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## **Delaware Bay New Jersey Oyster Seedbed Monitoring Program 2022 Status Report**

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## Executive Summary

The 2022 Seedbed Monitoring (SBM) Program tracked oyster size, dermo disease and oyster mortality monthly at six fixed sites, three additional sites of interest, five shellplant sites and six 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 above a 22-yr average from June to November during 2022. Moderate freshwater inflow throughout the spring and early summer maintained salinity near seasonal averages but drier conditions from mid-Summer through Fall increased salinity across the sampling area. Mean oyster size decreased on many beds during the year due to a large recruitment event on the upper beds, but overall remained steady to the prior season. Dermo disease followed typical seasonal and spatial patterns, but levels were generally below average and this likely contributed to relatively low levels of mortality observed during 2022. By comparison, the 2-yr old cohorts monitored on the Cape Shore flats incurred higher levels associated with mortality reported by farmers in the region.

Fall spatial patterns of dermo showed the typical increase from upper to lower bay beds with highest levels observed from Ship John south. Overall, however, levels remain relatively low with respect to the time series and oysters on nearly all beds entered winter with dermo levels below long-term means. Mortality increased across all high mortality beds showing a level closer to the normal means from upper to lower bay beds reflected in the long-term timeseries. The long-term patterns from the Fall survey continues to indicate an attenuation in both duration and amplitude of interannual dermo and mortality cycling. In fact, bay-wide mortality no longer appears to be cycling with dermo and has decreased from 20-30% in the 1990s to less than 20% over the past several years. MSX was present at all but the uppermost bed, mostly at low prevalence and intensity in Fall 2022. Although lower than historic peaks, prevalence and intensity has been increasing since 2020.

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. 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, particularly in the face of climate change, upstream management of reservoirs that impact freshwater inflow, 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 not the focus of this report though some information is included where relevant and available.

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 that virulence remains high (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 or at least not causing levels of mortality to warrant concern. With the continuing progression of global warming and climate change, dermo disease has remained a major source of oyster mortality in Delaware Bay since 1990 and a primary concern for managing the oyster fishery and the oyster stock (Bushek et al. 2012).

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 positively correlated to salinity which increases from an average of about 6 to 18 across these beds. 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 reconnaissance indicated a high abundance of oysters in a region that the fishery had exploited in the past and wished to do so again. These beds were collectively designated Hope Creek in 2007, but were subsequently subdivided into Hope Creek, Fishing Creek and Liston Range and categorized as the Very Low Mortality (VLM) beds in reference to the level of disease-induced mortality they experience –

the VLM beds experience little disease, but episodic high mortality occurs in response to freshets (Munroe et al. 2013). Current area management strategies separate Shell Rock (SR) from the original medium mortality region and further subdivide the remaining medium mortality region beds into Medium Mortality Transplant (MMT) and Medium Mortality Market (MMM) beds (Figure 1) based on how they are managed 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: <http://hsrl.rutgers.edu/SAWreports/index.htm>.

The majority of fresh water entering the system comes from the Delaware River and tributaries located above the oyster beds. 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 and growth, disease transmission dynamics and, ultimately, 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 viable fishery as well as a healthy oyster population and a functional ecosystem. 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 a spatially comprehensive survey in the Fall. The monitoring supports additional directed research and sampling efforts that are necessary to develop deeper insights of the dynamics controlling the oyster population within the Delaware Bay ecosystem. As funding permits, these efforts include monitoring transplants (i.e., oysters moved from upper to lower seedbeds), shellplants (i.e., shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (i.e., cultch planted in the lower bay high recruitment zone near the Cape Shore then moved and replanted on the seedbeds) as well as other natural events (e.g., freshets) and additional experiments that may be sanctioned. The 2022 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 2022 Fall Stock Assessment Survey
3. Monitor growth, disease and mortality on 2020 through 2022 shell plantings
4. Monitor growth, mortality and disease on the 2021 and 2022 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. 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

*COVID-19 Impacts:* Despite the continuing presence of COVID-19, sampling was able to return to prior protocols and scheduling for the 2022 season. Data from 2020 are incomplete due to a curtailment in work activities that prevented sampling, reduced shellplanting and restricted the amount of samples that could be collected as staff restrictions were lifted. No essential data is missing from 2021 or 2022.

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 2022. 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 2022 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). 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 R/V James W Joseph. Dots in Figure 1 represent locations of grids selected for disease sampling from a stratified random sampling design for the Fall oyster stock assessment. Typically, one grid is selected from each of the high and medium density strata sampled for population 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 strata contains 50% of the total oyster abundance, the medium density strata contains the next 48% of total oyster abundance, and the low density strata 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 Tables 1 and 2. Table 3 identifies beds that have been monitored since 1990 as part of the long-term Fall dermo monitoring program that is affiliated with the Annual Fall Oyster Stock Assessment. Table 4 specifies the grids sampled during the 2022 Annual Fall Oyster Stock Assessment to complete Objective 2.

To complete Objective 1, three one-minute tows with a 0.81 m (2.7 ft) oyster dredge were collected at each site using about 14 m (46 ft) of cable from the R/V James W Joseph. Bottom water temperature and salinity were recorded with a handheld YSI® Pro2030 instrument at each site. A composite bushel (37 L total volume with one third coming from each dredge tow<sup>1</sup>) 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 returned to the laboratory where shell heights (hinge to bill) were measured to determine size frequency from each site. Care was taken to avoid any bias in sampling oysters by systematically working through the sample until 100 oysters were identified. It is understood that the sampling gear will bias the collection toward larger animals (Powell et al. 2007), but such bias is presumed constant across sampling dates and countered to some extent by clumping when oysters attach to one another (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 of these sites were monitored as described for Objective 1 with the following modifications for Objective 3. Shellplant samples for Objective 3 continued monitoring the 2020 and 2021 shell plantings, and initiated the 2022 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

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

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 until 100 live spat or oysters were collected. Boxes were enumerated and categorized as new or old as described above. Live oysters attached to planted shell were returned to the laboratory for size measurements ( $n = 50-100$  per site). No disease sampling was performed on the 2022 shellplants as it was in its first year and not expected to have contracted any disease by this point.

## Results 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 to be prepared for flood control.

River flow during 2022 followed a long-term seasonal pattern with periodic spikes in discharge that maintained flow near or above long-term values. Discharge typically decreases from the end of winter through late summer which causes salinity to increase across the oyster beds (see below). During 2022, discharge fell below long-term levels from July to September 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.

**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 2022 were more or less typical with respect to the past 22 years. Water temperatures measured during 2022 collections followed a typical seasonal cycle with little spatial variability across the seedbeds but were slightly warmer than average from July to September (Figures 3A and 4A). Spawning temperatures (approximately  $25 \text{ C} = 77 \text{ F}$ ) were reached between June and July sampling dates. Salinity followed the typical estuarine gradient, increasing from upbay to downbay beds (Figure 3B) but the seasonal increase was steeper than average creating late summer levels of higher than normal salinity (Figure 4B).

**Oyster size.** Shell height (measured hinge to bill) roughly corresponds to age and therefore provides insight into both the size and age structure of the population. Seasonal changes in a population's mean shell height may be affected by growth, recruitment and mortality (both natural mortality and fishing mortality). Mean shell height remained relatively stable on most beds during 2022, with the exception of the uppermost beds which received a significant recruitment event reducing their shell height. (Figure 3C). Intuitively, oysters should grow over the summer and increase in size, but average size may not increase or even decrease over the season as small spat become large enough to be measured while larger older animals are

harvested or die. In 2022, the overall average size decreased (Figure 4C), driven largely by large recruitment events, particularly on Arnolds and Hope Creek (Figure 3C). Figure 5 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. The overall 2022 size frequency had a mean of 68 mm (2.7 inches).

**Dermo Disease.** Dermo prevalence (the percent of the population with detectable infections), weighted prevalence (WP; the average intensity of dermo in the population, including uninfected oysters) and intensity (the average level of infections in infected animals only) followed typical spatial and seasonal patterns (Figures 3D-F) but were generally lower than long-term means until the end of the season (Figures 4D-F). Each measure of dermo disease increased to a peak in fall with levels increasing with the salinity gradient. Recruitment during the year is likely partly responsible for the late season declines in dermo disease. The population as a whole entered the winter with average levels of dermo.

