# Delaware Bay New Jersey Oyster Seedbed Monitoring Program 2017 Status Report

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Prepared by


David Bushek, Iris Burt and Emily McGurk
Haskin Shellfish Research Laboratory
New Jersey Agricultural Experiment Station
Rutgers, The State University of New Jersey
6959 Miller Avenue, Port Norris, NJ 08349


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- NJ Delaware Bay Section of the Shell Fisheries Council
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# Executive Summary

The 2017 Program monitored dermo disease, oyster growth, and oyster mortality monthly at six fixed sites, three transplant sites, and nine shellplants (three each from 2015, 2016 and 2017). The program also continued its long-term disease analysis for 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 fixed monitoring sites.

Temperature was near or slightly above seasonal averages throughout the year. High fresh water inflow depressed salinity well below seasonal averages at the beginning of the year and while reductions in flow allowed salinity to increase as the year progressed, higher than average daily flows continued through summer such that salinity remained lower than average for much of the year. Mean oyster size decreased throughout the year as a strong year class increased throughout the population. Dermo disease followed typical seasonal and spatial patterns but levels remained well below average until October, which likely contributed to the relatively low levels of mortality observed during 2017. Dermo levels fell from October to November but were still slightly above average heading into winter.

Long-term spatial patterns of dermo continued to display a departure from the expected pattern of increase with salinity. That is, oysters in the center of the fishery (Cohansey to Shell Rock) have been sustaining higher levels of dermo disease than those further down bay. Despite this, mortality continues to be highest further down bay. Long-term annual patterns from the Fall survey continue to indicate an approximate 7-year cycle of dermo and mortality with an attenuation of both amplitude and overall magnitude. MSX was nearly undetectable across the seedbeds in Fall 2017, but continues to be present in other areas of the Bay.

The overall picture continues to be one of improvement, but remains highly dependent upon environmental conditions, particularly temperature and salinity, in any given year. Continued vigilance is warranted for monitoring disease and mortality across the natural seedbeds, on transplants and on shell plants to evaluate performance and inform management of the resource. As production in the lower bay increases via aquaculture and revitalization of leased grounds, consideration should be made to expand monitoring efforts in those areas to understand how the lower bay may impact production and disease development across the seedbeds.

## Introduction

The Delaware Bay Oyster Seedbed Monitoring Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds located in the upper portion of Delaware Bay above the mouth of the Maurice River. 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, oyster farms or in waters outside the New Jersey Delaware Bay oyster fishery was not monitored by this program during 2017. Monthly monitoring occurred at selected sites along a transect spanning the salinity gradient across the beds. Additional sites were included where there was a need to evaluate management activities such as transplanting and shellplanting. Monthly reporting to the Delaware Bay Section of the New Jersey Shell Fisheries Council provided timely information on seasonal changes for management and harvest needs. A spatially comprehensive sampling occurred during the annual Delaware Bay New Jersey oyster stock assessment in Fall 2017. Herein, these data are evaluated to provide insight into inter-annual patterns, long-term trends, and factors affecting the oyster stock to inform management.

Oyster mortality on the Delaware Bay oyster beds is caused by a variety of factors including predation, siltation, freshets, disease and fishing. Since the appearance of *Haplosporidium nelsoni* (the agent of MSX disease) in 1957, disease mortality has been the primary concern (Powell et al. 2008). Following a severe and widespread MSX epizootic in 1986, the Delaware Bay population as a whole appears to have developed significant resistance to MSX disease (Ford and Bushek 2012). Nevertheless, routine monitoring continues to detect the MSX parasite in Delaware Bay and naïve oysters quickly succumb to the disease indicating that virulence remains high. 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 has remained a major source of oyster mortality in Delaware Bay since 1990 and a primary concern for managing the oyster fishery and the oyster stock (Bushek et al. 2012).

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 three major groups: Low Mortality (LM) beds (formerly called the upper seedbeds), Medium Mortality (MM) beds (formerly called the upper-central seedbeds), and High Mortality (HM) beds (formerly called central and lower seedbeds). These designations are positively correlated to increases in salinity regime. A group of beds above the low mortality region was added to the survey in 2007 after reconnaissance indicated that their abundance represented a significant proportion of the natural population and should therefore be included in the overall management of the fishery. These beds were collectively designated Hope Creek in 2007, but were subsequently subdivided into Hope Creek, Fishing Creek and Liston Range, collectively referred to as the Very Low Mortality (VLM) beds although they periodically experience very high mortality in response to freshets such as that following tropical storms Irene and Lee in 2011 (Munroe et al. 2013). Current area management strategies separate Shell Rock (SR) from the original medium mortality region and further subdivide the remaining medium mortality region beds into Medium Mortality Transplant (MMT) and Medium Mortality Market (MMM) beds (Figure 1). Additional details on management strategies and actions are available in annual stock assessment workshop reports at http://hsrl.rutgers.edu/SAWreports/index.htm.

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 complex ways. These factors undoubtedly interact to influence disease transmission dynamics, larval dispersal, oyster growth and recruitment, and, ultimately, disease mortality (Wang et al. 2012). It is the objective of this monitoring program to provide information on seasonal and interannual patterns of disease, mortality, recruitment and growth to help understand these dynamics and how they change through time. Additional directed research and sampling efforts are likely necessary to develop a full understanding.

The temporal and spatial sampling efforts of the Oyster 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), shellplants (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 recruitment zone near the Cape Shore then moved and replanted on the seedbeds). The 2017 objectives for the Oyster Seedbed Monitoring Program were to:

1. Continue the standard monthly time series monitoring New Beds, Bennies, Shell Rock, Cohansey, Arnolds, and Hope Creek, for size, mortality and dermo disease
2. Conduct dermo and MSX assays and determine condition indices for each bed sampled during the 2017 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on 2015 through 2017 shell plantings
4. Monitor growth mortality and disease on the 2016 and 2017 intermediate transplants

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 is an annual effort of the management plan for sustaining and rebuilding the oyster beds, scaled by available funds. Objective 4 examines the performance of the intermediate transplant program that moves oysters downbay from upbay beds. This activity provides access to a portion of the resource that is otherwise unavailable to direct market harvest and helps to rebuild and sustain harvested beds.

## Methods

Figure 1 depicts the sampling locations for the 2017 Annual Fall Oyster Stock Assessment with beds outlined in black and area management regions indicated by blue lines. Management activities and this report reference both regions and beds as appropriate. Beds that fall within the jurisdiction of the state of Delaware comprise about 10-15% of the oyster population in the main stem of the Bay but are neither monitored nor shown. For sampling, the beds shown in Figure 1 were divided into grids measuring 0.2 x 0.2 minutes of latitude and longitude. Dots in Figure 1 represent locations of grids selected via a stratified random sampling design for the Fall oyster stock assessment; a subsample of which, generally one high quality and one medium quality, were selected for Fall disease sampling. Additional details on regions, beds and sampling design are provided in Powell et al. (2008 and 2012a) as well as Alcox et al. (2017).

Monthly samples were collected from April through November for Objectives 1, 3 and 4 as indicated in Tables 1 and 2. Table 3 identifies beds that have been monitored since 1990 as part of the long-term Fall dermo monitoring program that is affiliated with the Annual Fall Oyster Stock Assessment. Table 4 specifies the grids sampled during the 2017 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 R/V James W Joseph. Bottom water temperature and salinity were recorded with a handheld YSI® Pro2030 Dissolved Oxygen, Conductivity, Salinity Instrument 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 from each site. 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 and countered to some extent by clumping when oysters attach to one another. 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 (i.e., weighted) for intensity 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 Hope Creek, sample volumes were halved.

disease level in the sample of oysters (Dungan and Bushek 2015). The average intensity of infections, which excludes samples scored as zero, was similarly determined.

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 that are outlined in Figure 1 and listed in Table 4. The two lowermost beds, Ledge and Egg Island, contain very few oysters and are only sampled in alternate years; Egg Island was sampled during 2017. 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. 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 Objectives 3 and 4, samples were collected monthly from April through November (Table 1) for sites manipulated as indicated in Table 2. All of these sites were monitored as described for objective 1 with the following modifications for objective 3 shellplants. Shellplant samples for objective 3 continued monitoring the 2015 and 2016 shell plantings, and initiated the 2017 shell plantings listed in Table 2 – the latter of which was only sampled during the final 3 months. On each shellplant site, at least three and up to five 1-minute dredge tows were 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 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 2017 shellplants. Disease sampling began in April on the 2015 shellplants and in July on the 2016 shellplants.

## Results and Discussion

**Freshwater Inflow**. Data obtained from the USGS stream gauge at Trenton (Figure 2) indicated three large pulses of fresh water prior to May. Freshwater inflow followed a typical seasonal decline throughout the season, but remained well above average until October. Other than a large, brief peak in flow during November, inflow was low for the remainder of the year. Extended periods of above average runoff can depress salinity over the seed beds and decrease the residence time of water both of which can reduce disease transmission and development.

