Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2008 Status Report

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Executive Summary:

During 2008 the Seedbed Monitoring Program followed disease, growth, and mortality at five long-term monitoring sites, three transplant sites, 32 shellplant sites (including both direct plants and replants) and compared survival of animals collected from Shell Rock and Hope Creek on racks at Cape Shore to obtain an initial determination of differences in disease resistance. The program also collected condition index and disease data for the Fall Random Sampling Oyster Stock Assessment Survey. Size distributions of oysters continue to remain skewed towards larger animals, but are dropping on some beds. Temperature and salinity favored dermo disease and the population experienced another epizootic year. An early mortality occurred in late spring as over-wintering animals became active revealing those that had survived the winter in a moribund state. A second, large mortality event occurred in late summer/early fall and can be largely attributed to dermo disease. Long term periodicity of about 7 years continues to appear on the data with an indication that successive cycles have diminished slightly. The outlook for 2009 appears to be similar, although if the cycling is consistent, the population should be entering a phase of reduced dermo disease.

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Introduction

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

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 as a whole appears to have developed significant resistance 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 is being investigated further with support from the National Science Foundation. Nevertheless, naïve oysters routinely deployed at the Rutgers Cape Shore field site become heavily infected, indicating that the parasite is still present in the Bay. In 1990, an epizootic of dermo disease (= perkinsosis, 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 the lower Chesapeake Bay. Termination of those importations resulted in the disappearance of the disease. The 1990 appearance of dermo disease was not associated with any known importations but was related to a regional warming trend after which the documented northern range of *P. marinus* was extended to Maine (Ford 1996). Dermo disease is now a major source of oyster mortality in Delaware Bay and a primary focus of the Seedbed 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 (Figure 1): low mortality seedbeds (formerly called the upper seedbeds), medium mortality seedbeds (formerly called the upper-central seedbeds), and high mortality beds (formerly called central and lower seedbeds). These designations correspond to increases in salinity regime from the low to high mortality beds. In 2007 oysters above Round Island were added to the survey after discovering that their abundance represented a significant proportion of the population. These oysters were designated Hope Creek oysters in 2007, but were subsequently subdivided into three new beds: Hope Creek, Fishing Creek and Liston Range.

The majority of fresh water entering the system comes from the Delaware River and tributaries located above the oyster beds, however, inputs from several tributaries that enter the bay adjacent to the seed beds (Hope Creek, Stow Creek, Cohansey River, Back Creek, Cedar Creek and Nantuxent Creek) combine with the geomorphologic configuration of the shoreline to influence salinity, nutrients, food supply, circulation and flushing in ways that are not completely understood. These factors undoubtedly interact to influence the spatial and temporal prevalence and intensity of disease and mortality on the seedbeds.

Area management strategies typically follow the mortality designations, but have recently managed Shell Rock independently as the Stock Assessment has identified this as a bed of key importance to the natural stock and to the industry. The temporal and spatial sampling efforts of the Seedbed Monitoring Program are designed to continually develop a better understanding of factors influencing oyster growth, disease and mortality patterns to support adaptive management efforts. As funding permits, these efforts include monitoring transplants (i.e., oysters moved from upper to lower seedbeds), shell plants (i.e., shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (i.e., cultch planted in the lower bay high set zone near the Cape Shore then moved and replanted on the seed beds). The 2008 objectives for the Seedbed Monitoring Program were:

1. Continue the standard monthly seedbed monitoring time series from March – November 2008, including 2007 and 2008 transplant sites
2. Conduct dermo and MSX assays and determine condition indices for Fall 2008 Stock Assessment Random Sampling survey
3. Monitor growth, mortality and disease on 2006, 2007 and 2008 shell plants and replants April – November 2007.
4. Conduct a preliminary assessment of disease resistance of Hope Creek oysters by comparing their survival against Shell Rock oysters when adults from both beds are maintained at the Cape Shore.

Objectives 1 and 2 comprise the basis of the long-term seedbed monitoring program that provides fundamental information necessary for both immediate and long-term adaptive management of the resource. This provides essential baseline/background information against which the success of other objectives and independent research can be judged. Objective 3 is related to the Delaware Bay oyster restoration program designed to enhance recruitment on the seedbeds. Results are incomplete and will be reported elsewhere. Objective 4 was requested as an initial measure to determine if these beds could be incorporated into the intermediate transplant program without introducing potentially MSX-susceptible oysters into the heart of the extant seed bed population.

HSRL staff, especially Iris Burt, along with NJDEP Bureau of Shellfisheries staff, especially Jason Hearon and Craig Tomlin, provided field, logistical and technical support. Emily Scarpa performed histology for MSX and Dr. Susan Ford provided helpful advice throughout.

Methods

Figure 1 depicts the grid system used during 2008 for the seed bed monitoring program. Beds that fall in the jurisdiction of the state of Delaware are not shown. The grid system is nearly contiguous, but the 23 areas differentiated by color represent concentrations of oysters that are referenced by historical names traditionally used by the industry and resource managers. Darker shades of color indicated higher densities of oysters relative to the rest of the bed. On any given bed 98% of the oysters exist on the colored grids while only 2% exist at low density on the surrounding grids. Samples were collected from March through November for Objective 1 and 3 as indicated in Tables 1 and 2, respectively. Table 3 lists the beds and grids that were monitored for Shell plants, transplants and replants. Table 4 shows which beds have been monitored since 1990 as part of the long-term dermo monitoring program that is affiliated with the annual Fall oyster stock assessment. Table 5 shows the grids sampled for Objective 2 as part of the Annual Fall Stock Assessment. As indicated above, the dotted lines in Figure 1 demarcate the low, medium and high mortality zones that correspond with salinity regimes of 0-15 ppt, 5-20 ppt and 10-24 ppt. Management activities and this report reference both regions and beds as appropriate.

To complete objective 1, 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® 85 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; at Arnolds total sample volume was only one half a bushel and subsamples adjusted accordingly) was created and then sorted to enumerate gapers (= dead oysters with meat remaining in the valves), boxes (= hinged oyster valves without any meat remaining) and live oysters. Boxes were further categorized as new (= no indication of fouling or heavy sedimentation 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 bushel were returned to the laboratory and shell heights (hinge to bill) measured to determine size frequencies. Care was taken to avoid any bias in sampling oysters by systematically working through the sample until 100 oysters were identified. Nevertheless, the sampling gear will bias the collection toward larger animals as dredge efficiency studies have shown (Powell et al 2007). 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 was then weighted using the "Mackin scale" from zero (= pathogen not detected) to five (= heavily infected) (Ray 1954). These values were 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, gametes were examined from a subset of the oysters collected to estimate sex ratios and assess reproductive status from the five long-term monitoring stations.

Samples for objective 2 were collected from excess oysters collected during the Fall Stock Assessment. The stock assessment survey consists of a stratified random sampling of the medium and high quality grids on the 23 named beds. Samples were collected using the commercial oyster boat H. W. Sockwell. After a third of a bushel was removed from each of three dredge hauls, remaining catch was searched to collect oysters for disease analysis, size frequency and condition as indicated in Table 5. Dermo was diagnosed as described above. MSX was diagnosed using standard histology (Howard et al. 2004).

To complete objectives 3, samples were collected monthly from March through November (Table 2) for sites manipulated as indicated in table 3. Samples were collected from up to five 1 minute dredge tows that were emptied on deck and then searched for planted shell containing live or dead oysters until up to 100 live spat or oysters were collected. If 100 live oysters were not collected within three tows then, time permitting, a fourth or fifth tow was made. As a result, some samples contained fewer than 100 oysters. Care was taken to search systematically and avoid sampling bias by working systematically through the sample until 100 live spat or oysters were collected. Boxes were enumerated and categorized as new or old as described above. Live oysters attached to planted shell were returned to the laboratory for size measurements each month and for dermo analyses (n = 20 per site) during July, September and November.

Results and Discussion

Water temperatures measured during 2008 collections across the seedbeds followed typical patterns with a peak in July and little spatial variability (Figure 2A). Compared to recent years, however, temperatures were slightly warmer than average during most measurements taken from March until August (Figure 2B). Salinity followed a typical spatial pattern, increasing from upbay to downbay beds (Figure 2C), but was lower than normal early in the year and higher than normal from July into November (Figure 2D). The combination of a longer warm period and higher than average salinity for much of the year are conditions that generally favor the development of dermo disease in oysters. Continuous monitoring of temperature (Figure 2E) and salinity (Figure 2F) at the NOAA PORTS Ship John Shoal Light station corresponded with data collected during seedbed monitoring and suggested no unusual fluctuations during the year. The continuous temperature and salinity data for Ship John Shoal Light can be accessed to obtain near real-time or archived data on the Internet at http://tidesandcurrents.noaa.gov/. As indicated by figures 2E and 2F, temperature and salinity can vary widely within a day. The Seedbed Monitoring Program only measures salinity when collecting oysters and only over those sites being sampled. An array of continuous monitoring stations across the seed beds may facilitate a better interpretation of conditions that influence recruitment, growth, disease and mortality of oysters.

Oysters appeared reproductively mature by mid-June and remained at least partially ripe into August. Sex ratios were equal in June (48% female, 47% male, 2% hermaphrodites and 3% indeterminant; n = 288), biased toward females in July (55%, female, 41% male, 0% hermaphrodites and 4% indeterminant n = 371), and slightly biased toward males in August (45% female, 49% male, 1% hermaphrodite and 6% indeterminant; n = 142). As indicated in Figure 2, temperatures that are generally considered warm enough to trigger spawning (25°C = 77°F) were reached by late June and were maintained into September. Salinity also continued to increase during this period. These conditions are favorable for the production and survival of oyster larvae and likely contributed to produce multiple successful spawns and subsequent sets of oysters that were reported from several areas in the bay during 2008.

Mean shell height of oysters fluctuated slightly around a relatively constant bed-specific size throughout the summer of 2008 with the exception of Cohansey were mean shell height dropped from 76 mm (3 in) to 64 mm (2.5 in) (Figure 4A). A comparison of the average size across all seedbeds during 2008 with the average across beds and years since 2000 (Figure 4B) indicates that the size frequency of oysters presently on the seed beds is dominated by larger size classes. The larger sizes for 2008 continue to be a result of poor recruitment during several previous years. Standard seedbed monitoring includes all cohorts present. Mean size may be affected by mortality of larger animals, growth of animals present and recruitment of younger animals. These processes may cancel each other out resulting in no net change in mean size. Recruitment will add smaller oysters to the population and consequently reduce the average size. In the absence of recruitment the opposite occurs. That is, the absolute abundance of large oysters need not increase to shift the average, rather the paucity of small animals recruiting into the population has more likely shifted the average. The result is an apparent increase in abundance of large animals in the population.

