Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2016 Status Report

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- NJ Delaware Bay Oyster Stock Assessment Review Committee
- NJ Delaware Bay Section of the Shell Fisheries Council
- NJDEP Bureau of Shell Fisheries
- NJ Delaware Bay Oyster Industry Science Steering Committee
- NJ Agricultural Experiment Station at Rutgers, The State University of NJ
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Executive Summary

The Delaware Bay NJ Oyster Seedbed Monitoring Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds to provide information in support of the sustainable management of the oyster resource and harvest. Oyster production on privately owned leases, oyster farms or in waters outside the New Jersey Delaware Bay oyster fishery was not monitored by this program during 2016. The 2016 Program monitored dermo disease, oyster growth, and oyster mortality at six monthly monitoring sites, two transplant sites, and nine shellplants (three each from 2014, 2015 and 2016). One additional site (ACE) was continued from those monitored previously in conjunction with the Delaware Bay Channel Deepening project. 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 and salinity, the dominant environmental factors controlling oyster growth, reproduction, disease and mortality, followed typical seasonal cycles. Relative to means since 1999, temperature was cooler than normal early in the year then higher than normal after July while salinity increased fluctuated around average values increasing to higher than normal levels during late summer and fall. The mean size of oysters collected was larger than one standard deviation of the long-term mean supporting reports from oystermen that there are a lot of larger oysters present. Dermo disease also followed typical seasonal and spatial patterns with prevalence following the pattern described for temperature, which appeared to delay the onset of the disease, and intensity following the pattern described for salinity that might have helped produce a spike in infection intensities in October. Nevertheless, mortality rates estimated throughout the year were below average for much of the year and rarely exceeded mean values.

Long-term spatial patterns of dermo and mortality continue to follow an overall upbay-downbay gradient with an apparent shift in peak levels in an upbay direction. Long-term annual patterns continue to indicate a cycling of dermo disease with an approximate periodicity of seven years and a dampening of the cycle over time. Most beds entered winter with relatively low levels of dermo disease, Shell Rock being the exception. MSX continues to be present, but remains at low levels in the native population which continues to maintain a relatively high level of resistance to this otherwise devastating oyster pathogen.

The overall picture appears 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 2016. Monthly monitoring occurs at selected sites along a transect spanning the salinity gradient across the beds. Additional sites are included where there is 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 the Fall. Together, these data provide insight into inter-annual patterns, long-term trends, and factors affecting the oyster stock that can inform management of the oyster stock.

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 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. 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 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 from the original medium mortality region and further subdivide the remaining beds into Medium Mortality Transplant and Medium Mortality Market 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). Continued long-term spatial monitoring as well as directed research and sampling efforts are necessary to understand these dynamics and how they change through time.

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 2016 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 2016 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on 2014 through 2016 shell plantings
4. Monitor growth mortality and disease on the 2016 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 grid system used during 2016 for the monitoring program with area management regions distinguished by color. Management activities and this report reference both regions and beds as appropriate. Beds that fall within the jurisdiction of the state of Delaware are neither monitored nor shown. The grid system is contiguous, but only those areas containing significant concentrations of oysters (= beds) are shown (n = 23). Each bed is referenced by the name traditionally used by the industry and resource managers. On any given bed, grids of the highest density that collectively contain 50% of the oysters from the bed are indicated with darker shading and referred to as 'high quality' strata. Grids containing the next 48% of the population ranked by density are referred to as 'medium quality' and indicated in lighter shading. Remaining grids (not shown or sampled) contain the lowest densities of oysters and collectively comprise no more than 2% of the population on their respective bed. Additional details on bed quality designations are provided in Powell et al. (2008 an 2012a).

Monthly samples were collected from April through November for Objectives 1, 3 and 4 as indicated in Tables 1 and 2. Table 3 shows which beds have been monitored since 1990 as part of the long-term dermo monitoring program that is affiliated with the Annual Fall Oyster Stock Assessment. Table 4 specifies the grids sampled during the 2016 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 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 (Dungan and Bushek 2015). The average intensity of infections was similarly determined but did not include any oysters in which infections were not detected.

[1] At Arnolds and Hope Creek, sample volumes were halved.

Samples for Objective 2 were collected during the Fall Stock Assessment using the commercial oyster boat H. W. Sockwell. The stock assessment survey consists of a stratified random sampling of the medium and high quality grids on the 23 named beds (colored grids in Figure 1). Ledge and Egg Island beds contain very few oysters and are only sampled in alternate years; Ledge was sampled during 2016. 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 2014 and 2015 shell plantings, and initiated the 2016 shell plantings listed in Table 2 – the latter of which was only sampled during the final 3 months. On each 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 2016 shellplants. Disease sampling commenced immediately on the 2014 shellplants and in July on the 2015 shellplants.

Results and Discussion

Data obtained from the USGS stream gages indicated an early spring inflow tailing off and remaiming low throughout the remainder of the year (Figure 2). Extended periods of reduced runoff permit increases in salinity via salt flux from the ocean as well as increases in residence time, both of which can support increased retention and transmission of pathogens.

Temperature. Water temperatures measured during 2016 collections followed a typical seasonal increase and decrease but an unusually high peak occurred in August exceeding the more common July peak (Figures 3A and 4A). There was little spatial variability across the seedbeds. Temperatures remained above normal ranges into October (Figure 4A).

Salinity. Salinity followed the typical estuarine gradient, increasing from upbay to downbay beds (Figure 3B), but seasonally it began to exceed normal values at all locations in September, October and November (see also Figure 4B). This pattern is likely associated with the river discharge shown in Figure 2.

Temperature and salinity are arguably the most important environmental factors controlling oyster growth, reproduction, disease and mortality. The conditions observed over the seedbeds are conducive to the development of disease and consequent mortality as described below. Researchers at Rutgers have developed a powerful 3D numerical circulation model of the Delaware Bay using ROMS (Regional Ocean Modeling System) that has already been employed to understand disease processes in Delaware Bay (Wang et al. 2012, Munroe et al. 2013). *An array of continuous monitoring stations across the seedbeds will facilitate validation of the model and a better interpretation of conditions that influence recruitment, growth, disease and mortality of oysters.*

Oyster size. Shell height (measured hinge to bill) roughly corresponds to age and therefore provides insight into both the size and age structure of the population. Seasonal changes in a population's mean shell height may be affected by growth, recruitment and mortality (both natural and fishing mortality). During 2016, mean shell height was relatively stable with a slight increase over the growing season (Figures 3C). Shell height decreased on Shell Rock at the end of the season, possibly due to the concentration of fishing and a relatively high level of recruitment (see HSRL Stock Assessment Report for same year). Both Bennies and New Beds showed an increase in mean shell height owing to higher levels of survival (see below). Compared to mean levels over time, mean size has increased considerably; each month, mean shell height of the five primary beds was above the standard error of means since 1999 (Figure 4C). Overall mean shell height was the highest recorded since 2000 though sizes were similar in the mid to late 2000s (Figure 5).

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) followed typical seasonal patterns. Each began low, then rapidly increased to higher than average levels during the latter portion of the season (Figures 3D-F and 4D-F). The higher than normal levels are likely related to the elevated temperatures and salinities during August through October, and the larger size of oysters in general (Figures 4A-C). These conditions indicate that oysters are entering winter with moderate infections that could lead to increased mortality next year if infections do not decline sufficiently before waters warm up in late spring and summer.

Mortality. The levels of disease just described were not associated with unusually high levels of mortality (Figures 3G-I and 4G-I). This could be related to an increase in tolerance to infections. Compared with long term means, recent and cumulative mortality were relatively low (Figures 4H and I). Note that the Annual Delaware Bay Oyster Stock Assessment has defined 20% mortality as an epizootic and mortality reached that level by the end of the season.

Transplants. Figure 6 shows that transplants performed similarly to the receiving bed, which is typical during the first year of a transplant. Preliminary data from previous reports indicated increases in disease and mortality on transplant sites after the first year but recruitment may increase on these sites. Continued examination of transplant sites over time should be performed to evaluate the persistence of these enhancement activities on the receiving site.

