Delaware Bay New Jersey
Oyster Seedbed Monitoring Program
2015 Status Report

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Prepared by

David Bushek, Iris Burt and Emily McGurk
Haskin Shellfish Research Laboratory
New Jersey Agricultural Experiment Station
Rutgers, The State University of New Jersey
6959 Miller Avenue, Port Norris, NJ 08349

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Executive Summary

The Delaware Bay NJ Oyster Seedbed Monitoring Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds to provide information in support of the sustainable management of the oyster resource and harvest. Oyster production on privately owned leases or in closed waters was not monitored by this program during 2015. The 2015 Program followed Dermo disease, oyster growth, and oyster mortality at six monthly monitoring sites, two transplant sites, and ten shell plants (three from 2013 and four from 2014 and three from 2015). Three additional sites were monitored in conjunction with the Delaware Bay Channel Deepening project. The program also continued its long-term disease analysis for the annual Fall Oyster Stock Assessment Survey by collecting condition indices and Dermo disease data from 22 seedbeds as well as MSX disease data from seven fixed monitoring sites.

Temperature and salinity, the dominant environmental factors controlling oyster growth, reproduction, disease and mortality, followed average seasonal cycles and were generally at average levels during the year. Growth was good on shell plants, but mean size increased indicating a possible return to a potentially unstable size/age distribution dominated by larger older animals. Dermo disease levels also followed typical seasonal and spatial patterns at average levels over the course of the year except intensities were lower than average on the lower bay, high mortality beds. These conditions appeared to provide for higher than average survival and may partially account for the increase in average size.

Long-term annual patterns continue to indicate a dampening of the Dermo disease cycling that began in 1990. Perhaps most intriguing is the reduction in both disease and mortality on the lower bay, high mortality beds. This pattern may reflect a density-dependent response from a reduction in abundance on those beds, the development of some level of resistance, environmentally favorable conditions, or a combination of these and other factors. Regardless, it bodes well for the population and the fishery in the coming year. MSX was present, but remains at low levels in the native population which continues to maintain a relatively high level of resistance to this otherwise devastating oyster pathogen. Continued vigilance is warranted for the natural beds, but it is suggested that efforts expand to the leased grounds where aquaculture production is expanding and where there is potential for reviving traditional shell planting possibly combined with remote setting of spat on shell.

Introduction

The Delaware Bay Oyster Seedbed Monitoring Program tracks disease, growth and mortality of oysters on the Delaware Bay, New Jersey public oyster beds. The purpose is to provide information that supports the management of the oyster resource for sustainable harvest. Oyster production that occurred on privately owned leases or in closed waters was not monitored by this program during 2015. Monthly monitoring occurs at selected sites along a transect spanning the salinity gradient across the beds. Additional sites are included where there is a need to evaluate management activities such as transplanting and shellplanting. Monthly reporting to the Delaware Bay Section of the New Jersey Shell Fisheries Council provides timely information on seasonal changes for management and harvest needs. A spatially comprehensive sampling occurs during the annual Delaware Bay New Jersey oyster stock assessment in the Fall. Together, these data provide insight into inter-annual patterns, long-term trends, and factors affecting the oyster stock that can be used to assist with managing the oyster stock.

Oyster mortality on the Delaware Bay oyster beds is caused by a variety of factors including predation, siltation, freshets, disease and fishing. Since the appearance of *Haplosporidium nelsoni* (the agent of MSX disease) in 1957, disease mortality has been the primary concern (Powell et al. 2008). Following a severe and widespread MSX epizootic in 1986, the Delaware Bay population as a whole appears to have developed significant resistance to MSX disease (Ford and Bushek 2012). Nevertheless, routine monitoring continues to detect the MSX parasite in Delaware Bay and naïve oysters quickly succumb to the disease indicating that virulence remains high. In 1990, an epizootic of Dermo disease occurred; a form of perkinsosis in the eastern oyster *Crassostrea virginica* that is caused by the protozoan *Perkinsus marinus*. This was not the first occurrence of *P. marinus* in Delaware Bay, but previous occurrences were associated with importations of oysters from the lower Chesapeake Bay (Ford 1996). Termination of those importations resulted in the virtual disappearance of the disease. The 1990 appearance of Dermo disease was not associated with any known importations but was related to a regional warming trend after which the documented northern range of *P. marinus* was extended to Maine (Ford 1996). Dermo disease has remained a major source of oyster mortality in Delaware Bay since 1990 and a primary concern for managing the oyster fishery and the oyster stock (Bushek et al 2012).

Since the appearance of Dermo disease in 1990, average mortality on the seedbeds, as assessed by total box counts during the fall survey, has fallen into 3 major groups: low mortality seedbeds (formerly called the upper seedbeds), medium mortality seedbeds (formerly called the upper-central seedbeds), and high mortality beds (formerly called central and lower seedbeds). These designations correspond to increases in salinity regime from the low to high mortality beds. A group of beds above the low mortality region was added to the survey in 2007 after reconnaissance indicated that their abundance represented a significant proportion of the natural population and should therefore be included in the overall management of the fishery. These beds were collectively designated Hope Creek in 2007, but were subsequently subdivided into Hope Creek, Fishing Creek and Liston Range, collectively referred to as the very low mortality beds although they periodically experience very high mortality in response to freshets such as that following tropical storms Irene and Lee in 2011 (Munroe et al. 2013). Current area management strategies separate Shell Rock from the original medium mortality region and further subdivide the remaining beds into Medium Mortality Transplant and Medium Mortality Market beds (Figure 1). Additional details on management strategies and actions are available in the Annual Stock Assessment Workshop reports at http://hsrl.rutgers.edu.

The majority of fresh water entering the system comes from the Delaware River and tributaries located above the oyster beds, however, inputs from several tributaries that enter the bay adjacent to the seedbeds (Hope Creek, Stow Creek, Cohansey River, Back Creek, Cedar Creek and Nantuxent Creek) combine with the geomorphologic configuration of the shoreline to influence salinity, nutrients, food supply, circulation and flushing in complex ways. These factors undoubtedly interact to influence disease transmission dynamics, larval dispersal, oyster growth and recruitment, and, ultimately, disease mortality. Continued long-term spatial monitoring as well as directed research and sampling efforts are necessary to understand these dynamics and how they change through time.

The temporal and spatial sampling efforts of the Oyster Seedbed Monitoring Program are designed to continually develop a better understanding of factors influencing oyster growth, disease and mortality patterns to support adaptive management efforts. As funding permits, these efforts include monitoring transplants (i.e., oysters moved from upper to lower seedbeds), shell plants (i.e., shell placed directly on the seedbeds to increase the supply of clean cultch for recruitment), and replants (i.e., cultch planted in the lower bay high recruitment zone near the Cape Shore then moved and replanted on the seedbeds). The 2015 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
2. Conduct Dermo and MSX assays and determine condition indices for each bed sampled during the 2015 Fall Stock Assessment Random Sampling Survey
3. Monitor growth, disease and mortality on 2013 through 2015 shell plantings
4. Monitor growth mortality and disease on the 2015 intermediate transplants

Objectives 1 and 2 comprise the basis of the long-term program that provides fundamental information necessary for both immediate and long-term adaptive management of the resource. These objectives also provide essential baseline/background information against which the success of other objectives and independent research can be evaluated. Objective 1 began in 1998 with five beds (Arnolds, Cohansey, Shell Rock, Bennies and New Beds). In 2007 Hope Creek was added as part of the monthly monitoring program. Objective 3 was initiated as part of the Delaware Bay Oyster Restoration program designed to enhance recruitment on the seedbeds. Shell planting is an annual effort of the management plan for sustaining and rebuilding the oyster beds, scaled by available funds. Objective 4 examines the performance of the intermediate transplant program that moves oysters downbay from upbay beds. This activity provides access to a portion of the resource that is otherwise unavailable to direct market harvest and helps to replenish a portion of the previous years harvest.

