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Delaware Bay New Jersey Oyster Seedbed Monitoring Program 2024 Status Report

January 23, 2025
Final

Prepared by

Iris Burt, Emily McGurk and David Bushek
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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Executive Summary

The 2024 Seedbed Monitoring (SBM) Program tracked oyster size, dermo disease and oyster mortality monthly at six fixed sites, three additional sites of interest, seven shellplant sites and nine intermediate transplant sites. The Program also continued its long-term disease analyses for the annual Fall Oyster Stock Assessment Survey by assessing dermo disease from 23 beds as well as MSX disease data from eight fixed monitoring sites.

Monthly monitoring indicated that temperature was fairly consistent with a 24-yr average from May to November during 2024. Heavy freshwater inflow during the spring started the seasonal salinity at a relatively low level but extended drought during summer and fall resulted in a quick increase that led to above average salinity during summer. Mean oyster size decreased on many beds during the year due to recent recruitment. Dermo disease followed typical seasonal and spatial patterns, but levels were generally close to long-term averages during 2024.

Fall spatial patterns of dermo showed the typical increase from upper to lower bay beds with most beds near or slightly above long-term means. Box counts indicated low levels of mortality with highest levels occurring on Bennies, New Beds, Shell Rock and Nantuxent. The overall long-term patterns from the Fall survey continues to indicate an attenuation of dermo and mortality over time. Bay-wide mortality stopped cycling with dermo around 2015 and has decreased from 20-30% in the 1990s to less than 15% since 2020. MSX was only detected on Hope Creek and New Beds during the Fall survey, continuing a period of low prevalence and intensity that have lasted about 3 to 5 years in the recent past. One point to note, however, is the presence of disease on Hope Creek, which may be due to lack of rainfall in summer and fall.

The overall picture continues to be one of improvement, but remains highly dependent upon environmental conditions, particularly temperature, salinity and Delaware River discharge in any given year. Increased freshwater inflow, even with freshet driven mortality events, has been beneficial in curtailing dermo related mortality and generally explains the difference between upper and lower bay rates of dermo infection as well as the apparent suppression of MSX. Continued monitoring of disease and mortality across the natural seedbeds, on transplants and on shell plants is warranted to evaluate performance and to inform management of the resource and the impacts of freshwater inflow that can be determined in part by upstream reservoir management. This is particularly important in the face of climate change and increasing aquaculture activities.

Introduction

The Delaware Bay Oyster Seedbed Monitoring (SBM) Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds located in the upper portion of the Bay (Figure 1). The purpose is to provide information that supports the sustainable management of the oyster resource in this region of the bay. 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 beyond the scope of this annual report though some information may be included when relevant.

Oyster mortality on the Delaware Bay oyster beds is caused by a variety of factors including predation, siltation, freshets, disease and fishing. Prior to 1957, predation by oyster drills was a primary concern with their abundance and distribution determined by salinity which is controlled by the amount of freshwater inflow (Carriker 1955). 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 developed significant resistance to MSX disease that extends into low salinity regions where MSX is not typically prevalent in oysters (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 continued MSX disease pressure (Ford et al. 2012). In 1990, an epizootic of dermo disease occurred and changed the population dynamics of the system further. Dermo disease is a form of the molluscan disease perkinsosis that is specific to the eastern oyster *Crassostrea virginica*. It is caused by the alveolate protist *Perkinsus marinus*. Prior to 1990, occurrences of dermo disease were associated with importations of oysters from the lower Chesapeake Bay (Ford 1996) and often subsided once importations ceased, presumably due to the colder climate. 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). It is likely that *P. marinus* was present in the bay for many years prior to 1990 at levels below detection without causing any notable mortality. Regional warming from climate change has enable the persistence of dermo disease in Delaware Bay since 1990 and as a primary concern for managing the oyster resource and fishery (Bushek et al. 2012).

Following 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 correlated with salinity which increases from around 6 in the uppermost beds to about 18 on beds located further downbay. Higher salinity generally promotes better growth and meat quality but also favors predation and disease. A group of beds above the low mortality region was added to the survey in 2007 after a survey indicated the presence of a high abundance of oysters was present in an area that the fishery had exploited in the past but consider of negligible importance. The low salinity across this region minimizes predation and disease resulting in very low mortality in most years, hence their designation as the Very Low Mortality (VLM) region, although episodic freshets periodically cause substantial mortality, Munroe et al. 2013. It is worth noting that the low salinity also

reduces growth and condition such that oysters are generally small even though they may be relatively old. 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) corresponding to their management within the fishery. Additional details on management strategies and actions are available in annual stock assessment workshop reports from the Haskin Shellfish Research Laboratory website: <https://hsrl.rutgers.edu/documents/delaware-bay-oyster-stock-assessment-reports/>.

Most of the fresh water entering the system comes from the Delaware River and tributaries located above the oyster beds. Additional 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 larval dispersal, recruitment, growth, disease transmission dynamics, and disease mortality (Wang et al. 2012). 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 to inform management and sustain a healthy oyster population and a functional ecosystem that can sustain a viable commercial fishery. A major objective is to identify seasonal and interannual patterns of disease, mortality, recruitment and growth through time. The core effort monitors six sites along the salinity gradient on monthly basis and conducts a spatially comprehensive survey in the Fall. The monitoring supports additional directed research and sampling efforts to develop insights into the dynamics controlling the oyster population within the Delaware Bay ecosystem. As funding permits, these efforts include monitoring transplants (oysters moved from upper to lower seedbeds), shellplants (shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (cultch planted in the lower bay high recruitment zone near the Cape Shore then moved and replanted on the seedbeds) as well as other natural events (e.g., freshets) and additional experiments that may be sanctioned. The 2024 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 for each bed sampled during the 2024 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on the 2022 through 2024 shell plantings
4. Monitor growth, mortality and disease on the 2023 and 2024 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 2010 Hope Creek was added as part of the monthly monitoring program. During 2024, samples of oysters collected for objective 1 were fixed for potential histological examination to help assess any seasonal mortality from sources other than dermo disease. 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

Monthly monitoring occurred at the six long-term sites along a transect spanning the salinity gradient from Hope Creek to New Beds as well as three additional sites of interest (Nantuxent, Egg Island and Cape Shore). Reports were presented during scheduled meetings of the Delaware Bay Section of the New Jersey Shell Fisheries Council to provide 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 2024. All data were evaluated and compared to prior years to provide insight into inter-annual patterns, long-term trends, and factors affecting the oyster stock.

Figure 1 depicts the sampling locations for the 2024 Annual Fall Oyster Stock Assessment with beds outlined in black. Different management regions are indicated by different colors. 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. Details on regions, beds and sampling design are provided in Powell et al. (2008 and 2012) as well as Alcox et al. (2017) and other annual reports available on the Haskin Shellfish Research Laboratory website. Briefly, the beds shown in Figure 1 were divided into grids measuring 0.2 x 0.2 minutes of latitude and longitude (roughly 26 acres or 10.5 hectares each). Monthly samples were collected at fixed stations using a composite bushel of three 1-minute tows with a 0.81 m wide oyster dredge from the NJ Division of Fisheries and Wildlife’s R/V James W Joseph. Dots in Figure 1 represent locations from a stratified random sampling design for the Fall oyster stock assessment. Two locations within each bed, typically one each of high and medium density strata, were sampled for disease assessment (see below). Grid quality is determined by relative oyster density within each bed as described in Alcox et al. (2017). When ranked by oyster abundance, the high-density stratum contains 50% of the total oyster abundance, the medium density stratum contains the next 48% of total oyster abundance, and the low-density stratum contains the remaining 2% of the total oyster abundance on a bed.

Monthly samples were collected from April through November for Objectives 1, 3 and 4 as indicated in Table 1. Table 2 lists the beds sampled for objectives 3 and 4 and the respective enhancement activity for each location. 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 2024 Annual Fall Oyster Stock Assessment to complete Objective 2 along with respective sample sizes for dermo, MSX and condition index analyses.

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 instrument at each site. A composite bushel (37 L total volume with one third coming from each dredge tow¹) was created and then sorted to enumerate gapers (i.e., dead oysters with meat remaining in the valves), boxes (i.e., hinged oyster valves without any meat remaining) and live oysters. Because boxes persist for varying amounts of time, they were further categorized as new (i.e., no indication of fouling with little sedimentation inside valves) or old (i.e., heavily fouled and/or containing 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 measured for shell height (hinge to bill of the flat or right valve) to determine the size frequency of oysters 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 (Morson et al. 2018). 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) after Ray (1954). These values, including zeros, were averaged to produce a weighted prevalence (WP), which provides an estimate of the average disease level in the sample of oysters (Mackin 1962, Dungan and Bushek 2015). The average intensity of infections, which excludes samples scored as zero, was similarly determined. Though related and similar, each measure provides a different understanding of how disease impacts the population.

Samples for Objective 2 were collected during the Annual Fall Stock Assessment Survey using the commercial oyster boat F/V HW 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 3 (see Ashton-Alcox et al. 2017 for survey method details). 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 sites were monitored as described for Objective 1 with the following modifications for Objective 3. Objective 3 continued monitoring the 2022 and 2023 shell plantings, and initiated sampling of the 2024 shell plantings listed in Table 2 – the latter of which was only sampled during the final 3 months. On each shellplant site, three 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

¹ At Arnolds and Hope Creek, sample volumes were halved due to small size of the oysters.

boxes and gapers encountered during this process were collected. If five tows were insufficient to collect 100 oysters the effort was stopped, and all oysters collected to that point were used. Care was taken to avoid sampling bias while sorting the catch 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 ($n = 50\text{-}100$ per site). No disease sampling was performed on the 2024 shellplants as it was in its first year and not expected to have many detectable infections if any by this point.

Results² and Discussion

Freshwater Inflow. The Delaware River Basin Commission is tasked with maintaining sufficient flow to prevent upward movement of the salt line (defined here as $250\text{ mg/L} = 0.25\text{ ppt}$) below the city of Philadelphia to maintain drinking water standards, protect industries from corrosive effects of salt water and to protect aquatic life located further downstream (DRBC 2021). This is done by maintaining a minimum flow at Trenton via the metered release of water from reservoirs located in the watershed. Reservoirs are also used to store water for other purposes and as catch basins for flood control. When full, water must be released so that reservoirs can be used for flood control. Discharge typically decreases from the end of winter through late summer which causes salinity to increase across the oyster beds (see below). During 2024, discharge fell below long-term levels for much of the spring and early summer permitting ocean water to penetrate further upbay and increase salinity even higher during this portion of the year (Figure 2). Lower discharge increases water residence time over the oyster beds, which can increase the retention of larvae as well as free living forms of oyster pathogens such as dermo. A large discharge during August had little impact on salinity due to a relatively short duration. During the remainder of the year, discharge was well above average. Higher discharge decreases residence time of water and reduces salinity pushing disease and predators in a downbay direction.

