Maryland Oyster Population Status Report
2015 Fall Survey

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Cover: Power dredging on a foggy morning in the Choptank River. (Photo: R. Bussell)
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Power dredge fleet working on Great Bar in the mouth of Broad Creek, November 2015. (Photo: Robert Bussell)
IN MEMORIAM

Sally (Sara V.) Otto

Born an only child to dairy industry parents of Pittsburgh, Pa. in 1942, Sally Otto relocated with her family to the Eastern Shore of Chesapeake Bay as a young woman in 1962.

In 1964 she earned her Bachelor of Arts in biology from MacMurray College, and quickly went to laboratory work on both surf clam histology and electrophoresis of marine invertebrate blood proteins, at the new Bureau of Commercial Fisheries Biological Laboratory in Oxford, Md. Sally then broadened her skills during a year of virology research at Johns Hopkins University. In 1967, she returned to Oxford Laboratory to begin what became an accomplished 34-year career with the Maryland Department of Natural Resources, as a microbiologist and pathologist of molluscs, and also occasionally of crustacea and finfish.

During three of those years, Sally served a pioneering role as the first female co-editor of Proceedings of the National Shellfisheries Association (now Journal of Shellfish Research), as she edited that research journal in partnership with Bill Shaw (1972) and Haskell Tubiash (1973-1974). Sally was well-educated, highly literate, and articulate in both English and French. She routinely exercised a sharp wit that issued a steady stream of buoyant, occasionally salty, observations and commentary. Among her many research and monitoring efforts on diseases and reproduction of marine invertebrates, the results of several were published for posterity; frequently in collaboration with renowned co-authors.

In 1989, Sally helped develop and implement revised methods for the Maryland Department of Natural Resources’ annual Fall Survey of oyster populations, whose consistent and systematic data inform the management of Maryland oyster resources today. Sally expertly and diligently analyzed oyster and clam histological slides for such surveys, until her retirement in 2001. Her knowledge of parasites, pathogens, and diseases of oysters and clams was encyclopedic, and it was Sally’s passion to share that knowledge enthusiastically with several generations of oyster pathologist protégés. Her generous and illuminating torch has now been passed.
EXECUTIVE SUMMARY

Since 1939, the Maryland Department of Natural Resources and its predecessor agencies have been monitoring the status of the State’s oyster population by means of annual field surveys – one of the longest running programs of this kind in the world.

Integral to the Fall Oyster Survey are four indices intended to assess Maryland’s oyster populations: the Spatfall Intensity Index, a measure of recruitment success and potential increase of the population obtained from a subset of 53 oyster bars; the Oyster Disease Index, which documents disease infection levels and rates as derived from a subset of 43 oyster bars; the Total Observed Mortality Index, an indicator of annual mortality rates of post-spat stage oysters calculated from the 43 oyster bar Disease Index subset; and the Biomass Index, which measures the number and weight of oysters from the 43 Disease Bar subset relative to the 1993 baseline.

The 2015 Fall Oyster Survey was conducted from 1 October to 8 December throughout the Maryland portion of the Chesapeake Bay and its tributaries, including the Potomac River. A total of 323 samples were collected from 259 oyster bars. Despite a generally low spatfall, the results were otherwise encouraging, with sustained multi-year trends of low disease pressure, below-average mortality, and elevated biomass.

This was a mixed year for recruitment. The Spatfall Intensity Index of 34.2 was 50% higher than the 31-year median value and three times as high as the previous year. Most of this gain occurred in southern Maryland, where the north shore of the lower Potomac River experienced the best spatfall in nearly a third of a century. However, spatfall generally was average to poor upbay from the Patuxent River, with large expanses of the upper and middle bay and upper Potomac River receiving no spat.

Dermo disease remained below long-term average levels, continuing a trend that began in 2003, although prevalence and intensity indices increased slightly from the previous year and it continued to be widely distributed throughout Maryland waters. Oysters at all but two of the standard disease monitoring sites were infected with Perkinsus marinus, the parasite which causes dermo disease. Some oyster populations, especially on bars from the Choptank River and south, had elevated intensities that may be cause for concern in the future. For the second consecutive year, MSX disease showed an increase in prevalence while expanding its range upbay, reaching as far north as the Eastern Bay and the Miles River, although at very low prevalences. This was the furthest upbay MSX has been detected since 2009.