Methods

Figure 1 depicts the grid system used during 2015 for the monitoring program with area management regions distinguished by color. Management activities and this report reference both regions and beds as appropriate. Beds that fall within the jurisdiction of the state of Delaware are neither monitored nor shown. The grid system is contiguous, but only those areas containing significant concentrations of oysters (= beds) are shown (n = 23). Each bed is referenced by the name traditionally used by the industry and resource managers. On any given bed, grids of the highest density that collectively contain 50% of the oysters from the bed are indicated with darker shading and referred to as 'high quality' strata. Grids containing the next 48% of the population ranked by density are referred to as 'medium quality' and indicated in lighter shading. Grids not shown surrounding each bed contain the lowest density of oysters if they contain any oysters at all and collectively amount to no more than 2% of the population on their respective bed. Additional details on bed quality designations are provided in Powell et al. (2008).

Monthly samples were collected from April through November for Objectives 1, 3 and 4 as indicated in Tables 1 and 2. Table 3 shows which beds have been monitored since 1990 as part of the long-term Dermo monitoring program that is affiliated with the Annual Fall Oyster Stock Assessment. Table 4 specifies the grids sampled during the 2015 Annual Fall Oyster Stock Assessment to complete Objective 2.

To complete Objective 1, three one-minute tows with a 0.81 m (2.7 ft) oyster dredge were collected at each site using about 14 m (46 ft) of cable from the R/V James W Joseph. Bottom water temperature and salinity were recorded with a handheld YSI® Pro2030 Dissolved Oxygen, Conductivity, Salinity Instrument at each site. A composite bushel (37 L total volume with one third coming from each dredge tow[1]) was created and then sorted to enumerate gapers (= dead oysters with meat remaining in the valves), boxes (= hinged oyster valves without any meat remaining) and live oysters. Boxes were further categorized as new (= no indication of fouling with little sedimentation inside valves) or old (= heavily fouled and/or containing extensive sediments) to provide an indication of recent mortality. These data were used to estimate mortality as described by Ford et al. (2006). Up to one hundred randomly selected oysters from the composite bushel were returned to the laboratory where shell heights (hinge to bill) were measured to determine size frequency in the population. 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 of smaller animals when they attach to one another. Twenty individuals representing the size frequency distribution were then sacrificed for Ray's fluid thioglycollate medium assay (RFTM, Ray 1952, 1966) to determine prevalence and intensity of Dermo infections. The percent of oysters in the sample with detectable infections is termed the prevalence. Each infection was then scored using the "Mackin scale" from zero (= pathogen not detected) to five (= heavily infected) (Ray 1954,). These values, including zeros, were averaged

[1] At Arnolds and Hope Creek, total sample volume was only one half bushel.

to produce a 'weighted prevalence' (Mackin 1962), which provides an estimate of the average disease level in the sample of oysters (Dungan and Bushek 2015). The average intensity of infections was similarly determined but did not include any oysters in which infections were not detected. Sex was determined histologically for each oyster sacrificed for Dermo analysis during May, June, July and August.

Samples for Objective 2 were collected during the Fall Stock Assessment using the commercial oyster boat H. W. Sockwell. The stock assessment survey consists of a stratified random sampling of the medium and high quality grids on the 23 named beds (colored grids in Figure 1). Ledge and Egg Island beds contain very few oysters and are only sampled in alternate years; Egg Island was sampled during 2015. 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 Objective 3, samples were collected monthly from April through November (Table 1) for sites manipulated as indicated in Table 2. The Middle replant sites were part of the ATHOS I oil spill mitigation project and suffered from poor sets downbay as well as drifting of replants across multiple grids making recovery for sampling difficult at best. All these sites were monitored as described for objective 1.

The shell planting program began in 2005 to enhance recruitment on the seedbeds after several consecutive years of recruitment failures. The program has successfully increased recruitment (see previous annual stock assessment reports) and because the planted shell (ocean quahog or surf clam shell) is traceable through time, it provides an opportunity to obtain specific data on growth and mortality of young animals (age class 0-2). Shell plant samples for objective 4 continued the 2013 and 2014 shell plantings, and initiated the 2015 shell plantings listed in Table 2 – the latter of which was only sampled during the final 3 months. On each site, at least three and up to five 1-minute dredge tows were systematically searched on deck for planted shell containing live or dead oysters until 100 live oysters attached to planted shell were collected. All boxes and gapers encountered during this process were collected. In some instances, five tows were insufficient to collect 100 oysters, but time limitations precluded devoting additional effort to any one site and this was often the case on the Middle bed replants. Care was taken to search systematically and avoid sampling bias by working systematically through the sample until 100 live spat or oysters were collected. Boxes were enumerated and categorized as new or old as described above. Live oysters attached to planted shell were returned to the laboratory for size measurements (n = 50-100 per site). No disease sampling was performed on the 2015 shell plants. Disease sampling commenced immediately on the 2013 shell plants and in July on the 2014 shell plants.

Results and Discussion

Data obtained from the USGS stream gages indicated a sustained pulse of fresh water following melting of ice and winter snow pack along with a rainy spring. A second large pulse resulted from a wet June peaking in early July. (Figure 2). Increased runoff lowers salinity and decreases residence time potentially flushing free-living pathogens down bay.

Temperature. Water temperatures measured during 2015 collections followed a typical seasonal increase and decrease with a peak in July and little spatial variability across the seedbeds (Figures 3A and 4A). Temperatures increased more rapidly than usual in May and June followed by near average levels throughout the rest of the year.

Salinity. Salinity followed a typical spatial pattern, increasing from upbay to downbay beds (Figure 3B), but mid-summer levels were well below average (Figure 4B), likely associated with the peak river discharge shown in Figure 2. Reductions in salinity are commonly associated with reductions in both Dermo and MSX. By Fall, runoff had declined significantly and salinity had risen above long-term levels.

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

Oyster size. Shell height (measured hinge to bill) roughly corresponds to age and therefore provides insight into both the size and age structure of the population. Seasonal changes in mean shell height may be affected by growth, recruitment and mortality (both natural and fishing mortality). Mean size data (shell height) collected during 2015 show relatively stable patterns with slight increases on the lower bay beds during the year (Figure 3C). Average shell height increased strikingly in the latter part of the year with residual values near or above one standard deviation of the long-term mean (Figure 4C). Overall, shell heights were above the long-term means that have been increasing following an extended period of low recruitment in the early-mid 2000s.

Disease. Dermo prevalence (the percent of the population with detectable infections), weighted prevalence (WP; the average intensity of Dermo in the population, including unifected oysters) and intensity (the average level of infections) followed typical patterns. That is, all three increased from spring to fall and from upper bay beds to lower bay beds (Figures 3D-F). Average levels across the beds tracked the long-term average in each case (Figures 4D-F). All three measures increased from low values in April and May to peak values in September or October before beginning to decline.

Mortality. Mortality estimated from both total and recent box count frequencies showed a typical seasonal pattern that was generally lower than average during much of the year (Figure 3G and 4G). As a result, cumulative new box counts remained below the long-term average (Figures 3I and 4I). In most years, cumulative box counts exceed total box counts at the end of the year indicating that total box counts underestimate mortality, but in 2015 total box counts substantially exceeded cumulative box counts (20% vs 15%; Figures 4G and 4I) suggesting a higher level of survival than on average. Regardless of which measure is used, the Annual Delaware Bay Oyster Stock Assessment defines 20% mortality as an epizootic. Cumulative mortality figures remained below 15% on all beds monitored during 2015 and total box counts were generally below 20%.

Transplants. Transplants performed similarly to the receiving bed (Figure 6), which is typical during the first year of a transplant. It is recommended that successive years be examined to evaluate the persistence of these enhancement activities on the receiving site. Preliminary data from previous reports indicated increases in disease and mortality on transplant sites after the first year but recruitment may increase on these sites.

Shellplants. Growth on shell plants followed levels from prior years with early growth on the 2015 shell plants being higher than previous years for new plantings (Figure 7A). The apparently higher early performance on Middle results from a very low number on animals recovered and may well be biased towards recovering a few larger individuals (Figure 7; upper panel). Dermo levels increased rapidly during 2015 on both 2013 and 2014 shellplants reaching levels expected to begin causing mortality (Bushek et al. 2012). Dermo was not monitored on 2015 shellplants. Regardless of shellplanting performance in any particular year, shell planting remains one of the most positive management efforts to sustain and increase oyster abundance. Shell planting should be pursued annually and expanded whenever resources permit.

