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# Delaware Bay New Jersey Oyster Bed Monitoring Program 2012 Status Report

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# Executive Summary:

The 2012 Delaware Bay New Jersey Oyster Seedbed Monitoring Program followed Dermo disease, oyster growth, and oyster mortality at six long-term monitoring sites, two transplant sites, a special yearling transplant from Beadons, and eight shell plants (two from 2010 and three each from 2011 and 2012). The program also continued its participation in the annual Fall Oyster Stock Assessment Survey by collecting condition indices and Dermo disease data from 22 seedbeds as well as MSX disease data from seven long-term monitoring sites.

Monthly monitoring data collected during 2012 indicated a return to more typical temperature and salinity patterns and that was followed by typical patterns of growth, Dermo disease and mortality. Impacts of Hurricane Irene and Tropical Storm Lee from 2011 continued to be evident as an increase in new boxes on the upper seed beds and a decline in Dermo disease on the lower beds. Boxes on the very low mortality bed were overly abundant at the beginning of 2012 comprising nearly 70% of the sample. By November this number had declined to approximately 30%, but even this level is two or more times the typical percentage. An early warming of water to a higher than average peak along with elevated salinities created conditions favorable to the development of MSX and Dermo disease resulting in a resurgence of both diseases. Hurricane Sandy appears to have had little effect, although the storm surge may be related to the rediscovery of MSX across all of the beds. Mean oyster size across the beds continued to decline indicating a return to a more normal size (and age) distribution that had become skewed towards larger and older larger animals. Larger animals, however, continued to constitute a larger fraction of the population on Cohansey and Shell Rock and this may partially account for the higher levels of Dermo disease on these beds, which also sustained higher levels of mortality. Shell plants performed similarly to previous years, but the Beadon's transplant of yearlings became too difficulty to follow with any degree of confidence.

**Prognosis:** The bay appears to have reset itself following several storms that have had varying impacts. The resilience of Dermo and MSX was evident in their rapid returns to previous levels. MSX continues to linger in the background while Dermo continues to pose a considerable risk across the seedbeds whenever conditions are conducive to its spread and intensification. Although Dermo levels reached higher than average peak levels, they fell to average levels entering winter and condition indices were relatively good. These conditions do not signal imminent problems for the oyster population in the coming year so long as environmental conditions remain near average levels.

## Introduction

The Delaware Bay Oyster Bed Monitoring Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds. The purpose is to provide information that supports the management of the oyster resource for sustainable harvest. Oyster production that occurred on privately owned leases or in closed waters was not monitored by this program during 2012. Monthly monitoring provides timely information on seasonal changes for the New Jersey Department of Environmental Protection Bureau of Shellfisheries and the New Jersey Delaware Bay Shellfisheries Council. More spatially comprehensive sampling occurs during the annual stock assessment. Together, these data provide insight into inter-annual patterns, long-term trends, and factors affecting the oyster stock that can be used to assist with managing the oyster stock.

Oyster mortality on the Delaware Bay oyster beds 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 (Ford and Bushek 2006, 2012). Nevertheless, naïve oysters routinely deployed at the Rutgers Cape Shore field site become heavily infected, indicating that the parasite is still common in the Bay and virulent to naïve oysters. In 1990, an epizootic of Dermo disease occurred; a form of perkinsosis in the eastern oyster *Crassostrea virginica* that is caused by the protozoan *Perkinsus marinus*. This was not the first occurrence of *P. marinus* in Delaware Bay, but previous occurrences were associated with importations of oysters from the lower Chesapeake Bay (Ford 1996). Termination of those importations resulted in the virtual 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 concern for managing the oyster fishery and the oyster stock.

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. Beds above Round Island were added to the survey in 2007 after sampling data indicated that their abundance represented a significant proportion of the population that should therefore be included in management of the seedbeds. These beds were collectively designated Hope Creek in 2007, but were subsequently subdivided into the beds Hope Creek, Fishing Creek and Liston Range. They are frequently referred to as the very low mortality beds.

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 seedbeds (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 as well as larval dispersal, oyster growth and recruitment. Continued long-term spatial monitoring as well as directed research and sampling efforts are necessary to understand these dynamics and how they change through time.

Area management strategies are currently employed that typically follow the mortality designations in Figure 1 (Powell et al. 2008). Annual Stock Assessment Workshop reports are available at http://hsrl.rutgers.edu. Recently, Shell Rock has been managed independently after the Stock Assessment Review Committee identified it as a bed of key importance to the natural stock and to the industry, and the medium mortality beds have been split into direct market beds and transplant beds. In general, these beds remain combined for the purposes of this report. The very low mortality beds are also managed separately and with caution owing to the lack of long-term data to understand how they respond to harvest and transplanting as well as environmental (i.e., salinity) variation. The temporal and spatial sampling efforts of the Oyster Bed 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 seedbeds). The 2012 objectives for the Oyster Bed Monitoring Program were to:

1. Continue the standard monthly time series monitoring New Beds, Bennies, Shell Rock, Cohansey, Arnolds, and now including Hope Creek, for size, mortality and Dermo
2. Conduct Dermo and MSX assays and determine condition indices for each bed sampled during the 2012 Fall Stock Assessment Random Sampling Survey
3. Monitor growth, disease and mortality on 2010 through 2012 shell plantings
4. Monitor growth mortality and disease on intermediate transplants, and the 2011 Beadons transplant

Objectives 1 and 2 comprise the basis of the long-term program that provides fundamental information necessary for both immediate and long-term adaptive management of the resource. These objectives also provide essential baseline/background information against which the success of other objectives and independent research can be evaluated. Objective 1 began in 1998 with five beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). In 2007 Hope Creek was added as part of the monthly monitoring program. Objective 3 was initiated as part of the Delaware Bay Oyster Restoration program designed to enhance recruitment on the seedbeds. Shell planting has become an annual effort of the management plan for sustaining and rebuilding the oyster beds. Objective 4 examines the performance of the intermediate transplant program that moves oysters from upbay beds where survival is good, but growth and condition are typically poor. This activity helps to replenish a portion of the previous years harvest.

## Methods

Figure 1 depicts the grid system used during 2012 for the monitoring program. The cross-bay lines in Figure 1 demarcate the low, medium and high mortality zones that correspond with salinity regimes of approximately 0-15 ppt, 5-20 ppt and 10-24 ppt. Management activities and this report reference both regions and beds as appropriate. Beds that fall in the jurisdiction of the state of Delaware are neither monitored nor shown. The grid system is contiguous, but only those areas containing significant concentrations of oysters (= beds) are shown (n = 23). Each bed is referenced by the name traditionally used by the industry and resource managers. On any given bed, grids of the highest density that collectively contain 50% of the oysters from the bed are indicated with darker shading and referred to as 'high quality' strata. Grids containing the next 48% of the population ranked by density are referred to as 'medium quality' and indicated in lighter shading. Grids not shown surrounding each bed contain the lowest density of oysters if they contain any oysters at all and collectively amount to no more than 2% of the population on their respective bed. Additional details on bed quality designations are provided in Powell et al. (2008).

Monthly samples were collected from March through November for Objectives 1, 3 and 4 as indicated in Tables 1 and 2. Table 3 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 4 specifies the grids sampled during the Annual Fall Oyster Stock Assessment to complete Objective 2.

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 from the NJDEP R/V Zephyrus or R/V James W Joseph. Bottom water temperature and salinity were recorded with a handheld YSI® 85 meter at each site. A composite bushel (37 L total volume with one third coming from each dredge tow[1]) 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 with little sedimentation inside valves) or old (= heavily fouled and/or containing extensive sediments) to provide an indication of recent mortality. These data were used to estimate mortality as described by Ford et al. (2006). Up to one hundred randomly selected oysters from the composite bushel were returned to the laboratory where shell heights (hinge to bill) were measured to determine size frequency in the population. Care was taken to avoid any bias in sampling oysters by systematically working through the sample until 100 oysters were identified. It is understood that the sampling gear will bias the collection toward larger animals (Powell et al. 2007), but such bias is presumed constant across sampling dates. 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 scored using the "Mackin scale" from zero (= pathogen not detected) to five (= heavily infected) (Ray 1954). These values, including zeros, were averaged to produce a 'weighted prevalence' (Mackin 1962), which provides an estimate of the average

[1] At Arnolds and Round Island, total sample volume was only one half a bushel.

disease level in the sample of oysters. Sex was determined histologically for each oyster sacrificed for Dermo analysis during May, June, July and August.

Samples for Objective 2 were collected during the Fall Stock Assessment using the commercial oyster boat H. W. Sockwell. The stock assessment survey consists of a stratified random sampling of the medium and high quality grids on the 23 named beds (colored grids in Figure 1). Ledge and Egg Island beds contain very few oysters and are only sampled in alternate years; Ledge was sampled during 2012. After samples were collected for the stock assessment, the remaining catch was searched to collect oysters for disease analysis, size frequency and condition as indicated in Table 4. Oysters for disease analysis were collected to represent the general size distribution of oysters in the sample, excluding spat and yearlings. Oysters for size frequency and condition index were collected without regard to size. Dermo was diagnosed as described above. MSX was diagnosed using standard histology (Howard et al. 2004).

To complete Objective 3, samples were collected monthly from May through November (Table 1) for sites manipulated as indicated in Table 2. The Beadons transplant was a special case in which a high set of oysters from the previous year were relocated from an area known for high recruitment and poor survival to an area of notably higher survival. In this way it was more similar to a replant of spatted shell from the lower bay than a transplant of submarket animals from the upper bay. All these sites were monitored as described for objective 1.

The shell planting program began in 2005 to enhance recruitment on the seedbeds after several consecutive years of recruitment failures. The program has successfully increased recruitment (see previous annual stock assessment reports) and because the planted shell (ocean quahog or surf clam shell) is traceable through time, it provides an opportunity to obtain specific data on growth and mortality of young animals (age class 0-2). Shell plant samples for objective 4 continued the 2011 shell plantings, resumed the 2010 shell plantings, and began the 2012 shell plantings listed in Table 2 – the latter of which was only sampled during October and November. On each site, at least three and up to five 1-minute dredge tows were systematically searched on deck for planted shell containing live or dead oysters until 100 live oysters attached to planted shell were collected. All boxes and gapers encountered during this process were collected. In some instances, five tows were insufficient to collect 100 oysters, but time limitations precluded devoting additional effort to any one site. 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 (n = 50-100 per site). No disease sampling was performed on the 2012 shell plants. Disease sampling commenced immediately on the 2010 shell plants and in July on the 2011 shell plants.

## Results and Discussion

**Temperature**. Water temperatures measured during 2012 collections followed a typical seasonal increase and decrease with a peak in July and little spatial variability across the seedbeds; however, temperatures began the year well above average and remained above average until August (Figure 2A, B). The NOAA PORTS station at Ship John Light recorded similar patterns and indicated that winter of 2012 was not particularly cold with temperatures in January and February hovering around 5° C (41° F; Figure 2C). Temperature measured at Ship John indicated water had reached 5°C by the end of the year. Warm winter temperatures and early increases during spring favor proliferation of Dermo disease.

**Salinity**. Salinity followed a typical spatial pattern, increasing from upbay to downbay beds (Figure 2D). Salinity level, however, was relatively high in April, August and September and did not fall below average levels according to monthly samples. (Figures 2D and E). The depression of salinity from Hurricane Irene and Tropical Storm Lee has clearly dissipated. Maintaining low salinity levels that inhibit disease requires a continual input of fresh water from run off in the watershed. Hurricane Sandy and a December 21st wind storm were not large precipitation events in the Delaware watershed and had little impact on salinity. In fact, the storm surges from these events (approximately 5 ft) pushed high salinity water up into the bay. High salinity generally favors the proliferation of Dermo disease in oyster populations.

