Delaware Bay New Jersey
Oyster Bed Monitoring Program
2014 Status Report

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Executive Summary:

The 2014 Delaware Bay New Jersey Oyster Seedbed Monitoring Program followed Dermo disease, oyster growth, and oyster mortality at six long-term monitoring sites, two transplant sites, and nine shell plants (two from 2012, three from 2013 and four from 2014). Three additional sites were monitored in conjunction with the Delaware Bay Channel Deepening project. The program also continued its participation in 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 long-term monitoring sites.

Monthly monitoring data collected during 2014 indicated an average or typical temperature cycle across the seed beds. High levels of freshwater input following a particularly snowy winter depressed salinity during spring, but levels increased during summer to higher than normal levels in fall. These conditions have been associated with reduced levels of disease and disease related mortality, which certainly was the case this year as well. Dermo disease levels remain high on the medium mortality beds as well as Shell Rock. Analyses of existing data regarding oyster size, population density and harvest activities should be examined to identify any associations. MSX levels remain low, but continue to increase slowly and high spring levels of MSX from oysters in the lower portion of Delaware Bay were reported in a separate project. These observations warrant concern and indicate a need to expand MSX monitoring beyond the fall survey.

Prognosis: Physical conditions favored growth and survival of oysters over disease and mortality during 2014. Low levels of both disease and mortality help to explain the increased abundance and stability of market-size oysters in the face of otherwise low recruitment rates. These conditions do not signal imminent problems for the oyster population in the coming year so long as environmental conditions remain near average levels. Environmental conditions replicating 2014 should bode well for the oyster population. Nevertheless, MSX continues to linger in the background while Dermo continues to pose the primary threat. The resilience of both diseases has been evident when conditions that are conducive to their spread and intensification occur. As a result, one cannot become complacent to the risk of future disease epizootics.

Introduction

The Delaware Bay Oyster Bed 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 2014. 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 Shell Fisheries Council provides timely information on seasonal changes for management and harvest needs. A spatially comprehensive sampling occurs during the annual Fall Stock Assessment. 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. 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.

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 (Figure 1): 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. Beds above Round Island were 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 three beds: Hope Creek, Fishing Creek and Liston Range. These uppermost beds are frequently referred to as the very low mortality beds, although a major freshet in 2011 killed up to 70% of the oysters in some areas of these beds.

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 and progression 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.

Current area management strategies further subdivide the mortality designations above into those shown in Figure 1 (Powell et al. 2008). Recently, Shell Rock has been managed independently after the Stock Assessment Review Committee identified it as a bed of key importance to the natural stock and to the industry, and the medium mortality beds have been split into direct market beds and transplant beds. In past monitoring status reports, medium mortality regions and Shell Rock were combined as one region for analysis. Herein they are separated according to the area management plan so that management decisions can be more appropriately evaluated. The very low mortality beds are also managed separately and with caution owing to the lack of long-term data to understand how they respond to harvest and transplanting as well as environmental (i.e., salinity) variation. Additional details on management strategies and actions are available in the Annual Stock Assessment Workshop reports at http://hsrl.rutgers.edu.

The temporal and spatial sampling efforts of the Oyster Bed 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 set zone near the Cape Shore then moved and replanted on the seedbeds). The 2014 objectives for the Oyster Bed Monitoring Program were to:

1. Continue the standard monthly time series monitoring New Beds, Bennies, Shell Rock, Cohansey, Arnolds, and now including Hope Creek, for size, mortality and Dermo
2. Conduct Dermo and MSX assays and determine condition indices for each bed sampled during the 2014 Fall Stock Assessment Random Sampling Survey
3. Monitor growth, disease and mortality on 2012 through 2014 shell plantings
4. Monitor growth mortality and disease on the 2014 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 has become an annual effort of the management plan for sustaining and rebuilding the oyster beds. Objective 4 examines the performance of the intermediate transplant program that moves oysters from upbay beds where survival is good, but growth and condition are typically poor. 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 year's harvest.

Methods

Figure 1 depicts the grid system used during 2014 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 in 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 May through December 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 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 NJDEP R/V Zephyrus or R/V James W. Joseph. Bottom water temperature and salinity were recorded with a handheld YSI® 85 meter 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

[1] At Arnolds and Round Island, total sample volume was only one half a bushel.

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 to produce a 'weighted prevalence' (Mackin 1962), which provides an estimate of the average disease level in the sample of oysters. The average intensity of infections was similarly determined by 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; Ledge was sampled during 2014. 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 May through December (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 years). Shell plant samples for Objective 4 continued the 2012 and 2013 shell plantings, and initiated the 2014 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 methodically 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 2014 shell plants. Disease sampling commenced immediately on the 2012 shell plants and in July on the 2013 shell plants.

Results and Discussion

Data obtained from the USGS stream gauges indicated several pulses of water between March and June resulting in a relatively high spring runoff compared to the remainder of the year (Figure 2). This increased runoff is likely the result of melting snow pack and subsequent releases from reservoirs combined with rainfall in what was characterized by a wet spring followed by a distinctively dry period. Increased runoff lowers salinity and decreases residence time potentially flushing free-living pathogens down bay.

Temperature. Water temperatures measured during 2014 collections followed a typical seasonal increase and decrease with a peak in July and little spatial variability across the seedbeds (Figures 3A and 4A). Furthermore, temperatures followed near average levels throughout the year.

Salinity. Salinity followed a typical spatial pattern, increasing from upbay to downbay beds (Figure 3B), but began the year quite low at levels well below average (Figure 4B). In fact, early spring salinity reached levels lethal to oysters if sustained for enough time (Munroe et al. 2013). 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. An investigation similar to Munroe et al. 2013 could shed light on any direct impacts on oyster survival from the 2014 spring freshet as well as similar events in the time series.*

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 2014 show relatively stable patterns across the oyster beds during the year (Figure 3C) and an average that was relatively stable around 60 mm (2.4 inches) throughout the year (Figure 4C). Overall, shell heights were below the long-term means that had been increasing following an extended period of low recruitment in the early-mid 2000s. Notably, there was a decrease in size on Hope Creek resulting from recent recruitment events to that region. The overall pattern measured during the annual fall stock assessment survey shows the increase in average size has reversed itself during the past several years (see Figure 9).

Seasonal Disease and Mortality. Dermo prevalence and weighted prevalence (WP) followed similar seasonal patterns across the seedbeds that were temporally typical, increasing from spring to fall, but were considerably lower than the average long-term levels (Figures 3D-E and 4D-E). Intensity was an exception in that the relatively few oysters that were infected had average intensities of infection (Figures 3F and 4F). All three measures increased from low values in April and May to peak values in September or October before beginning to decline. Spatially, Dermo typically increases with salinity, but relatively high levels occurred on Shell Rock, albeit lower than in recent years. Because Dermo tends to be more prevalent and intense in larger animals, this pattern may reflect the size distribution of oysters. Nonetheless, an evaluation of management and harvest activities associated with Dermo levels is worthy of closer examination.