Spawning and reproduction. Spawning temperatures were reached by mid-June and visual observations during monthly dissections for Dermo diagnostics indicated that oysters were in good condition for spawning. Sex ratios of oysters has been a concern due to shifts towards an larger size structure of the population indicating an older overall population structure. Because oysters are protandric, that is some will begin their lives as males then change to females later in life, an older population is likely to have more females present and the distribution of males may be insufficient to maintain adequate fertilization success (Powell et al. 2012b). On the other hand, Dermo tends to have a greater impact on older and larger animals than on younger oysters. An imbalance in the sex ratio can theoretically reduce fertilization success negatively impacting the population. We do not have a mechanism to measure fertilization success, but we can determine sex ratio throughout the year. Results from 2015 indicate that the percentage of oysters with discernable gonad tissue increased from May to June when virtually all animals were in reproductive status, then dropped in in August indicative of a spawning event. Table 5 shows that sex ratios began biased towards females, but largely evened out by the period of pea spawning in July before shifting towards females again in August.

Long-Term Fall Patterns. Examination of Dermo prevalence, weighted prevalence and mortality on a bed-by-bed basis (Figure 8) indicates higher Dermo levels in the middle region of the bay during 2015 compared to the typical pattern that increases from upbay to downbay beds. Although mortality still showed the upbay to down bay increase, values in the middle region of the seedbeds were closer to long-term means than either the upper or lower region. A similar pattern was observed the past two years and its stability suggests that changes in disease dynamics may be occurring across the Bay. In particular, reductions in disease on the lower bay beds are associated with reductions in mortality. It is unclear whether or not this observation is a density-dependent response to reductions in oyster abundance on the lower beds, evidence of the development of resistance by oysters under heavier disease pressure in the lower bay, or a result of changing environmental conditions.

Figure 9 depicts annual Dermo prevalence, weighted prevalence and box-count estimated mortality from 1989 to 2015 by mortality region. Each parameter generally decreases from high to low mortality regions, although prevalence is typically high below the Low Mortality region. Dermo prevalence and weighted prevalence track each other well within and across regions, but mortality patterns on the low and very low mortality regions are distinct from the medium and high mortality regions. Within the high and medium mortality regions, mortality lags disease by about one year. Within the low and very low mortality regions, mortality is nearly out of phase with Dermo disease. Since 1990, there have been two relatively low periods of Dermo disease, most easily seen in 1997 and 2004 on the medium mortality region curve. It looks as though we have entered a period of reduced Dermo intensity and also reduced mortality circa 2003 onward.

Many factors such as temperature, salinity and recruitment are known to influence Dermo disease (Villalba et al. 2004) but the confluence of these factors is difficult to predict. Moreover, while there is some understanding of how these factors influence spatial and seasonal variations in Dermo disease, it is less clear how they interact to influence inter-annual variation. The data continue to indicate an attenuation of Dermo-induced mortality in the three successive epizootics across the medium and high mortality regions (Figure 9). This observation remains difficult to interpret. It could be entirely environmentally driven or it could indicate an increase in tolerance (the relative ability of an oyster to survive an infection of a given intensity) versus resistance (the ability of an oyster to limit the development of an infection) to Dermo disease. Lagged correlations between river flow and WP produce a significant negative correlation (Bushek et al. 2012). As mentioned in previous years, the apparent cycling may be driven by larger regional climate patterns, but this remains a hypothesis.

Because MSX has not been problematic on the seedbeds for nearly two decades, samples from only seven beds along the up- to downbay gradient were examined (Table 4). MSX infections were detected in < 10% of the oysters assayed (Figure 10 upper panel), but infections were spread across several beds (Figure 10 lower panel) indicating that MSX remains a threat to virtually the entire stock. Because MSX continues to be a serious problem in other areas and remains virulent to naïve oyster stocks, monitoring for MSX remains as an important component of the monitoring program to understand sources of mortality from year to year. Moreover, because MSX can cause mortality in Spring, it is recommended that some routine monitoring of MSX occur throughout the year to provide an adequate level of surveillance.

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Table 1. 2015 sampling schedule for the NJ Delaware Bay Oyster Seedbed 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. Additional sites are listed in Table 2. Parameters measured included temperature, salinity, dissolved oxygen, counts of live oysters and boxes, size frequency (shell height), and Dermo levels. All samples were collected from NJDEP R/V James W. Joseph captained by either Jason Hearon[1] or Craig Tomlin[2].

Date	Samples
Apr 29, 2015[2]	long-term (6) + additional ACE (3); shellplant sites: 2013 (3); 2014 (4)
May 18, 2015[2]	long-term (6) + additional ACE (3)
Jun 11, 2015[1]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4)
Jun 22, 2015[2]	long-term (6) + additional ACE (3) sites
Jun 29, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4)
Jul 20, 2015[2]	long-term (6) + additional ACE (3) sites
Aug 5, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4)
Aug 17, 2015[2]	long-term (6) + additional ACE (3) sites
Aug 25, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4)
Sep 23, 2015[2]	long-term (6) + additional ACE (3) sites
Sep 30, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4); 2015 (3)
Oct 20, 2015[2]	long-term (6) + additional ACE (3) sites
Oct 26, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4)
Nov 17, 2015[2]	long-term (6) + additional ACE (3) sites
Nov 23, 2015[2]	intermediate transplants (2); shellplant sites: 2013 (3); 2014 (4); 2015 (3)

Table 2. Additional sites sampled during 2015. Replant = shell planted in lower Delaware Bay then moved to bed indicated after spat have recruited. Transplant = oysters moved from upper bay region indicated to the lower bay bed listed in the first column

Bed	Grid	Plant material	Plant yr
Bennies	110	ocean quahog	2015
Shell Rock	31	ocean quahog	2015
Cohansey	56	ocean quahog	2015
Shell Rock	89	medium mortality transplant	2015
Ship John	34	low mortality transplant	2015
Nantuxent	23	ocean quahog	2014
Shell Rock	31	ocean quahog	2014
Ship John	33	ocean quahog	2014
Middle	28	surf clam shell replant	2014
Shell Rock	29	ocean quahog	2013
Shell Rock	30	ocean quahog	2013
Middle	27/28	surf clam shell replant	2011-2013

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

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

Table 4. 2015 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	61	10		15
Hope Creek	74	10		15
Hope Creek	62			10
Hope Creek	53			10
Hope Creek	63		20	0
Fishing Creek	25	10		15
Fishing Creek	10	10		15
Fishing Creek	16			10
Fishing Creek	26			10
Liston Range	12	10		15
Liston Range	14	10		15
Liston Range	17			10
Liston Range	23			10
Round Island	11	10		16
Round Island	73	10		16
Round Island	26			18
Upper Arnolds	10	10		17
Upper Arnolds	22	10		17
Upper Arnolds	18			16
Arnolds	57	10		15
Arnolds	16	10		15
Arnolds	9			10
Arnolds	43			10
Arnolds	18		20	0
Upper Middle	58	10		15
Upper Middle	63	10		15
Upper Middle	71			10
Upper Middle	64			10
Middle	34	10		15
Middle	45	10		14
Middle	42			10
Middle	37			11
Cohansey	5	10		15
Cohansey	57	10		15
Cohansey	50			10
Cohansey	58			10
Cohansey	44		20	0
Sea Breeze	20	10		17
Sea Breeze	31	10		16
Sea Breeze	46			17
Ship John	42	10		15
Ship John	35	10		15
Ship John	58			10
Ship John	28			10

Bed	Grid	Dermo	MSX	CI
Shell Rock	34	10		15
Shell Rock	1	10		15
Shell Rock	31			10
Shell Rock	24			10
Shell Rock	11		20	0
Bennies Sand	7	10		15
Bennies Sand	37	10		13
Bennies Sand	16			11
Bennies Sand	11			11
Bennies	87	10		15
Bennies	124	10		15
Bennies	135			10
Bennies	103			10
Bennies	110		20	0
Nantuxent	18	10		14
Nantuxent	12	10		15
Nantuxent	13			10
Nantuxent	25			11
Hog Shoal	4	10		15
Hog Shoal	11	10		14
Hog Shoal	19			11
Hog Shoal	1			10
New Beds	24	10		15
New Beds	54	10		15
New Beds	3			10
New Beds	28			10
New Beds	26		20	0
Strawberry	5	10		10
Strawberry	24	10		25
Strawberry	20			11
Strawberry	2,28			4
Hawks Nest	5	10		10
Hawks Nest	2	10		34
Hawks Nest	18			4
Hawks Nest	9			2
Beadons	4	10		16
Beadons	15	10		12
Beadons	3,5			15
Beadons	18			7
Vexton	9	10		15
Vexton	2	10		10
Vexton	11			10
Vexton	3			15
Egg Island	63	20	20	28
Egg Island	77,64,46			4
Total beds	**22**	**22**	**7**	**22**
Total grids	**93**	**43**	**7**	**90**
Total oysters		**440**	**140**	**1070**

Table 5. Sex ratios detected during monthly seedbed monitoring expressed as the percentage of males or females detected in each Dermo sample (n = 20, data are shown as percent). Beds are listed upbay to downbay. Hermaphrodites and individuals whose gender was indiscernible are not shown. Out of the 480 individuals examined (20 per bed per month), two were hermaphrodites and 35 were indiscernible.

