Delaware Bay New Jersey Oyster Seedbed Monitoring Program 2007 Status Report

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Executive Summary:

During 2007 the Seedbed Monitoring Program followed disease, growth, and mortality at five long-term monitoring sites, three transplant sites, 21 direct shellplant sites and 6 replant sites. Size distributions of oysters continue to remain skewed towards larger animals. This will likely continue until a good recruitment event survives well enough to add a sizeable fraction of smaller animals to the population. Warm temperatures and elevated salinity for extended periods during key times of the year contributed to elevated levels of dermo and subsequent mortality, a trend that began after a low in 2004. MSX was detected, but remained a relatively insignificant factor in disease mortality. Accumulating data on intermediate transplant performance (oysters transplanted from upper bay seedbeds to direct market seedbeds) indicate that higher disease and mortality occur on transplant sites compared to nearby non-transplant sites. A more rigorous evaluation of this practice is necessary to fully evaluate its impacts on both donor and recipient beds. Spat and oysters on direct shell plants and replants (spat captured from the lower bay then replanted on the seedbeds) are performing well and support continued investment in these management strategies.

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 interannual patterns as well as long-term trends. 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 and is presumably related to a natural range extension of *P. marinus* following a regional warming trend (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. Fresh water inputs from several tributaries (Hope Creek, Stow Creek, Cohansey River, Back Creek, Cedar Creek and Nantuxent Creek) combine with the geomorphologic configuration of the coves to influence salinity, nutrients, food supply, circulation and flushing in ways that are not completely defined, and all of which interact to influence the spatial and temporal prevalence and intensity of disease and mortality on the seedbeds. Area management strategies currently follow the mortality designations and have recently managed Shell Rock independently. 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 (oyster moved from upper seedbeds to lower seedbeds), shell plants (shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (cultch planted in the lower bay high set zone near the Cape Shore then moved and replanted on the seed beds). The 2007 objectives for the Seedbed Monitoring Program were:

1. Continue the standard seedbed monitoring time series March – November 2007, including 2006 and 2007 transplant sites
2. Conduct dermo and MSX assays and determine condition indices for Fall 2007 Stock Assessment Random Sampling survey
3. Monitor growth, mortality and disease on 2005 shell plant and replant sites from April – November 2007
4. Monitor growth and mortality on 2006 shell plant, and replant sites from April – November 2007, disease beginning in July 2007
5. Examine growth and mortality on 2007 shell plant and replant sites in September and November 2007

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. Objectives 3-5 are part of a joint effort between New Jersey and Delaware supported by the Army Corps of Engineers to enhance recruitment on the seedbeds. Objectives 1 and 2 provide essential baseline/background information against which the success of objectives 3, 4, and 5 can be judged.

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 performed histology for MSX and Dr. Susan Ford provided helpful advice throughout.

Methods

Figure 1 is a map of the grid system in use at the start of the 2007 season to manage the New Jersey oyster seedbeds in Delaware Bay. Beds on the Delaware side of the bay that are referenced elsewhere in this report are not shown, nor are new grids added during 2007 around New Beds, the low mortality beds, or the newly surveyed bed called Hope Creek. The grid system is nearly contiguous, but the 20 areas differentiated by shading are referenced by historical names traditionally used by the industry and resource managers (see Table 2). 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. Monitoring stations, shell plants, replants and transplants are indicated on Figure 1. Shell plants are locations where shell (dredged oyster shell, surf clam or ocean quahog) was planted directly; replants are sites where surf clam shell was first planted down bay to collect spat, then moved to the site indicated; transplants are sites that received oysters moved from upper to lower beds.

Samples were collected monthly from March through November to complete objective 1 (Table 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 oysters sacrificed for dermo assays (N = 140 per month from five monitoring stations and two transplant sites).

Objective 2 was completed in coordination with the annual fall seedbed stock assessment survey. Samples were collected as described for monthly samples, except that samples were collected from multiple grids within each bed using the commercial oyster boat H. W. Sockwell and then processed to determine condition indices, dermo disease levels and MSX disease levels as indicated in Table 2. Dermo was diagnosed as described above. MSX was diagnosed using standard histology (Howard et al. 2004).

To complete objectives 3-5, samples were collected monthly from March through November (Table 1). Table 3 lists the locations and types of plantings sampled during 2007. Note that some plantings from 2005 were not monitored because efforts to find planted material were unsuccessful or it was not possible to distinguish planted Maryland dredged oyster shell from native shell. Samples were collected from up to three 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 samples contained fewer than 100 oysters. Care was taken to search systematically and avoid sampling bias by working systematically through until 100 live spat or oysters were collected. Boxes were enumerated, categorized as new or old as described above, and then returned to the bed with the remainder of the dredge haul. Live oysters attached to planted shell were returned to the laboratory for size measurements (up to 100 per site) and dermo analyses (n = 20 per site).

Results and Discussion

Water temperatures measured during 2006 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 late Spring/early Summer (May-July) and early Fall (September and October) (Figure 2B). As a result, the period when temperatures were near or above 20 C was longer than the recent average. 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 the Ship John Shoal Light, 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 favored females across the seed beds during this period (48% female, 38% male and 14% indeterminate). As indicated in Figure 2, temperatures that are generally considered warm enough to trigger spawning (25ºC = 77ºF) were reached by late June and were maintained into September. Salinity also remained relatively high 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 2007.

Mean shell height of oysters fluctuated slightly around a relatively constant bed-specific size throughout the summer of 2007 (Figure 4A). A comparison of the average size across all seedbeds during 2007 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 mean shell height (hinge to bill) of oysters across the seed beds during 2007 was 70.4 mm (± 17.2) with a median value of 70.7 (= 2 ¾ inches). By comparison, the overall mean since 2000 is much smaller and on the order of 62.5 mm (2 ½ inches). The larger mean and median sizes for 2007 are partly attributed to greater fractions of larger oysters on Cohansey and Arnolds as a result of poor recruitment for 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. Monthly plots of size frequency (Figure 4) reveal such shifts in the populations sampled. These plots are interpreted with some caution regarding recruitment, however, because mesh size on the sampling dredge and increased difficulty in detecting spat relative to large oysters when sorting the catch on deck will lead to a bias toward larger oysters. Nevertheless, several of these plots appear to have detected growth of a 2006 cohort into the population early in the year, and recruitment of a 2007 cohort into the population later in the year. If these cohorts continue to survive, the mean size of oysters is likely to decrease next year in areas where high recruitment occurred. Such a decrease in size may be compounded by mortality of larger oysters if they succumb to elevated dermo levels reported below. Of course some of this will be offset by growth of the oysters.

Dermo prevalence, weighted prevalence (WP) and intensity followed typical seasonal and spatial patterns across the seedbeds (Figure 5 A, C and D). That is, all three 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 during spring (Figure 5B, D and F). By July the average intensity of detectable infections had increased above long-term means (Figure 5F), and both weighted prevalence and prevalence followed suit in August (Figure 5B and D). These three measures remained above average at least until November when sampling stopped. By August, all beds except Arnolds had dermo levels that were expected to begin causing noticeable mortality (i.e., WP > 2.0).

Total box counts from monthly samples (Figure 6A and B), 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. Lowest box counts were on Arnolds (< 5%), while levels ranging from 20 to 37% occurred across the other beds. 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 and by November was Arnolds < Shell Rock < Bennies < Cohansey < New Beds. The fluctuations in box count data is noteworthy because the stock assessment uses values obtained in October. 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 2007 mortality occurred from July to September (Figure 6C and D) and followed increases in dermo disease (Figure 5). Cumulative recent mortality estimates for 2007 indicate greater mortality occurred than estimated by total box counts (Figure 6 C and E). This discrepancy 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 2007.

Figure 7 presents and contrasts data from transplant sites. Transplants are used as a mechanism to move oysters from beds closed to direct marketing onto beds open to the direct market program. Transplanted oysters usually experience a burst in growth and quickly become integrated into the existing population making them difficult to distinguish from oysters already present on site. Grids 44 and 90 on Shell Rock received oysters from Upper Middle and Middle or Arnolds, respectively, in 2006. Nantuxent grids 15 and 16 received oysters from Middle in

2007. The Shell Rock grids receiving the 2006 transplants experienced greater dermo disease and mortality compared to the standard Shell Rock monitoring grid. Dermo disease in oysters sampled from the Nantuxent grid which received oysters from Middle in June 2007 began with relatively low disease levels that rose quickly to levels representative of nearby sampling stations (see New Beds and Bennies, Figure 5). Mortality followed a similar pattern. Accumulating data from monitoring transplant sites suggests that oysters arrive with lower levels of disease, but infections increase quickly and may subsequently exceed local levels ultimately resulting in greater mortality. A more rigorous evaluation of the positive and negative impacts of this practice on donor and recipient beds as well as to the overall oyster population abundance is warranted.

The stratified random sampling stock assessment survey (aka RanSam) was conducted in late October and November with disease sample processing completed by the end of December. Details of dermo and mortality are presented below. Condition indices and size frequencies are 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 stations along the up to down bay gradient were examined (Table 2). Prevalence was 10% on Cohansey and Shell Rock, 20% on Egg Island and undetected elsewhere. No systemic infections were observed. An unplanned January 2008 collection of oysters from two sites on the Tonger's Beds in the mouth of the Maurice River, which is located below the seedbeds, indicated an overall prevalence of 28% most of which occurred at the site which was further offshore (9 of 19 versus 2 of 20 oysters sampled). Spores were also observed in several of these oysters. Naïve oysters deployed at the Cape Shore in the lower bay experienced heavy MSX as well as dermo. These observations continue to indicate that MSX is present throughout much of the bay.

