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New Jersey Agricultural Experiment Station

Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2025 Status Report

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Executive Summary

The 2025 Seedbed Monitoring (SBM) Program tracked oyster size, dermo disease and oyster mortality monthly at six fixed sites, two additional sites of interest, ten shellplant sites, and eight 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.

Water temperature continues to show an expanding warm season spending 180 days above 15 C (59 F) which is the temperature that promotes *Perkinsus marinus* proliferation, the agent of dermo disease. Low freshwater inflow at the start of the year resulted in higher-than-normal salinity that was driven down by a high sustained peak in river discharge followed by a period of low flow that drove salinity back above normal levels by fall.

Dermo prevalence was high, but individual infection intensities were lower than average resulting in an overall population infection intensity that followed average levels and continues to indicate some level of tolerance or resistance is developing. MSX remains present across most of the seed beds and increased slightly, likely due to the higher salinities, but remains well below historic levels. Its presence helps maintain naturally developed MSX resistance across the population.

Mortality was generally low, increasing as expected from upbay to down bay with peaks on Bennies and New Beds. A late spring peak may have been associated with increased levels of MSX from elevated salinity. A second fall peak was associated with the seasonal increase of dermo.

Transplants and shellplants followed similar patterns to those described above. Of particular note, the recipient areas of VLM transplants from 2024 and 2025 to the MMM and MMT regions respectively showed patterns similar to nearby beds. That is, the transplant grids did not have substantially different levels of disease and mortality. It is worth noting, however, that transplanted oysters were indistinguishable from indigenous oysters on transplant grids.

Fall spatial patterns of dermo increased from upper to lower bay beds until reaching New Beds where levels became unusually low. Overall, mortality estimates were unusually low in the fall survey, which contrasts levels closer to average from the monthly monitoring sites.

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 periodic 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 changing environmental conditions 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.

The temporal and spatial sampling efforts of the SBM 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 monthly 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. The 2025 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 disease
2. Conduct dermo and MSX assays for each bed sampled during the 2025 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on the 2023 through 2025 shell plantings
4. Monitor growth, mortality and disease on the 2024 and 2025 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. Because MSX can cause mortality in spring, it was recommended that some level of routine monitoring of MSX occur throughout the year to improve surveillance, so the twenty oysters sampled for dermo disease each month were processed via histology to look for MSX infections. 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 (Alcox et al. 2021).

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 (Alcox et al. 2013).

Background

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 1957 and the appearance of *Haplosporidium nelsoni* (the agent of MSX disease), 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 enabled 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). In the past two years, dermo disease has been detected as far north as Prince Edward Island, Canada (CFIA 2026) indicating an expansion of negative impacts from climate change on oyster populations.

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). A group of beds above the low mortality region was added to the survey in 2007 after a survey indicated a high abundance of oysters was present in an area that had not fished in many years. The low salinity across this uppermost region minimizes predation and disease resulting in very low mortality in most years, hence their designation as the Very Low Mortality (VLM) region. Despite that mortality classification, episodic freshets periodically cause substantial mortality on the upbay beds, particularly those in the so-called VLM region (Munroe et al. 2013). The regional designations are correlated with salinity which increases from around 6 on the uppermost beds to about 18 on beds located further downbay. Higher salinity generally promotes better oyster growth, reproduction, settlement and meat quality but also favors predation and disease. As a result, population dynamics vary among regions.

It is worth noting that the reduced growth in low salinity regions produces smaller oysters that are relatively old compared to faster growing oysters of the same size in higher salinity regions. 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 corresponding to their management within the fishery which incorporates growth, mortality, condition, disease, risk of human pathogens, and other factors into the overall management scheme. 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/.

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 two additional sites of interest (Nantuxent and Cape Shore). Status 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 2025. 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 2025 Annual Fall Oyster Stock Assessment with beds outlined in black and different management regions 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 are divided into grids measuring 0.2 x 0.2 minutes of latitude and longitude (roughly 26 acres or 10.5 hectares each). 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. 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 high and one medium density strata, were sampled for disease assessment (see below).

For Objectives 1, 3 and 4, samples were collected monthly at fixed stations from April through November (Table 1). Table 2 lists the beds sampled for objectives 3 and 4 and the respective enhancement activity for each location. Table 3 shows which beds and grids were sampled during the 2025 Fall 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 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 (i.e., dead oysters with meat remaining in the valves), boxes (i.e., hinged oyster valves without any meat remaining) and live oysters, including spat. 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 of the sorted oysters were randomly selected and measured for shell height (hinge to bill of the flat or right valve) to determine the size frequency of oysters from each site. 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 and processed for histological examination to detect *Haplosporidium nelsoni*, the agent of MSX disease. The percent of oysters in the sample with detectable infections is termed prevalence. Each infection was then scored (i.e., weighted) for dermo 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. An advanced prevalence was calculated as the percent of oysters in the sample with Mackin ratings at or above 3.0. Each metric provides a different understanding of how disease impacts the population. An analogous scale developed by Susan Ford was used to determine the intensity of MSX infections.

Samples for Objective 2 were collected during the Annual Fall Stock Assessment Survey as listed in Table 3 (see Ashton-Alcox et al. 2017 for survey method details). Oysters for size frequency and condition index were collected without regard to size. Oysters for disease analysis were collected to represent the general size distribution of oysters in the sample, excluding spat. Dermo was diagnosed as described above. MSX was diagnosed using standard histology (Howard et al. 2004). Because MSX has not been problematic on the

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

seedbeds since 1987, samples from only eight beds along the upbay-downbay gradient have been examined during the fall survey (Table 3).

Objective 3 continued monitoring the 2023 and 2024 shell plantings, and initiated sampling of the 2025 shell plantings in September. 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 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. 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 2025 shellplants as they were not expected to contain many detectable infections, if any, in the first year. Samples for objective 4 were collected and processed as described for objective 1.

Results and Discussion

Temperature and Salinity. Temperature and salinity are dominant environmental factors influencing oyster growth, reproduction, disease, and mortality. Water temperatures measured during 2025 collections followed a typical seasonal cycle with little spatial variability across the seedbeds (Figure 2A). Oyster spawning typically occurs once temperatures reach about 25 C (77 F) which occurred between the June and July sampling dates. Laboratory investigations indicate that dermo proliferation occurs above 15 C (Dungan and Hamilton 1995), so these data suggest dermo was likely proliferating from April 28 to October 24, 2025, a period of 180 days. Scott (2025) explored the seasonality of temperature in Delaware Bay and discovered that the period above 15 C has increased from 146 days in 2003 to 197 days in 2024. This results from water temperatures reaching 15 C three to four weeks earlier in Spring and remaining above 15 C for one to two weeks later in fall.

Salinity was above the 26-yr mean in April 2025 but declined to a level below average by June before increasing to an above average peak in October (Figure 2B). Salinity is largely determined by freshwater inflow from the Delaware River basin where the majority of the freshwater entering Delaware Bay flows past the USGS stream gage in Trenton, NJ. Flow varies seasonally with peak discharge in late winter or early spring that decreases through late summer and into fall to produce the seasonal pattern of salinity observed in the SBM program. During 2025, discharge at Trenton was frequently below the normal range (Figure 3) leading to the above average levels of salinity. A large late April peak in discharge drove salinity to the June low. Subsequently, declining flow and an extended period of lower-than-normal discharge beginning in August drove salinity back up across the seed beds.

Oyster size. The mean shell height of oysters in any given population may be affected by growth, recruitment, harvest and mortality. Counter-intuitively, mean height tends to decrease during the season as small oysters recruit into the population (Figure 4A). Mean shell height was relatively stable at each monitoring site during 2025 indicating a balance between recruitment and mortality but varied across sites with size increasing from the upper to lower bay sites. The five-bed mean, however, tracked closely to the 26-yr mean. Figure 4B shows a cyclical pattern in oyster size over time 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 oysters. Mean overall annual oyster size increased slightly in 2025 to the long-term median value of 63.4 mm (2.5 inches) ranging from an average of 37.7 mm on Hope Creek to 87.2 mm on New Beds.

Dermo Disease. All metrics for dermo disease followed typical seasonal increases with low levels on the two uppermost beds and higher levels on the lower bay beds in higher salinity (Figure 5). Comparing the 2025 average dermo levels on the five beds that have been monitored consistently since 1999 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) with the long-term mean indicates that prevalence was slightly higher than normal (Figure 6A) while intensity was slightly lower (Figure 6B). This results in an average weighted prevalence (Figure 6B). Weighted prevalence did not decline in November sending the population into winter with 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.

MSX Disease. Figure 7 compares MSX prevalence from 2024 with 2025. It shows higher overall levels in 2025. Moreover, the higher levels in 2025 show a seasonal cycle with increased MSX prevalence in spring, especially at Bennies, and smaller peaks in fall, a pattern that corresponds with prior studies on the seasonality of MSX and may account for some of the spring mortality described below.

Mortality. Mortality across the upper beds was negligible but increased with salinity (Figure 8). Spikes in mortality were observed on Bennies and New Beds in spring and fall, and mortality increased steadily on Shell Rock from August to November. As a result, cumulative mortality reached 29% on Bennies, 25% on New Beds, and 23% on Shell Rock.

Transplants. Figures 9 and 10 show levels of dermo and mortality on the 2024 and 2025 transplants, respectively. Dermo followed expected seasonal patterns 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 most sites, except those placed on the Medium Mortality region of Ship John and inshore Sea Breeze which is considered sufficient to increase overall mortality (Bushek et al. 2012). It is worth noting that transplanted oysters cannot be distinguished from autochthonous oysters, so results represent a mixture of both. Nevertheless, transplantation of oysters did not appear to alter patterns of dermo and mortality from the recipient bed.

Transplants from the VLM region have generated considerable discussion with respect to the expense, the quantity of market oysters to transfer, the survival of transplanted oysters, and the impacts to the beds at the very upper portion of the system. Transplants from the VLM region occurred in 2024 to the MMM region (Hope Creek to Ship John), and to the MMT region in 2025 ((a mix of VLM beds to Sea Breeze, Table 2). In both years, the SBM monitored Cohansey and Shell Rock that bracket the recipient beds. Comparing the performance of the nearby beds from Figures 5 and 8 with the recipient beds shown in figures 9 and 10 indicates that VLM transplant performance varied. In Fall 2025, the 2024 VLM transplant had 50% prevalence of dermo with a WP of 1.5 which was considerably lower than that on Cohansey and Shell Rock (80-95% prevalence and 2.5-2.8 WP). However, cumulative mortality of the 2024 VLM transplant during 2025 was comparable to the surrounding beds (20% versus 15-22%). In contrast, the 2025 VLM transplant more closely matched dermo and mortality levels (90% prevalence and 20% mortality) although WP was somewhat lower at 2.0.

