Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2011 Status Report

Prepared by

David Bushek
Haskin Shellfish Research Laboratory
New Jersey Agricultural Experiment Station
Rutgers, The State University of New Jersey

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Distribution List:
- Stock Assessment Review Committee
- Delaware Bay Section of the Shell Fisheries Council
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Executive Summary:

The 2011 Delaware Bay New Jersey Oyster Seedbed Monitoring Program followed Dermo disease, oyster growth, and oyster mortality at six long-term monitoring sites (Hope Creek was added in 2007), three transplant sites, a special yearling transplant from Beadons, and three 2011 shell plants. Limited funding restricts what can be monitored so monitoring performance of 2009 and 2010 shell plants was not completed during 2011. 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 seedbeds.

Monthly monitoring data from 2011 indicated an unusual year resulting from unusually low salinity throughout much of the year; particularly following the passage of Hurricane Irene and Tropical Storm Lee, which dropped copious amounts of precipitation in the Bay's watershed. These conditions were unfavorable to the development of MSX and Dermo disease resulting in an overall depression of these diseases across the seedbeds. In fact, MSX was not detected on the seedbeds during the Fall Stock Assessment signaling the end of a brief resurgence that never presented a significant threat to the oyster population. The depression of Dermo disease coincides with an apparent 7-year cycle, but the driving force of this cycle remains elusive. Unfortunately, salinity was depressed so low that it caused extensive oyster mortality on the uppermost beds. Mortality also increased on the low mortality beds that have recently become an important contributor to the intermediate transplant program. Mean oyster size continued to decline indicating a return to a more normal size (and age) distribution that had become skewed towards larger and older larger animals. Shell plants performed similarly to previous years, while the Beadon's transplant of yearlings experienced relatively slow growth and high mortality relative to shell plantings during this first year of that transplant. Overall, oysters entered the winter with relatively little disease, but many, especially on the upper half of the seedbeds were in relatively poor condition from the depressed salinity following tropical storms Irene and Lee.

Prognosis: The impacts of tropical storms Irene and Lee were mixed. Dramatically depressed salinity caused fresh water mortality and poor condition on the upper half of the seedbeds. Low salinity also depressed MSX and Dermo across the seedbed region, which improved survival on downbay beds. The resilience of Dermo, however, was evident as prevalence and infection intensities began to increase quickly as salinity began to increase. While MSX lingers in the background it poses significantly less risk than in the past. In contrast, Dermo continues to pose a considerable risk across the seedbeds whenever conditions are conducive to its spread and intensification. Fortunately, Dermo levels were low entering winter and spring usually brings a further reduction in disease levels. Assuming favorable conditions in the coming spring, the impact of Dermo may remain comparatively low during 2012. Of greater immediate concern is the condition of oysters entering winter and their overwintering survival. **An overwintering mortality estimate should be completed in April to guide final decisions on management of the resource. Furthermore, the continuing increase in mortality on the low mortality beds is a cause for concern of their stability and continued role in the intermediate transplant program.**

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 oyster resource for sustainable harvest. Oyster production that occurs on privately owned leases below the state managed natural seedbeds or in closed waters is not currently monitored by this program. 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. Long-term spatial monitoring during the annual stock assessment provides insight into inter-annual patterns, including long-term trends and potential factors affecting the oyster stock.

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 (Ford and Bushek 2006, 2012 in press). Naïve oysters routinely deployed at the Rutgers Cape Shore field site become heavily infected, indicating that the parasite is still present and abundant in the Bay. 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 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. 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 three new beds: Hope Creek, Fishing Creek and Liston Range.

The majority of fresh water entering the system comes from the Delaware River and tributaries located above the oyster beds, however, inputs from several tributaries that enter the bay adjacent to the 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. Continued long-term spatial monitoring as well as directed research and sampling efforts are needed to understand these dynamics.

Area management strategies are currently employed that typically follow the mortality designations in Figure 1. 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. The beds above Round Island (aka, very low mortality beds) are 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 Seedbed Monitoring Program are designed to continually develop a better understanding of factors influencing oyster growth, disease and mortality patterns to support adaptive management efforts. As funding permits, these efforts include monitoring transplants (i.e., oysters moved from upper to lower seedbeds), shell plants (i.e., shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (i.e., cultch planted in the lower bay high set zone near the Cape Shore then moved and replanted on the seedbeds). The 2011 objectives for the Seedbed Monitoring Program were to:

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

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. 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 is related to the Delaware Bay Oyster Restoration program designed to enhance recruitment on the seedbeds. There is a continuing effort to make this a routine component of managing the natural seedbeds but funding limits the amount of planting, monitoring and assessment that can be accomplished. Similarly, Objective 4 examines the performance of the intermediate transplant program that moves oysters from poor growing waters where they are otherwise abundant to the lower beds where growth and condition are better. This activity helps to replenish a portion of the previous years harvest.

Methods

Figure 1 depicts the grid system used during 2011 for the seedbed 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) and each 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 in a 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 the 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 April through November for Objectives 1 and 4, and in September and November for Objective 3 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. 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 (> 20 mm) 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 disease level in the sample of oysters. Sex and gross reproductive status was determined 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; Egg Island was sampled during 2011. 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

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

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 Beadon's 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 were limited to the 2011 shell plantings listed in Table 2, and were collected during September 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 2011 shell plants. The shell plant on Middle was problematic in that only a fraction of the plant occurred before Hurricane Irene and the remainder of the planting was not completed until just before the November sampling to avoid lingering low salinity and scheduling conflicts.

Results and Discussion

Temperature. Water temperatures measured during 2011 collections followed a typical seasonal increase and decrease with a peak in July and little spatial variability across the seedbeds; however, temperatures were much warmer than the recent decadal mean during May and slightly warmer during June and July (Figure 2A, B). The NOAA PORTS station at Ship John Shoal Light recorded similar patterns and indicated that winter temperatures in January and February were quite cold whereas temperatures at the end of the year had not fallen nearly so low (Figure 2C). **Although the cold temperatures at the beginning of the year were favorable for depressing Dermo disease, the rapid increase during spring and average decline into what has been a relatively warm fall and winter typically favor increasing the spread and development of Dermo disease.**

Salinity. Salinity during 2011 followed a typical spatial pattern, increasing from upbay to downbay beds (Figure 2D), *but* were distinctly lower than normal throughout most of the year

Figures 2D and E). Low salinity at the beginning of the year resulted from higher than normal seasonal runoff from snowmelt and rainfall in the watershed. Salinity increased to average levels by June before beginning a steady decline beginning in July from a wet summer punctuated by Hurricane Irene and the remnants of Tropical Storm Lee that dumped large amounts of precipitation in the Delaware watershed. Conductivity and temperature data recorded at the NOAA PORTS Ship John Light station at six-minute intervals was converted to salinity and indicated that salinity fell below 5 psu for three distinct periods in late winter and early spring, then again following Hurricane Irene (Figure 2F). While Irene lowered salinity to less than five psu, precipitation from TS Lee pushed salinity at Ship John to zero. **As discussed below, the occurrence of several low salinity events throughout much of the year had significant effects on disease during 2011.**

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. *An array of continuous monitoring stations across the seedbeds will facilitate a better interpretation of conditions that influence recruitment, growth, disease and mortality of oysters.*

Oyster size. Shell height (oyster size from 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 2011 show a slight decrease in across most beds during the year, which is likely indicative of recruitment of small animals (spat) into the population and harvest or mortality of larger animals (Figure 3A). This was particularly evident on New Beds where staff reported routinely hitting pockets of good recruitment as the year progressed. Transplant beds showed patterns that were similar to their respective long-term monitoring beds. Oysters from the Beadon's transplant grew steadily from May to October, but at a relatively low rate when compared to shell plants of similar age (Figure 4A). **Monitoring of the Beadon's transplant should continue to fully evaluate this experiment.**

Averaging the mean size across the five long-term monitoring beds for each year since 2000 shows that the increase in the mean size of oysters resulting from a lack of recruitment peaked in 2009 and has declined during the past two years (Figure 3B). Recent increases in recruitment along with harvesting and mortality of larger animals is the likely cause of the recent declines in mean shell height.

A concern from the changing age/size structure has been the effect on sex ratios and fertilization success. 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. We do not have a mechanism to measure fertilization success, but we can determine sex ratio throughout the year. For this reason, gender was determined on oysters sacrificed for Dermo from May to August. Results from 2011 indicate the population began with what appears as a strong bias towards males in May – this is most likely a result of miss-classifying indeterminant stages as male (Table 5). Oysters were clearly mature by June and remained in good reproductive condition during July. There was a bias towards females in both June and July. Most oysters had spawned by August and were no longer reproductive in September. Two hermaphrodites were detected during June 2011, one on Cohansey and one on Shell Rock.

Shell Plants. Figure 4 shows the growth and mortality of the initial cohorts that set on this 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; in 2011 the maximum was about 26 mm. Defining spat as oysters < 20 mm in the stock assessment survey results in low estimates of annual recruitment while overestimating the abundance of juvenile oysters. 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 would help reconcile this error.**

The 2011 shell plant growth fell within the variation of previous years (Figure 4A). The Beadon's transplant is also plotted with these data, and while growth falls within that observed for previous plantings, the growth on the Beadons transplant was relatively low. Survival data suggest 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 only partially completed before Hurricane Irene and then delayed until the end of the year so the interpretation of these data is uncertain. Based on counts from the stock assessment survey, this effort appears to have largely failed (Powell et al. 2012).

Seasonal Disease and Mortality. Dermo prevalence, weighted prevalence (WP) and intensity followed similar seasonal patterns across the seedbeds that were distinct from long-term average patterns (Figure 5). All three measures increased from low values in April and May to peak values in July or August before a sharp decrease following the passing of Hurricane Irene and TS Lee. Spatially, Dermo increased from upper to lower bay sites as expected, but were particularly high on Shell Rock. **Shell Rock has been an area of concentration for management and harvesting and the relationship of this increased activity to increased levels of Dermo is worthy of closer examination and consideration in upcoming management of the fishery.** 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).