Figures 8, 9 and 10 depict annual fall dermo prevalence, dermo infection intensity (= weighted prevalence) and Fall box-count estimated mortality from 1989 to 2007 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 in 2007 continued an increasing trend that began from a low in 2004 and is indicative of 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). 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 year periodicity indicates that dermo may be reaching a peak. Assuming that the reportedly high recruitment of spat survives well, then *the mean* dermo measures will likely decrease in 2008 as younger, uninfected or lightly infected oysters are collected in samples. Older oysters that are presently infected, are likely to develop relatively heavier infections in 2008 and may die such that box counts may actually increase in the coming year, as suggested by the one-year lag between infection levels and mortality (Figures 8-10).

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 all three parameters exceeded long-term means on most beds during 2007 except those at the extremes of the range. A plot of long-term mean fall box-count mortality estimates against long-term mean dermo infection intensities (Figure 14), shows 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. Round Island, Upper Arnolds and Arnolds comprise a low disease, low mortality zone with weighted prevalence of dermo generally well below 1.0 on the Mackin Scale. Hope Creek, added this year, had no detectable dermo infections. 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 50%. 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 14 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 15, 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 40% of the variation in mortality (Figure 15A). 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 23 and 22 percent of the variability in mortality on the middle and lower beds, respectively (Figure 15B, C and D). 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 13B) is not related to dermo levels (Figures 11B and 12B). 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. **2007 sampling dates and vessels used for Seed Bed Monitoring Program**

Date	Samples	Vessel	Captain
Long-term Seed Bed Monitoring:			
Mar 21, 2007	5 long-term sites	Oyster Boat John McVey	Mike McVey
Apr 23, 2007	5 long-term sites 2006 Transplants	RV East Point	Jason Hearon
May 21, 2007	5 long-term sites 3 May sites 2006 Transplants	RV East Point	Jason Hearon
Jun 18, 2007	5 long-term sites 2006 Transplants	RV East Point	Jason Hearon
Jul 30, 2007	5 long-term sites 2006 Transplants 2007 transplants	RV Zephryus	Jason Hearon
Aug 20, 2007	5 long-term sites 2006 Transplants 2007 transplants	RV Zephryus	Craig Tomlin
Sep 17, 2007	5 long-term sites 2006 Transplants 2007 transplants	RV Zephryus	Jason Hearon
Oct *, 2007 *taken from RanSam	5 long-term sites 2006 Transplants 2007 transplants	Oyster Boat HW Sockwell	Greg Peachey
Nov 21, 2007	5 long-term sites 2006 Transplants 2007 transplants	RV Zephryus	Craig Tomlin
Shellplant Monitoring			
Apr, 9, 2007	NJ 05&06 plants	RV East Point	Jason Hearon
	DE 05&06 plants	RV First State	Mike Garvilla
May 8, 2007	NJ 05&06 plants	RV East Point	Jason Hearon
	DE 05&06 plants	RV First State	Mike Garvilla
Jun 4, 2007	DE 05 plants	RV First State	Mike Garvilla
Jun 5, 2007	NJ 05&06 plants	RV East Point	Jason Hearon
Jul 6, 2007	DE 05&06 plants	RV First State	Mike Garvilla
Jul 9, 2007	NJ 05&06 plants	RV Zephryus	Jason Hearon
Aug 7, 2007	NJ 05&06 plants	RV Zephyrus	Jason Hearon
	DE 05&06 plants	RV First State	Mike Garvilla
Sep 4, 2007	NJ 05&06 plants	RV Zephyrus	Jason Hearon
Sep 5, 2007	DE 05&06 plants	RV First State	Mike Garvilla
Sep 25, 2007	NJ 07 shell plants	RV Zephryus	Jason Hearon
Oct 9, 2007	NJ 05&06 plants	RV Zephyrus	Jason Hearon
	DE all yrs	RV First State	Mike Garvilla
did not sample 07 plants in Oct done as Ransam			
Nov 1, 2007	DE all yrs	RV First State	Mike Garvilla
Nov 5, 2007	NJ 05&O6 plants	RV Zephryus	Craig Tomlin
Nov 28, 2007	NJ 07	RV Zephryus	Craig Tomlin

Table 2. 2007 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 ID or oysters processed.

Bed	Grid	Dermo	MSX	CI
Hope Creek	4	10		15
Hope Creek	28			15
Hope Creek	30	10		14
Hope Creek	66			15
Round Island	12	10		15
Round Island	24			15
Round Island	47			15
Round Island	73	10		15
Upper Arnolds	5			10
Upper Arnolds	9	10		10
Upper Arnolds	11			10
Upper Arnolds	15			10
Upper Arnolds	18	10		10
Arnolds	8			15
Arnolds	17	10	10	10
Arnolds	26			16
Arnolds	72	10	10	9
Upper Middle	36	10		15
Upper Middle	48	10		15
Upper Middle	49			10
Upper Middle	63			10
Middle	18	10		15
Middle	25			10
Middle	31			10
Middle	44	10		15
Cohansey	19	10	10	7
Cohansey	44	10	10	12
Cohansey	49			13
Cohansey	55			18
Sea Breeze	16	10		14
Sea Breeze	24			10
Sea Breeze	31	10		15
Sea Breeze	37			10
Ship John	3			10
Ship John	13	10		15
Ship John	26			10
Ship John	29	10		15
Shell Rock	9	10	10	9
Shell Rock	17			15
Shell Rock	31	10	10	14
Shell Rock	58			13
Bennies Sand	10	10		12
Bennies Sand	13			12
Bennies Sand	21			14
Bennies Sand	27	10		11
Bennies	17	10	10	5
Bennies	56			10
Bennies	87			10
Bennies	108	10	10	12
Bennies	147			13
Nantuxent	17			10
Nantuxent	20	10		15
Nantuxent	22			10
Nantuxent	66	10		15
Hog Shoal	3			10
Hog Shoal	4	10		10
Hog Shoal	5	10		10
Hog Shoal	10			10
Hog Shoal	13			10
New Beds	12			10
New Beds	27	10	10	10
New Beds	41			10
New Beds	54			10
New Beds	66	10	10	10
Strawberry	1			6
Strawberry	5	12		13
Strawberry	6			16
Strawberry	18	8		8
Hawks Nest	2	10		12
Hawks Nest	3			10
Hawks Nest	5			12
Hawks Nest	17			5
Hawks Nest	18	10		11
Beadons	4	10		13
Beadons	10			14
Beadons	18	10		12
Beadons	30			10
Vexton	3			10
Vexton	9			9
Vexton	11	10		10
Vexton	17	10		10
Vexton	18			11
Egg Island	46	11	11	25
Egg Island	58			3
Egg Island	82			6
Egg Island	83	9	9	
Egg Island	100			8
Total beds	**20**	**20**	**6**	**20**
Total grids	**87**	**40**	**12**	**86**
Total samples		**400**	**120**	**1002**

Table 3. Shell plant and transplant sites sampled during 2007. 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 to bed indicated after spat have recruited.

Bed	Grid	Plant material	Plant yr
Shell Rock	12	MD + quahog shell	2005
Shell Rock	43Q	ocean quahog shell	2005
Shell Rock	43SC	surf clam shell	2005
Bennies Sand	11	surf clam replant	2005
Lower Middle	DE	MD + quahog shell	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	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	Transplant from Middle	2007