Dermo prevalence, weighted prevalence (WP) and intensity followed typical seasonal and spatial patterns across the seedbeds (Figure 4). That is, all three increased from a low in Spring to a peak in late summer and were generally higher on beds in higher salinity regions. Compared to levels since 1999, mean intensity across the seedbeds was at or below long-term levels initially, but quickly increased to levels well above average where they remained for the rest of the year (Figure 4B, D and F). By July, all beds except Arnolds had dermo levels that were expected to begin causing noticeable mortality (i.e., WP > 1.5) and by Sept, weighted prevalence on Arnolds was well above 1.5. It is worth noting that dermo levels on the 2007 transplants were among the highest throughout the year and that the 2008 transplants followed dermo levels representative of nearby beds.

Total box counts from monthly samples, which are used in the estimate of annual mortality by the stock assessment survey, fluctuated throughout the year with highest levels occurring in November for most beds (Figure 5A and B). Lowest box counts were on Arnolds (consistenly < 12%), while levels ranging from 10 to 50% occurred on the other beds during the year. Box counts did not increase in a strictly linear fashion from Arnolds to New Beds, which is the general long term pattern. Instead, the pattern fluctuated over the year. The fluctuations in box count data is noteworthy because the stock assessment uses values obtained in late October or early November. Boxes are labile with half lives of less than a year so the timing of mortality can significantly contribute to error for estimates made but once annually (Ford et al. 2006). Recent box counts indicated that the majority of the 2008 mortality occurred from August to October with another small peak in April (Figure 5C and D). The April mortality may represent over winter mortality enhanced by high dermo levels observed during Fall 2007. The September and October mortalities correspond to the high Dermo levels observed during 2008 (Figure 4). Cumulative recent mortality estimates indicate somewhat greater mortality occurred than estimated by total box counts (Figure 5C and E) and may account for a portion of the persistent underestimate of mortality by the annual stock assessment models (Powell et al. 2007). Regardless, by either total box count or cumulative recent box count estimates, and using 20% mortality as a definition of an epizootic mortality (the level used in previous stock assessments), all beds monitored except Arnolds experienced epizootic mortalities in 2008. It is worth noting that mortality levels on transplant grids were as high or higher than the recipient or nearby bed.

The stratified random sampling stock assessment survey was conducted in November 2008, a month later than normal. As such, disease data should be compared to previous years with a bit of caution because disease levels are typically decreasing by this point in the seasonal cycle (see Figure 4). Details of dermo and mortality are presented below. Condition indices and size frequencies were reported elsewhere as part of the stock assessment. Because MSX has not been problematic on the seed beds for nearly two decades, samples from only six beds along the up to down bay gradient were examined (Table 5). At least one infected oyster was present on each bed examined indicating the persistence of MSX despite the absence of MSX epizootics. Moving from up bay to down bay, prevalence was 5% on Hope Creek, 25% on Arnolds, 5% on Cohansey, 10% on Shell Rock, 30% on Bennies and 5% on New Beds. Only two oysters from Bennies had systemic infections and only one of these was advanced. Remaining infections were all light and localized. This is represents a slight increase over 2007 (from 6.7% overall to 15%) and indicates the continuing need to monitor MSX. Naïve oysters deployed at the Cape Shore in the lower bay experienced heavy MSX as well as dermo. An unrelated study funded by the National Science Foundation has examined oysters from several sites around the bay as far up as Hope Creek and in three different tributaries. These data indicate MSX is present throughout most of the bay at similar prevalence, including all of the seedbeds, although oysters are not developing advanced infections. Lowest prevalence is consistently detected in the tributary populations.

Figure 6 compares survival of Hope Creek oysters against Shell Rock oysters when both were deployed on aquaculture racks at the Cape Shore. Mortality curves are similar with both stocks sustaining high mortality (~80%) by the end of the trial. Disease sampling indicates that Shell Rock oysters were collected with slightly heavier dermo and MSX infections (Table 6) and this may explain the earlier onset of mortality. By the end of the study both stocks had similar infections levels suggesting they may possess similar levels of resistance.

Figures 7, 8 and 9 depict annual fall dermo prevalence, dermo infection intensity (= weighted prevalence) and Fall box-count estimated mortality from 1989 to 2008 for the entire seedbed region (upper panel), the low mortality beds (second panel), the medium mortality beds (third panel) and the high mortality beds (bottom panel). Dermo prevalence and intensity remained relatively high in 2008 continuing an increasing trend that began from a low in 2004 and is indicative of a cycle of approximately seven or eight years (Figures 7 and 8). 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 9). Note that mortality appears to lag disease by about one year and that mortality on the low mortality beds is not only much lower, but less correlated to dermo patterns. As mentioned in previous years, the apparent cycling may be driven by larger regional climate patterns, but this remains a hypothesis that additional research and continued monitoring could help address. The apparent 7-8 year periodicity indicates that dermo may have reached a peak. There is also an apparent attenuation of the successive peaks. This observation is difficult to interpret at this point, but could indicate a positive response leading to an increase in resistance to dermo disease. The one year lag between dermo and mortality, however, suggests high mortality may be expected to continue next year.

Examination of dermo prevalence, dermo intensity and box-count mortality estimates on a bed-by-bed basis for 2008 indicated a shift in the area of maximum dermo impact up the bay. (Figures 10-12). These data show that all three parameters exceeded long-term means on beds further up the bay, but not on beds located further down bay. Nevertheless, a plot of long-term mean fall box-count mortality estimates against long-term mean dermo infection intensities

(Figure 13) continues to show how the seedbeds segregate into three or four disease and mortality zones. Two thresholds of dermo intensity appear to exist at weighted prevalence of 1.5 and 2.0, above which distinct increases in mortality occur. The low mortality beds comprise a low disease zone with weighted prevalence of dermo generally well below 1.0 on the Mackin Scale. This low mortality zone generally experiences an estimated 5 to 12% annual mortality. Beds on which dermo intensities increase above a weighted prevalence of 1.5 experience annual mortalities of 15 to 20 %. These beds define the medium mortality zone. Once dermo levels exceed 2.0, average mortality increases to between 25 and 40%. Interestingly, beds in this third group segregate further into those with weighted prevalence between 2.0 and 2.5 and those with weighted prevalence 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 Bennies and Egg Island Points (Nantuxent, Hog Shoal, Hawk's Nest, Beadon's, Vexton and Egg Island). Reasons for this discrepancy are not clear and may relate to differences in transmission dynamics, physical conditions favoring dermo proliferation (e.g., temperature and salinity), differences in host resistance, differences in parasite virulence or some combination of these factors. Given our current limited understanding, the latter two factors seem less likely than either of the first two. A better understanding of these processes could enhance management strategies to increase oyster production and sustainability of the fishery.

Figure 13 does not show the variability associated with each point in order to demonstrate the mortality thresholds apparent at weighted prevalences of 1.5 and 2.0. Figure 14, on the other hand, shows the individual data points for each bed and each year sampled since 1990. The overall relationship between dermo weighted prevalence and mortality estimated by fall-survey box counts is highly significant and explains 35% of the variation in mortality (Figure 14A). Removing an outlier of 100% mortality on Egg Island from 2008 increases the r-square value to about 40%. This relationship suggests that for each integer increment in weighted prevalence, mortality will increase by about 9% (95% CI = 7.6 to 10.4) on average across the seedbeds. But when examined by bed region the relationship is not significant on the low mortality beds and only explains about 23% of the variability in mortality on the middle and lower beds, respectively (Figure 14B, C and D, not the outlier in Fig 14D dramatically reduces the r-square value). Dermo levels are too low to impact mortality on the low mortality beds. As a result, the long-term estimated mortality on the low mortality beds (Figure 14B) is not related to dermo levels (Figures 10B and 11B). On medium and high mortality beds the increased correlation between these variables indicates the increased influence of dermo on oyster survival in these bay regions. Dermo increases mortality above baseline levels of about 10% on medium mortality beds and above baseline levels of about 20% on high mortality beds. Note that using 20% as a definition of epizootic levels implies that eliminating dermo cannot prevent epizootic mortality on the high mortality beds. This observation further indicates that bed location and the inherent background level of mortality must be considered when designating what defines a disease-caused epizootic. Moreover, unless the oyster population age structure is significantly different among regions, then significantly greater recruitment is required to sustain downbay populations compared to upbay populations. Collectively, these data indicate that increased care is needed to manage these beds.

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Table 1. **2008 sampling schedule for long-term Dermo Monitoring Program.** Five long-term sites are Arnolds grid , Cohansey grid , Shell Rock grid , Bennies grid and New Beds grid . Three May sites are Middle, Bennies Sand and Ship John

Date	Samples	Vessel	Captain
Long-term Seed Bed Monitoring:			
Mar 18, 2008	5 long-term sites 2007 Transplant	RV Zephryus	Jason Hearon
Apr 18, 2008	5 long-term sites 2007 Transplants	RV Zephryus	Jason Hearon
May 18, 2008	5 long-term sites 3 May sites 2007 Transplants	RV Zephryus	Craig Tomlin
Jun 23, 2008	5 long-term sites 2007 Transplants	RV Zephryus	Jason Hearon
Jul 21, 2008	5 long-term sites 2007 Transplants 2008 transplants	RV Zephryus	Craig Tomlin
Aug 18, 2008	5 long-term sites 2007 Transplants 2008 transplants	RV Zephryus	Jason Hearon
Sep 22, 2008	5 long-term sites 2007 Transplants 2008 transplants	RV Zephryus	Craig Tomlin
Oct 20, 2008	5 long-term sites 2007 Transplants 2008 transplants	RV Zephryus	Craig Tomlin
Nov 14, 2008	5 long-term sites 2007 Transplants 2008 transplants	RV Zephryus	Craig Tomlin

Table 2. **2008 sampling schedule shell plant monitoring**

Date	Samples	Vessel	Captain
Apr, 9, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07 plants	RV First State	Mike Garvilla
May 5, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07 plants	RV First State	Mike Garvilla
Jun 9, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07 plants	RV First State	Mike Garvilla
Jul 8, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07 plants	RV First State	Mike Garvilla
Aug 4, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07 plants	RV First State	Mike Garvilla
Sep 8, 2008	NJ 06&07 plants	RV Zephyrus	Jason Hearon
	DE 06&07&08 plants	RV First State	Mike Garvilla
Sep 22, 2008	NJ 08 shell plants	RV Zephyrus	Craig Tomlin
Oct 6, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07&08 plants	RV First State	Mike Garvilla
Nov 3, 2008	NJ 06&07 plants	RV Zephyrus	Craig Tomlin
	DE 06&07&08 plants	RV First State	Mike Garvilla
Nov 14, 2008	NJ 08 shell plants	RV Zephyrus	Craig Tomlin

Table 3. Shell plant and transplant sites sampled during 2008. DE = State of Delaware beds. Replant = shell planted in lower Delaware Bay then moved to bed indicated after spat have recruited.