	May 18		June 22		July 20		August 17		Overall	
Bed	M	F	M	F	M	F	M	F	M	F
Hope Creek	20	65	40	55	50	50	50	45	40	54
Arnolds	15	60	15	85	35	65	15	85	20	74
Cohansey	40	55	25	75	45	50	40	55	38	59
Shell Rock	40	50	50	50	50	45	25	55	41	50
Bennies	30	40	50	45	50	45	30	65	40	49
New Beds	20	50	30	70	45	55	35	55	33	58
Total	28	53	35	63	46	52	33	60	35	57

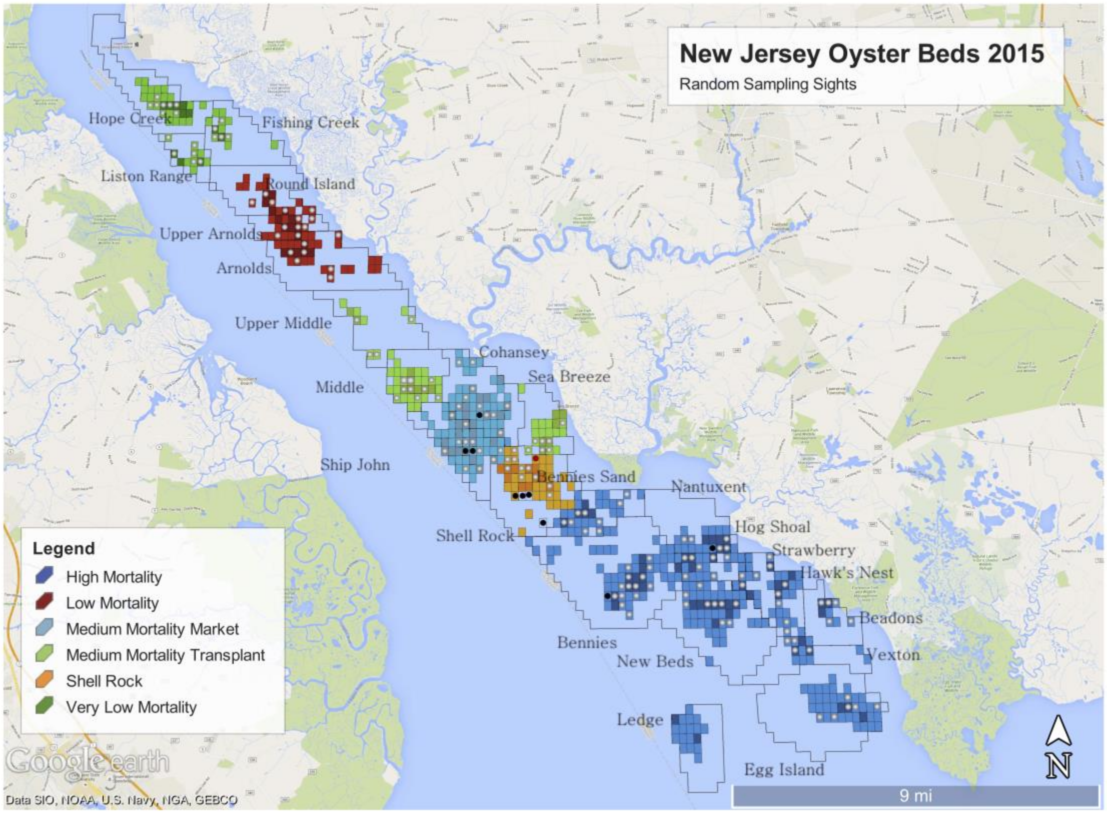


Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka ‘seedbeds’). Lines differentiate different beds with traditional bed names indicated. Colors differentiate boundaries of regions defined by the area management system shown in the figure legend. Grids are 0.2” latitude x 0.2” longitude; approx. 25 acres or 10.1 hectares. Bed footprints show grids from the High (dark shade) and Medium (light shade) quality strata which contain 98% of the population within each bed. Strata designation is described in the text with further details provided in Powell et al. (2008 and 2012a). The sites for the 2015 stock assessment survey are indicated by dots. A stratified random sampling program identified white dots whereas red dots were transplant sites and black dots were shellplant sites. Figure credit P. Woodruff and J. Gius.

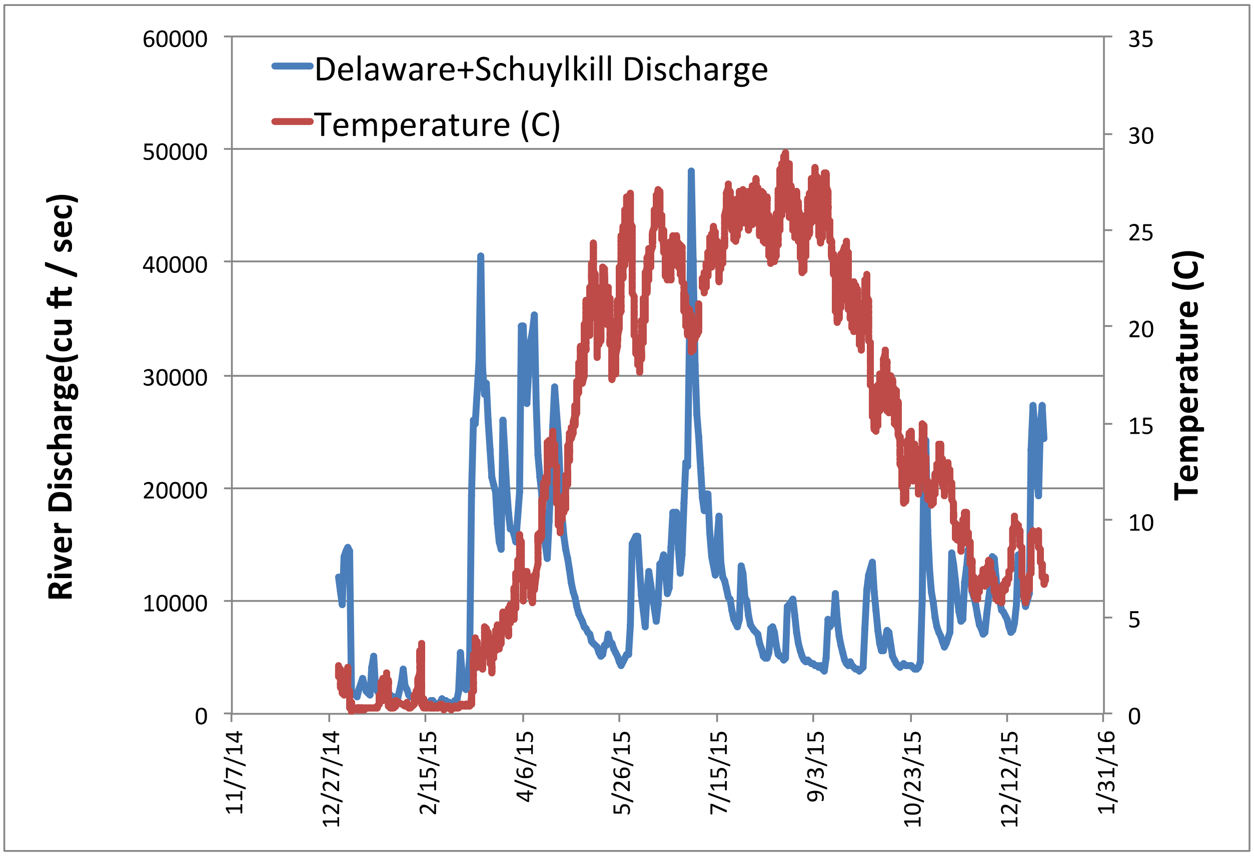


Figure 2. USGS discharge from Delaware River at Trenton and Schuylkill River at Philadelphia with water temperature from Trenton. These two sources provide the majority of fresh water to the Delaware Bay. In 2015, ice formed over the Delaware from mid-January to late February preventing accurate measurements. A large sustained pulse of fresh water resulted from the melting of the ice and winter snow pack. A wet June brought lots of water in early July. This pattern is reflected in the salinity data shown in Figures 3 and 4.