Shellplants. Eight shell plants have been placed on four different beds during the past three years (Table 2). Growth varied among shellplants (Figure 11) with the largest increase on the 2024 shellplants averaging 22.6 mm while the 2023 averaged 14.3 mm and 2025 plants grew an average of 14.3 mm. Mortality varied from 1 to 69% and was concentrated on the 2023 Bennies plant site. Consistent with sampling efforts at the end of 2024, no live spat were found during 2025 on the 2024 Bennies shellplant site (Figure 11C). Dermo increased on the 2023 plants during 2025 but remained below levels of the recipient beds (Figure 5D). Shell planting remains one of the most beneficial management efforts to sustain and increase oyster abundance and should be pursued annually to the level that resources permit.

Long-Term Fall Dermo and Mortality. 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 12). Dermo prevalence was near or slightly below long term means on most beds. In contrast, weighted prevalence and mortality were generally well below long-term means with a few exceptions. Curiously, dermo weighted prevalence was particularly low on several high mortality beds (New Beds, Strawberry, Hawks Nest, Beadons and Egg Island).

Figure 13 depicts annual dermo prevalence, weighted prevalence, and box-count estimated mortality from 1989 to 2025 for each mortality region. Each parameter shows a weak cyclical pattern with a general downward trend 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 attenuated in the latter half of the time series (Figure 13B) and corresponds to a reduction in fall box count mortality (Figure 13C).

Dermo is not the only source of mortality, and multiple factors such as time since infection, freshwater inflow, and food availability all affect the impact of dermo on the population. Nevertheless, these data continue to support the notion that resistance and/or tolerance is developing in the Delaware Bay population where weighted prevalence routinely exceeds 1.5 on the Mackin Scale.

While many factors such as temperature, salinity and recruitment are known to influence dermo disease (Villalba et al. 2004), 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 14). Furthermore, the bay-wide pattern of attenuation shown in Figure 14 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 12 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 and as mentioned above, the season of dermo proliferation (i.e., when water temperature is above 15 C) has lengthened by several weeks (Scott 2025). All else being equal, this should give the disease a longer period 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. It may also be that the period in which oysters are active and dermo is not (roughly the time between 10 and 15 C) has lengthened allowing the oysters more time to rid themselves of infections in both spring and fall. The mechanism(s) responsible is (are) unclear and requires further investigation.

Figure 15 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 15, 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 for that region. Overall, dermo levels explain about 34% of the variation observed in mortality.

MSX was detected in 12 of the 139 oysters assayed: a prevalence of 8.6% (Figure 16A). Over the past 36 years, MSX infections nearly always occur at a higher prevalence and intensity as salinity increases (Figure 16B). In 2025, infections were detected at all but one site, Hope Creek (Figure 16C). The lack of Delaware River inflow in summer and fall (Figure 3) allowed the oyster beds to reach higher salinity levels (Figure 2B), which may be the reason for increased infection prevalence. Infections were mostly in the early stages of infection and restricted to epithelial cells. Infections at Shell Rock, Bennies, and New Beds had progressed further, but only one at Bennies that was systemic and advanced. Previous years have found MSX distributed across the seed beds and the increase in prevalence during 2025 continues an episodic cycle of intensification and remission, although with a much more limited impact than levels observed prior to 1990.

These data indicate that MSX remains a threat to the Delaware Bay oyster population. Its persistence in Delaware Bay serves to help maintain resistance that has developed in the native population (Ford and Bushek 2012). As such, it remains an important component of the monitoring program to understand sources of mortality from year to year.

Science Advice

- Continue monitoring spatial and temporal patters to examine and reveal temporal relationships among environmental drivers, disease and mortality.
    - Investigate the relationship of Delaware River discharge with disease and mortality dynamics to determine how flow management may influence oyster survival.
    - Investigate why the increased duration of temperature coincides with a dampening of disease pressure.
- 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.
- Compare enhancement site performance with adjacent unenhanced sites.

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References

Ashton-Alcox, K., D. Bushek, J Gius, J. Morson and D. Munroe. 2017. Stock Assessment Workshop: New Jersey Delaware Bay Oyster Beds (19th SAW) February 14-15, 2016. Final Report. 127 pp. https://hsrl.rutgers.edu/SAWreports/SAW2017.pdf

Bushek, D., S.E. Ford and I. Burt. 2012. Long-term patterns of an estuarine pathogen along a salinity gradient. *J Marine Research.* 70:225-251.

CFIA (Canadian Food Inspection Service). 2026. Locations infected with *Perkinsus marinus*. https://inspection.canada.ca/en/animal-health/aquatic-animals/diseases/reportable-diseases/perkinsus-marinus/locations-infected. Accessed Jan 14, 2026.

Carriker, M.R. 1955. Critical review of biology and control of oyster drills *Urosalpinx* and *Eupleura*. US DOI FWS. Special Scientific Report: Fisheries No, 148, Washington, D.C. 150 pp. https://spo.nmfs.noaa.gov/sites/default/files/legacy-pdfs/SSRF148.pdf

Dungan, C.F. and D. Bushek. 2015. Development and applications of Ray's fluid thioglycollate media for detection and manipulation of *Perkinsus spp*. pathogens of marine molluscs. J. Invert. Pathol., 131: 68–82. http://dx.doi.org/10.1016/j.jip.2015.05.004.

Dungan CF, Hamilton RM (1995) Use of a tetrazolium-based cell proliferation assay to measure effects of *in vitro* conditions on *Perkinsus marinus* (Apicomplexa) proliferation. J Eukaryot Microbiol 42:379-388

Fegley, S. R., S. E. Ford, J. N. Kraeuter, and H. H. Haskin. 2003. The persistence of New Jersey's oyster seedbeds in the presence of MSX disease and harvest: management's role J. Shellfish Res. 22:451-464.

Ford, S.E. 1996. Range extension by the oyster parasite *Perkinsus marinus* into the northeastern United States: Response to climate change? *J. Shellfish Res*. 15:45-56.

Ford, S.E. and D. Bushek. 2012. Development of resistance to an introduced marine pathogen by a native host. *J. Marine Research*, 70(2-3):205-223.

Ford, S.E., M.J. Cummings and E.N. Powell. 2006. Estimating mortality in natural assemblages of oysters. *Estuaries and Coasts*, 29 (3): 361-374.

Ford, S.E., E. Scarpa, D. Bushek. 2012. Spatial and temporal variability of disease refuges in an estuary: Implications for the development of resistance. J. Mar. Res. 70:253-277. DOI: 10.1357/002224012802851850

Howard D.W., E.J. Lewis, B.J. Keller and C.S Smith (eds). 2004. Histological Techniques for Marine Bivalve Mollusks and Crustaceans. NOAA Tech. Memo NOS NCCOS 5, 218 pp.

Mackin, J.G. 1962. Oyster disease caused by *Dermocystidium marinum* and other microorganisms in Louisiana. *Publ. Inst. Mar. Sci. Univ. Tex.*, 7:132-229.

Morson, J. M., D. Munroe, K. Ashton-Alcox, E. N. Powell, D. Bushek, and J. E. Gius. 2018. Density-dependent capture efficiency of a survey dredge and its influence on the stock assessment of eastern oysters (*Crassostrea virginica*) in Delaware Bay. *Fisheries Research, 205*, 115-121. DOI: 10.1016/j.fishres.2018.04.012

Munroe, D., A. Tabatabai, I. Burt, D. Bushek, E.N. Powell, and J. Wilkin. 2013. Oyster Mortality and Disease in Delaware Bay: Impact and Recovery Following Hurricane Irene and Tropical Storm Lee. Estuarine, Coastal and Shelf Science, 135:209-219.

Powell, E. N., J. M. Morson, K. A. Alcox, and Y. Kim. 2012. Accommodation of the sex ratio in eastern oysters to variation in growth and mortality across the estuarine salinity gradient in Delaware Bay. *J. Mar. Biol. Assoc.* U.K., doi: 10.1017/S0022377807006861, Published online by Cambridge University Press 24 April 2012.

Powell, E.N., K.A. Ashton-Alcox and J.N. Kraeuter. 2007. Reevaluation of eastern oyster dredge efficiency in survey mode: Application in stock assessment. *North Amer. J. Fisheries Management*., 27(2): 492-511

Powell, E.N., K.A. Ashton-Alcox, J.N. Kraeuter, S.E. Ford and D. Bushek. 2008. Long-term trends in oyster population dynamics in Delaware Bay: Regime shifts and response to disease. *J. Shellfish Res.* 27:729-755.

Ray, S.M. 1952. A culture technique for the diagnosis of infection with *Dermocystidium marinum* Mackin, Owen, and Collier in oysters. *Science* 116:360-361.

Ray, S.M. 1954. Biological Studies of *Dermocystidium marinum*. The Rice Inst. Pamphlet, Special Issue.

Ray, S.M. 1966. A review of the culture method for detecting *Dermocystidium marinum*, with suggested modifications and precautions. *Proc. Natl. Shellfish. Assoc.* 54:55-69.

Scott, Leah. 2025. Seasonal dynamics of an oyster pathogen during a period of climate change: *Perkinsus marinus* in Delaware Bay 1999-2024. A thesis submitted to the School of Graduate Studies Rutgers, the State University of New Jersey in partial fulfillment of the requirements for a master’s degree. 70 pp. https://rucore.libraries.rutgers.edu/rutgers-lib/74805/PDF/1/play/

Villalba, A., K.S. Reece, M.C. Ordás, S.M. Casas and A. Figueras. 2004. Perkinsosis in molluscs: A review. Aquat. Liv. Res., 17: 411-432. doi:10.1051/alr:2004050.

Table 1. The 2025 sampling schedule for the NJ Delaware Bay Oyster Seed Bed Long-term Monitoring Program. The six long-term sites were 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. The extra site was Nantuxent grid 10. Selected stocks from the Rutgers breeding program were also monitored at the Cape Shore for comparison. 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 28, 2025	5 long-term sites, 1 extra site	NJDEP RV James W. Joseph	Andrew Hassall
May 1, 2025	1 long-term site, 3 intermediate transplant sites, 5 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
May 27, 2025	6 long-term sites, 1 extra site, 2 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
May 29, 2025	8 intermediate transplant sites, 3 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
June 17, 2025	6 long-term sites, 2 extra sites, 2 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
June 23, 2025	8 intermediate transplant sites, 3 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
July 22, 2025	6 long-term sites, 1 extra sites, 2 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
July 28, 2025	8 intermediate transplant sites, 3 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
August 25, 2025	6 long-term sites, 1 extra sites, 2 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
August 28, 2025	8 intermediate transplant sites, 3 shellplant sites	NJDEP RV James W. Joseph	Craig Tomlin
September 18, 2025	6 long-term sites, 1 extra site, 2 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
September 22, 2025	8 intermediate transplant sites, 6 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
October 24, 2025	6 long-term sites, 1 extra site, 2 shellplant site	NJDEP RV James W. Joseph	Craig Tomlin
October 27, 2025	8 intermediate transplant sites, 6 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall
November 18, 2025	6 long-term sites, 1 extra site, 2 shellplant site	NJDEP RV James W. Joseph	Andrew Hassall
November 25, 2025	8 intermediate transplant sites, 6 shellplant sites	NJDEP RV James W. Joseph	Andrew Hassall

Table 2. Enhancement sites sampled during 2025.