The situation at the Cape Shore was entirely different with very high levels of dermo detected in July that was associated with mortality reported by growers (Figure 3D-F). Here, a 2 yr-old year class of a hatchery line produced from NEH broodstock collected from the Cape Shore along with a similar co-hort of wild Delaware Bay stock was monitored to provide a comparison index of disease pressure. Using a single cohort from a single line stabilizes variation arising from different culture environments and methods such as intertidal vs subtidal, source and age of seed, husbandry differences among farms, and other factors. In 2022, both of these oyster lines became heavily infected with dermo in June and sustained heavy infections through the fall, with the wild stock having higher levels of dermo disease than the NEH stock. This is partly due to the fact that the oysters monitored at the Cape Shore were from a single cohort of near market- or market-size oysters. Corresponding mortality data has not been available for comparison, but a late fall decline in intensity likely corresponds to mortality of heavily infected individuals. While not part of the fishery, aquacultured populations interact with wild populations via disease and can be an important source or sink of disease making co-management and potential mechanism for managing disease across the Bay.

**Mortality.** Mortality across all beds was relatively steady running near or slightly below long-term levels (Figures 3G-H and 4G-H). As a result, cumulative mortality increased steadily as well. An epizootic is defined as a sudden increase in the appearance or intensification of a disease that may or may not be associated with mortality. Despite the widespread prevalence and seasonal intensification of dermo disease, Delaware Bay did not experience a dermo epizootic during 2022, but the potential for an epizootic to develop and cause significant mortality remains high.

**Transplants, shellplants and replants.** Figure 6 shows the conditions and performance of 2021-2022 transplants compared to the five bed mean of the long term sites. The monthly monitoring samples were generally offset by about a week from routine monthly samples due to sampling and scheduling logistics. Temperature and salinity (Figure 6A and B) were effectively identical; apparent differences in salinity are attributed to sampling different tidal stages on



different dates. No particular or surprising trends in size were apparent. Dermo levels on transplant sites were similar to long-term site values. Values were higher than the five bed mean because that mean includes values from beds in regions upbay and less impacted by disease. The levels of dermo ( $>1.5$  weighted prevalence) were sufficient to cause mortality (Bushek et al. 2012), but relatively little mortality was observed after an initial bout of overwinter mortality (Figure 6G, H and I). Previous monitoring efforts have indicated transplants develop higher levels of disease and higher rates of mortality by the end of the first year that continues into the second year, this was the case for five of the 6 transplant beds. A small experimental transplant from Hope Creek (very low mortality bed) to Upper Arnolds (low mortality bed) had very little dermo disease or mortality. This bed was also a recipient of a large recruitment event.

Five shell plants have been placed on three different beds during the past three years (Table 2). Growth varied among shellplants (Figure 7A) with largest increase on the 2021 shellplants at  $\sim 22.6$  mm while the 2020 plant grew 13 mm. The 2022 shell plants had reached 15 mm by November indicating modest growth before sampled stopped. Mortality varied from 2 to 31% and was mostly noted on the 2020 plant site. (Figure 7B). Dermo increased on 2020 and 2021 shellplants across the season with levels occurring in both year classes equivalent to the recipient beds (Figure 7C and D). Shell planting remains one of the most positive management efforts to sustain and increase oyster abundance, and should be pursued annually to the level that resources permit. No replanting occurred in 2022, but replanting remains a potentially valuable management strategy. Similarly, spat-on-shell technologies (i.e., remote setting of hatchery-reared oyster larvae) provide an alternative that has worked in other locations and warrants consideration.

**Long-Term Fall Patterns.** Examination of dermo prevalence, weighted prevalence and mortality by bed indicated a continued significant departure from long-term patterns during 2022 (Figure 8). The long-term patterns typically increase from upper to lower bay beds, but since 2013, dermo prevalence and weighted prevalence have been highest in the central portion of the fishery with the highest levels often on or around Shell Rock. Fall 2022, dermo levels were below mean long-term values on many beds, and often below the 95% confidence intervals, but near or above levels on more centrally located beds. Only Shell Rock and Sea Breeze, sustained mortality levels above longterm means. The processes that make this a productive oyster region may similarly make it conducive for dermo disease.

Figure 9 depicts annual dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2022 for each mortality region. Each parameter generally decreases from high to low mortality regions. Exceptions are predominantly related to freshets causing mortality in the low mortality regions and recruitment events to the high mortality regions. Dermo prevalence and weighted prevalence track each other well within and across regions, but mortality patterns on the low and very low mortality regions are distinct from the medium and high mortality regions. Within the high and medium mortality regions, mortality lags disease by about one year. In the LM and VLM regions, mortality is nearly out of phase with dermo disease indicating that dermo is not a primary cause of mortality in these regions. 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 9B). This dampening also corresponds to a reduction in Fall box count mortality (Figure 9C).

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 10). This observation could be entirely environmentally driven or it could indicate an increase in tolerance (the relative ability of an oyster to survive an infection of a given intensity) or resistance (the ability of an oyster to limit the development of an infection) to dermo disease. Alternatively, dermo virulence may have declined over time. 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 at play and, more importantly to this assessment, whether or not management strategies can improve the situation.

Figure 11 depicts the regional mortality rates from each fall assessment since 1990 as a function of dermo disease level (weighted prevalence). Bushek et al. (2012) demonstrated that once weighted prevalence begins to exceed 1.5 mortality begins to increase exponentially. In Figure 11, 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 approximately 46% of the annual variability in mortality. The 2022 data points all show relatively low mortality, even on the HM region where dermo levels were approaching 2. Highest mortality was on SR (19%) where dermo WP was 1.5 and had been above 2.0 since August. The pulses of fresh water entering the system appear to be associated with curbing dermo levels sufficiently to eliminate it as a leading source of mortality during 2022. This relationship warrants additional study and coordination with the entities managing water flow through the Delaware River Basin Commission.

Because MSX has not been problematic on the seedbeds for nearly two decades, samples from only eight beds along the upbay-downbay gradient have been examined during the fall survey (Table 4). MSX was detected in 22 of the 160 oysters assayed; a prevalence of 13.8%, an increase from last year at 2.1%, and the highest prevalence since 2014 (Figure 12A). Over the past 33 years, MSX infections occur at a higher prevalence and intensity with increasing salinity (Figure 12B). In 2022, infections were detected at every site except Hope Creek (Figure 12C). Most infections were in the early stages of progression, generally restricted to epithelial cells. While systemic infections were observed across the salinity gradient at Arnolds, Shell Rock, Bennies, Egg Island and Ledge, advanced infections were only observed at Egg Island and Ledge (Figure 11C), higher salinity sites where MSX disease is more likely to occur (Ford et al. 2012). Two 2 yr-old hatchery spawned oyster stocks, one produced from NEH broodstock and one produced from Delaware Bay wild oysters, held on aquaculture racks at Cape Shore were also tested April through November 2022. MSX was detected in the NEH stock at 5% prevalence in April, 10% in June, July, and August, 25% in October, and 10% in November with no systemic infections observed. MSX was detected in the wild stock at 30% prevalence in April, 15% in May, 20% in June, 5% in July, and 5% in November, with systemic infections observed April

through June and advanced infections observed April and May. Previous years have found MSX distributed across the seed beds and these data confirm its continued presence in the bay. MSX remains a threat to the Delaware Bay oyster population as it continues to cause mortalities elsewhere along the East Coast. Therefore, it remains an important component of the monitoring program to understand sources of mortality from year to year. Because MSX can cause mortality in spring and appears to be more prevalent in the lower bay, it is recommended that some level of routine monitoring of MSX occur throughout the year to improve surveillance.

### **Science Advice**

- Continue to examine the spatial and temporal relationships between environmental drivers of temperature, salinity and fresh water 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.
- Because of the complex relationships between prevalence, intensity and weighted prevalence of dermo disease and how they change with temperature and salinity, consider plotting long-term seasonal patterns by bed to look for further insights.
- Investigate the potential evidence for the development of dermo disease resistance and/or attenuation of dermo virulence. Plot the relationship of disease by size class and explore it spatially and temporally for changes.
- Consider where and when mortality is occurring during the year to help interpret fall mortality patterns.
- Consider revisiting prior analyses of inshore versus offshore disease and mortality.
- Compile condition index data, although highly variable, to show current year versus long-term means by bed along the bay axis.

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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.
- 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>
- DRBC 2021. Delaware River Basin Commission website. Salt Line. Accessed February 1, 2021. <https://www.state.nj.us/drbc/hydrological/river/salt-front.html>
- 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>.
- 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](https://doi.org/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](https://doi.org/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.
- 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.
- Wang, Z., D. Haidvogel, D. Bushek, S. Ford, E. Hoffman, E. Powell and J. Wilkins. 2012. Circulation and water properties and their relationship to the oyster disease, MSX, in Delaware Bay. *J. Mar. Res.* 70:279-308.