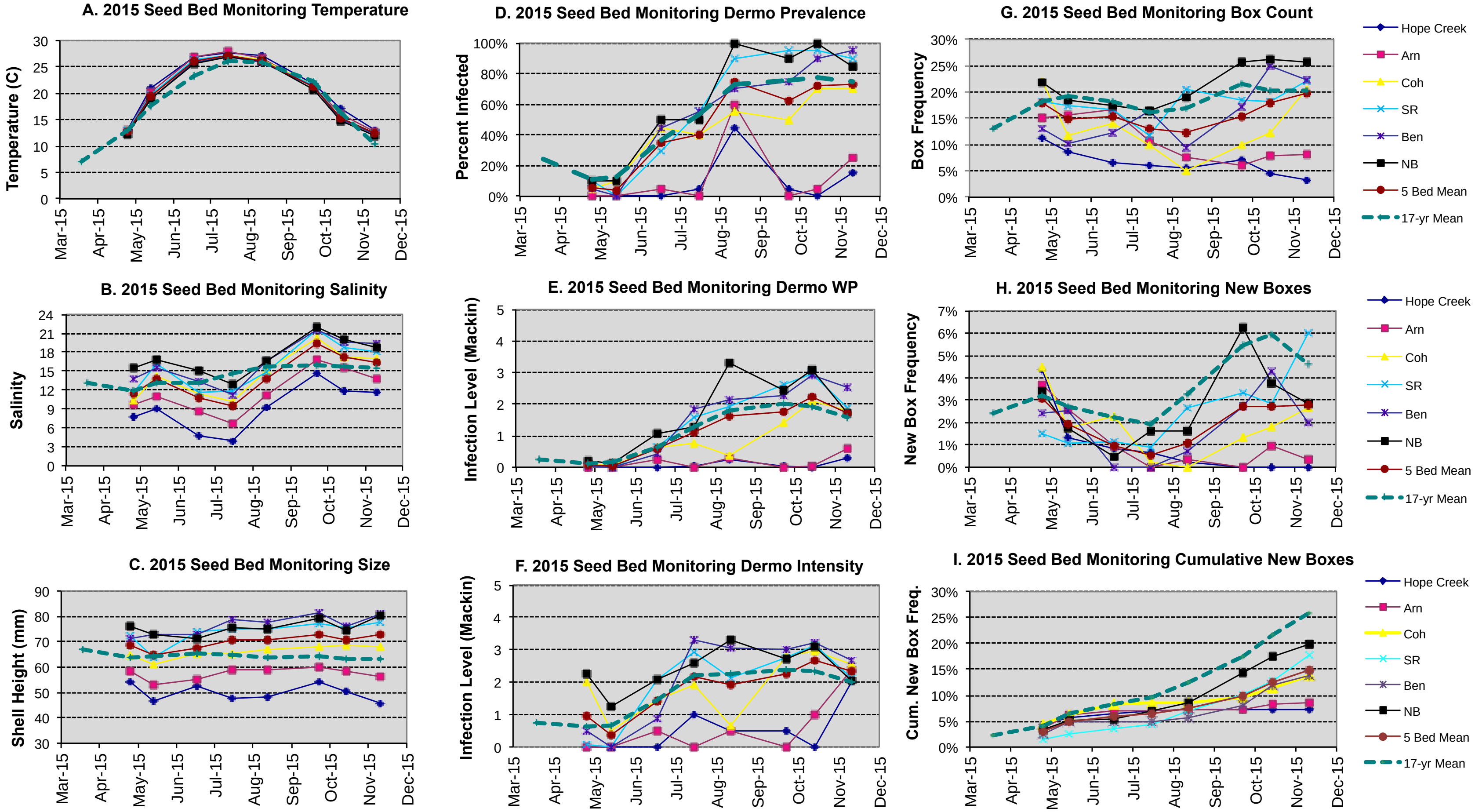


Figure 3. Results of 2015 Seed Bed Monitoring Program for the six primary beds along an upbay to downbay transect. Legends list beds from higher to lower latitude (i.e., up to down bay. Left Panels show temperature, salinity and mean size. Center panels show Dermo levels as overall prevalence (= percent infected), weighted prevalence (average overall population infection intensity), and intensity of detectable infections. Right panels show mortality rates as overall monthly box counts, percent of new boxes (mortality over the past month) and cumulative new boxes across the year. Red circle and line is the average the 6 beds shown. Dashed green line is the average of those same beds since 1999.

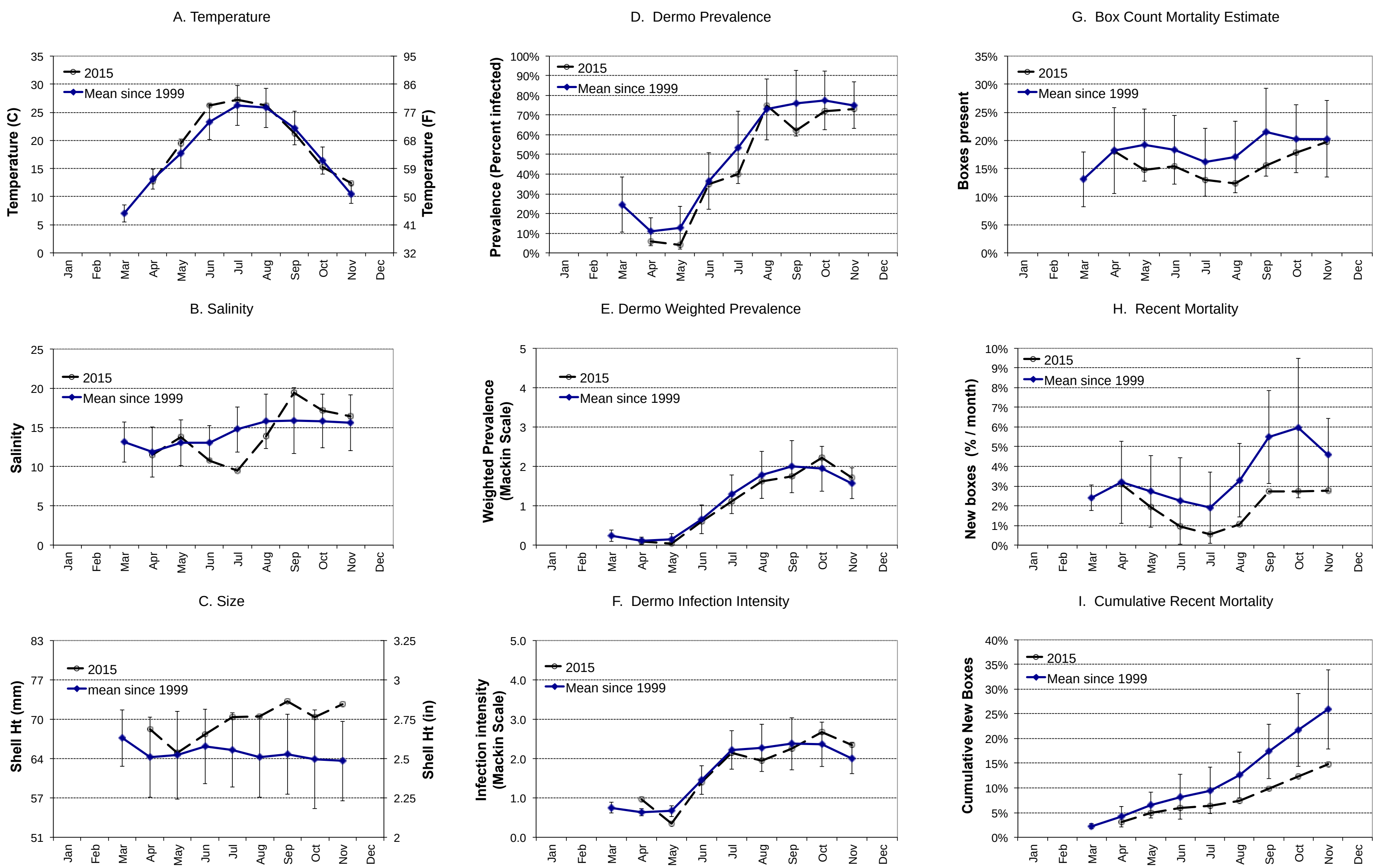


Figure 4. Means of 2015 Seed Bed Monitoring Program for the six primary beds compared to long-term seasonal patterns. Panels arranged as in Figure 3. Error bars represent one standard deviation.

