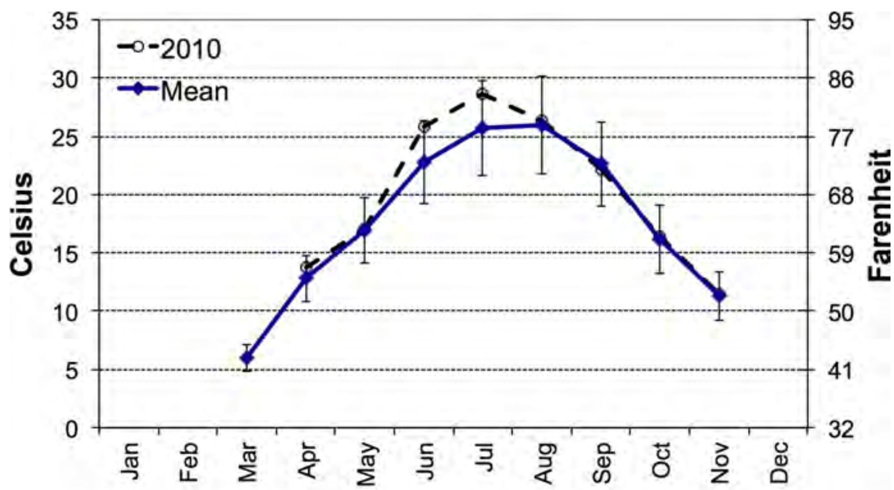


Figure 35. Temperature and salinity across the seedbeds during 2010. Data are mean values for five long-term monitoring beds each month for 2010 and the average of these same calculations for each year since 1999.



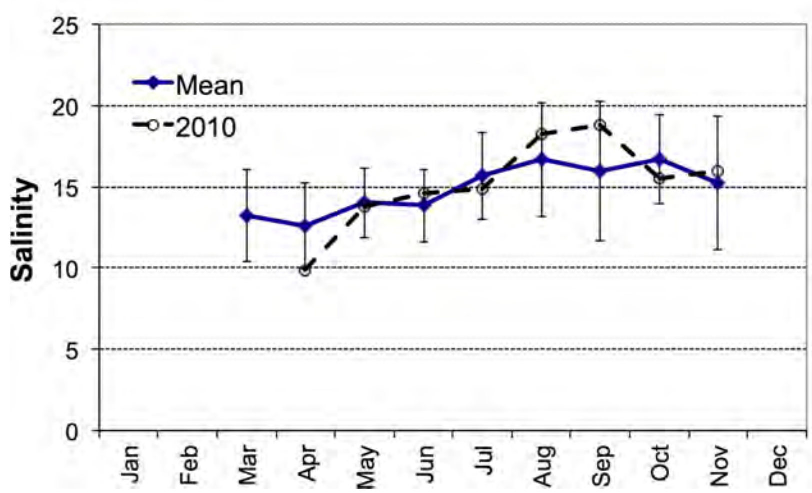
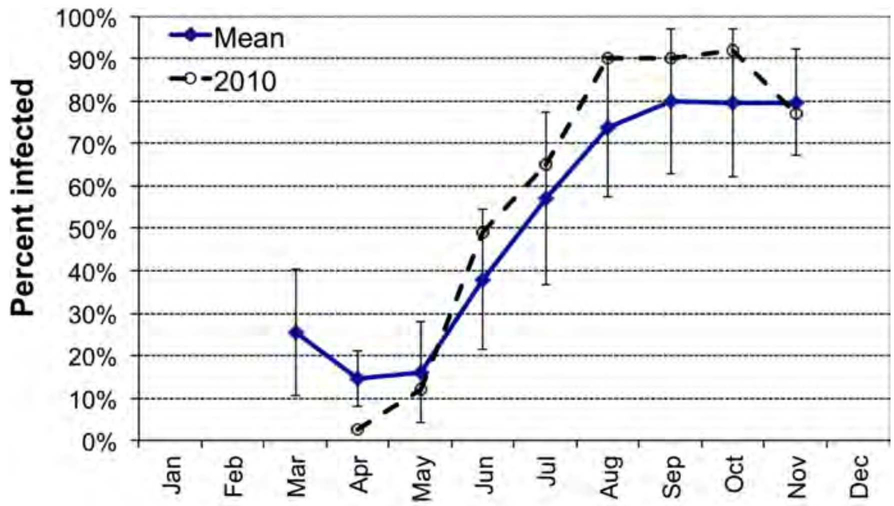


Figure 36. Comparison of 2010 Dermo prevalence and weighted prevalence against mean levels since 1990. Error bars are 95% confidence intervals for the 1990-2010 mean.



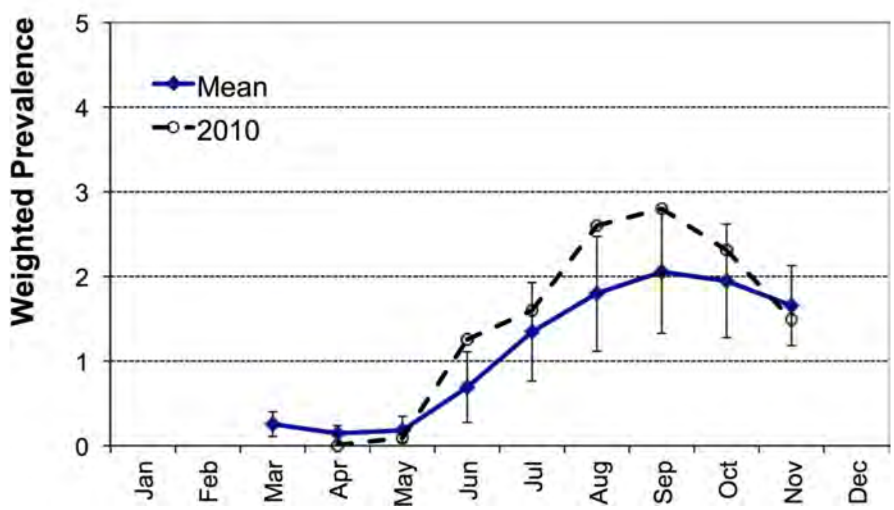


Figure 37. Comparison of average annual fall Dermo prevalence and weighted prevalence in oysters since 1990 (open bars with 95% confidence intervals) with 2010 levels (shaded area). Egg Island bed was not sampled in 2010.

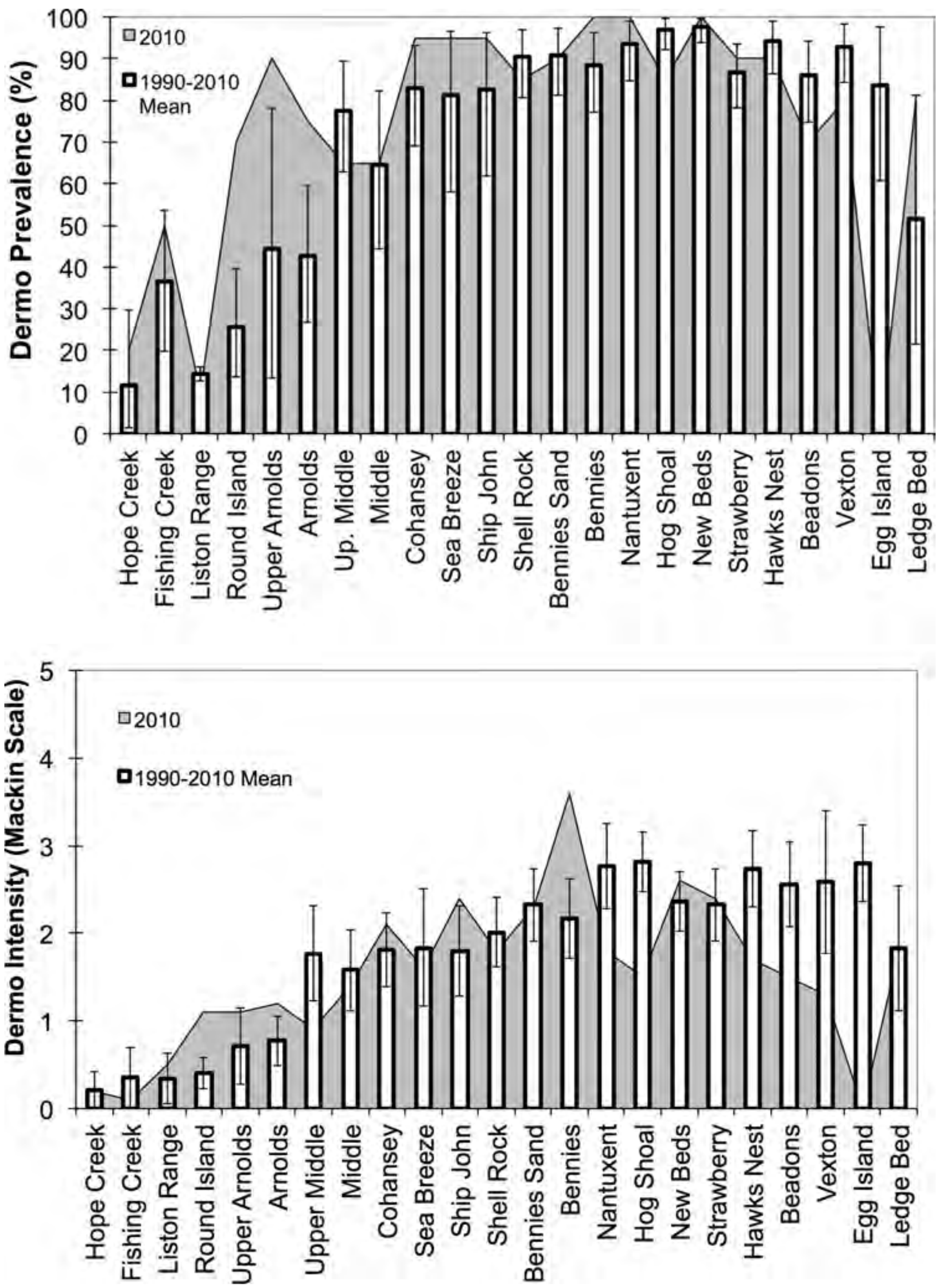


Figure 38. Time series showing the cyclic nature of Dermo prevalence and weighted prevalence by bed region. Note the tendency for epizootics to be of a number of years in duration and to occur about every 7 years in the downbay regions. The very-low-mortality beds were not sampled prior to 2007.

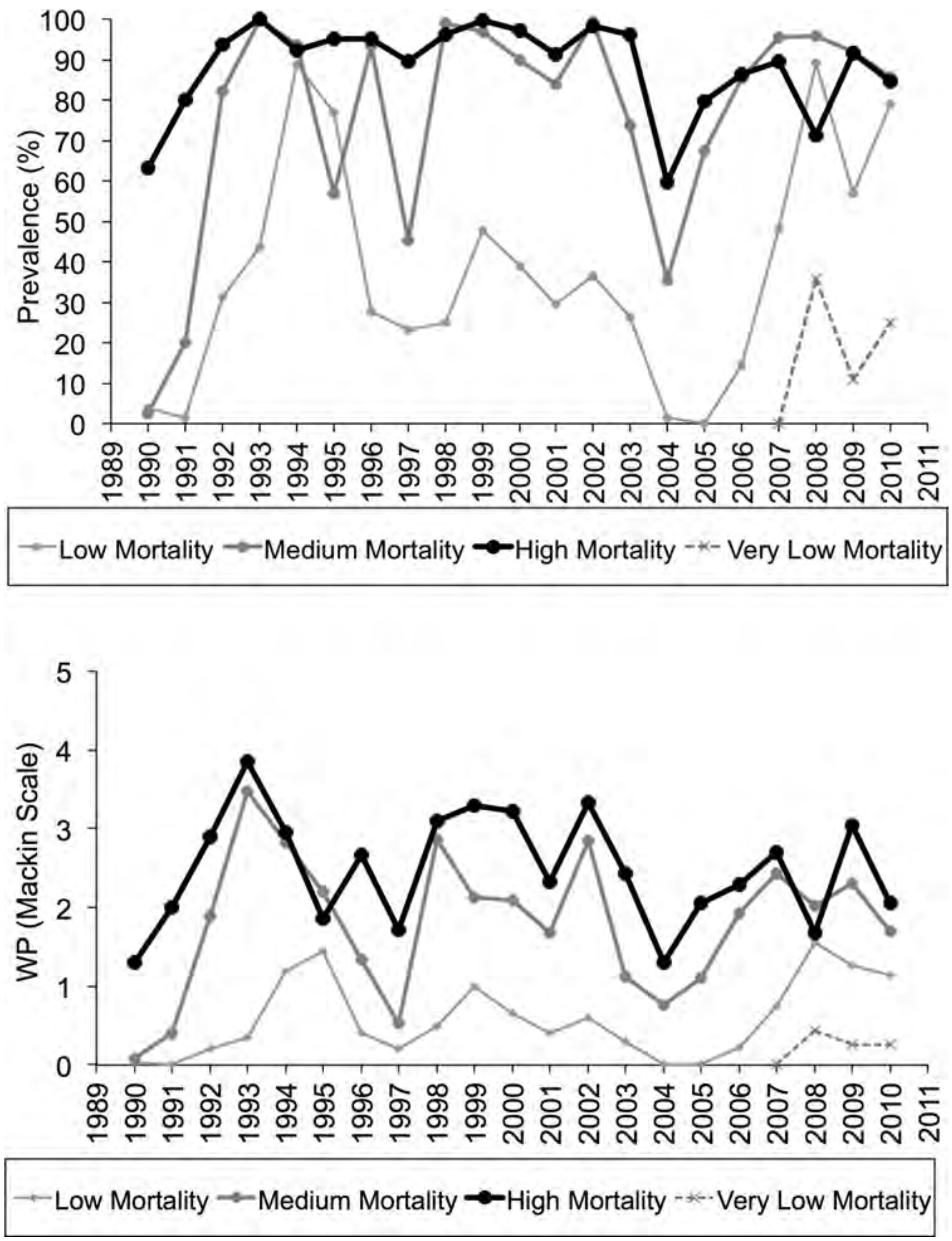
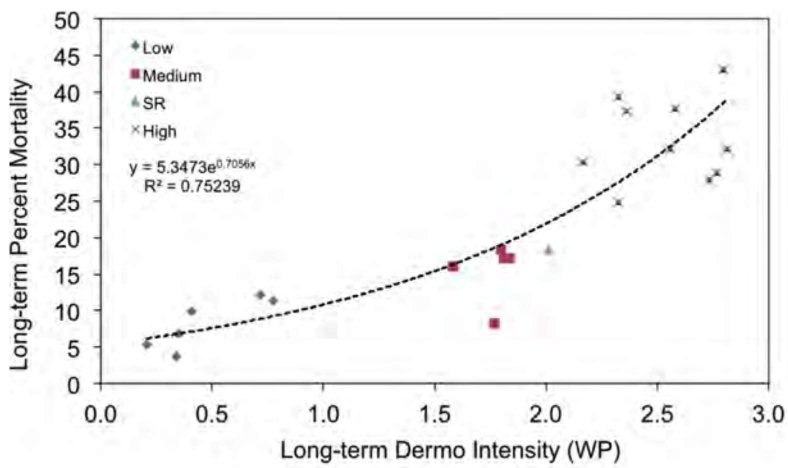
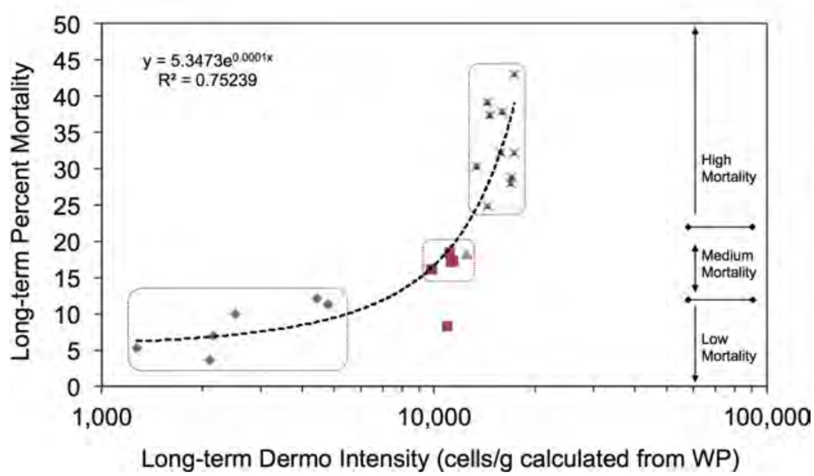


Figure 39. Relationship between the long-term mean box-count mortality estimate and the long-term mean intensity of Dermo infections since 1990. Data are individual bed estimates. The relationship between mortality and weighted prevalence is approximately linear with different bay regions falling out according to their mortality designation. Converting weighted prevalence to parasite densities per Choi et al. (1989)[℘] indicates an exponential relationship in which clusters fall out that clearly demarcate low-mortality, medium-mortality and high-mortality regions. Specifically, a doubling of parasite densities from 5,000 cells per gram to 10,000 moves oysters from low mortality to medium mortality, while another doubling moves oysters into the high-mortality region.