**Temperature**. Water temperatures measured during 2017 collections followed a typical seasonal increase and decrease with little spatial variability across the seedbeds (Figure 3A). Temperatures were near or slightly above average levels measured since 1999 throughout the year (Figure 4A) There was little spatial variability across the seedbeds. Spawning temperatures were reached by mid-June and remained at this level until September.

**Salinity**. Salinity followed the typical estuarine gradient, increasing from upbay to downbay beds (Figure 3B). The high fresh water inflow shown in Figure 2 depressed salinity at the start of the year and although salinity began to rise as inflow began to decline, the continued higher than normal daily freshwater inflow kept salinity below average levels into September (Figure 4B).

Temperature and salinity are arguably the most important environmental factors controlling oyster growth, reproduction, disease and mortality. The conditions observed over the seedbeds during 2017 were favorable for growth and reproduction, but not particularly favorable to the development of disease and consequent mortality as described below.

**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 a population's mean shell height may be affected by growth, recruitment and mortality (both natural mortality and fishing mortality). Over the past few years, oystermen have persistently commented on the large size of oysters present across the seedbeds and this is evident in the increase in average size since 2014 (Figure 5). During 2017, however, mean shell height decreased during the year to varying degrees on each bed (Figure 3C) leading to an overall bringing the end of the season mean size to average levels observed since 1999 (figure 4C). Because mortality has not been particularly high as described below, the decreases observed during 2017 likely represent recruitment of smaller oysters and a stabilization of both size and age distributions that had previously been out of balance (see recent HSRL Stock Assessment Reports https://hsrl.rutgers.edu/SAWreports/index.htm). Figure 5 still shows an overall large mean size, but with a higher standard deviation indicative of a wider range of sizes present. Additional recruitment will be needed to depress the overall mean size of oysters across the seedbeds.

**Dermo Disease**. Dermo prevalence (the percent of the population with detectable infections), weighted prevalence (WP; the average intensity of dermo in the population, including uninfected oysters) and intensity (the average level of infections in infected animals) followed typical spatial and seasonal patterns (Figures 3D-F), but were depressed for much of the year relative to the long-term average (Figures 4D-F). Infection levels were relatively high at the end of 2016, but it appears that the high flow of fresh water helped to flush dermo from the seedbeds and maintained it relatively low throughout much of 2017. Dermo levels were near or slightly above average at the end of the year but were not at those levels long enough to begin causing extensive mortality. Winter and spring conditions will largely dictate how well dermo persists into 2018.

**Mortality.** The low levels and delayed onset of dermo disease just described was associated with relatively low levels of mortality (Figures 3G-I and 4G-I). An epizootic is technically defined as a sudden increase in the appearance or intensification of a disease that may or may not be associated with mortality. Under this definition, despite the widespread prevalence and seasonal intensification of dermo disease, Delaware Bay did not experience a dermo epizootic during 2017, but the potential for an epizootic to develop and cause significant mortality remains high.

**Transplants, Shellplants and replants**. Figure 6 shows that transplants performed similarly to the average in essentially all metrics. Previous monitoring efforts have indicated transplants develop high levels of disease and higher rates of mortality after the first year of the transplant. This did not appear to be the case for 2017. Growth on shellplants was steady and similar to rates observed in prior years of approximately 25 mm per year (Figure 7A). Dermo levels increased during 2017 on both 2015 and 2016 shellplants exceeding levels expected to begin causing mortality (Bushek et al. 2012). Dermo was not monitored on 2017 shellplants. Regardless of shellplanting performance in any particular year, shell planting remains one of the most positive management efforts to sustain and increase oyster abundance. Shell planting should be pursued annually and expanded whenever resources permit. No replanting occurred in 2017, but replanting should remain as a potential as should spat-on-shell, both of which have proven effective elsewhere.

**Spawning and reproduction**. Spawning temperatures were reached by late-June and visual observations during monthly dissections for dermo diagnostics indicated that oysters were in good condition for spawning. Sex ratios were not determined during 2017.

**Long-Term Fall Patterns**. Examination of dermo prevalence, weighted prevalence and mortality by bed indicated higher dermo levels in the middle region of the bay during 2017 (Figure 8). This pattern has been consistent over the past five years indicating changes in disease dynamics across the Bay. Prior to this, dermo levels increased from upbay to downbay. Reasons for this shift remain unclear but could be associated with low oyster abundance on the lower beds, or evidence of the development of resistance by oysters under heavier disease pressure in the lower bay, or may be a result of changing environmental conditions.

Figure 9 depicts annual dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2017 for each mortality region. Each parameter generally decreases from high to low mortality regions, although prevalence is typically high below the Low Mortality region. 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 nearly out of phase with dermo disease indicating that dermo is not a primary cause of mortality in these regions. 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 we may have entered a period of reduced dermo intensity with less variability and also reduced mortality circa 2003 onward.

Many factors such as temperature, salinity and recruitment are known to influence dermo disease (Villalba et al. 2004) but the confluence and interaction of these factors is difficult to predict. Moreover, while there is some understanding of how these factors influence spatial and seasonal variation in dermo disease, it is less clear how they interact to influence interannual variation. The data continue to indicate an attenuation of dermo-induced mortality in the three successive epizootics across the medium and high mortality regions (Figure 10). This observation 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. Lagged correlations between river flow and WP produce a significant negative correlation (Bushek et al. 2012). As mentioned in previous years, the apparent cycling may be driven by larger regional climate patterns such as the North Atlantic Oscillation, but this remains a hypothesis until sufficient time series data can be collected.

Figure 11 depicts the regional mortality rates from each fall assessment since 1990 as a function of dermo disease level (weighted prevalence). Bushek et al. (2012) demonstrated that once weighted prevalence begins to exceed 1.5 mortality begins to increase exponentially. In Figure 11, low mortality regions show no relationship to dermo infection level because all infections are near or below the 1.5 threshold. A relationship begins to develop across the medium mortality regions as infections increase. This relationship continues to strengthen on Shell Rock until becoming well established across the high mortality region where it explains approximately 45% of the variability observed in mortality from year to year. The 2017 data points show that while mortality was low, the Fall disease levels on MMT, MMM and SR are relatively high. As discussed above, the short period of time that infection levels were high at the end of 2017 likely reduced the level of associated mortality.

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). MSX was detected in only one of the 140 oysters assayed (Figure 12A), and this infection was located on a medium mortality bed (Figure 12B). In contrast, MSX infections were observed at 10-30% prevalence from June through November on a leased ground in section C and at 17-67% prevalence in gapers from the Cape Shore tested in September and October. Previous years have found MSX distributed across the seed beds and these data confirm its continued presence in the Bay. MSX continues to cause mortalities elsewhere along the East coast. Thus, MSX remains a threat to the Delaware Bay oyster population and an important component of the monitoring program to understand sources of mortality from year to year. Because MSX can cause mortality in Spring and appears to be more prevalent in the lower Bay, it is recommended that some level of routine monitoring of MSX occur throughout the year to improve surveillance. Additionally, there have been requests to monitor dermo disease and mortality on aquaculture leases as that activity grows and develops. There are several logistical problems owing to the different culture environments and methods (intertidal vs subtidal, floating versus bottom culture, source and age of seed, etc.). To provide a baseline we began monitoring a single stock of known parentage (a Rutgers NEH line) at the Cape Shore to provide an index of disease. The stock was spawned in 2016 and was 25 mm with no detectable infections when monitoring began in April. By November they were 50 mm in shell length with 80% prevalence, a weighted prevalence of 1.1 and an average intensity of 1.38. We plan to follow this stock during 2018 and add a wild control line of the same age then continue this monitoring in subsequent years using two year old animals that are near or have reached market size. Because these will be single cohorts and not a population, they will be more comparable to tracking shell plants than the population present on other areas of the seed beds. Expansion of monitoring onto subtidal areas can be considered, but how to do that and eliminate or minimize effects due to gear, husbandry or other factors will need to be carefully considered in designing a sampling strategy. The Delaware Bay NJ Oyster Stock Assessment Review Committee should consider the value of such information to the management of the Delaware Bay oyster population and fishery.