Shellplants. Growth on shellplants was steady and followed levels from prior years (Figure 7A). Dermo levels increased rapidly during 2016 on both 2014 and 2015 shellplants exceeding levels expected to begin causing mortality (Bushek et al. 2012). Dermo was not monitored on 2016 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. Replanting should be reevaluated as a strategy as should spat-on-shell which has 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 2016.

Long-Term Fall Patterns. Examination of dermo prevalence, weighted prevalence and mortality on a bed-by-bed basis (Figure 8) indicates higher dermo levels in the middle region of the bay during 2016 compared to the typical pattern that increases from upbay to downbay beds. This is the fourth year of this pattern indicating changes in disease dynamics across the Bay. In contrast, however, reductions in disease on the lower bay beds were not as clearly or uniformly associated with reductions in mortality on a bed by bed . It is unclear whether or not this observation is a density-dependent response to reductions in oyster abundance on the lower beds, evidence of the development of tolerance or resistance by oysters under heavier disease pressure in the lower bay, or a result of changing environmental conditions.

Figure 9 depicts annual dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2016 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. Given the disease levels observed during 2016, 2017 may witness an increase in mortality. 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 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 variations in dermo disease, it is less clear how they interact to influence inter-annual 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 2016 data points show most regions in relatively good positions, the exception being Shell Rock.

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 infections were detected in < 5% of the 140 oysters assayed (Figure 12A), and those infections were limited to two lower bay beds (Figure 12B). Nevertheless, previous years have found MSX distributed across the seed beds indicating that MSX remains a threat to the entire stock. Because MSX continues to be a serious problem in other areas and remains virulent to naïve oyster stocks, monitoring for MSX remains as an important component of the monitoring program to understand sources of mortality from year to year. Moreover, because MSX can cause mortality in Spring, it is recommended that some routine monitoring of MSX occur throughout the year to provide an adequate level of surveillance.

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Table 1. 2016 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 was the ACE site. 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 18, 2016	6 long-term + 1 ACE site	NJDEP RV James W. Joseph	Craig Tomlin
April 27, 2016	6 2014-15 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
May 17, 2016	6 long-term + 1 ACE site	NJDEP RV James W. Joseph	Craig Tomlin
May 25, 2016	2 intermediate transplants 6 2014-15 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
Jun 14, 2016	6 long-term + 1 ACE site	NJDEP RV James W. Joseph	Craig Tomlin
June 20, 2016	2 intermediate transplants 6 2014-15 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
July 18, 2016	6 long-term + 1 ACE site	NJDEP RV James W. Joseph	Craig Tomlin
July 25, 2016	2 intermediate transplants 6 2014-15 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
August 15, 2016	6 long-term + 1 ACE site	NJDEP RV James W. Joseph	Craig Tomlin
August 26, 2016	2 intermediate transplants 6 2014-15 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
September 19, 2016	6 long-term + 1 ACE site 2 intermediate transplants	NJDEP RV James W. Joseph	Craig Tomlin
September 26, 2016	9 2014-16 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
October 17, 2016	6 long-term + 1 ACE site 2 Intermediate Transplants	NJDEP RV James W. Joseph	Craig Tomlin
October 26, 2016	9 2014-16 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
November 23, 2016	6 long-term + 1 ACE site 2 Intermediate Transplants	NJDEP RV James W. Joseph	Craig Tomlin
November 28, 2016	9 2014-16 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin

Table 2. Additional sites sampled during 2016. Replant = shell planted in lower Delaware Bay then moved to bed indicated after spat have recruited.

Bed	Grid	Plant material	Plant yr
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
Nantuxent	23	ocean quahog	2014
Shell Rock	31	ocean quahog	2014
Ship John	33	ocean quahog	2014
Middle	28	surf clam shell replant	2014

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

SEEDBED	90	91	92	93	94	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Hope Creek																		X	X	X	X	X	X	X	X	X	X
Liston Range																			X	X	X	X	X	X	X	X	X
Fishing Creek																			X	X	X	X	X	X	X	X	X
Round Island	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Arnolds														X		X	X	X	X	X	X	X	X	X	X	X	X
Arnolds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Middle																	X	X	X	X	X	X	X	X	X	X	X
Middle	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cohansey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sea Breeze															X	X	X	X	X	X	X	X	X	X	X	X	X
Ship John	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Shell Rock	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bennies Sand	X	X	X	X	X			X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Bennies	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nantuxent		X		X		X		X		X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
Hog Shoal		X		X						X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
New Beds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Strawberry	X		X		X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hawks Nest	X		X		X		X		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Beadons	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vexton										X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Egg Island	X	X	X	X	X	X	X	X		X	X	X		X		X		X		X		X		X		X	
Ledge Bed			X		X				X		X		X		X		X		X		X		X		X		X

Table 4. 2016 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	35	10		15
Hope Creek	75	10		15
Hope Creek	85			10
Hope Creek	55			10
Hope Creek	63		20	0
Fishing Creek	25	10		15
Fishing Creek	4	10		15
Fishing Creek	16			10
Fishing Creek	8			10
Liston Range	12	10		15
Liston Range	14	10		15
Liston Range	30			10
Liston Range	24			10
Round Island	50	10		15
Round Island	24	10		15
Round Island	26			10
Round Island	25			10
Upper Arnolds	10	10		15
Upper Arnolds	22	10		15
Upper Arnolds	18			10
Upper Arnolds	14			10
Arnolds	43	10		15
Arnolds	15	10		15
Arnolds	29			10
Arnolds	19			10
Arnolds	18		20	0
Upper Middle	48	10		15
Upper Middle	63	10		15
Upper Middle	56			20
Middle	10	10		15
Middle	36	10		15
Middle	42			10
Middle	20			10
Cohansey	8	10		15
Cohansey	57	10		13
Cohansey	66			11
Cohansey	25			11
Cohansey	44		20	0
Sea Breeze	30	10		15
Sea Breeze	18	10		15
Sea Breeze	15			10
Sea Breeze	24			10
Ship John	47	10		15
Ship John	25	10		15
Ship John	8			10
Ship John	31			10

Bed	Grid	Dermo	MSX	CI
Shell Rock	25	10		10
Shell Rock	3	10		15
Shell Rock	71			12
Shell Rock	43			13
Shell Rock	11		20	0
Bennies Sand	4	10		15
Bennies Sand	43	10		15
Bennies Sand	32			10
Bennies Sand	11			10
Bennies	146	10		15
Bennies	102	10		15
Bennies	56			10
Bennies	82			10
Bennies	110		20	0
Nantuxent	18	10		15
Nantuxent	13	10		15
Nantuxent	15			10
Nantuxent	30			10
Hog Shoal	4	10		15
Hog Shoal	6	10		15
Hog Shoal	9			10
Hog Shoal	1			10
New Beds	24	10		14
New Beds	55	10		15
New Beds	53			10
New Beds	3			11
New Beds	26		20	0
Strawberry	10	10		17
Strawberry	28,29	10		15
Strawberry	18			1
Strawberry	2			3
Hawks Nest	5	10		13
Hawks Nest	14	10		15
Hawks Nest	4			11
Hawks Nest	27			11
Beadons	3	10		19
Beadons	8	10		13
Beadons	5			2
Beadons	18			8
Vexton	9	10		16
Vexton	3	10		17
Vexton	4			17
Ledge	6	20	20	0
Ledge	35			2
Total beds	**22**	**22**	**7**	**22**
Total grids	**91**	**44**	**7**	**85**
Total oysters		**440**	**140**	**1030**