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

Figure 40. 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.

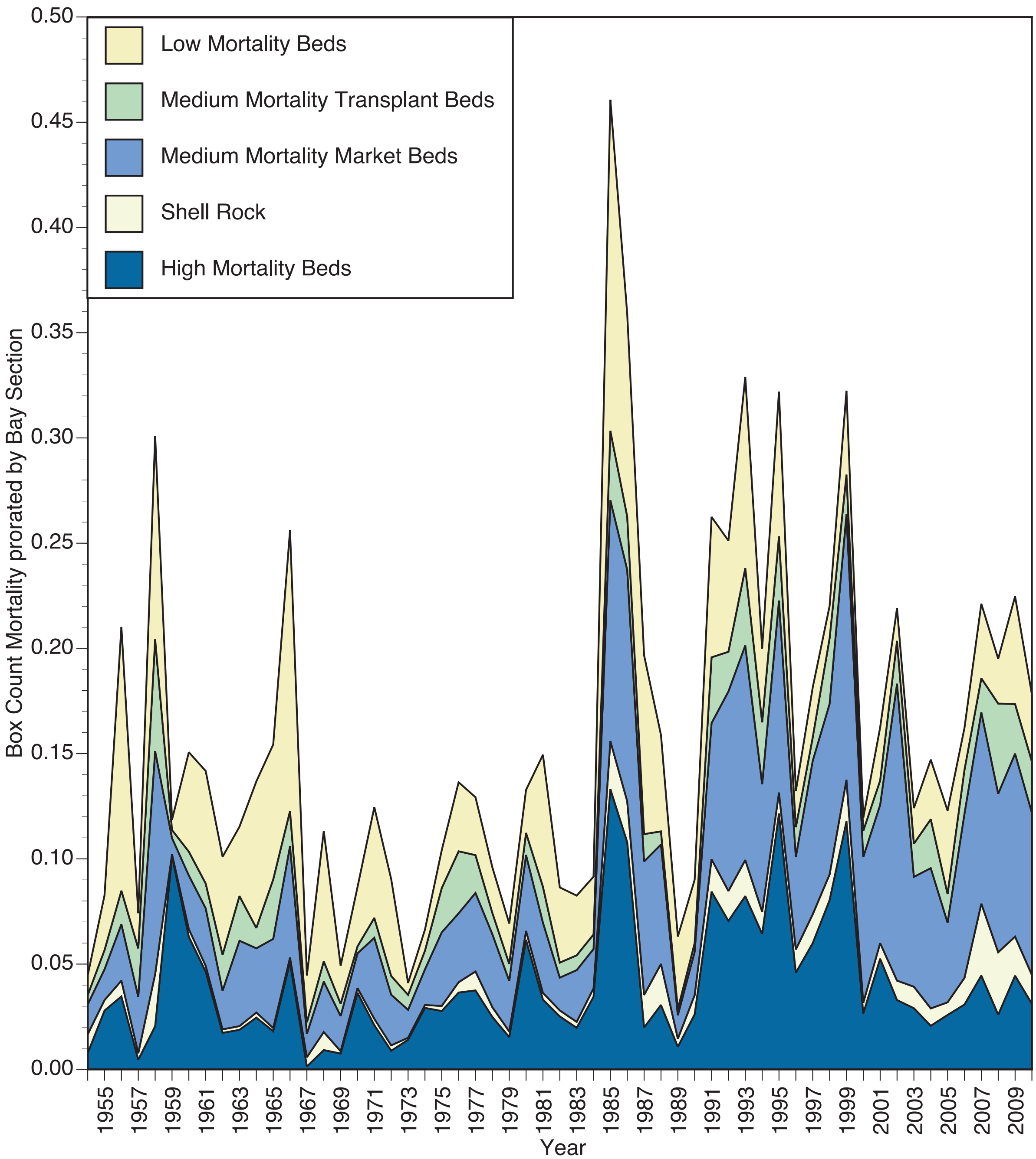


Figure 41. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region. No data are available for the very-low-mortality beds prior to 2007.

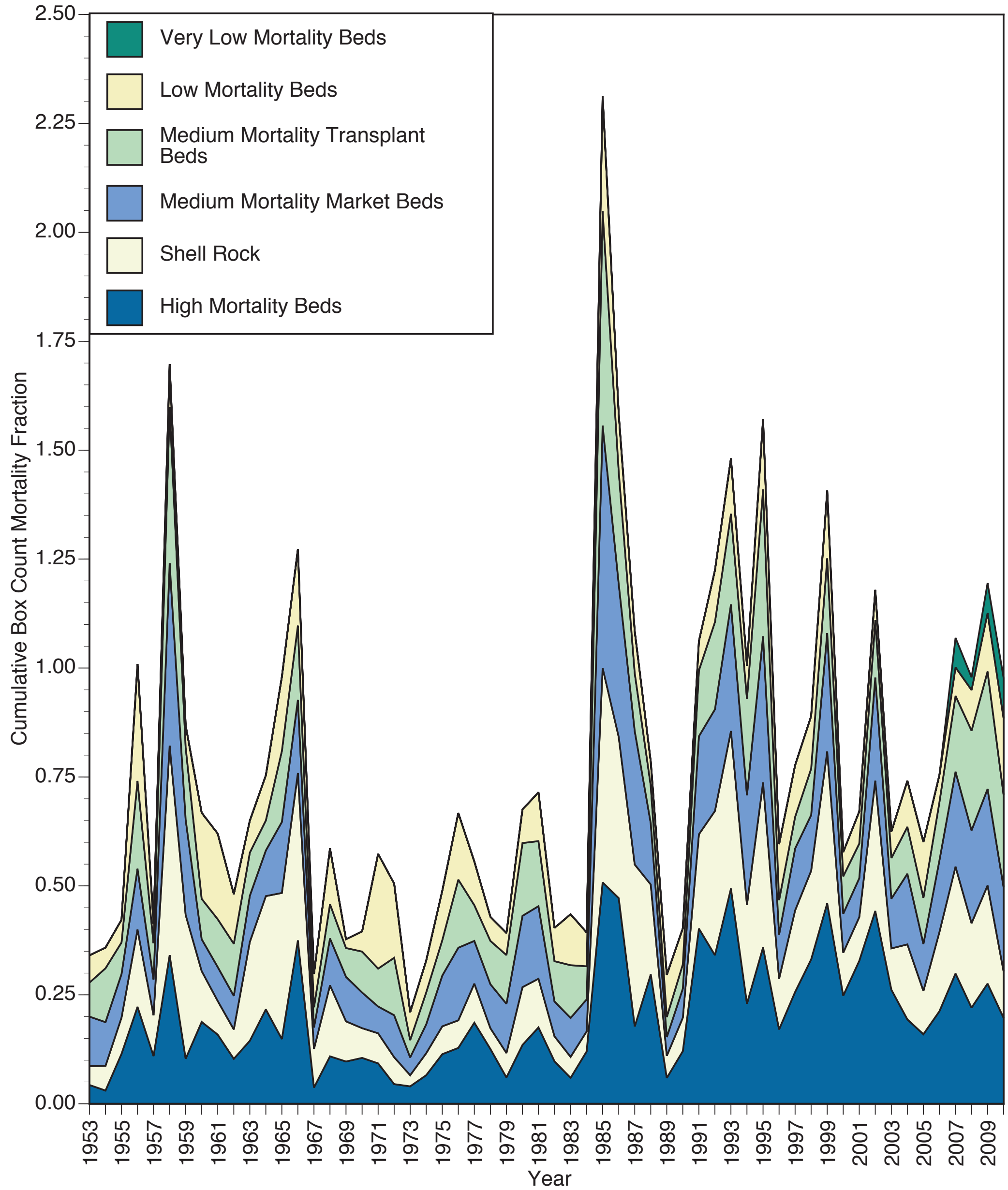


Figure 42. Broodstock-recruitment relationship for the 1953-2010 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2009 because the plot compares end-of-2009 oyster abundance with 2010 recruitment. Blue lines identify the 58-year medians used for calculation of first passage times (Table 17).

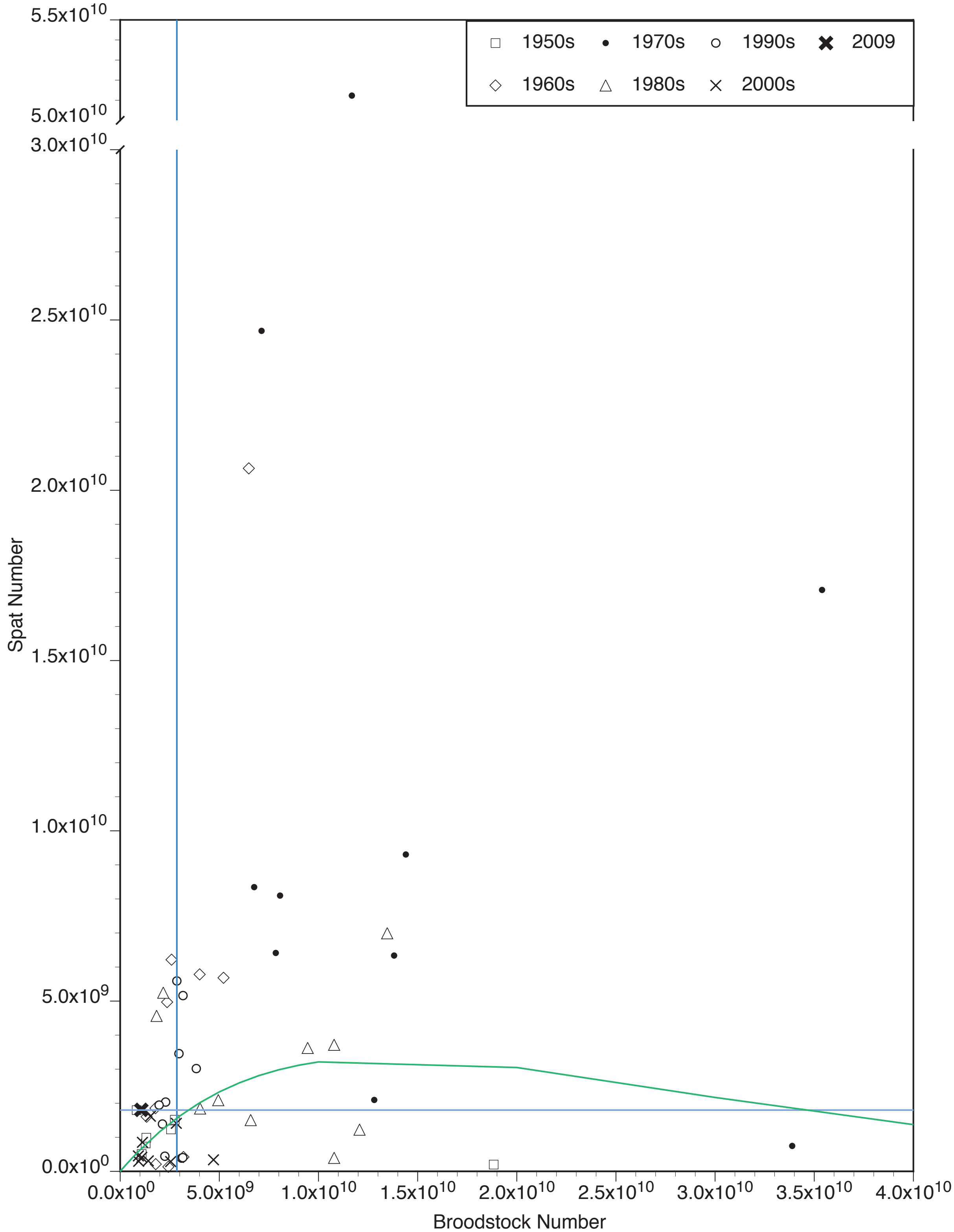


Figure 43. The quadrant numbering convention used to calculate mean first passage times. The one year transition probabilities are obtained by examining the position of consecutive x-y data pairs in quadrant space. Four transitions are possible for each starting position, the possibilities for Quadrant 1 being depicted. Sixteen total trajectories are possible.