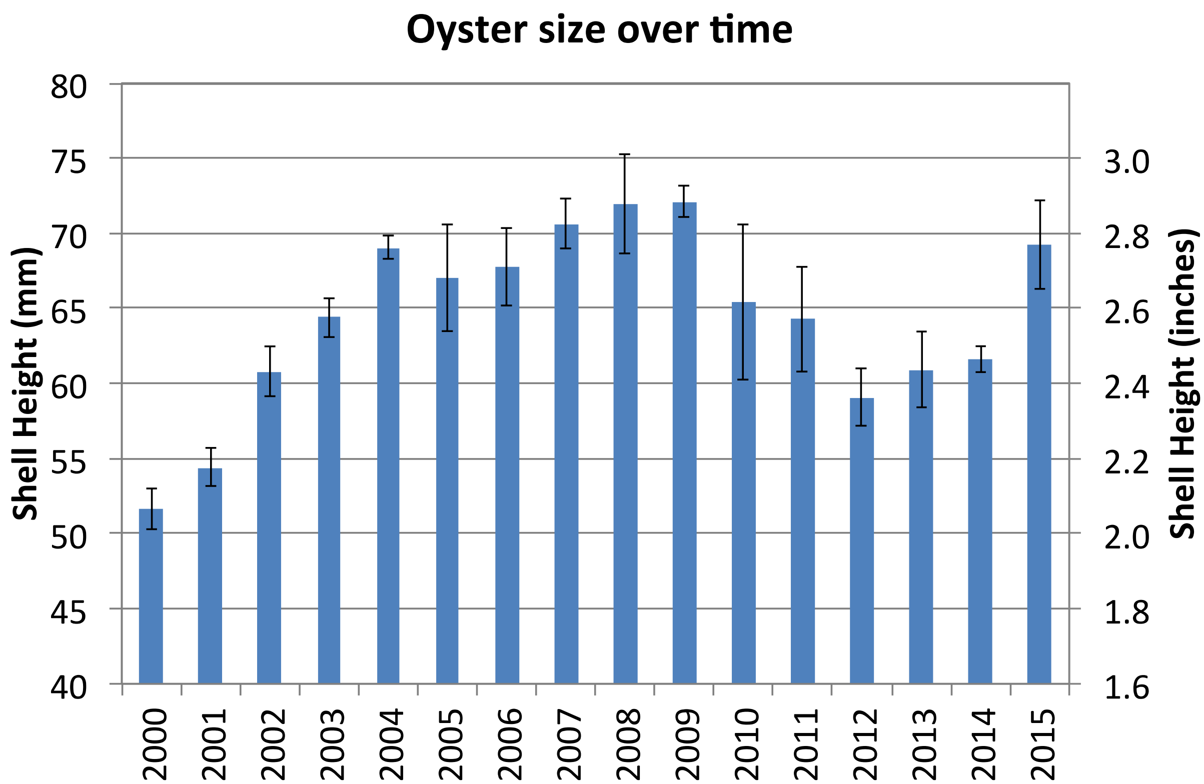


Figure 5. Interannual variation in mean shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds. Error bars represent one standard deviation of the mean of all oysters measured throughout each year. N = 50-100 oysters per month from each of the five primary long-term beds (Arnolds,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

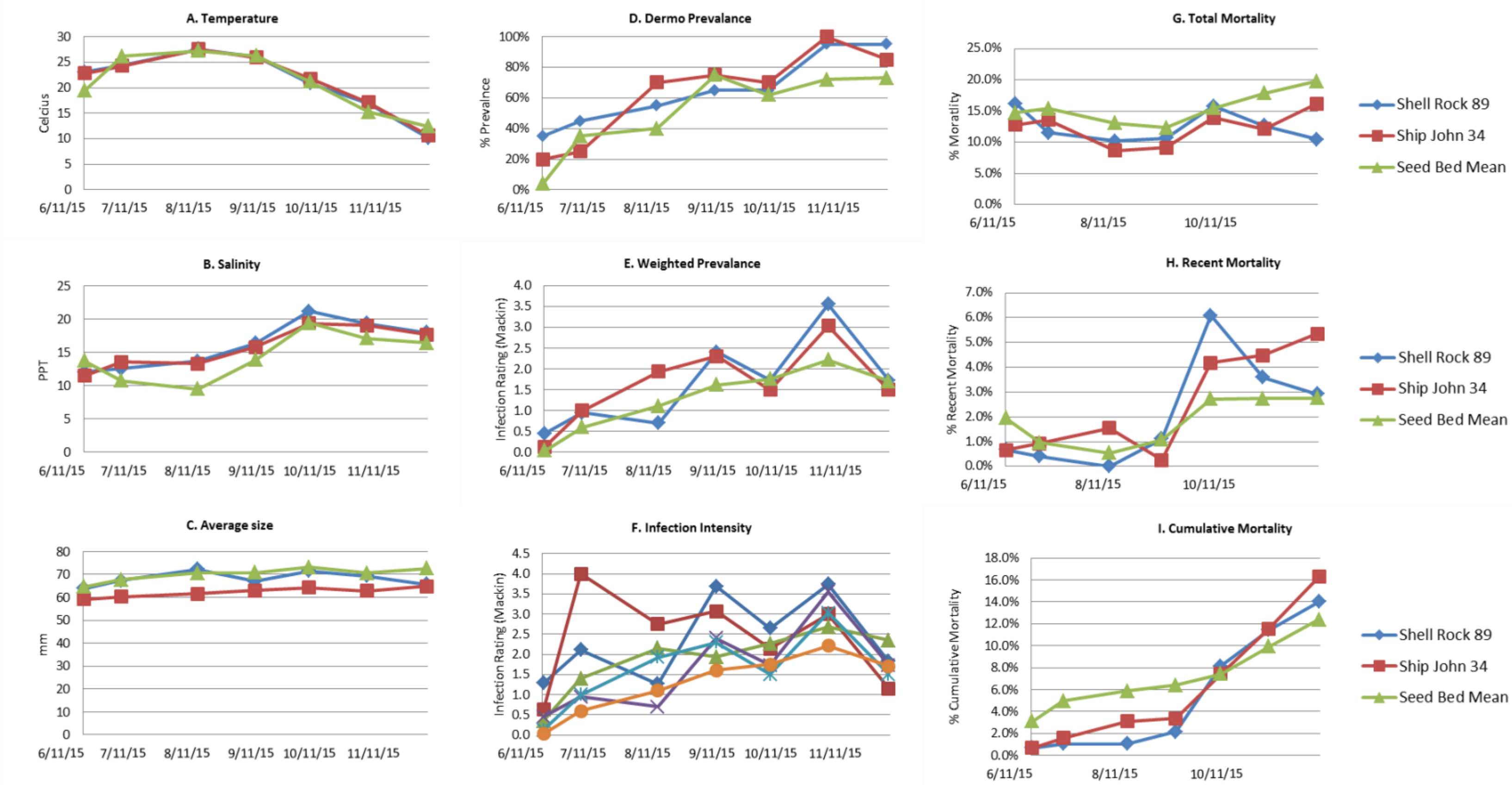


Figure 6. Performance of 2015 Transplants compared to mean of six primary beds. Panels arranged as in Figure 3. Oysters transplanted to Shell Rock were derived from the Medium Mortality Transplant beds while oysters transplanted to Ship John were derived from the Low Mortality beds (see Figure 1).