Mortality estimated from both total and recent box count frequencies shows several interesting patterns. Average total box counts showed a typical seasonal pattern (Figure 3G and 4G). An unusually high number of boxes were present in spring on virtually every bed (Figures 3H-I and 4H-I). Such mortalities could be associated with the spring runoff, but it is unusual for such to occur further downbay than the Very Low and Low Mortality beds. Because increases in MSX have been reported in fall sampling (see last year's report and below in this year's report), it may be advised to look for MSX more frequently than solely during the Fall Assessment Survey.

Box counts are known to underestimate mortality, but it is worth noting that cumulative recent box count mortality measured at the end of the season consistently exceeds the total box count mortality by 5-15%. Therefore, annual box count estimates may be a greater underestimate of mortality than cumulative mortality estimates made throughout the year. Regardless of which measure is used, the Annual Delaware Bay Oyster Stock Assessment defines 20% mortality as an epizootic. Cumulative mortality exceeded 20% on 5 of 6 beds monitored during 2014, while total box counts were generally below 20%.

Transplants. Transplants performed similarly to the receiving bed (Figure 5)

Shellplants. Growth on shell plants followed levels from prior years. The apparently higher performance on Middle results from a very low number on animals recovered and may well be biased towards recovering a few larger individuals (Figure 6; upper panel). Dermo levels on shell plants were relatively low (Figure 6; middle panel) and had not reached levels typically thought to initiate detectable levels of mortality (i.e., above 1.5). Regardless of shellplanting performance in any particular year, **shell planting remains one of the most positive management efforts to sustain and increase oyster abundance and should be continued and expanded annually.**

Sex ratios of oysters has been a concern due to the changing age/size structure of the population shown in Figure 3B. Oysters are protandric, that is some will begin their lives as males then change to females later in life. Hence, 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. 2012). 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 2014 indicate a relatively equal allocation with most of the variability likely due to sampling error rather than any real change or bias during the season (Table 5). One hermaphrodite each was detected on New Beds in June and on Bennies in July and is not recorded in Table 5. The percentage of oysters with sexually discernable gonad increased from May to June when virtually all animals were in reproductive status. This dropped in August indicative of a spawning event.

Long-Term Fall Patterns. Examination of Dermo prevalence, weighted prevalence and mortality on a bed-by-bed basis (Figure 7) indicates higher values in the middle region of the bay during 2014 compared to the typical pattern that increases from upbay to downbay beds. The low levels bode well for the population as a whole.

Figure 8 depicts annual Dermo prevalence, Dermo infection intensity (= weighted prevalence) and box-count estimated mortality from 1989 to 2014 for each mortality region sampled during the annual stock assessment. Each plot segregates the data based on seedbed mortality regions defined by Powell et al. (2008). Each parameter 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 approximately 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 may 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 and 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. As mentioned in previous years, the apparent cycling may be driven by larger regional climate patterns, but this remains a hypothesis in need of additional research and continued monitoring. The data continue to indicate an attenuation of Dermo-induced mortality in the three successive epizootics across the medium and high mortality regions (Figure 8). This observation remains difficult to interpret, because lagged correlations between river flow and WP produce a significant negative correlation (Bushek et al. 2012). 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. Continued monitoring and directed research is needed to fully understand what is happening.

From 1988 to 1993, MSX prevalence from fall survey samples oscillated annually between 6-17% and 26-32%. However, because MSX has not been problematic on the seedbeds for nearly two decades, samples from only seven beds along the up- to downbay gradient have been examined in recent years and such was the case in 2014 (Table 4). While the heaviest infections have typically been found in the lower bay, in peak years the disease has been observed as far upbay as Arnolds (Figure 10 lower panel). In 2014, MSX infections were detected in 18.5% of the oysters assayed (Figure 10 upper panel), but infections were spread across the seedbeds (Figure 10 lower panel) indicating that MSX remains a threat to the entire stock. MSX prevalence is now the highest it has been since 1992, and because it 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. 2014 sampling schedule for the NJ Delaware Bay Oyster Bed 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**
May 2, 2014[1]	long-term (6) + additional ACE (3) sites
May 6, 2014[2]	shellplant sites: 2012 (2); 2013 (3)
May 19, 2014[2]	long-term (6) + additional ACE (3) sites
May 27, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3)
Jun 23, 2014[2]	long-term (6) + additional ACE (3) sites
June 30, 2014[1]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3)
July 21, 2014[1]	long-term (6) + additional ACE (3) sites
July 29, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3)
August 18, 2014[2]	long-term (6) + additional ACE (3) sites
August 25, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3)
September 23, 2014[2]	long-term (6) + additional ACE (3) sites
September 30, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3); 2014 (4)
October 20, 2014[1]	long-term (6) + additional ACE (3) sites
October 27, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3); 2014 (4)
November 25, 2014[2]	long-term (6) + additional ACE (3) sites
December 3, 2014[2]	intermediate transplants (2); shellplant sites: 2012 (2); 2013 (3); 2014 (4)

Table 2. Additional sites sampled during 2014. "Transplant" indicates oysters moved from an upbay bed to a direct market bed down bay; "replant" indicates shell was planted in lower Delaware Bay leased ground region, then moved to the bed listed after spat had recruited. All other grids received planted shell only. The grids planted on Middle were part of the ATHOS I oil spill mitigation.

Bed	Grid	Plant material	Plant yr
Shell Rock	7	medium mortality transplant	2014
Ship John	21	low mortality transplant	2014
Middle	28	surf clam shell replant	2014
Middle	27-28	surf clam shell replant	2011-2013
Nantuxent	23	ocean quahog	2014
Shell Rock	31	ocean quahog	2014
Ship John	33	ocean quahog	2014
Shell Rock	29	ocean quahog	2013
Shell Rock	30	ocean quahog	2013
Ship John	36	ocean quahog	2012
Ship John	53	ocean quahog	2012

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
Hope Creek																		X	X	X	X	X	X	X	X
Liston Range																			X	X	X	X	X	X	X
Fishing Creek																			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
Upper Arnolds														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
Upper Middle																	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
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
Sea Breeze															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
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
Bennies Sand	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
Nantuxent		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
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
Strawberry	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
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
Vexton										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	
Ledge Bed			X		X				X		X		X		X		X		X		X		X		X

Table 4. 2014 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	75	10		15
Hope Creek	44	10		15
Hope Creek	61			10
Hope Creek	85			10
Hope Creek	63		20	0
Fishing Creek	43	5		5
Fishing Creek	25	10		15
Fishing Creek	16	5		16
Fishing Creek	24			13
Liston Range	18	10		15
Liston Range	14	10		15
Liston Range	2			10
Liston Range	25			10
Round Island	11	10		15
Round Island	2	10		15
Round Island	73			10
Round Island	24			10
Upper Arnolds	13	10		15
Upper Arnolds	3	10		15
Upper Arnolds	17			10
Upper Arnolds	2			10
Arnolds	10	10		13
Arnolds	6	10		15
Arnolds	7			11
Arnolds	17			11
Arnolds	18		20	0
Upper Middle	48	10		16
Upper Middle	56	10		16
Upper Middle	71			6
Upper Middle	36			12
Middle	40	10		15
Middle	36	10		15
Middle	20			10
Middle	51			10
Cohansey	5	10		15
Cohansey	57	10		15
Cohansey	20			10
Cohansey	25			10
Cohansey	44		20	0
Sea Breeze	46	10		15
Sea Breeze	15	10		15
Sea Breeze	22			10
Sea Breeze	38			10
Ship John	57	10		15
Ship John	50	10		15
Ship John	24			10
Ship John	38			10
Shell Rock	43	10		15
Shell Rock	2	10		15