The previous four years had recorded an upbay movement of Dermo disease, but this pattern appears to have subsided, in part as a result of the low salinity observed across the seedbeds. Following Irene and Lee, all three measures of Dermo dropped suddenly in a distinct departure of typical seasonal patterns (Figure 5). Intensity recovered first, resuming average levels by November, but weighted prevalence and prevalence were both lower than average as animals entered the winter. Unfortunately, temperatures have remained relatively warm and there is little accumulation of snowpack in the watershed to drive salinity down in the coming spring.

Mortality was estimated from box count frequencies (Figure 6). Total box counts (Figures 6A and 6B) are influenced by the addition of new boxes and the disarticulation of old boxes, both of which can vary across the year. New boxes tend to appear in two peaks during the year; a smaller peak in spring (= overwintering mortality) and a larger peak following the intensification of Dermo disease in fall (Figures 6C and D). In 2011, the spring mortality was heavily driven by upper bay mortality that was likely due to the high levels of Dermo disease that had been present on Cohansey and Arnolds from the previous year. Total box counts tended to decrease throughout the year on all beds except Hope Creek, which experienced significant mortality from fresh water runoff following Irene and Lee. The effect of these storms changed downbay with an overall effect of disrupting the typical pattern of mortality (Figure 6E). Typically, highest cumulative mortality occurs on New Beds followed by Bennies, Shell Rock, Cohansey, Arnolds and Hope Creek, but in 2011 the pattern was Hope Creek, Cohansey, Bennies, Arnolds, Shell Rock and New Beds. This reversal resulted from high overwintering mortality upbay, due to lingering Dermo infections, followed by fresh water inflow later in the year that caused mortality upbay while reducing Dermo and related mortality downbay. Despite this shift in the spatial distribution of mortality, overall cumulative mortality was about average during 2011 (Figure 6F).

Box counts are known to underestimate mortality, but it is worth noting that cumulative recent box count mortality consistently exceeds the total box count mortality. 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 all but New Beds during 2011, but this cannot be strictly attributed to Dermo. Total box count mortality only exceeded 20% on Hope Creek and Bennies – an unusual pattern resulting from the fresh water kill on Hope Creek.

Annual Stock Assessment. Samples for the 2011 Random Sampling Stock Assessment were collected during October and November. Condition index and size frequency data were provided for inclusion in the “Report of the 2012 Stock Assessment Workshop” (Powell et al. 2012). 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, no MSX infections were detected ending a small resurgence of MSX prevalence (Figure 7A). This is most likely related to the reduced salinity experienced across the seedbeds from increased freshwater inflow (Haskin and Ford 1982, Wang et al. submitted). Because no infections were detected, no upbay-downbay pattern was present as indicated in the long-term data (Figure 7B). Because MSX continues to be a serious problem in other areas and remains deadly to naïve oyster stocks, monitoring for MSX remains a high priority.

Figure 8 depicts annual Dermo prevalence, Dermo infection intensity (= weighted prevalence) and box-count estimated mortality from 1989 to 2011 for each mortality region sampled during the annual stock assessment. Each plot segregates the data based on seedbed mortality regions defined by the Stock Assessment (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 (1997 and 2004) and 2011 data indicate a third period has begun suggestive of a seven-year cycle. Unfortunately, periods of remission have been much shorter than the duration of the epizootics.

Mortality within the high and medium mortality regions follows this seven-year cycle, but not in the low and very low mortality regions. Two different patterns are evident in the data in the upper bay regions. On the low mortality beds there has been a steady increase in mortality since 2007. This steady increase follows both a moderate increase in Dermo as well as an increase in the in the use of these beds for the intermediate transplant program. Concern over the stability of these beds and their response to dredging has been expressed annually at the Stock Assessment Workshop. **The association of the increase in mortality on the low mortality beds with Dermo and with harvest for intermediate transplants cannot be distinguished. Therefore, continued use of these beds for the intermediate transplant program should be considered with increased caution.** 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. These beds should be removed from the intermediate transplant program due to this extensive mortality. Oysters in both the low mortality and very low mortality regions entered the winter in poor condition (Powell et al. 2012) and, as a result, are at increased risk to overwinter mortality. **A final assessment of the impact of Irene and Lee should be conducted in April 2012 when over wintering mortality is expected to occur. A similar assessment on the medium and high mortality beds is also recommended to determine if disease depression increased over winter survival.**

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 apparent 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. in press). 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 indicated a return to the typical increase from upbay to downbay beds whereas in 2010 there was a shift of Dermo upbay. These figures also highlight the reduction in Dermo levels across the seedbeds with nearly all falling below long term means. Exceptions include Nantuxent, Hog Shoal and New Beds. In sharp contrast, mortality followed a very different pattern with lower than normal mortality downbay and record or near record mortality occurring upbay (Figure 11).

Figure 12 shows the relationship between the average long-term Dermo level and average long-term mortality by bed. Mortality levels from Figure 11 are used along the y-axis in both panels. The upper panel uses weighted prevalence from Figure 10 while the lower panel converts these weighted prevalence values to parasite burdens after Choi et al. (1989). In both panels, the various mortality regions fall out into zones clearly defined by disease level. The low and very low mortality beds comprise a low disease zone with weighted prevalence of Dermo generally well below 1.0 on the Mackin Scale. This low mortality zone generally experiences mortality less than 15% annually, the present year 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 zone. One exception is Upper Middle, but this may be a result of low sampling effort on that bed. Once Dermo levels exceed 2.0, average mortality increases to 25-40%. The relationship was fitted with the polyfunction $y = a(\cos(x)) + b(\cosh(x))$ via the zunzun.com curvefitting program (http://zunsun.com). In the lower panel, beds segregate into mortality zones differentiated by parasite doublings from about 4,000 to 8,000 to 16,000 cells per gram. Running these data through the 2D curve fitting program at zunzun.com produced a strong fit to the plant disease logistic growth model. This means that infections can linger at low levels for long periods with little effect and then suddenly they develop quickly into lethal infections across two doublings of the parasite. Note the precarious position of Shell Rock at the edge of the medium mortality zone.

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 was dataset was run through the 2D curve fitting program at zunzun.com using the model that produced the best fit for the overall dataset. The overall relationship between Dermo weighted prevalence and mortality estimated by fall survey box counts is highly significant ($p < 0.0001$) and explains 37% of the variation in mortality (Figure 13A). Like figure 12, this relationship suggests an exponential increase in mortality as Dermo disease intensity increases in the population. When examined by bed region the role of salinity is revealed: no relationship was present on the low mortality beds where Dermo levels are relatively low, but a relationship appears and strengthens as Dermo levels increase over medium and high mortality regions (Figure 13B, 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 imply that the background mortality rate across the seedbeds is about 14% overall (Figure 13A), but is lower on the low and medium mortality beds (13%, Figs 13B and C) and may be as high as 23.4% on the high mortality beds (Figure 13D). 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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Table 1. 2011 sampling schedule for the NJ Delaware Bay Oyster Seedbed Long-term Monitoring Program. 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, counts of live oysters and boxes, size frequency (shell height), and Dermo levels.

Date	Samples	Vessel	Captain
Apr 18, 2011	6 long-term sites	NJDEP RV Zephryus	Jason Hearon
May 11, 2011	3 intermediate transplants	NJDEP RV Zephryus	Jason Hearon
May 23, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant	NJDEP RV Zephryus	Craig Tomlin
Jun 20, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant	NJDEP RV Zephryus	Jason Hearon
Jul 18, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant	NJDEP RV Zephryus	Craig Tomlin
Aug 24, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant	NJDEP RV Zephryus	Craig Tomlin
Sep 19, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant post-Irene mortality check	NJDEP RV Zephryus	Jason Hearon
Oct 4, 2011	3 - 2011 shellplant sites post-Irene mortality check	NJDEP RV Zephryus	Jason Hearon
Oct 18, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant post-Irene mortality check	NJDEP RV Zephryus	Craig Tomlin
Nov 21, 2011	6 long-term sites 3 intermediate transplants Beadon's spat transplant 3 - 2011 shellplant sites post-Irene mortality check	NJDEP RV Zephryus	Craig Tomlin

Table 2. Additional sites sampled during 2011. Replant = shell planted in lower Delaware Bay then moved to bed indicated after spat have recruited. MRC = Maurice River Cove. No funding was provided to track previous years shell plants.

Bed	Grid	Purpose/material	Plant yr
		Shell plants	
Bennies Sand	11	ocean quahog	2011
Shell Rock	11	ocean quahog	2011
Middle	26	surf clam shell replant	2011
		Intermediate transplants	
Cohansey	65	very low mortality beds	2011
Bennies	70	low mortality beds	2011
Bennies	71	Middle bed	2011
Bennies	102	Beadons' spat	2011
		Hurricane Irene impact	
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
Ship John	25	Post-Irene mortality check	2011
Tonger's Bed	MRC	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
Hope Creek																		X	X	X	X	X
Liston Range																			X	X	X	X
Fishing Creek																			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
Upper Arnolds														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
Upper Middle																	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
Cohansey	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
Ship John	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
Bennies Sand	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
Nantuxent		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
New Beds	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
Hawks Nest	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
Vexton										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	