Temperature and salinity are arguably the most important environmental factors controlling oyster growth, reproduction, disease and mortality. The Seedbed Monitoring Program only measures temperature and salinity when collecting oysters and only over those sites being sampled. Overlaying Seedbed Monitoring Data on the NOAA data from Ship John Shoal Light shows good correspondence (Figures 2C and F), but spatial and temporal interpretation remains limited. Researchers at Rutgers have developed a powerful 3D numerical circulation model of the Delaware Bay using ROMS (Regional Ocean Modeling System) that has already been employed to understand disease processes in Delaware Bay (Wang et al. 2012). *An array of continuous monitoring stations across the seedbeds will facilitate validation of the model and a better interpretation of conditions that influence recruitment, growth, disease and mortality of oysters.*

**Oyster size**. Shell height (measured hinge to bill) roughly corresponds to age and therefore provides insight into both the size and age structure of the population. Seasonal changes in mean shell height may be affected by growth, recruitment and mortality (both natural and fishing mortality). Mean size data (shell height) collected during 2012 (Figure 3A) show highly variable patterns across the oyster beds during the year and an average that was relatively stable around 60 mm (2.4 inches). This is below the long-term mean that had been increasing following an extended period of low recruitment in the early-mid 2000s. Notably, there was a decrease in size on Hope Creek resulting from the fresh water mortality event in 2011 that impacted larger animals more than smaller animals (Powell et al. 2012a). In contrast to this is an increase in the average size of oysters on Shell Rock. The overall pattern measured during the annual fall stock assessment survey shows the increase in average size has reversed itself during the past three years (Figure 3B).

Growth on shell plants continues to accumulate and is providing valuable data on seasonal, interannual, and spatial variability. Figure 4A shows a relatively consistent level of variability, although these data are not parsed by location. Each data point is a mean of 50-100 animals and the variability about each point (not shown for clarity) indicates that a small proportion of animals on shell plants reach legal harvestable size (2.5 inches) in about 14-15 months. The proportion of animals reaching market size begins to exceed 50% by 24 months on the fastest growing sites. Growth on the 2010, 2011 and 2012 shell plants all fell within the range of variability shown. Oysters from the 2011 Beadons transplant grew steadily during the previous year, but apparently not so much during 2012 and size eventually decreased. This was clearly an artifact produced from a decreasing ability to correctly differentiate the Beadons transplant oysters from oysters native to the recipient bed. Mortality on the Beadons transplant was high (Figure 4 B), possibly from these same sampling difficulties and should be interpreted cautiously. As a result, monitoring of the Beadons transplant was stopped after July 2012. The shell planting on Middle 26 was interrupted by Hurricane Irene and Tropical Storm Lee and this partially accounts for the increased mortality observed on that site. In contrast, shell plants on Bennies Sand 11 and Shell Rock 11 followed more typical patterns. **Shell planting remains one of the most positive management efforts to sustain and increase oyster abundance.**

Sex ratios of oysters has been a concern due to the changing age/size structure of the population shown in Figure 3B. Oysters are protandric, that is some will begin their lives as males then change to females later in life. Hence, an older population is likely to have more females present and the distribution of males may be insufficient to maintain adequate fertilization success (Powell et al 2012b). On the other hand, Dermo tends to have a greater impact on older and larger animals than on younger oysters. An imbalance in the sex ratio can theoretically reduce fertilization success negatively impacting the population. We do not have a mechanism to measure fertilization success, but we can determine sex ratio throughout the year. Results from 2012 indicate a bias towards females based on samples collected for disease analysis (Table 5). One hermaphrodite was detected on Hope Creek in July and is not recorded in Table 5. The percentage of oysters with sexually discernable gonad increased from May to June when virtually all animals were in reproductive status. This dropped in August indicating a spawning event, but increase slightly in September suggestion the possibility of a second spawning event.

**Shell Plants**. Figure 4 shows the growth and mortality of the initial cohorts that set on planted material each year since 2005. The data indicate that oysters reach an average size of nearly 25 mm (about 1 inch) during the year they set, essentially double in size the following year, and, on average, reach a legal harvestable size (63.5 mm or 2.5 inches) by the end of the next year. These patterns are similar from year to year but do vary among years and spatially across the seedbeds. The observations fit well with the conventional dogma that it takes 2-3 years for oysters to reach market size in Delaware Bay. They also indicate that spat, on average, may be greater than 20 mm by October when the Fall Stock Assessment sampling takes place. The maximum mean size of spat on a shell plant during the year of setting has been 30 mm. Defining spat as oysters < 20 mm in the stock assessment survey results in low estimates of annual recruitment while overestimating the abundance of oysters. A more thorough analysis of these data are needed to parse the effects of location and year to determine if spat size varies across the beds in order to justify use of any particular threshold value for counting spat versus oyster. The minimum average size from a shell plant sampled during October one year after the planting is 38 mm. **Given this difference, it would seem that spat size limits of about 30 mm could help reconcile this error.**

Growth of the 2011 shell plants during 2012 fell within the variation of previous years (Figure 4A). The Beadon's transplant is also plotted with these data. As reported previously, the Beadons transplant was difficult to monitor because it was all natural set on natural cultch and very difficulty to distinguish. An increasing level of uncertainty in identifying oysters transplanted from Beadons resulted in poor data quality and so monitoring this transplant was abandoned in July 2012. Survival data across shell plants suggest that large differences in mortality among years, but much of this is likely due to poor estimation of very early mortality during the year of the planting (Figure 4B). High overall mortality during 2011 is biased from high and uncertain estimates from the Middle replant. Mortality on the Beadons transplant was somewhat higher than shell plants of similar age, but still within the range of mortality on shell plants. The Middle replant project was difficult to follow similar to Beadons, but available data are shown for comparison.

**Seasonal Disease and Mortality**. The reprieve from Dermo disease provided by Irene and Lee in 2011 appears to have subsided. Dermo prevalence, weighted prevalence (WP) and intensity followed similar seasonal patterns across the seedbeds that were temporally similar to long-term patterns (Figure 5). All three measures increased from low values in April and May to peak values in August or September before beginning to decline. Weighted prevalence and infection intensity peaked at higher than average levels, but returned to average levels by November. Spatially, Dermo typically increases with salinity, but highest levels occurred on Shell Rock and Cohansey, indicating a possible resurgence of Dermo upbay. Because Dermo tends to be more prevalent and intense in larger animals, this pattern may reflect the size distribution of oysters more than a progression of Dermo up the bay. **Shell Rock and, to a lesser degree, Cohansey have been areas of concentration for management and harvesting and the relationship of this increased activity to increased levels of Dermo is worthy of closer examination.** Similar concerns (correspondence of intensive repletion, high abundance and unusually high Dermo levels) have been expressed for oysters in the Great Wicomico of Chesapeake Bay (R. Carnegie, personal communication).

Mortality estimated from both total and recent box count frequencies shows several interesting patterns (Figure 6). Total box counts shown in Figure 6A is dominated by Hope Creek resulting from the massive mortality on the very low mortality beds (a misnomer last year) following Irene and Lee. Some elevated overwintering mortality was apparent on Hope Creek, but levels quickly returned to normal. Figures 6B, 6D and 6F do not include Hope Creek in their calculations. Note that the frequency of all boxes (new and old) was relatively low during much of 2012 (Figure 6B), but new boxes appeared at more typical rates and so cumulative mortality was average throughout the year (Figures 6D and 6F). Figures 6C and 6E show the elevated levels of mortality on Shell Rock and Cohansey that corresponds with the elevated levels of Dermo on these beds shown in Figure 5.

Box counts are known to underestimate mortality, but it is worth noting that cumulative recent box count mortality measured at the end of the season consistently exceeds the total box count mortality by 5-15%. Therefore, annual box count estimates may be a greater underestimate of mortality than cumulative mortality estimates made throughout the year. Regardless of which measure is used, the Annual Delaware Bay Oyster Stock Assessment defines 20% mortality as an epizootic. Cumulative mortality exceeded 20% on 4 of the 6 beds monitored during 2012, while total box counts exceeded 20% on only three beds.

**Annual Stock Assessment**. Condition index and size frequency data collected during the annual stock assessment are reported in the "Report of the 2013 Stock Assessment Workshop". Because MSX has not been problematic on the seedbeds for nearly two decades, samples from only seven beds along the up- to downbay gradient were examined (Table 4). Of 140 oysters examined, MSX infections were detected in only 10 animals (Figure 7A), but infections were spread across the seed beds (Figure 7B) indicating that MSX remains a threat to the entire stock. Because MSX continues to be a serious problem in other areas and remains virulent to naïve oyster stocks, monitoring for MSX remains as an important component of the monitoring program to understand sources of mortality from year to year.

Figure 8 depicts annual Dermo prevalence, Dermo infection intensity (= weighted prevalence) and box-count estimated mortality from 1989 to 2012 for each mortality region sampled during the annual stock assessment. Each plot segregates the data based on seedbed mortality regions defined by Powell et al. (2008). Each parameter decreases from high to low mortality regions. Dermo prevalence and weighted prevalence track each other well within and across regions, but mortality patterns on the low and very low mortality regions are distinct from the medium and high mortality regions. Within the high and medium mortality regions, mortality lags disease by about one year. Within the low and very low mortality regions, mortality is approximately out of phase with Dermo disease. Since 1990, there have been two relatively low periods of Dermo disease, most easily seen in 1997 and 2004 on the medium mortality region curve. It looks as though 2011 may have been a third period and this pattern is suggestive of a seven-year cycle. Unfortunately, periods of remission have been much shorter than the duration of the epizootics.

Two different patterns are evident in the data in the upper bay low and very low mortality regions. On the low mortality beds there has been a steady increase in mortality since 2007 culminating with a peak in 2011. This increase corresponded to a sustained increase in Dermo disease. This pattern also corresponds with an increase in the utilization of the low mortality beds for the intermediate transplant program. **Because the association of the increase in mortality on the low mortality beds with Dermo and with harvest for intermediate transplants cannot be distinguished, continued use of these beds for the intermediate transplant program should continue to be monitored carefully.** On the very low mortality beds a dramatic increase in mortality during 2011 is clearly a result of fresh water kill following tropical storms Irene and Lee. Dermo levels remained low on these beds during 2012 and mortality levels are returning to normal, though many boxes resulting from the freshet remain (Figure 6).

Many factors such as temperature, salinity and recruitment are known to influence Dermo disease and the confluence of these factors is difficult to predict. Moreover, while there is some understanding of how these factors influence spatial and seasonal variations in Dermo disease, it is less clear how they interact to influence inter-annual variation. As mentioned in previous years, the apparent cycling may be driven by larger regional climate patterns, but this remains a hypothesis in need of additional research and continued monitoring.

The data continue to indicate an attenuation of Dermo-induced mortality in the three successive epizootics across the medium and high mortality regions (Figure 8). This observation remains difficult to interpret, because lagged correlations between river flow and WP produce a significant negative correlation (Bushek et al. 2012). It could be entirely environmentally driven or it could indicate an increase in tolerance (the relative ability of an oyster to survive an infection of a given intensity) versus resistance (the ability of an oyster to limit the development of an infection) to Dermo disease. Continued monitoring and directed research is needed to fully understand what is happening.

Examination of Dermo prevalence and Dermo intensity on a bed-by-bed basis in Figures 9 and 10 indicate that the return to the typical increase from upbay to downbay beds in 2011 may have been only temporary as the levels across the medium mortality region beds are higher than long term means whereas the levels across the high mortality beds are lower than long term means. As in 2010 there appears to be a shift of Dermo upbay. These data also support the notion that some level of resistance is developing in the lower bay, but this may simply be a result of the larger reductions in density in the lower bay. Alternatively, it could be a lingering effect of Irene and Lee pushing Dermo levels down and in a down bay direction. In contrast, mortality measured as box counts from the fall random survey appears to indicate a relatively uniform mortality event across the bay with greater than average mortality up bay and lower than average mortality occurring down bay. As explained above, the higher mortality up bay appears as an artifact from the large number of boxes remaining from the massive mortality following Irene and Lee (Figure 11).