Temperature and Salinity. Temperature and salinity are arguably the most important environmental factors controlling oyster growth, reproduction, disease and mortality. The conditions observed over the seedbeds during 2024 were average with respect to the past 24 years. Water temperatures measured during 2024 collections followed a typical seasonal cycle with little spatial variability across the seedbeds (Figure 3A and B). Spawning temperatures of approximately 25 C (77 F) were reached between June and July sampling dates. Salinity followed the typical estuarine gradient, increasing from upbay to downbay beds (Figure 3C), and increased during the year from an unseasonably low in April to an unseasonably high in November (Figure 3D). This salinity pattern reflects the river discharge data from Trenton shown in Figure 2.

Oyster size. Within a given salinity regime, shell height roughly corresponds to age and therefore provides insight into both the size and age structure of the population. Seasonal changes in the mean shell height of a population may be affected by growth, recruitment and mortality (including harvest). Mean shell height tended to decrease over time during 2024 as

² *COVID-19 Impacts:* Data from 2020 are incomplete due to a curtailment in work activities but no essential data is missing from 2021 to present.

younger oysters presumably recruited into the population and larger older oysters were harvested or died (Figure 3E and F). Figure 4 shows how oyster size has changed annually and shows a cyclical pattern that is likely reflective of the interplay between recruitment and mortality such that mean size increases when mortality and recruitment are low while decreasing as recruitment increases along with mortality of larger sized oysters. Mean oyster size decreased in 2024 as the result of recruitment events throughout the bay. The overall 2024 size frequency had a mean of 61.3 mm (2.4 inches) ranging from 29.95 mm on Hope Creek to 86.67 mm on New Beds.

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 increasing across the summer with the upper bay beds showing much lower levels of infection (Figure 5A, C and E). Average levels followed the typical season patterns (Figure 5 B, D and F). The population entered the winter with slightly higher levels of dermo than average. Those individuals with the heaviest infections are likely to die over the winter or soon after they begin filtering if they are too weak to rid themselves of infections once the water warms up in spring.

Mortality. Mortality across the upper beds was negligible, but variable in other regions increasing with salinity (Figure 6A, C and E). Spikes in mortality were observed on Bennies and New Beds in spring, and on New Beds, Shell Rock and Nantuxent in October (Figure 6C). As a result, cumulative mortality reached 25% on Bennies and 14-16% on New Beds, Nantuxent and Shell Rock. These beds, particularly Bennies and New Beds, experienced increased MSX infections in spring and fall which may account for some of the higher levels of mortality.

Transplants. Figures 7 and 8 show levels of dermo and mortality on the 2023 and 2024 transplants, respectively. Dermo followed expected seasonal patterns (panels A and C in Figures 7 and 8) and were similar in magnitude to long-term monitoring sites (Figure 5). Dermo levels followed the salinity gradient, increasing in prevalence and intensity from Low to High Mortality regions. The levels of dermo exceeded 1.5 WP on all sites, except those placed on the Low Mortality region, which was sufficient to cause mortality (Bushek et al. 2012). It is worth noting that transplanted oysters cannot be distinguished from oysters originating on the site, so results represent a mixture of both, nevertheless, transplantation of oysters did not appear impact patterns of dermo and mortality from the recipient bed.

Shellplants. Seven shell plants have been placed on four different beds during the past three years (Table 2). Growth varied among shellplants (Figure 9A) with the largest increase on the 2022 shellplants averaging 20.7 mm while the 2023 and 2024 plants grew an average of 19.9 mm. Mortality varied from 1 to 55% and was mostly noted on the 2024 Bennies plant site as a result of heavy drill predation at that site (Figure 9C). Dermo increased on 2022 plants during 2024 but remained below levels of the recipient beds (Figure 6D). 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 of shell planted in the lower bay or spat-on-shell occurred during 2024 but remain potentially viable management strategies.

Long-Term Fall Patterns. Fall levels of dermo and mortality generally increased from low salinity areas in the upper bay to higher salinity areas of the lower bay (Figure 10). Dermo levels were near or above long term means with only three exceptions: Upper Arnolds, Arnolds and Beadons. In contrast, mortality was well below long-term means except on Upper Middle and Sea Breeze where it was within the 95% confidence interval. Dermo is not the only source of mortality and multiple factors such as time since of infection, freshwater inflow, food availability all affect the virulence of dermo, but these data continue to support the notion that tolerance is developing in the Delaware Bay population where weighted prevalence routinely exceeds 1.5.

Figure 11 depicts annual dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2024 for each mortality region. Each parameter shows a weak cyclical pattern with a general decrease over time. Exceptions are related to freshets that caused mortality in the Very Low and Low Mortality regions during 2004, 2011 and 2018 while suppressing mortality in the other regions by driving pathogens and predators down bay. These events put mortality and disease on the VLM and LM regions out of phase with the other regions where mortality generally tracks increases in disease. Dermo intensity was much more volatile in the early portion of the time series, but this volatility has dampened in the latter half of the time series (Figure 11B) and corresponds to a reduction in Fall box count mortality (Figure 11C).

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 bay wide data continue to indicate an attenuation of dermo-induced mortality over time (Figure 12). Moreover, the bay-wide pattern of attenuation shown in Figure 12 indicates a decoupling of dermo and mortality as dermo has attenuated. It is tempting to think this is an indication of the development of resistance (the ability to prevent infections) and/or tolerance (the ability to endure infections), but figure 11 suggests there remains a strong environmental component associated with the salinity gradient determined by freshwater inflow. Lagged correlations between river flow and WP produce a significant negative correlation (Bushek et al. 2012). Additional analyses as well as directed studies and experiments are necessary to develop a better understanding of what factors are important and whether management strategies can effectively improve the situation. Along these lines, a Rutgers Masters student Leah Scott has been examining the relationships between long-term patterns of temperature, salinity, freshwater inflow, dermo disease and oyster mortality from the data collected here and available from other sources. In looking at data from the past two decades, she has found that temperatures which influence the development of dermo disease in oysters (i.e., those above 15 C) have become more prevalent over time. Specifically, the day that temperatures begin to remain above 15 C is reached about three weeks earlier in the spring and the date when temperatures fall below 15 C occurs about one week later in the fall. This effectively lengthens the time dermo is active by about one month. All else being equal, this should give the disease a longer period of time to develop and lead to higher mortality. This is clearly not the case and may reflect the development of resistance or tolerance in the population. The mechanism responsible is unclear and under further investigation.

Figure 13 depicts the regional mortality rates from each fall assessment since 1990 as a function of dermo weighted prevalence. Bushek et al. (2012) demonstrated that once weighted prevalence begins to exceed 1.5 mortality begins to increase exponentially. In Figure 13, VLM and LM regions show no increase in mortality with dermo infection level because all infections are below the 1.5 threshold – the high mortality events in the VLM were a result of freshets. 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 about 48% of the annual variability in mortality.

Because MSX has not been problematic on the seedbeds since 1987, samples from only eight beds along the upbay-downbay gradient have been examined during the fall survey (Table 4). MSX was detected in only 3 of the 140 oysters assayed: a prevalence of just 2.1% (Figure 14A). Over the past 36 years, MSX infections nearly always occur at a higher prevalence and intensity as salinity increases (Figure 14B). In 2024, infections were only detected at two sites (Figure 14C), Hope Creek and New Beds. Lack of rainfall in summer and fall allowed the upper bay beds to reach higher salinity levels, which may be the reason for infection at Hope Creek. Infections at Hope Creek were in the early stages of infection and restricted to epithelial cells. Infections at New Beds had progressed further, with one that was systemic but neither were advanced. Previous years have found MSX distributed across the seed beds and these data confirm its continued presence in the Bay although with a much more limited impact than levels observed prior to 1990. Because MSX can cause mortality in spring and appears to be more prevalent in the lower bay, it was recommended that some level of routine monitoring of MSX occur throughout the year to improve surveillance, so twenty oysters sampled for dermo disease each month were processed via histology from selected beds to look for MSX infections. Figure 15 shows highest prevalence in spring, albeit low and of low intensity, with smaller peaks in fall, likely due to the summer/fall drought. This pattern corresponds with prior studies on the seasonality of MSX. Collectively, these data indicate that MSX remains a threat to the Delaware Bay oyster population as it continues to cause mortalities elsewhere along the East Coast. Its persistence in Delaware Bay serves to help maintain resistance that has developed in the native population (Ford and Bushek 2012). Therefore, it remains an important component of the monitoring program to understand sources of mortality from year to year.

Science Advice

- Continue to examine the spatial and temporal relationships between environmental drivers of temperature, salinity and freshwater inflow on disease and mortality.
 - Long-term patterns now provide a clear indication that dermo levels drop following freshets resulting in a net positive effect on the population (through reduced mortality). The potential of controlling disease and mortality through coordination of reservoir releases up the estuary should be explored with appropriate agencies.
 - Long-term patterns indicate an attenuation of dermo and dermo-related mortality despite an increase in the duration of warm temperatures which warrants an investigation into the development of resistance and tolerance and any relevant mechanisms.

- Conduct a more thorough analysis of where and when monthly mortality has occurred to help interpret fall mortality patterns. Bed-level investigations may be helpful.
- Compile condition index data to examine current year versus long-term means by bed along the bay axis.

Acknowledgements

HSRL staff and students along with NJDEP Bureau of Shellfisheries staff, especially Craig Tomlin, Andrew Hassall and Michael Lindner provided field, logistical and technical support during 2024. In kind support was provided by Bivalve Packing, Inc. through the contribution of vessel time and staff. Their combined efforts were essential to ensuring samples were collected and processed and data analyzed to sustain the program which the late Susan Ford initiated in 1990 to understand and monitor dermo disease and its impacts on the Delaware Bay oyster population and fishery. Program guidance for 2024 was provided by the Oyster Industry Science Steering Committee, the Delaware Bay Shellfisheries Council and the Stock Assessment Review Committee with funding from Rutgers University and the State of New Jersey. Industry input is provided through the Shellfisheries Council. This work was supported by the USDA National Institute of Food and Agriculture Hatch project NJ30110.

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Table 1. 2024 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, Egg Island and the Rutgers Cape Shore Lab were the additional sites of interest that were sampled in 2024. 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.

