Delaware Bay New Jersey Oyster Seedbed Monitoring Program
2006 Status Report

Prepared by

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To

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New Jersey Delaware Bay Oyster Seedbeds

Introduction

The Delaware Bay Seedbed Monitoring Program tracks disease, growth and mortality with guidance from the Oyster Industry Science Committee of the Delaware Bay Shellfisheries Council and the Stock Assessment Review Committee. The purpose is to provide information that supports management of the New Jersey Delaware Bay oyster resource for sustainable harvest. Commercial oyster production occurs on privately owned leases below the state managed natural seed beds but is not monitored by this program. Monthly monitoring provides information on current initiatives as well as seasonal changes. Long-term monitoring provides insight into interannual patterns as well as long-term trends.

Oyster mortality on the Delaware Bay seedbeds is caused by a variety of factors including predation, siltation, freshets and disease. Since the appearance of *Haplosporidium nelsoni* (the agent of MSX disease) in 1957, disease mortality has been the primary concern. Following two distinct periods of severe MSX epizootics, the Delaware Bay population appears to have become largely resistant to MSX disease. A small experiment conducted in 2005 as part of the Delaware Bay Seedbed Monitoring program supported this contention (Ford and Bushek 2006) and provided some of the impetus for a larger scale study on oyster disease dynamics with support from the National Science Foundation. Deployment of naïve oysters at the Rutgers Cape Shore Hatchery indicate that MSX remains an important risk, but it has not been problematic for native oysters in Delaware Bay for several years. In 1990, an epizootic of dermo disease (caused by the protozoan *Perkinsus marinus*) occurred. This was not the first appearance of this disease, but previous appearances were associated with importations of oysters from southern estuaries. Termination of those importations resulted in the disappearance of the disease (Ford 1996). Such is not the case for the 1990 appearance of dermo disease. Dermo disease is now a major source of oyster mortality in Delaware Bay and a primary focus of the monitoring program.

Since the appearance of dermo disease in 1990, average mortality on the seedbeds, as assessed by total box counts during the fall survey, has fallen into 3 major groups that are now classified as Low Mortality, Medium Mortality and High Mortality beds (Figure 1). The seedbeds were previously divided into regions based roughly on salinity regime with the following designations: Upper (= Low Mortality beds), Upper-Central (= Medium Mortality beds), and Central and Lower (regions = High Mortality beds). Salinity increases from the upper beds to the lower beds with fresh water inputs from several tributaries in New Jersey, including Hope Creek, Stow Creek, Cohansey River, Back Creek, Cedar Creek and Nantuxent Creek. The freshwater inputs and the geomorphologic configuration of the coves influence salinity, nutrients, food supply, circulation and flushing, all of which interact to influence the spatial and temporal prevalence and intensity of dermo disease on the seedbeds and ultimately oyster mortality. Area management currently follows the mortality designations with selected beds such as Shell Rock occasionally managed independently. The temporal and spatial sampling efforts of the Seedbed Monitoring Program are designed to continually develop a better understanding of dermo disease patterns and processes to support adaptive management efforts. For 2006, the Seedbed Monitoring Program pursued the following objectives:

1. Continue monthly monitoring from March to November of size, mortality and disease at the five long-term beds: Arnolds grid 18, Cohansey grid 44, Shell Rock grid 10, Bennies grid

110 and New Beds grid 26. Supplement these sites in May with samples from Middle, Bennies Sand and Ship John to improve spatial coverage and provide a preliminary fall disease mortality forecast.
2. In coordination with objective 1, continue monthly monitoring of size, mortality and disease on the 2003 Bennies Sand clam shell plant demonstration project, and the 2005 transplants from Arnolds to Shell Rock grid 25.
3. In coordination with the annual stock assessment survey, conduct a spatial survey of dermo disease covering all beds sampled by the survey, with a subset of sites sampled for MSX. Additionally, collect size frequencies (shell height, length and width), wet meat weight (wt) and dry meat wt for 50 individuals from each bed.
4. Monitor growth, disease and mortality on selected 2005 shell plants and growth and mortality on selected 2006 shell plants and transplants.

Objectives 1, 2 and 3 comprise the basis of the long-term monitoring program that provides fundamental information necessary for both immediate and long-term adaptive management of the resource. Objective 4 is part of the joint effort between New Jersey and Delaware. Details of that objective will be provided elsewhere.

HSRL staff, especially Iris Burt and Fernando Fuentes, along with NJDEP Bureau of Shellfisheries staff, especially Jason Hearon, provided field, logistical and technical support for much of this work. Emily Scarpa was responsible for MSX histology and Dr. Susan Ford has assisted with data interpretation and analyses.

Methods

To complete objectives 1 and 2, samples were collected monthly from March through November at locations referenced above and shown in Figure 1. The NJDEP R/V Zephyrus, captained by Jason Hearon, was used to collect all but the final monthly samples. The final samples were collected with the commercial oyster vessel John McVey captained by Mike McVey due to engine failure aboard the R/V Zephyrus. Three one-minute tows with a 0.81 m (2.7 ft) oyster dredge were collected at each site using about 14 m (46 ft) of cable. Bottom water temperature and salinity were recorded with a handheld YSI® ctd meter for each sample. A composite bushel consisting of randomly collected oysters and boxes from the three replicate dredge hauls (approximately one third of a bushel from each haul; one sixth at Arnolds) was created and then sorted to enumerate gapers (= dead oysters with meats remaining), boxes (= hinged oyster valves without any meat remaining) and live oysters. Boxes were further categorized as new (= no indication of fouling or accumulation of sediments inside valves) or old to provide an indication of recent mortality. These data were used to estimate mortality as described by Ford et al. (2006). One hundred randomly selected oysters (> 20 mm) from this second bushel were returned to the laboratory and shell heights (hinge to bill) measured to determine size frequencies. Twenty individuals representing the size frequency distribution were then sacrificed for Ray's fluid thioglycollate medium assay (RFTM, Ray 1952, 1966) to determine prevalence and intensity of dermo infections. The percent of oysters in the sample with detectable infections is termed the prevalence. Each infection is then weighted using the "Mackin scale" from zero (= pathogen not detected) to five (= heavily infected) (Ray 1954). These values are then averaged to produce a weighted prevalence (Mackin 1962), which provides an estimate of the average disease level in the sample of oysters. From June to August, a sub-sample of the oysters returned to the laboratory were inspected for reproductive maturity and assigned ranks of not ripe, slightly ripe, moderately ripe or fully ripe based on the appearance of the gonad. These ranks were assigned values of 0 to 3 and averaged to obtain a general indication of reproductive maturity for the sample. Gametes from each individual inspected were also examined microscopically to determine sex. In April and August, a composite sample was collected from the three replicate tows at each site by combining a 12-14 qt sub-sample from each of the three one-minute dredge hauls. This bushel was sorted on deck to determine numbers and volumes of oysters, boxes and cultch present in order to provide an estimate of oyster densities relative to boxes and cultch material. GPS readings were recorded during these tows for future use to determine location within each grid and to estimate individual tow distances in order to provide more accurate density estimates of oysters on the bottom.

Completion of objective 3 was coordinated with the annual fall seedbed stock assessment survey. Samples were collected as described for monthly samples, except the H. W. Sockwell, a commercial oyster vessel captained by Greg Peachy, collected the samples. In addition, monthly monitoring samples from the five long-term sites were used in lieu of stock assessment samples from those beds for dermo analysis. Samples of oysters were collected from multiple grids within each bed and processed for size, condition and dermo disease (Table 1). Dermo was diagnosed as described above. Histological analyses were performed on samples of 20 oysters from selected beds (Table 1) to determine prevalence and intensity of MSX disease using standard histological procedures for bivalve molluscs. Dermo disease data have been collected since 1990 and MSX disease data since 1958, providing insight into year-to-year variation and long-term cycling.

To complete objective 4, samples were collected monthly from March through October for 2005 shell planting efforts and during September and October for 2006 shell planting efforts. Table 2 lists the locations and type of shell plants sampled. Samples were collected with the R/V Zephyrus. For shell plant sites, the first 100 live oysters that could be identified as having set on planted material were selected for growth and disease analysis as needed. Any boxes that were attached to planted shell and encountered as the live oysters were being collected were counted and the number of live and dead oysters used to estimate mortality. Details of these data are reported elsewhere.

Results and Discussion

During 2006, temperature and salinity showed normal seasonal fluctuations. Bottom water temperatures were virtually identical across the seedbeds and were slightly above a 5-year average during spring and summer, but returned to average levels during September and October. Salinity increased normally from the upper to lower seedbeds with a seasonal low occurring in July (Figure 2B). Salinity across the seedbeds during 2006 was generally higher than average for the past 5 years. Although monthly data shows only a slight depression in salinity, NOAA data from Ship John Shoal indicates a large event drove salinity down during this period (Figure 3B). The continuous temperature and salinity data for Ship John Shoal can be accessed for near real-time or archived data at http://tidesandcurrents.noaa.gov/.

Oysters were reproductively mature by mid-June and remained at least partially ripe into August. Temperatures generally considered warm enough to trigger widespread spawning (25^{o}C = 77^{o}F) were reached by late June and maintained through August (Figures 2A and 3A). A major freshet occurred at the end of June (Figure 2B) just as spawning temperatures were reached and may have impacted spawning activity. Reproductive status was highest on all beds during June, decreasing thereafter. Shell Rock and Bennies Sand clam shell plant attained the greatest values, followed by New Beds, Arnolds, Cohansey and Bennies. Shell Rock and the Bennies Sand clam shell plant were dominated (~60%) by females. The opposite ratios occurred on Arnolds and New Beds while ratios were approximately equal on Cohansey and Bennies.

Mean shell height of oysters fluctuated around a relatively constant bed-specific size throughout the summer, the 2003 Bennies Sand clam shell plant being an exception (Figure 2C). On the 2003 plant, oysters attached directly to surf clam were targeted in order to develop a best estimate of growth for the 2003 cohort. On the other beds, a random sample, including all cohorts present, was processed. On these other beds, the size frequency plots in Figure 4 indicate that fluctuation in mean size reflected recruitment of smaller animals. That is, mean size generally increased from March to July then decreased as smaller animals recruited onto the bed (note the increase in smaller animals beginning in July, Figure 2C). The apparent cessation of growth on the 2003 surf clam shell plant is likely attributable to harvesting and/or mortality of larger oysters.