Despite an uptick in oyster mortalities, the Mortality Index of 14% remained below the 31-year mean, continuing a 12-year trend as a consequence of the low disease pressure. This is a remarkable turnaround from 2002 when record high disease levels devastated the Maryland population, killing 58% of the oysters statewide.

The 2015 Maryland Oyster Biomass Index dipped slightly from record highs of the two previous years. Nonetheless, the 2015 Biomass Index of 1.77 was the third highest of the 26-year time series, reflecting the high oyster survivorship over the past few years, particularly the strong 2010 and 2012 year classes.

The major oyster sanctuaries were sampled during the 2015 Fall Survey. Like the rest of the region, recruitment was generally indifferent except in the southern part of state waters. No evidence of MSX was found in either Harris Creek or the Tred Avon River, but was found in the Little Choptank River at elevated prevalence. Mortality rates continue to be well below the long-term average, including in the Manokin River sanctuary, where there were anecdotal reports of oysters dying. Overall, those sanctuaries that received strong spatfalls in 2010 and 2012 and those receiving supplemental oyster seed plantings appeared to be in good condition.

With reported harvests of 389,000 bushels during the 2014-15 season, commercial oyster landings decreased by 7% from the previous year, yet the dockside value of $17.1 million was the highest since 1982. Power dredging accounted for 42% of the landings, primarily from the Lower Eastern Shore and Choptank regions. In addition, 16% of the total harvest was reported from Broad Creek, the highest for any region.
Figure 1a. 2015 Maryland Fall Oyster Survey station locations, all bar types (standard, Key, Disease, seed) included.
Figure 1b. Maryland Fall Oyster Survey Key Bar locations included in determining the annual Spatfall Intensity Index.
Figure 1c. Maryland Fall Oyster Survey standard Disease Bar monitoring location and additional 2014 disease sample stations.
INTRODUCTION
Since 1939, a succession of Maryland state agencies has conducted annual dredge-based surveys of oyster bars. These oyster population assessments have provided biologists and managers with information on spatfall intensity, observed mortality, and more recently on parasitic infections in Maryland’s Chesapeake Bay. The long-term nature of the data set is a unique and valuable aspect of the survey that gives a historical perspective and reveals trends in the oyster population. Monitored sites have included natural oyster bars, seed production and planting areas, dredged and fresh shell plantings, and sanctuaries.

Since this survey began, several changes and additions have been made to allow the development of structured indices and statistical frameworks while preserving the continuity of the long-term data set. In 1975, 53 sites and their alternates, referred to as the historical “Key Bar” set, were fixed to form the basis of an annual spatfall intensity index (Krantz and Webster 1980). These sites were selected to provide both adequate geographic coverage and continuity with data going back to 1939. An oyster parasite diagnosis component was added in 1958, and in 1990 a 43-bar subset (Disease Bar set) was established for obtaining standardized parasite prevalence and intensity data. Thirty-one of the Disease Bars are among the 53 spatfall index oyster bars (Key Bars).

Collaborative Studies and Outreach
Throughout the years, the Fall Survey has been a source of collaborative research opportunities for scientists within and outside of the Department of Natural Resources. In 2015, the Fall Survey provided scientific support to a researcher from the University of California – Davis studying microplastic concentrations in the bay and to a student from William and Mary College looking into the geochemistry of oyster shells to develop techniques for sourcing shells from archeological middens. Fall Survey data were provided to an environmental consulting firm working on National Oceanic and Atmospheric Administration’s Environmental Sensitivity Index, a project to establish baseline biological data for possible responses in the event of an oil spill. The Survey also assisted with an innovative pilot fishery program, examining triploid oyster plantings on Ragged Point for the Potomac River Fisheries Commission. Data from the Fall Survey continue to be used extensively by the multi-partner Oyster Restoration Project.