<u>Date</u>	<u>Samples</u>	<u>Vessel</u>	<u>Captain</u>
April 15, 2024	6 long-term sites, 2 extra sites, 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
April 22, 2024	3 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
May 20, 2024	6 long-term sites, 1 extra site, 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
May 28, 2024	7 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
June 17, 2024	6 long-term sites, 2 extra sites, 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
June 25, 2024	7 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
July 15, 2024	6 long-term sites, 1 extra sites, 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
July 23, 2024	6 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
August 19, 2024	6 long-term sites, 1 extra sites, 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
August 26, 2024	6 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
September 19, 2024	6 long-term sites, 1 extra site, 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
September 23, 2024	6 intermediate transplant sites, 7 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
October 21, 2024	6 long-term sites, 1 extra site, 2 intermediate transplant sites, 1 shellplant site	NJDEP RV James W. Joseph	Andrew Hassall
October 28, 2024	5 intermediate transplant sites, 6 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
November 18, 2024	6 long-term sites, 1 extra site, 2 intermediate transplant sites, 1 shellplant site	NJDEP RV James W. Joseph	Craig Tomlin
November 25, 2024	5 intermediate transplant sites, 6 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall

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Table 2. Enhancement sites sampled during 2024.

<u>Bed</u>	<u>Grid</u>	<u>Plant material</u>	<u>Plant year</u>
Nantuxent	20	clam shell	2022
Shell Rock	14	clam shell	2022
Bennies Sand	3	medium mortality transplant	2022
Shell Rock	10	low mortality transplant	2022
Upper Arnolds	10	very low mortality transplant	2022
Nantuxent	8	medium mortality transplant	2023
Shell Rock	9	low mortality transplant	2023
Ship John	35	low mortality transplant	2023
Bennies	124	clam shell	2023
Shell Rock	13	clam shell	2023
Ship John	15	clam shell	2023
Bennies	70	medium mortality transplant	2024
Shell Rock	30/31	low mortality transplant	2024
Ship John	19	very low mortality transplant	2024
Bennies	55	clam shell	2024
Shell Rock	35	clam shell	2024

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Table 3. Record of collections for annual fall dermo monitoring since 1990. X indicates bed was sampled in respective year for that column. 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. In 2021, however, both Ledge and Egg Island were sampled. Beds are listed approximately by latitude from north to south, 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	--	--	22	23	24
Hope Creek (HC)																		X	X	X	--	--	X	X	X
Liston Range (LR)																			X	X	--	--	X	X	X
Fishing Creek (FC)																			X	X	--	--	X	X	X
Round Island (RI)	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	--	--	X	X	X
Upper Arnolds (UA)														X		X	X	X	X	X	--	--	X	X	X
Arnolds (AR)	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 (UM)																	X	X	X	X	--	--	X	X	X
Middle (MI)	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Cohansey (CO)	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 (SB)													X	X	X	X	X	X	X	X	--	--	X	X	X
Ship John (SJ)	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Shell Rock (SR)	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 (BS)	X	X	X	X	X			X	X	X	X	X	X		X	X	X	X	X	X	--	--	X	X	X
Bennies (Ben)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Nantuxent (Nan)		X		X		X		X		X	X	X		X		X	X	X	X	X	--	--	X	X	X
Hog Shoal (HS)		X		X						X		X	X	X	X	X	X	X	X	X	--	--	X	X	X
New Beds (NB)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Strawberry (ST))	X		X		X								X	X	X	X	X	X	X	X	--	--	X	X	X
Hawks Nest (HN)	X		X		X		X		X		X		X	X	X	X	X	X	X	X	--	--	X	X	X
Beadons (Bea)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	--	--	X	X	X
Vexton (Vex)										X		X	X	X	X	X	X	X	X	X	--	--	X	X	X
Egg Island (EI)	X	X	X	X	X	X	X	X		X	X	X		X		X		X		X	--	--	X	X	
Ledge Bed (LB)			X		X				X		X		X		X		X		X		--	--	X		X

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Table 4. 2024 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.

<u>Bed</u>	<u>Grid</u>	<u>Dermo</u>	<u>MSX</u>	<u>CI</u>		<u>Bed</u>	<u>Grid</u>	<u>Dermo</u>	<u>MSX</u>	<u>CI</u>
Hope Creek	85	10		15		Shell Rock	75	10		15
Hope Creek	76	10		15		Shell Rock	46	10		15
Hope Creek	77			10		Shell Rock	38			8
Hope Creek	43			10		Shell Rock	71			12
Hope Creek	63		20	0		Shell Rock	10,11		20	0
Fishing Creek	36	10		15		Bennies Sand	36	10		15
Fishing Creek	25	10		15		Bennies Sand	6	10		15
Fishing Creek	4			10		Bennies Sand	8			10
Fishing Creek	26			10		Bennies Sand	34			10
Liston Range	12	10		15		Bennies	121	10		15
Liston Range	24	10		15		Bennies	58	10		15
Liston Range	16			10		Bennies	122			10
Liston Range	30			10		Bennies	83			10
Round Island	8	10		15		Bennies	110		20	0
Round Island	24	10		15		Nantuxent	15	10		15
Round Island	25			10		Nantuxent	24	10		15
Round Island	12			10		Nantuxent	13			10
Upper Arnolds	10	10		15		Nantuxent	29			10
Upper Arnolds	12	10		15		Hog Shoal	6	10		15
Upper Arnolds	14			10		Hog Shoal	20	10		15
Upper Arnolds	17			10		Hog Shoal	1			10
Arnolds	15	10		15		Hog Shoal	13			10
Arnolds	46	10		15		New Beds	36	10		15
Arnolds	9			10		New Beds	38	10		15
Arnolds	59			10		New Beds	66			9
Arnolds	18		20	0		New Beds	9,54			10
Upper Middle	64	10		15		New Beds	26		20	0
Upper Middle	71	10		15		Strawberry	5	10		12
Upper Middle	63			10		Strawberry	mix	10		17
Upper Middle	65			10		Hawks Nest	25	10		15
Middle	26	10		15		Hawks Nest	13	10		12
Middle	40	10		15		Hawks Nest	1			12
Middle	41			10		Hawks Nest	27			11
Middle	39			10		Beadons	17	10		10
Cohansey	10	10		15		Beadons	22,18	10		14
Cohansey	57	10		15		Beadons	mix			9
Cohansey	8			10		Vexton	5	10		15
Cohansey	9			10		Vexton	10	10		15
Cohansey	44		20	0		Vexton	4			10
Sea Breeze	33	10		15		Vexton	8			10
Sea Breeze	14	10		15		Ledge	8	10	10	0
Sea Breeze	13			10		Ledge	14	10	10	0
Sea Breeze	24			10		Ledge	mix			50
Ship John	52	10		15		Total beds		22	7	22
Ship John	25	10		15		Total grids		42	8	94
Ship John	32			10		Total oysters		440	140	1061
Ship John	5			10						

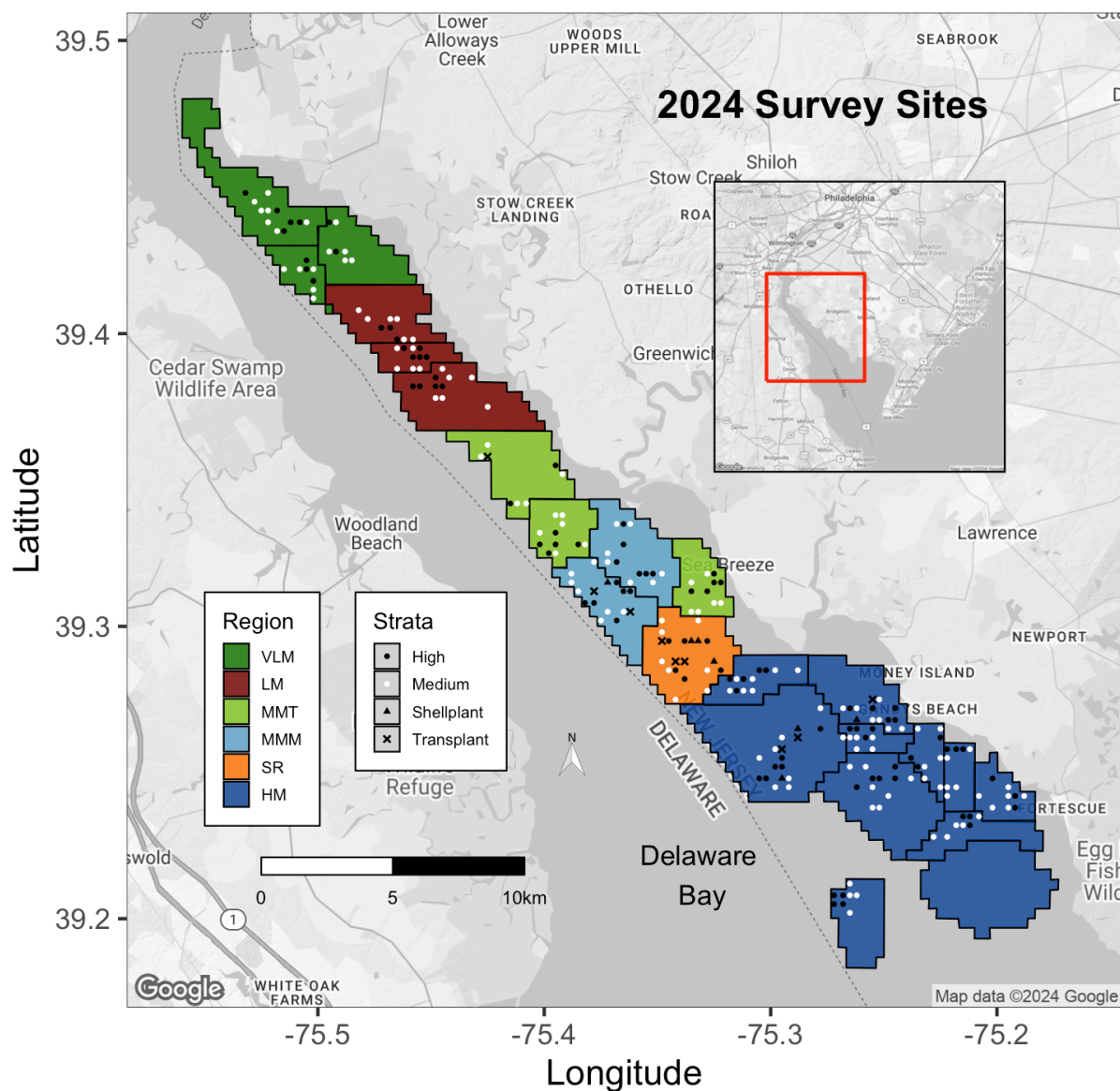


Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka ‘seedbeds’). Black lines demarcate named beds. Beds of the same color represent different management regions (dark green = very low mortality region (VLM), maroon = low mortality region (LM), light green = medium mortality transplant region (MMT), light blue = medium mortality management region (MMM), orange = Shell Rock region (SR), dark blue = high mortality region (HM)). The sites for the 2024 stock assessment survey are indicated by dots. Black dots are in high density strata and white dots are in medium density strata that were identified from a stratified random sampling design to determine overall bed oyster abundance. Transplant sites and shellplant sites are denoted by x’s and triangles, respectively. See Alcox et al. (2017) for full description of the stratified random sampling design and management regions. Oysters were drawn for disease monitoring from survey sites as indicated in Table 4.