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**Table 1**. 2017 sampling schedule for the NJ Delaware Bay Oyster Seed Bed 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. Nantuxent grid 10, Cape Shore natives and a Maurice River Cove lease were the additional sites of interest that were sampled in 2017. Shellplant and transplant sites are described in Table 2. Parameters measured include temperature, salinity, dissolved oxygen, counts of live oysters and boxes, size frequency (shell height), and dermo levels.

| Date | Samples | Vessel | Captain |
|---|---|---|---|
| April 19, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| April 27, 2017 | 6 2015-16 shellplant sites | NJDEP RV James W. Joseph | Andrew Hassel |
| May 16, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| May 22, 2017 | 3 intermediate transplants<br>6 2015-16 shellplant sites | NJDEP RV James W. Joseph | Craig Tomlin |
| Jun 26, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| June 27, 2017 | 3 intermediate transplants<br>6 2015-16 shellplant sites | NJDEP RV James W. Joseph | Craig Tomlin |
| July 17, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| July 24, 2017 | 3 intermediate transplants<br>6 2015-16 shellplant sites | NJDEP RV James W. Joseph | Craig Tomlin |
| August 25, 2017 | 6 long-term sites+2 extra sites<br>3 intermediate transplants<br>6 2015-16 shellplant sites | NJDEP RV James W. Joseph | Craig Tomlin |
| September 18, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| September 25, 2017 | 3 intermediate transplants<br>9 2015-16 shellplant sites | NJDEP RV James W. Joseph | Craig Tomlin |
| October 16, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Craig Tomlin |
| October 23, 2017 | 3 intermediate transplants<br>9 2015-16 shellplant sites | NJDEP RV James W. Joseph | Andrew Hassel |
| November 29, 2017 | 6 long-term sites+2 extra sites | NJDEP RV James W. Joseph | Andrew Hassel |
| November 30, 2017 | 3 intermediate transplants<br>9 2015-16 shellplant sites | NJDEP RV James W. Joseph | Andrew Hassel |

**Table 2.** Additional enhancement sites sampled during 2017.

| Bed | Grid | Plant material | Plant yr |
|---|---|---|---|
| Bennies Sand | 41 | ocean quahog | 2017 |
| Shell Rock | 37 | ocean quahog | 2017 |
| Cohansey | 50 | ocean quahog | 2017 |
| | | | |
| Bennies | 73 | medium mortality transplant | 2017 |
| | | | |
| Bennies | 99 | ocean quahog | 2016 |
| Shell Rock | 15 | ocean quahog | 2016 |
| Ship John | 28 | ocean quahog | 2016 |
| | | | |
| Shell Rock | 59 | medium mortality transplant | 2016 |
| Cohansey | 45 | low mortality transplant | 2016 |
| | | | |
| Bennies | 110 | ocean quahog | 2015 |
| Shell Rock | 31 | ocean quahog | 2015 |
| Cohansey | 56 | ocean quahog | 2015 |

**Table 3.** Record of collections for annual fall dermo monitoring since 1990. X indicates bed was sampled in respective year for that column. Prior to 2008, not all beds were sampled. Beginning in 2008, all beds were sampled every year except Ledge and Egg Island which were alternated annually due to a general lack of oysters. 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** | **--** | **--** | **16** | **17** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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**. 2017 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 | 51 | 10 | 10 | 13 |
| Hope Creek | 87 | 10 | 10 | 7 |
| Hope Creek | 76 | | | 17 |
| Hope Creek | 52 | | | 13 |
| Fishing Creek | 25 | 10 | | 17 |
| Fishing Creek | 10 | 10 | | 15 |
| Fishing Creek | 16 | | | 18 |
| Liston Range | 12 | 10 | | 15 |
| Liston Range | 14 | 10 | | 15 |
| Liston Range | 5 | | | 10 |
| Liston Range | 17 | | | 10 |
| Round Island | 11 | 10 | | 18 |
| Round Island | 12 | 10 | | 15 |
| Round Island | 5 | | | 17 |
| Upper Arnolds | 10 | 10 | | 15 |
| Upper Arnolds | 14 | 10 | | 15 |
| Upper Arnolds | 3 | | | 10 |
| Upper Arnolds | 17 | | | 10 |
| Arnolds | 16 | 10 | 10 | 4 |
| Arnolds | 57 | 10 | 10 | 7 |
| Arnolds | 43 | | | 15 |
| Arnolds | 19 | | | 24 |
| Upper Middle | 48 | 12 | | 15 |
| Upper Middle | 71 | 8 | | 14 |
| Upper Middle | 56 | | | 11 |
| Upper Middle | 63 | | | 10 |
| Middle | 43 | 10 | | 12 |
| Middle | 34 | 10 | | 15 |
| Middle | 40 | | | 11 |
| Middle | 31 | | | 12 |
| Cohansey | 19 | 10 | 10 | 15 |
| Cohansey | 57 | 10 | 10 | 15 |
| Cohansey | 38 | | | 10 |
| Cohansey | 25 | | | 10 |
| Sea Breeze | 19 | 10 | | 15 |
| Sea Breeze | 22 | 10 | | 13 |
| Sea Breeze | 15 | | | 11 |
| Sea Breeze | 17 | | | 11 |
| Ship John | 51 | 10 | | 14 |
| Ship John | 25 | 10 | | 14 |
| Ship John | 48 | | | 11 |
| Ship John | 15 | | | 11 |
| Shell Rock | 38 | 10 | 10 | 14 |
| Shell Rock | 7 | 10 | 10 | 11 |

| Bed | Grid | Dermo | MSX | CI |
|---|---|---|---|---|
| Shell Rock | 44 | | | 12 |
| Shell Rock | 65 | | | 13 |
| Bennies Sand | 8 | 10 | | 13 |
| Bennies Sand | 20 | 10 | | 15 |
| Bennies Sand | 1 | | | 11 |
| Bennies Sand | 26 | | | 11 |
| Bennies | 34 | 10 | 10 | 10 |
| Bennies | 56 | 10 | 10 | 12 |
| Bennies | 146 | | | 13 |
| Bennies | 85 | | | 15 |
| Nantuxent | 25 | 10 | | 14 |
| Nantuxent | 13 | 10 | | 14 |
| Nantuxent | 15 | | | 11 |
| Nantuxent | 29 | | | 11 |
| Hog Shoal | 12 | 10 | | 15 |
| Hog Shoal | 6 | 10 | | 13 |
| Hog Shoal | 5 | | | 10 |
| Hog Shoal | 1 | | | 10 |
| New Beds | 24 | 10 | 10 | 22 |
| New Beds | 31 | 10 | 10 | 22 |
| New Beds | 41 | | | 14 |
| New Beds | 12 | | | 12 |
| Strawberry | 5 | 10 | | 16 |
| Strawberry | 25 | 10 | | 12 |
| Strawberry | 28 | | | 6 |
| Strawberry | 14,2 | | | 10 |
| Hawks Nest | 27 | 10 | | 15 |
| Hawks Nest | 13 | 10 | | 10 |
| Hawks Nest | 28 | | | 11 |
| Hawks Nest | 25 | | | 14 |
| Beadons | 16 | 8 | | 8 |
| Beadons | 3,5 | 12 | | 25 |
| Vexton | 4 | 10 | | 30 |
| Vexton | 11 | 10 | | 20 |
| Egg Island | 28 | 10 | 10 | 7 |
| Egg Island | 63,31 | 10 | 10 | 3 |
| | | | | |
| **Total beds** | **22** | **22** | **7** | **22** |
| **Total grids** | **83** | **46** | **15** | **83** |
| **Total oysters** | | **440** | **140** | **1037** |