Table 4. 2011 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	46	5	5	0
Hope Creek	55	5	5	15
Hope Creek	86	10	10	11
Hope Creek	61			10
Hope Creek	63			14
Fishing Creek	4	10		15
Fishing Creek	25	10		15
Fishing Creek	16			10
Fishing Creek	5			10
Liston Range	21	10		10
Liston Range	25	10		10
Liston Range	17			15
Liston Range	23			15
Round Island	12	10		15
Round Island	26	10		15
Round Island	4			8
Round Island	25			12
Upper Arnolds	13	10		15
Upper Arnolds	21	10		15
Upper Arnolds	18			10
Upper Arnolds	5			10
Arnolds	7	10	10	15
Arnolds	72	10	10	15
Arnolds	16			10
Arnolds	10			10
Upper Middle	48	10		16
Upper Middle	56	10		17
Upper Middle	36			17
Middle	21	10		15
Middle	41	10		15
Middle	28			10
Middle	1			10
Cohansey	8	10	10	15
Cohansey	50	10	10	15
Cohansey	3			10
Cohansey	66			10
Sea Breeze	15	10		15
Sea Breeze	16	10		15
Sea Breeze	13			10
Sea Breeze	18			10
Ship John	15	10		10
Ship John	31	10		15
Ship John	18			13
Ship John	52			12
Shell Rock	14	10	10	15
Shell Rock	42	10	10	15
Shell Rock	27			10
Shell Rock	19			10

Bed	Grid	Dermo	MSX	CI
Bennies Sand	8	10		15
Bennies Sand	26	10		15
Bennies Sand	22			9
Bennies Sand	9			11
Bennies	123	10	10	10
Bennies	97	10	10	3
Bennies	7			10
Bennies	84			8
Bennies	133			9
Bennies	148			10
Nantuxent	16	10		15
Nantuxent	29	10		15
Nantuxent	13			10
Nantuxent	18			10
Hog Shoal	4	10		14
Hog Shoal	20	10		15
Hog Shoal	1			10
Hog Shoal	12			11
New Beds	17	10	10	15
New Beds	68	10	10	12
New Beds	55			10
New Beds	39			13
Strawberry	24	10		16
Strawberry	29	10		16
Strawberry	9			16
Strawberry	20			2
Hawks Nest	2	10		15
Hawks Nest	9	10		13
Hawks Nest	1			9
Hawks Nest	25			9
Hawks Nest	19			4
Beadons	4	10		20
Beadons	5	4		9
Beadons	15	6		6
Beadons	9			15
Vexton	4	10		20
Vexton	9	8		17
Vexton	33	2		2
Vexton	5			11
Egg Island	44	11	11	20
Egg Island	101	6	6	0
Egg Island	62	3	3	3
Egg Island	82			1
Total beds	**22**	**22**	**7**	**22**
Total grids	**91**	**48**	**16**	**89**
Total oysters		**440**	**140**	**1080**

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 23		June 20		July 18		August 24		Overall	
Bed	M	F	M	F	M	F	M	F	M	F
Hope Creek	60	0	35	45	25	75	20	50	35	43
Arnolds	80	15	40	45	30	70	50	20	50	38
Cohansey	100	0	45	50	30	60	50	40	56	38
Shell Rock	75	15	25	70	20	80	55	35	44	50
Bennies	95	5	30	70	50	50	65	30	60	39
New Beds	80	15	40	60	20	80	55	35	49	48
Total	82	8	36	57	29	69	49	35	49	42

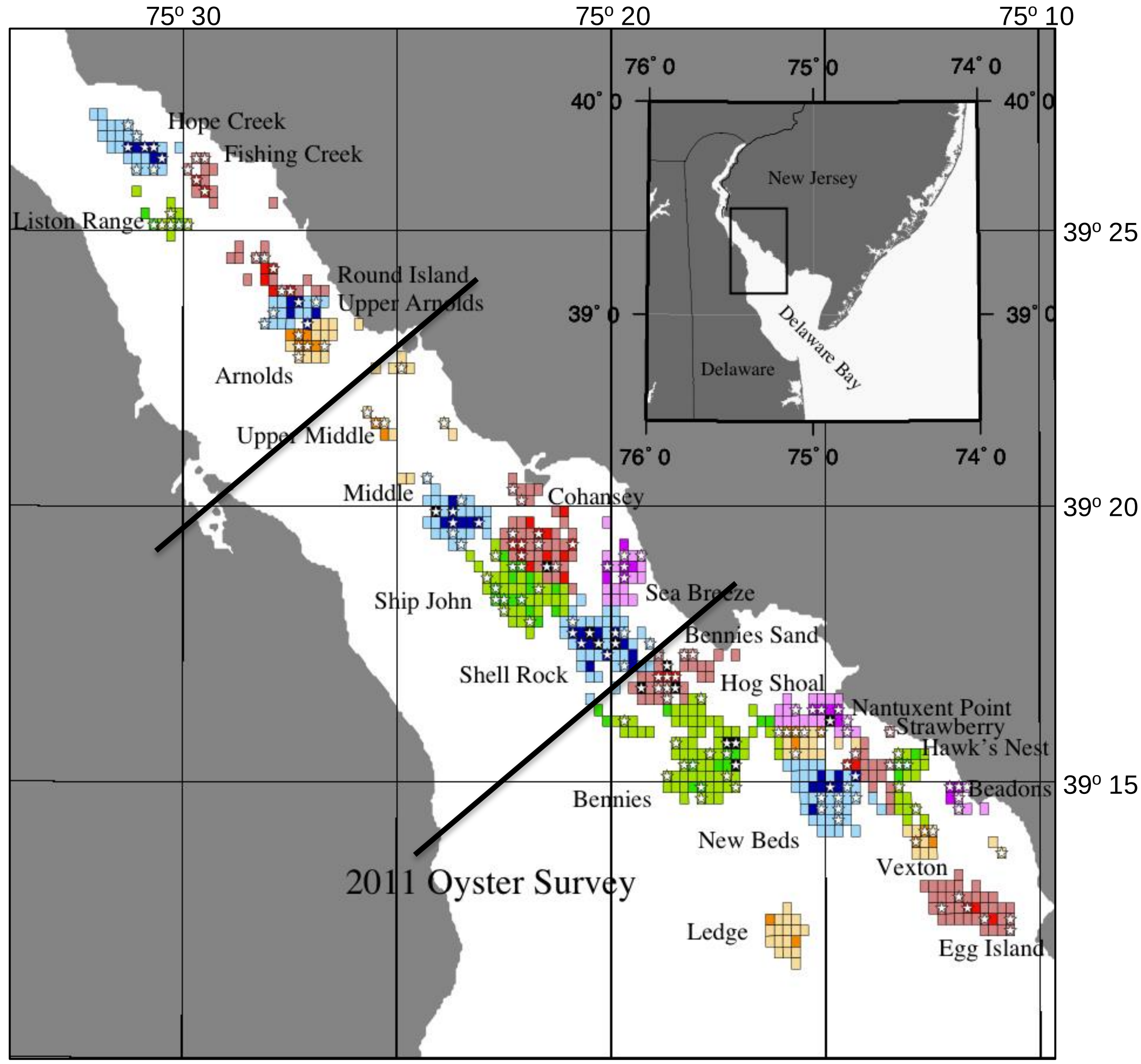


Figure 1. Footprint of the Delaware Bay, NJ state managed oyster beds (aka 'seedbeds') from Powell et al. (2012). Colors differentiate boundaries of named beds with darker colors indicating higher densities of oysters. Stars indicate sampling locations for the 2011 Fall Random Sampling program from which a subset were sampled for MSX, Dermo and condition. Cross bay diagonal lines differentiate regions referenced elsewhere as the low, medium or high mortality beds from the upper to lower portions of the bay.

