Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2018 Status Report

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Executive Summary

The 2018 Program monitored dermo disease, oyster growth, and oyster mortality monthly at six fixed sites, three transplant sites, and nine shellplants (three each from 2016, 2017 and 2018). 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 for much of the year depressing disease across the seed beds but elevating mortality on the uppermost beds of the (normally) Very Low Mortality region. Mean oyster size decreased throughout the year, apparently as a result of high survival of recruiting oysters. Dermo disease followed typical seasonal and spatial patterns but levels were below average from July through November such that oysters have entered the winter at levels well below average. The low dermo levels likely contributed to the relatively low levels of mortality observed during 2018. Transplants and shell plants performed as expected; similar to nearby observations but with slightly elevated disease and mortality as time progressed.

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 oysters 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 2018, but was detected 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 portion of the Delaware Bay oyster fishery is not included as part of this report. Monthly monitoring occurred at selected sites along a transect spanning the salinity gradient from NEW Beds downbay to Hope Creek upbay. Transplant and shellplant sites were included to evaluate performance and inform management activities. 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 2018. 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 has 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 which supports additional directed research and sampling efforts that are necessary to develop a fuller understanding of the oyster population within the Delaware Bay ecosystem.

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 inform management efforts and sustain a viable fishery as well as a healthy oyster population and a functional ecosystem. The core effort monitors six sites along the salinity gradient on monthly basis and a spatially comprehensive survey in the Fall. 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 2018 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 2018 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on 2016 through 2018 shell plantings
4. Monitor growth mortality and disease on the 2017 and 2018 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, but was available to the former "Bay Season" seed fishery (Fegley et al., 2003). In addition to sustaining the industry it helps to rebuild and sustain harvested beds.

Methods

Figure 1 depicts the sampling locations for the 2018 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 not considered in the report nor shown in Figure 1. 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 2018 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

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

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 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 Annual Fall Stock Assessment Survey using the commercial oyster boat F/V H.W. Sockwell. The stock assessment survey consists of a stratified random sampling of the medium and high quality grids on the 23 beds that are outlined in Figure 1 and listed in Table 4 (see Ashton-Alcox et al. 2017 for survey method details). The two lowermost beds, Ledge and Egg Island, contain very few oysters and are only sampled in alternate years; Ledge was sampled during 2018. 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. Shellplant samples for objective 3 continued monitoring the 2016 and 2017 shell plantings, and initiated the 2018 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 2018 shellplants. Disease sampling began in April on the 2016 shellplants and in July on the 2017 shellplants.

Results and Discussion

Freshwater Inflow. Data obtained from the USGS stream gauge at Trenton (Figure 2) indicated unusually high levels of fresh water discharge for much of the year that was routinely and order of magnitude (10 x) higher than average, particularly during the second half of the year. The excessive freshwater discharge depressed salinity over the seed beds and decreased the residence time of water both of which can reduce disease transmission and development. Extended periods of low salinity can cause significant mortality (Munroe et al. 2013), and did so on the uppermost beds as shown below.

Temperature. Water temperatures measured during 2018 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). Spawning temperatures were reached by mid-June and remained at this level into 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 again from August into the fall (Figure 4B). On Hope Creek, the salinity appears to have remained below 6 from August into November when sampling ceased. Munroe et al. (2013) associated high mortality in 2011 with a depression of salinity below 7 for a period of just 20 days. We did not monitor salinity daily, but observed elevated mortality (see below and Figure 3G, H and I) on Hope Creek that is likely related to low salinity stress.

Temperature and salinity are arguably the most important environmental factors controlling oyster growth, reproduction, disease and mortality. The conditions observed over the seedbeds during 2018 below the Very Low Mortality region that includes Hope Creek were favorable for growth and reproduction, but not particularly favorable to the development of disease and consequent mortality as described below. Low salinity is also often associated with lower levels of predation, particularly by oyster drills (Manzi 1970).

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 consistently 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 2018, however, mean shell height decreased during the year to varying degrees on each bed (Figure 3C) leading to an overall decrease bringing the end of the season mean size to levels below the long-term average (figure 4C). Because mortality has not been particularly high as described below, the decreases observed during 2018 likely represent survival of smaller oysters and a return to 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. Continued high survival of recruits could depress the overall mean size of oysters further.

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 only) followed typical spatial and seasonal patterns (Figures 3D-F). That is, each increased from spring to summer and began to decrease in fall with levels increasing with salinity from upper to lower bay beds. Overall, however, dermo prevalence and weighted prevalence were depressed for much of the year relative to long-term averages (Figures 4D and E) while those that were infected tended to have average intensities that more closely followed the average seasonal pattern (Figure 4F). Infection levels were relatively high at the end of 2017, but it appears that the high flow of fresh water during the latter half of 2018 reduced the spread of dermo among oysters to depress prevalence and thus weighted prevalence. As a result, Dermo levels for each metric were well below average at the end of the year.

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 2018, but the potential for an epizootic to develop and cause significant mortality remains high. The exception is the high level of mortality on Hope Creek in what is normally a very low mortality region. As discussed above, this mortality appears to be clearly associated with fresh water stress caused by the persistent high discharge of fresh water from the Delaware River (Figure 2). Experience from prior years indicates that a reduction in fresh water inflow and the concomitant increase in salinity quickly result high levels of disease mortality.

Transplants, shellplants and replants. Figure 6 shows the conditions and performance of 2017 and 2018 transplants during 2018. For comparison, the mean of each metric measured at the long-term Shell Rock and New Beds sites are shown – data from Bennies, specifically mortality data, were unreliable due to low sample size as the bed appears to have become depleted of oysters. The monthly monitoring samples were generally offset by about a week due to sampling logistics. Temperature and salinity (Figure 6A and B) were effectively identical; apparent differences in salinity are attributed to sampling different tidal stages on different dates. Size declined toward the end of the year as recruitment occurred and increased the proportion of smaller animals on the bed. Dermo levels on transplant sites were similar to the long-term site value, but reached slightly higher levels by July and remained higher than the long-term site until November. These levels of dermo (>1.5 weighted prevalence) are sufficient to cause mortality that exceeds background levels (Bushek et al. 2012); an unfortunate pattern that is reflected in measures of mortality (Figure 6G, H and I). Previous monitoring efforts have indicated transplants develop high levels of disease and higher rates of mortality after the first year of the transplant and frequently by the end of the first year.

Three shell plants per year were placed on six different beds during the last three years: Bennies, Shell Rock and Ship John (2016), Bennies Sand, Shell Rock and Cohansey (2017), and Hog Shoal, Shell Rock and Ship John. Shell Rock is the heart of the population and the fishery, hence there are few years it does not receive a shell plant. Only the 2016 Bennies shell plant failed to catch a reasonable set of spat that survived. Growth on all other shellplants was steady and similar to rates observed in prior years of approximately 25 mm per year although the increase in mean shell height slows each year as additional oysters recruit (Figure 7A). Dermo levels followed the seasonal cycle during 2018 but remained relatively low with the 2016 shellplants briefly exceeding 1.5 weighted prevalence and the 2017 shell plants barely exceeding 0.5. These levels and duration are not expected to cause significant mortality (Bushek et al. 2012) as observed in Figure 7C. Dermo was not monitored on 2018 shellplants because they don't typically acquire significant infections during their first year, however, the higher levels of mortality observed are likely due to predation or sedimentation. Shell planting remains one of the most positive management efforts to sustain and increase oyster abundance, and should be pursued annually to the level that resources permit. No replanting occurred in 2018, but replanting should remain as a potential management strategy. Similarly, s spat-on-shell technologies (i.e., remote setting of hatchery-reared oyster larvae) provide an alternative that should be considered and evaluated.

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. Histological samples collect from May through August indicated that maturation occurred earlier on New Beds and Bennies than other regions and was delayed the longest on Hope Creek (Figure 8). Sex ratios were generally skewed toward females (18%:38% in May; 32%:53% in June; 41%:53% in July; 33%:53% in August), but this may be in part due to the selection of market-size oysters for histopathology as oysters are known to be protandric so the sex ratio skews from males to females as they grow.