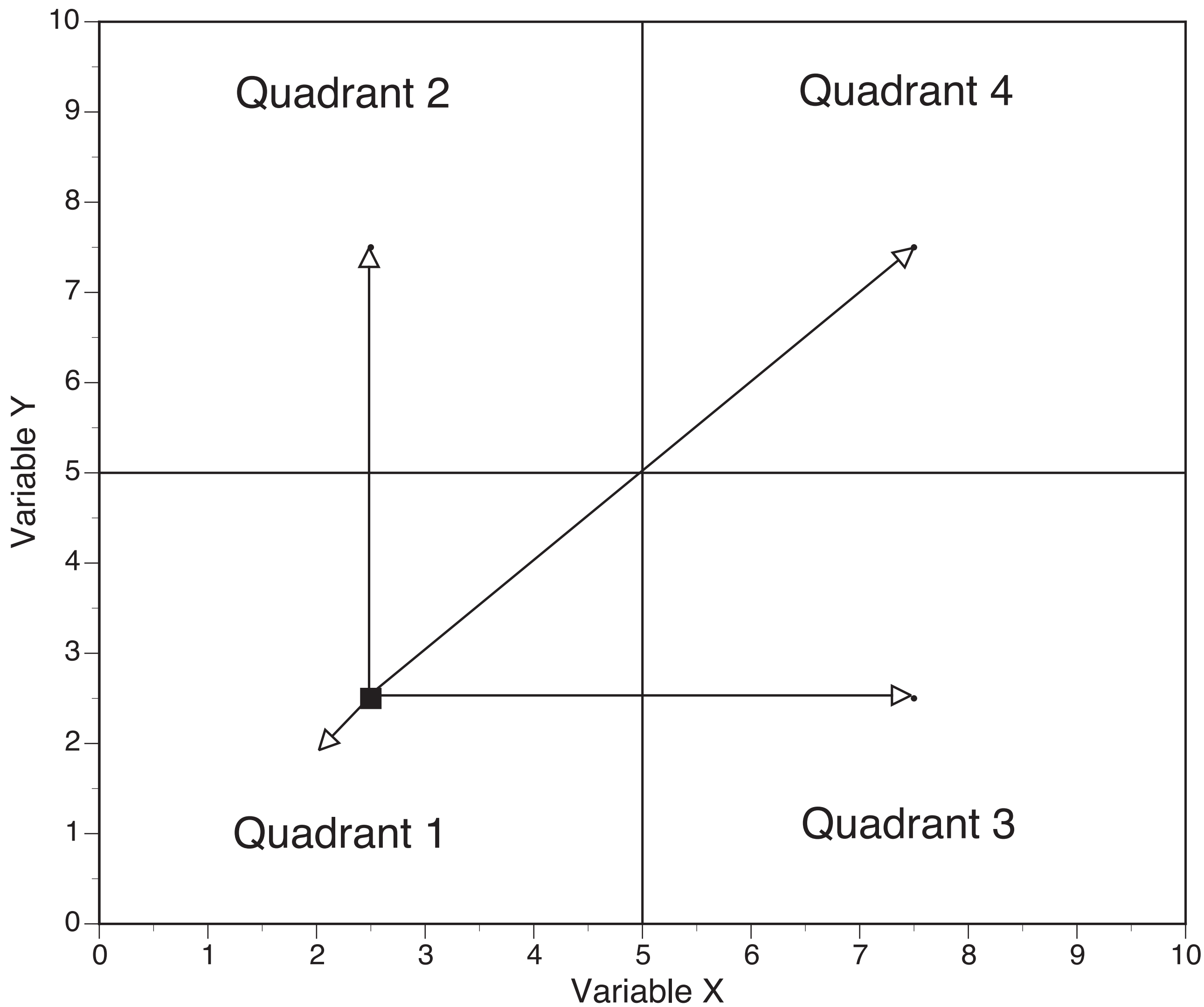


Figure 44. The relationship between oyster abundance and box-count mortality for the 1953-2010 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2009 because the plot compares end-of-2009 oyster abundance with 2010 mortality. Blue lines identify the 58-year medians used for calculation of first passage times (Table 18).

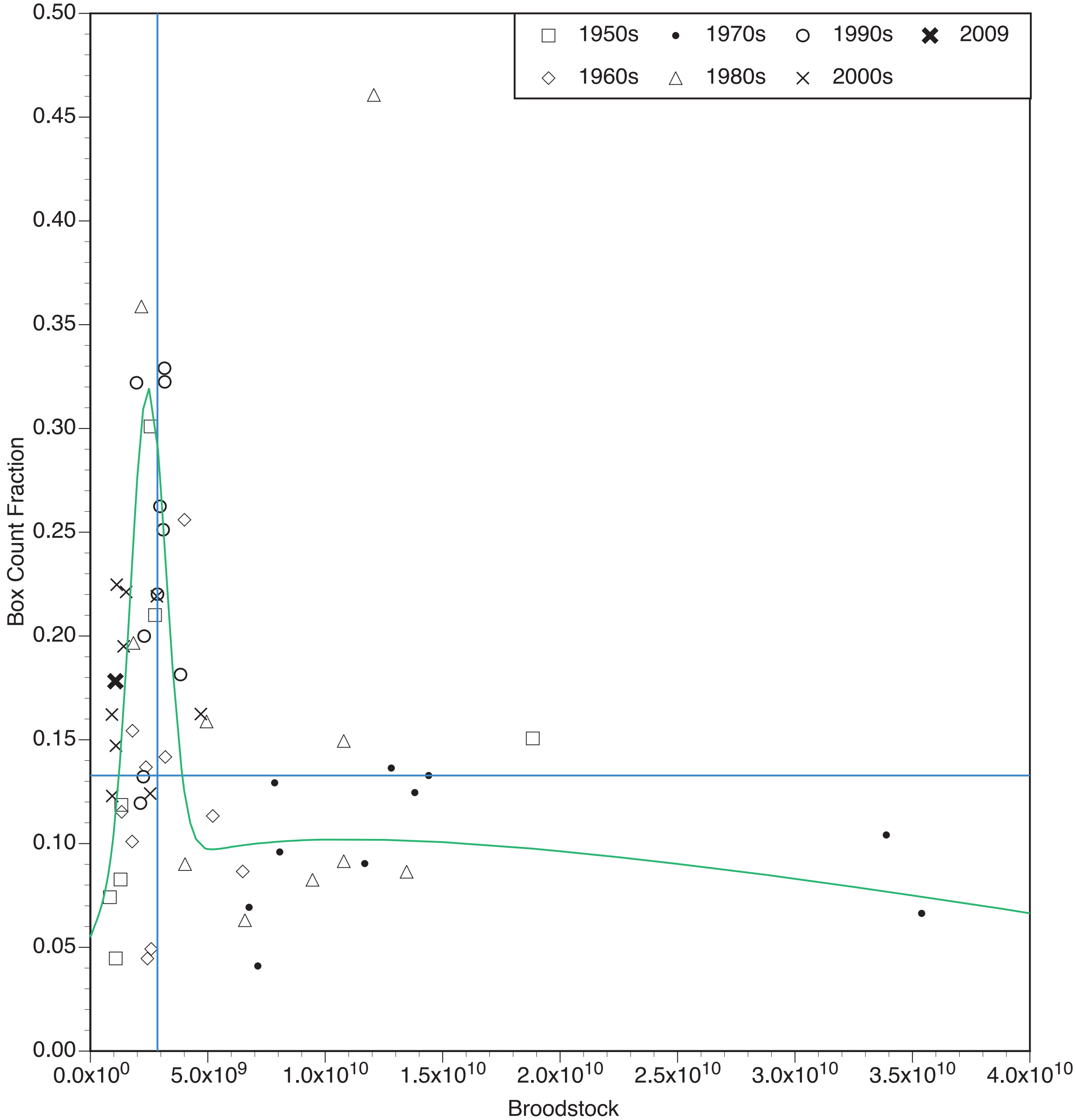


Figure 45. A closer look at the lower end of the oyster abundance and box-count mortality relationship. The entire dataset is depicted in Figure 44. Latest year listed as 2009 because the plot compares end-of-2009 oyster abundance with 2010 mortality. Blue lines identify the 58-year medians used for calculation of first passage times (Table 18).

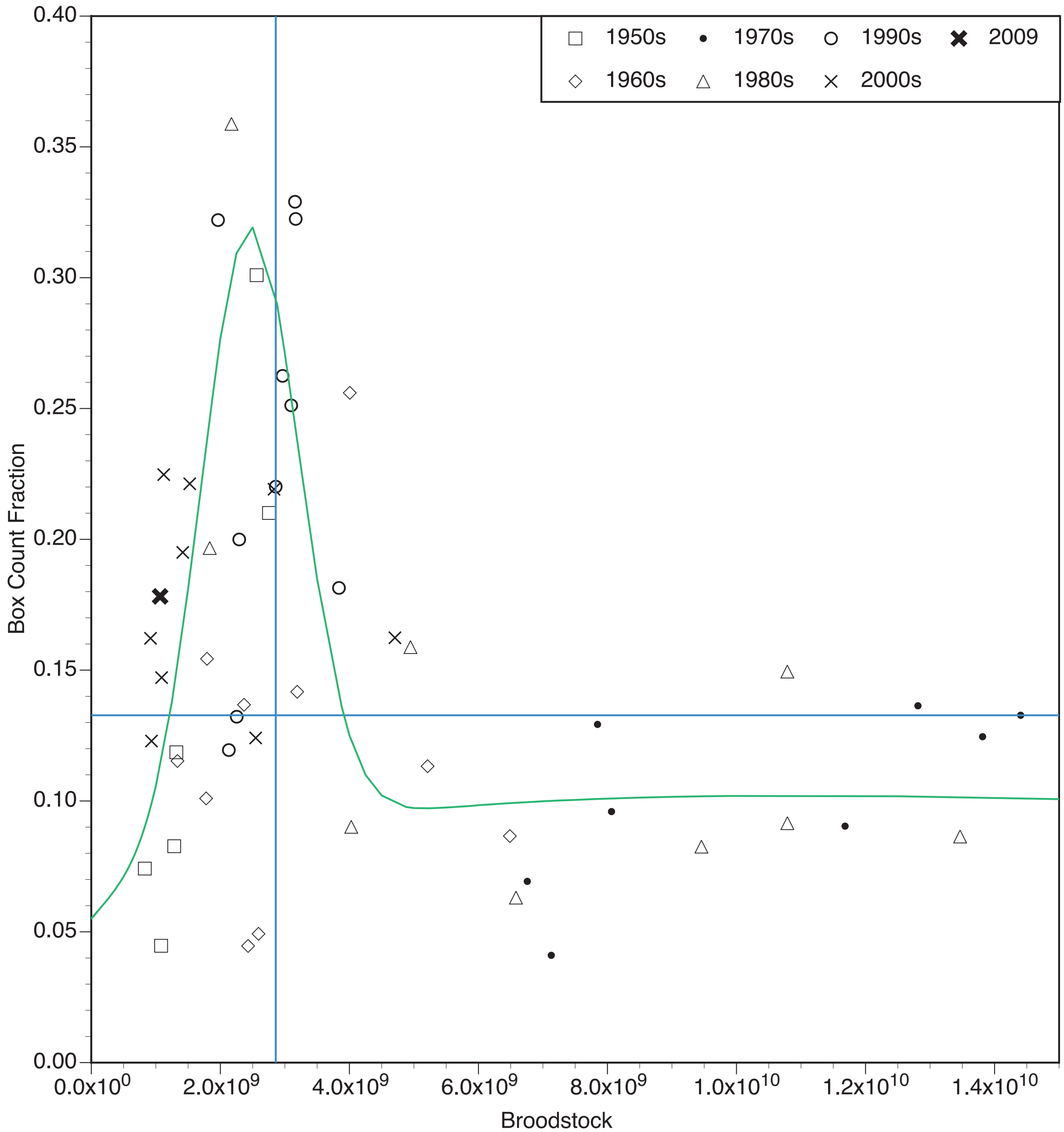


Figure 46. The relationship between recruitment and box-count mortality for the 1953-2010 time period for the natural oyster beds of Delaware Bay. Blue lines identify the 58-year medians used for calculation of first passage times (Table 19).

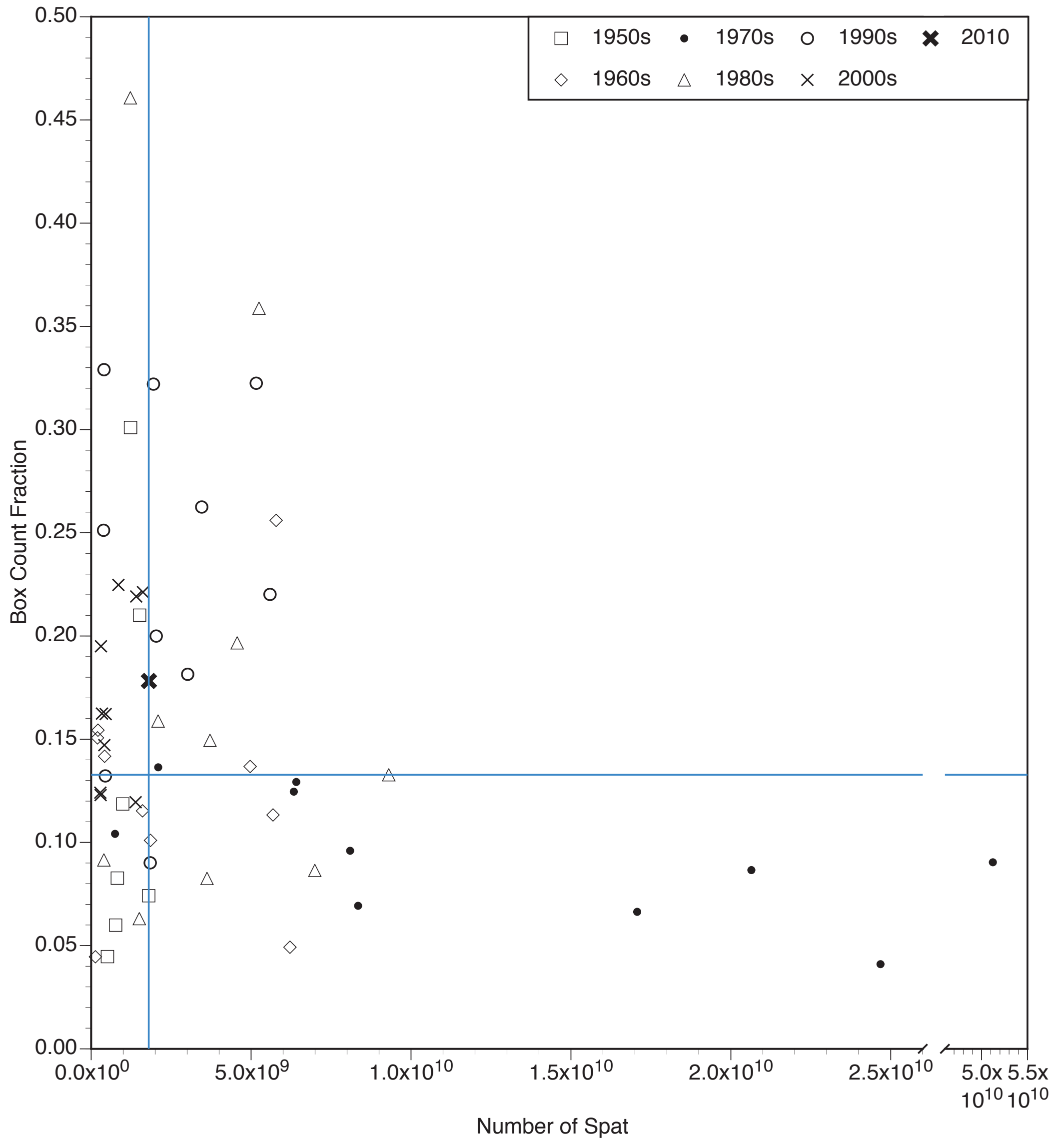


Figure 47. Estimated fractional reduction in food from within-bed density (upstream-downstream) effects. Light bars assume no vertical mixing over the oyster beds. Dark bars assume vigorous vertical mixing.