Figure 12 shows the relationship between the average long-term Dermo level and average long-term mortality by bed. Weighted prevalence and mortality values from Figure 11 are used along the x- and y-axes respectively. The various mortality regions fall out into zones clearly defined by disease intensity. The low and very low mortality beds comprise a low disease zone with weighted prevalence of Dermo typically well below 1.0 on the Mackin scale. Beds in these regions experience mortality that averages less than 15% annually, 2011 clearly being an exception. Beds on which Dermo intensities increase above a weighted prevalence of 1.5 experience annual mortalities of 15 to 20% and are designated the medium mortality beds. Once Dermo levels exceed 2.0, average mortality increases to 25-40%. Two exceptions are Upper Middle and Egg Island with mean WPs of about 1.7, but mean mortalities of about 10% and 40% respectively. These exceptions appear to be related to inconsistent sampling over the years and so they are not included in Figure 12. The relationship was fitted as a dose response curve via the zunzun.com curvefitting program (http://zunzun.com) because mortality appears to be responding in a dose-dependent fashion. This produced a better fit to the data than the plant disease logistic growth model used previously (Bushek et al. 2012) which was selected based on growth of the Dermo parasite *Perkinsus marinus* within infected oysters. It is not yet clear which curve-fitting model provides a more biologically compelling argument for its use. Regardless, both models indicate a rapid increase in mortality once Dermo infection intensities exceed 1.5, a level often referenced as indicative of the onset of an epizootic. The bottom line is that infections can linger at low levels for long periods with little effect and then suddenly develop quickly into lethal infections across two doublings of the parasite. With this in mind, note the precarious position of Shell Rock and the medium mortality beds in general.

Figure 13 shows the individual data points for each bed and each year sampled since 1990 as one plot and then broken down by mortality region (very low and low mortality regions combined). Each dataset was fit with the same dose response curve used in Figure 12. The complete data set indicates an exponential relationship (Figure 13A), but each region shows a different process. In the low mortality region, there is no relationship with Dermo disease because levels are low and mortality is controlled by other processes such as freshets (Figure 13B). In the medium mortality region the curve shows a dose response that levels off (Figure 13C) whereas the high mortality region indicates and exponential increase (Figure 13D). The overall relationship is highly significant ($p < 0.0001$) and explains 35% of the variation in mortality, while the regional relationships are either not explanatory (Figure 13B) or explain 20 or 21% of the variability observed (Figures 13 C and D). It is tempting to compare mortality rates for different Dermo levels in Figures 13C and D. For example, a Dermo weighted prevalence of 3 on the high mortality beds corresponds to nearly double the mortality rate indicated on the medium mortality beds. This is, however, misleading as monthly monitoring (Figure 5) indicates that infections on higher mortality beds exist at higher levels for longer periods of time, leading to a higher annual mortality rate. That is, lower bay beds typically experience higher Dermo levels sooner and for longer periods of time resulting in higher rates of mortality over time. Furthermore, the intercepts of regression lines in Figure 13 vary among regions suggesting that different factors are involved in different regions. Note, however, that there are relatively few measures of Dermo weighted prevalence below 1.0 on the high mortality beds and none of zero. Collectively, these data indicate that a significantly greater recruitment rate is required to sustain downbay populations compared to upbay populations.

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**References**

Bushek, D., S.E. Ford and I. Burt (2012) Long-term patterns of an estuarine pathogen along a salinity gradient. *J Marine Research*. 70:225-251.

Ford, SE 1996. Range extension by the oyster parasite *Perkinsus marinus* into the northeastern United States: Response to climate change? *J. Shellfish Res*. 15:45-56.

Ford, SE and D Bushek. 2006. Additional evidence of high resistance to *Haplosporidium nelsoni* (MSX) in the native oyster population of Delaware Bay. *J. Shellfish Res.*, 25(2):726-727.

Ford, S.E. and D. Bushek. (accepted with revision). Development of resistance to an introduced marine pathogen by a native host. *J. Marine Research*.

Ford, SE, MJ Cummings and EN Powell. 2006. Estimating mortality in natural assemblages of oysters. *Estuaries and Coasts*, 29 (3): 361-374.

Howard DW, EJ Lewis, BJ Keller, and CS Smith (eds.). 2004. Histological Techniques for Marine Bivalve Mollusks and Crustaceans. NOAA Tech. Memo NOS NCCOS 5, 218 pp.

Mackin, JG 1962. Oyster disease caused by *Dermocystidium marinum* and other microorganisms in Louisiana. *Publ. Inst. Mar. Sci. Univ. Tex.*, 7:132-229.

Powell, EN, KA Ashton-Alcox and D Bushek. 2012a. Report of the 2012 Stock Assessment Workshop (14th SAW) for the New Jersey Delaware Bay Oyster Beds.

Powell, E. N., J. M. Morson, K. A. Alcox, and Y. Kim. 2012b. Accommodation of the sex ratio in eastern oysters to variation in growth and mortality across the estuarine salinity gradient in Delaware Bay. *J. Mar. Biol. Assoc.* U.K., doi: 10.1017/S0022377807006861, Published online by Cambridge University Press 24 April 2012.

Powell, EN, Ashton-Alcox, KA; Kraeuter, JN. 2007. Reevaluation of eastern oyster dredge efficiency in survey mode: Application in stock assessment. *North Amer. J. Fisheries Management*., 27(2): 492-511

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

Ray, S.M. 1952. A culture technique for the diagnosis of infection with *Dermocystidium marinum* Mackin, Owen, and Collier in oysters. *Science* 116:360-361.

Ray, S.M. 1954. Biological Studies of *Dermocystidium marinum*. The Rice Institute Pamphlet, Special Issue.

Ray, S.M. 1966. A review of the culture method for detecting *Dermocystidium marinum*, with suggested modifications and precautions (1963 Proceedings). *Proc. Natl. Shellfish. Assoc.* 54:55-69.

Wang, Z., D. Haidvogel, D. Bushek, S. Ford, E. Hoffman, E. Powell and J. Wilkins. 2012. Circulation and water properties and their relationship to the oyster disease, MSX, in Delaware Bay. *J. Mar. Res*. 70:279-308.

Table 1. Sampling schedule for the NJ Delaware Bay Oyster Seed Bed Long-term Monitoring Program during 2012. The six long-term sites are Hope Creek grid 64, Arnolds grid 18, Cohansey grid 44, Shell Rock corner of grids 10, 11, 19 & 20, Bennies grid 110 and New Beds grid 26. Parameters measured include temperature, salinity, dissolved oxygen, counts of live oysters and boxes, size frequency (shell height), and Dermo levels.

| Date | Samples | Vessel | Captain |
|---|---|---|---|
| Mar 21, 2012 | 6 long-term sites<br>Beadon's spat transplant<br>Post – Irene mortality check | NJDEP RV Zephryus | Jason Hearon |
| May 4, 2012 | 6 long-term sites<br>2 intermediate transplants<br>Beadon's spat transplant<br>5 shellplant sites (2010, 2011) | NJDEP RV Zephryus | Jason Hearon |
| May 21, 2012 | 6 long-term sites<br>2 intermediate transplants<br>Beadon's spat transplant<br>5 shellplant sites (2010, 2011) | NJDEP RV Zephryus | Craig Tomlin |
| Jun 18, 2012 | 6 long-term sites<br>3 intermediate transplants<br>Beadon's spat transplant<br>5 shellplant sites (2010, 2011) | NJDEP RV Zephryus | Craig Tomlin |
| July 16, 2012 | 6 long-term sites<br>2 intermediate transplants<br>Beadon's spat transplant<br>5 shellplant sites (2010, 2011) | NJDEP RV Zephryus | Craig Tomlin |
| Aug 20, 2012 | 6 long-term sites<br>2 intermediate transplants<br>5 shellplant sites (2010, 2011) | NJDEP RV James W. Joseph | Craig Tomlin |
| Sep 17, 2012 | 6 long-term sites<br>2 intermediate transplants<br>5 shellplant sites (2010, 2011) | NJDEP RV James W. Joseph | Craig Tomlin |
| Oct 1, 2012 | 3 new shellplant sites (2012) | NJDEP RV James W. Joseph | Jason Hearon |
| Oct 22, 2012 | 6 long-term sites<br>2 intermediate transplants<br>5 shellplant sites (2010, 2011) | NJDEP RV James W. Joseph | Craig Tomlin |
| Nov 16, 2012 | 8 shellplant sites (2010, 2011, 2012) | NJDEP RV James W. Joseph | Craig Tomlin |
| Nov 30, 2012 | 6 long-term sites<br>2 intermediate transplants | NJDEP RV James W. Joseph | Craig Tomlin |

**Table 2.** Additional sites sampled during 2012. Replant = shell planted in lower Delaware Bay then moved to bed indicated after spat have recruited.

| Bed | Grid | Plant material | Plant yr |
|---|---|---|---|
| Ship John | 36 | ocean quahog | 2012 |
| Ship John | 53 | ocean quahog | 2012 |
| Middle | 27 | surf clam shell replant | 2012 |
| | | | |
| Bennies Sand | 11 | ocean quahog | 2011 |
| Shell Rock | 11 | ocean quahog | 2011 |
| Middle | 26 | surf clam shell replant | 2011 |
| | | | |
| Bennies Sand | 4 | surf clam | 2010 |
| Shell Rock | 23 | ocean quahog | 2010 |
| | | | |
| Nantuxent | 20 | med mortality transplant | 2012 |
| Bennies Sand | 12 | med mortality transplant | 2012 |
| Bennies | 102 | Beadon’s spat transplant | 2011 |
| | | | |
| Fishing Creek | 16 | post-Irene mortality check | 2011 |
| Liston Range | 24 | post-Irene mortality check | 2011 |
| Round Island | 11 | post-Irene mortality check | 2011 |
| Middle | 20 | post-Irene mortality check | 2011 |

**Table 3.** Record of collections for annual fall Dermo monitoring since 1990. X indicates bed was sampled in respective year for that column. Beds are listed approximately by latitude, although some lie at the same latitude with different longitudes.

| SEEDBED | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 2000 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hope Creek | | | | | | | | | | | | | | | | | | X | X | X | X | X | X |
| Liston Range | | | | | | | | | | | | | | | | | | | X | X | X | X | X |
| Fishing Creek | | | | | | | | | | | | | | | | | | | X | X | X | X | X |
| Round Island | X | X | X | X | 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 | X | X | X | X |
| Arnolds | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Upper Middle | | | | | | | | | | | | | | | | | X | X | X | X | X | X | X |
| Middle | X | X | X | X | 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 | X | X | X | X |
| Sea Breeze | | | | | | | | | | | | | | | X | X | X | X | X | X | X | X | X |
| Ship John | X | X | X | X | 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 | X | X | X | X |
| Bennies Sand | X | X | X | X | 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 | X | X | X | X |
| Nantuxent | | X | | X | | X | | X | | 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 | 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 | X | X | X | X |
| Strawberry | X | | X | | X | | | | | | | | X | 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 | X | X | X | X |
| Beadons | X | X | X | X | 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 | X | X | X | X |
| Egg Island | X | X | X | X | X | X | X | X | | X | X | X | | X | | X | | X | | X | | X | |
| Ledge Bed | | | X | | X | | | | X | | X | | X | | X | | X | | X | | X | | X |

Table 4. 2012 Delaware Bay Oyster Seedbed Stock Assessment Survey grids sampled for Dermo, MSX, condition index (CI) and size frequencies. Numbers represent grid ID or the number of oysters processed.