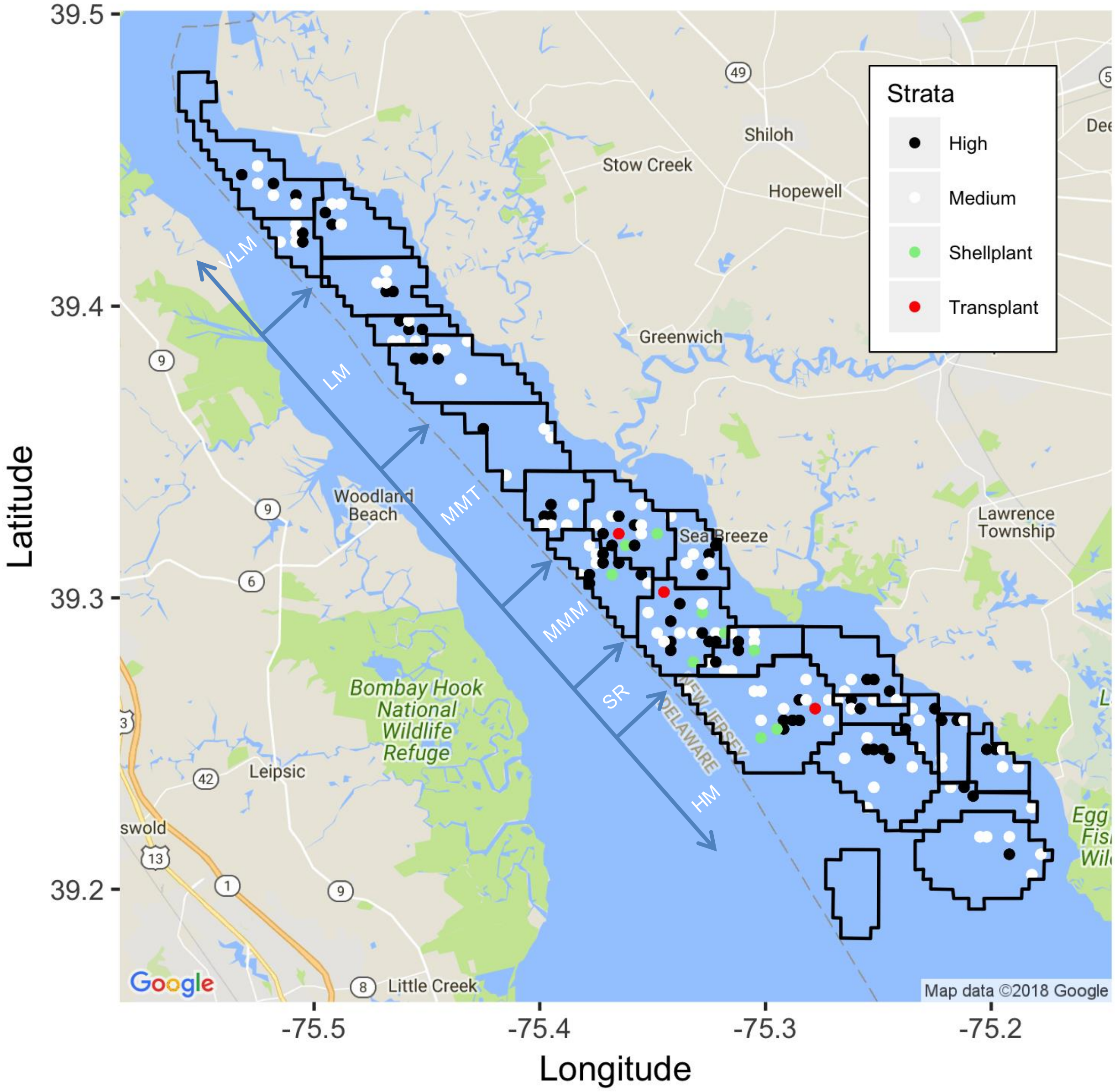


**Figure 1.** Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Black lines demarcate named beds with management regions indicated by blue lines (abbreviations as in text). The sites for the 2017 stock assessment survey are indicated by dots. A stratified random sampling program identified black and white dots for high and medium density strata whereas red dots were transplant sites and green dots were shellplant sites. See Alcox et al. (2017) for full description.

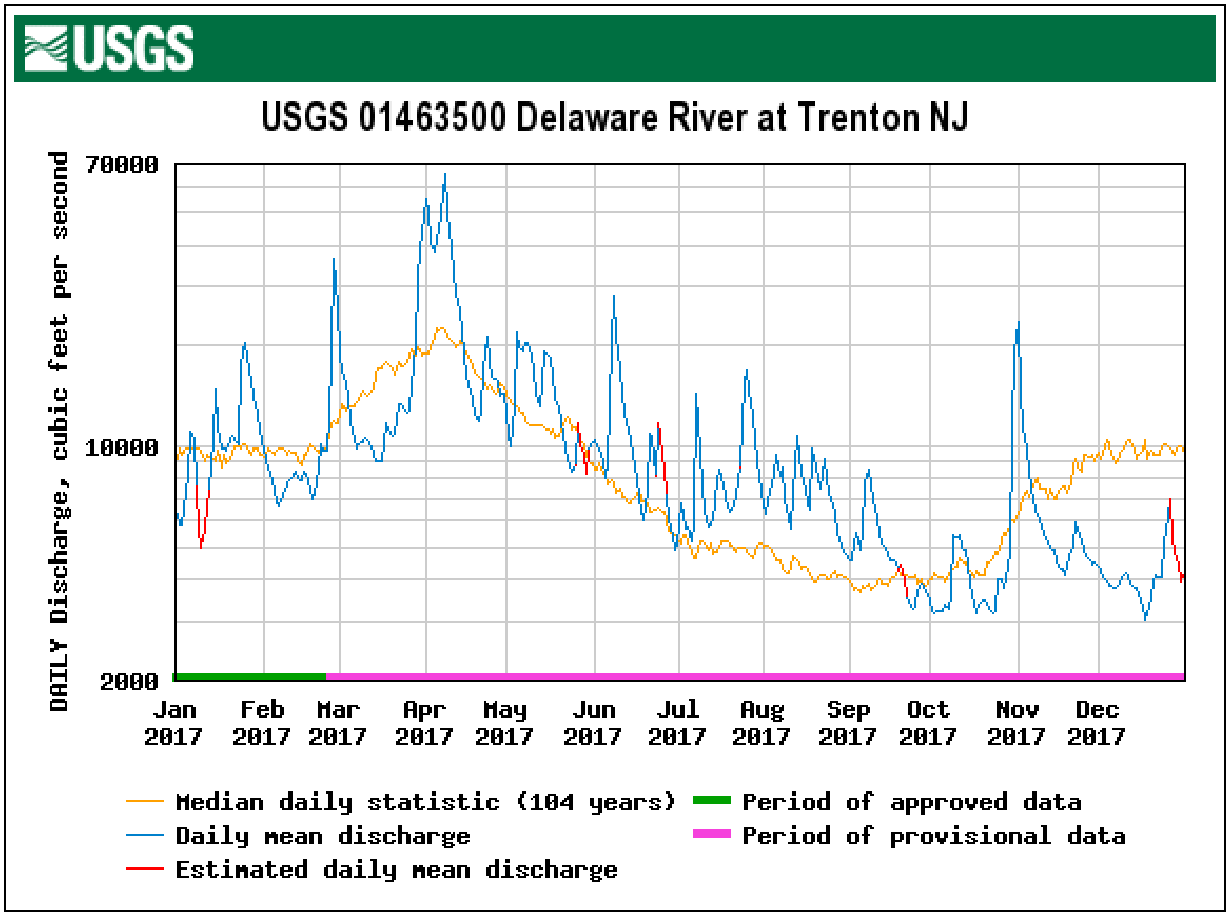


**Figure 2.** USGS discharge from Delaware River at Trenton (USGS station 01463500) during 2017. Freshwater inflow was well above the long term average for much of the year, particularly during spring and summer. These conditions result in reduced salinities over the oyster beds as shown in figures 3 and 4 below.

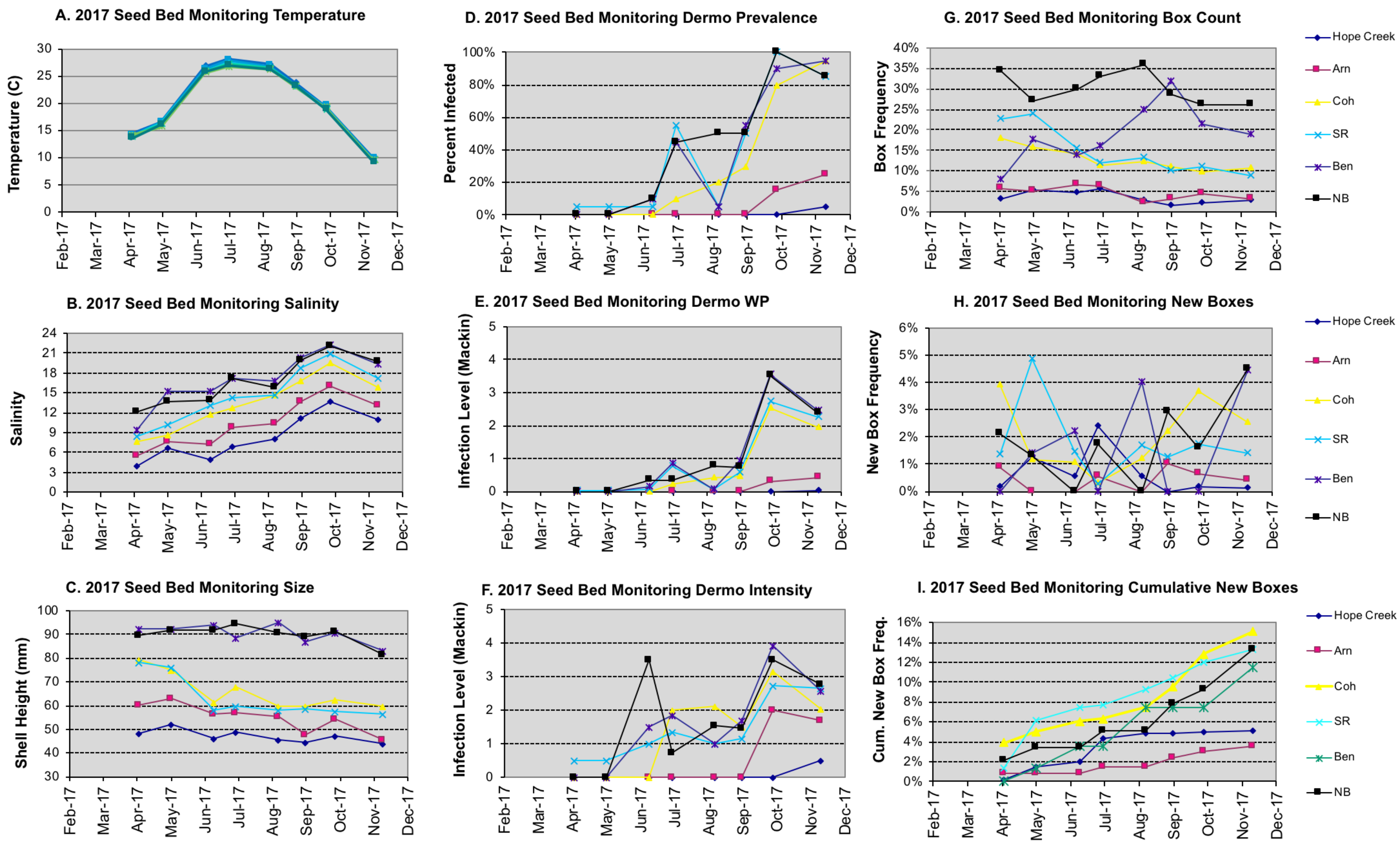


**Figure 3**. Results of 2017 Seed Bed Monitoring Program for the six beds monitored monthly along an upbay to downbay transect. Legends list beds from upbay to downbay. (A) Temperature. (B) Salinity. (C) Mean size. (D) Dermo prevalence (= percent infected). (E) Weighted prevalence (= average population infection intensity). (F) Mean intensity of detectable infections (large spike during June resulted from one heavily infected individual). (G) Total box count mortality estimate. (H) New box count mortality estimate. (I) Cumulative new box count mortality estimate.