Dermo prevalence, weighted prevalence (WP) and intensity were at or below long-term levels during spring, but quickly increased above average levels by July on all but Arnolds (Figure 5). This rapid increase was likely promoted in part by the above average spring and summer temperatures (Figure 2A). By August, all beds except Arnolds had dermo levels that were expected to begin causing noticeable levels of mortality (i.e., WP > 2.0). However, mortality levels remained below average until October when cumulative recent mortality approached or exceeded 30% on New Beds and Shell Rock. The late June freshet did not appear to affect disease or mortality. The 2003 Bennies Sand clam shell plant had higher mortalities because these oysters were essentially all three year old animals. Oysters transplanted to Shell Rock grid 25 (SR 25T) during 2005 did not survive better than native oysters.

A summary of growth and mortality for the 2003 Bennies Sand clam shell plant is shown in Figure 7. These oysters set during July of 2003 and July 1 is used as a start date in the upper panel. A power function provided a nearly perfect fit to the data with an R-square approaching 0.99. Mean shell height reached legal market size of 2.5" (63.5 mm) by in September 19, 2005. A mean shell height of 3" (76.2 mm), the industry preferred market size, was reached by July 2006. Mean shell height remained above this level through October 2006 with 65% exceeding 3" and 92% exceeding 2.5". This project planted 16,500 bushels of surf clam shell containing 1800 spat per bushel in September 2003 for a total of 29.7 million spat. Over-wintering mortality was not measured between October 2003 and March 2004. Assuming negligible mortality during that period, applying the cumulative mortality since March 2004 this project should have provided a total of about 8 million market animals by October 2006:

= 16,000 bushels x 1800 spat/bushel x 0.2718 survivors x 0.92% market size
= 7,426,663 market size oysters / 300 oysters per bushel

= 24,756 bushels

Some portion of these oysters were likely harvested during 2005 and 2006, so this is not to be considered an estimate of what remains on the bed at this time. Rather, it is a rough estimate of the impact of this project.

Figures 8, 9 and 10 depict annual fall dermo prevalence, dermo infection intensity (= weighted prevalence) and box-count estimated mortality from 1989 to 2006 for the entire seed bed region (upper panel), the low mortality bed (second panel), the medium mortality beds (third panel) and the high mortality beds (bottom panel). Dermo prevalence and intensity increased in 2006 compared to 2005 and continue to indicate a cycle of approximately seven years (Figures 8 and 9). Mortality roughly tracks the same spatial and temporal patterns, with greatest correspondence on the high mortality beds and least on the low mortality beds (Figure 10). As mentioned last year, the apparent cycling may be driven by larger regional climate patterns. Additional research and continued monitoring could help identify such a relationship as the time series grows. The apparent periodicity indicates that dermo and possibly dermo-related mortality will increase next year.

Examination of dermo prevalence, dermo intensity and box-count mortality estimates on a bed-by-bed basis continues to reflect the overall positive correlation with increasing salinity from up bay sites to down bay sites (Figures 11-13). These data show that dermo prevalence and weighted prevalence exceeded long-term means on many beds even though mortality did not. The increases in dermo may, unfortunately, forecast increases in dermo-related mortality for 2007, unless local conditions such as an extended cool, wet spring inhibit the development of dermo disease.

A plot of long-term mean fall box-count mortality estimates against long-term mean dermo infection intensities (Figure 14), shows how the seedbeds can be segregated into three or four disease and mortality zones. Round Island, Upper Arnolds and Arnolds comprise a low disease, low mortality zone with weighted prevalence of dermo generally below 1.0 on the Mackin Rank Scale. This zone generally experiences a mortality of 10 to 12 percent. As dermo intensities increase above 1.0, it begins to generate higher levels of mortality. Dermo intensities between 1 and 2 occur on Middle, Cohansey, Sea Breeze, Ship John and Shell Rock. These beds typically experience 15-20% mortality based on box counts. Once dermo levels exceed 2.0, average mortality increases to between 25 and 50%. Interestingly, these beds separate into those with WPs between 2.0 and 2.5 and those with WPs between 2.5 and 3.0. The former group contains Bennies Sand, Bennies, New Beds, Strawberry and Ledge, which tend to be slightly up bay and/or offshore compared to the other beds that tend to lie inside the cove formed by Egg Island Point (Nantuxent, Hog Shoal, Hawk's Nest, Beadon's, Vexton and Egg Island).

Finally, plots of fall box count mortality against dermo weighted prevalence indicate significant relationships across the beds and within regions except on the low mortality beds. The upper panel of Figure 15 shows that approximately 41% of the fall box counts can be explained by dermo infection level. The relationship is not consistent within, however, largely because each region experiences different levels of dermo. On the low mortality beds (second panel, Fig 15) there is no apparent effect of dermo, but dermo WP has never exceeded 2.0 and rarely exceeded 1.0. With no influence of dermo, fall box counts on the low mortality beds average around 11% with variation most likely driven by freshets. On the medium mortality beds (third panel, Fig 15) the relationship is significant and explains about 23% of the variation in fall box counts since 1990. In the absence of dermo, fall box count mortality on the medium mortality beds is about 10% and for every dermo WP increase of 1.0, the fall box counts increase by about 4%. A significant relationship also exists on the high mortality beds where dermo explains about 24% of the variation in fall box counts since 1990. In the absence of dermo, fall box count mortality on the high mortality beds is about 18%. Here dermo has the greatest impact and every integer increase in dermo WP results in an average increase in box count mortality of about 8%. In conclusion, the long-term trends indicate that dermo is likely to increase in 2007, resulting in an increase in mortality of oysters on both the medium and high mortality beds.

Table 1. 2006 Delaware Bay Oyster Seedbed Stock Assessment Survey grids sampled for dermo, MSX, condition index (CI) and size frequencies. * Samples obtained from monthly seedbed monitoring program. Numbers represent grid# or sample size.

Bed	Grid	Dermo	MSX	CI
Round Island	5	10		10
Round Island	6			15
Round Island	16			10
Round Island	18	10		15
Upper Arnolds	7	10		25
Upper Arnolds	16	10		20
Arnolds	8		10	5
Arnolds	10			10
Arnolds	15			10
Arnolds	18	20*		
Arnolds	19		10	15
Arnolds	46			10
Upper Middle	6	15		15
Middle	18	10		15
Middle	30	10		15
Middle	34			10
Middle	41			10
Cohansey	8		10	15
Cohansey	38			15
Cohansey	43		10	10
Cohansey	44	20*		
Cohansey	57			10
Ship John	22			10
Ship John	25	10		15
Ship John	48			10
Ship John	57	10		5
Sea Breeze	18	10		10
Sea Breeze	19	10		15
Sea Breeze	24			10
Sea Breeze	37	10		15
Shell Rock	11		10	10
Shell Rock	13		10	15
Shell Rock	44	20*		
Shell Rock	55			10
Shell Rock	65			15
Shell Rock	90	20*		
Shell Rock	10,11	20*		
Shell Rock	25T	20*		
Bennies Sand	8	10		10
Bennies Sand	10	20*		
Bennies Sand	21	10		15

Bed	Grid	Dermo	MSX	CI
Bennies Sand	24			15
Bennies Sand	27			10
Bennies	19			7
Bennies	43			15
Bennies	86			8
Bennies	110	20*		
Bennies	123		10	15
Bennies	125			7
Bennies	152		10	5
Nantuxent	11	10		15
Nantuxent	20	10		15
Nantuxent	23			15
Hog Shoal	1			10
Hog Shoal	5	10		15
Hog Shoal	14			10
Hog Shoal	18	10		15
New Beds	8			10
New Beds	26	20*		
New Beds	42			10
New Beds	52			15
New Beds	52		10	
New Beds	68		10	15
Strawberry	29	10		15
Hawks Nest	2	10		15
Hawks Nest	4	10		15
Hawks Nest	9			10
Hawks Nest	27			10
Beadons	4	10		15
Beadons	10			10
Beadons	15			10
Beadons	20	7		7
Beadons	24	1	8	
Beadons	38	2		2
Vexton	4			15
Vexton	7	10		10
Vexton	9			10
Vexton	10	10		15
Ledge	7	4	4	
Total beds	**19**	**19**	**6**	**18**
Total grids	**77**	**37**	**12**	**67**
Total samples		**439**	**112**	**811**

Table 2. Shell plant and transplant sites sampled during 2006. DE = State of Delaware beds. Replant = shell planted in lower Delaware Bay to catch spat, then moved to area indicated. MD = dredged oyster shell from Chesapeake Bay, Maryland. Replant = shell planted in lower Delaware Bay then moved after collecting spat.

Bed	Grid	Plant material	Plant yr
Shell Rock	4	MD oyster shell	2005
Shell Rock	12	MD + quahog shell	2005
Shell Rock	43	ocean quahog shell	2005
Shell Rock	43	surf clam shell	2005
Bennies Sand	11	surf clam replant	2005
Jigger Hill	DE	MD oyster shell	2005
Lower Middle	DE	MD + quahog shell	2005
Shell Rock	25	Middle oysters	2005
Hawks Nest	1	ocean quahog shell	2006
Nantuxent	25	ocean quahog shell	2006
Bennies Sand	7	ocean quahog shell	2006
Shell Rock	20	ocean quahog shell	2006
Shell Rock	24	ocean quahog shell	2006
Shell Rock	32	ocean quahog shell	2006
Pleasaton's Rock	DE	ocean quahog shell	2006
Drum Beds	DE	ocean quahog shell	2006
Silver Bed	DE	ocean quahog shell	2006
Bennies Sand	6	surf clam replant	2006
Bennies Sand	12	surf clam replant	2006
Shell Rock	44	Upper Middle & Middle oysters	2006
Shell Rock	90	Arnolds oysters	2006

Table 3. Comparisons of 2006 mortalities, dermo prevalence and dermo weighted prevalence with long-term averages (1989-2006) by seedbed region. Numbers are means ±95% CI.