Bed	Grid	Plant material	Plant yr
Hawks Nest	1	surf clam 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	Up. Middle & Middle oysters	2006
Shell Rock	90	Arnolds oysters	2006
Nantuxent	28	ocean quahog shell	2007
Ship John	22	ocean quahog shell	2007
Ship John	48	ocean quahog shell	2007
Ship John	50	ocean quahog shell	2007
Over the Bar	DE	ocean quahog shell	2007
Ridge	DE	ocean quahog shell	2007
Silver Bed (SE)	DE	ocean quahog shell	2007
Lower Middle (S)	DE	ocean quahog shell	2007
Middle	34	ocean quahog shell & surf clam replant	2007
Ship John	53	surf clam replant	2007
Cohansey	59	surf clam replant	2007
Nantuxent	15&16	Middle oysters	2007
Bennies Sand	13	Middle oysters	2008
Cohansey	43	Arnolds oysters	2008
Cohansey	64	surf clam replant	2008
Bennies Sand	8	ocean quahog shell	2008
Bennies Sand	9	ocean quahog shell	2008
Nantuxent	17	ocean quahog shell	2008
Nantuxent	68	ocean quahog shell	2008
Ridge	DE	ocean quahog shell	2008
Lower Middle	DE	ocean quahog shell	2008
Over the Bar	DE	ocean quahog shell	2008
Over the Bar (North)	DE	ocean quahog shell	2008

Table 4. Record of collections for annual Fall dermo monitoring since 1990. X indicates bed was sampled in respective year for that column. Beds are listed more or less by latitude, although some lie at the same latitude with different longitudes.

SEED BED	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Hope Creek																		X	X
Liston Range																			X
Fishing Creek																			X
Round Island	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Upper Arnolds														X		X	X	X	X
Arnolds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Middle																	X	X	X
Middle	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X
Cohansey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sea Breeze															X	X	X	X	X
Ship John	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X	X
Shell Rock	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bennies Sand	X	X	X	X	X			X	X	X	X	X	X		X	X	X	X	X
Bennies	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nantuxent		X		X		X		X		X	X	X		X		X	X	X	X
Hog Shoal		X		X						X		X	X	X	X	X	X	X	X
New Beds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Strawberry	X		X		X								X	X	X	X	X	X	X
Hawks Nest	X		X		X		X		X		X		X	X	X	X	X	X	X
Beadons	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vexton										X		X	X	X	X	X	X	X	X
Egg Island	X	X	X	X	X	X	X	X		X	X	X		X		X		X	
Ledge Bed			X		X				X		X		X		X		X		X

Table 5. 2008 Delaware Bay Oyster Seedbed Stock Assessment Survey grids sampled for dermo, MSX, condition index (CI) and size frequencies. Numbers represent grid ID or oysters processed.

Bed	Grid	Dermo	MSX	CI
Hope Creek	35	10	10	15
Hope Creek	52			10
Hope Creek	62	10	10	15
Hope Creek	76			10
Fishing Creek	4	10		15
Fishing Creek	11			10
Fishing Creek	16			10
Fishing Creek	25	10		15
Liston Range	14	10		15
Liston Range	17			17
Liston Range	21			2
Liston Range	23	10		16
Round Island	5			10
Round Island	12	10		15
Round Island	68	10		15
Round Island	73			10
Upper Arnolds	4	10		10
Upper Arnolds	10			12
Upper Arnolds	12			13
Upper Arnolds	13	10		15
Arnolds	3			10
Arnolds	16			10
Arnolds	18	10	10	15
Arnolds	73	10	10	15
Upper Middle	56	10		15
Upper Middle	58	10		20
Upper Middle	63			15
Middle	20	10		15
Middle	29			10
Middle	31			10
Middle	43	10		15
Cohansey	58	10	10	15
Cohansey	44	10	10	15
Sea Breeze	16	10		15
Sea Breeze	18			12
Sea Breeze	35			8
Sea Breeze	38	10		15
Ship John	13	7		7
Ship John	18	3		15
Ship John	28			13
Ship John	39	10		15
Shell Rock	7			11
Shell Rock	10	10	10	14
Shell Rock	15	10	10	15
Shell Rock	35			10
Bennies Sand	3			10
Bennies Sand	44	10		15
Bennies Sand	10	10		15
Bennies Sand	21			10
Bennies	141			13
Bennies	43			11
Bennies	152	10	10	11
Bennies	124	10	10	15
Nantuxent	18			10
Nantuxent	20	10		15
Nantuxent	22			10
Nantuxent	10	10		15
Hog Shoal	1	10		15
Hog Shoal	4			10
Hog Shoal	12			8
Hog Shoal	16	7		7
Hog Shoal	18	3		10
New Beds	17			11
New Beds	27	10	10	15
New Beds	37			12
New Beds	39	10	10	12
Strawberry	24	10		17
Strawberry	5	10		17
Strawberry	11			16
Hawks Nest	9	10		15
Hawks Nest	14			10
Hawks Nest	5			10
Hawks Nest	27	10		15
Beadons	4			12
Beadons	7	7		7
Beadons	10	3		8
Beadons	16	10		13
Beadons	22			10
Vexton	10			15
Vexton	11			14
Vexton	13	11		12
Vexton	16	9		9
Ledge	8	2		2
Ledge	22	6		6
Total beds	**22**	**22**	**6**	**22**
Total grids	**84**	**47**	**12**	**84**
Total samples		**428**	**120**	**1038**

Table 6. Results of Cape Shore challenge trial comparing oysters from Hope Creek and Shell Rock. WP = weighted prevalence.

	Hope Creek		**Shell Rock**	
Dermo	Prevalence	WP	Prevalence	WP
8-Mar	0%	0	15%	0.08
8-Aug	100%	2.78	100%	4.28
8-Oct	100%	4.08	100%	3.9
MSX	Prevalence	WP	Prevalence	WP
8-Aug	25%	0.4	6%	0.1
8-Oct	10%	0.1	5%	0.1

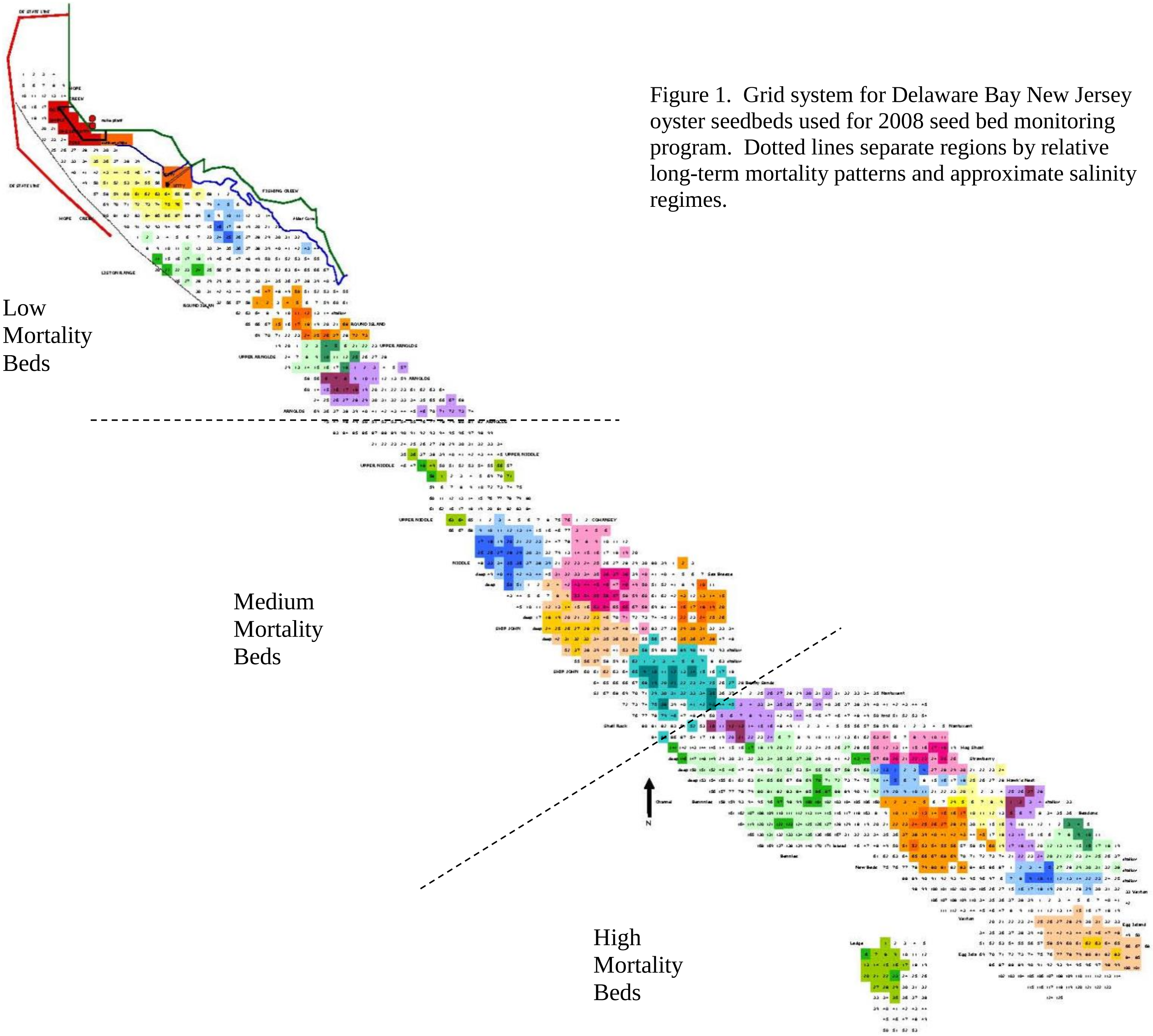


Figure 1. Grid system for Delaware Bay New Jersey oyster seedbeds used for 2008 seed bed monitoring program. Dotted lines separate regions by relative long-term mortality patterns and approximate salinity regimes.