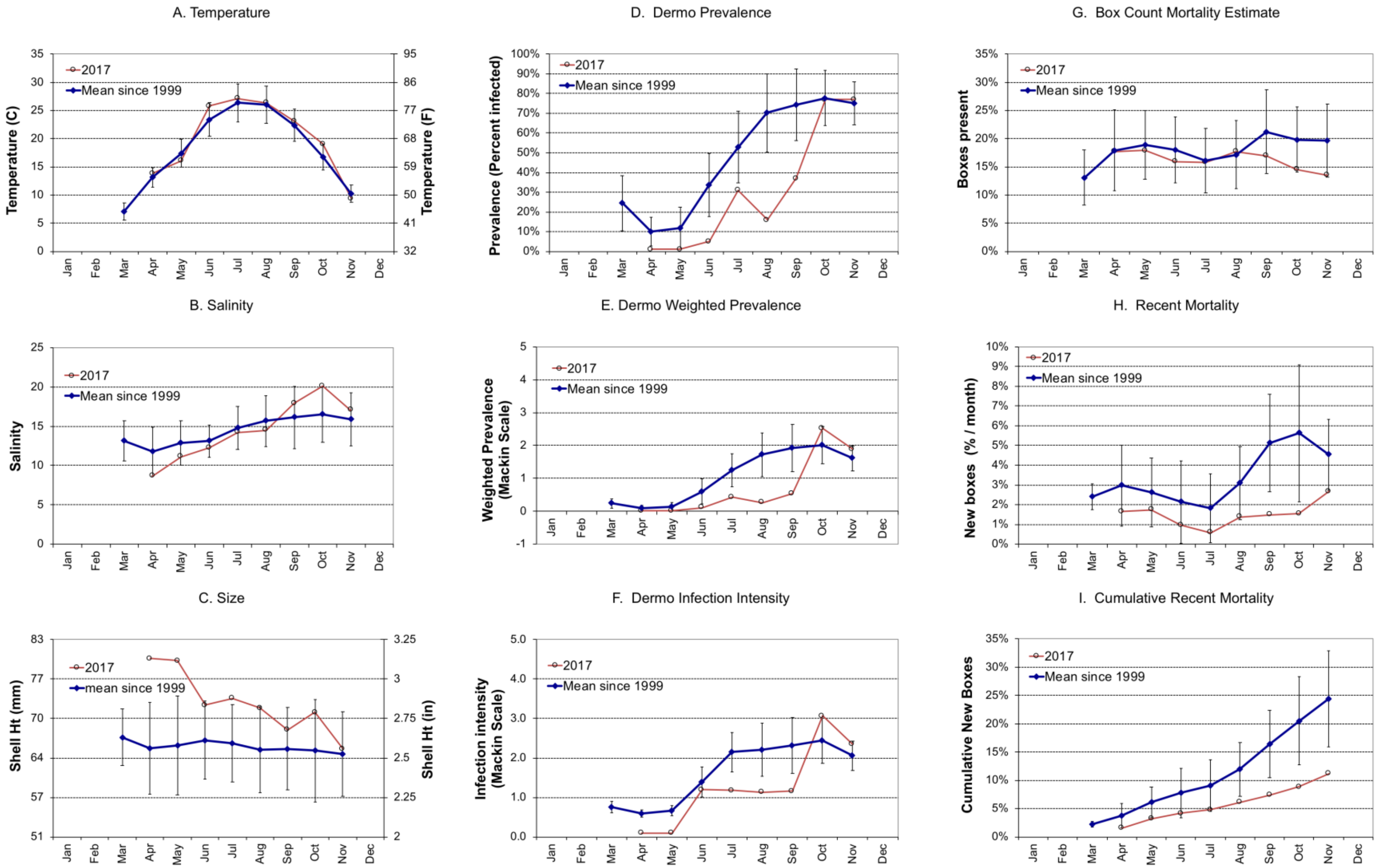


**Figure 4.** Means of 2017 Seed Bed Monitoring Program for the five primary beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) compared to long-term seasonal patterns. Panels arranged as in Figure 3. Error bars represent one standard deviation.

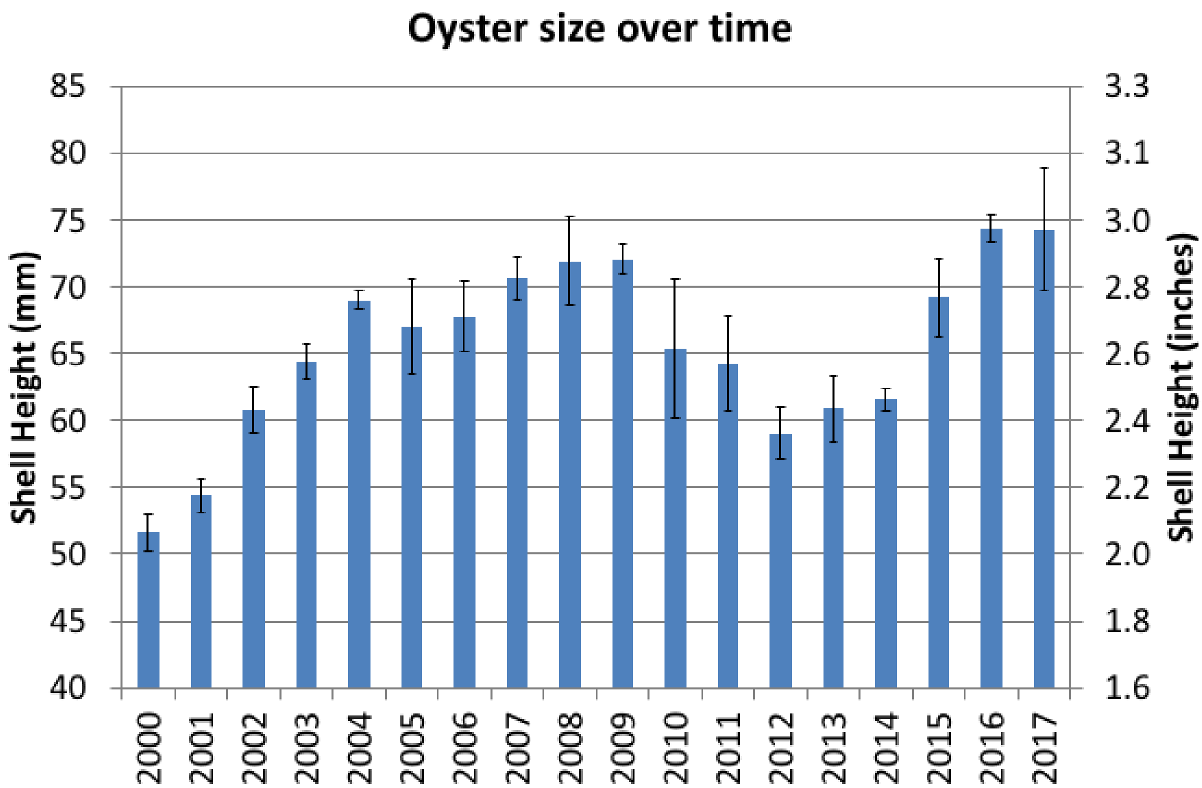


**Figure 5.** Interannual variation in mean shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) sampled from March to November.