	Percent Mortality		Prevalence		Weighted Prevalence	
Region	**2006**	**long-term**	**2006**	**long-term**	**2006**	**long-term**
Low Mortality	9 (6)	12 (1)	15 (10)	24 (15)	0.2 (0.0)	0.4 (0.2)
Medium Mortality	14 (6)	17 (2)	82 (18)	68 (12)	1.9 (0.7)	1.7 (0.3)
High Mortality	14 (5)	37 (3)	90 (7)	86 (4)	2.3 (0.4)	2.5 (0.2)
All regions	**18(4)**	**26 (2)**	**75 (14)**	**71 (11)**	**1.9 (0.4)**	**2.0 (0.2)**

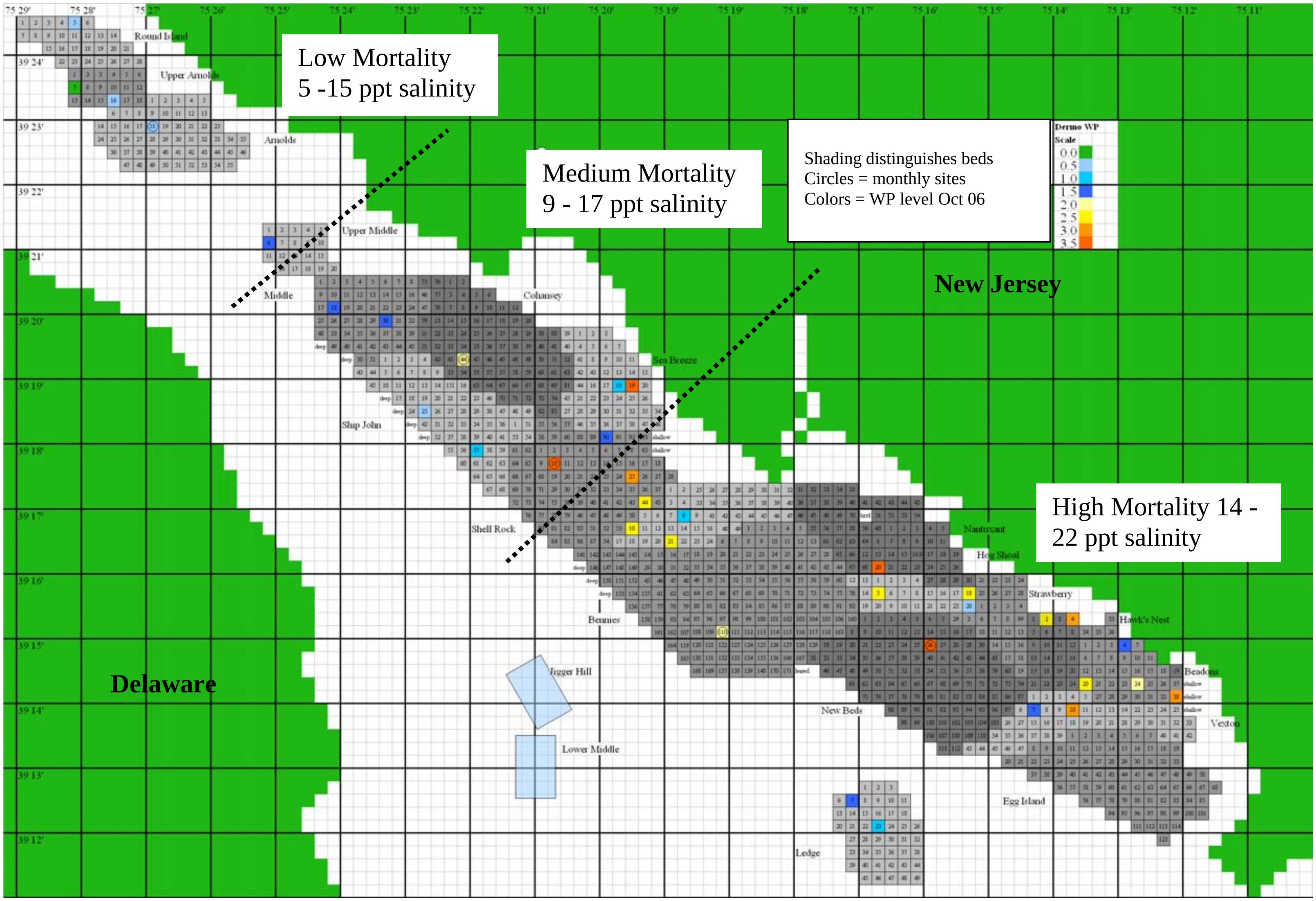


Figure 1. Delaware Bay New Jersey Natural Oyster Seedbeds and two shell plant sites in Delaware waters. Dotted lines separate regions by relative long-term mortality patterns and approximate salinity regimes.

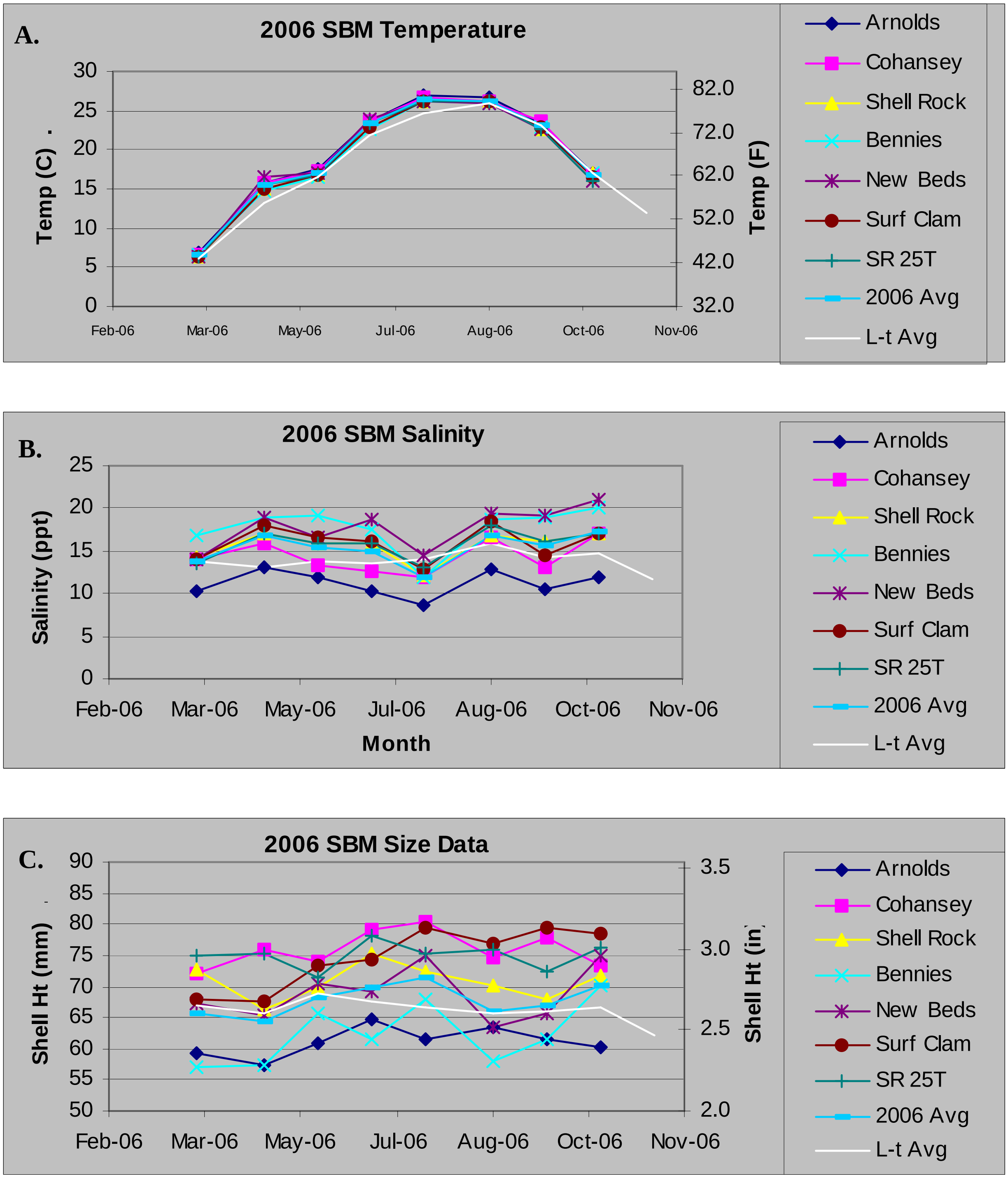


Figure 2. Monthly bottom water temperature (A), salinity (B) and mean shell heights of oysters (C) over New Jersey Delaware Bay oyster seedbeds during 2006.

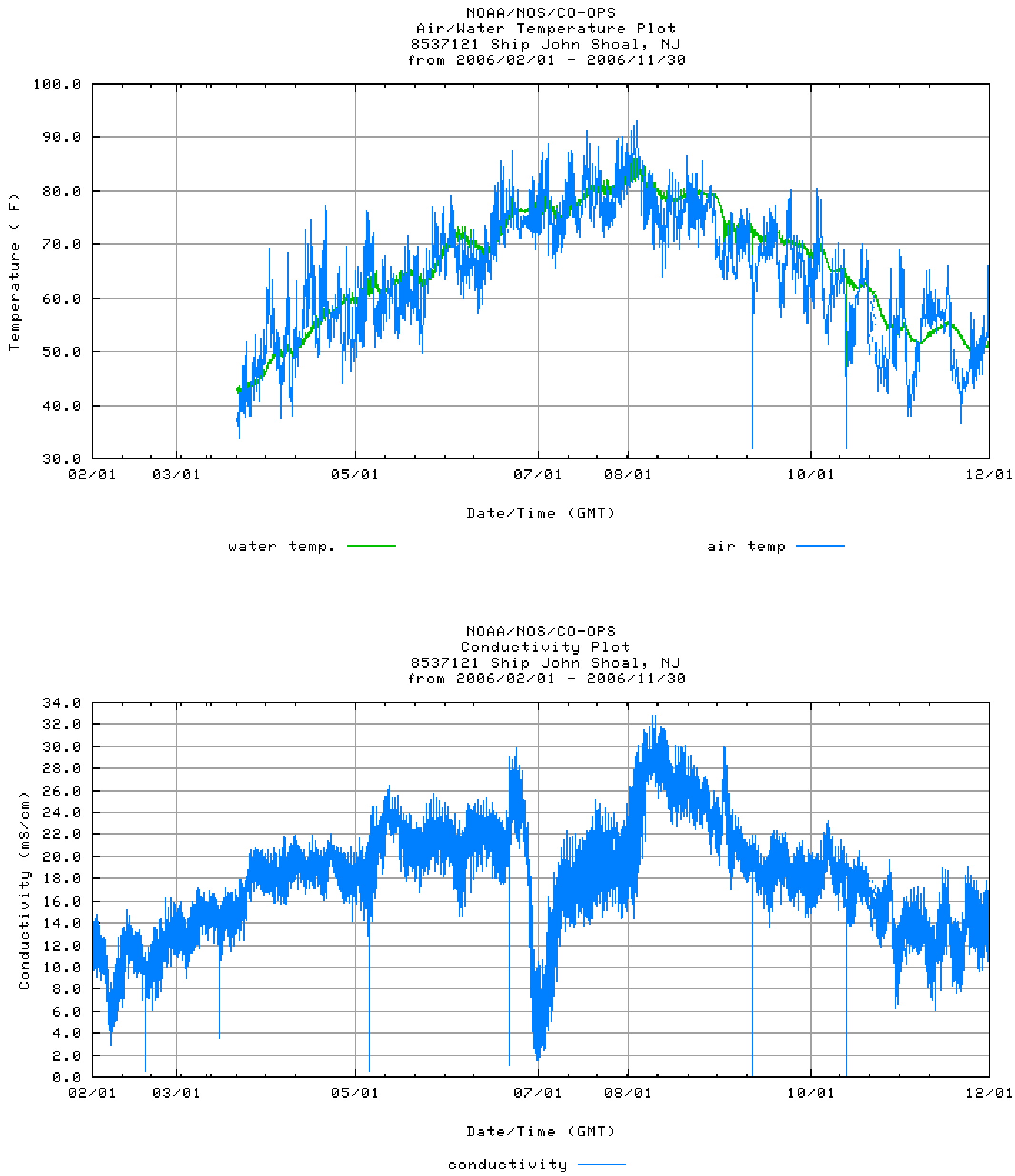


Figure 3. Temperature and conductivity data from Ship John Shoal during 2006 sampling period.