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**Table 1.** 2022 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 2022. Cape Shore was sampled by foot and dates were not always coincident with other sites but generally within 2 or 3 days. 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 26, 2022	6 long-term sites, 1 extra site, 3-2020/21 shellplant sites 3 intermediate transplant sites	NJDEP RV James W. Joseph	Andrew Hassall
May 16, 2022	6 long-term sites, 1 extra site, 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
May 23, 2022	3-2020/21 shellplant sites and 5 intermediate transplant sites	NJDEP RV James W. Joseph	Craig Tomlin
June 20, 2022	6 longterm sites, 1extra 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
June 29, 2022	3 shellplant sites and 3 intermediate transplant sites	NJDEP RV James W. Joseph	Craig Tomlin
July 19, 2022	6 long-term sites, 1 extra site 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
July 26, 2022	3 shellplant sites and 5 intermediate transplant sites	NJDEP RV James W. Joseph	Andrew Hassall
August 15, 2022	6 long-term sites, 1 extra sites, 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
August 23, 2022	3 shellplant sites, 1 extra site, 5 intermediate transplant sites	NJDEP RV James W. Joseph	Andrew Hassall
September 19, 2022	6 long-term sites, 2 extra sites 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
September 27, 2022	5 shellplant sites and 5 intermediate transplant sites	NJDEP RV James W. Joseph	Craig Tomlin
October 21, 2022	6 long-term sites, 2 extra sites 1 intermediate transplant site	NJDEP RV James W. Joseph	Craig Tomlin
October 28, 2022	5 shellplant sites and 5 intermediate transplant sites	NJDEP RV James W. Joseph	Craig Tomlin
November 21, 2022	6 long-term sites, 2 extra sites 1 intermediate transplant site	NJDEP RV James W. Joseph	Andrew Hassall
November 23, 2022	5 shellplant sites and 5 intermediate transplant sites	NJDEP RV James W. Joseph	Andrew Hassall

**Table 2.** Additional enhancement sites sampled during 2022.

Bed	Grid	Plant material	Plant yr
Bennies Sand	34/35	clam shell	2020
Nantuxent	9	clam shell	2021
Shell Rock	6	clam shell	2021
Bennies	60	medium mortality transplant	2021
Nantuxent	21	medium mortality transplant	2021
Shell Rock	60	low mortality tansplant	2021
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

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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. Prior to 2008, not all beds were sampled. Beginning in 2008, all beds were sampled every year except Ledge and Egg Island which were alternated annually due to a general lack of oysters. In 2021, however, both Ledge and Egg Island were sampled. Beds are listed approximately by latitude, although some lie at the same latitude with different longitudes.

SEEDBED	90	91	92	93	94	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	--	--	20	21	22
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	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
Ledge Bed (LB)			X		X				X		X		X		X		X		X		--	--	X	X	X

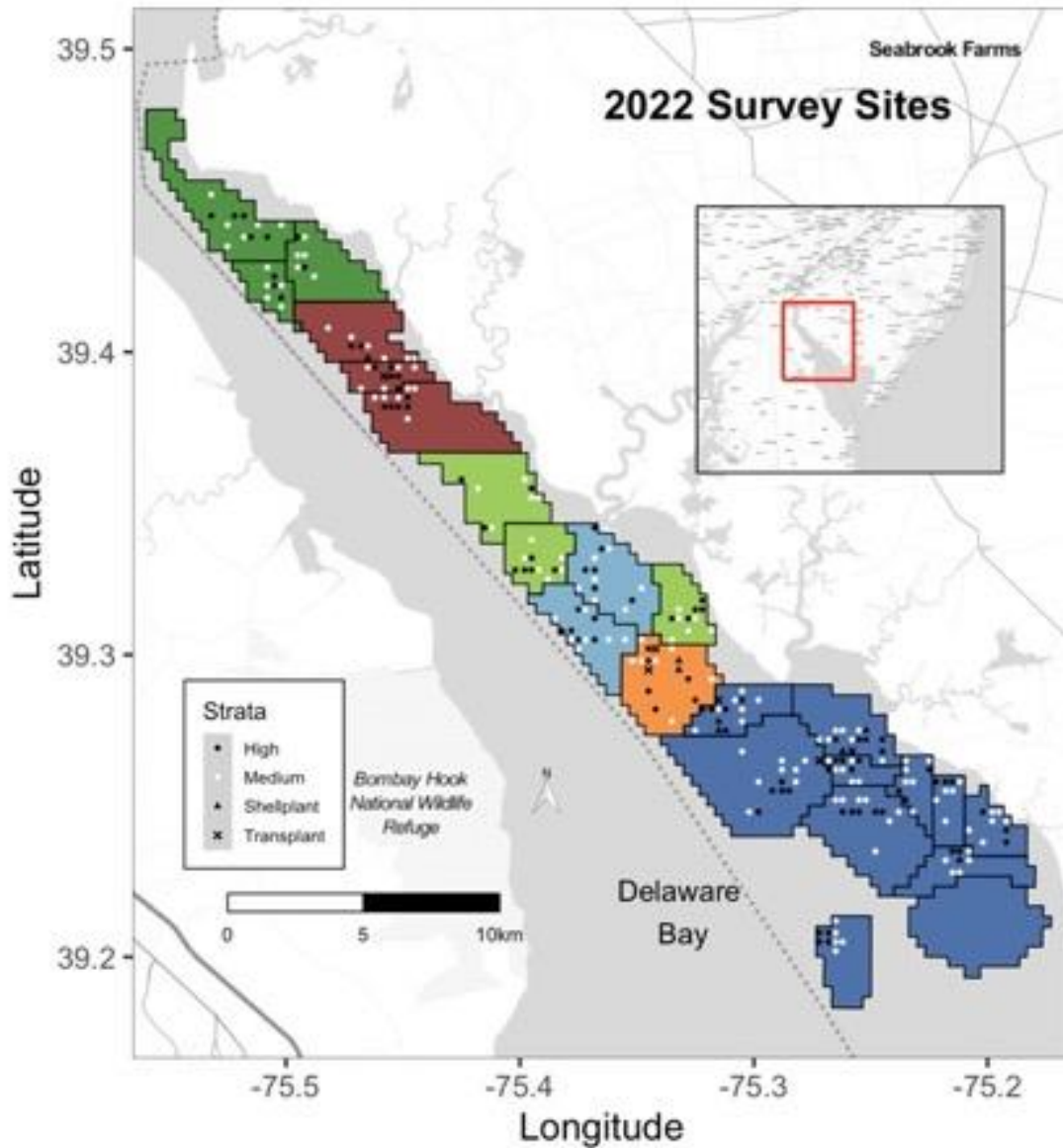


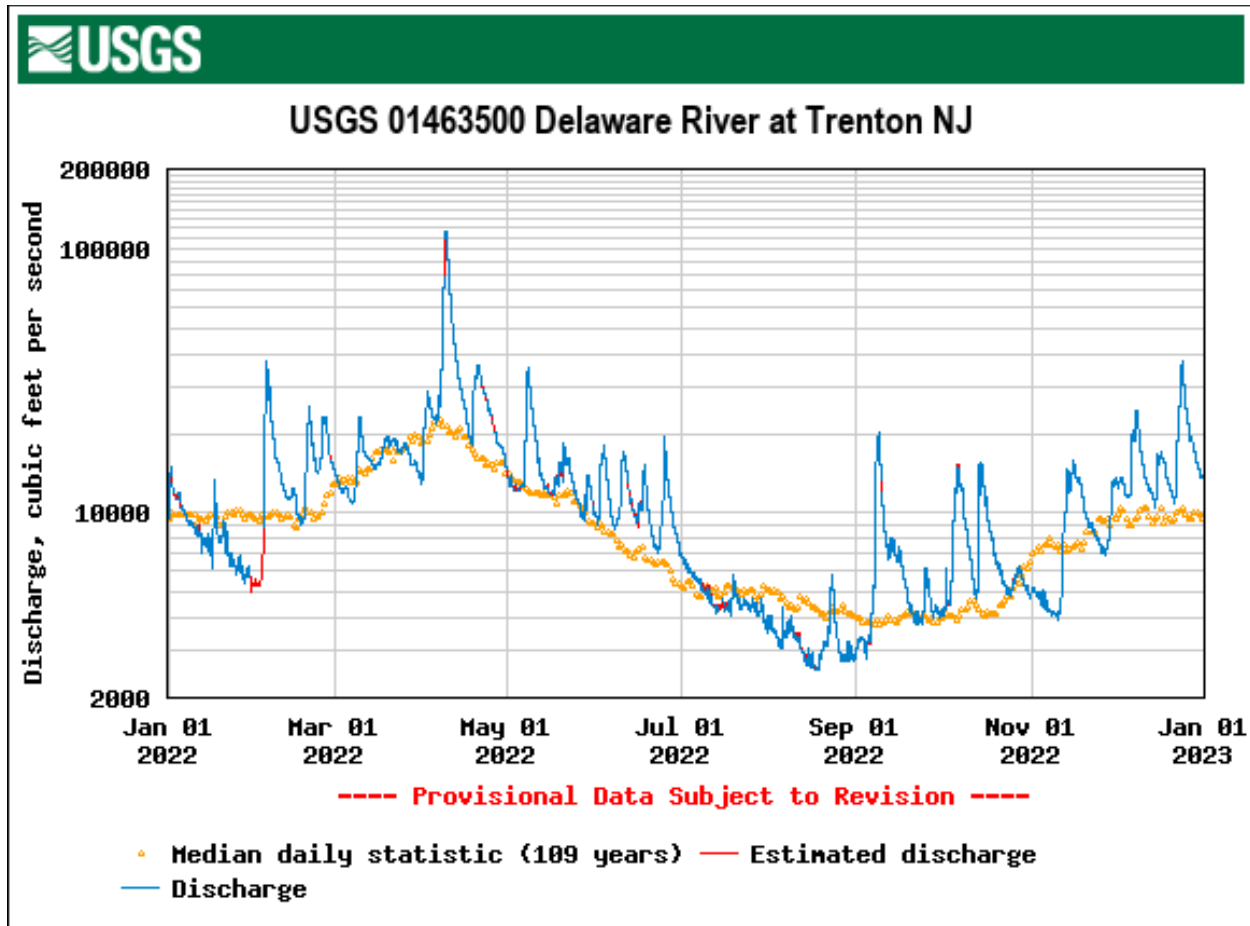
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**Table 4.** 2022 Delaware Bay Oyster Seedbed Stock Assessment Survey grids sampled for dermo, MSX, condition index (CI) and size frequencies. Numbers represent grid ID or the number of oysters processed.