METHODS
Field Collection
The 2015 Annual Fall Oyster Survey was conducted by Shellfish Division staff of the Maryland Department of Natural Resources Fisheries Service from 13 October to 8 December. A total of 323 samples was collected during surveys on 259 natural oyster bars (Figure 1a), including Key Bar (Figure 1b) and Disease Bar (Figure 1c) sentinel sites as well as sanctuaries, contemporary seed oyster planting sites, shell planting locations, and seed production areas.

A 32-inch-wide oyster dredge was used to obtain the samples. The number of samples collected varied with the type of site. Sample volumes were measured in Maryland bushels (bu) (Appendix 2). At each of the 53 Key Bar sites and the 43 Disease Bars, two 0.5-bu subsamples were collected from replicate dredge tows. On seed production areas, five 0.2-bu subsamples were taken from replicate dredge tows. At all other sites, one 0.5-bu subsample was collected. A list of data categories recorded from each sample appears in Table 1. Oyster counts were reported as numbers per Maryland bushel. Since 2005, tow distances have been recorded for all samples (providing the dredge was not full) using the odometer function of a global positioning system unit, and the total volumes of dredged material.
per tow were noted before the subsamples were removed. Photos illustrating the collection process can be viewed here:

http://dnr2.maryland.gov/fisheries/Pages/shellfish-monitoring/sample.aspx

**Fall Oyster Survey Indices**

Integral to the Fall Oyster Survey are four categories of indices used to assess Maryland oyster populations: spatfall, disease, mortality, and biomass. The Spatfall Intensity Index is a measure of recruitment success and potential increase of the population obtained from an established subset of 53 oyster bars (Key Bars); it is the arithmetic mean of spat/bushel counts from this subset. Disease levels are documented by oyster disease prevalence indices (dermo and MSX disease) and the Intensity Index (dermo disease only) as derived from a subset of 43 oyster bars; these indices were established in 1990. The Total Observed Mortality Index is an indicator of annual natural mortality rates of post-spat stage oysters from the 43 oyster bar Disease Index subset, calculated as the number of dead oysters (boxes and gaps) divided by the sum of live and dead oysters (Appendix 2). Although keyed to the Disease Index subset established in 1990, the Total Observed Mortality Index also includes data from 1985-1989. The Biomass Index measures the number and estimates the weight of post-spat oysters from the 43 Disease Bar subset relative to the 1993 survey year baseline.

**Oyster Disease Analyses**

Representative samples of 30 oysters older than one year were taken at each of the 43 Disease Bar sites. Additional samples for disease diagnostics were collected from seed production areas, seed planting areas, sanctuaries, and other areas of special interest. Due to scarcities of oysters at two sampling sites (Holland Point, Flag Pond), smaller samples \((n = 7, 17\) respectively) were secured for disease assays. Oyster parasite diagnostic tests were performed by staff of the Cooperative Oxford Laboratory. Data reported for *Perkinsus marinus* (dermo disease) are from Ray’s fluid thioglycollate medium (RFTM) assays of rectum tissues. Prior to 1999, less-sensitive hemolymph assays were performed. Data reported for *Haplosporidium nelsoni* (MSX disease) have been generated by histology since 1999. Before 1999, hemolymph cytology was performed, while histology samples were examined for *H. nelsoni* only from selected locations.

In this report, prevalence refers to the percentage of oysters in a sample that were infected, regardless of infection intensity. Infection intensity categorically ranks the relative abundance of pathogen cells in analyzed oyster tissues. Mean infection intensities are calculated for all oysters in a sample or larger group (e.g. Disease Bars set), including zeroes for uninfected oysters. A categorical infection intensity range from 0-7 is used to rank dermo disease intensities (Calvo et al. 1996). See Gieseker (2001) for a complete description of parasite diagnostic techniques and calculations.

