Executive Summary of the
2012 Stock Assessment Workshop
(14^{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

Jason Hearon, New Jersey Department of Environmental Protection
Steve Fegley, University of North Carolina-Chapel Hill
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
Russ Babb, New Jersey Department of Environmental Protection
Selected faculty and staff, Haskin Shellfish Research Laboratory
Oyster Industry Science Steering Committee
Stock Assessment Review Committee

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Status of the Stock

The Stock Assessment Review Committee (SARC) concludes that the Delaware Bay oyster stock is not overfished and that overfishing is not occurring in 2011, 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 submarket surplus. The 1990-2011 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 submarket surplus has been positive in every year since port-sampling began; that is, the number of oysters growing into the 76-mm size class has contributed at least as much if not more than the number required to compensate the 76-mm size class for removals through natural mortality and fishing (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 total mortality rate (fishing + natural) 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 2011, the stock presents a mixture of positive and negative indicators with the central bed regions, Shell Rock and the medium-mortality beds, showing mostly positive indicators and the salinity extremes mostly negative indicators (Figure 4). Declining stock status upbay of the medium-mortality market beds in 2011 is a response to the 2011 flood generated by Hurricane Irene and Tropical Storm Lee.

Abundance is relatively high, despite flood losses. Abundance is increasing in four of six bay regions relative to 2010 and in four of five bay regions relative to the previous five-year median (Figure 5). Abundance dropped precipitously on the very-low-mortality beds and declined significantly on the low-mortality beds, however. Much of this decline was in the market size classes. Abundance remains below target levels in all but one bay region, but is above the threshold in all but one bay region, that being the high-mortality beds (Figure 6). The increase in abundance in 2011 is explained by the well-above-average recruitment event of 2010 that offset losses due to the 2011 flood (Figures 5 and 7). The stock continues to be disproportionately consolidated on the medium-mortality beds, a factor exacerbated by the high mortality rate in 2011 at the extremes of the salinity range.

The 2011 recruitment was poor upbay of the high-mortality beds (Figures 4 and 7). However, comparisons to 2010 are amplified by the unusually high recruitment in that year. As a consequence, recruitment decreased in all bed regions except the high-mortality beds in 2011 relative to 2010. Recruitment in 2011 was sufficiently poor to show a decline relative to the previous five-year median in three of five bed regions.

Based on total recruits, the 2011 spatfall exceeded the 50^{th} percentile for the 1989-2011 time period in only one bed region, the high-mortality beds. On a spat-per-adult basis, the 2011 recruitment trends are nearly identical to total recruitment. Recruitment was well below 0.5 spat per adult in all but one bed region, the high-mortality beds (Figure 7).

Spawning stock biomass trended opposite to abundance in most bay regions (Figure 4). SSB increased only on Shell Rock. Declines were substantial in all other bay regions relative to 2010 and in four of the remaining five relative to the previous five-year median (Figure 8). Much of this decrease originates from a natural mortality rate imposed by the 2011 flood. However, the trends in SSB exceed the trends in market-size abundance, likely due to the extraordinarily low condition of the stock at the end of 2011. SSB fell below the biomass target in five of six regions, but distinctly below the threshold in only one, the very-low-mortality beds. However, in two other regions, biomass fell near or modestly below the threshold (Figure 6). In contrast, marketable abundance increased in two of five bay regions relative to the previous five-year median and in two of six regions relative to 2010 (Figure 9). Marketable abundance was stable or increasing in the core bed regions, while decreasing substantively at the range extremes. Marketable abundance fell above the target in four of six bay regions and only modestly below the target in a fifth. Marketable abundance fell above the threshold in all bed regions, although only modestly above for the very-low-mortality beds.

Dermo was modestly or substantively abated by the flood in all bed regions (Figure 4). This marks a clear break in the pattern observed in 2008-2010. Natural mortality was high and increasing relative to preceding years in the two uppermost bed regions due to the 2011 flood and likewise high and modestly increasing on the high-mortality beds. The upbay two bed regions saw the highest mortality rates on record for the Dermo era, although the mortality was due to extreme low salinity rather than disease. Natural mortality rate fell on the medium-mortality beds and Shell Rock. Mortality rate was average or low in these three regions by historical standards (Figure 4).

Overall, the six bed regions cover a wider range of stock status than normally observed. Few cautionary data exist for Shell Rock or for the medium-mortality market beds. Exploitation rates have routinely been low in all bed regions over most of the direct-market period. No evidence of impact from the higher exploitation rate permitted in 2011 on the medium-mortality market beds could be discerned, supporting the retention of this option for exploitation in 2012. On the other hand, conditions have deteriorated on the high-mortality beds. These beds are below, though near, the threshold for abundance and SSB and below the target for market-size abundance. All three metrics dropped significantly in 2011 relative to the previous five-year median and relative to the previous year, 2010. Intermediate transplant limited the effect of the fishery on these beds in 2011 (Figure 10); thus, the observed trends are due nearly in their entirety to natural trends in mortality and recruitment of the stock in this region. A continued emphasis on intermediate transplant to this bed region in 2012 would seem prudent, as the 2011 recruitment provides an opportunity to improve the condition of this region in 2012.

Conditions have deteriorated markedly on the low-mortality and very-low-mortality beds as abundance and SSB have declined to undesirable levels, relative to the 1989-2011 (or 2007-2011) historical record and marketable abundance has also declined substantively, due to unusually high rates of natural mortality from the 2011 flood and a decadal dearth in recruitment, broken only by the higher event of 2010. Recruitment was abysmal in 2011 in both regions. An even poorer stock status was prevented by the biased mortality towards the large size classes from the 2011 flood, that left the smaller sizes less affected. Condition however ended the year at extremely low levels. Abundance, SSB, and marketable abundance are near or below the targets in both areas and only distinctly above the threshold for abundance and marketable abundance on the low-mortality beds.

2012 Management Goals

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, but conditions worsened in 2011 (Figure 11). Thus, a reduction in shell planting in 2009-2011 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, the program has proven to be a useful recruitment enhancement tool. Design of a 2012 program, funds permitting, should consider the following recommendations.

1. Shell Rock is in very good shape. No shell plant or intermediate transplant to this bed is recommended for 2012

2. Ship John and Cohansey are of increased importance to the industry in 2012 as a product of stock consolidation following the 2011 flood. The SARC recommends that shell planting in 2012 target the lower portion of Ship John. The SARC further recommends that a replant rather than a direct plant should be considered if financing is adequate.

3. The SARC notes that the very-low-mortality beds, because of the 2011 flood, would be a location for a replant program. Direct shell planting is discouraged due to the anticipated infrequency and unpredictability of good recruitment events.

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 continuing efforts should be undertaken to minimize the downbay transplant of cultch. As data collected in 2011 show that cultch fractions below 25% are routinely achievable, the transplant program should emphasize the goal of limiting cultch fraction to 25% or less in 2012.

Abundance-based Exploitation Reference Point Projections – Direct Marketing

In 2011, the high-mortality beds continue to be at low abundance, with declining abundance relative to 2010 and the preceding 5-year median. Marketable abundance has also declined relative to the preceding 5-year median. Abundance is below the threshold, as is SSB; however, market abundance is above the threshold and near, though below, the target (Figures 6 and 9). 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 that these beds 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 (Figures 6 and 9). 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 2007-2011 on Ship John and Cohansey have not resulted in an observable decline in marketable abundance (Figure 9). 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 within survey error of the abundance target and above the market-size abundance target (Figure 4). Mortality rate was low in 2011; however, condition was also very low at survey time and SSB is near the stock-performance threshold. The possibility of a delayed impact of the 2011 flood on these beds should not be discounted. As a consequence, the SARC recommends that management be precautionary, with an intermediate transplant quota not to exceed the 50^{th} percentile level.

The low-mortality beds are near, but above, the marketable-abundance target, but below the abundance target and only modestly above the threshold (Figure 4). The beds have suffered two consecutive years of historically high mortality, with 2011 being the highest recorded in the 1989-2011 time series, as a consequence of the 2011 flood. Biomass mortality was distinctly higher than mortality measured by abundance due to increased mortality in the market size classes. 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 typically lower rate of natural mortality. However, the region sustained an unusually good recruitment event in 2010 and these smaller animals suffered a lesser mortality in 2011 than the marketable size classes. Condition was extremely poor at survey time. The SARC emphasizes that the status of the stock in this region requires that a precautionary approach be taken in 2012. Furthermore, the SARC expresses concern that condition was low enough that a significant overwinter mortality event might occur. The SARC, therefore, recommends that the intermediate transplant be no higher than the 40^{th} percentile.

In 2011, the transplant was distributed across the three beds. The 2011 mortality event was modestly lower on Arnolds, suggesting that Arnolds might be targeted preferentially in 2012. However, the SARC recommends that a resampling of survey grids be conducted prior to the transplant. A significant increase in mortality rate since the fall survey would indicate ongoing damage from the flood and subsequent low condition that would necessitate that this bed region be closed in 2012.

The very-low-mortality beds suffered an extreme mortality event in 2012. Modeling using DyPoGEn suggests a 10-yr recovery time frame. Stock performance reference points were estimated for the first time in 2012. These are considered provisional. Nevertheless, the very-low-mortality beds are below the SSB threshold and above, but near the abundance and market-abundance threshold (Figure 4). As the abundance threshold in particular may be underestimated, it is possible that this region falls below the abundance threshold. As a consequence of its uniquely poor stock status, the SARC recommends that this bed region be closed for 2012.

Projections for intermediate transplant are provided in Table 2.

Caveats Apropos Risk for 2012 Fishery Yield

1. The SARC notes that the recommendation for Sea Breeze, once considered a medium-mortality market bed, to be managed for intermediate transplant as part of the Middle and Upper Middle group of beds be retained. SAW-12 recommended that Middle not be targeted in consecutive years and, as a consequence, transplant from Sea Breeze was attempted in 2010. Results of this program show that Sea Breeze/Upper Middle as the sole target beds represent a transplant challenge due to patchiness on Sea Breeze and small areal size of Upper Middle. As a consequence, the SARC recommends that the 2012 transplant be distributed 50% from Middle and 50% from Upper Middle/Sea Breeze. The SARC further stresses that no more than 50% of the transplant be taken off Middle, so that limited success on Sea Breeze will result in a reduction of the total number of oysters moved and, hence, a reduction in the quota increase for 2012 that might otherwise

be achieved.

2. The SARC discussed the option of using a suction dredge for the Sea Breeze/Middle transplant. Earlier detailed evaluation of suction dredge performance has shown that the suction dredge catch is biased towards the smaller size classes. The use of a standard dredge and cullers has routinely been recommended because deck loads obtained in this way are biased towards the larger size classes. This increases the augmentation of the direct-market quota while also retaining on the donor beds under a lower natural mortality rate more of the smaller animals that can, then, support future transplant activities. However, the SARC recognizes that any transplant is better than no transplant. Accordingly, the SARC recommends that transplant be carried out with a standard dry dredge and cullers, but, if the use of this method proves inadequate to reach recommended goals, then a suction dredge may be used.

3. 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 an exploitation rate above the 40^{th} percentile.

4. The SARC believes that more can be accomplished in stock enhancement this year on the high-mortality beds through intermediate transplant, rather than shell planting. 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.

5. The SARC notes 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.

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 considered whether the resurvey plan should be modified due to the severe impact of the 2011 flood on the two upbay regions. Patchy high mortality on these upper beds may put into question the validity of the present assignments of sampling grids to strata. However, one cannot evaluate the likelihood that the patchiness of abundance may change rapidly from year to year during the recovery of these beds, thus putting into question survey estimates for a decade, if these beds are re-surveyed earlier than in the original plan. The SARC also notes that

important production beds are scheduled for resurvey in 2012. Consequently, the SARC recommends that the original plan be followed, as this will permit recovery to progress for a few years prior to a new survey.

8. The SARC continues to support the experimentally-increased exploitation rates on the medium-mortality market beds.

9. The heavy set on Beadons in 2012 resulted in a transplant of seed to Bennies. The SARC recommends that this transplant be treated as a shell plant and followed for three years, rather than the typical one year, as is done for other intermediate transplants.

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 265 derived from the 2004-2011 port-sampling program. Arrows indicate recommended options. Footnotes identify alternatives available under specified conditions.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	597,054	2,185
	$^{\Gamma}50^{th}$	.0652	3,094,618	11,678
	$^{\Gamma}60^{th}$	.0782	3,711,643	14,006
Shell Rock	$\longrightarrow 40^{th}$	.0870	4,463,587	16,844
	$\longrightarrow 50^{th}$	.0880	4,514,893	17,037
	$\longrightarrow 60^{th}$	.1140	5,848,839	22,071
Medium Mortality Market	$\longrightarrow 40^{th}$	.0178	3,581,466	13,515
	$\longrightarrow 50^{th}$	.0214	4,305,808	16,248
	$\longrightarrow 60^{th}$	.0267	5,372,199	20,272
	$\longrightarrow 100^{th}$	.0398	8,007,998	30,219
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 2. Projections for intermediate transplant assuming that intermediate transplant might 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 2011 intermediate transplant program. Cullers were used for this transplant; however, numbers per bushel are similar to survey numbers 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 ≥2.5″ and these animals are converted to bushels using the 265 animal/bu conversion. Percentiles for the very-low-mortality and low-mortality beds use the exploitation reference points for the medium-mortality transplant beds. Footnotes identify alternatives available under specified conditions.

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	$^{\Psi}40^{th}$	.0127	4,894,750	332	14,743	3,965
	$^{\Psi}50^{th}$	.0188	7,245,772	332	22,502	5,869
	60^{th}	.0233	8,980,132	332	27,889	7,274
Low Mortality	$^{\Sigma}40^{th}$	.0127	4,730,022	419	11,289	3,509
	50^{th}	.0188	7,001,923	419	16,711	5,195
	60^{th}	.0233	8,677,914	419	20,711	6,426
Very Low Mortality	Closed					

$^{\Psi}$Recommended with the proviso that no more than 50% of the recommended number be taken from Middle

$^{\Sigma}$Recommended if resampling in April finds no significant increase in mortality relative to the 2011 survey.

§NA: not applicable to this reference point.

Figure 1. Abundance of market-size (≥2.5″) oysters, excluding the very-low-mortality beds.

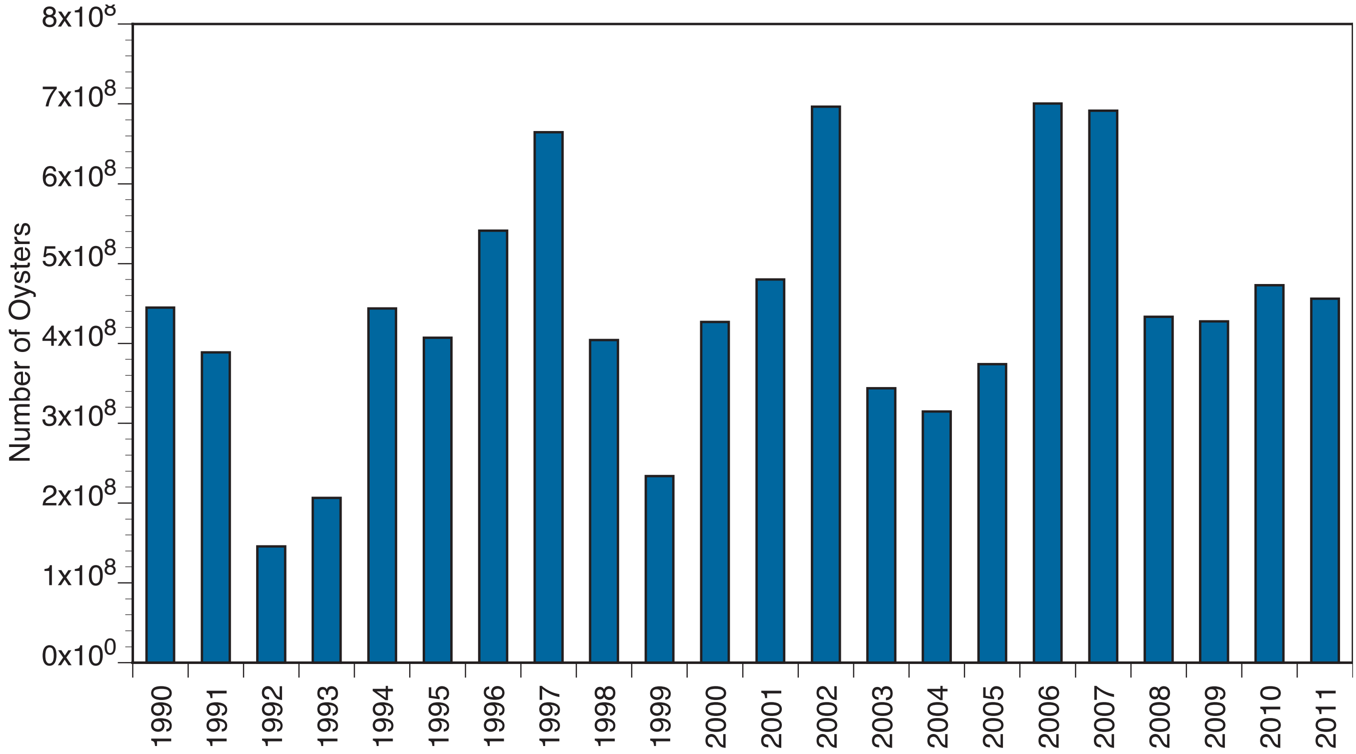


Figure 2. Net submarket surplus for the entire stock from a retrospective analysis of survey indices and landings. Submarket surplus was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous years survey. This provides high and low bounds for the estimates. Left column: green indicates that net submarket surplus 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	Pos-Neg Method	Average Method
2005		5.67
2006		5.25
2007		5.70
2008		5.75
2009		5.36
2010		4.65
2011		5.22

Figure 3. The percentage of total mortality attributable to fishing as opposed to natural mortality for animals $\geq 2.5''$ in size.

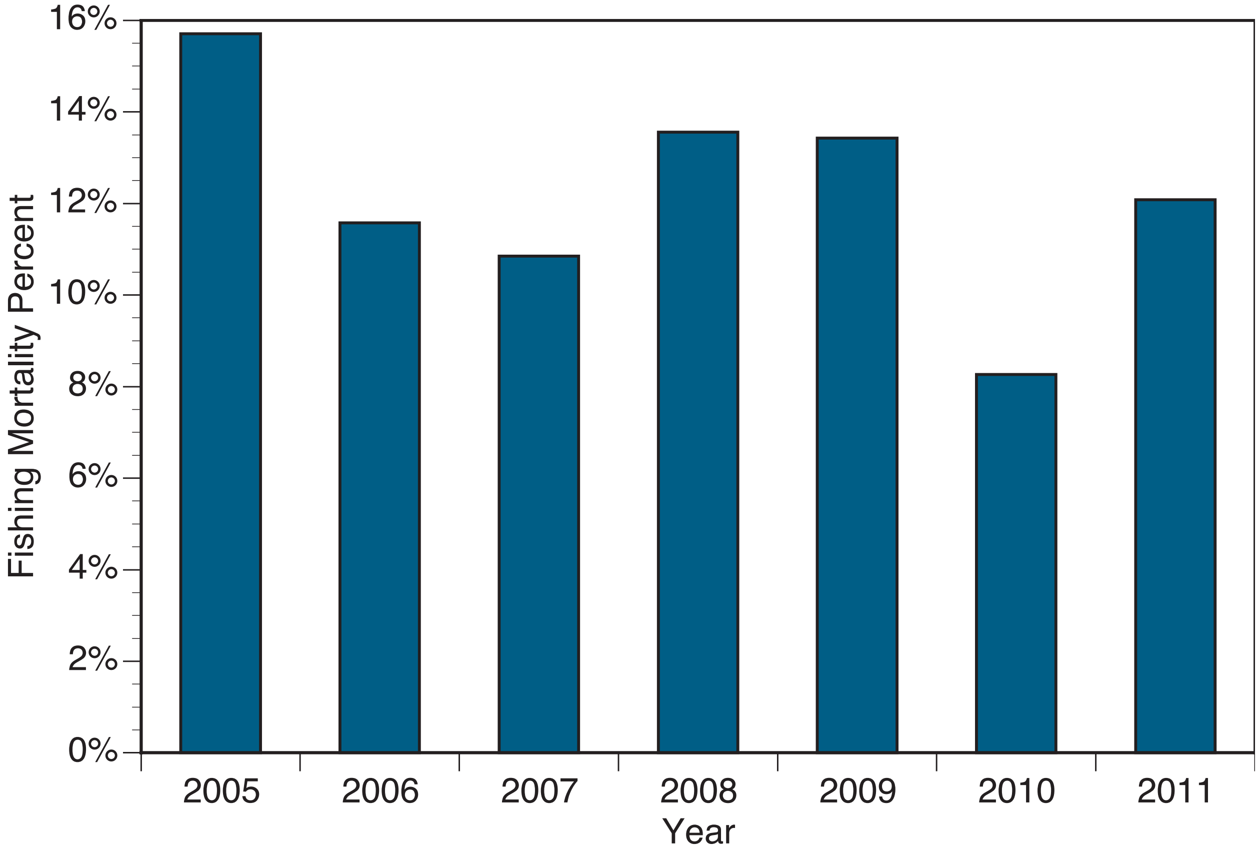


Figure 4. Summary status of the stock for 2011. Lime green indicates variables judged to be above average relative to the 1989-2011 (or 1990-2011) time period or having an improving trend relative to the previous year or to the previous five-year median. Orange indicates variables judged to be below average relative to the 1989-2011 (or 1990-2011) time period or having a degrading trend relative to the previous year or the previous five-year median. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2011 (or 1990-2011) 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 1989-2011 (or 1990-2011) time series. The 2006-2010 median identifies comparisons between the 2011 value and the 5-yr median value from 2006-2010.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.12	0.17	0.18	0.34	0.12	0.07
Fraction of Stock (No Very Low)	Not Incl.	0.20	0.20	0.39	0.13	0.08
Total Abundance						
2011 Percentile	Not Incl.	0.33	0.63	0.60	0.85	0.20
2006-2010 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Increasing	Increasing	Increasing	Increasing	Decreasing
Spawning Stock Biomass						
2011 Percentile	Not Incl.	0.11	0.21	0.30	0.71	0.08
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Decreasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Increasing	Decreasing
Market Abundance						
2011 Percentile	Not Incl.	0.52	0.81	0.67	0.86	0.29
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Increasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Decreasing	Increasing	Decreasing	Increasing	Decreasing
Recruitment						
2011 Percentile	Not Incl.	0.15	0.33	0.46	0.41	0.63
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Increasing	Decreasing	Increasing
2010-2011 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Increasing
Spat per Adult						
2011 Ratio	0.05	0.10	0.22	0.27	0.31	3.03
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Decreasing	Decreasing	Increasing
2011 Percentile	Not Incl.	0.24	0.38	0.41	0.20	0.85
Small Oys (fract.<2.5")	0.91	0.80	0.78	0.73	0.80	0.68
2011 Percentile	Not Incl.	0.43	0.52	0.48	0.67	0.38
2006-2010 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
Dermo Infection Status						
Weighted Prevalence	0.30	0.20	0.70	1.50	1.60	1.50
2010-2011 Trend	Increasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Mortality Rate	0.47	0.21	0.15	0.14	0.14	0.24
2011 Percentile	Not Incl.	1.00	0.50	0.38	0.38	0.41
2006-2010 Median	Not Incl.	Increasing	Decreasing	Decreasing	Decreasing	Increasing
2010-2011 Trend	Increasing	Increasing	Decreasing	Decreasing	Increasing	Increasing
Abundance Position vs						
Target	Below	Below	Above	Below	Above	Below
Threshold	Above	Above	Above	Above	Above	Below
SSB Position vs						
Target	Below	Below	Below	Below	Above	Below
Threshold	Below	Near	Above	Above	Above	Below
Market Abundance vs						
Target	Below	Above	Above	Above	Above	Below
Threshold	Above	Above	Above	Above	Above	Above
Surplus Production						
50^{th} percentile mortality	Positive	Positive	Positive	Positive	Positive	Positive
75^{th} percentile mortality	Positive	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; medium mortality transplant: Middle, Upper Middle, Sea Breeze; 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.

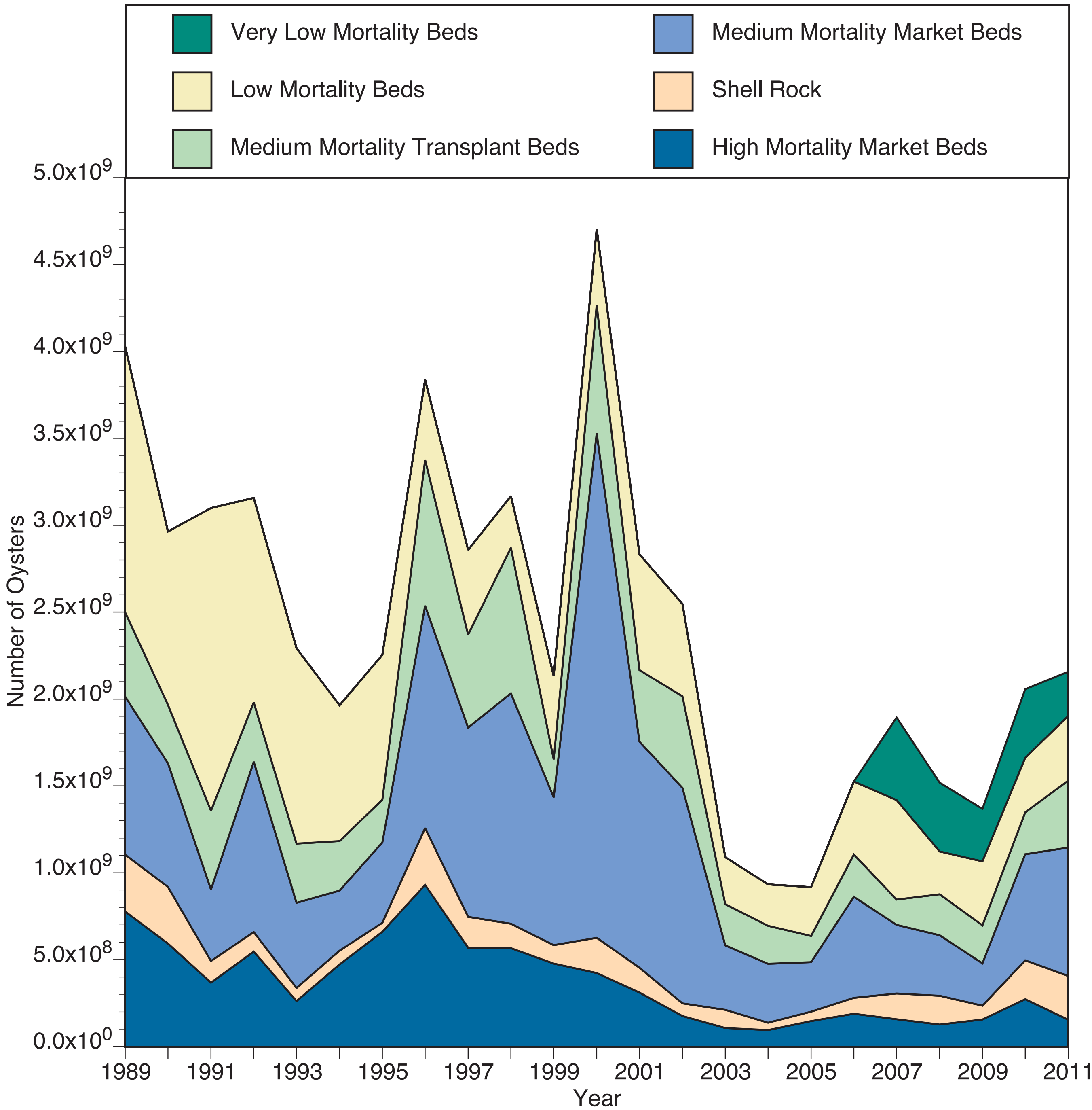


Figure 6. Position of the oyster stock in 2006-2011 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 (1990-2005) time period.

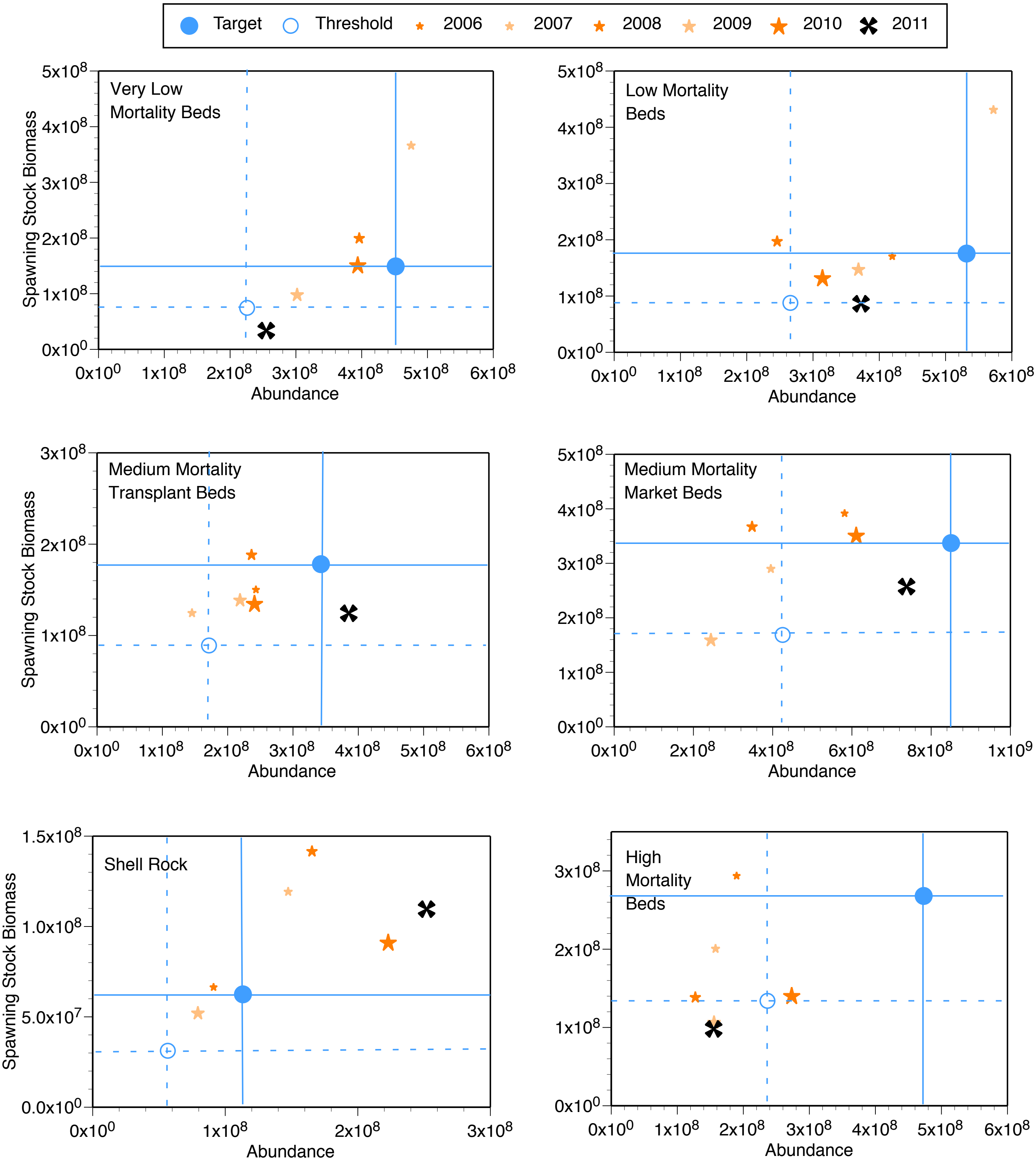


Figure 7. Number of spat recruiting per adult for each bay region and for the stock as a whole, for the 1989-2011 time period. Bed distributions by bay region are given in Figure 5.

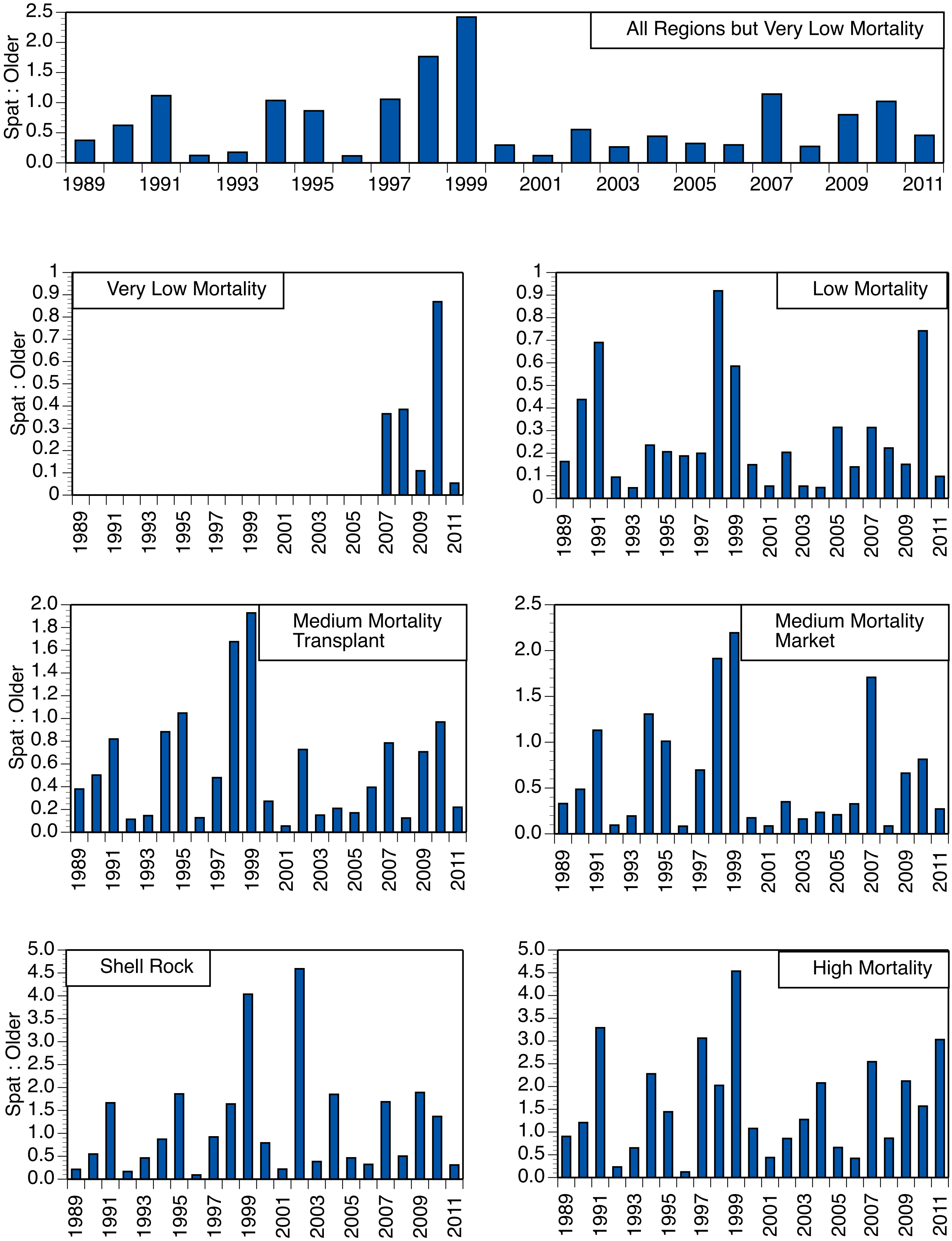


Figure 8. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 5. No data are available for the very-low-mortality beds prior to 2007.

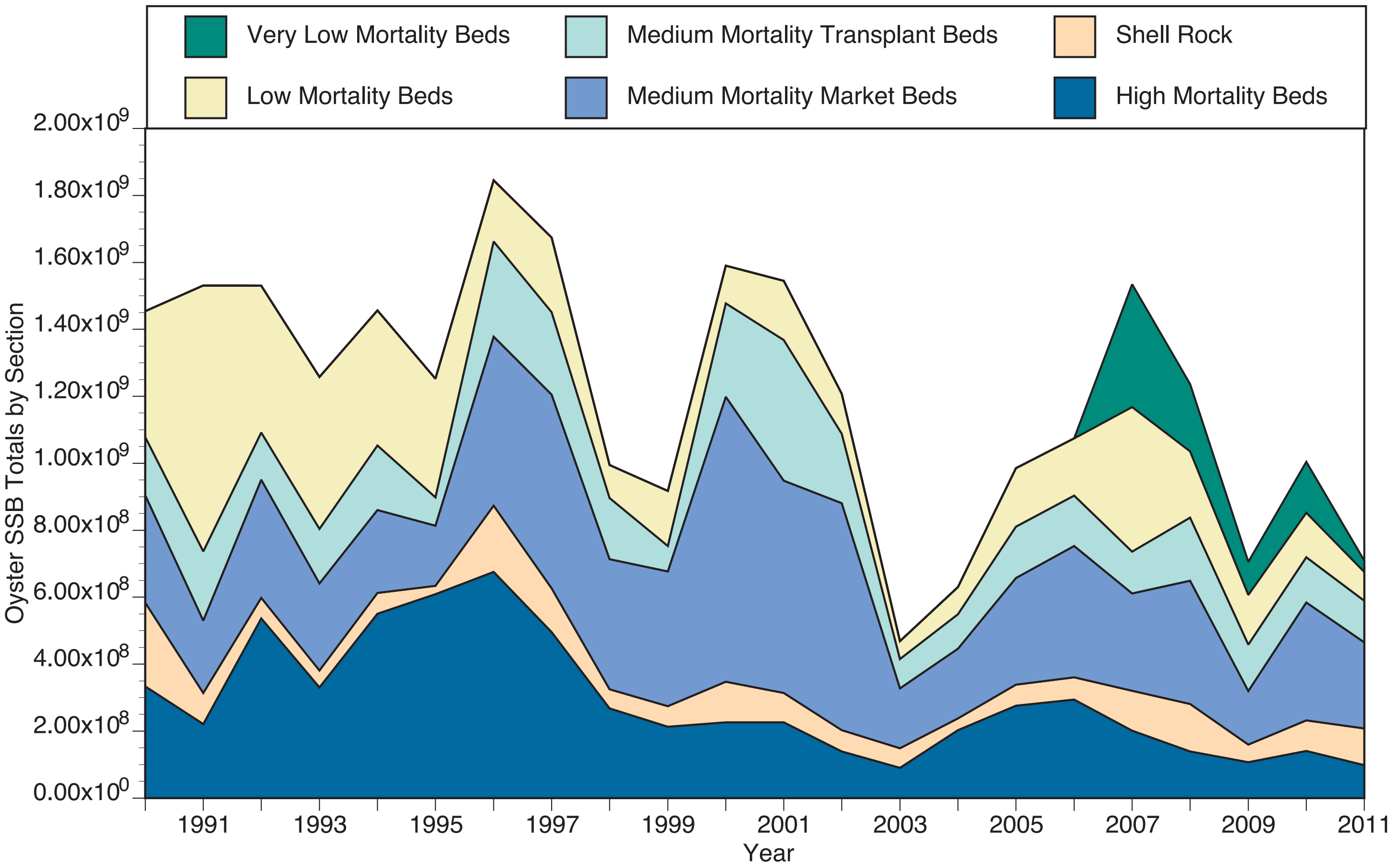


Figure 9. Position of the oyster stock in 2006-2011 with respect to market abundance ($\geq 2.5''$) and abundance targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989-2005 time period. The threshold is taken as half these values.

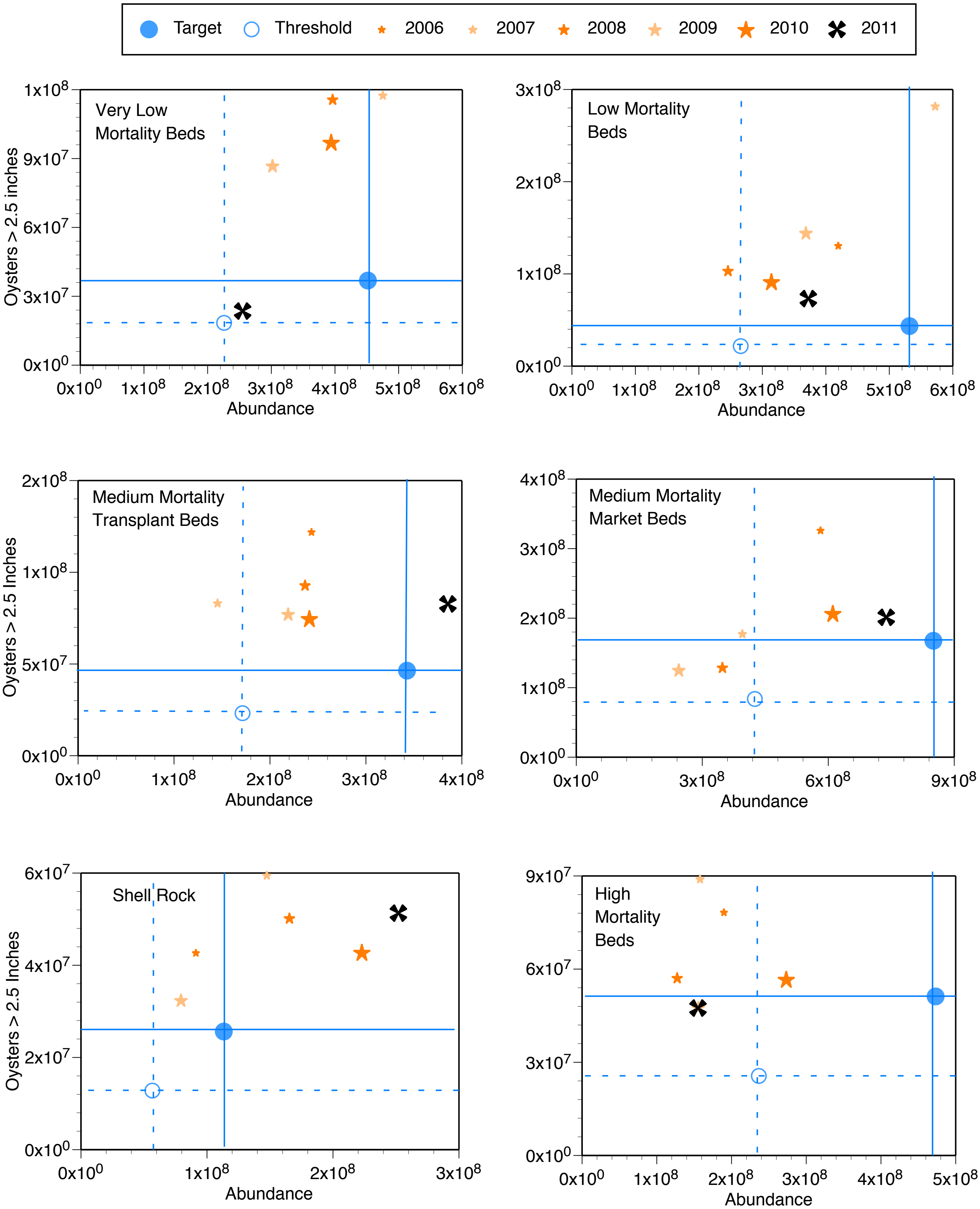


Figure 10. Fishing mortality rates by bay region during the 1989-2011 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 5. Negative numbers indicate bay regions in which the addition of animals by 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.

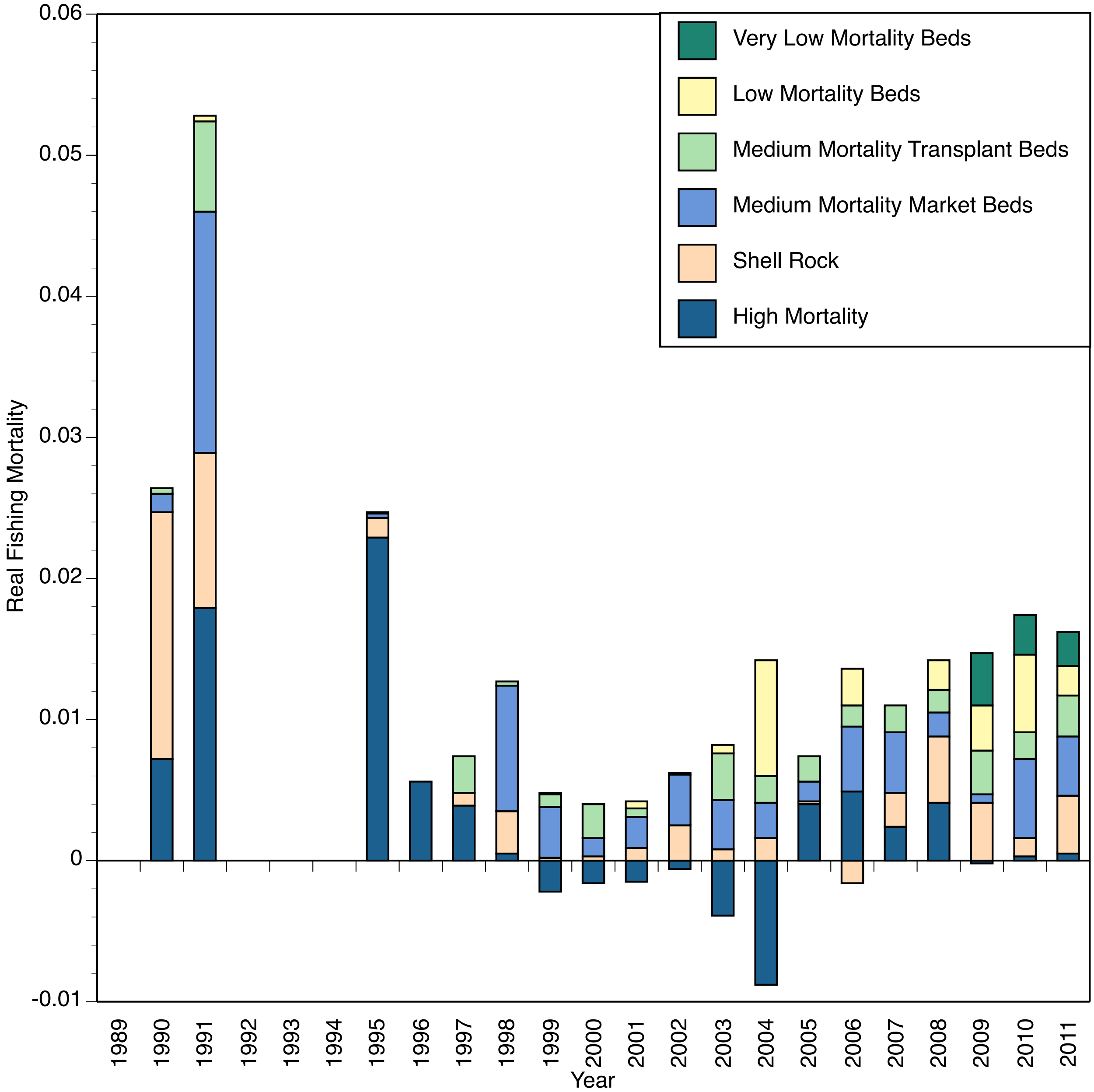
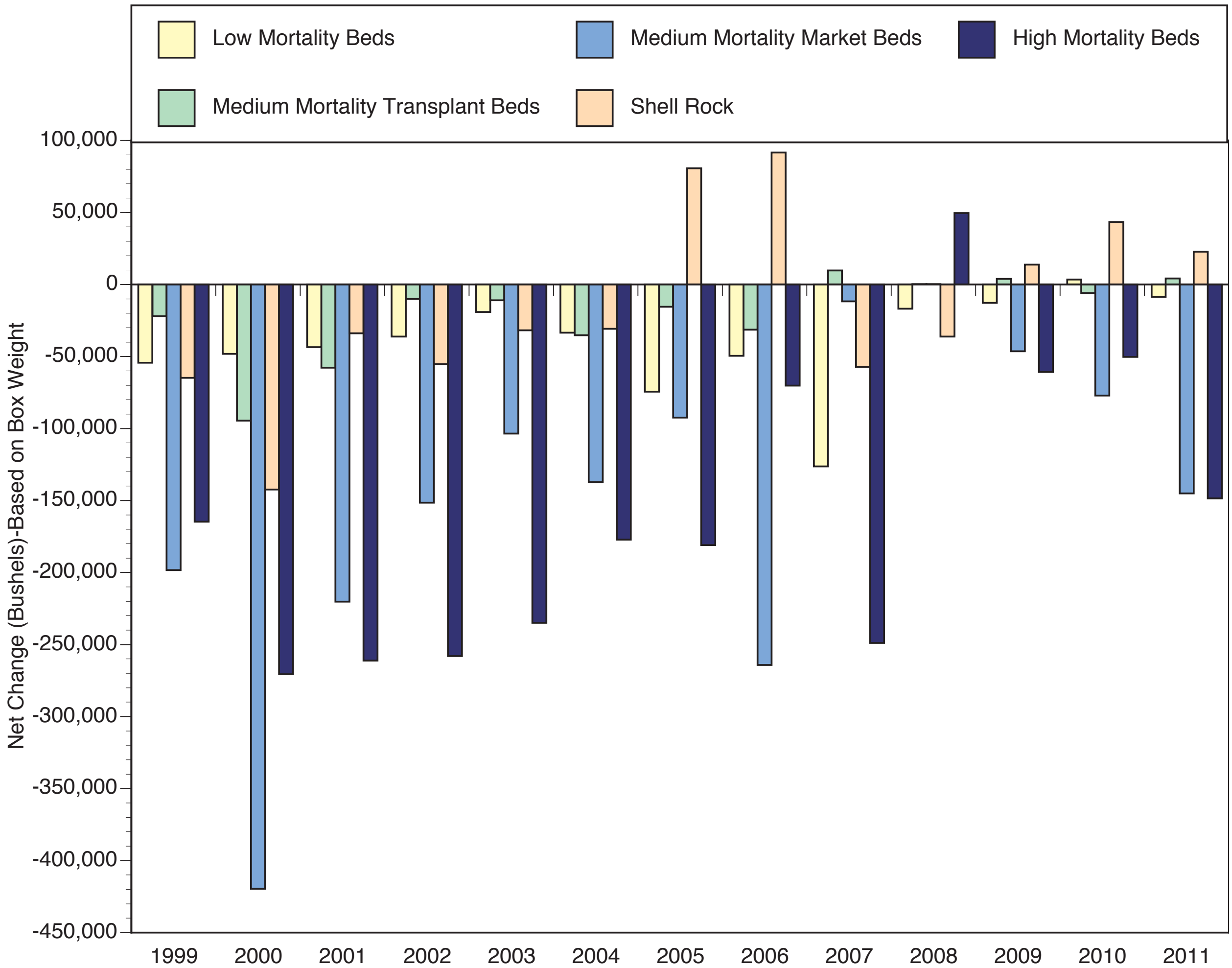


Figure 11. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2011. Positive values reflect the addition of shell through shell planting to offset shell loss. Bed groups defined in Figure 5.



Report of the 2012 Stock Assessment Workshop (14^{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

Jason Hearon, New Jersey Department of Environmental Protection
Steve Fegley, University of North Carolina-Chapel Hill
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
Russ Babb, New Jersey Department of Environmental Protection
Selected faculty and staff, Haskin Shellfish Research Laboratory
Oyster Industry Science Steering Committee
Stock Assessment Review Committee

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Status of Stock and Fishery

Historical Overview

The natural oyster beds of the New Jersey portion of Delaware Bay (Figure 1) have been surveyed yearly beginning in 1953. Circa-1989, Dermo became prevalent in the bay. Nearly coincidentally, beginning in 1990, the survey protocol was updated to include the measurement of oysters, thereby permitting calculation of biomass as well as abundance. Throughout this report, except where noted, present-day conditions will be compared to these two periods of time, the 1953-2011 period encompassing the entire survey time series and the 1989-2011 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 1989-2011 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 1989-2011 time series. All size-dependent indices begin in 1990 for reasons indicated previously. Evaluation of fishery exploitation by abundance focuses on the 1997-2011 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 weeks in the latter part of October to early November and has been conducted using a stratified random sampling method. The survey time frame was extended in 2011 to permit sampling of the beds in the uppermost part of the bay as late in the year as possible in order to provide the best assessment of increased mortality due to the flood associated with the passage of Hurricane Irene and Tropical Storm Lee. Each bed is divided into 0.2-min latitude $\times$ 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 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,

[‡] 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.

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 port sampling 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 port sampling program to reconstruct the 1996-2003 exploitation rates.

Through 2004, most beds were sampled yearly; however a selection of minor beds was 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 rotating schedule (Table 1). For this assessment, the strata for Vexton, Beadons, and Middle have been updated from 2010 based on the 2011 re-survey of these three 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

• 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.

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).

A comparison of the Middle, Beadons, and Vexton grid systems prior to the 2011 re-survey (Figure 3) with the revised grid system after the 2011 re-survey (Figure 4) 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 Beadons, but also for Middle (Figure 5). In all three cases, a considerable number of grids were re-assigned to low quality. As a consequence, the total number of grids in the high-quality and medium-quality strata declined, and particularly so on Beadons and Vexton. Beadons was characterized by an extreme degree of patchiness. Using the 48% and 50% rule would have retained only 6 grids in the survey for this bed. This was caused by the very high abundances on three grids due to an unusually high recruitment event on these three grids in 2010. Accordingly, two additional grids were retained in the survey strata to expand the bed footprint beyond the standard 98% (Figure 2).

For Middle, three medium-quality grids were redesignated high quality, and five low-quality grids were redesignated medium quality. Eight high-quality grids were redesignated medium quality, eight medium-quality grids were redesignated low quality, and one high-quality grid was redesignated low quality. Thus a total of 25 of the 51 grids changed designations. Figure 5 shows that most grids increasing in quality were on the southern side of the bed. Most grids declining in quality were on the northern and western bed region. The number of low-quality grids increased by four. The number of high-quality grids decreased by six. The number of medium-quality grids increased by two.

For Beadons, one medium-quality grid was redesignated high quality, one high quality grid was redesignated low quality, and two high-quality grids were redesignated medium quality. One low-quality grid was redesignated medium quality and fifteen medium-quality grids were redesignated low quality. Thus, 20 of the 38 grids changed designation. The number of low-quality grids increased by fifteen, the number of medium-quality grids decreased by thirteen and the number of high-quality grids decreased by two. Overall, the bed template was reduced to a core group of inshore grids

For Vexton, one medium-quality grid was redesignated high quality and two high-quality grids were redesignated medium quality. Two low-quality grids were redesignated medium quality and nine medium-quality grids were redesignated low quality. Thus, 14 of the 47 grids changed designation. The number of low-quality grids increased by thirteen, the number of medium-quality grids decreased by six and the number of high-quality grids decreased by one. Overall, the bed template was reduced to a core group of grids south and offshore of Beadons.

The Fall 2011 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 24 to November 22 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 2011 was 158 grids, a value comparable to 2010. These included 12 transplant grids selectively sampled because they were sites of 2009, 2010, and 2011 shell plants or 2011 intermediate transplants.

Evaluation of 2011 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 2010 survey using the equations of Powell et al. (2007)[∇] estimated a value of q for total oysters for the upbay region as 11.85 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 6.74 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 2011 survey are within the envelope of previous estimates for the upbay and downbay beds. The upward trend overall suggests a possible decrease in dredge efficiency that, if true, would bias low the abundance estimates from the 2011 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 bed regions. Six bed regions are referred to throughout this report: the very-low-mortality beds, the low-mortality beds, the medium-mortality transplant beds, the medium-mortality market beds, Shell Rock, and the high-mortality beds. Beds assigned to these regions are identified in Figure 7. The bed regions are distinguished by long-term trends in natural mortality rate. The medium-mortality bed region is subdivided into two groups according to area management application. These subdivisions identify beds used for direct market (along with the high mortality

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

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

beds) and beds used for intermediate transplant (along with the low-mortality and very-low-mortality beds). In addition, Shell Rock, which otherwise would qualify as a medium-mortality bed, is retained separate from the remaining medium-mortality market beds due to its consistent high productivity. In previous reports, all stock status data for the medium-mortality beds were compiled with Sea Breeze assigned to the market, rather than the transplant, group. However, beginning in SAW-12, as discussed subsequently, management advice was provided based on the assumption that Sea Breeze would be used as a transplant, rather than a direct-market, bed. As a consequence, in this document, all time series for the medium-mortality region have been reconstituted such that Sea Breeze is now included in the transplant category, rather than the market category.

Throughout this report, the quantitative point estimates 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, 2003, 2005, and 2006. The differential in dredge efficiency between the upper and lower beds was retained in all cases (Table 3).

Throughout this report, 'oyster' refers to all animals ≥ 20 mm. Animals <20 mm are referred to as 'spat'. Adult oysters are animals ≥ 35 mm. Calculations of spawning stock biomass (SSB) are based on this size class and were derived using bed-specific and year-specific regressions between dry weight (g) and shell length (mm) to convert size to biomass. Market-size animals are divided into animals ≥ 76 mm and animals ≥ 63.5 mm, but <76 mm. These two size categories are based on 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 ≥ 63.5 mm and the historical use of the 76-mm boundary to define a market oyster. In 2011, 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

[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.

depending on yearly growth increment and analytical goals as indicated.