<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	76	10		15	Shell Rock	43			9
Hope Creek	51	10		15	Shell Rock	27			11
Hope Creek	36			10	Shell Rock	10,11		20	0
Hope Creek	64			10	Bennies Sand	36	10		15
Hope Creek	63		20	0	Bennies Sand	34	10		15
Fishing Creek	36	10		15	Bennies Sand	33			10
Fishing Creek	5	10		15	Bennies Sand	5			10
Fishing Creek	17			10	Bennies	76	10		15
Fishing Creek	24			10	Bennies	70	10		15
Liston Range	5	10		15	Bennies	58			10
Liston Range	22	10		15	Bennies	55			10
Liston Range	18			10	Bennies	110		20	0
Liston Range	28			10	Nantuxent	6,8	10		10
Round Island	72	10		15	Nantuxent	25	10		16
Round Island	24	10		15	Nantuxent	8			12
Round Island	18			10	Nantuxent	15			12
Round Island	10			10	Hog Shoal	2	10		15
Upper Arnolds	3	10		15	Hog Shoal	13	10		15
Upper Arnolds	13	10		15	Hog Shoal	14			10
Upper Arnolds	6			10	Hog Shoal	3			10
Upper Arnolds	18			10	New Beds	42	10		15
Arnolds	15	10		15	New Beds	10	10		15
Arnolds	2	10		15	New Beds	13			10
Arnolds	16			10	New Beds	29			10
Arnolds	8			10	New Beds	26		20	0
Arnolds	18		20	0	Strawberry	1,2,5,10	9		9
Upper Middle	48	10		15	Strawberry	14,24,25	5		5
Upper Middle	64	10		15	Hawks Nest	28	10		13
Upper Middle	1			10	Hawks Nest	14	10		11
Upper Middle	74			10	Hawks Nest	2,3			16
Middle	12	10		15	Hawks Nest	25			10
Middle	36	10		15	Beadons	9,11	10		17
Middle	28			10	Beadons	3,4,5	10		3
Middle	27			10	Vexton	10	10		15
Cohansey	2	10		15	Vexton	18	10		15
Cohansey	59	10		15	Vexton	4			10
Cohansey	10			10	Vexton	11			10
Cohansey	24			10	Egg Island	63		20	0
Cohansey	44		20	0	Ledge	14	10	10	5
Sea Breeze	15	10		15	Ledge	6	10	10	20
Sea Breeze	34	10		15	Ledge	8			21
Sea Breeze	20			10	Ledge	16			4
Sea Breeze	31			10	<b>Total beds</b>		<b>22</b>	<b>8</b>	<b>22</b>
Ship John	15	10		15	<b>Total grids</b>		<b>53</b>	<b>9</b>	<b>95</b>
Ship John	25	10		15	<b>Total oysters</b>		<b>434</b>	<b>160</b>	<b>1034</b>
Ship John	17			10					
Ship John	50			10					
Shell Rock	24	10		15					
Shell Rock	62	10		15					

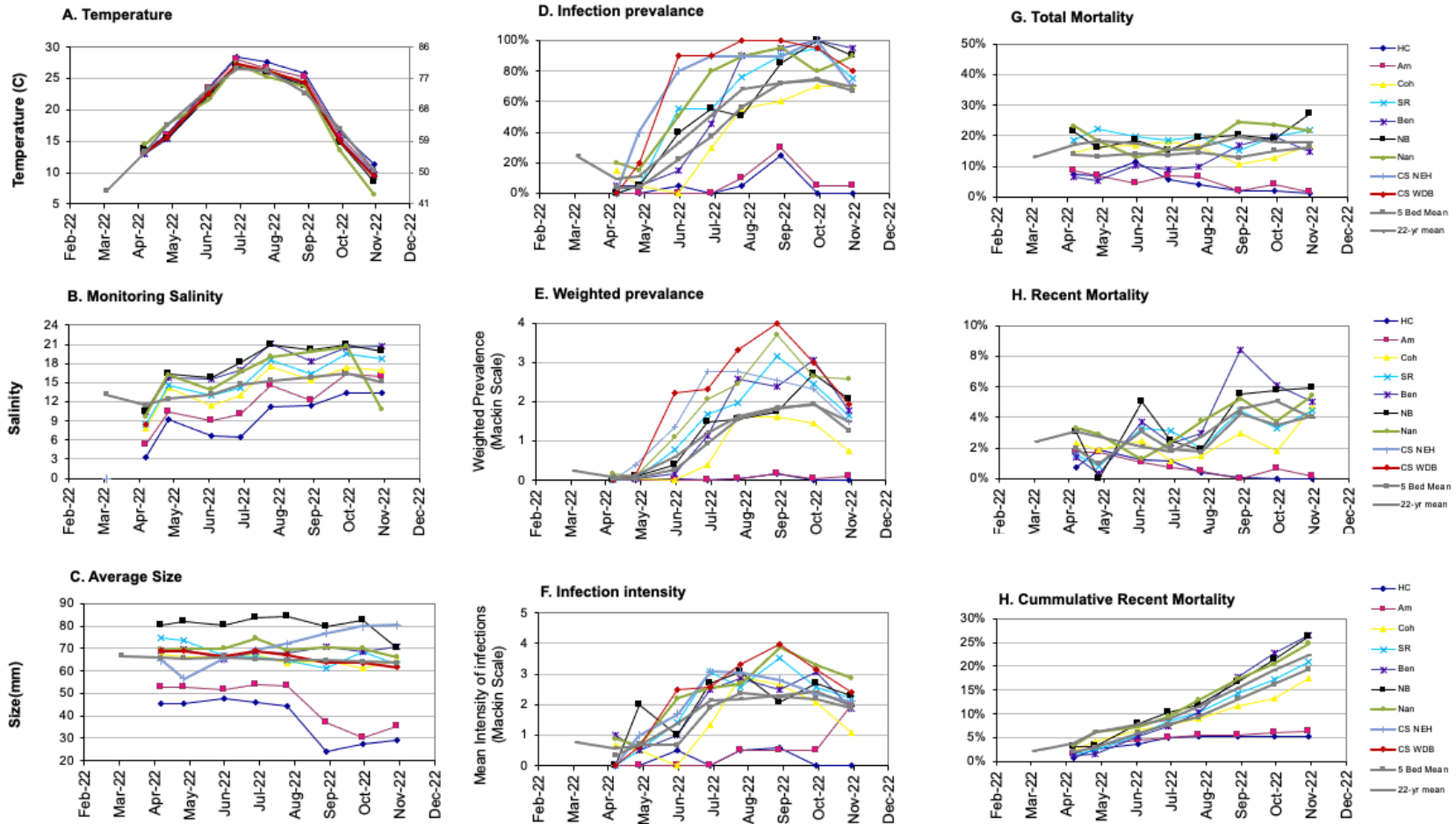
**Figure 1.** Footprint of the Delaware Bay, NJ public oyster beds (aka ‘seedbeds’). Black lines demarcate named beds (see Alcox et al. 2017). Beds of the same color represent different management regions. The sites for the 2022 stock assessment survey are indicated by dots. Black dots are in high density 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.