Long-Term Fall Patterns. Examination of dermo prevalence, weighted prevalence and mortality by bed indicated a departure from long-term patterns during 2018 (Figure 9). Since 2013, dermo prevalence and weighted prevalence have been highest in the central portion of the resource with highest levels often on Shell Rock. The long-term pattern typically increases from upper to lower bay beds. Dermo levels were consistently low with Sea Breeze, Shell Rock and Strawberry being the only exceptions. Corresponding with the depressed dermo levels were reduced levels of mortality measured as the fraction of boxes present. However, boxes were increasingly abundant and above long-term levels above Arnolds likely from the ongoing freshet described above.

Figure 10 depicts annual dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2018 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 11). 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 12 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 12, VLM and LM 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 is strongest across the high mortality region where it explains approximately 45% of the annual variability in mortality. The 2018 data points show relatively low mortality where oysters were beyond the reach of the ongoing freshet.

Because MSX has not been problematic on the seedbeds for nearly two decades, samples from only seven beds along the up- to downbay gradient have been examined during the fall survey (Table 4). MSX was detected in three of the 135 oysters assayed (Figure 13A), one from each of three beds. Quite surprisingly, one of those was on Hope Creek where infections are normally rare as this is a low salinity refuge from MSX (Ford et al. 2012). The infections at the very low and medium mortality beds were both rare (less than 10 plasmodia) and the infection at the high mortality bed was light (more than 100 plasmodia); no systemic or advanced infections were observed (Figure 13B). In contrast, MSX infections were observed at 5-15% prevalence from April through November 2018 on a leased ground in section C of the lower bay below the natural beds, with advanced infections observed from April through June. In an ancillary study, monthly samples regularly detected low prevalence and intensity across the seed beds throughout the year, but not sufficient to cause concern or increase rates of mortality. Interestingly, these data show an increase in ciliates (*Nematopsis* spp.) on beds where dermo was highest (Shell Rock and Cohansey), but this pattern does not appear to be consistent across years making any association difficult to interpret. Hatchery spawned Cape Shore natives were also tested April through November 2018; MSX was detected at 15% prevalence in April with 10% advanced systemic infections and at 5% prevalence in July with no systemic infections. Previous years have found MSX distributed across the seed beds and these data confirm its continued presence in the bay albeit at very low levels. MSX remains a threat to the Delaware Bay oyster population as it continues to cause mortalities elsewhere along the East Coast. Therefore, it remains 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, source and age of seed, husbandry differences among farms, etc.). Nevertheless, to provide a baseline we began monitoring a hatchery line produced from wild broodstock collected from 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 2017. By October 2018 they were 64 mm in shell length with 85% prevalence, a weighted prevalence of 1.9 and an average intensity of 2.2. We plan to 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 when 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. 2018 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 2018. 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 27, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Craig Tomlin
May 3, 2018	6 2016-17 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
May 21, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Craig Tomlin
May 24, 2018	3 intermediate transplants 6 2016-17 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
Jun 18, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Andrew Hassall
June 25, 2018	3 intermediate transplants 6 2016-17 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
July 16, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Andrew Hassall
July 26, 2018	3 intermediate transplants 6 2016-17 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
August 20, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Craig Tomlin
August 27, 2018	3 intermediate transplants 6 2016-17 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
September 21, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Andrew Hassall
September 26, 2018	3 intermediate transplants 9 2016-18 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
October 19, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Craig Tomlin
October 22, 2018	3 intermediate transplants 9 2016-18 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
November 19, 2018	6 long-term sites + 2 extra sites	NJDEP RV James W. Joseph	Andrew Hassall
November 20, 2018	3 intermediate transplants 9 2016-18 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin

Table 2. Additional enhancement sites sampled during 2018.

Bed	Grid	Plant material	Plant yr
Hog Shoal	4	ocean quahog	2018
Shell Rock	68	ocean quahog	2018
Ship John	14	ocean quahog	2018
Bennies Sand	41	ocean quahog	2017
Shell Rock	37	ocean quahog	2017
Cohansey	50	ocean quahog	2017
Bennies	73	medium mortality transplant	2017
Bennies	72	medium mortality transplant	2018
Bennies	58	medium mortality transplant	2018
Bennies	99	ocean quahog	2016
Shell Rock	15	ocean quahog	2016
Ship John	28	ocean quahog	2016

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	18
Hope Creek																		X	X	X	--	--	X	X	X
Liston Range																			X	X	--	--	X	X	X
Fishing Creek																			X	X	--	--	X	X	X
Round Island	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	--	--	X	X	X
Upper Arnolds														X		X	X	X	X	X	--	--	X	X	X
Arnolds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Upper Middle																	X	X	X	X	--	--	X	X	X
Middle	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Cohansey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Sea Breeze															X	X	X	X	X	X	--	--	X	X	X
Ship John	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Shell Rock	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Bennies Sand	X	X	X	X	X			X	X	X	X	X	X		X	X	X	X	X	X	--	--	X	X	X
Bennies	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Nantuxent		X		X		X		X		X	X	X		X		X	X	X	X	X	--	--	X	X	X
Hog Shoal		X		X						X		X	X	X	X	X	X	X	X	X	--	--	X	X	X
New Beds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Strawberry	X		X		X								X	X	X	X	X	X	X	X	--	--	X	X	X
Hawks Nest	X		X		X		X		X		X		X	X	X	X	X	X	X	X	--	--	X	X	X
Beadons	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Vexton										X		X	X	X	X	X	X	X	X	X	--	--	X	X	X
Egg Island	X	X	X	X	X	X	X	X		X	X	X		X		X		X		X	--	--		X	
Ledge Bed			X		X				X		X		X		X		X		X		--	--	X		X

Table 4. 2018 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	52	10	10	13
Hope Creek	90	10	10	19
Hope Creek	36			8
Hope Creek	55			10
Fishing Creek	25	10		15
Fishing Creek	16	10		14
Fishing Creek	17			11
Fishing Creek	11			10
Liston Range	27	10		15
Liston Range	17	10		13
Liston Range	22			10
Liston Range	24			12
Round Island	16	10		15
Round Island	2	10		13
Round Island	24			15
Round Island	73			7
Upper Arnolds	5	10		15
Upper Arnolds	14	10		15
Upper Arnolds	2			10
Upper Arnolds	18			10
Arnolds	16	10	10	10
Arnolds	43	10	10	10
Arnolds	2			15
Arnolds	68			15
Upper Middle	58	10		20
Upper Middle	71	10		16
Upper Middle	1			14
Middle	38	10		15
Middle	10	10		15
Middle	34			10
Middle	49			10
Cohansey	20	10	10	10
Cohansey	66	10	10	12
Cohansey	64			15
Cohansey	1			13
Sea Breeze	15	10		15
Sea Breeze	29	10		15
Sea Breeze	37			10
Sea Breeze	14			10
Ship John	33	10		15
Ship John	19	10		15
Ship John	42			10
Ship John	53			10

Bed	Grid	Dermo	MSX	CI
Shell Rock	1	10	10	13
Shell Rock	25	10	10	12
Shell Rock	90			11
Shell Rock	79			14
Bennies Sand	26	10		14
Bennies Sand	11	10		14
Bennies Sand	14			11
Bennies Sand	3			11
Bennies	149	10	10	15
Bennies	71	10	10	15
Bennies	83			10
Bennies	7			10
Nantuxent	25	10		15
Nantuxent	6	10		14
Nantuxent	12			11
Nantuxent	26			10
Hog Shoal	10	10		15
Hog Shoal	13	10		15
Hog Shoal	9			10
Hog Shoal	2			10
New Beds	24	10	10	12
New Beds	12	10	10	9
New Beds	3			16
New Beds	13			12
Strawberry	2,21	10		12
Strawberry	10			13
Strawberry	29			11
Strawberry	28			14
Hawks Nest	27	10		14
Hawks Nest	13	10		16
Hawks Nest	5			10
Hawks Nest	3			10
Beadons	15	10		10
Beadons	3,4	10		15
Beadons	9			15
Beadons	5			7
Vexton	4	10		17
Vexton	9	10		25
Vexton	2			8
Ledge	All	15	15	0
Total beds	**22**	**22**	**7**	**22**
Total grids	**84**	**46**	**15**	**84**
Total oysters		**435**	**135**	**1047**