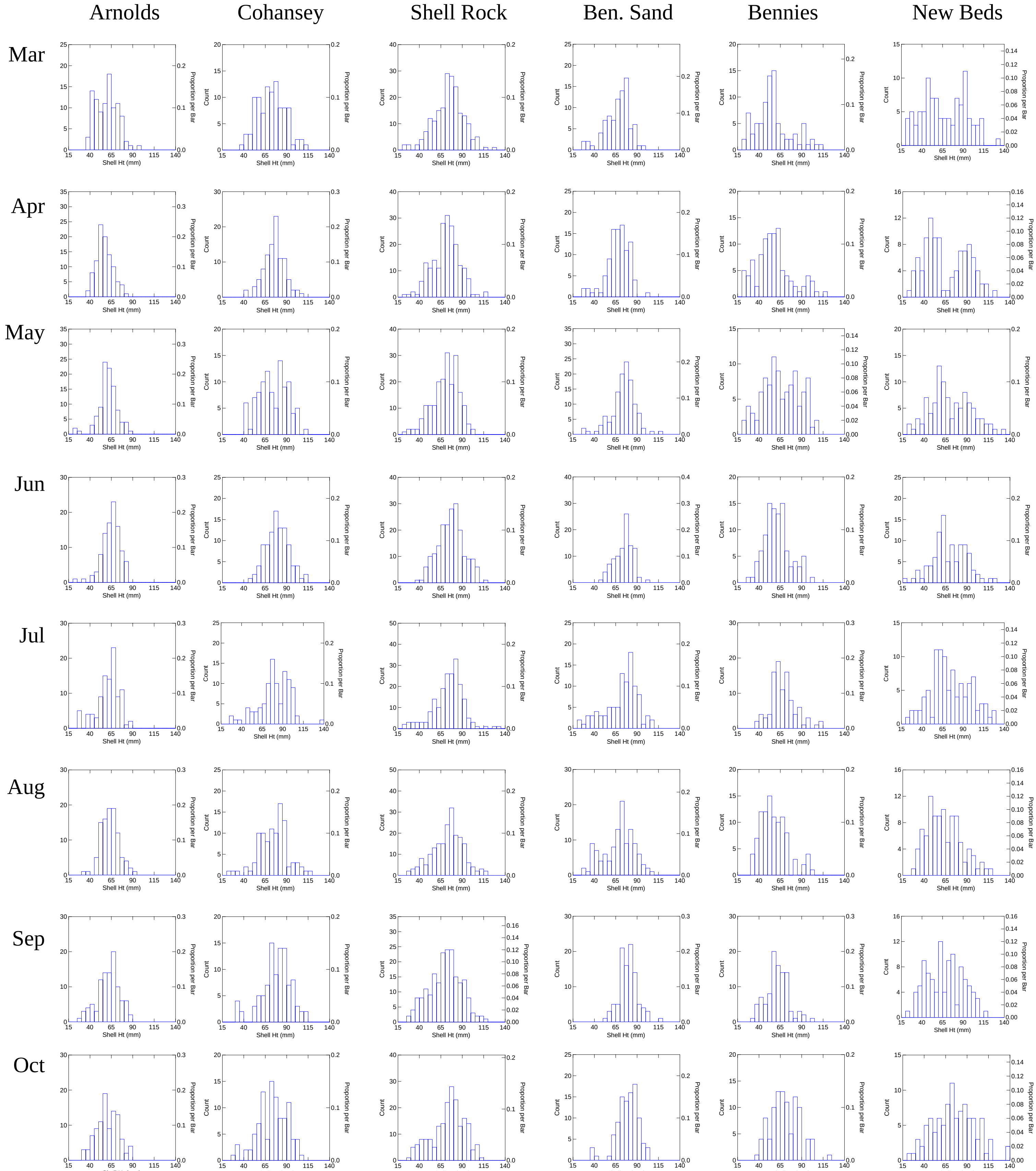
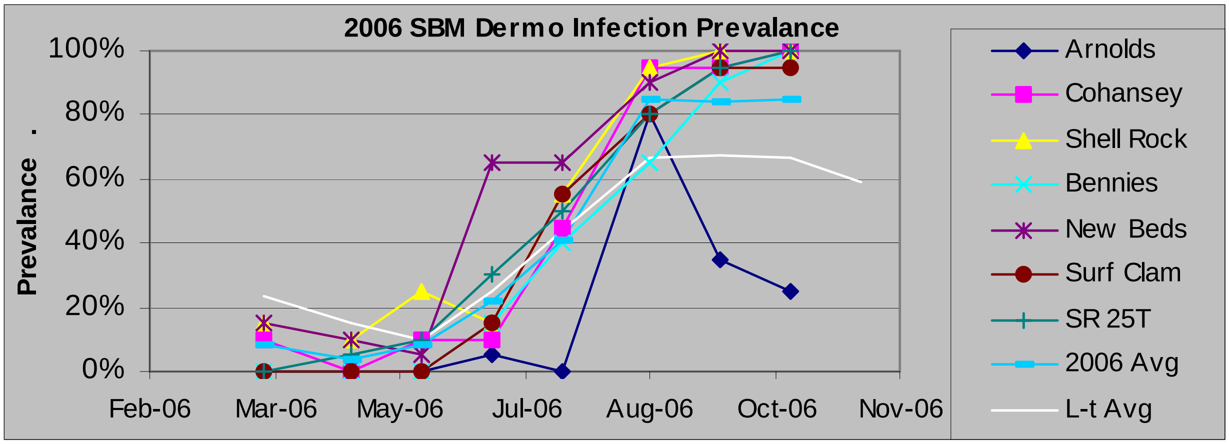
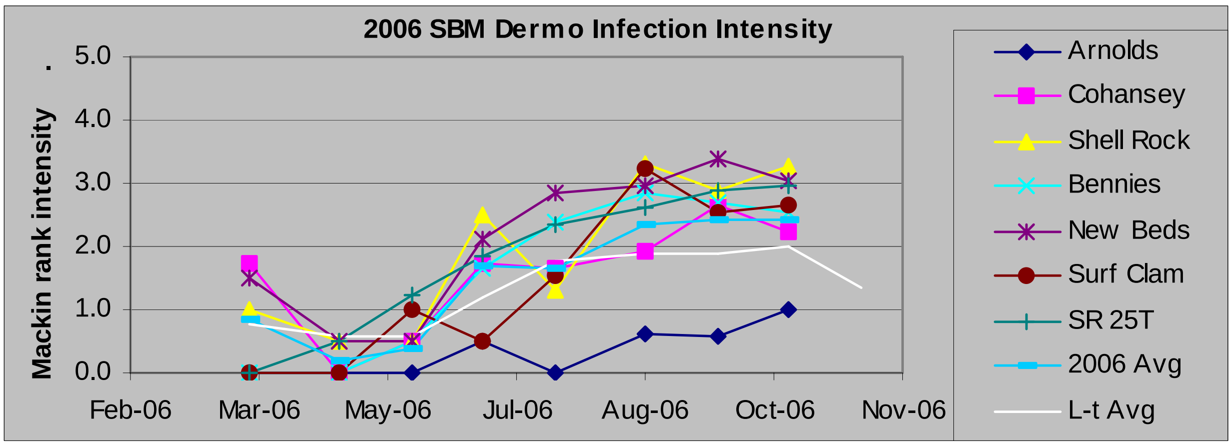


Figure 4. Size frequency plots for 2006 monthly seedbed monitoring sites. Size, shown on the x-axis, ranges from 15 to 140 mm in 5 mm increments for all plots. The frequency scale (y-axis) varies among plots. N = 100 for each plot.