| Bed | Grid | Dermo | MSX | CI |
|---|---|---|---|---|
| Hope Creek | 43 | 10 | | 15 |
| Hope Creek | 75 | 10 | | 15 |
| Hope Creek | 86 | | | 10 |
| Hope Creek | 54 | | | 10 |
| Hope Creek | 63 | | 20 | 0 |
| Fishing Creek | 16 | 10 | | 17 |
| Fishing Creek | 25 | 10 | | 17 |
| Fishing Creek | 36 | | | 16 |
| Liston Range | 21/22 | 10 | | 14 |
| Liston Range | 24 | 10 | | 15 |
| Liston Range | 18 | | | 11 |
| Liston Range | 2 | | | 10 |
| Round Island | 12 | 10 | | 15 |
| Round Island | 2 | 10 | | 15 |
| Round Island | 11 | | | 10 |
| Round Island | 68 | | | 10 |
| Upper Arnolds | 10 | 10 | | 15 |
| Upper Arnolds | 16 | 10 | | 15 |
| Upper Arnolds | 2 | | | 10 |
| Upper Arnolds | 5 | | | 10 |
| Arnolds | 3 | 10 | | 15 |
| Arnolds | 16 | 10 | | 15 |
| Arnolds | 2 | | | 10 |
| Arnolds | 7 | | | 10 |
| Arnolds | 18 | | 20 | 0 |
| Upper Middle | 63 | 10 | | 15 |
| Upper Middle | 58 | 10 | | 15 |
| Upper Middle | 71 | | | 10 |
| Upper Middle | 1 | | | 10 |
| Middle | 28 | 10 | | 15 |
| Middle | 43 | 10 | | 15 |
| Middle | 17 | | | 10 |
| Middle | 35 | | | 10 |
| Cohansey | 8 | 10 | | 15 |
| Cohansey | 57 | 10 | | 15 |
| Cohansey | 20 | | | 10 |
| Cohansey | 54 | | | 10 |
| Cohansey | 44 | | 20 | 0 |
| Sea Breeze | 37 | 10 | | 15 |
| Sea Breeze | 20 | 10 | | 15 |
| Sea Breeze | 29 | | | 10 |
| Sea Breeze | 15 | | | 10 |
| Ship John | 21 | 10 | | 15 |
| Ship John | 39 | 10 | | 15 |
| Ship John | 24 | | | 10 |
| Ship John | 49 | | | 10 |
| Shell Rock | 9 | 10 | | 15 |
| Shell Rock | 46 | 10 | | 15 |
| Shell Rock | 35 | | | 10 |
| Shell Rock | 7 | | | 10 |
| Shell Rock | 11 | | 20 | 0 |
| Bennies Sand | 7 | 10 | | 15 |
| Bennies Sand | 20 | 10 | | 15 |
| Bennies Sand | 5 | | | 10 |
| Bennies Sand | 1 | | | 10 |
| Bennies | 148 | 10 | | 13 |
| Bennies | 43 | 10 | | 12 |
| Bennies | 114 | | | 11 |
| Bennies | 18 | | | 14 |
| Bennies | 110 | | 20 | 0 |
| Nantuxent | 18 | 10 | | 15 |
| Nantuxent | 13 | 10 | | 15 |
| Nantuxent | 8 | | | 10 |
| Nantuxent | 30 | | | 10 |
| Hog Shoal | 19 | 10 | | 12 |
| Hog Shoal | 4 | 10 | | 15 |
| Hog Shoal | 7 | | | 12 |
| Hog Shoal | 12 | | | 11 |
| New Beds | 16 | 10 | | 13 |
| New Beds | 83 | 10 | | 10 |
| New Beds | 2 | | | 14 |
| New Beds | 55 | | | 13 |
| New Beds | 26 | | 20 | 0 |
| Strawberry | 5 | 10 | | 23 |
| Strawberry | 16 | 5 | | 5 |
| Strawberry | 1 | 5 | | 17 |
| Strawberry | 11 | | | 5 |
| Hawks Nest | 27 | 10 | | 16 |
| Hawks Nest | 9 | 6 | | 12 |
| Hawks Nest | 1 | | | 18 |
| Hawks Nest | 28 | | | 4 |
| Beadons | 18 | 10 | | 10 |
| Beadons | 4 | 10 | | 10 |
| Beadons | 5 | | | 15 |
| Beadons | 3 | | | 15 |
| Vexton | 4 | 10 | | 14 |
| Vexton | 9 | 10 | | 14 |
| Vexton | 3 | | | 22 |
| Ledge | 6 | 10 | 10 | 7 |
| Ledge | 13/14 | 10 | 10 | 18 |
| Ledge | 8 | | | 6 |
| **Total beds** | **22** | **22** | **7** | **22** |
| **Total grids** | **91** | **45** | **8** | **85** |
| **Total oysters** | | **436** | **140** | **1081** |

Table 5. Sex ratios detected during monthly seedbed monitoring expressed as the percentage of males or females detected in each Dermo sample (n = 20, data are shown as percent). Beds are listed upbay to downbay. Hermaphrodites and individuals whose sex was not discernable are not shown.

| | May 21 | | June 18 | | July 16 | | August 20 | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bed | M | F | M | F | M | F | M | F | M | F |
| Hope Creek | 40 | 30 | 40 | 55 | 25 | 30 | 35 | 60 | 36 | 51 |
| Arnolds | 45 | 55 | 25 | 75 | 30 | 35 | 30 | 45 | 34 | 60 |
| Cohansey | 20 | 50 | 45 | 55 | 30 | 35 | 15 | 50 | 29 | 54 |
| Shell Rock | 40 | 50 | 30 | 70 | 20 | 40 | 0 | 55 | 28 | 59 |
| Bennies | 50 | 50 | 55 | 45 | 50 | 25 | 30 | 35 | 40 | 51 |
| New Beds | 25 | 75 | 55 | 45 | 20 | 30 | 25 | 50 | 34 | 60 |
| Total | 37 | 52 | 42 | 58 | 33 | 65 | 23 | 49 | 33 | 56 |

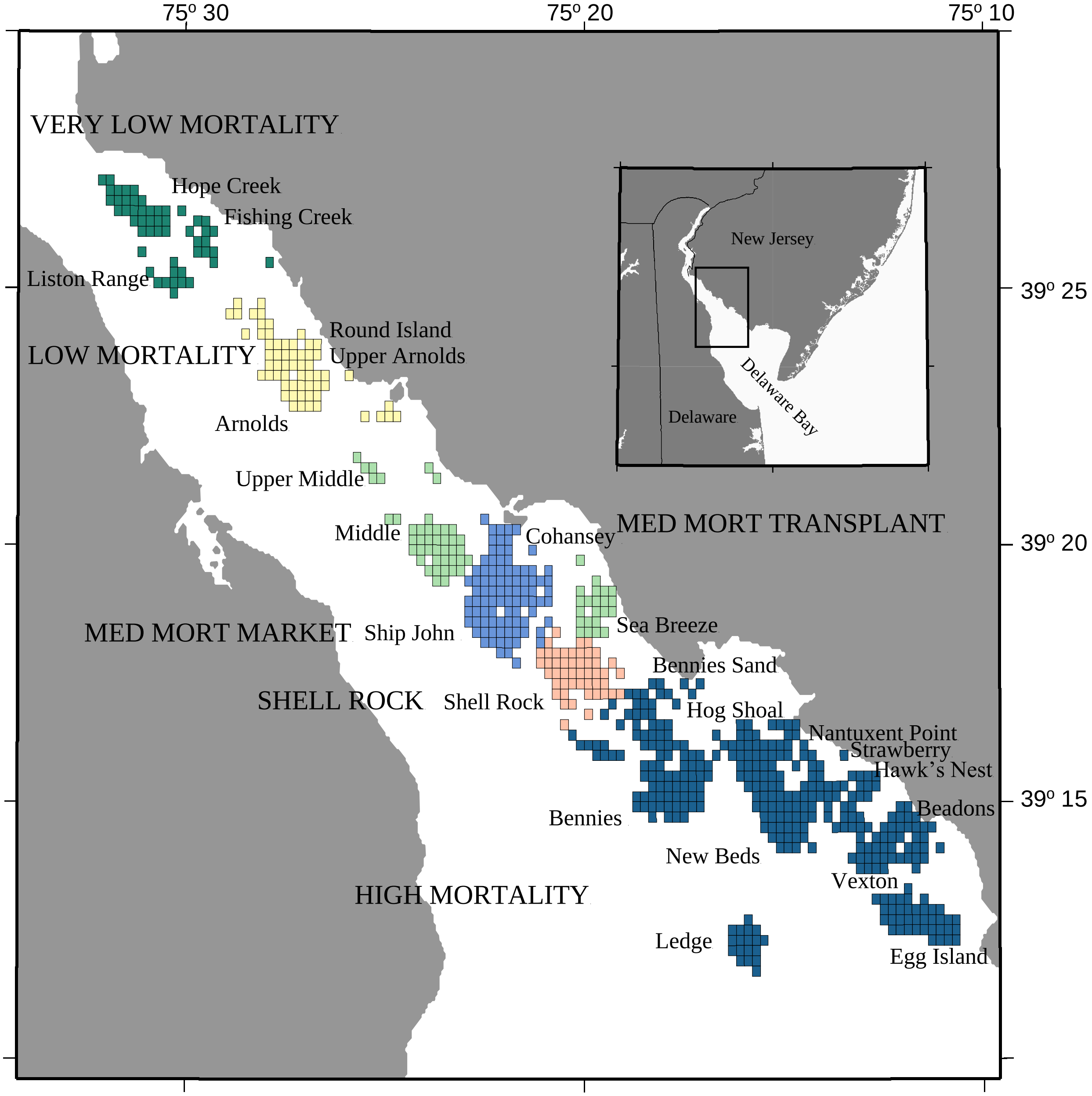



Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Colors differentiate boundaries of regions as defined by the area management system (Powell et al 2012a). For this report, references to the low mortality region generally includes the very low region unless noted, and the medium mortality region includes the medium mortality transplant, medium mortality market and shell rock.

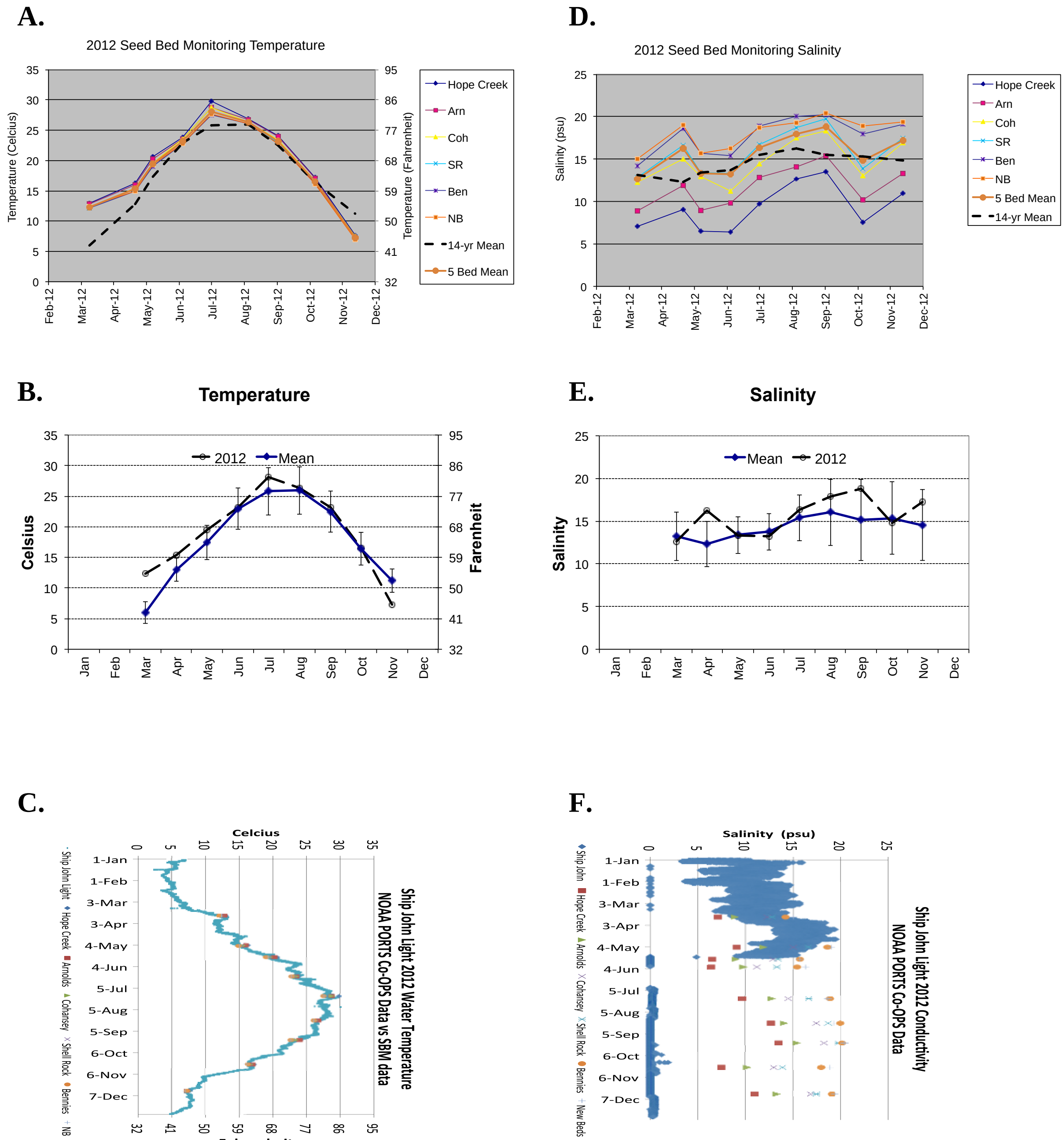
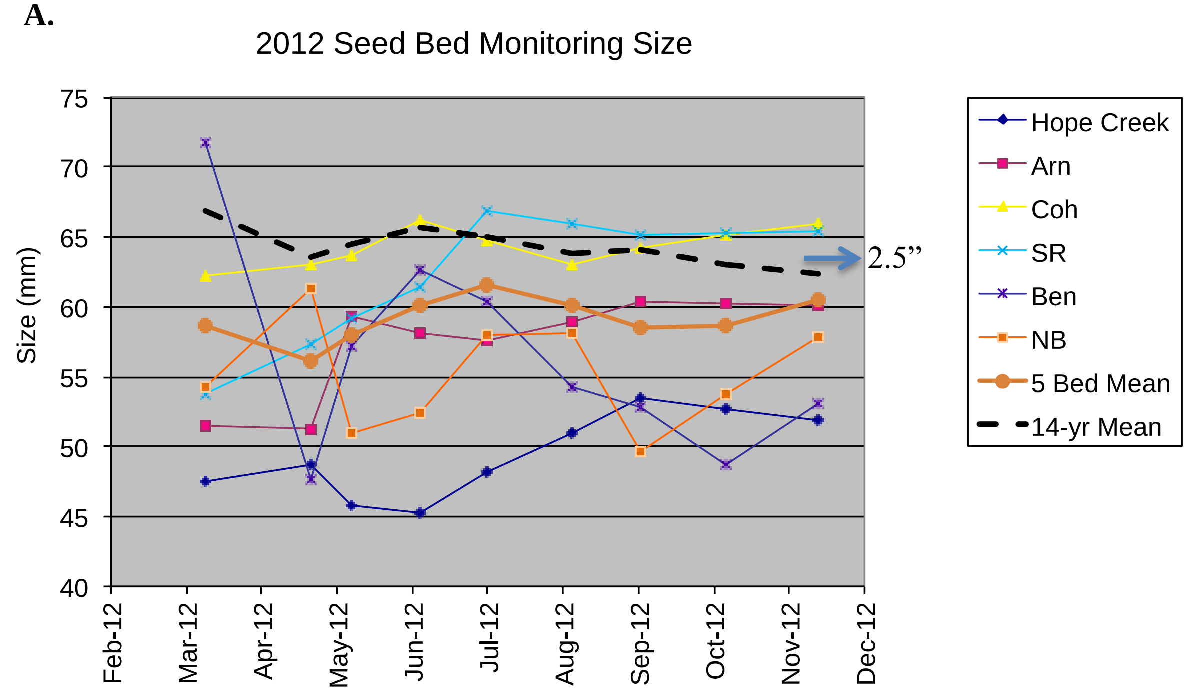