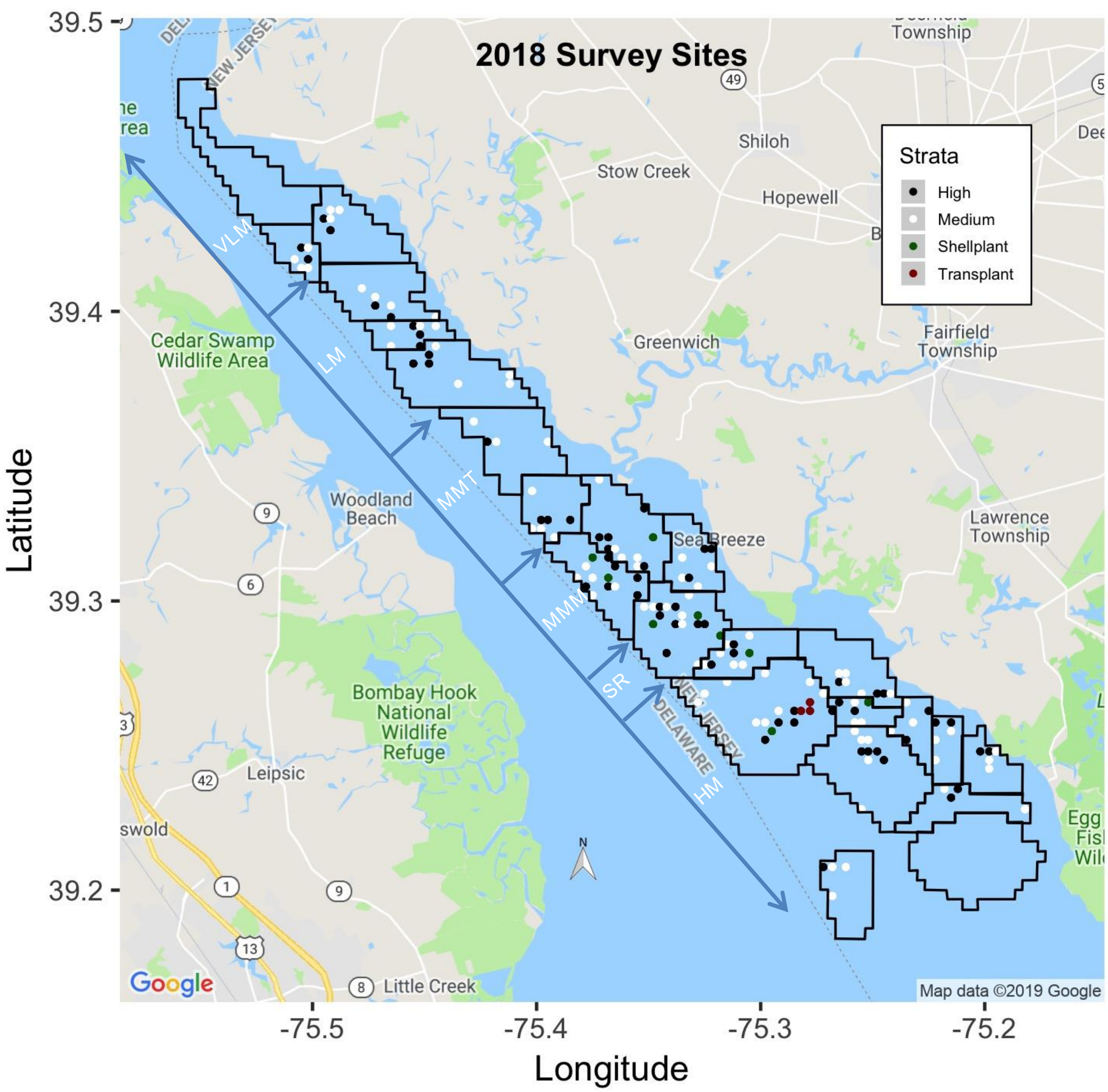

Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Black lines demarcate named beds with management regions indicated by blue lines (abbreviations as in text). The sites for the 2018 stock assessment survey are indicated by dots. A stratified random sampling program identified black and white dots for high and medium density strata, respectively, whereas red dots were transplant sites and green dots were shellplant sites. See Alcox et al. (2017) for full description.

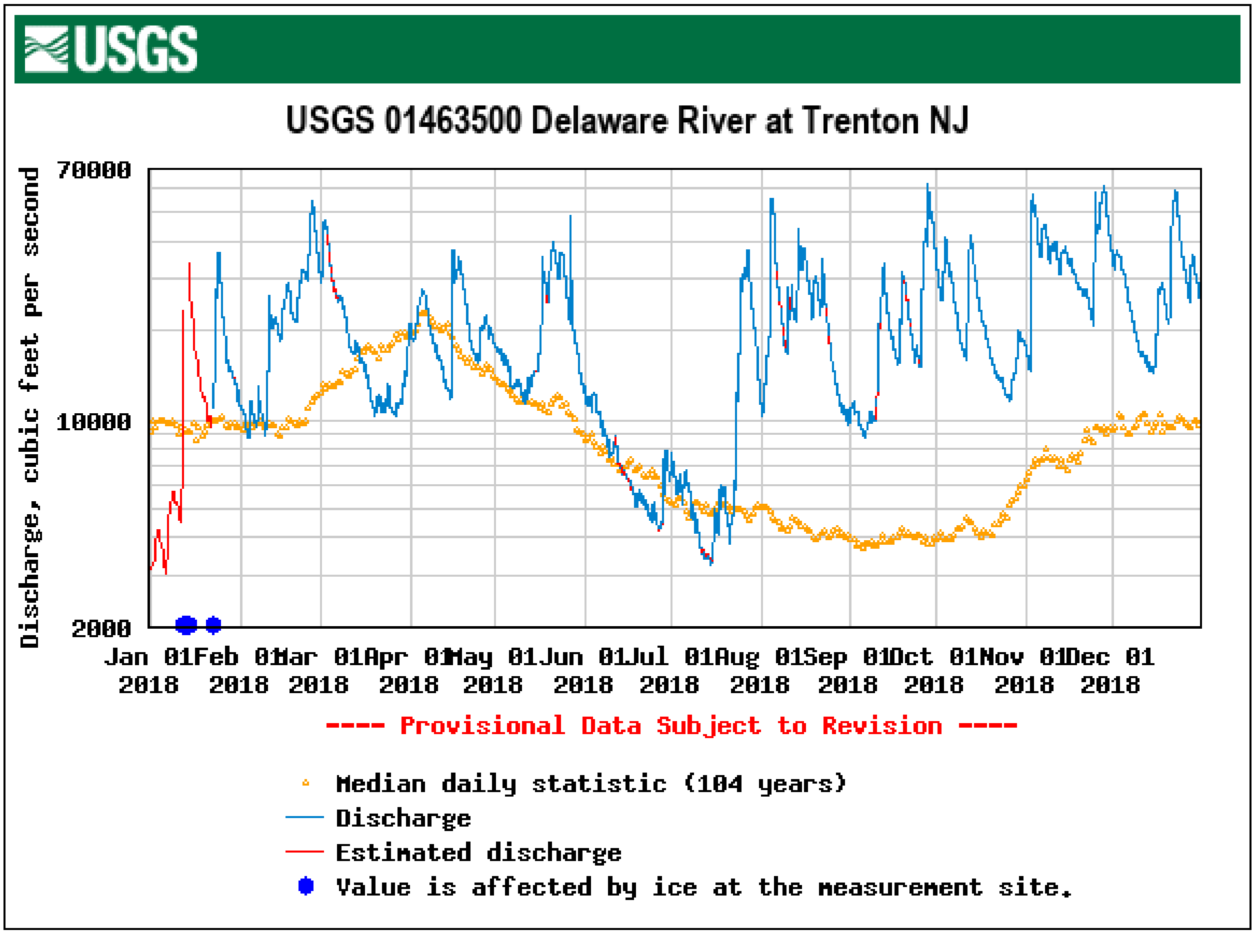

Figure 2. USGS discharge from Delaware River at Trenton (USGS station 01463500) during 2018. Freshwater inflow was well above the long-term average for much of the year, particularly during late summer and fall. These conditions reduced salinity over the oyster beds as shown in figures 3 and 4 below.