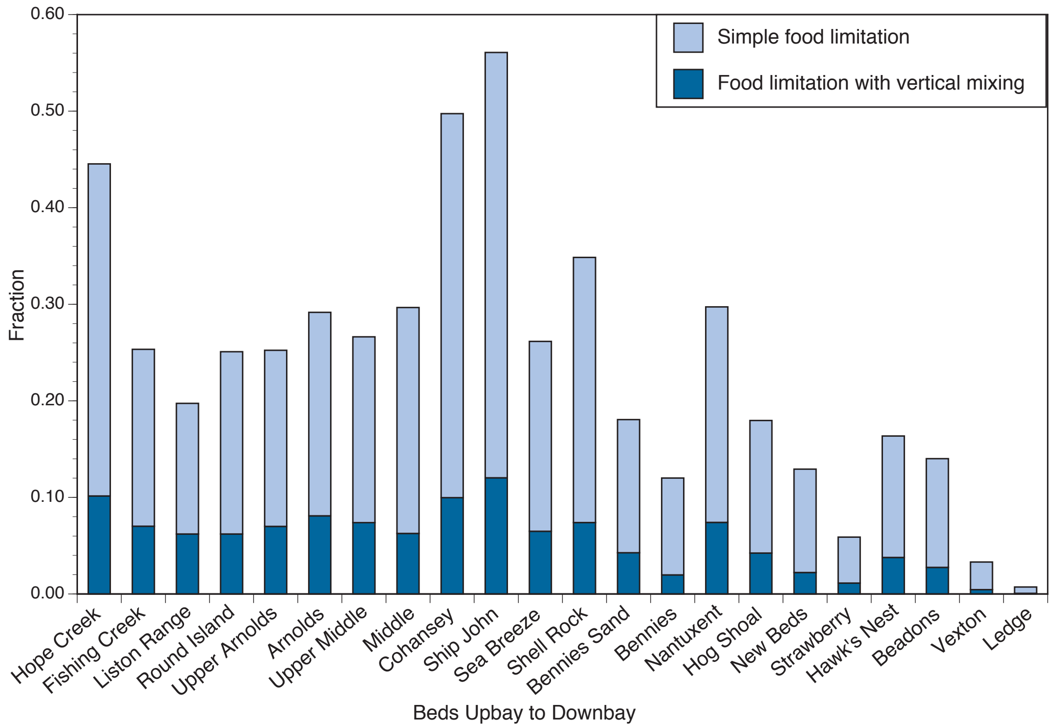


Figure 48. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

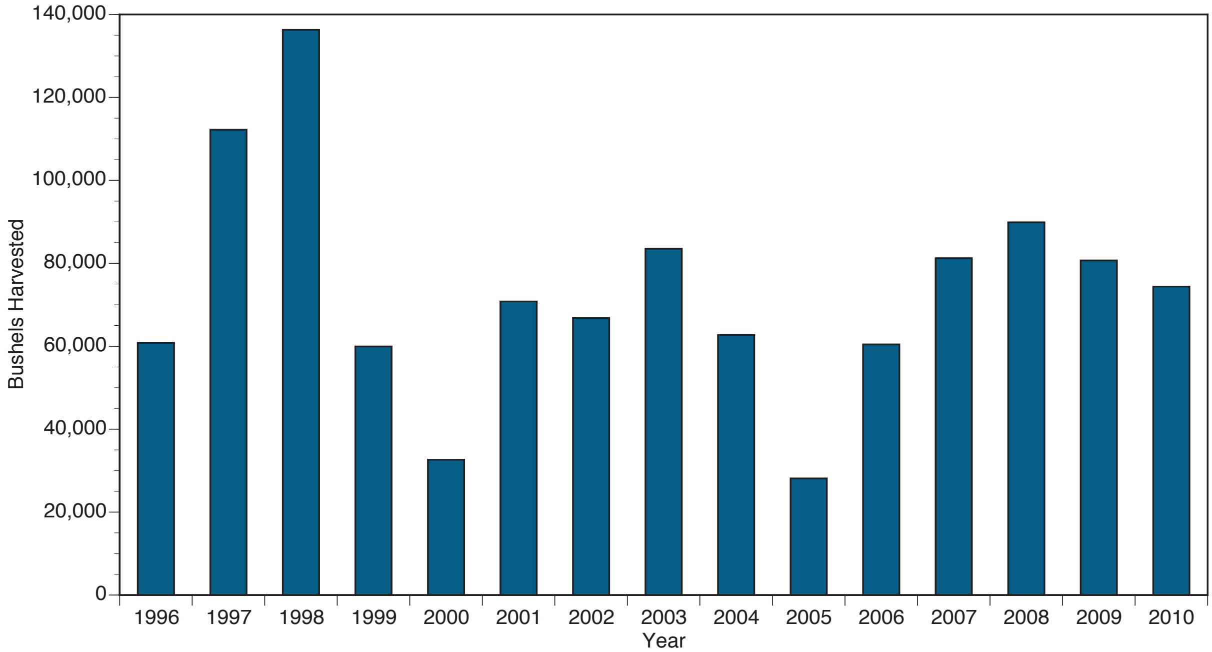


Figure 49. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

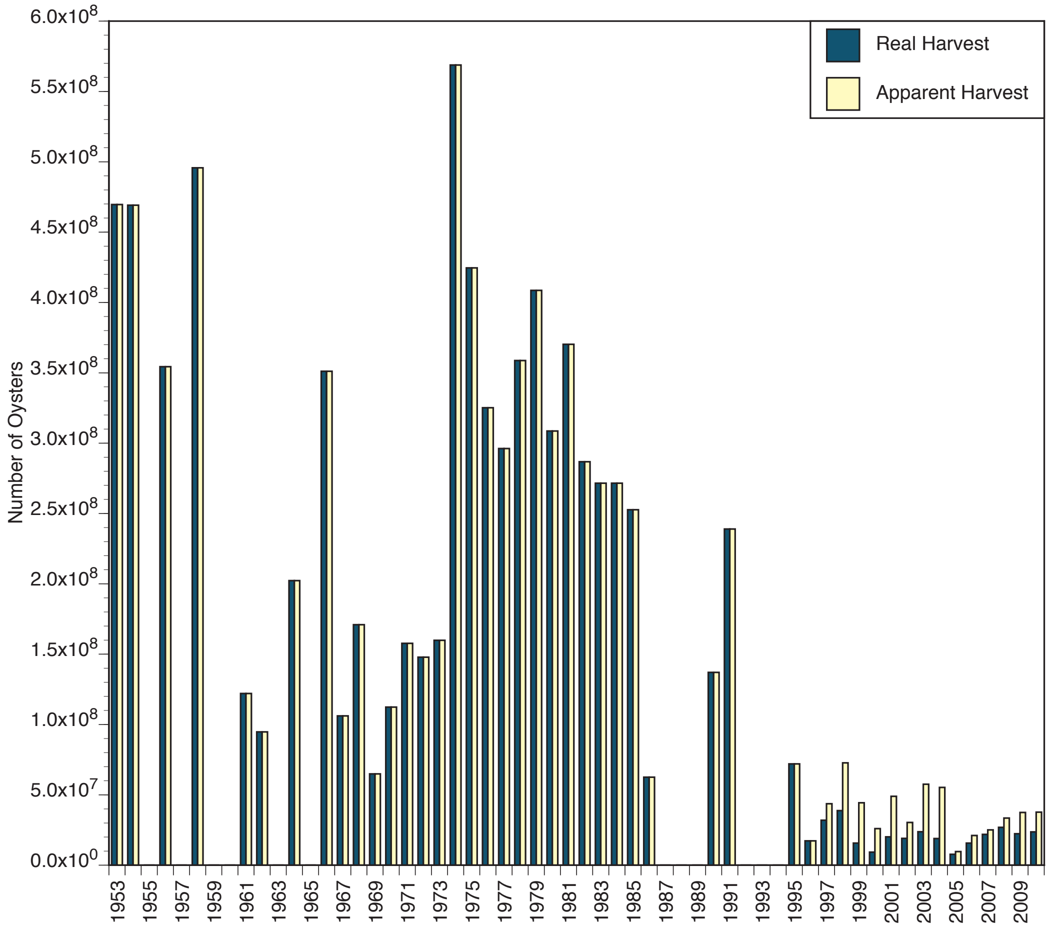


Figure 50. Catch (in bushels) per boat-day by vessel style.

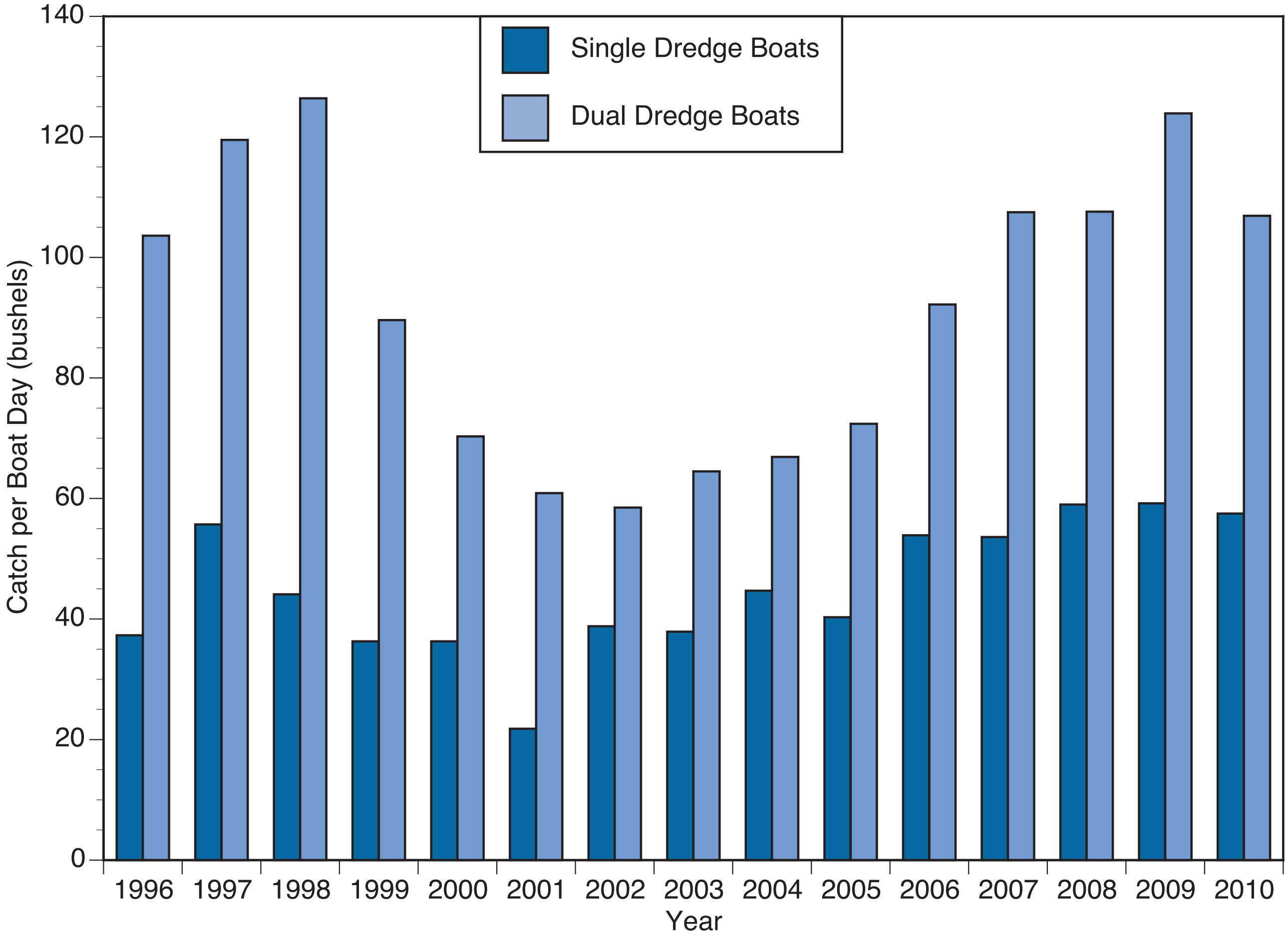


Figure 51. The number of oysters per landed bushel judged to have been landed due to failure to cull small attached oysters from those of market size (attached) and unattached oysters judged to have been too small to be targeted for market ($<2.5''$).

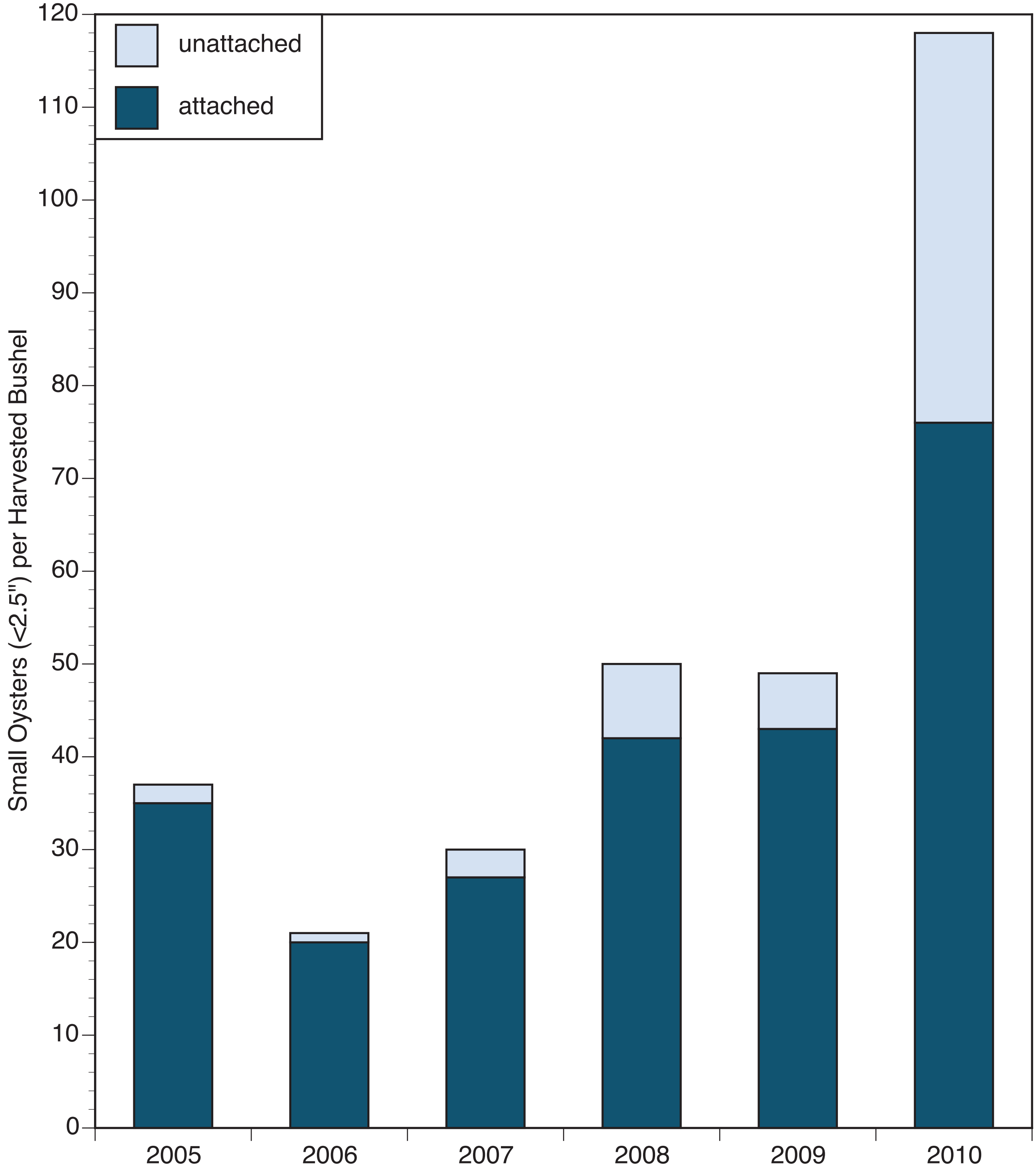


Figure 52. Size frequency of oysters landed in 2010 compared to 2009. Size class values are the lower bounds of the size class.