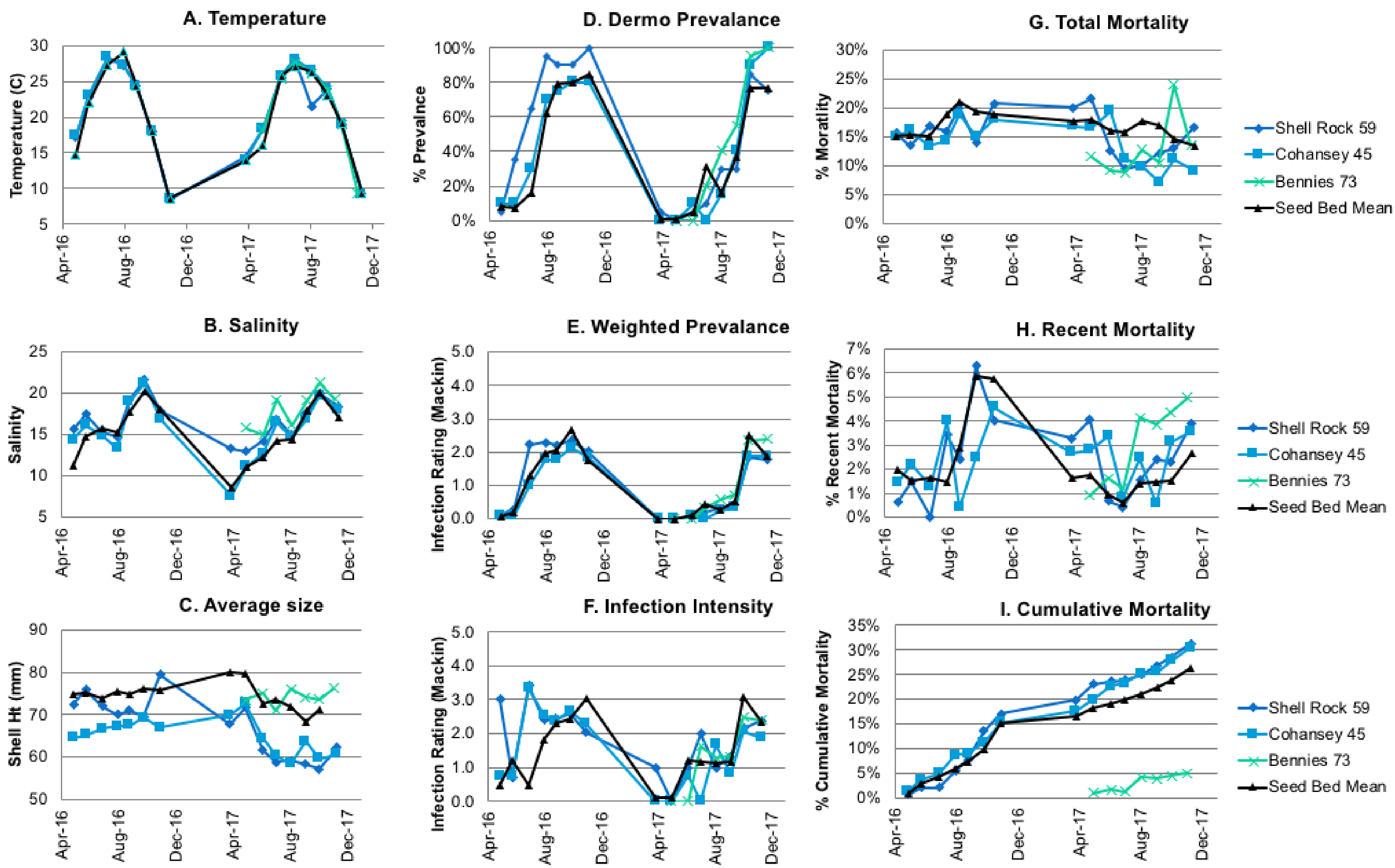


**Figure 6.** Performance of 2016 and 2017 transplants relative to mean of five primary beds monitoring monthly. Panels arranged as in Figure 3. Oysters transplanted in 2016 to Shell Rock were derived from the Medium Mortality Transplant beds while oysters transplanted to Cohansey were derived from the Low Mortality beds (see Figure 1 and Table 2). Oysters transplanted to Bennies 73 in 2017 were moved from Medium Mortality Transplant beds.

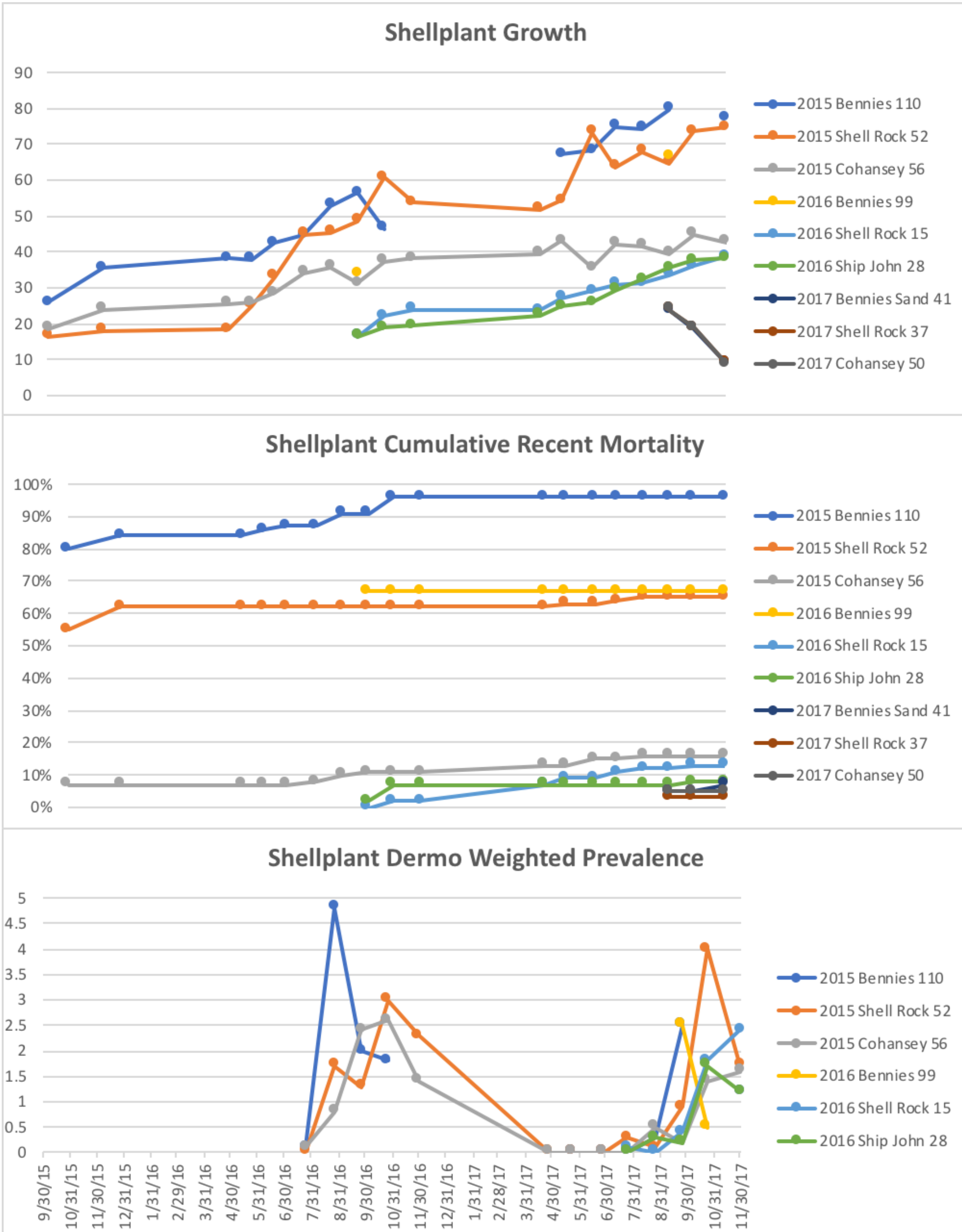


**Figure 7.** Performance of shellplants monitored during 2017. Monitoring for growth and mortality began in September or October during the year of the plant with a hiatus from November to April each year thereafter. Dermo monitoring began in July following the year of planting. High initial levels of mortality are usually caused by high levels of predation or siltation.