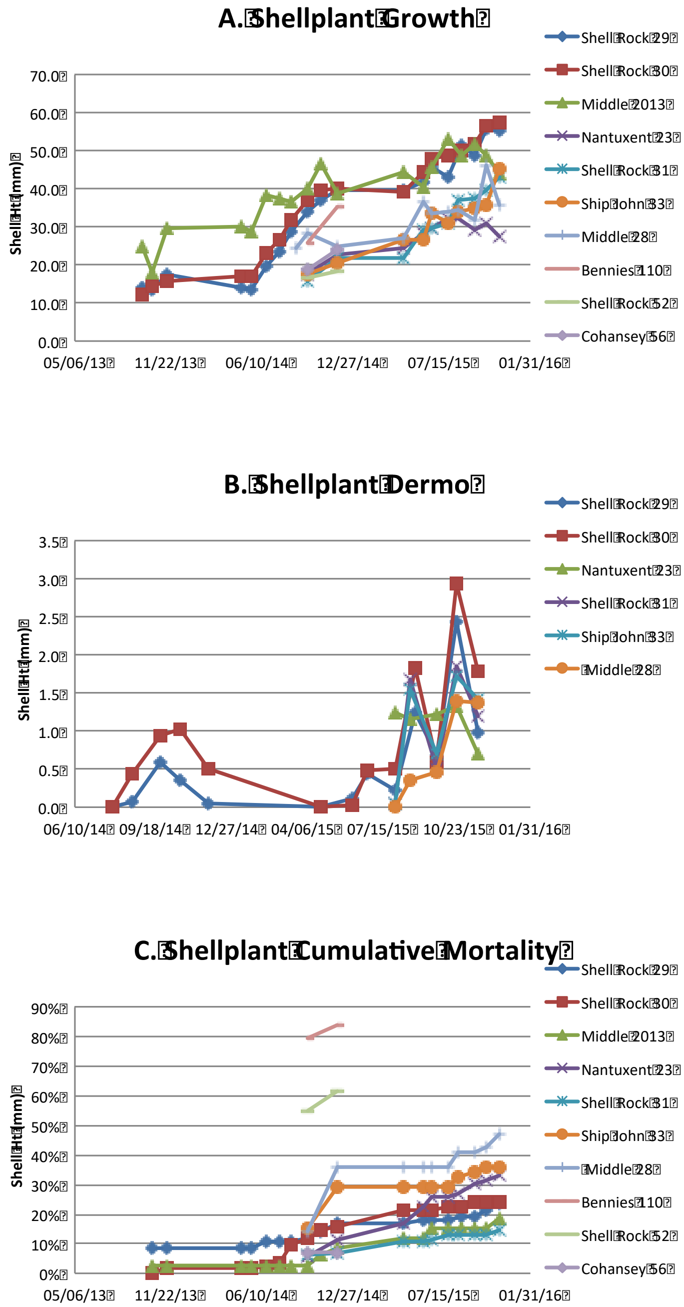


Figure 7. Performance of shellplants monitored during 2015. Shell Rock 29 and 30 were planted in 2013 along with the Middle 28 which was part of the 2013 ATHOS I mitigation planting. ATHOS I plantings began in 2012 and ended up distributed across grids 26-28 on Middle Bed. Nantuxent 23, Shell Rock 31, and Ship John 33 were all planted in 2014 with additional shell added to Middle 28. Bennies 110, Shell Rock 52 and Cohansey 56 were all planted in 2015. Monitoring for growth and mortality began in September or October during the year of the plant with a hiatus from November to April. Dermo monitoring began during July of the year following the year of planting.

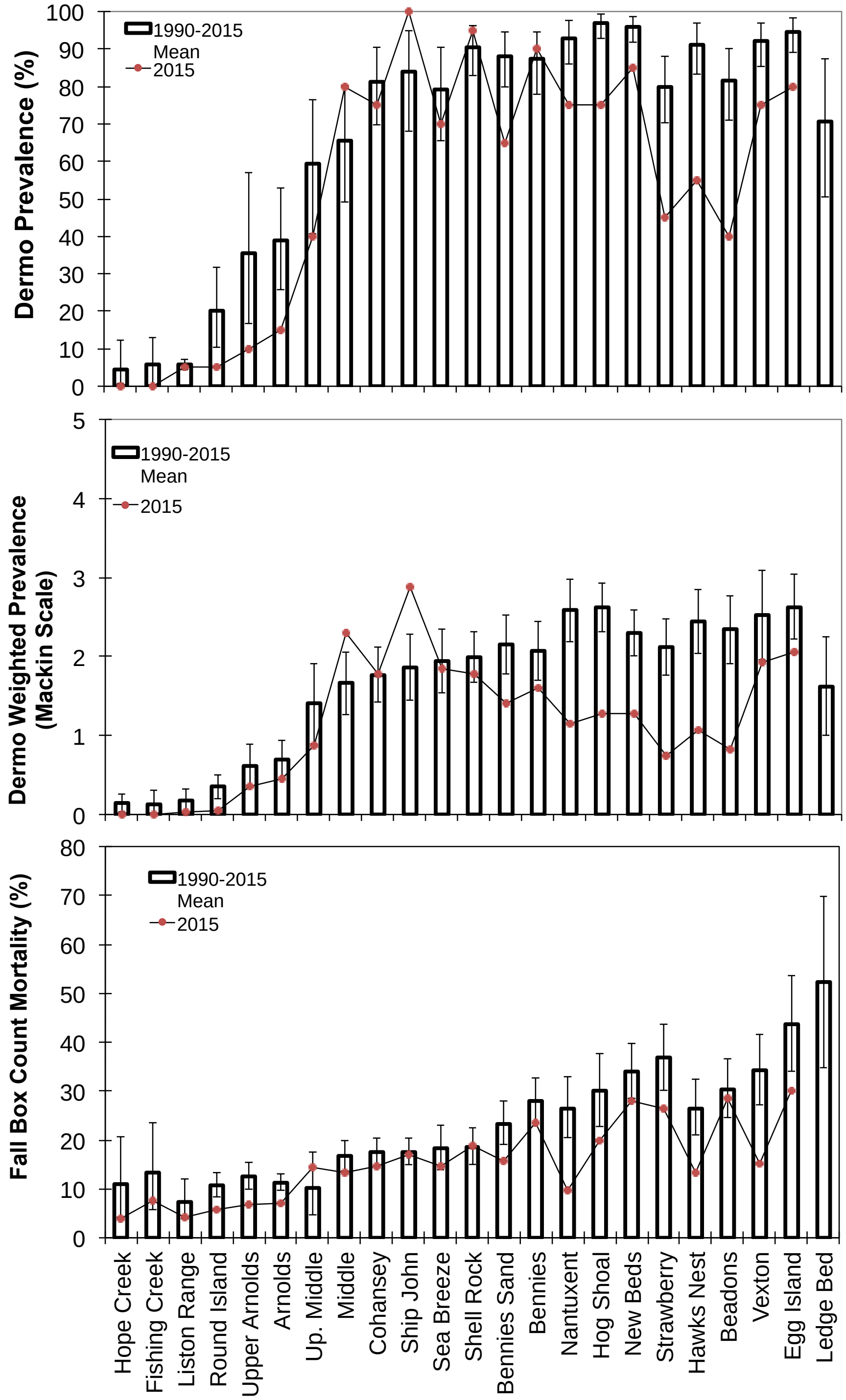


Figure 8. Long-term spatial patterns of Dermo prevalence (upper panel), Dermo weighted prevalence (middle panel) and natural mortality (bottom panel) across the oyster beds. Beds are listed from upbay to downbay left to right. All three metrics increase from upper to lower bay regions. Not all beds have been sampled every year (see Table 5). Ledge Bed was not sampled in 2015. Error bars represent 95% confidence intervals.