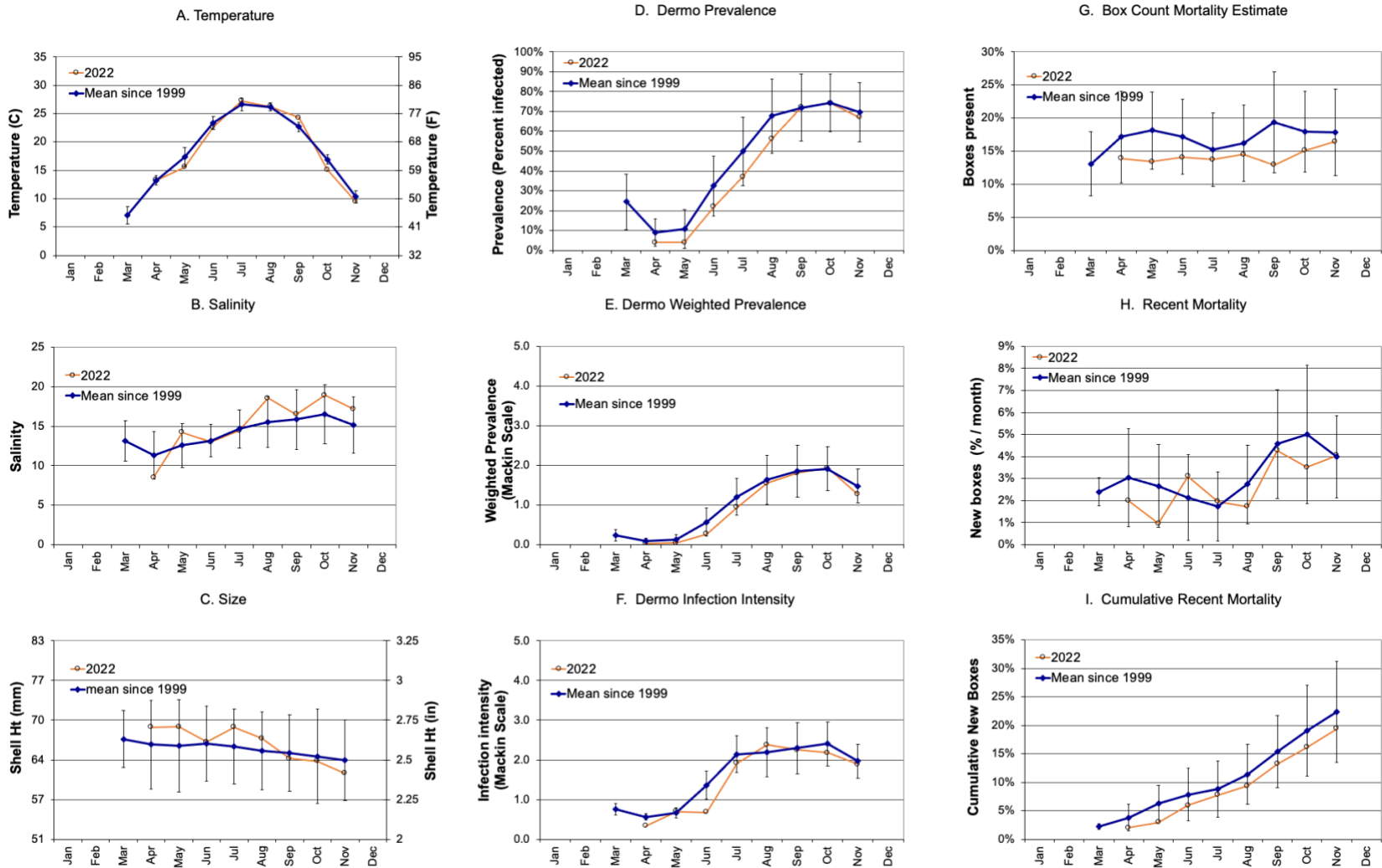
**Figure 2.** Delaware River discharge measured at Trenton, NJ USGS monitoring station 01463500. Yellow line represents daily discharge for 2021 relative to the 1913-2020 median values shown as a dotted black line. Flows were well above median values for much of the latter half of 2021 resulting in depressed salinity across all beds. The peak indicated by the dotted black vertical line of 149,000 cubic feet per second was associated with severe flooding from Hurricane Ida. Data source: [https://nwis.waterdata.usgs.gov/usa/nwis/uv/?cb\\_00060=on&format=gif\\_stats&site\\_no=01463500&legacy=1&period=&begin\\_date=2022-01-01&end\\_date=2022-12-31](https://nwis.waterdata.usgs.gov/usa/nwis/uv/?cb_00060=on&format=gif_stats&site_no=01463500&legacy=1&period=&begin_date=2022-01-01&end_date=2022-12-31)

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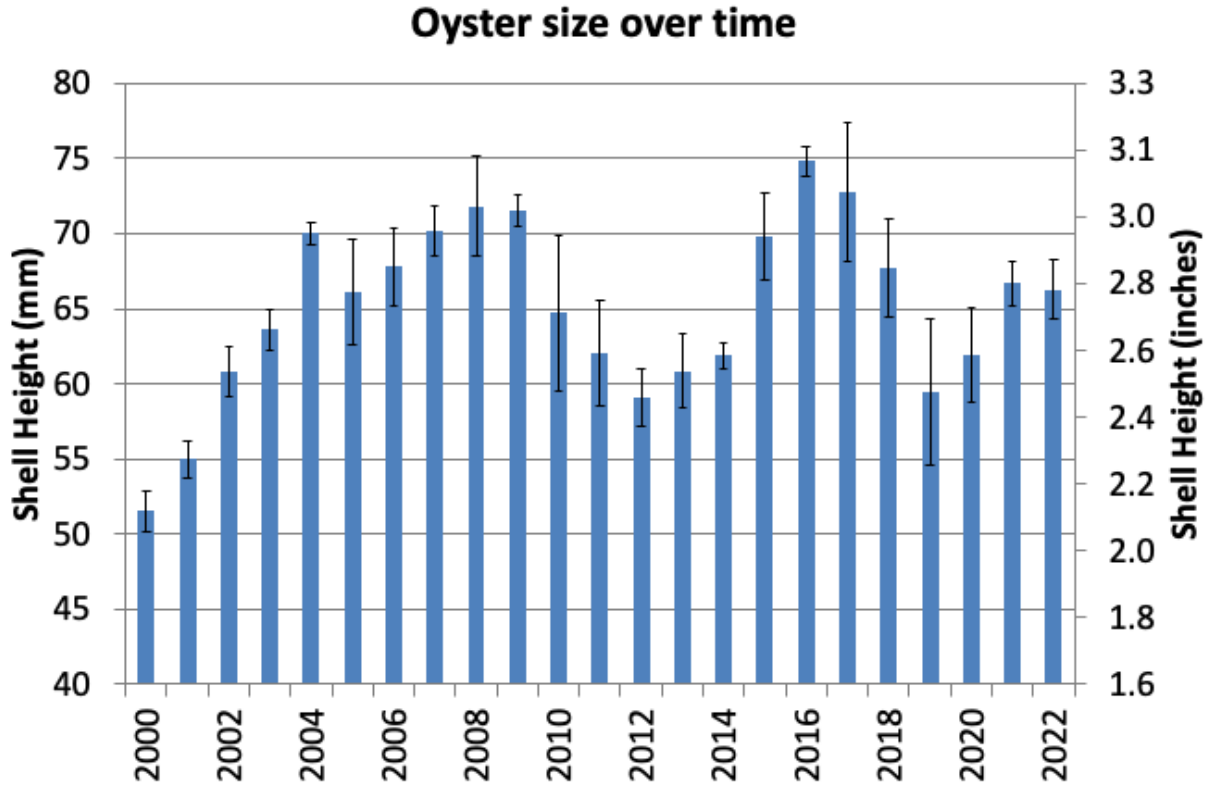


**Figure 3.** Results of 2022 Seed Bed Monitoring Program. Panels present data as labeled. HC = Hope Creek, Arn = Arnolds, Coh = Cohansey, SR = Shell Rock, Ben = Bennies, NB = New Beds, Nan = Nantuxent, CS = Cape Shore.