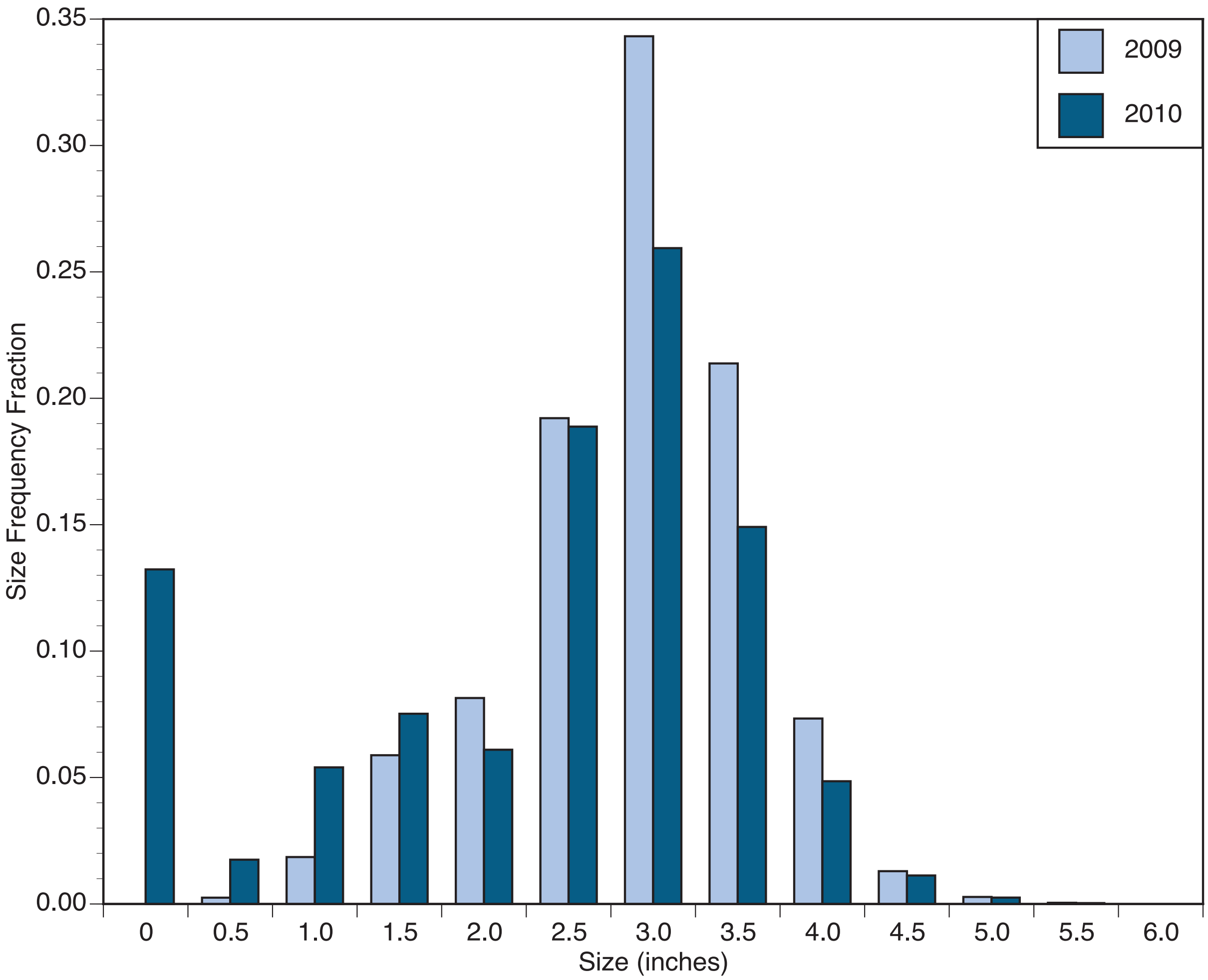


Figure 53. Fishing mortality rates by bay region during the 1954-2010 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 9. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality rate in that bay region. The total column height is the total fraction for the year.

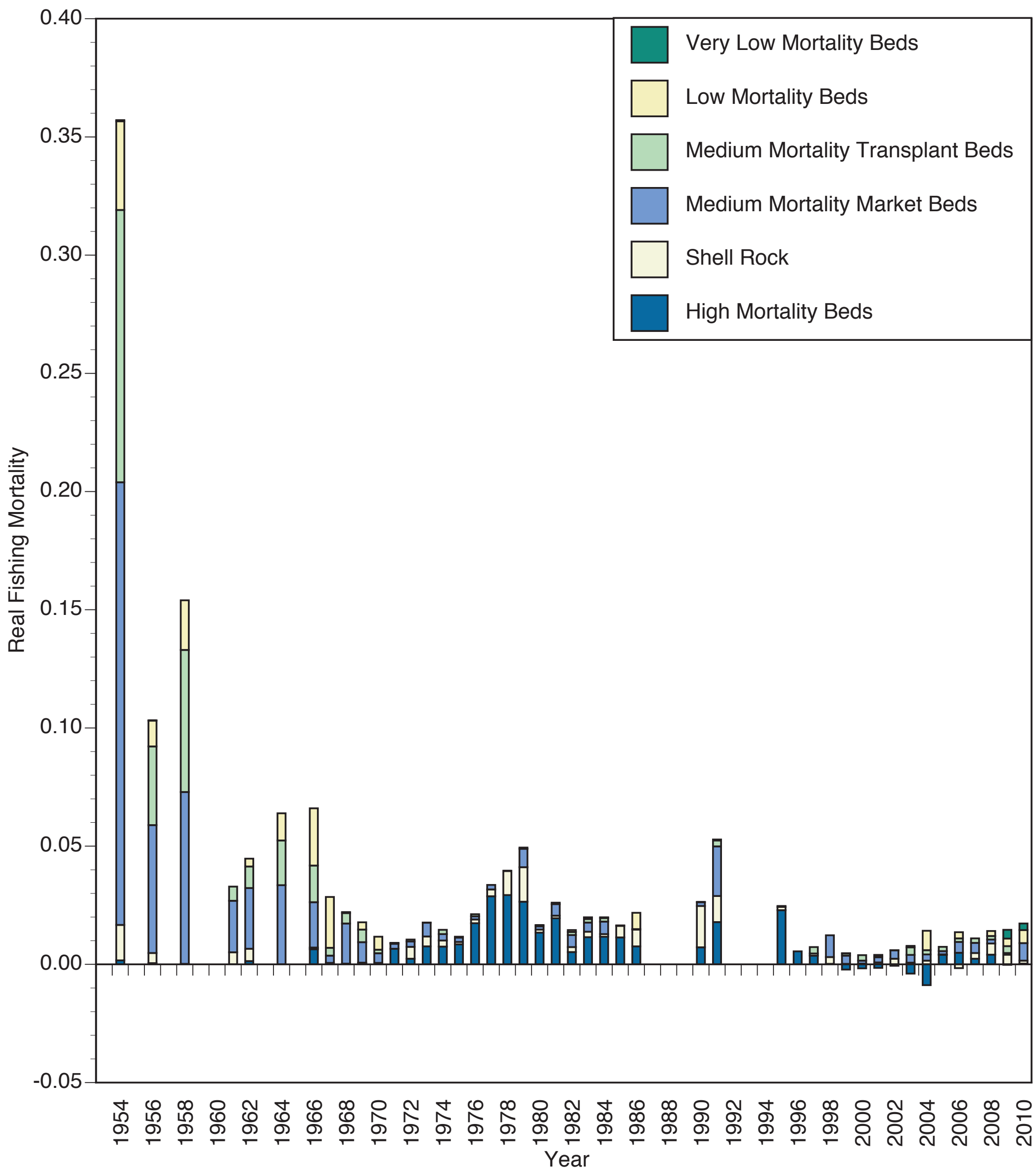


Figure 54. Fishing mortality rates by bay region during the 1989-2010 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 9. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality in that bay region. The total column height is the total fraction for the year.

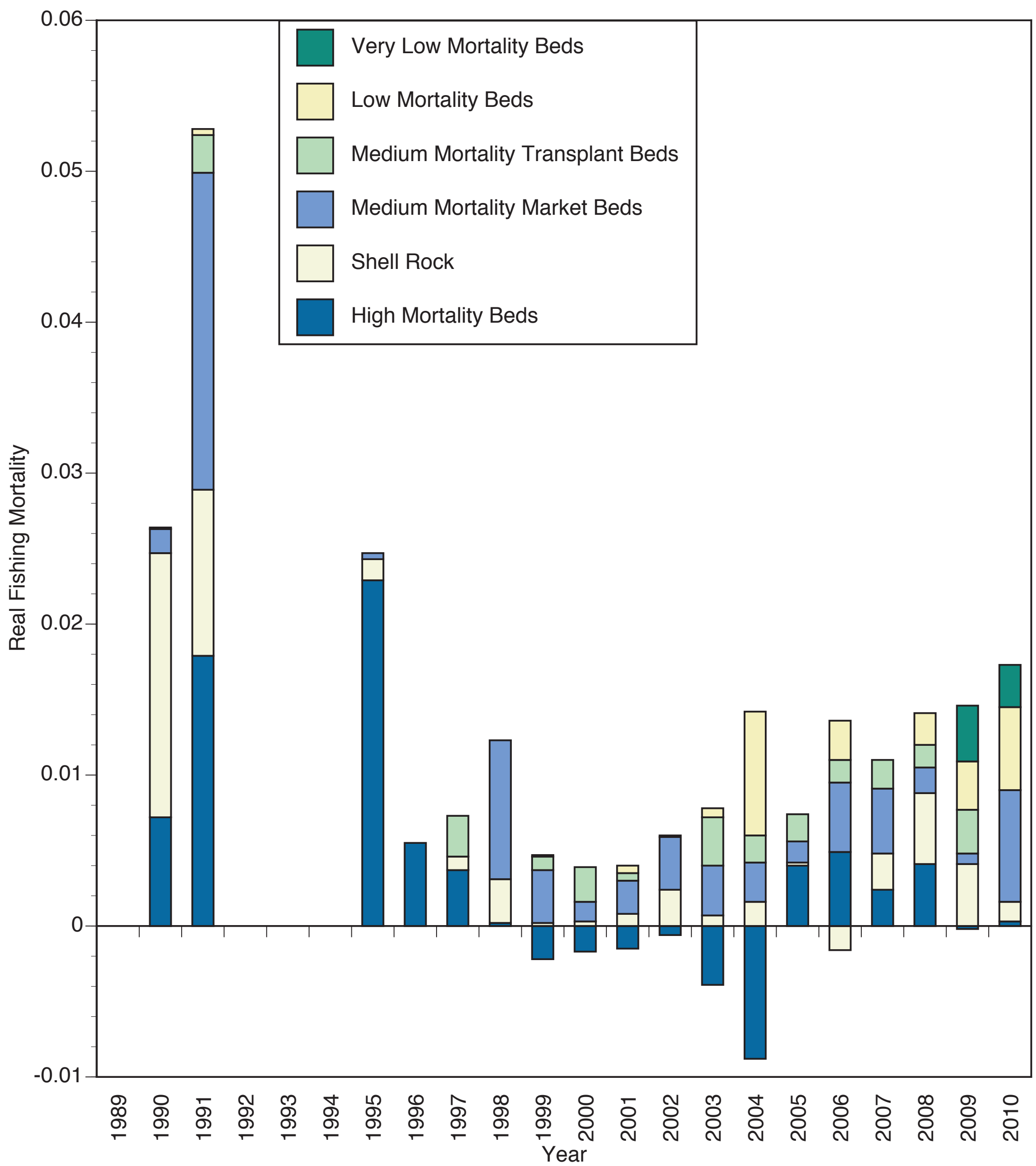


Figure 55. Real fishing mortality as a fraction of the stock during the 1991-2010 time period. Zeros represent years of fishery closure.

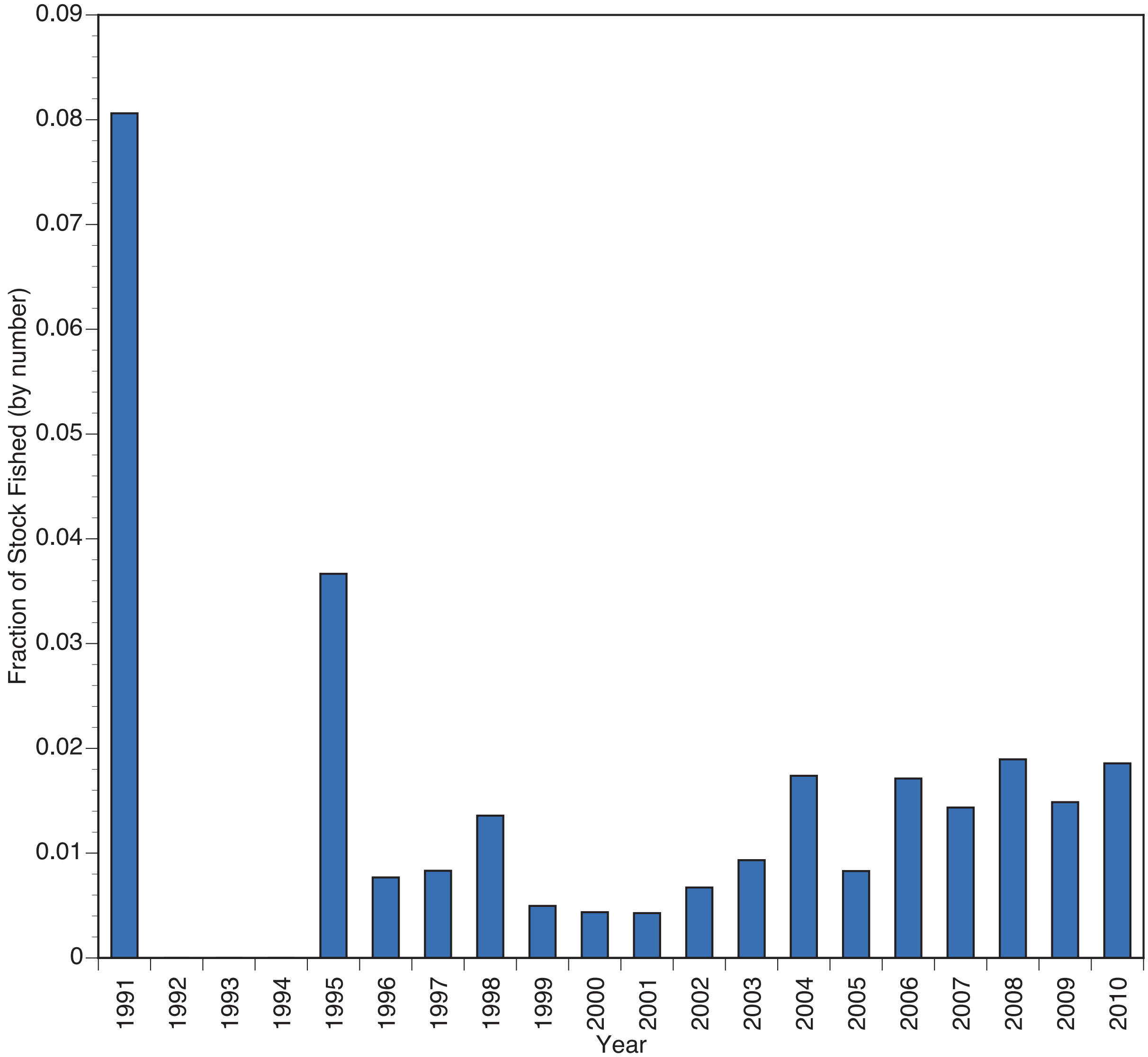


Figure 56. Fishing mortality as a fraction of the stock during the 1997-2010 time period based on spawning stock biomass.