Bed	Grid	Plant material	Plant year
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
Bennies	100/101	low mortality transplant	2025
Shell Rock	46	medium/low mortality transplant	2025
Sea Breeze	14	very low mortality transplant	2025
Sea Breeze	22	very low mortality transplant	2025
Cohansey	44	medium mortality transplant	2025
Bennies Sand	4	clam shell	2025
Shell Rock	7	clam shell	2025
Ship John	57	clam shell	2025

Table 3. 2025 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	53	10		15
Hope Creek	76	10		15
Hope Creek	60			10
Hope Creek	63			10
Hope Creek	62		20	0
Fishing Creek	4	10		30
Fishing Creek	24	10		11
Fishing Creek	17			4
Fishing Creek	37			5
Liston Range	28	10		20
Liston Range	17	10		20
Liston Range	16			10
Round Island	17	10		15
Round Island	16	10		15
Round Island	2			10
Round Island	25			10
Upper Arnolds	3	10		15
Upper Arnolds	9	10		15
Upper Arnolds	5			10
Upper Arnolds	25			10
Arnolds	6	10		15
Arnolds	67	10		15
Arnolds	8			10
Arnolds	79			10
Arnolds	18		20	0
Upper Middle	63	10		15
Upper Middle	47	10		15
Upper Middle	71			10
Upper Middle	56			10
Middle	31	10		15
Middle	33	10		15
Middle	21			10
Middle	37			10
Cohansey	1	10		15
Cohansey	40	10		15
Cohansey	5			10
Cohansey	50			10
Cohansey	44		20	0
Sea Breeze	15	10		15
Sea Breeze	31	10		15
Sea Breeze	24			10
Sea Breeze	17			10
Ship John	18	10		15
Ship John	8	10		15
Ship John	4			10
Ship John	22			10
Shell Rock	51	10		13
Shell Rock	38	10		15
Shell Rock	38			11
Shell Rock	43			11
Shell Rock	10,11,19,20		20	0
Bennies Sand	8	10		15
Bennies Sand	26	10		15
Bennies Sand	5			10
Bennies Sand	30			10
Bennies	27	10		15
Bennies	111	10		15
Bennies	108			10
Bennies	60			10
Bennies	110		20	0
Nantuxent	4	10		15
Nantuxent	15	10		15
Nantuxent	6			10
Nantuxent	22			10
Hog Shoal	4	10		15
Hog Shoal	43	10		15
Hog Shoal	7			9
Hog Shoal	13			11
New Beds	22	10		15
New Beds	51	10		15
New Beds	24			10
New Beds	52			10
New Beds	26		19	0
Strawberry	10	10		10
Strawberry	11,15	10		10
Strawberry	mix			23
Hawks Nest	25	10		15
Hawks Nest	2	10		15
Hawks Nest	3			10
Hawks Nest	26			10
Beadons	3	15		17
Beadons	17	5		11
Beadons	mix			22
Vexton	4	10		15
Vexton	19	10		15
Vexton	3			10
Vexton	8			10
Egg Island	28,29	9	9	0
Egg Island	82,63	11	11	0
Egg Island	mix			30
Total beds		**22**	**7**	**22**
Total grids		**42**	**8**	**90+**
Total oysters		**440**	**139**	**1073**

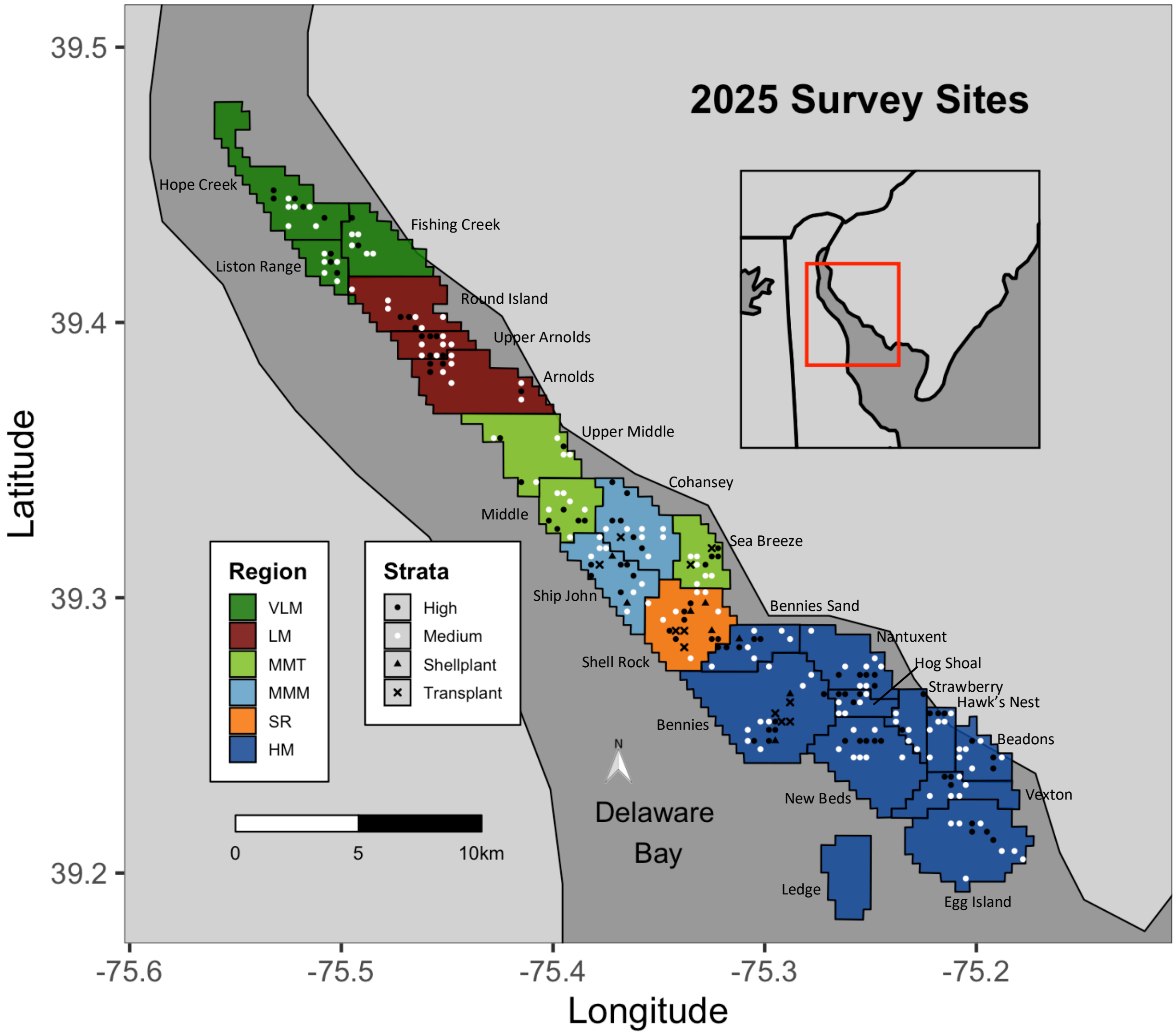


Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Black lines demarcate named beds. Beds of the same color represent different management regions (dark green = very low mortality region (VLM), maroon = low mortality region (LM), light green = medium mortality transplant region (MMT), light blue = medium mortality management region (MMM), orange = Shell Rock region (SR), dark blue = high mortality region (HM). The sites for the 2025 stock assessment survey are indicated by dots. Black dots were in high density strata, and white dots were in medium density strata per the stratified random sampling of the overall stock assessment. 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 3.