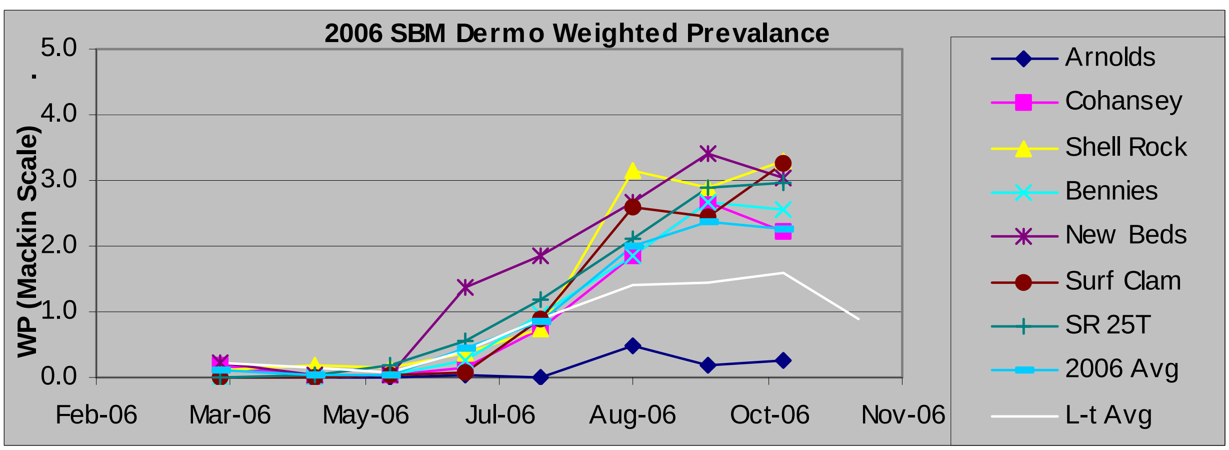
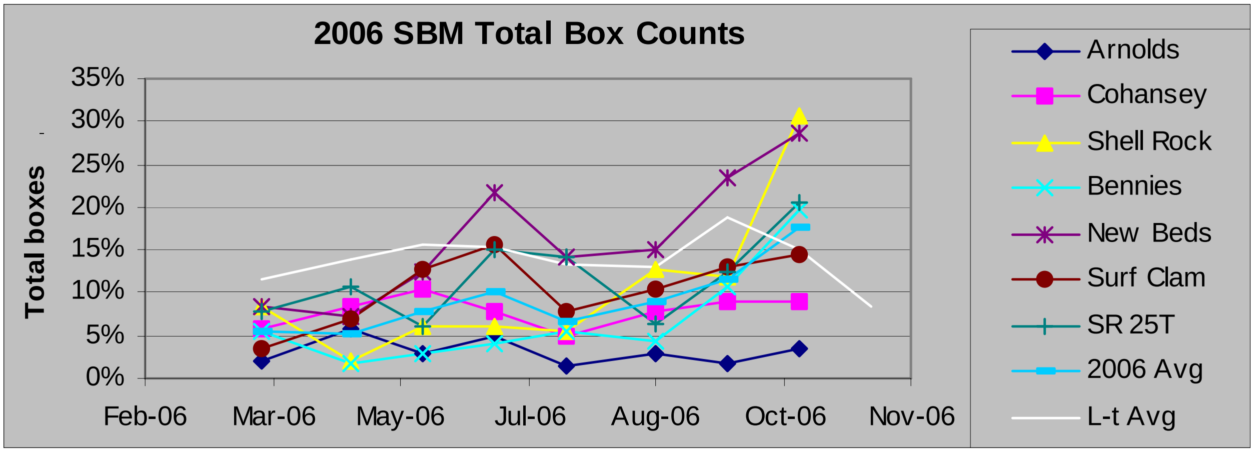
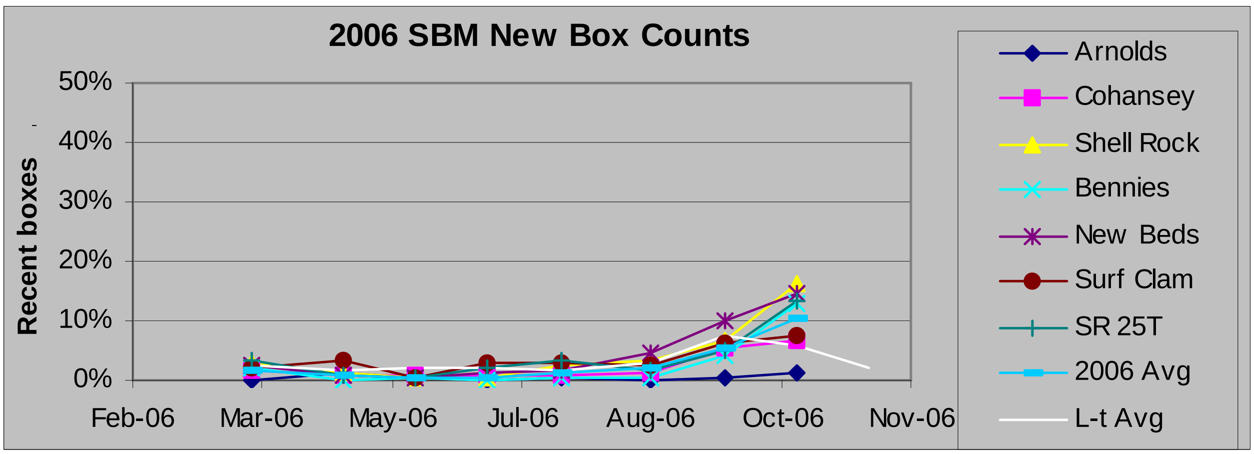


Figure 5. Monthly measures of dermo disease in oysters from New Jersey Delaware Bay seedbeds during 2006. Prevalence = percent of infected oysters. Intensity = average Mackin of detectable infections.





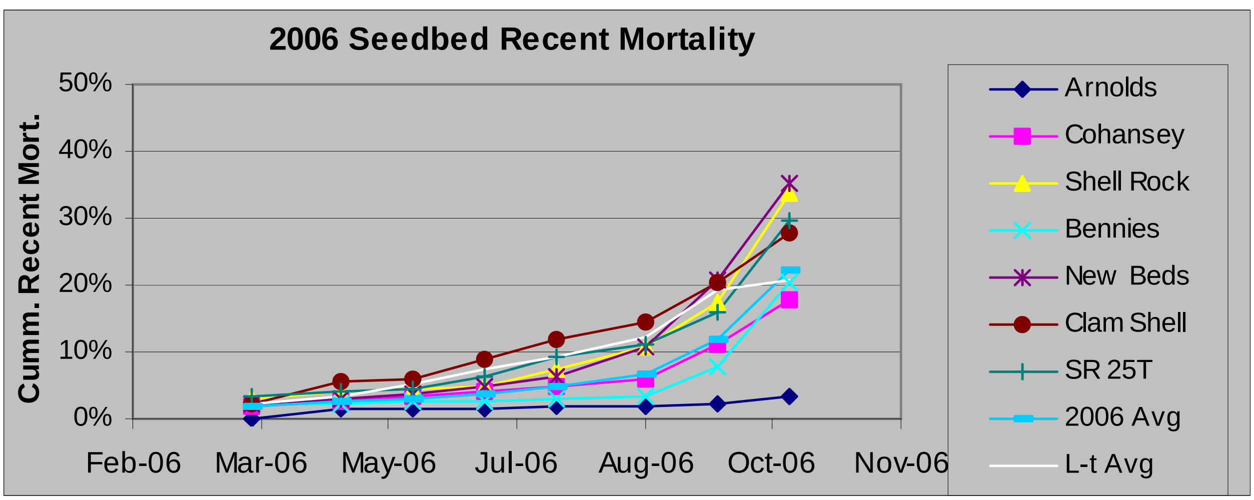
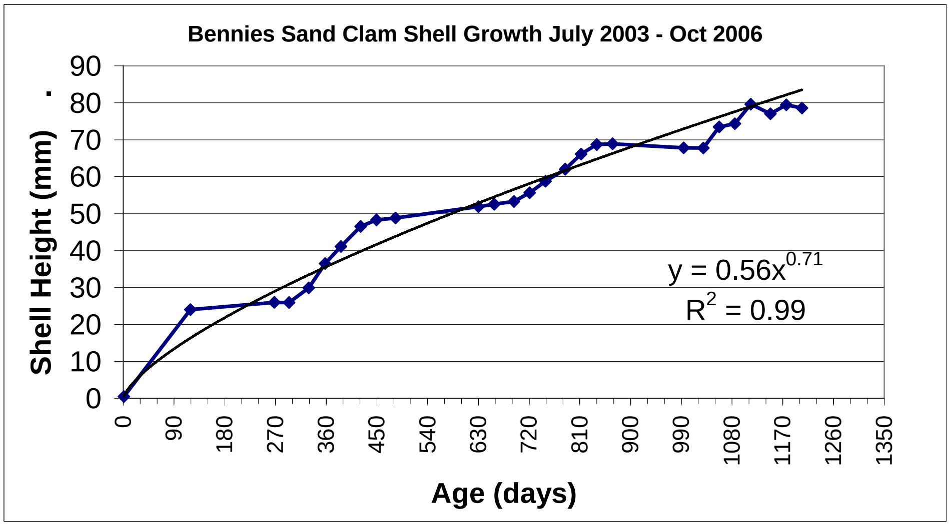
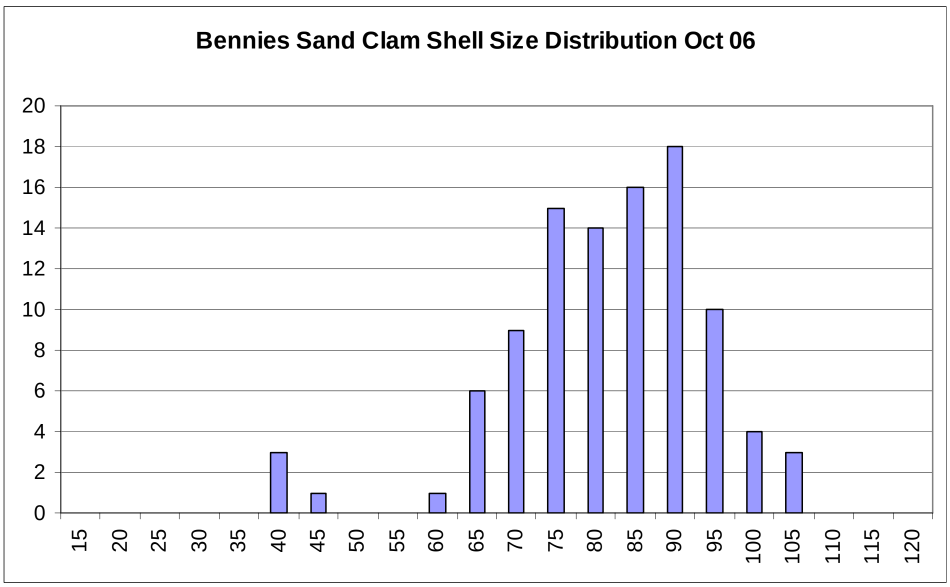


Figure 6. Monthly estimates of oyster mortality on the New Jersey Delaware Bay seedbeds during 2006.