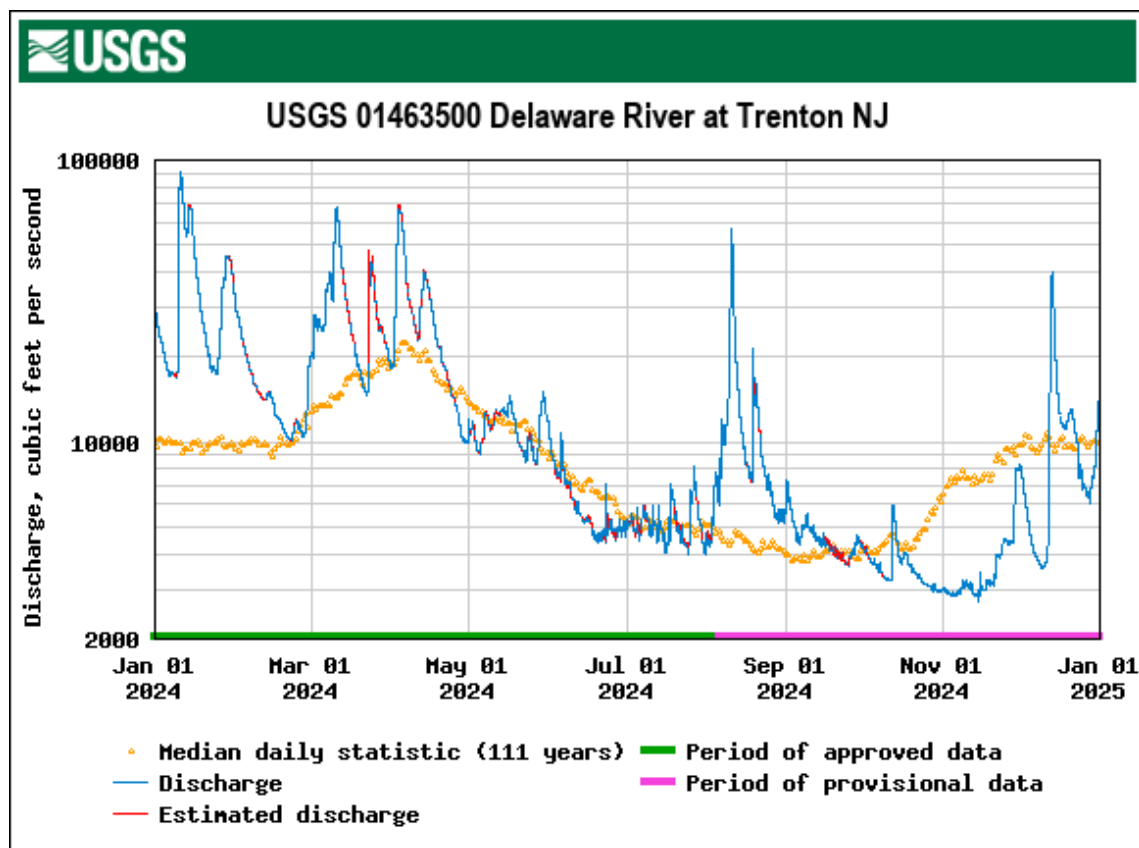


Figure 2. Delaware River discharge measured at Trenton, NJ USGS monitoring station 01463500. Yellow line represents daily discharge relative to the 1913-2023 median values. Flows were below median values for much of the latter half of 2024. Data source: https://nwis.waterdata.usgs.gov/nwis/uv/?ts_id=195092&format=img_stats&site_no=01463500&begin_date=20240101&end_date=20241231

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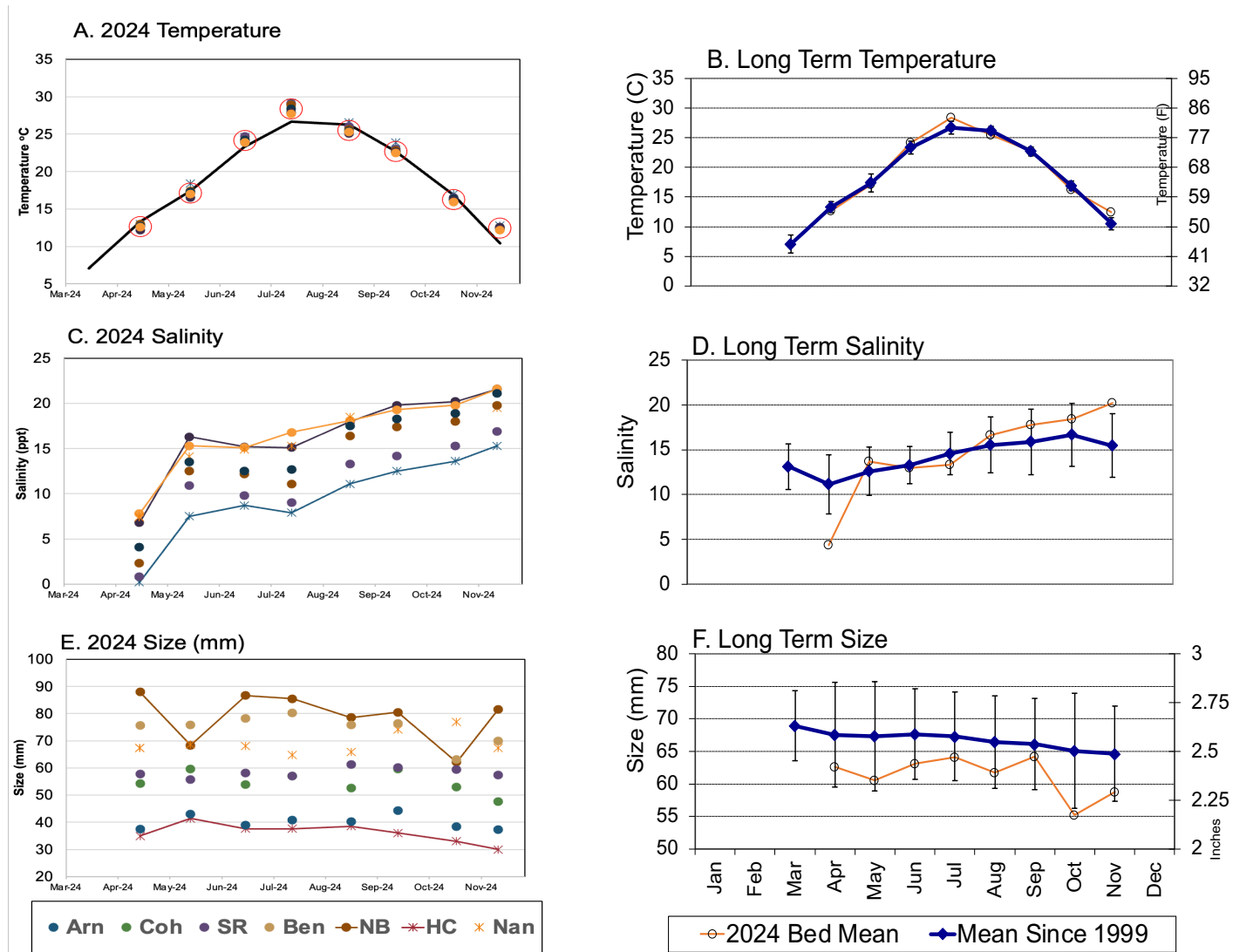


Figure 3. Results of 2024 Seed Bed Monitoring Program monthly temperature (A), salinity (C) and size frequencies (E) compared to the long-term mean data (B, D, and F, respectively). Panels present data as labeled. HC = Hope Creek, Arn = Arnolds, Coh = Cohansey, SR = Shell Rock, Ben = Bennies, NB = New Beds, Nan = Nantuxent.

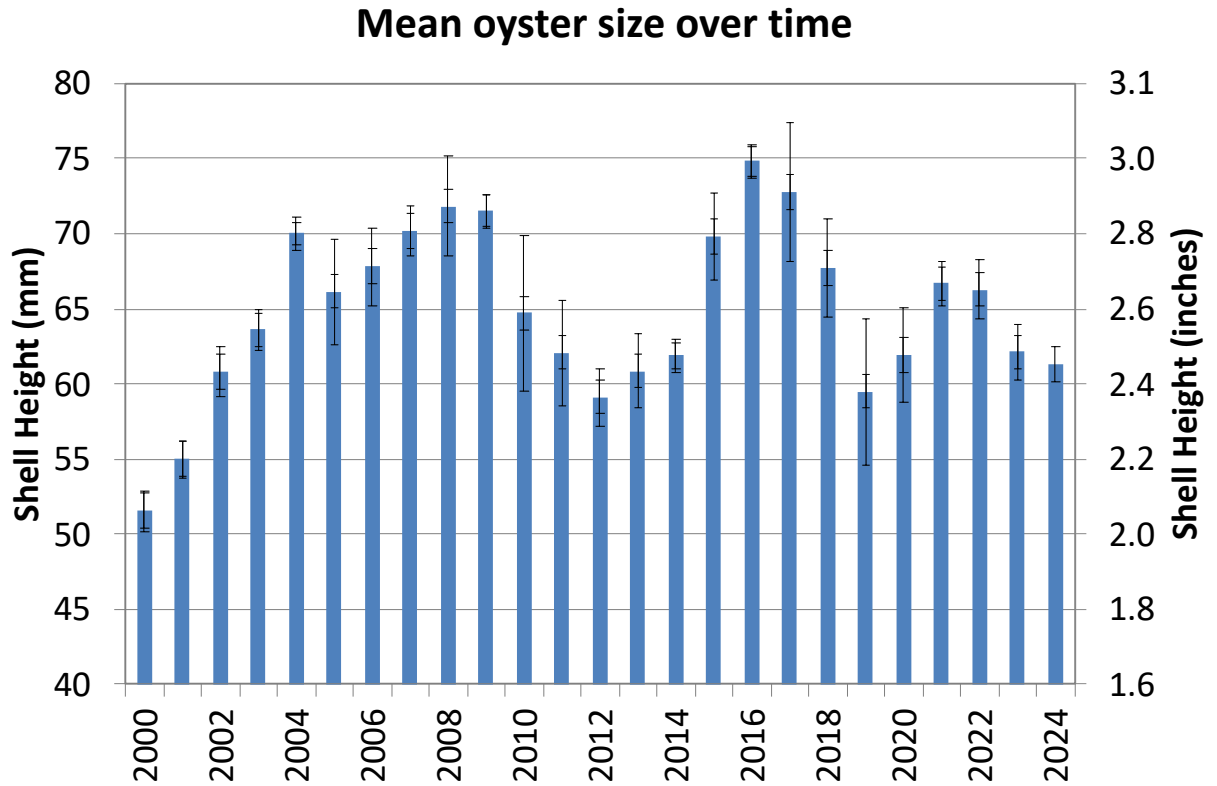


Figure 4. Interannual variation in mean shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) sampled from March to November. Samples from 2024 were collected from April to November.