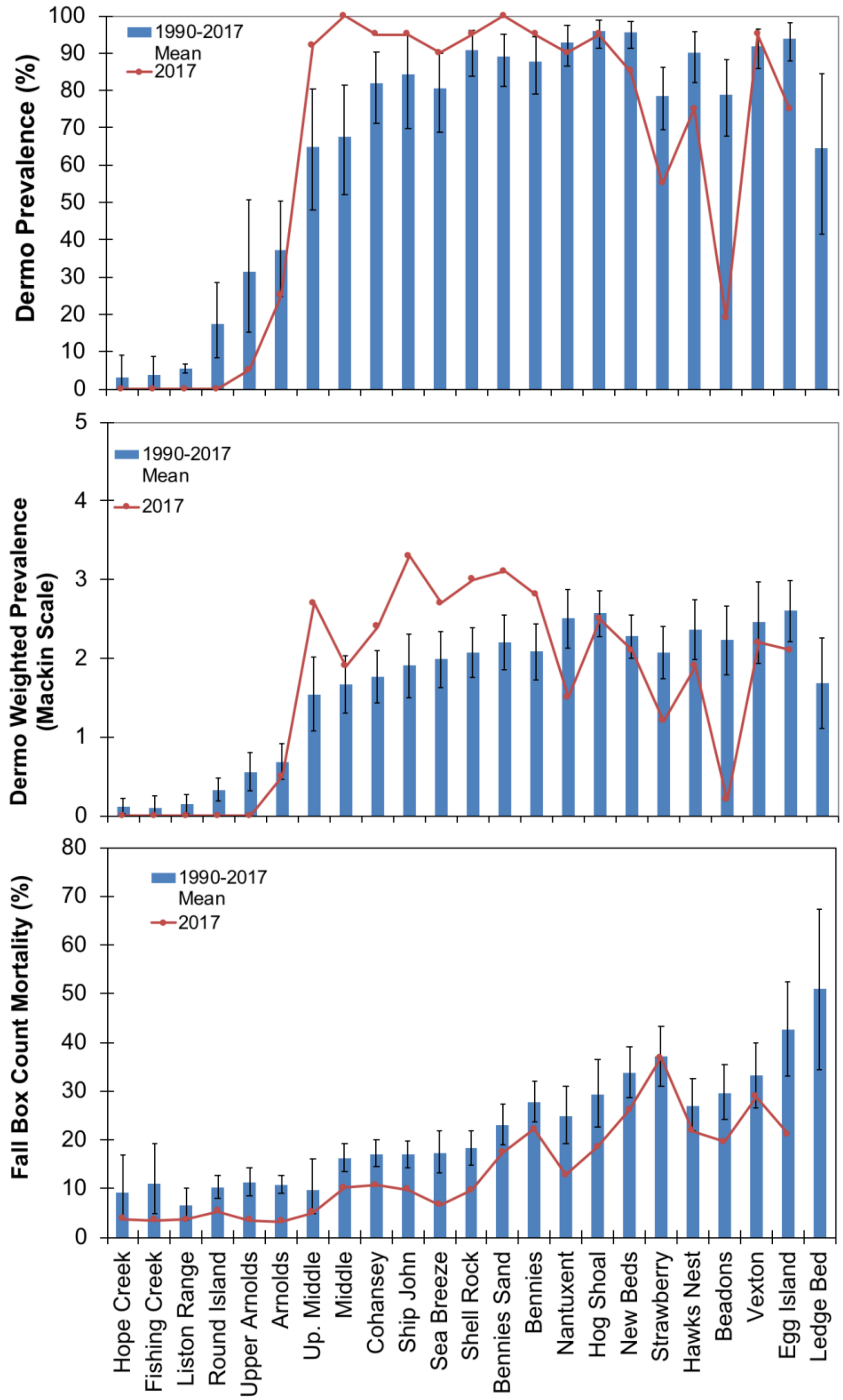


**Figure 8.** Long-term spatial patterns of dermo prevalence (upper panel), dermo weighted prevalence (middle panel) and natural mortality (bottom panel) across the oyster beds. Beds are listed from upbay to downbay left to right. All three metrics increase from upper to lower bay regions. Not all beds have been sampled every year (see Table 3). Ledge was not sampled in 2017. Error bars represent 95% confidence intervals.

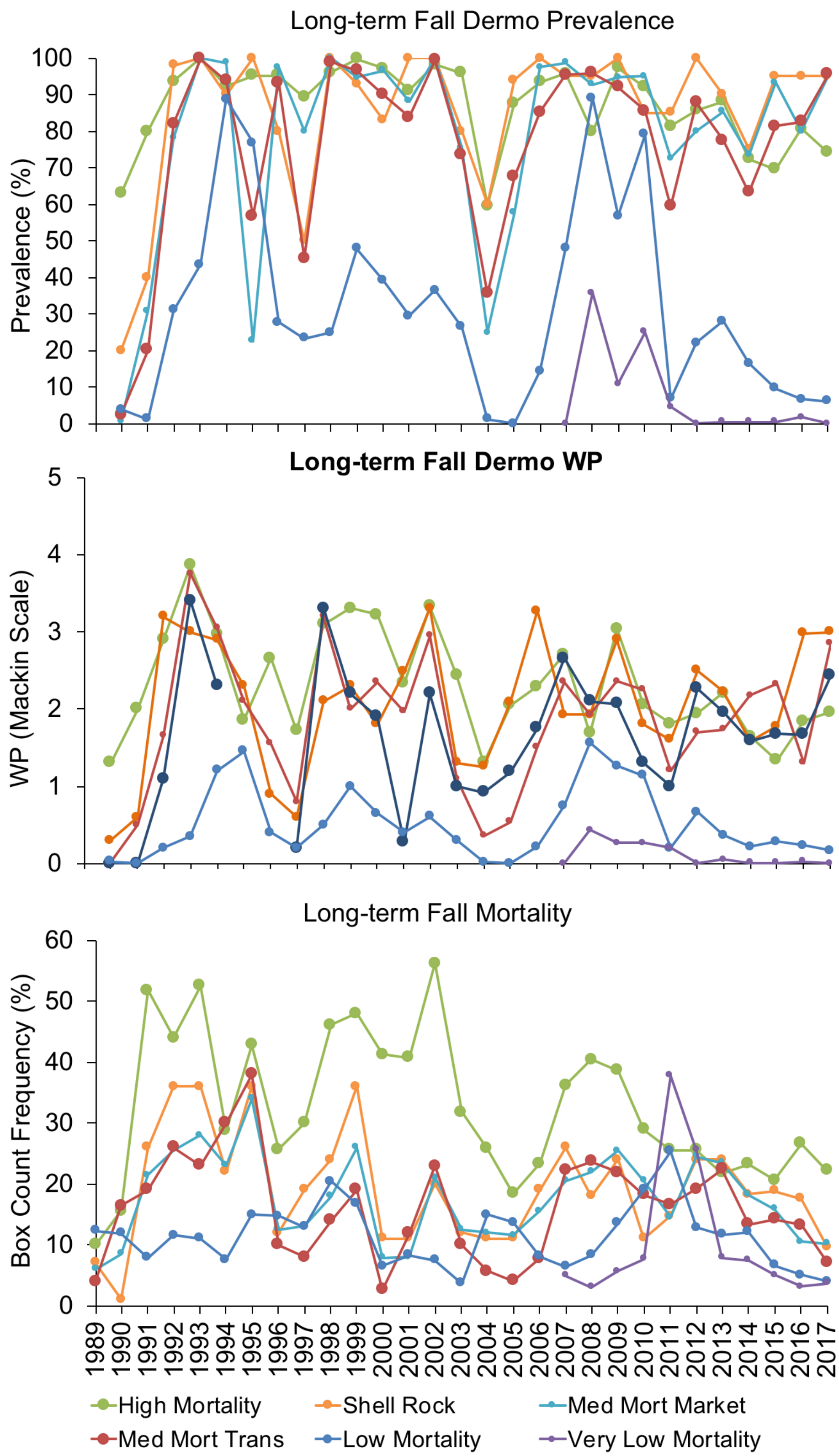


**Figure 9.** Annual Fall dermo prevalence (upper panel), weighted prevalence (middle panel) and box count mortality (bottom panel) on New Jersey Delaware Bay seedbeds. Regions correspond to management regions in Figure 1.

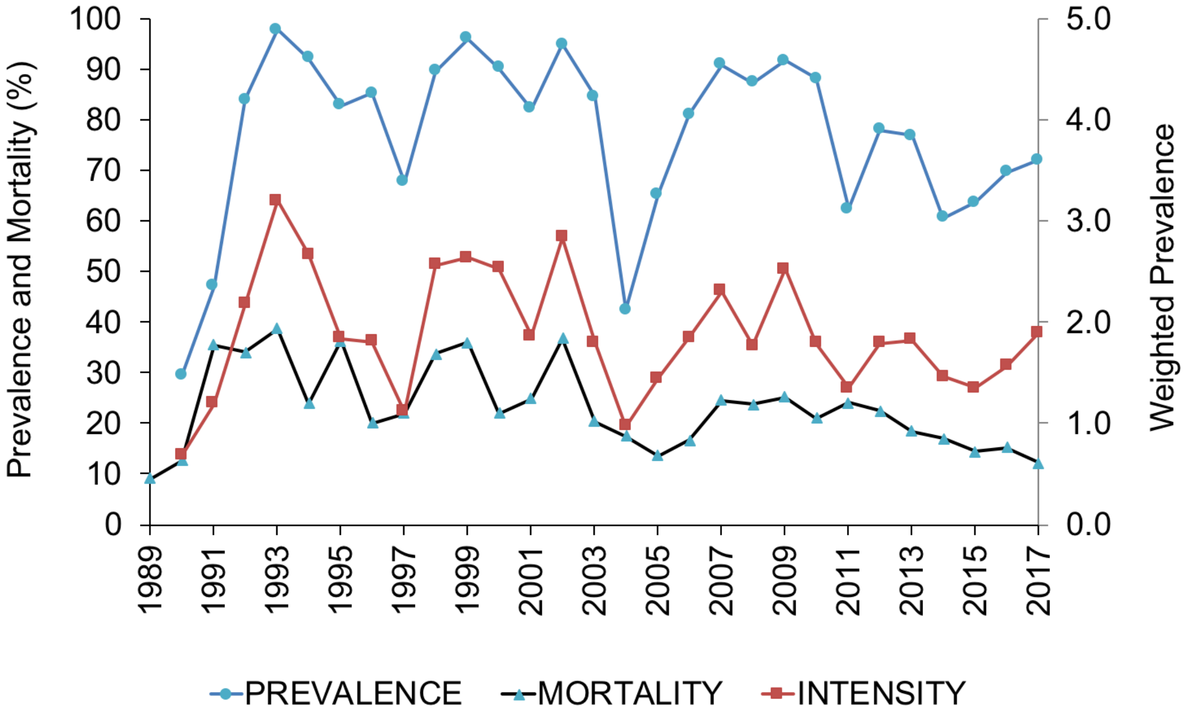


**Figure 10.** Long-term patterns of Fall dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data appear to show cycles with an approximate periodicity of seven years, and a dampening of the cycling resulting in lower levels of each metric over time.