A summary of the per-sampled-grid dataset providing the 2011 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, 2011 abundance, bay-wide, was significantly higher than many of the past years in the first vicennial of the 21^{st} century and most years in the 1990s (Table 5). The bay-wide average number of 199 oysters bu^{-1} in 2011 fell well above the 1990-2011 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 through 2011 (Figures 7 and 8). The 2011 abundance of 1,902,971,520 was distinctly higher than any year since 2002. Including the very-low-mortality beds raises the total to 2,157,938,432 (Figures 7 and 8). The time series of abundance, including the very-low-mortality beds, cannot be reconstructed prior to 2007; however, of the last five years, the 2011 abundance level is the highest. Abundance in 2011 fell at the 28^{th} percentile of the 1953-2011 time series and the 38^{th} percentile post-1988, so abundance remains well below historical mean values (Table 6).

Most (59.0%) (52.1% including the very-low-mortality beds) of the oysters were on the medium-mortality beds (Ship John, Cohansey, Sea Breeze, Middle, Upper Middle) (Figures 9 and 10), a proportion distinctly higher than the 51.3% (41.4% including the very-low-mortality beds) recorded in 2010, due primarily to a decrease in oyster abundance at both ends of the salinity range. Excluding the very-low-mortality beds, the distribution of oysters among bed regions is similar to most years post-1995. Including the very-low-mortality beds, however, the distribution is markedly changed from 2007-2010. Examination of the fraction of oysters on the medium-mortality beds shows that the period beginning in 1996 is unique in the 59-year time series in continual above-median proportions of oysters on these beds (Figure 11). This tradition continued in 2011. Within this bed region, 65.7% of the oyster stock was on the two market beds, Ship John and Cohansey. 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 42^{nd} percentile (transplant beds) and 52^{nd} percentile (market beds) of the 59-yr time series, and distinctly higher, at the 63^{rd} percentile (transplant) and 60^{th} percentile (market), for the post-1988 era (Table 6). The number of oysters per bushel deviated significantly from seven of the remaining years in the 1990-2011 time series, all but one in the mid 2000s (Table 7). Each of these averaged significantly lower than the 2011 value of 315 oysters bu^{-1}.

Abundance in 2011 on the low-mortality beds rose modestly from 2010, but remained consistent with most years since 2001 at a level that was low relative to the historical record; the 16^{th} percentile for the 1953-2011 time series and the 33^{rd} percentile for the post-1988 era (Table 6). The low-mortality beds contributed

19.6% of the stock in 2011 (17.3% including the very-low-mortality beds), about the same as in 2010, but much lower than the preceding ten years (Figure 9). However, much of this shift was due to increased abundance downbay, rather than a decline in abundance in this bed region. The number of oysters per bushel, 330, differed significantly only from four years in the early 1990s within the 1990-2011 time series (Table 8).

Abundance was distinctly lower in 2011 on the high-mortality beds than in 2010, consistent with the 2003-2009 time period, but distinctly lower than most years prior to 2002. The 2010 abundance of oysters <2.5″ was unusually high. The high value observed in 2010 may be a survey artifact, but it seems more likely that a large number of the small oysters observed in 2010 did not survive. The entire high-mortality bed region contributed 8.2% to the total stock (7.2% including the very-low-mortality beds), a value lower than observed since 2002, and not seen since 1986 (Figure 9). Abundance on the high-mortality beds ranked at the 13^{th} and 20^{th} percentiles, respectively, for the 59-year time series and the time series post-1988 (Table 6). The number of oysters per bushel of 97 differed significantly from only one year in the 1990-2011 time series, 1996 (Table 9).

Abundance in 2011 rose modestly from 2010 on Shell Rock, reaching a value substantively higher than all but a few years since 1984. Abundance in 2011 neared the highest value observed in the post-1988 era. The increase is consistent with increases observed on the medium-mortality beds, suggesting that survey bias is not a likely explanation for the observed abundance increase. Oyster abundance has increased substantively over the last three years in the central portion of the salinity range. Shell Rock contributed 13.2% of the stock in 2011 (10.7% including the very-low-mortality beds) (Figure 9). Abundance on Shell Rock ranked at the 64^{th} and 85^{th} percentiles, respectively, for the 59-year time series and the time series post-1988 (Table 6).

The very-low-mortality beds contained 19.6% of the stock in 2011. Insufficient data are available to generate percentile comparisons to earlier years, nor can long-term trends be evaluated at this time. However, this value represented the lowest value in the 2007-2011 time series and less than half the contribution that this bed region made to the total stock in 2008.

Spawning Stock Biomass (SSB)

Spawning stock biomass remained near the lowest value observed in the 1990-2011 time series in 2011, falling near the value observed in 2009. Only 2003 and 2004 were lower. The value continues a trend towards decreasing SSB since 2007 (Figure 12). SSB in 2011 was at the 16^{th} percentile of the 1990-2011 time series (Table 6). SSB declined in all bay regions except for Shell Rock, with greatest declines at the extremes of the salinity range (Figure 12). For the low-mortality beds, the medium-mortality beds, transplant and market, Shell Rock, and the high-mortality beds, the percentiles were the 11^{th}, 21^{th}, 30^{th}, 71^{st}, and 8^{th}, respectively (Table 6).

SSB is highest on the medium-mortality beds in most years. In 2011, these beds contributed 56.4% of the stock's SSB, nearly identical to 2010 (Figure 13). SSB was more concentrated on the medium-mortality beds in 2011 than during the 2004-2009 period, and higher than routinely observed except for the 1996-2003 time period. The low-mortality beds contributed an additional 12.3%. Shell Rock contributed 16.2% and the high-mortality beds, 14.5%. Including the very-low-mortality beds, the fractions of SSB contributed by the five bay regions are 4.8% (very-low-mortality), 12.2% (low-mortality), 53.8% (medium-mortality), 15.4% (Shell Rock), and 13.8% (high-mortality). These regional fractions are nearly identical to those observed in 2010, except for a large, 69%, decline on the very-low-mortality beds. This decline masked substantive changes in other bay regions. SSB declined by 36% on the low-mortality beds, by 22% on the medium-mortality beds and by 30% on the high-mortality beds. SSB rose only on Shell Rock. Thus, SSB declined by about 30% over large regions of the bay. Perusal of the last 10 years of the time series shows that SSB is relatively unchanged on the medium-mortality beds, has risen on Shell Rock, and has declined precipitously at the extremes of the salinity range. As a consequence, SSB is now concentrated in a relatively small region of the entire bay.

Oyster Size Frequency

Perusal of the 1990-2011 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 2000 (Figure 14). The fraction of animals below 2.5″ remained low thereafter until 2010, when the proportion of small individuals rose to values only slightly lower than routinely observed through most of the 1990s. In 2011, this fraction increased modestly over 2010. In 2011, including the very-low-mortality beds, 77.7% of the animals were below 2.5″ and 9.6% of the animals were ≥ 3″ in size. Excluding the very-low-mortality beds, animals below 2.5″ contributed a similar 76.0% of the stock; 10.6% of the stock exceeded 3″ (Figure 14). The number of animals <2.5″ in 2011 incremented from 2010 and nearly doubled from the 2009 value, 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 15). 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 (HSRL, 2011[θ]). The increase in abundance in 2010-2011 of animals below 2.5″, however, is consistent with the high recruitment events of 2009 and 2010. The increase in the fraction of animals below 2.5″ is consistent with the same plus the decrease in abundance of animals >3″ in size.

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 1990-2011 time period. The recruitment event in 2010 was unusual in being relatively robust throughout the bay, including the lower-salinity reaches. The 2011 increase in abundance of small animals (<2.5″) was noteworthy

[θ] HSRL. 2011. *Report of the 2011 Stock Assessment Workshop (13th SAW) for the New Jersey Delaware Bay Oyster Beds.* 155 pp.

on the low-mortality and medium-mortality beds, consistent with the 2009-2010 recruitment trends, and more modest on Shell Rock (Figure 16). Animals of $\geq$2.5″, however, increased substantively on Shell Rock, consistent with the higher growth rates that would have moved animals from the 2009 recruitment event more rapidly into market size than farther upbay. The number of small animals dropped at the two salinity extremes (Figure 16). The drop on the very-low-mortality beds, 22%, is due to a freshwater mortality event to be discussed subsequently. The drop on the high-mortality beds, 53%, may be partially due to rapid growth; however, the limited impact on the larger size classes suggests a high level of juvenile mortality in this bed region over 2011.

Small oysters accounted for 80.3% of the animals on the low-mortality beds, a fraction higher than recent years, but consistent with the pre-2006 time period (Figure 17). This increase in small oysters, however, was due in part to a relatively high mortality for the larger size classes rather than solely to increased abundance in this size class. Nearly 75% (transplant beds, 78.5%; market beds, 72.7%) on the medium-mortality beds were $\leq$2.5″ in size. This proportion is also high relative to recent years (2002-2010) and more representative of historical levels set in the 1990s through 2001 that routinely exceeded 70%. Unlike further upbay, the proportional increase in small oysters on the medium-mortality beds is not due to high mortality in the market sizes, but rather to an increase in the number of small oysters. Small oysters contributed 79.6% of the stock for Shell Rock, a value exceeding most previous years including the 1990s but very similar to 2010, and 68.4% for the high-mortality beds, a value consistent with previous years except for the low-recruitment years of the central 2000s (Figure 17).

Thus, on no bed area did marketable oysters contribute the majority of the stock. The time period since 2002 until 2010, was 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 began a dramatic change in size frequency from the previous decade that was enhanced considerably by events that occurred in 2011. In all bed areas, the 2011 size-frequency distribution was more similar to the small-oyster-dominated size frequency of the 1990s than to the size-frequency distribution that characterized most of the 2000s decade. This trend was produced primarily by an increase in the number of small animals in the central regions of the bay (Middle to Shell Rock), exacerbated in some cases by market-size mortality. At the salinity extremes, market-size mortality played a much bigger role.

Of the oysters $\geq$ 2.5″, 42.9% were $\geq$ 3″ in size (Figure 18). The proportion of small markets (<3″) relative to larger markets remained relatively stable from 2003 through this year, but was much higher earlier in the time series. Thus, the 2010-2011 shift in size frequency is primarily driven by a change in the relative proportion of animals < 2.5″ and $\geq$ 2.5″, rather than a change in the proportion of either of the marketable size classes. Large markets made up the larger percentage on the high-mortality beds: 54.3%. Large markets were relatively less abundant than small markets upbay, with the disparity incrementing considerably above the medium-mortality beds. The proportion of large markets for Shell Rock was 44.5%, for the medium-mortality market beds, 46.8%, and for the medium-mortality transplant beds, 42.2%. For the low-mortality beds, the proportion of large markets was 30.9% and for the very-low-mortality beds, 22.3%. In all six cases, this proportion decreased from 2010, though not precipitously. In 2010, in all bay regions except the medium-mortality transplant beds, the fraction of marketable animals >3″ was near historical highs and in this last bed region, the fraction exceeded values for all years except 2005-2009. Despite the decreased proportion in 2011, the fraction of marketable animals >3″ still routinely exceeded, by a substantial margin, values observed in the 1990s.

The number of animals of market size (≥2.5″) declined modestly in 2011 (Figure 19). Animals ≥2.5″ contributed 22.3% of the stock (24.0% excluding the very-low-mortality beds) in 2011, down from a value of 37.5% (40.0% excluding the very-low-mortality beds) in 2009, a value at the 67^{th} percentile of the 1990-2011 time series, excluding the very-low-mortality beds (Table 6, Figure 14). This decline is a considerable correction from the 2002-2009 time period when values routinely exceeded 35% downbay of the very-low-mortality beds. The abundance of these larger animals remained relatively unchanged downbay of the low-mortality beds in 2011, with three-year trends suggesting an increase in abundance on the medium-mortality market beds. Declines were observed on the low-mortality beds and very-low-mortality beds (Figure 20). The precipitous decline on the very-low-mortality beds reached 76%. By percentile, the number of marketable animals fell at the 52^{nd}, 81^{st}, 67^{th}, 86^{th}, and 29^{th} percentiles for the low-mortality beds, medium-mortality transplant beds, medium-mortality market beds, Shell Rock, and high-mortality beds, respectively, for the 1990-2011 time series (Table 6).

Oyster Condition and Growth

Condition index was the lowest recorded in the 1990-2011 time series in 2011 (Figure 21). Condition was just above or just below the 2010 value and relatively representative of some preceding years on Shell Rock and the high-mortality beds, although the value was well below average (Figure 22). The expected decline in condition upbay, observed in many years, was dramatic in 2011, however. Values were at or near historical lows in all bay regions upbay of Shell Rock. Low condition can be expected to lower SSB; this is the result observed (Figure 12). Thus, the decline in SSB noted on the high-mortality beds and upbay of Shell Rock is in part due to a drop in market-size abundance upbay and in part due to a drop in 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, 0.175 yr^{-1}, 0.2 yr; for the medium-mortality beds (data from Middle and Cohansey), 125 mm, 0.23 yr^{-1}, 0.2 yr; for Shell Rock, 125 mm, 0.25 yr^{-1}, 0.2 yr; and for the high-mortality beds (data from New Beds) 140 mm, 0.23 yr^{-1}, 0.2 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,

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

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. In SAW-13, a population dynamics model (DyPoGEn: Powell et al., 2011)[ς] was used 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 suggested that the change in length frequency between the mid-1990s and mid-2000s 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%.

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.

Submarket Surplus

Submarket surplus 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, submarket surplus 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 submarket surplus 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)[⊕]. Submarket surplus 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).

[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.

[⊕] 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.

Bay-wide submarket surplus projections for 2012 are positive, but moderately lower than in 2011 (Table 11). Submarket surplus was projected to be higher from the medium-mortality market beds downbay, but lower upbay, with a significant decline on the very-low-mortality, relative to 2011. However, the projection remains strongly positive. The projection for the very-low-mortality beds was 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 2007-2011 time series as a surrogate for the 50^{th} and 75^{th} percentile rate used for the remaining bed regions.

Submarket surplus 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 submarket surplus rates upbay led to the abandonment of the original submarket surplus reference point used in the early SAWs and replacement with the present exploitation-based reference point system[κ].

A retrospective analysis began with SAW-13. The purpose of this analysis is to evaluate how the implemented management measures for the year compared with the goal of sustainability of the stock. The retrospective examination is in two parts. First, we compare the realized submarket surplus 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 submarket surplus. Realized submarket surplus is calculated as:

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

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 Fall 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

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

where times t and $t+1$ represent consecutive Fall survey indices or, for landings, the yearly tally between surveys. A negative net submarket surplus would indicate landings higher than a sustainable level for the stock for that year under the assumed goal. A positive net submarket surplus 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, submarket surplus, as defined in this analysis is equivalent to the

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

number of animals that will recruit into the ≥76-mm 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 examination 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 submarket surplus 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 submarket surplus projections.

Results of the comparison between predicted (e.g., Table 11) and realized submarket surplus are found in Figure 23. Green shades in the table in Figure 23 indicate cases were the lower and upper bounds to the submarket surplus estimate were positive, indicating forgone yield. Red shades in the table in Figure 23 indicate cases were the lower and upper bounds to the submarket surplus 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. Submarket surplus projections frequently overestimate the coming year's actual submarket surplus. 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. Projections made for SAW-13 were relatively accurate based on this analysis for the medium-mortality market beds, Shell Rock, and the high-mortality beds, using the 75^{th} percentile of mortality rate. SAW-13 projections overestimated submarket surplus upbay of this region. Using the 50^{th} percentile yielded similar results, except for the medium-mortality market beds which were less accurately predicted.

To examine the outcomes of management policies, two additional sources of uncertainty are particularly important to evaluate; uncertainties 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 40% change in the Bertalanffy k parameter downbay of Shell Rock. 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 24 indicate cases where the estimate of net submarket surplus 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 24-25 indicate cases where the estimate of net submarket surplus 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 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 (Figure 25). No case occurred upbay of the medium-mortality beds and in only one case on Shell Rock prior to 2011. 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. 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, a view consistent with DyPoGEn simulations. In 2011, the pattern diverged. Market-size abundance was not conserved on the very-low-mortality and low-mortality beds for the first time (2008-2011, 2005-2011, respectively). A sustainable condition was observed downbay of these two bed regions. The negative submarket surplus observed on the two uppermost bed regions is primarily a product of the very high natural mortality rate that was present in 2011.

Care should be given to interpreting Figures 24 and 25 based on the uncertainty

[†] Op. cit.

of the survey indices (to be described in a subsequent section) and the uncertainty in the assumptions underlying oyster growth rate.

Recruitment

Recruits were defined as oysters ≤20-mm in size. 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 2010. These shell plants revealed that many spat exceeded 20 mm by early November, 2011 (Figures 26-27). This suggests that the 2011 recruitment index is biased low, particularly for the high-mortality beds.

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. Recruitment in 2011 returned to 2009 levels bay-wide (Figures 28 and 29). However, the spat numbers modestly increased on the high-mortality beds, continuing a four-year trend of increasing recruitment, and declined markedly upbay from 2010. With the exception of the medium-mortality market beds, these upbay regions had spat values distinctly lower than 2009 and in most cases distinctly lower than any year since the mid-2000s. Recruitment on the very-low-mortality beds was the lowest recorded in the short 2007-2011 time series, with recruitment on the low-mortality beds lower than any year since 2004. These values are biased low, at least for Shell Rock downbay, as an estimated 5% (Shell Rock) to 32% (Bennies Sand) of the spat observed this year were greater than 20 mm long (Figures 26-27). These fractions are considerably lower than the 40-60% value in the same region observed in 2010. 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. 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 below the long-term average of 90 for the 1990-2011 time series (Table 5). However, only four years were significantly higher than the 2011 value of 77 spat bu^{-1}, all in the 1990s (Table 5). The same metric by bay region reveals that the number of spat per bushel on the high-mortality beds, 111, was not significantly different from the 1990-2011 mean, and significantly different from only two years (Table 9). For the medium-mortality beds, the number of spat per bushel of 59 was significantly lower than five years in the 1990s, but not significantly different from the 1990-2011 mean (Table 7). A more extreme trend was observed on the low-mortality beds (Table 8), in which the 2011 value of 22 spat bu^{-1}, though not the lowest value on record, was significantly lower than four previous years, and well below the 1990-2011 mean of 76. Thus, 2011 was characterized by a strong downbay gradient in recruitment, with recruitment on the high-mortality beds near the 1990-2011 mean, but with recruitment declining upbay, so that recruitment on the low-mortality beds was well below the 1990-2011 mean.

The 2011 spat settlement ranked at the 33^{rd} percentile for the 1953-2011 time series and at the 46^{th} percentile post-1988 (Table 6). Recruitment estimated quantitatively for each bay region fell at the 13^{th}, 25^{th}, 36^{th}, 42^{nd}, and 55^{th} percentiles of the 1953-2011 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 1989-2011 time series, in the same order, were 15^{th}, 33^{rd}, 46^{th}, 41^{st}, and 63^{rd} (Table 6). The upbay-downbay gradient in recruitment in which recruitment tends to increase downbay, present in most years, was obvious in 2011. However, the trend in recruitment was exaggerated. Not only did the number of recruits decline upbay, but the quality of the recruitment event also declined, such that the recruitment rate was at or above average on the high-mortality beds, but well below average on the medium-mortality beds, and among the worst on record upbay of that region.

The number of spat recruiting per oyster fell at 0.46 in 2011 (Figure 30), a value at the 42^{nd} percentile of the 1953-2011 time series and at the 50^{th} percentile for the 1989-2011 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 2011, this trend was developed in the extreme due to unusually high freshwater inflow and low salinity upbay (see later discussion). The ratio of spat to adult was 3.03 on the high-mortality beds, but then fell to 0.31 on Shell Rock, 0.27 on the medium-mortality market beds, 0.22 on the medium-mortality transplant beds, 0.10 on the low-mortality beds, and 0.05 on the very-low-mortality beds (Figure 31). The respective percentiles for the 1953-2011 time series for the low-mortality, medium-mortality transplant, medium-mortality market, Shell Rock, and high-mortality beds are, respectively: 21^{st}, 28^{th}, 30^{th}, 25^{th}, and 86^{th}. Percentiles were similar for the 1989-2011 time series at 24^{th}, 38^{th}, 41^{st}, 20^{th}, and 85^{th}, respectively (Table 6). Overall, the percentile rankings show that the recruitment event upbay of the high-mortality beds fell well below the long-term mean, while the recruitment event on the high-mortality beds was one of the best ones on record.

Shell planting had a modest impact on the spat-to-adult ratio in 2011, similar to previous years, raising it from 0.46 to 0.49. The modest increase was due to the overall high recruitment on the high-mortality beds, relative to regions upbay and the limited success of the shell plant on Middle, likely as a consequence of the 2011 flood. However, the Shell Rock shell plant raised the spat-to-adult ratio on that bed by one-third (Table 12).

The regional variation in recruitment in 2011, and in most years, is consistent with recent information from coupled larval-hydrodynamic model simulations using ROMS (Regional Ocean Modeling System) and the Dekshenieks et al. larval model$^{\Omega}$.

$^{\Omega}$ Dekshenieks, M.M., E.E. Hofmann and E.N. Powell, 1993: Environmental effects on the growth and development of Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), larvae: a modeling study. *J. Shellfish Res.* 12:241-254; Dekshenieks, M.M., E.E. Hofmann, J.M. Klinck and E.N. Powell, 1996: Modeling the vertical distribution of oyster larvae in response to environmental

Simulated larval success rates show that the salinity gradient in Delaware Bay underpins a downestuary trend in larval success. Larvae produced upbay have less than a 40% chance of settling compared to an 80% chance for larvae produced downbay. Interannual variations in river discharge can modify the success rates, especially when low salinity conditions are extended in space and time. The simulated transport patterns showed that oyster larvae tended to drift downestuary during the spawning season, which is consistent with the reduced upestuary recruitment rate obtained from settlement and recruitment observations (Figure 31). The simulated transport patterns also suggest that the upper bay exports rather than receives larvae, and thus the population is less resilient to extreme events upbay.

A metapopulation implementation of DyPoGEn was parameterized to simulate four populations of oysters in Delaware Bay, the very-low-mortality, low-mortality, medium-mortality, and high-mortality populations. Simulations demonstrate a large difference in the magnitude of neutral allele transfer with changes in population abundance and mortality (on average between 14-25% depending on source population), whereas changes in larval dispersal were not effective in altering genetic connectivity (on average between 1-8%). Simulations also demonstrated large temporal changes in metapopulation connectivity with shifts in genetic sources and sinks occurring between two regimes, the 1970s and 2000s. Although larval dispersal in a sessile marine population is the mechanism for gene transfer among populations, these simulations demonstrate the importance of local dynamics and characteristics of the adult component of the populations in the flow of neutral alleles within a metapopulation. In particular, differential adult mortality rates among populations exert a controlling influence on dispersal of alleles, an outcome of latent consequence for management of marine populations. Of particular note is the downestuary gradient in adult mortality present in most years, though not in 2011, that promotes downestuary transport of genotypes from upbay populations. Simulations suggest that upbay populations act as genetic sources in most years and downbay populations act as genetic sinks (Figure 32). Note in Figure 32 that this has not always been the case. In the 1970s, today's sinks were sources and vice versa.

Recruitment-enhancement Program

Shell-planting was carried out in June-July, 2011. Ocean quahog and surf clam shell were used. Shell was planted in 2011 as follows: Middle 26, 18,000 bu; Shell Rock 11, 50,000 bu; Bennies Sand 11, 50,000 bu (Figure 33).

Total spat were estimated from suction dredge samples. Projections of marketable bushels on the 2011 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 1989-2011 time series. Bushel conversions assume 265 oysters bu^{-1}. 2011 shell plants are expected to provide 68,633 bushels of marketable size in 2014/2015 (Table 13). These oysters both support harvest and contribute to maintenance of abundance. For this reason, the terms 'harvest potential' or 'potential yield' are used hereafter. 2010 shell continued to attract spat

conditions. *Mar. Ecol. Prog. Ser.* 136:97-110.

in 2011. A minimal estimate of year-2 recruitment on this shell results in an estimated 49,893 bushels of marketable size (Table 14).

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 10 years, although a few beds had much higher values, with a median of 7.68 years (Table 15). Half lives for Round Island, 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, because some conversions are poorly known, and because the time series is still relatively short, being of the same order as many of the half-life estimates. Half-lives estimated in 2011 are in the same range to somewhat higher than estimates in 2010, 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 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 five beds with uncertain half lives (Table 15) 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 34). 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 1998-2011 time series versus the 1998-2010 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 2010 and 2011 (SAW-12, SAW-13).

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 34). Years 2008-2010 are the only years in the 1999-2010 time series when at least one estimate was above zero, estimates that suggest that shell balance may have been achieved in those years. For 2011, estimates using

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

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

2011 half-lives return to negative values, with shell loss falling between about 170,000 and 275,000 bushels.

The high-mortality beds, by their acreage and low abundance, contribute about half of the entire shell loss in most years (Figure 35). For the remainder of the bay, shell loss hovered around 150,000 bushels yearly before 2007. From 2007 to 2010, estimates bracket zero, indicating that shell was about in balance over this region in those years. Negative values returned in 2011.

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 36). 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 net gains more frequently since 2004 due to shell planting. The high-mortality beds typically have lost about 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 been less since 2004 due at least in part to the substantial shell planting that occurred downbay of Shell Rock over that time frame. This year, 2011, represents the fourth year in succession when three of the five bed regions were within (or very near) shell balance. In contrast, the medium-mortality market beds and the high-mortality beds demonstrated negative values, 150,000 bushels lost in both cases, and values considerably higher than observed in 2008-2010. The positive balance upbay in 2011 is in part due to the high mortality event of 2011 that resulted in a large shell addition and in part to shell planting on Middle. The negative balance on the high-mortality beds is primarily a function of the large area and low abundance that limits shell input, despite the routinely high natural mortality rates. The negative balance on the medium-mortality market beds is partly a function of an unusually low mortality rate in 2011 limiting shell input, despite the relatively high abundance observed in this region.

Reef Carbonate Model

The shell budget model was expanded to evaluate the carbonate budget for the reef as a whole, not just the surficial cultch. The goal of this exercise was to examine conditions leading to long-term reef accretion and degradation. For Mid-Atlantic estuaries, model simulations suggest that reef accretion only occurs if oyster abundance is near carrying capacity. Simulations further suggest that reef accretion is infeasible for any estuarine reach where Dermo is a controlling influence on population dynamics. Model simulations suggest that reefs with inadequate shell addition 'protect themselves' by limiting the volumetric content of carbonate in the TAZ (taphonomically-active zone). Thus, a dominant process is the transient expansion and contraction of the shell resource, otherwise termed cultch, within the TAZ, rarely expanding enough to generate reef accretion, yet rarely contracting enough to foster erosion of the reef framework. The loss of framework carbonate thusly is curtailed during periods when the surficial shell layer deteriorates. Stasis, a reef neither accreting nor eroding, is a preferred state. Reef recession requires an inordinately unbalanced carbonate budget. Model simulations suggest that attaining maximum sustainable yield and maintaining a biomass capable of supporting sufficient shell production for reef accretion are irreconcilable goals over a large component of the oyster's range. Reef stasis would appear to be the only achievable restoration goal in Mid-Atlantic estuarine reaches where Dermo holds sway.

Simulations of a range of exploitation rates show that exploitation rates much above 5% of the fishable stock per year in Delaware Bay restrict availability of surficial shell and foster reef erosion (Figure 37). In comparison, Gulf of Mexico reefs easily withstand twice that exploitation rate while retaining the prospect of accretion. This is a primary reason why lessons learned from Gulf of Mexico population dynamics are not applicable to the Mid-Atlantic region. These results support the continued reliance on an exploitation rate for the marketable stock below 5% per year in Delaware Bay.

Disease Prevalence and Intensity

Information on Dermo and MSX disease prevalence and infection intensity can be found in the accompanying report from the Dermo monitoring program: Bushek D. 2011. *Delaware Bay New Jersey oyster seedbed monitoring program 2011 status report*, Haskin Shellfish Research Laboratory, Port Norris, NJ.

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 17.9% bay-wide in 2011, excluding the very-low-mortality beds, and 22.1% including them. Excluding the very-low-mortality beds, 2011 mortality was little changed from 2010 (Figure 38). Including the very-low-mortality beds, mortality was substantively increased over 2010, and, in fact, the highest recorded in the 2007-2011 time series. The increment in mortality obtained by including the very-low-mortality beds is counterintuitive of the norm and evidences the high upbay mortality suffered due to high freshwater inflow in 2011. The implications of this event will be considered in a subsequent section. The mortality rate for 2011 was moderate for the 1989-2011 era. but still relatively high for the 59-year time series. Box-count mortality was at the 67^{th} percentile of the 59-yr time series, but only at the 41^{st} percentile post-1988 (Table 6).

Mortality rate in 2011 was typical for the high-mortality beds, relatively high, but not unusually so. Mortality rates were unusually low from Shell Rock upbay to the medium-mortality transplant beds. Mortality rates were extraordinarily high upbay of this region, with the mortality rate on the low-mortality beds being the highest since 1986 and the mortality rate on the very-low-mortality beds being nearly six times higher than the next highest value in the short 2007-2011 time series (Figure 39). The declines in SSB in these last two bed regions in 2011 is in part explained by this mortality event (Figure 12). The mortality rate was 24.2% on the high-mortality beds, 14.5% on Shell Rock, 13.5% on the medium-mortality market beds, 15.3% on

[ℵ] Op. cit.

the medium-mortality transplant beds, 21.3%, on the low-mortality beds, and 46.6% on the very-low-mortality beds.

The high-mortality beds contributed only 8.7% of the total deaths in 2011, 12.0% excluding the very-low-mortality beds. This value is the lowest value since 1987 and one of the lowest on record. The limited contribution of the high-mortality beds in 2011 is not due to a low mortality rate, but due to unusually high mortality rates upbay, plus the lower abundance in this region. Most deaths were contributed by the medium-mortality market beds, 23.2%, 32.0% excluding the very-low-mortality beds, due primarily to the high abundance in this region, as the mortality rate was low. Shell Rock contributed 11.7% of the deaths (8.5% including the very-low mortality beds) and the medium-mortality transplant beds 18.9% (13.7% including the very-low-mortality beds). More than one-quarter of the deaths came from the low-mortality beds (25.4%), excluding the very-low-mortality beds, a value exceeding any value since 1993. The low-mortality beds accounted for 18.4% of the deaths if the very-low-mortality beds are included. The very-low-mortality beds accounted for 27.6% of the deaths in 2011. The upper two bed regions accounted for an astonishing 45.9% of all deaths in 2011, despite contributing only 29.0% of the stock. Thus, 2011 was characterized by a higher than normal mortality rate for the stock, a highly unusual distribution of mortality rates in which rates were high at both ends of the salinity range, and a highly unusual distribution of deaths in which nearly half were upbay.

Box-count mortality on the high-mortality beds fell at the 69^{th} percentile of the 59-year time series, but only the 41^{st} percentile of the post-1988 time series, emphasizing the moderate mortality rate in this bed region in 2011 (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, 2011 mortality remained high in comparison to most years prior to the onset of Dermo disease circa 1989. Mortality on Shell Rock was also relatively moderate with percentile positions of 55^{th} and 38^{th}, respectively (Table 6), as was also true on the medium-mortality market beds, falling at the 55^{th} percentile for the 59-year time series and the 38^{th} percentile for the post-1988 era. Mortality rates were considerably above average upbay. For the medium-mortality transplant beds, the respective percentiles are 65^{th} and 50^{th} and for the low-mortality beds, an astounding 94^{th} percentile for the 59-year time series and the highest level recorded for the post-1988 period (Table 6).

Mortality can also be calculated based on biomass. Excluding the very-low-mortality beds, stock-wide, biomass-based mortality typically fell below 20% for most of the 2000s, but has averaged higher since 2007. The value for 2011 is 22.0%. The 2011 value was at the 67^{th} percentile of the time series, indicating that 2011 was distinctly above the long-term mean (Table 6). Including the very-low-mortality beds varies this picture. Stock-wide mortality was 25.0% in 2011, a value higher than any year in the short time series (2007-2011).

Mortalities based on biomass in 2011 were below those of 2010, and indeed lower than those observed since the early 2000s, downbay of the low-mortality beds (Figure 40). Rates, with percentiles in parentheses, were 20.4% (50^{th}) on the medium-mortality transplant beds, 19.2% (58^{th}) on the medium-mortality market beds, 16.1% (25^{th}) on Shell Rock, and 27.1% (33^{rd}) on the high-mortality beds. Thus, mortality rates were below average on Shell Rock and downbay, and near average on the medium-mortality beds. A different picture is found upbay. Biomass-based mortality was 32.0% on the low-mortality beds, the highest value recorded in the 1999-2011 time series. Biomass-based mortality reached 54.0% on the very-low-mortality beds, a value five times the next highest value observed during the 2007-2011 period (Figure 40).

Figure 40 shows the comparison between mortality rate estimated based on biomass or abundance. The mortality rate based on biomass is normally higher. Either large boxes are more likely to remain intact or larger animals are more likely to die. Both are probably contributors to the trend. In most years, the two numbers diverge downbay, as Dermo disease increases the mortality rate of the larger animals disproportionately. Downbay, the differential between the two is relatively stable over the last five years, as are the mortality rates observed. In contrast, in 2011, the two numbers diverged upbay. Larger animals suffered a higher mortality rate from exposure to low salinity during the 2011 flood event (to be discussed later). On the low-mortality beds, the mortality rate has been steadily rising, for reasons that are not clear. That rise has been increasingly biased towards the larger size classes. The jump in mortality in 2011 is accompanied by a clear increase in the disparity between the numbers-based and biomass-based mortality rate, suggesting that mortality in 2011 was more biased towards larger animals than normal. On the very-low-mortality beds, the rise in mortality in 2011 is dramatic, as is the increase in disparity between the two bases for its computation.

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 41). 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 59 and a rate half that occurs in 34 of 59 years[Λ], so that the expectation of a respectable recruitment event remains greater than 50%. The expectation, however, is lower since 1989 (Figure 41).

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

[Λ] Note that 1 spat-per adult results in about 0.5 spat per adult at market size on the medium-mortality beds, but only about 0.15 spat per adult at market size on the high-mortality beds.

Figure 41, into quadrants by the medians of the x and y variables (Figure 42). 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 41 relating broodstock to recruitment, the distribution of points in the four quadrants (x/y = broodstock abundance/recruitment) is: low/low = 20; 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 ($P < 0.05$; $P < 0.05$; $P < 0.05$; $P < 0.05$, respectively). First passage times show a high tendency for the population to remain in the low abundance-low recruitment or high abundance-high recruitment quadrants (Table 16).

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 16). Since 1989, the distribution of points in the four quadrants is: low/low = 12; low/high = 3; high/low = 3; high/high = 4, based on the 59-yr medians (Figure 41). This distribution is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P = 0.003$, $P > 0.10$; $P > 0.10$, $P > 0.10$, respectively. That is, the relationship between broodstock and recruitment in the post-1988 era is very different from the random expectation. The 2011 relationship between broodstock and recruitment falls into the category of a low-recruitment low-abundance year (Figure 41). This is by far the most likely outcome post-1988, and is probably characteristic of a Dermo-controlled population dynamics (Table 16). 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 59-yr time series.

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 (Figure 43). Epizootics (bay-wide mortality events greater than 20% of the stock) have occurred in about one-third (41%) of the years since 1989. Non-epizootic years tend to average around 10% mortality. The bay-wide average for 2011 was 17.9%, a non-epizootic, but still high, mortality rate similar to 2010, but in this case originating from the freshwater inflow event of 2011 rather than from Dermo disease. Year 2011 falls appropriately along the epizootic hump, well within the other points at the same approximate abundance, despite the origin of the mortality (Figure 43).

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 = 17; high/low =

17; high/high = 12 (Figure 43). 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 17). 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 = 11; high/low = 1; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P < 0.01$; $P < 0.015$, $P > 0.10$, 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 44). The distribution of points in the four quadrants (x/y = recruitment/mortality rate) is: low/low = 13; low/high = 17; high/low = 17; high/high = 12 (Table 18). 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. Since 1989, the distribution of points in the four quadrants is (recruitment/mortality): low/low = 5; low/high = 11; high/low = 1; high/high = 6. This is significantly different from the expectation that one-quarter of the years should fall into each quadrant: $P > 0.10$, $P < 0.15$; $P = 0.012$, $P > 0.10$, 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 45. 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.

Figure 45 suggests that the beds in the central part of the bay, Shell Rock,

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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.

Cohansey, Ship John, and Sea Breeze have oyster densities sufficient to materially affect near-bottom food supply and possibly limit growth, although this is less likely. Upbay of this region, densities may be sufficiently high to generate a drop in food supply over the bed, but not to the degree potentially achieved in the central region of the oyster beds.

In an independent study to evaluate oyster food supply, water samples were collected at fifteen sites in the Delaware Bay and River near-monthly in 2009 and 2010. Food was estimated as the sum of particulate protein, labile carbohydrate, and lipid. Delaware Bay shows a typical spring bloom, centered in March and April, with declining food supply thereafter into early fall, followed sporadically by a minor fall bloom (Figure 46). The geographic and temporal structure of food was more predictable in summer to early fall, and considerably less predictable in spring. Five variables each based on temperature and the spatial and temporal variability of temperature were significant contributors to a multiple regression (R^2=0.28). Cluster analysis on residuals identified two large groups of sites, one comprising most sites on the eastern side of the bay including all of the sites on the New Jersey oyster beds downestuary of the uppermost beds and one including most of the sites along the central channel and waters west. Food values over the New Jersey oyster beds were often depressed by as much as 50% relative to the bay-wide mean (Figures 47 and 48). Food values did not follow an upestuary-downestuary trend anticipated from the salinity gradient. Rather, the differential was cross-bay and was distinctive throughout the estuarine salinity gradient, thus explaining the lack of significance of any salinity-related variable in the multiple regression (compare Figures 47 and 48). The consequence is that food supply cannot be sufficiently predicted or modeled based on observed environmental variables or those predicted from a hydrodynamic model. The cross-bay differential cannot be extracted from such datasets. The oyster reefs of Delaware Bay are dominantly sited on the New Jersey side, where food supply was most depressed and where passive particle residence times were longest. While not conclusive, the results are wholly consistent with the analysis presented in Figure 45, that oysters can influence food values on the New Jersey side of the bay at present biomass, and this would explain the cross-bay gradient in food values as an outcome of oyster feeding.

Harvest Statistics

Direct-market Harvest

Total harvest in 2011 was 94,470 bushels[♭] (Table 19, Figure 49). This is considerably above the 1996-2011 average of 74,684 bushels. This marks the fifth consecutive year with a harvest at or above the 1996-2011 mean. Harvest in 2011 was the third highest in the time series. Figure 50 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

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

been relatively stable during direct-marketing times and below all bay-season[△] years.

Beds were harvested almost continually from April 4 to December 3, 2011. However, the fishery was closed from August 27 to September 30 due to coliform counts during and after the Hurricane Irene/Tropical Storm Lee flood. This closure was unprecedented. Ten beds were fished. Highest catches were on Shell Rock, Ship John, and Cohansey. Significant catches also came from Bennies Sand, Nantuxent Point, and Bennies, where catches approached or exceeded 5,000 bushels (Table 19). The area management policy recommended by SAW-13 resulted in significant catches upbay of Shell Rock. This effort was concentrated on Ship John and Cohansey.

Forty boats participated in the fishery and worked for a total of 1,027 boat-days. These included 19 single-dredge boats working for 521 boat-days (27.4 days/boat) and 21 dual-dredge boats working for 506 boat-days (24.1 days/boat). Total number of boats, and particularly the number of single-dredge boats, dropped significantly in 2011 due to license consolidation (35 down to 19 for single-dredge boats and 23 down to 21 for dual-dredge boats). Year 2011 was the first year license consolidation was permitted. As a result, the number of days worked per boat rose substantially, from 19.4 to 27.4 for the single-dredge boats and from 14.4 to 24.1 for dual dredge boats. CPUE in 2011 was the highest recorded in the 1996-2011 time frame for single-dredge boats, and the third highest recorded for dual-dredge boats (Figure 51).

Total dredging impact was estimated to exceed bed area in six cases[⊗] (Table 19): Bennies Sand, Hog Shoal, Nantuxent Point, Shell Rock, Cohansey, and Ship John. The highest value was 2.68 on Shell Rock. Two other beds exceeded 2: Ship John and Hog Shoal[@]. Cohansey fell barely under 2. Figure 52 shows trends in industry coverage over the last decade on Shell Rock, relative to important population characteristics. Coverage in 2011 was not unusual in comparison to this time series. Shell Rock has seen coverage over a factor of 2 nearly every year since 2000. No obvious trends with population characteristics exist. The same conclusions come from perusal of similar trends for another important market bed, Ship John (Figure 53).

The number of oysters per 37-qt marketed bushel averaged 350 oysters per bushel in 2011, substantially higher than the next highest value in the 2004-2011 time series. Of these, 238 were $\geq 2.5''$, a number representative of most previous years (Table 20). Landings included many more small oysters than in the previous seven years, an upward trend that began in 2010. Of the 112 oysters per bushel differential, 102 were

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

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

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

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 high recruitment event in 2010 (Figure 54). 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 most previous years (Table 20, Figure 55).

Conversion of oysters to bushels for allocation projections used the value of 265 oysters bu^{-1}, the average of the eight years 2004-2011 (median=261) (Table 20). This value is the mean of the total oysters and chosen oysters. The rationale for taking the mean is that the number of attached small animals will vary widely between years depending on recruitment dynamics, so the use of the total number risks underestimating the allocation. On the other hand, the smaller number does not account for all of the oyster removals and this undervalues the fishing mortality rate.

2011 Intermediate Transplant

In April, the intermediate transplant program moved 6,150 bushels of material from Hope Creek and 1,800 bushels from Liston Range to Cohansey 65; 3,350 bushels from Round Island, 2,800 bushels from Upper Arnolds, 4,000 bushels from Arnolds, and 7,600 bushels from Middle to Bennies 70; and an additional 10,150 bushels from Middle to Bennies 71 (Figure 56). Oysters per bushel of transplant averaged: 612 from Hope Creek; 603 from Liston Range; 487 from Round Island; 360 from Upper Arnolds; 410 from Arnolds; and 332 from Middle. Cullers were used for all of these transplants. Cultch moved with the transplanted oysters averaged 19% from Hope Creek, 15% from Liston Range, 20% from Round Island, 31% each from Upper Arnolds and Arnolds, and 25% from Middle. In addition to these culled transplants, a 500 bushel non-culled transplant from the Beadons Point area of Beadons to the northwest corner of Bennies 102 was conducted to move a heavy concentration of small oysters that had been seen in the fall 2010 stock assessment. The long-term dataset indicates that this area periodically gets heavy sets that do not typically survive. The number of oysters per bushel above 20 mm but primarily under market size was 1,423 while the number of spat per bushel was 1,028. Because this was an unculled transplant, the fraction of cultch (41%) was higher than in the other transplants.

Table 21 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. Cultch percentages in 2011 were below the long-term mean for each bed region. The records suggest that shell contents of $\leq$25% are achievable on a routine basis.

2011 Cultch Experiment

Throughout the years that the intermediate transplant program has been conducted, concerns have occasionally been raised over inconsistencies between boats regarding the amount of cultch and the numbers of very small oysters being removed from the donor regions. To address these concerns and to determine whether or not the current method and level of sampling is adequate to reasonably assess the transplant, HSRL conducted extra monitoring with an observer program during the April 2011 transplants. For the usual monitoring, the NJDEP boards every boat throughout each day of transplanting to determine the cultch and oyster proportions in quick samplings and to advise the captains if they are collecting excessive amounts of cultch. In addition to these samples, the NJDEP collects a composite sample of 3 one-third bushels during the day from each boat. NJDEP also measures the volume of the entire deck load just to its deployment onto the specified receiving area. These samples are processed at HSRL for numbers and sizes of oysters and fraction of cultch. The data are used to track the transplant progress toward the goal number of oysters to be moved and later, to determine the volume of oysters that are at or that will reach market size within the current season.

For the additional observer program, HSRL put an observer on one boat each day that transplanting occurred (Table 22). Throughout this time, the NJDEP did the standard monitoring and sampling each day for all other boats. The observer took samples approximately every half hour throughout the dredging period of four to seven hours and sorted them into oyster, cultch, box, and debris volumes. At the end of dredging, the observer took 12 one-third bushel samples following the standard NJDEP protocol and sorted them. The results were compared and analyzed to determine whether or not the standard NJDEP end-of-day samples were statistically representative of the samples taken throughout the day. The comparison of the arcsine-square root-transformed fractionated volumes by boat and bed indicate few significant differences in the nine sets of observations on the three beds (Table 23). The samples were significantly different from each other in only two cases, both from the same boat on different beds. In order to determine whether or not 3 one-third bushel samples were statistically equivalent to 12 one-third bushels, randomization tests were run on the cultch fractions from each sample. We extracted the first three samples (equivalent to the standard sample methodology) with replacement from the whole set of twelve for each observer day. There were no significant differences in fraction of cultch using three thirds versus using twelve thirds at $\alpha = 0.05$ (Table 24). Based on these results, the standard NJDEP transplant monitoring protocol is sufficient to assess the composition of intermediate transplant deck loads.

We also used randomization tests to look at differences in cultch fraction and oyster size parameters between boats on each bed. There were significant differences between boats transplanting from the same bed but the distribution of the five participating boats on each of the six beds was not consistent and the differences were not consistent for the same boat on different beds. These results indicate that significant differences may exist between boats, although these may not be extreme, so that continued vigilance of all participating boats to minimize cultch content in deck loads is required.

Fishing Mortality

In 2011, just over half of all oysters supporting the fishery came from Shell Rock and the medium-mortality market beds, but nearly half were supported through intermediate transplant from the beds upbay (Figures 57-58). Transplant removals as a fraction of the regional stock were relatively evenly distributed between the very-low-mortality, low-mortality, and medium-mortality transplant beds. In comparison to the 2005-2008 period, the upbay beds contributed a relatively high fraction, as they had in 2009 and 2010. In comparison to 2010, the fraction contributed was lower. Overall, the increased use of intermediate transplant to support harvest downbay is in keeping with the SAW-11 recommendation to expand the intermediate transplant program to a scale routinely employed in the 1997-2003 time frame.

Real fishing mortality was 1.7% of total abundance in 2011, excluding the very-low-mortality beds, and 1.6% including them, whereas apparent fishing mortality was 2.6% (2.4% including the very-low-mortality beds) (Figure 59). The increment reflects the intermediate transplant program that transplanted oysters downbay in 2011. Fishing mortality has been below 2% every year since 1995. 2011 fishing mortality was at the 33^{rd} percentile of the 59-yr time series excluding closure years, and at the 66^{th} percentile of years post-1995 (Table 6). By bed region, the percentiles for the era of the direct-market fishery were 63^{rd}, 50^{th}, and 50^{th} for the high-mortality beds, Shell Rock, and the medium-mortality market beds respectively (Table 6). The high percentile exploitation rate on the high-mortality beds belies the fact that only 0.39% of the stock was removed, taking into account intermediate transplant (Figure 58). The continued low net exploitation of the high-mortality bed region is consistent with the precautionary management approach established in 2009 to restrict fishing while these beds are at low abundance without compensation from intermediate transplant.

Fishing mortality, by SSB, was 2.2% in 2011 (2.7% excluding the very-low-mortality beds) (Figure 60). Fishing removed 4.1% of the animals $\geq 2.5''$ in 2011 (4.5% excluding the very-low-mortality beds) (Figure 61). This is a high value relative to the 1997-2011 time series, falling at the 86^{th} percentile, but the time series contains a narrow range of values encompassing less than a factor of 2.

By bay section, fishing and transplant activities removed 1.2%, 1.4%, 2.4%, 1.4%, 3.8%, and 0.4% 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%, 1.7%, 3.6%, 3.7%, 12.9%, and 6.8%. Percentile ranks excluding the very-low-mortality beds are, respectively, 64^{th}, 79^{th}, 86^{th}, 79^{th}, and 42^{nd} (Table 6). 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 years preceding 2009. Values are consistent with most preceding years downbay of this region.

Results of 2011 Experimental Fishery

SAW-11 proposed two experimental fisheries for 2009 and these were continued pursuant to SAW-12 into 2010 and 2011. The first of these was an intermediate transplant from the very-low-mortality beds. These beds had not been previously exploited prior to 2009, so that no exploitation record existed 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. Hope Creek contributed most of the animals in 2011. Due to the 2011 flood, no further examination of the influence of this fishery could be made in 2011.

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 62 suggests that this exploitation rate did not materially influence the stock. Total abundance increased in 2010 and in 2011. Market-size abundance was little changed in 2011 from 2010 and higher than observed in 2009. The submarket surplus retrospective is consistent with this interpretation (Figure 24).

The 2011 Flood

Hurricane Irene moved up the eastern seaboard making landfall for a second time at Little Egg Inlet, New Jersey, early Sunday morning August 28, 2011. This is the first time a hurricane made landfall in New Jersey since 1903. Six to seven inches of rain fell across most of the state. Thirty-eight of the 93 USGS gauges with greater than or equal to 20 years of record had record high peaks. Another 24 gauges recorded the second highest peaks of record and 5 gauges recorded the third highest. Thirty gauges experienced peaks greater than the 100-year recurrence interval and ten of these gauges experienced greater than a 500-year event. Hurricane Irene was followed a few weeks later by Tropical Storm Lee that added additional rainfall to the Delaware River watershed. The Delaware River Basin has a 6% chance every year of experiencing a rain event as large as produced by Hurricane Irene. The Delaware River Basin has an 18% chance every year of experiencing a rain event as large as produced by Lee[‖] Consecutive storms of this magnitude have a probability of 1%; thus, the August/September flood event likely was a 100-year event.

The freshwater inflow depressed salinity in Delaware Bay to historical lows. Between early September and late October, salinities fell below 5‰ over much of the oyster beds upbay of the medium-mortality market beds (Figure 63). Salinities fell below 10‰ over the majority of the oyster beds. Although sampling is insufficient to ascribe all oddities in the survey dataset for 2011 to this flood, it seems likely that the majority can be. For the purposes of this assessment, several of these are unusually important.

1. Normally, natural mortality rate rises with rising salinity, due to the increased presence of predators and disease. In 2011, mortality was highest upbay and mortality had a bimodal high, a hyperbolic distribution, being lowest in the central portion of the oyster-growing region (Shell Rock, medium-mortality market beds), and higher both downbay and upbay of this region. The upbay mortality levels were near or at historical highs (Table 6). The hyperbolic mortality trajectory is

[‖] Information provided by Robert Tudor, Delaware River Basin Commission, and Anna Marie Gonnella, Delaware River and Bay Authority.

not unique, but occurs rarely in the 59-year time series.

2. The mortality rate upbay was biased towards the market-size animals. On the very-low-mortality beds, 47% of the individuals were lost, but 54% of the biomass was lost (Figure 40). Abundance declined from 2010 by only 22% for those animals <2.5″, but by 76% for larger animals (Figure 16). The same trend was observed on the low-mortality beds. Thus, mortality from exposure to extreme low salinity was heavily biased towards the larger size classes.

3. In most years, recruitment rises downbay with increasing salinity. In 2011, this trend was exaggerated. Recruitment rate was very poor upbay, but the high-mortality beds, relative to the number of animals already there, had one of the best recruitment events in many years (Figure 31).

4. Typically, condition rises downbay with increasing salinity. In 2011, this trend was exaggerated. Condition was low, but not unusually low on the high-mortality beds. Upbay of Shell Rock, condition was near or below the lowest value recorded previously (Figure 22).

Thus, key population characteristics of the oyster stock a month post-flood were marginal upbay of the medium-mortality market beds, but much improved in this region and downbay. Examination of the long-term record provides potential constraints on the rate of recovery of the two upbay bed regions. Recruitment has been historically sporadic upbay of the medium-mortality market beds and good recruitment events (≥1 spat per adult) have occurred rarely (Figure 31). Growth rates are slow (Table 10). Counterweighing these inauspicious facts is the observation that many of the smaller animals, and most downbay of the very-low-mortality beds, appear to have survived (Figure 16). These animals should provide a resource for more rapid recovery of the size-frequency distribution typical of previous years than would be anticipated if sole reliance on recruitment was necessary. Total abundance, however, may still be expected to recover at a relatively slow rate.

The metapopulation implementation of DyPoGen was parameterized for Delaware Bay and used to hindcast the population dynamics preceding and during the flood and to forecast population recovery in the years following. Simulations used environmental and population characteristics corresponding to four populations spanning the range of commercial oyster beds in Delaware Bay (populations 1 through 4 were parameterized to reflect Hope Creek, Arnolds, Shell Rock, and Bennies conditions, respectively). Simulated impacts of the flood on population characteristics include depression of size frequency and adult abundance in the upper bay population that lasts approximately 10 years after the flood event (Figure 64). Recovery time after the flood in the simulations is dependent on the growth rates, larval dynamics, and general population characteristics in years following the flood. The simulations were performed with the assumption that those general parameters will be reflective of that of years prior to the flood.

Conditions upbay of the medium-mortality market beds impose a number of challenges with respect to the typical management strategy successfully employed for a number of years. These beds have been used to supplement abundance on the direct-market beds, and thus lower the realized fishing mortality rate on these beds. This has resulted in two principal outcomes for the fishery. (a) The animals of market size transported downbay have been added to the yearly quota in the receiving regions, permitting a larger harvest. (b) The smaller animals transplanted downbay, assumed to grow into market size in the next 1-2 years, have permitted the use of higher exploitation rates for market-size animals in these downbay regions. The debilitation of these upbay beds impinges on a number of management precedents.

1. The overall biased decline in market-size animals will directly impact quota calculations, as recent precedent has applied exploitation levels exclusively to market-size animals ($\geq 2.5''$) on the direct-market beds, thus minimizing the possibility of overfishing the larger size classes in a case where proportionately more animals are below market size.

2. Over the last few years, downbay transplant has particularly permitted enhanced fishing on the high-mortality beds, otherwise characterized by an abundance low enough to trigger precautionary fishing levels. This strategy has been premised on one assumption and a goal. The assumption is that Dermo disease will limit and probably prevent the success of any substantive rebuilding program to enhance abundance. The goal, therefore, has been to manage these beds in a put and take fashion, thereby limiting the influence of the fishery in generating a further decline in abundance. Without transplant, these beds may not provide sufficient submarket surplus to meet the 'constant abundance' management goal. Previous SAWs have routinely advised fishing above the 40^{th} percentile exploitation rate only if coordinated with a robust transplant program.

4. A regional closure recommendation has occurred only once (SAW-9, 2007, low-mortality beds), and was promulgated based on a simultaneous decline in abundance and marketable abundance below threshold levels (see later discussion).

5. Adequate reference points for the very-low-mortality beds have not yet been promulgated.

6. Condition has never been used to support precautionary management. However, condition has rarely been as low across the entire bay as it was at the end of 2011.

7. Management routinely addresses the expected population characteristics in the coming year, but long-term projections have not routinely been made. Inference from simulations by DyPoGEn suggests that longer-term expectations may be required for the upbay beds, as anticipated recovery times may be decadal.

The SARC considered whether the re-survey plan should be modified due to the severe impact of the 2011 flood on the two upbay regions (Table 1). Patchy high mortality on these upper beds may put into question the validity of the present assignments of sampling grids to strata. However, one cannot evaluate the likelihood that the patchiness of abundance may change rapidly from year to year during the recovery of these beds, thus putting into question survey estimates for a decade, if these beds are re-surveyed earlier than in the original plan. The SARC also notes that important production beds are scheduled for resurvey in 2012. Consequently, the SARC recommends that the original plan be followed, as this will permit recovery to progress for a few years prior to a new survey.

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 25). Due to the absence of a time series, the very-low-mortality beds do not have these target and threshold reference points derived in this way.

As the very-low-mortality beds were heavily impacted by low-salinity event in 2011, an effort is made to develop 'rule-of-thumb' stock performance reference points for these beds. Values are obtained based on an assumption that the per-area values for abundance, SSB, and market-size abundance should be equivalent to those on the low-mortality beds. Consequently, the values for the low-mortality beds in Table 25 are multiplied by the ratio of the regional bed areas, 0.849, to obtain reference-point estimates for the very-low-mortality beds. As the growth rate is likely slower in this region than on the low-mortality beds, so that average adult size is smaller, reference points for SSB and market-size abundance may be overestimated using this approach. As a consequence, an alternate examination was performed by examining the ratios between the two bed regions in abundance, biomass, and market abundance for the 2008-2010 time period. The ratios are highly variable, but the 3-year averages are 1.23 (abundance), 0.94 (SSB), and 0.93 (market abundance). None are likely to be significantly different from the ratio based on acreage; however, the abundance value suggests that reference points based on acreage may be biased low.