Bed

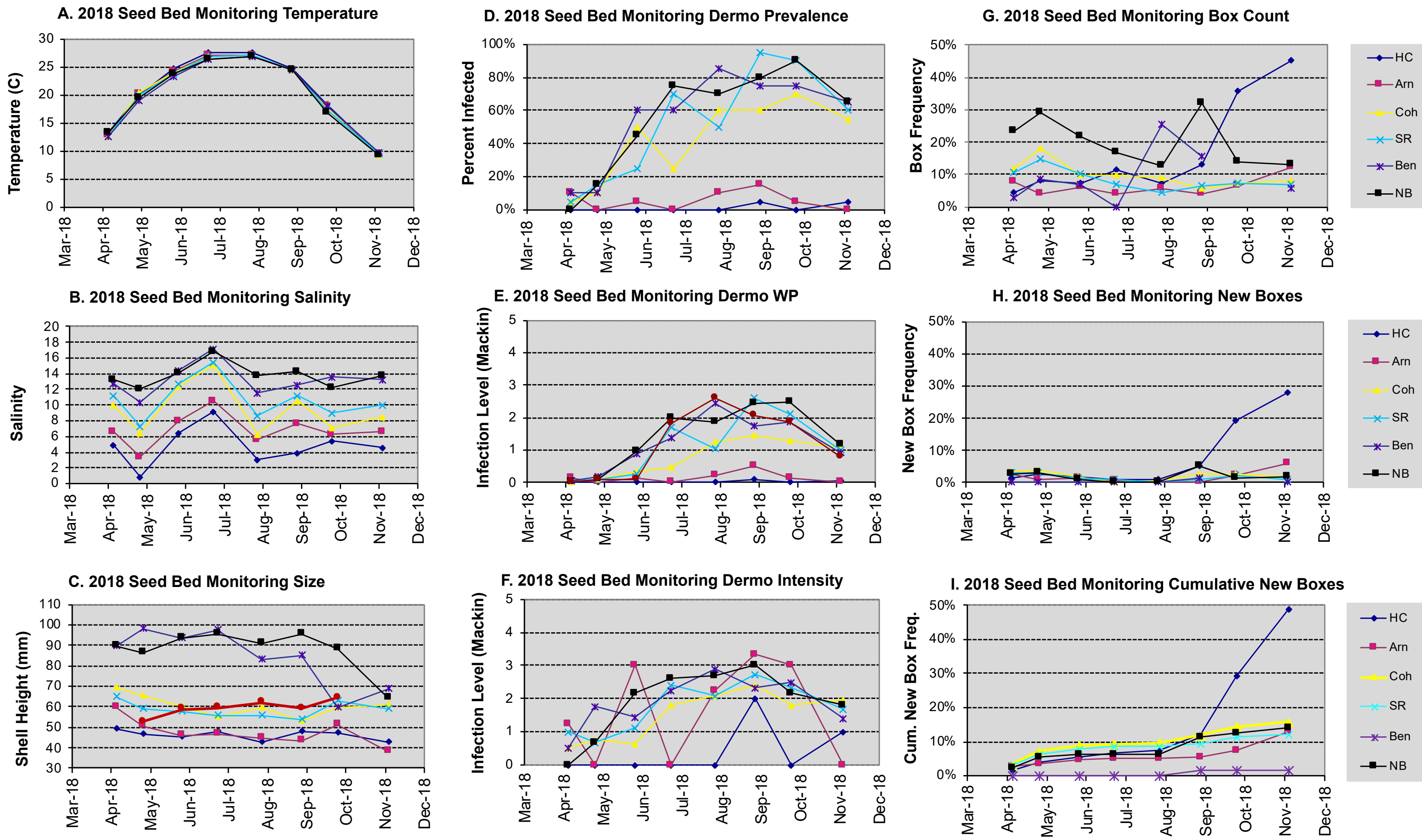

Figure 3. Results of 2018 Seed Bed Monitoring Program for the six beds monitored monthly along an upbay to downbay transect. Legends list beds from upbay to downbay: HC = Hope Creek, Arn = Arnolds, Coh = Cohansey, SR = Shell Rock, Ben = Bennies, NB = New Beds. (A) Temperature. (B) Salinity. (C) Mean 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.

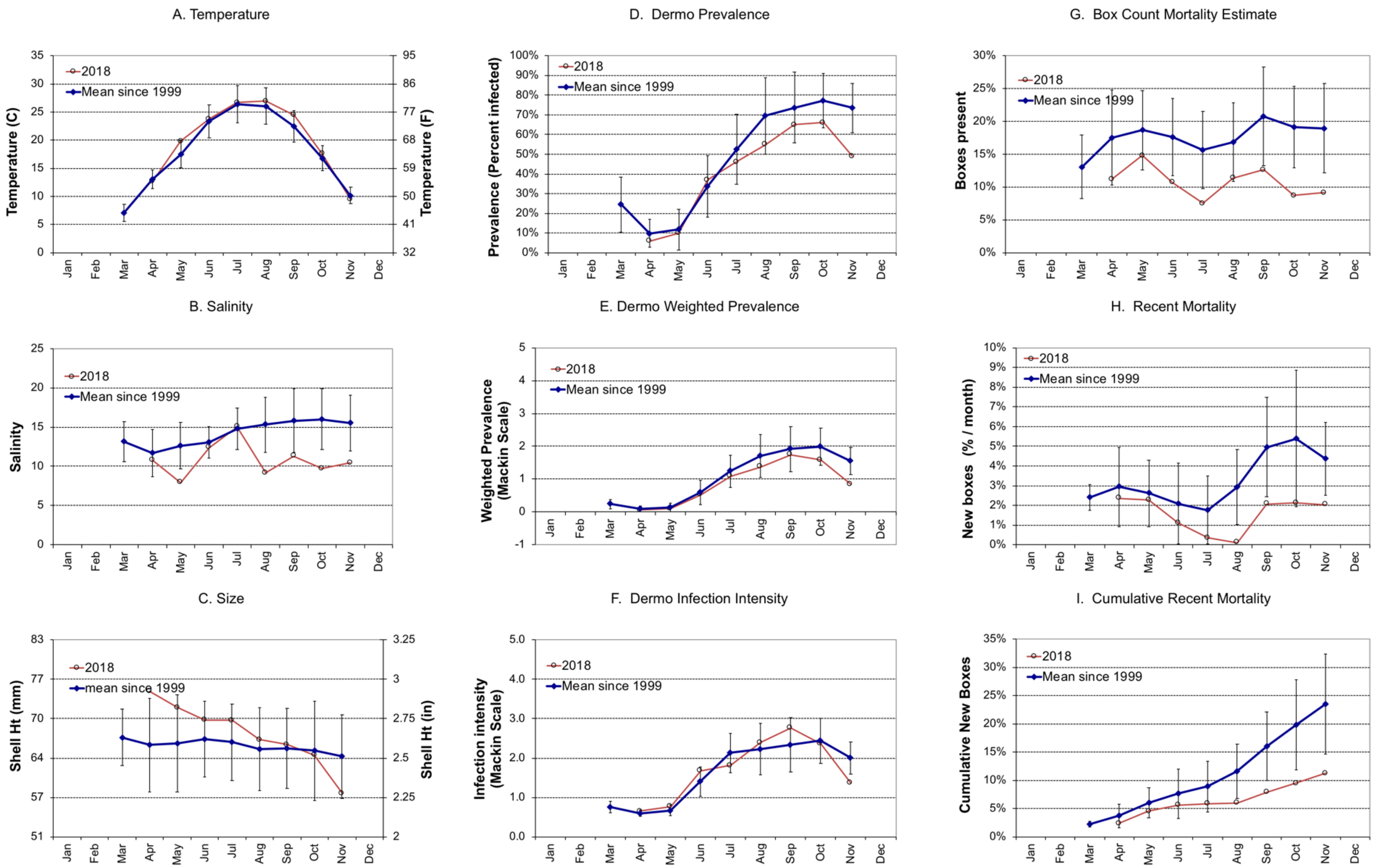

Figure 4. Means of 2018 Seed Bed Monitoring Program for the five primary beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) compared to long-term seasonal patterns. Panels arranged as in Figure 3. Error bars represent one standard deviation.