Figure 2. Monthly water temperature and salinity measurements taken during 2012 seedbed monitoring at long-term stations and at a continuous monitoring station at the Ship John Shoal Light. A) Temperature at each bed, mean of five long-term beds for 2012 and mean of five long-term beds since 1999. B) Mean temperature across beds for 2012 and since 1999 (+/- 1 sd). C) Continuously monitored temperature at Ship John Shoal Light during 2012 with SBM data. D) Salinity at each bed, mean of five long-term beds for 2012 and mean of five long-term beds since 1999. E) Mean salinity across beds for 2012 and since 1999 (+/- 1 sd). F) Continuously monitored salinity at Ship John Shoal Light (source: http://tidesandcurrents.noaa.gov/) during 2012 with SBM collection data.

A.




B.

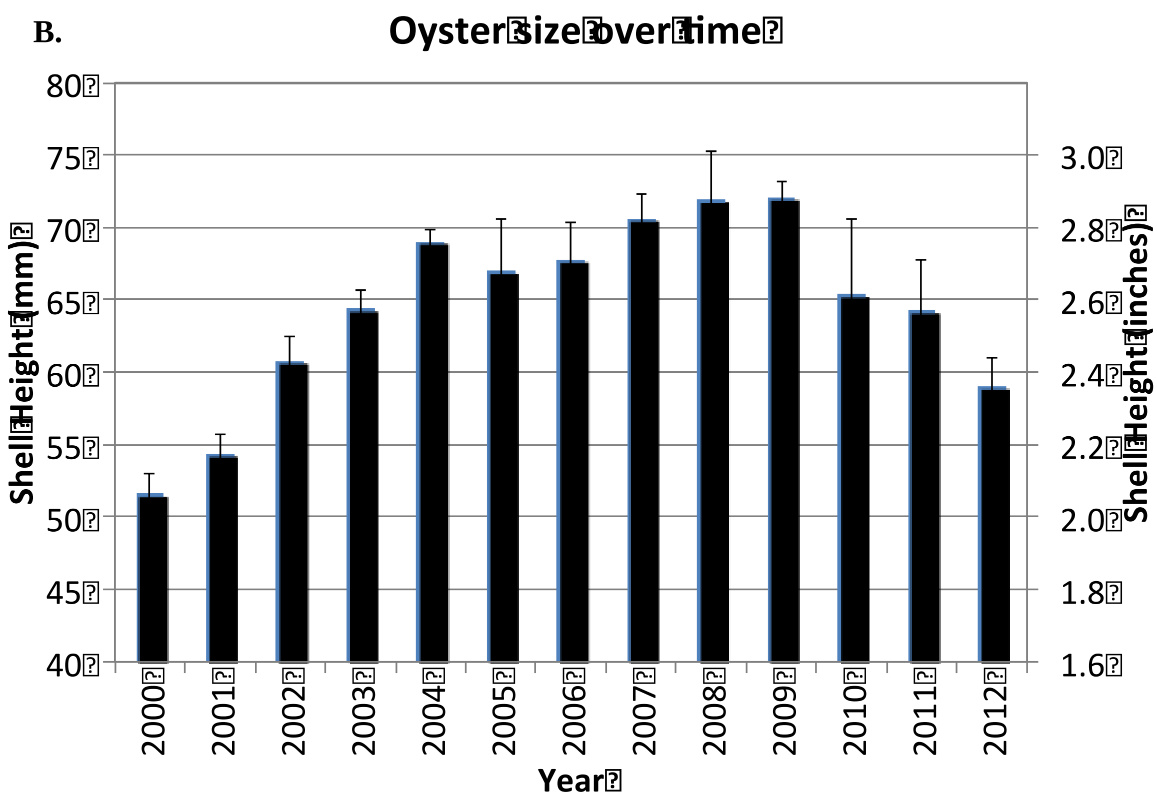



Figure 3. Mean shell height of oysters collected from Delaware Bay NJ oyster seedbeds. A) Mean size collected in monthly dredge samples by bed. B) Means of monthly collections from April to September averaged across beds annually.

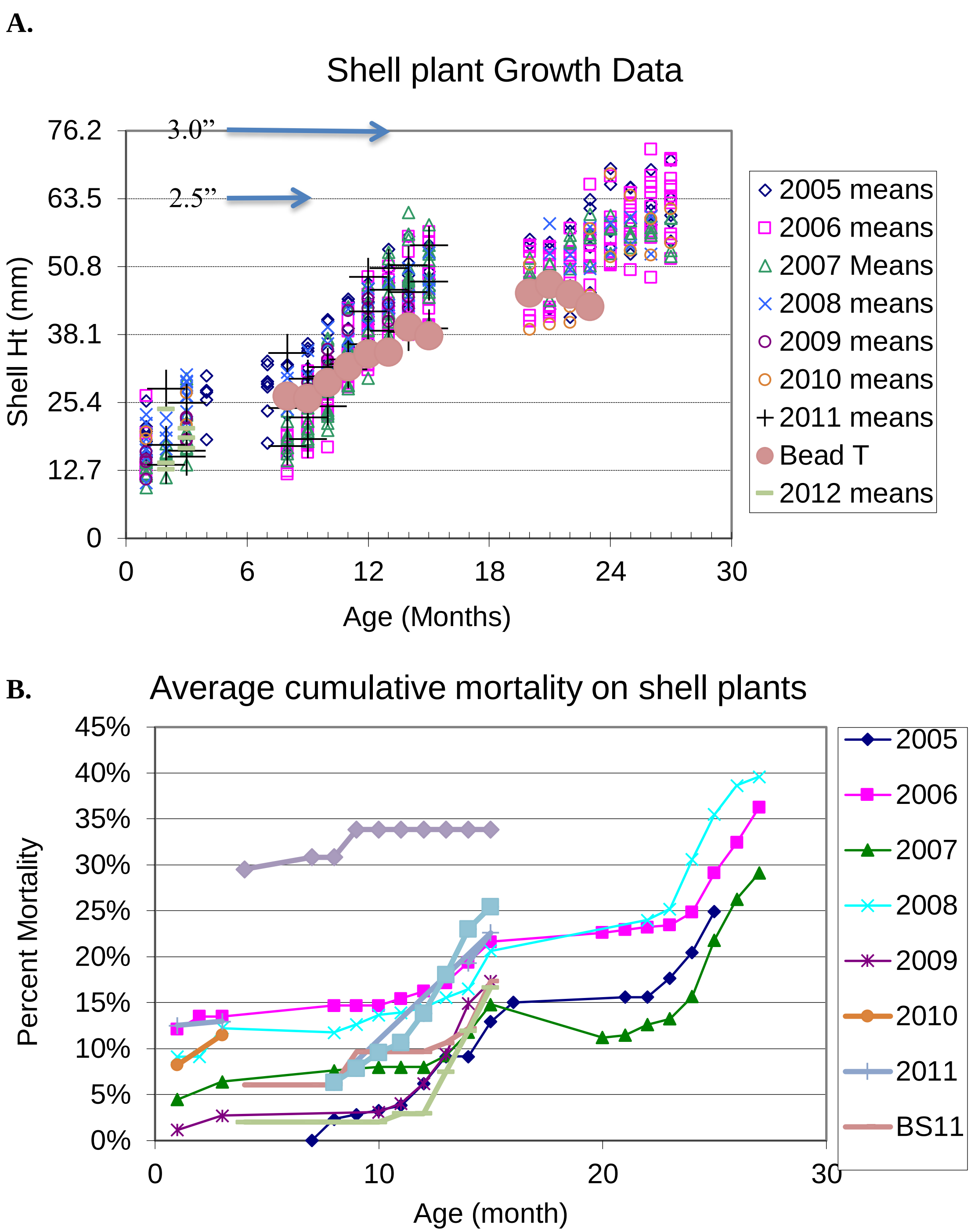



Figure 4. Growth (A) and mortality (B) on shell plantings since 2005 and the 2011 Beadons yearling transplant. Growth data are means of ~100 individuals per shell plant. Mortality data are averaged across plantings, with individual values for 2011 (BS = Bennies Sand, SR = Shell Rock, Mid = Middle, BeadT = Beadons transplant). Initial collections are made the year the shell is planted. Age during the first collection is presumed to be about one month, but could be a few days to three months depending on the timing of setting during that year. Efforts were made to only measure oysters from the year class corresponding to the year of the shell plant.