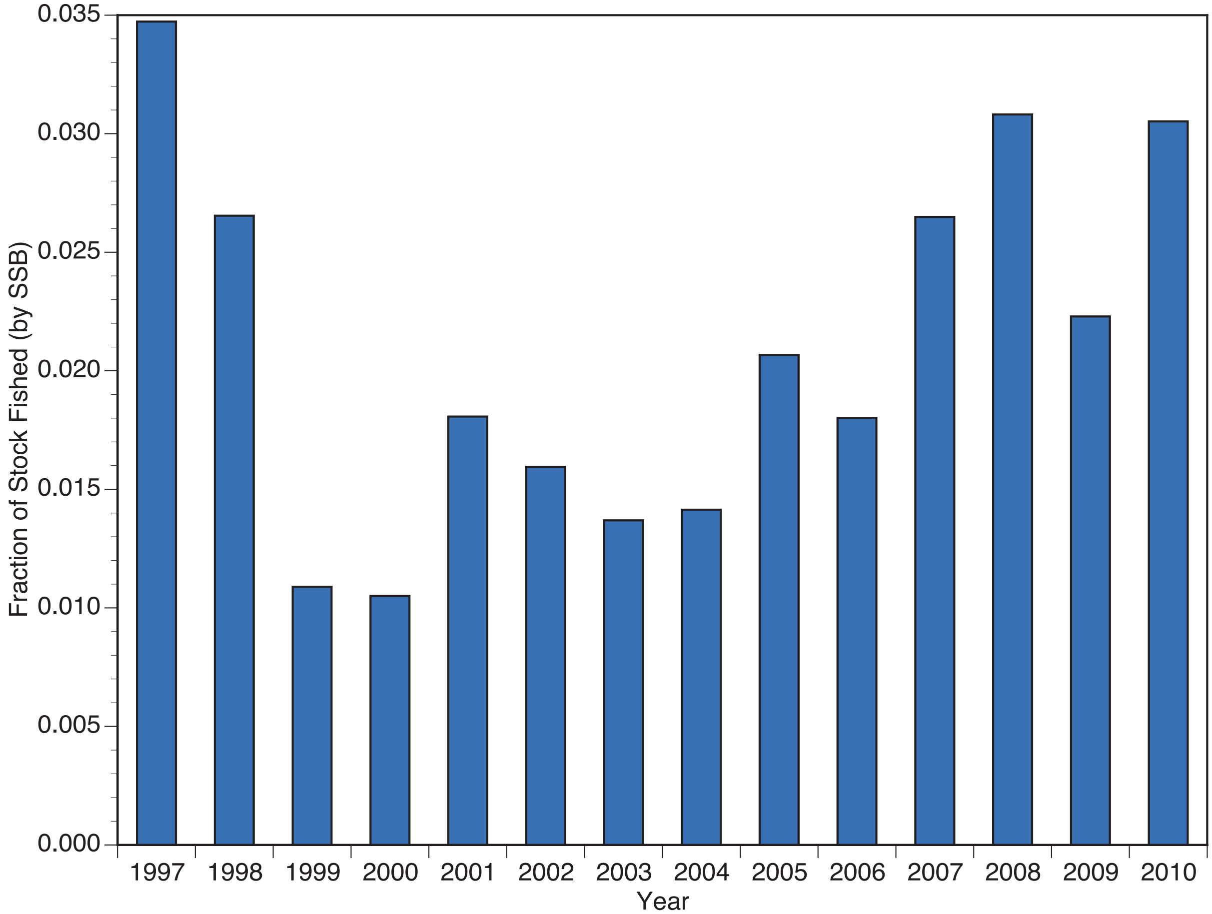


Figure 57. Fishing mortality as a fraction of the stock during the 1997-2009 time period based on marketable abundance (animals $\geq 2.5''$).

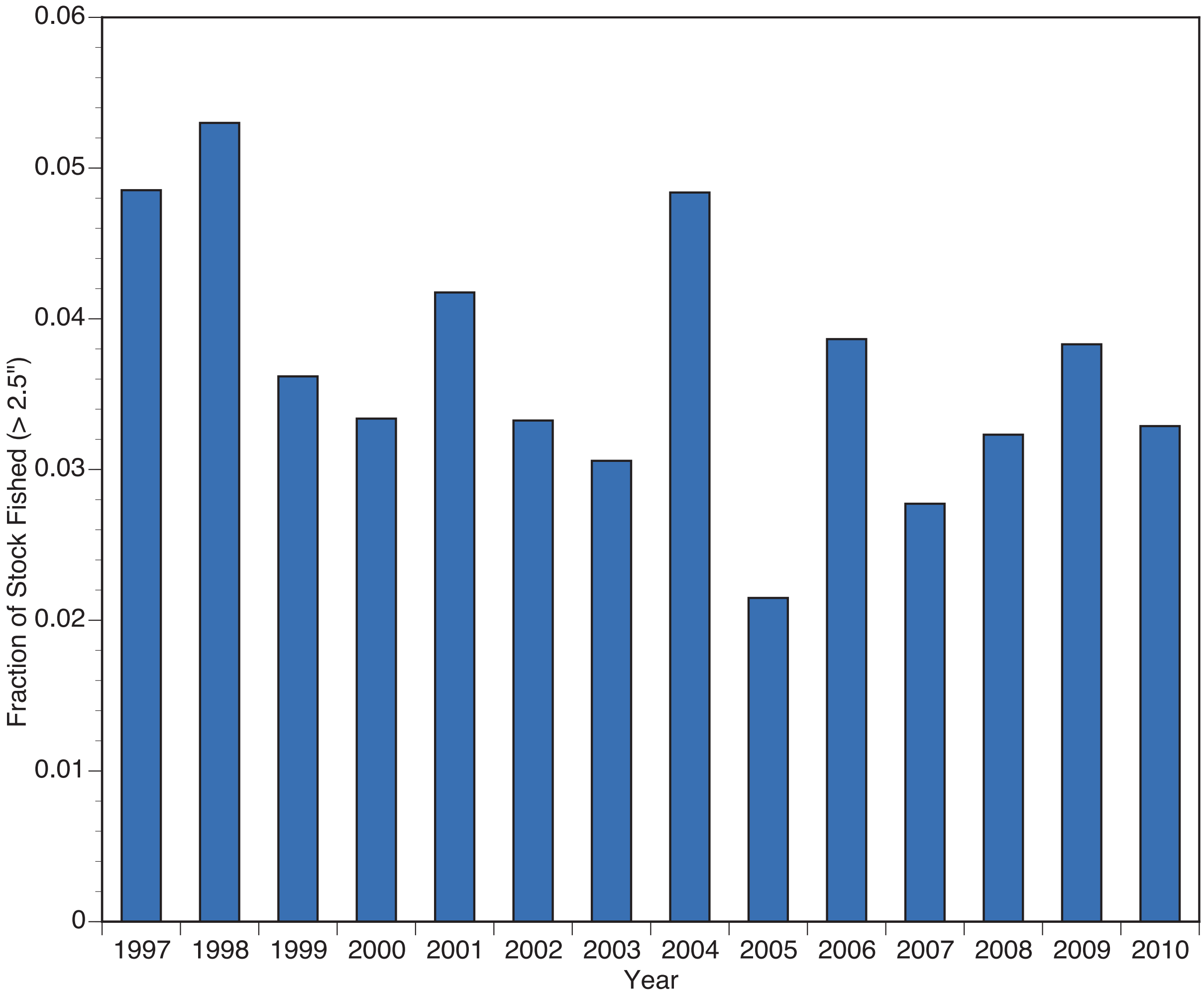


Figure 58. Abundance, SSB, marketable abundance, and recruitment trends on the very-low-mortality beds from 2008 to 2010.

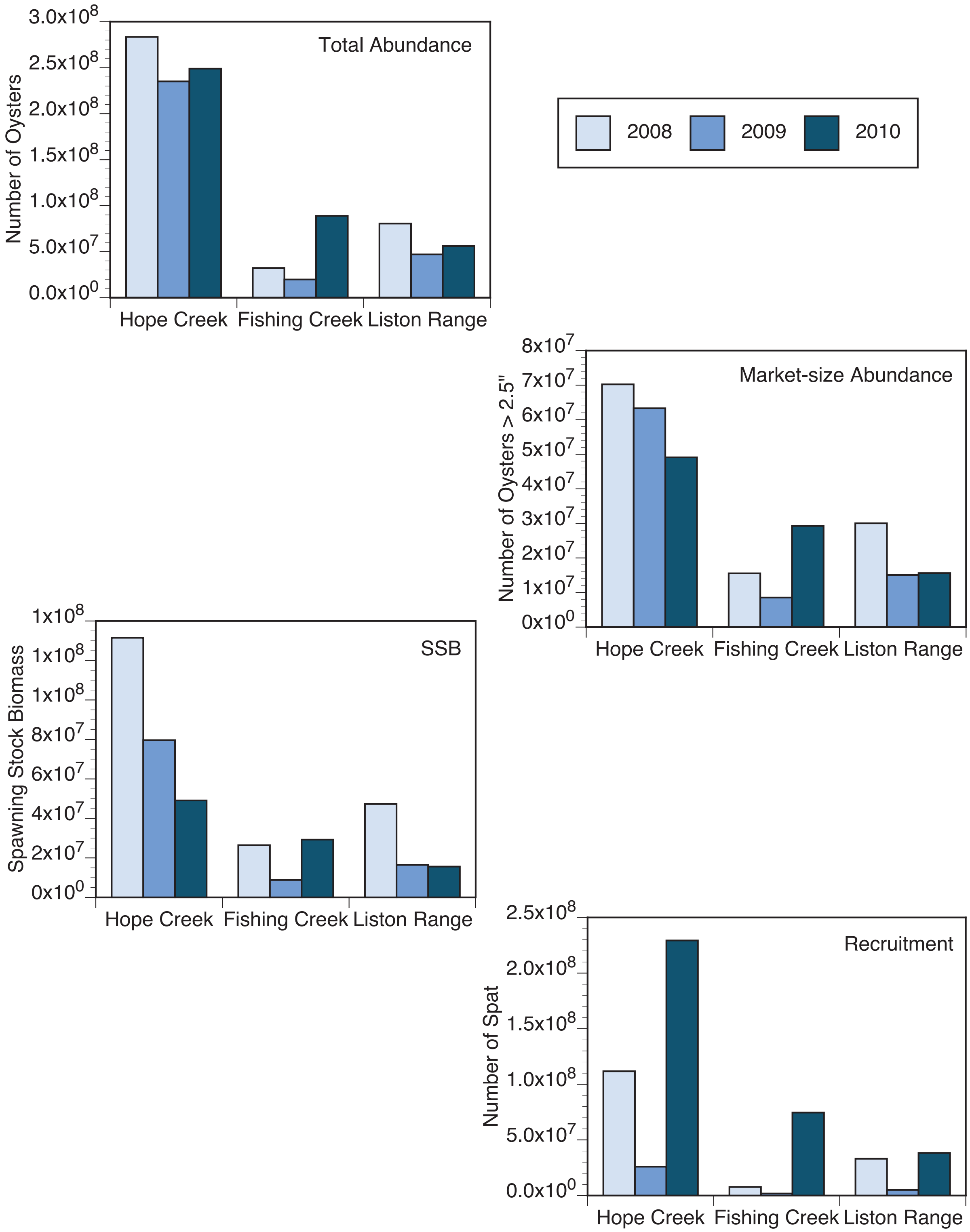


Figure 59. Abundance trends for oysters $\geq 2.5''$ for the medium-mortality market beds.

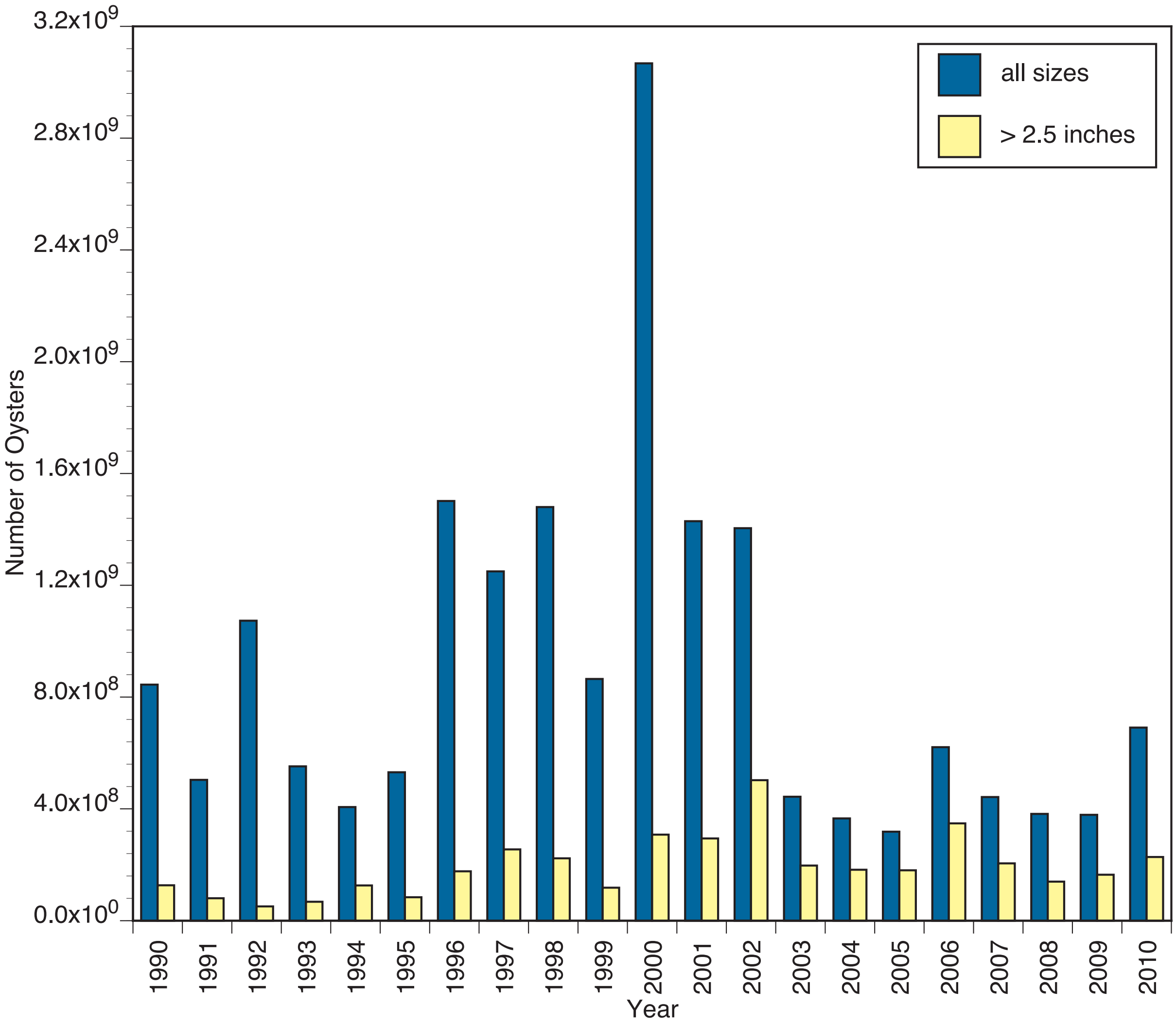


Figure 60. Position of the oyster stock in 2006-2010 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 time period. The threshold is taken as half these values (Table 23).