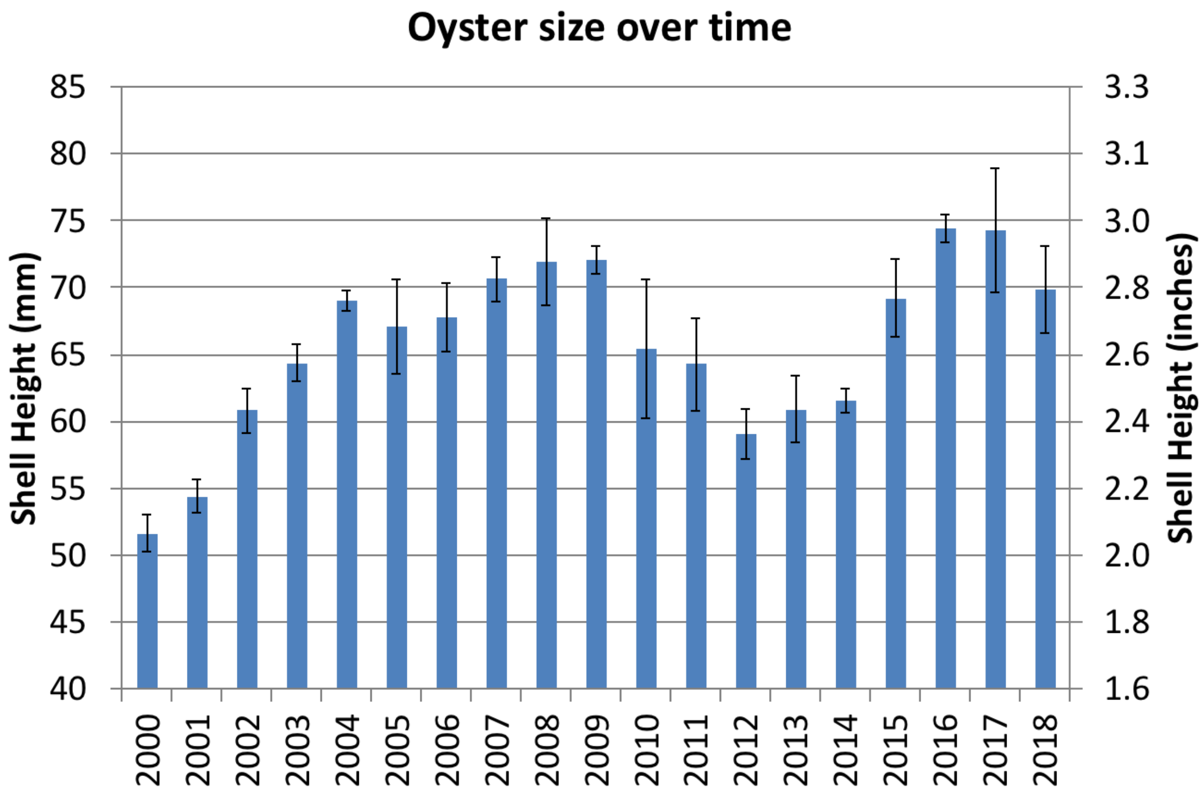

Figure 5. Interannual variation in mean shell height of oysters collected monthly between from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds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

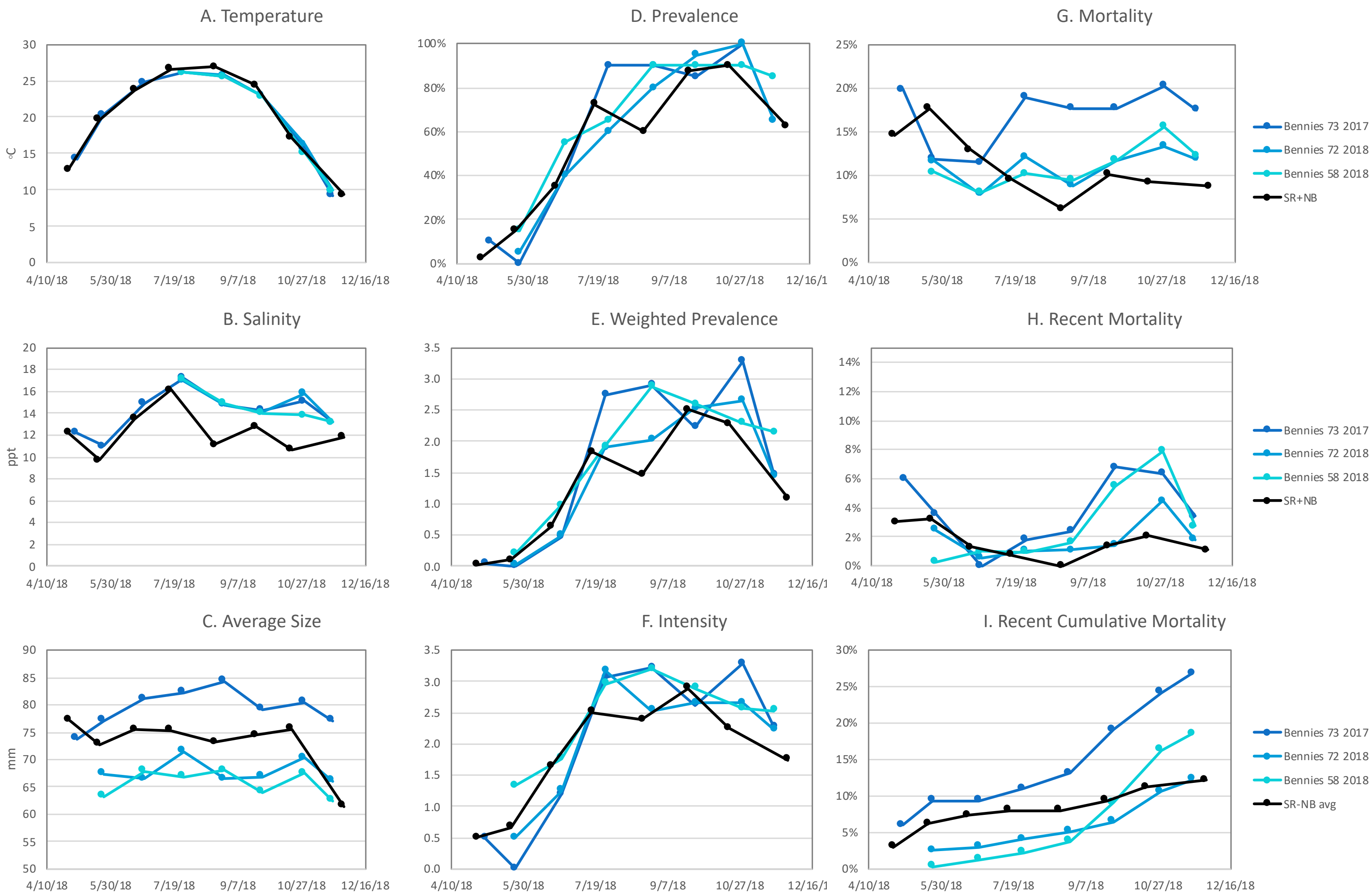

Figure 6. Performance of 2017 and 2018 transplants from MMT region to Bennies relative to mean of same parameters from Shell Rock and New Beds long-term sites. Insufficient oysters on the long-term Bennies site preclude using it in these comparisons. Panels arranged as in Figure 3.