Bed	Grid	Dermo	MSX	CI
Shell Rock	32			10
Shell Rock	7			10
Shell Rock	11		20	0
Bennies Sand	19	10		15
Bennies Sand	8	10		15
Bennies Sand	37			6
Bennies Sand	14			14
Bennies	149	10		15
Bennies	85	10		15
Bennies	141			10
Bennies	36			11
Bennies	110		20	0
Nantuxent	17	10		15
Nantuxent	21	10		15
Nantuxent	8			10
Nantuxent	11			10
Hog Shoal	1	10		17
Hog Shoal	5	10		17
Hog Shoal	4			13
Hog Shoal	16			3
New Beds	9	10		17
New Beds	53	10		17
New Beds	6			10
New Beds	98			6
New Beds	26		20	0
Strawberry	5	20		24
Strawberry	1			3
Hawks Nest	5	10		16
Hawks Nest	27	10		19
Hawks Nest	6			9
Hawks Nest	17			6
Beadons	3	10		15
Beadons	5	10		10
Beadons	15			10
Beadons	4			15
Vexton	11	10		15
Vexton	3	10		15
Vexton	4			10
Vexton	17			10
Ledge	6	8	8	0
Ledge	7	6	6	0
Total beds	**22**	**22**	**7**	**22**
Total grids	**90**	**44**	**8**	**82**
Total oysters		**434**	**134**	**1027**

Table 5. Sex ratios detected during 2014 monthly seedbed monitoring expressed as the percentage of males or females detected in each Dermo sample (n = 20). Beds are listed upbay to downbay. Hermaphrodites and individuals whose sex was not discernable are not shown.

	May 19		June 23		July 21		August 18		Overall	
Bed	M	F	M	F	M	F	M	F	M	F
Hope Creek	0	20	40	60	35	65	70	15	36	40
Arnolds	20	40	45	55	55	25	35	65	39	46
Cohansey	25	35	40	55	60	40	25	75	38	51
Shell Rock	25	25	35	60	55	45	45	50	40	45
Bennies	10	25	50	45	55	40	30	35	36	36
New Beds	15	55	65	25	60	35	45	50	46	41
Total	16	33	46	50	53	42	42	48	39	43

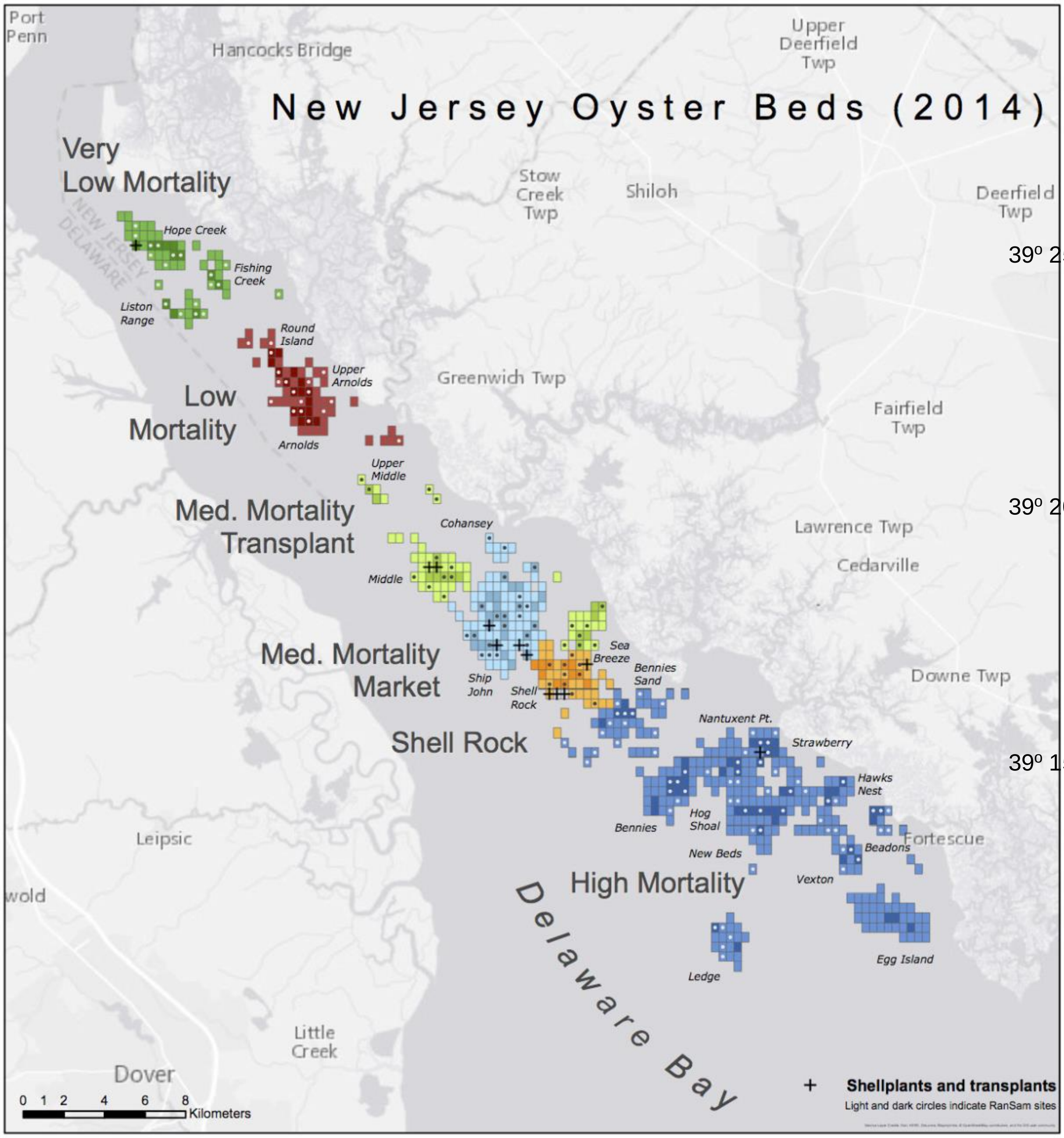


Figure 1. Footprint of the Delaware Bay, NJ public oyster beds (aka 'seedbeds'). Colors differentiate boundaries of regions as defined by the area management system (Powell et al. 2008 and 2012). For this report, references to the low mortality region generally include the very low region unless noted. Additionally, references to the medium mortality region include both the medium mortality transplant, medium mortality market and Shell Rock as the mortality pattern since 1953 distinguishes these regions.