Time series data show 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 9), 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 39). 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 in 2010 with DyPoGEn reported in SAW-13 strongly imply that growth rates have risen between the 1990s and 2000s. Increased growth rate may be an important contributor to the 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, SAW-13 noted that this was due to consecutive good recruiting years which may not be sustained. Return to 2000s conditions might be expected if growth rate remains high and recruitment rate drops to decadal norms. This year, 2011, fostered to a significant degree by size-biased mortality from the late-season flood and high recruitment on the high-mortality beds, continued the 2010 trend. The 2011 100-year flood is a uniquely extreme event, with long-term impacts to be expected, but not expected to be predictable. Thus, it is uncertain to what extent the oyster stock will return to the state characteristic of the 2000s after the flood, nor is it clear to what extent a 1990s population dynamics might reappear. SAW-13 suggested that the application of reference points based on 1990s data to 2010 conditions should be done with caution, but noted that an adequate replacement is also unavailable. Consequently, SAW-13 recommended that the "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 was unclear. The extreme low-salinity event imposes an addition challenge to the reliance on these reference points, as the stock size frequency upbay has been markedly changed by a mortality event unlikely to re-occur over decadal time periods and one biased such as to shift the size-frequency towards smaller size classes.

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 and which certainly played a supporting role in the decline in SSB in 2011. 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 25.

In 2011, abundance on the very-low-mortality beds is below the target and near, but above the threshold (Figure 65). Abundance has been below the target over most of the history of the time series, 2008-2011, suggesting that this target may be too high. However, the same can be said for the low-mortality beds over the same time frame. SSB on the very-low-mortality beds in 2011 is less than half of the threshold value, having been routinely above the threshold and often above the target over most of the previous few years (Figure 65). Market abundance falls well below the target, but above the threshold, having been above the target for all of the preceding years (Figure 66). Recruitment was less than half the next lowest value in the short time series.

The low-mortality beds are below the abundance and biomass targets. Abundance remains above the threshold, but SSB falls just below this value (Figure 65). Abundance rose modestly relative to 2010, but remained near the median for the the 2006-2011 period. SSB is distinctly below SSB levels observed during the 2006-2010 period (Figure 65). Market abundance remains well above the target, as it has been since 2004, despite the higher mortality due to the 2011 flood. The 2011 value, nevertheless, represents a considerable decline from 2010 and half the value of 2009 (Figure 66). Recruitment was substantively lower than any year since 2004.

The medium-mortality transplant beds are above the abundance target having been increasing steadily in abundance since 2006. Abundance rose substantially again in 2011. Abundance on the medium-mortality market beds was well above the threshold, but below the target, having risen above the threshold in 2010 and rising again significantly in 2011 (Figure 65). SSB was well above the threshold, but well below the target in 2011 on the medium-mortality transplant beds. The value was modestly lower than observed in 2010, but representative of four of the last five years (Figure 65). SSB on the medium-mortality market beds was in the same relative position. Market abundance fell well above the target in 2011 in both regions (Figure 66). Recruitment was modest in both regions, though not inordinately low relative to performance over the last decade.

Abundance on Shell Rock is well above the abundance target. The same superior position is true for SSB and market abundance (Figures 65-66). Recruitment was the lowest since 2006, however.

The high-mortality beds are below the abundance threshold, a position occupied every year but one since 2001 (Figure 65). Abundance declined markedly in 2011, but remained representative of abundances recorded throughout the last decade. SSB is below the SSB threshold, a position occupied only once in the last five years (Figure 65). SSB is low in comparison to the previous five years. Some portion of this low value likely originates from the relatively low condition index observed in 2011. Market abundance fell below the target in 2011, after rising briefly above it in 2010 (Figure 66). Market abundance has remained near the target for the last four years. Recruitment was the highest since 1999 and on a per-adult basis, one of the highest on record.

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 26). Second, the simulated surveys were sorted by the total number of oysters (Table 27). 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 25 and figured in Figures 65-66 are compared to the uncertainty surrounding the 2011 point estimate for each bay region in Figures 67 and 68. These generally confirm the significance of the position of the 2011 point estimate relative to the Table-25 stock-performance reference points. Of particular note is that four of six bay regions fall distinctly above the abundance threshold, taking into account survey uncertainty (Figure 67). One, the high-mortality beds, falls significantly below. The abundance targets for four of six fall within or above the survey envelope, although the abundance target on the low-mortality beds is near the upper 90^{th} percentile of the survey envelope. (Figure 67). The probability envelop for the high-mortality beds falls well below the abundance threshold. For the very-low-mortality beds, the survey probability envelope encompasses the abundance threshold and falls significantly below the abundance target.

The market-abundance threshold reference point falls below the survey uncertainty envelope for five of six regions (Figure 68). The target falls below or within the envelope for the same five. Thus, these bed regions meet stock-performance abundance goals by this measure in 2011. The exception is the very-low-mortality beds, for which market abundance falls significantly below the target, but not the threshold (Figure 68).

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 2011 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 25. 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 1953-2011 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 28).

Five simulations were conducted to address a range of uncertainties in the property-property plots (Figures 41 and 43). These show 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; thus, N_{msy} values can be obtained, but f_{msy} estimates cannot. SAW-12 noted that the greatest uncertainty may be the position and height of the epizootic hump in the abundance-mortality relationship (Figure 43) and that further simulations to evaluate this uncertainty are desirable.

[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.

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. The SARC did not identify a preferred simulation. For comparison to 2011 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 25). 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 25). The two respective values are 2.311 billion and 1.156 billion. The equivalent reference points based on marketable ($\geq 2.5''$) numbers from Table 25 are 334.0 million and 167.0 million.

SAW-10 opined that the stock-performance target for the whole stock (2.311 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[Φ] 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.

SAW-10 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. SAW-10 recommended 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 2011 abundance is 1.903 billion animals excluding the very-low-mortality beds, of which 456 million are $\geq 2.5''$ in size. Ninety-percent confidence limits are 1.866 and 2.554 billion animals, so that the 2011 point estimate falls near the 20^{th} percentile (Figure 69). This suggests that the point estimate maybe an underestimate of 2011 abundance. The potential underestimate of the 2011 point estimate 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 2011 point estimate of 1.903 billion animals falls significantly above the N_{msy} target (Figure 69).

[Φ] Op. cit.

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

The whole-stock stock-performance reference point falls above the 2011 point estimate but well within the survey uncertainty envelope, suggesting that 2011 abundance is not significantly below this target reference point. The marketable abundance of 456 million falls near the 50^{th} percentile of the survey uncertainty envelope with the 90% confidence limits being 379 and 546 million animals (Figure 70). The 2011 point estimate is significantly above the target value.

In summary, the N_{msy} reference point target falls below the 10^{th} percentile of the survey index, suggesting that 2011 abundance is very likely to be above this reference point (Figure 68). A similar comparison against the stock-performance reference points for total abundance shows that the 2011 point estimate falls below, but not significantly below, the target, and significantly above the threshold value (Figure 67). Application of the marketable abundance reference point to an equivalent set of percentiles (Figure 69) reveals that the 2011 point estimate is significantly above the stock-performance target.

Summary of Stock Status and Population Management Goals

Figure 71 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 1989-2011 (or 1990-2011) 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 50).

In 2011, the effect of the flood modified trends in the status of the stock in most regions upbay of the high-mortality beds, in comparison to previous years. The stock presents a mixture of positive and negative indicators, frequently in the same bay region, with indicators relevant to the market-size portion of the stock frequently showing trends opposite of indicators relevant to the entire stock (Figure 71). Abundance is relatively high, being significantly above one whole-stock target and not significantly different from the other. This development, which was initiated in 2010 and advanced in 2011, despite flood losses, places the whole-stock abundance value at a level not seen since 2002. Abundance is increasing in four of six bay regions relative to 2010 and in four of five bay regions relative to the previous five-year median. Abundance remains below target levels in all but one bay region, but is above the threshold in all but one bay region, that being the high-mortality beds. The increase in abundance in 2011 is explained by the well-above-average recruitment event of 2010. The stock continues to be disproportionately consolidated on the medium-mortality beds, a factor exacerbated by the hyperbolic distribution of mortality in 2011. Only 36% of the stock resides outside of the core bed region (Middle to Shell Rock).

Spawning stock biomass trended opposite to abundance in most bay regions. SSB increased only on Shell Rock. Declines were substantial in all other bay regions relative to 2010 and in four of the remaining five relative to the previous five-year median (Figure 71). Much of this decrease originates from a natural mortality rate imposed by the 2011 flood. However, the trends in SSB exceed the trends in market-size abundance, likely due to the extraordinarily low condition of the stock at the end of 2011. The decline on the high-mortality beds occurred despite low salinity that positively influenced adult mortality in the regions immediately upbay. SSB fell below the biomass target in five of six regions, but distinctly below the threshold in only one, the very-low-mortality beds. However, in two other regions, biomass fell near or modestly below the threshold.

In contrast, marketable abundance increased in two of five bay regions relative to the previous five-year median and in two of six regions relative to 2010. Marketable abundance was stable or increasing in the core bed regions, while decreasing substantively at the range extremes. Marketable abundance fell above the target in four of six bay regions and only modestly below the target in a fifth. Marketable abundance fell above the threshold in all bed regions, although only modestly above for the very-low-mortality beds. The reference points for this region are less certain than for the remaining five.

The 2011 recruitment was poor upbay of the high-mortality beds. However, comparisons to 2010 are amplified by the unusually high recruitment in that year. As a consequence, recruitment decreased in all bed regions except the high-mortality beds in 2011 relative to 2010. Recruitment in 2011 was sufficiently poor to show a decline relative to the previous five-year median in three of five bed regions, however. Based on total recruits, the 2011 spatfall exceeded the 50^{th} percentile for the 1989-2011 time period in only one bed region, the high-mortality beds. On a spat-per-adult basis, the 2011 recruitment trends are nearly identical to total recruitment. Recruitment was well below 0.5 spat per adult in all but one bed region, the high-mortality beds.

The oyster population as a whole continues to be depauperate in the smaller size classes relative to the early 1990s; however, much less so than in previous years. Percentiles neared or exceeded the 50^{th} in all but one bed region. This change in size frequency stems from two good recruitment years, 2009 and 2010, and a biased loss of the larger size classes in 2011. The high-mortality beds distinctly lag behind by this measure. Submarket surplus, though likely overestimated, is expected to permit an increase in marketable abundance bay-wide and in all bay regions, though less so on the low-mortality and very-low-mortality beds.

Dermo was modestly or substantively abated by the flood in all bed regions[℘]. This marks a clear break in the pattern observed in 2008-2010. More noteworthy is the lessening of Dermo weighted prevalence in the core bed regions that had seen unusually high infection levels in 2009-2010. Natural mortality followed an unusual hyperbolic trend. The mortality rate was high and increasing relative to preceding years in the two uppermost bed regions due to the 2011 flood and likewise high and

[℘] Details are in the associated document: Bushek, D. 2011. *Delaware Bay New Jersey oyster seedbed monitoring program 2011 status report*, Haskin Shellfish Research Laboratory, Port Norris, NJ.

modestly increasing on the high-mortality beds. The upbay two bed regions saw the highest mortality rates on record for the Dermo era (post-1988 for the low-mortality beds and post-2006 for the very-low-mortality beds). Natural mortality rate fell on the medium-mortality beds and Shell Rock. Mortality rate was average or low in these three regions by historical standards. The odd increase in mortality rate on Shell Rock relative to 2010 is recorded solely due to an extraordinarily low mortality rate observed on that bed in 2010.

Fishery exploitation levels since 1989 have been low (<2% of abundance per year). Exploitation in terms of biomass and market abundance have been ≤3% for most of that time. Exploitation rates were near average in 2011 on Shell Rock and the medium-mortality market beds, but well above average on the high-mortality beds, the low-mortality beds and the medium-mortality transplant beds. For the latter two, the high exploitation rate was nevertheless below 1.5% of the stock. High percentile ranks accrue from the limited exploitation on these beds early in the time series. For the high-mortality beds, although the percentile rank was the 63^{rd}, the fishery took only 0.4% of the stock. Intermediate transplant to this bed region nearly balanced removals. These trends are consistent with SAW-13 recommendations. However, these exploitation rates were still below 5% of the marketable stock by number in all bed regions except Shell Rock and the high-mortality beds, for which exploitation, uncorrected for transplant, was 13.0% and 6.8%, respectively. For the medium-mortality market beds, despite the increased exploitation recommended over the last three years (the 100^{th} percentile - see later discussion), the fishery removed only 3.7% of the marketable stock. Overall, due to the intermediate transplant program, the landings were supported relatively evenly by all bed regions in 2011.

In summary, the fact that only one bay region fell well above 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 above 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. Due to the 2011 flood, although all but one bay region was distinctly above the threshold for this metric, only two regions were distinctly above the target and only one of these is a direct-market region, Shell Rock. Thus, management measures have been successful at maintaining market abundance during a period of unprecedentedly low recruitment in the mid-2000s, but higher than average mortality in 2011 has placed the stock in a less favorable position by this metric than seen over much of the last decade.

Overall, the six bed regions cover a wider range of stock status than normally observed. Few cautionary data exist for Shell Rock or for the medium-mortality market beds. No evidence of impact from the higher exploitation rate permitted in 2011 on the medium-mortality market beds could be discerned, supporting the retention of this option for exploitation in 2012. On the other hand, conditions have deteriorated on the high-mortality beds. These beds are below, though near, the threshold for abundance and SSB and below the target for market-size abundance. All three metrics dropped significantly in 2011 relative to the previous five-year median and relative to the previous year, 2010. Intermediate transplant limited the effect of the fishery on these beds in 2011; thus, the observed trends are due nearly in their entirety to natural trends in mortality and recruitment of the stock in this region. A continued emphasis on intermediate transplant to this bed region in 2012 would seem prudent, as the 2011 recruitment provides an opportunity to improve the condition of this region in 2012.

Conditions have deteriorated markedly on the low-mortality and very-low-mortality beds as abundance and SSB have declined to undesirable levels, relative to the 1989-2011 (or 2007-2011) historical record and marketable abundance has also declined substantively, due to unusually high rates of natural mortality from the 2011 flood and a decadal dearth in recruitment, broken only by the higher event of 2010. Recruitment was abysmal in 2011 in both regions. An even poorer stock status was prevented by the biased mortality towards the large size classes from the 2011 flood, that left the smaller sizes less affected. Condition however ended the year at extremely low levels. Abundance, SSB, and marketable abundance are near or below the targets in both areas and only distinctly above the threshold for abundance and marketable abundance on the low-mortality beds.

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, SAW-13 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: 1990-2011 (Figure 12). 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 59-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 2011, the survey point estimate of whole-stock abundance is significantly above the N_{msy} reference point (Figure 69). Thus, by this measure, the stock is not overfished.

SAW-13 considered the efficacy of relying on this measure and noted the uncer-

ℵ Powell et al. (2008), Op. cit.

tainty posed by the uncertain shape of the epizootic hump in the abundance-mortality relationship (Figure 43). As a consequence, SAW-13 recommended greater reliance on alternative metrics 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 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 38) and that much of this mortality is concentrated on the larger size classes (Figure 40). 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[℘]. The 1990-2011 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.

The stability in market-size abundance in 2011 relative to previous years belies the high mortality of market-size individuals from the 2011 flood. The counterintuitive trend accrues from two sources. First, the unusually high decline in market-size abundance on the low-mortality beds was offset by lower mortality rates on Shell Rock and the medium-mortality beds due to lessening of Dermo disease by the influx of low-salinity water. Second, Figure 19 does not include the very-low-mortality beds. Mortality in this bay region was too high to be offset downbay. Nevertheless, removals by the fishery fell below 5% of the marketable stock in 2011, despite the decline in market-size abundance due to the flood which magnified the influence of the fishery on the stock in 2011 beyond what was anticipated at SAW-13.

A second metric of importance permits a determination of overfishing. A characteristic of overfishing is a negative surplus production in a stock. For oysters, under the management goal of conserving marketable abundance, this is best expressed by submarket surplus as defined in an earlier section. In populations controlled by epizootic disease, submarket surplus 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 submarket surplus. A retrospective examination of the tendency for forgone yield to

[℘] Op. cit.

exist under this management approach shows that net submarket surplus has been near zero or positive in every year since port-sampling began[II] (Figure 72). That is, some potential yield to the fishery has been forgone in all years except, possibly, 2010. This retrospective was based on observed stock dynamics 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 2005-2011 management program. Further support comes from a comparison of the natural mortality rate with the fishing mortality rate (Figure 73). In this case, the fishing mortality rate has been distinctly less than 20% of the total mortality rate (natural + fishing) throughout this time period. A rule of thumb is that the natural mortality rate of the stock is an estimate of the fishing mortality rate that can be sustained. The fishing mortality rate has been well below the natural mortality rate consistently over the time period over which the calculation can be made (2005-2011). As a consequence, no evidence exists that overfishing has occurred under the present management regime.

Finally, a new carbonate reef budget model suggests that habitat integrity may be compromised at fishing mortality rates much exceeding 5% per year (Figure 37). Simulations with this model remain uncertain due to inadequate information from Delaware Bay on the small-scale spatial structure of carbonate on the oyster beds. Nevertheless, extensive simulations covering a range of conditions suggest that fishing rates much above 5% may result in long-term degradation of the reef framework. Fishing mortality rates have remained below 5% consistently over much of the 1953-2011 times series post-1960. This is likely an important reason that reef loss has not occurred in Delaware Bay as it has in other bays throughout the oyster's range.

Thus, the SARC concludes that the Delaware Bay oyster stock is not overfished and that overfishing is not occurring in 2011, 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, but conditions worsened in 2011. Thus, a reduction in shell planting in 2009-2011 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, the program has proven to be a useful recruitment enhancement tool. Design of a 2012 program, funds permitting, should consider the following recommendations.

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

1. Shell Rock is in very good shape. No shell plant or intermediate transplant to this bed is recommended for 2012

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. The SARC believes that more can be accomplished this year in stock enhancement in this bed region through intermediate transplant, rather than shell planting. Consequently, the SARC recommends that any transplant from the low-mortality and medium-mortality transplant beds be placed somewhere in the upper portion of the high-mortality beds.

3. Ship John and Cohansey are of increased importance to the industry in 2012 as a product of stock consolidation following the 2011 flood. The SARC recommends that shell planting in 2012 target the lower portion of Ship John. The SARC further recommends that a replant rather than a direct plant should be considered if financing is adequate.

4. The SARC notes that the very-low-mortality beds, because of the 2011 flood, would be a location for a replant program. Direct shell planting is discouraged due to the anticipated infrequency and unpredictability of good recruitment events, based on the recruitment time series of the low-mortality beds (Figure 16).

5. 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 continuing efforts should be undertaken to minimize the downbay transplant of cultch. As data collected in 2011 show that cultch fractions below 25% are routinely achievable, the transplant program should emphasize the goal of limiting cultch fraction to 25% or less in 2012.

2011 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 2012 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. Mortality on this bed region reached an historical high in 2011 after a year, 2010, with a mortality that previously was the historical high. The 2010 event may be due to a lingering Dermo epizootic in the central part of the stock. The larger 2011 event is a result of the 2011 flood. Condition index on these beds at the end of October was extremely low. The declining stock status on these beds requires particularly precautionary management in 2012.

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. The low-mortality beds provide the best analogy. Presumably growth rates are as low or lower on the very-low-mortality beds than on the low-mortality beds. Simulations using the ROMS/Dekshenieks larval model suggests that recruitment on these beds should be even less frequent than on the low-mortality beds, where recruitment is already highly unpredictable and characterized by spatfalls exceeding 0.5 spat per adult being exceedingly rare since 1990. In addition, the 2011 flood generated an extreme mortality event biased towards the market size classes. The devastating impact of the flood in 2011 re-enforces the need to retain a highly precautionary management approach for these beds.

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 continue evaluation of increased exploitation of this bed region.

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. SAW-8 and subsequent SAWs have recommended that the exploitation indices for the transplant group of medium-mortality beds (Middle+Upper Middle) be 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 29). That value is carried forward in the projection tables that follow.

Exploitation rates can be calculated based on real removals and apparent removals (Tables 29-30). 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 submarket surplus projections which routinely exceed the historical values by a significant margin.

It is the SARC's recommendation that this experimental fishery continue in 2012.

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 this bed and the desire to limit intermediate transplant from Middle to alternate years. The SARC recommended 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 31)

In 2011, the high-mortality beds continue to be at low abundance, with declining abundance relative to 2010 and the preceding 5-year median. Marketable abundance has also declined relative to the preceding 5-year median. Abundance is below the threshold, as is SSB; however, market abundance is above the threshold and near, though below, the target. 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

[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.

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 2007-2011 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. 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 for 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 at the 100^{th} percentile begun in 2009 on these beds to evaluate their response under increased exploitation rates.

Projections are provided in Table 31 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 32)

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. SAW-12 recommended that Middle not be targeted in consecutive years and, as a consequence, transplant from Sea Breeze was attempted in 2010. Results of this program show that Sea Breeze/Upper Middle as the sole target beds represents a transplant challenge due to patchiness on Sea Breeze and small areal size of Upper Middle. Good survey data for Upper Middle are only available since 2005. Prior to that time, the survey did not survey this bed with adequate sample size. The 6-year median fraction of oysters on Middle (versus Sea Breeze + Upper Middle) is 0.41; however, the variation among the 6 years is high. The fractional distribution is not significantly different from a 50:50 split. As a consequence, the SARC recommends that the 2012 transplant be distributed 50% from Middle and 50% from Upper Middle/Sea Breeze. The SARC further stresses that no more than

50% of the transplant be taken off Middle, so that limited success on Sea Breeze will result in a reduction of the total number of oysters moved and, hence, a reduction in the quota increase for 2012 that might otherwise be achieved.

The SARC discussed the option of using a suction dredge for the Sea Breeze/Middle transplant. Earlier detailed evaluation of suction dredge performance[ϒ] has shown that the suction dredge catch is biased towards the smaller size classes. The use of a standard dredge and cullers has routinely been recommended because deck loads obtained in this way are biased towards the larger size classes. This increases the augmentation of the direct-market quota while also retaining on the donor beds under a lower natural mortality rate more of the smaller animals that can, then, support future transplant activities. However, the SARC recognizes that any transplant is better than no transplant. Accordingly, the SARC recommends that the Sea Breeze/Upper Middle transplant be carried out with a standard dry dredge and cullers, but, if the use of this method proves inadequate to reach recommended goals, then a suction dredge may be used. However, the SARC strongly urges that all efforts be made to accomplish this transplant with a dry dredge and culler.

The medium-mortality transplant beds are within survey error of the abundance target (Figure 67) and above the market-size abundance target (Figure 68). Mortality rate was low in 2011; however, condition was also very low at survey time and SSB is near the stock-performance threshold. The possibility of a delayed impact of the 2011 flood on these beds should not be discounted. In addition, a change in recommended transplant strategy perforce will result in Middle being a source bed in two consecutive years, in contradiction to recommendations made at previous SAWs. As a consequence, the SARC recommends that management be precautionary, with an intermediate transplant quota not to exceed the 50^{th} percentile level.

The low-mortality beds are near, but above, the marketable-abundance target, but below the abundance target and only modestly above the threshold. The beds have suffered two consecutive years of historically high mortality, with 2011 being the highest recorded in the 1989-2011 time series, as a consequence of the 2011 flood. Biomass mortality was distinctly higher than mortality measured by abundance due to increased mortality in the market size classes. 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 typically lower rate of natural mortality. However, the region sustained an unusually good recruitment event in 2010 and these smaller animals suffered a lesser mortality in 2011 than the marketable size classes. Condition was extremely poor at survey time. The SARC emphasizes that the status of the stock in this region requires that a precautionary approach be taken in 2012. Furthermore, the SARC expresses concern that condition was low enough that a significant overwinter mortality event might occur. The SARC, therefore, recommends that the intermediate transplant be no higher than the 40^{th} percentile. In 2011, the transplant was distributed across the three beds. The 2011 mortality event was modestly lower on Arnolds, suggesting that Arnolds might be targeted preferentially in 2012. However, the SARC recommends that a resampling of survey

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[ϒ] Op. cit.

grids be conducted prior to the transplant. A significant increase in mortality rate since the fall survey would indicate ongoing damage from the flood and subsequent low condition that would necessitate that this bed region be closed in 2012. The SARC notes that resampling the survey grids will permit a simple difference test, with H0: the difference between the fall 2011 and April mortality estimates = 0. A significant result (one-sided $\alpha = 0.05$) would engender a bed region closure.

The very-low-mortality beds suffered an extreme mortality event in 2012. Modeling using DyPoGEn suggests a 10-yr recovery time frame. Stock performance reference points were estimated for the first time in 2012. These are considered provisional. Nevertheless, the very-low-mortality beds are below the SSB threshold and above, but near the abundance and market-abundance threshold. As the abundance threshold in particular may be underestimated, it is possible that this region falls below the abundance threshold. As a consequence of its uniquely poor stock status, the SARC recommends that this bed region be closed for 2012.

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.

Projections for intermediate transplant are provided in Table 32.

Science and Management Issues

Management Issues

Abundance is near or below the abundance target in most bay regions and near or below the threshold in three of six. 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 resurvey 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 in 2012 resulted in a transplant of seed to Bennies. The SARC recommends that this transplant be treated as a shell plant and followed for three years, rather than the typical 1-yr, as is done for other intermediate transplants.

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 2011-2012 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.

An evaluation of the rate of box disarticulation on the very-low-mortality beds is needed to determine the degree to which the 2011 mortality event may falsely bias high the 2012 survey estimate of mortality.

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 importance of the variables used in the dredge calibration multiple regression model should be examined to determine if any one variable is responsible for the tendency for tow-based dredge efficiencies to be estimated higher than experimental observations on the high-mortality beds.

Spat growth rates upbay of Shell Rock are needed to reconfigure the recruitment index and retire the 20-mm rule. The growth rates that are present from the 2005-2011 shell plants should be examined to develop an improved spat cut-off size for the high-mortality beds, Shell Rock, and the medium-mortality market beds. The same analysis should be used to update the growth indices.

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.

A field experiment should be undertaken to evaluate the influence of dredging on recruitment.

Resurvey data should be evaluated to determine the frequency and extent of overwintering mortality.

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

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.

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 .

Data on fecundity and spawning potential are needed for oysters on the very-low-mortality beds.

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	Year Resurveyed		
Cohansey	83	132	2009
Bennies Sand	49		
Year 2			
Ship John	68	136	2010
Nantuxent Point	68		
Year 3			
Beadons	38	136	2011
Middle	51		
Vexton	47		
Year 4			
Sea Breeze	48	141	Scheduled in 2012
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. 2011 sampling scheme for the Fall survey of the Delaware Bay oyster beds in New Jersey. The numbers given are the number of samples devoted to that bed stratum. Ledge was not sampled.

Sampled Bed	High-quality	Medium-quality	Low-quality	Transplant
Hope Creek	4	4	0	0
Fishing Creek	2	3	0	0
Liston Range	2	4	0	0
Round Island	2	3	0	0
Upper Arnolds	2	3	0	0
Arnolds	3	3	0	0
Upper Middle	1	3	0	0
Cohansey	5	5	0	1
Ship John	6	5	0	0
Middle	3	4	0	1
Sea Breeze	3	2	0	0
Shell Rock	4	4	0	3
Bennies Sand	3	6	0	3
Bennies	3	9	0	3
New Beds	2	7	0	0
Nantuxent Point	3	3	0	1
Hog Shoal	3	3	0	0
Strawberry	1	3	0	0
Vexton	2	2	0	0
Beadons	2	3	0	0
Hawk's Nest	2	3	0	0
Egg Island	1	5	0	0
Ledge	0	0	0	0
Total	59	87	0	12

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 2011 random sampling program for the Delaware Bay natural oyster beds of New Jersey. Included for comparison are data for 2009 and 2010. 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[℈].

[℈] The use of weighted averages represents a change from SAW reference documents prior to 2007 (the 10th 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		
		2011	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009
Hope Creek	1.6	37.0 M	64.2 H	59.6 H																								
Hope Creek	4.2	30.5 H	58.8 H	54.3 M																								
Hope Creek	3.6	29.6 H	58.3 H	52.8 H																								
Hope Creek	3.6	27.1 H	57.2 M	52.4 M	317	453	399	10	290	32	46	8	6	10	20	05	0.30	0.20	0.25	33	87	110	10	19	27	0.003	0.007	0.006
Hope Creek	0.0	24.8 M	52.4 H	47.8 H																								
Hope Creek	4.5	24.7 M	41.0 M	42.8 H																								
Hope Creek	3.4	23.7 M	34.1 M	37.7 M																								
Hope Creek	5.0	22.9 H	32.9 M	37.3 M																								
Liston Range	1.2	54.2 M	75.2 H	73.5 M																								
Liston Range	5.0	39.1 H	42.7 H	59.6 H																								
Liston Range	0.3	35.9 H	39.7 M	57.8 H	352	316	428	19	164	29	21	4	4	10	10	10	0.30	0.50	0.05	72	83	139	20	26	32	0.004	0.008	0.006
Liston Range	1.1	30.0 M	35.2 M	57.3 M																								
Liston Range	0.6	28.5 M	34.7 M	46.9 M																								
Liston Range	0.7	13.0 M	12.3 M	40.2 M																								
Fishing Creek	3.6	41.1 M	62.8 M	64.3 H																								
Fishing Creek	4.5	36.1 H	54.6 H	63.0 M	224	350	331	4	190	28	48	12	7	0	50	20	0.00	0.10	0.50	23	113	164	10	32	49	0.005	0.007	0.007
Fishing Creek	3.0	28.3 M	51.3 H	60.2 M																								
Fishing Creek	0.6	21.1 M	36.3 M	44.0 M																								
Fishing Creek	2.0	14.6 H	31.2 M	37.6 H																								
Round Island	6.7	48.8 H	64.5 H	56.2 H																								
Round Island	3.9	42.7 M	54.3 M	46.8 M	294	348	260	15	203	23	28	19	10	0	70	50	0.00	1.10	0.90	39	130	118	13	37	45	0.004	0.007	0.007
Round Island	1.3	35.3 M	50.6 M	45.9 H																								
Round Island	4.6	32.6 H	47.5 M	35.2 M																								
Round Island	0.1	2.2 M	40.4 H	17.7 M																								
Upper Arnolds	2.7	54.0 H	58.5 H	65.3 H																								
Upper Arnolds	0.5	46.7 M	58.3 H	64.2 H	295	288	343	24	141	29	28	21	15	15	90	65	0.40	1.10	1.40	75	85	149	25	29	43	0.005	0.007	0.007
Upper Arnolds	3.3	38.7 H	45.0 M	61.3 M																								
Upper Arnolds	3.7	36.7 M	32.6 M	46.9 M																								
Upper Arnolds	3.1	20.6 M	18.5 M	46.5 M																								

Bed	Bushels/ Haul	Percent Oyster			Oysters/ Bushel			Spat/ Bushel			Percent Mortality			Dermo Prevalence			Dermo Weighted Prevalence			Size #/bu >2.5″			Size %oysters >2.5″			Condition Index/ Dry-Meat/Height		
		2011	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009
Arnolds	2.9	62.9 H	72.1 H	64.3 H																								
Arnolds	4.2	59.6 H	66.7 H	54.7 H																								
Arnolds	3.7	57.7 H	61.4 H	53.4 M	279	302	335	23	126	42	20	17	16	15	75	55	0.20	1.20	1.48	52	87	121	19	29	36	0.005	0.009	0.006
Arnolds	0.5	35.8 M	57.8 M	52.5 H																								
Arnolds	4.3	18.6 M	25.9 M	49.5 M																								
Arnolds	3.6	10.2 M	18.3 M	41.1 M																								
Upper Middle	4.7	40.3 H	57.4 M	34.6 M																								
Upper Middle	1.1	25.1 M	50.2 H	19.7 M	118	212	80	5	109	30	21	20	28	15	65	85	0.30	0.90	2.48	31	67	37	26	32	47	0.007	0.010	0.007
Upper Middle	1.1	6.1 M	27.2 M	19.5 H																								
Upper Middle	0.8	5.1 M	0.0 M	0.0 M																								
Middle	1.7	74.5 H	57.3 H	75.4 T																								
Middle	4.7	59.1 H	48.2 M	49.5 H																								
Middle	1.4	39.1 M	34.9 M	38.7 H																								
Middle	4.3	33.7 H	33.1 H	37.9 M	216	187	124	32	118	40	17	22	27	40	65	75	1.10	1.40	1.78	64	62	59	30	33	47	0.006	0.011	0.009
Middle	1.6	31.0 M	5.6 M	8.4 M																								
Middle	4.2	29.8 M		2.0 M																								
Middle	1.1	28.8 T																										
Middle	2.9	16.6 M																										
Ship John	2.7	71.4 H	72.0 H	63.0 T																								
Ship John	3.7	68.6 H	69.8 M	63.0 H																								
Ship John	2.0	67.3 M	69.1 H	55.9 T																								
Ship John	3.2	63.0 H	60.6 M	52.5 T																								
Ship John	4.5	62.0 H	59.1 M	52.4 T																								
Ship John	6.1	59.2 M	58.6 H	43.7 H	299	255	153	77	167	86	14	22	27	75	95	100	1.50	2.40	2.33	69	91	70	23	36	46	0.006	0.011	0.009
Ship John	3.5	57.2 H	57.6 H	43.3 T																								
Ship John	5.4	55.8 H	56.9 H	41.5 M																								
Ship John	4.5	52.1 M	52.0 H	40.4 H																								
Ship John	3.6	9.8 M	44.2 M	37.0 M																								
Ship John	2.7	8.0 M	23.8 M	21.6 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		
		2011	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009
Cohansey	3.3	75.1 H	74.6 T	70.6 M																								
Cohansey	4.9	73.5 H	63.7 M	63.0 H																								
Cohansey	5.1	69.4 H	59.2 H	57.0 H																								
Cohansey	1.5	65.1 T	57.6 M	56.6 M																								
Cohansey	3.0	64.3 H	53.1 H	54.7 T																								
Cohansey	4.0	62.9 M	46.5 H	47.5 H	253	228	173	25	131	96	15	19	24	70	95	80	0.90	2.10	2.38	78	67	84	31	29	48	0.008	0.010	0.011
Cohansey	4.2	61.2 H	41.2 H	44.4 T																								
Cohansey	3.4	42.3 M	36.0 M	40.3 H																								
Cohansey	2.4	31.9 M	30.4 H	33.8 M																								
Cohansey	2.1	31.9 M	27.9 M	33.3 M																								
Cohansey	2.4	19.3 M	27.7 M	31.2 H																								
Cohansey				26.1 M																								
Sea Breeze	3.2	61.9 M	74.3 H	49.2 M																								
Sea Breeze	2.2	50.6 H	64.9 M	44.3 M	413	250	221	71	277	141	13	13	12	70	95	90	1.60	1.60	1.93	64	68	60	16	27	27	0.007	0.010	0.012
Sea Breeze	4.8	45.3 H	64.0 H	40.1 H																								
Sea Breeze	2.6	31.9 M	18.4 M	34.1 H																								
Sea Breeze	1.9	28.9 H	18.0 H	29.1 H																								
Shell Rock	4.0	81.9 T	85.2 T	61.6 T																								
Shell Rock	4.4	79.9 H	82.1 T	57.7 H																								
Shell Rock	2.5	76.7 T	82.0 M	54.4 M																								
Shell Rock	4.3	72.1 H	80.0 T	52.2 H																								
Shell Rock	7.0	71.2 M	76.8 H	50.3 H	367	482	157	77	481	190	15	11	24	85	85	100	1.60	1.80	2.90	76	97	69	21	20	44	0.009	0.008	0.010
Shell Rock	4.9	69.8 H	76.5 H	45.0 H																								
Shell Rock	3.1	67.8 M	75.4 H	42.2 M																								
Shell Rock	3.6	56.5 H	72.5 H	23.5 M																								
Shell Rock	5.2	54.7 T	64.8 M	9.2 M																								
Shell Rock	1.9	36.1 M	55.1 M																									
Shell Rock	1.3	18.3 M	39.4 M																									

Bed	Bushels/ Haul	Percent Oyster 2011	Percent Oyster 2010	Percent Oyster 2009	Oysters/ Bushel 2011	Oysters/ Bushel 2010	Oysters/ Bushel 2009	Spat/ Bushel 2011	Spat/ Bushel 2010	Spat/ Bushel 2009	Percent Mortality 2011	Percent Mortality 2010	Percent Mortality 2009	Dermo Prevalence 2011	Dermo Prevalence 2010	Dermo Prevalence 2009	Dermo Weighted Prevalence 2011	Dermo Weighted Prevalence 2010	Dermo Weighted Prevalence 2009	Size #/bu >2.5″ 2011	Size #/bu >2.5″ 2010	Size #/bu >2.5″ 2009	Size %oysters >2.5″ 2011	Size %oysters >2.5″ 2010	Size %oysters >2.5″ 2009	Condition Index/ Dry-Meat/Height 2011	Condition Index/ Dry-Meat/Height 2010	Condition Index/ Dry-Meat/Height 2009
Bennies Sand	4.7	74.1 T	81.0 T	61.7 T																								
Bennies Sand	2.8	41.2 H	54.4 T	56.7 H																								
Bennies Sand	3.2	39.1 T	50.2 T	45.0 H																								
Bennies Sand	3.4	33.1 H	45.6 M	43.7 T																								
Bennies Sand	6.5	32.9 H	43.1 T	35.0 T																								
Bennies Sand	2.9	19.7 M	39.8 H	24.9 M	117	208	98	101	129	118	25	22	26	60	90	95	0.80	2.30	2.70	37	58	41	32	28	42	0.009	0.010	0.012
Bennies Sand	1.8	18.4 M	27.8 M	24.0 M																								
Bennies Sand	4.0	17.1 M	25.8 M	20.3 M																								
Bennies Sand	2.0	16.9 M	25.8 M	18.2 H																								
Bennies Sand	1.6	16.3 M	23.0 M	12.7 M																								
Bennies Sand	3.2	9.3 T	21.6 H	8.3 M																								
Bennies Sand	4.9	5.6 M	14.3 M	3.9 M																								
Bennies	5.0	21.2 T	43.8 T	31.3 T																								
Bennies	3.3	20.9 T	39.4 M	24.3 H																								
Bennies	2.3	19.4 H	35.0 H	17.1 H																								
Bennies	0.5	17.8 M	24.4 T	15.8 T																								
Bennies	2.5	9.2 H	16.6 M	11.6 M																								
Bennies	3.4	3.3 M	13.4 H	11.1 H																								
Bennies	4.1	2.7 T	11.9 M	5.0 M	16	44	17	36	20	18	32	34	39	80	100	100	1.50	3.60	3.10	10	19	12	59	43	72	0.011	0.015	0.018
Bennies	4.0	1.2 M	11.6 M	3.3 M																								
Bennies	4.5	0.9 M	10.4 M	2.2 M																								
Bennies	2.3	0.6 M	5.7 H	2.2 M																								
Bennies	3.9	0.3 M	4.0 M	0.9 M																								
Bennies	4.4	0.1 H	1.3 M	0.7 M																								
Bennies	1.0	0.0 M	0.3 M	0.0 M																								
Bennies	4.6	0.0 M	0.2 M	0.0 M																								
Bennies	1.9	0.0 M																										
Hog Shoal	3.1	43.3 M	48.2 H	52.2 H																								
Hog Shoal	2.4	36.8 M	44.1 M	42.9 M																								
Hog Shoal	4.1	28.8 H	33.2 H	42.2 H	97	119	116	90	103	279	22	24	31	95	85	100	2.30	1.50	3.40	35	29	46	36	24	40	0.010	0.010	0.013
Hog Shoal	5.9	21.9 H	6.7 H	21.0 H																								
Hog Shoal	1.9	7.9 H	2.8 M	17.2 M																								
Hog Shoal	2.1	3.5 M	0.7 M	13.4 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		
		2011	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009
Nantuxent Point	2.3	72.9 H	72.5 H	60.0 T																								
Nantuxent Point	0.6	38.1 M	67.2 T	53.5 H																								
Nantuxent Point	5.4	31.6 T	60.8 T	50.5 T																								
Nantuxent Point	4.7	29.7 H	58.4 M	48.6 T																								
Nantuxent Point	4.3	25.6 H	57.9 H	46.8 M	146	329	172	69	340	287	30	22	24	95	100	85	2.20	1.80	2.93	35	58	45	24	18	26	0.011	0.012	0.009
Nantuxent Point	1.2	11.5 M	50.4 T	44.0 H																								
Nantuxent Point	1.5	4.0 M	45.4 H	35.7 H																								
Nantuxent Point			31.3 M	18.6 M																								
Nantuxent Point			23.8 M	11.1 T																								
Nantuxent Point				10.8 M																								
New Beds	3.9	18.4 H	27.8 H	25.5 H																								
New Beds	2.4	17.3 M	22.7 M	16.9 M																								
New Beds	3.9	10.1 H	17.8 M	16.0 H																								
New Beds	3.1	9.9 M	17.2 H	7.0 M	36	43	24	93	17	29	25	38	41	100	100	100	2.80	2.60	2.50	20	22	14	54	51	60	0.014	0.018	0.016
New Beds	2.0	9.5 M	15.0 M	6.5 M																								
New Beds	1.3	9.2 M	6.1 M	4.4 M																								
New Beds	4.7	8.6 M	5.5 M	3.0 M																								
New Beds	2.3	3.4 M	2.2 M	2.3 M																								
New Beds	2.0	3.2 M	0.5 M	0.0 M																								
Strawberry	0.1	37.2 M	4.6 M	10.3 H																								
Strawberry	4.6	7.9 M	3.4 H	4.0 M	71	7	6	40	4	2	27	51	57	55	90	100	1.30	2.40	3.23	21	3	4	30	44	78	0.015	0.011	0.019
Strawberry	0.4	4.1 M	0.4 M	0.4 M																								
Strawberry	4.8	2.8 H	0.0 M	0.3 M																								
Hawk's Nest	2.2	57.7 M	85.6 M	69.7 M																								
Hawk's Nest	2.1	39.1 H	32.7 H	45.3 H	186	278	208	104	252	195	23	23	17	75	90	100	1.30	1.70	2.95	47	60	36	26	21	17	0.011	0.010	0.011
Hawk's Nest	1.7	36.6 H	14.0 H	23.6 H																								
Hawk's Nest	1.2	10.8 M	12.0 M	8.3 M																								
Hawk's Nest	1.8	0.4 M	1.7 M	6.0 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		
		2011	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009	**2011**	2010	2009
Vexton	2.9	31.7 H	15.5 H	4.0 M																								
Vexton	6.4	6.6 H	4.4 H	1.7 H	31	31	6	94	46	5	29	16	60	85	80	95	2.50	1.30	3.77	6	5	2	21	15	28	0.011	0.009	0.010
Vexton	5.1	2.9 M	2.0 M	1.2 H																								
Vexton	0.1	0.0 M	0.7 M	0.3 M																								
Vexton			0.0 M	0.0 M																								
Beadons	0.2	48.6 M	78.4 H	25.6 H																								
Beadons	0.1	26.6 M	67.1 H	20.9 M																								
Beadons	1.8	14.9 H	19.0 H	19.6 H	182	315	72	362	300	101	15	9	34	65	70	80	1.40	1.50	2.80	21	10	18	11	3	25	0.007	0.006	0.013
Beadons	0.5	11.6 M	2.5 M	14.5 M																								
Beadons	4.3	10.5 H	2.5 M	10.0 M																								
Beadons			2.3 M	9.6 H																								
Beadons			1.5 M	4.1 M																								
Ledge			0.5 M																									
Ledge			0.3 M			1			0			63			80			1.80			1			87			0.035	
Ledge			0.2 H																									
Ledge			0.0 M																									
Ledge			0.0 M																									
Egg Island	4.6	2.1 M		0.7 M																								
Egg Island	1.9	2.0 M		0.6 M																								
Egg Island	4.4	0.3 M		0.6 H																								
Egg Island	3.9	0.3 H		0.5 M	4		1	8		0	31		62	71			2.00			1		1	29		84	0.015		0.031
Egg Island	0.6	0.0 M		0.0 M																								
Egg Island	2.6	0.0 M		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 1990-2011 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 1990-2011: oyster abundance = 167; spat abundance = 90.

Oyster Abundance

Tukey's Rankings								Mean	Year
A								262.18	1996
A	B							242.10	1990
A	B	C						236.95	1992
A	B	C	D					210.55	1991
A	**B**	**C**	**D**	**E**				**199.20**	**2011**
A	B	C	D	E	F			195.80	1995
A	B	C	D	E	F			195.41	2010
A	B	C	D	E	F			186.57	1997
A	B	C	D	E	F	G		182.63	1998
	B	C	D	E	F	G		178.10	1993
	B	C	D	E	F	G		168.92	2000
		C	D	E	F	G	H	154.69	1994
			D	E	F	G	H	153.01	2009
			D	E	F	G	H	148.80	1999
			D	E	F	G	H	144.89	2001
			D	E	F	G	H	143.64	2008
			D	E	F	G	H	133.92	2002
				E	F	G	H	122.98	2003
				E	F	G	H	122.59	2007
					F	G	H	113.30	2004
						G	H	101.08	2006
							H	81.46	2005

Spat Abundance

Tukey's Rankings						Mean	Year
A						266.61	1991
A	B					209.11	1997
A	B	C				204.37	1999
	B	C				174.72	1994
	B	C	D			156.34	1995
	B	C	D			154.05	1990
	B	C	D			141.37	2010
		C	D	E		125.80	1998
			D	E	F	87.71	2009
			D	E	F	81.24	2007
			D	**E**	**F**	**76.60**	**2011**
				E	F	46.13	2002
					F	44.73	1993
					F	35.12	2000
					F	29.12	2008
					F	25.00	1992
					F	24.17	1996
					F	22.62	2004
					F	20.37	2003
					F	19.18	2005
					F	18.75	2006
					F	12.18	2001

Table 6. Percentile positions in the indicated time series for the given bay regions and stock variables. Note that a lower percentile equates with a lower value of the variable relative to the entire 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	Biomass Mortality*	Fishing Mortality$^{\triangle}$	Market Fishing Mortality*
Bay-wide: 1953-2011	.280			.331	.415	.669		.330	
Bay-wide: 1989-2011	.375	.159	.667	.457	.500	.413	.667	.656	.857
Low-mortality: 1953-2011	.161			.127	.212	.941		.802	
Low-mortality: 1989-2011	.326	.114	.524	.152	.239	1.000	1.000	.767	.643
Medium-mortality Transplant: 1953-2011	.415			.246	.280	.653		.647	
Medium-mortality Transplant: 1989-2011	.630	.205	.810	.326	.375	.500	.500	.767	.786
Medium-mortality Market: 1953-2011	.517			.364	.297	.551		.560	
Medium-mortality Market: 1989-2011	.600	.295	.667	.457	.413	.375	.583	.500	.857
Shell Rock: 1953-2011	.636			.415	.246	.551		.491	
Shell Rock: 1989-2011	.848	.705	.857	.413	.196	.375	.250	.500	.786
High-mortality: 1953-2011	.127			.551	.856	.686		.457	
High-mortality: 1989-2011	.196	.075	.286	.630	.848	.413	.333	.633	.429

*SSB and market abundance values and biomass mortality used the 1990-2011 time series

$^{\triangle}$Whole-stock fishing mortality used the 1953-2011 and 1997-2011 time series

*Market-size fishing mortality used the 1997-2011 time series

Table 7. Average annual oyster and spat abundance per 37-qt. bushel for the medium-mortality beds for the 1990-2011 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 1990-2011: oyster abundance = 242; spat abundance = 102.

Oyster Abundance

Tukey's Rankings								Mean	Year
A								433.61	1996
A	B							363.77	2000
A	B	C						328.04	1990
A	**B**	**C**	**D**					**315.27**	**2011**
	B	C	D	E				304.43	1992
	B	C	D	E	F			290.91	1997
	B	C	D	E	F	G		270.36	1998
	B	C	D	E	F	G		257.91	2003
	B	C	D	E	F	G		254.75	1991
		C	D	E	F	G	H	234.45	2010
		C	D	E	F	G	H	232.99	2001
		C	D	E	F	G	H	226.94	1993
		C	D	E	F	G	H	211.90	2002
			D	E	F	G	H	207.60	1999
			D	E	F	G	H	197.28	1995
				E	F	G	H	195.53	1994
				E	F	G	H	191.16	2005
					F	G	H	179.59	2008
						G	H	171.88	2006
						G	H	168.45	2009
						G	H	157.24	2004
							H	132.04	2007

Spat Abundance

Tukey's Rankings						Mean	Year
A						302.38	1999
A	B					268.28	1991
A	B	C				195.48	1995
A	B	C				194.59	1998
	B	C				181.78	1994
	B	C	D			161.20	2010
		C	D	E		140.16	1990
		C	D	E	F	127.47	1997
		C	D	E	F	114.47	2007
		C	D	E	F	88.92	2002
		C	D	E	F	84.23	2009
			D	**E**	**F**	**59.41**	**2011**
			D	E	F	53.89	1993
			D	E	F	47.43	2000
				E	F	37.42	1996
				E	F	34.86	2006
				E	F	29.97	2004
				E	F	28.33	2003
				E	F	27.77	1992
				E	F	27.27	2005
				E	F	25.39	2008
					F	11.65	2001

Table 8. Average annual oyster and spat abundance per 37-qt. bushel for the low-mortality beds for the 1990-2011 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 1990-2011: oyster abundance = 380; spat abundance = 76.

Oyster Abundance

Tukey's Rankings							Mean	Year
A							698.22	1992
A	B						662.89	1991
A	B	C					587.68	1993
A	B	C	D				574.69	1990
A	B	C	D	E			482.69	1995
	B	C	D	E	F		450.44	1994
		C	D	E	F	G	405.47	2002
		C	D	E	F	G	375.39	2001
			D	E	F	G	353.05	1996
				E	F	G	345.84	2010
				E	F	G	336.80	2009
				E	**F**	**G**	**329.78**	**2011**
				E	F	G	327.77	1999
				E	F	G	318.13	2000
				E	F	G	310.92	1997
				E	F	G	309.79	2003
				E	F	G	302.39	2008
				E	F	G	262.81	2005
				E	F	G	258.54	1998
					F	G	254.58	2004
						G	220.83	2006
						G	199.00	2007

Spat Abundance

Tukey's Rankings						Mean	Year
A						370.54	1991
	B					227.59	1990
	B	C				179.47	2010
		C	D			116.91	1999
		C	D	E		98.58	1998
			D	E	F	84.06	1995
			D	E	F	83.54	1994
			D	E	F	80.09	2007
			D	E	F	52.81	2005
			D	E	F	51.88	1996
			D	E	F	51.83	1997
			D	E	F	47.50	2008
			D	E	F	44.67	2002
			D	E	F	38.29	1992
			D	E	F	35.93	2009
				E	F	23.00	1993
				E	**F**	**22.41**	**2011**
				E	F	20.15	2000
				E	F	15.72	2006
				E	F	13.96	2001
					F	10.63	2003
					F	4.95	2004

Table 9. Average annual oyster and spat abundance per 37-qt. bushel for the high-mortality beds for the 1990-2011 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 1990-2011: oyster abundance = 106; spat abundance = 100.

Oyster Abundance

Tukey's Rankings						Mean	Year
A						230.33	1996
A	B					161.61	1995
A	B	C				159.26	1998
A	B	C				157.79	1990
A	B	C				152.35	1992
A	B	C	D			148.86	2010
A	B	C	D	E		132.09	1997
	B	C	D	E	F	117.31	2009
	B	C	D	E	F	114.23	1994
	B	C	D	E	F	112.27	1991
	B	C	D	E	F	106.20	1999
	B	**C**	**D**	**E**	**F**	**96.88**	**2011**
	B	C	D	E	F	87.58	2000
	B	C	D	E	F	83.71	2008
	B	C	D	E	F	77.42	2001
	B	C	D	E	F	74.96	1993
	B	C	D	E	F	67.03	2006
	B	C	D	E	F	62.90	2005
		C	D	E	F	61.87	2004
			D	E	F	50.32	2007
				E	F	45.74	2003
					F	29.03	2002

Spat Abundance

Tukey's Rankings							Mean	Year
A							306.63	1997
A	B						272.61	1991
A	B	C					247.31	1994
A	B	C	D				201.29	1999
A	B	C	D	E			182.36	1995
	B	C	D	E	F		160.97	1990
	B	C	D	E	F	G	135.27	1998
		C	D	E	F	G	126.68	2010
		C	**D**	**E**	**F**	**G**	**110.87**	**2011**
		C	D	E	F	G	110.18	2009
			D	E	F	G	66.20	2007
				E	F	G	48.98	1993
				E	F	G	43.96	2000
					F	G	29.25	2008
					F	G	26.61	2002
					F	G	24.77	1992
					F	G	24.00	2004
						G	20.13	2003
						G	17.35	1996
						G	15.20	2005
						G	13.83	2001
						G	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. Submarket surplus as projected for 2010 and 2011 by SAW-12 and SAW-13 and as projected for 2012. Projections for 2012 were conducted using the 50^{th} and 75^{th} percentiles of natural mortality and a conversion of 265 oysters bu^{-1}. Mortality rate for the very-low-mortality beds was chosen to represent a high and a low value from the 2007-2011 time series. Growth rate on the very-low-mortality beds was assumed to be similar to that on the low-mortality beds.

SAW-12 Submarket Surplus Estimate for 2010

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

SAW-13 Submarket Surplus Estimate for 2011

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

SAW-14 Submarket Surplus Estimate for 2012

Bay Region	50^{th} Percentile Estimate Submarket Surplus (market-equivalent bushels)	75^{th} Percentile Estimate Submarket Surplus (market-equivalent bushels)
Very-low mortality	24,903	24,170
Low mortality	61,567	58,526
Medium mortality		
Transplant	149,274	133,297
Market	304,149	265,258
Shell Rock	87,424	80,712
High mortality	73,821	57,988
Total	671,826	619,951

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 7. Parentheses show the ratio taking into account recruitment enhancement through shell planting.

Year	Very Low Mortality	Low Mortality	Medium Mortality Transplant	Medium Mortality Market	Shell Rock	High Mortality
1996		0.19	0.13	0.08	0.09	0.12
1997		0.20	0.48	0.70	0.92	3.06
1998		0.92	1.68	1.91	1.64	2.03
1999		0.59	1.93	2.19	4.04	4.54
2000		0.15	0.27	0.17	0.79	1.08
2001		0.05	0.05	0.09	0.22	0.44
2002		0.20	0.73	0.35	4.59	0.86
2003		0.05	0.15	0.16	0.38	1.28 (1.54)
2004		0.05	0.21	0.23	1.85	2.07
2005		0.31	0.17	0.21	0.46 (1.01)	0.54 (0.62)
2006		0.14	0.40	0.33	0.32 (0.64)	0.42 (1.00)
2007	0.37	0.18	0.78 (0.88)	1.71 (1.80)	1.53	2.54 (2.59)
2008	0.39	0.22	0.12	0.09 (0.10)	0.50	0.86 (1.64)
2009	0.11	0.15	0.71	0.66	1.89 (2.75)	2.12 (2.56)
2010	0.87	0.74	0.97	0.81	1.37 (1.94)	1.57 (2.12)
2011	0.05	0.10	0.22 (0.27)	0.27	0.31 (0.46)	3.03 (3.15)

Table 13. Summary of shell-planting activities for 2011. Shell-planting was carried out in early summer, 2011. Direct plants occurred on Shell Rock 11 and Bennies Sand 11. The replant of spatted clamshell was moved from downbay up to Middle 26 by suction dredge primarily in October 2011. 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 1989-2011 time series: for the Medium Mortality beds, 0.187, 0.155, 0.155; for Shell Rock, 0.459, 0.187, 0.187; for the High Mortality beds: 0.446, 0.257. 0.257, for years 1, 2, and 3, respectively. Bushel conversions assume 265 oysters per bushel.

Site	Plant Type	Clamshell Planted (bu)	Spat Collected	Spat/Bu	Potential Yield (bushels)
Middle 26	Replant	18,000	342,000	19	724
Shell Rock 11	Direct	50,000	38,350,000	767	49,011
Bennies Sand 11	Direct	50,000	18,600,000	372	18,898
Total		118,000	57,292,000		68,633

Table 14. Summary of 2011 recruitment on 2010 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 1989-2011 time series: for Shell Rock, 0.459, 0.187, 0.187; for the High Mortality beds: 0.446, 0.257. 0.257, for years 1, 2, and 3, respectively. Bushel conversions assume 265 oysters per bushel.

Site	Plant Type	Clamshell Planted (bu)	Spat Collected	Spat/Bu	Potential Yield (bushels)
Shell Rock 23	Direct	40,199	22,029,052	548	28,153
Bennies Sand 4	Direct	49,645	21,396,995	431	21,740
Total		89,844	43,426,047		49,893

Table 15. Average half-lives for surficial oyster shell on Delaware Bay oyster beds, for the 1999-2011 time period.