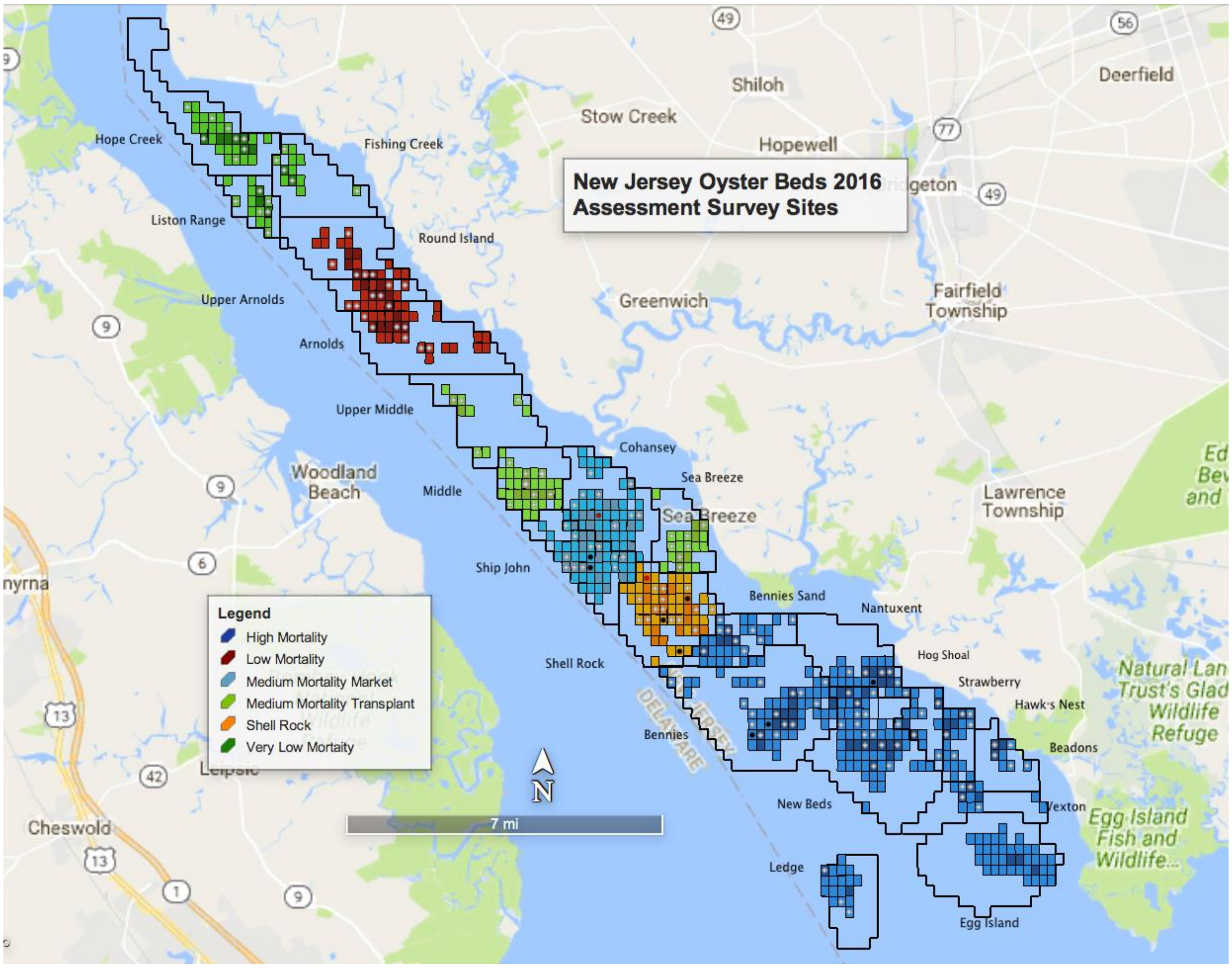

Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Lines differentiate different beds with traditional bed names indicated. Colors differentiate boundaries of regions defined by the area management system shown in the figure legend. Grids are 0.2 minute latitude x 0.2 minute longitude; approx. 25 acres or 10.1 hectares. Bed footprints show grids from the high (dark shade) and medium (light shade) quality strata which together contain 98% of the population within each bed. Strata designation is described in the text with further details provided in Powell et al. (2008 and 2012a). The sites for the 2016 stock assessment survey are indicated by dots. A stratified random sampling program identified white dots whereas red dots were transplant sites and black dots were shellplant sites. Figure credit J Mikus.

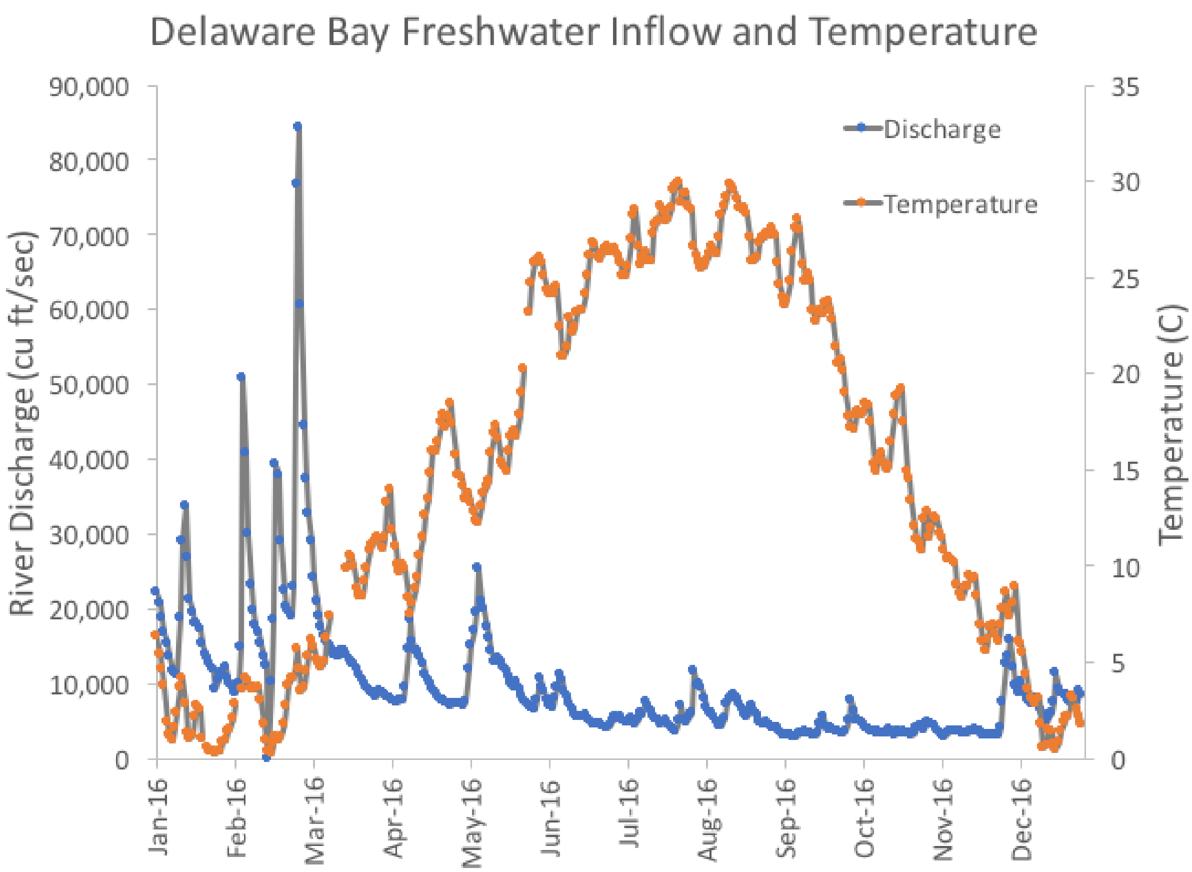

Figure 2. USGS discharge from Delaware River at Trenton (USGS station 01463500) and Schuylkill River at Philadelphia (01474500) with water temperature from Trenton. These two inputs provide the majority of fresh water to the Delaware Bay with the Schuylkill averaging about 18% of their total. Ice was only present once across the Delaware River preventing accurate measurements. Snow pack melted and dispersed early in the year with little rain to supplement flow throughout much of the year. These dry conditions resulting in increasing salinity over the seed beds as shown in figures 3 and 4 below.