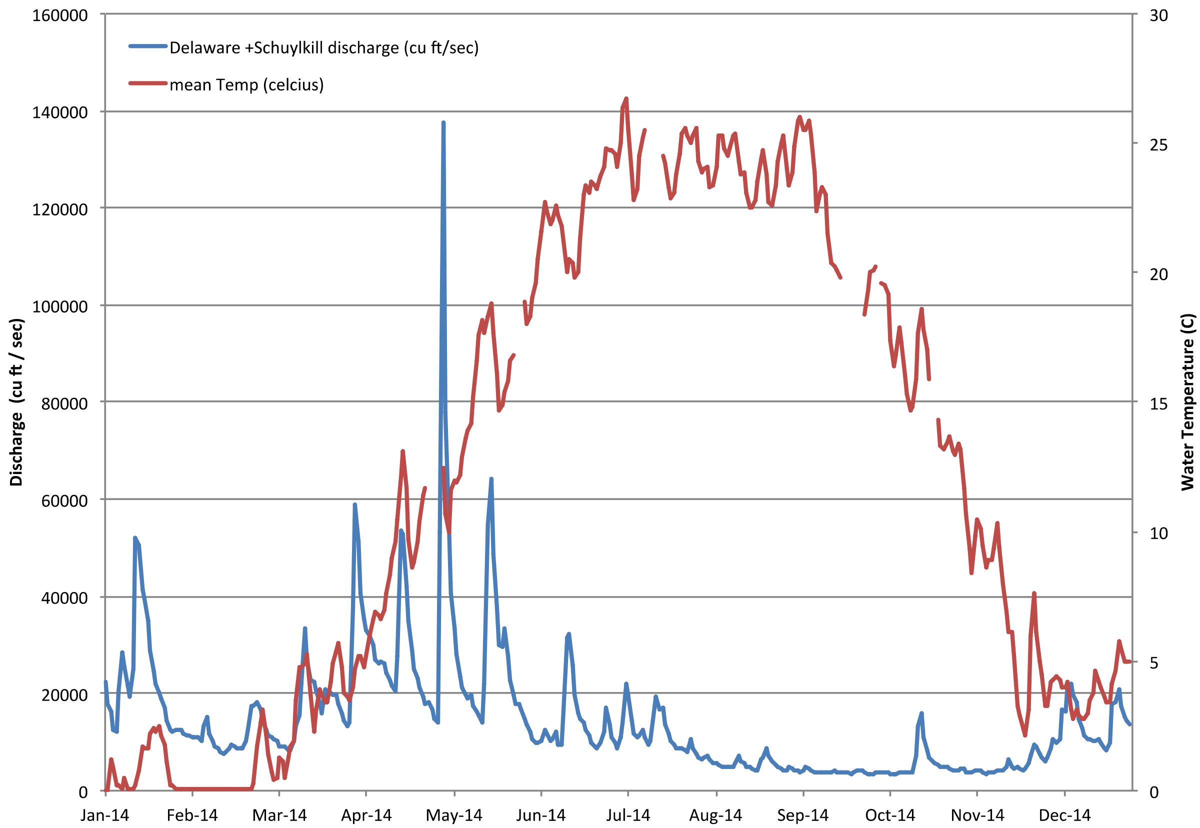


Figure 2. USGS discharge from Delaware River at Trenton and Schuylkill River at Philadelphia. These two sources provide the majority of fresh water to the Delaware Bay. In 2014, a large pulse of fresh water resulted from the melting of the winter snow pack that dissipated into the summer with relatively little inflow through the fall. This pattern is reflected in the salinity data shown in Figures 3 and 4.

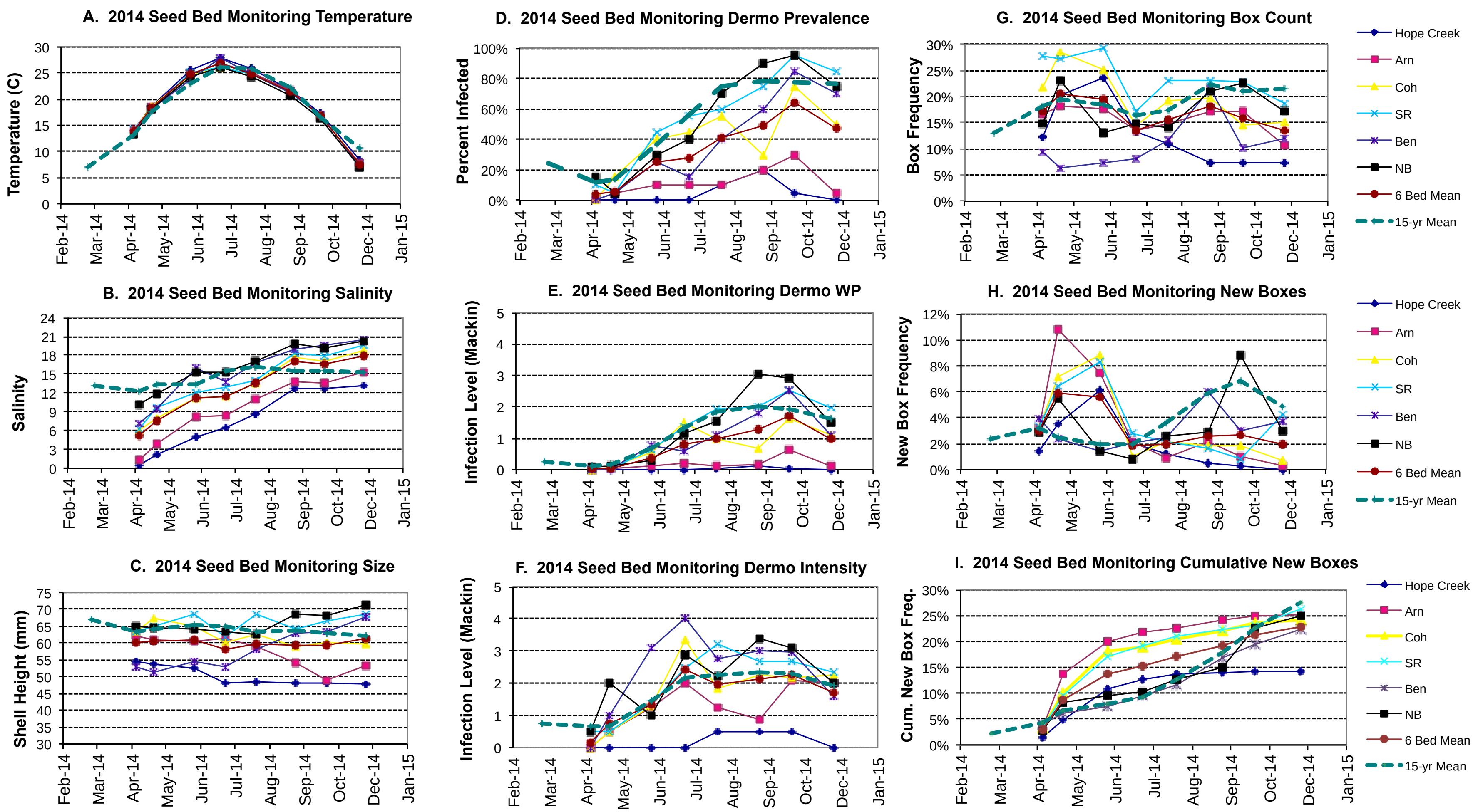


Figure 3. Results of 2014 Seed Bed Monitoring Program for the six primary beds along an upbay to downbay transect. Legends list beds from higher to lower latitude (i.e., up to down bay). Left Panels show temperature, salinity and mean size. Center panels show Dermo levels as overall prevalence (= percent 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 of the 6 beds shown. Dashed green line is the average of those same beds since 1999.