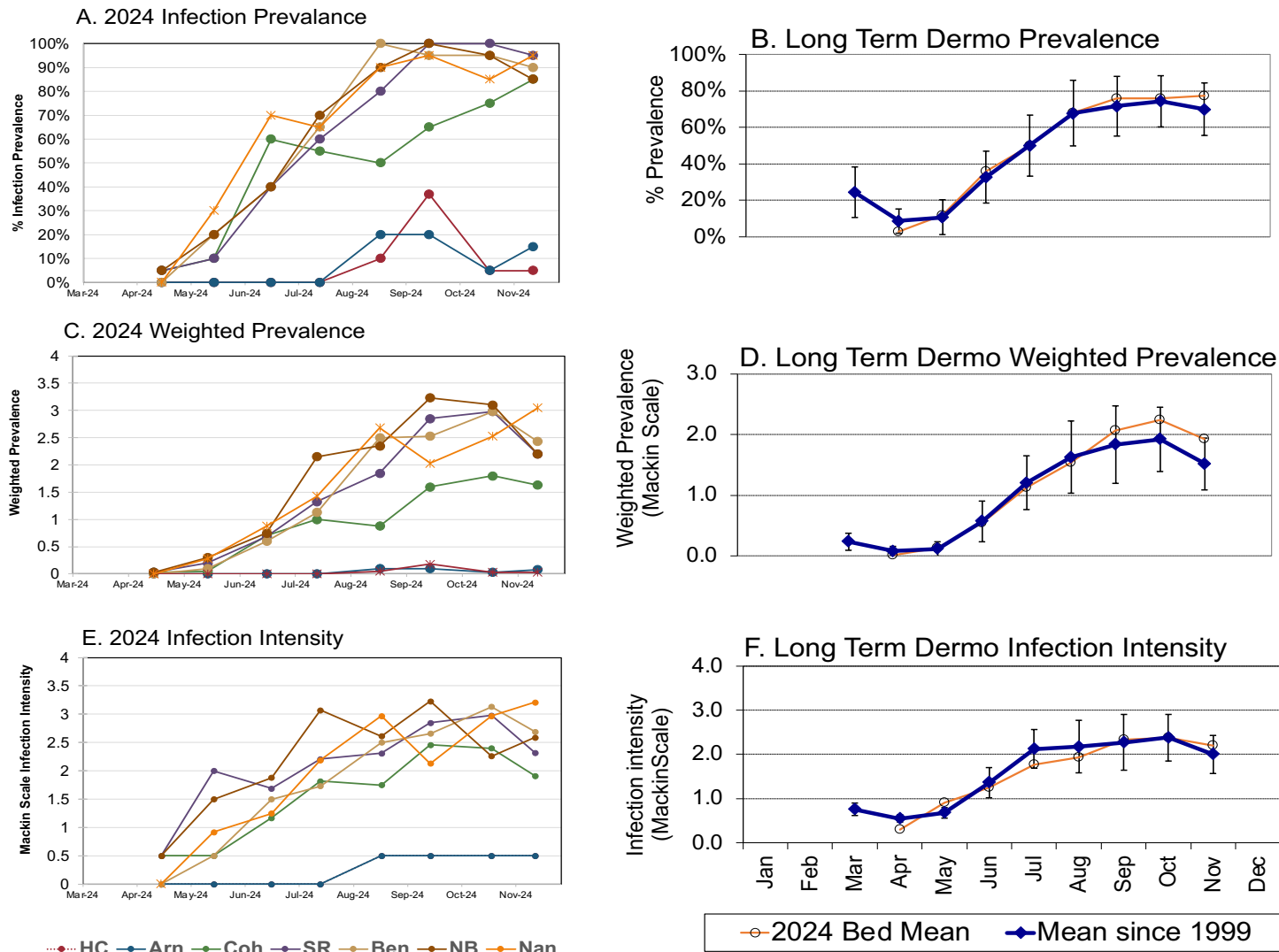


Figure 5. Results of 2024 Seed Bed Monitoring Program monthly Dermo disease prevalence (A), weighted prevalence (C) and intensity (E) compared to the long-term mean data (B, D, and F, respectively). Bed abbreviations as in Fig 3A.

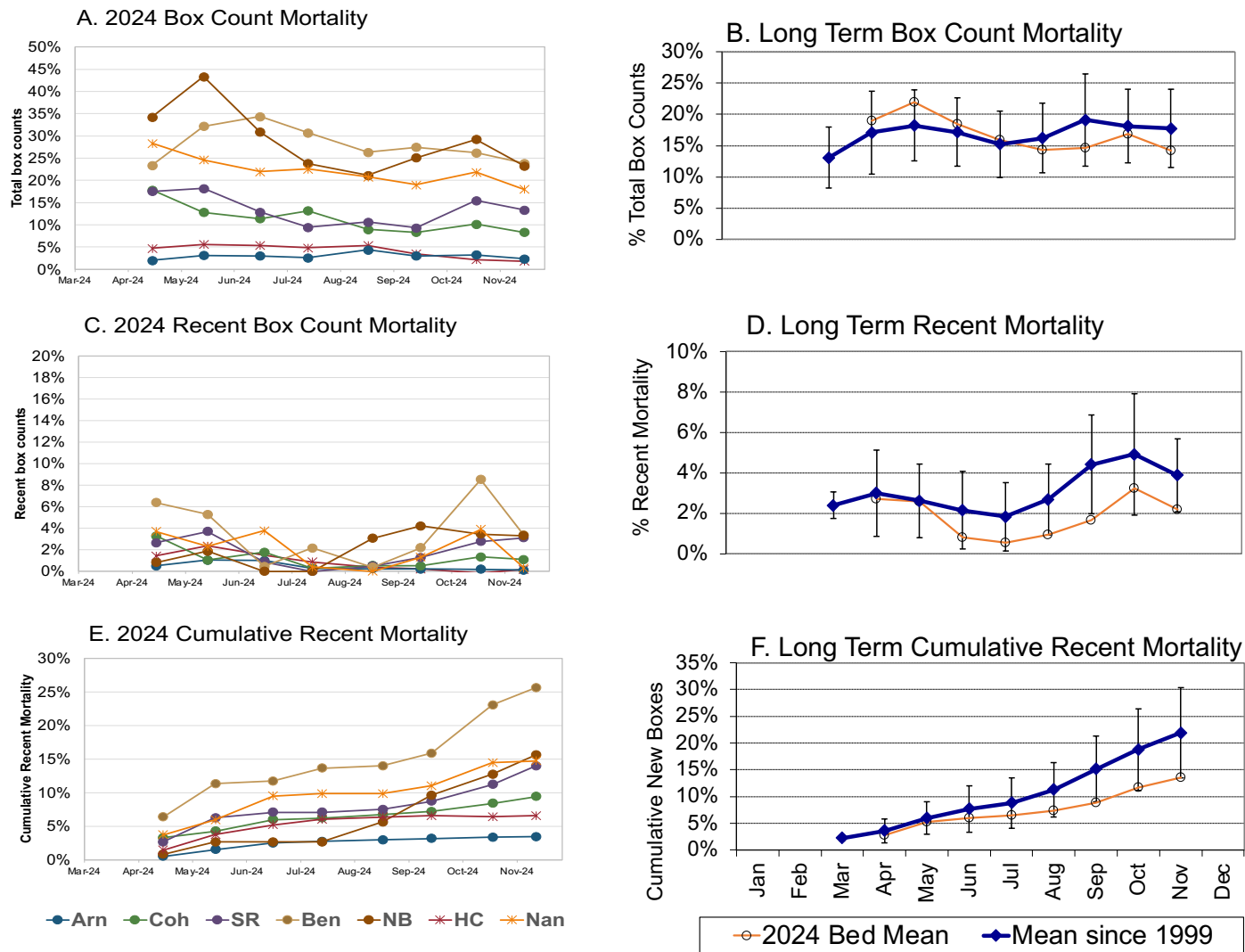


Figure 6. Results of 2024 Seed Bed Monitoring Program monthly total box count (A), recent box count (C) and cumulative mortality (E) compared to the long-term mean data (B, D, and F, respectively). Bed abbreviations as in Fig 3A.