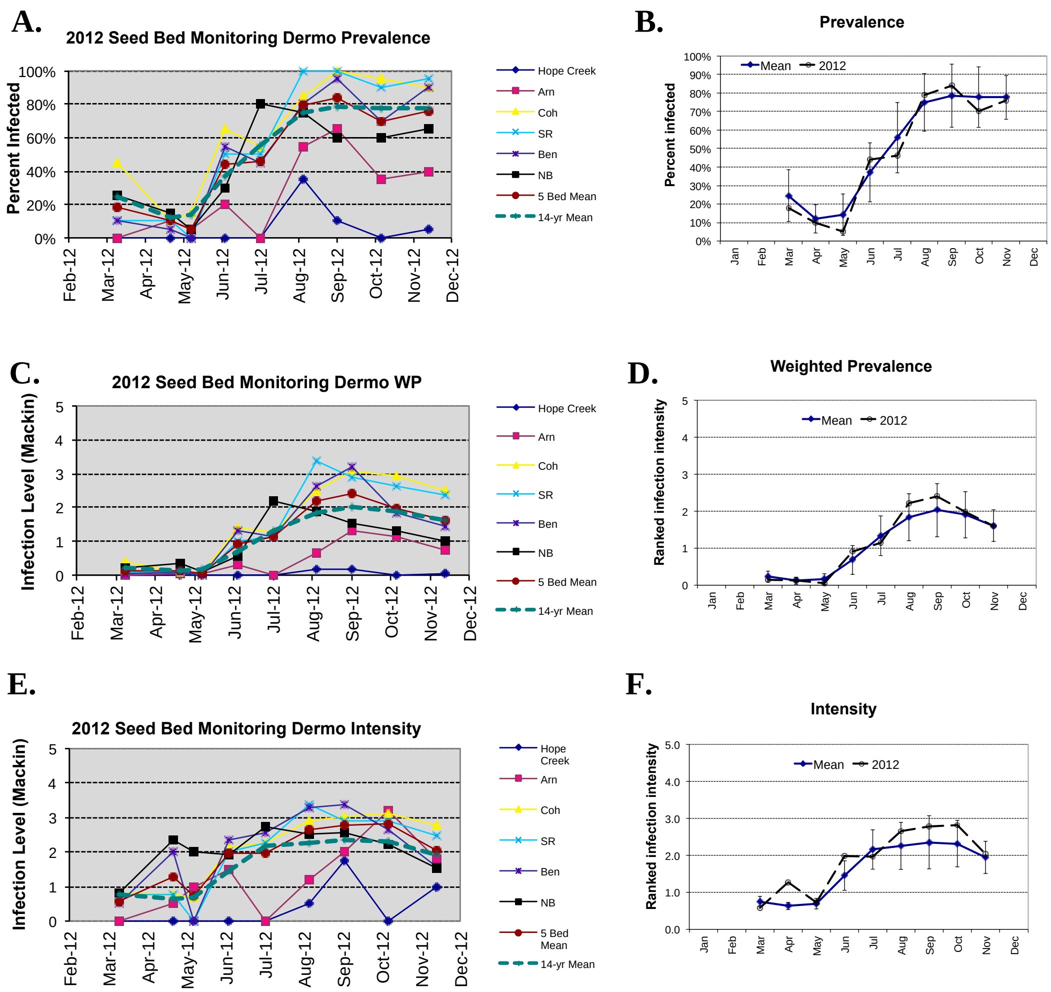



Figure 5. Monthly measures of Dermo disease in oysters from New Jersey Delaware Bay. Prevalence = percent of infected oysters. Weight prevalence (WP) = the average Mackin scale Dermo infection intensity rank of all oysters sampled including those with no detectable infection (i.e., rank = zero). Intensity = average Mackin rank of detectable infections only. Right panels compare mortality for 2012 with mean and standard deviation since 1999 on five long-term monitoring beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds).

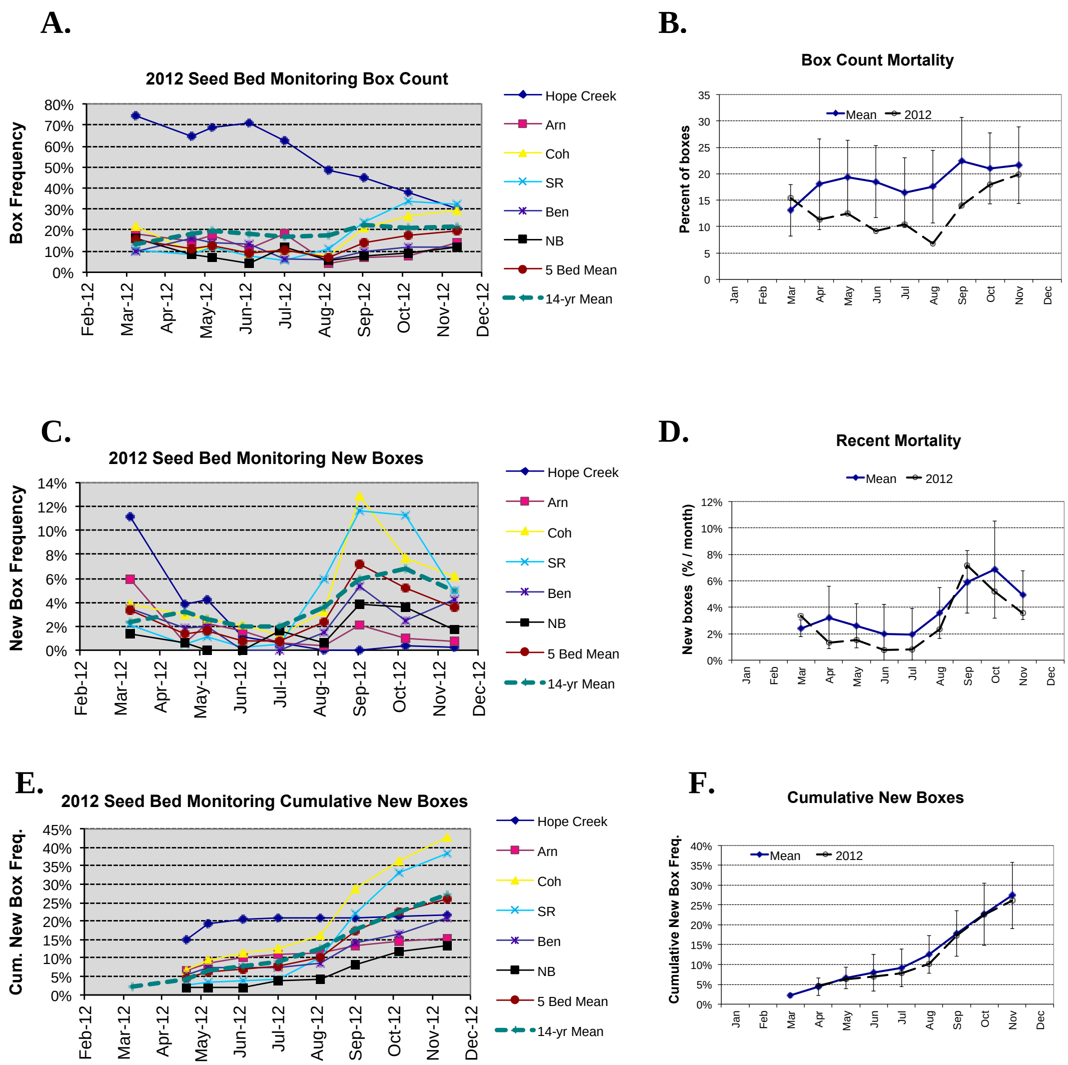
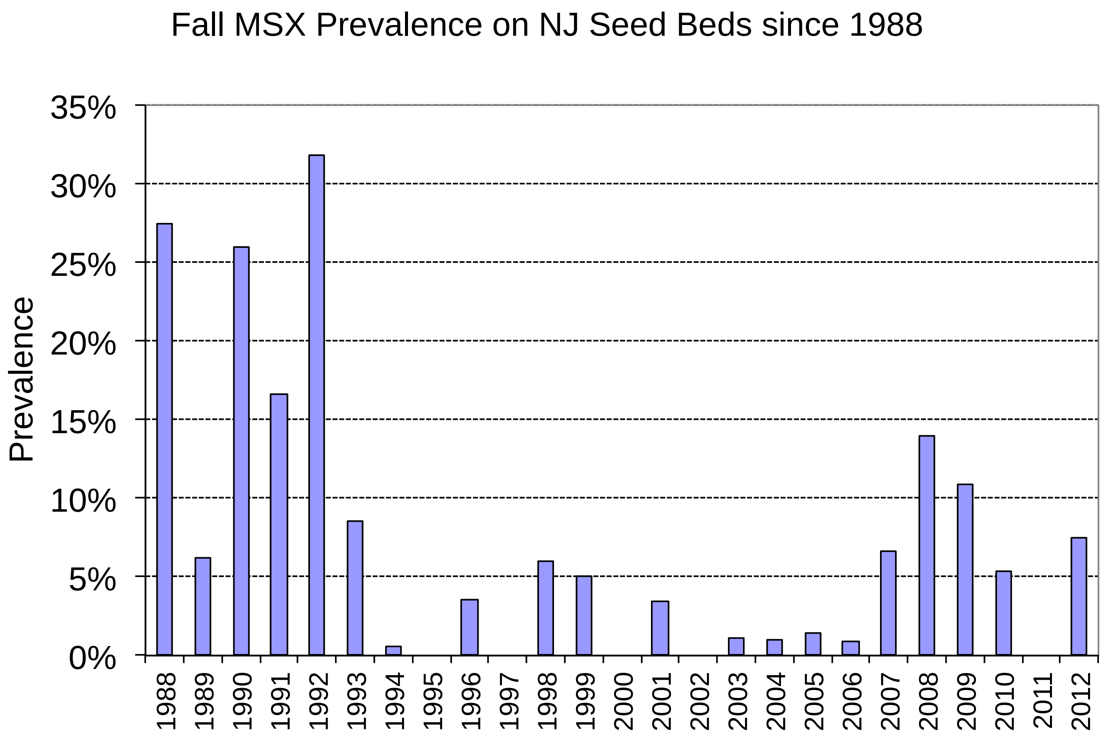



Figure 6. Monthly estimates of oyster mortality on the New Jersey Delaware Bay seedbeds. Left panels show mortality by bed. Right panels compare mortality for 2012 with mean and standard deviation since 1999 on five long-term monitoring beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds – note Hope Creek is not included).

**A.**




**B.**

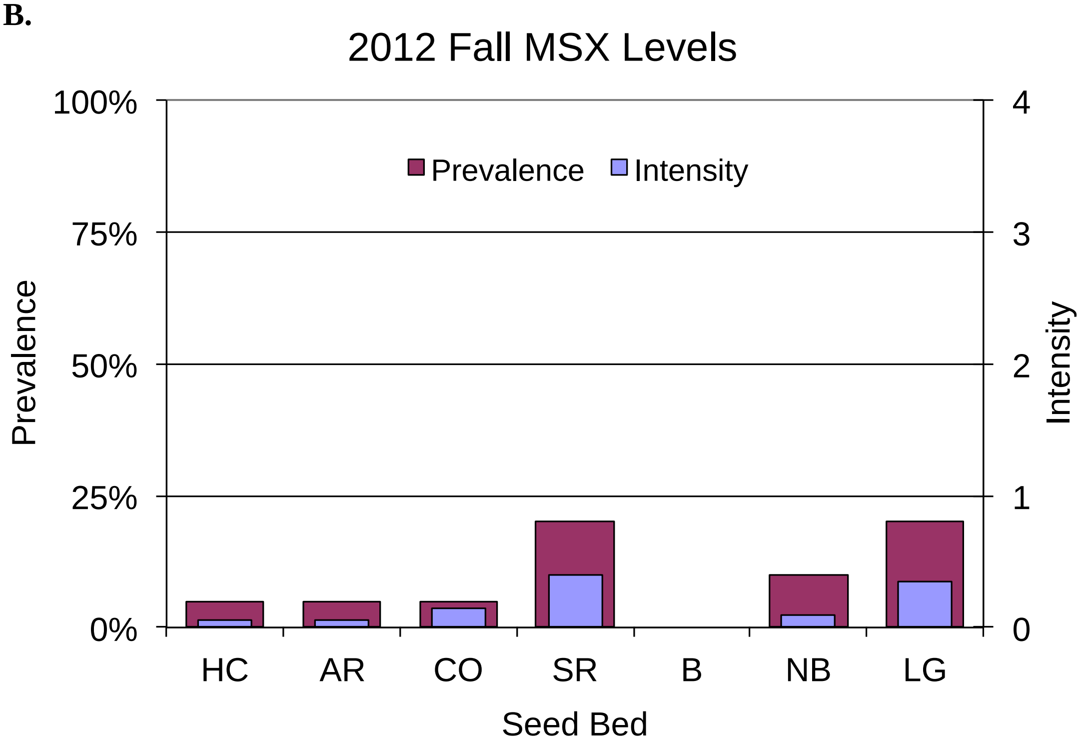



Figure 7. MSX disease on the New Jersey Delaware Bay oyster seedbeds. (A). Annual Fall MSX Prevalence. (B). Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) since 1988 (2007 for HC). HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, LG = Ledge.