Location	Half-life (yr)
Hope Creek	insufficient data
Fishing Creek	insufficient data
Liston Range	insufficient data
Round Island	insufficient data
Upper Arnolds	7.67
Arnolds	7.09
Upper Middle	insufficient data
Middle	6.29
Cohansey	5.56
Ship John	3.49
Sea Breeze	33.17
Shell Rock	4.62
Bennies Sand	10.61
Bennies	11.12
Nantuxent Point	3.58
Hog Shoal	4.71
Hawk's Nest	4.61
Strawberry	19.65
New Beds	36.22
Beadons	9.55
Vexton	18.80
Egg Island	78.65
Ledge	5.84

Table 16. The one-year transition probabilities for the broodstock-recruitment diagram shown as Figure 41 for each quadrant in the 59-year time series and mean first passage times. The 1989-2011 first passage times are also based on the 59-yr medians. The medians are: abundance $= 2.86 \times 10^9$, recruitment $= 1.70 \times 10^9$. Quadrant definitions are in Figure 42. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.63	0.11	0.11	0.16
2→	0.44	0.22	0.00	0.33
3→	0.11	0.33	0.33	0.22
4→	0.10	0.10	0.20	0.60

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	3.00	6.98	8.12	5.22
2→	3.98	6.33	8.81	4.27
3→	5.59	4.89	6.33	4.51
4→	6.29	6.69	6.73	2.85

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.333	0.158	0.158	0.351

Mean First Passage Time (years): 1989-2011

Quadrant	1	2	3	4
1→	1.60	14.33	9.43	10.60
2→	3.22	8.78	10.14	6.80
3→	3.11	8.67	7.52	10.20
4→	3.44	9.00	7.86	7.90

Table 17. The one-year transition probabilities for the broodstock-mortality diagram shown as Figure 43 for each quadrant in the 59-year time series and the mean first passage times. The 1989-2011 first passage times are also based on the 59-yr medians. The medians are: abundance = 2.86×10^9, mortality fraction= 0.14. Quadrant definitions are in Figure 42. 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→	0.31	0.50	0.00	0.19
3→	0.06	0.00	0.77	0.18
4→	0.25	0.33	0.17	0.25

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	5.07	4.43	10.61	4.78
2→	3.78	3.29	12.55	4.99
3→	7.81	8.96	3.47	5.45
4→	4.75	4.81	10.44	4.77

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.20	0.30	0.29	0.21

Mean First Passage Time (years): 1989-2011

Quadrant	1	2	3	4
1→	4.85	2.00	Un-est	3.60
2→	3.52	1.80	Un-est	5.20
3→	5.15	3.00	Un-est	1.00
4→	4.15	2.00	Un-est	4.20

Table 18. The one-year transition probabilities for the recruitment-mortality diagram shown as Figure 44 for each quadrant in the 59-year time series and the mean first passage times. The 1989-2011 first passage times are also based on the 59-yr medians. The medians are: recruitment = 1.70×10^9, mortality fraction = 0.14. Quadrant definitions are in Figure 42. Arrows indicate trajectory direction.

One-year Transition Probabilities

Quadrant	1	2	3	4
1→	0.17	0.50	0.17	0.17
2→	0.19	0.50	0.13	0.19
3→	0.18	0.06	0.65	0.12
4→	0.33	0.17	0.08	0.42

Mean First Passage Time (years)

Quadrant	1	2	3	4
1→	4.73	3.28	8.72	6.24
2→	4.61	3.19	8.06	6.08
3→	4.84	5.95	3.83	6.97
4→	3.72	4.44	8.43	4.68

Distribution of Occurrence After Infinite Steps

Quadrant	1	2	3	4
	0.21	0.31	0.26	0.21

Mean First Passage Time (years): 1989-2011

Quadrant	1	2	3	4
1→	5.30	2.73	22.00	5.33
2→	4.50	1.93	26.50	6.89
3→	4.50	4.82	26.50	1.00
4→	3.50	3.82	25.50	3.93

Table 19. Harvest statistics for 2011. 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
Arnolds	2,548,739	0.00	0	0.00
Beadons	851,243	0.00	0	0.00
Bennies	8,404,238	0.33	4,997	0.05
Bennies Sand	3,190,495	1.51	8,825	0.09
Cohansey	4,995,452	1.88	19,074	0.20
Egg Island	4,045,293	0.00	0	0.00
Fishing Creek	1,273,459	0.00	0	0.00
Hawk's Nest	2,021,560	0.63	1,954	0.02
Hog Shoal	1,808,455	2.44	9,049	0.10
Hope Creek	2,970,947	0.00	0	0.00
Ledge	1,916,423	0.00	0	0.00
Liston Range	1,167,525	0.00	0	0.00
Middle	3,294,561	0.00	0	0.00
Nantuxent Point	2,552,807	1.53	5,467	0.06
New Beds	4,788,189	0.19	1,778	0.02
Round Island	1,910,960	0.00	0	0.00
Sea Breeze	2,338,640	0.00	0	0.00
Shell Rock	5,104,046	2.68	24,112	0.26
Ship John	4,890,278	2.11	19,212	0.20
Strawberry	1,808,668	0.00	0	0.00
Upper Arnolds	1,911,274	0.00	0	0.00
Upper Middle	0,956,159	0.00	0	0.00
Vexton	1,277,106	0.00	2	0.00
Total or Mean	66,026,520	1.48	94,470	1.00

Table 20. Statistics for oysters going to market, obtained from port sampling 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
2011	2.78	2.13	2.99	3.38	350	238

Table 21. Proportion of cultch moved downbay during intermediate transplant from the various bed regions targeted between 2003 and 2011. 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 (2003-2010)	Very Low Mortality	551	68%	30%	2%
	Low Mortality	439	67%	28%	5%
	Medium Mortality Transplant	334	65%	29%	5%
	Medium Mortality Market	325	75%	18%	7%
Culled Transplants (2011)	Very Low Mortality	601	73%	20%	8%
	Low Mortality	444	65%	25%	10%
	Medium Mortality Transplant	338	67%	23%	9%
Unculled Transplants (2004-2006)	Low Mortality	378	36%	61%	3%
	Medium Mortality Transplant	388	68%	30%	2%
	High Mortality	163	30%	64%	6%
Unculled Transplants 2011	Medium Mortality Transplant	396	68%	23%	9%
	High Mortality	1428	52%	46%	2%
Suction Dredge Transplants (2004)	Low Mortality	438	35%	61%	5%
	Overall Culled	433	69%	25%	7%
	Overall Unculled	551	51%	45%	4%
	Overall Suction	438	35%	61%	5%

Table 22. Transplant boat participation. A single letter identifies each boat. Large letters in bold indicate that an observer was aboard.

Date	Bed	Boat ID				
4/12/11	Hope Creek	**A**	B	C		
4/13/11	Hope Creek	A	**B**	C	D	
4/14/11	Hope Creek			**C**		
4/14/11	Liston Range	A	B		D	
4/15/11	Round Island	A			**D**	
4/18/11	Round Island	**A**			D	
4/15/11	Upper Arnolds		B			
4/18/11	Upper Arnolds		B	C		
4/18/11	Arnolds					E
4/19/11	Arnolds	A	B	C	D	
4/20/11	Middle	A		C		**E**
4/25/11	Middle	A	**B**	C	D	
4/26/11	Middle	A	B	C	**D**	E
4/27/11	Middle		B	**C**		E

Table 23. Comparison of offline samples taken throughout the day to thirds taken from the deck load at the end of the day. Data are arcsine square-root transformed volume fractions of samples sorted into: material containing live oyster (Oyster), material without live oyster but with dead oyster (Box), shell-only material (Cultch), or other material (Other). Comparisons were done by boat and bed. NS, not significant at $\alpha = 0.05$. The means for third and offline sample cultch fractions are given for comparison.

		Fractionated Sample Volume Significance				Cultch Fraction Mean	
Donor Bed	Boat ID	Oyster	Box	Cultch	Other	Offline	Thirds
Hope Creek	A	0.0019	NS	0.0032	NS	0.1661	0.1141
	C	NS	NS	NS	NS	0.1837	0.1836
	B	NS	NS	NS	NS	0.2079	0.2431
Round Island	A	0.0196	NS	0.0023	NS	0.2027	0.1420
	D	NS	NS	NS	NS	0.2467	0.2684
Middle	B	NS	NS	NS	NS	0.1931	0.2013
	E	NS	NS	NS	NS	0.1763	0.2032
	D	NS	NS	NS	NS	0.1893	0.2107
	C	NS	NS	NS	NS	0.2091	0.2387

Table 24. Randomization test results for the probability distribution of the cultch fractions from three thirds extracted with replacement from a set of twelve thirds from the deck load pile. In each case, the sample of three was compared to the probability distribution of all twelve. Because of the numbers of ties in the distribution resulting from the low observed sample number, a probability range is given in each case. NS, not significant at $\alpha = 0.05$.

Bed	Boat ID	Observed Mean of 3	Observed Mean of 12	Alpha Range	Significance
Hope Creek	A	0.175	0.114	0.056 - 0.063	NS
	C	0.219	0.184	0.131 - 0.138	NS
	B	0.236	0.243	0.432 - 0.438	NS
Round Island	A	0.137	0.144	0.423 - 0.428	NS
	D	0.227	0.268	0.158 - 0.165	NS
Middle	E	0.189	0.203	0.318 - 0.324	NS
	B	0.199	0.201	0.467 - 0.474	NS
	D	0.202	0.211	0.417 - 0.422	NS
	C	0.225	0.239	0.332 - 0.339	NS

Table 25. 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, with the exception of the very-low-mortality beds. The threshold is taken as half these values. Reference point estimates for the very-low-mortality beds are obtained by assuming the equivalent condition on a per-area basis to the low-mortality beds and using the low-mortality-bed numbers so-corrected as the base values (see text).

	Very Low Mortality Beds	Low Mortality Beds	Medium Transplant Mortality Beds	Medium Market Mortality Beds	Shell Rock	High Mortality Beds
Abundance						
Target (50^{th} Percentile)	451,681,800	531,733,632	342,824,960	850,364,224	113,350,896	473,125,088
Threshold (1/2 Target)	225,840,900	265,866,816	171,412,480	425,182,112	56,675,448	236,562,544
Spawning Stock Biomass						
Target (50^{th} Percentile)	149,078,151	175,499,360	178,104,672	337,117,920	62,450,392	267,982,768
Threshold (1/2 Target)	74,539,075	87,749,680	89,052,336	168,558,960	31,225,196	133,991,384
Market ($\geq 2.5''$) Abundance						
Target (50^{th} Percentile)	36,856,056	43,388,077	46,366,382	167,407,462	25,622,244	51,205,771
Threshold (1/2 Target)	18,428,028	21,694,039	23,183,191	83,703,731	12,811,122	25,602,886

Table 26. Confidence percentiles for the 2011-survey abundance point estimate with rank order based on the number of small market and large market animals. Values include the very-low-mortality beds.

Percentile	Oysters $<2.5''$	Oysters 2.5-$<2.95''$	Oysters $\geq 2.95''$	Total Oysters
10.	1,680,167,296	229,919,776	169,700,720	399,620,480
20.	2,238,537,984	228,730,336	191,801,248	420,531,584
30.	1,883,315,584	229,323,280	207,471,984	436,795,264
40.	1,774,941,440	246,050,544	206,483,344	452,533,888
50.	1,867,230,336	256,687,344	212,497,008	469,184,352
60.	2,116,059,776	258,334,672	226,395,440	484,730,112
70.	1,814,644,736	273,398,784	231,352,848	504,751,616
80.	2,006,999,680	288,149,216	243,089,552	531,238,784
90.	2,326,926,848	308,246,976	260,645,904	568,892,864

Table 27. Confidence percentiles for the 2011-survey abundance point estimate with rank order based on the total number of animals. Values include the very-low-mortality beds.

Percentile	Oysters <2.5″	Oysters 2.5-<2.95″	Oysters ≥2.95″	Total Oysters ≥ 2.5″
10.	1,660,516,864	222,918,448	213,403,664	2,096,838,912
20.	1,817,342,720	218,760,656	168,881,024	2,204,984,320
30.	1,897,724,672	207,788,688	194,176,320	2,299,689,728
40.	1,933,112,704	244,576,736	205,128,048	2,382,817,280
50.	1,990,353,792	258,180,800	212,075,984	2,460,610,560
60.	2,051,396,608	257,947,360	213,630,048	2,522,973,952
70.	1,988,535,296	328,606,016	294,460,448	2,611,601,664
80.	2,196,451,840	277,572,128	239,607,568	2,713,631,488
90.	2,315,461,888	298,543,168	261,987,744	2,875,992,832

Table 28. 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 41), predicted recruitment from each reduced by 5%, plotted adult mortality rate (Figure 43), median unrecorded mortality rate.

[2]Linear broodstock-recruitment curve for 0-4 billion animals; then Ricker curve (Figure 41), plotted adult mortality rate (Figure 43), median unrecorded mortality rate.

[3]Ricker recruitment curve (Figure 41), plotted adult mortality rate (Figure 43), median unrecorded mortality rate.

[4]Ricker recruitment curve (Figure 41), plotted adult mortality rate (Figure 43), mean unrecorded mortality rate.

[5]Ricker recruitment curve (Figure 41), average of background (10%) and plotted adult mortality rate (Figure 43), median unrecorded mortality rate.

Table 29. Percentiles of the real exploitation rates for all oysters for each region and for one bay region for oysters ≥2.5″ based on the fishing record for 1996-2006. The medium-mortality transplant bed group is Middle, Sea Breeze, and Upper Middle. The medium-mortality market bed group is Cohansey and Ship John. The all-oyster upper medium-mortality percentiles are also used for the low-mortality beds and the very-low-mortality beds.

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

Table 30. 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 31. 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 265 derived from the 2004-2011 port-sampling program. Arrows indicate recommended options. Footnotes identify alternatives available under specified conditions.

Bay Region	Percentile	Exploitation Rate	Number of Animals Removed	Direct-market Bushels
High Mortality	$\longrightarrow 40^{th}$	.0122	597,054	2,185
	$^{\Gamma}50^{th}$	.0652	3,094,618	11,678
	$^{\Gamma}60^{th}$	.0782	3,711,643	14,006
Shell Rock	$\longrightarrow 40^{th}$	.0870	4,463,587	16,844
	$\longrightarrow 50^{th}$	.0880	4,514,893	17,037
	$\longrightarrow 60^{th}$	.1140	5,848,839	22,071
Medium Mortality Market	$\longrightarrow 40^{th}$	.0178	3,581,466	13,515
	$\longrightarrow 50^{th}$	.0214	4,305,808	16,248
	$\longrightarrow 60^{th}$	.0267	5,372,199	20,272
	$\longrightarrow 100^{th}$	.0398	8,007,998	30,219
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 32. Projections for intermediate transplant assuming that intermediate transplant might 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 2011 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 265 animal/bu conversion. Percentiles for the very-low-mortality and low-mortality beds use the exploitation reference points for the medium-mortality transplant beds. The 50^{th} percentile exploitation rate of 0.0188 is the average of the 50^{th} and 60^{th} percentiles from Table 29, consistent with the decision made in earlier SAWs that the original gap between these two percentiles was too large for effective management. Footnotes identify alternatives available under specified conditions.

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	$^{\Psi}40^{th}$	.0127	4,894,750	332	14,743	3,965
	$^{\Psi}50^{th}$	.0188	7,245,772	332	22,502	5,869
	60^{th}	.0233	8,980,132	332	27,889	7,274
Low Mortality	$^{\Sigma}40^{th}$	.0127	4,730,022	419	11,289	3,509
	50^{th}	.0188	7,001,923	419	16,711	5,195
	60^{th}	.0233	8,677,914	419	20,711	6,426
Very Low Mortality	Closed					

$^{\Psi}$Recommended with the proviso that no more than 50% of the recommended number be taken from Middle

$^{\Sigma}$Recommended if resampling in April finds no significant increase in mortality relative to the 2011 survey.

§NA: not applicable to this reference point.

Figure 1. The footprint of the Delaware Bay natural oyster beds showing the locations of the high-quality (dark shade) and medium-quality (light shade) grids. Each grid is a rectangle 0.2-min latitude × 0.2-min longitude, equivalent to approximately 25 acres. The 2011 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. Beadons, Middle, and Vexton were re-surveyed in 2011 and their footprints updated on this map.

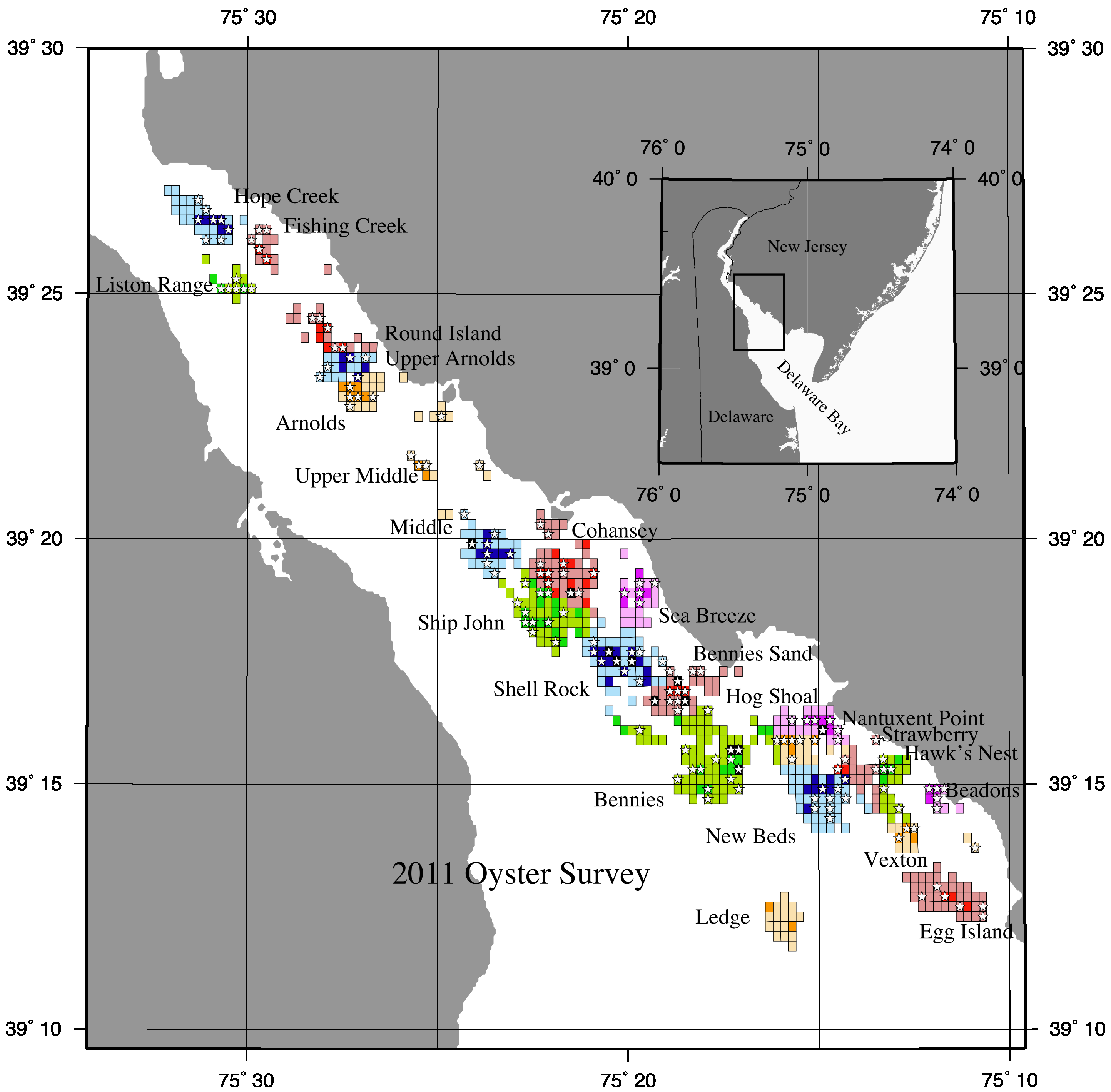


Figure 2. Relationship of cumulative abundance versus sample number for grids ordered by increasing abundance for all grids sampled on Middle, Vexton, and Beadons during the 2011 re-survey. The 2011 re-survey program covered all navigable grids associated with these beds. The vertical lines mark the boundary between the low-, medium-, and high-quality strata. The additional vertical line on the Beadons plot, marked 'added grids', shows additional grids retained in the medium-quality stratum (see text).

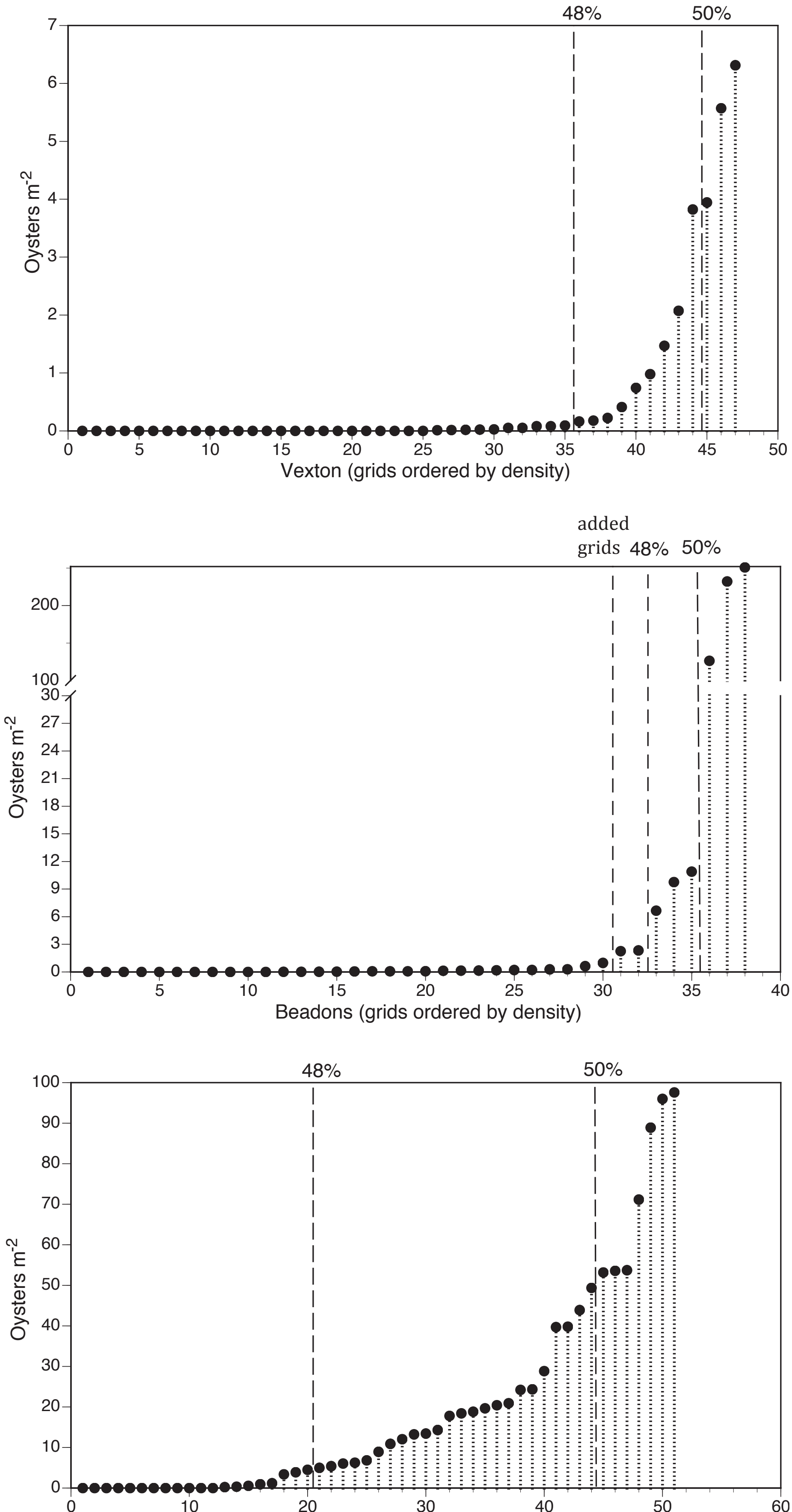


Figure 3. Distribution of grids for Middle, Beadons, and Vexton prior to the 2011 re-survey, shaded accordingly to oyster density. The 2011 survey program covered all navigable grids associated with these three beds. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded a light color.

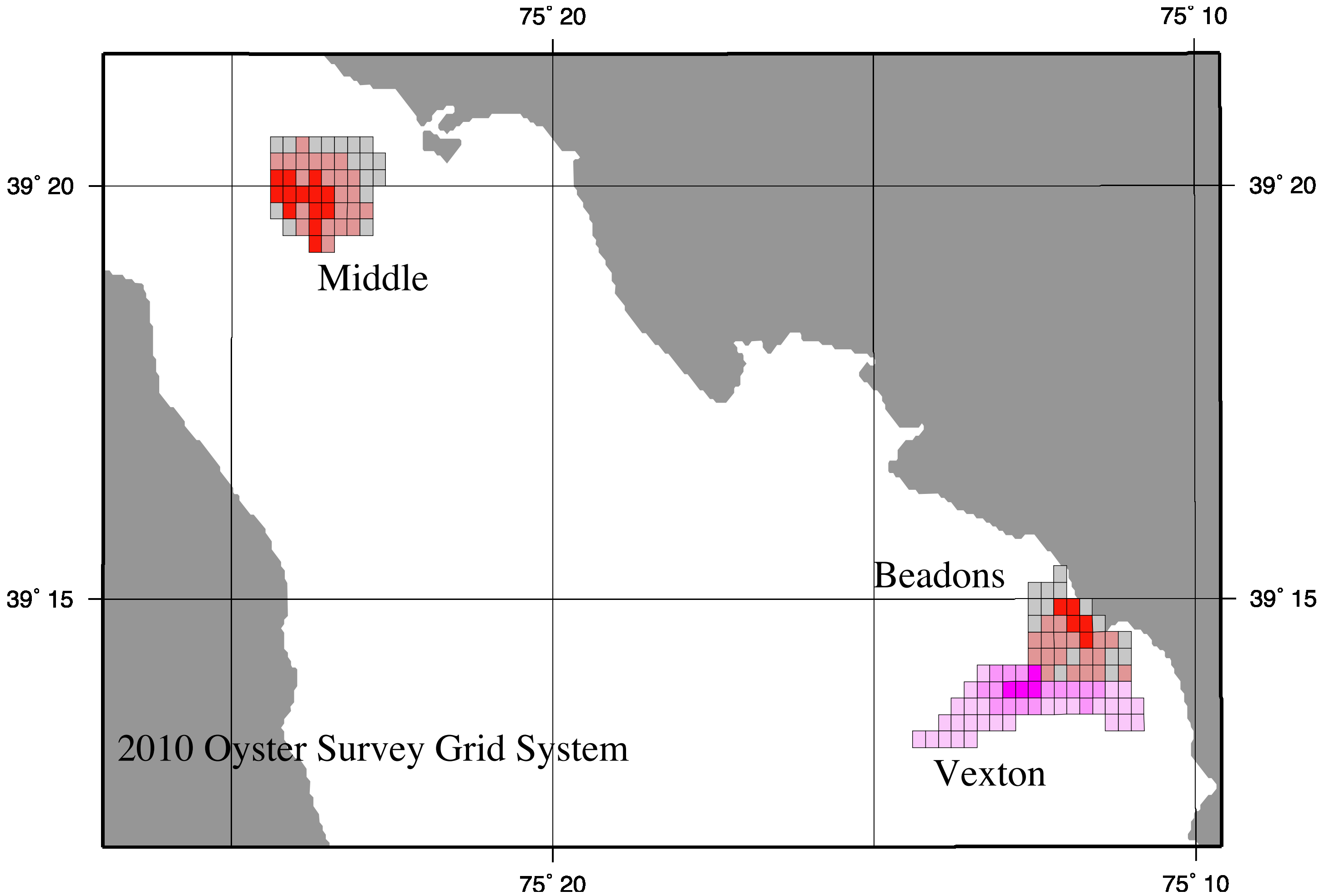


Figure 4. Distribution of grids for Middle, Beadons, and Vexton after the 2011 re-survey, shaded accordingly to oyster density. The 2011 re-survey program covered all navigable grids associated with these three beds. High-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded a light color.

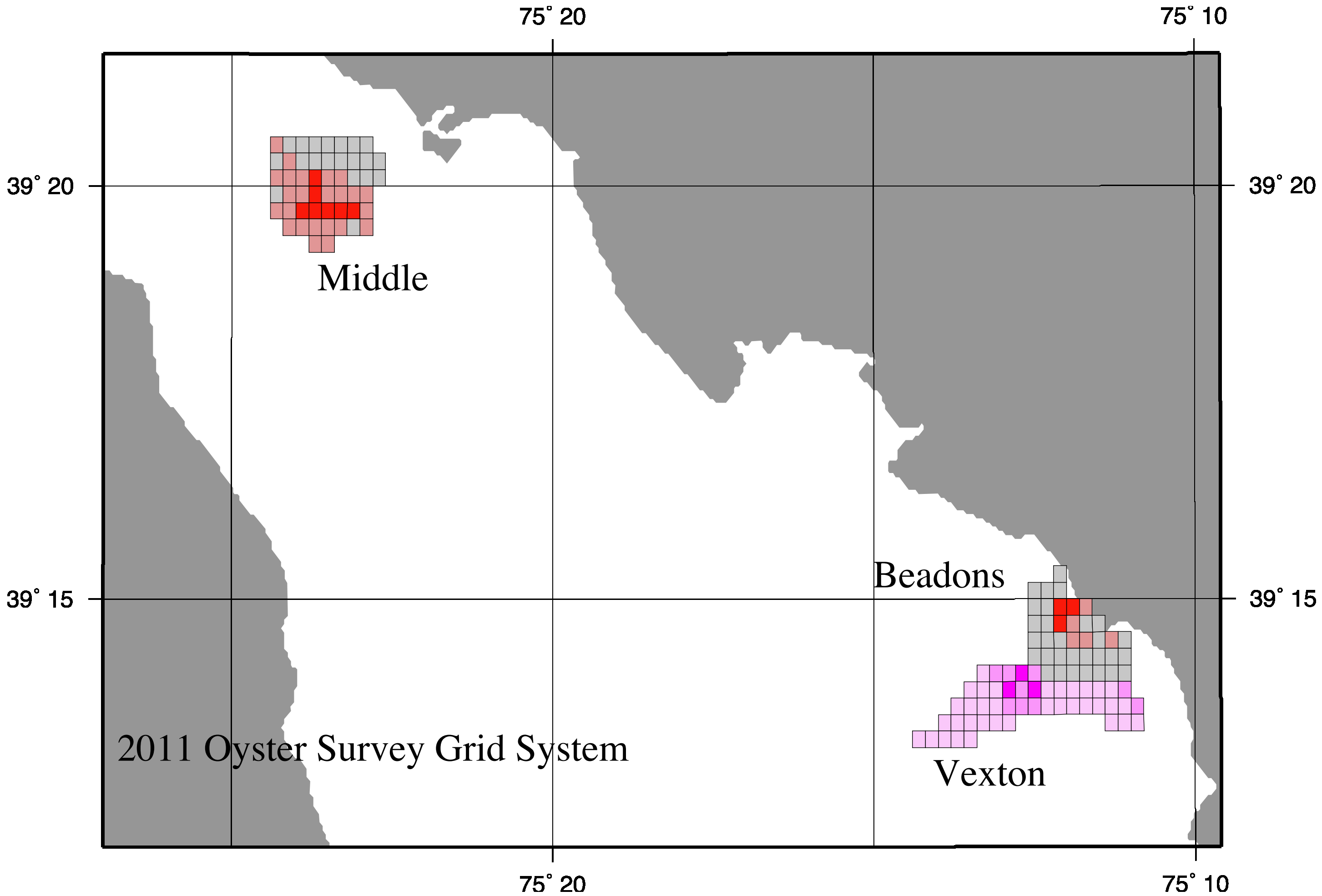


Figure 5. Middle, Beadons, and Vexton beds, showing grids that changed in quality designation between the 2010 and 2011 assessments based on the 2011 re-survey of these beds. For those grids not changing quality, high-quality grids are shaded darkly, medium-quality grids are shaded an intermediate color, and low-quality grids are shaded lightly consistent with Figures 2 and 3. Numbers in the legend record the number of grids changing in quality, rendered in the order: Middle, Vexton, Beadons.

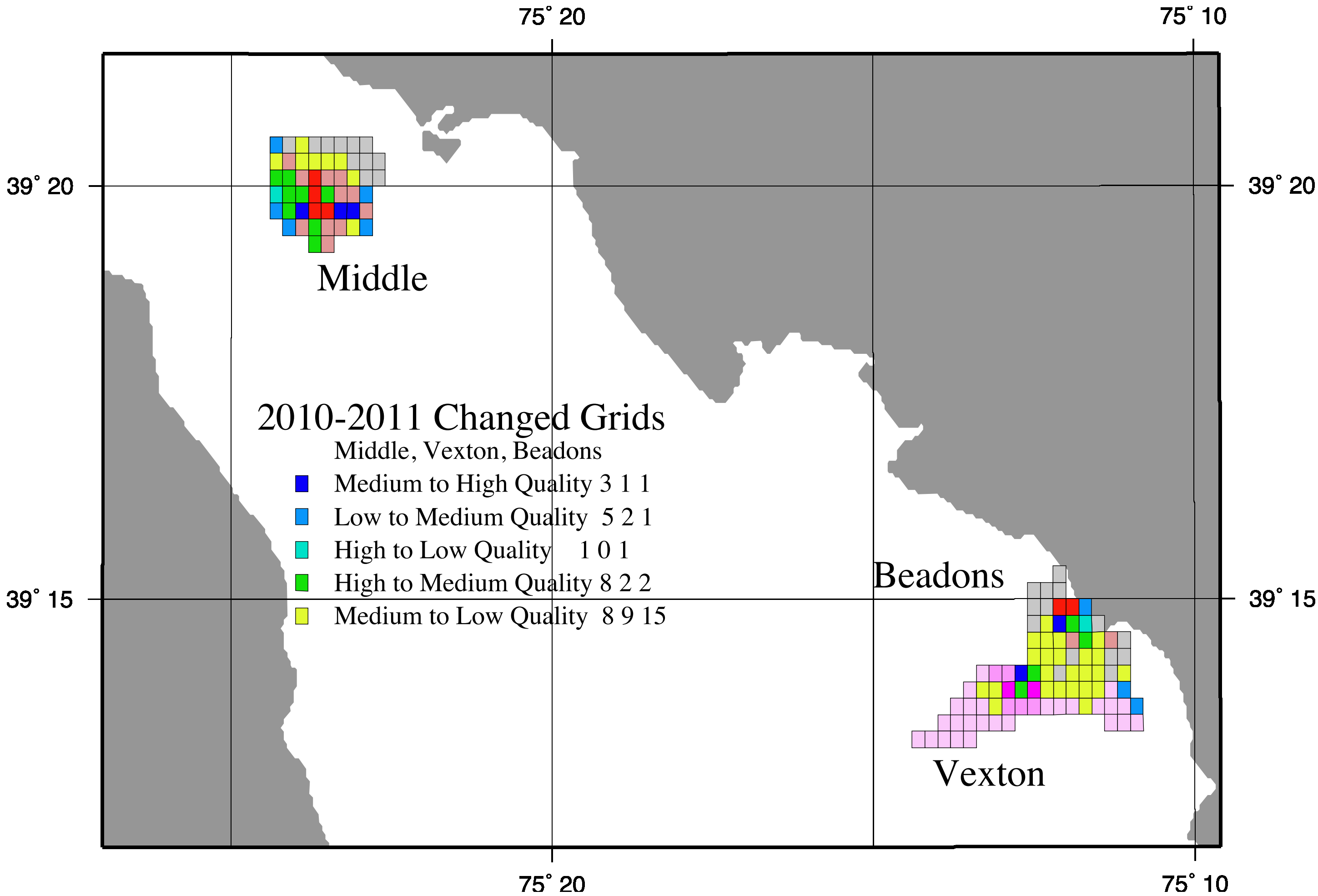
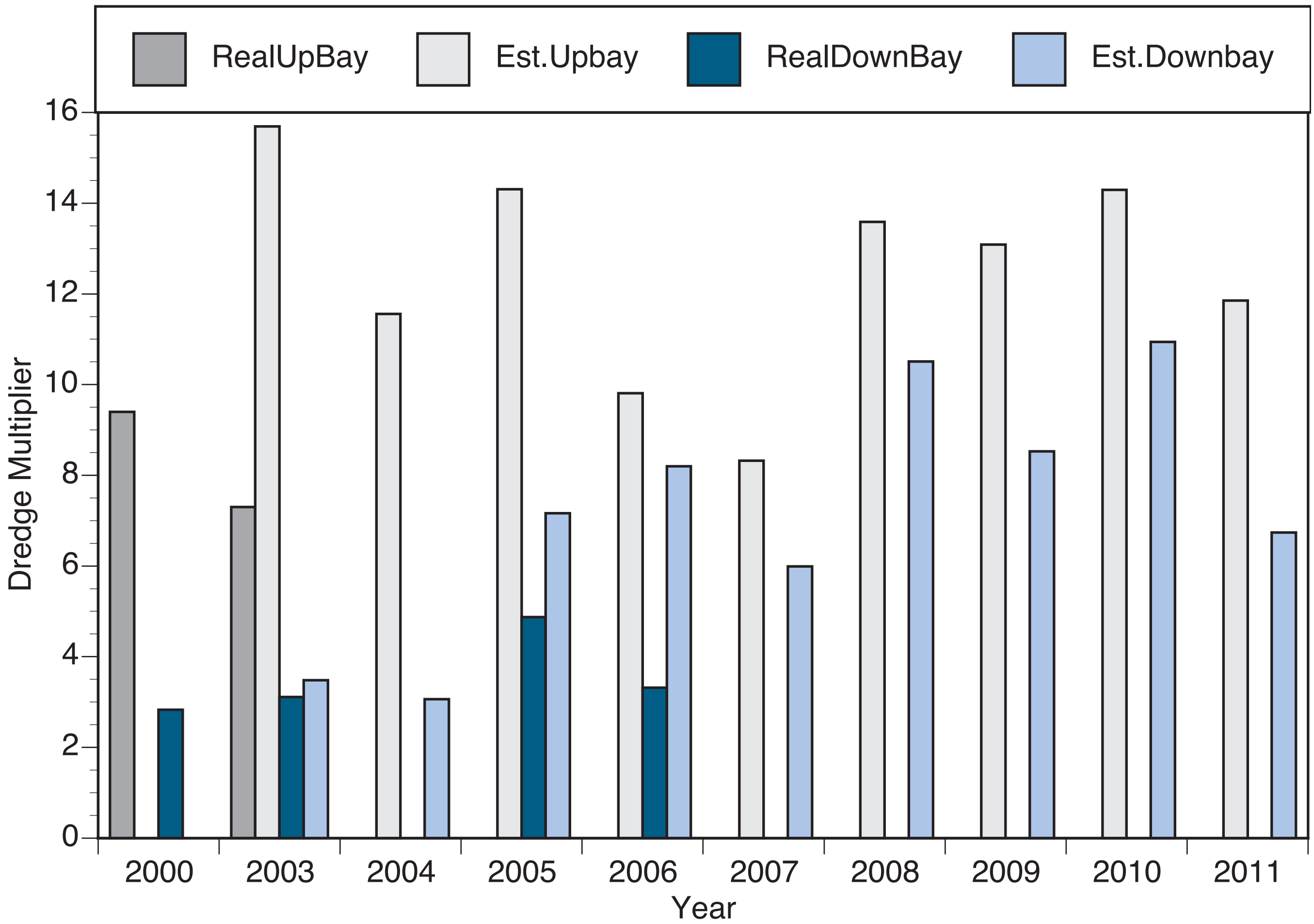


Figure 6. Estimates of q from retrospective analyses described in Powell et al. (2007)[▽] compared with directly measured values. The upbay estimates do not include the very-low-mortality beds, as no direct measurements are available for these beds.



▽ 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. 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: Ship John, Cohansey; medium mortality transplant: Middle, Upper Middle, Sea Breeze; low mortality: Arnolds, Upper Arnolds, Round Island; very-low mortality: Hope Creek, Fishing Creek, Liston Range. Shell Rock is retained as a separate single-bed region. No data are available for the very-low-mortality beds prior to 2007.

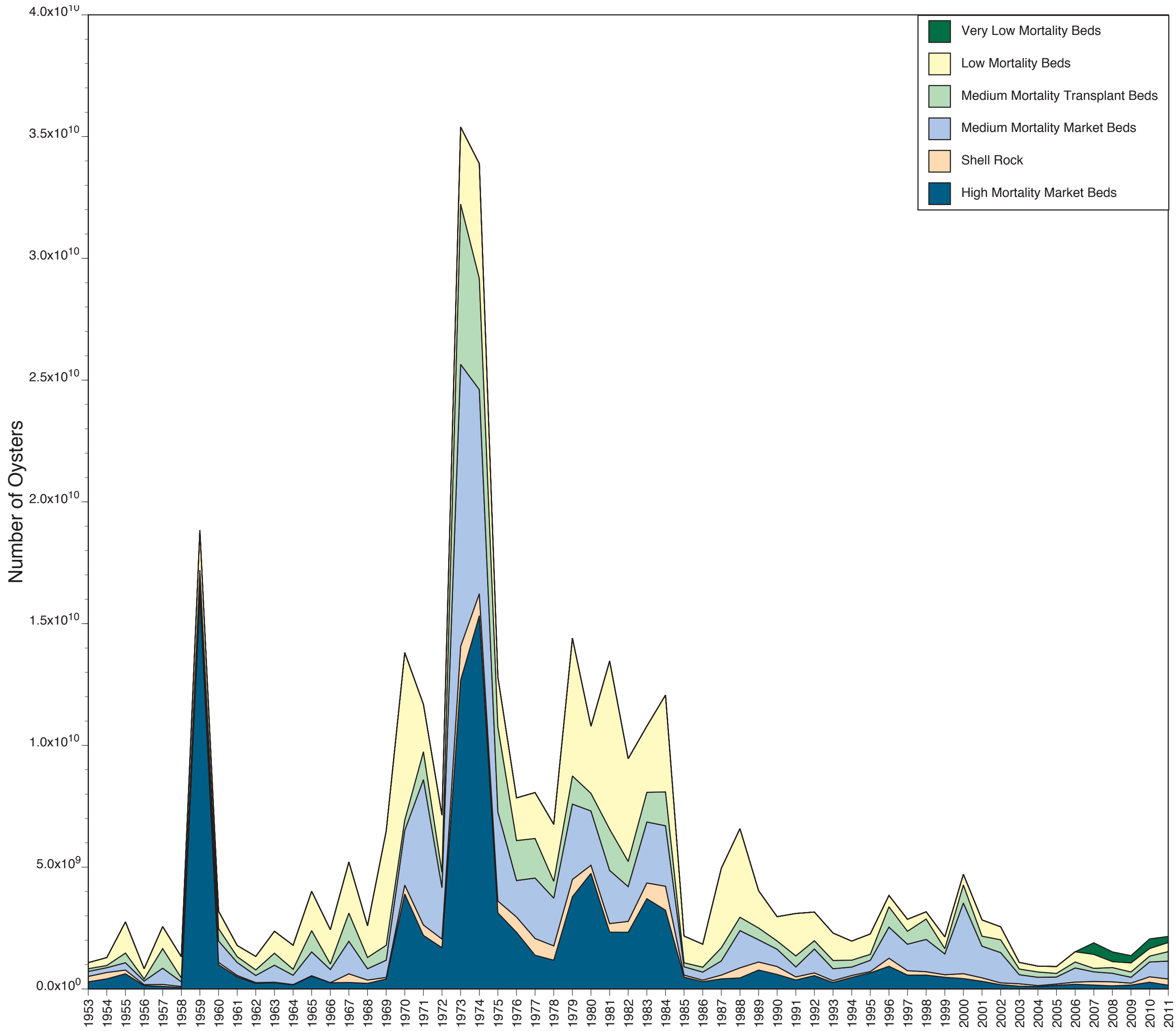


Figure 8. Time series of oyster abundance, by bay region, for the Dermo era, 1989-2011. Bed regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

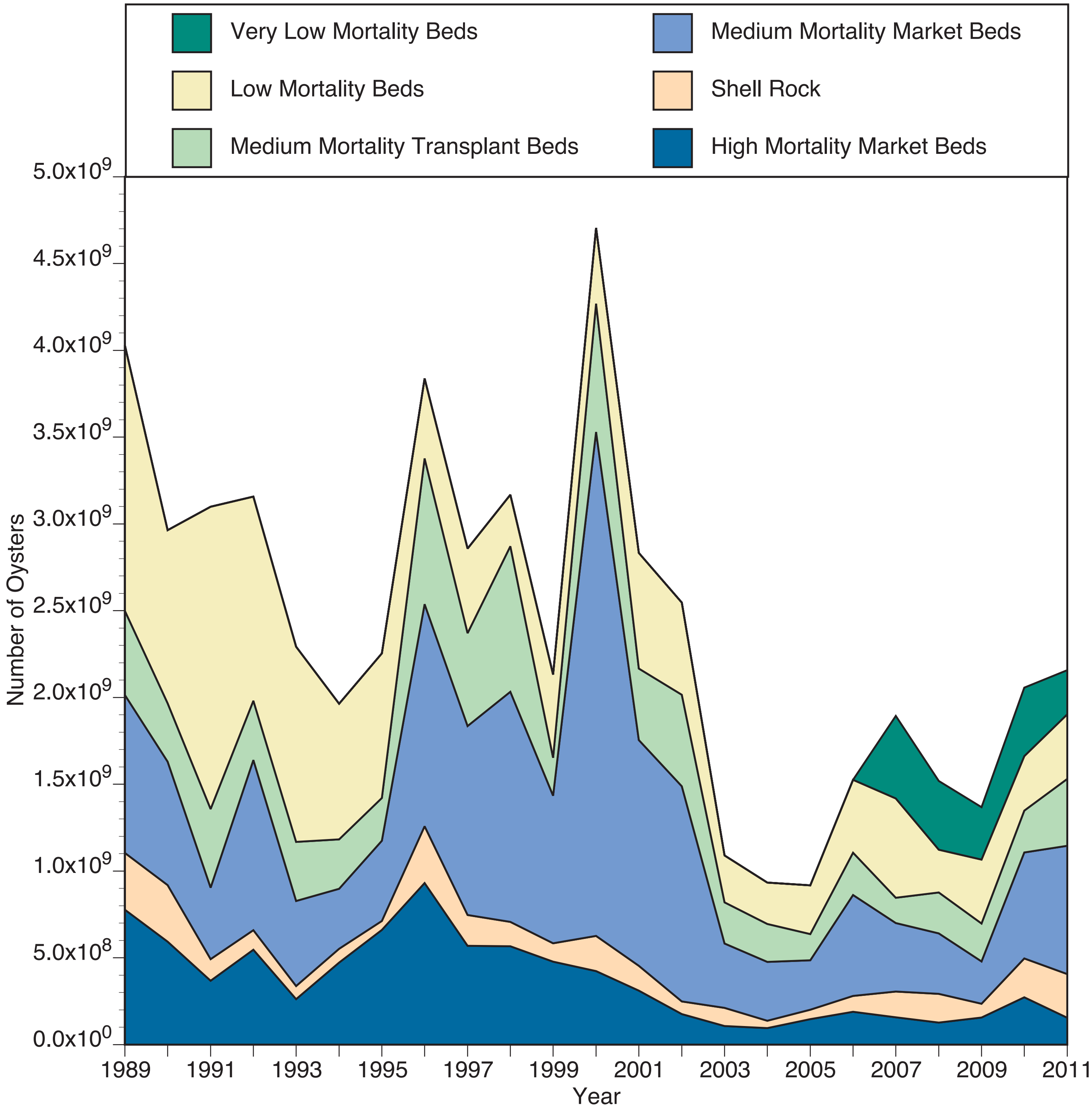


Figure 9. Time series of the fractional distribution of oyster abundance, among bay regions. Bed distributions by region are given in Figure 7.

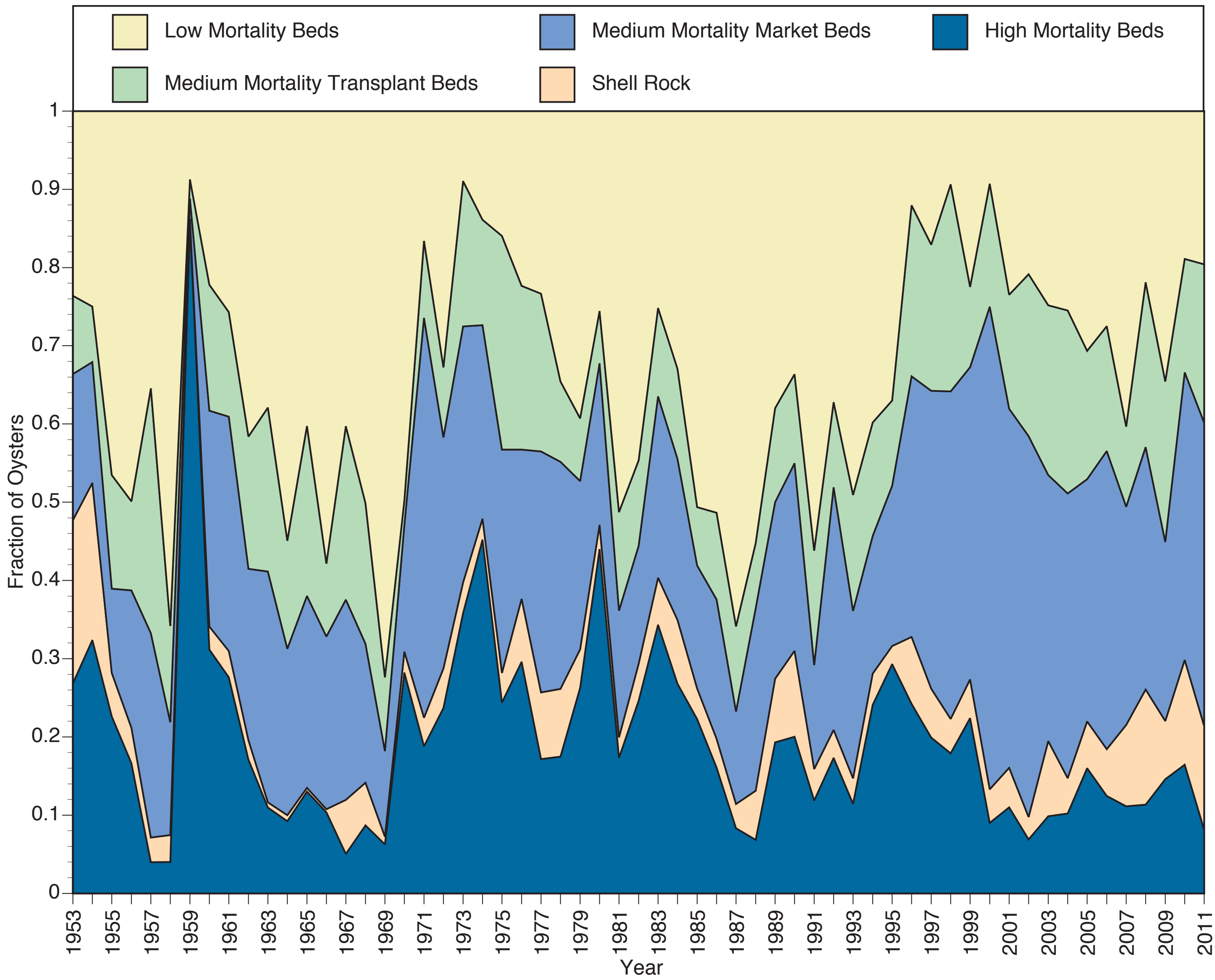


Figure 10. Time series of the fractional distribution of oyster abundance, among bay regions, including the very-low-mortality beds. Bed distributions by region are given in Figure 7.

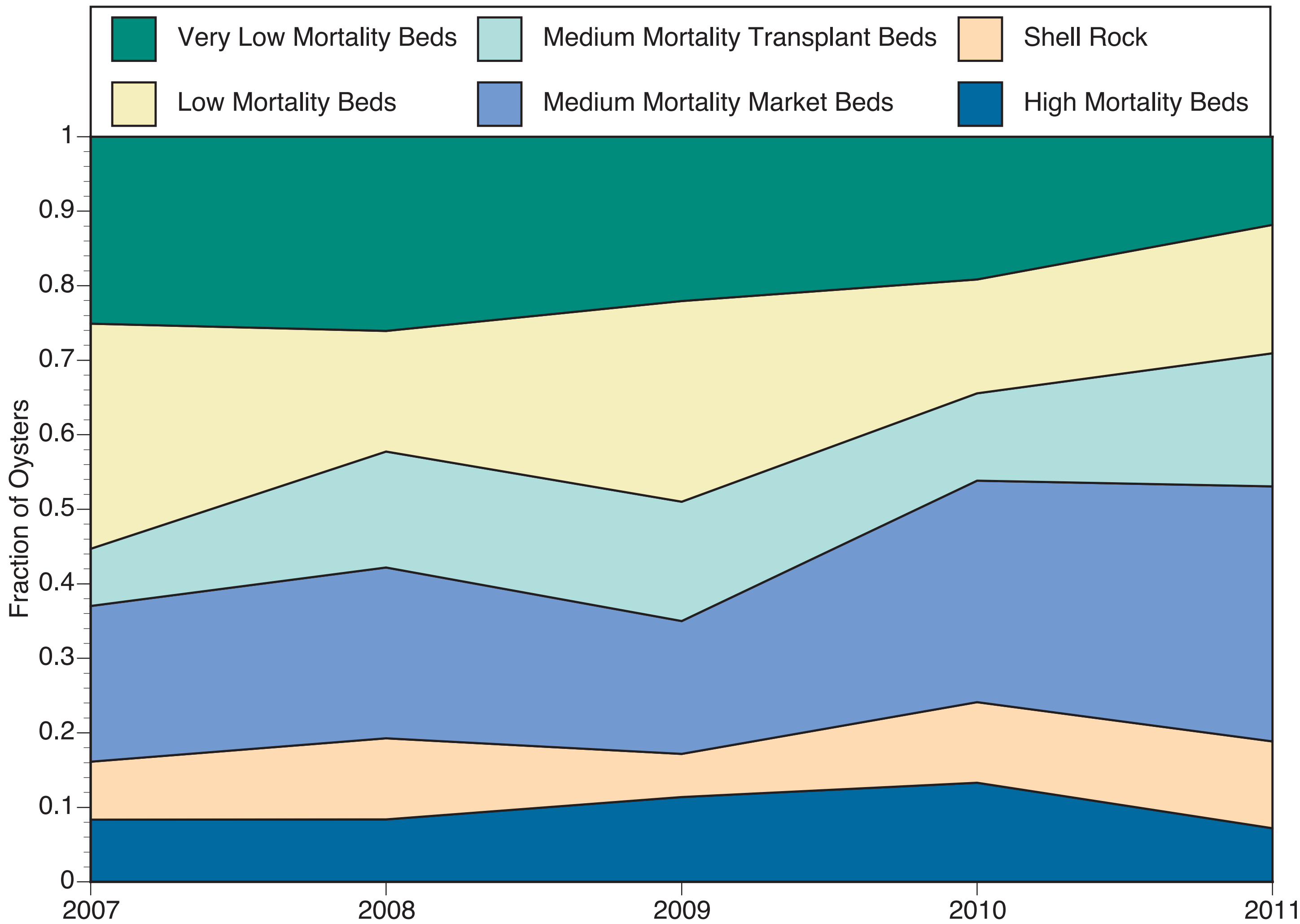


Figure 11. Fraction of animals on the medium-mortality beds, 1953-2011. The horizontal line identifies the median value of 0.385.