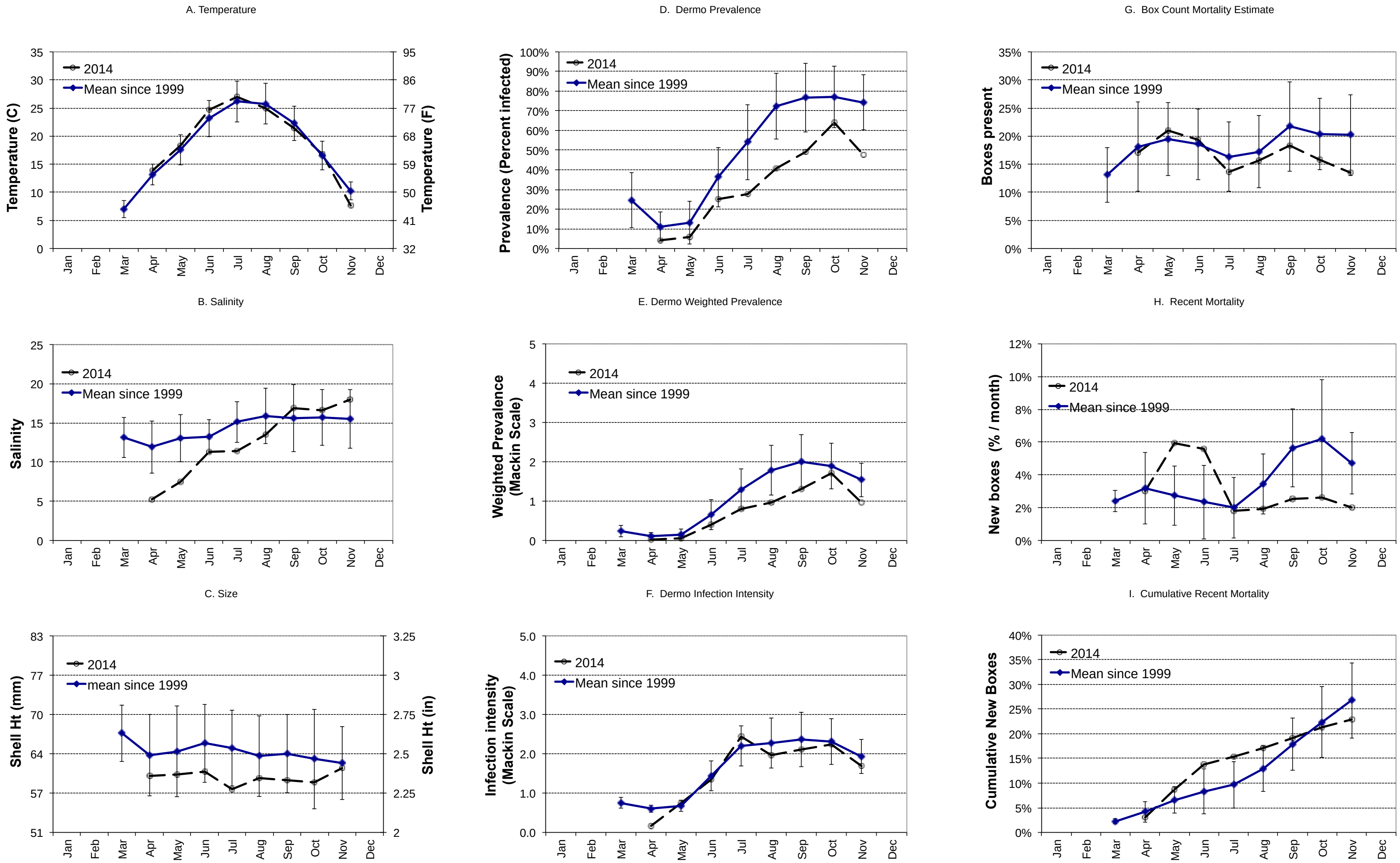


Figure 4. Means of 2014 Seed Bed Monitoring Program for the six primary beds compared to long-term seasonal patterns. Panels arranged as in Figure 2. Error bars represent one standard deviation.

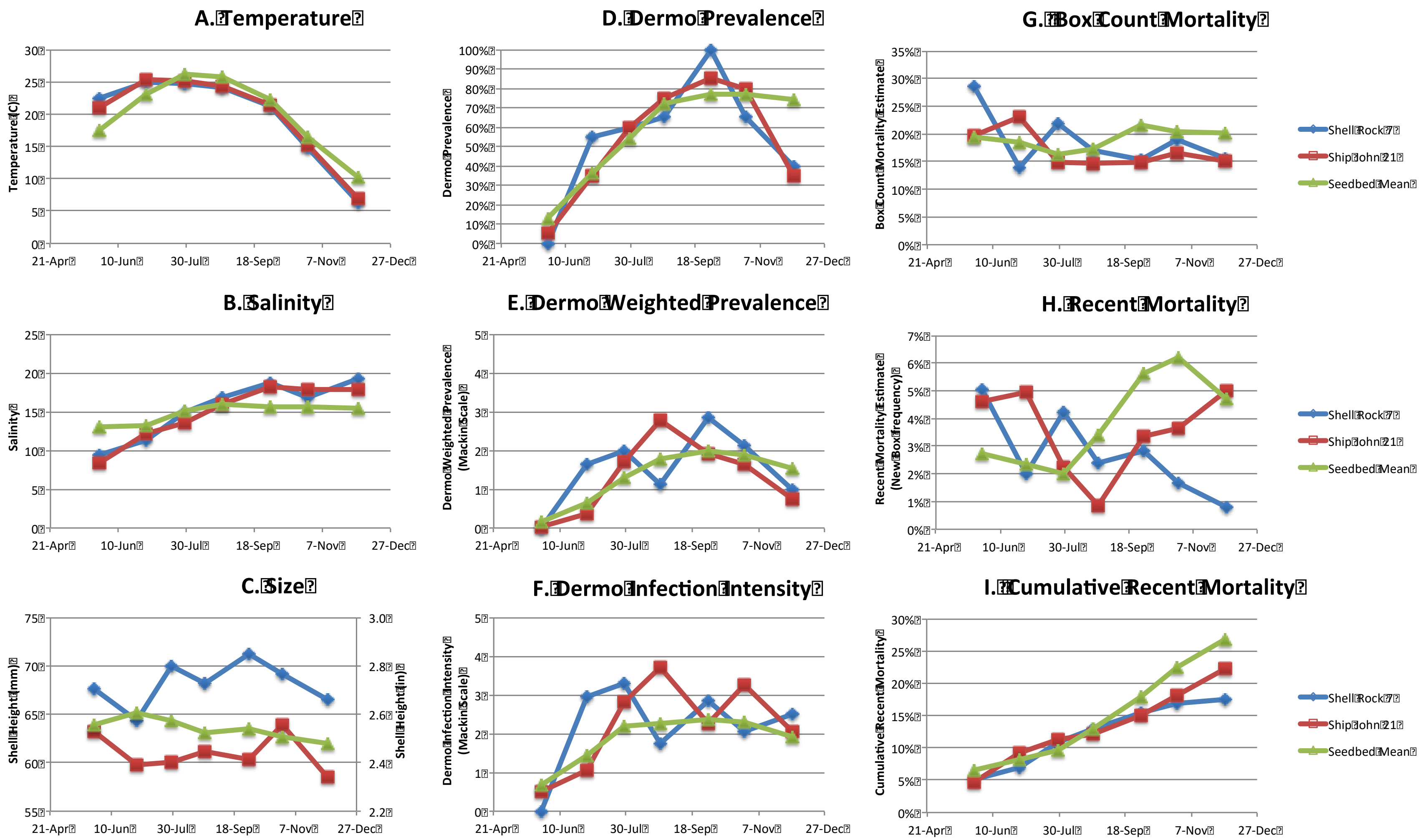
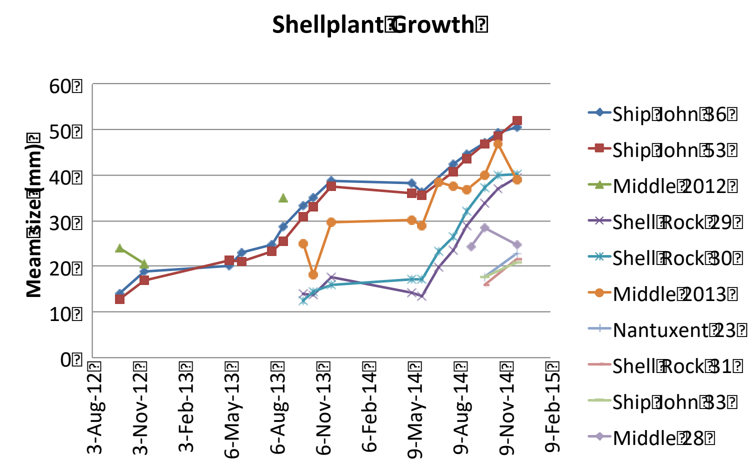
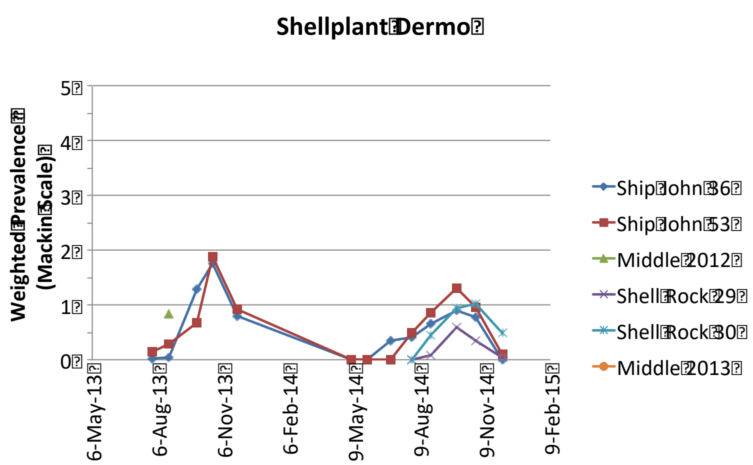