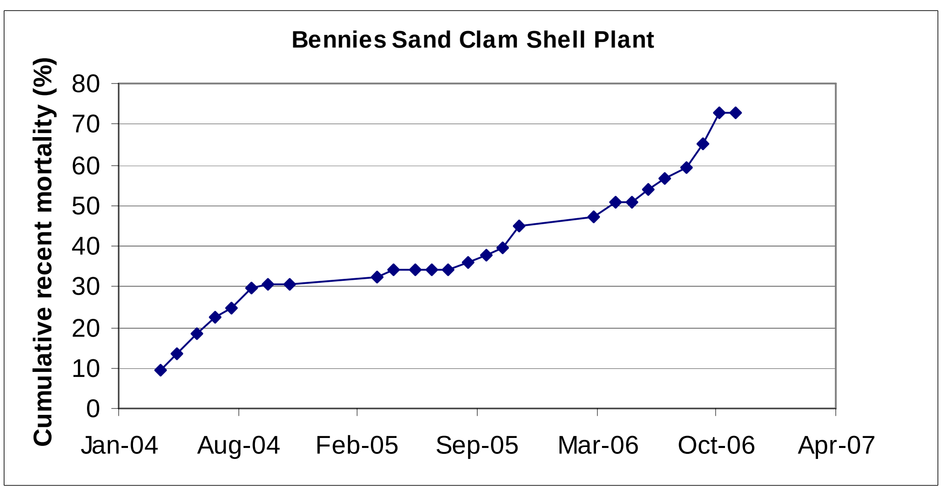


Figure 7. Performance of spatted surf clam shell transplanted from Cape Shore to Bennies Sand in 2003. Upper panel: mean monthly growth (n = 100). Middle panel: size frequency in October 2006. Bottom panel: cumulative recent mortality for the entire study period.

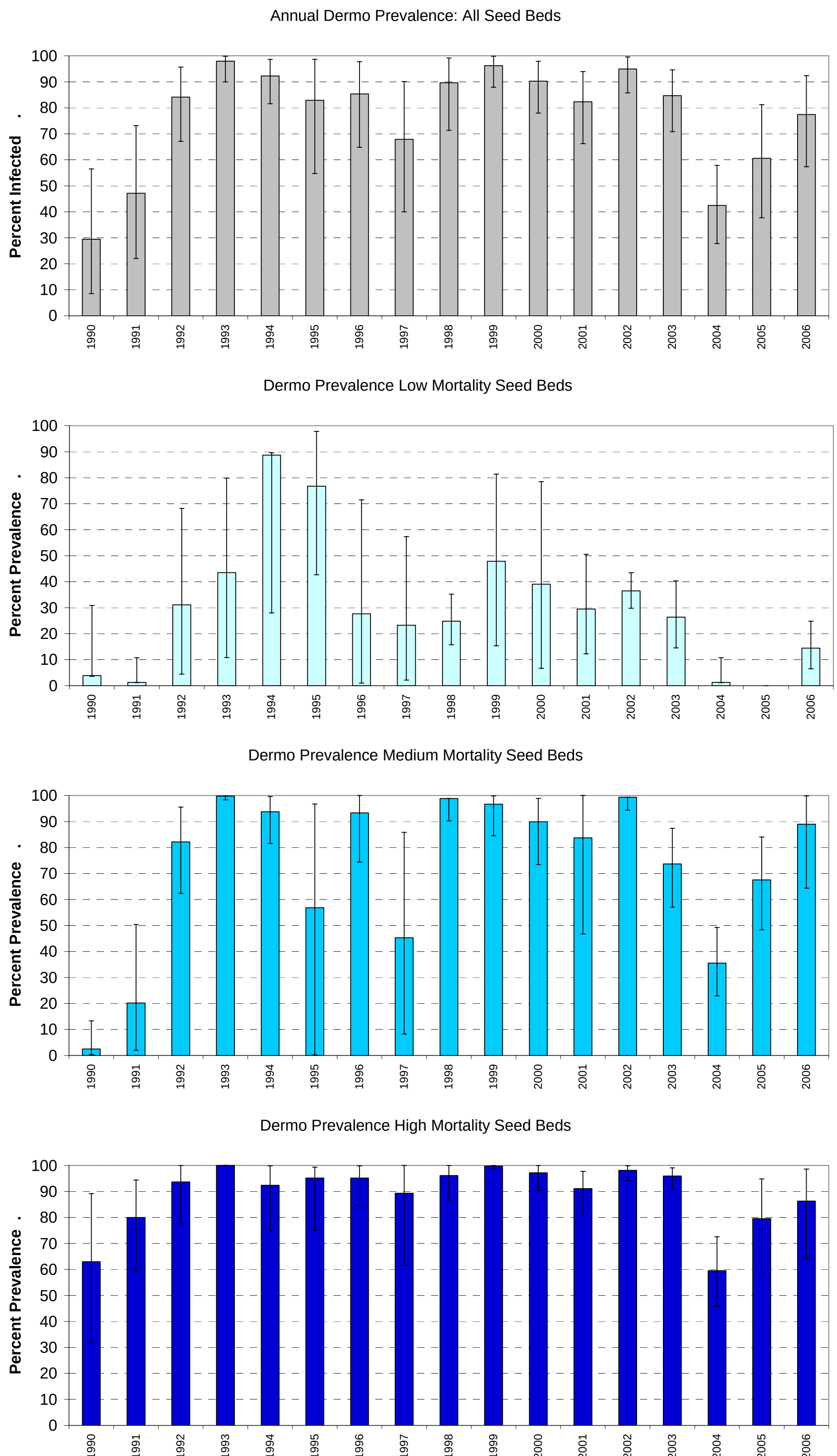


Figure 8. Annual mean fall dermo prevalence on New Jersey Delaware Bay seedbeds.

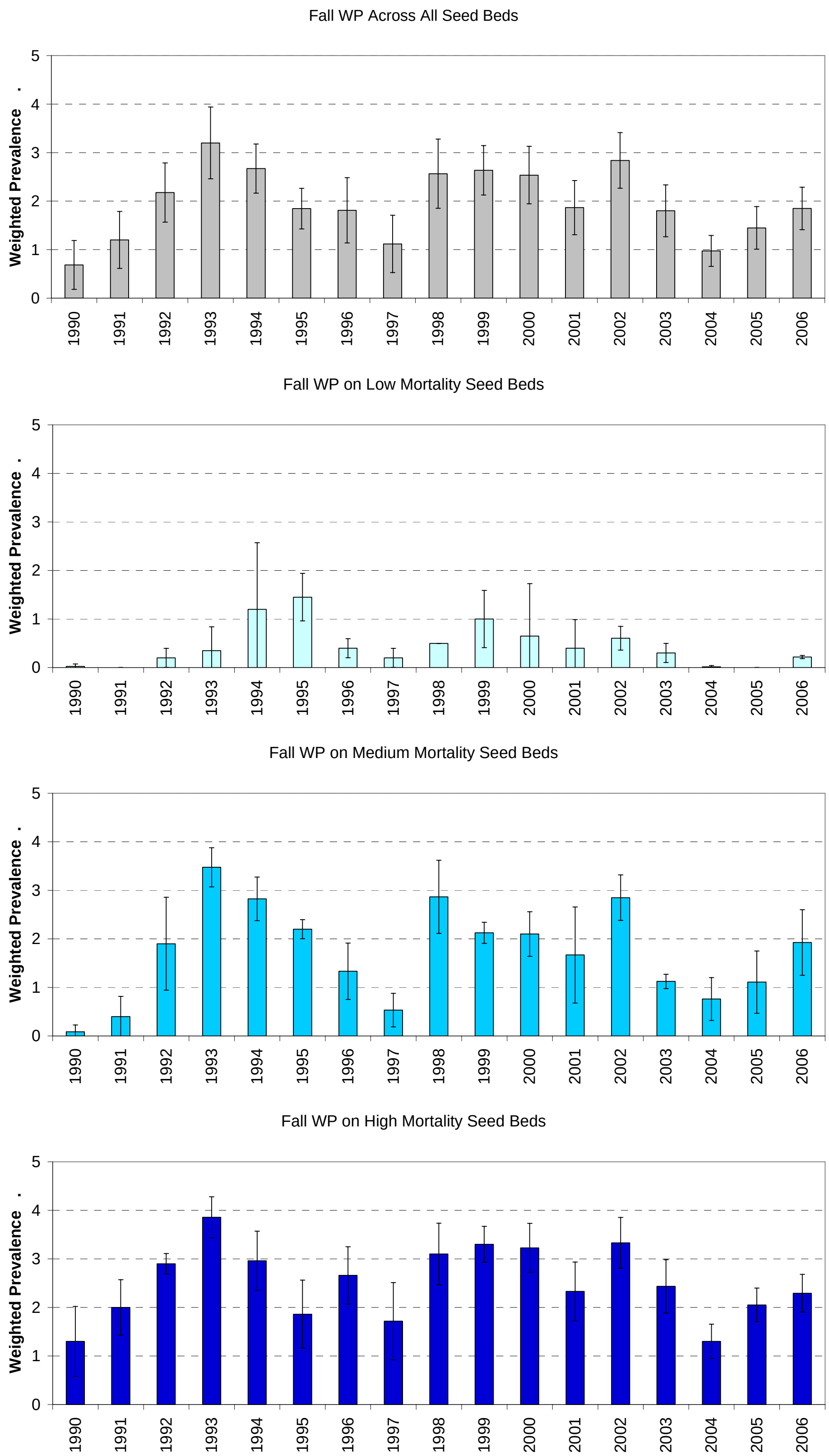


Figure 9. Annual mean fall dermo weighted prevalence on New Jersey Delaware Bay seedbeds.