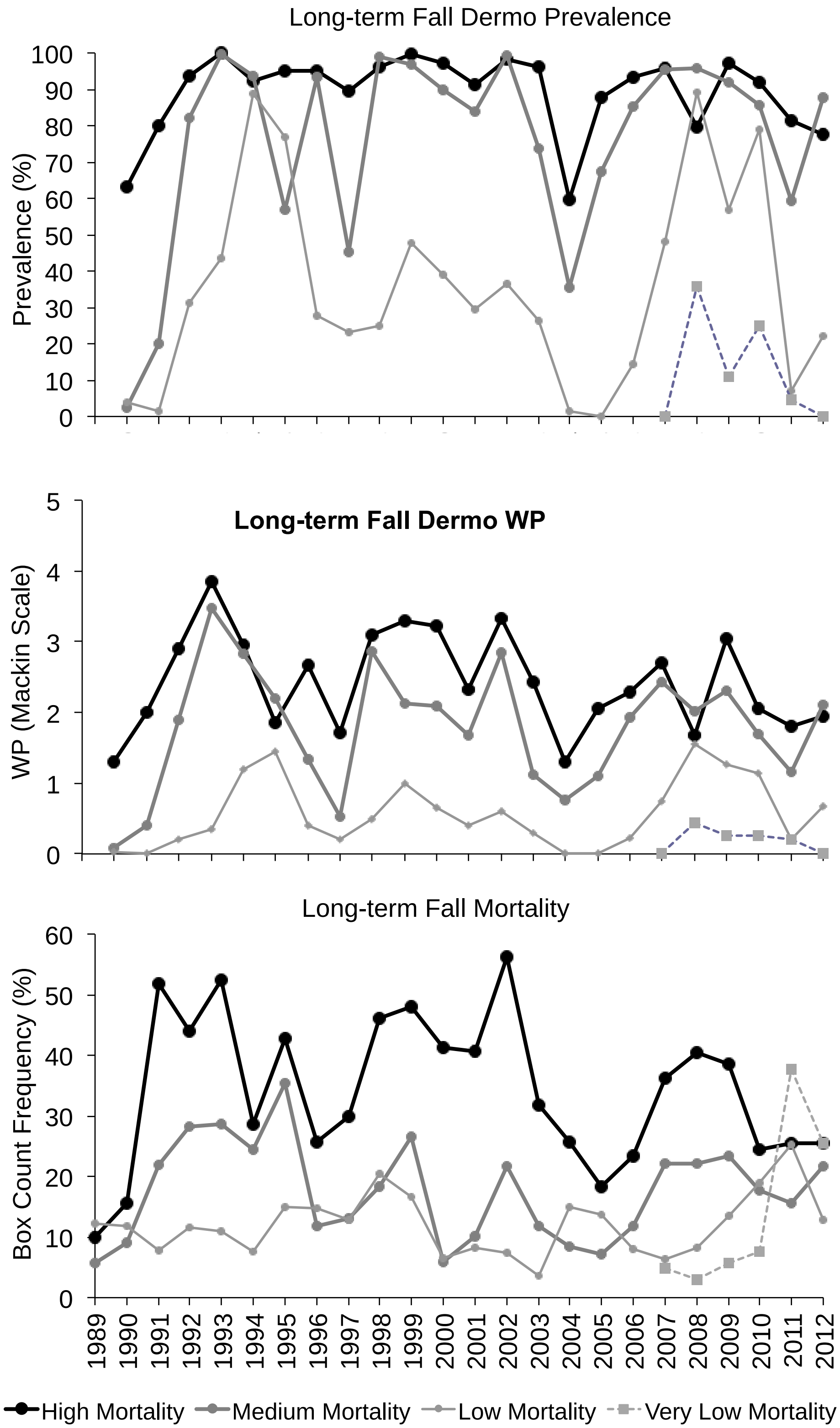



Figure 8. Annual Fall Dermo prevalence, weighted prevalence and box count mortality on New Jersey Delaware Bay seedbeds.

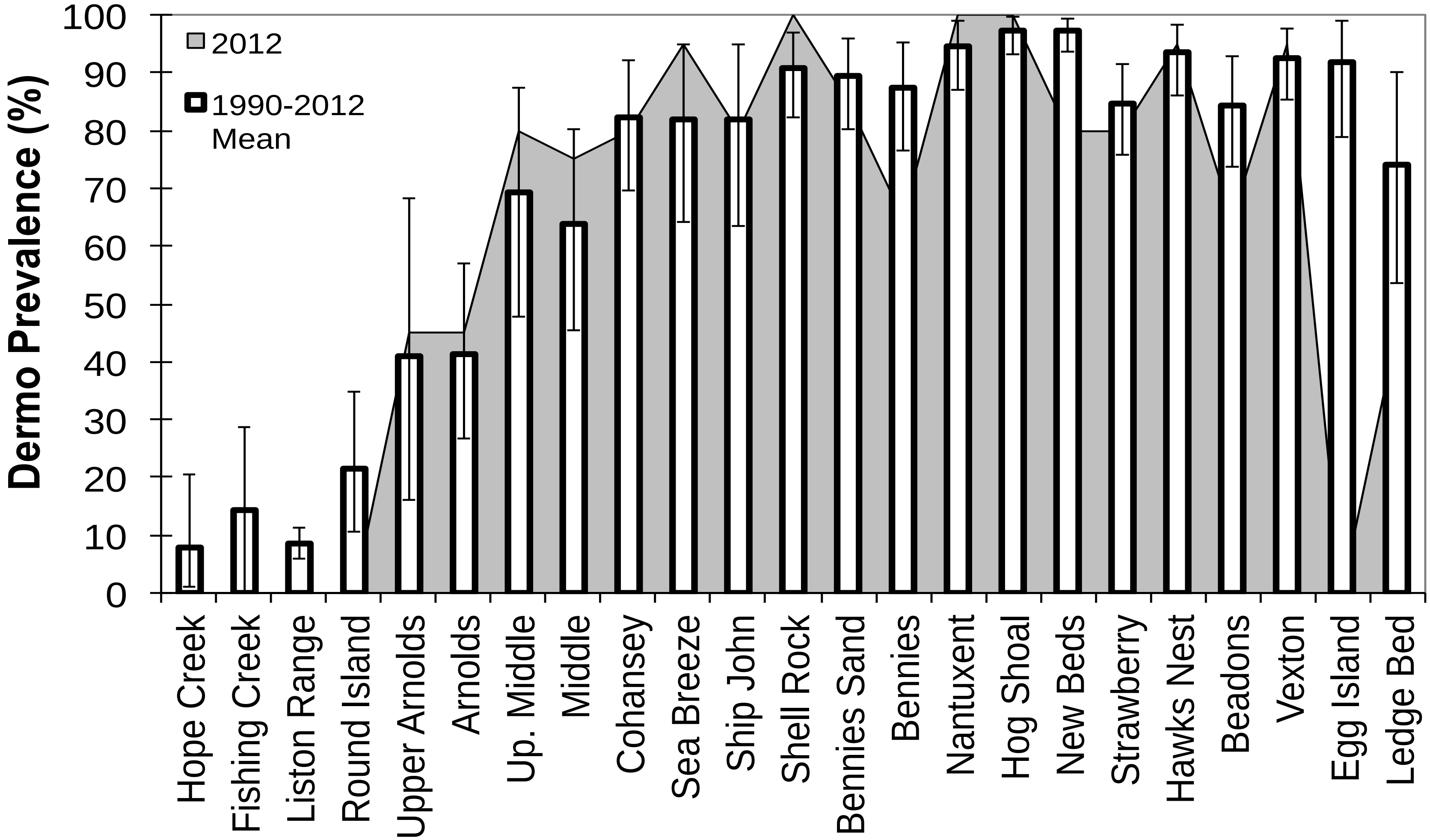



Figure 9. Comparison of average fall *Perkinsus marinus* (Dermo) prevalence in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars) with 2012 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2012. Error bars represent 95% confidence intervals.

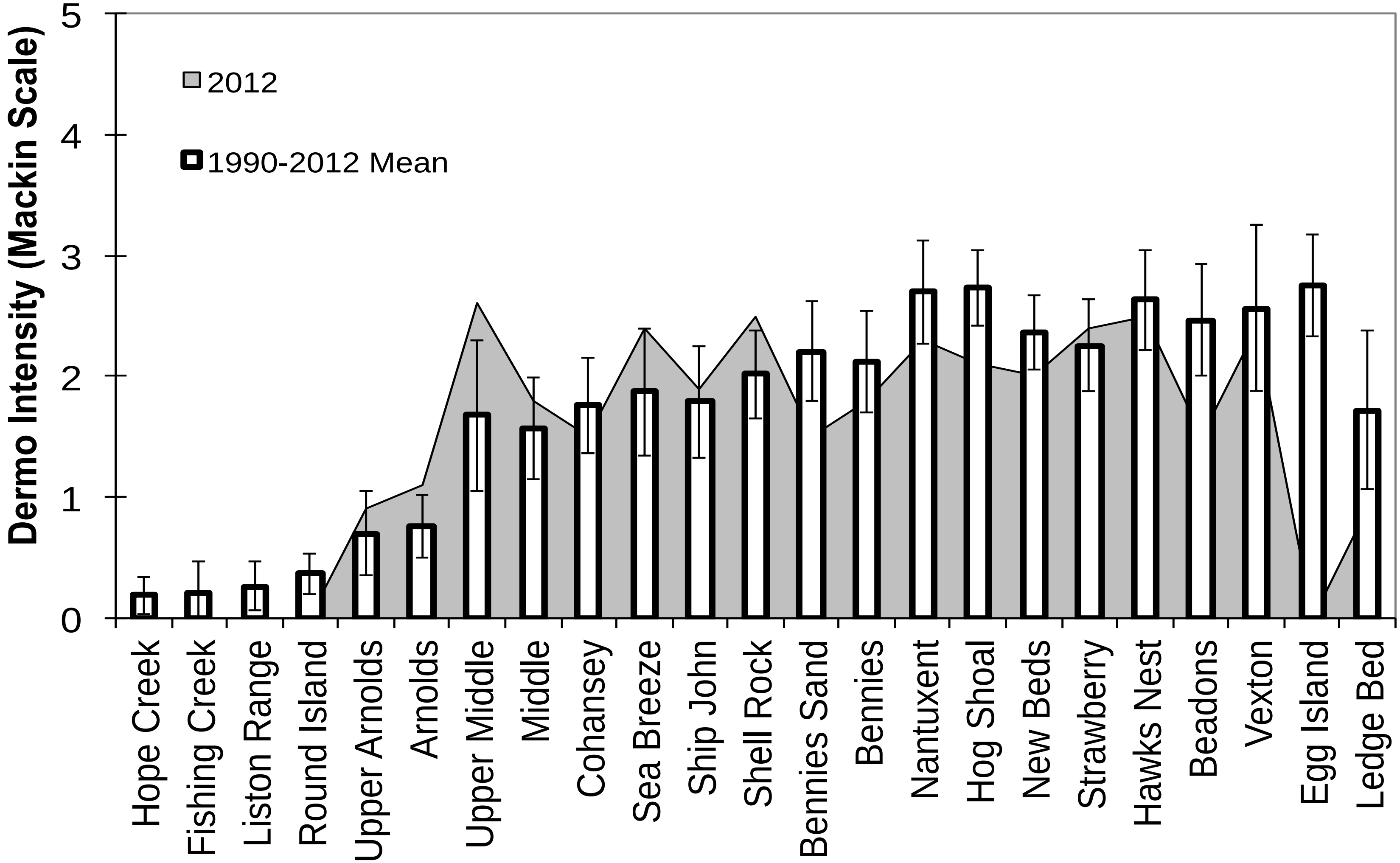



Figure 10. Comparison of average fall Dermo infection intensities (weighted prevalence) in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars) with 2012 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2012. Error bars represent 95% confidence intervals.