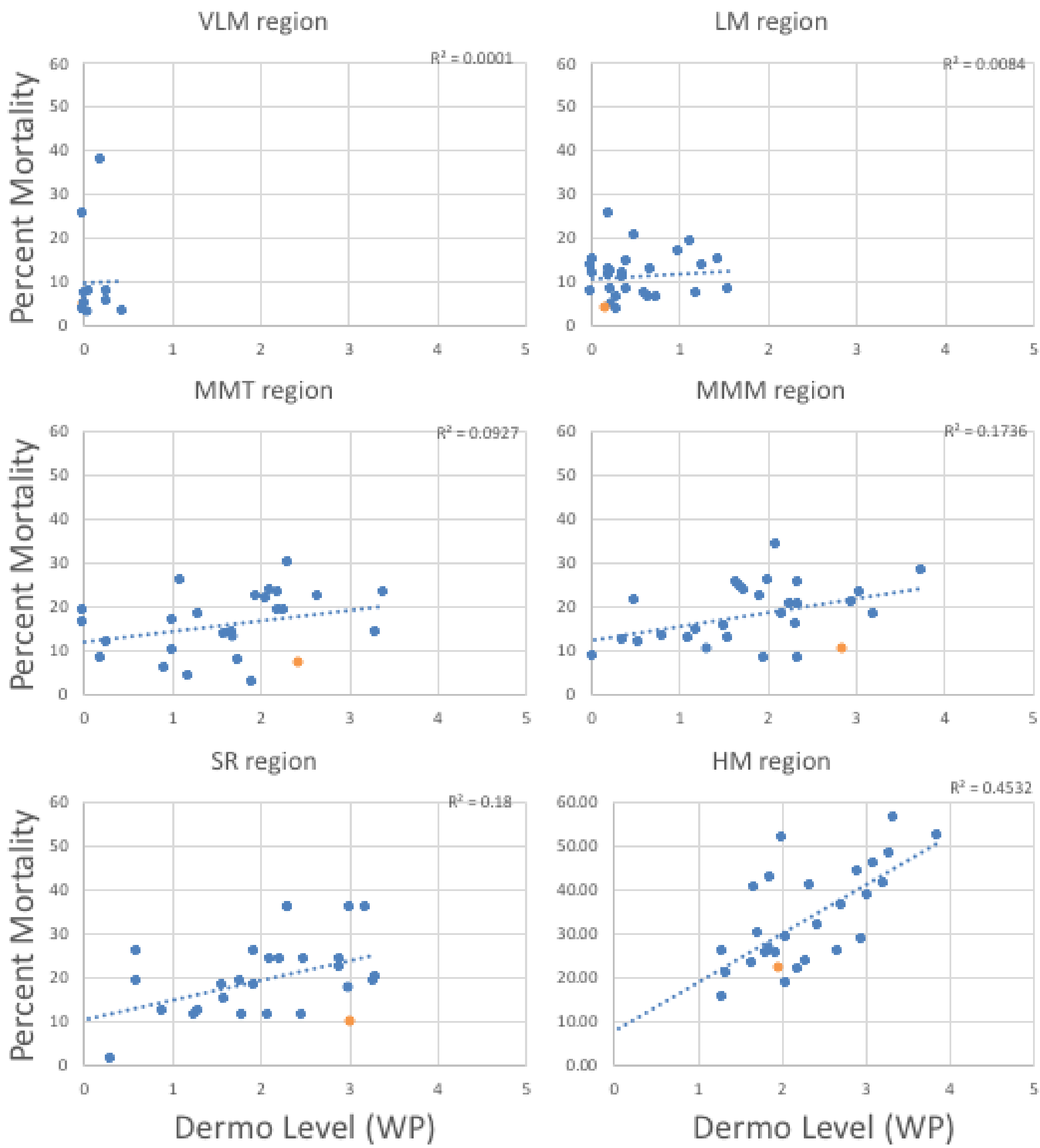


**Figure 11**. Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). Orange points represent 2017 data. VLM = Very Low Mortality region, LM = Low Mortality region, MMT = Medium Mortality Transplant region, MMM = Medium Mortality Market region, SR = Shell Rock, and HM = High Mortality Region.

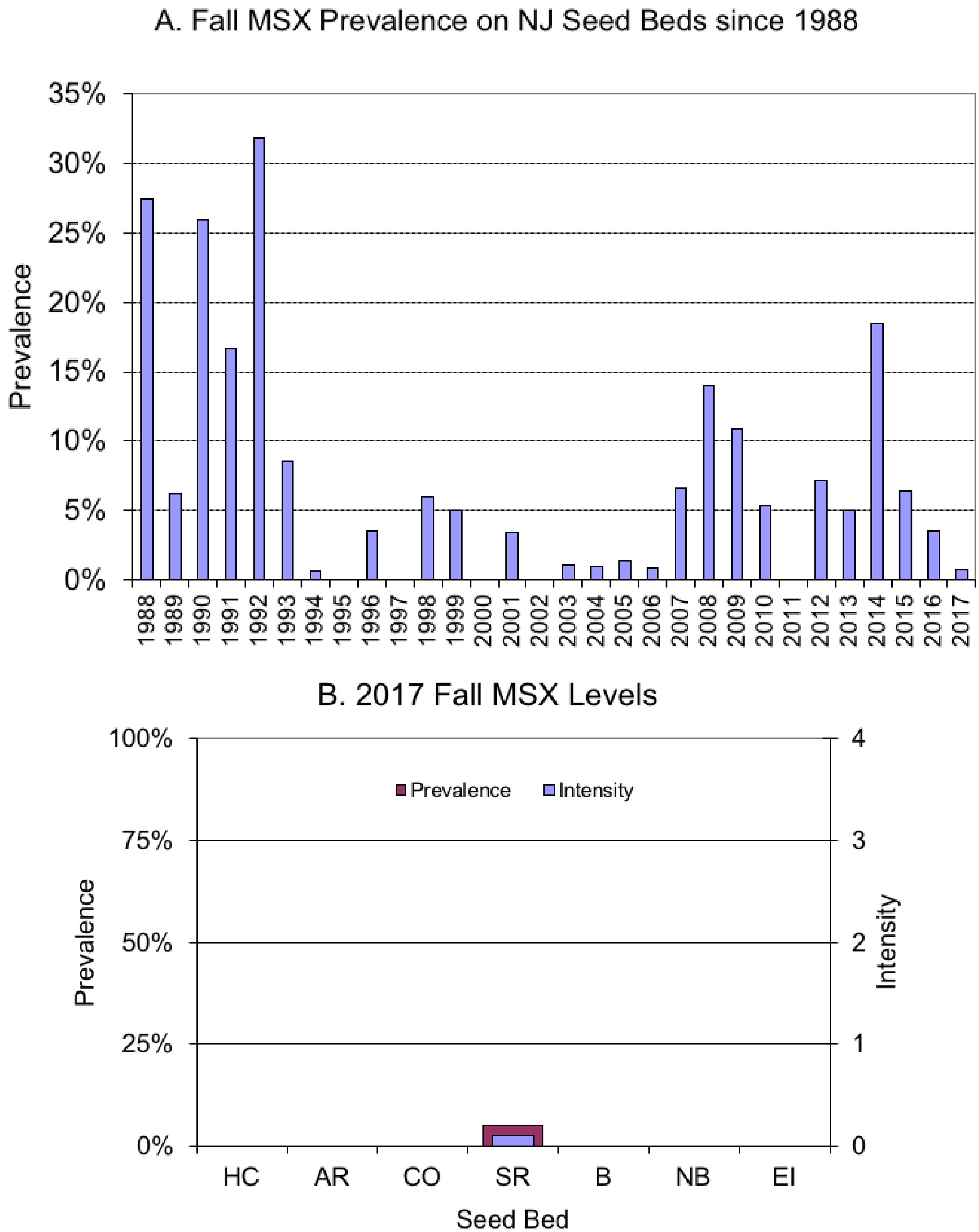


**Figure 12.** MSX disease on the New Jersey Delaware Bay oyster seedbeds. Upper: annual Fall MSX Prevalence since 1988 (2007 for HC). Lower: Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) on selected beds in 2017. HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, EI = Egg Island.