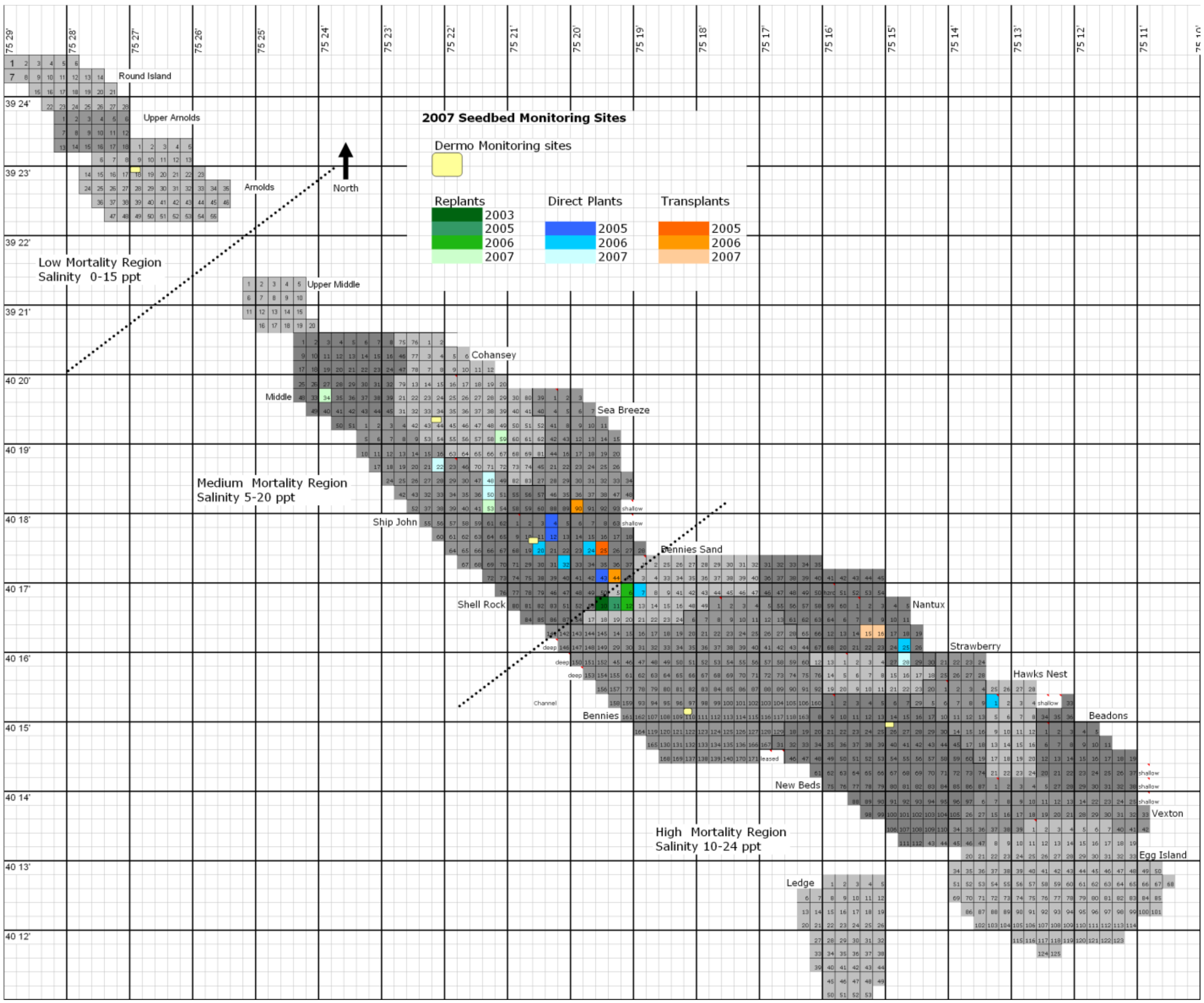


Figure 1. Grid system for Delaware Bay New Jersey oyster seedbeds used for 2007 seed bed monitoring program. Dotted lines separate regions by relative long-term mortality patterns and approximate salinity regimes.

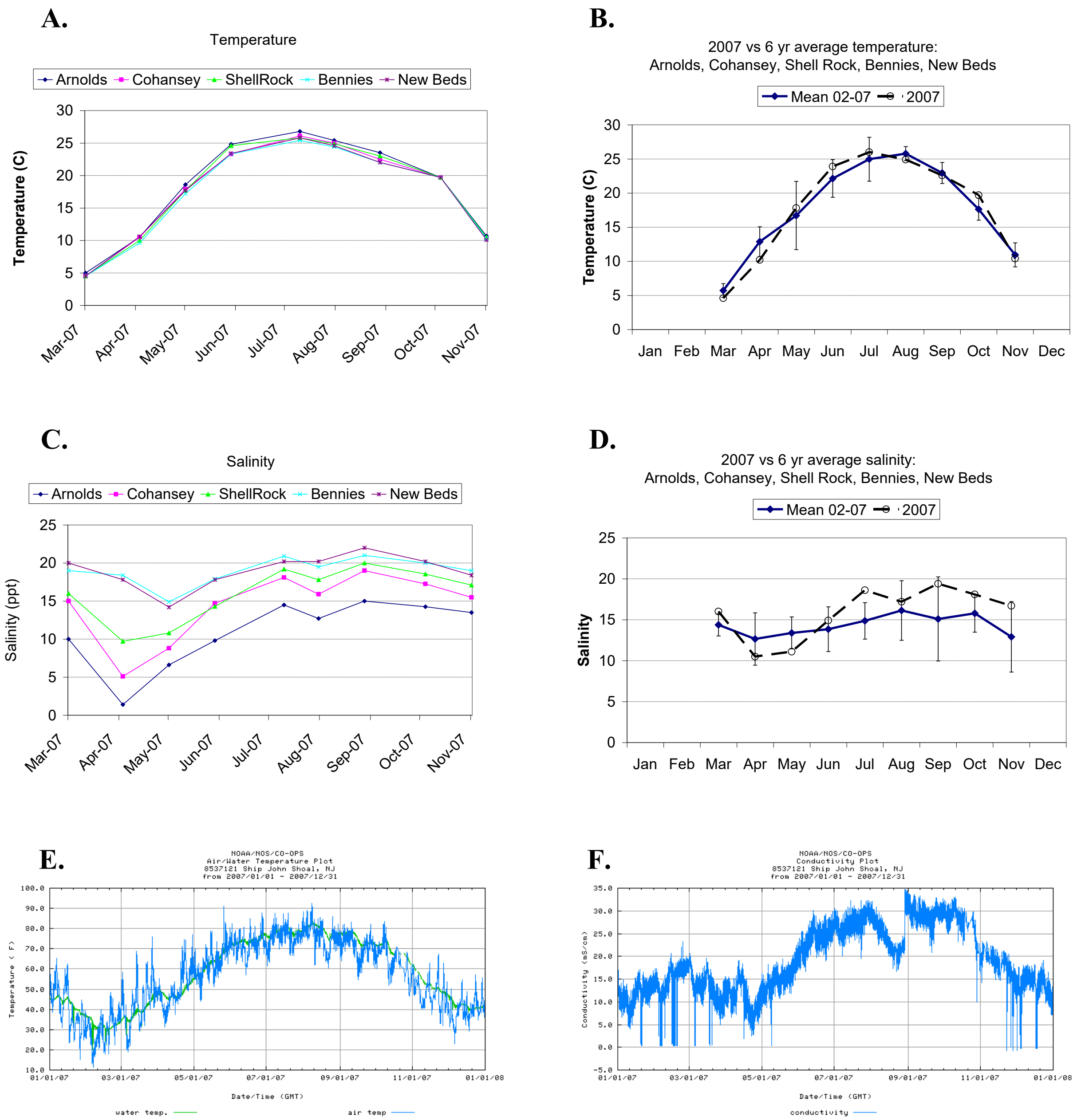
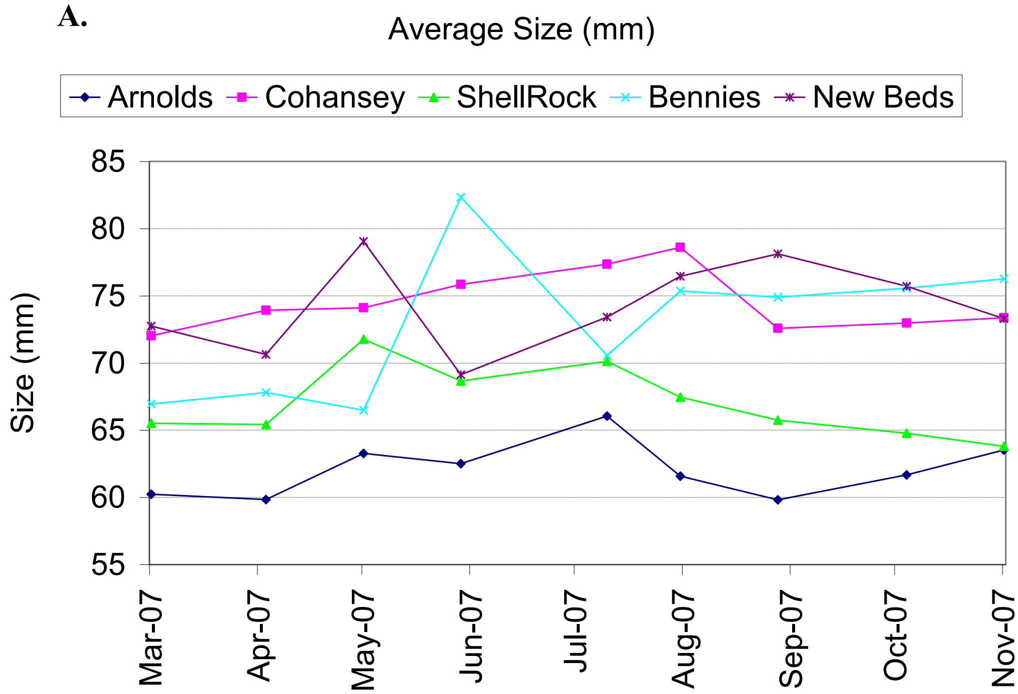


Figure 2. Monthly bottom water temperature and salinity measurements taken during seedbed monitoring at long-term stations and at a continuous monitoring station at the Ship John Shoal Light. A) 2007 temperatures for each bed. B) 2007 mean temperature across beds and mean temperature across beds since 2002. C) 2007 salinity for each bed. D) 2007 mean salinity across beds and mean temperature across beds since 2002. E) Continuously monitored temperature at Ship John Shoal Light during 2007. F) Continuously monitored conductivity (a surrogate for salinity) at Ship John Shoal Light during 2007. Ship John Shoal Light monitoring data are publicly available in near real-time and archival data http://tidesandcurrents.noaa.gov/.

A.



B.