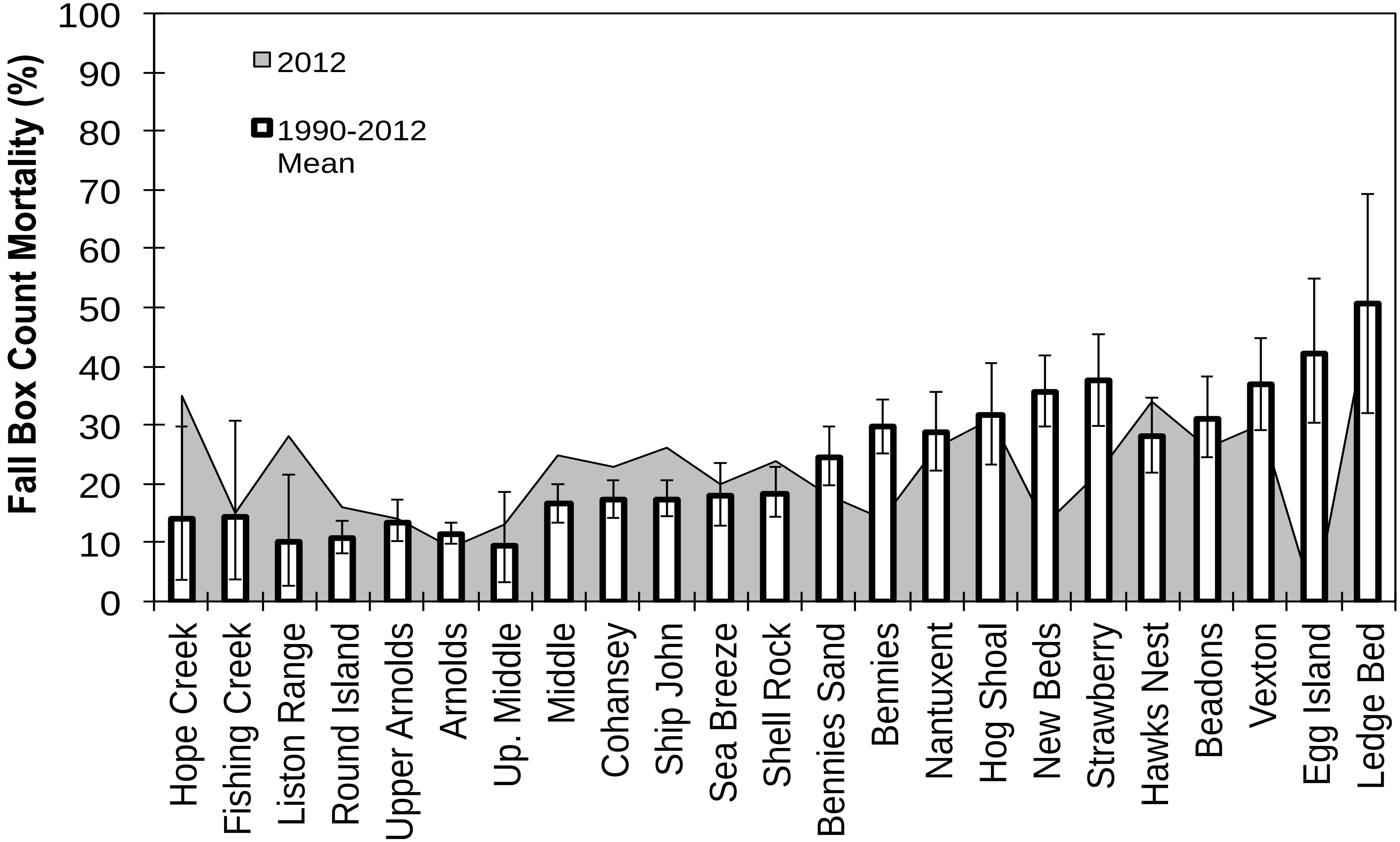



Figure 11. Comparison of average annual fall estimated box-count mortality of oysters on New Jersey Delaware Bay seedbeds since 1989 (open bars) with 2012 levels (shaded area). Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2012. Error bars represent 95% confidence intervals.

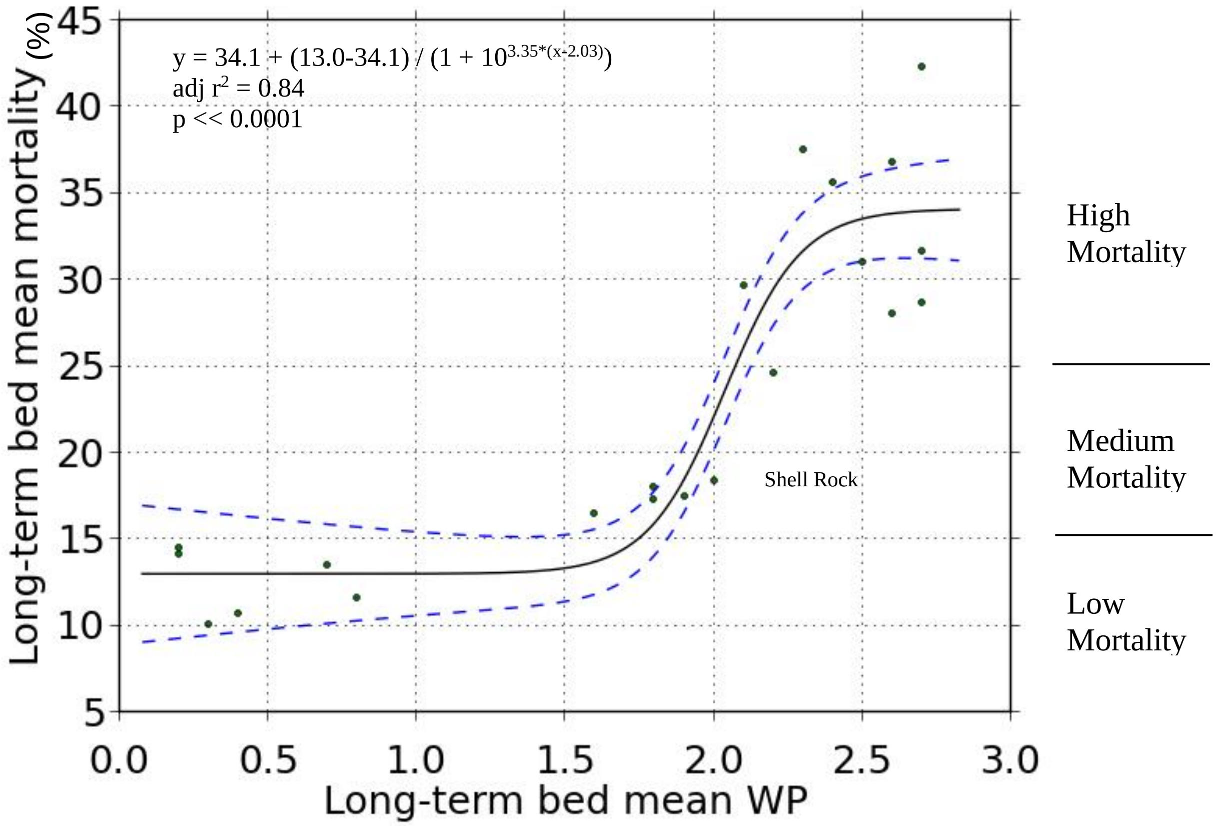
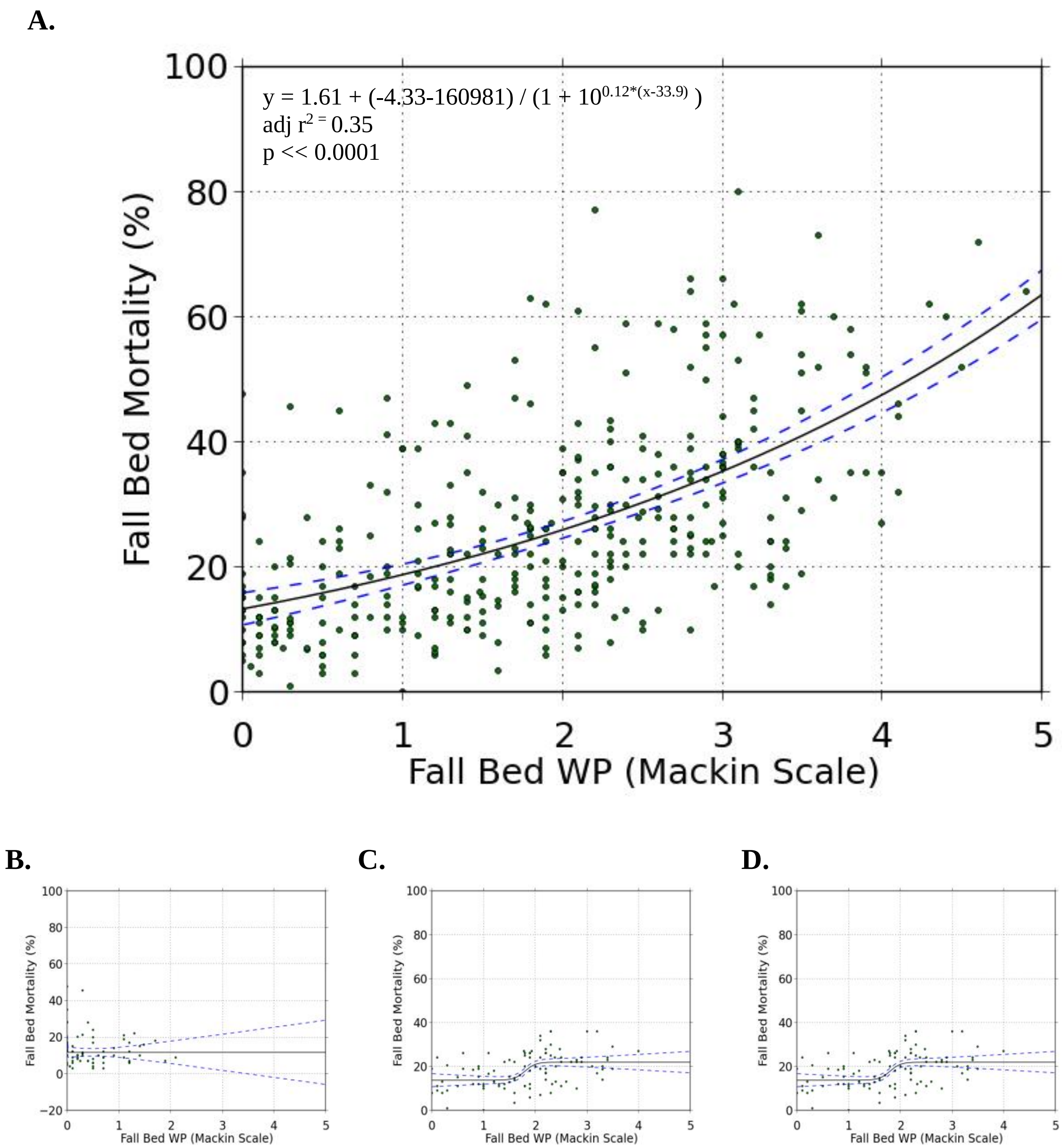



Figure 12. Relationship between long-term mean fall box count mortality estimate and the long-term mean intensity of Dermo infections since 1990. Data are individual bed estimates. Error bars not shown for clarity. Ledge and Upper Middle removed as outliers, each with WP = 1.7 and mortalities equal to 9.5% and 50.7% respectively. Regression equation calculated as a dose-response function using the equation shown in online software from ZunZun.com. Dashed lines are 95% confidence intervals. Note the precarious position of Shell Rock.




$y = -11.9 + (21.8-11.9) / (1 + 10^{197.5*(x-0.00148)})$
adj $r^2 = 0.06$
$p = 0.08$

$y = 13.8 + (22.1-13.8) / (1 + 10^{\wedge 4.19*(x-1.79)})$
adj $r^2 = 0.20$
$p << 0.0001$

$y=138147+(17.9-138147)/(1+10^{0.179*(x-24.3)})$
adj $r^2 = 0.21$
$p << 0.0001$

Figure 13. Relationship between fall box count mortality and Dermo infection levels (WP). Data are values for individual beds collected during the annual fall stock assessment from 1990 through 2012. A. All beds. B. Very low and low mortality beds. C. Medium mortality beds. D. High mortality beds.