Figure 5. Performance of 2014 Transplants compared to mean of six primary beds (= Seedbed Mean). Panels arranged as in Figure 2. Oysters transplanted to Shell Rock were derived from the Medium Mortality Transplant beds while oysters transplanted to Ship John were derived from the Low Mortality beds (see Figure 1).





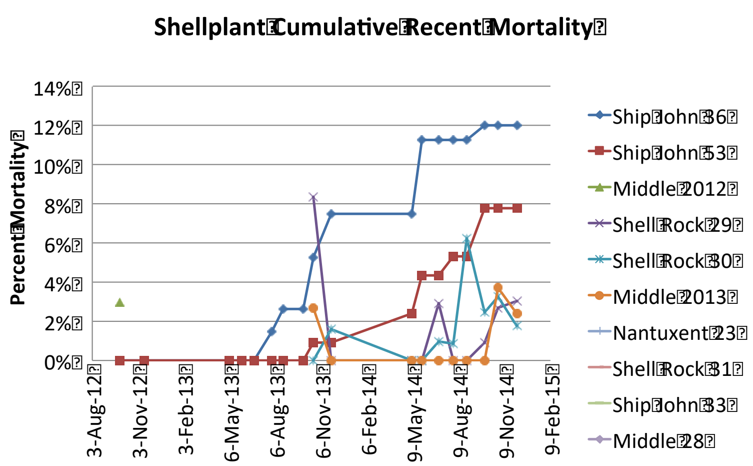


Figure 6. Performance of shellplants monitored during 2014. Ship John 26 and 53 were planted in 2012 along with the Middle 2012 ATHOS I planting that ended up distributed across grids 27-28. Shell Rock 29 and 30 were planted in 2013 along with the Middle 2013 ATHOS I planting that ended up distributed across grids 26-28. Nantuxent 23, Shell Rock 31, Ship John 33 and Middle 28 were all planted in 2014. Monitoring for growth and mortality began in September or October during the year of the plant, and during July of the following year for Dermo.