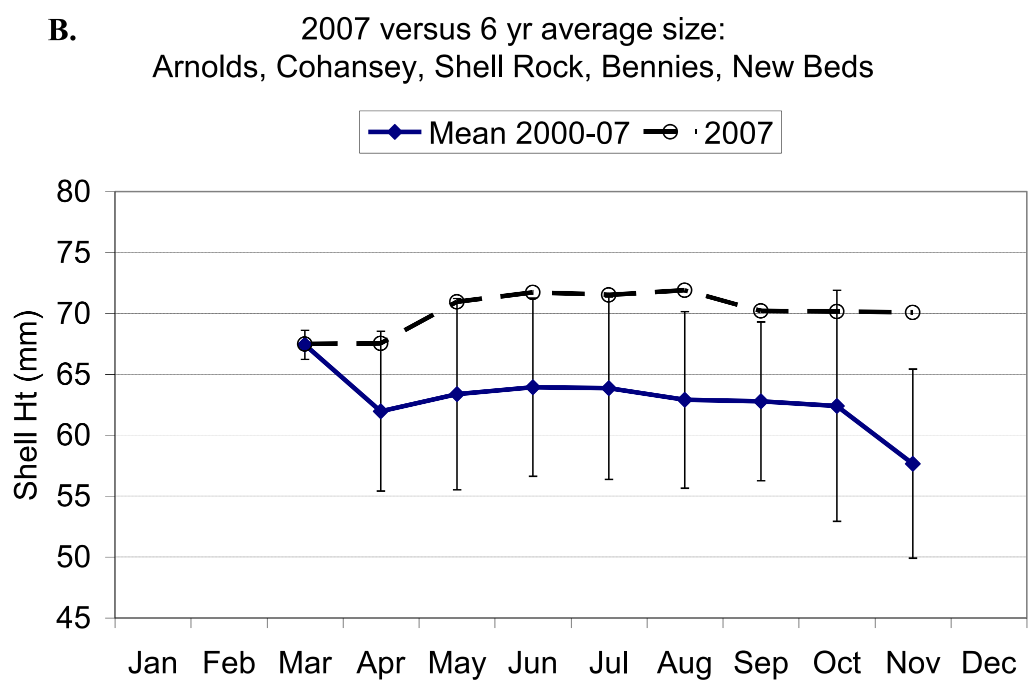


Figure 3. Mean size of oysters collected from Delaware Bay NJ oyster seedbeds. A) Mean size by bed. B) Mean size across beds for 2007 compared to the past 8 years.

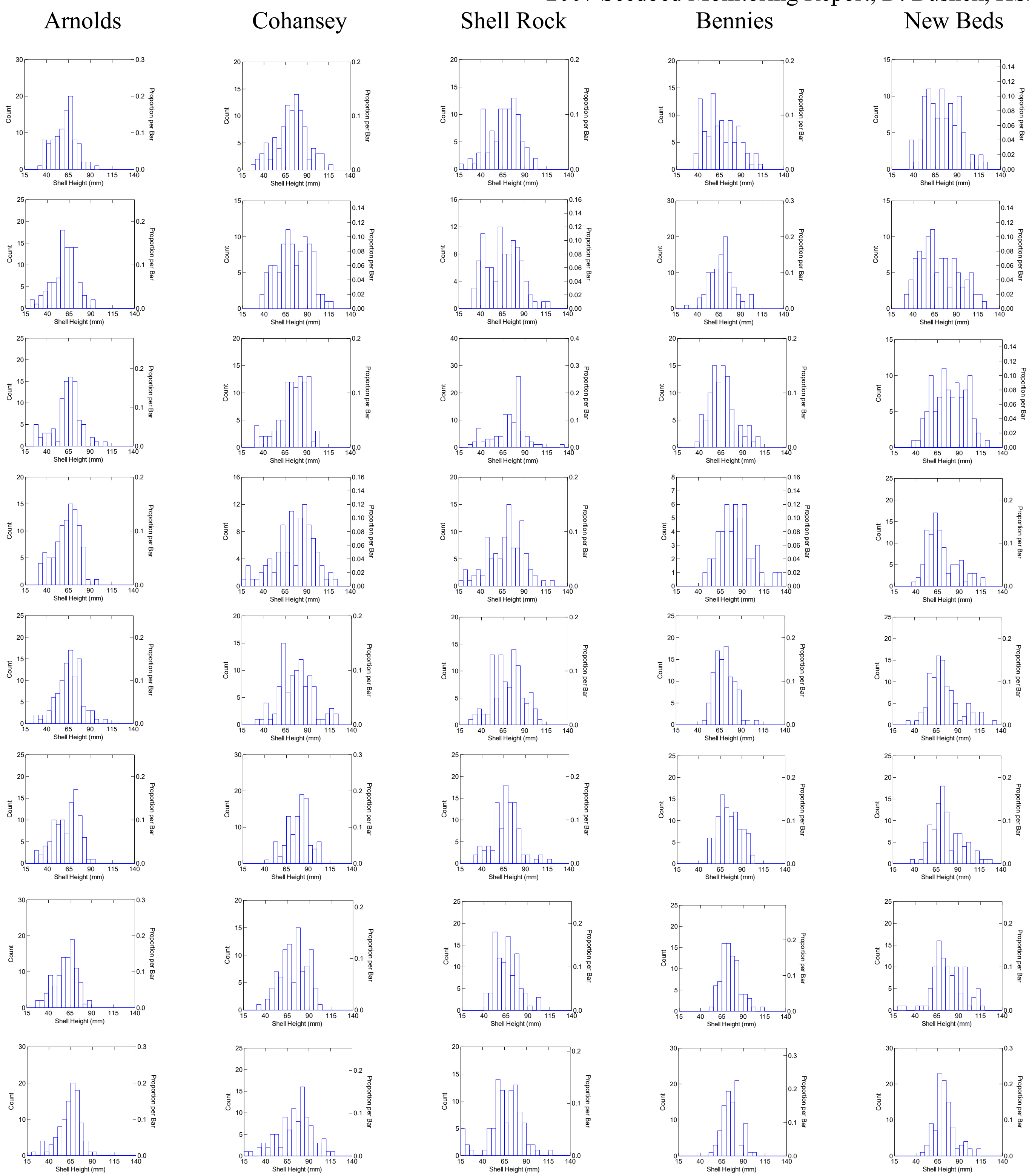


Figure 4. Size frequency plots for 2007 monthly seedbed monitoring sites. Rows of charts represent data for March, April, May, June, July, August, September and November, respectively. Size, shown on the x-axis, ranges from 15 to 140 mm in 5 mm increments for all plots. The frequency scale (y-axis) varies among plots. N = 100 for each plot with the following exceptions: Arnolds May = 90; Bennies June = 50; Cohansey September = 94; Bennies September = 84; Bennies November = 93.

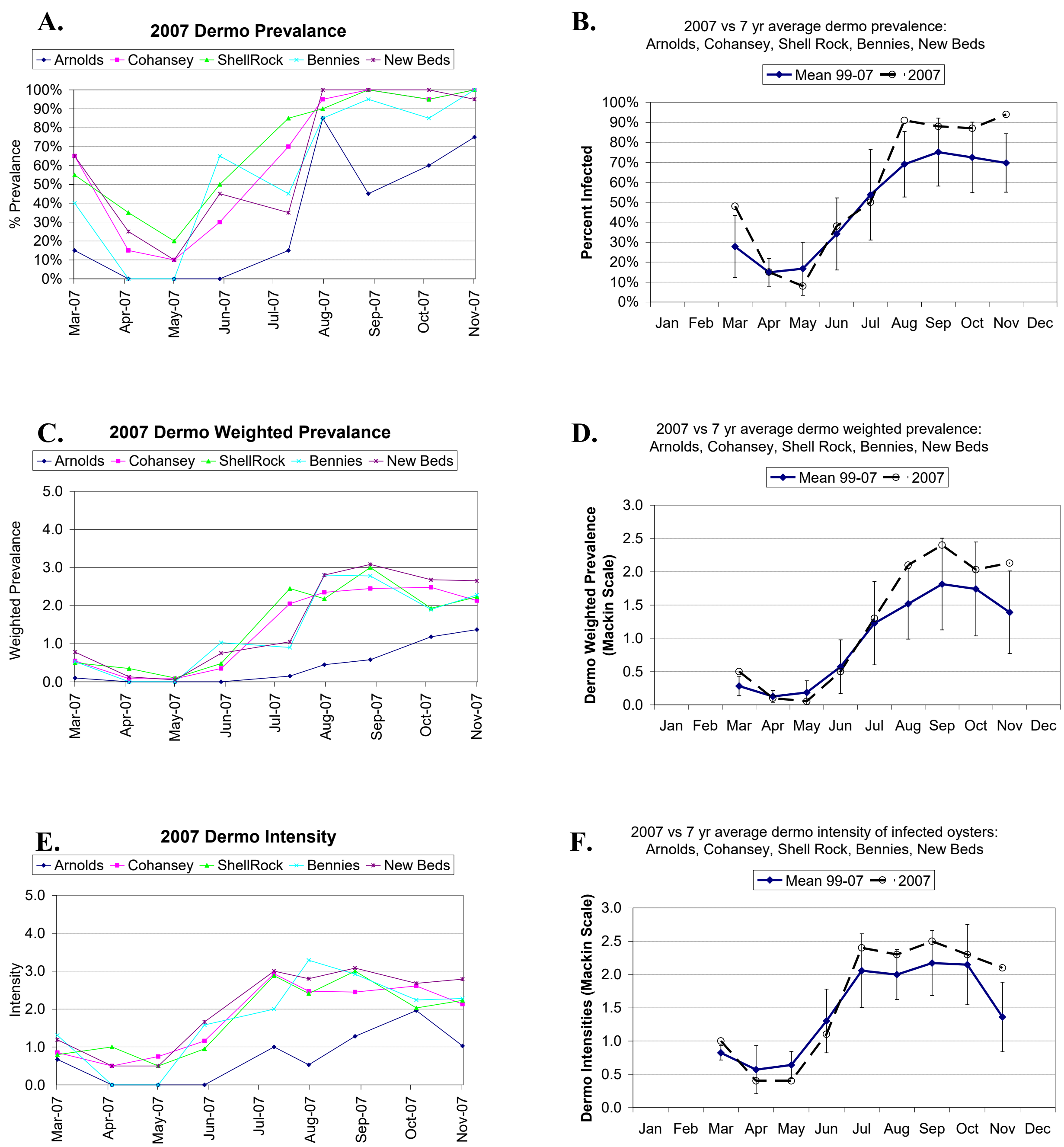


Figure 5. Monthly measures of dermo disease in oysters from New Jersey Delaware Bay seedbeds during 2007. Prevalence = percent of infected oysters. Weight Prevalence (WP) = the average Mackin rank of all oysters sampled including those with no detectable infection (i.e., rank = zero). Intensity = average Mackin rank of detectable infections.