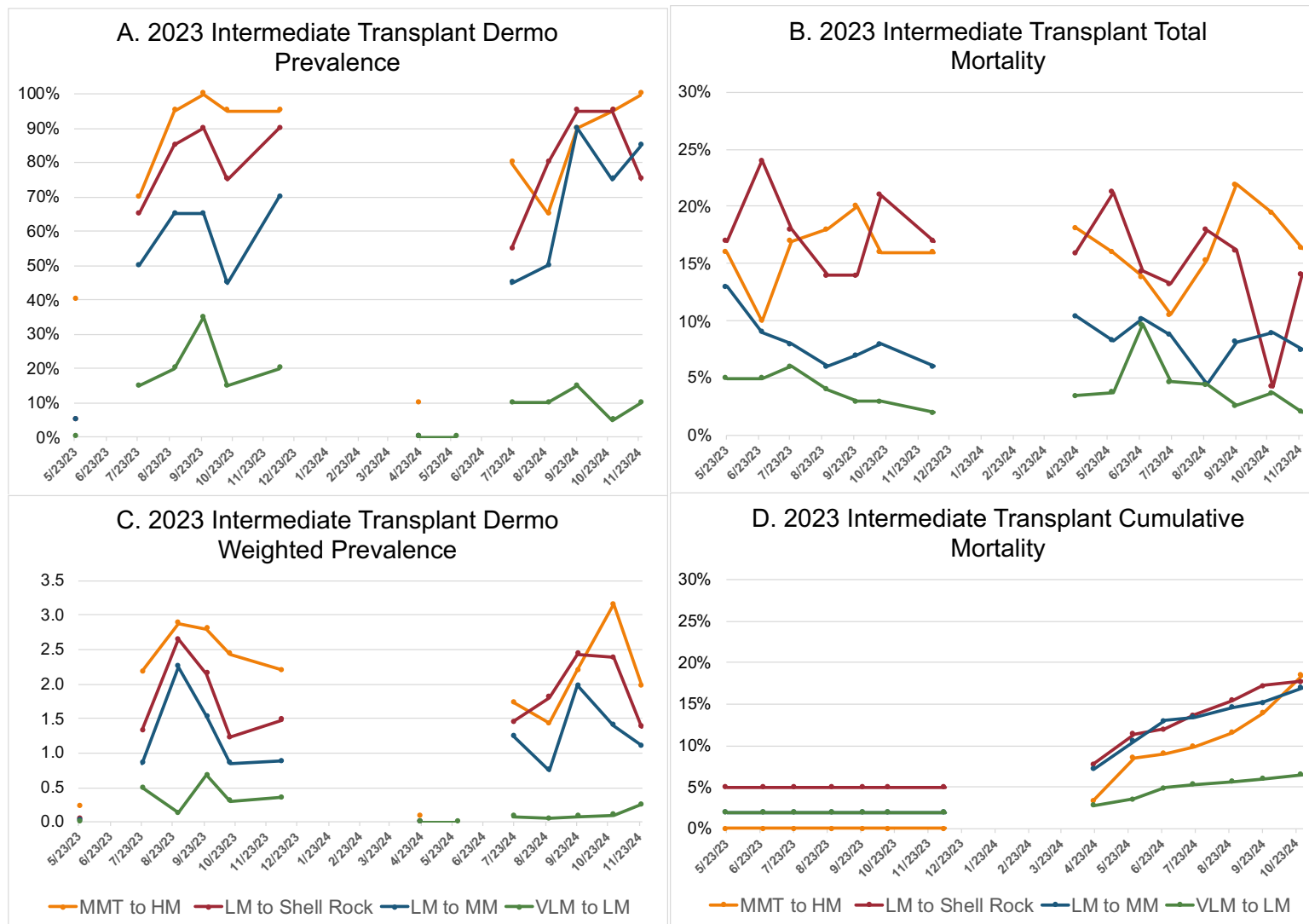


Figure 7. Dermo and mortality on the 2023 intermediate transplant sites. The 2023 donor to recipient beds were as follows: MMT to HM – Upper Middle, Middle and Sea Breeze to Bennies; LM to SR and MM – Upper Arnolds and Arnolds to Shell Rock and Ship John; VLM to LM – Hope Creek to Upper Middle.

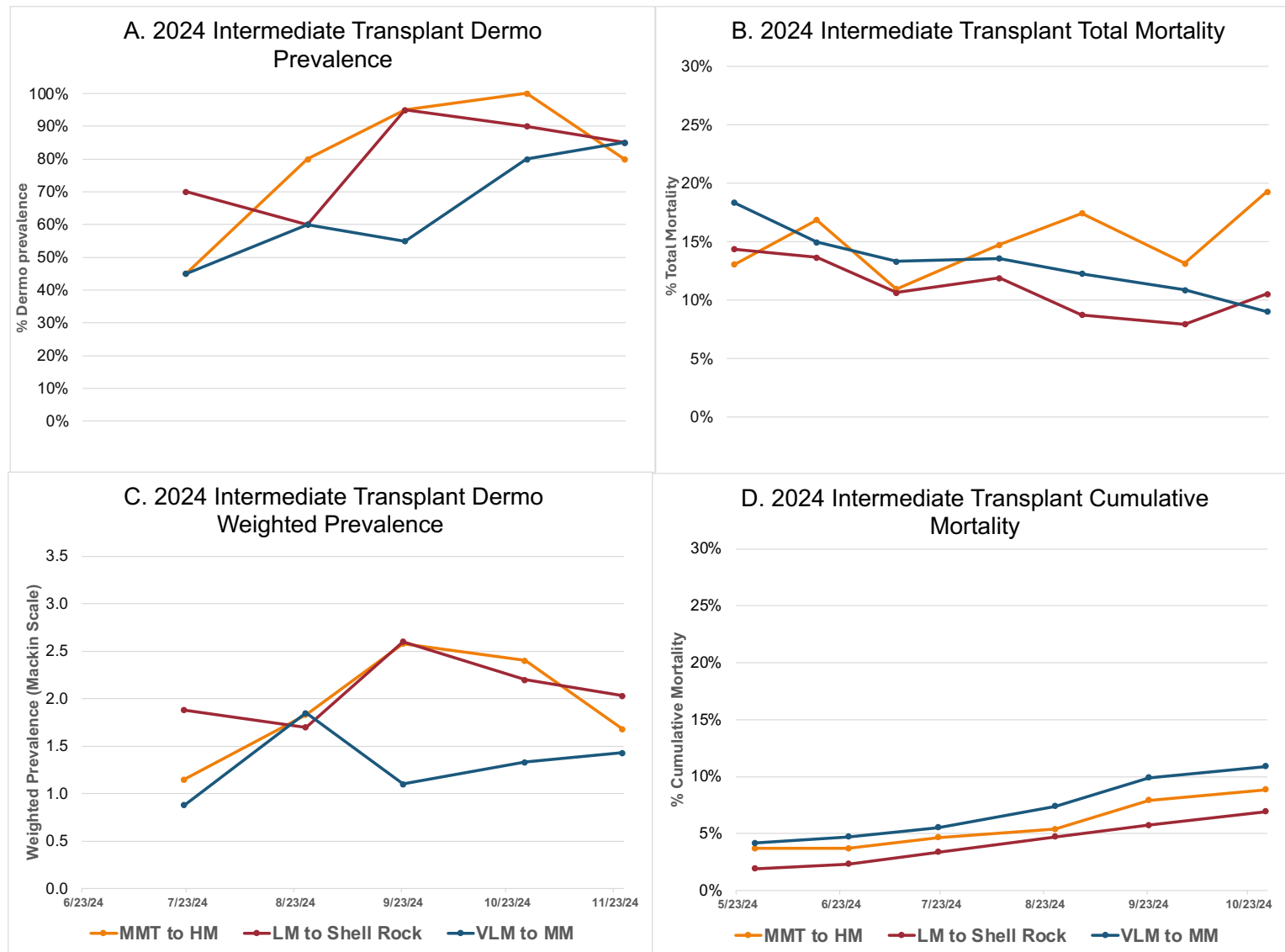


Figure 8. First year of box count and dermo disease performance of the 2024 intermediate transplants. The 2024 donor to recipient beds were as follows: MMT to HM – Upper Middle, Middle and Sea Breeze to Bennies; LM to SR – Upper Arnold and Arnolds to Shell Rock; VLM to MMM – Hope Creek to Ship John.

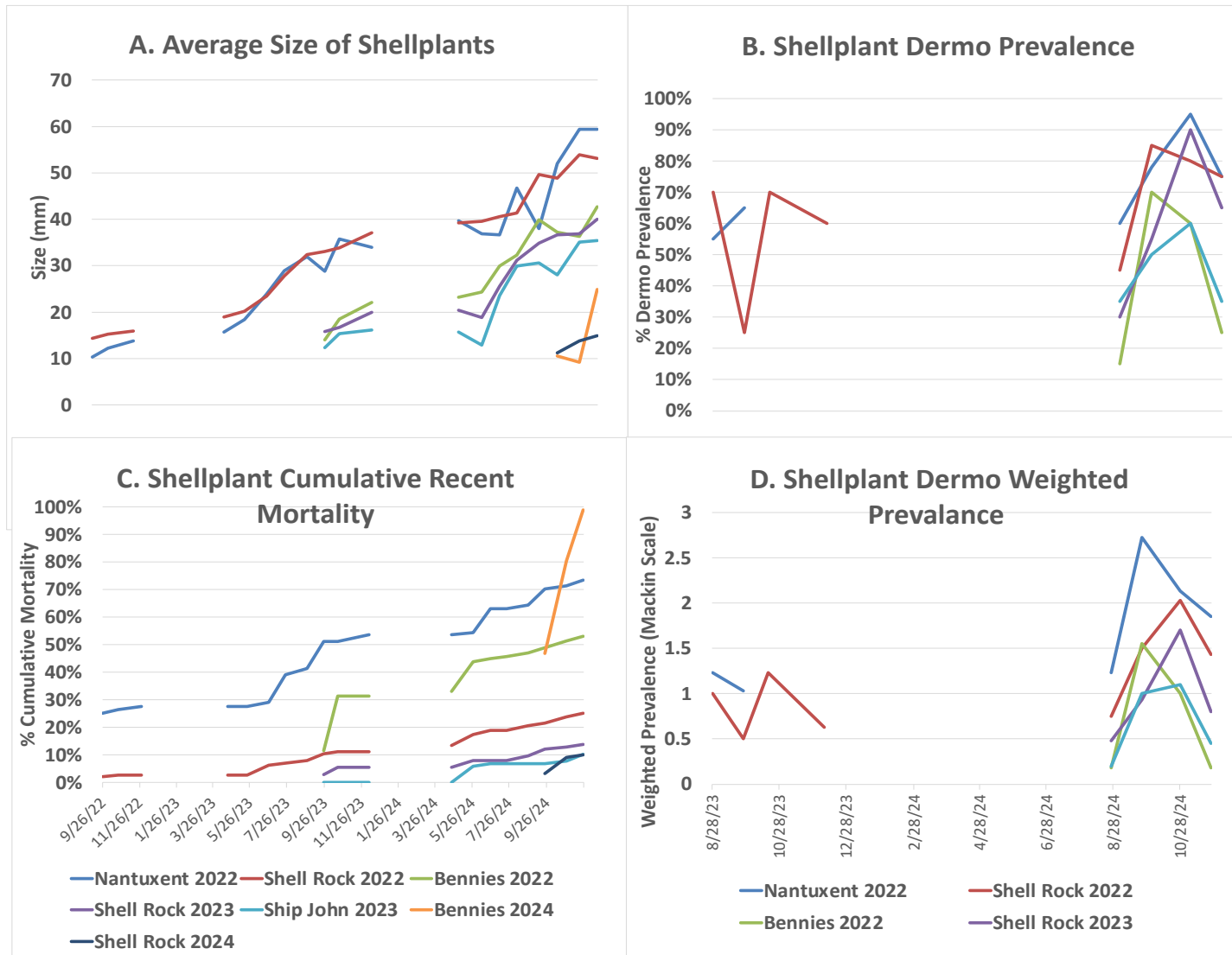


Figure 9. Performance of 2022, 2023 and 2024 shellplants. Growth and mortality monitoring began in September during the year of the plant while dermo monitoring began in August of the following year.