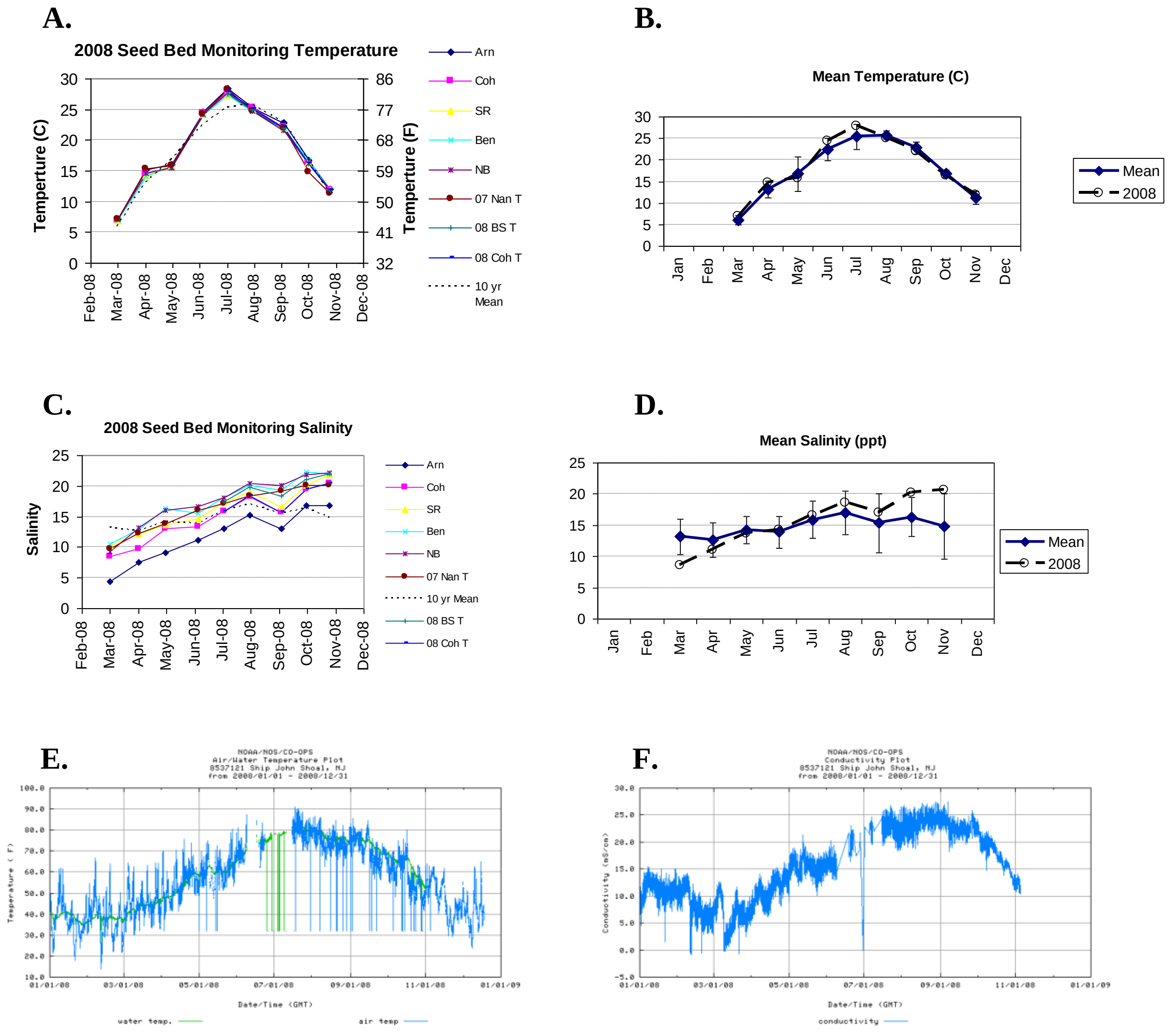
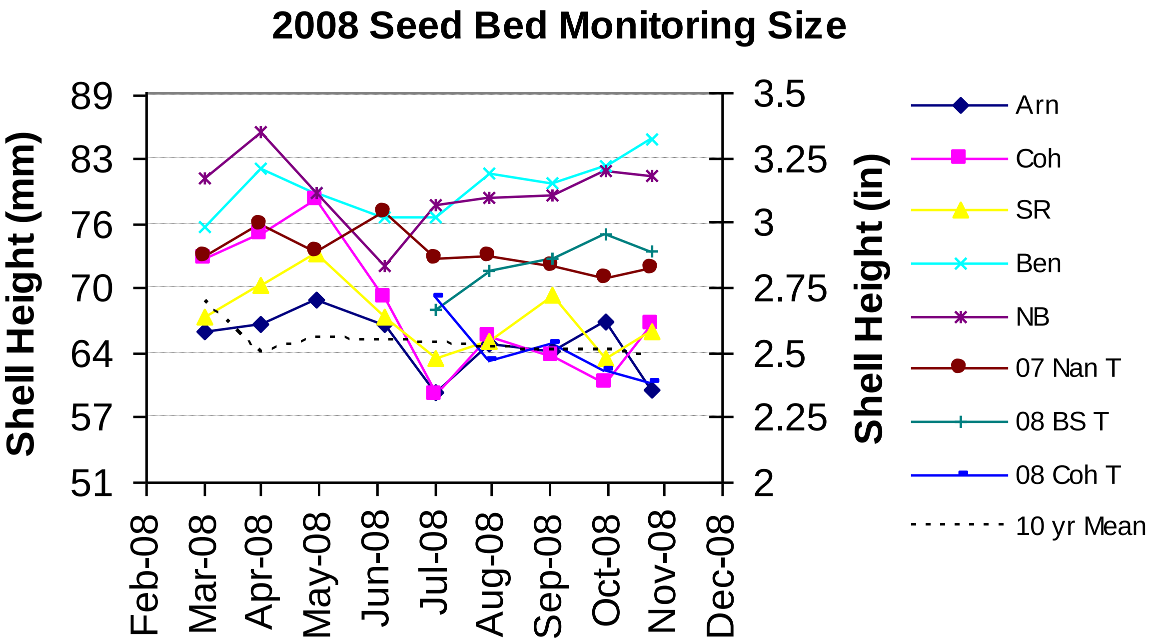


Figure 2. Monthly bottom water temperature and salinity measurements taken during seedbed monitoring at long-term stations and at a continuous monitoring station at the Ship John Shoal Light. A) 2008 temperatures for each bed. B) 2008 mean temperature across beds and mean temperature across beds since 2002. C) 2008 salinity for each bed. D) 2008 mean salinity across beds and mean temperature across beds since 2002. E) Continuously monitored temperature at Ship John Shoal Light during 2008. F) Continuously monitored conductivity (a surrogate for salinity) at Ship John Shoal Light during 2008. Ship John Shoal Light monitoring data are publicly available in near real-time and archival data http://tidesandcurrents.noaa.gov/.

A.



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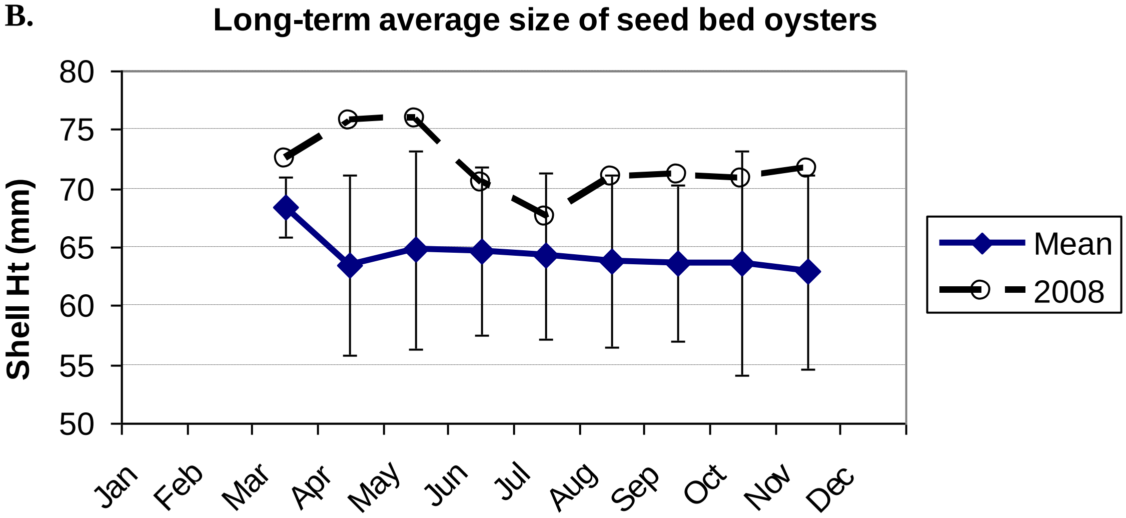


Figure 3. Mean size of oysters collected from Delaware Bay NJ oyster seedbeds. A) Mean size by bed. B) Mean size across beds for 2008 compared to the past 9 years.