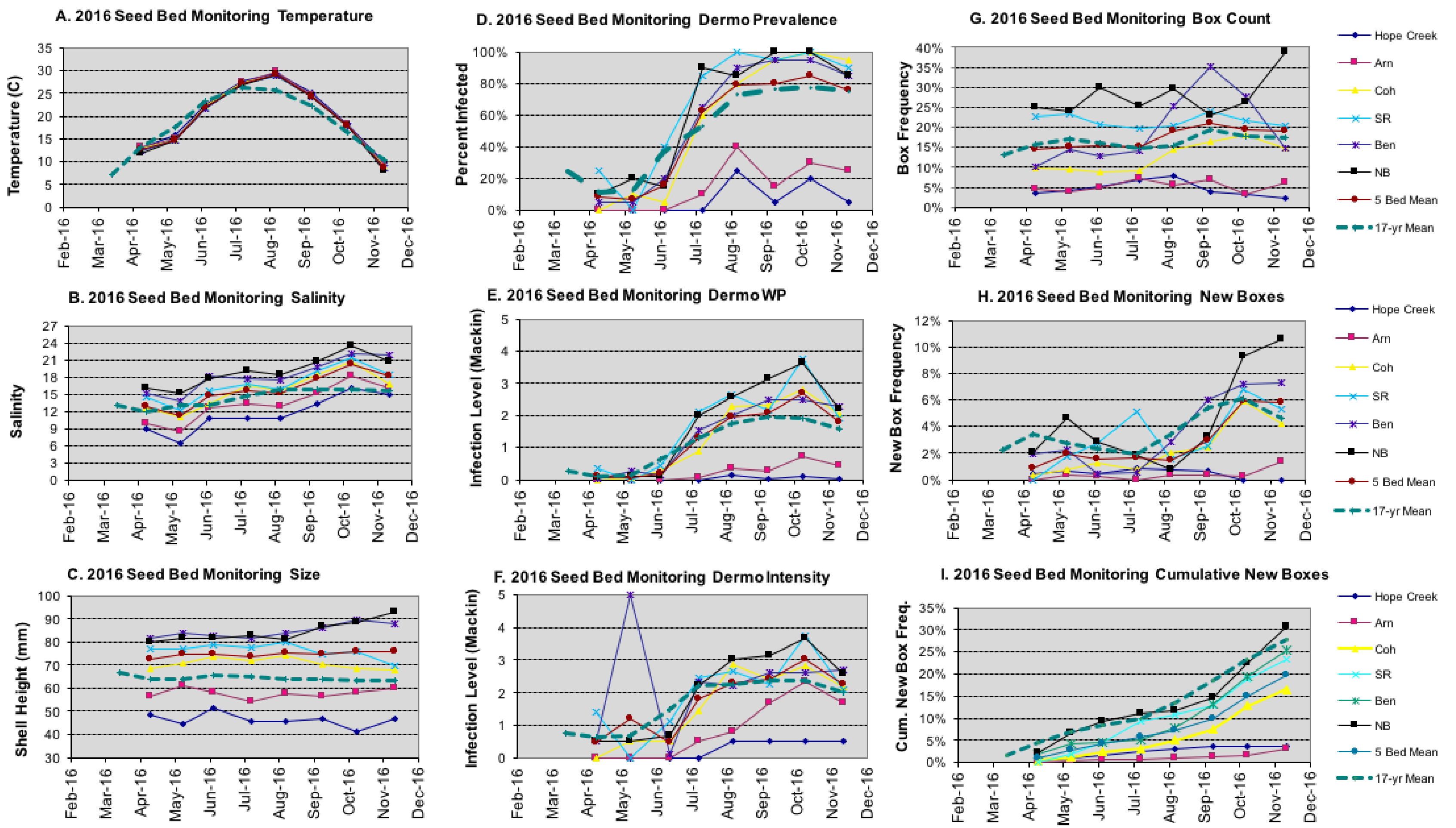

Figure 3. Results of 2016 Seed Bed Monitoring Program for the five primary beds and Hope Creek along an upbay to downbay transect. Legends list beds from upper to lower bay. Left Panels show temperature, salinity and mean size. Center panels show dermo levels as overall prevalence (= percent infected), weighted prevalence (average overall population infection intensity), and intensity of detectable infections. The large spike in panel F during May is due to one heavily infected individual. Right panels show mortality rates as overall monthly box counts, percent of new boxes (mortality over the past month) and cumulative new boxes across the year. Red circle and line is the average the 6 beds shown. Dashed green line is the average of those same beds since 1999.

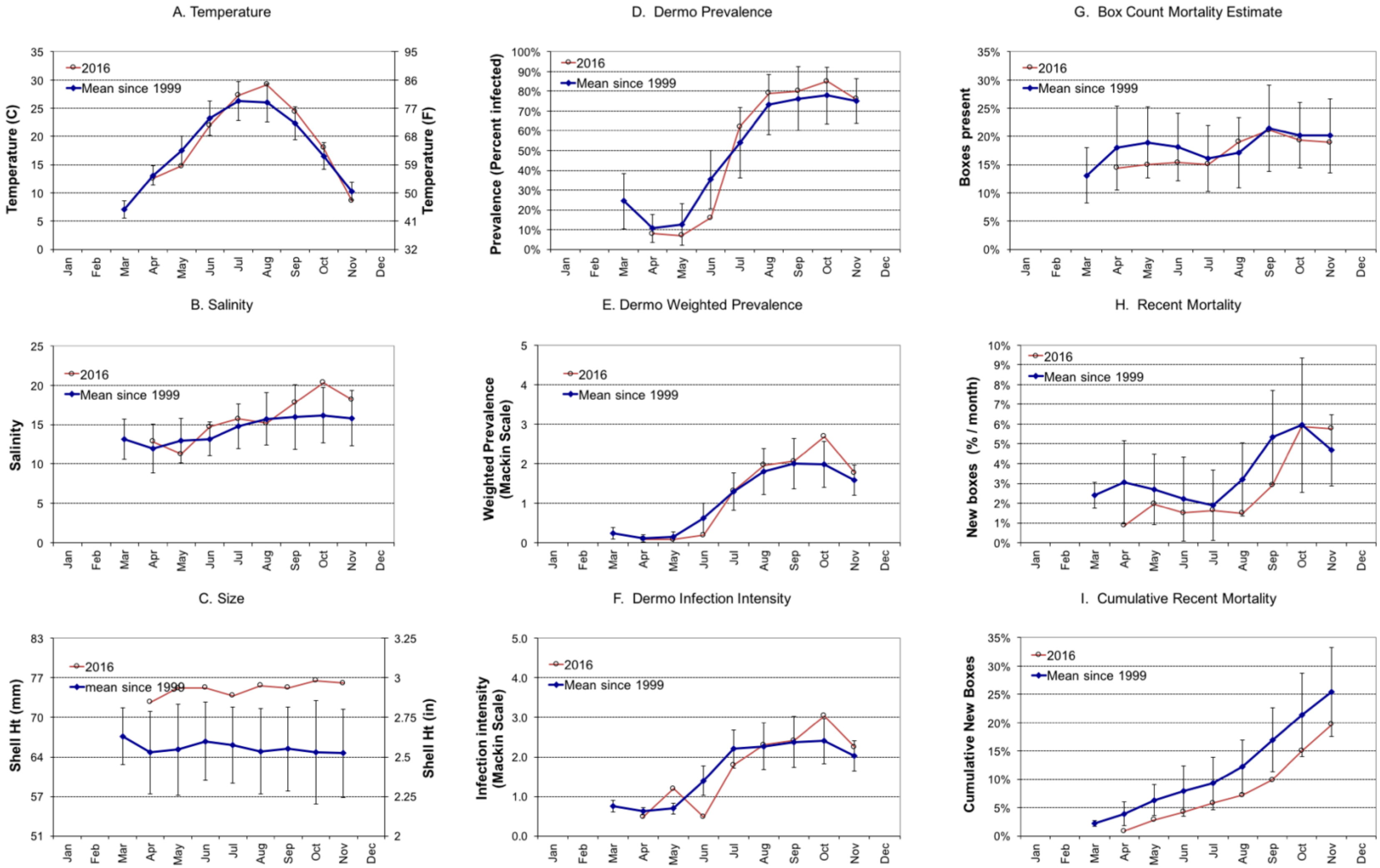

Figure 4. Means of 2016 Seed Bed Monitoring Program for the five primary beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) compared to long-term seasonal patterns. Panels arranged as in Figure 3. Error bars represent one standard deviation.