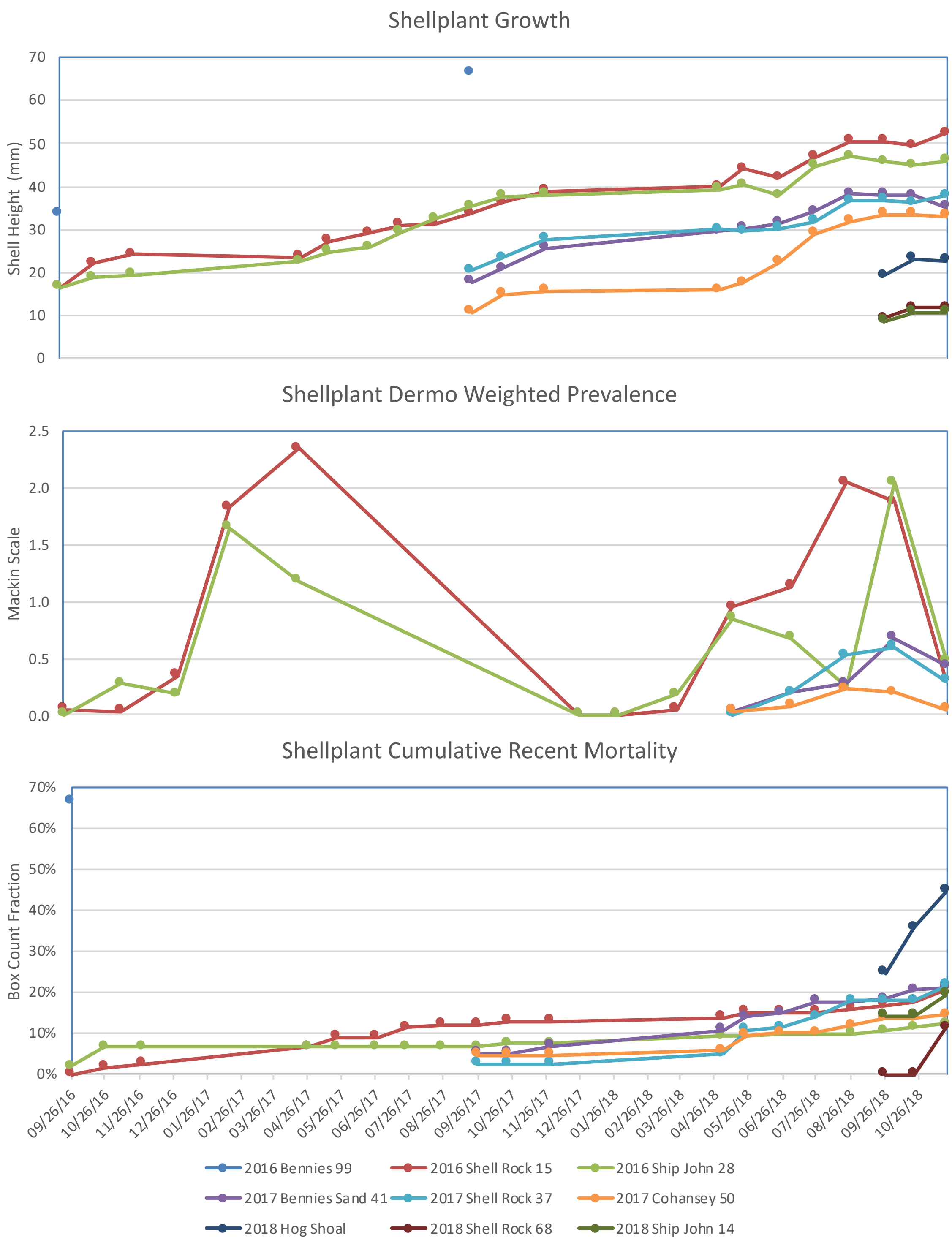

Figure 7. Performance of shellplants monitored during 2018. Monitoring for growth and mortality began in September or October during the year of the plant with a hiatus from November to April each year thereafter. Dermo monitoring began in July following the year of planting. High initial levels of mortality are usually caused by predation or siltation.

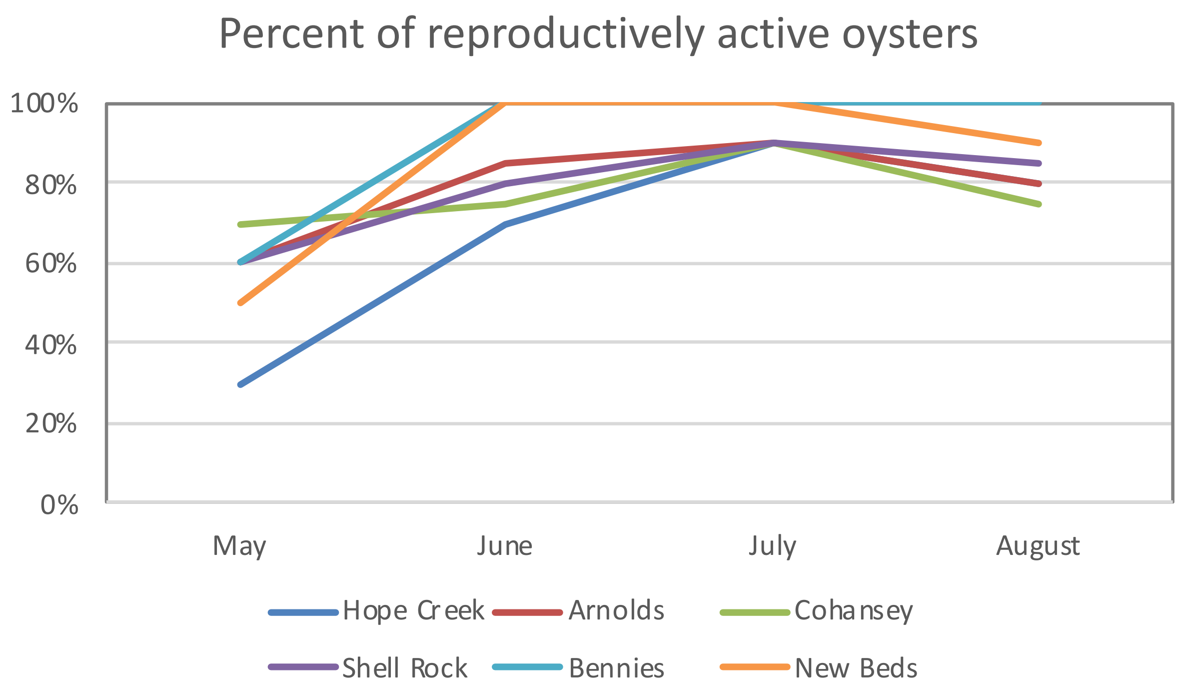

Figure 8. The percent of oysters with active gonadal tissue that can be assigned to a gender. Two simultaneous hermaphrodites were detected from Cohansey in July. Twenty market-size (>2.5 inch) oysters were processed histologically each month from each bed shown for a total of 480 samples. The overall sex ratio was 49% female, 31% male and 20% indeterminant. The female bias is likely related to the size of oysters examined as oysters are protandric hermaphrodites switching from male to female as they grow.