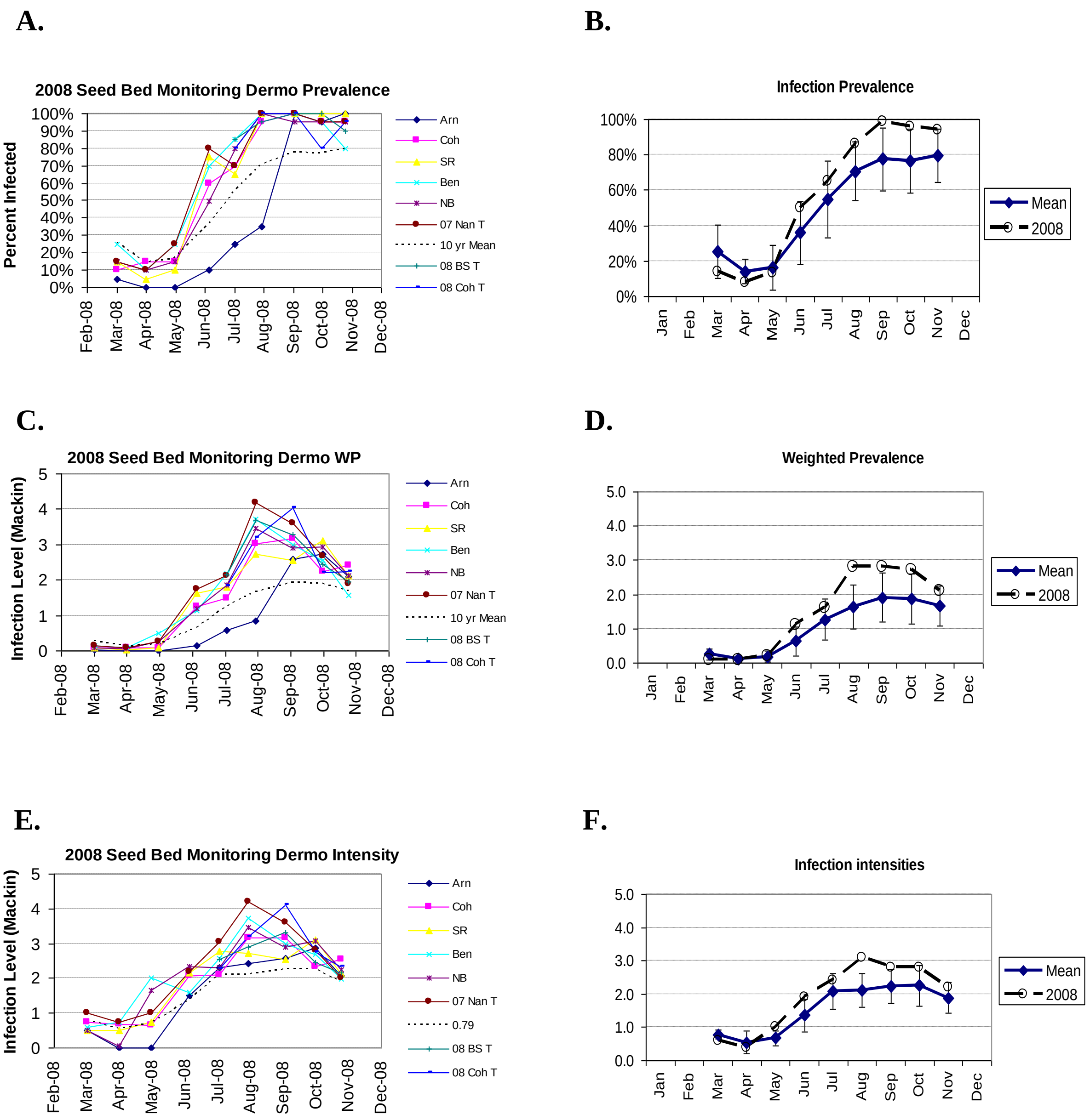


Figure 4. Monthly measures of dermo disease in oysters from New Jersey Delaware Bay seedbeds during 2008. Prevalence = percent of infected oysters. Weight prevalence (WP) = the average Mackin scale dermo infection intensity rank of all oysters sampled including those with no detectable infection (i.e., rank = zero). Intensity = average Mackin rank of detectable infections only.

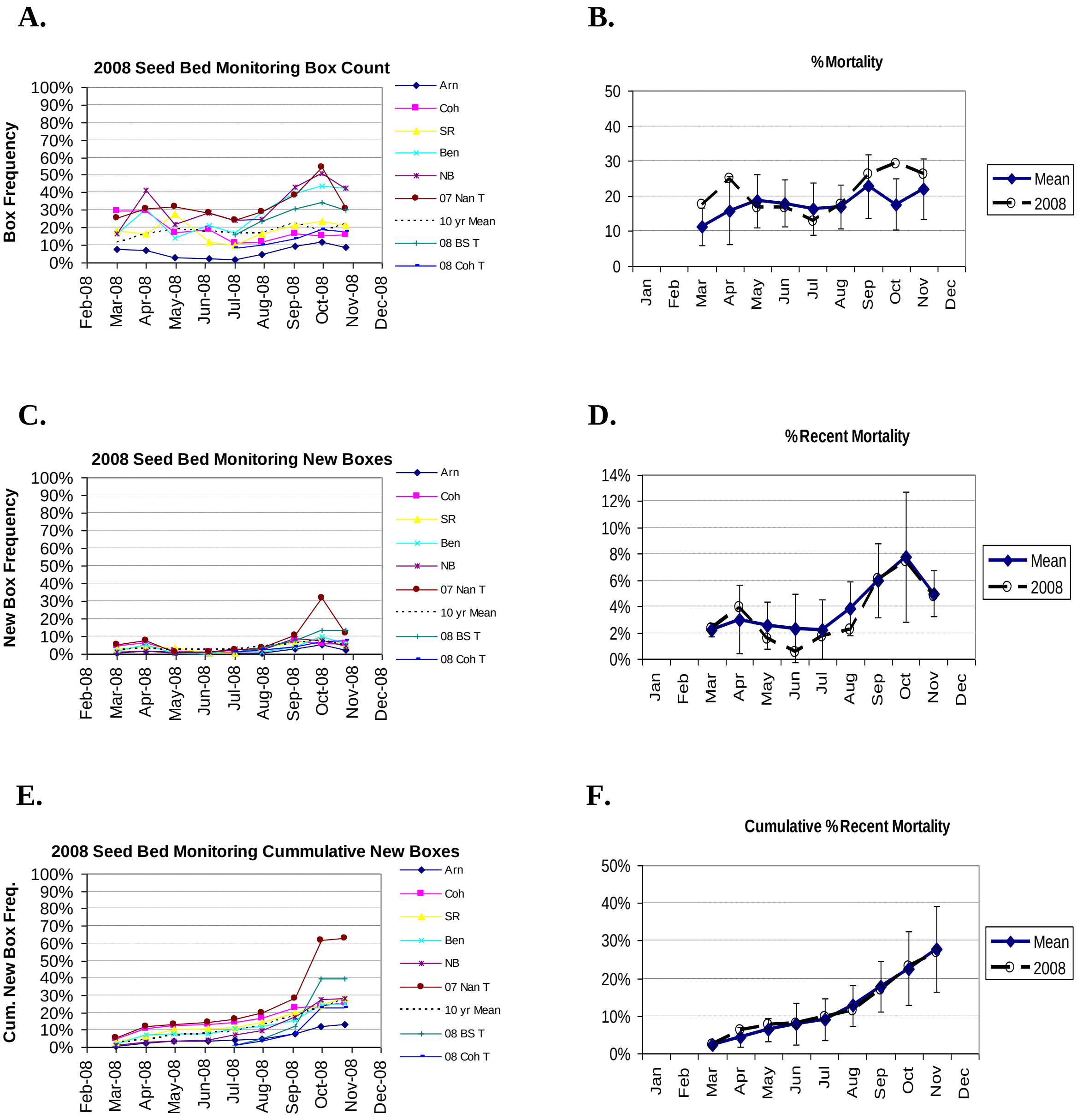


Figure 5. Monthly estimates of oyster mortality on the New Jersey Delaware Bay seedbeds. Left panels show mortality by bed. Right panels compare mortality for 2008 from five long-term beds with mean and standard deviation since 1999.

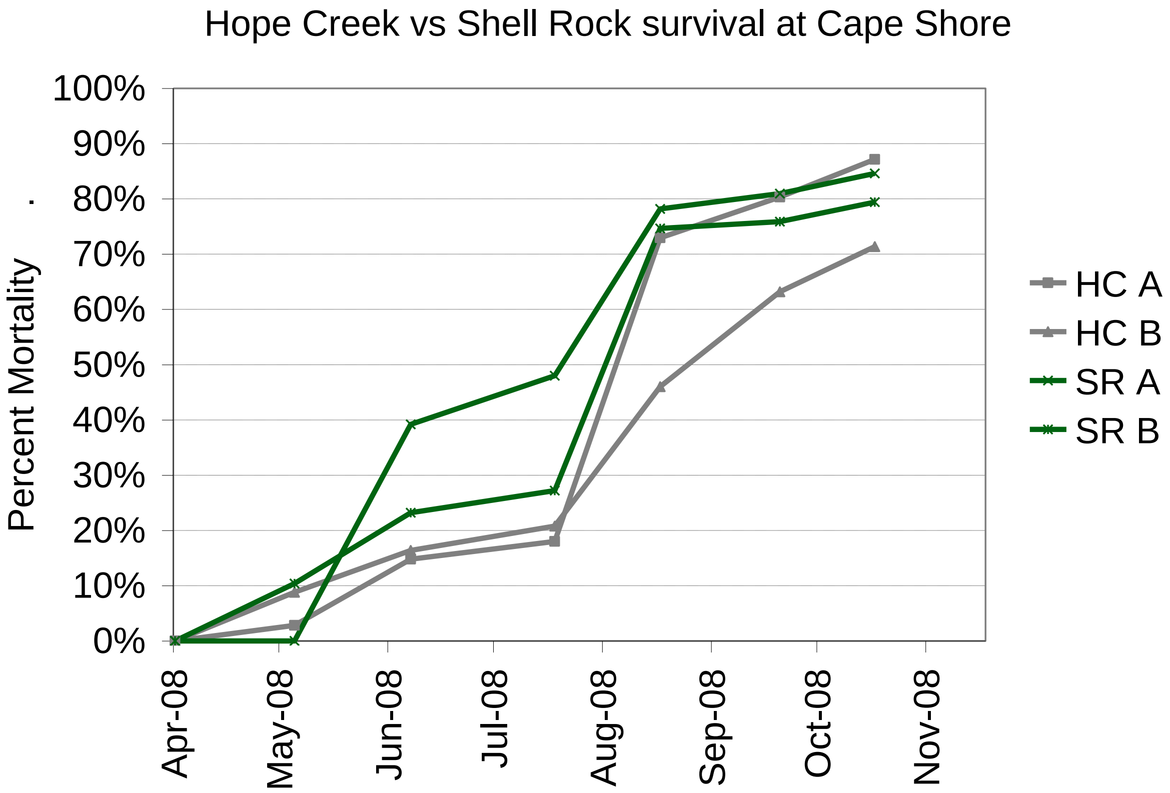
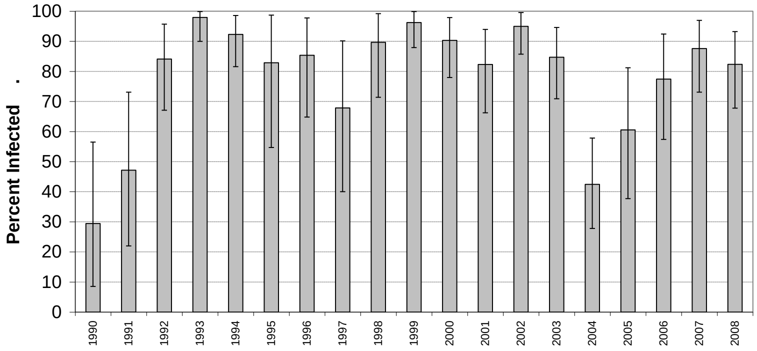
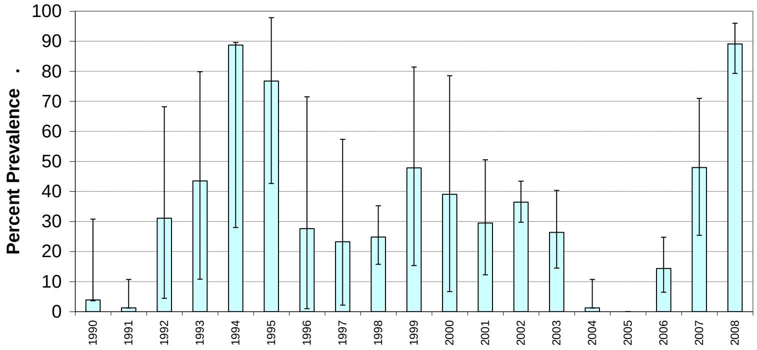