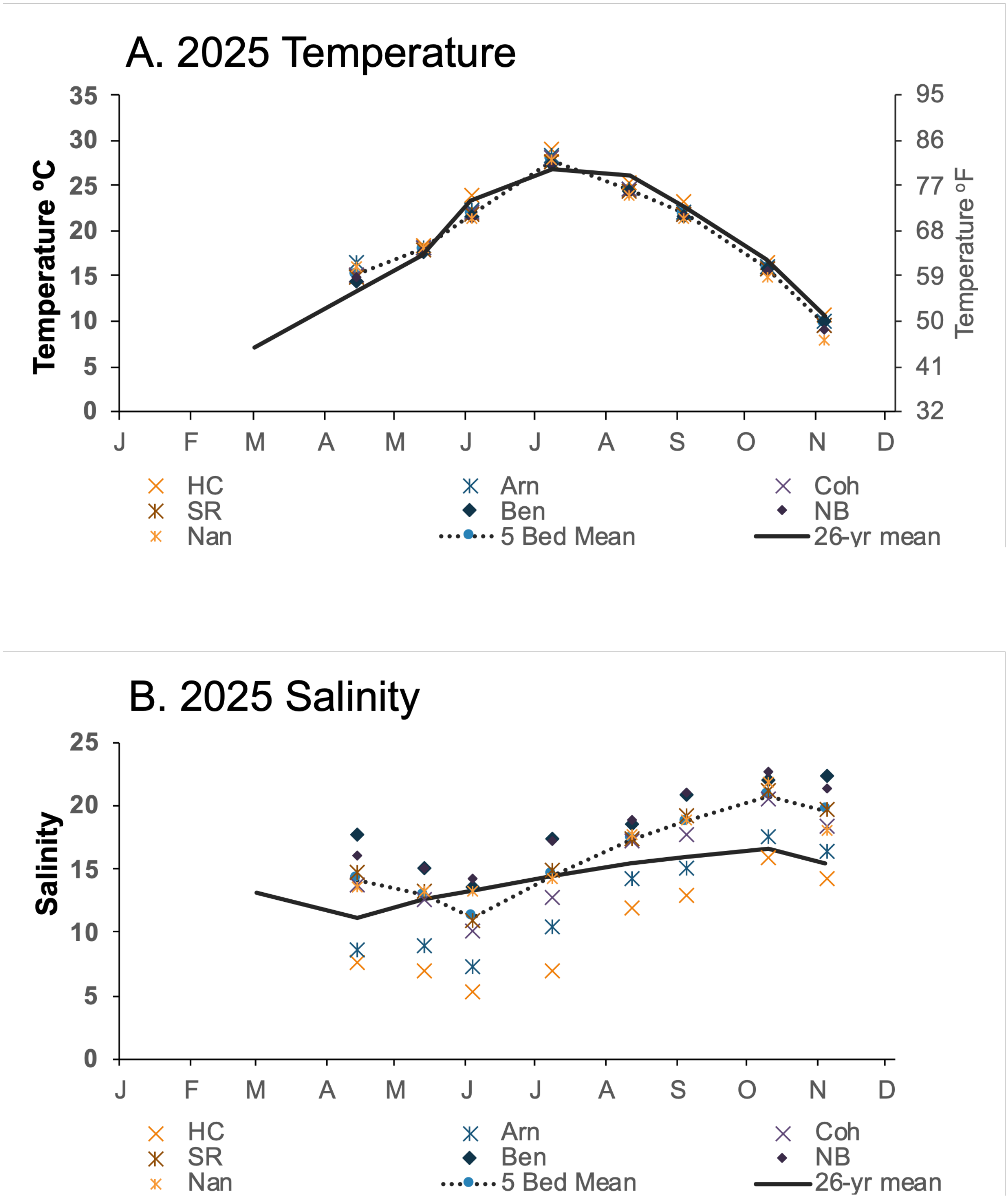


Figure 2. Temperature (A) and salinity (B) with 5-bed mean (Arn, Coh, SR, Ben, NB) during 2025 at monthly monitoring stations of the Seed Bed Monitoring Program compared to the long-term 26-yr mean data. HC = Hope Creek, Arn = Arnolds, Coh = Cohansey, SR = Shell Rock, Ben = Bennies, NB = New Beds, Nan = Nantuxent.

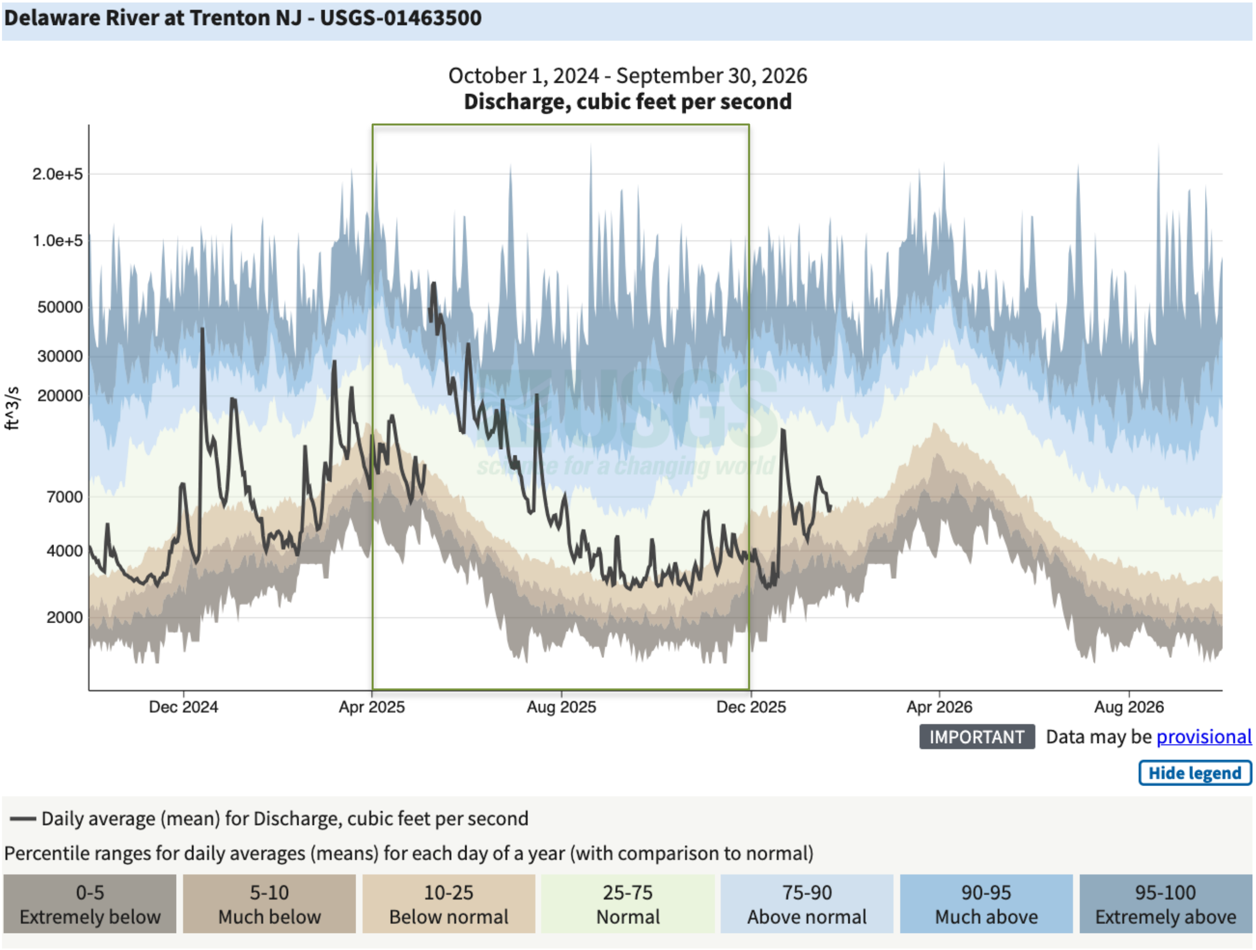


Figure 3. Delaware River discharge measured at Trenton, NJ USGS monitoring station 01463500. Dark line represents mean daily discharge. Green box outlines the period of SBM measurements. Data source: https://waterdata.usgs.gov/monitoring-location/USGS-01463500/statistical-graphs/

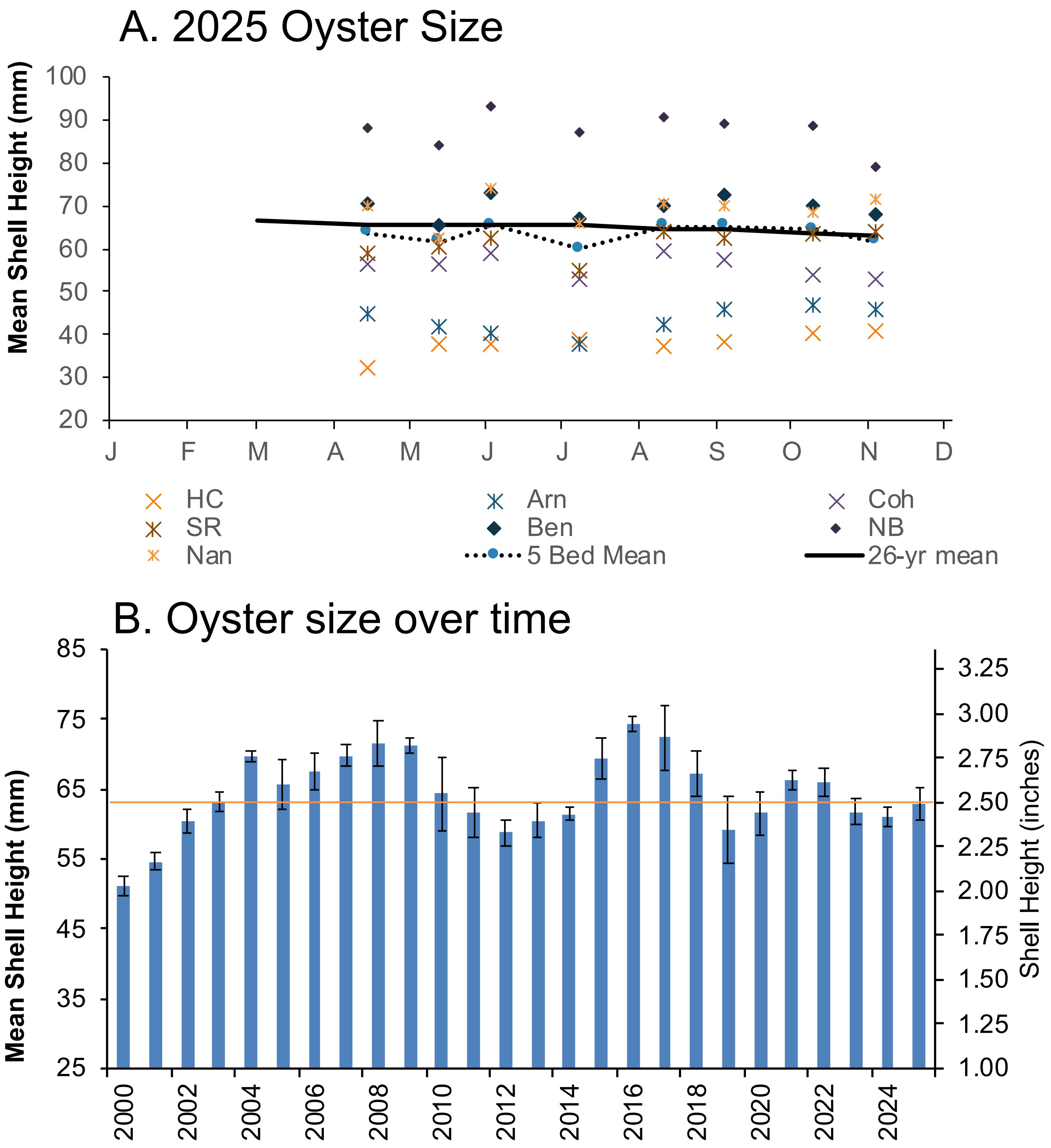


Figure 4. A) 2025 variation in oyster size (shell height). Bed abbreviations as in Figure 2. B) Interannual variation in mean shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each 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 between March and November. Orange line represents the long-term median size of 64 mm (2.5 inches)