**Biomass Index**

Department of Natural Resources staff at the Cooperative Oxford Laboratory developed the size-weight relationships used in calculating the Biomass Index (Jordan et al. 2002). Oyster shells were measured in the longest dimension and the meats were removed, oven-dried, then weighed. Average dry-meat weights (dmw) were calculated for oysters in each 5-mm grouping used in the field measurements, and those standards have been used to calculate the annual Biomass Index from size-frequency data collected from Fall Survey field samples, as follows:

For each of the 43 disease monitoring stations, the number of small and market oysters (= post-spat or 1+ year classes) in each 5-mm size class was multiplied by the average dry-meat weight (dmw) for that size class to obtain the total weight for each size grouping (Eq. 1). These were summed to get the total dry-meat weight of a 1 bu sample (two 0.5 bu subsamples) from a disease monitoring bar (Eq. 2). The sum of dry-meat weights from the 43 disease monitoring
stations, divided by 43, yielded an annual average biomass value from the previous year’s survey (Eq. 3). These annual average biomass values were keyed to the biomass value for 1993. The Biomass Index was derived by dividing the year’s average biomass value by the 1993 average biomass value (1993 biomass index = 1.0) (Eq. 4).

Note that the baseline data are from the 1993 Fall Survey. In previous years the biomass index year followed the year the data were actually collected e.g. the 1994 baseline biomass index was from the 1993 Fall Survey. To avoid the confusion this caused, in this report the biomass index refers to the year the data were collected (survey year) i.e. the 2012 biomass index is derived from the 2012 Fall Survey data.

**Equations**

For each monitoring station:
1. \((\text{# post-spat oysters per size class}) \times (\text{avg. dmw per size class}) = \text{total dmw per size class}\)
2. \(\sum \text{dmw per size class} = \text{total dmw per 1 bu station sample}\)

For all monitoring stations:
3. \((\sum \text{dmw per 1 bu station sample})/43 = \text{annual average biomass value}\)
4. \(\text{(annual average biomass value)/(1993 average biomass value)} = \text{Biomass Index}\)

**Statistical Framework**

To provide a statistical framework for some of the Annual Fall Survey data sets, a non-parametric treatment, Friedman’s Two-Way Rank Sum Test, was used (Hollander and Wolfe 1973). This procedure, along with an associated multiple-range test, allowed among-year comparisons for several parameters. Additionally, mean rank data can be viewed as annual indices, thereby allowing temporal patterns to emerge. Friedman’s Two-Way Rank Sum Test, an analog of the normal scores general Q statistic (Hájek and Šidák 1967), is an expansion of paired replicate tests (e.g. Wilcoxon’s Signed Rank Test or Fisher’s Sign Test). Friedman’s Test differs substantively from a Two-Way ANOVA, in that interactions between blocks and treatments are not allowed by the computational model (See Lehman 1963 for a more general model that allows such interactions). The lack of block-treatment interaction terms is crucial in the application of Friedman’s Test to the various sets of Fall Survey oyster data, since it eliminates nuisance effects associated with intrinsic, site-specific characteristics. That is, since rankings are assigned across treatments (in this report - years), but rank summations are made along blocks (oyster bars), intrinsic differences among oyster bars are not an element in the test result. All Friedman’s Test results in this report were evaluated at \(\alpha = 0.05\).

To quantify annual relationships, a distribution-free multiple comparison procedure, based on Friedman’s Rank Sum Test, was used to produce the “tiers” discussed in this report. Each tier consists of a set of annual mean ranks that are statistically similar to one another. This procedure (McDonald and Thompson 1967) is relatively robust, very efficient, and, unlike many multiple comparison tests, allows the results to be interpreted as hypothesis tests. Multiple comparisons were evaluated using “yardsticks” developed from experimental error rates of \(\alpha = 0.15\).

**Harvest Records**

Two data sources are used to estimate seasonal oyster harvests - dealer reports (also called Buy Tickets) and harvester reports. The volume of oysters in Maryland bushels caught each day by each license holder is reported to the Department of Natural Resources on both forms (Appendix 2). Dealer reports are submitted weekly by licensed dealers who buy oysters directly from harvesters on the day of catch. Reported on each buy ticket is the catch per day along with effort information, gear type, and location of catch. Both the dealer and the harvester must sign the buy ticket and include their license numbers. Each dealer is also responsible for paying a one dollar per
bushel tax and an additional thirty cents tax on each bushel exported. Harvester reports are submitted monthly by each license holder authorized to catch oysters and include the catch each day along with effort information, gear type, and location of catch.