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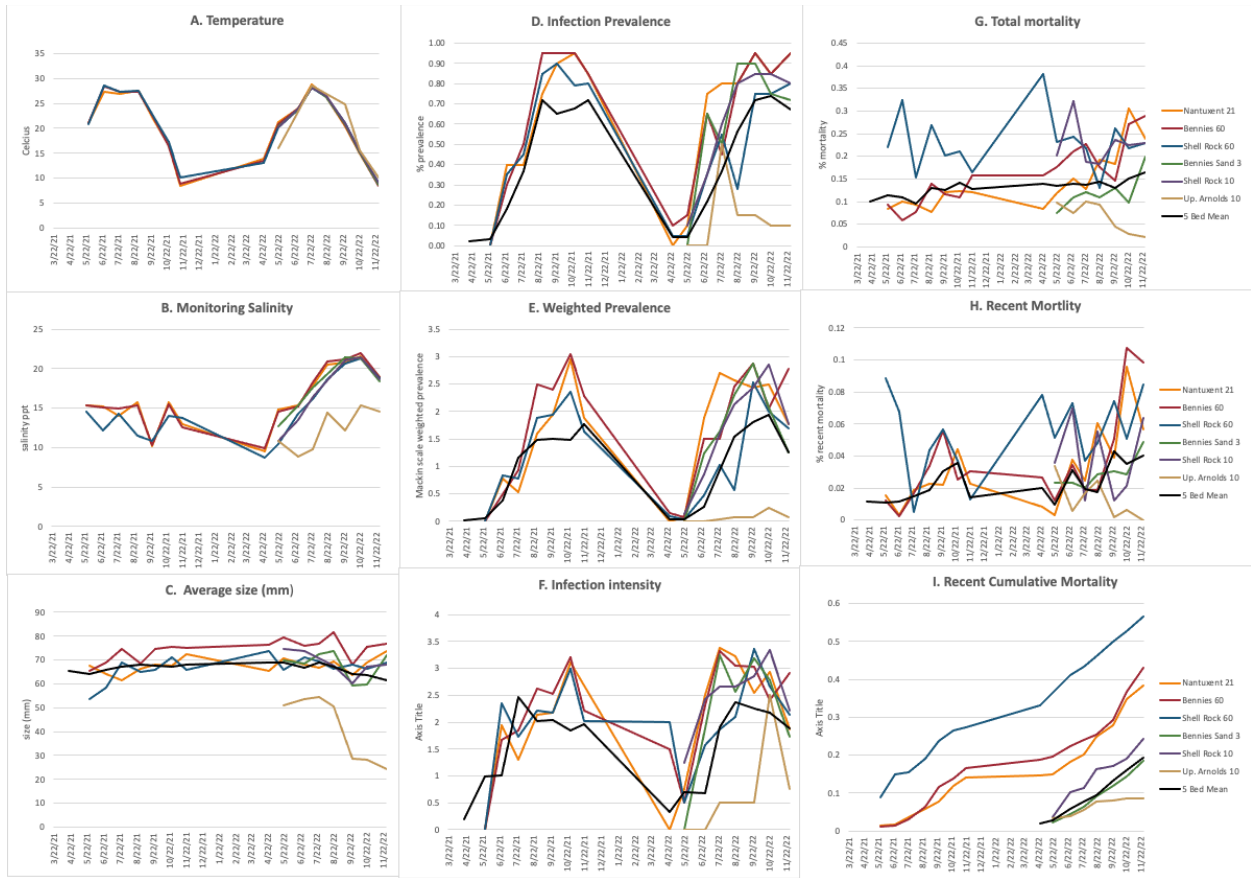


**Figure 4.** Seasonal patterns of the 2022 average Arnolds, Cohansey, Shell Rock, Bennies and New Beds) compared to the long-term values. Panels arranged as in Figure 3. Error bars represent one standard deviation.



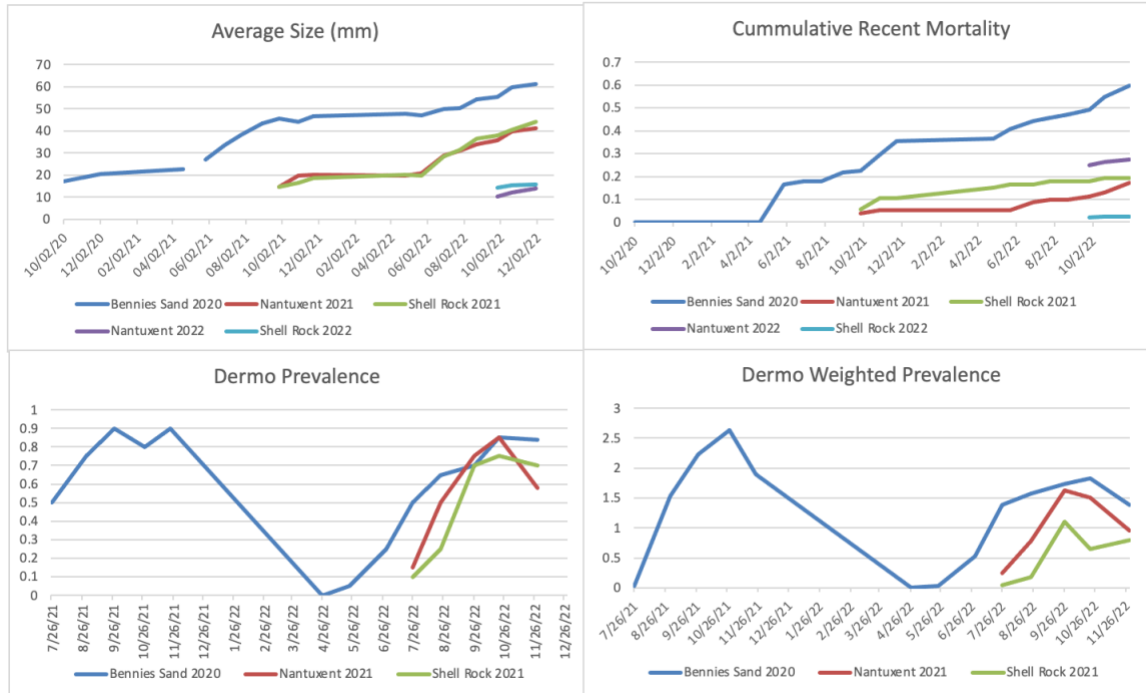
**Figure 5.** Interannual variation in mean shell height of oysters collected monthly between from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds) sampled from March to November. Samples from 2022 were collected from April to November.

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**Figure 6.** Performance of 2021 and 2022 transplants relative to the five bed mean from monthly monitoring sites. Panels arranged as in Figure 3.

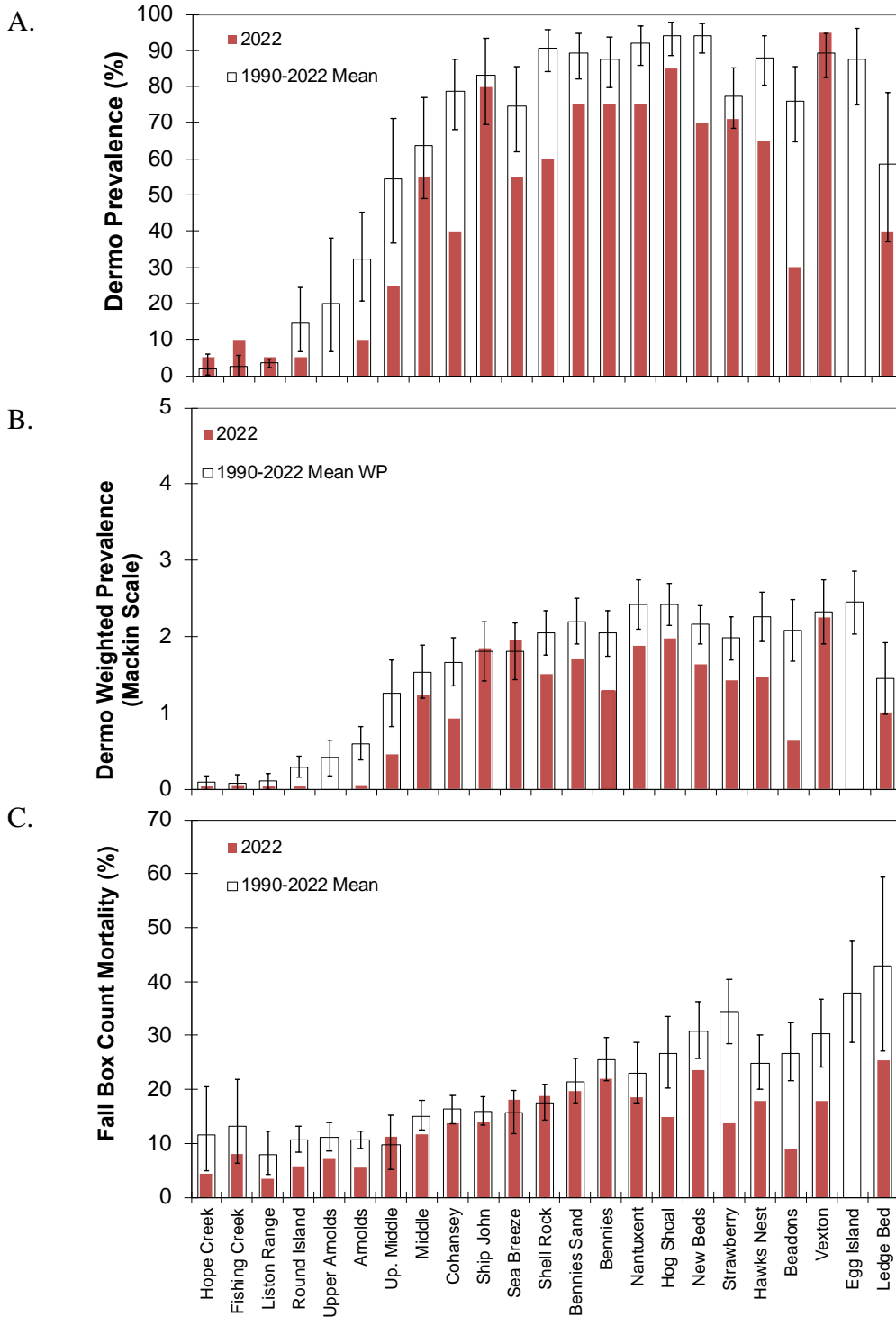
## 2022 Delaware Bay, NJ Oyster Seedbed Monitoring Report