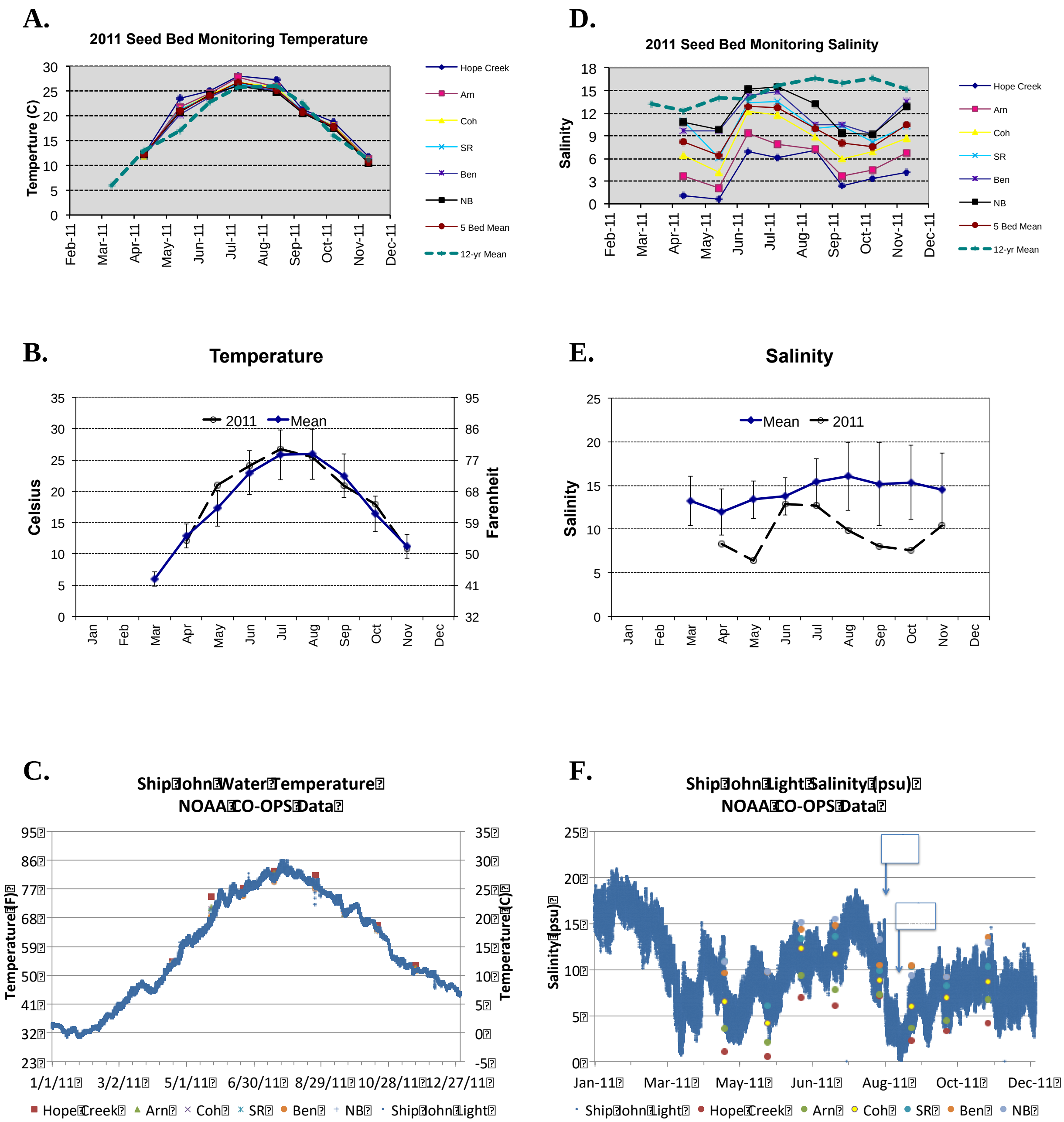
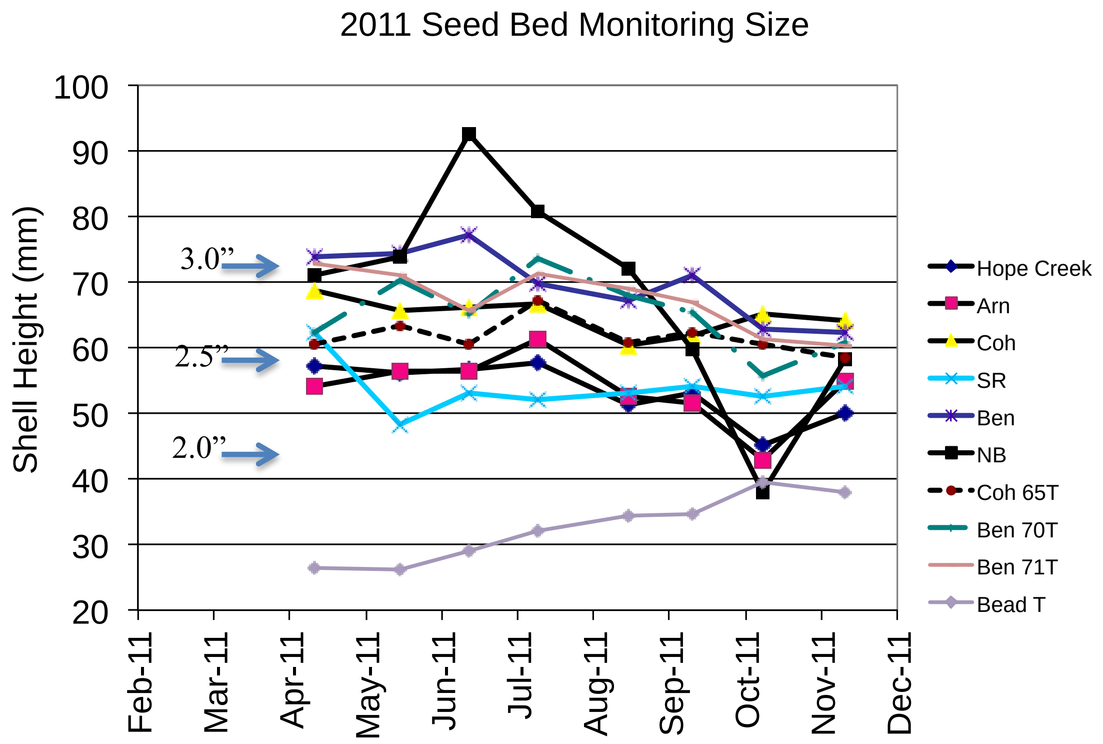


Figure 2. Monthly water temperature and salinity measurements taken during seedbed monitoring at long-term stations and at a continuous monitoring station at the Ship John Shoal Light. A) 2011 temperatures for each bed, the mean of the five long-term beds, and the mean of the last 12 years. B) 2011 mean temperature across beds and mean temperature across beds since 1999. C) 2011 salinity for each bed the mean of the five long-term beds, and the mean of the last 12 years. D) 2011 mean salinity across beds and mean temperature across beds since 1999. E) Continuously monitored temperature at Ship John Shoal Light during 2011. F) Continuously monitored salinity at Ship John Shoal Light during 2011. Ship John Shoal Light monitoring data are publicly available from http://tidesandcurrents.noaa.gov/.

A.



B.

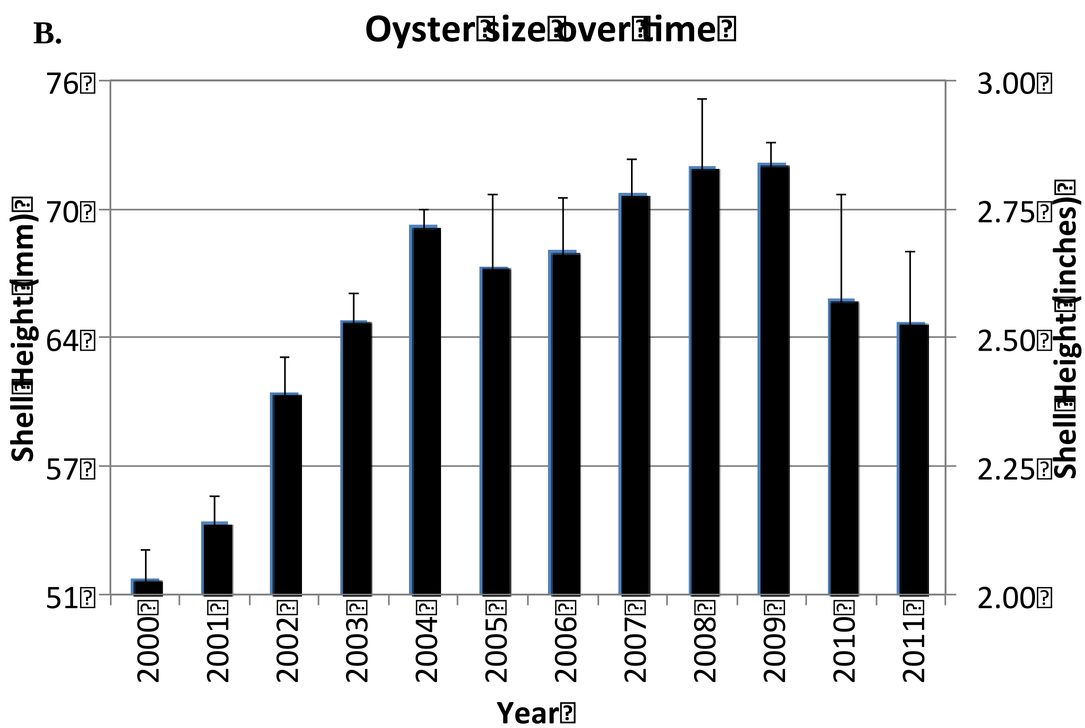
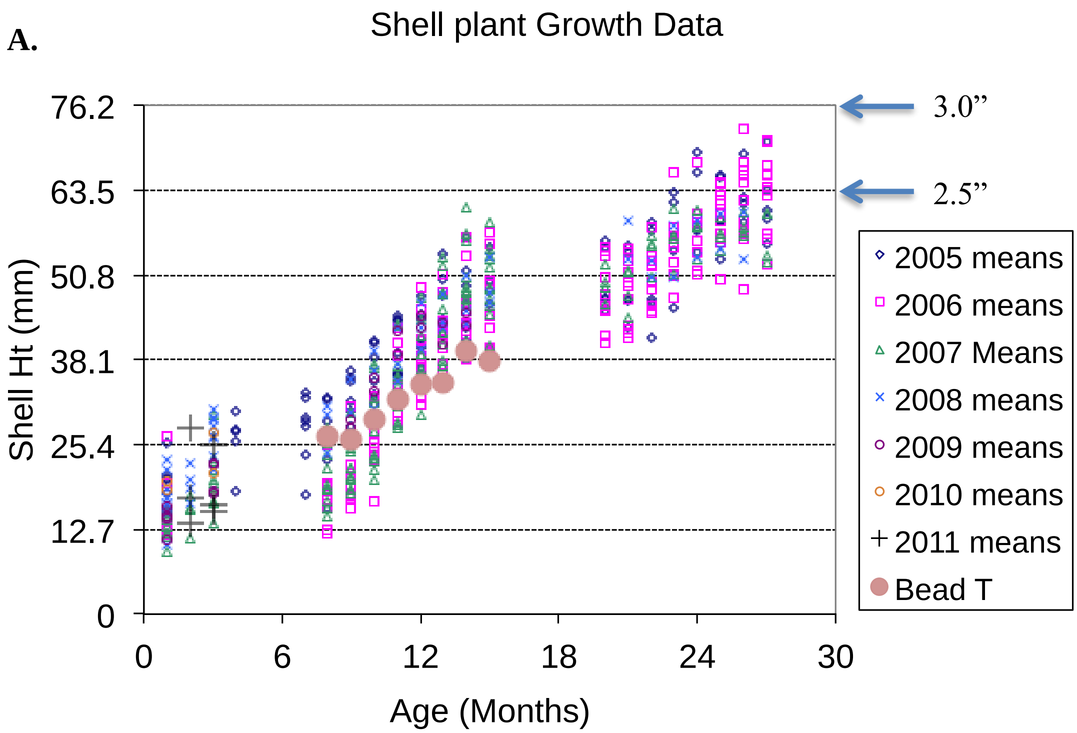


Figure 3. Mean size of oysters collected from Delaware Bay NJ oyster seedbeds. A) Mean size collected in monthly dredge samples by bed. B) Mean monthly (April – September) size averaged across beds annually.

A.



B.