Buy ticket records are available from 1989 to present and harvester reports are available from 2009 to present. Although the area or river system was often recorded on buy tickets for much of the time series, the completeness of oyster bar- and gear-specific information is much more variable. Generally, harvester reports are more complete with regard to gear type and oyster bar name. Due to the longer time series available from the buy ticket record, this is the standard data source for long-term trends in harvest. For applications where gear or oyster bar name is considered critical, the harvester report data source is often used instead.

RESULTS
FRESHWATER DISCHARGE CONDITIONS
Salinity is a key quantifiable factor influencing oyster reproduction and recruitment, disease, and mortality. Whereas salinity is a site-specific measurement which varies widely throughout the Maryland oyster grounds, freshwater flow, which influences salinity, provides a more synoptic view of baywide conditions and is therefore used as a surrogate for salinity.

According to the U.S. Geological Survey, 2015 was considered to be a dry year, with the annual streamflow into the Maryland portion of Chesapeake Bay below the 25th percentile over 78 years (Sec. “C” in Bue 1968). This is only the second year since the 1999-2002 drought that streamflows have been below the normal range, and it follows three consecutive years of near average flows (USGS 2015). Annual streamflows in eight of the past eleven years were within the normal range, in contrast to the sometimes extreme interannual variations in streamflow witnessed during the 1990s and early 2000s, including an extended drought from 1999 to 2002 followed by near-record high flows in 2003 and 2004 (Figure 2a).

Below average monthly discharges, which began in September 2014, persisted through the following March (Figure 2b). Flows in February were only 33% of the 71-year mean for that month. For the year, nine of twelve months had lower than mean freshwater input. The primary exception to this trend was during July, when flows were 2.5 times above average, but they fell off steeply in August and by September were only 55% of the mean.

Monthly surface salinities, as seen in the following two examples, reflect the influence of streamflow to varying degrees
depending on location. As a consequence of the low freshwater flows, salinities were generally higher than average (CBP Data Hub). At CB4.2C, a mid-bay station off the mouth of the Choptank River, salinities over the year varied by as much as 8.3 ppt (Figure 4c). Salinities were above average into April, then plunged in May after high April flows. They remained below average in July and August following a strong freshwater pulse in July, then climbed upward again, peaking at 17 ppt in November. One important point is the salinities were above 12 ppt for nine months, five of which had salinities over 15 ppt, which are critical minimum values for the spread and virulence of MSX disease. On average, the highest salinity for this station is 15 ppt in October.

The South Tangier Sound station (EE3.2) experienced much lower intra-annual variation in salinities, ranging from 16.2 ppt to 19.9 ppt (Figure 4d). For the most part, salinities remained above average save in August and September, when they dipped slightly as a result of July’s high flows.

**SPATFALL INTENSITY**

This was a mixed year for recruitment. The 2015 Spatfall Intensity Index, a measure of recruitment success and potential increase of the population, was 34.2 spat per bushel, triple the previous year’s index and about 1.5 times the 31-year median index. Although the 2015 spat index seems favorable, over a third of the index is attributable to a single bar, thus ranking it in the same statistical tier as the 2014 index. This is the third lowest statistical grouping out of six for the period from 1985 to 2015 (Figure 3a).
Two of the previous five years (2010, 2012) have had strong year classes which boosted the population and increased commercial landings; the average 2013 and poor 2014 spatfalls may have implications for population abundance, possibly leading to declining harvests in the upcoming years until the 2015 year class enters the fishery (Figure 3b).

Figure 3b. Recent Maryland spatfall indices, 1998-2015.