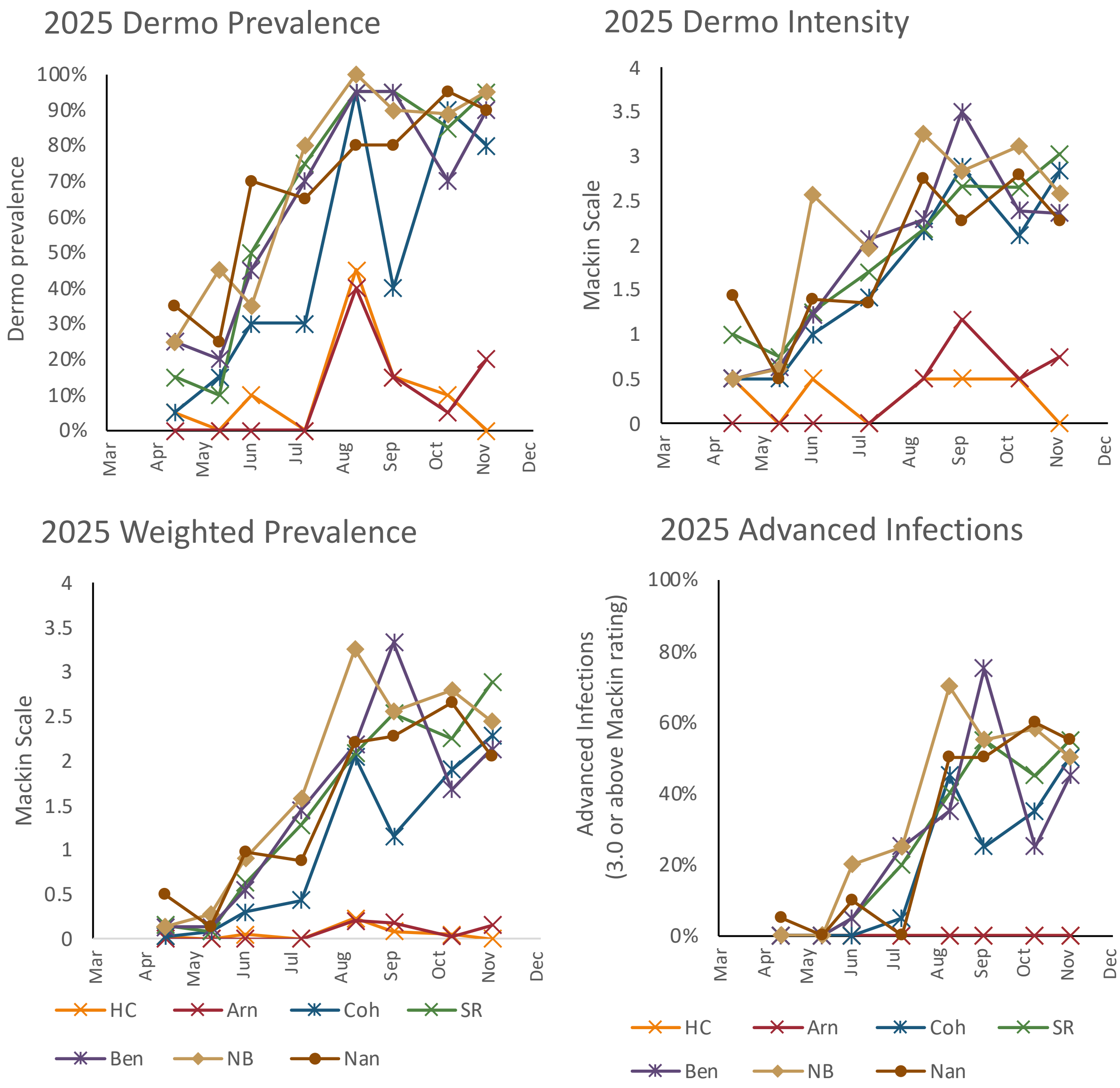


Figure 5. Monthly levels of dermo disease. A) Prevalence = percent of population with detectable infections. B) Intensity = average infection rating of infected individuals. C) Weighted prevalence = Prevalence weighted by intensity. D) Advanced infection prevalence = percent of individuals with ratings ³ 3. Bed abbreviations as in Figure 2.

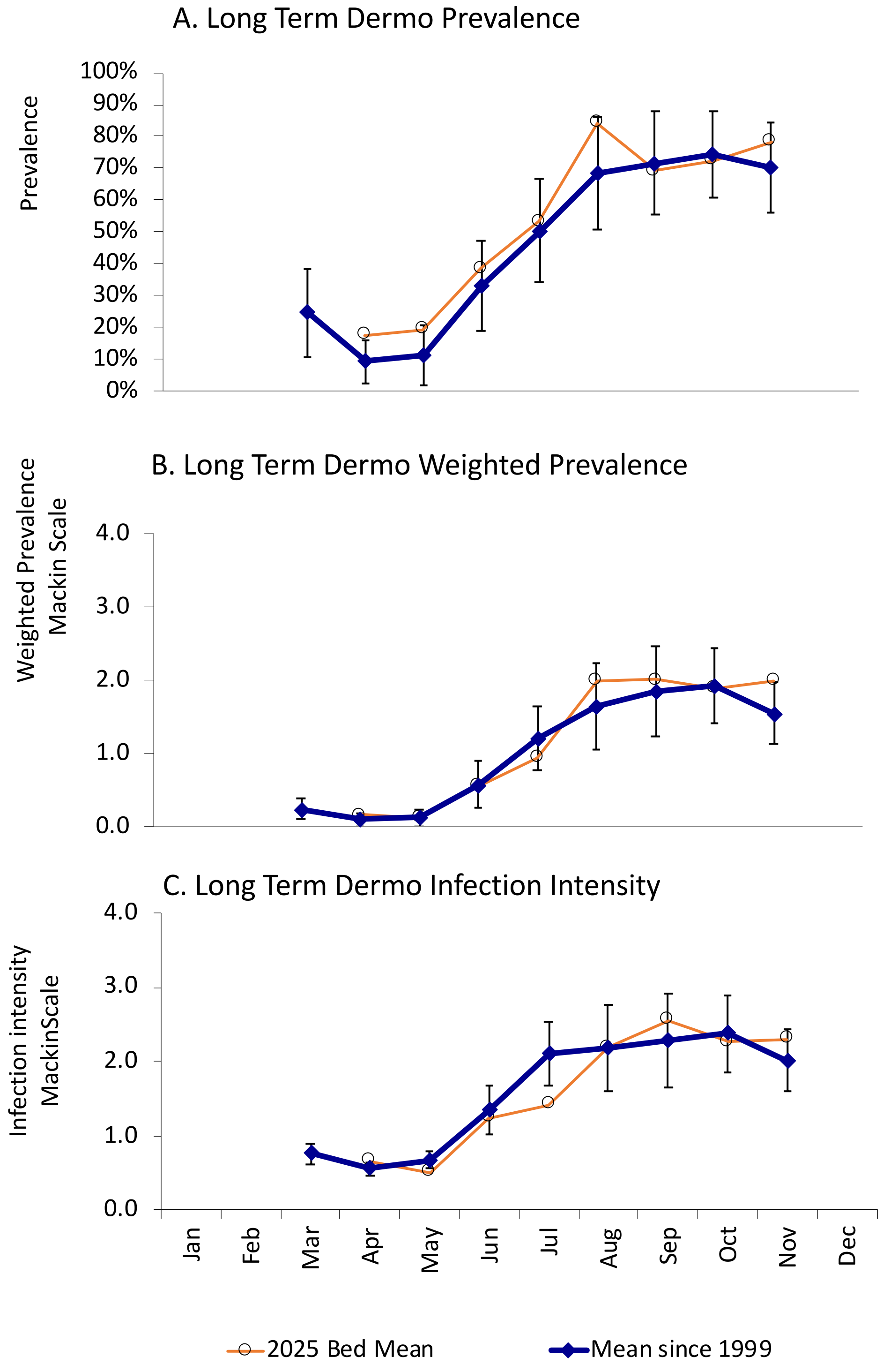


Figure 6. Comparison of long-term (26 yr mean) dermo levels vs 2025 levels. A) Prevalence. B) Weighted prevalence. C) Intensity.

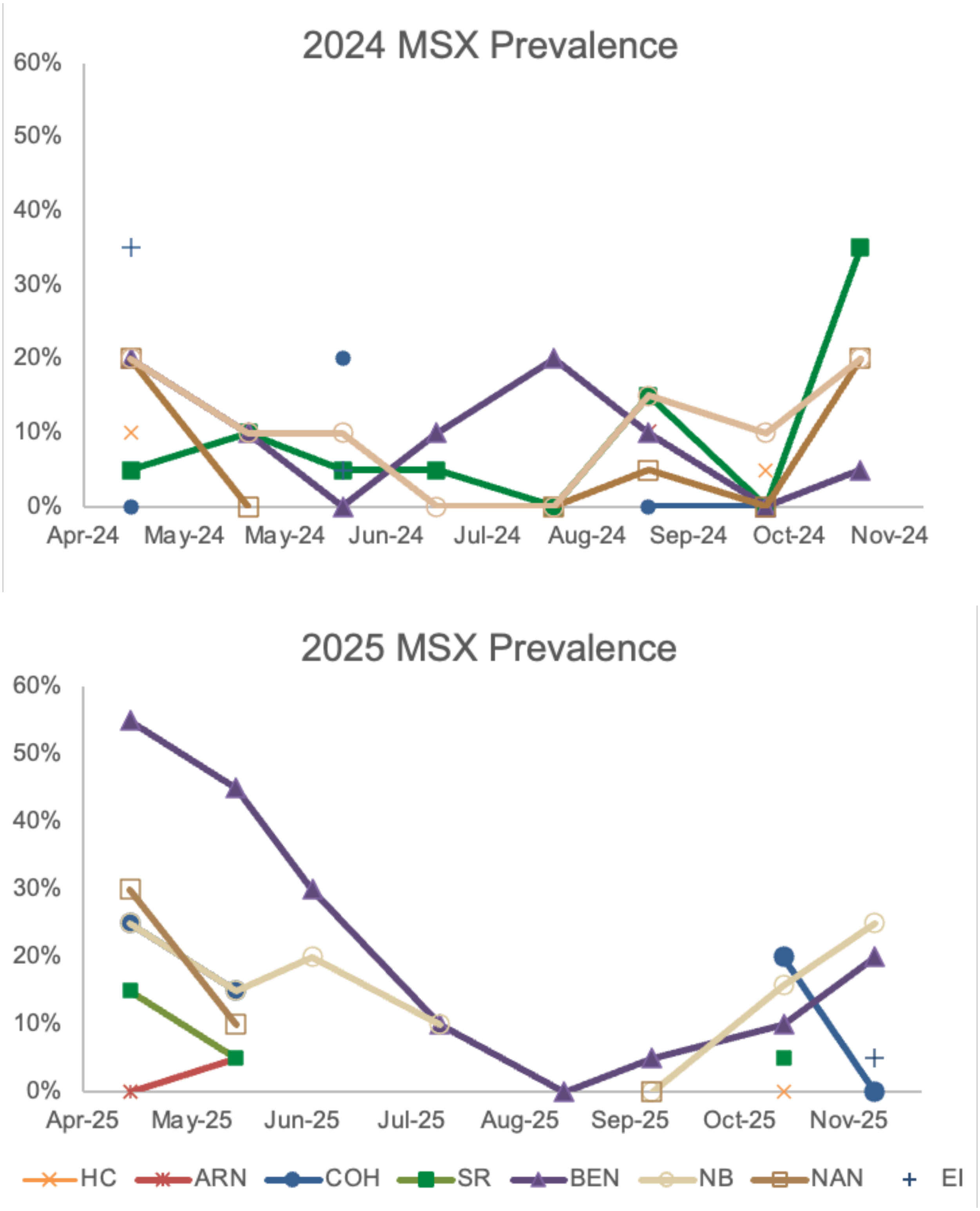


Figure 7. Seasonal prevalence of MSX during 2024 and 2025.