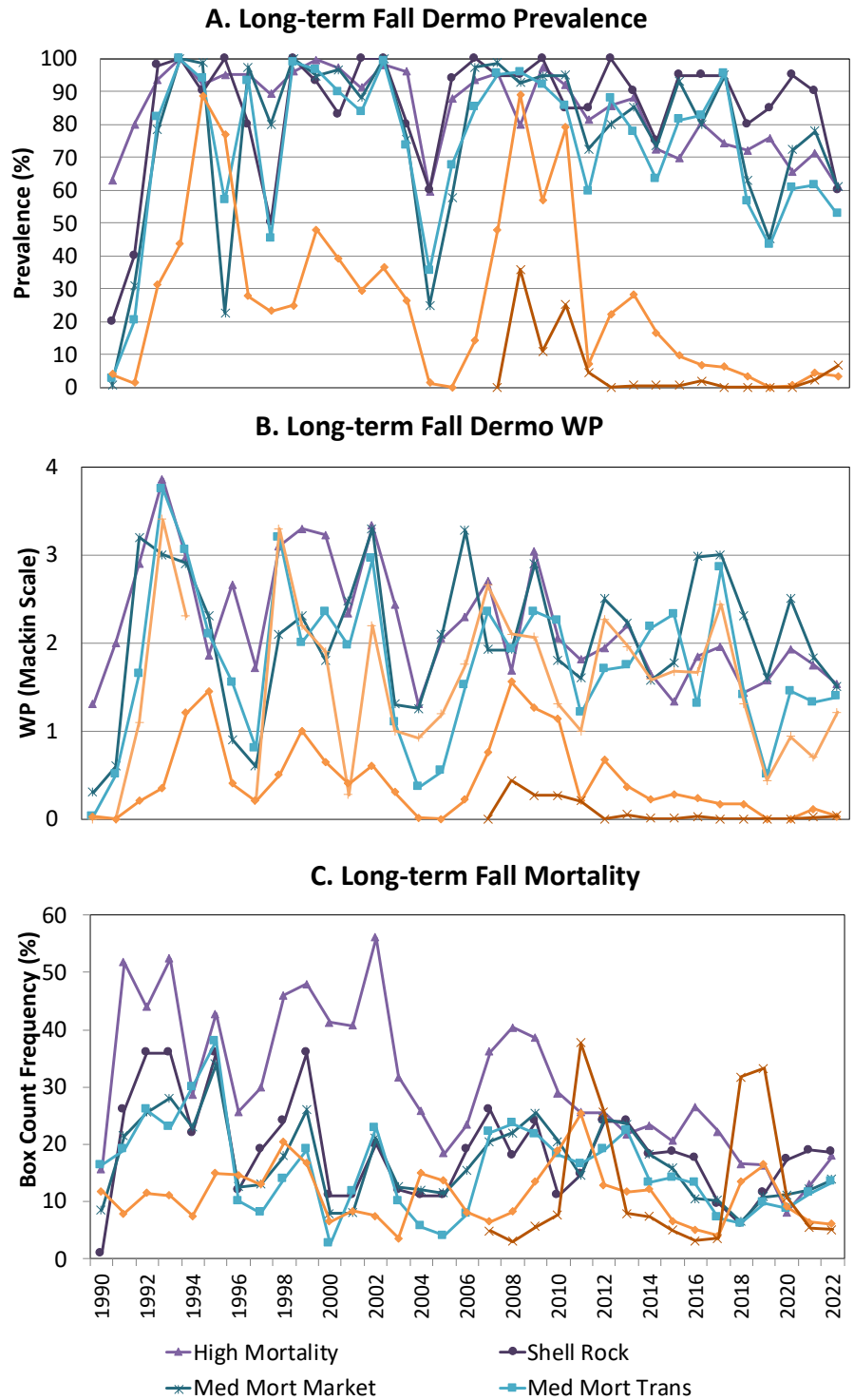
**Figure 7.** Performance of shellplants monitored during 2022. Monitoring for growth and mortality began in September during the year of the plant. Dermo monitoring began in July following the year of planting.