Figure 4a. Oyster spatfall intensity and distribution in Maryland, 2015. Intensity ranges represent regional averages.
Spatfall was widely but unevenly distributed among the Key Bars in 2015. Spat were observed on 40 of the 53 Key Bars vs. 33 bars in 2013 (Table 2). However, only three bars accounted for 53% of the index, with mediocre counts on the remaining bars having spat. Nine bars contributed 75% of the spat index, while 23 sites were needed to reach 95% of the spat index. Two of the top-five Key Bars for spat counts in 2015 were in the Lower Potomac region, including Cornfield Harbor in the mouth of the Potomac, and Chicken Cock in the St. Marys River, which with 712 spat/bu. had the highest Key Bar spat count (Table 2). Two of the other top-five Key Bars were in Pocomoke Sound (Marumsco, Gunby), while the fifth was Deep Neck in Broad Creek.

When considering all bars surveyed in addition to the Key Bars, the heaviest spatfall occurred in southern Maryland, where the north shore of the lower Potomac River experienced the best recruitment in nearly a third of a century (Figure 4a,b). Other high spat concentrations were found in the lower mainstem of the bay, Pocomoke Sound, and the Manokin River sanctuary. However, spatfall was extremely patchy, especially in Tangier Sound, where the overall average was below normal despite some high counts, ranging from 0 to 518 spat/bu (Figure 4c). Likewise, in the lower Potomac region, the normally high recruitment area of the upper St. Marys River had below average spat sets, while counts in the mouth of the river were extraordinarily high (Figure 4b). The Choptank River in the vicinity of Harris and Broad creeks had a moderate spatfall; otherwise recruitment was generally average to poor upbay from about the Patuxent River, with large expanses of the upper and middle bay and upper Potomac River receiving no spat whatsoever (Figure 4a).

A final comment on the annual Spatfall Intensity Index: this index is an arithmetic mean that does not take into account geographic distribution, whereas the statistical tiers do. For example, the near-record high spatfall intensity in 1997 was actually limited in extent, being concentrated in the eastern portion of Eastern Bay, the northeast portion of the lower Choptank River, and to a lesser extent, in parts of the Little Choptank and St. Marys rivers (Homer & Scott 2001). Over 75% of the 1997 index was accounted for by only five of the 53 Key Bars, while ten contributed nearly 95% (Table 2). As a result, the 1997 spat index fell into the third statistical tier despite being the second highest index on record and an order of magnitude higher than other Tier 3 indexes. In contrast, the 1991 spatfall (the third highest on record) was far more widespread. Fifteen Key Bars comprised 75% of the index that year, while 28 sites were needed to attain 95% of the spatfall intensity index, placing it in the first statistical tier notwithstanding having a lower spatfall index than 1997. The uneven spatfall distribution accounts for the 2015 index falling into the same statistical Tier 4 as the 2014 index, despite being three times as high (Figure 3a).
Figure 4b. Spat counts per bushel at individual stations in the lower Potomac region, 2015.

Figure 4c. Spat counts per bushel at individual stations in the lower Tangier Sound region, 2015.
OYSTER DISEASES

Dermo disease remained below long-term average levels, continuing a trend that began in 2003. Oysters at all but two of the standard disease monitoring sites were infected with *Perkinsus marinus*, the parasite which causes dermo disease. Some oyster populations, especially on bars from the Choptank River and south, had elevated intensities that may be cause for concern in the future. MSX disease showed a prevalence increase while expanding its range upbay, reaching as far north as Eastern Bay and the Miles River, although at very low prevalences.

Dermo disease was detected in oysters on 95% of the Disease Bars (Table 3). The overall mean infection prevalence in oysters sampled on the Disease Bars was 61%, an increase from 2014 (52%) and the highest since 2007, but substantially below the record-high 2002 mean prevalence of 94%, ranking 2015 in the second lowest statistical grouping for prevalence (Figure 5). Twelve of the past thirteen years have had dermo disease mean prevalences below the 26-year average.