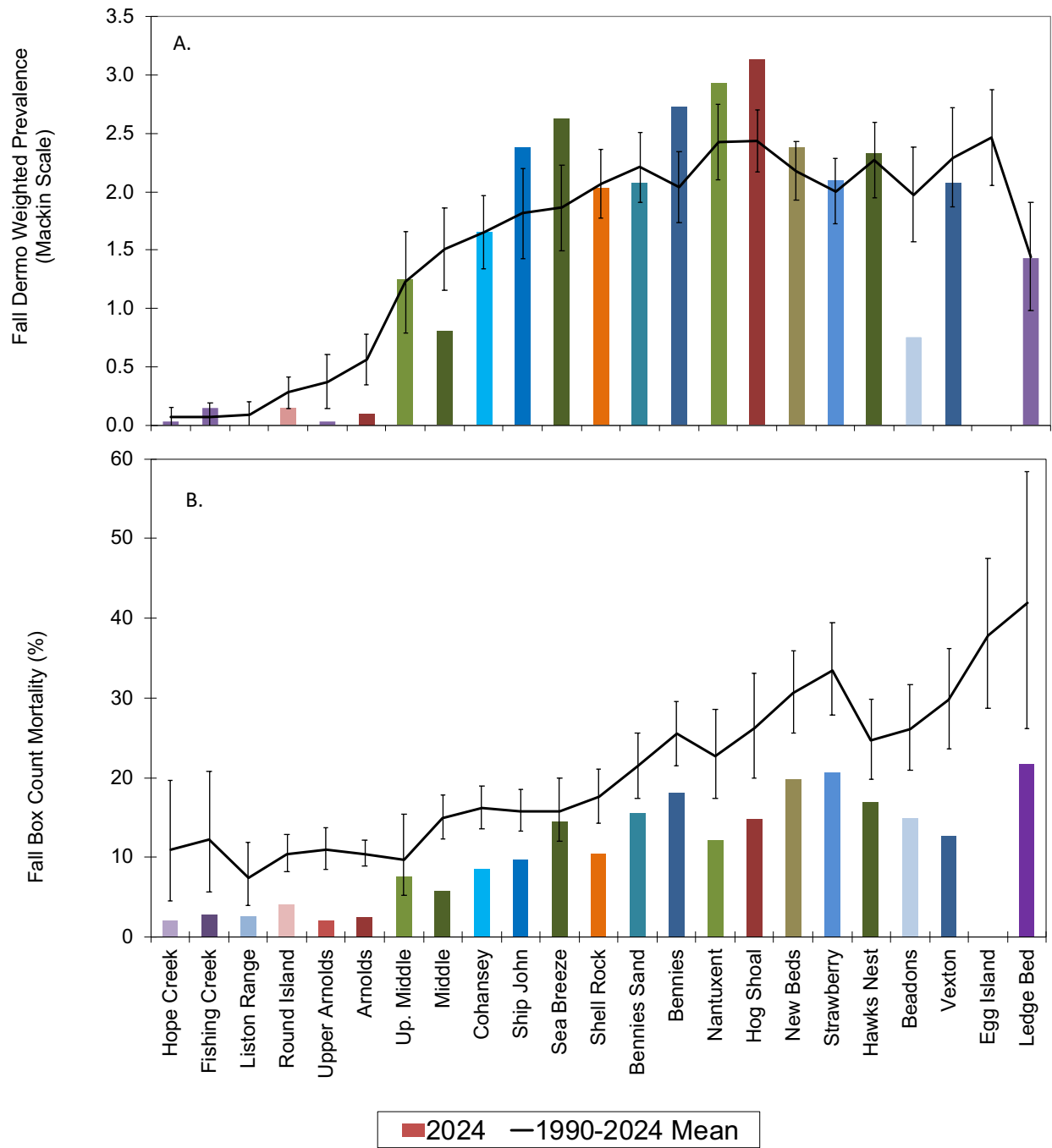


Figure 10. Long-term spatial patterns of dermo weighted prevalence (A), and natural mortality (B) across the oyster beds. Beds are listed upbay to downbay from left to right; colors simply provided as an aide to follow x-axis labels from lower to upper panel. Not all beds have been sampled every year (see Table 3). Egg Island was not sampled in 2024. Error bars represent 95% confidence intervals.

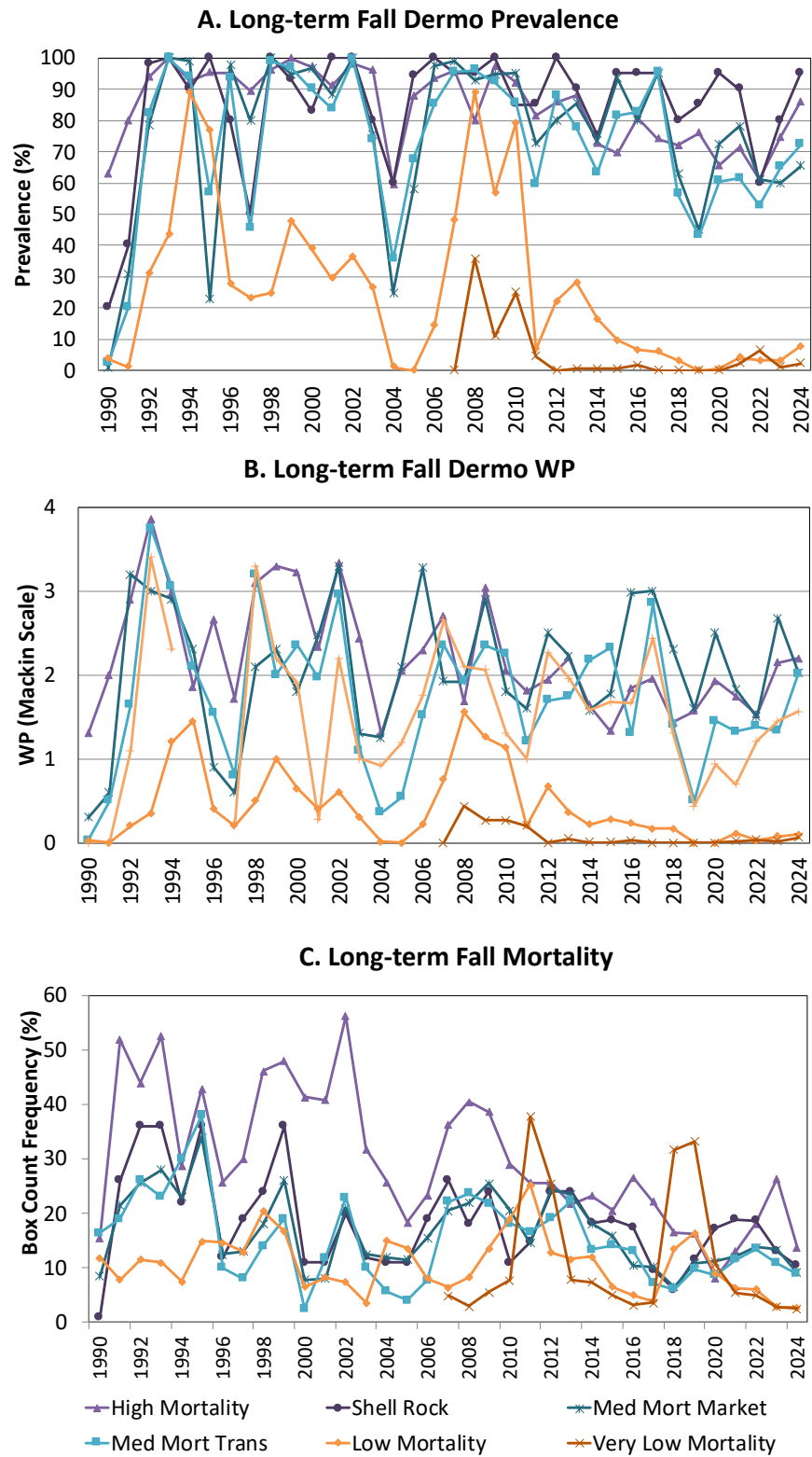


Figure 11. Annual Fall dermo prevalence (A), weighted prevalence (B) and box count mortality (C) on New Jersey Delaware Bay seedbeds by management regions shown in Figure 1.

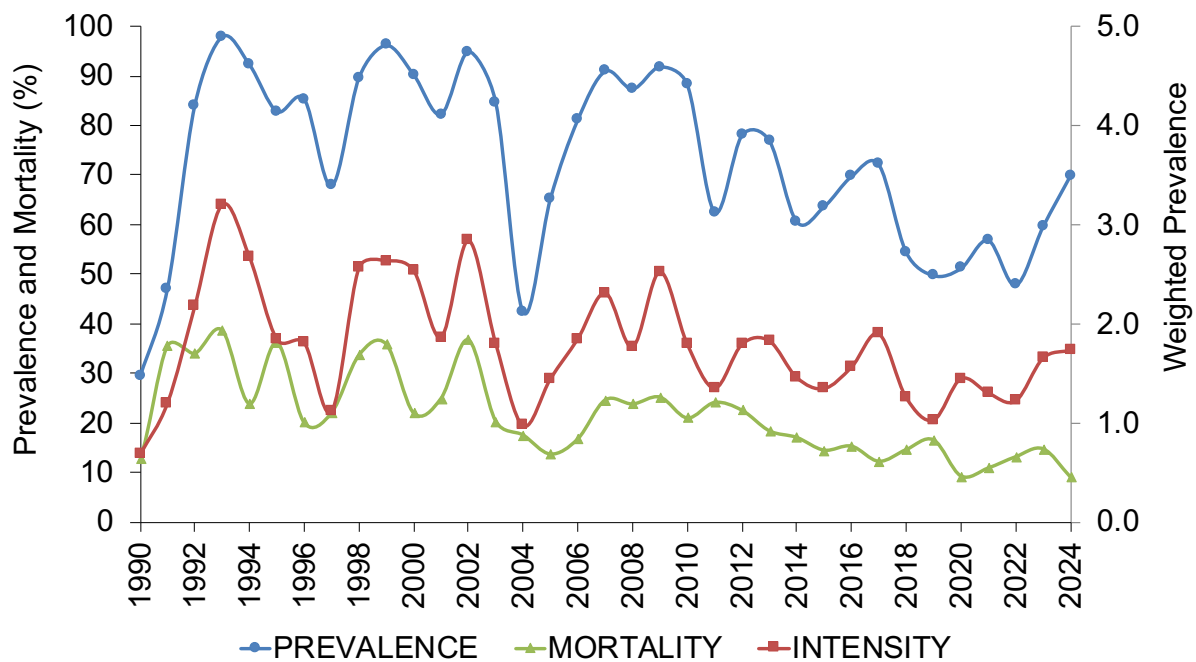


Figure 12. Long-term patterns of Fall dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data show cycles of dermo dampening over time but with a slight increase this year.