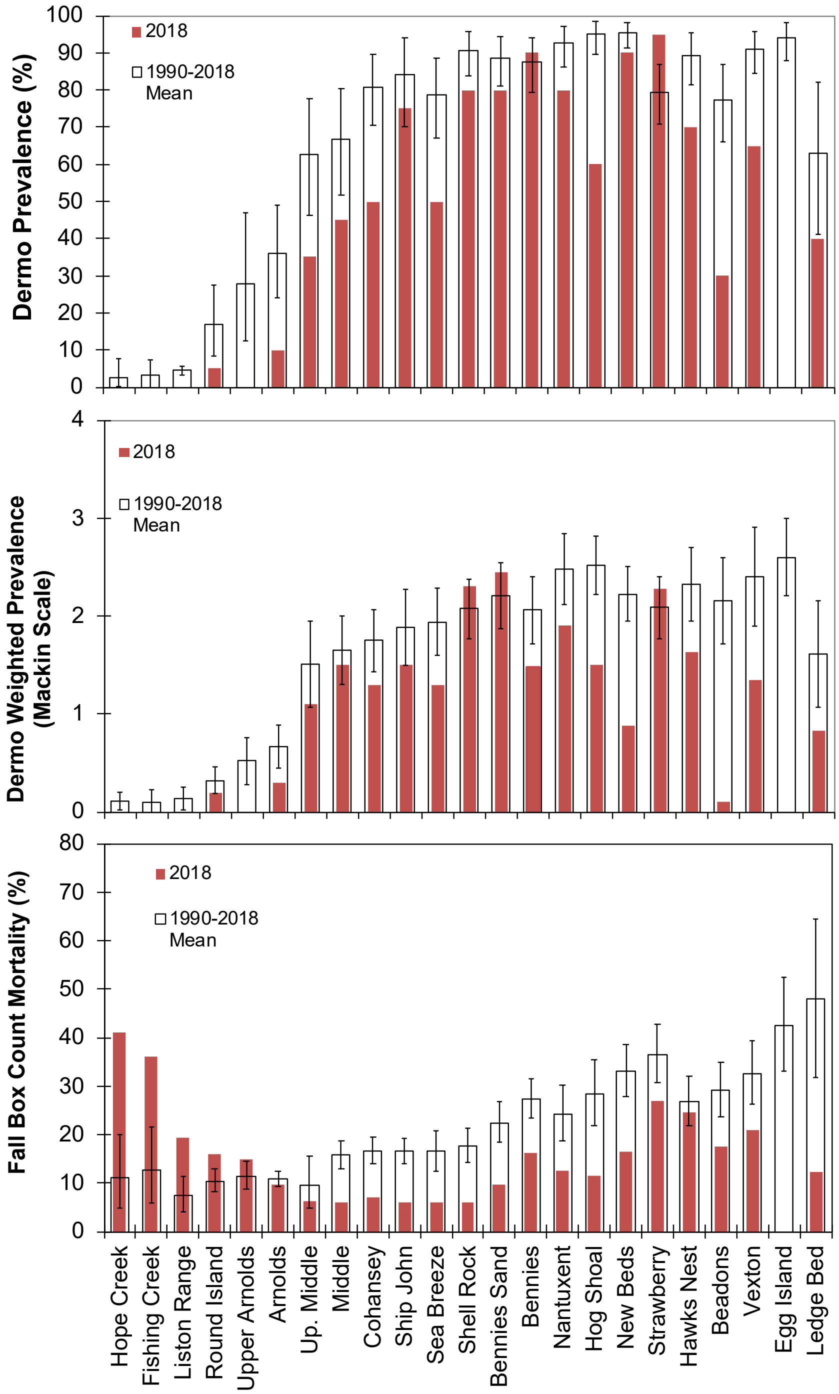

Figure 9. Long-term spatial patterns of dermo prevalence (upper panel), dermo weighted prevalence (middle panel) and natural mortality (bottom panel) across the oyster beds. Beds are listed from upbay to downbay left to right. Not all beds have been sampled every year (see Table 3). Ledge was not sampled in 2017. Error bars represent 95% confidence intervals.

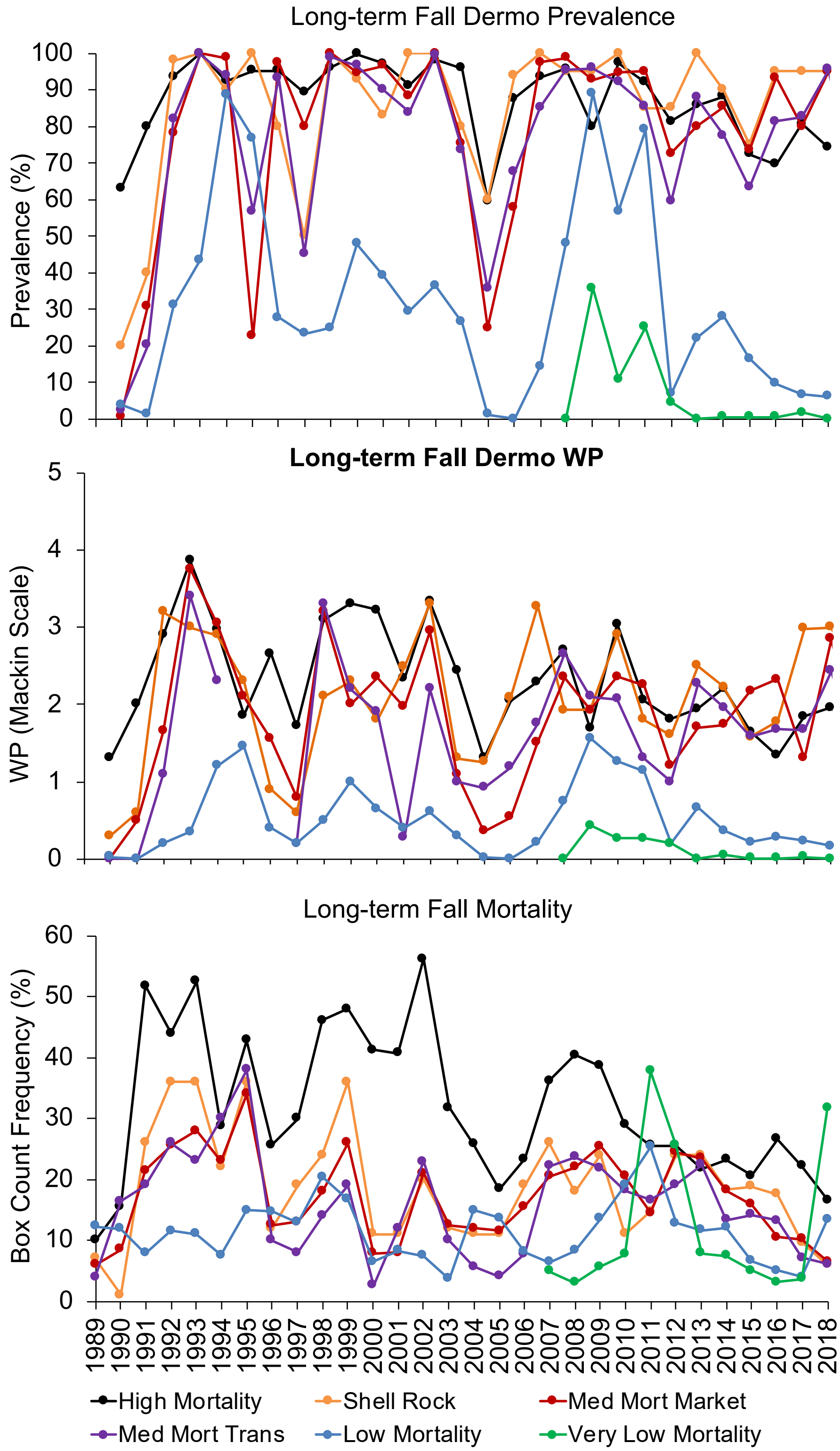

Figure 10. Annual Fall dermo prevalence (upper panel), weighted prevalence (middle panel) and box count mortality (bottom panel) on New Jersey Delaware Bay seedbeds. Regions correspond to management regions in Figure 1.

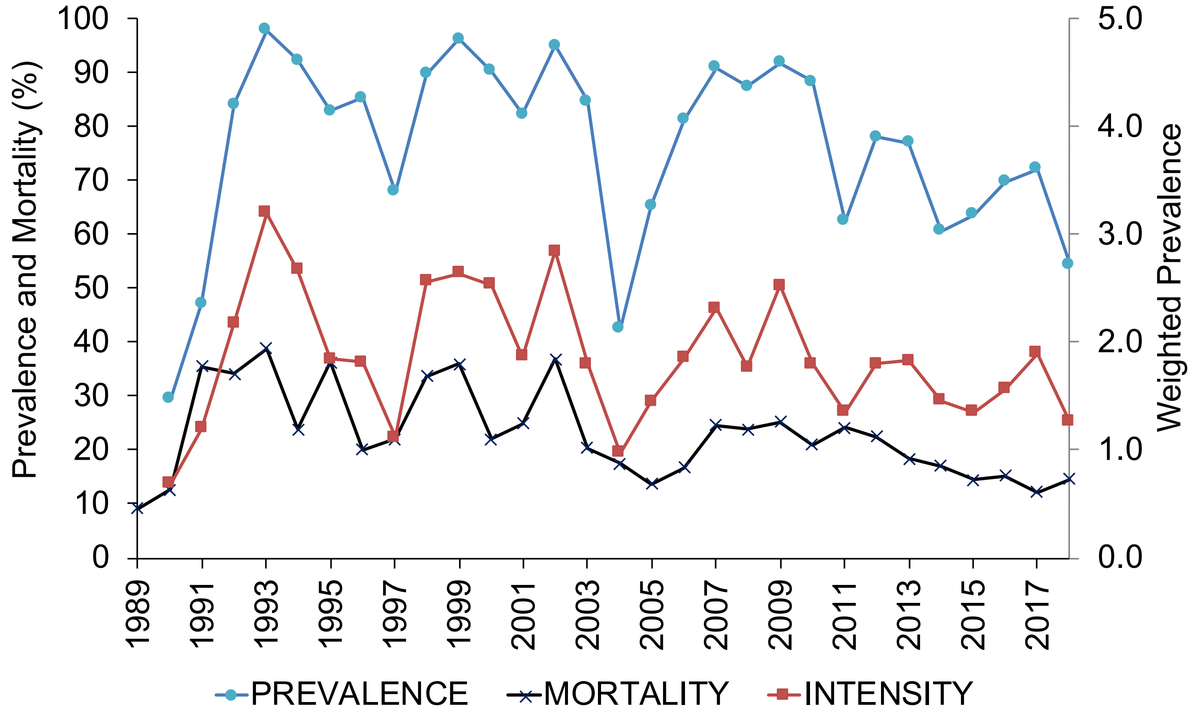

Figure 11. Long-term patterns of Fall dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data appear to show cycles with an approximate periodicity of seven years, and a dampening of the cycling resulting in lower levels of each metric over time.