Figure 6. Monthly estimates of oyster mortality on the New Jersey Delaware Bay seedbeds during 2007 and since 2000.

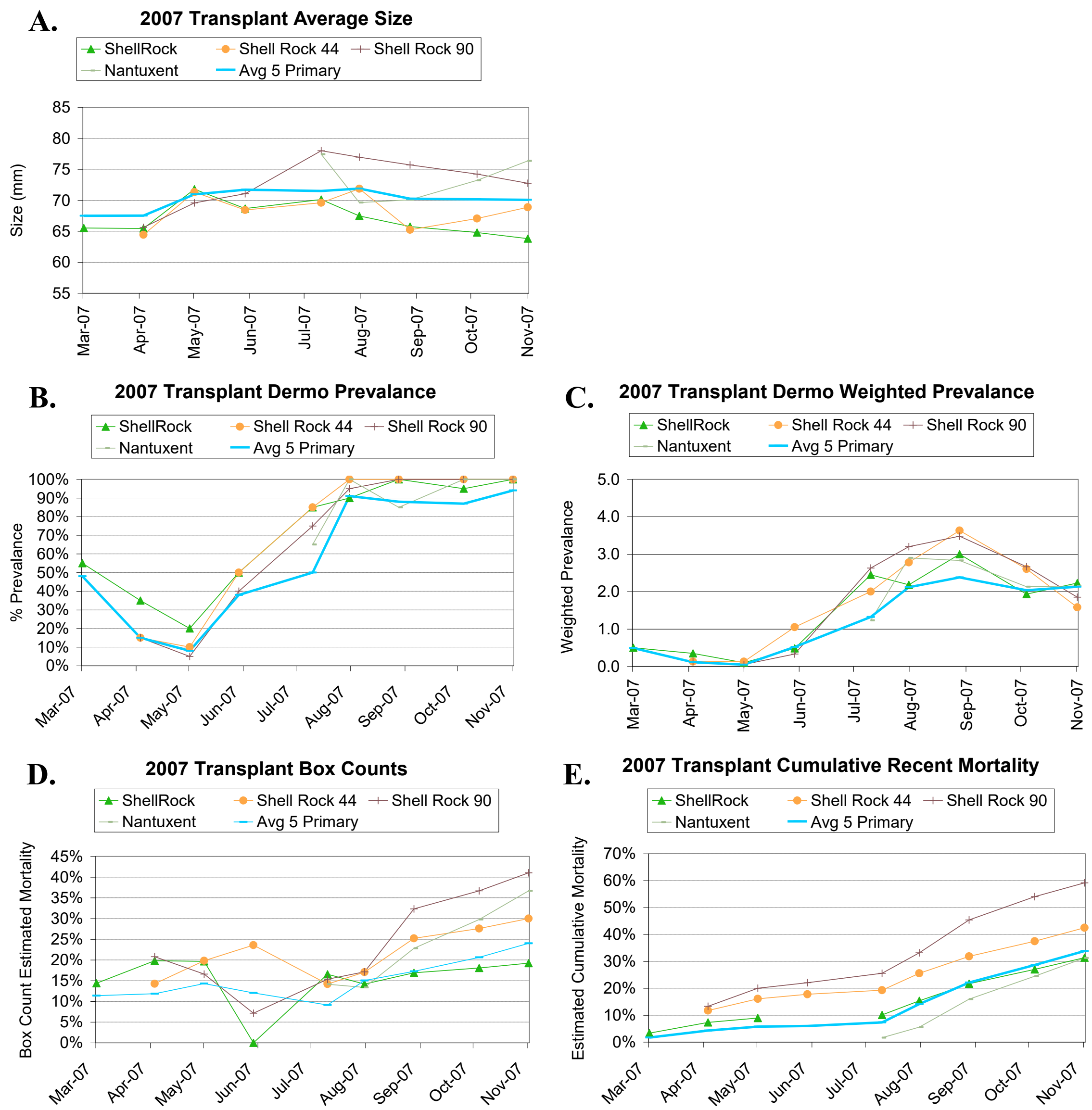


Figure 7. Performance of transplant sites where oysters from upbay were moved to downbay beds compared to nearby beds and the average across the long-term monitoring sites.

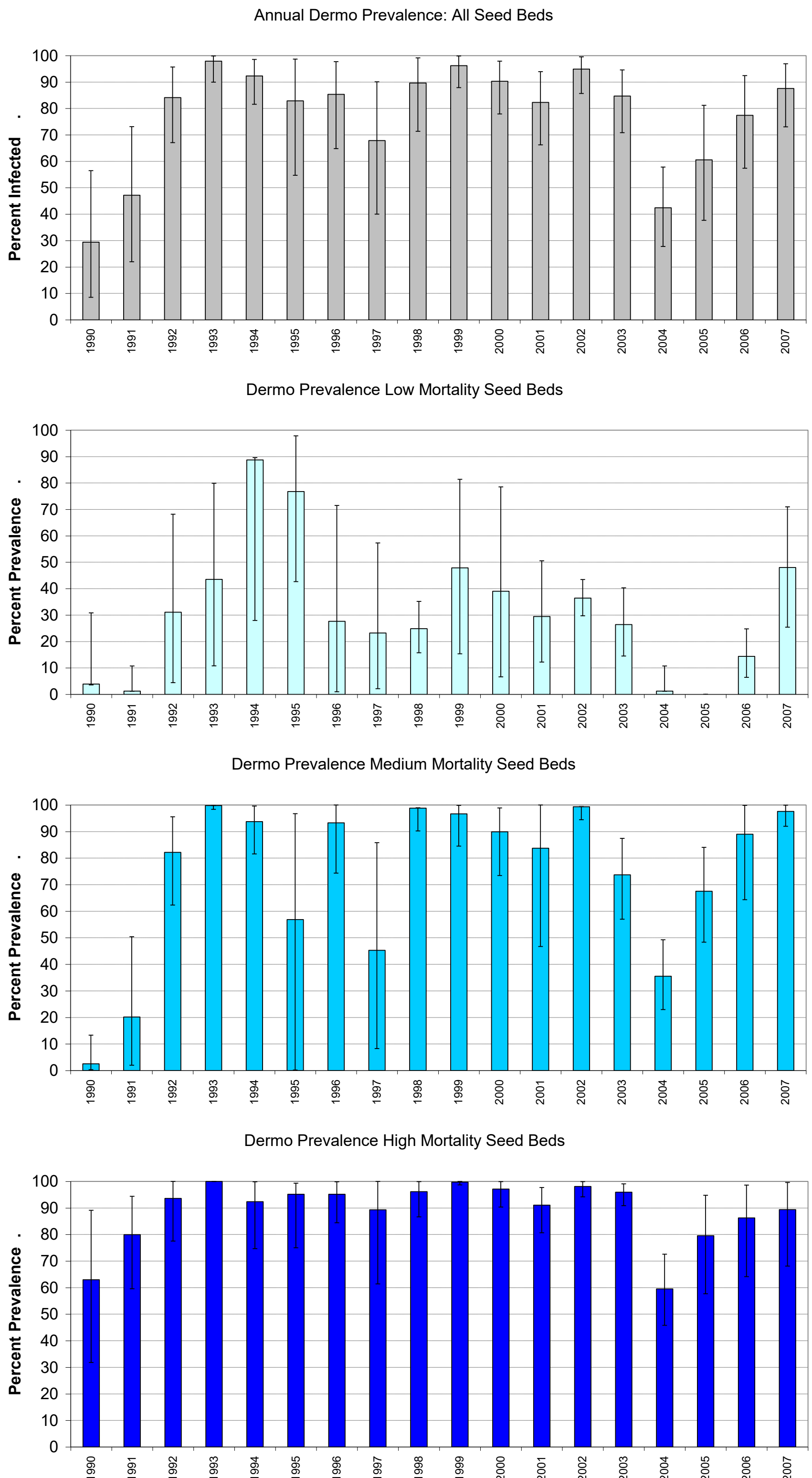


Figure 8. Annual mean fall dermo prevalence on New Jersey Delaware Bay seedbeds.