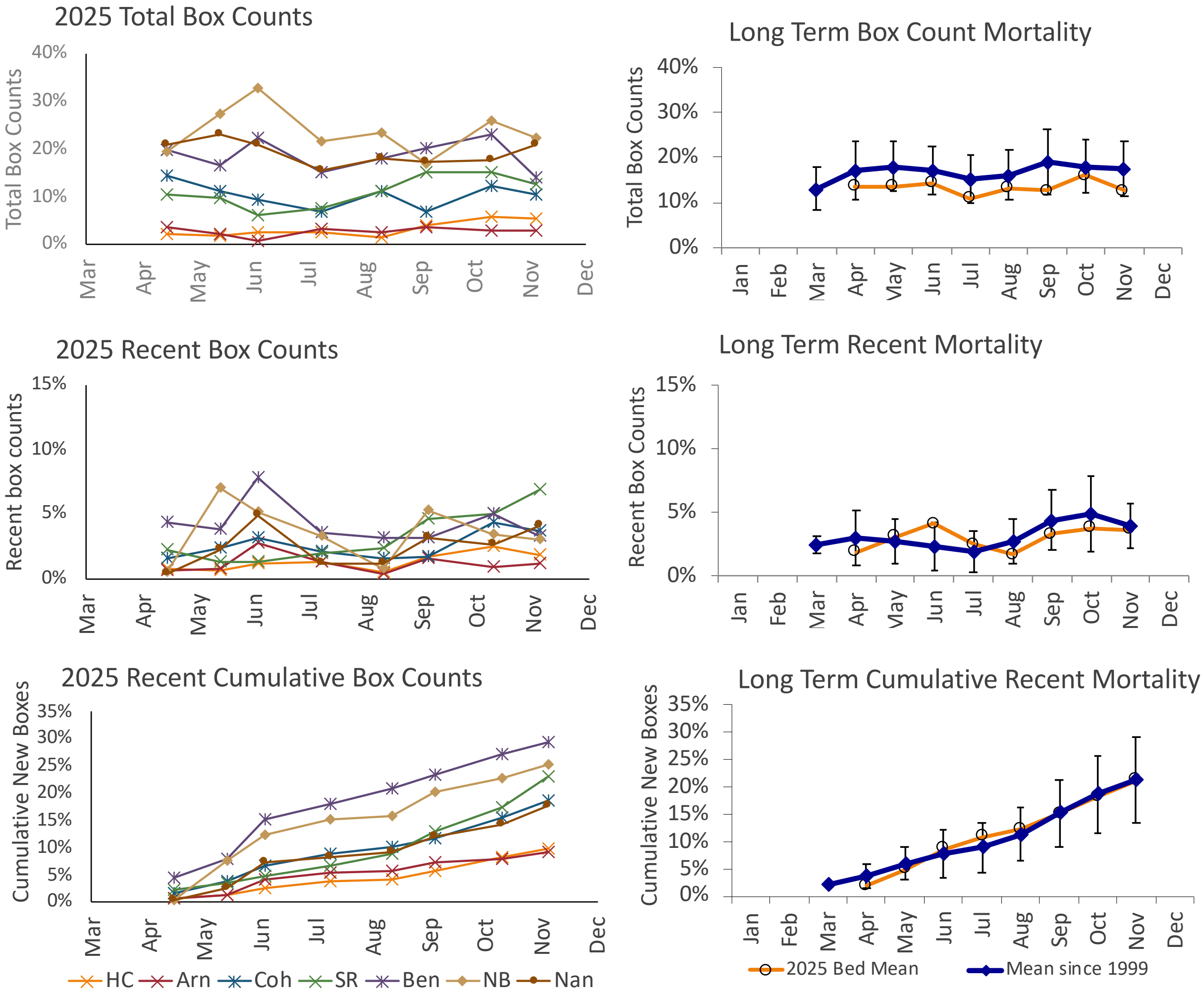


Figure 8. Monthly mortality estimates from total and recent box counts during 2025 Seed Bed Monitoring Program. Left panels show data for 2025 by sampling location (bed) while right panels show 2025 average compared to long-term patterns for total, recent and cumulative recent box counts. Bed abbreviations as in Fig 3A.

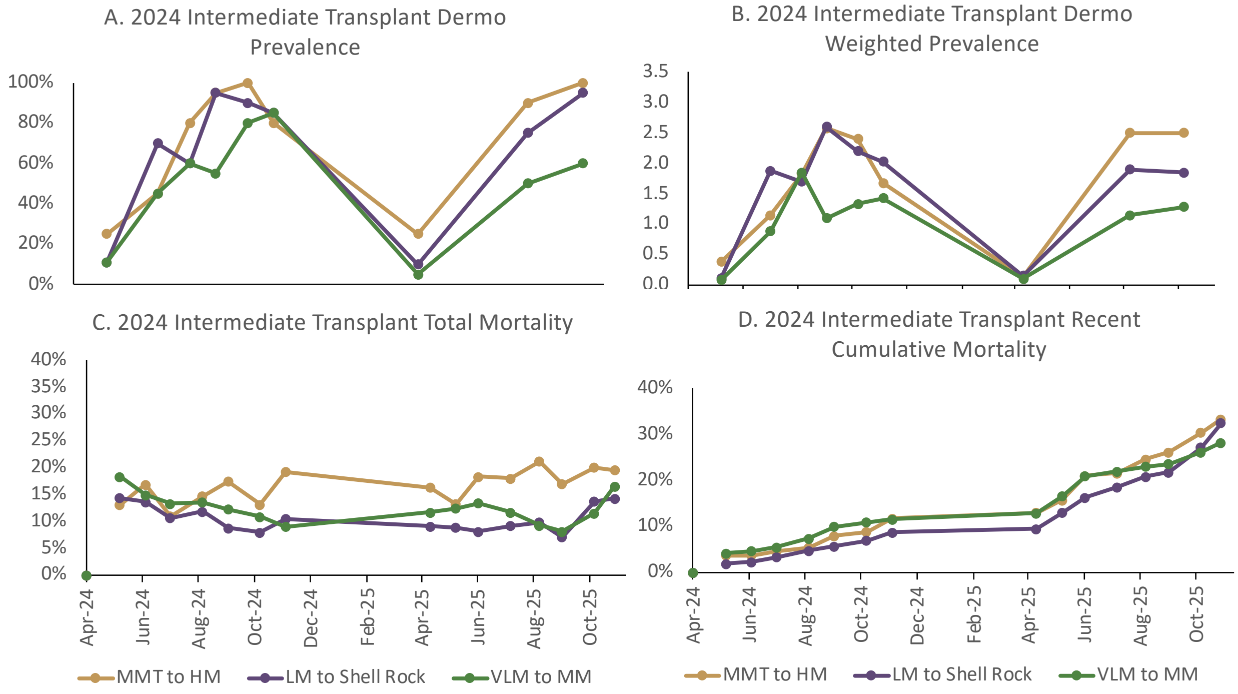


Figure 9. Dermo and mortality on the 2024 intermediate transplant sites. The 2024 donor to recipient beds were as follows: MMT to HM – Middle and Sea Breeze to Bennies; LM to SR – Upper Arnolds and Arnolds to Shell Rock, and VLM to MMM – Hope Creek to Ship John.

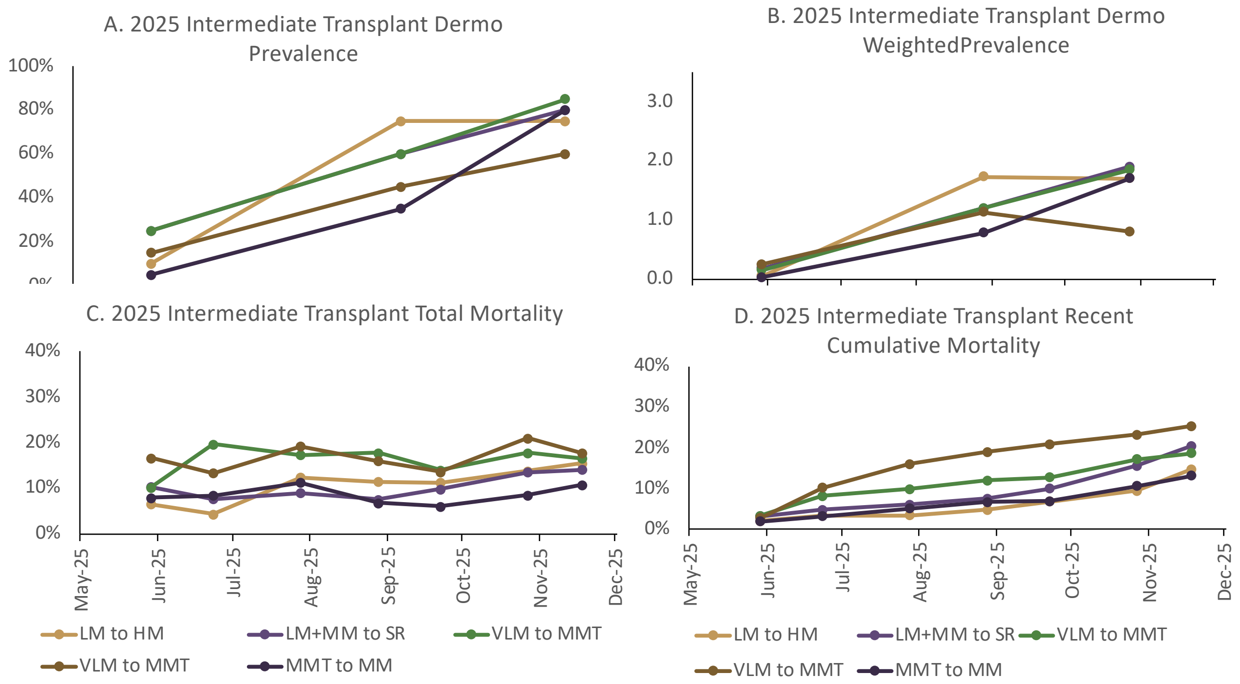


Figure 10. First year of box count and dermo disease performance of the 2025 intermediate transplants. The 2025 donor to recipient beds were as follows: LM to HM – Upper Arnolds and Arnolds to Bennies; LM and MMT to SR – Arnolds and Middle to Shell Rock; MMT to MM – Middle to Cohansey; VLM to MMT – Hope Creek, Fishing Creek and Liston Range to Sea Breeze – 2 grids.