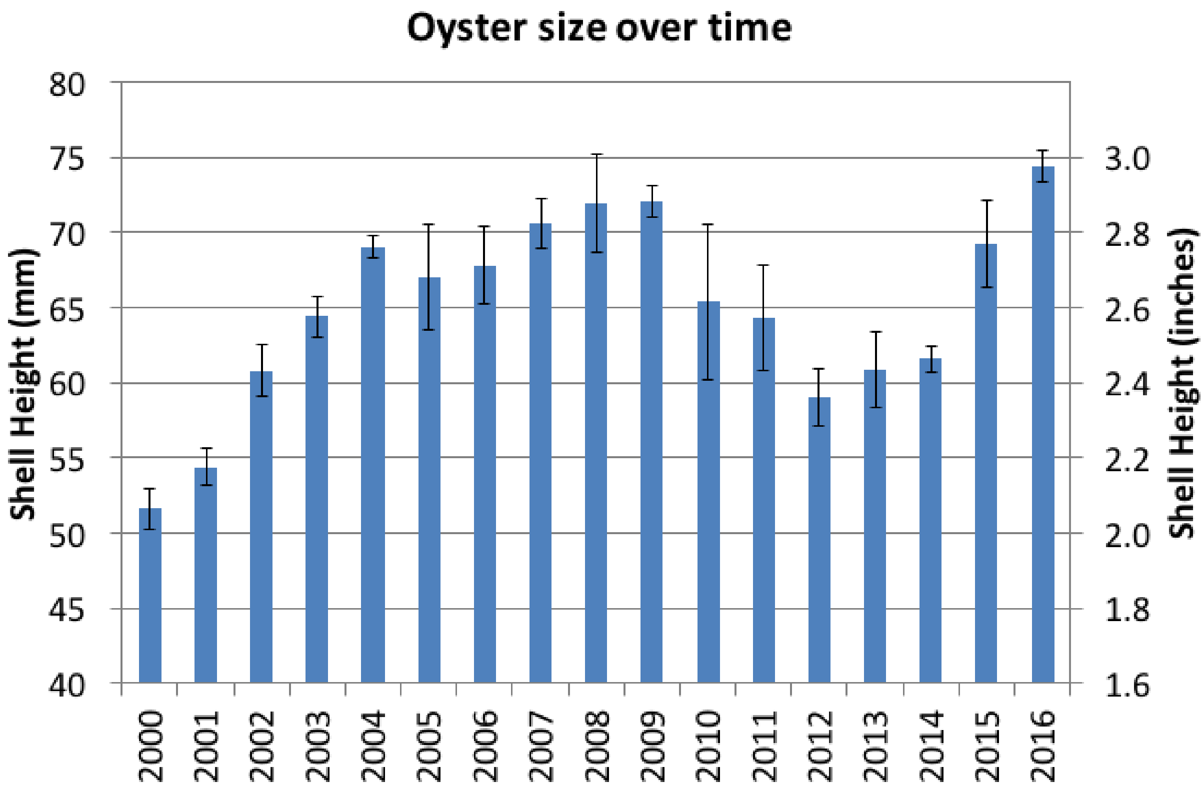

Figure 5. Interannual variation in mean shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds (Arnolds,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

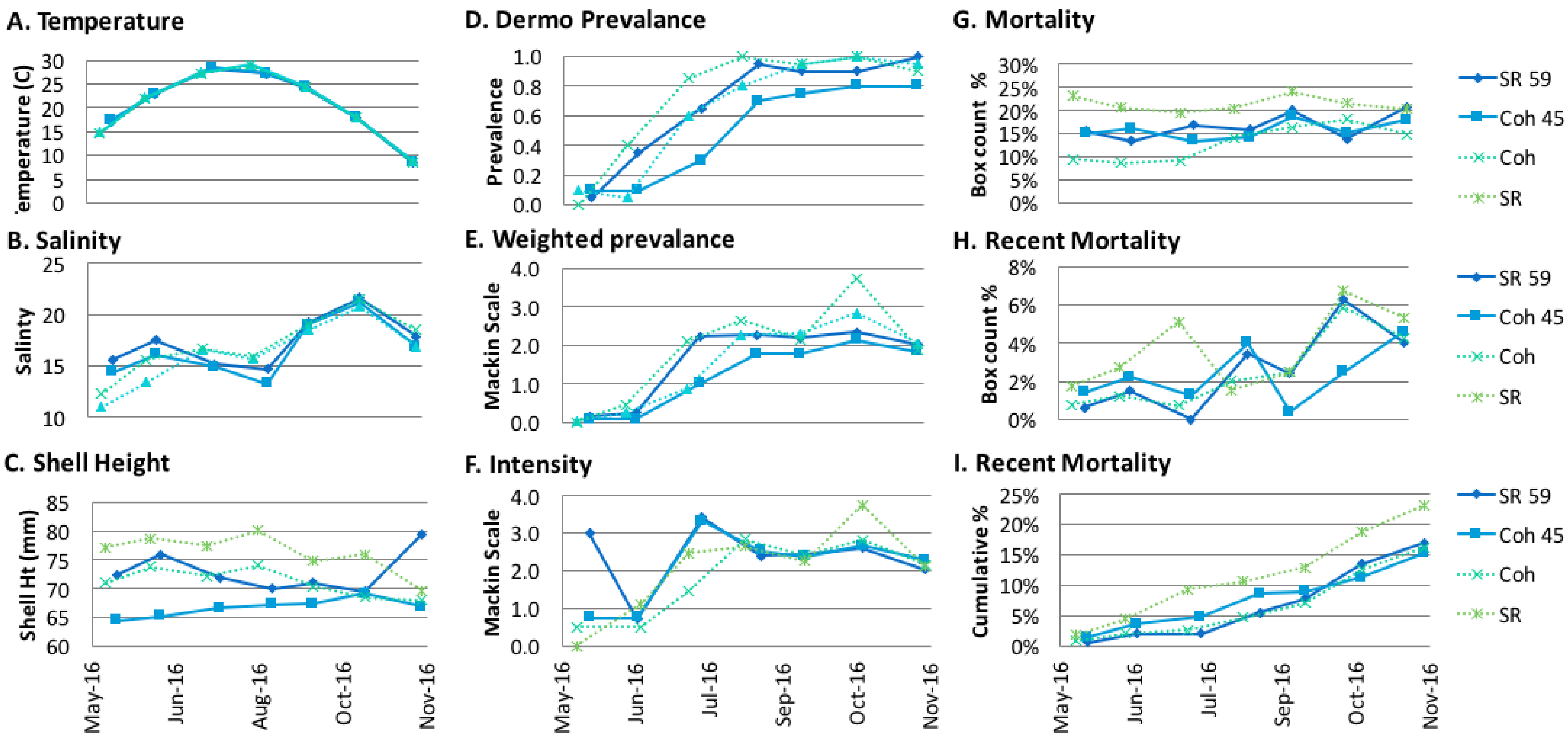

Figure 6. Performance of 2016 transplants compared to nearby long-term stations. Panels arranged as in Figure 3. Oysters transplanted to SR 59 were derived from the Medium Mortality Transplant beds while oysters transplanted to Coh 45 were derived from the Low Mortality beds (see Figure 1 and Table). Solid lines represent transplant grids, dotted lines represent nearby beds. SR = Shell Rock and Coh = Cohansey.