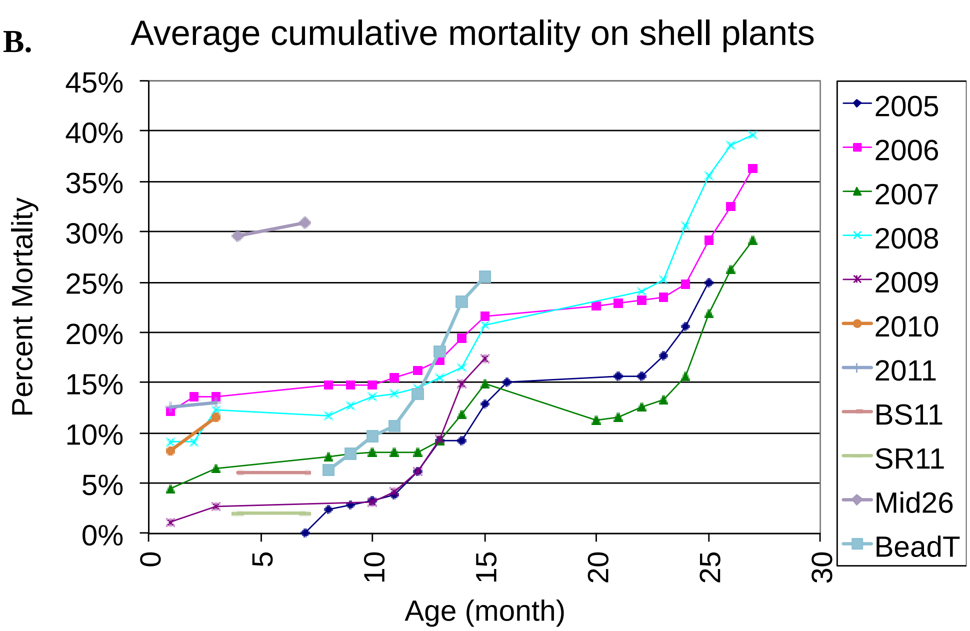


Figure 4. Growth (A) and mortality (B) on shell plantings since 2005 and the 2011 Beadons yearling transplant. Growth data are means of ~100 individuals per shell plant. Mortality data are averaged across plantings, with individual values for 2011 (BS = Bennies Sand, SR = Shell Rock, Mid = Middle, BeadT = 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.

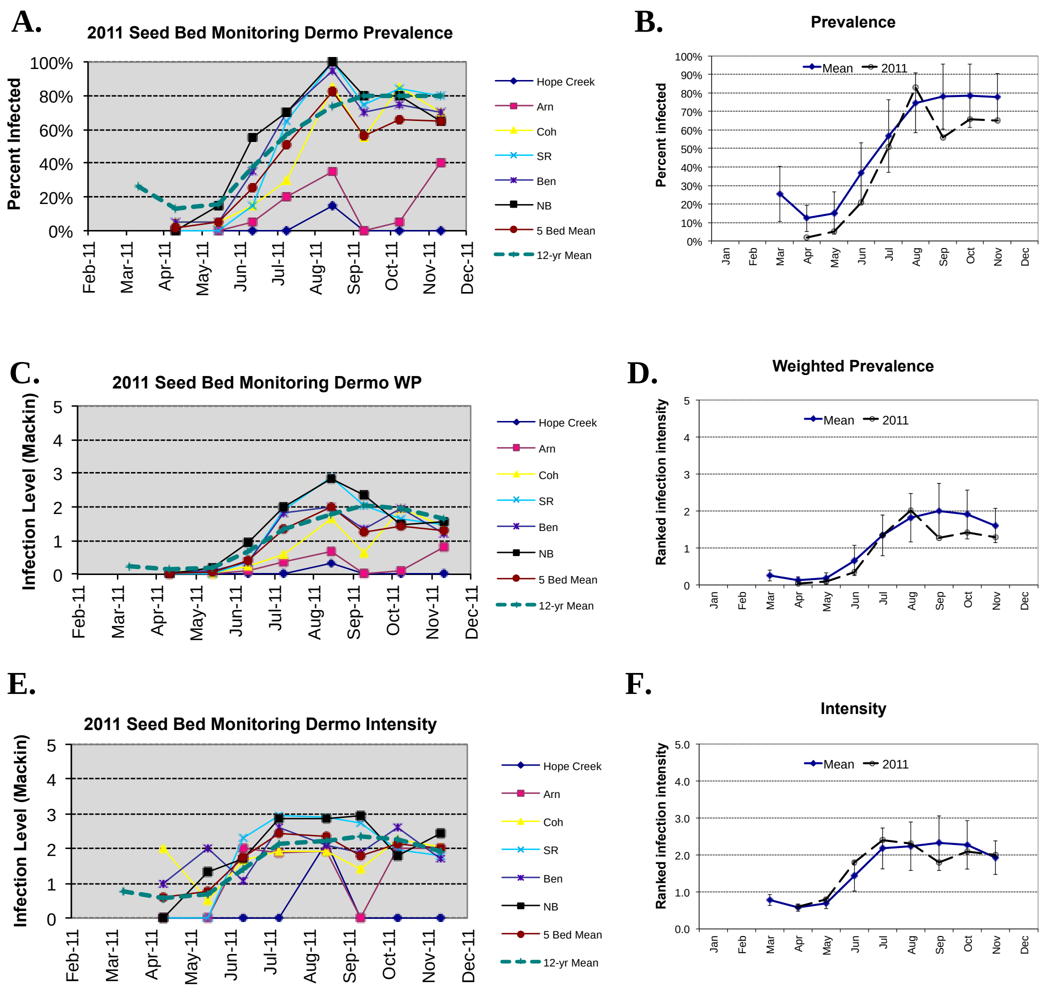


Figure 5. Monthly measures of Dermo disease in oysters from New Jersey Delaware Bay. Prevalence = percent of infected oysters. Weight prevalence (WP) = the average Mackin scale Dermo infection intensity rank of all oysters sampled including those with no detectable infection (i.e., rank = zero). Intensity = average Mackin rank of detectable infections only. Right panels compare mortality for 2010 with mean and standard deviation since 1999 on five long-term monitoring beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds).

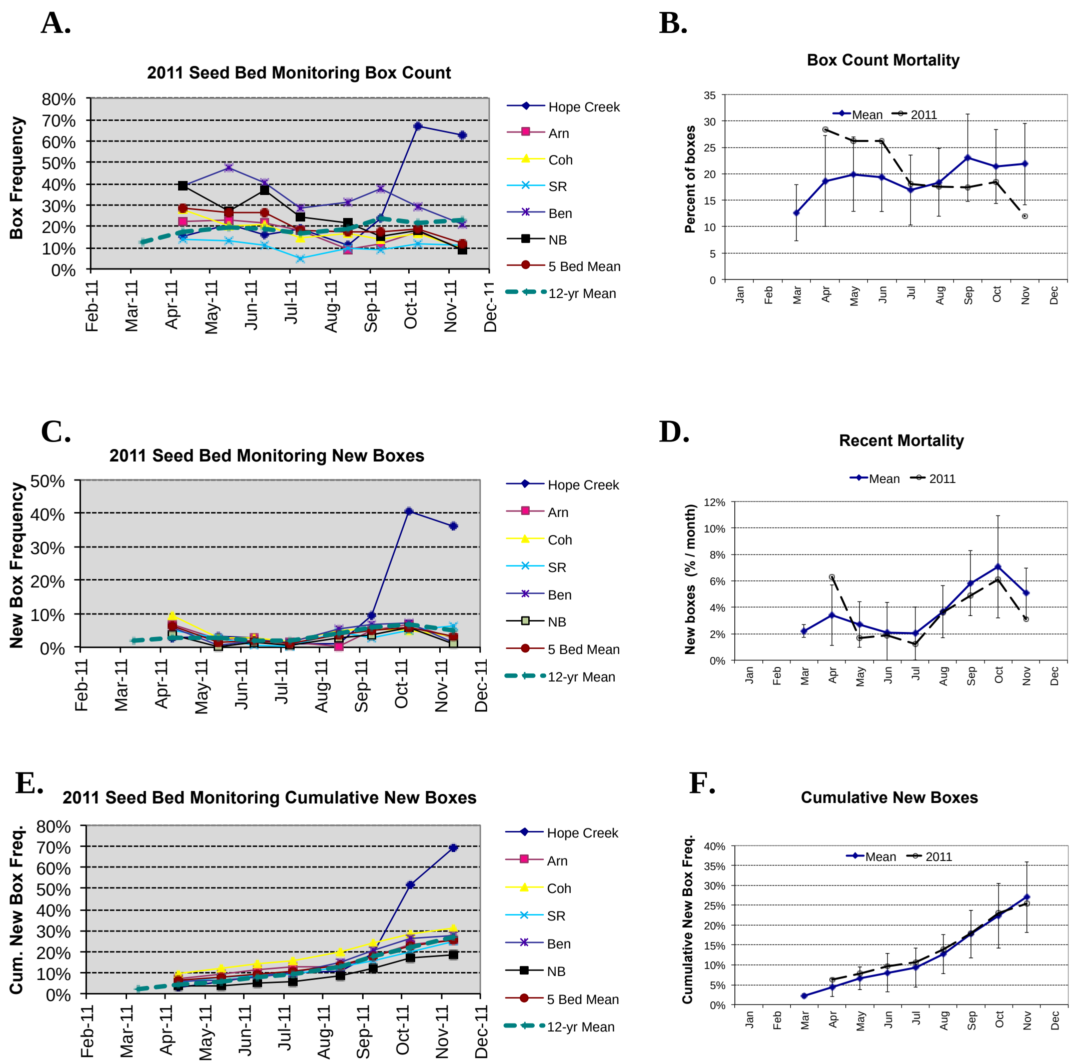
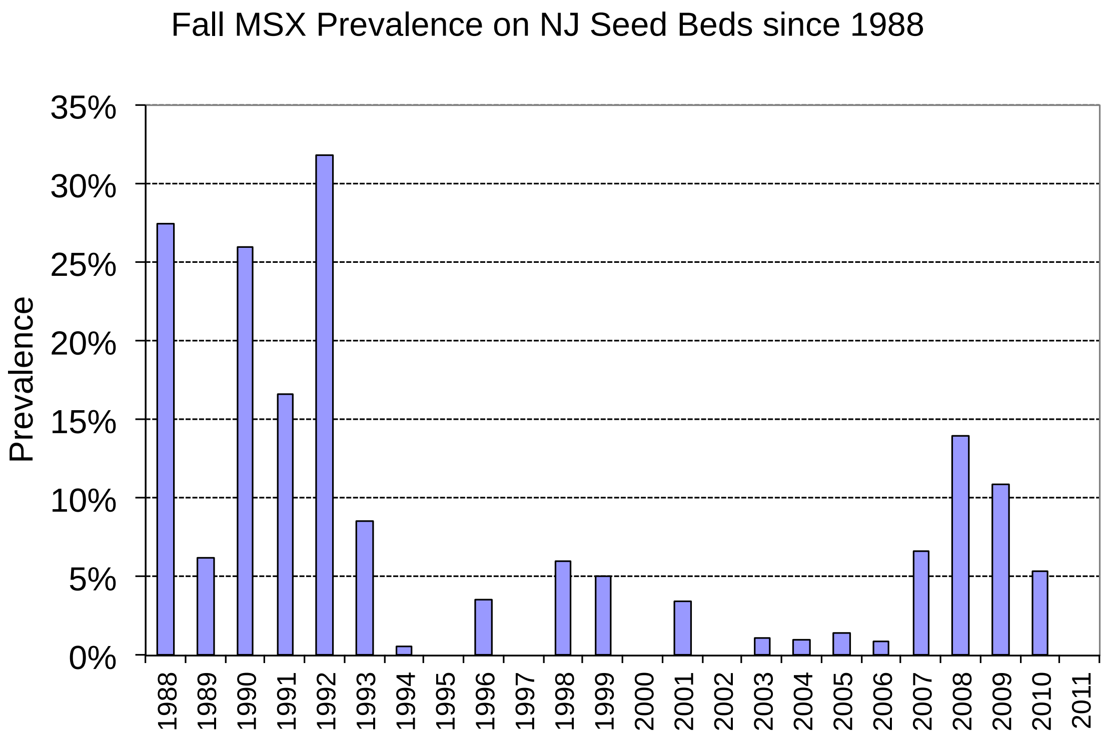