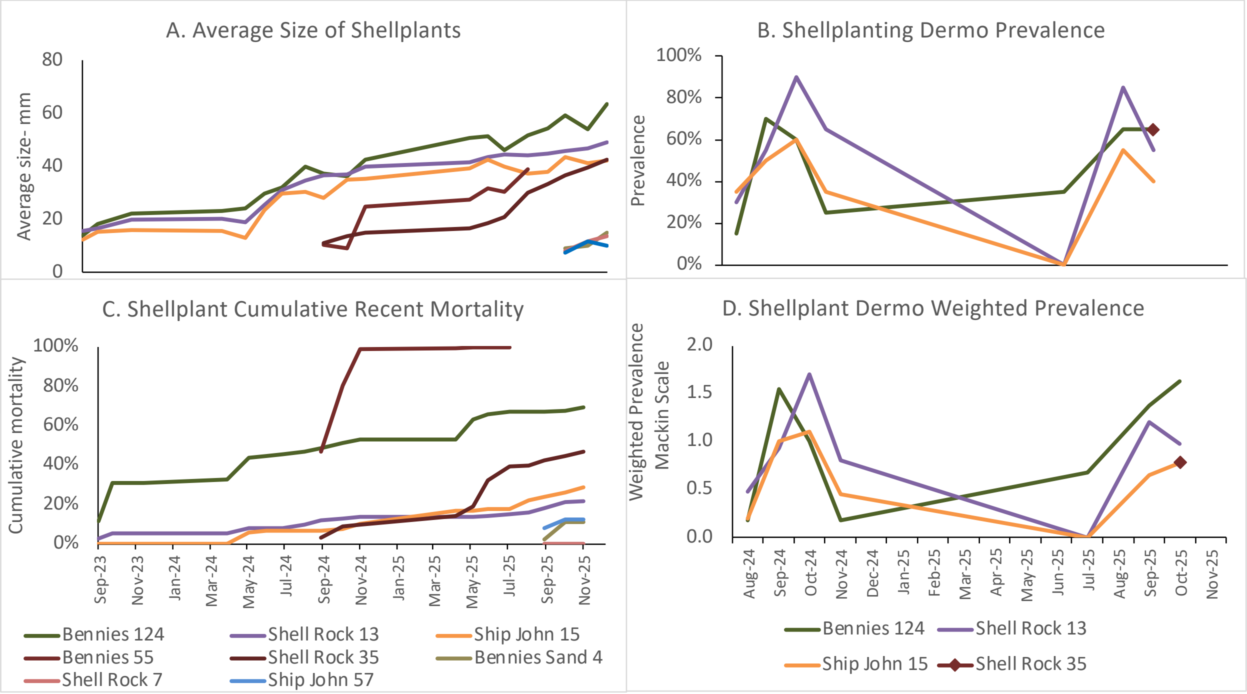


Figure 11. Performance of 2023, 2024 and 2025 shellplants. Growth and mortality monitoring began in September during the year of the plant while dermo monitoring began in July for the 2023 shellplants and an October sample only for the 2024 shellplants.

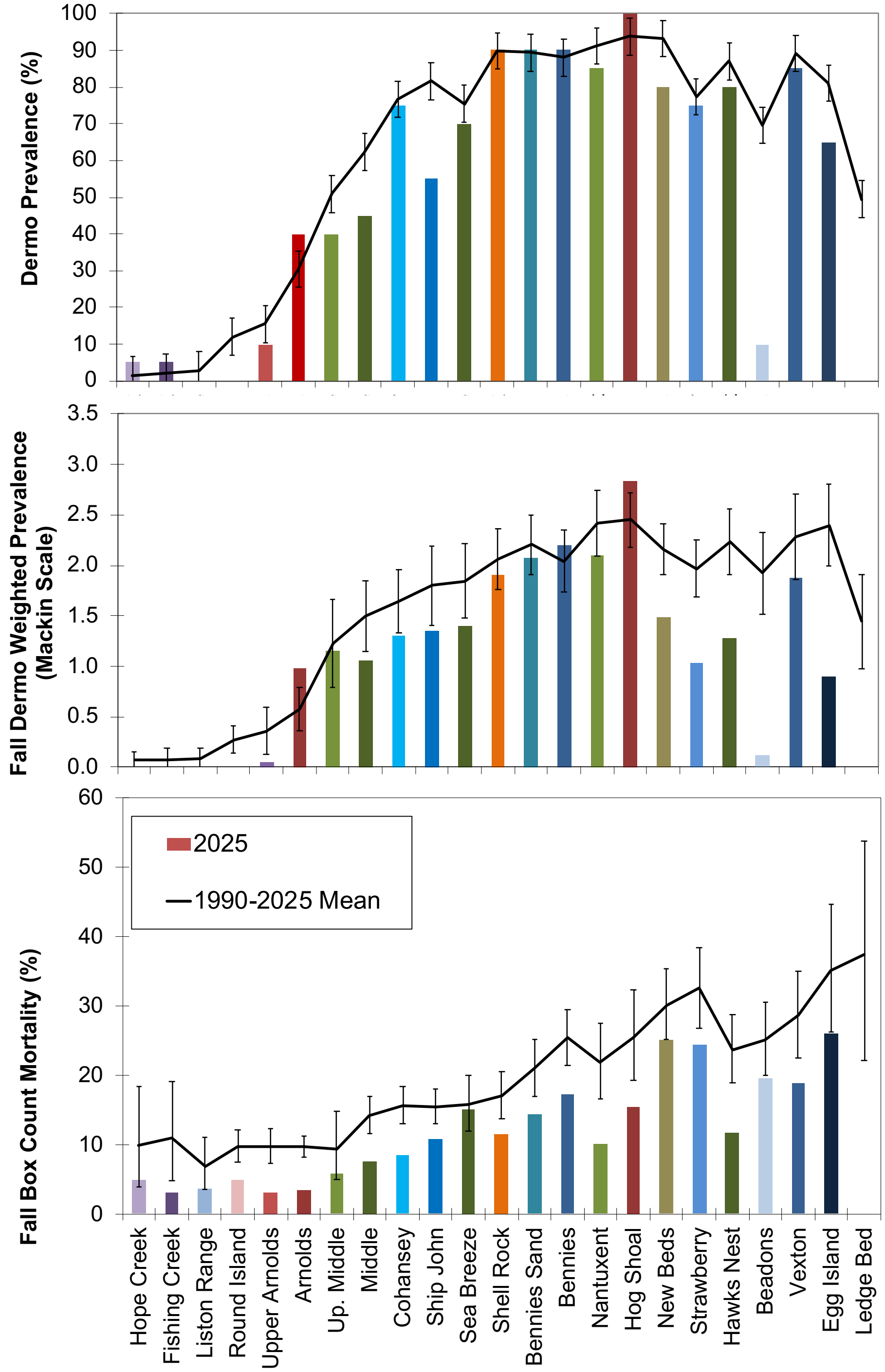
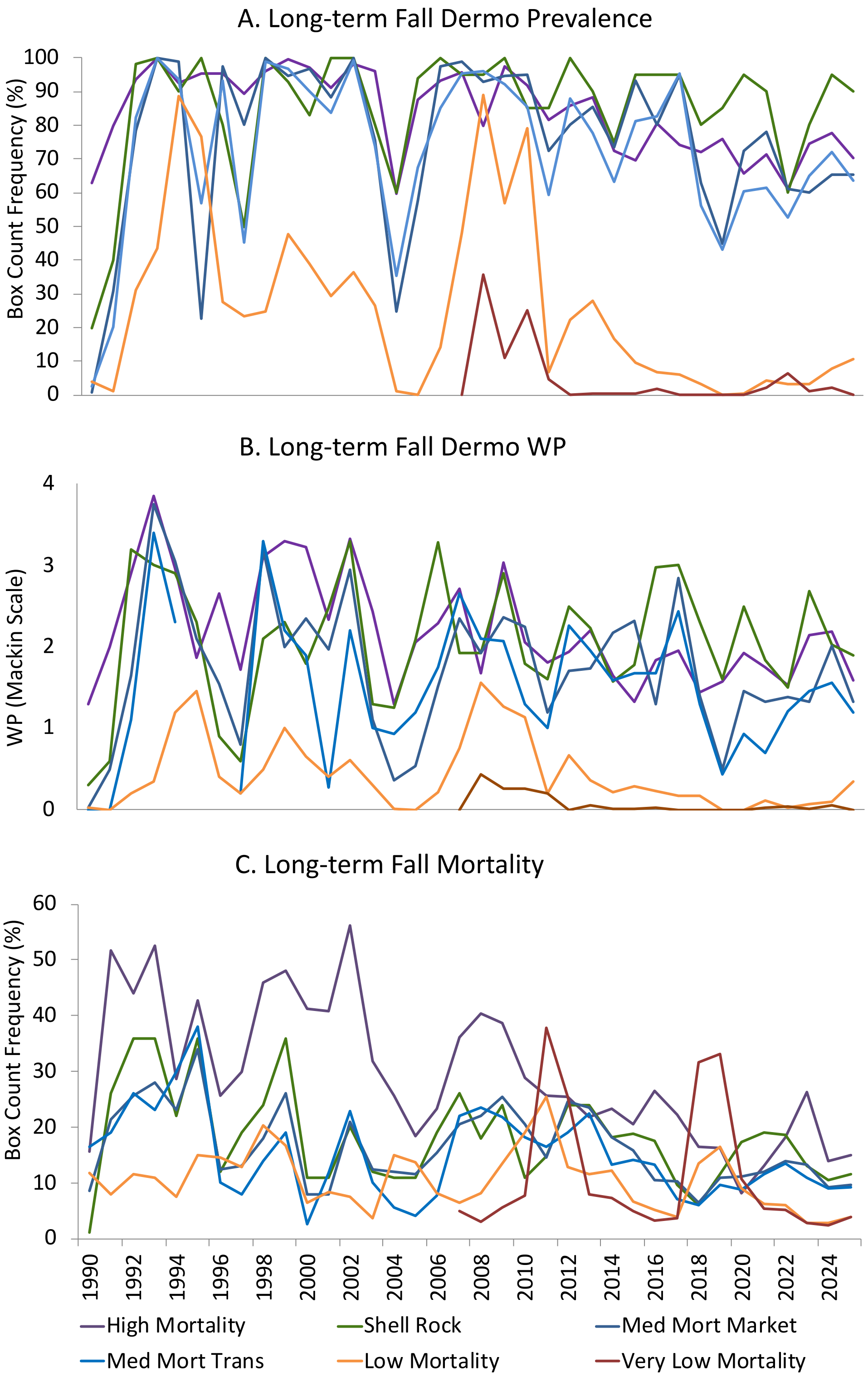


Figure 12. Long-term spatial patterns of dermo weighted prevalence (A), and natural mortality (B) across the oyster beds. Beds are listed upbay to downbay from left to right; colors simply provided as an aide to follow x-axis labels from lower to upper panel. Not all beds have been sampled every year (see Table 3). Ledge was not sampled in 2025. Error bars represent 95% confidence intervals.