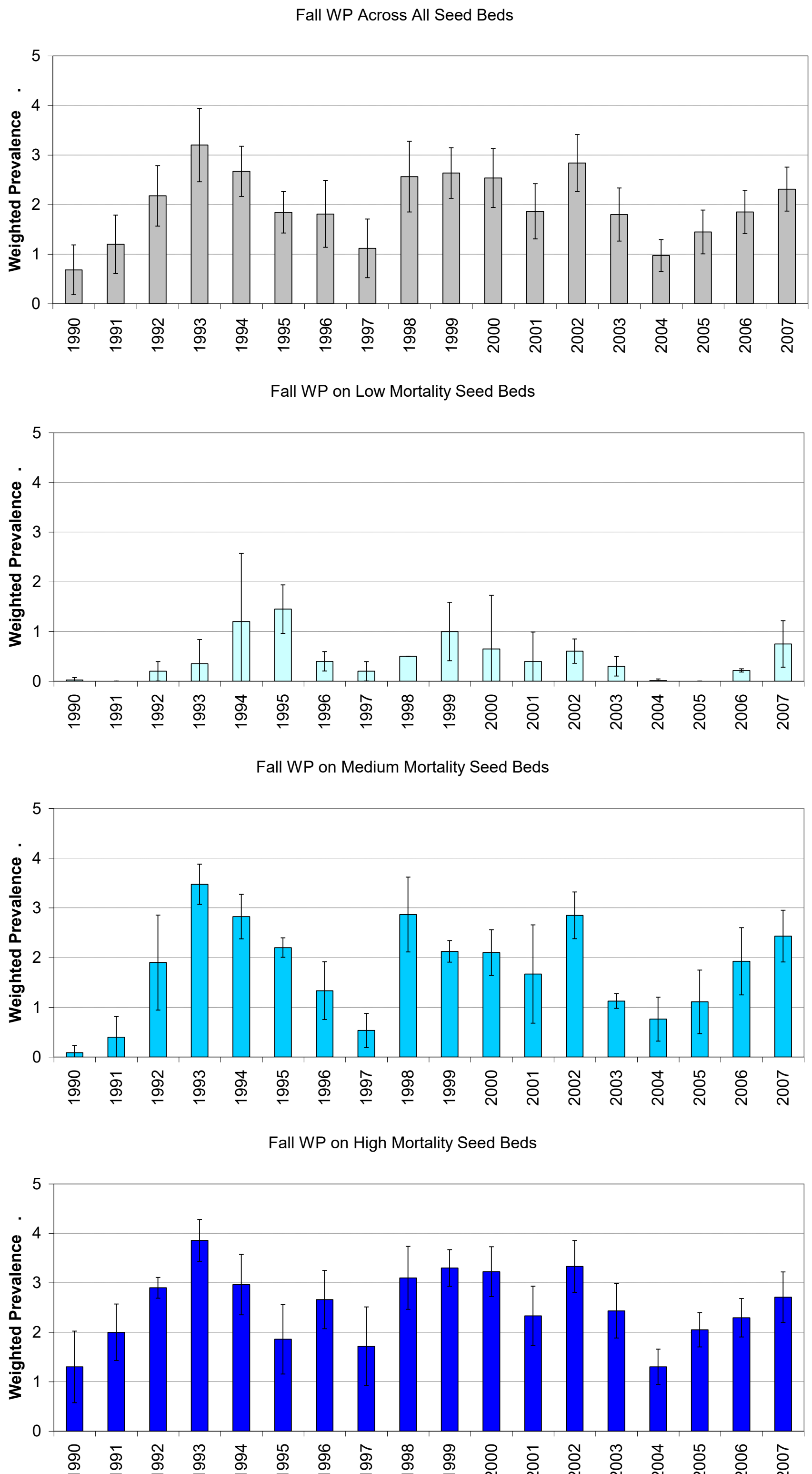


Figure 9. Annual mean fall dermo weighted prevalence on New Jersey Delaware Bay seedbeds.

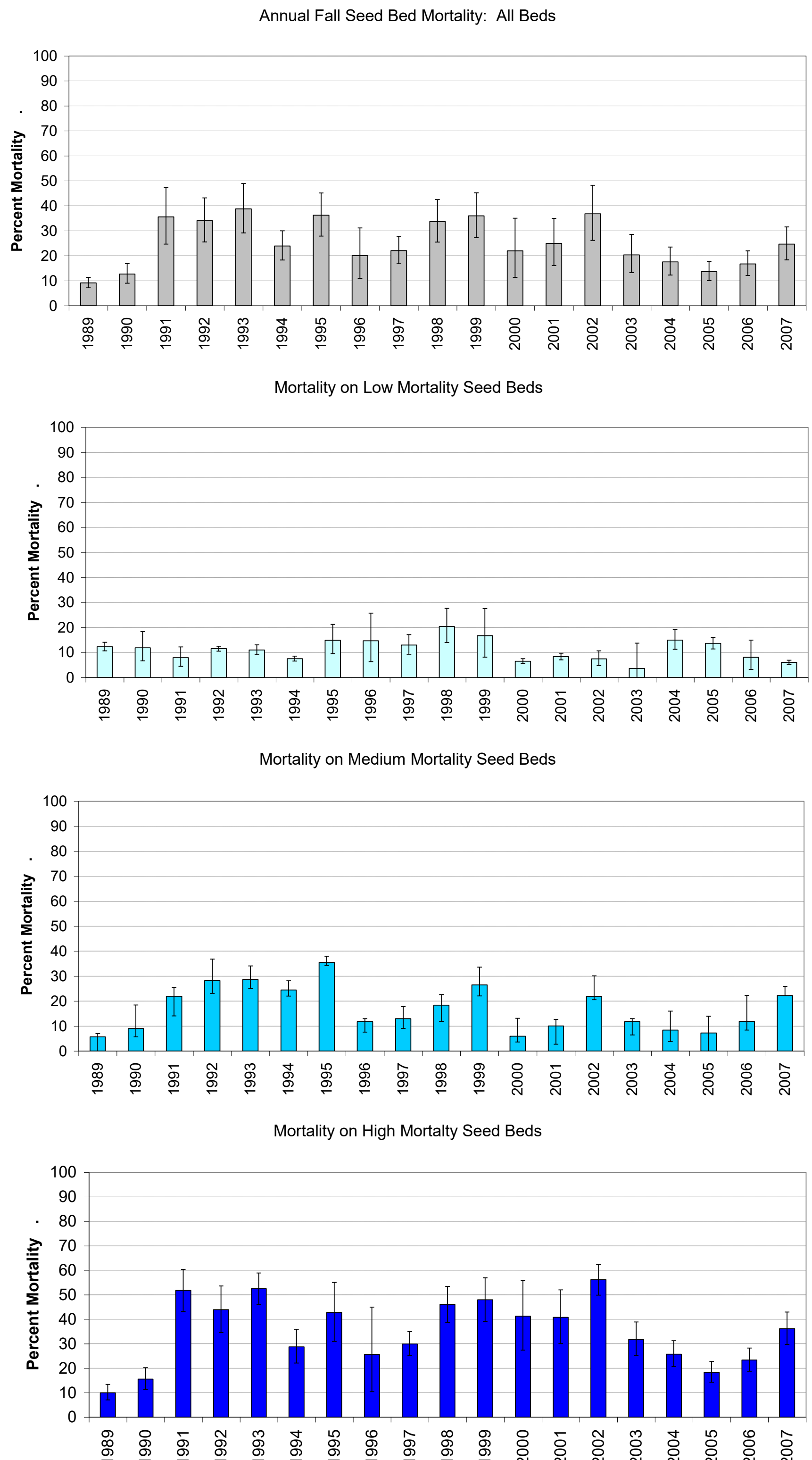


Figure 10. Annual mean fall box-count estimated mortality on New Jersey Delaware Bay Seedbeds.