Figure 6. Monthly estimates of oyster mortality on the New Jersey Delaware Bay seedbeds. Left panels show mortality by bed. Right panels compare mortality for 2011 with mean and standard deviation since 1999 on five long-term monitoring beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds – note Hope Creek is not included).

A.



B.

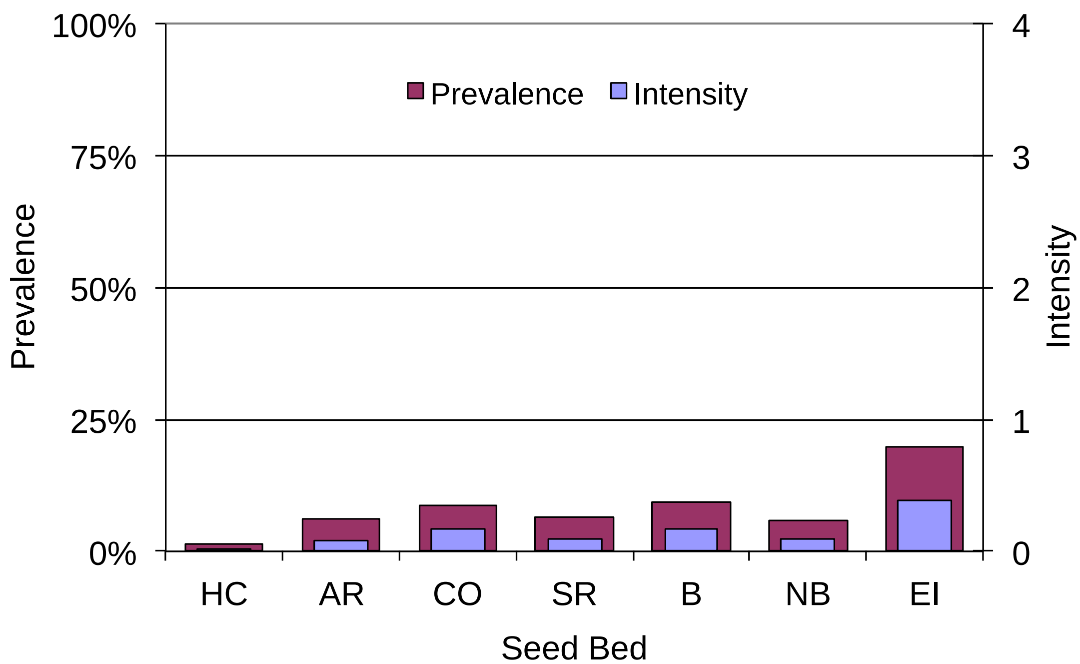


Figure 7. MSX disease on the New Jersey Delaware Bay oyster seedbeds. (A). Annual Fall MSX Prevalence. (B). Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) since 1988 (2007 for HC). HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New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

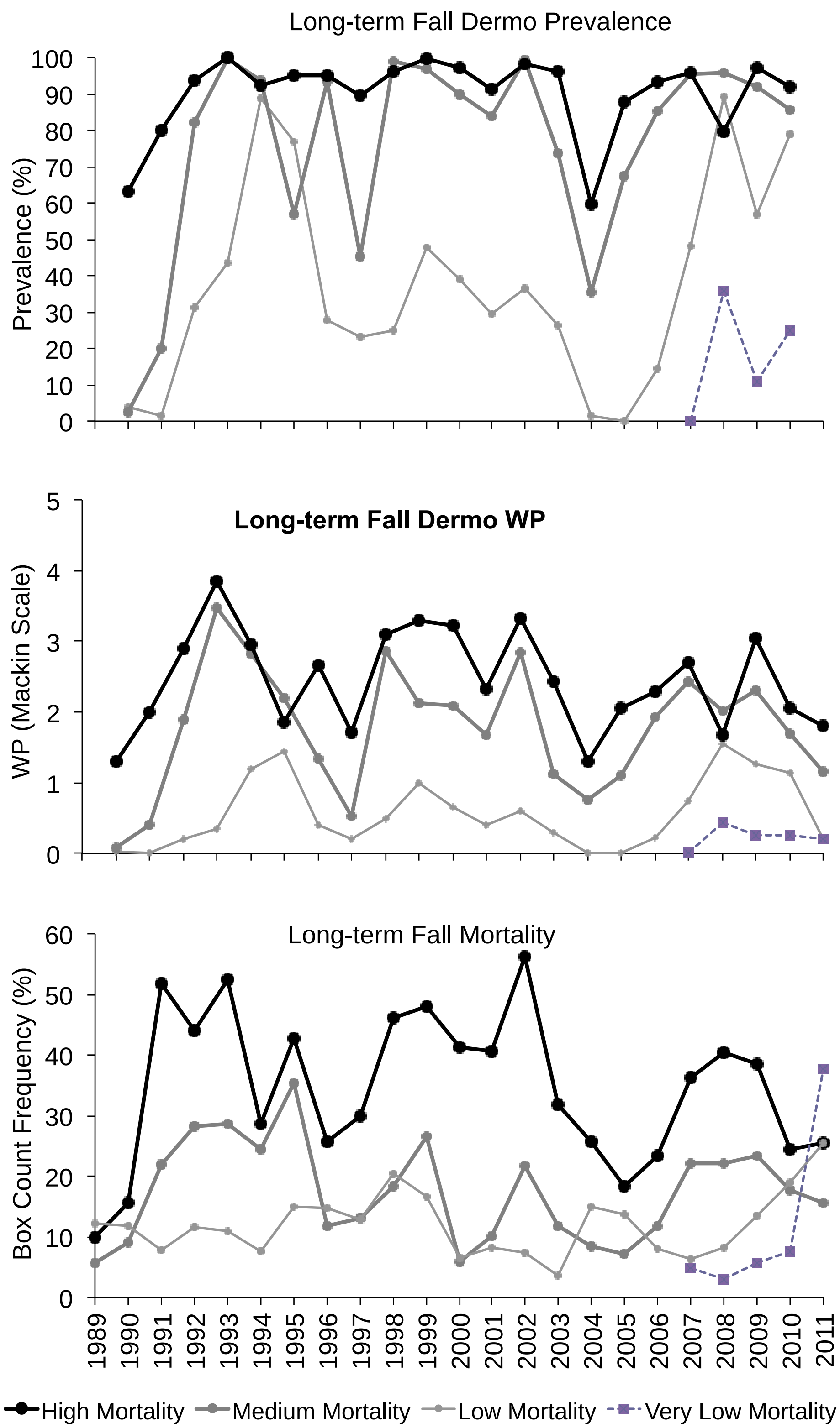


Figure 8. Annual Fall Dermo prevalence, weighted prevalence and box count mortality on New Jersey Delaware Bay seedbeds.