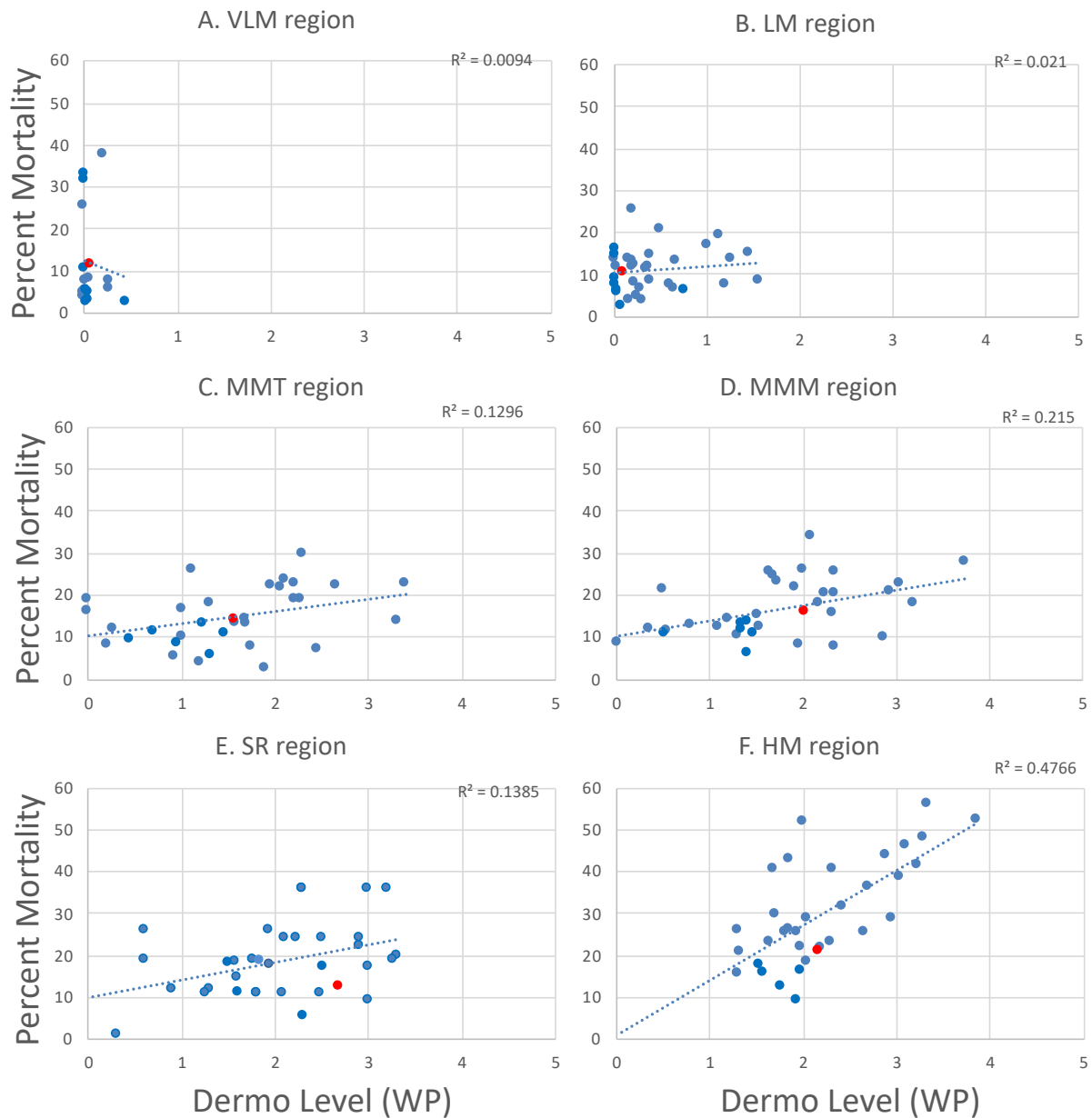
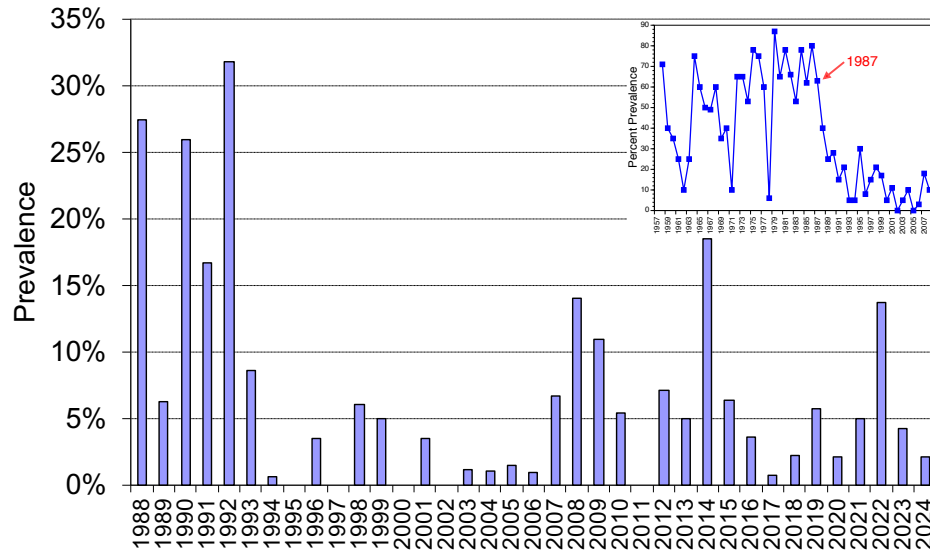
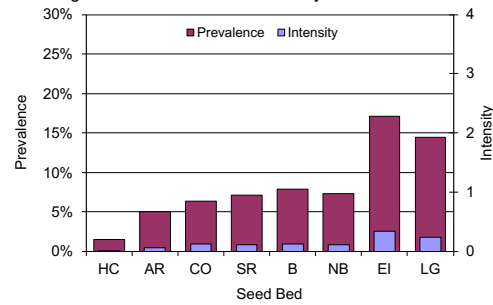


Figure 13. Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). Red points represent 2024 data. VLM = Very Low Mortality, LM = Low Mortality, MMT = Medium Mortality Transplant, MMM = Medium Mortality Market, SR = Shell Rock, and HM = High Mortality.

A. Fall MSX Prevalence on NJ Seed Beds since 1988



B. Long-term Fall MSX Across Salinity Gradient



C. 2024 Fall MSX Across Salinity Gradient

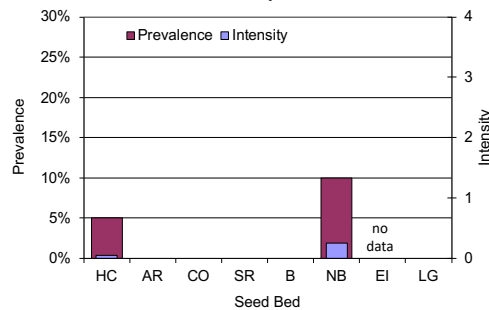


Figure 14. MSX disease on the New Jersey Delaware Bay oyster seedbeds. A. Annual Fall MSX prevalence across all beds since 1988 (2007 for HC). Inset shows lower Delaware Bay levels 1958-2008 for comparison (Ford and Bushek 2012). B. Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) across seedbed salinity gradient since 1988. C. 2024 Fall MSX prevalence and intensity across seedbeds. HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, EI = Egg Island, LG = Ledge.

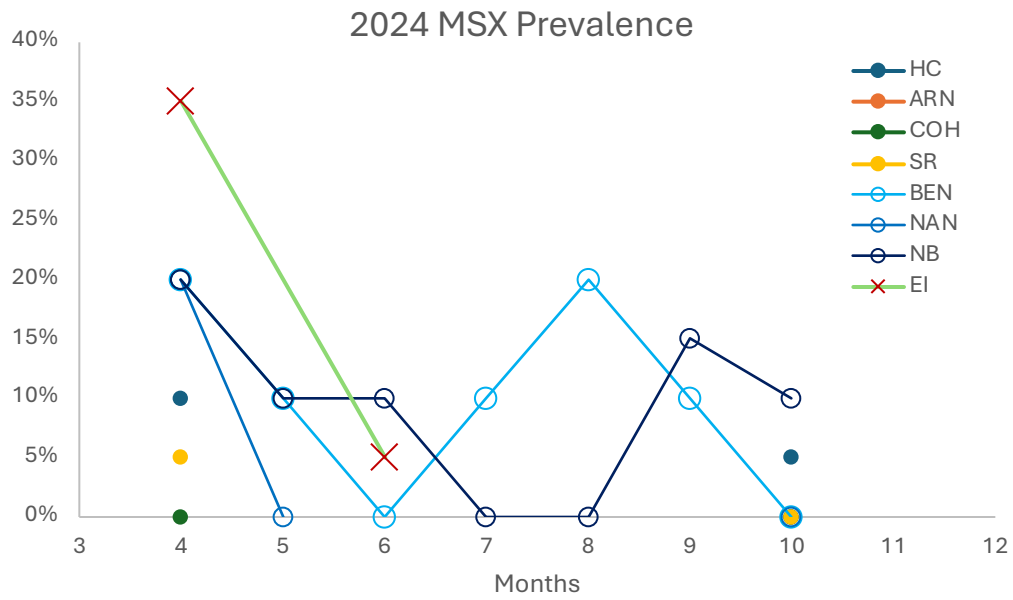


Figure 15. Seasonal prevalence of MSX during 2024