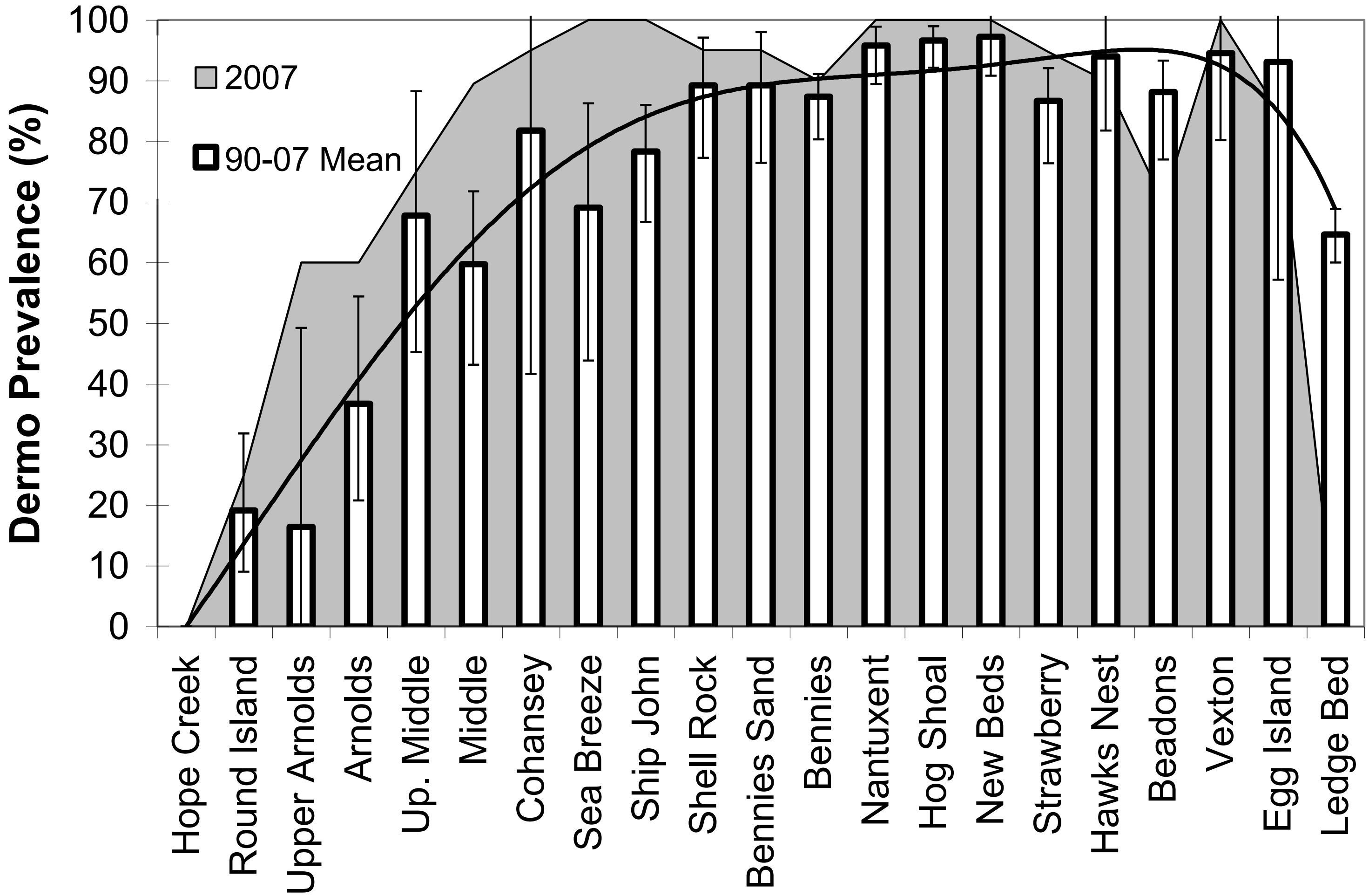


Figure 11. Comparison of average fall *Perkinsus marinus* (dermo) prevalence in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2007 levels (shaded area). Trend line is a 6th order polynomial fit of long-term data. Not all beds have been sampled every year. Ledge was not sampled in 2007 and 2007 was the first year of data for Hope Creek.

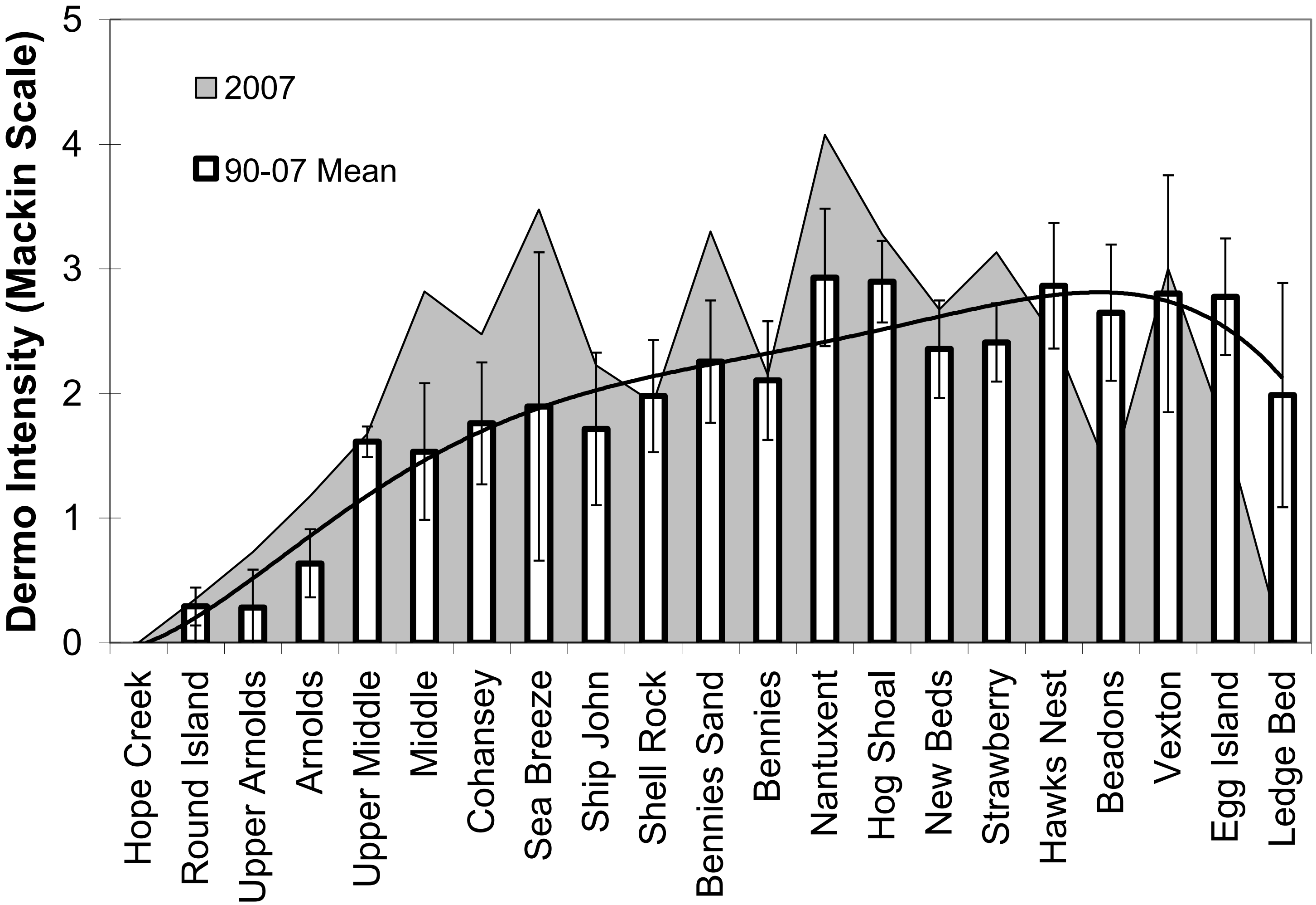


Figure 12. Comparison of average fall dermo infection intensities (weighted prevalence) in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars with 95% confidence intervals) with 2007 levels (shaded area). Trend line is a 6^{th} order polynomial fit of long-term data. Not all beds have been sampled every year. Ledge was not sampled in 2007 and 2007 was the first year of data for Hope Creek.