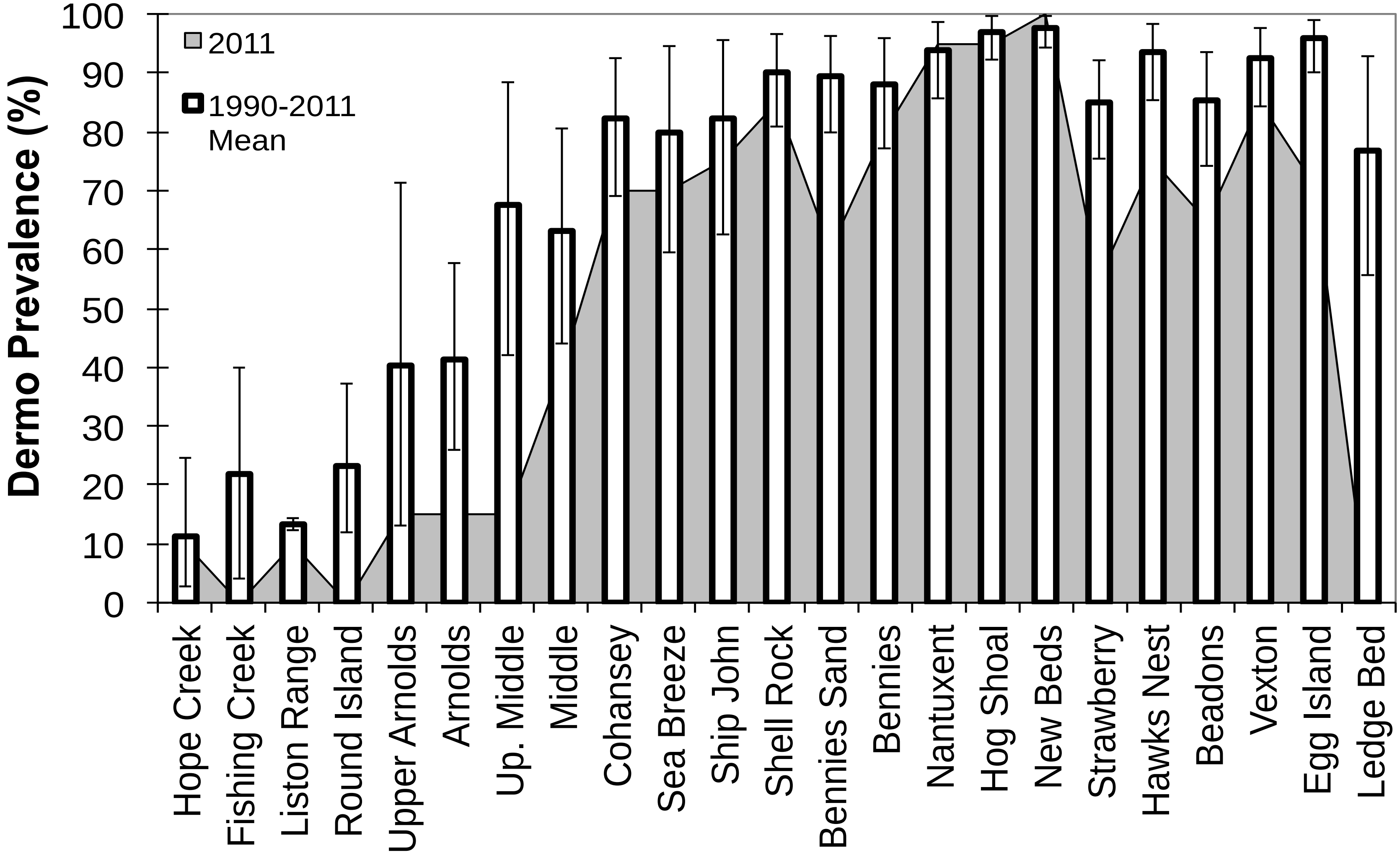


Figure 9. Comparison of average fall *Perkinsus marinus* (Dermo) prevalence in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars) with 2011 levels (shaded area). Not all beds have been sampled every year (see Table 5). Ledge Bed was not sampled in 2011. Error bars represent 95% confidence intervals.

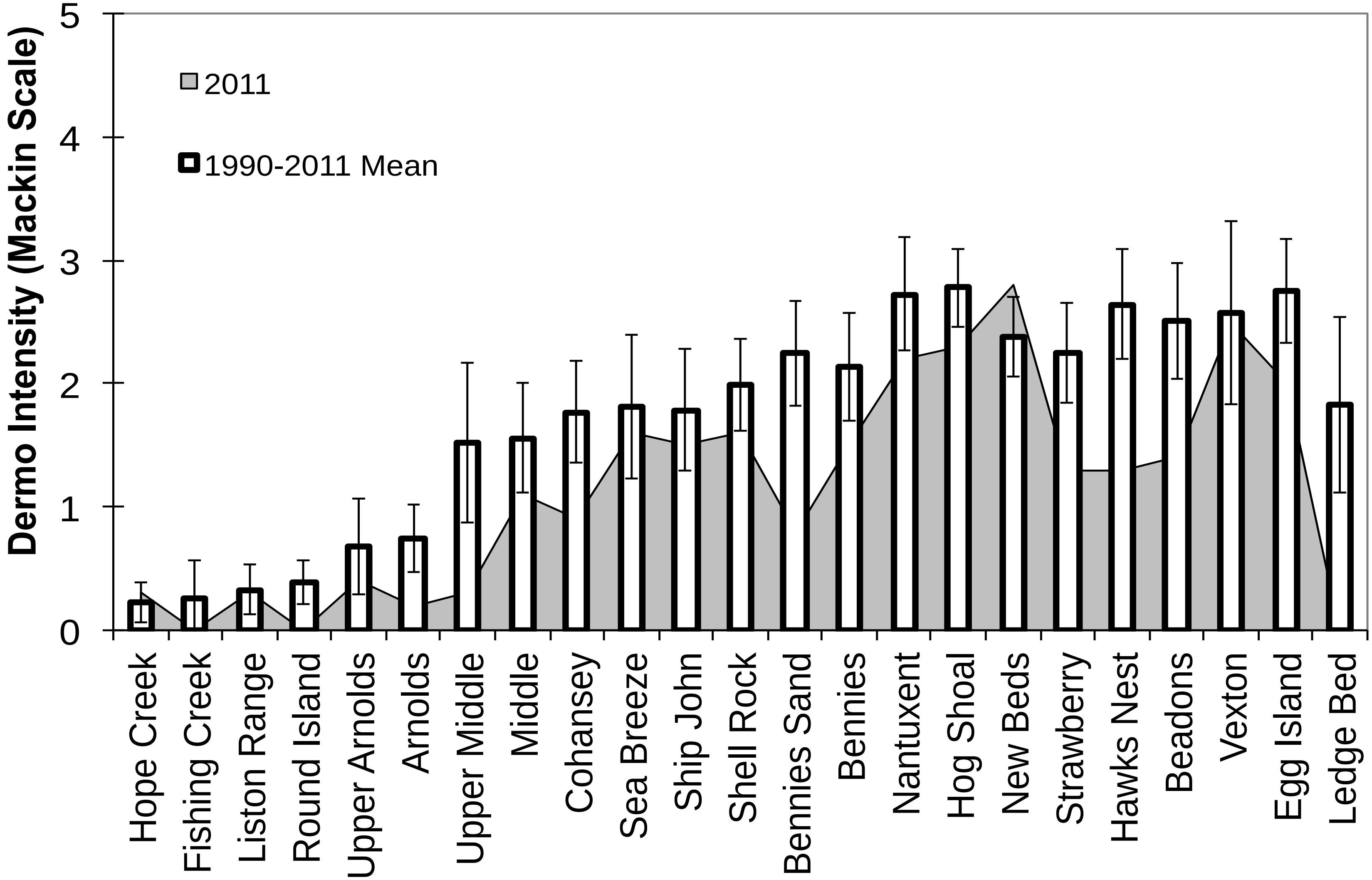


Figure 10. Comparison of average fall Dermo infection intensities (weighted prevalence) in oysters on New Jersey Delaware Bay seedbeds since 1990 (open bars) with 2011 levels (shaded area). Not all beds have been sampled every year (see Table 5). Ledge Bed was not sampled in 2011. Error bars represent 95% confidence intervals.