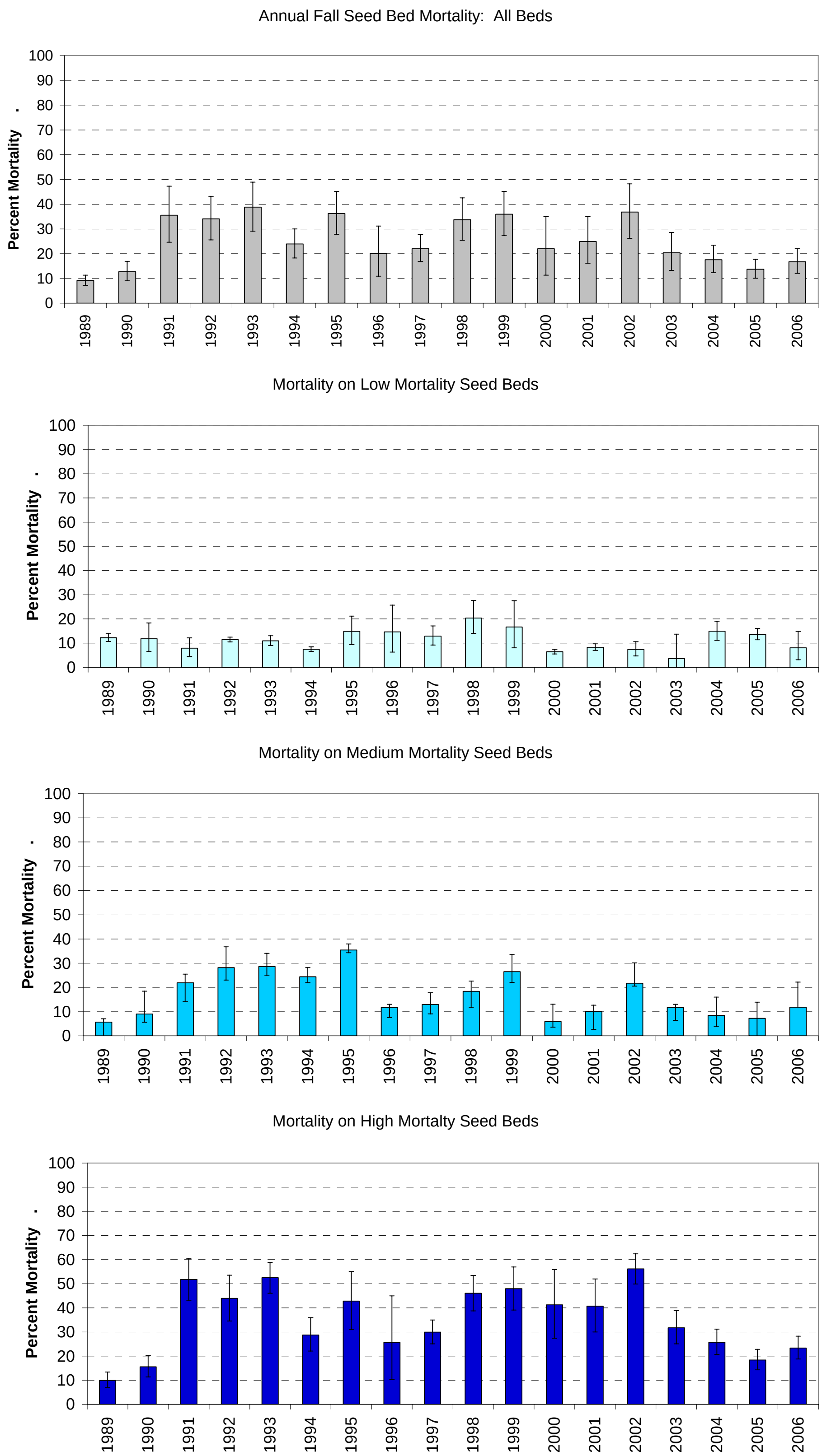


Figure 10. Annual mean fall box-count estimated mortality on New Jersey Delaware Bay Seedbeds.

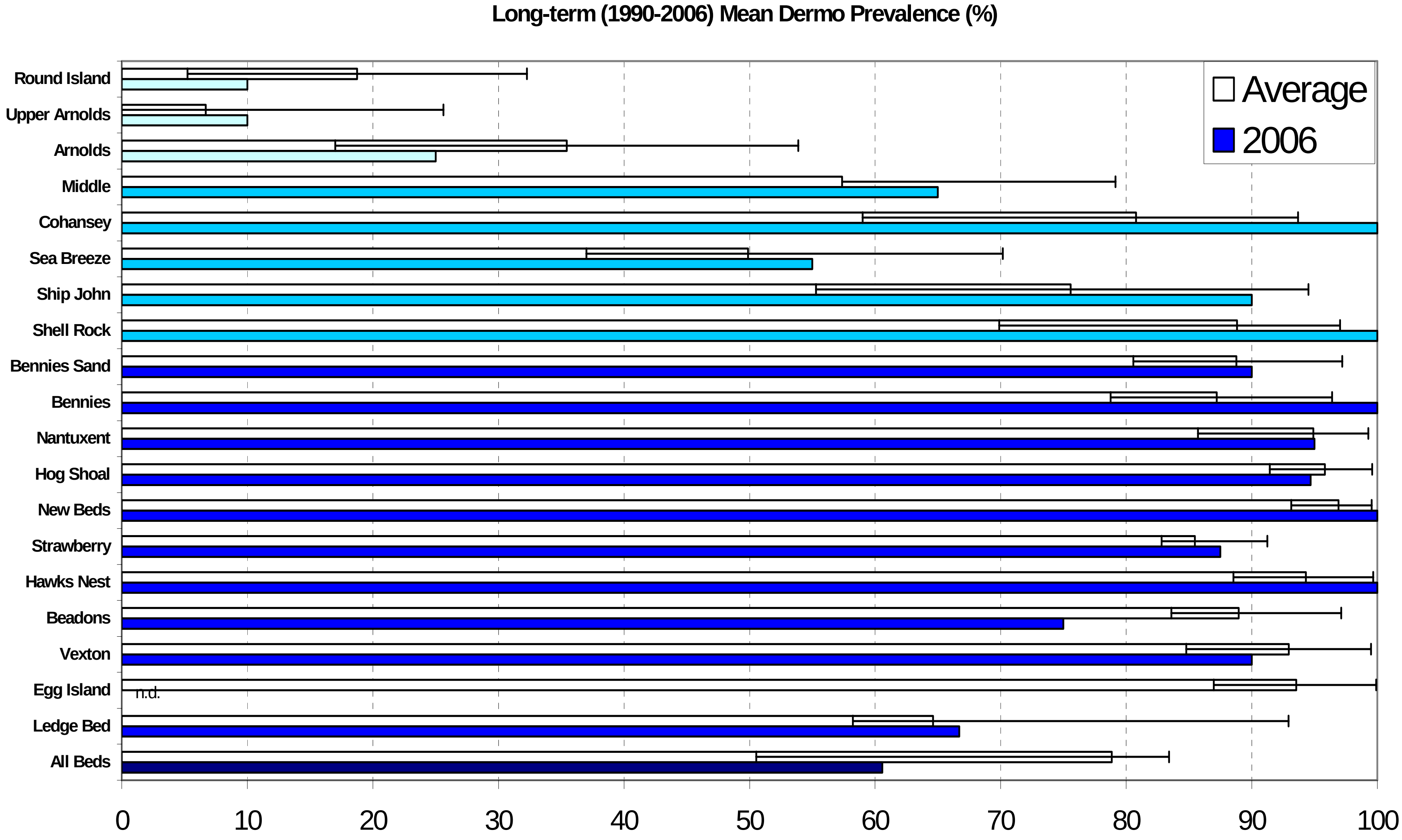


Figure 11. Comparison of average fall *Perkinsus marinus* (dermo) prevalence in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2006 levels (shaded bars). Bar shading for 2006 corresponds to low, medium and high mortality beds. Not all beds were sampled every year.

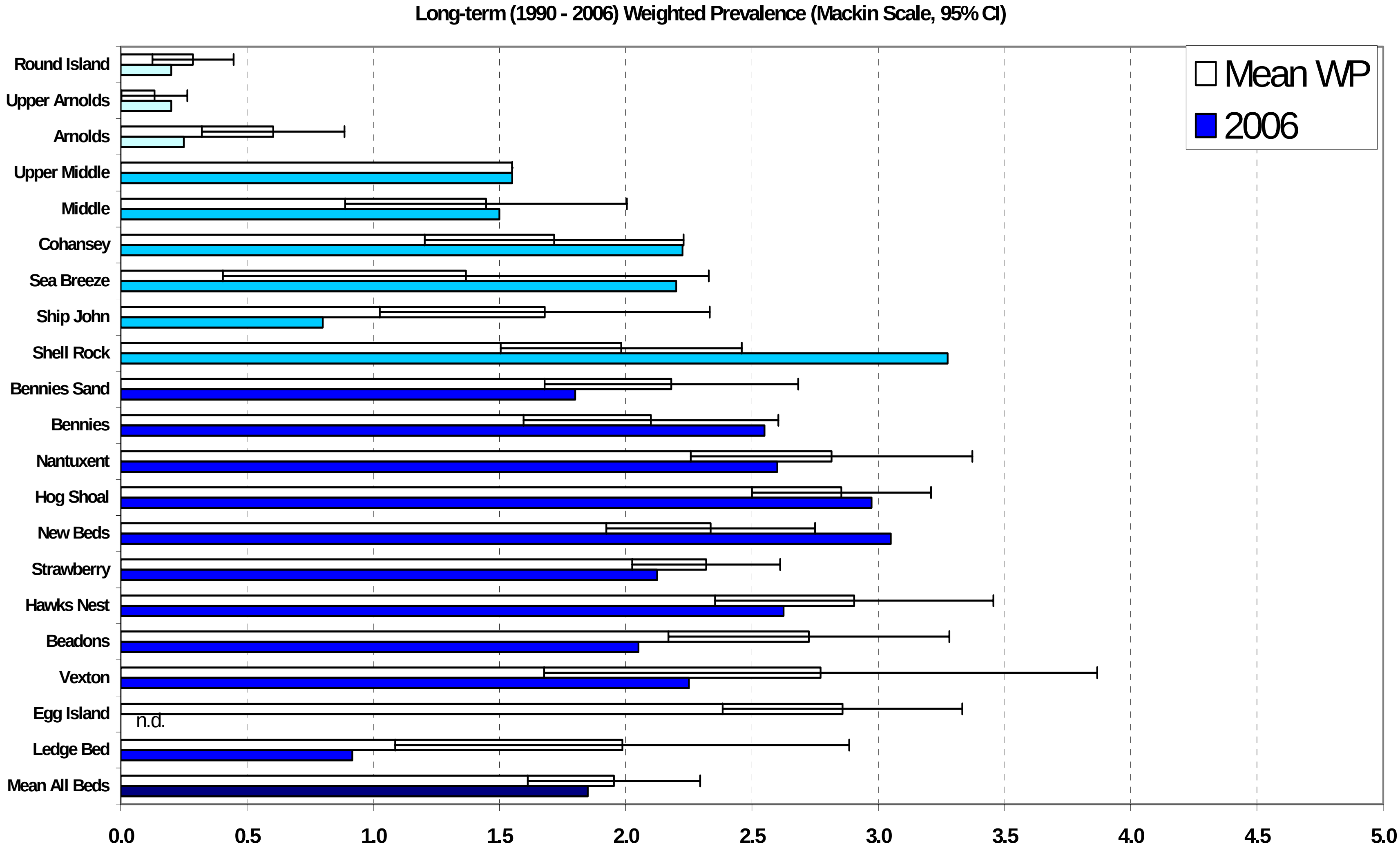


Figure 12. Comparison of average fall dermo infection intensities (weighted prevalence) in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2006 levels (shaded bars). Bar shading for 2006 corresponds to low, medium and high mortality beds. Not all beds were sampled every year.