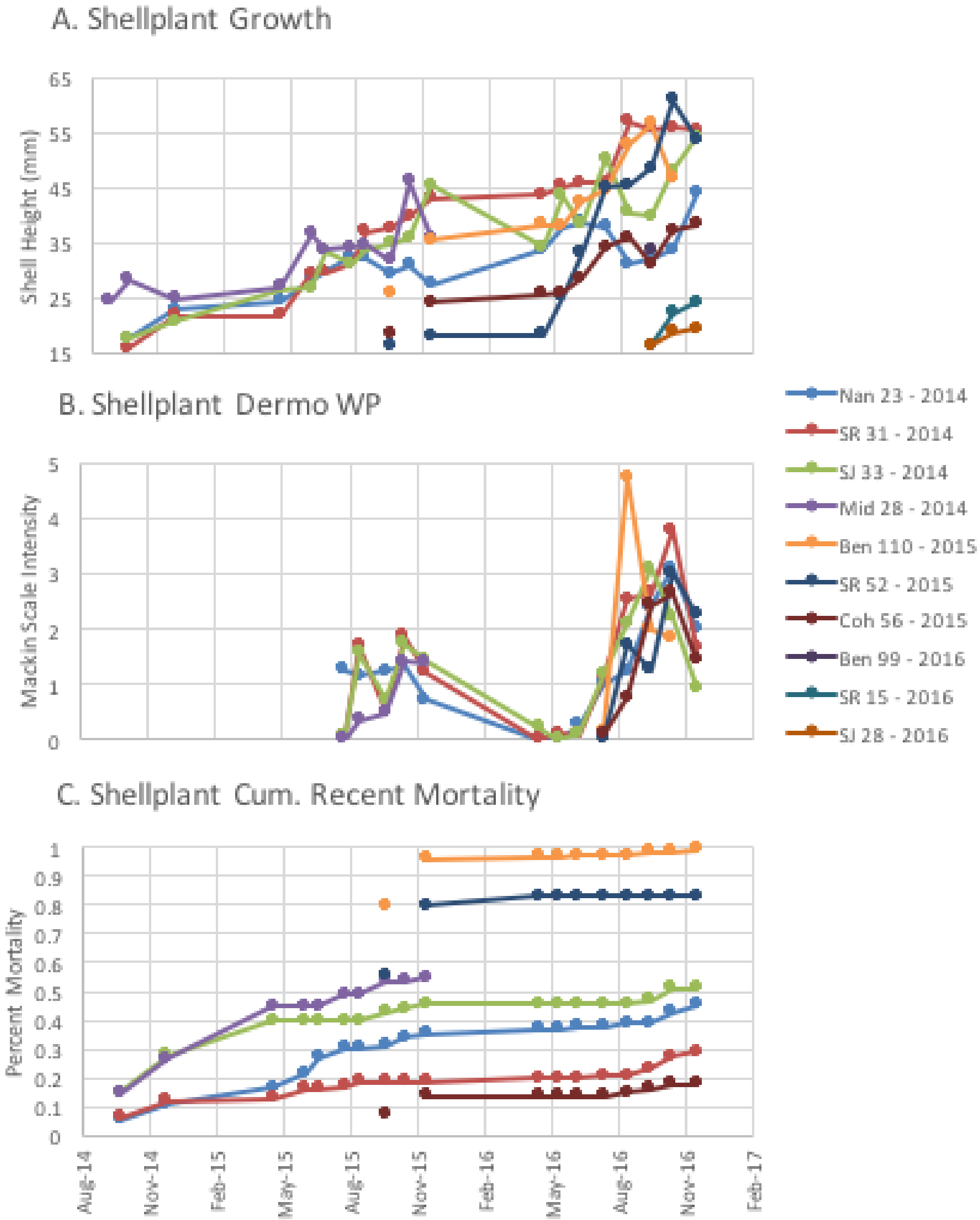

Figure 7. Performance of shellplants monitored during 2016. Monitoring for growth and mortality began in September or October during the year of the plant with a hiatus from November to April. Dermo monitoring began during July of the year following the year of planting. The high levels of mortality apparent on Ben 110 and SR 52 from 2015 are due to low recovery of planted shell containing any oysters. Bed abbreviations: Ben = Bennies, Coh = Cohansey, Mid = Middle, Nan = Nantuxent, SJ = Ship John, SR = Shell Rock.

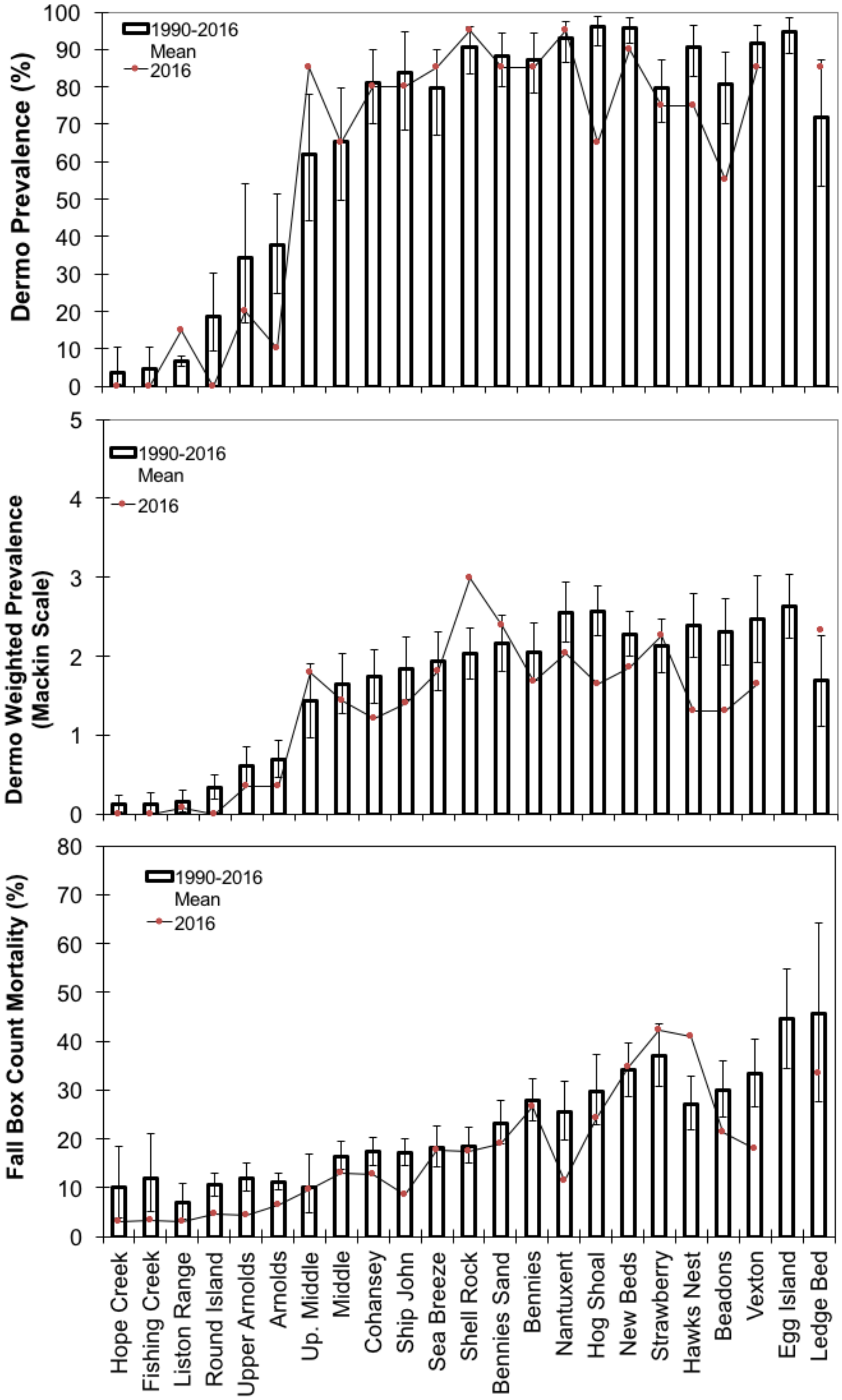

Figure 8. Long-term spatial patterns of dermo prevalence (upper panel), dermo weighted prevalence (middle panel) and natural mortality (bottom panel) across the oyster beds. Beds are listed from upbay to downbay left to right. All three metrics increase from upper to lower bay regions. Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2016. Error bars represent 95% confidence intervals.