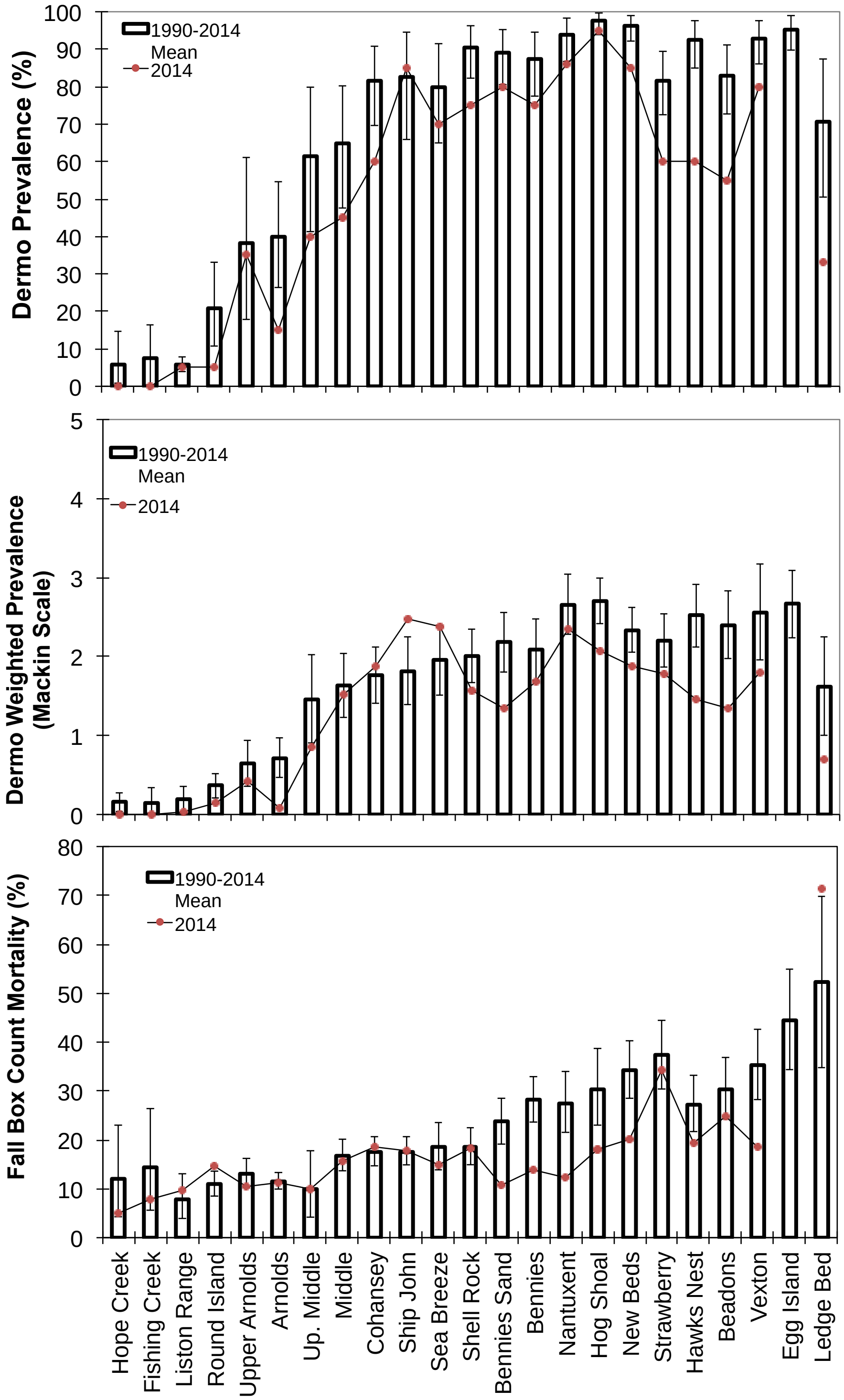


Figure 7. Long-term spatial patterns of Dermo prevalence (upper panel), Dermo weighted prevalence (middle panel) and natural mortality (bottom panel) across the beds. Beds are listed from upbay to downbay left to right. All three metrics increase from upper to lower bay regions. Not all beds have been sampled every year (see Table 5). Egg Island was not sampled in 2014. Error bars represent 95% confidence intervals.

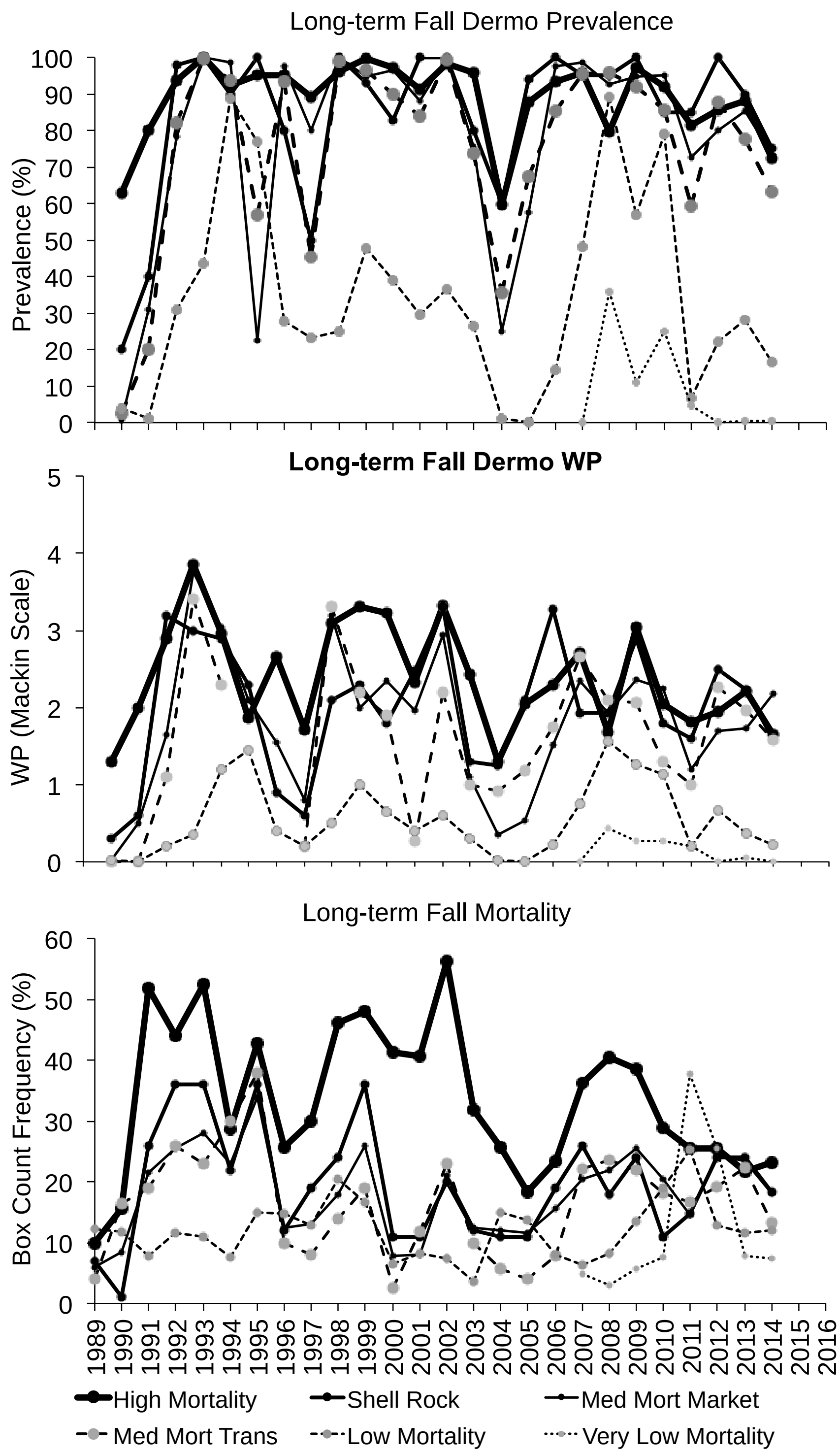


Figure 8. Annual fall Dermo prevalence (upper panel), weighted prevalence (middle panel) and box count mortality (bottom panel) on New Jersey Delaware Bay seedbeds. Regions correspond to management regions in Figure 1.