Figure 6. Survival of oysters collected from Hope Creek (HC) and Shell Rock (SR) held in bags on racks at the Cape Shore flats.

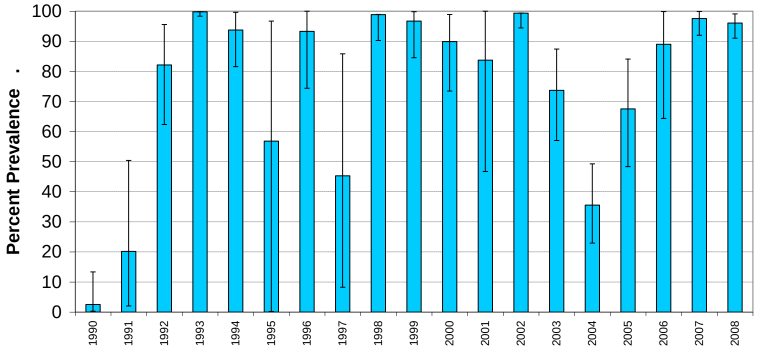
Annual Dermo Prevalence: All Seed Beds



Dermo Prevalence Low Mortality Seed Beds



Dermo Prevalence Medium Mortality Seed Beds



Dermo Prevalence High Mortality Seed Beds

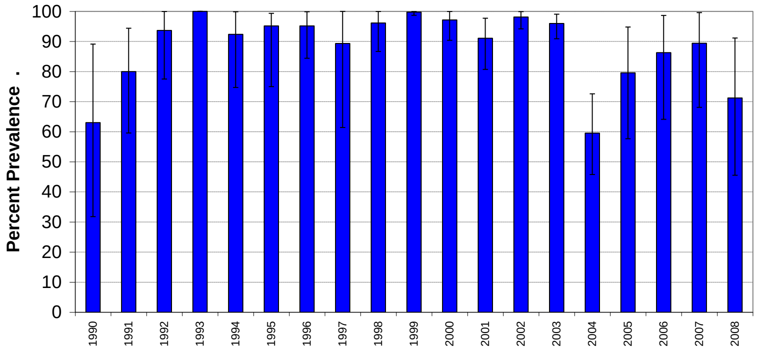
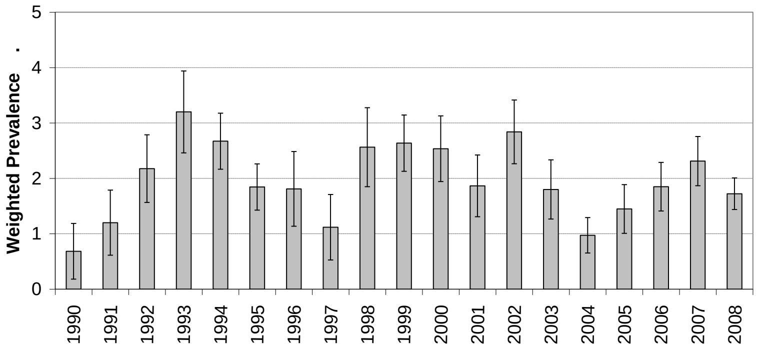
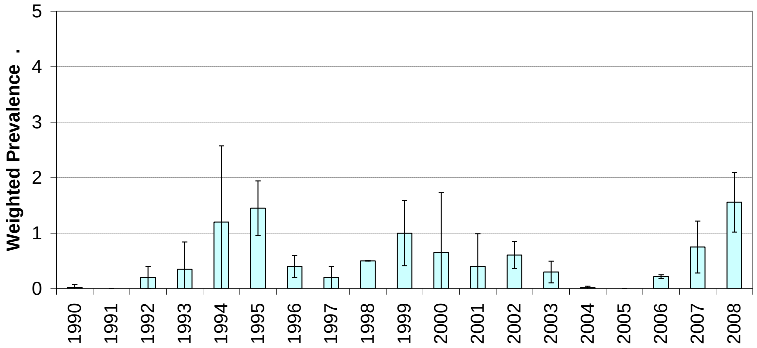


Figure 7. Annual mean fall dermo prevalence on New Jersey Delaware Bay seedbeds.

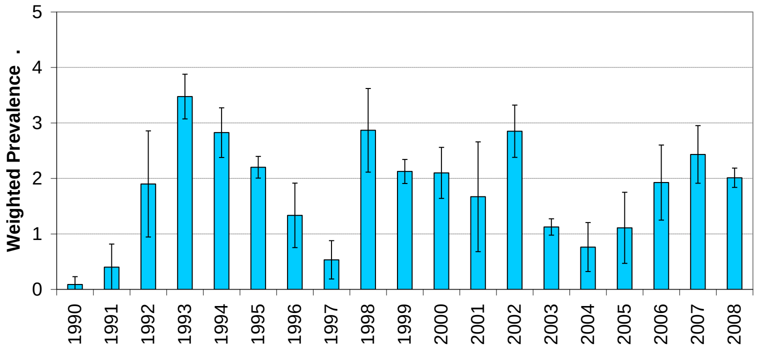
Fall WP Across All Seed Beds



Fall WP on Low Mortality Seed Beds



Fall WP on Medium Mortality Seed Beds



Fall WP on High Mortality Seed Beds

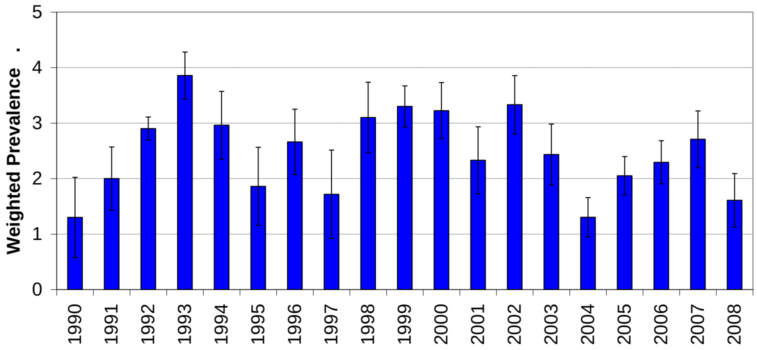
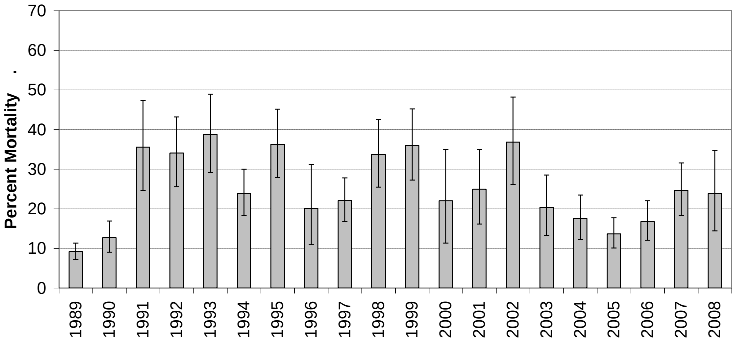
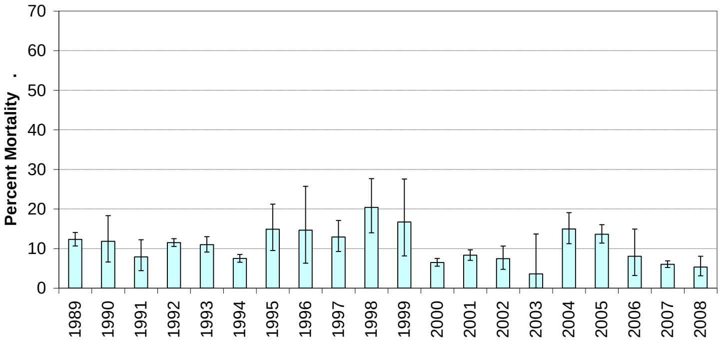


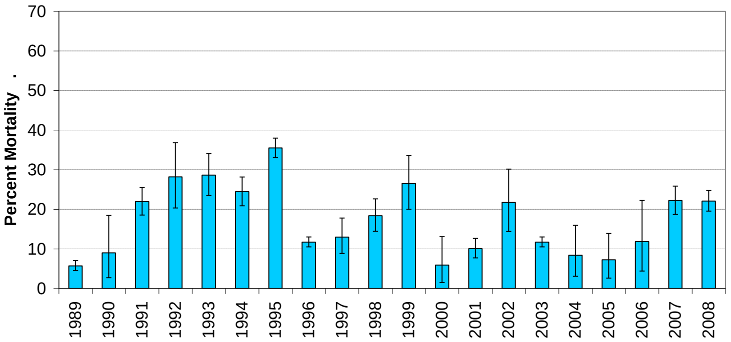
Figure 8. Annual mean fall dermo weighted prevalence on New Jersey Delaware Bay seedbeds.