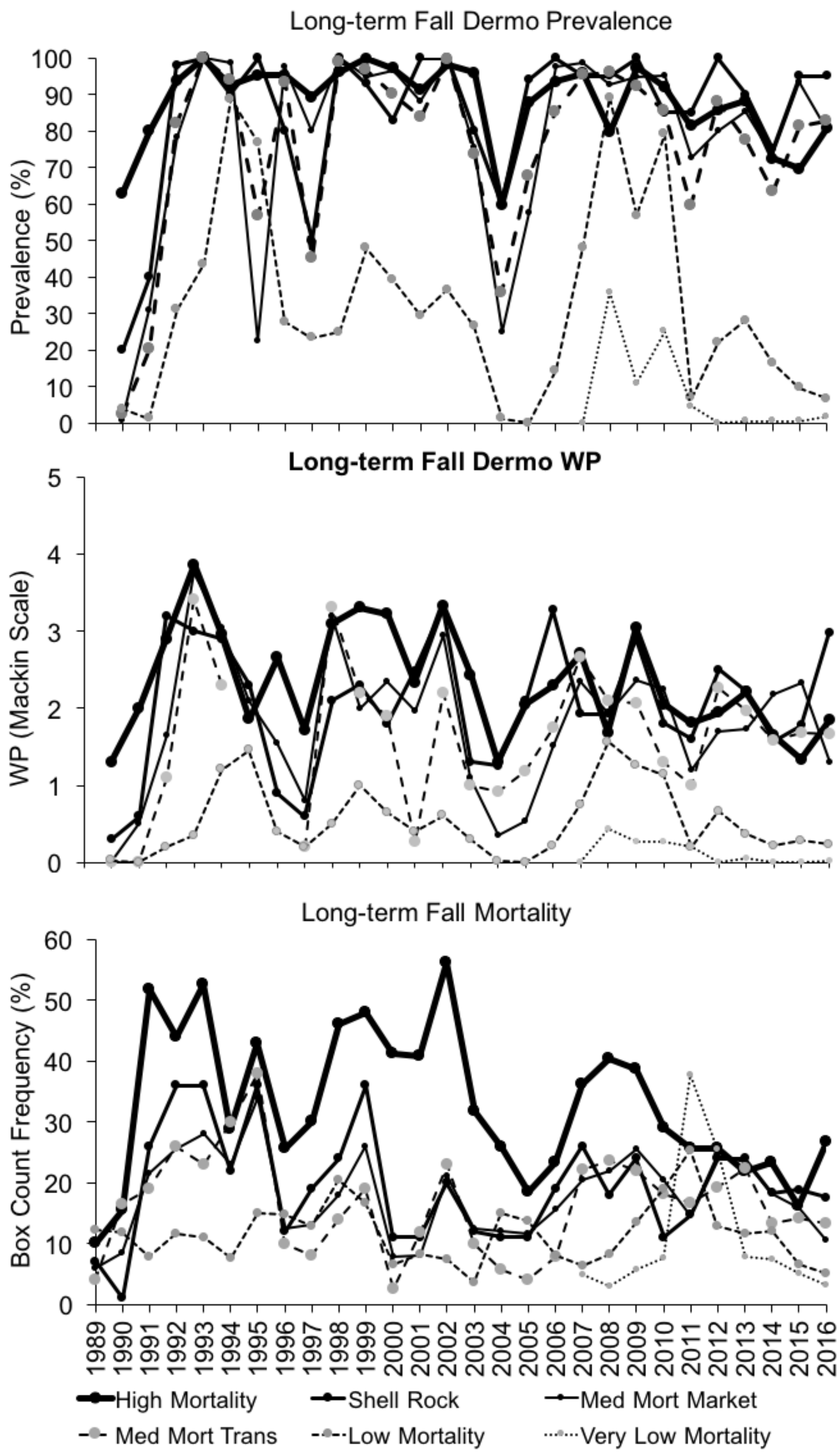

Figure 9. Annual Fall dermo prevalence (upper panel), weighted prevalence (middle panel) and box count mortality (bottom panel) on New Jersey Delaware Bay seedbeds. Regions correspond to management regions in Figure 1.

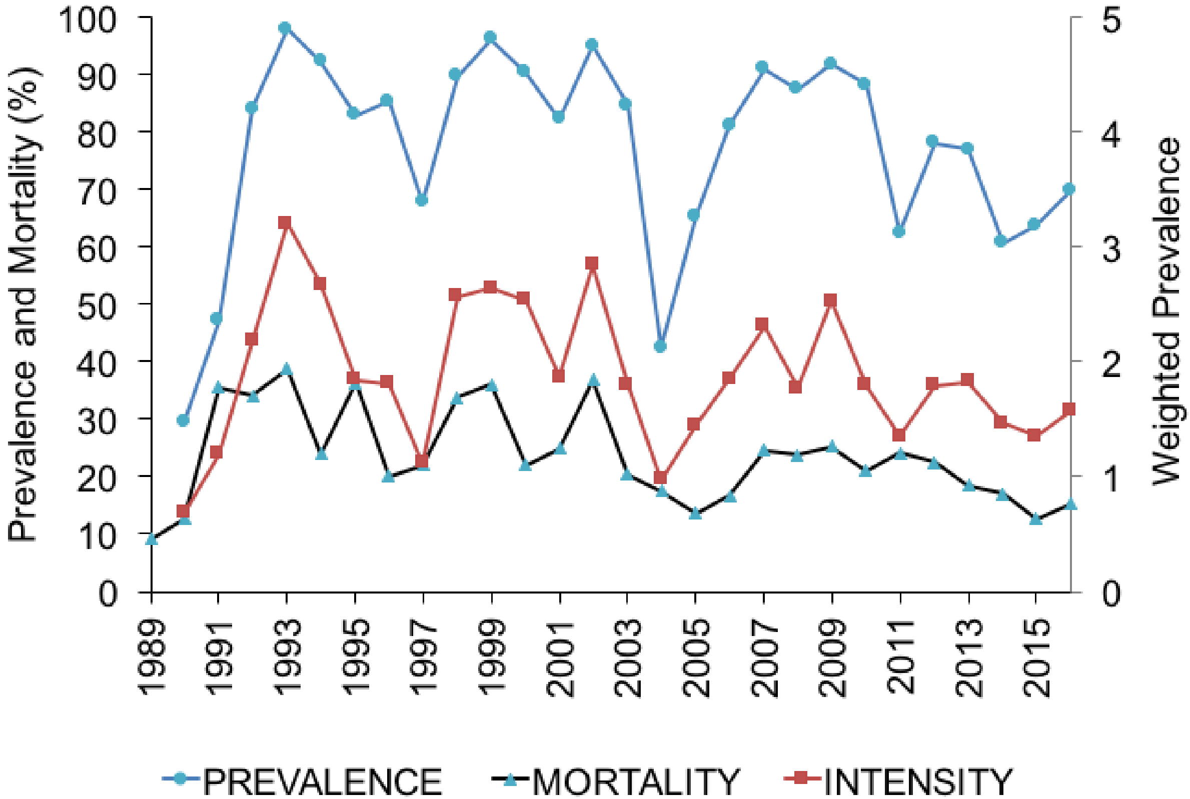

Figure 10. Long-term patterns of dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data appear to show a cycles with an approximate periodicity of seven years, and a dampening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