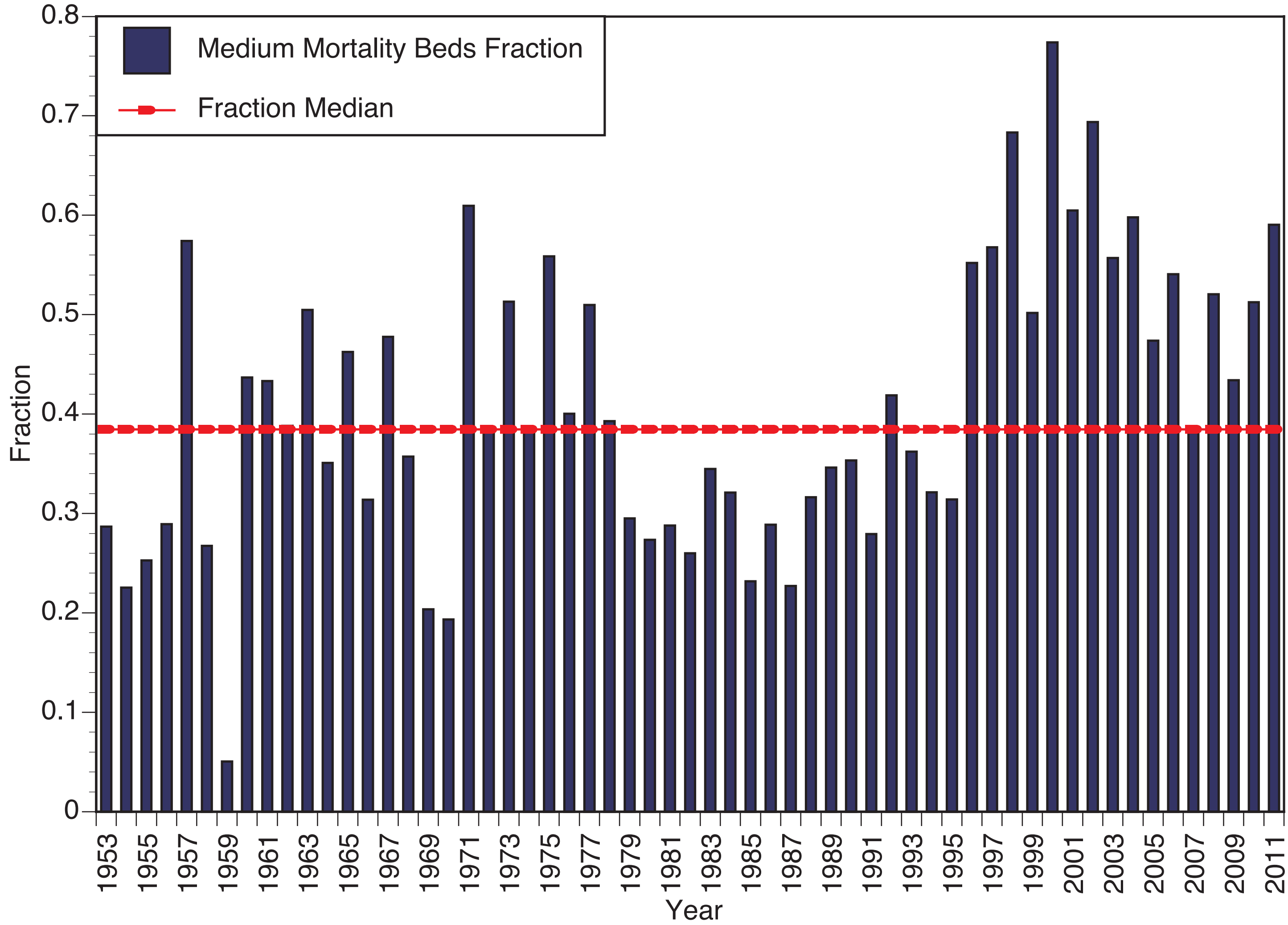


Figure 12. Time series of spawning stock biomass by bay region. Bed distributions by region are given in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

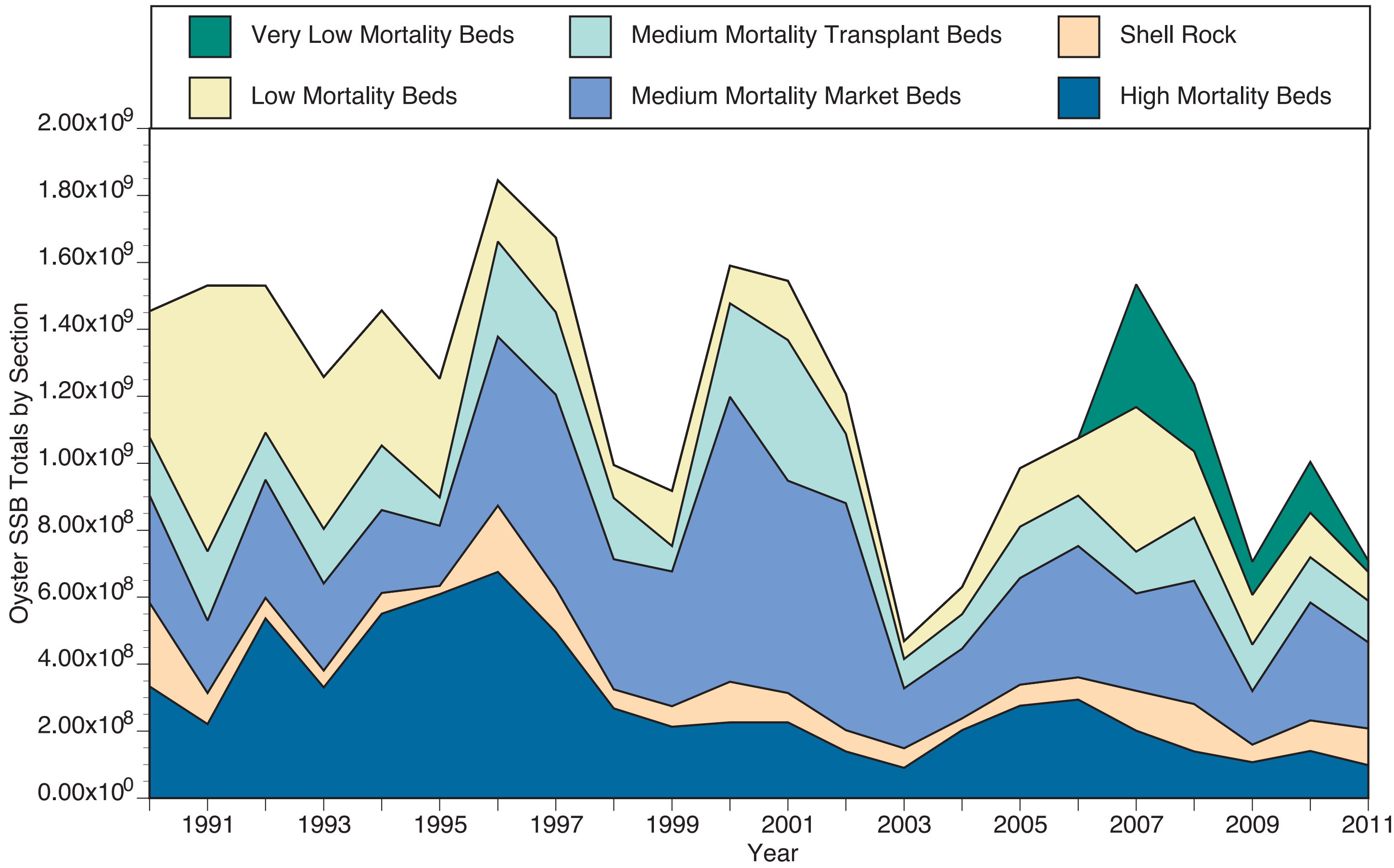


Figure 13. Time series of the fractional distribution of spawning stock biomass among the bay regions, excluding the very-low-mortality beds. Bed distributions by region are given in Figure 7.

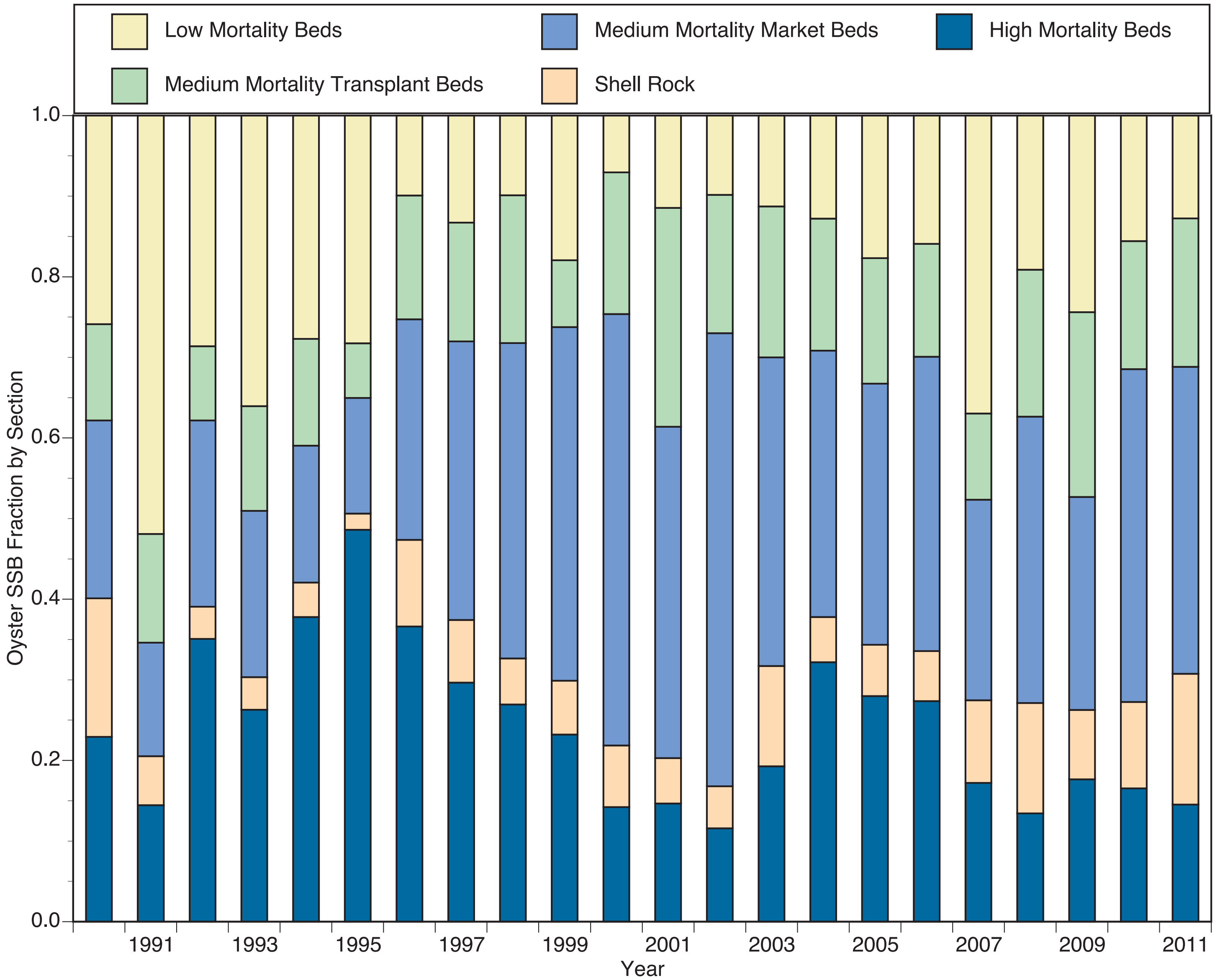


Figure 14. The fraction of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

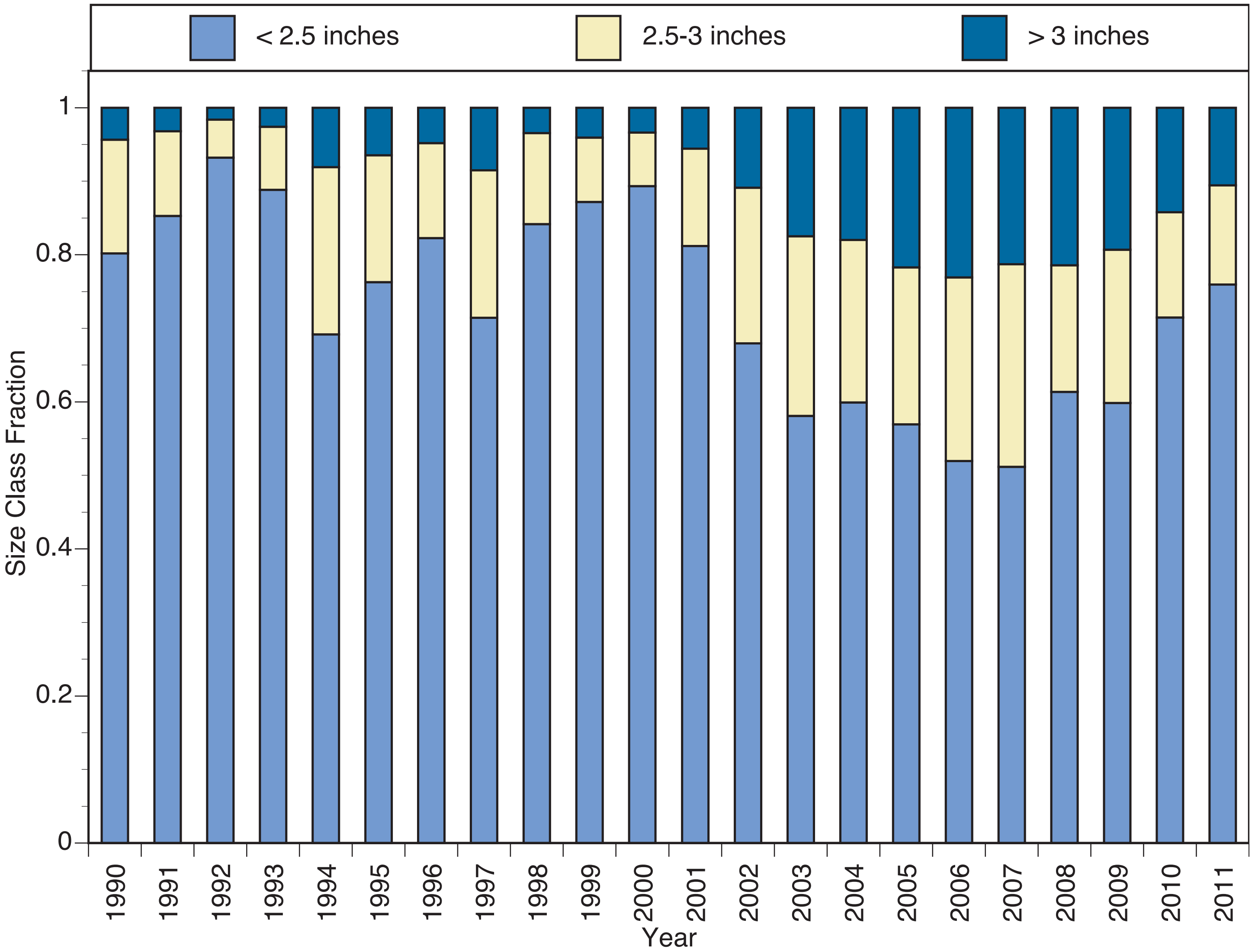


Figure 15. The abundance of small, small market, and large market-size animals since 1990, excluding the very-low-mortality beds.

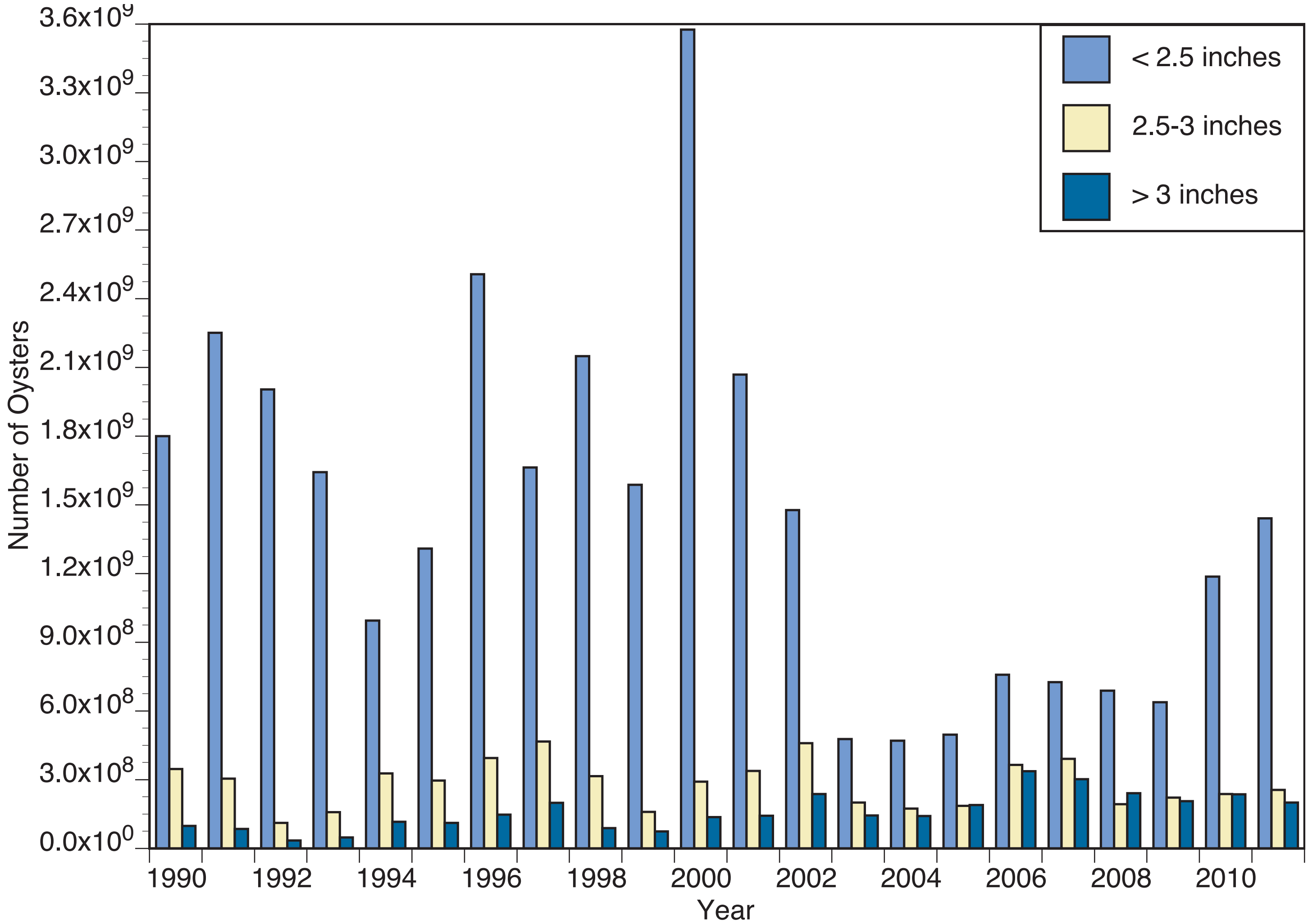


Figure 16. The abundance of small, small market, and large market-size animals since 1990 by bay region. Bed distributions by region are given in Figure 7. Note variation in y-axis scale between graphs.

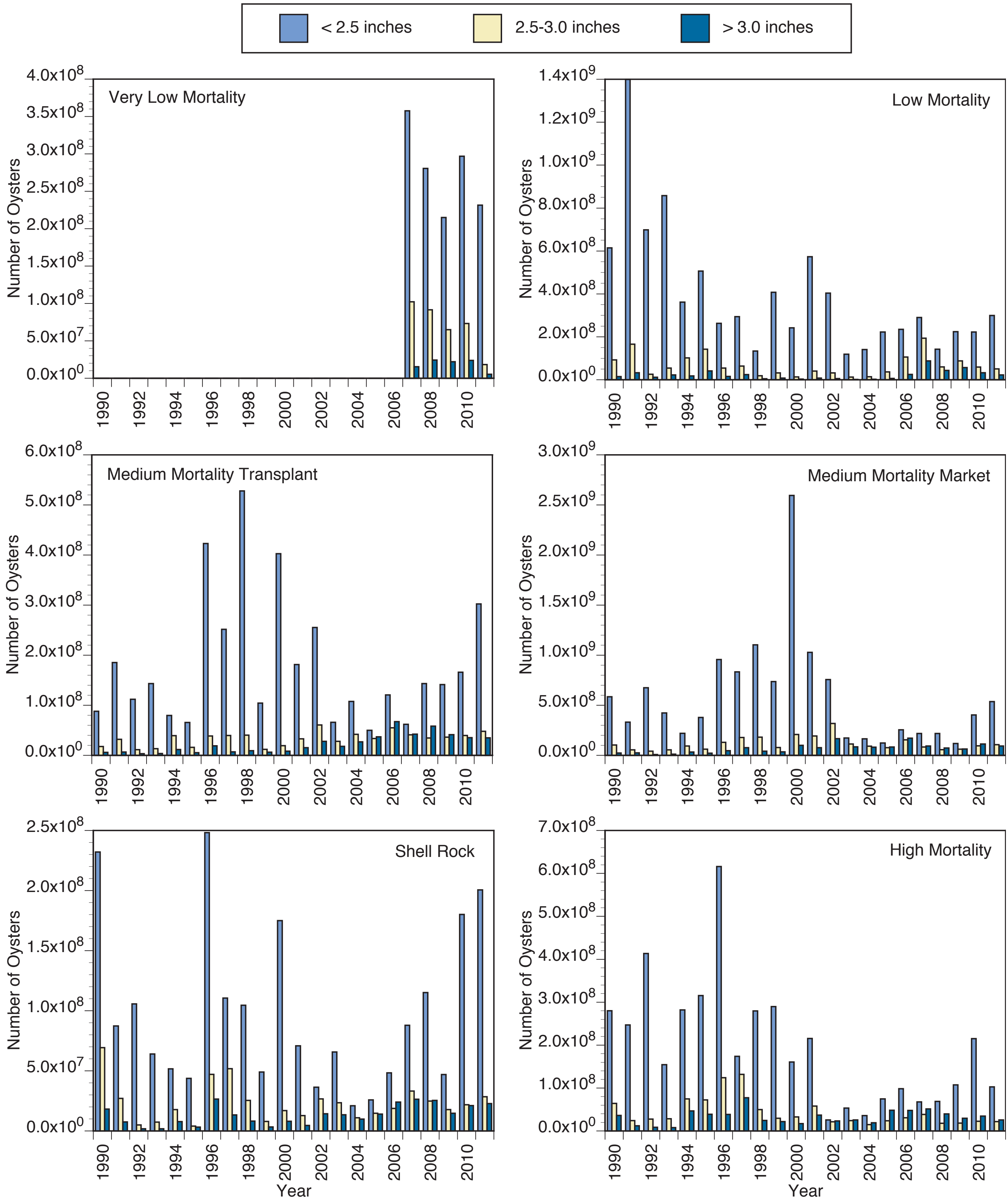


Figure 17. The percentage of small, small market, and large market-size oysters by bed region.

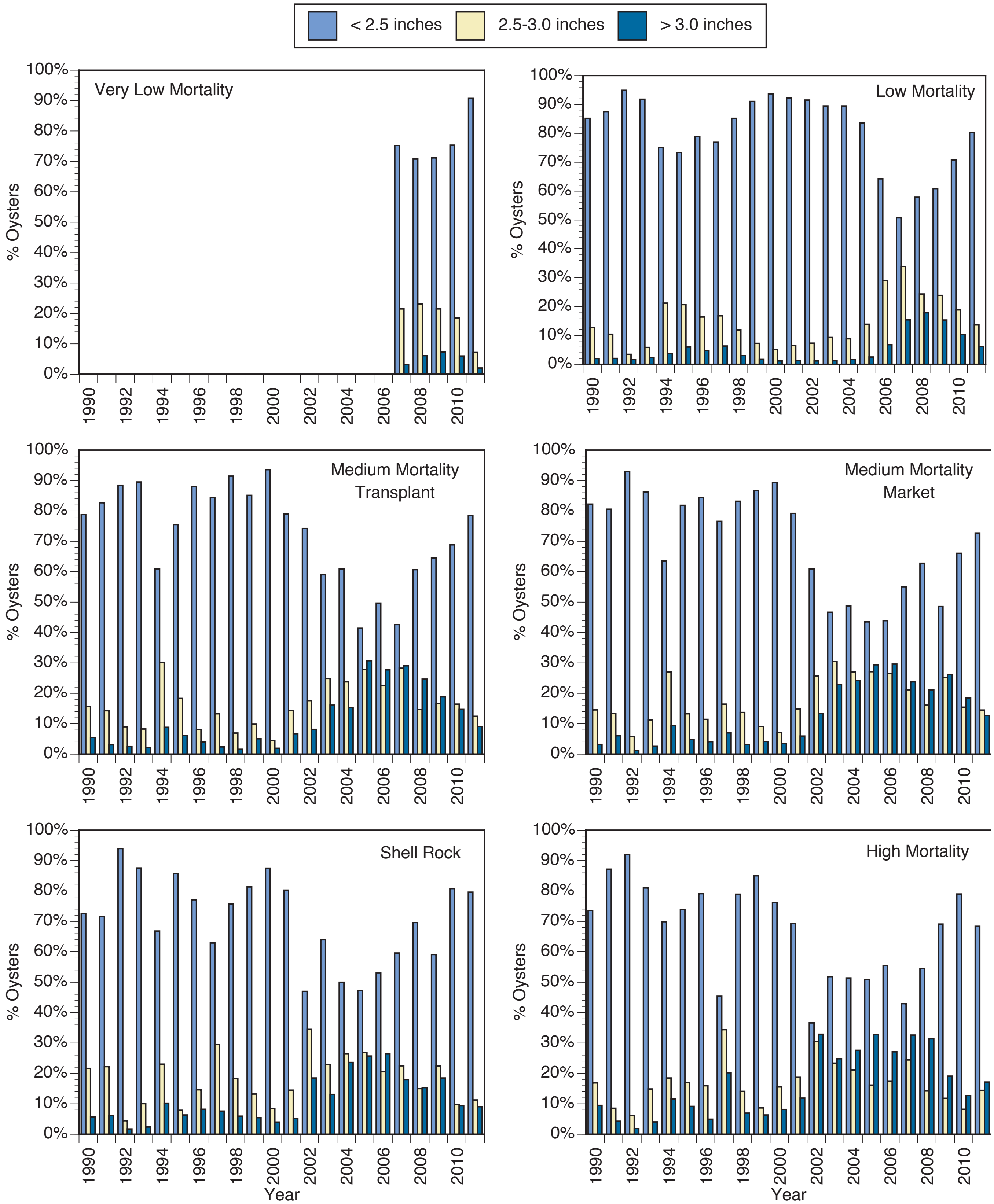


Figure 18. The fraction of marketable animals that were $\geq 2.5''$-$<3''$ and $\geq 3''$, excluding the very-low-mortality beds.

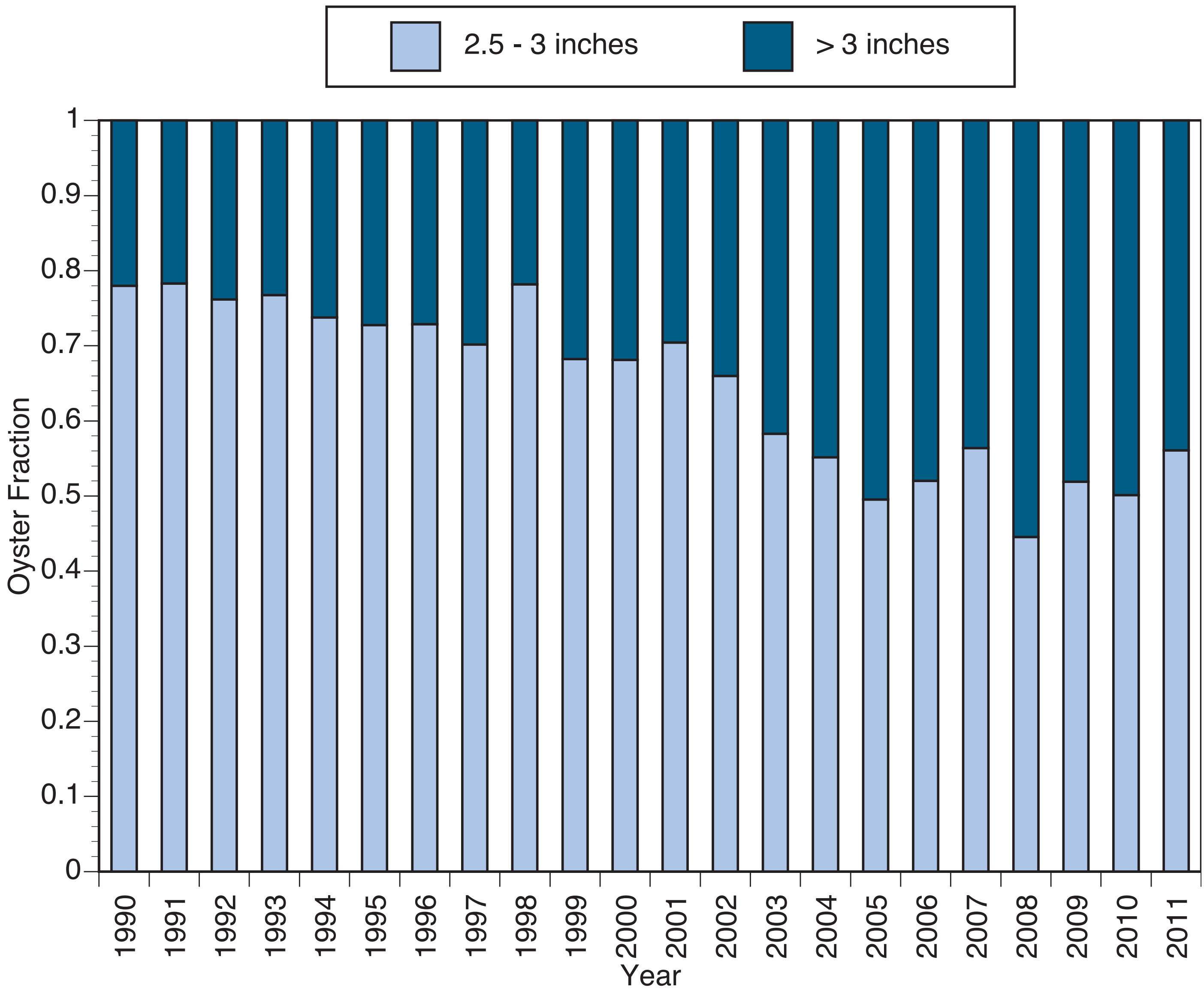


Figure 19. Abundance of market-size (≥2.5″) oysters, excluding the very-low-mortality beds.

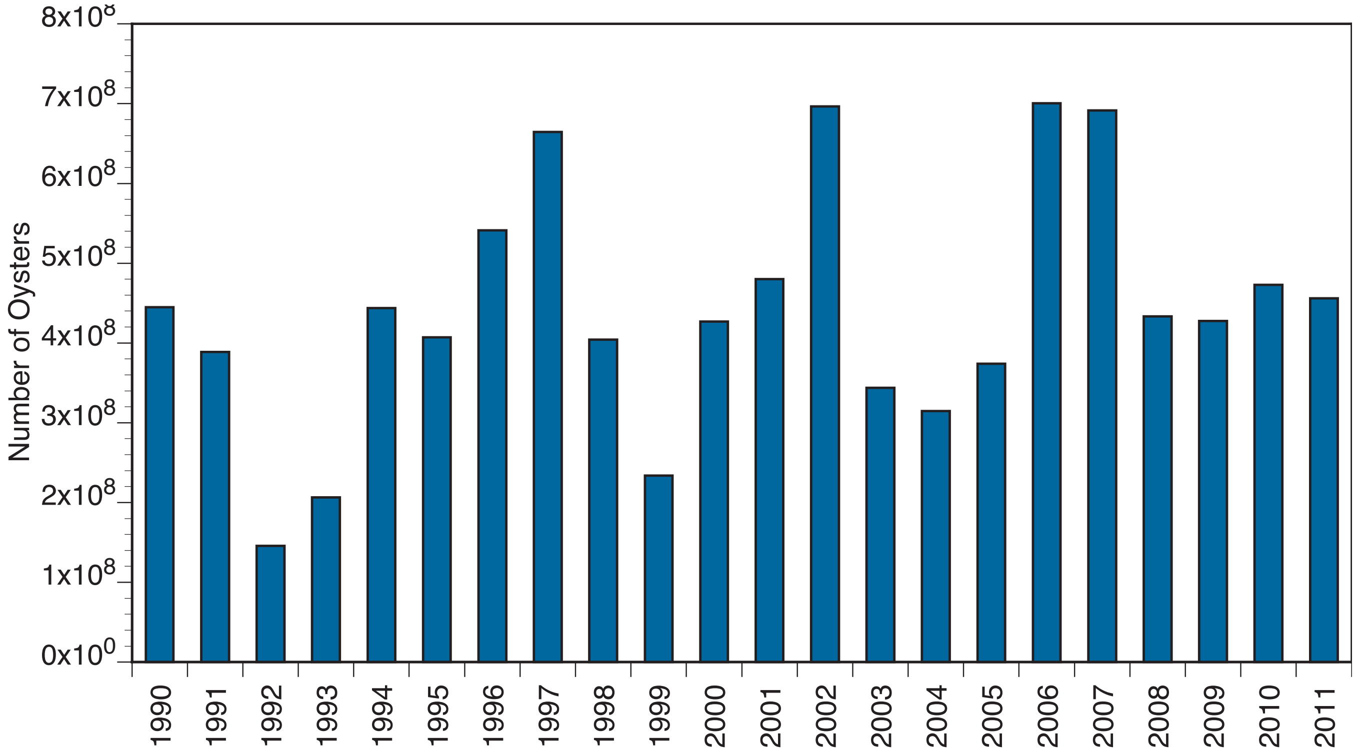


Figure 20. Abundance of market-size (≥2.5″) oysters by bay region. Bed regions are defined in Figure 7. Note variation in y-axis scale between graphs.

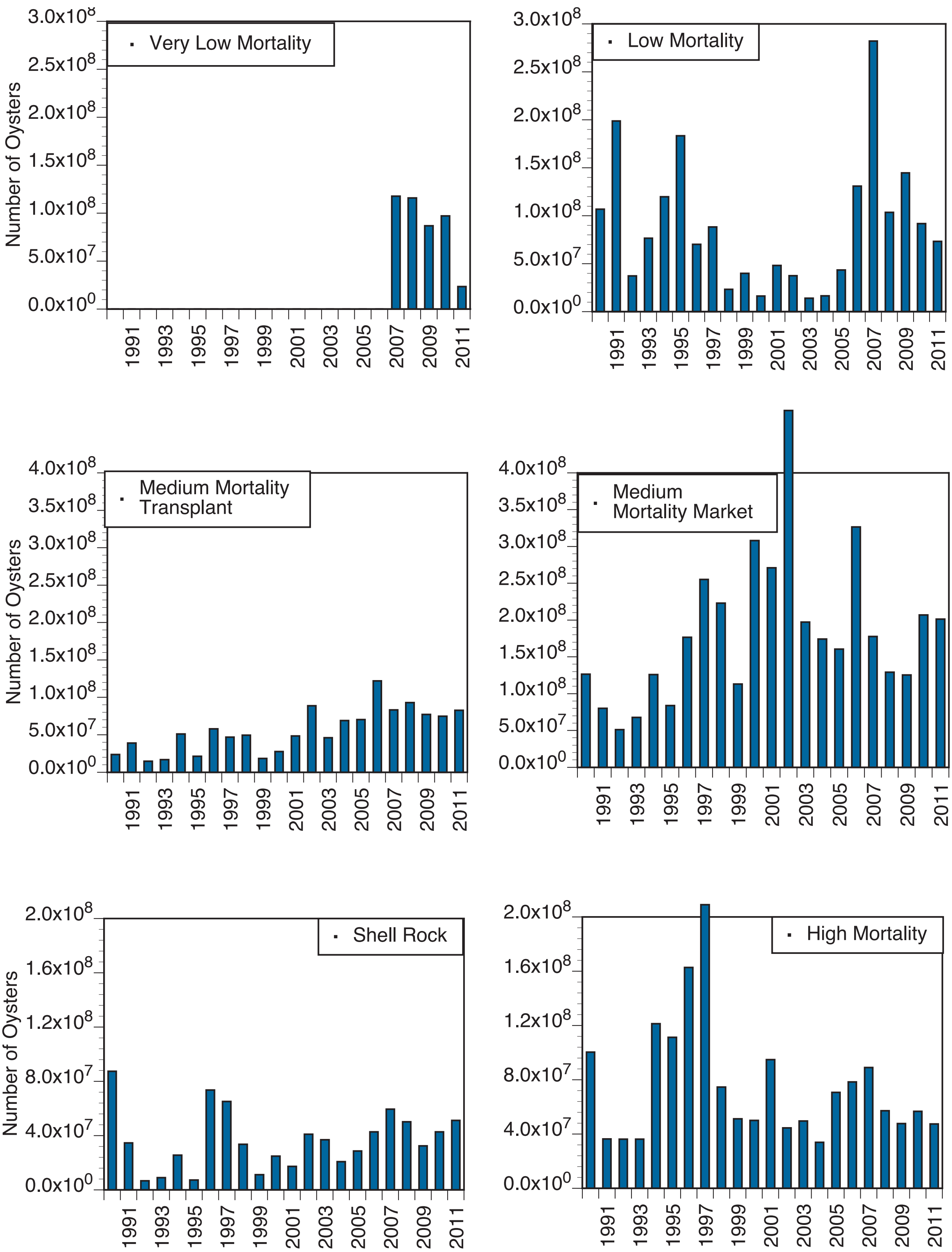


Figure 21. Average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)] at the time of the survey, excluding the very-low-mortality beds.

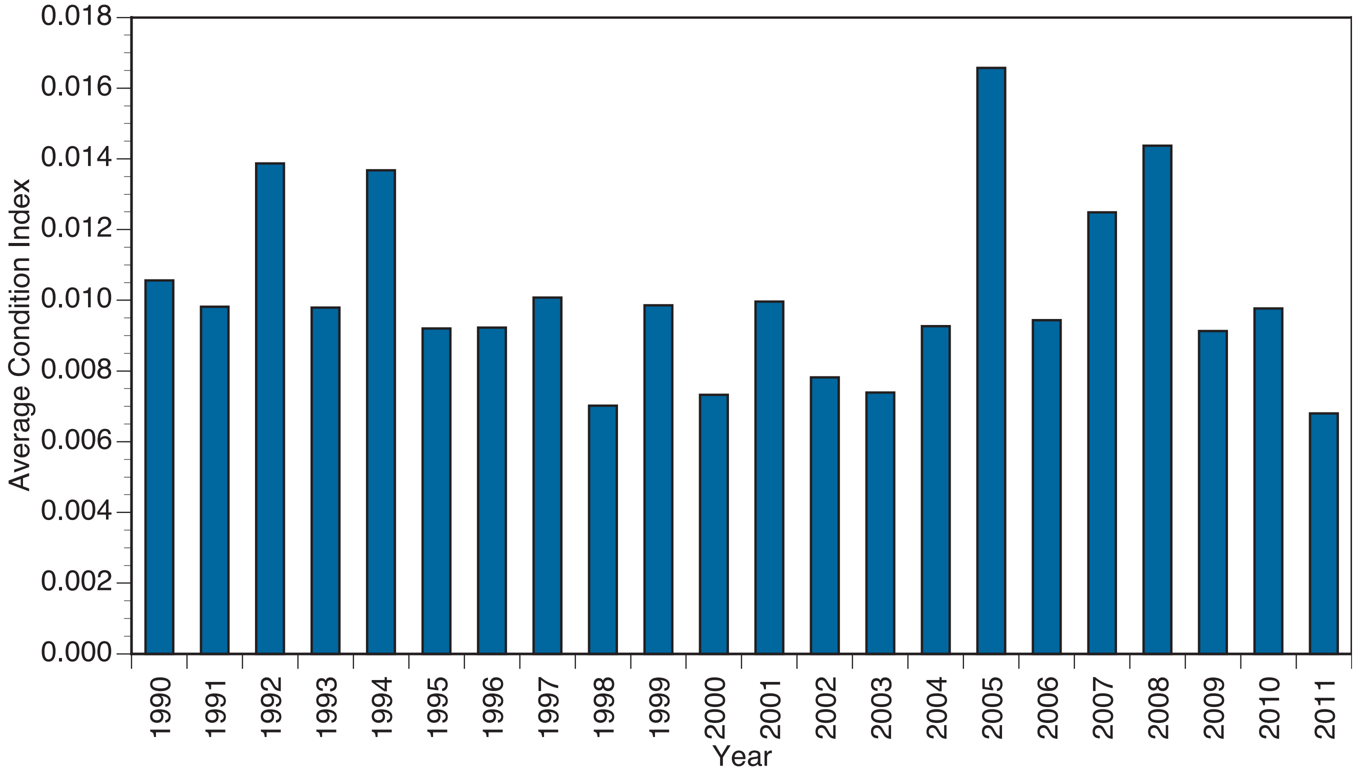


Figure 22. Average condition index [dry meat weight (g)/hinge-to-lip shell length (mm)] at the time of the survey by bay group. Bed distributions by region are given in Figure 7.

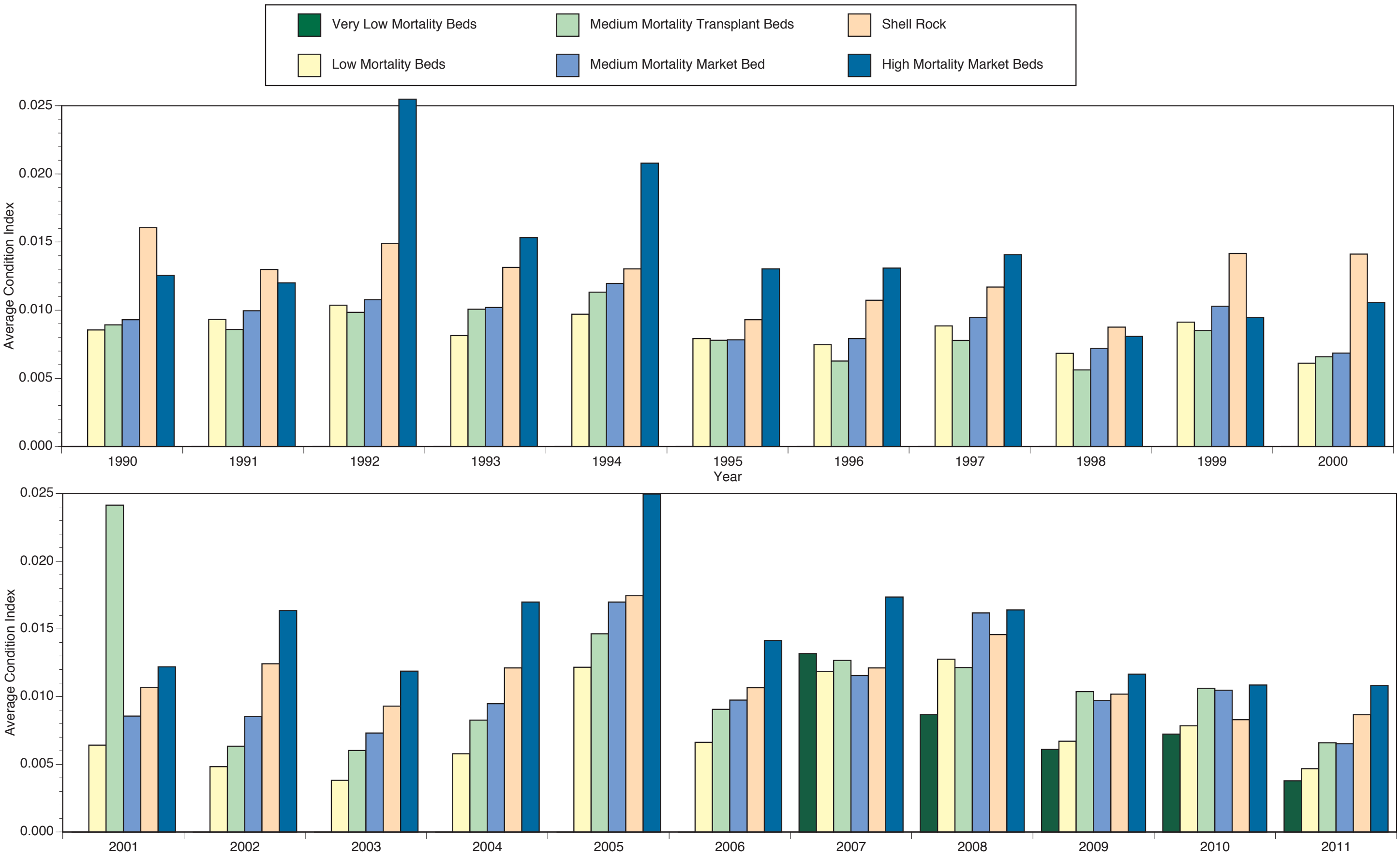


Figure 23. The differential between predicted and observed submarket surplus from a retrospective analysis of survey indices under a series of assumptions. Predictions assumed a 50^{th} and a 75^{th} percentile mortality rate (e.g., Table 11). Submarket surplus was calculated based on the assumption 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. The differential is evaluated 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 submarket surplus.

Bay Section	Year	50th Percentile	75th Percentile
Low Mortality Beds	2005		
Medium Mortality Transplant	2005		
Medium Mortality Market Beds	2005		
Shell Rock	2005		
High Mortality Market Beds	2005		
Low Mortality Beds	2006		
Medium Mortality Transplant	2006		
Medium Mortality Market Beds	2006		
Shell Rock	2006		
High Mortality Market Beds	2006		
Low Mortality Beds	2007		
Medium Mortality Transplant	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	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	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	2010		
Medium Mortality Market Beds	2010		
Shell Rock	2010		
High Mortality Market Beds	2010		
Very Low Mortality Beds	2011		
Low Mortality Beds	2011		
Medium Mortality Transplant	2011		
Medium Mortality Market Beds	2011		
Shell Rock	2011		
High Mortality Market Beds	2011		

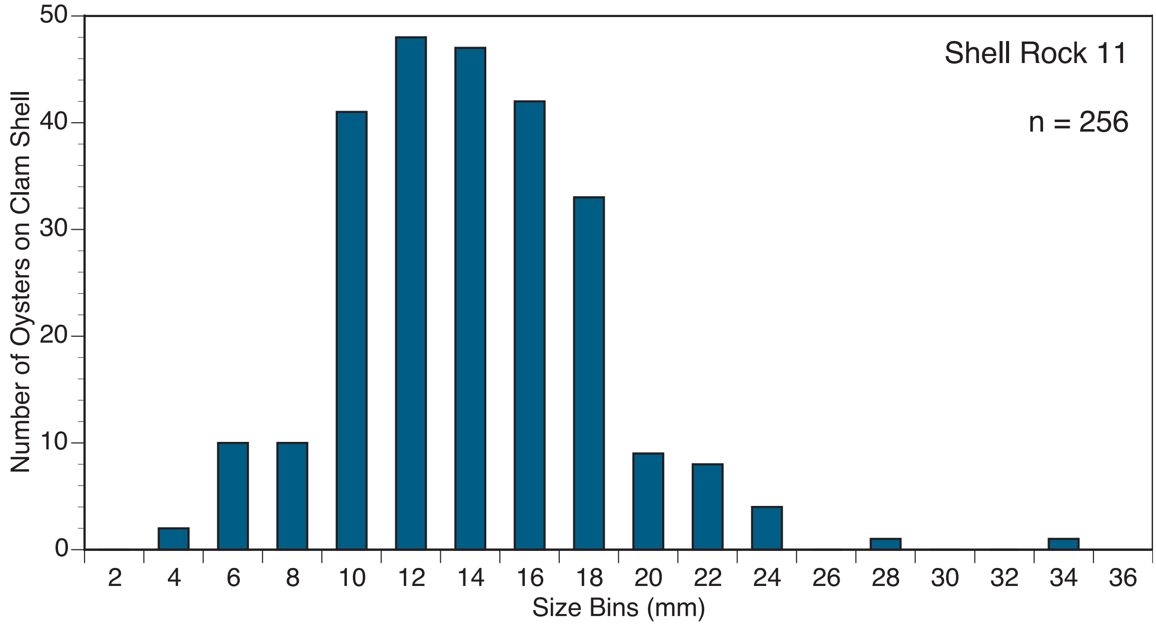
Figure 24. Net submarket surplus from a retrospective analysis of survey indices and landings, under a series of assumptions. Submarket surplus was calculated based on the assumption that all deaths and landings of recruit size were of recruit size in the previous year's survey or smaller than recruit size in the previous year's survey. This provides high and low bounds for the estimates. Green indicates that net submarket surplus 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 submarket surplus 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).

Bay Section	Year	Observed Data	Slow Growth	High Mortality	Medium Mortality	Fast Growth
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					
Very Low Mortality Beds	2011					
Low Mortality Beds	2011					
Medium Mortality Transplant Beds	2011					
Medium Mortality Market Beds	2011					
Shell Rock	2011					
High Mortality Market Beds	2011					

Figure 25. Figure 24 sorted by bed region rather than by year. See Figure 24 for further explanation.

Bay Section	Year	Observed Data	Slow Growth	High Mortality	Medium Mortality	Fast Growth
Very Low Mortality Beds	2008					
Very Low Mortality Beds	2009					
Very Low Mortality Beds	2010					
Very Low Mortality Beds	2011					
Low Mortality Beds	2005					
Low Mortality Beds	2006					
Low Mortality Beds	2007					
Low Mortality Beds	2008					
Low Mortality Beds	2009					
Low Mortality Beds	2010					
Low Mortality Beds	2011					
Medium Mortality Transplant Beds	2005					
Medium Mortality Transplant Beds	2006					
Medium Mortality Transplant Beds	2007					
Medium Mortality Transplant Beds	2008					
Medium Mortality Transplant Beds	2009					
Medium Mortality Transplant Beds	2010					
Medium Mortality Transplant Beds	2011					
Medium Mortality Market Beds	2005					
Medium Mortality Market Beds	2006					
Medium Mortality Market Beds	2007					
Medium Mortality Market Beds	2008					
Medium Mortality Market Beds	2009					
Medium Mortality Market Beds	2010					
Medium Mortality Market Beds	2011					
Shell Rock	2005					
Shell Rock	2006					
Shell Rock	2007					
Shell Rock	2008					
Shell Rock	2009					
Shell Rock	2010					
Shell Rock	2011					
High Mortality Market Beds	2005					
High Mortality Market Beds	2006					
High Mortality Market Beds	2007					
High Mortality Market Beds	2008					
High Mortality Market Beds	2009					
High Mortality Market Beds	2010					
High Mortality Market Beds	2011					

Figure 26. Example size-frequency distributions for spat recruiting in 2011 to shell planted in 2011 on Bennies Sand and Shell Rock. X-axis class intervals mark the upper bound of the size class.



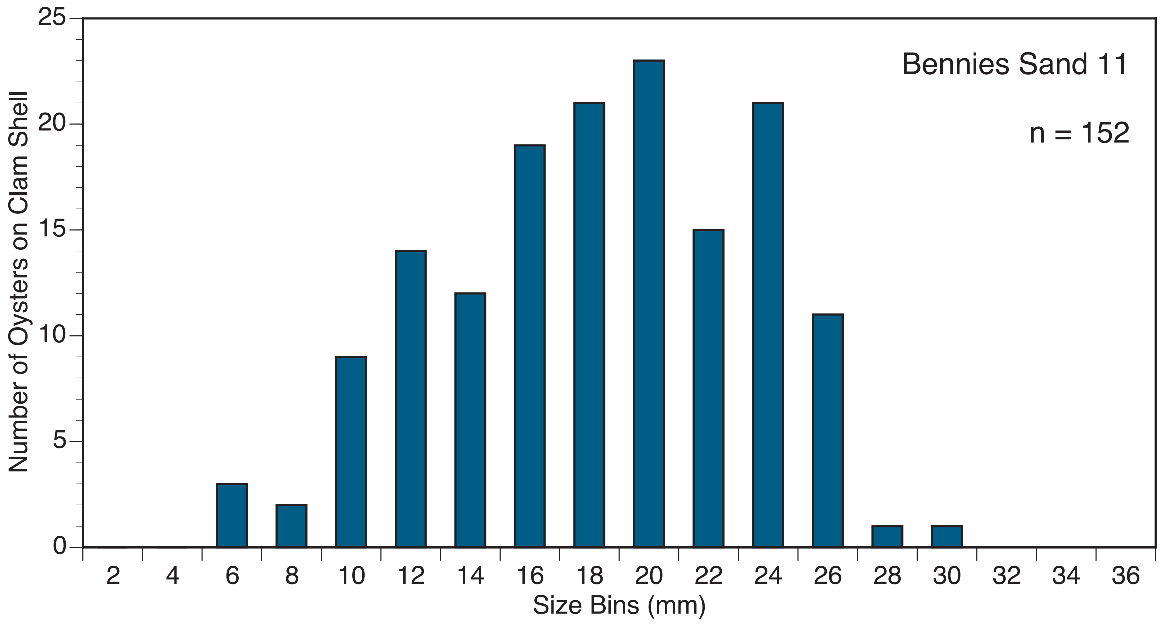
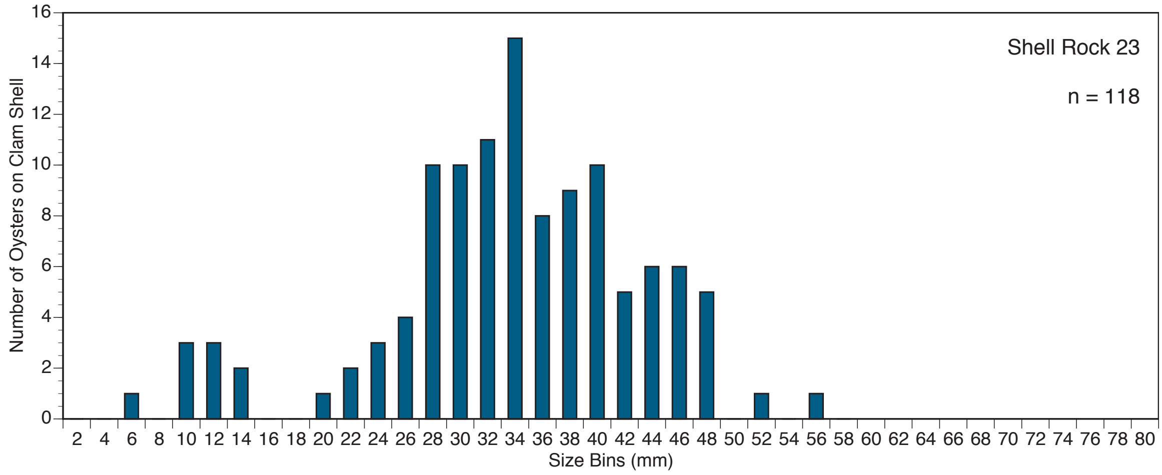


Figure 27. The size frequency of spat and yearlings on shell planted in 2010. X-axis class intervals mark the upper bound of the size class. Larger oysters are animals attached to previously planted clam shell on nearby grids likely redistributed by fishing activities.



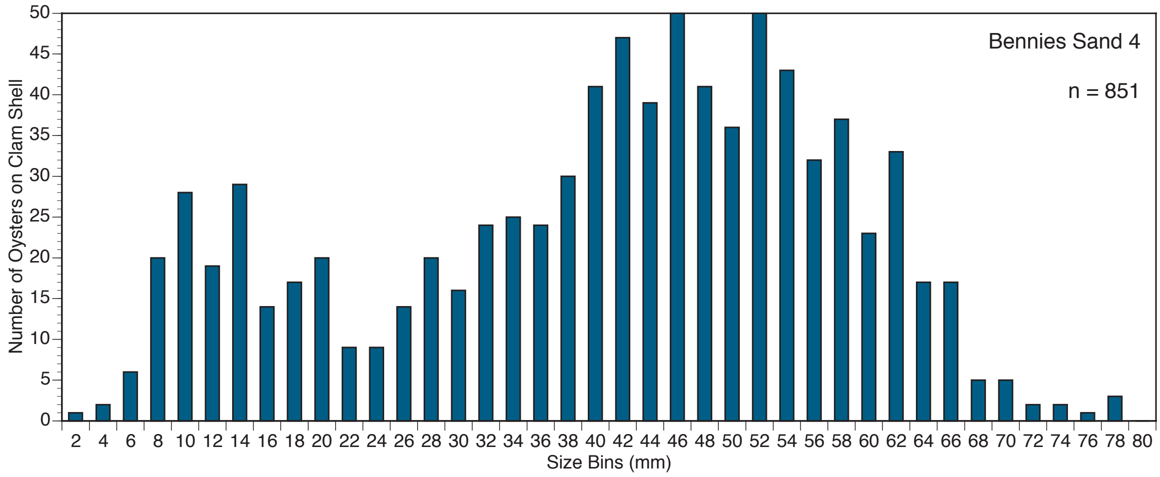


Figure 28. Number of spat recruiting per year for the 1953-2011 time series, cumulatively by bay region. Bay regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

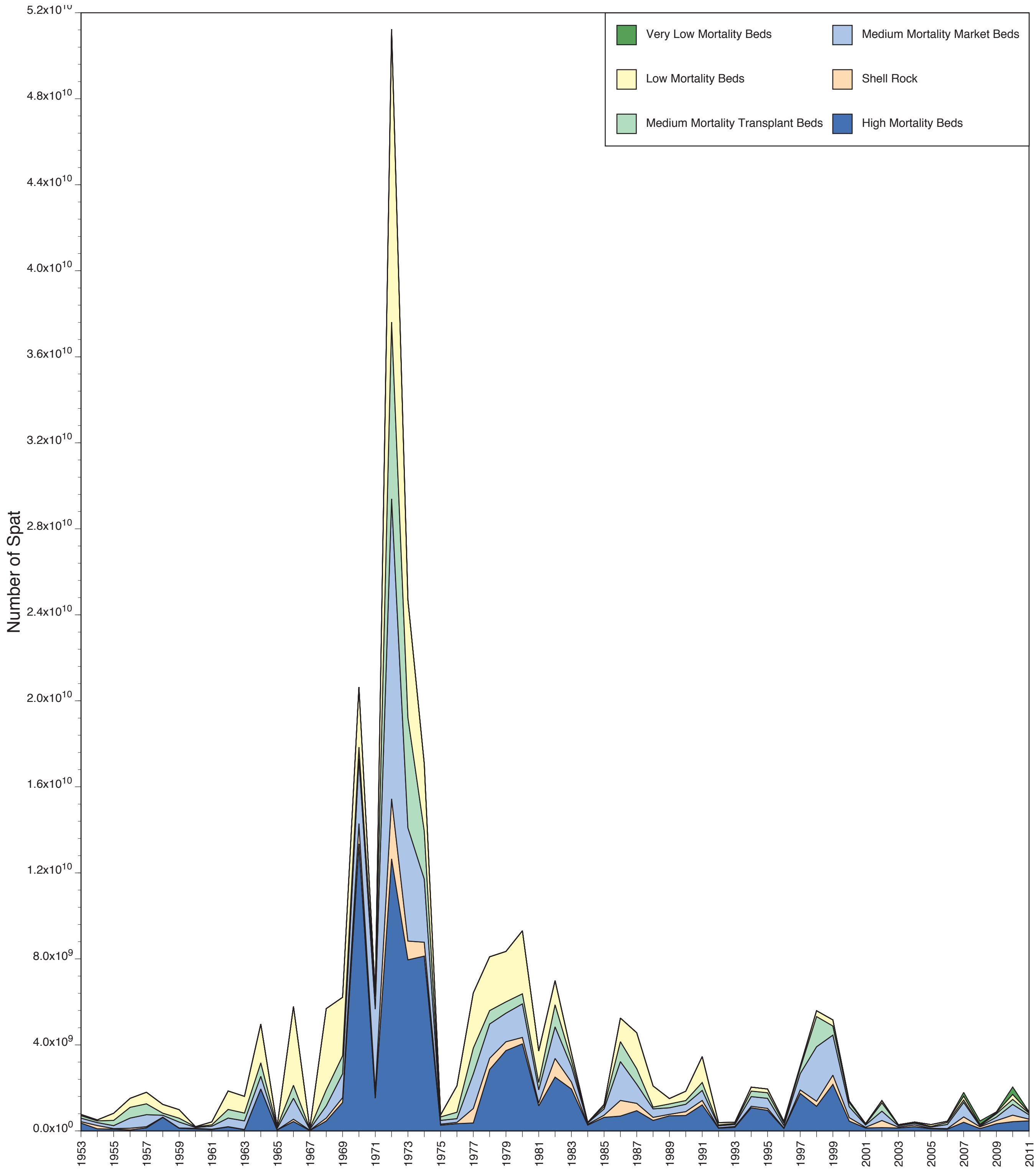


Figure 29. Number of spat recruiting per year for the 1989-2011 time series. Bay regions are defined in Figure 7. No data are available for the very-low-mortality beds prior to 2007.