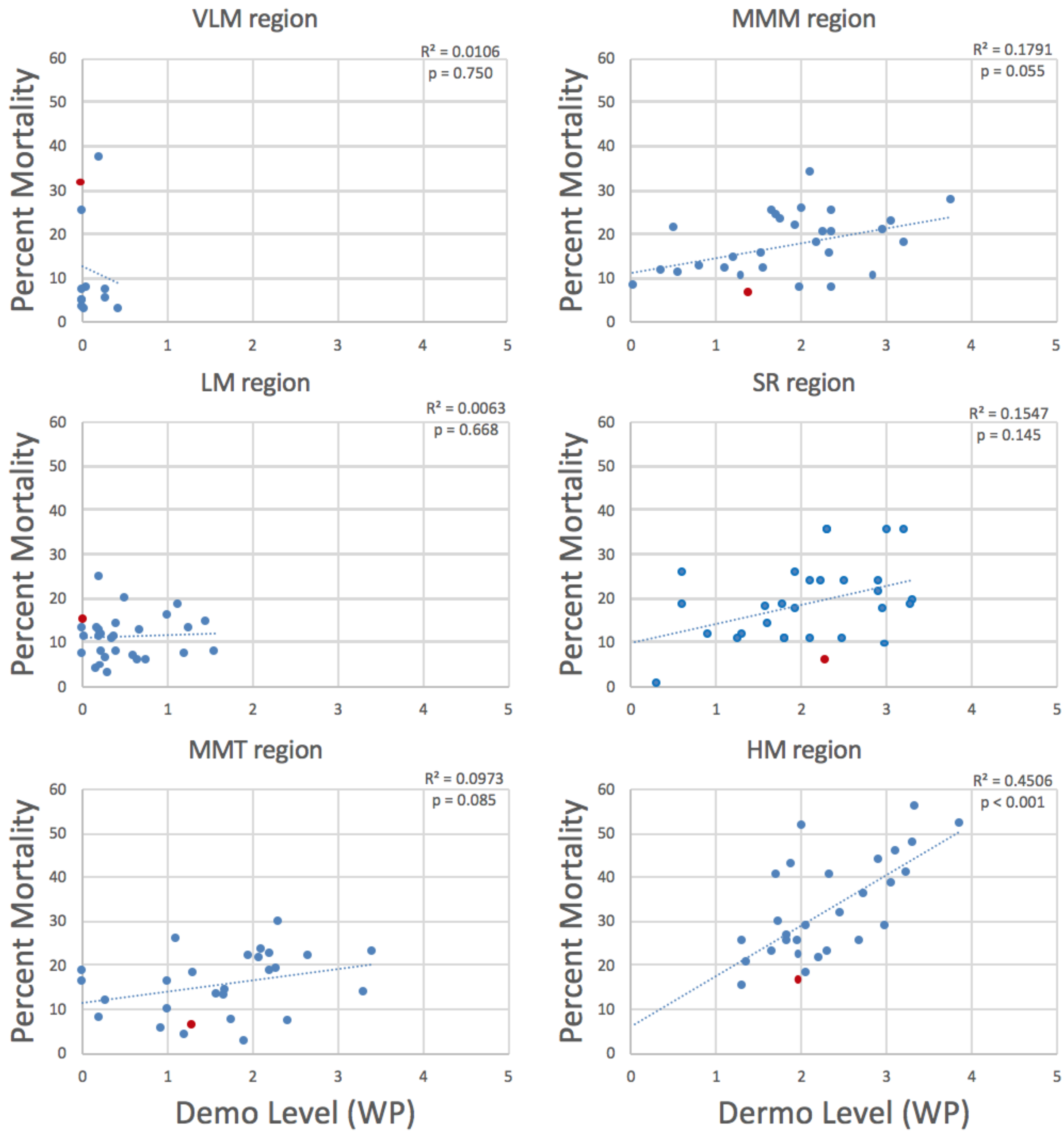

Figure 12. Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). Red points represent 2018 data. VLM = Very Low Mortality region, LM = Low Mortality region, MMT = Medium Mortality Transplant region, MMM = Medium Mortality Market region, SR = Shell Rock, and HM = High Mortality Region.

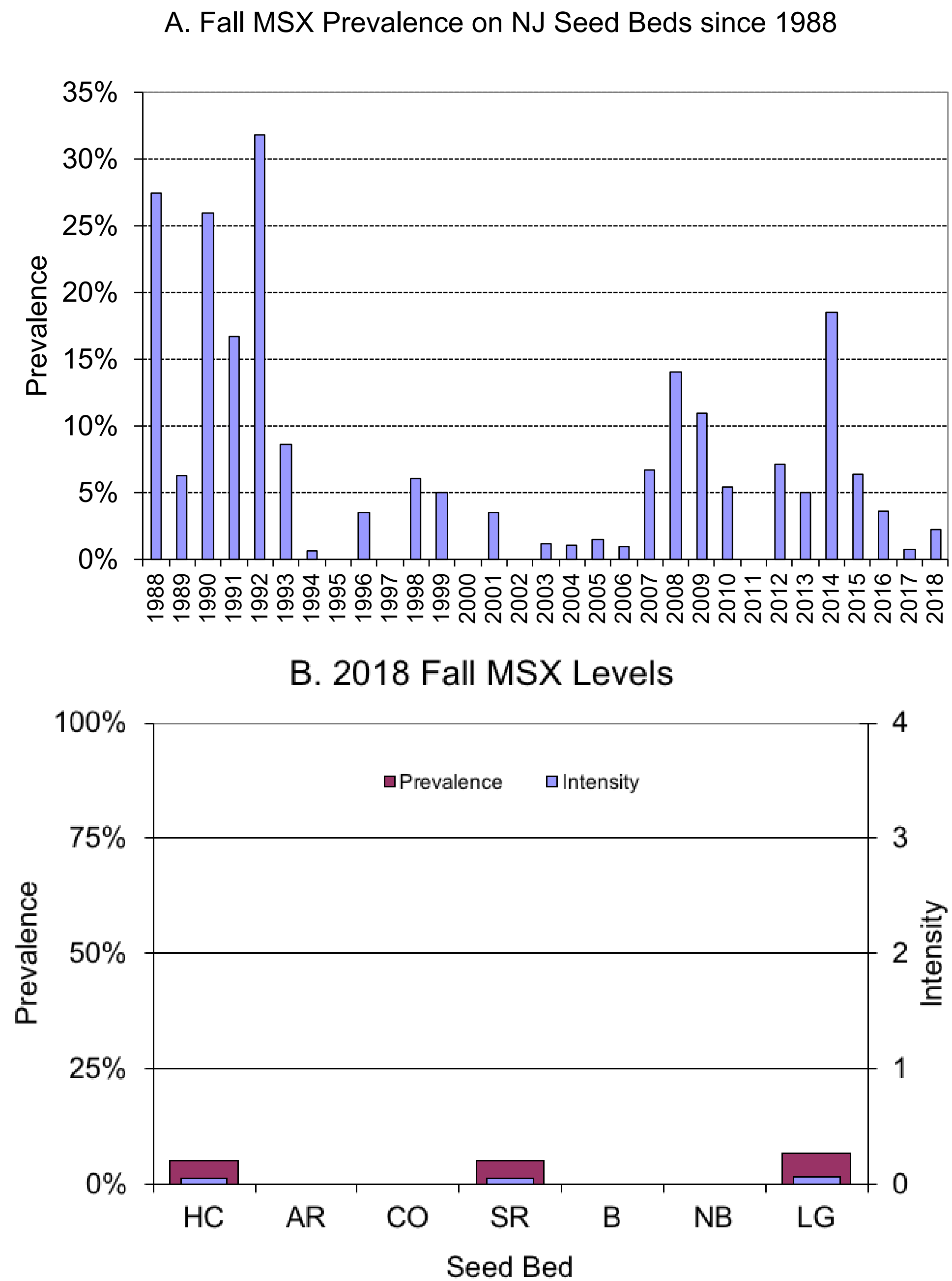

Figure 13. MSX disease on the New Jersey Delaware Bay oyster seedbeds. Upper: annual Fall MSX Prevalence since 1988 (2007 for HC). Lower: Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) on selected beds in 2018. HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, LG = Ledge.