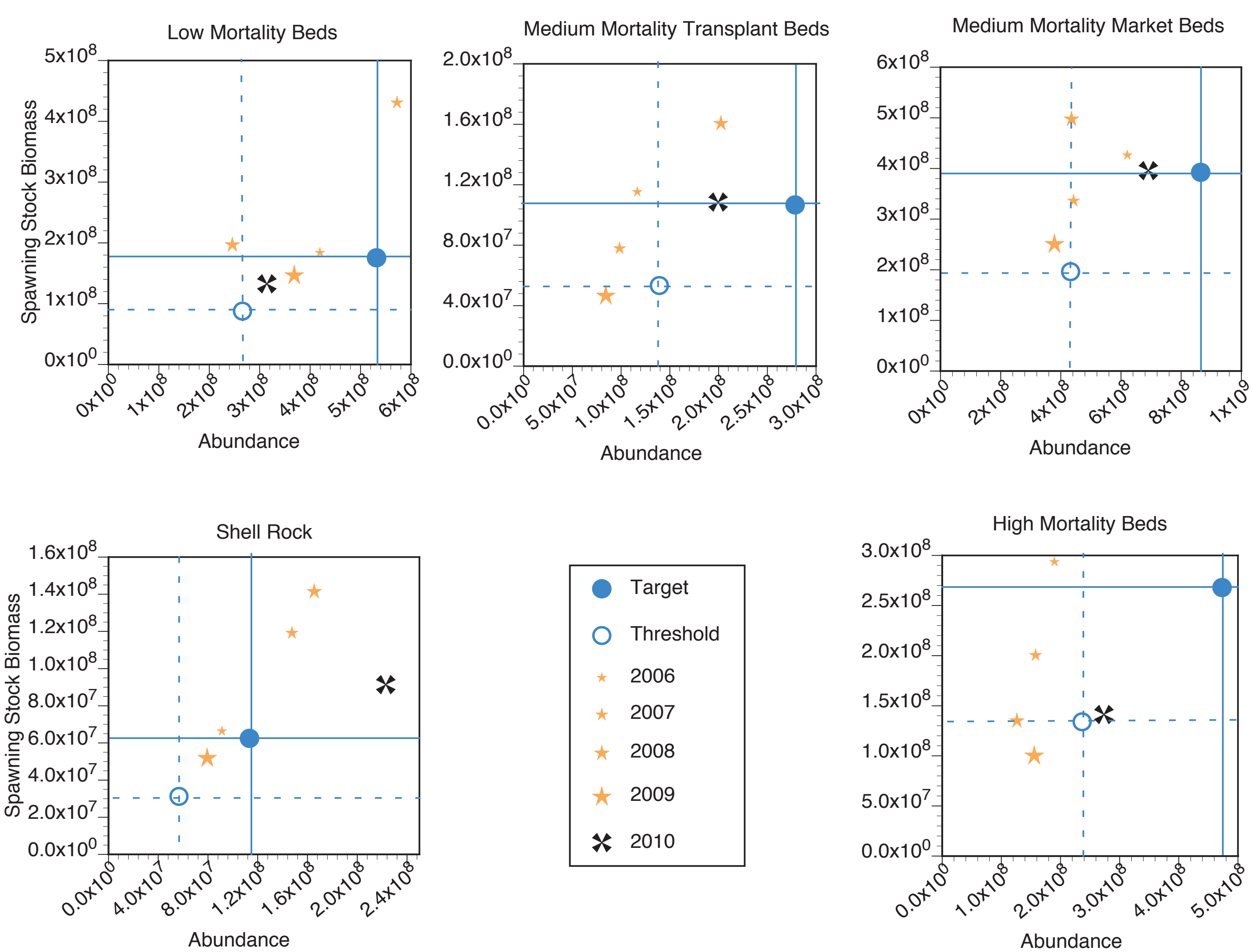


Figure 61. Position of the oyster stock in 2006-2010 with respect to market abundance ($\geq 2.5''$) and abundance targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989-2005 time period. The threshold is taken as half these values (Table 23).

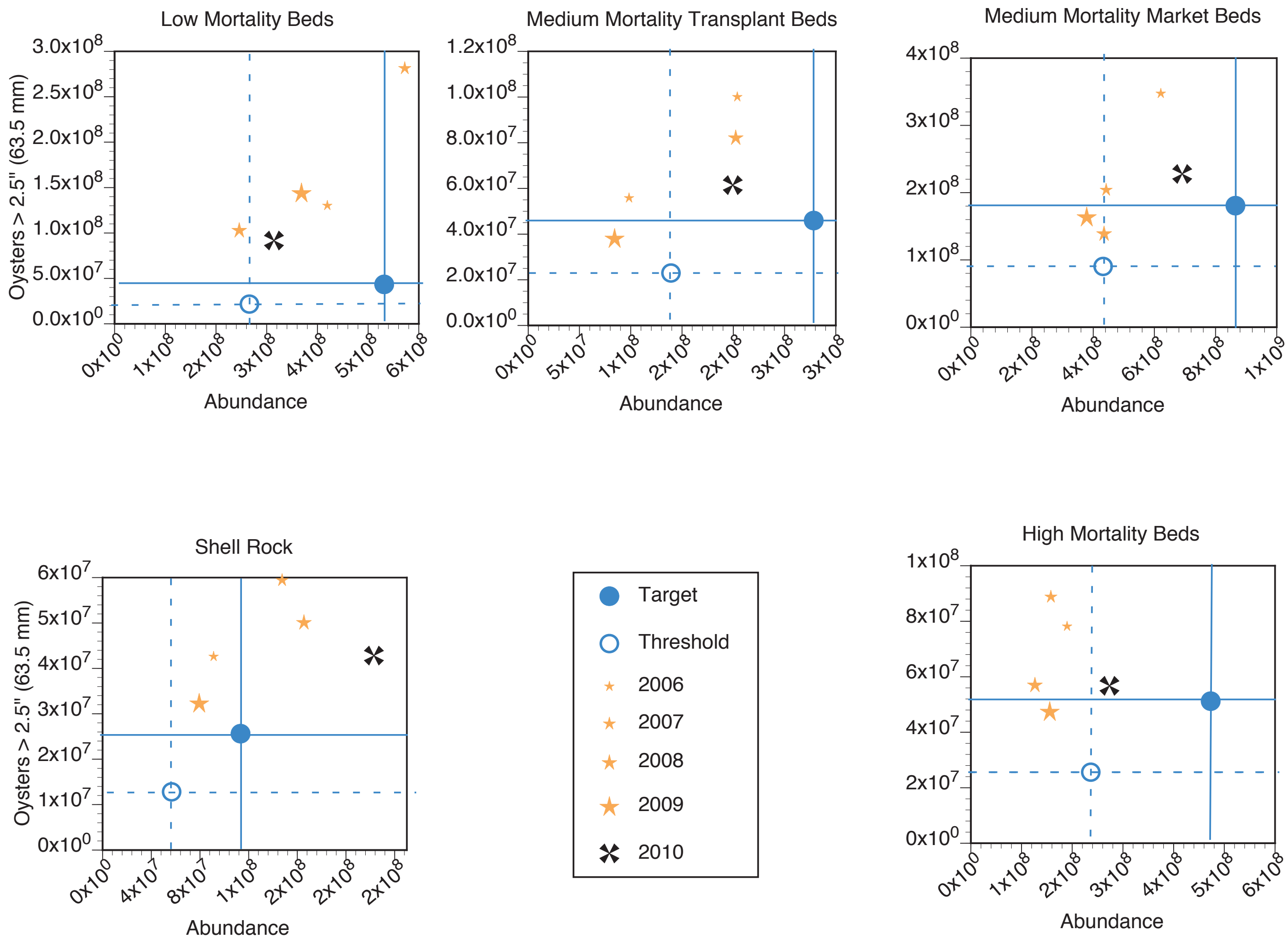


Figure 62. Relationship of the stock-performance reference points for total abundance from Table 23 to the 2010-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1-P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

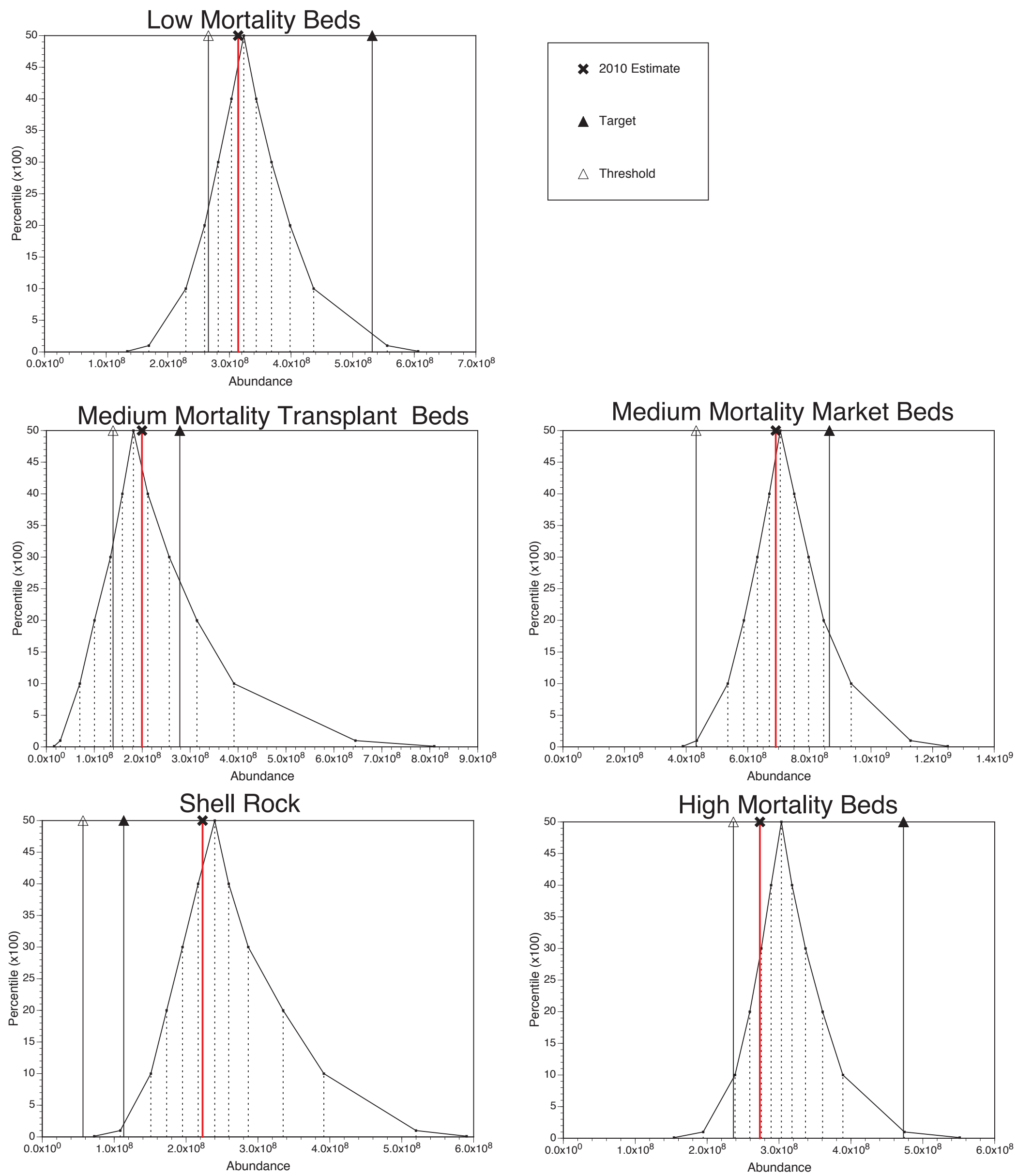


Figure 63. Relationship of the stock-performance reference points for marketable abundance (animals $\geq 2.5''$) from Table 23 to the 2010-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate for that bed. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

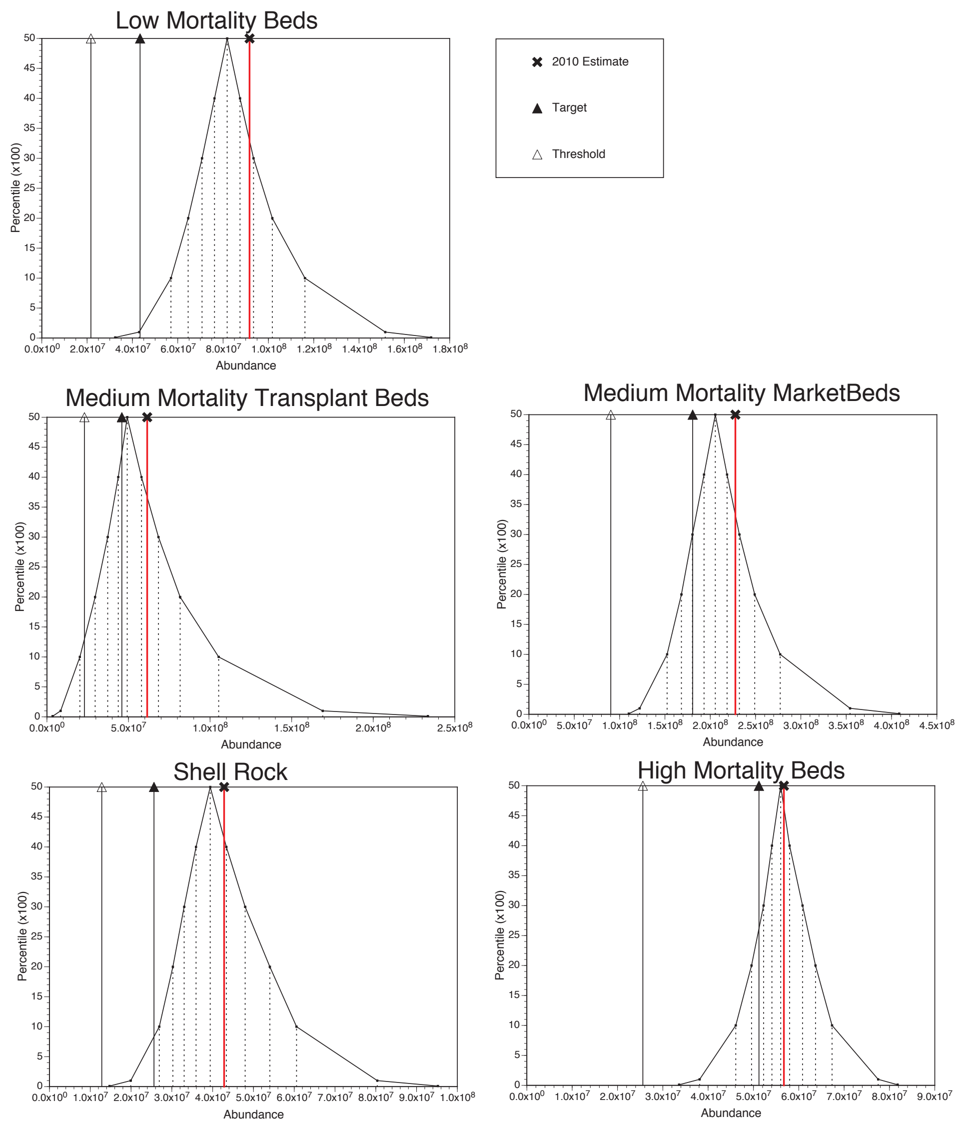


Figure 64. Plot of surplus production trajectories obtained from simulations of the stable-point surplus-production model. Descriptions of the simulations are given in Table 26 and the text. Vertical bars correspond to four whole-stock reference points. Two are derived from the surplus production model, a target defined as the median of five estimates of the N_{msy} for the low-abundance state and a threshold set at half that value. Two are derived from stock performance data for the 1989-2005 time period. The target is the median stock abundance for that period and the threshold is half that value (Table 23). The four respective values are: 1.628 billion, 0.814 billion, 2.262 billion, and 1.130 billion. All abundances exclude the very-low-mortality beds.