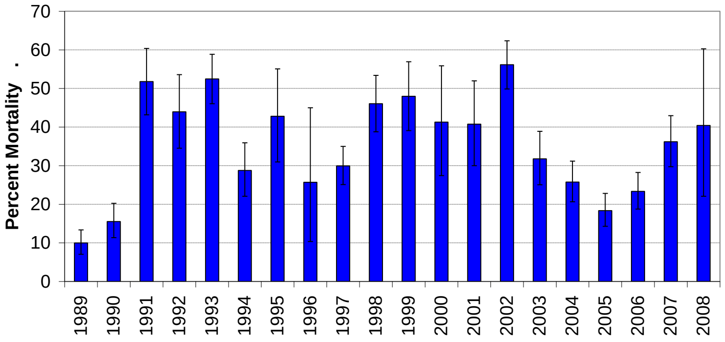
Annual Fall Seed Bed Mortality: All Beds



Mortality on Low Mortality Seed Beds



Mortality on Medium Mortality Seed Beds



Mortality on High Mortalty Seed Beds

Figure 9. Annual mean fall box-count estimated mortality on New Jersey Delaware Bay Seedbeds.

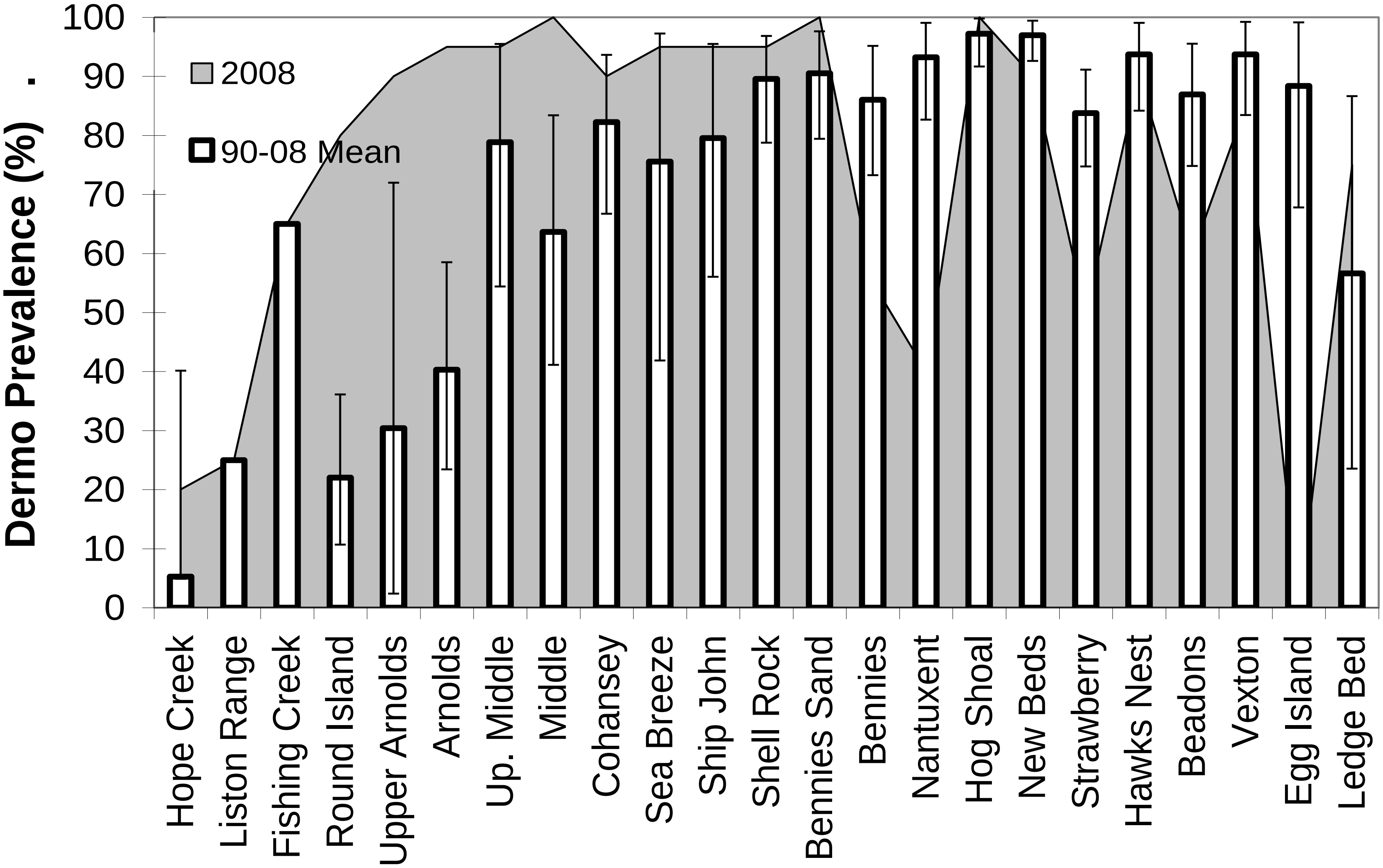


Figure 10. Comparison of average fall *Perkinsus marinus* (dermo) prevalence in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2008 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2008.

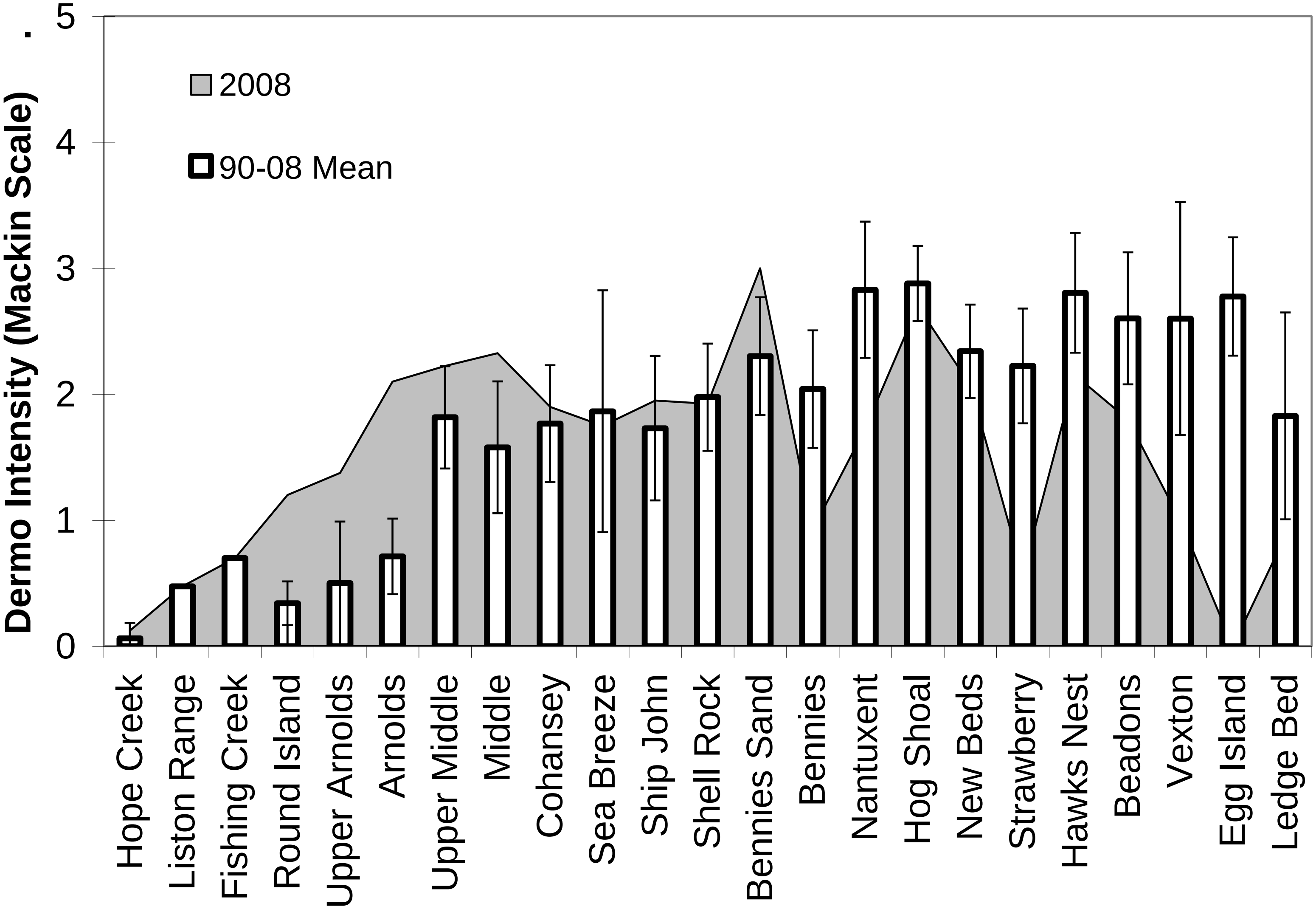


Figure 11. Comparison of average fall dermo infection intensities (weighted prevalence) in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2008 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2008.