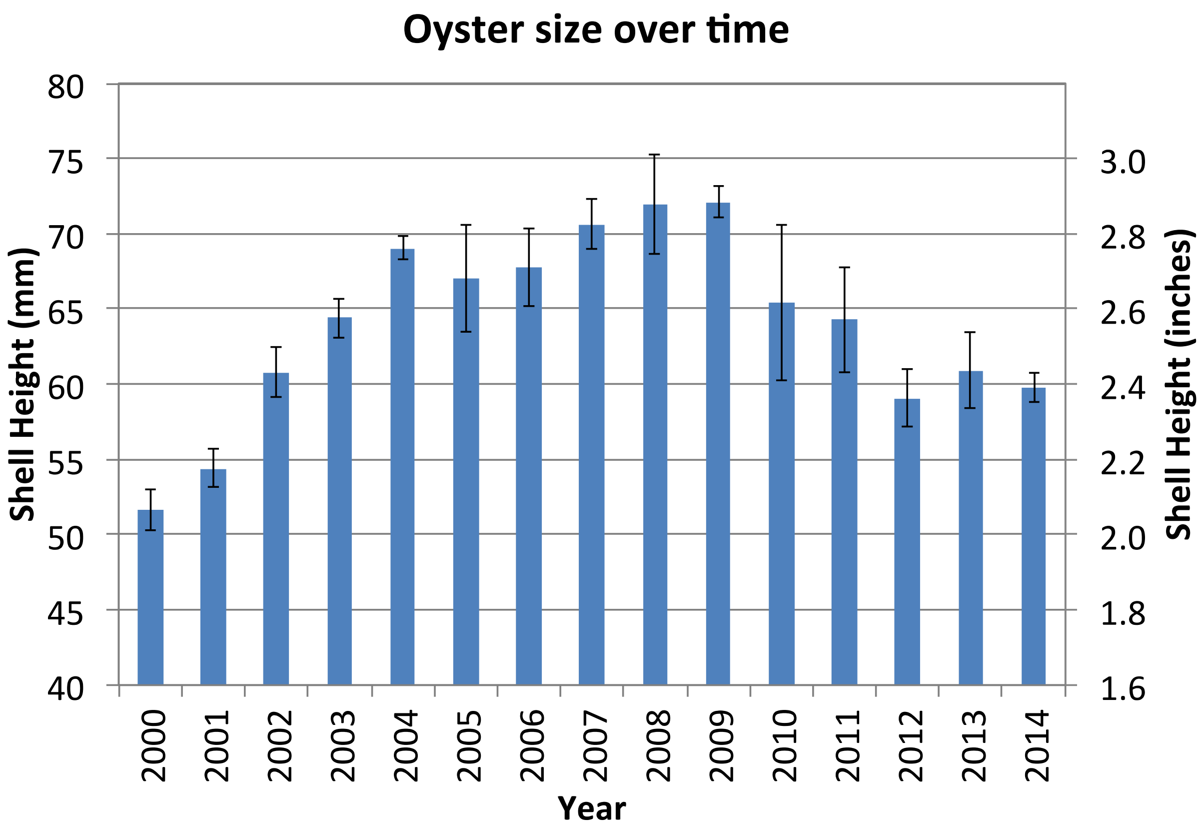
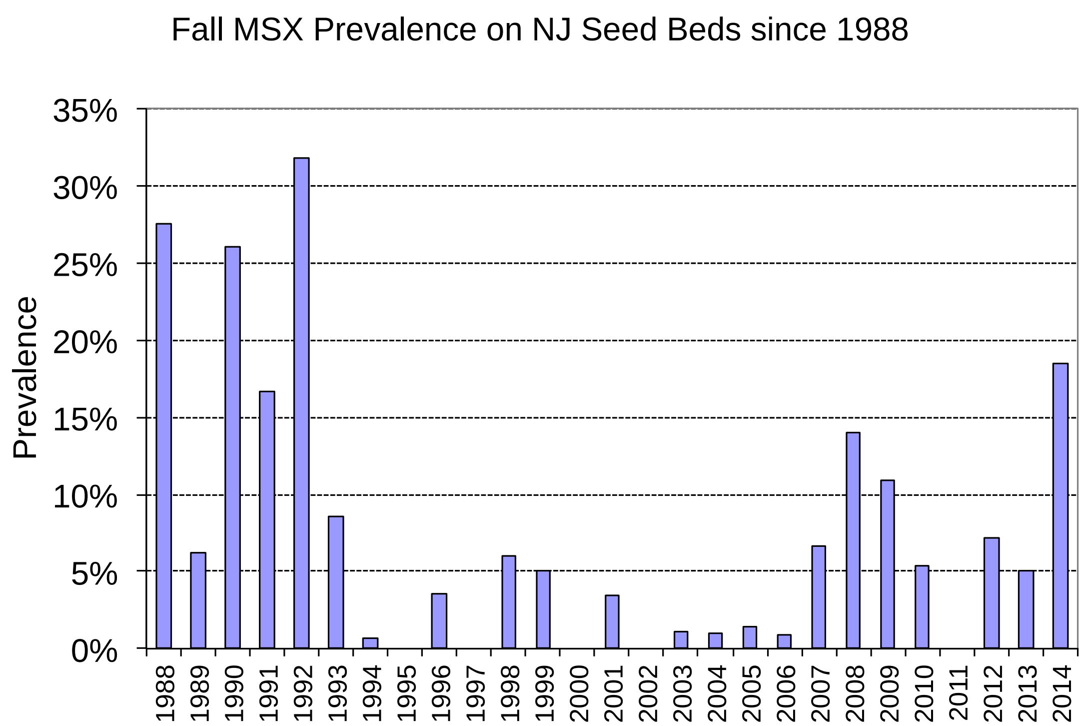


Figure 9. Mean (+/- s.d.) shell height of oysters collected monthly from Delaware Bay NJ oyster seedbeds.



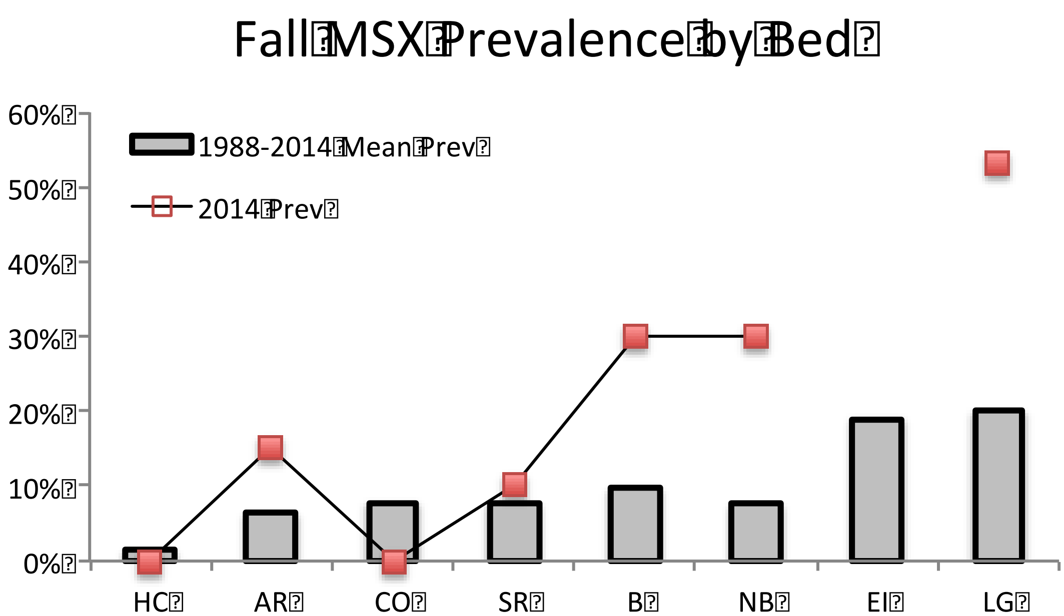


Figure 10. MSX disease on the New Jersey Delaware Bay oyster seedbeds. Upper: annual fall MSX Prevalence. Lower: Total fall MSX prevalence on selected beds since 1988 (2007 for HC). HC = Hope Creek, AR = Arnolds, CO = Cohansey, SR = Shell Rock, B = Bennies, NB = New Beds, EI = Egg Island, LG = Ledge.