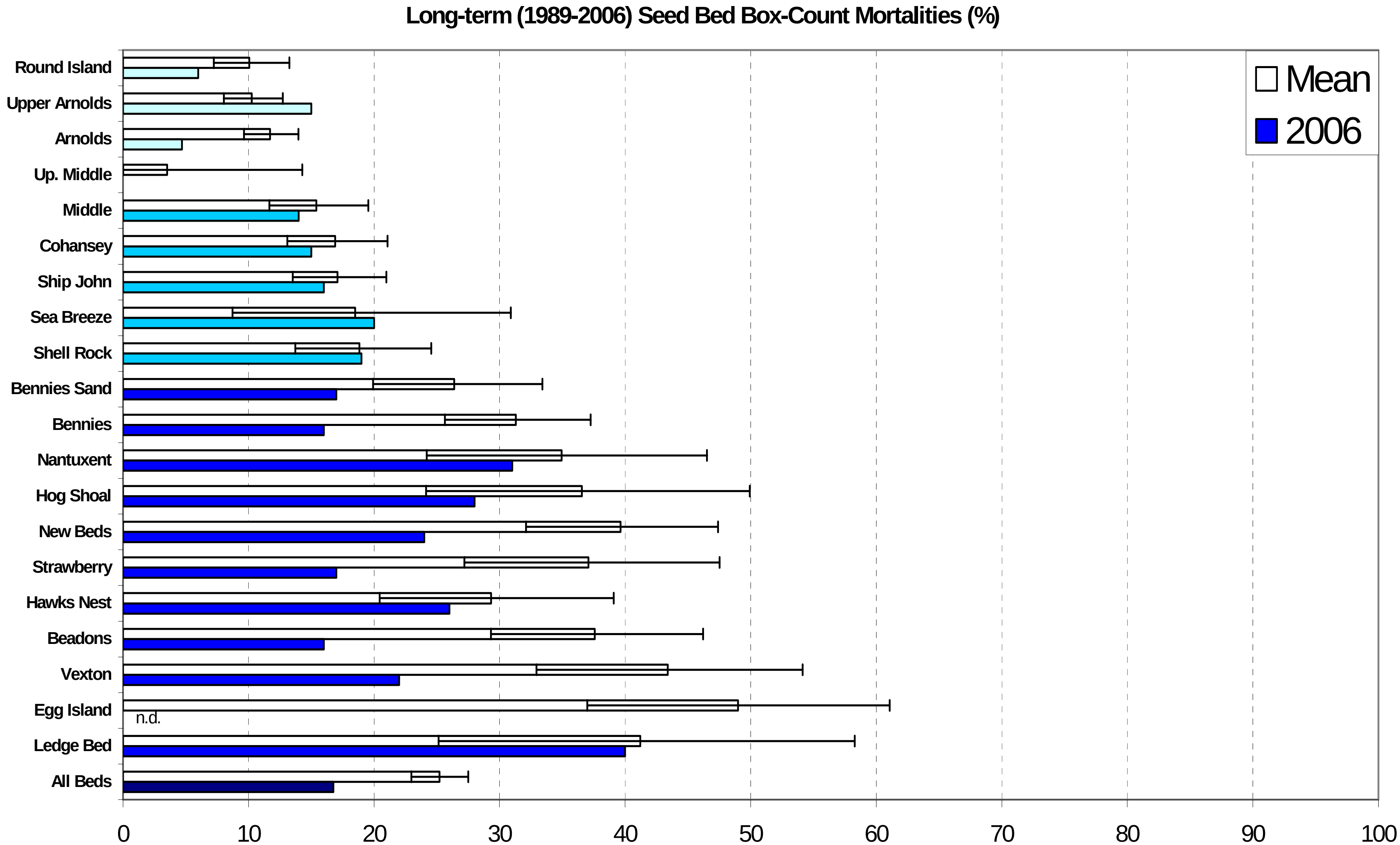


Figure 13. Comparison of average annual fall estimated box-count mortality of oysters on New Jersey Delaware Bay seedbeds since 1989 (open bars with 95% confidence intervals) with 2006 levels (shaded bars). Bar shading for 2006 corresponds to low, medium and high mortality beds. Not all beds were sampled every year.

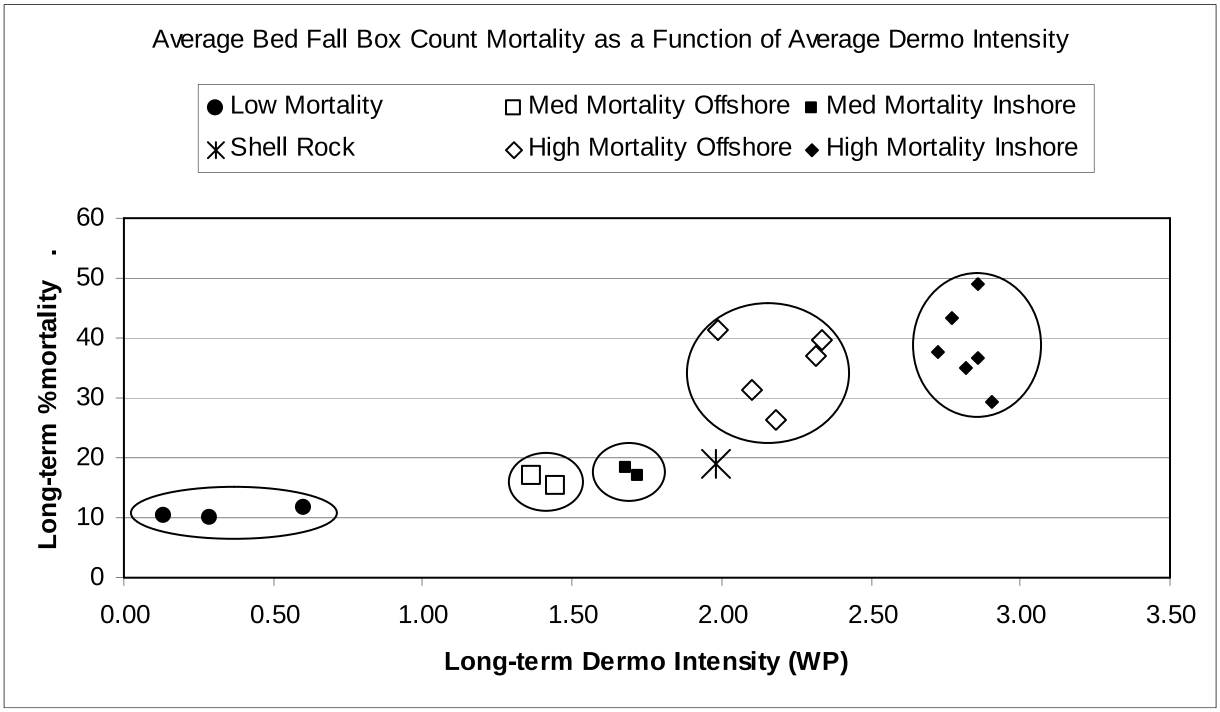


Figure 14. Relationship between long-term mean percent mortality estimate based on fall box-counts and the long-term mean intensity of dermo infections since 1990. Data are individual bed estimates. Note increase in mortality appears to be a step function with thresholds at weighted prevalence of about 1 and 2 on the standard 0-5 Mackin Rank scale.

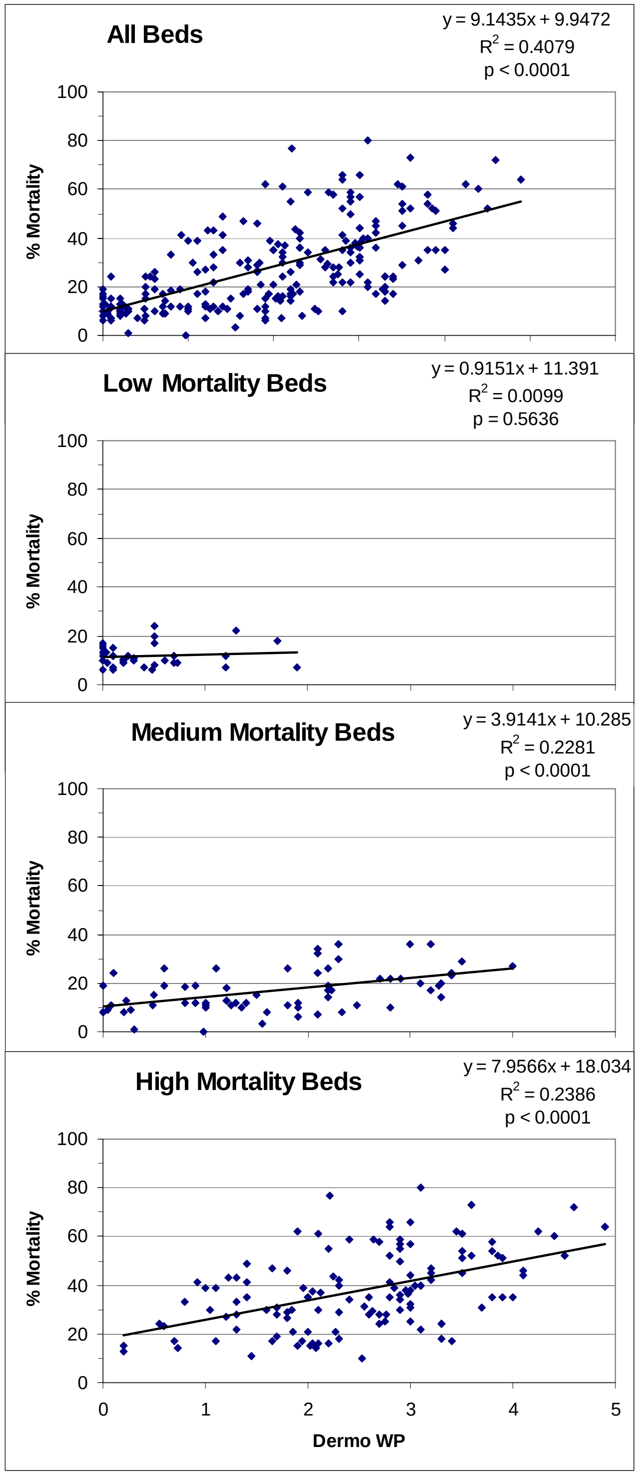


Figure 15. Relationships between fall box count mortality and Dermo infection levels (WP). Data are values for individual beds from 1990 to 2006.

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