A. Long-term Fall Dermo Prevalence

B. Long-term Fall Dermo WP

C. Long-term Fall Mortality

Figure 13. 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.

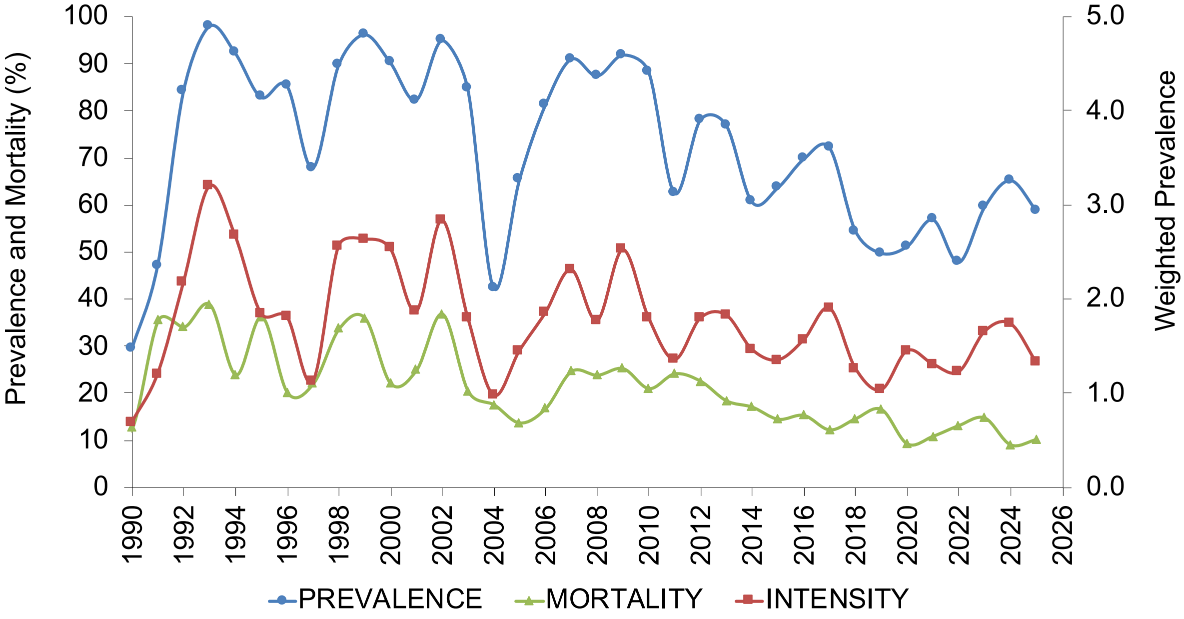


Figure 14. Long-term patterns of fall dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data show cycles of dermo attenuating over time.

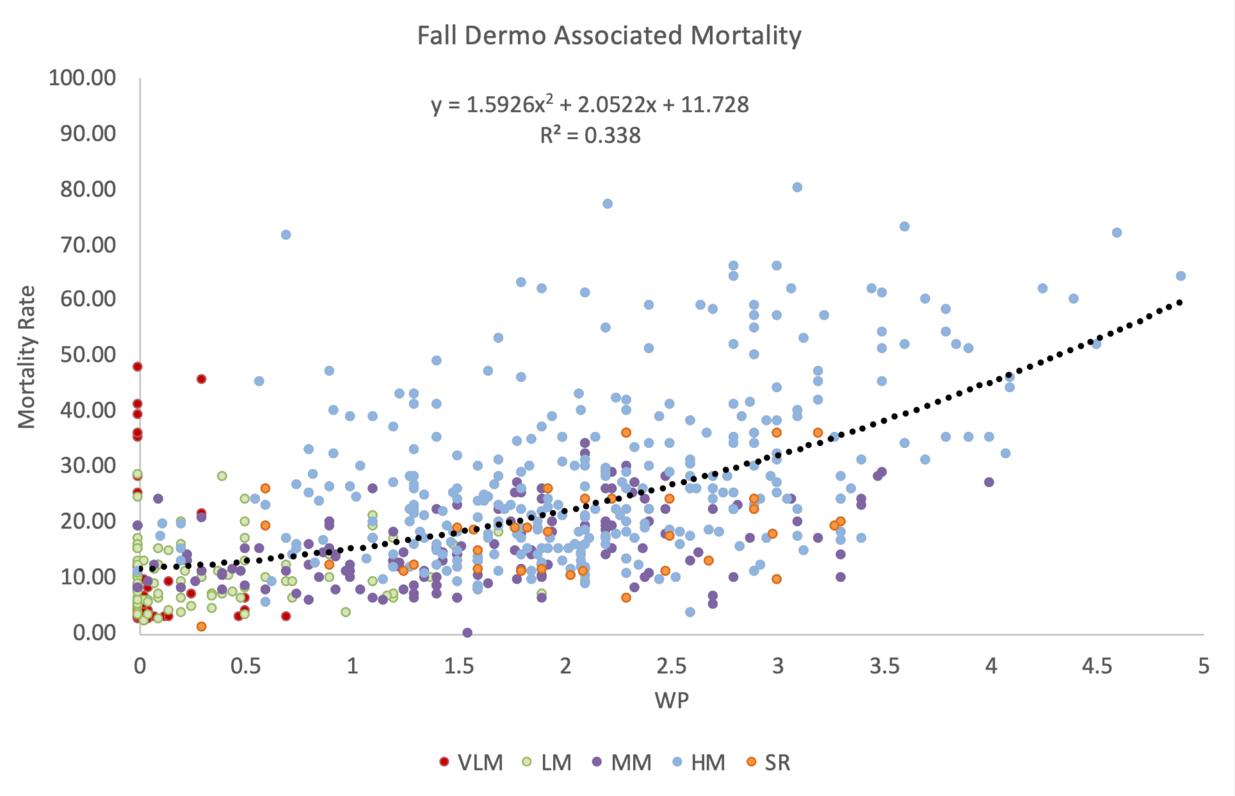
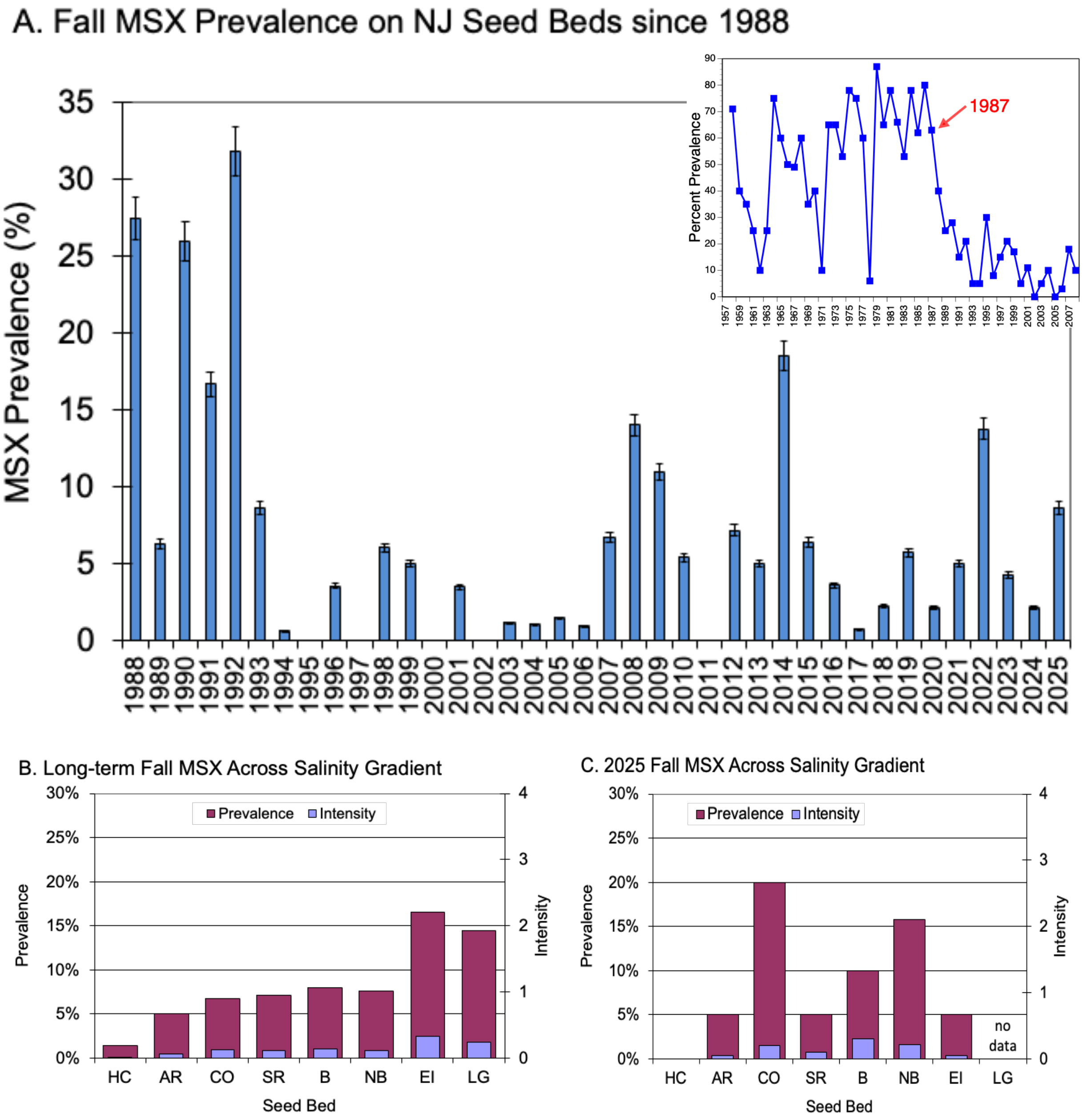


Figure 15. Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). VLM = Very Low Mortality, LM = Low Mortality, MMT = Medium Mortality Transplant, MMM = Medium Mortality Market, SR = Shell Rock, and HM = High Mortality.



A. Fall MSX Prevalence on NJ Seed Beds since 1988

B. Long-term Fall MSX Across Salinity Gradient

C. 2025 Fall MSX Across Salinity Gradient

Figure 16. 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 (calculated as a weighted prevalence on a scale of 0 to 4) across seedbed salinity gradient since 1988. C. 2025 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.