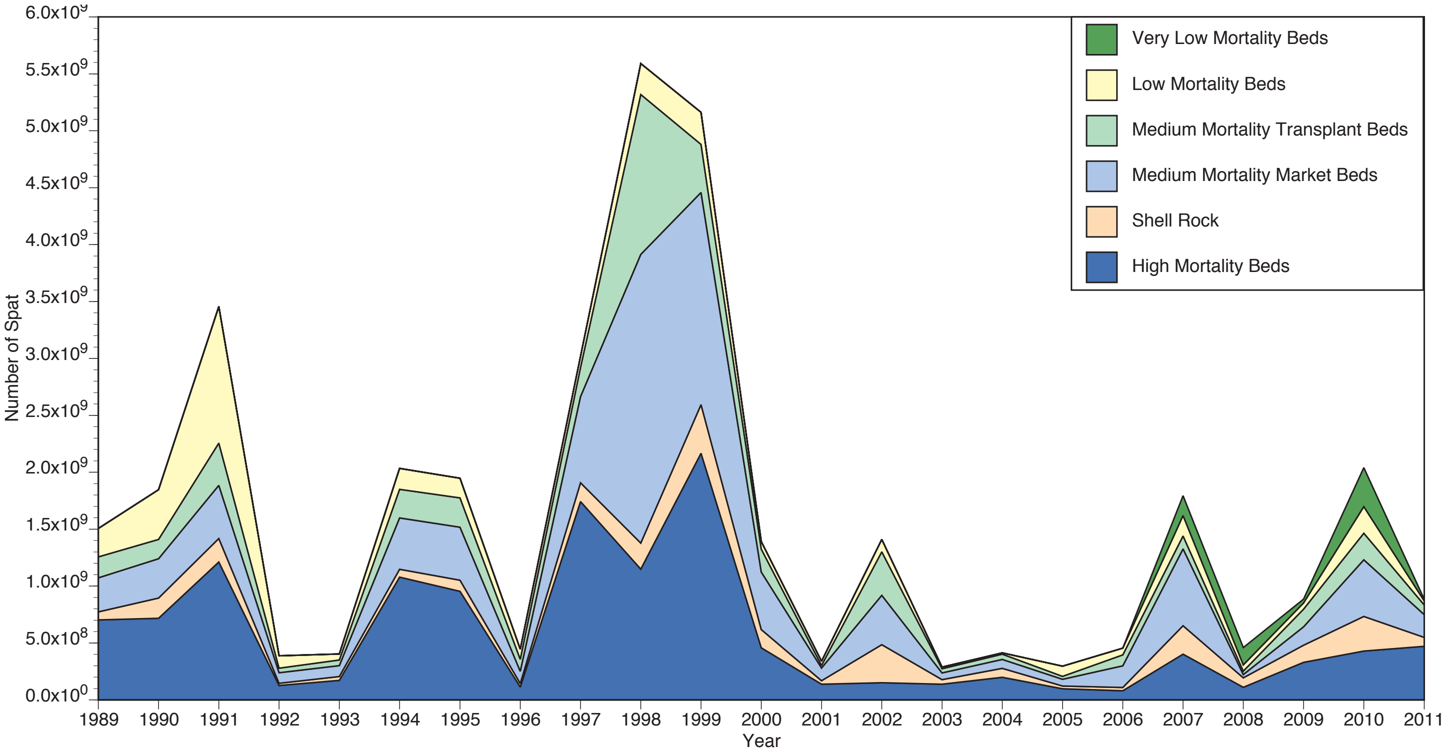


Figure 30. The number of spat recruiting per >20-mm oyster per year, excluding the very-low-mortality beds.

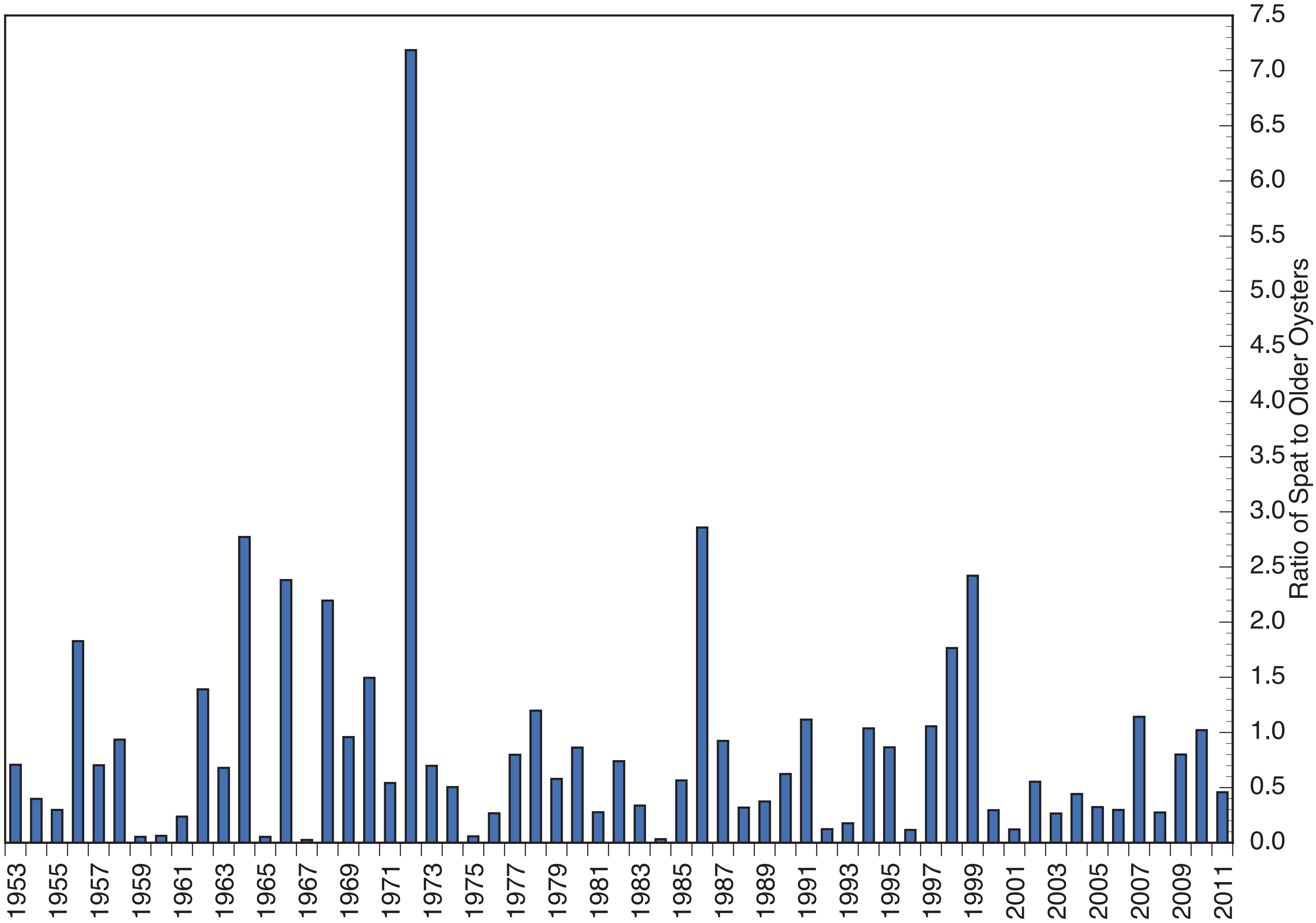


Figure 31. Spat-to-adult oyster ratio for each bay region. Bed distributions by bay region are given in Figure 7. Note variation in y-axis scale between graphs.

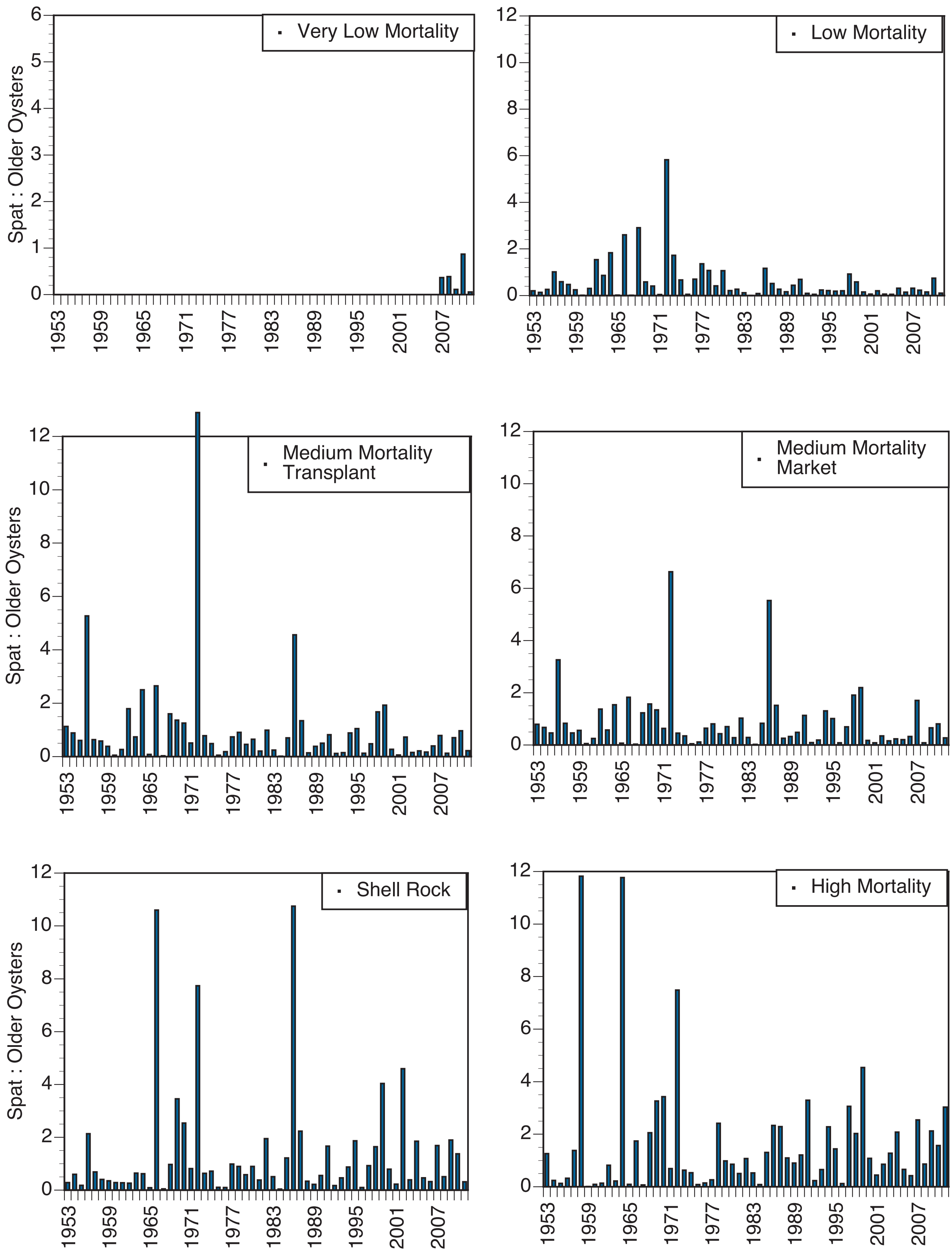


Figure 32. Change in simulated metapopulation allele frequency (the frequency of a neutral B-allele originally fixed in each of the indicated populations, but absent from the remaining populations at generation 0) for each of the four simulated populations. Change in frequency is calculated as the difference in metapopulation frequency for that allele in generation 100 of the simulation compared to generation 0. Simulations were run with DyPoGEn, an individual-based numerical model that simulates genetic structure and population dynamics for a metapopulation. Simulations were parameterized for 4 populations (1, very-low-mortality; 2, low-mortality; 3, Shell Rock; 4, high-mortality) and used population dynamics reflective of those for oysters in Delaware Bay during two time periods, the 1970's (yellow bars) and the 2000's (purple bars).

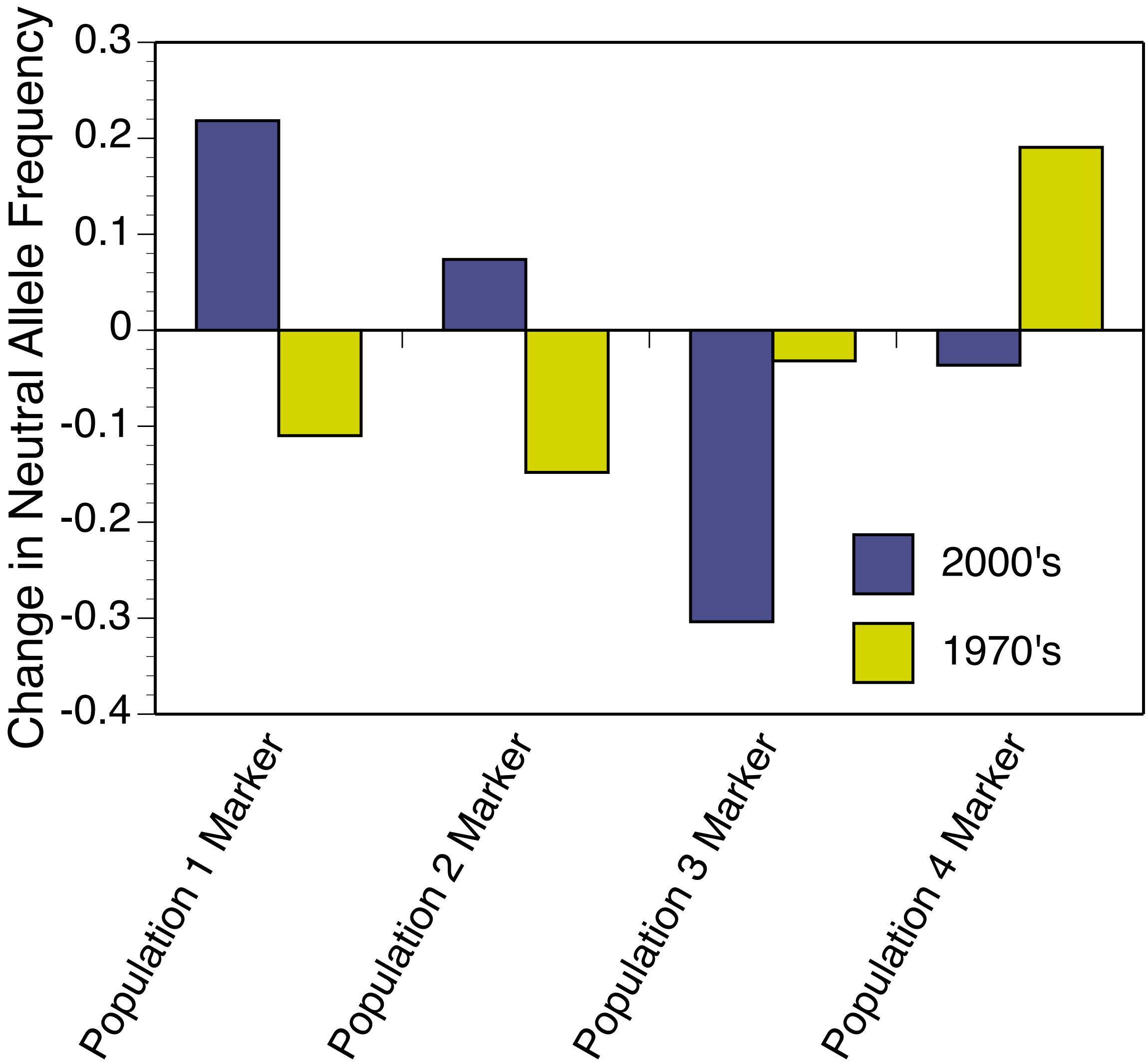


Figure 33. Location of 2011 shell plants, denoted by white stars.

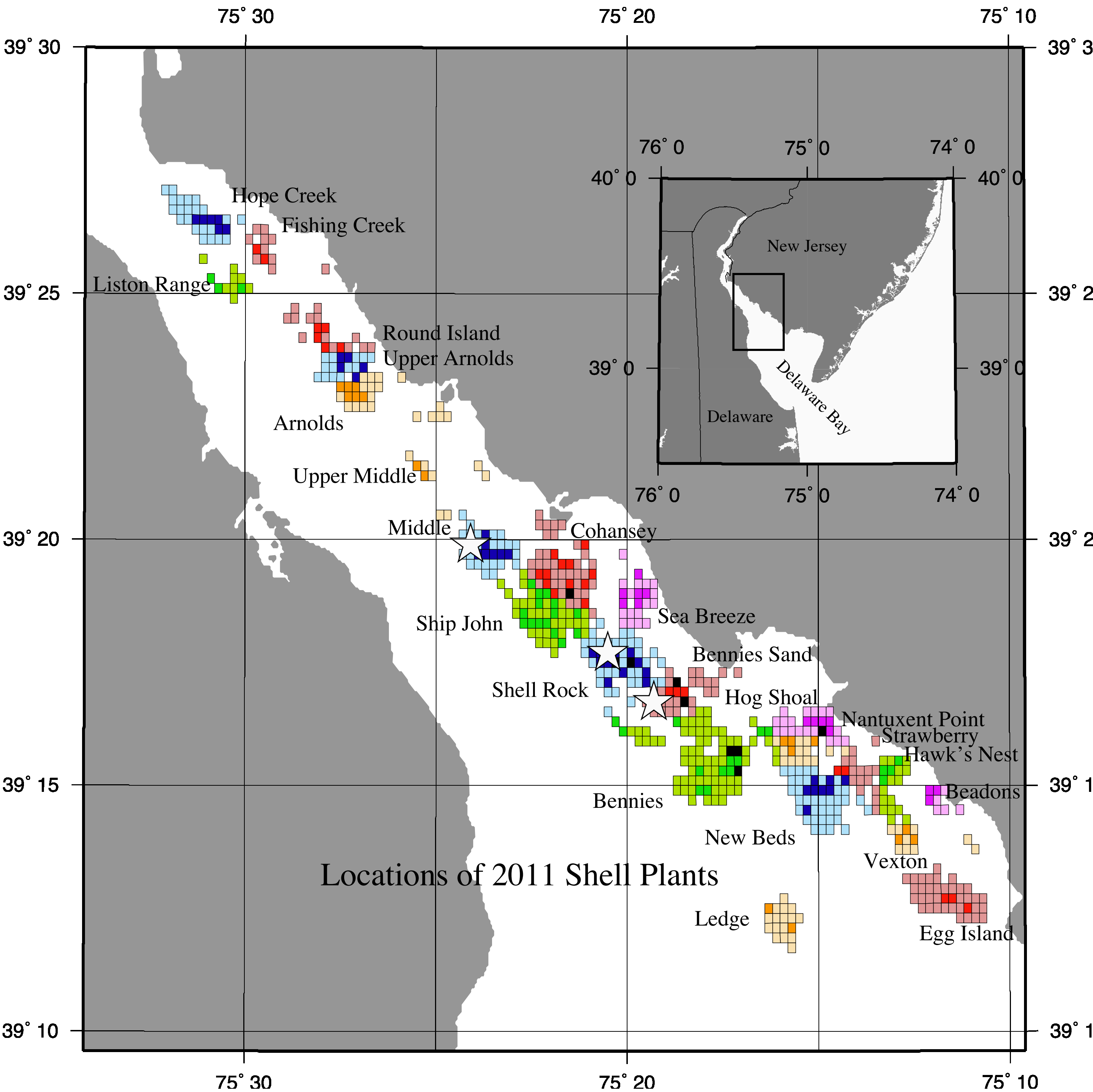


Figure 34. Estimated number of bushels of shell lost from the New Jersey oyster beds for the time period 1999-2011. Shell planting began in 2005 and increased in 2006-2008, but declined again in 2009-2011. Shell budgets are calculated using the updated half-lives estimated in this assessment and using the half-lives estimated in 2009 and 2010 (SAW-11, SAW-12) for comparison.

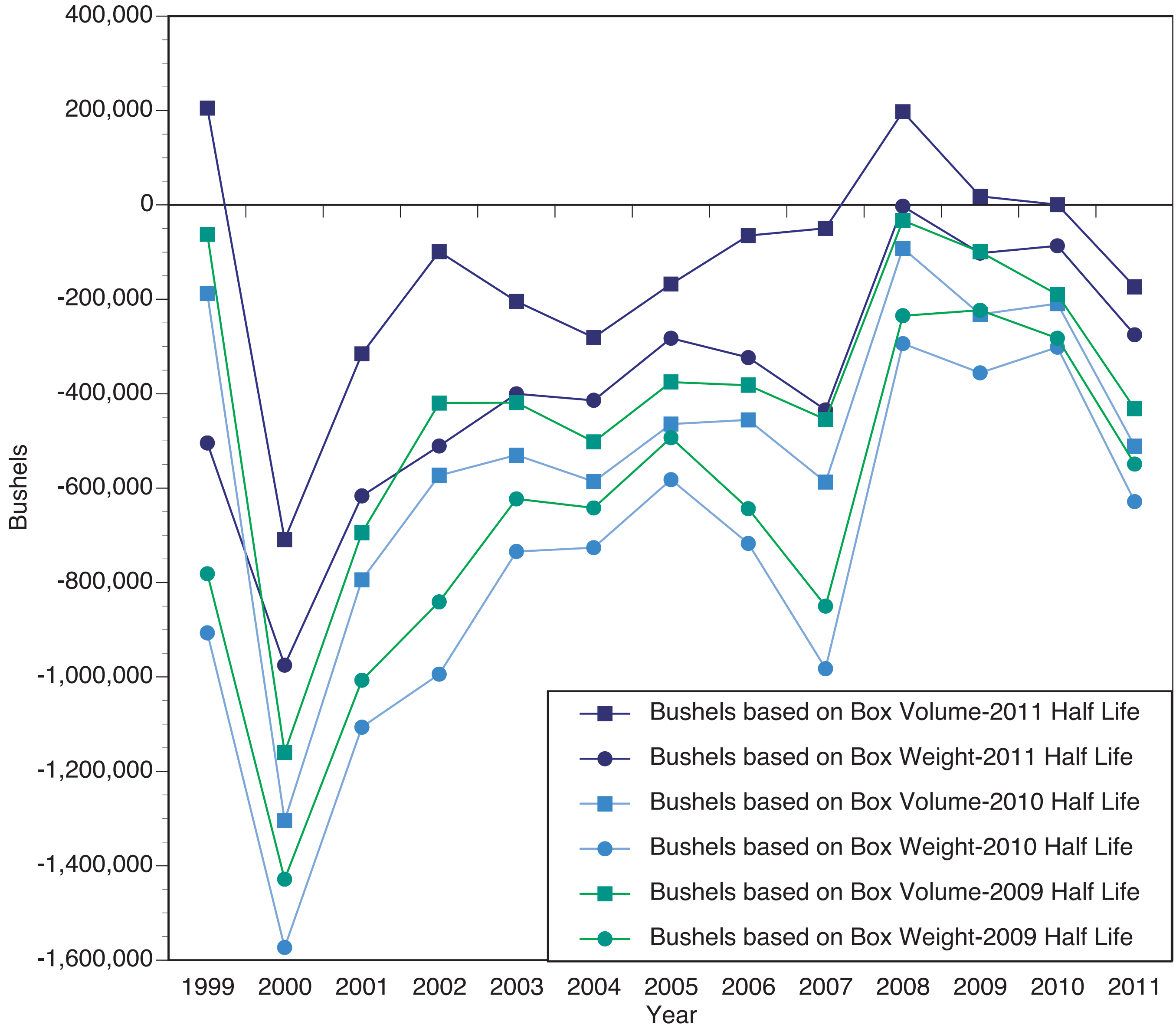


Figure 35. Estimated net change in surficial shell content in bushels for the New Jersey high-mortality beds and for the remaining oyster beds for the time period 1999-2011.

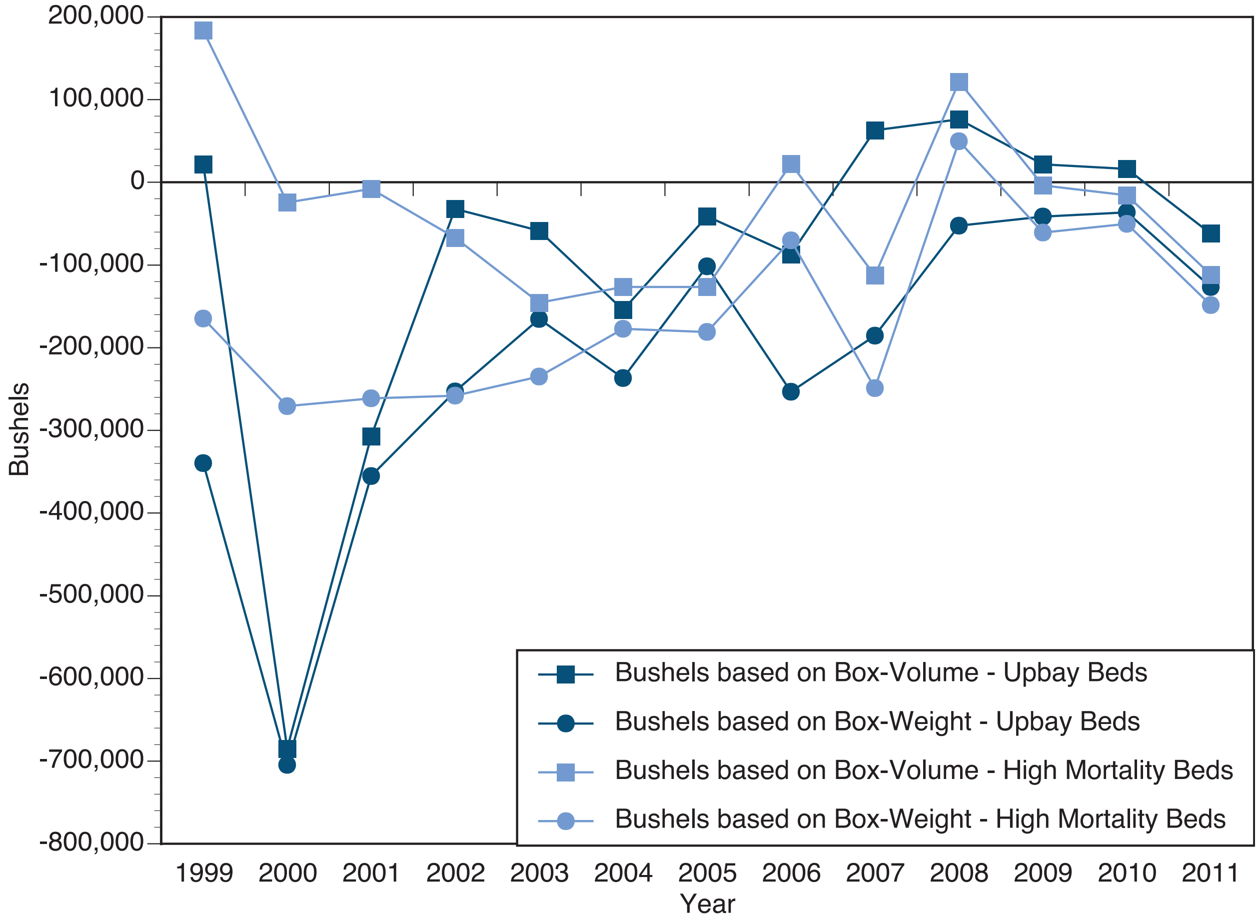


Figure 36. Estimated net change in surficial shell content in bushels by bay region for the New Jersey oyster beds for the time period 1999-2011.

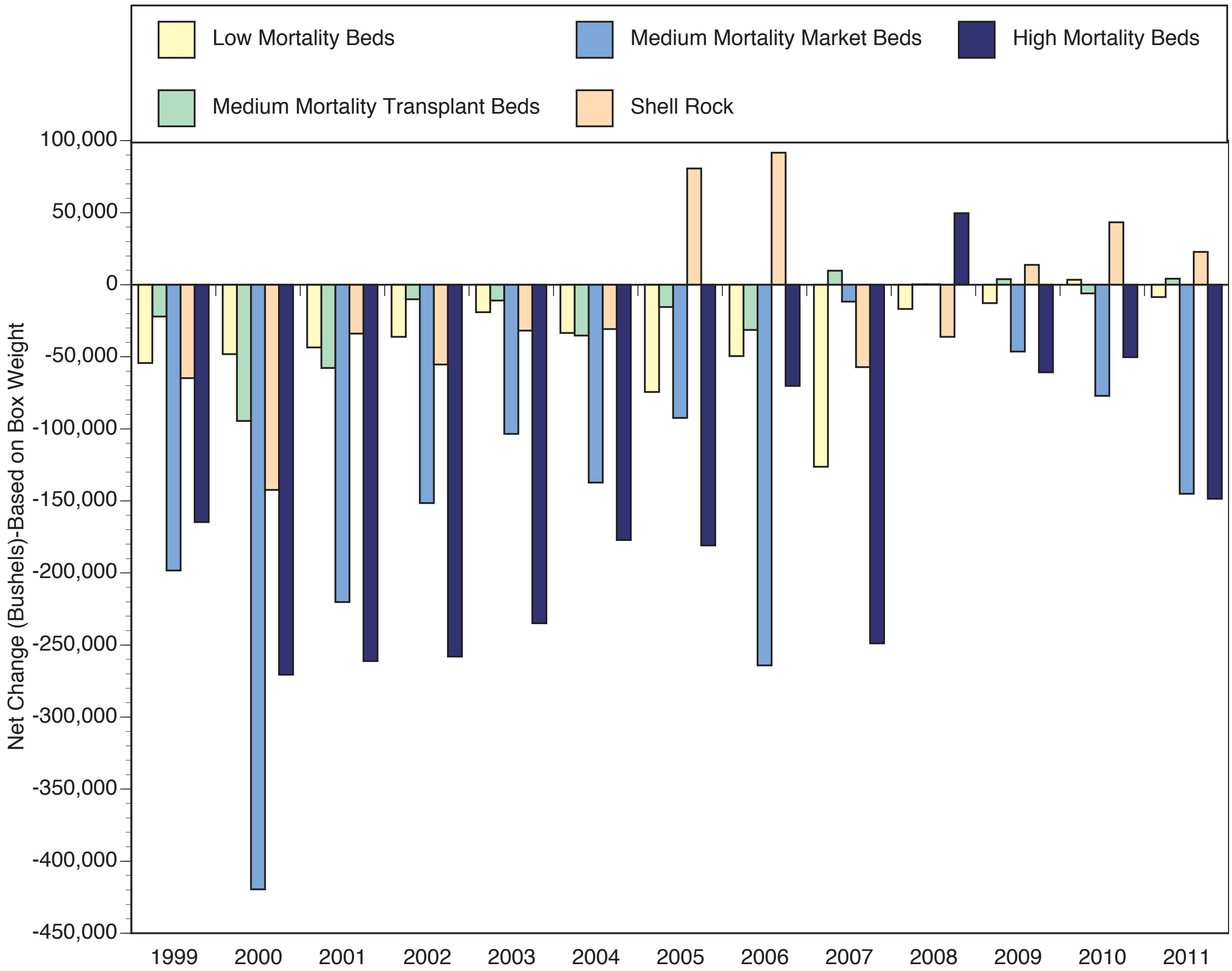


Figure 37. Temporal history of surficial (TAZ) and subsurface reef carbonate for a simulated oyster reef exposed to fishing and Dermo disease In year 201, fishing was implemented under a constant-F (fishing mortality rate) assumption. Removal rates are equivalent to the removal of 10% ($F = 0.105$), 20% ($F = 0.222$), and 40% ($F = 0.511$) of the fishable stock yearly. For Delaware Bay, a removal rate of 5% ($F = 0.053$) is also shown. Dermo was imposed at a moderate mortality rate, 22% of the population yearly. DB, a Delaware Bay case; GM, a Gulf of Mexico case from a high-productivity region capable of sustaining two generations per year. Left: the vertical extent of the TAZ over the last 250 years of a 400-year simulation relative to the threshold eliciting burial of shell for a pristine and a fished reef ($T_{max} = 5$ or 10 cm). Right, the relief of the reef framework relative to the 1-m relief defined at the initiation of the simulation. The lower rate of reef accretion prior to year 200 for the Gulf of Mexico originates from the lower value for L_∞ used for these simulations.

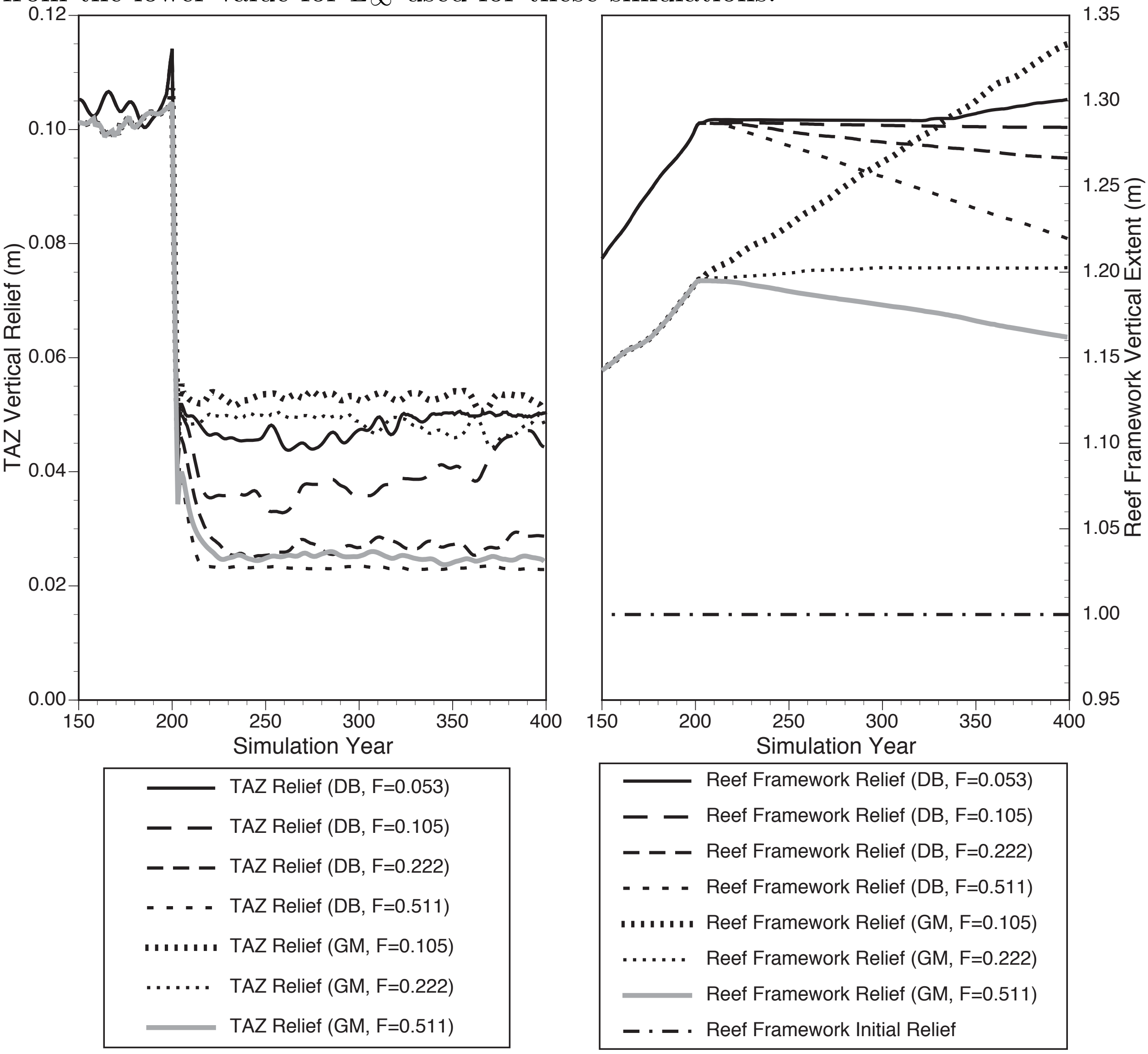


Figure 38. Time series of box-count mortality on New Jersey Delaware Bay oyster beds prorated by bay section. The height of each shaded area is proportional to the total number of deaths contributed by that bay region. The cumulative sum of the four bay regions measures the bay-wide mortality rate for that year.

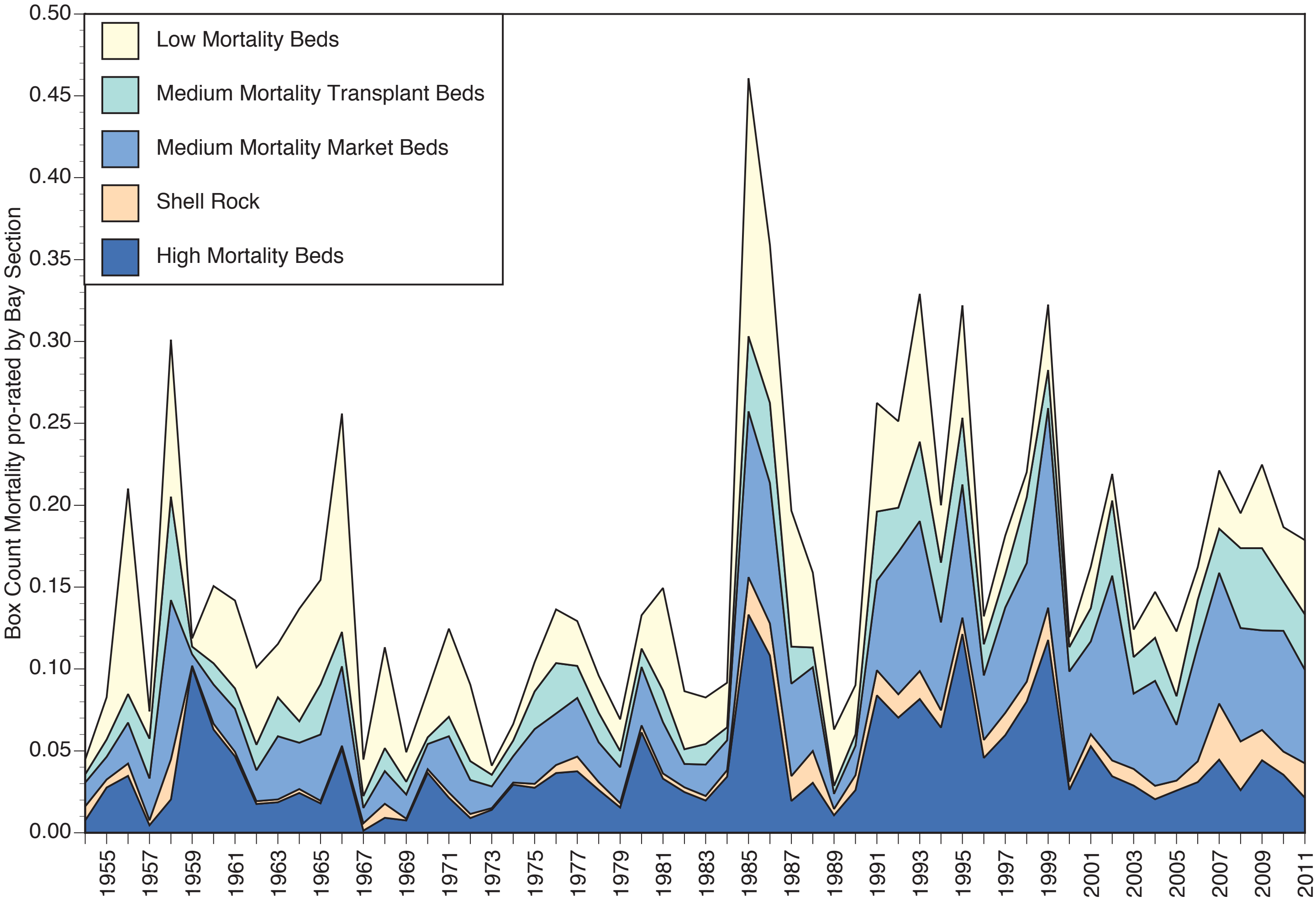


Figure 39. Time series of box-count mortality on New Jersey Delaware Bay oyster beds by bay section. The height of each shaded area measures the mortality rate in that bay region. The bay-region value can be obtained by the difference between the top and bottom ordinate values for the region. No data are available for the very-low-mortality beds prior to 2007.

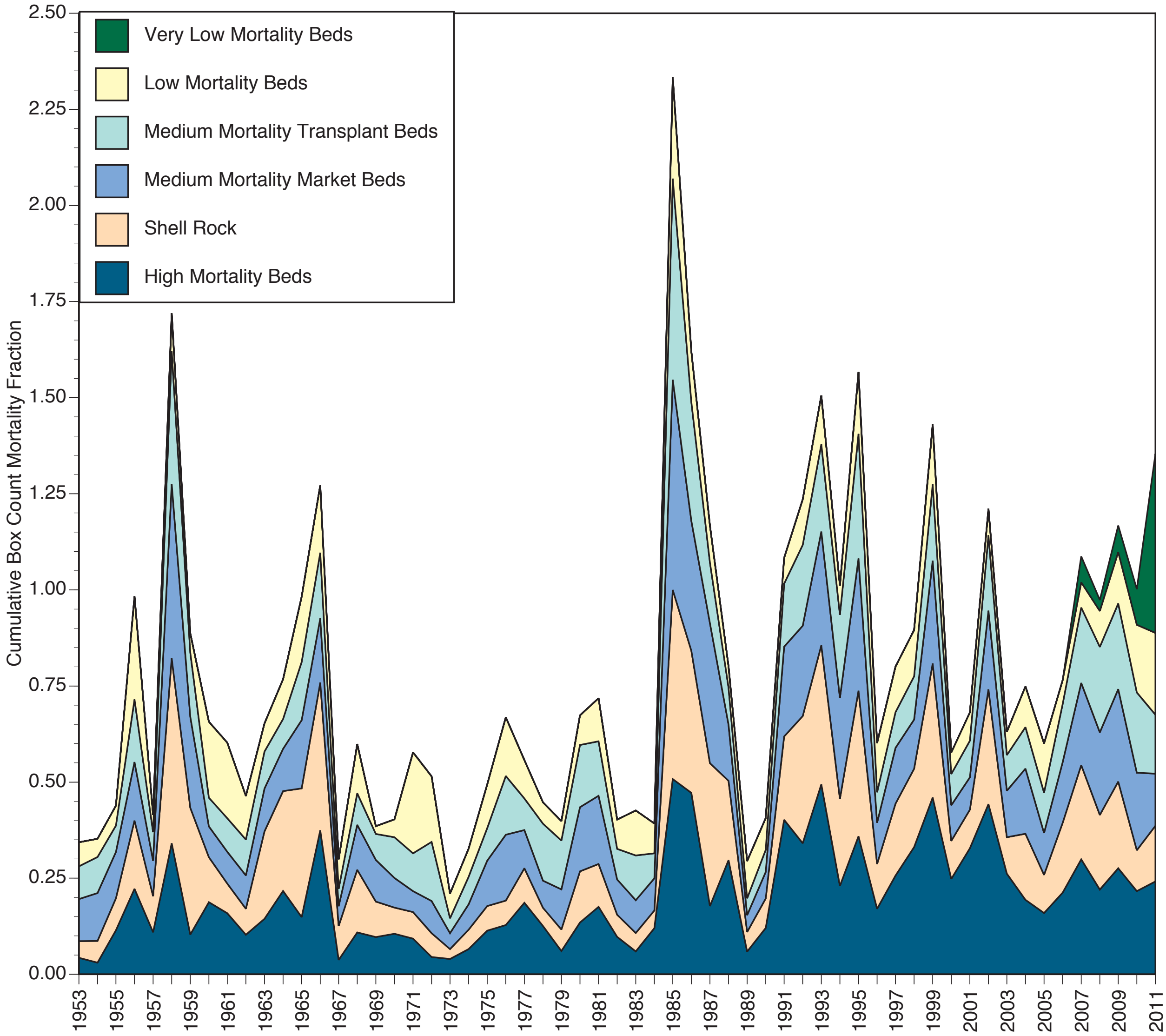


Figure 40. Comparison of the mortality rate by number and by biomass for the six bed regions for the last five years. Bed distributions by bay region are given in Figure 7.

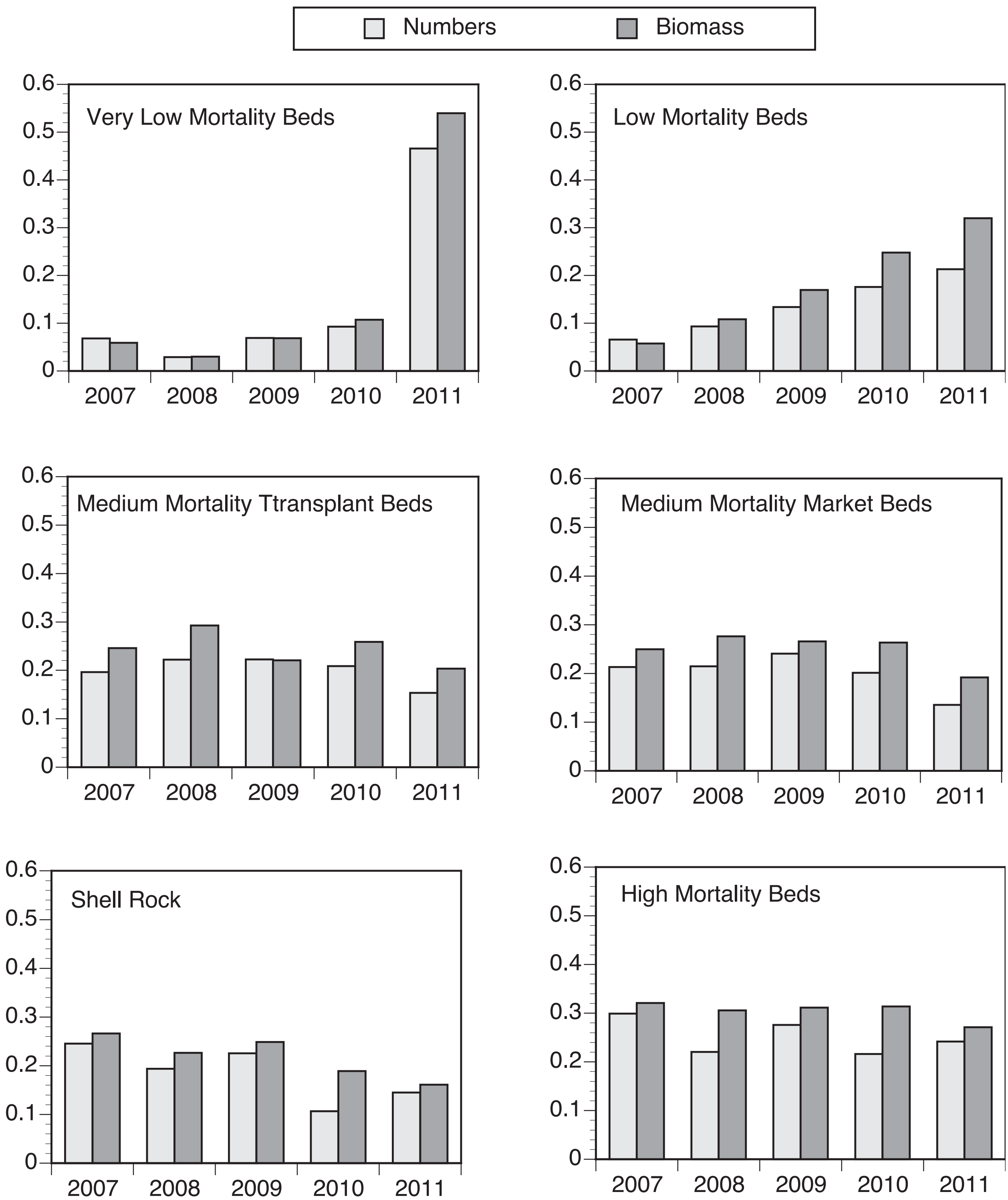


Figure 41. Broodstock-recruitment relationship for the 1953-2011 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2010 because the plot compares end-of-2010 oyster abundance with 2011 recruitment. Blue lines identify the 59-year medians used for calculation of first passage times (Table 16). The Ricker curve fit is in green.

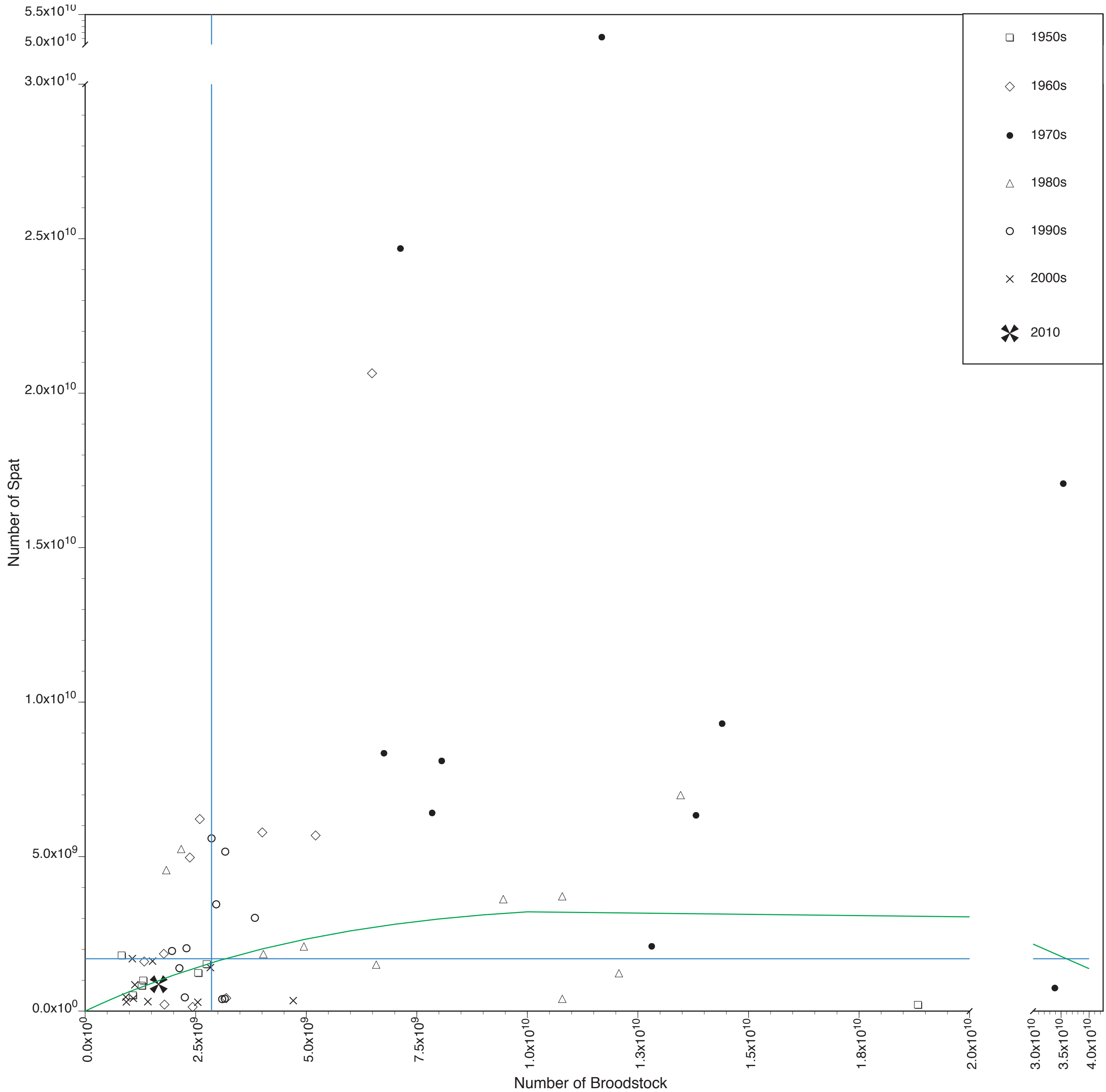


Figure 42. The quadrant numbering convention used to calculate mean first passage times. The one year transition probabilities are obtained by examining the position of consecutive x-y data pairs in quadrant space. Four transitions are possible for each starting position, the possibilities for Quadrant 1 being depicted. Sixteen total trajectories are possible.

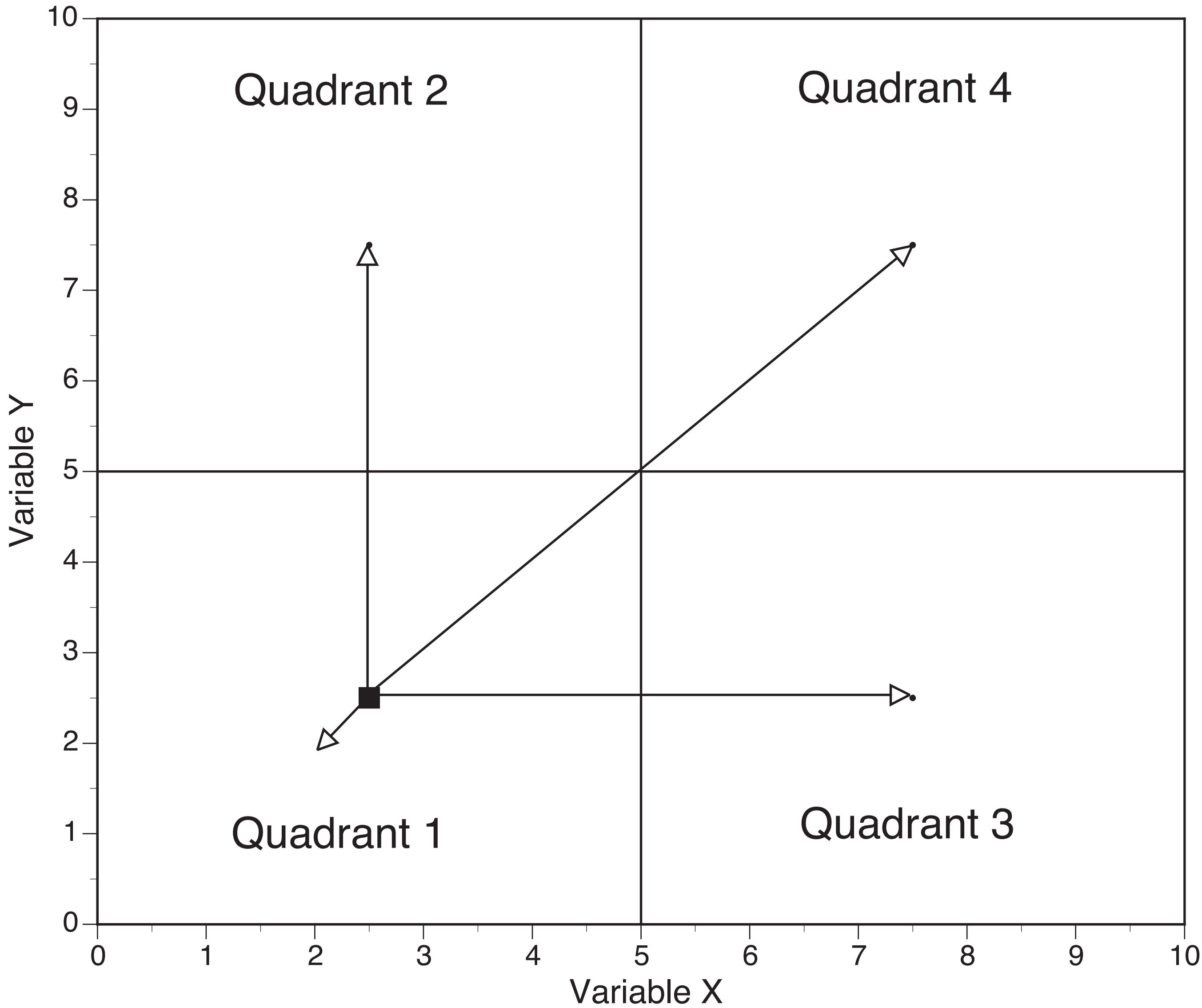


Figure 43. The relationship between oyster abundance and box-count mortality for the 1953-2011 time period for the natural oyster beds of Delaware Bay. Latest year listed as 2010 because the plot compares end-of-2010 oyster abundance with 2011 mortality. Blue lines identify the 59-year medians used for calculation of first passage times (Table 17). The nonlinear curve used for modeling surplus production is in green.