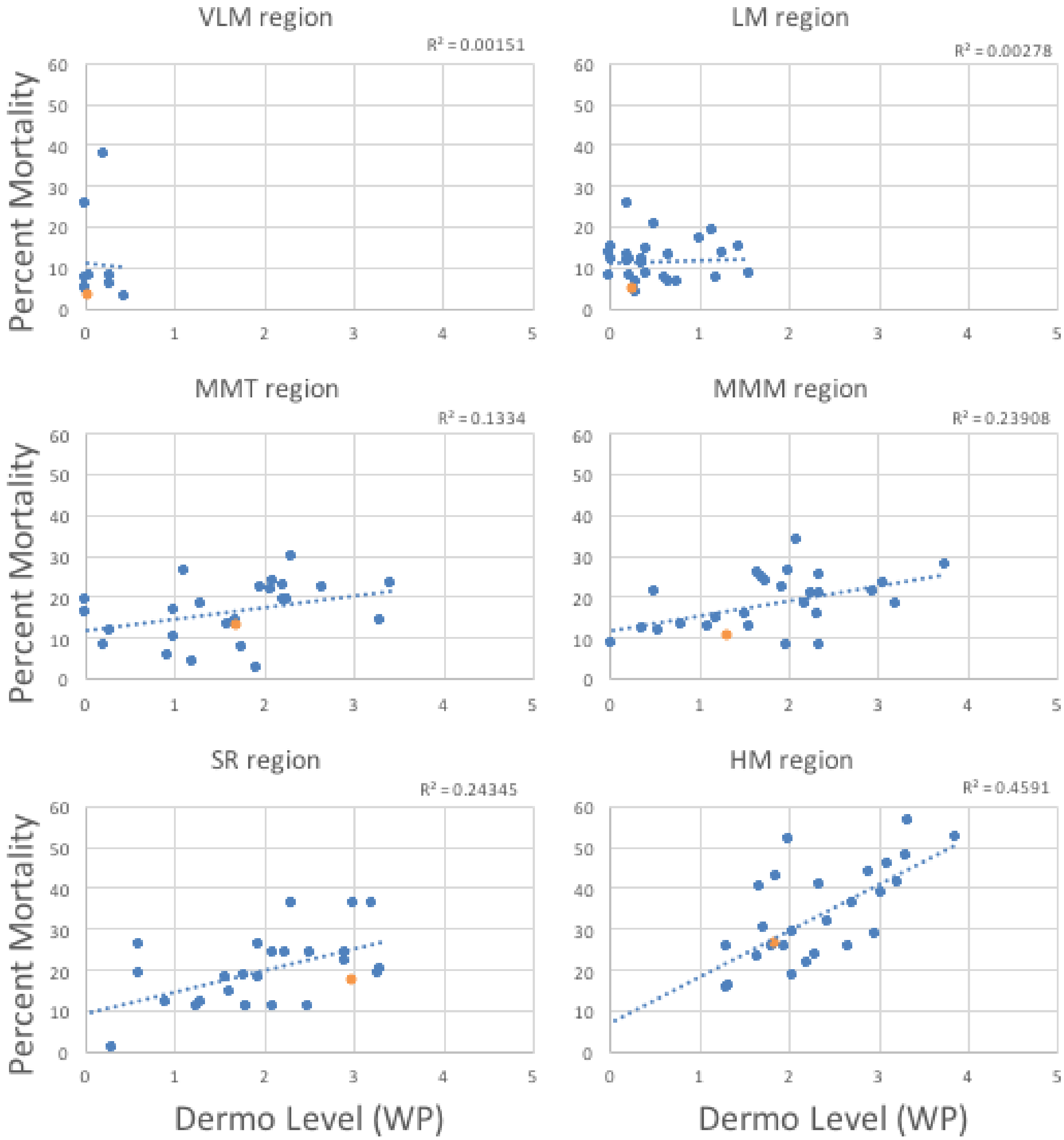

Figure 11. Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). Orange points represent 2016 data. VLM = Very Low Mortality region, LM = Low Mortality region, MMT = Medium Mortality Transplant region, MMM = Medium Mortality Market region, SR = Shell Rock, and HM = High Mortality Region.

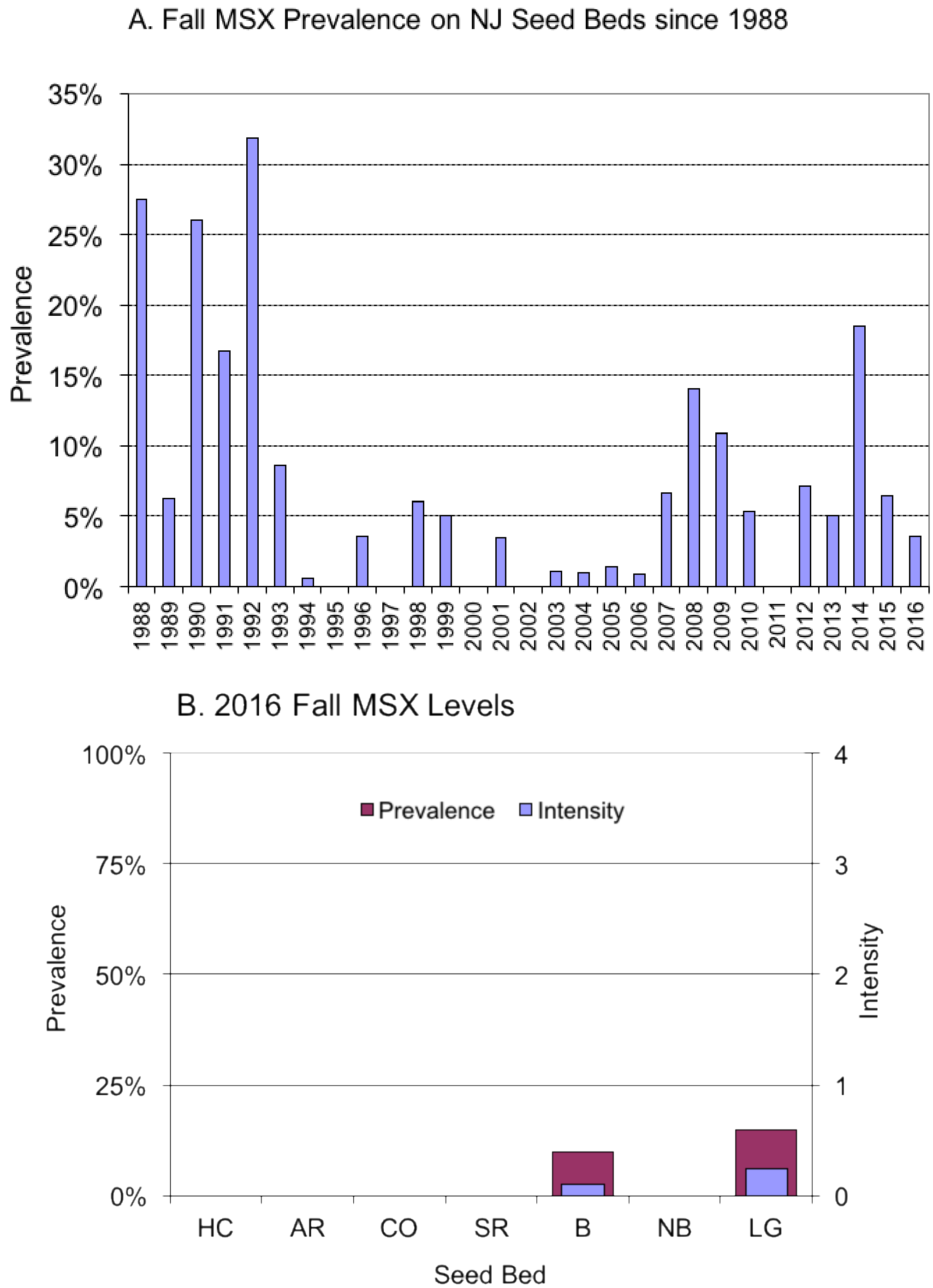

Figure 12. MSX disease on the New Jersey Delaware Bay oyster seedbeds. Upper: annual Fall MSX Prevalence. Lower: Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) on selected beds since 1988 (2007 for HC). HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock,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