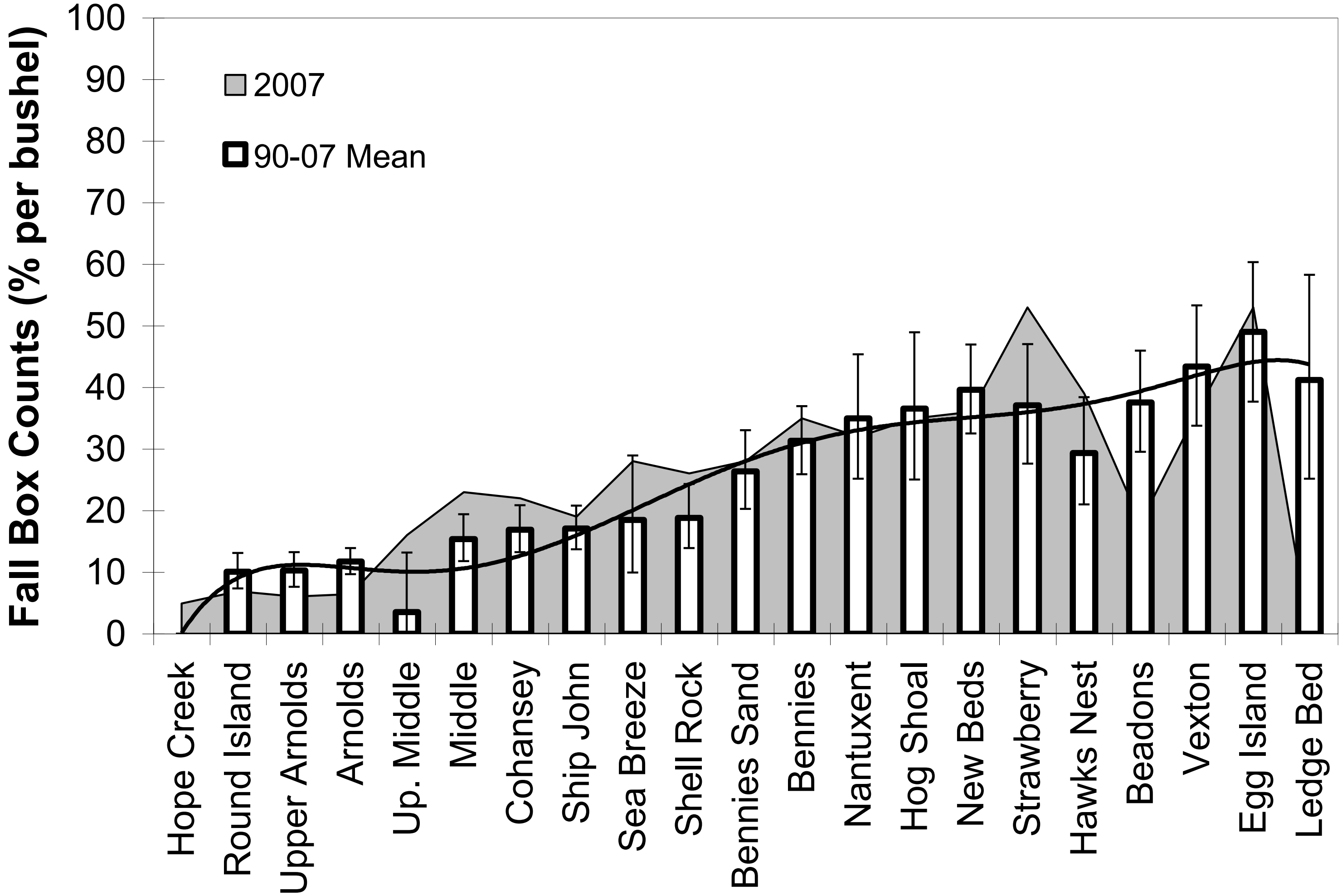


Figure 13. Comparison of average annual fall estimated box-count mortality of oysters on New Jersey Delaware Bay seedbeds since 1989 (open bars with 95% confidence intervals) with 2007 levels (shaded area). Trend line is a 6th order polynomial fit of long-term data. Not all beds have been sampled every year. Ledge was not sampled in 2007 and 2007 was the first year of data for Hope Creek.

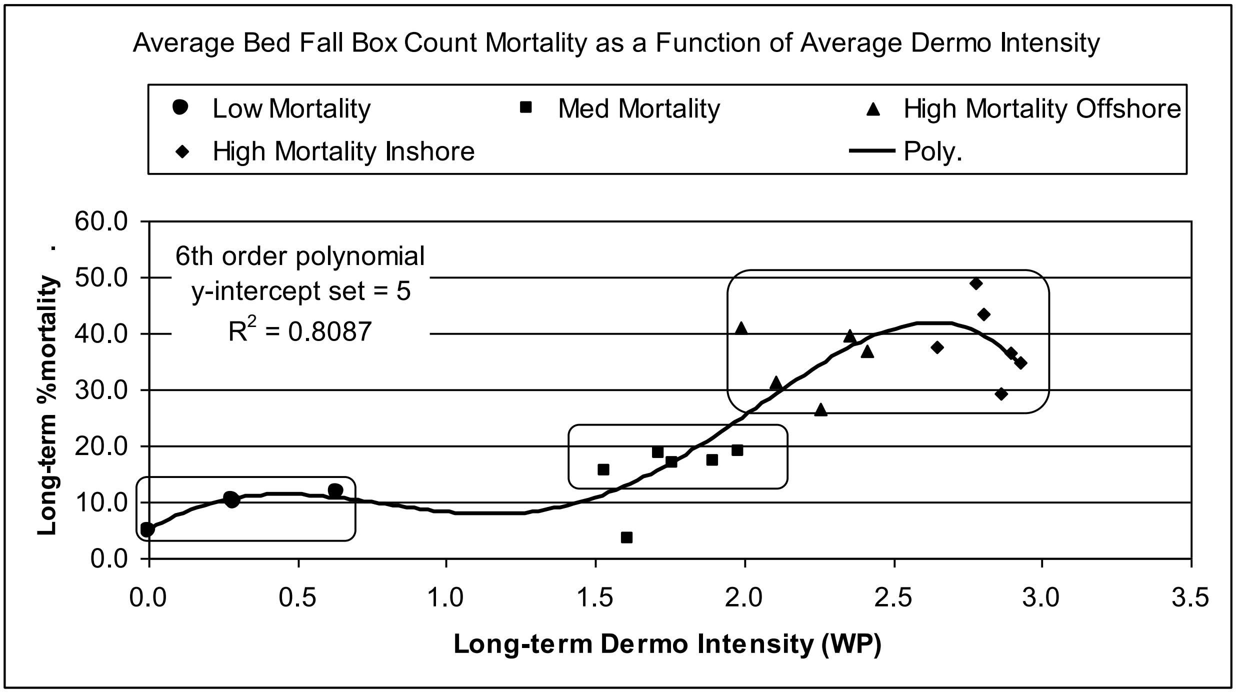
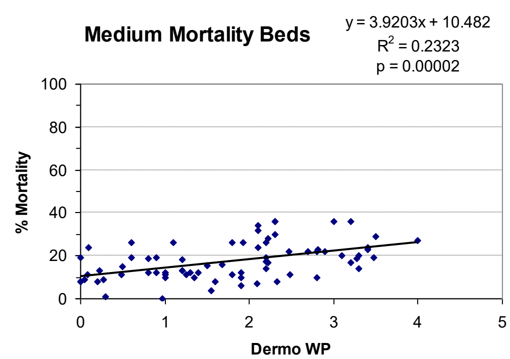
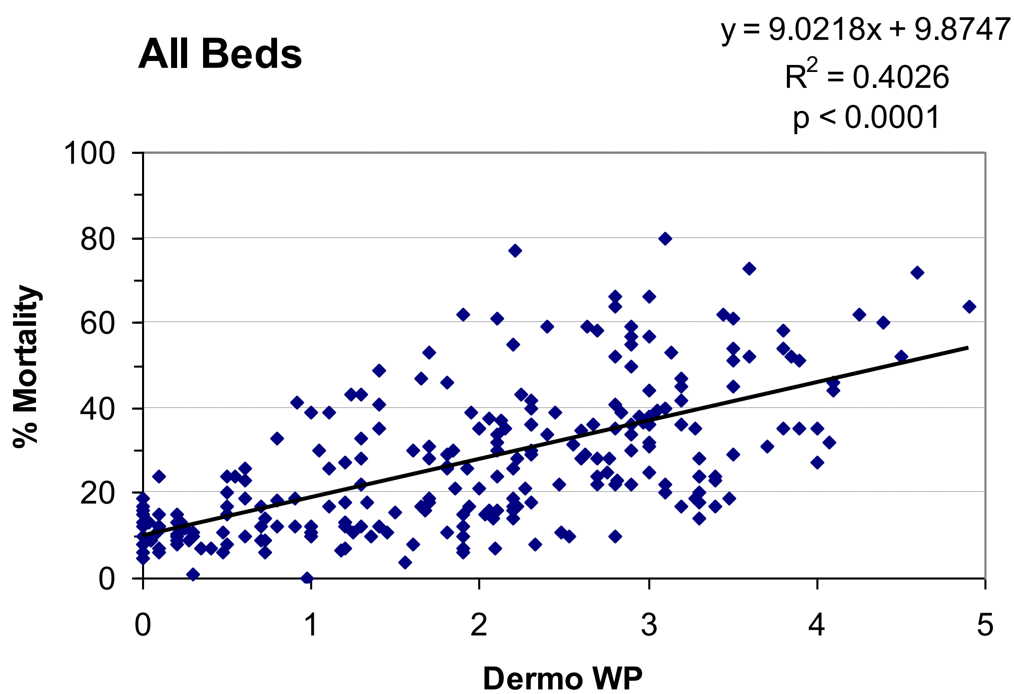


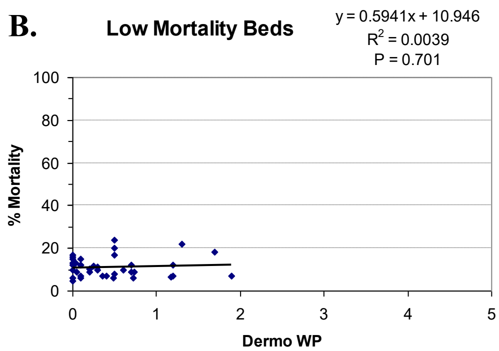
Figure 14. Relationship between long-term mean percent mortality estimate based on fall box-counts and the long-term mean intensity of dermo infections since 1990. Data are individual bed estimates. The relationship is not linear and appears to indicate thresholds for dermo-caused mortality at weighted prevalences of about 1.5 and 2 on the standard 0 to 5 Mackin Rank scale.

A.


Medium Mortality Beds
y = 3.9203x + 10.482
R2 = 0.2323
p = 0.00002
% Mortality
Dermo WP
0
20
40
60
80
100
0
1
2
3
4
5


All Beds
y = 9.0218x + 9.8747
R2 = 0.4026
p < 0.0001
% Mortality
Dermo WP
0
20
40
60
80
100
0
1
2
3
4
5

B.



C.

D.

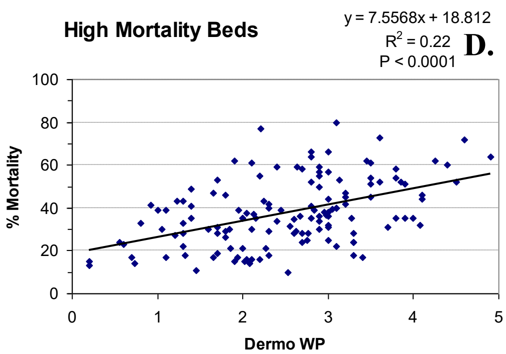


Figure 15. Relationships between fall box count mortality and dermo infection levels (WP). Data are values for individual beds from 1990 to 2007.