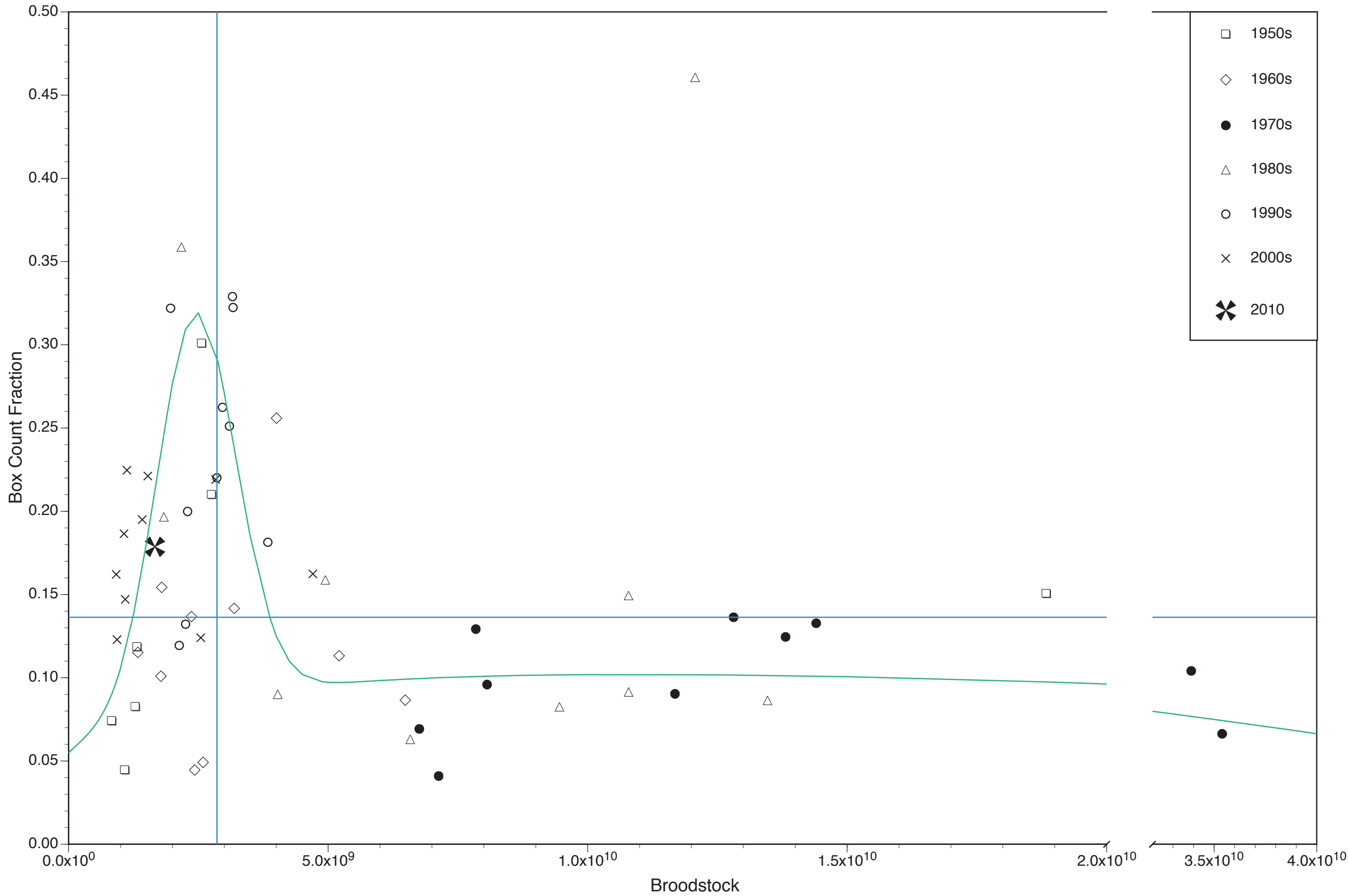


Figure 44. The relationship between recruitment and box-count mortality for the 1953-2011 time period for the natural oyster beds of Delaware Bay. Blue lines identify the 59-year medians used for calculation of first passage times (Table 18).

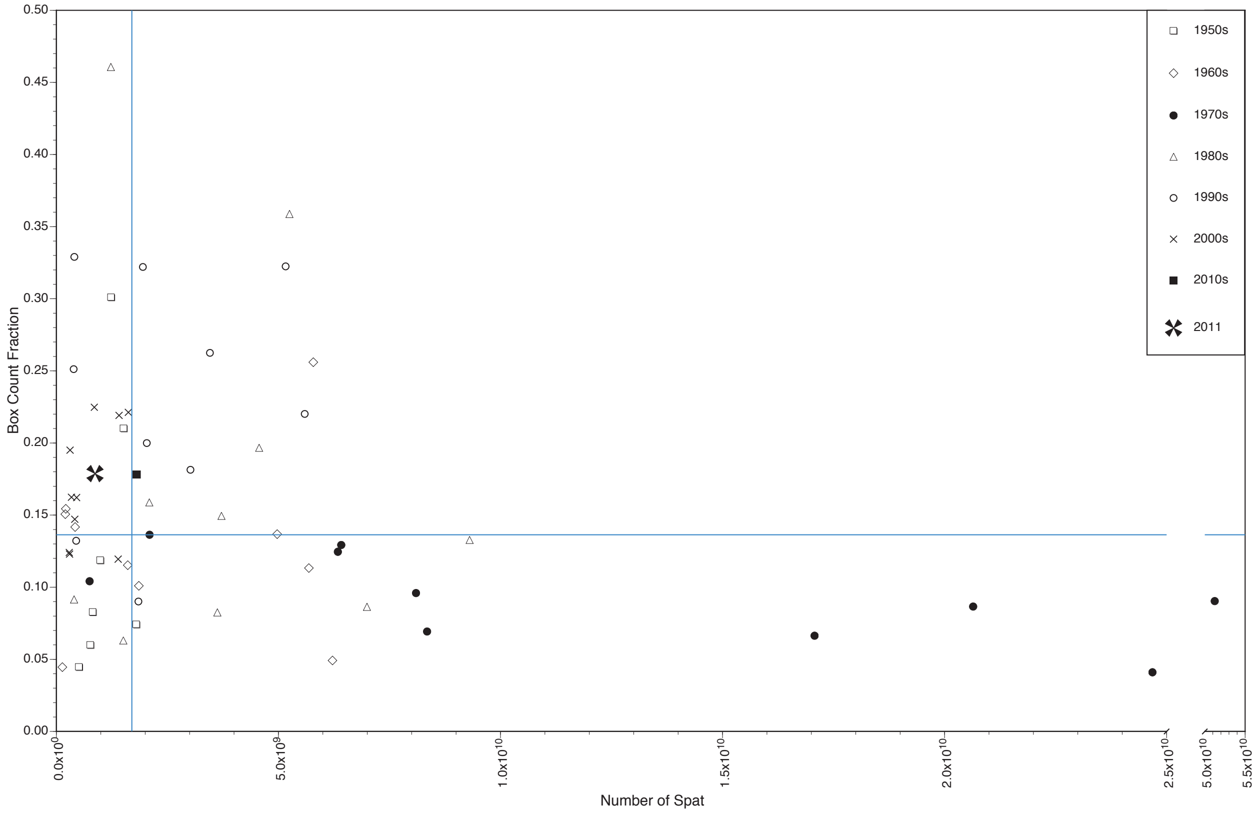
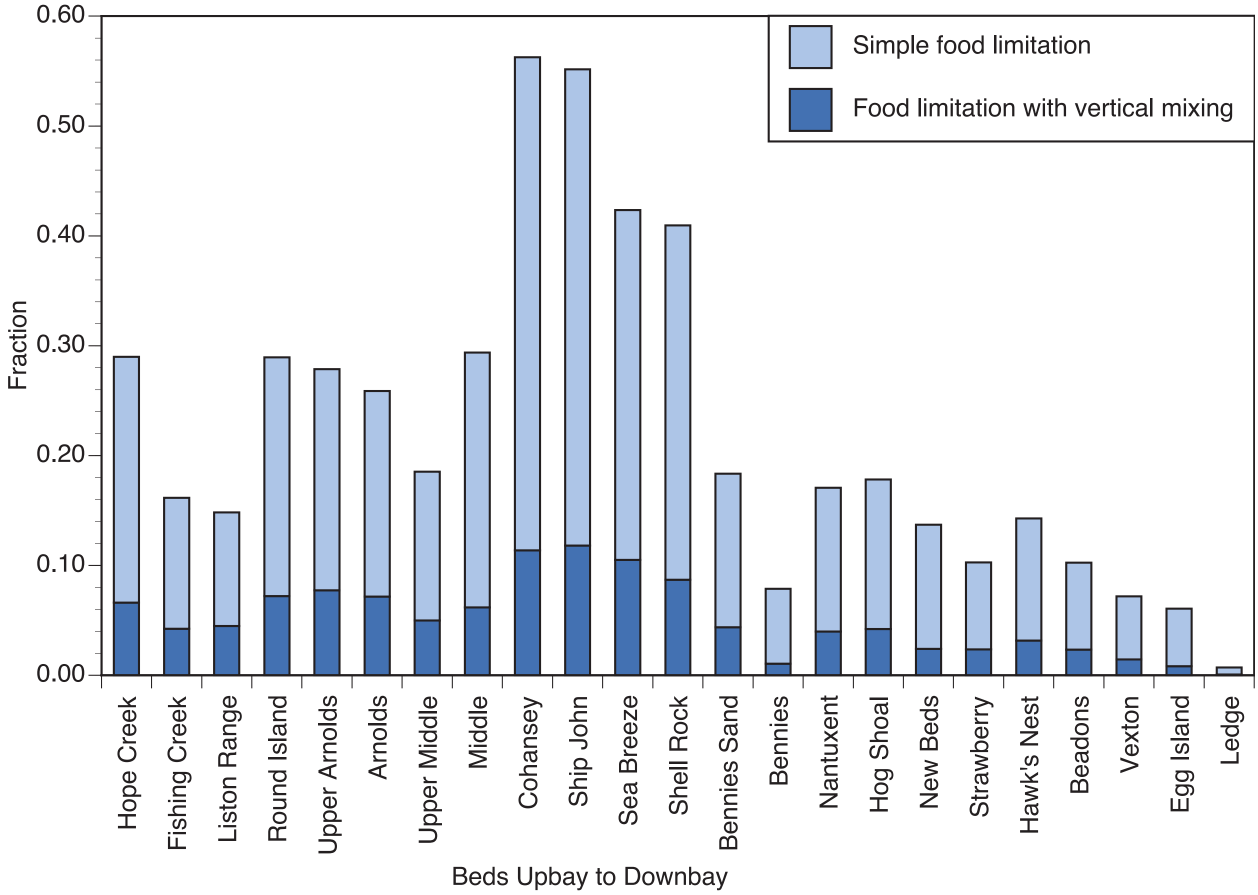


Figure 45. Estimated fractional reduction in food from within-bed density (upstream-downstream) effects based on the Wilson-Ormond model . Light bars assume no vertical mixing over the oyster beds. Dark bars assume vigorous vertical mixing.



Op. cit.

Figure 46. Time series of average food values in the Delaware Bay at New Jersey oyster bed and downestuary sites.

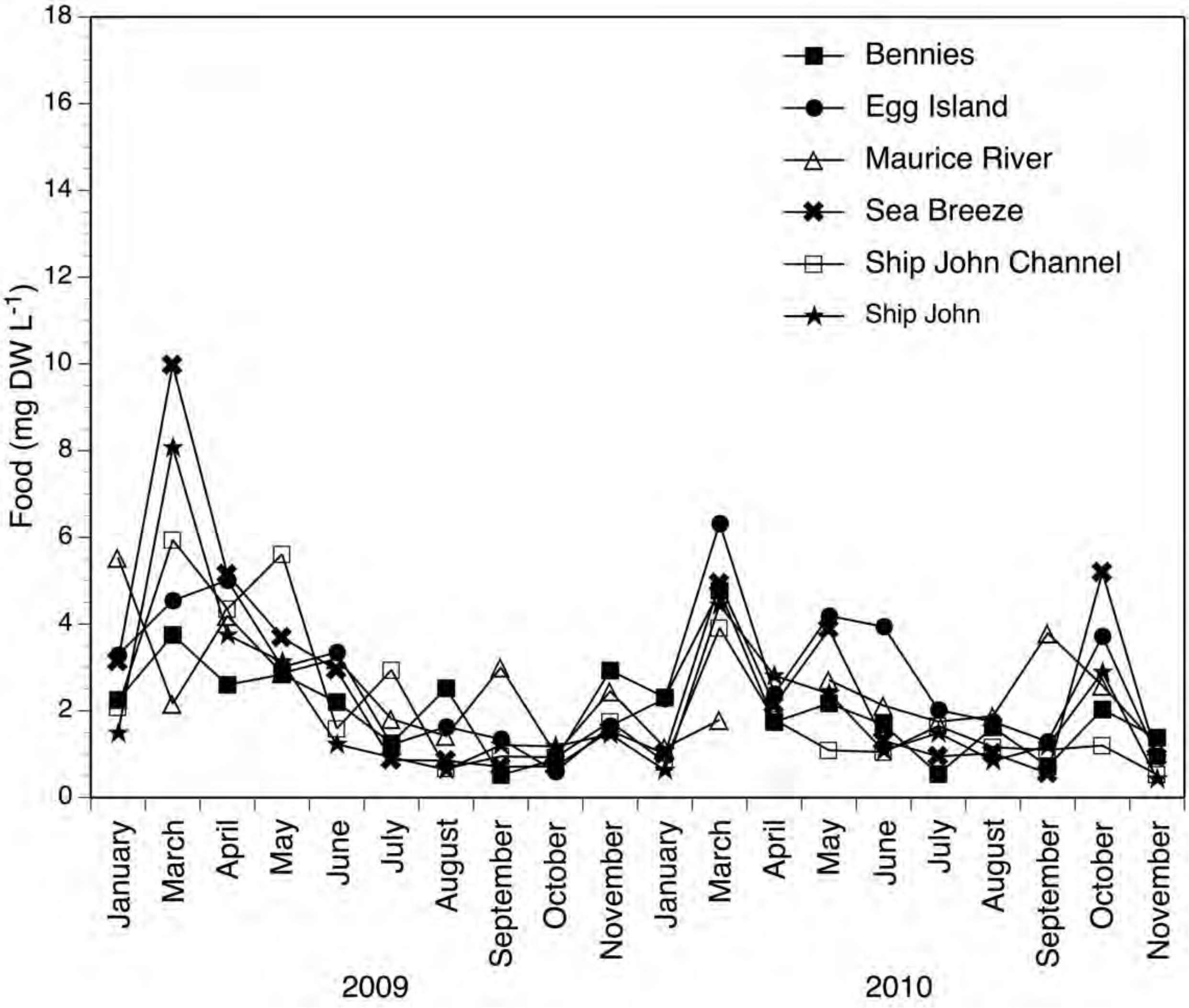


Figure 47. The differential in site values for a given sampling time relative to the monthly 15-site mean for each site. Sites depicted are those that fell into a large cluster of sites comprising most of the New Jersey oyster beds. Plotted values are the fractional deviation of each site's food value for each sampling relative to the average for all 15 samplings for that site in each month calculated as $(\frac{value - average\,value}{average\,value})$.

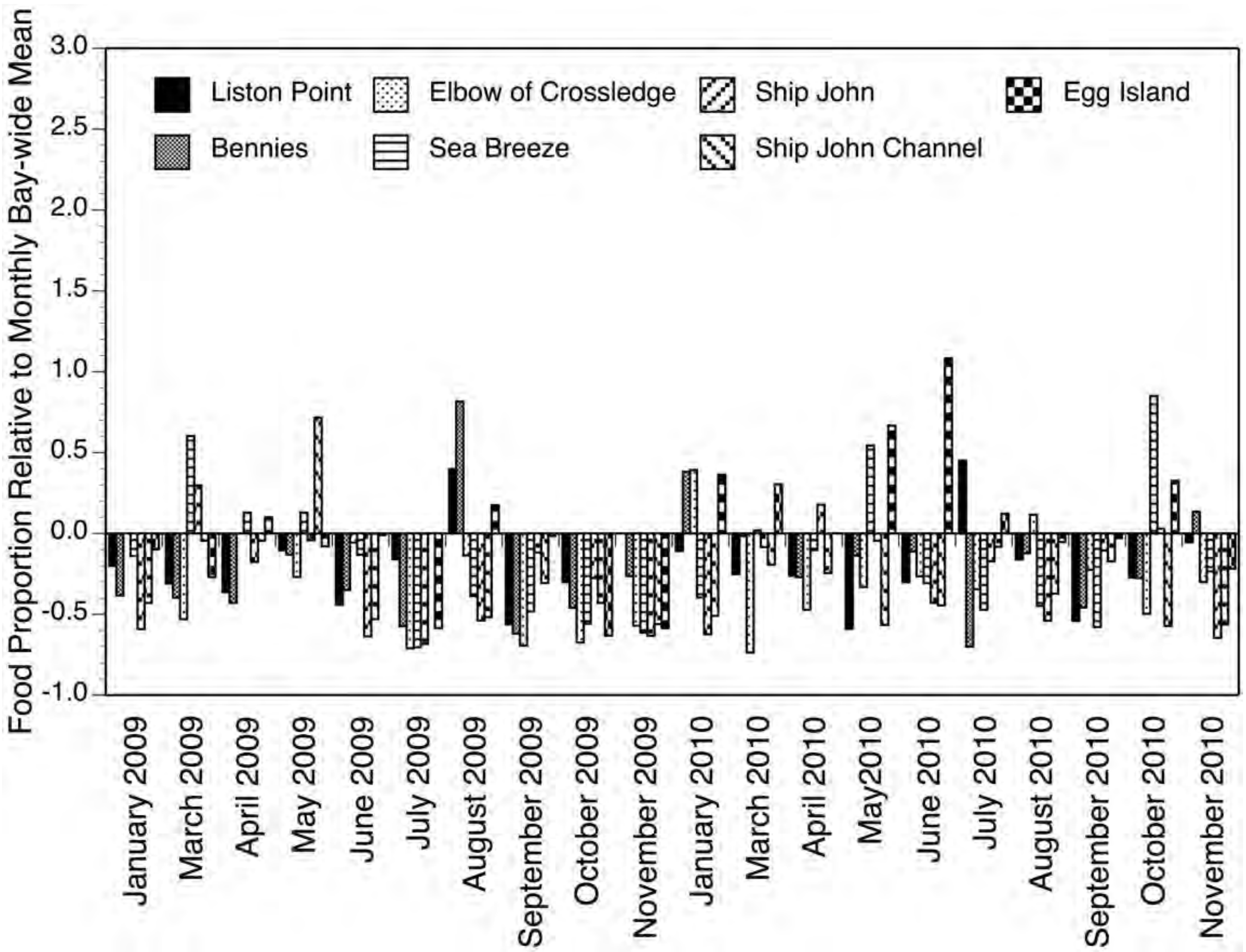


Figure 48. The differential in site values for a given sampling time relative to the monthly 15-site mean for each site. Sites depicted are those that fell into a large cluster of sites comprising most of the Delaware oyster beds. Plotted values are the fractional deviation of each site's food value for each sampling relative to the average for all 15 samplings for that site in each month calculated as $(\frac{value - average\,value}{average\,value})$.

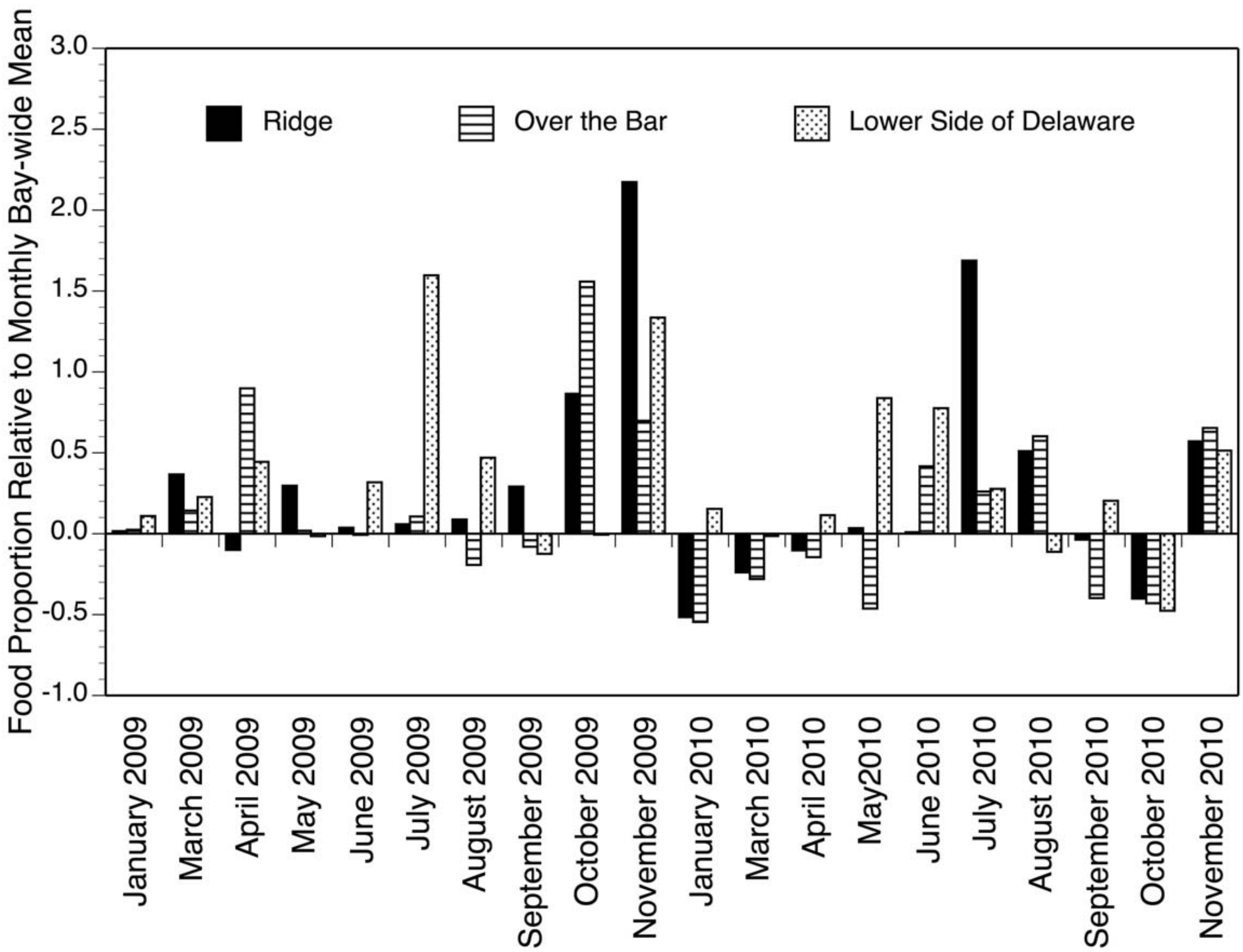


Figure 49. Number of bushels harvested from the natural oyster beds of Delaware Bay since the inception of the direct-market program.

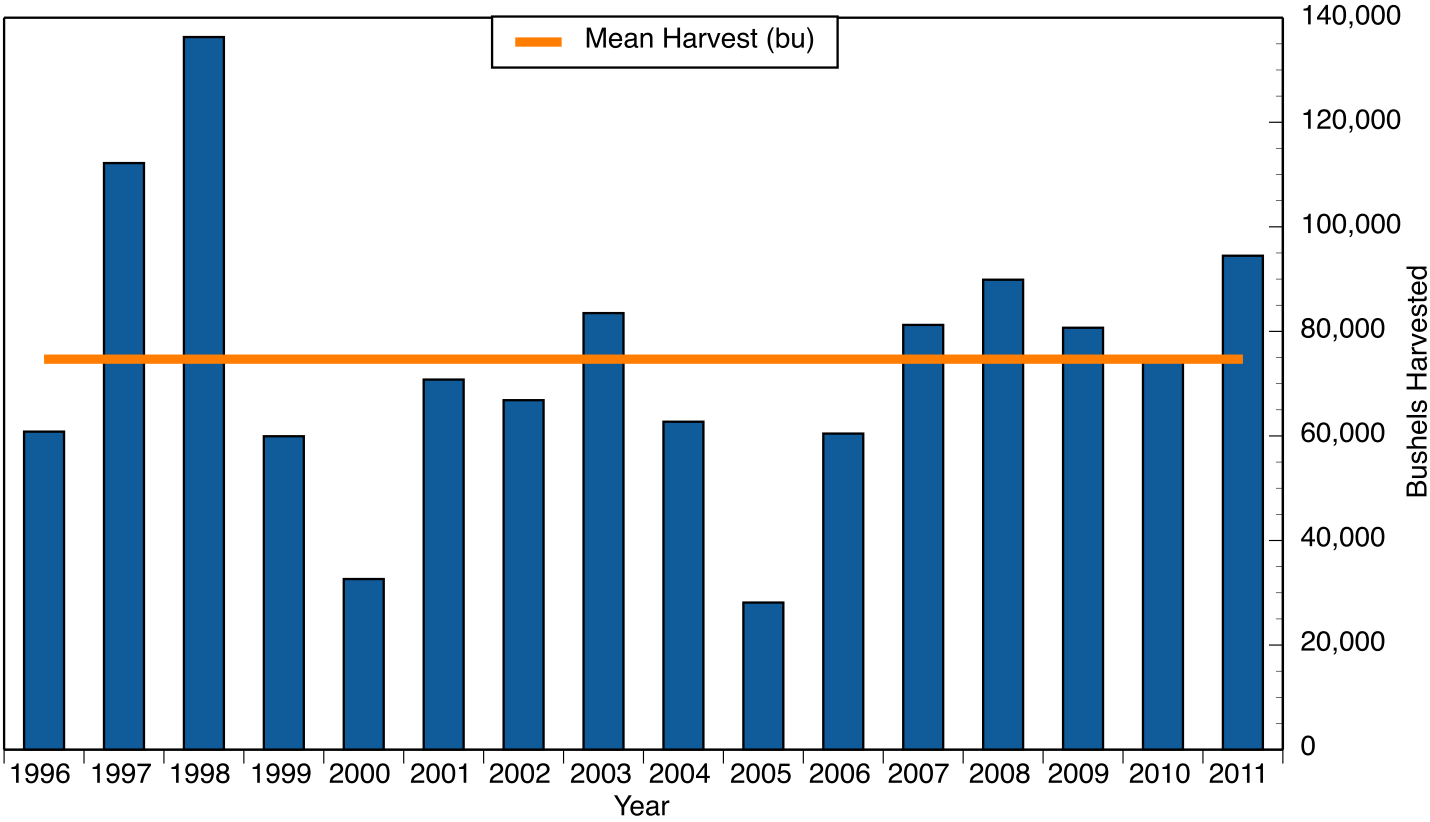


Figure 50. Number of oysters harvested from the natural oyster beds of Delaware Bay. Prior to 1996, the bay-season fishery removed oysters from the beds and transplanted them downbay to leased grounds. The direct-market fishery began in 1996. In 1997, an intermediate transplant program began. In this 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.

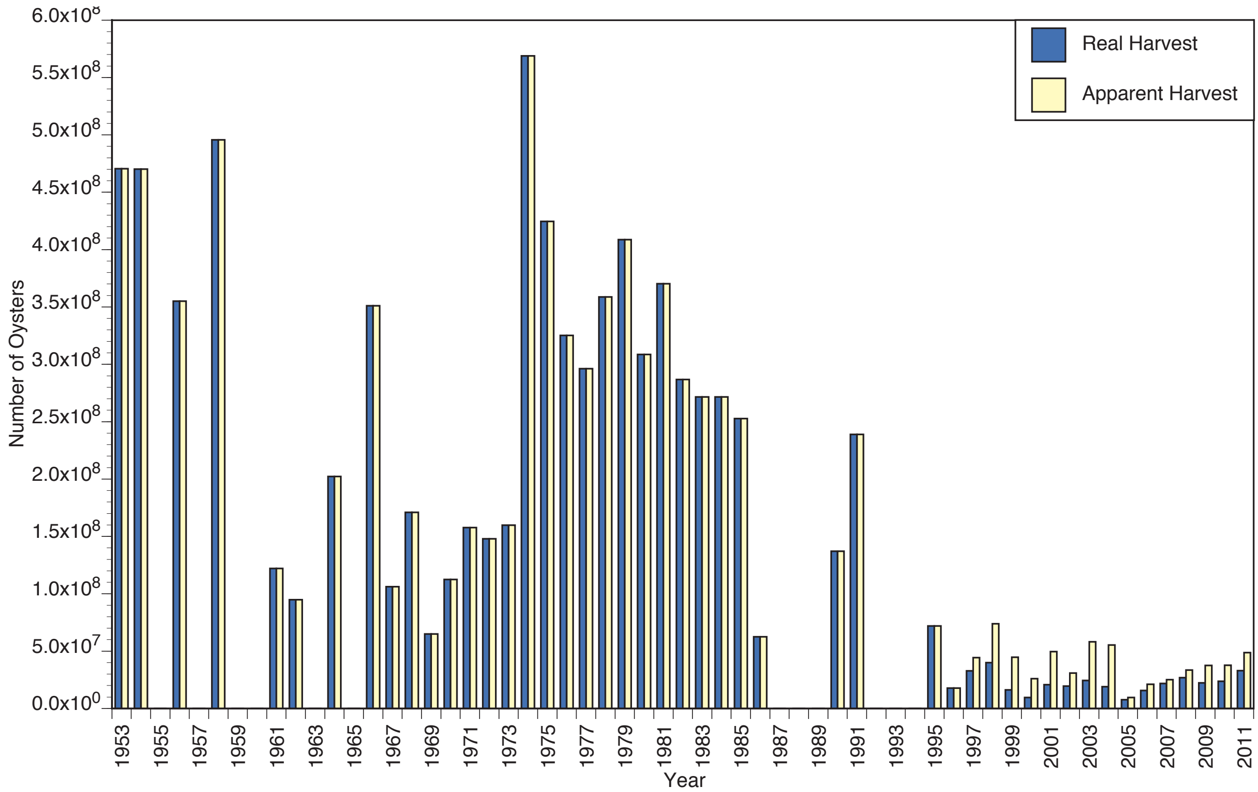


Figure 51. Catch (in bushels) per boat-day by vessel type.

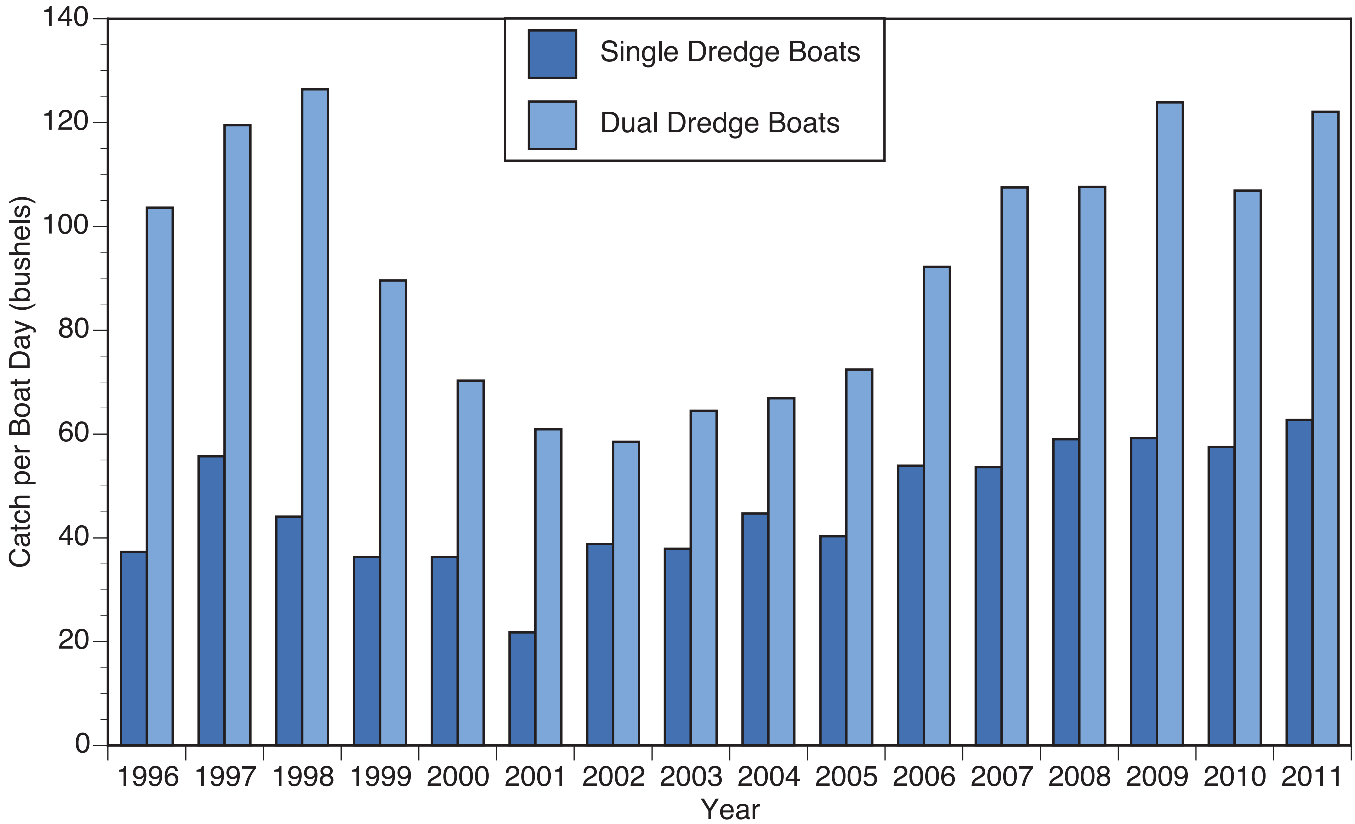


Figure 52. Trends in dredge coverage as a fraction of total bed area for Shell Rock, compared to four population characteristics.

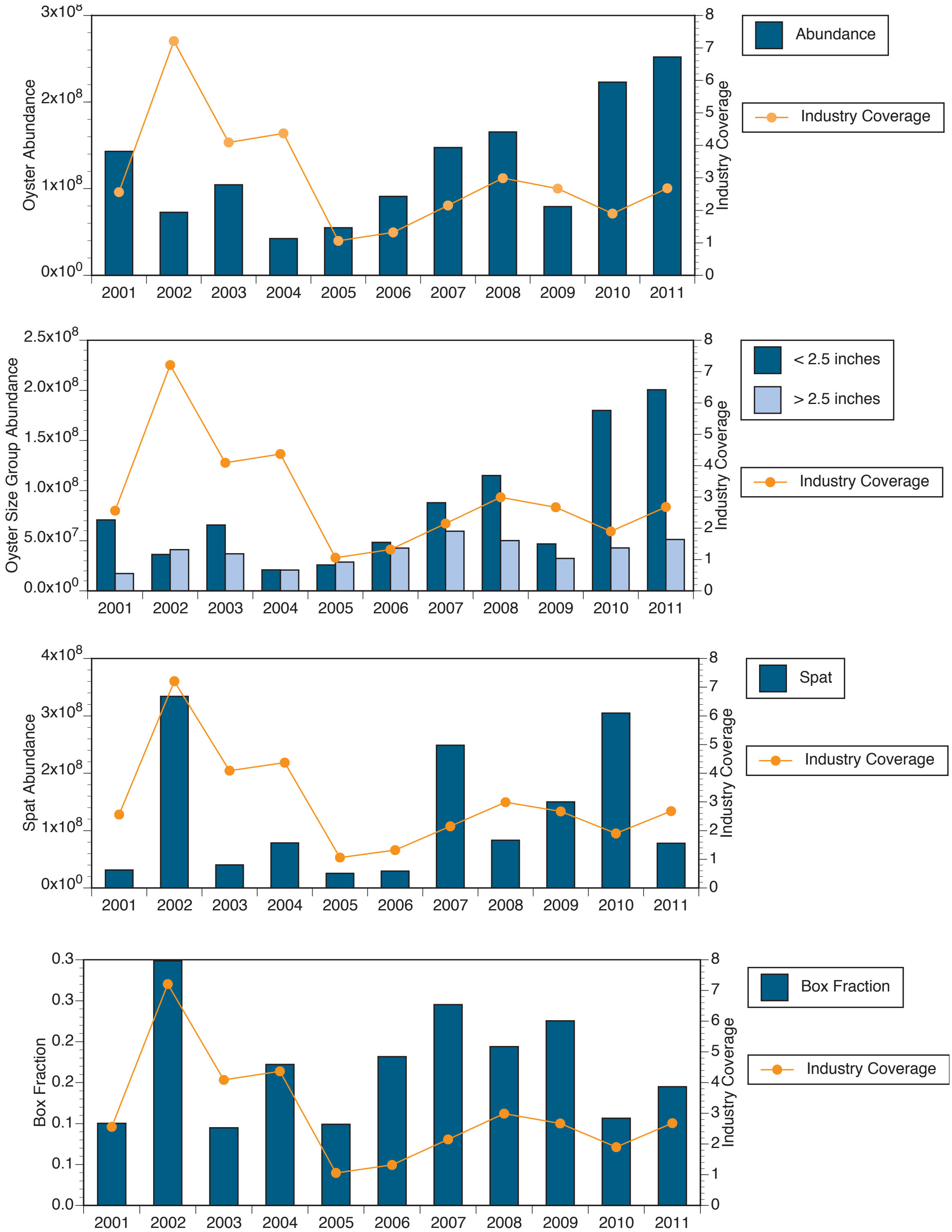


Figure 53. Trends in dredge coverage as a fraction of total bed area for Ship John, compared to four population characteristics.

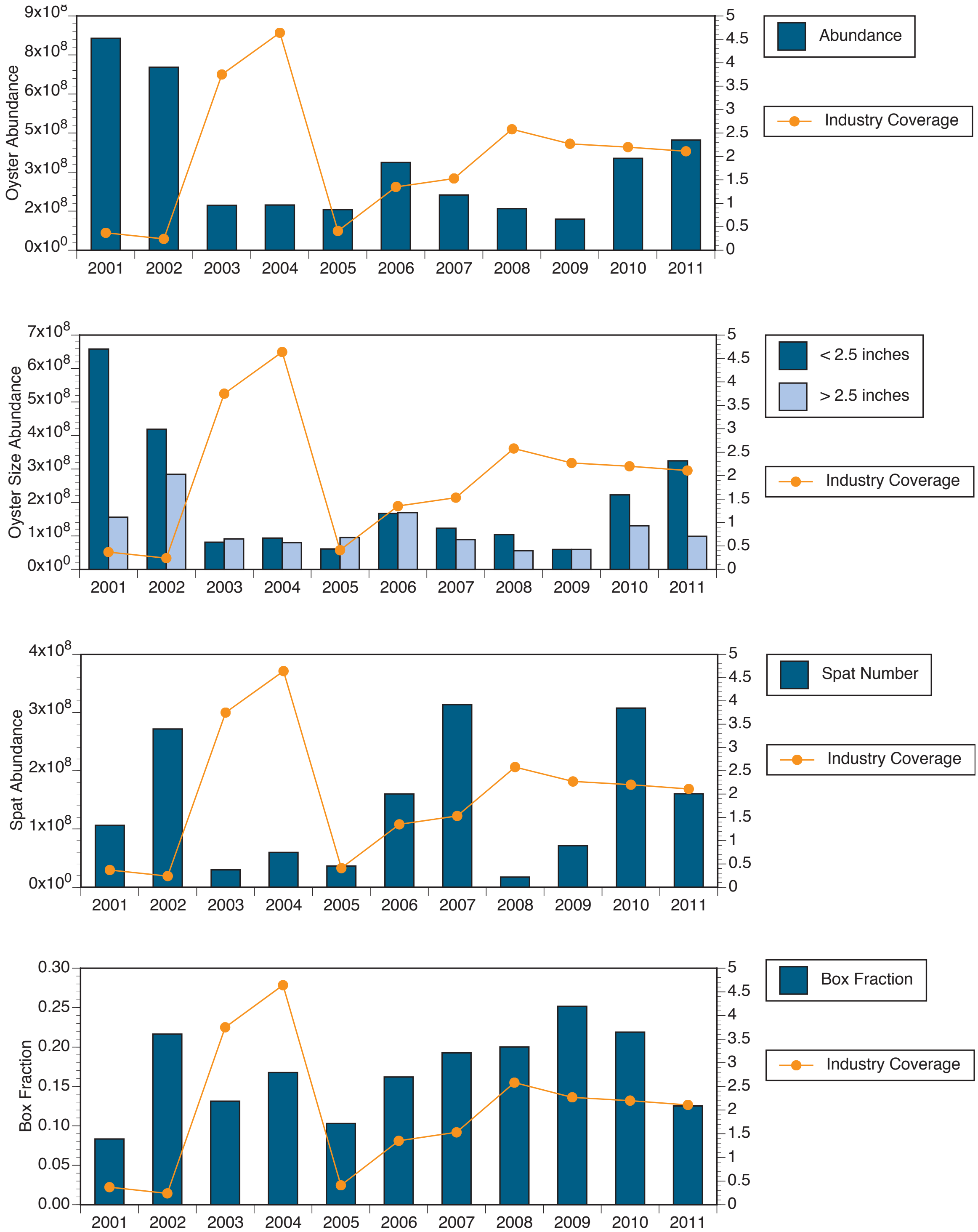


Figure 54. The number of oysters per landed bushel judged to have been landed due to failure to cull small attached oysters from those of market size (attached) and unattached oysters judged to have been too small to be targeted for market ($<2.5''$).

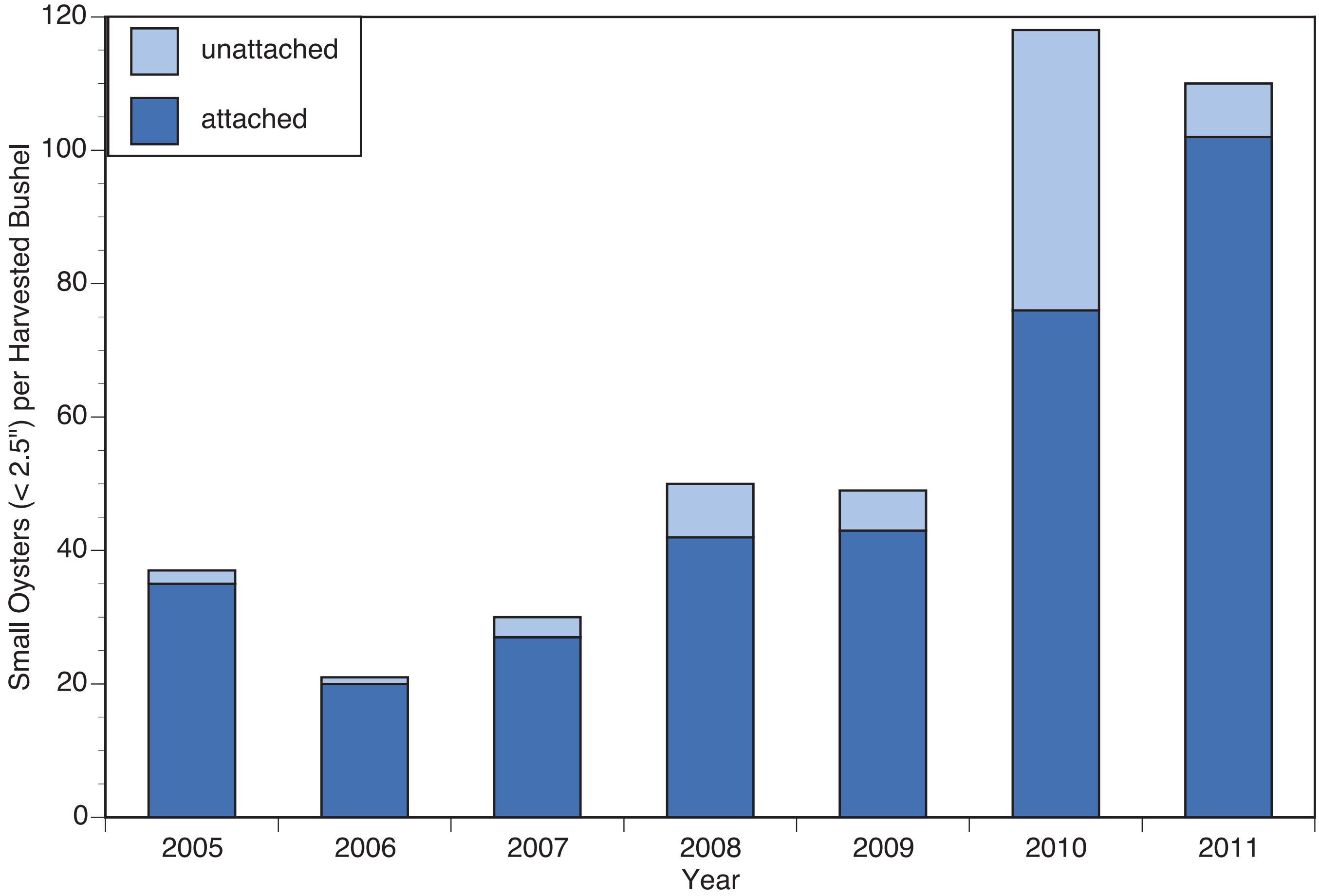


Figure 55. Size frequency of oysters landed in 2011 compared to 2009 and 2010. Size class values are the lower bounds of the size class.

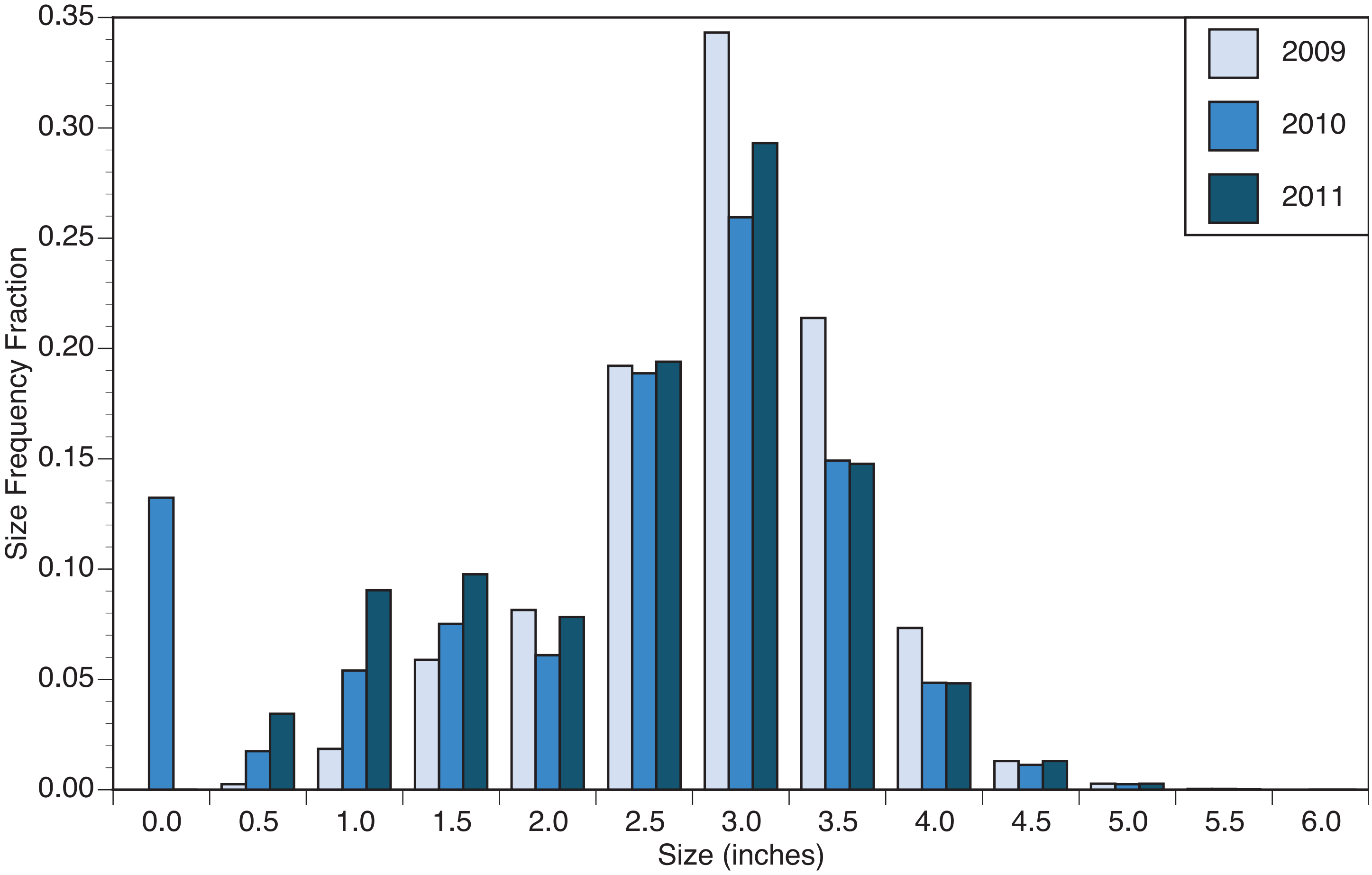


Figure 56. Location of intermediate transplants on Cohansey and Bennies. See Figure 1 for details on bed coloration.

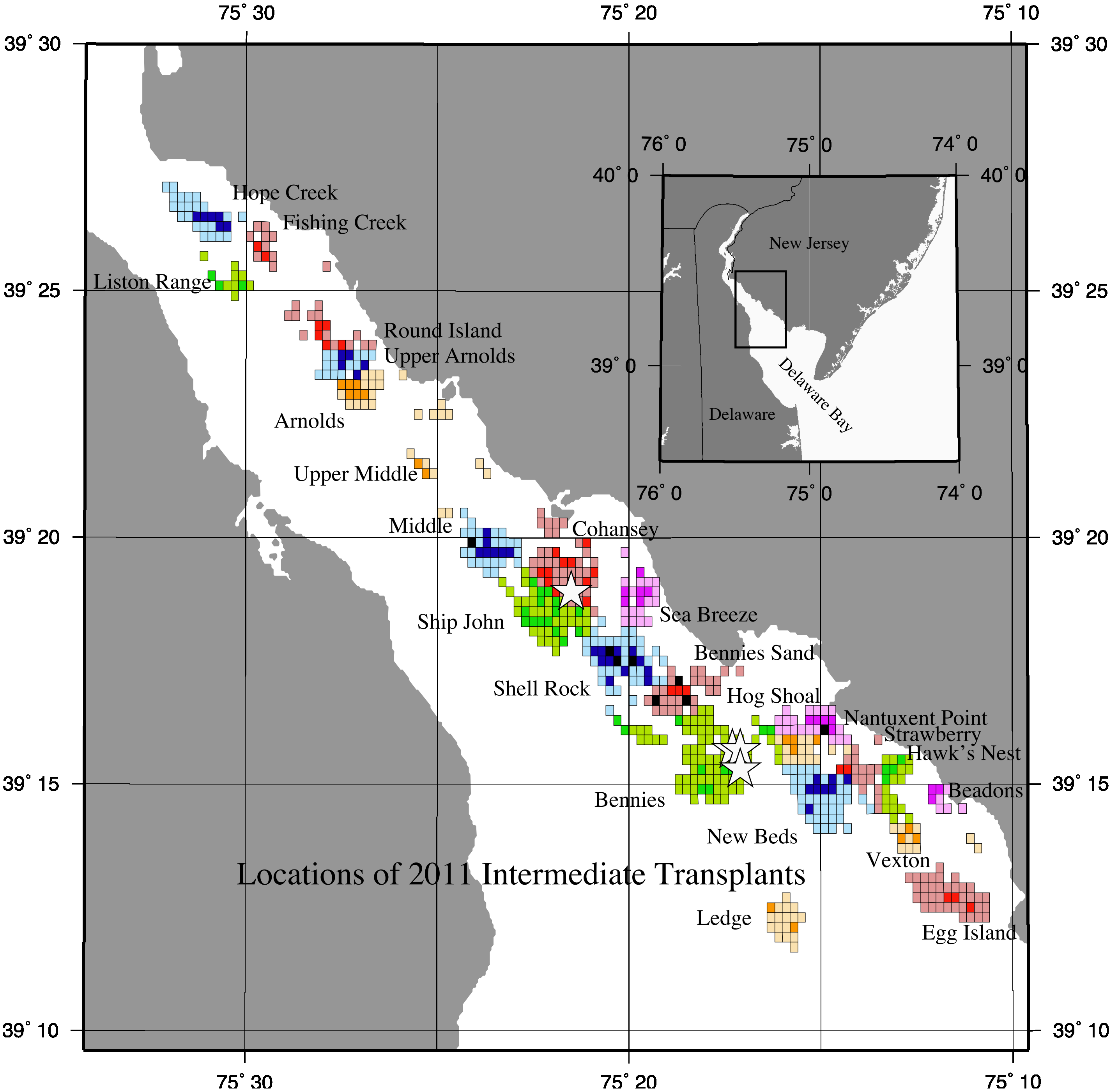


Figure 57. Fishing mortality rates by bay region during the 1954-2011 time period. After 1996, the total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 7. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality rate in that bay region. The total column height is the total fraction for the year.

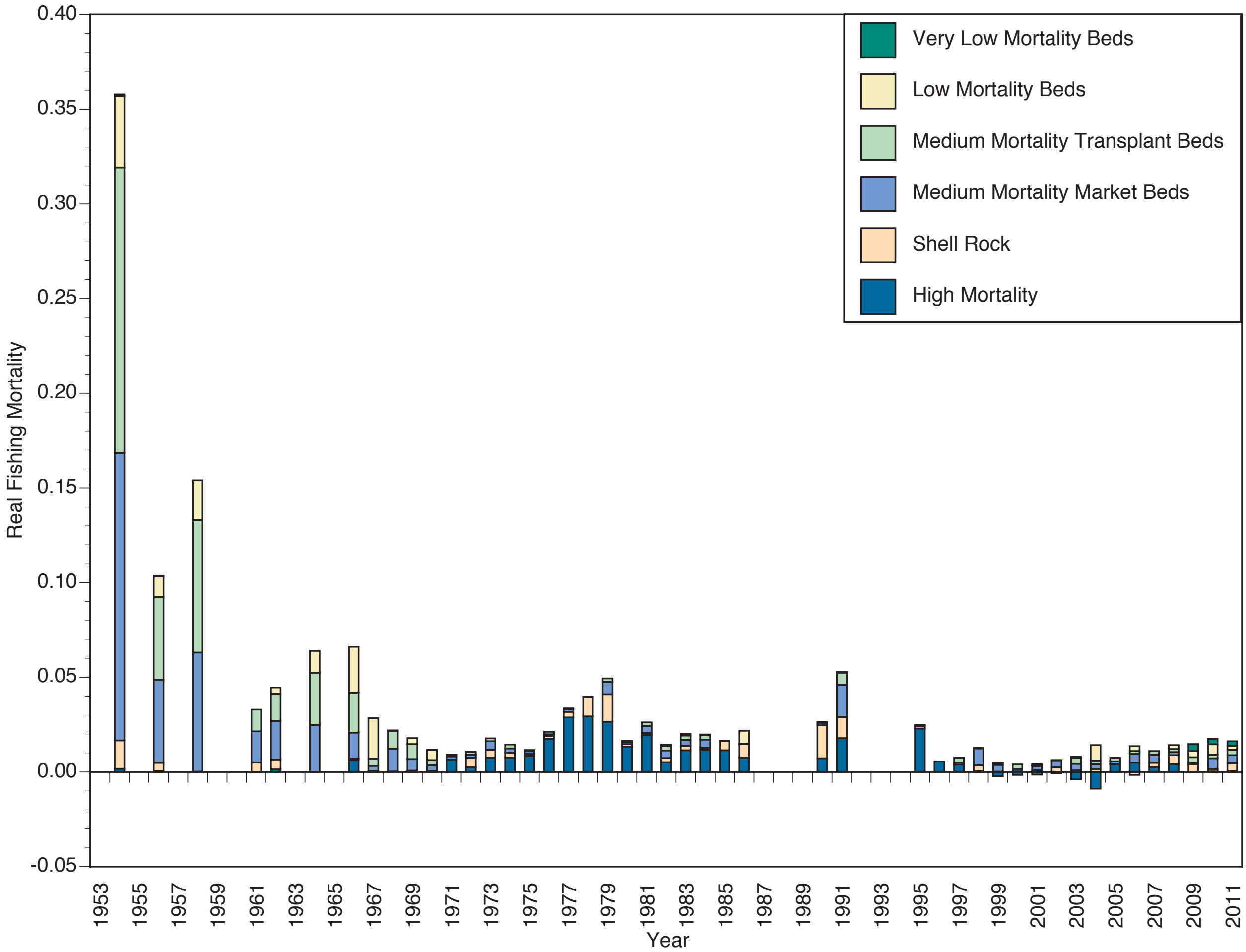


Figure 58. Fishing mortality rates by bay region during the 1989-2011 time period. The total reflects both the direct-market removals and those transplanted by the intermediate transplant program. Bed groups defined in Figure 7. Negative numbers indicate bay regions in which the addition of animals by transplant exceeded the loss due to fishing. Height of each bar section shows the proportion of fishing mortality in that bay region. The total column height is the total fraction for the year.