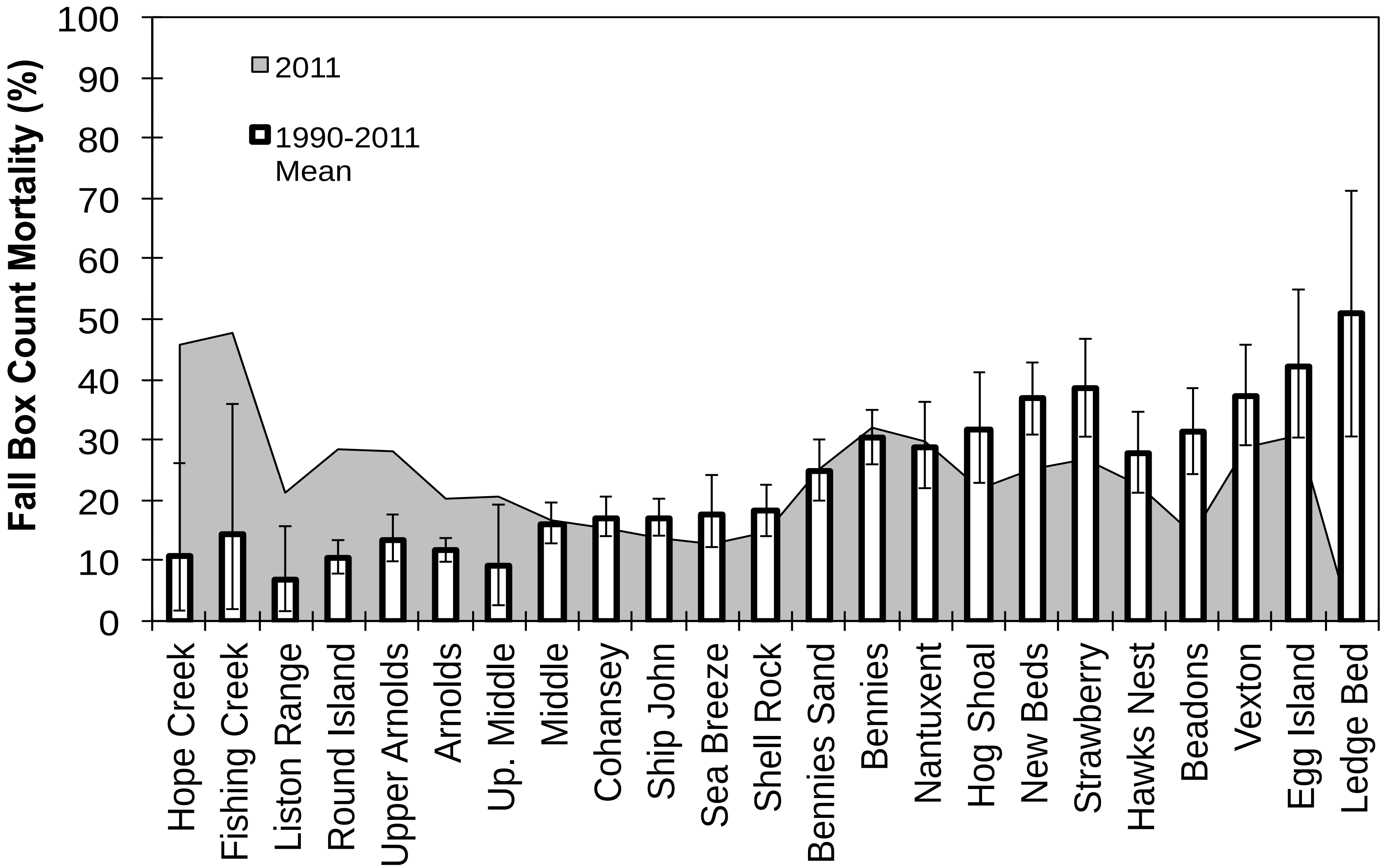


Figure 11. Comparison of average annual fall estimated box-count mortality of oysters on New Jersey Delaware Bay seedbeds since 1989 (open bars) with 2011 levels (shaded area). Not all beds have been sampled every year (see Table 5). Ledge Bed was not sampled in 2011. Error bars represent 95% confidence intervals.

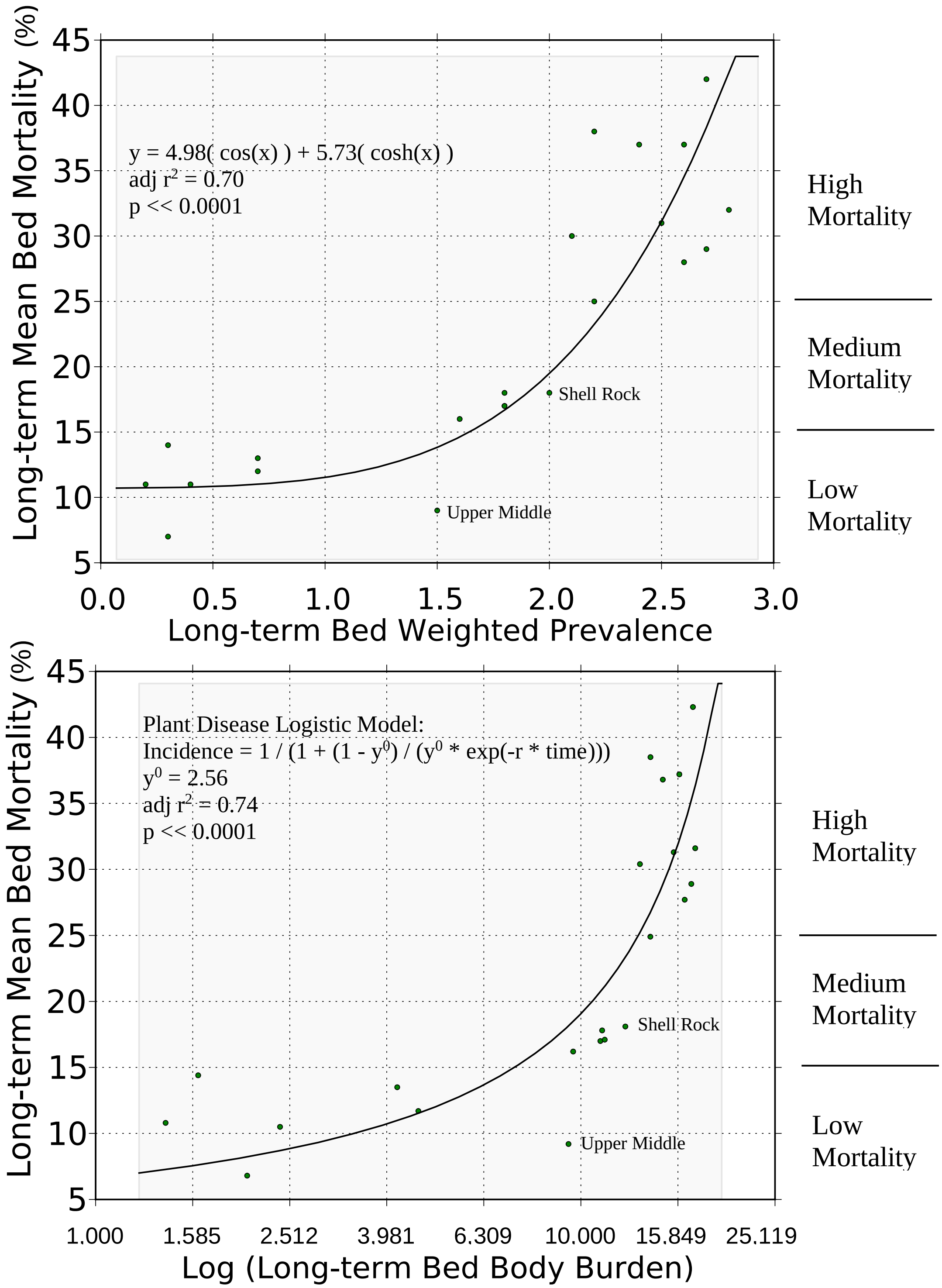


Figure 12. Relationship between long-term mean fall box count mortality estimate and the long-term mean intensity of Dermo infections since 1990. Data are individual bed estimates. Error bars not shown for clarity. Upper panel uses weighted prevalence; lower panel converts weighted prevalence to parasite density per gram wet tissue after Choi et al. (1989).

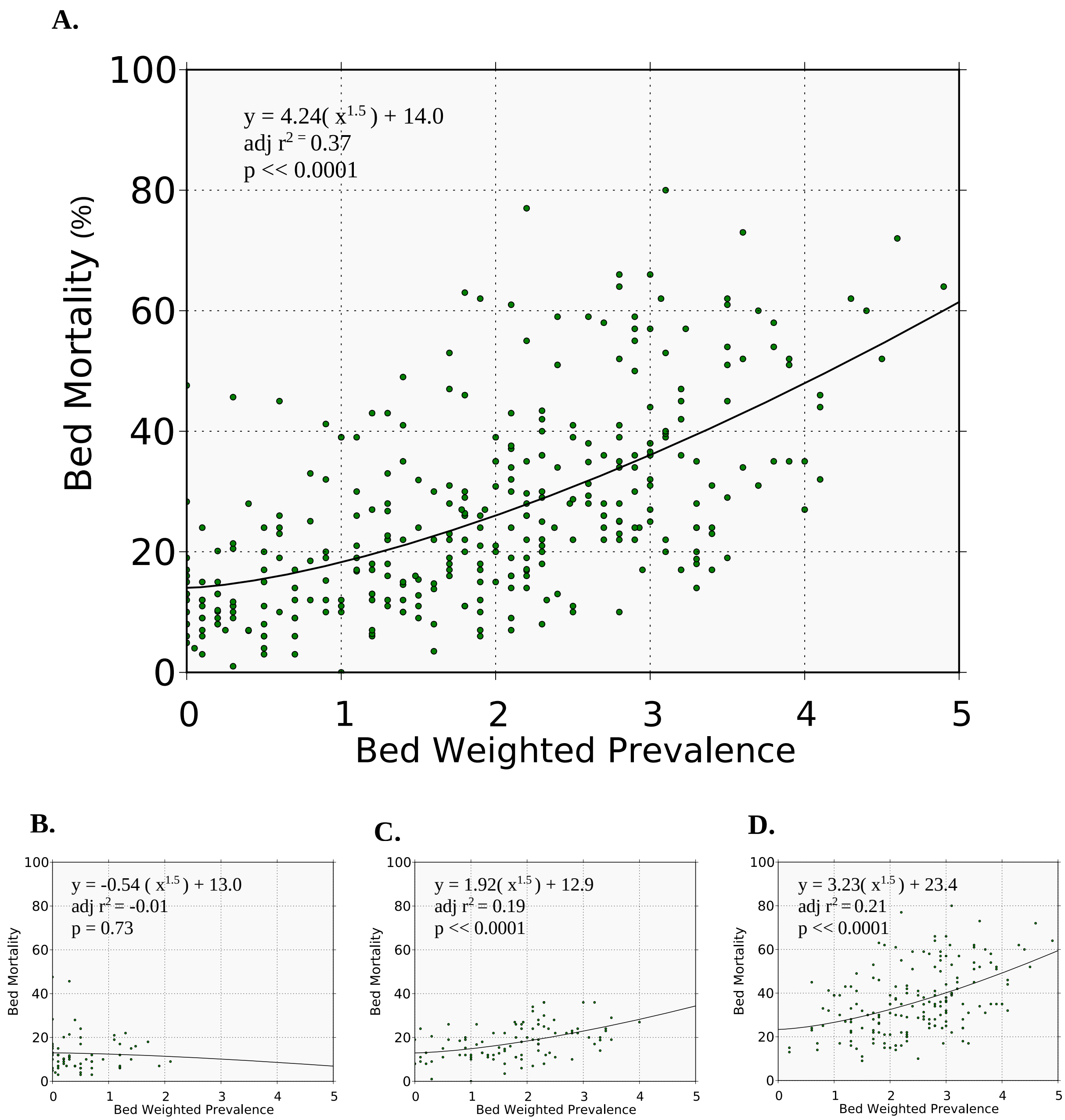


Figure 13. Relationship between fall box count mortality and Dermo infection levels (WP). Data are values for individual beds collected during the annual fall stock assessment from 1990 through 2011. A. All beds. B. Very low and low mortality beds. C. Medium mortality beds. D. High mortality beds.