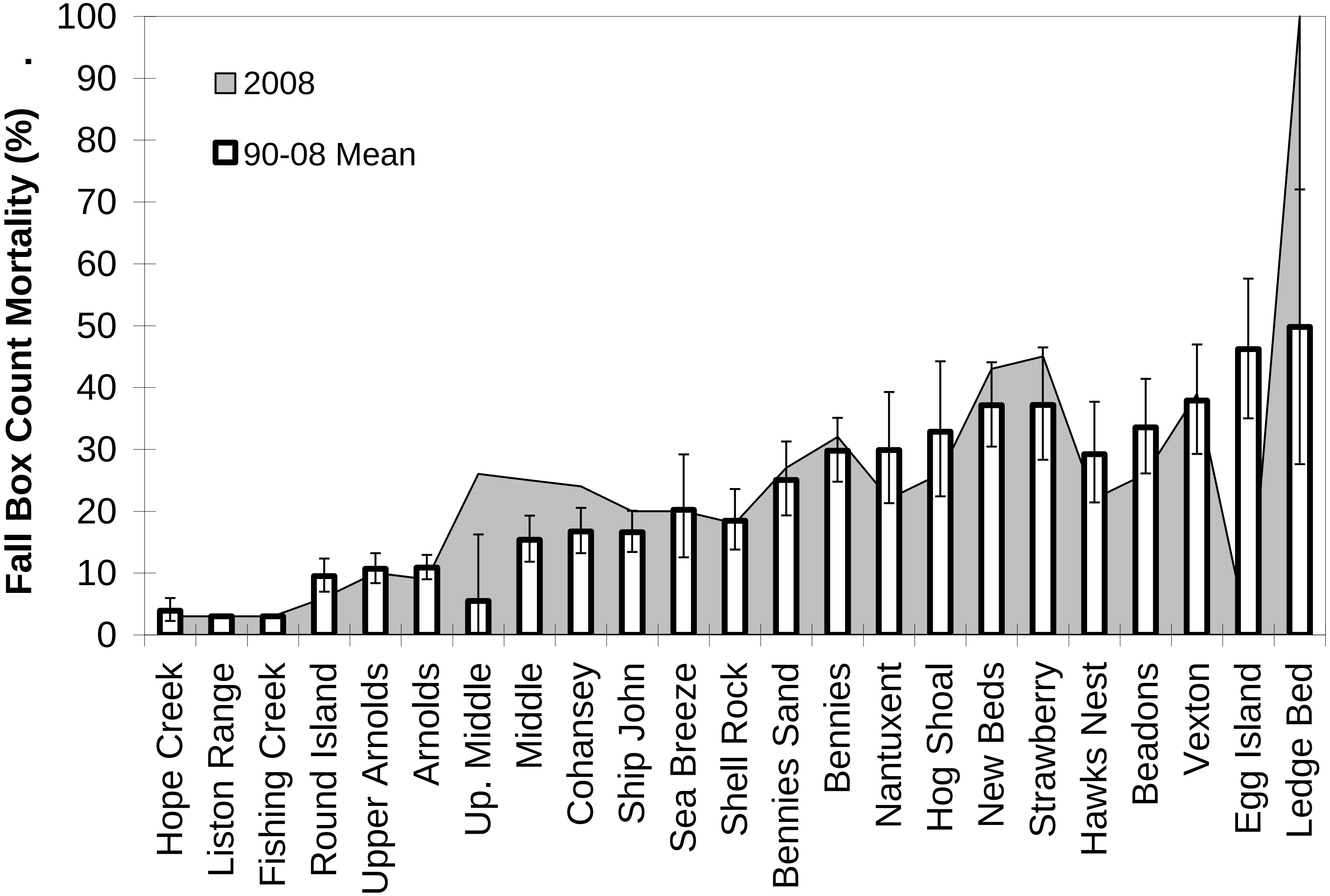


Figure 12. Comparison of average annual fall estimated box-count mortality of oysters on New Jersey Delaware Bay seedbeds since 1989 (open bars with 95% confidence intervals) with 2008 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2008.

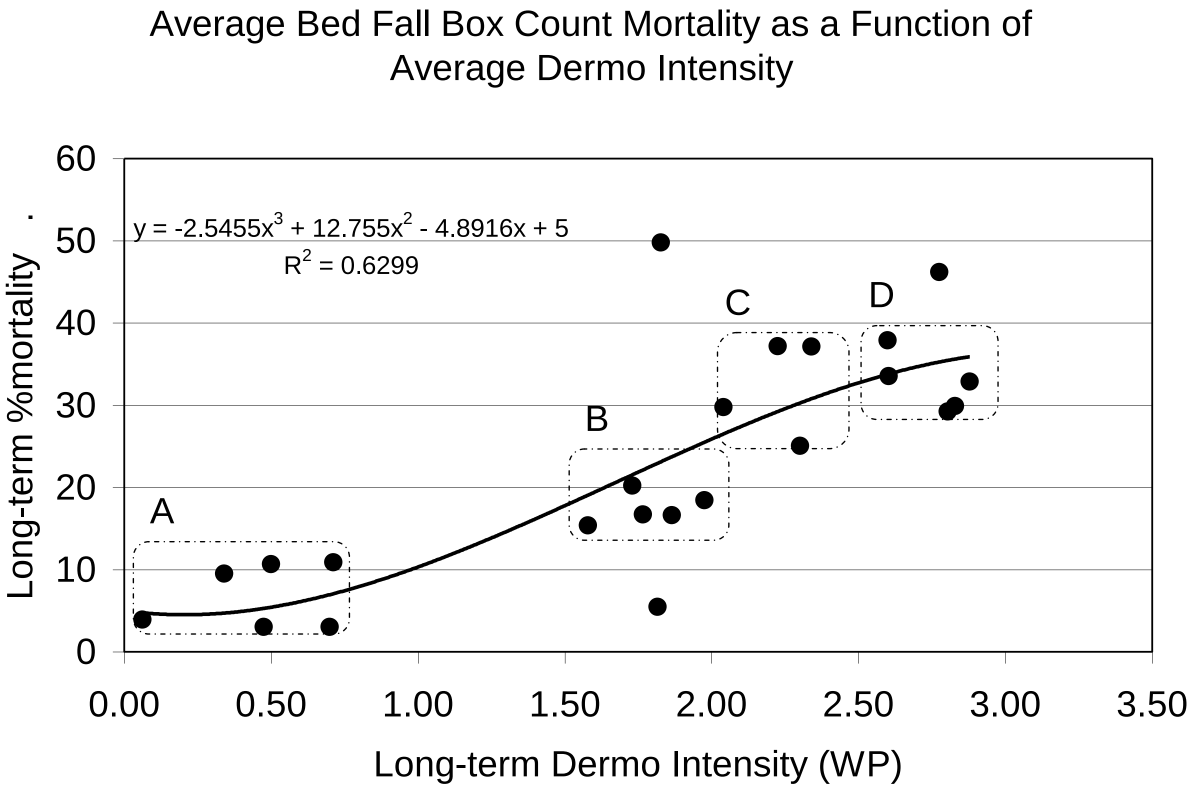


Figure 13. Relationship between long-term mean percent fall box count mortality estimate and the long-term mean intensity of dermo infections since 1990. Data are individual bed estimates. Error bars are not shown for clarity. The relationship is not linear and indicates a thresholds for dermo-caused mortality at weighted prevalences of about 1.5 and 2 on the standard 0 to 5 Mackin Rank scale. Boxes labeled A through D represent clusters of beds in distinct regions and fall along the x-axis as follows: A) Hope Creek, Round Island, Liston Range, Upper Arnolds, Fishing Creek and Arnolds; B) Middle, Ship John, Cohansey, Sea Breeze, and Shell Rock; C) Bennies, Strawberry, Bennies, Sand and New Beds; D) Vexton, Beadons, Hawks Nest, Nantuxent and Hog Shoal. Upper middle (5% mortality), Ledge (50% mortality) and Egg Island (48%) mortality represent outliers largely resulting from inconsistent sampling over the time series. The trend line is a third order polynomial forced through a 5% mortality representing the average mortality on the upper seed beds encompassed by box A.

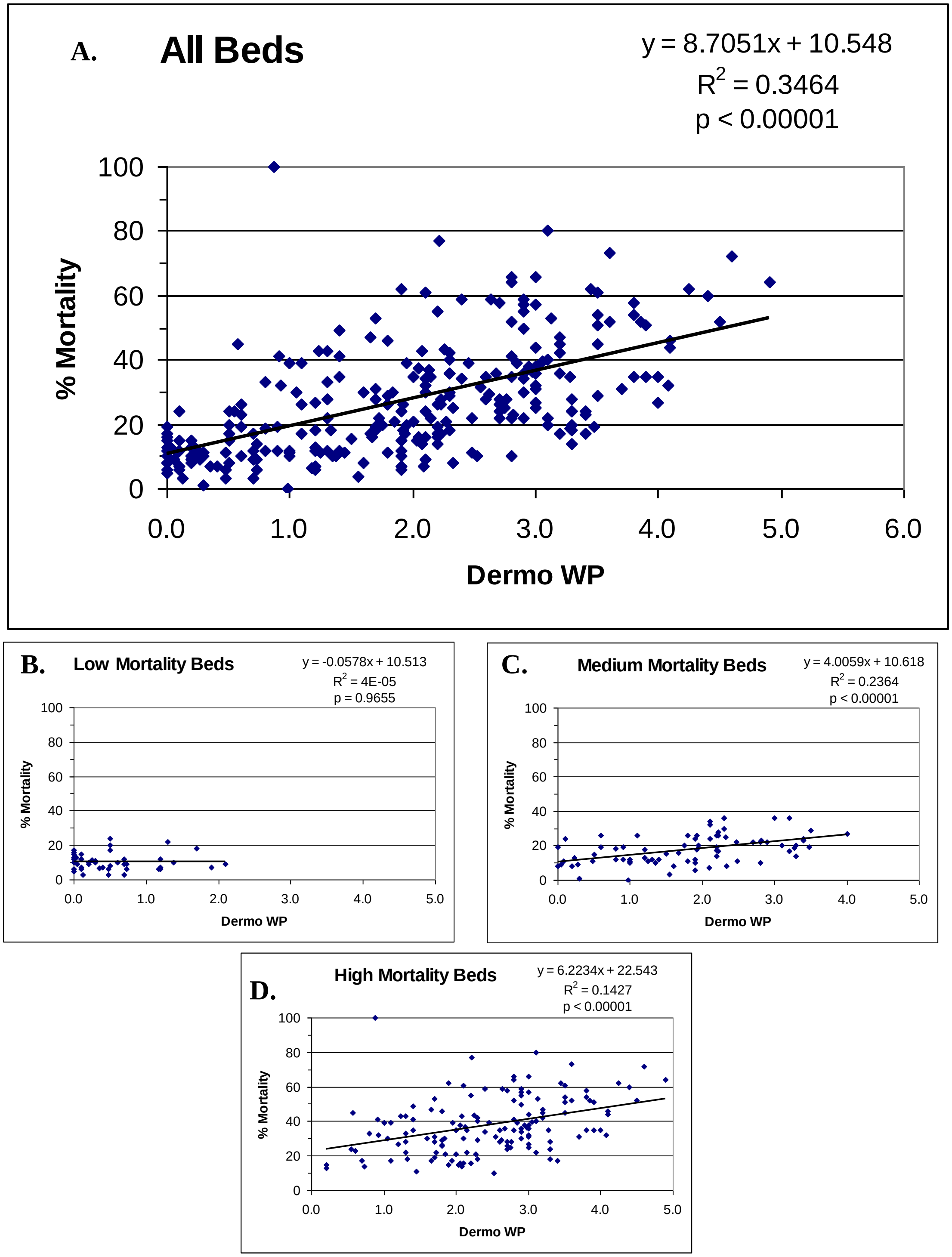


Figure 14. Relationships between fall box count mortality and dermo infection levels (WP). Data are values for individual beds from 1990 to 2008.