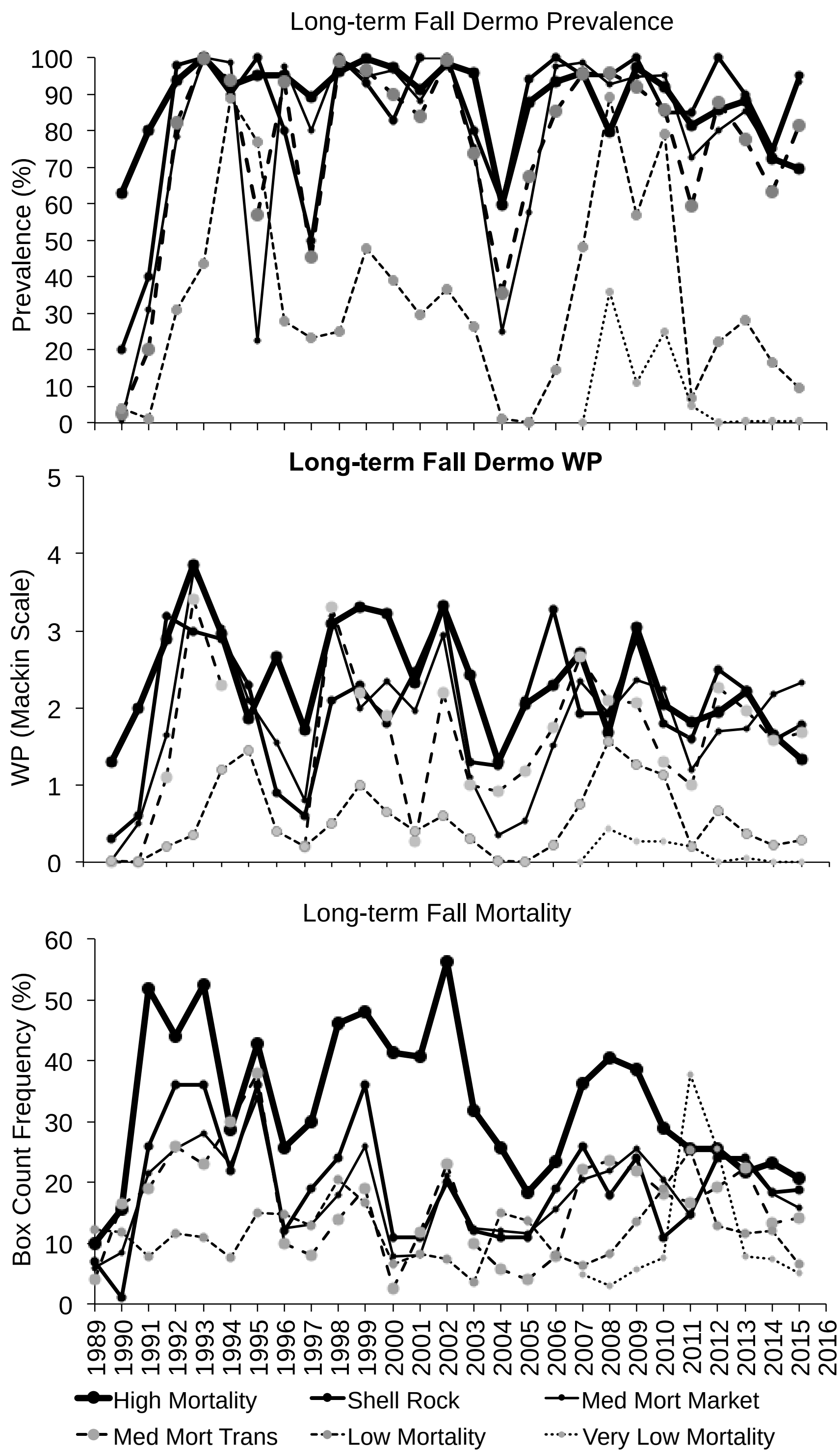
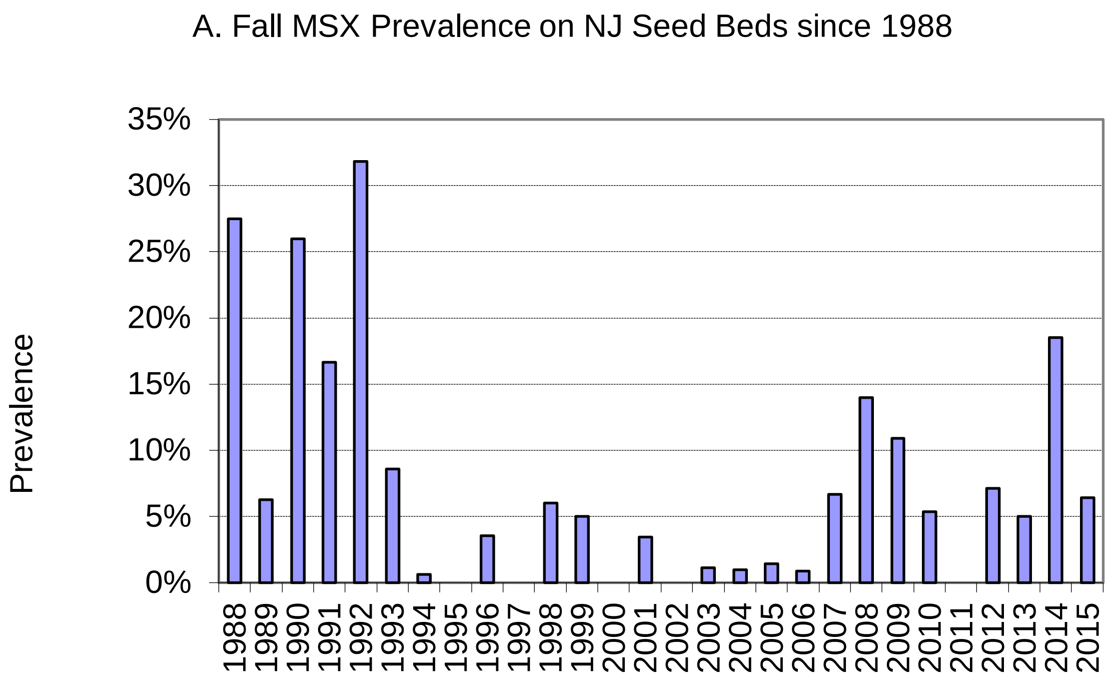


Figure 9. Annual Fall Dermo prevalence (upper panel), weighted prevalence (middle panel) and box count mortality (bottom panel) on New Jersey Delaware Bay seedbeds. Regions correspond to management regions in Figure 1.



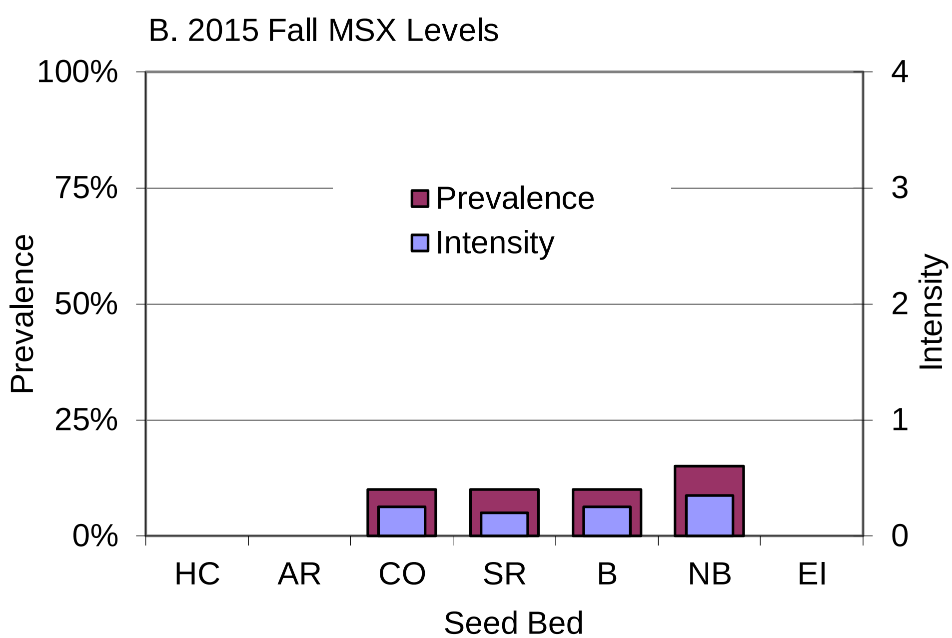


Figure 10. MSX disease on the New Jersey Delaware Bay oyster seedbeds. Upper: annual Fall MSX Prevalence. Lower: Total fall MSX prevalence and intensity (weighted prevalence on a scale of 0 to 4) on selected beds since 1988 (2007 for HC). HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, EI = Egg Island.