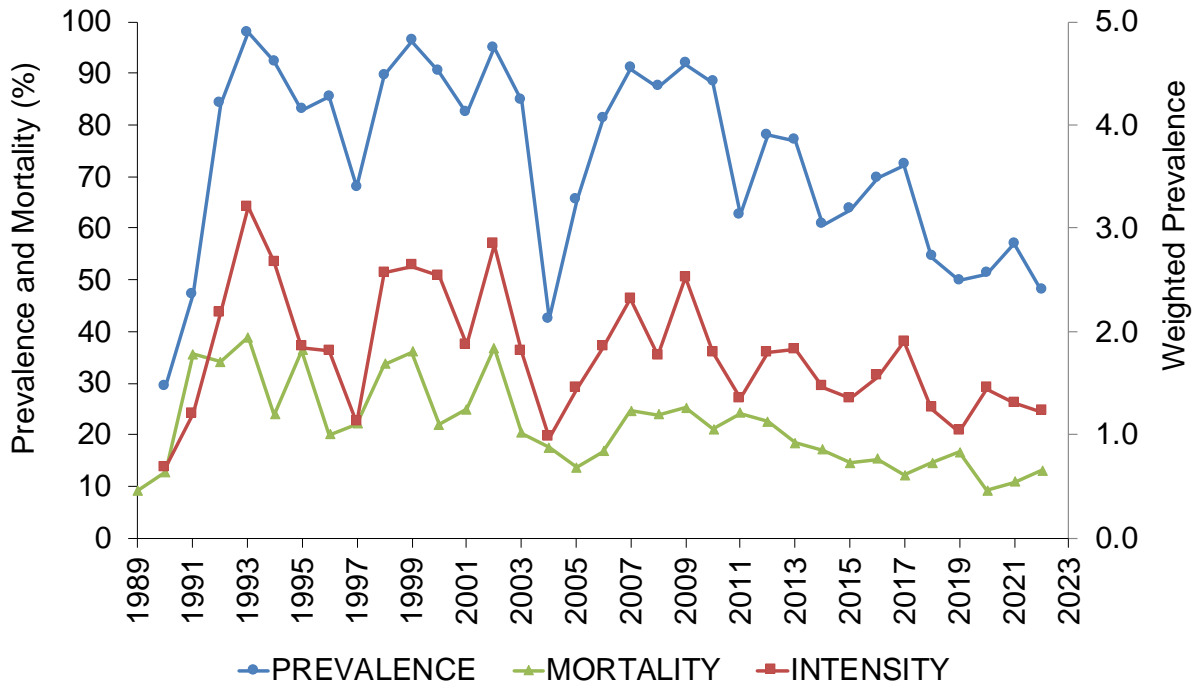
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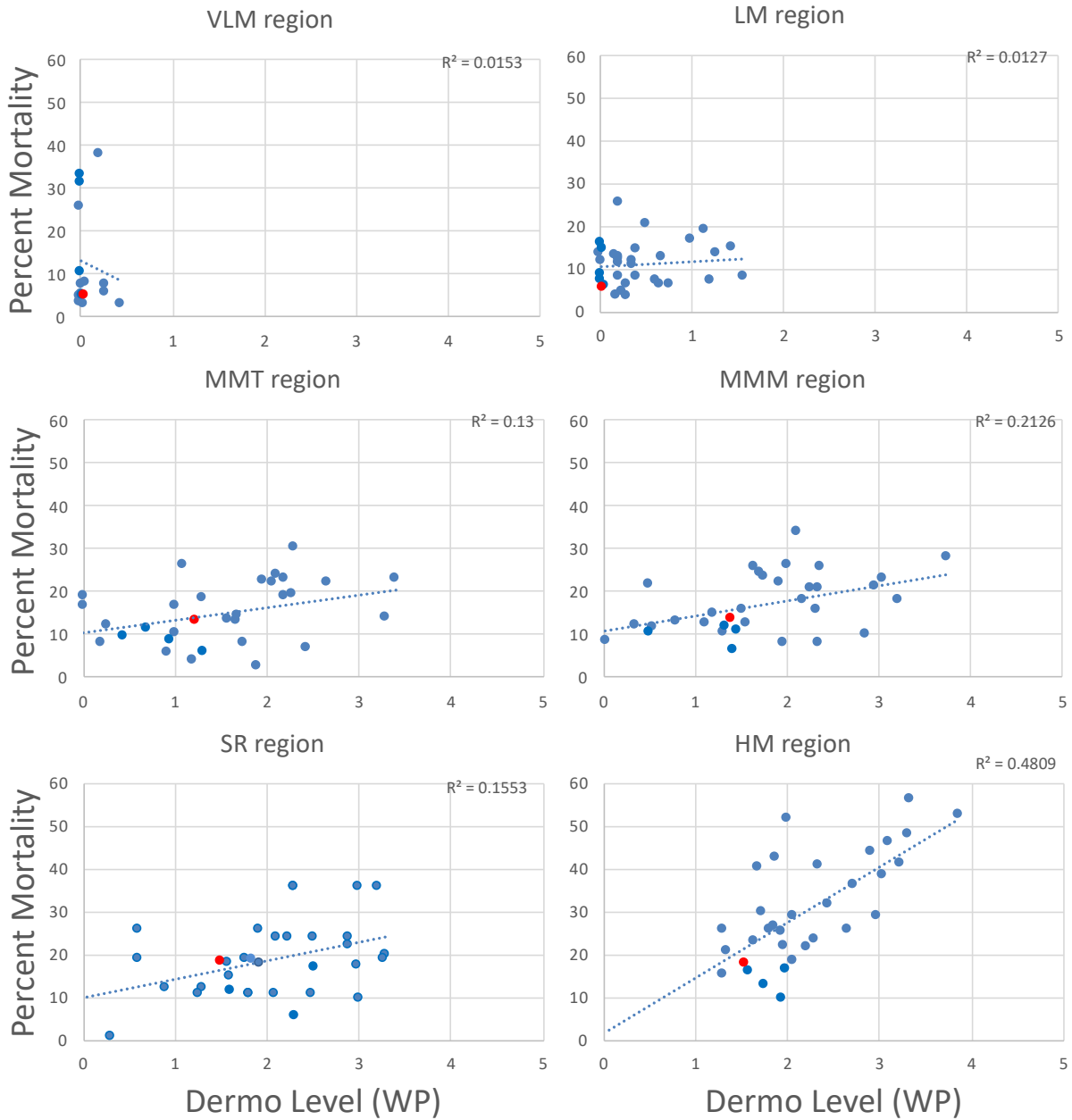
**Figure 8.** Long-term spatial patterns of dermo prevalence (A), dermo weighted prevalence (B) and natural mortality (C) across the oyster beds. From left to right, beds are listed upbay to downbay. Not all beds have been sampled every year (see Table 3). Egg Island was not sampled in 2020. Error bars represent 95% confidence intervals.



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

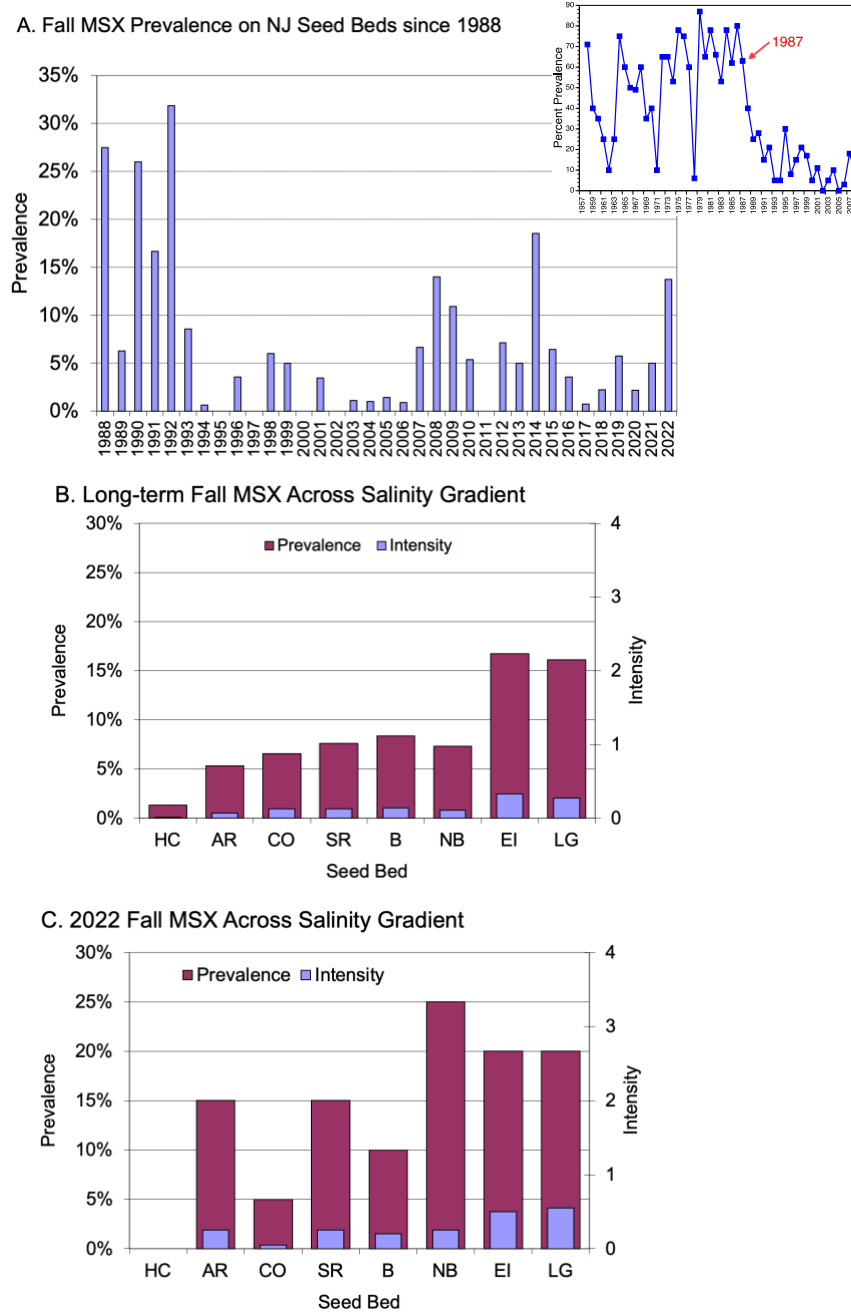


**Figure 10.** Long-term patterns of Fall dermo prevalence, intensity (weighted prevalence) and mortality averaged across the five beds monitored since 1990 (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). These data show cycles of dermo dampening over time.



**Figure 11.** Region mortality as a function of dermo disease levels since 1990 (2007 for the VLM region). Red points represent 2021 data. VLM = Very Low Mortality region, LM = Low Mortality region, MMT = Medium Mortality Transplant region, MMM = Medium Mortality Market region, SR = Shell Rock, and HM = High Mortality Region.

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**Figure 12.** 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 for comparison from 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. 2022 Fall MSX prevalence and intensity across seedbeds. HC = Hope Creek, AR = Arnolds, CO = Cohansy, SR = Shell Rock, B = Bennies, NB = New Beds, EI = Egg Island, LG = Ledge.