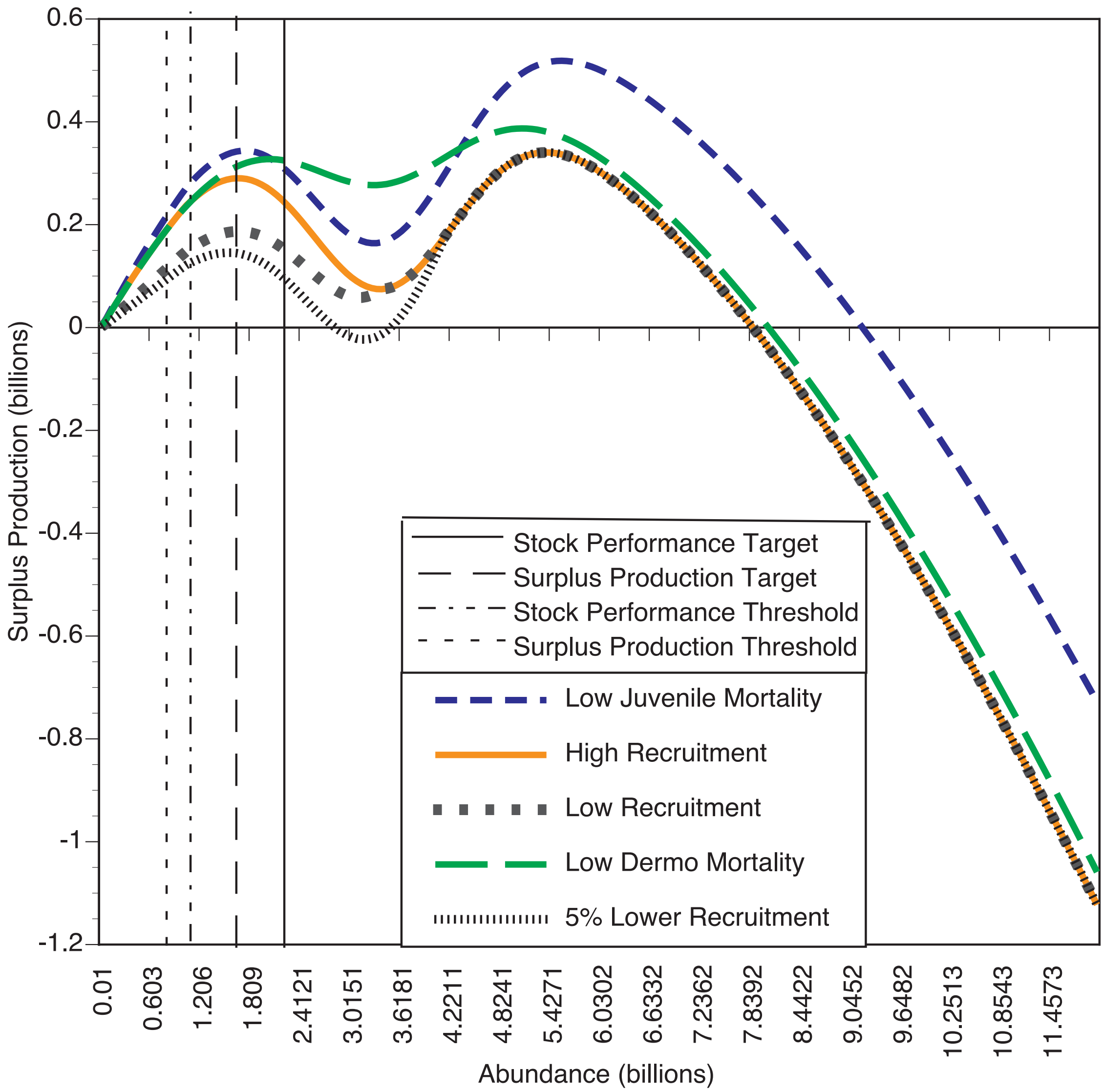


Figure 65. Position of the 2010 whole-stock abundance estimate within confidence percentiles for the 2010-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. Also indicated are the positions of the whole-stock stock-performance reference points from Table 23 and the N_{msy} reference points from Figure 64. All values exclude the very-low-mortality beds. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

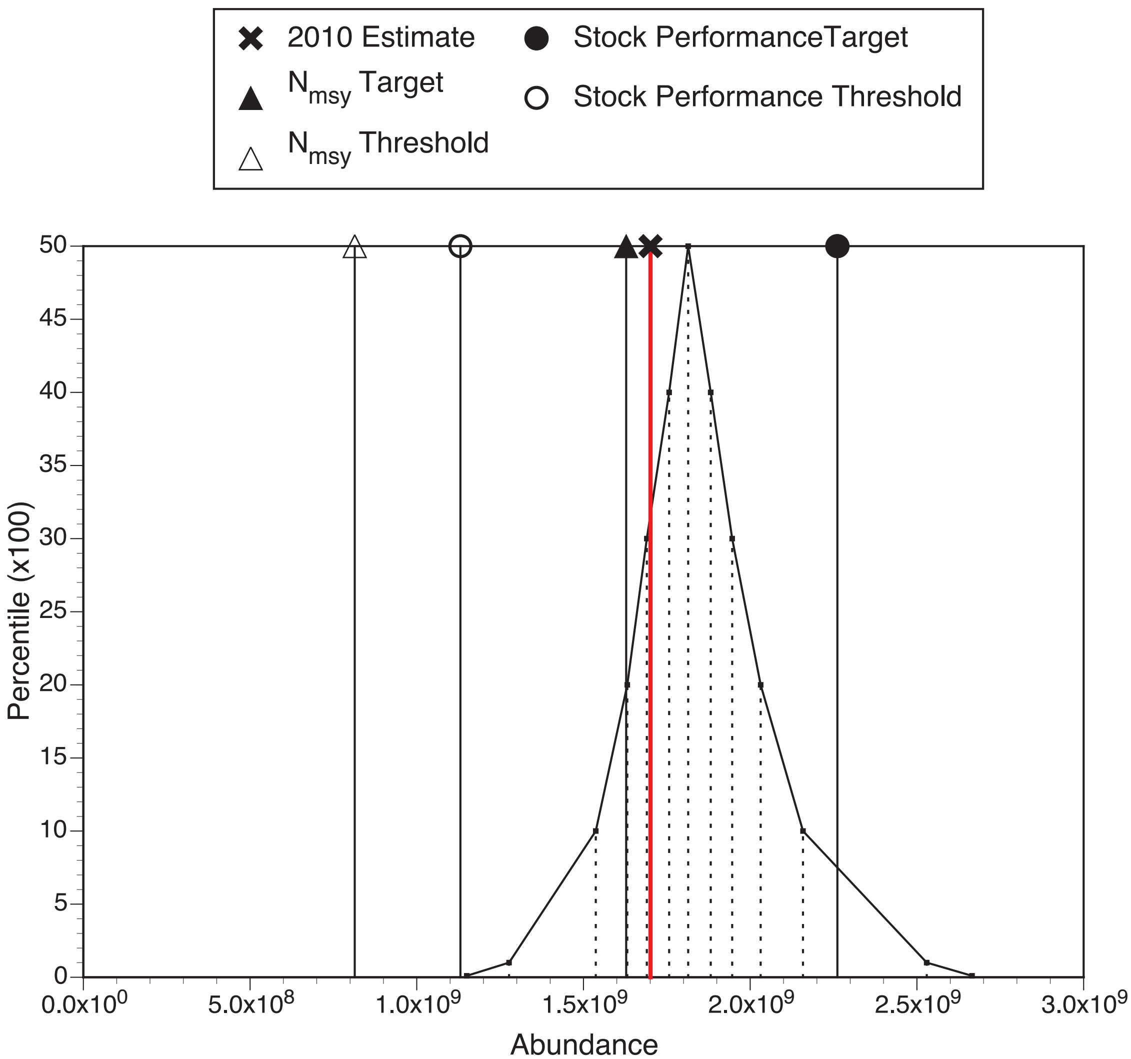


Figure 66. Position of the 2009 whole-stock marketable-abundance ($\geq$ 2.5″) estimate within confidence percentiles for the 2010-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency. Also indicated are the positions of the whole-stock stock-performance reference points from Table 23. All values exclude the very-low-mortality beds. Note that the percentiles above the 50^{th} are rendered as $1 - P$, so that, for example, the 60^{th} percentile is indicated as the upper 40^{th} percentile on this plot.

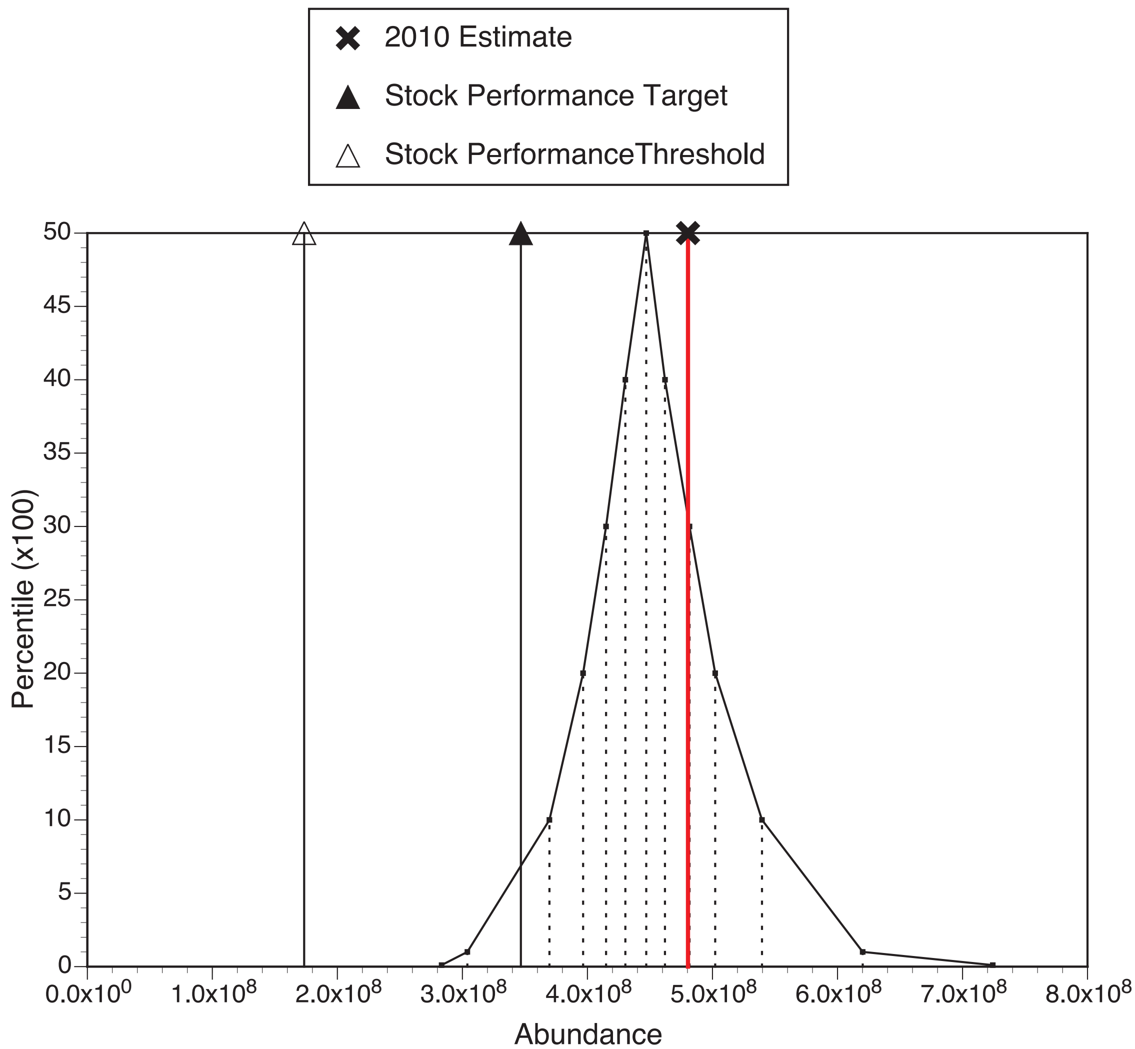


Figure 67. Summary status of the stock for 2010. Lime green indicates variables judged to be above average relative to the 1989-2010 time period or having an improving trend relative to the previous year or to the previous five years' median. Orange indicates variables judged to be below average relative to the 1989-2010 time period or having a degrading trend relative to the previous year or the previous five years' median. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2010 time period, but sometimes determined by scientific judgment. Trends in light green indicate a change $< \pm 15\%$. Fraction of stock refers to the dispersion of the stock across the salinity gradient in the six bay regions. All percentiles are relative to the 1989-2010 time series (1990-2010 for SSB). The 2005-2009 median identifies comparisons between the 2010 value and the 5-yr median value from 2005-2009.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.19	0.15	0.10	0.33	0.11	0.13
Fraction of Stock (No Very Low)	Not Incl.	0.18	0.12	0.41	0.13	0.16
Total Abundance						
2010 Percentile	Not Incl.	0.25	0.33	0.52	0.84	0.43
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Increasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Spawning Stock Biomass						
2010 Percentile	Not Incl.	0.26	0.50	0.50	0.64	0.21
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Decreasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Market Abundance						
2010 Percentile	Not Incl.	0.50	0.64	0.69	0.69	0.31
2005-2009 Median	Not Incl.	Decreasing	Increasing	Increasing	Increasing	Decreasing
2009-2010 Trend	Increasing	Decreasing	Increasing	Increasing	Increasing	Increasing
Recruitment						
2010 Percentile	Not Incl.	0.75	0.84	0.75	0.89	0.57
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2009-2010 Trend	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing
Spat per Adult						
2010 Ratio	0.87	0.74	1.04	0.89	1.37	1.63
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
2010 Percentile	Not Incl.	0.93	0.90	0.71	0.61	0.61
Small Oys (fract.<2.5")	0.75	0.71	0.69	0.67	0.81	0.79
2010 Percentile	Not Incl.	0.25	0.45	0.50	0.75	0.70
2005-2009 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
Dermo Infection Status						
Weighted Prevalence	0.2	1.10	1.15	2.10	1.80	1.80
2009-2010 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Mortality Rate	0.09	0.18	0.21	0.19	0.11	0.20
2010 Percentile	Not Incl.	1.00	0.80	0.52	0.30	0.25
2005-2009 Median	Not Incl.	Increasing	Increasing	Decreasing	Decreasing	Decreasing
2009-2010 Trend	Increasing	Increasing	Decreasing	Decreasing	Decreasing	Decreasing
Abundance Position vs						
Target	Not Incl.	Below	Below	Below	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Near
SSB Position vs						
Target	Not Incl.	Below	Near	Near	Above	Below
Threshold	Not Incl.	Above	Above	Above	Above	Near
Market Abundance vs						
Target	Not Incl.	Above	Above	Above	Above	Near
Threshold	Not Incl.	Above	Above	Above	Above	Above
Surplus Production						
50^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Not Incl.	Positive	Positive	Positive	Positive	Positive

Figure 68. Net surplus production for the entire stock from a retrospective analysis of survey indices and landings. Surplus production was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous years survey. This provides high and low bounds for the estimates. Left column: green indicates that net surplus production was positive under both assumptions, indicating forgone yield; and grey, that the lower estimate was negative and the higher estimate was positive, indicating that the yield to the fishery approximated the potential yield available. Right column: green indicates conditions where the average of the two estimates was positive, indicating forgone yield.

Year	75th percentile	75th percentile
2005		5.68
2006		5.25
2007		5.71
2008		5.76
2009		5.36
2010		4.77

Figure 69. The relationship between the number of deaths per year from natural mortality and the number from fishing for animals $\geq 2.5''$ in size.