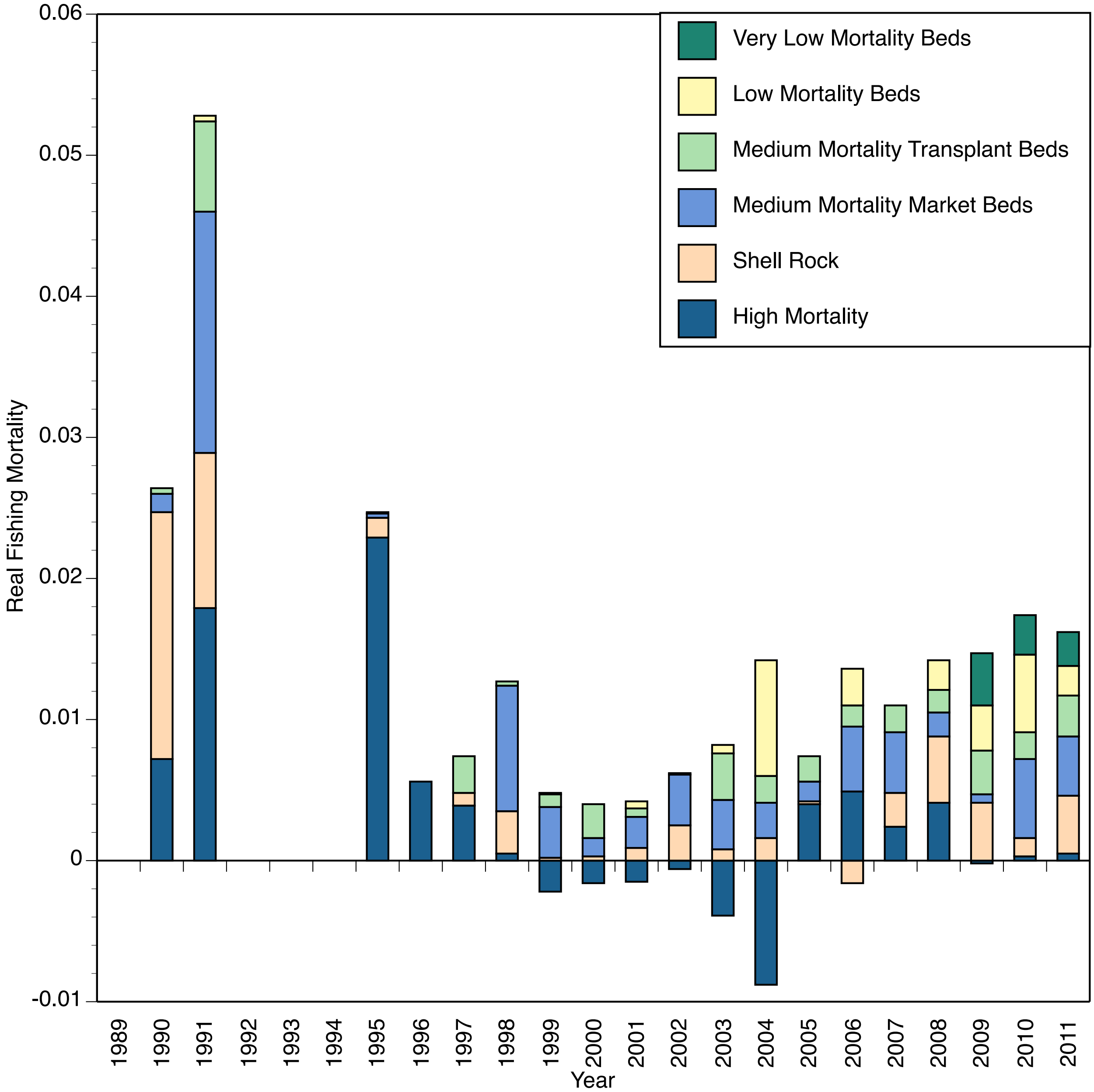


Figure 59. Real fishing mortality as a fraction of the stock during the 1991-2011 time period. Zeros represent years of fishery closure.

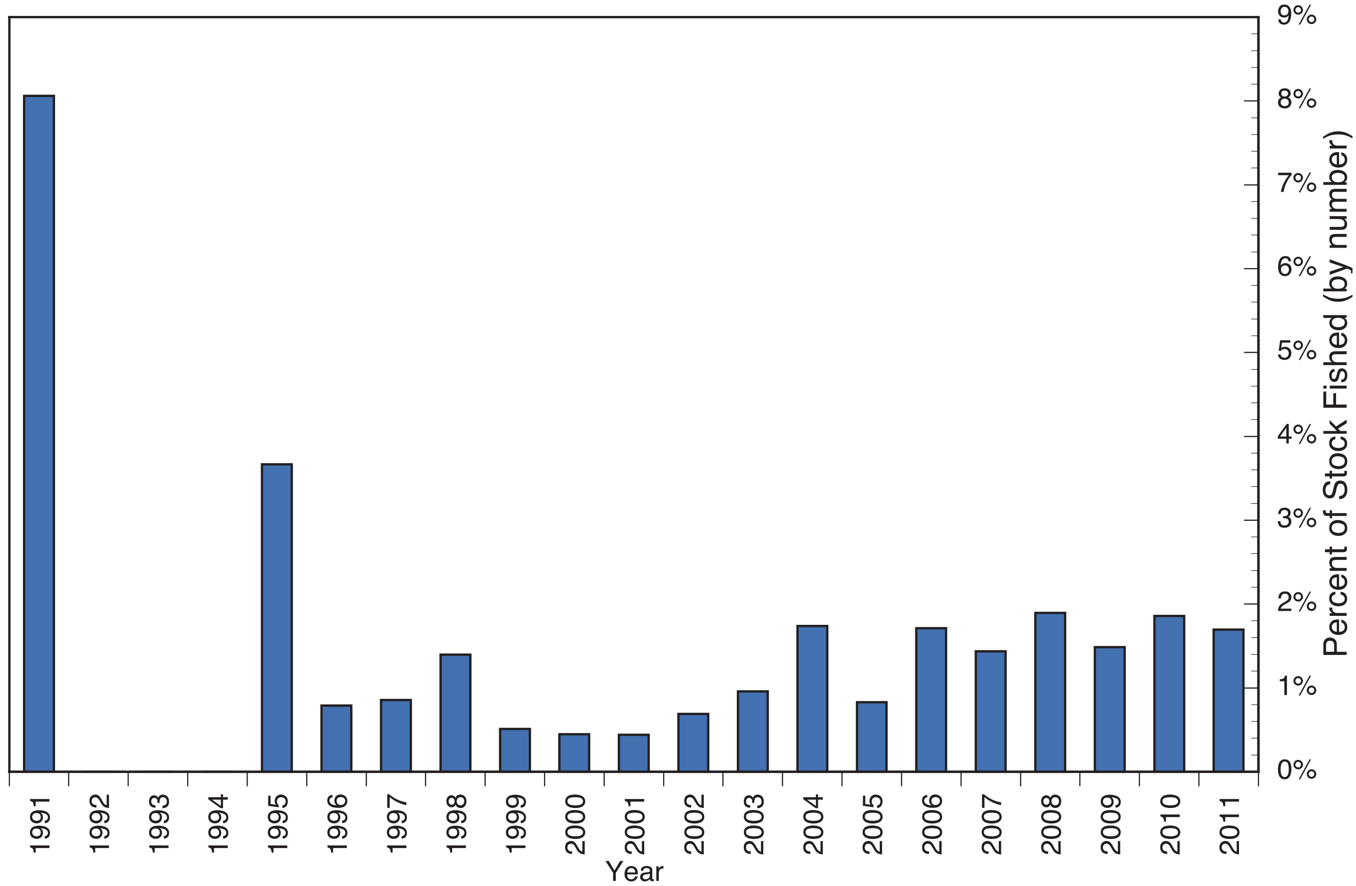


Figure 60. Fishing mortality as a fraction of the stock during the 1997-2011 time period based on spawning stock biomass. Values are based on the stock downbay of the very-low-mortality beds. Actual exploitation rates, including these beds, fall below these values.

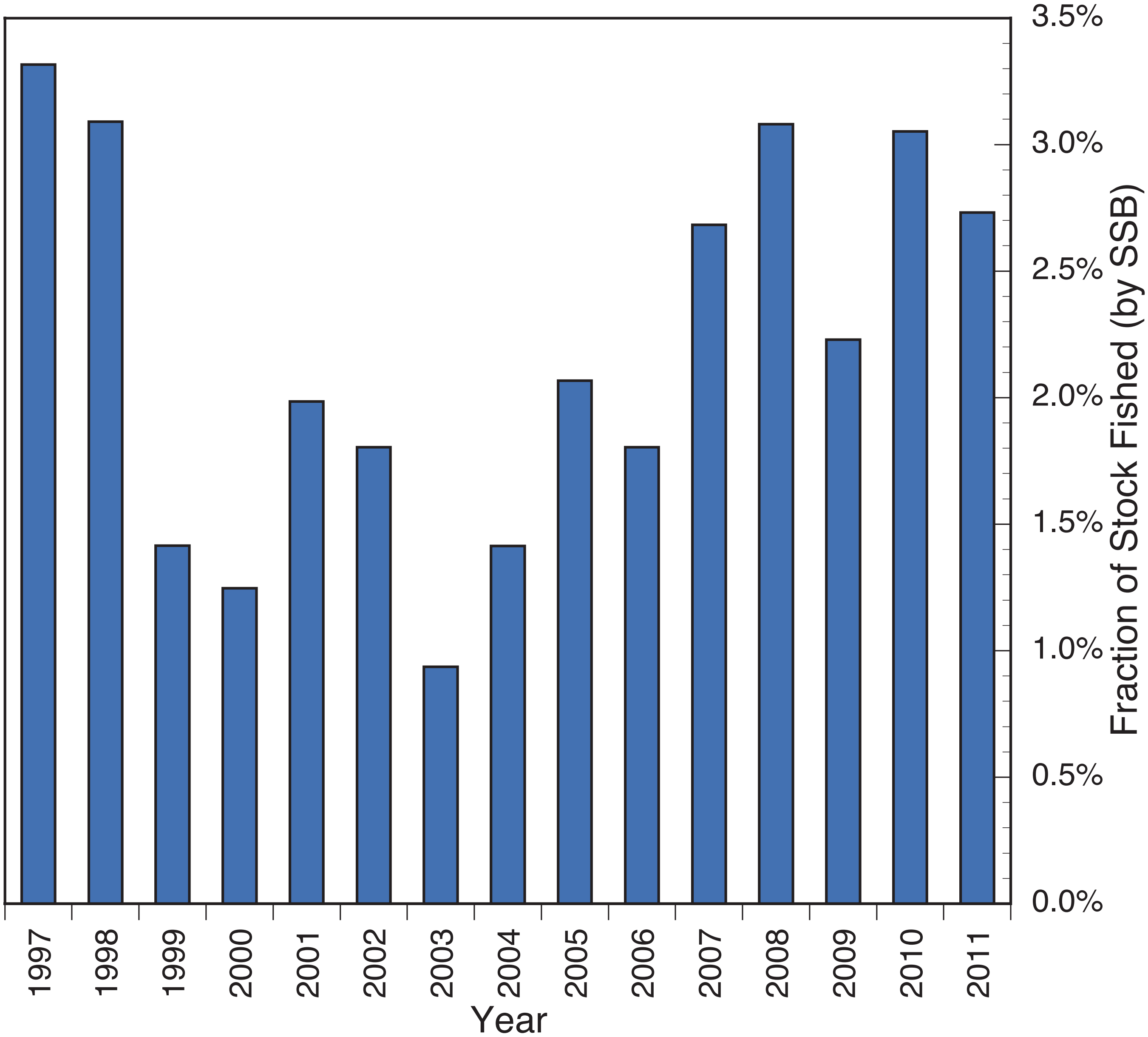


Figure 61. Fishing mortality as a fraction of the stock during the 1997-2011 time period based on marketable abundance (animals $\geq 2.5''$). Values are based on the stock downbay of the very-low-mortality beds. Actual exploitation rates, including these beds, fall below these values.

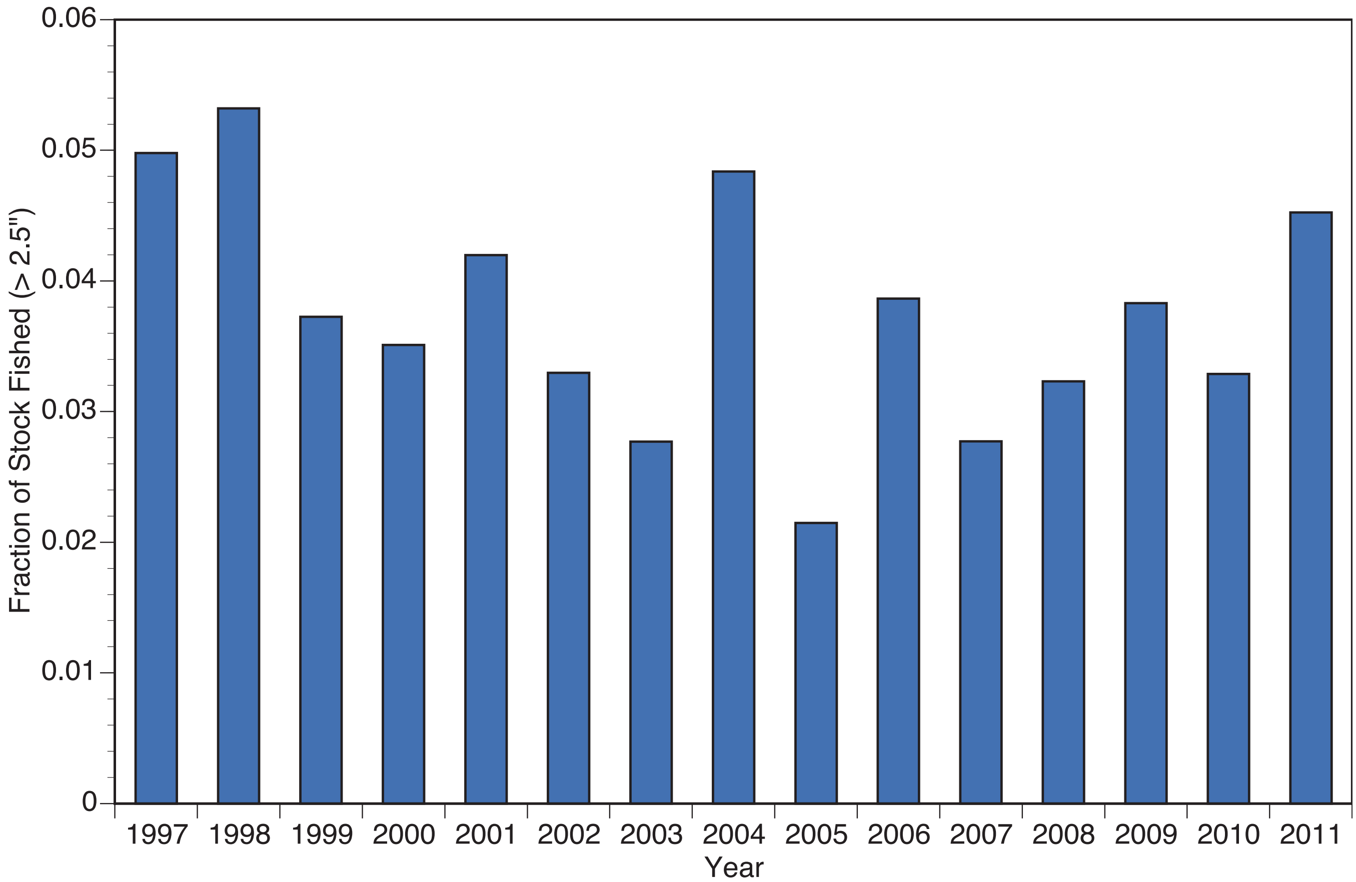


Figure 62. Abundance trends for oysters $\geq 2.5''$ for the medium-mortality market beds.

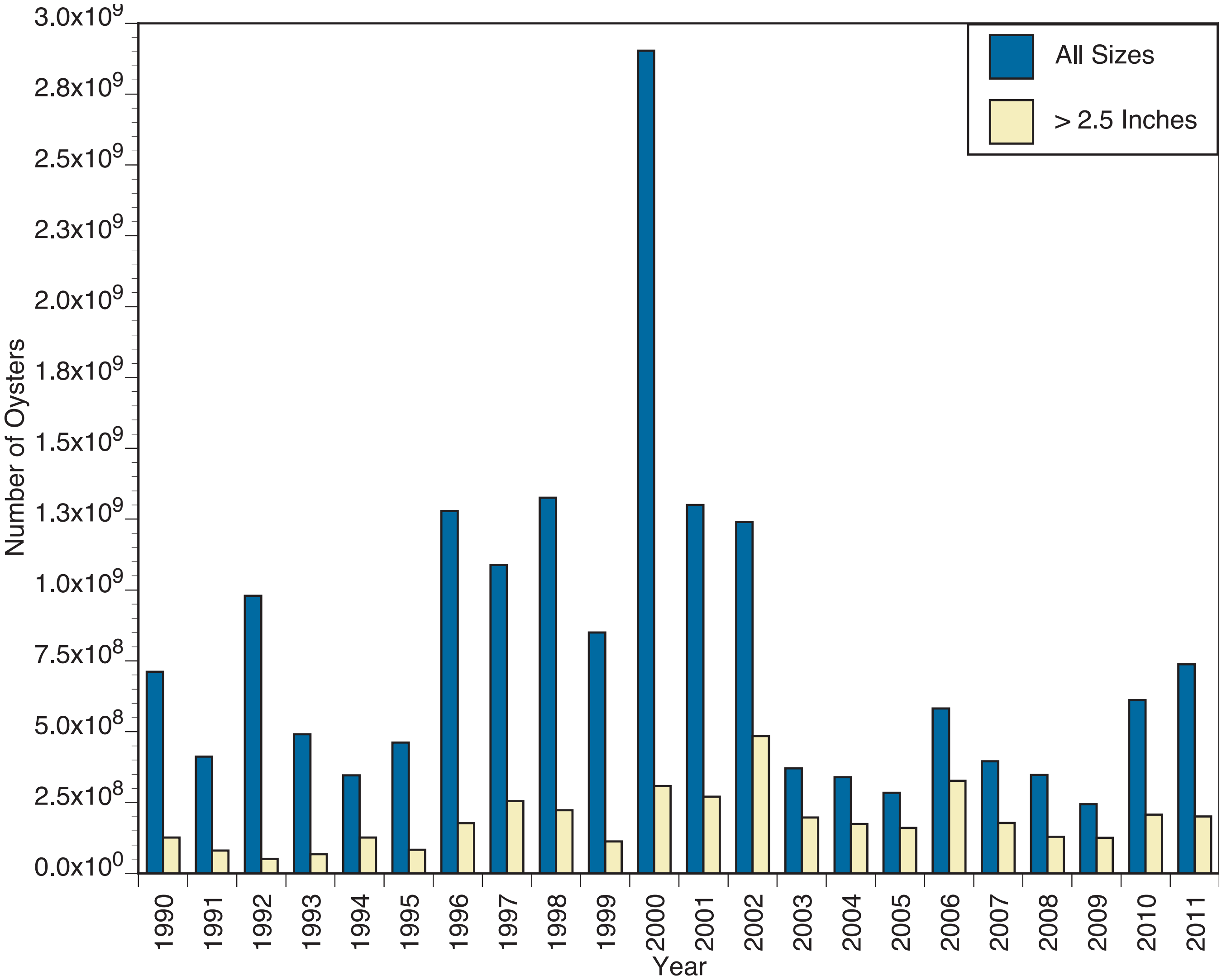


Figure 63. Salinity trends over select oyster beds for 2009-2011. Note that no August salinity is available in 2011, due to the timing of Hurricane Irene.

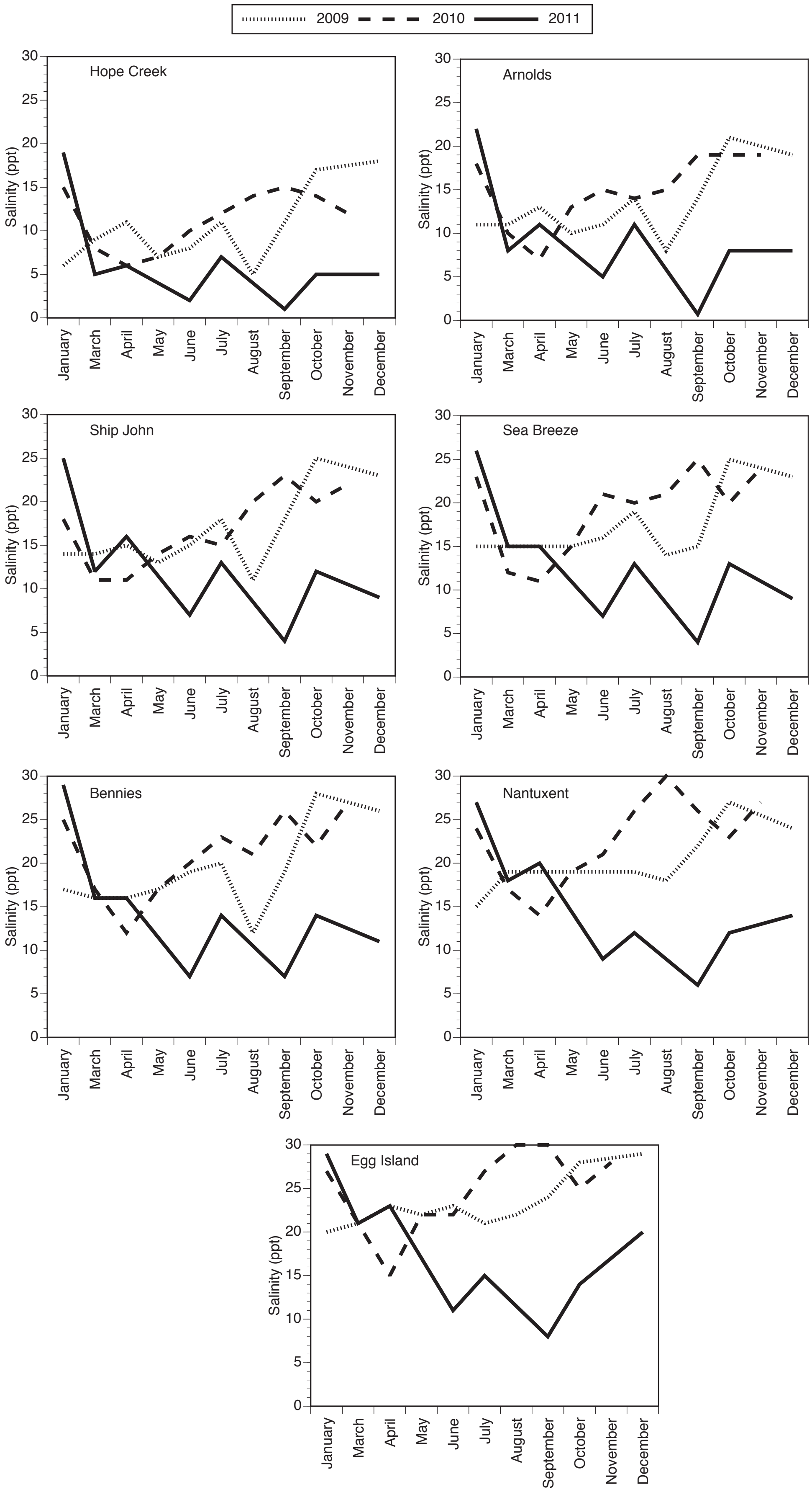


Figure 64. Time series of abundance of adult oysters from metapopulation simulations. Simulations were parameterized for 4 populations and used population dynamics reflective of those for oysters in Delaware Bay during the 2000-2008 period. A simulated 2011 flood event was included in generation 51 of the time series shown with the solid line; the flood event was absent in the time series shown with the dashed line. The simulated flood event included high mortality rates of large adult oysters for the most upbay population (parameterized to represent the very-low-mortality beds). Simulations were run with DyPoGEn, an individual-based numerical model that simulates genetic structure and population dynamics for a metapopulation.

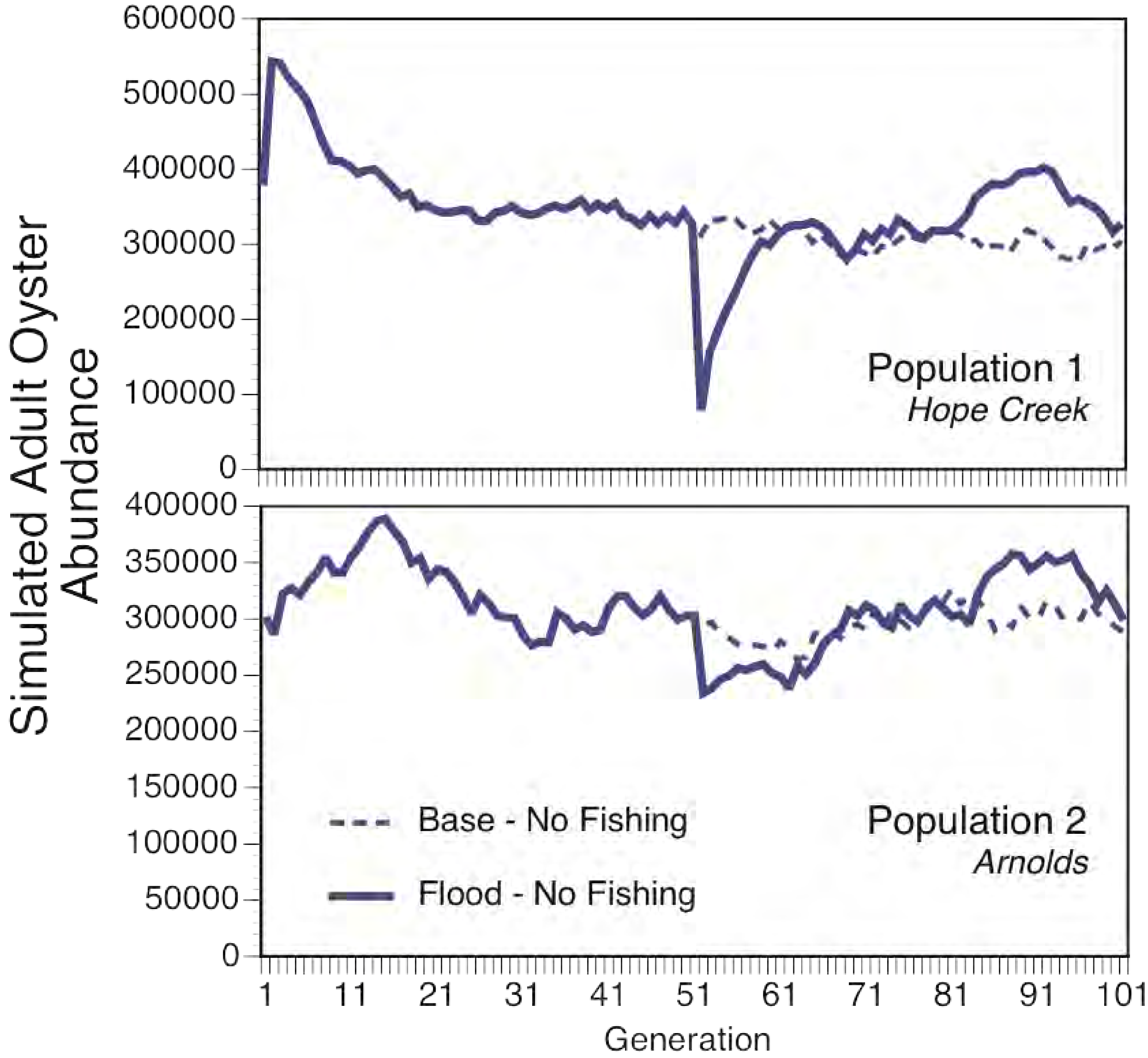


Figure 65. Position of the oyster stock in 2006-2011 with respect to biomass and abundance targets and thresholds. The target is taken as the median of abundance or biomass during the 1989-2005 (1990-2005) time period. The threshold is taken as half these values (Table 25). Reference points for the very-low-mortality beds were derived as described in the text and Table 25.

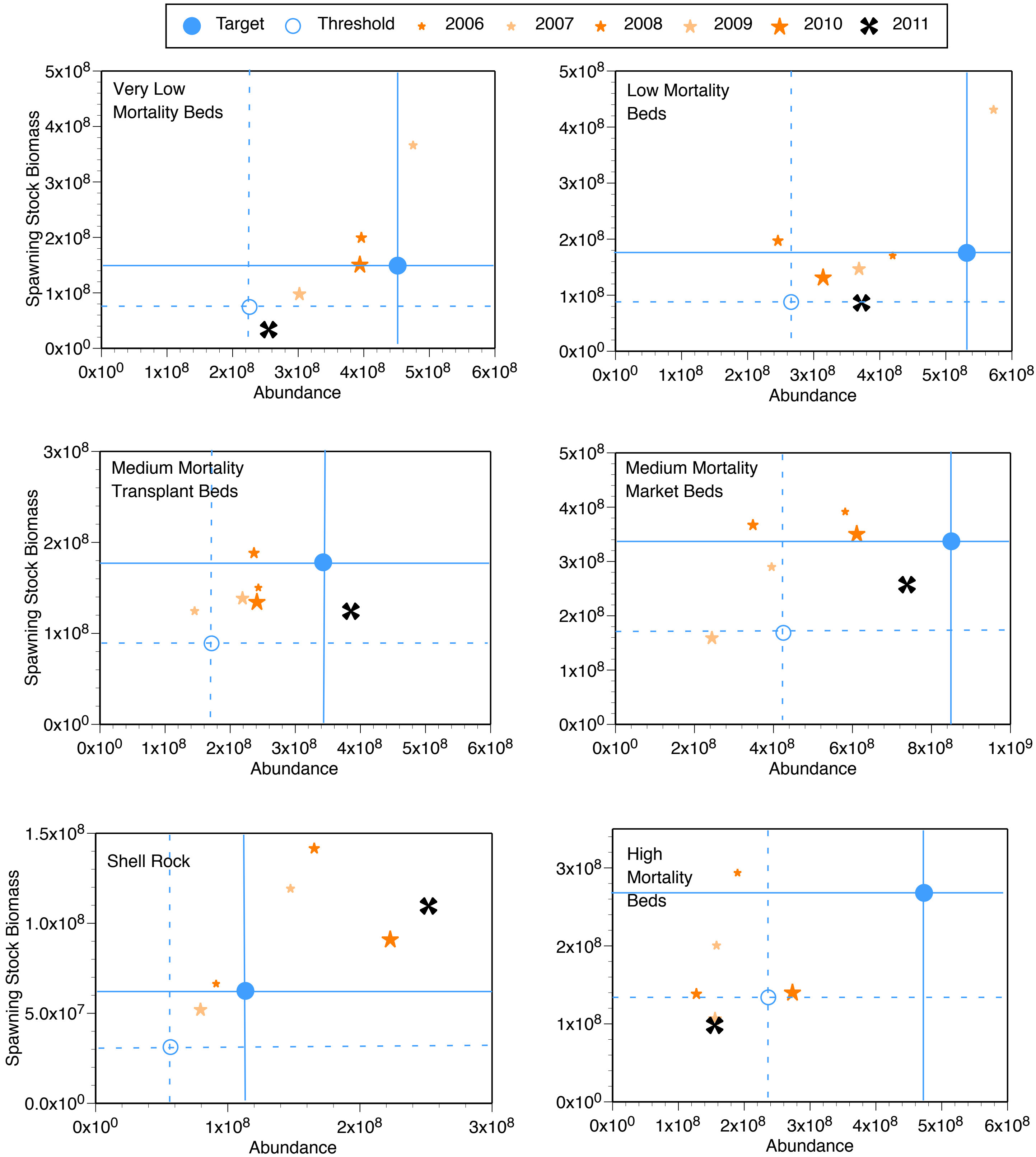


Figure 66. Position of the oyster stock in 2006-2011 with respect to market abundance ($\geq 2.5''$) and abundance targets and thresholds. The target is taken as the median of abundance or market abundance during the 1989-2005 (1990-2005) time period. The threshold is taken as half these values (Table 25). Reference points for the very-low-mortality beds were derived as described in the text and Table 25.

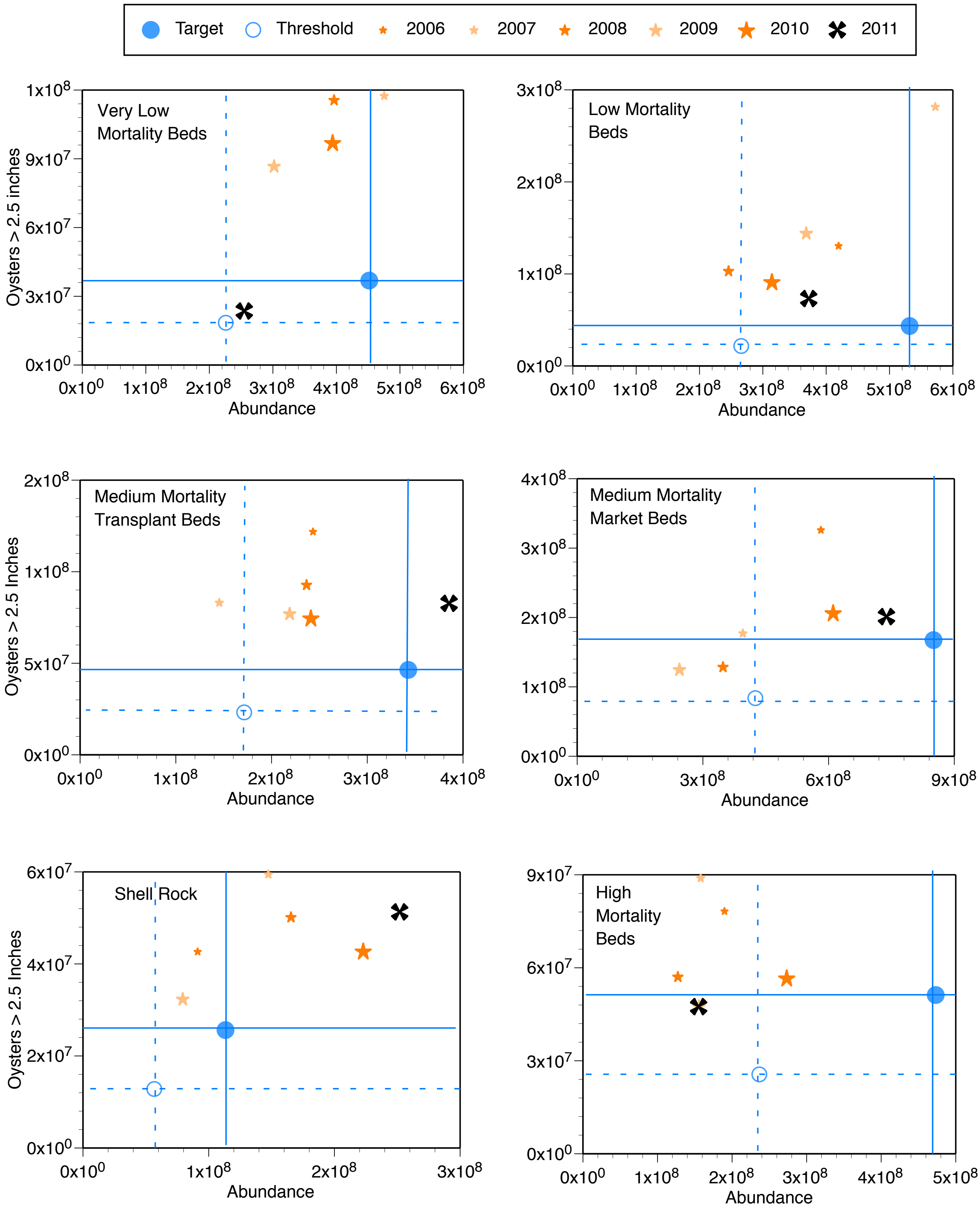


Figure 67. Relationship of the stock-performance reference points for total abundance from Table 25 to the 2011-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency correction appropriate 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.

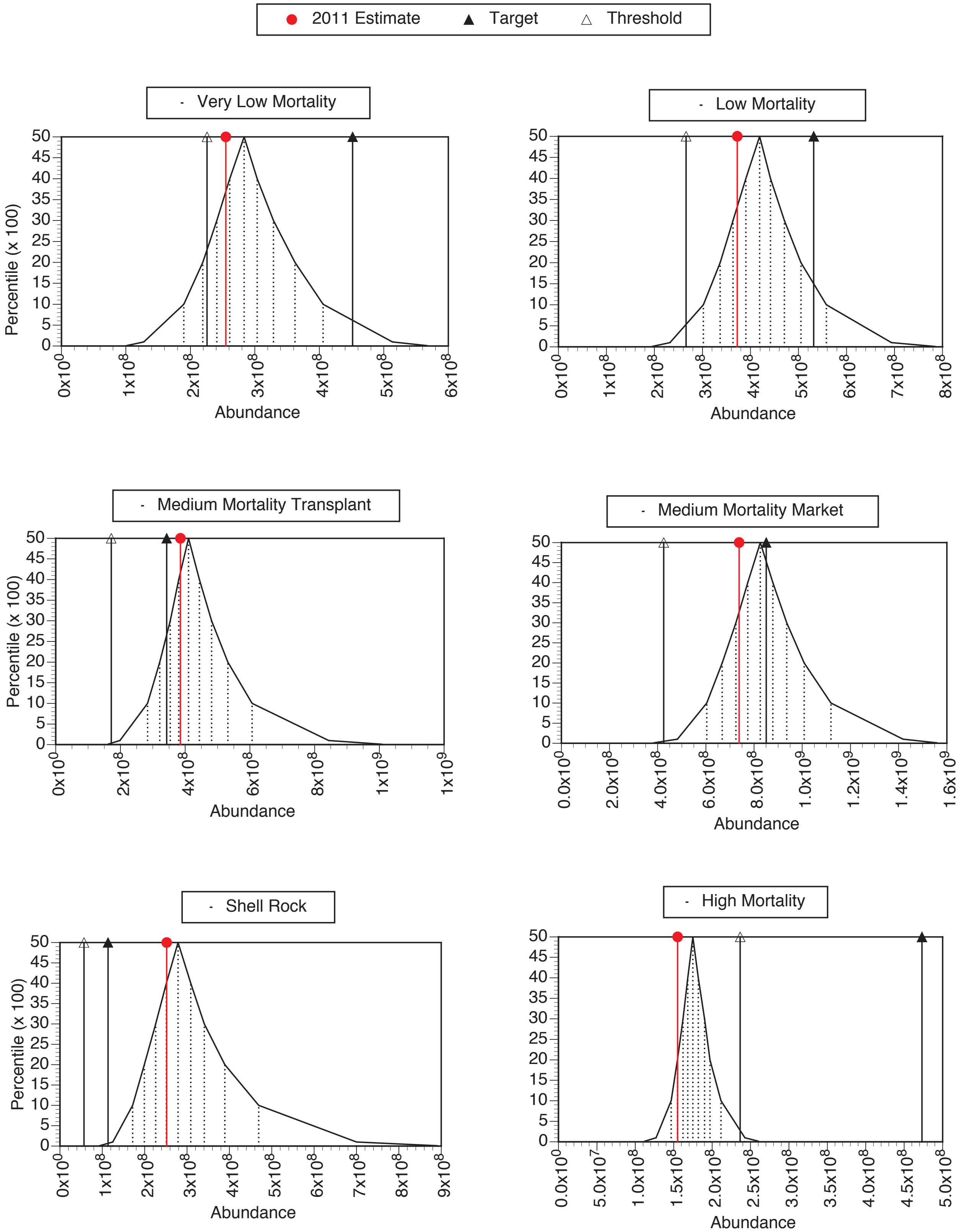


Figure 68. Relationship of the stock-performance reference points for marketable abundance (animals $\geq 2.5''$) from Table 25 to the 2011-survey point estimate, taking into account the uncertainty provided by variation in the within-bed within-stratum survey samples and the variance in the dredge efficiency 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.

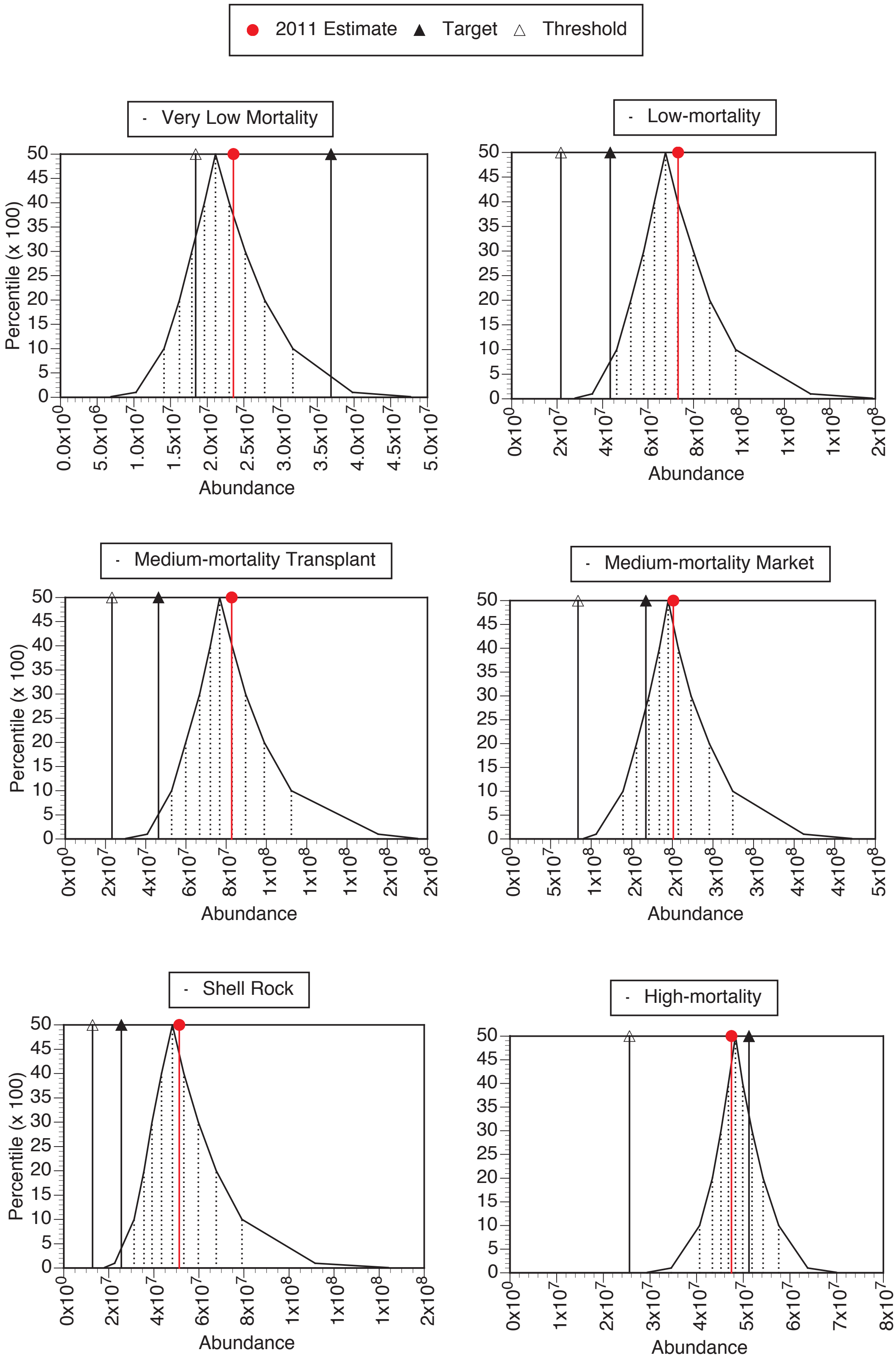


Figure 69. Position of the 2011 whole-stock abundance estimate within confidence percentiles for the 2011-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency, and excluding the very-low-mortality beds. Also indicated are the positions of the whole-stock stock-performance reference points from Table 25 and the N_{msy} reference points. 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.

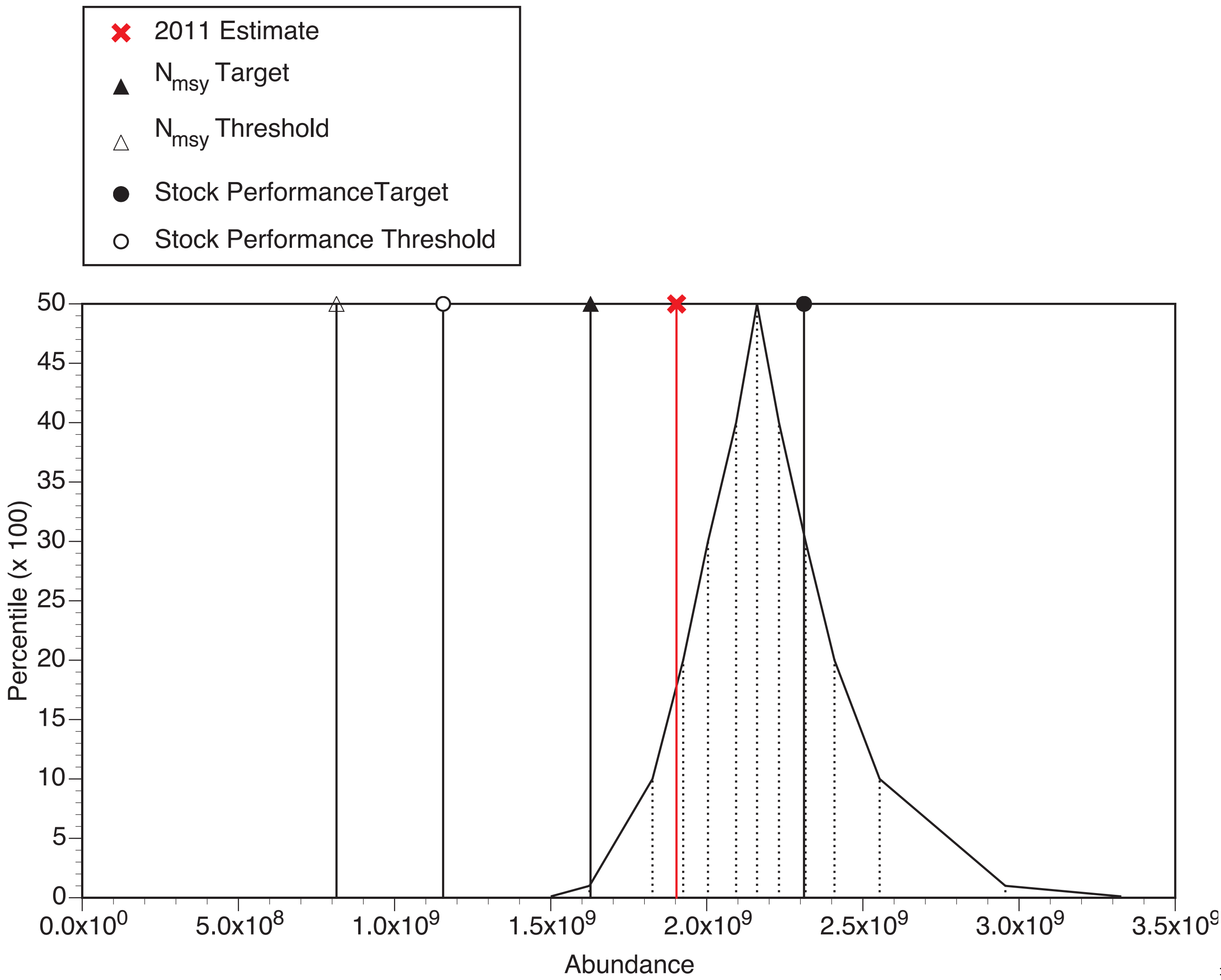


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Figure 70. Position of the 2011 whole-stock marketable-abundance ($\geq 2.5''$) estimate within confidence percentiles for the 2011-survey, taking into account between-sample variation in survey samples and uncertainty in dredge efficiency, and excluding the very-low-mortality beds. Also indicated are the positions of the whole-stock stock-performance reference points from Table 25. 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.

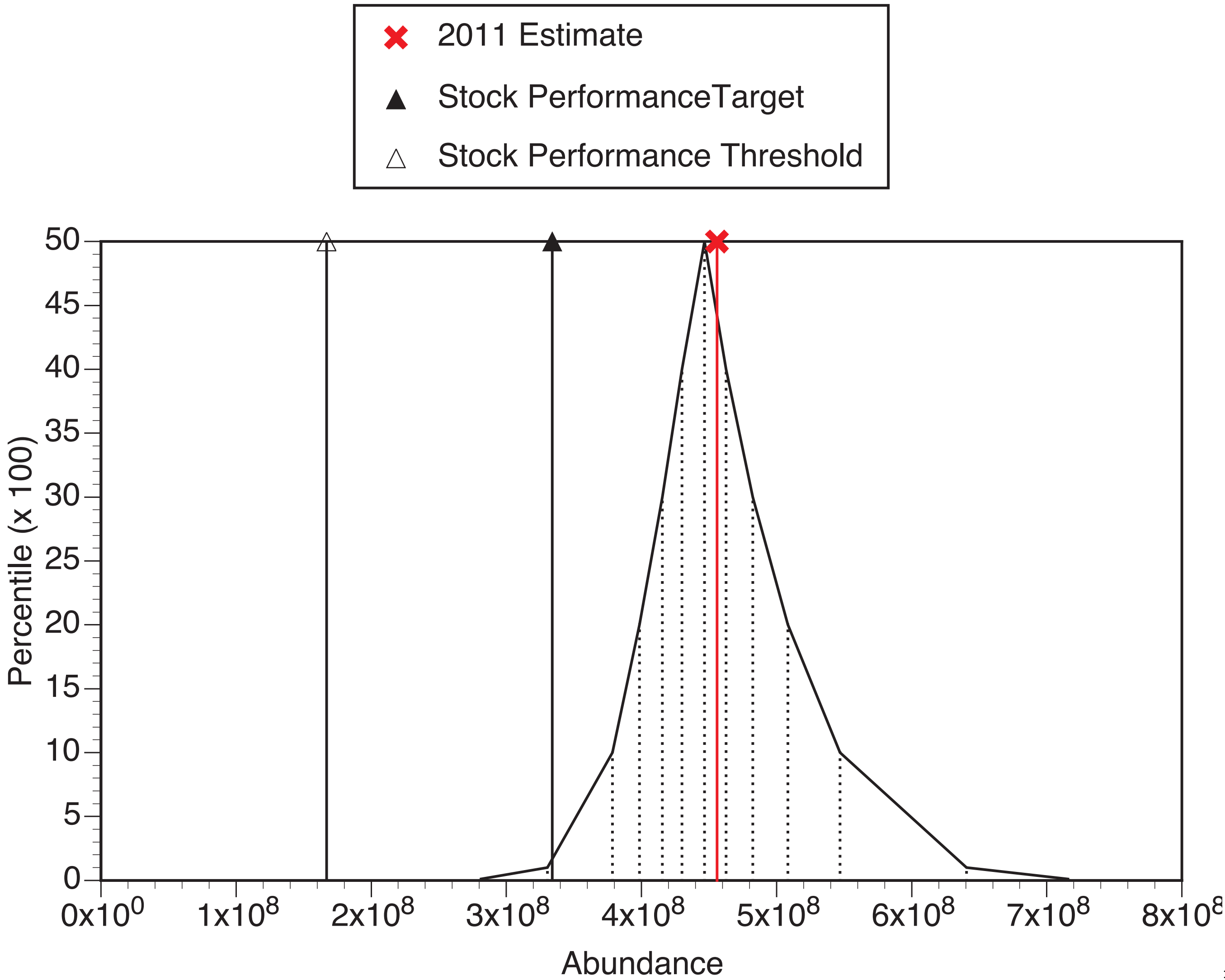

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Figure 71. Summary status of the stock for 2011. Lime green indicates variables judged to be above average relative to the 1989-2011 (or 1990-2011) time period or having an improving trend relative to the previous year or to the previous five-year median. Orange indicates variables judged to be below average relative to the 1989-2011 (or 1990-2011) time period or having a degrading trend relative to the previous year or the previous five-year median. Light green indicates near-average conditions, generally defined as conditions falling within the 40^{th}-to-60^{th} percentiles of the 1989-2011 (or 1990-2011) 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 1989-2011 (or 1990-2011) time series. The 2006-2010 median identifies comparisons between the 2011 value and the 5-yr median value from 2006-2010.

	Very Low Mortality Beds	Low Mortality Beds	Medium Mortality Transplant Beds	Medium Mortality Market Beds	Shell Rock	High Mortality Beds
Fraction of Stock	0.12	0.17	0.18	0.34	0.12	0.07
Fraction of Stock (No Very Low)	Not Incl.	0.20	0.20	0.39	0.13	0.08
Total Abundance						
2011 Percentile	Not Incl.	0.33	0.63	0.60	0.85	0.20
2006-2010 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Increasing	Increasing	Increasing	Increasing	Decreasing
Spawning Stock Biomass						
2011 Percentile	Not Incl.	0.11	0.21	0.30	0.71	0.08
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Decreasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Increasing	Decreasing
Market Abundance						
2011 Percentile	Not Incl.	0.52	0.81	0.67	0.86	0.29
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Increasing	Increasing	Decreasing
2010-2011 Trend	Decreasing	Decreasing	Increasing	Decreasing	Increasing	Decreasing
Recruitment						
2011 Percentile	Not Incl.	0.15	0.33	0.46	0.41	0.63
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Increasing	Decreasing	Increasing
2010-2011 Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Increasing
Spat per Adult						
2011 Ratio	0.05	0.10	0.22	0.27	0.31	3.03
2006-2010 Median	Not Incl.	Decreasing	Decreasing	Decreasing	Decreasing	Increasing
2011 Percentile	Not Incl.	0.24	0.38	0.41	0.20	0.85
Small Oys (fract.<2.5")	0.91	0.80	0.78	0.73	0.80	0.68
2011 Percentile	Not Incl.	0.43	0.52	0.48	0.67	0.38
2006-2010 Median	Not Incl.	Increasing	Increasing	Increasing	Increasing	Increasing
Dermo Infection Status						
Weighted Prevalence	0.30	0.20	0.70	1.50	1.60	1.50
2010-2011 Trend	Increasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Mortality Rate	0.47	0.21	0.15	0.14	0.14	0.24
2011 Percentile	Not Incl.	1.00	0.50	0.38	0.38	0.41
2006-2010 Median	Not Incl.	Increasing	Decreasing	Decreasing	Decreasing	Increasing
2010-2011 Trend	Increasing	Increasing	Decreasing	Decreasing	Increasing	Increasing
Abundance Position vs						
Target	Below	Below	Above	Below	Above	Below
Threshold	Above	Above	Above	Above	Above	Below
SSB Position vs						
Target	Below	Below	Below	Below	Above	Below
Threshold	Below	Near	Above	Above	Above	Below
Market Abundance vs						
Target	Below	Above	Above	Above	Above	Below
Threshold	Above	Above	Above	Above	Above	Above
Surplus Production						
50th percentile mortality	Positive	Positive	Positive	Positive	Positive	Positive
75th percentile mortality	Positive	Positive	Positive	Positive	Positive	Positive

Figure 72. Net submarket surplus for the entire stock from a retrospective analysis of survey indices and landings. Submarket surplus 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 submarket surplus 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	Pos-Neg Method	Average Method
2005		5.67
2006		5.25
2007		5.70
2008		5.75
2009		5.36
2010		4.65
2011		5.22

Figure 73. The percentage of total mortality attributable to fishing as opposed to natural mortality for animals $\geq 2.5''$ in size.