![Figure 5. Annual mean *P. marinus* prevalences and statistical groupings from Maryland disease monitoring bars.](image)

The geographic distribution of high prevalences (>60%) included the lower bay, the Patuxent and St. Marys rivers on the lower Western Shore, and all of the Eastern Shore tributaries from the Eastern Bay region southward, including Tangier and Pocomoke sounds (Figure 6). The only disease monitoring bars where dermo disease was not detected among tested oysters were Ragged Point in the Potomac River and Holland Point (n=7) on the mid-Western Shore. Outside of the regular disease monitoring sites, dermo disease was detected at low levels (13% prevalence, 0.2 intensity) as far north as Deep Shoal, an upper Bay bar heavily impacted by the 2011 freshets. In addition, oysters on Beacon bar in the upper reaches of the Potomac River oyster grounds have shown persistently low levels of dermo disease (13% prevalence, 0.1 intensity) over the past four years, after the disease was undetected there in 2011.

![Figure 6. Geographic extent and prevalence of dermo disease in Maryland, 2015.](image)
The 2015 annual mean infection intensity of 2.1 was somewhat higher than in 2014 (Table 3), but still within the second lowest statistical grouping (of five tiers) for dermo disease intensity (Figure 7). This is in contrast to the record high 2001 mean intensity of 3.8. The average intensity index over the thirteen years since the end of the 1999-2002 drought is 1.9, similar to another extended period of low to moderate dermo disease levels from 1994 to 1998 when annual mean infection intensities averaged 1.7. In comparison, the drought period of 1999-2002 had mean annual intensities that averaged 3.4.

In 2015, 26% of the Disease Bar samples had mean infection intensities of less than 1.0, compared with 49% in 2011, the lowest intensity year of the 25-year time series. Twelve bars (28%) had mean intensities of 3.0 or greater and two bars (Stone Rock, Turtle Back) were over 4.0. In contrast, 81% of the dermo disease intensities were ≥3.0 and 51% were ≥4.0 during the peak infection intensity year of 2001. Infection intensities in individual oysters that are ≥5 on a 0–7 scale are considered lethal; such infection intensities were detected in 17.8% of oysters sampled in 2015, an increasing trend from 2013 (14.8%) and 2014 (15.3%). The highest mean intensities in 2015 were scattered along the Eastern Shore from the Miles River to Pocomoke Sound (Table 3).

**MSX disease**, resulting from the parasite *Haplosporidium nelsoni*, is another potentially devastating oyster disease. This parasite can cause rapid mortality in oysters and generally kills a wide range of year classes, including younger oysters, over a long seasonal period.

For the second consecutive year, MSX disease showed an increase in prevalence while expanding its range upbay, reaching as far north as the Eastern Bay and the Miles River. This was the furthest upbay MSX has been detected since 2009 (Figure 9). *Haplosporidium nelsoni* was detected at 25 (21%) of the Disease Bars, 2.5 times the frequency of the previous year (Table 4). In contrast, the parasite was found on 90% of the bars in 2002. For the 43 disease monitoring bars, the average percentage of oysters infected with MSX disease was 7.0%, a tripling from 2014 (Figure 10, Table 4).

The abatement of MSX disease in 2003-2004 signified the end of the most severe *H. nelsoni* epizootic on record in Maryland waters. The 2002 epizootic set record high levels for both the frequency of affected disease monitoring bars (90%) and the mean annual prevalence within the oyster.
populations (28%), leaving in its wake observed oyster mortalities approaching 60%. Since 1990, there have been four H. nelsoni epizootics: 1991-92, 1995, 1999-2002, and 2009, the first three associated with spikes in observed mortalities (Figure 10).

All four of these epizootics coincided with dry years (Figure 2a). These were followed closely by periods of unusually high freshwater inputs into parts of Chesapeake Bay, which resulted in the purging of H. nelsoni infections from most Maryland oyster populations (Homer & Scott 2001; Tarnowski 2005, 2011). The current increase in H. nelsoni infections is associated with below normal streamflows since the latter portion of 2014.

**OBSERVED MORTALITY**

Despite an uptick in oyster mortalities, the Mortality Index of 14% remained below the 31-year mean, continuing a 12-year trend as a consequence of low to moderate disease pressure (Table 5). For the 43 disease monitoring bar subset, the average observed mortality of 13.6% over the last 12 years approaches the background mortality levels of 10% or less found prior to the mid-1980s disease epizootics (MDNR, unpubl. data). Because of the increase, the 2015 observed mortality on the Disease Bars was ranked in the second lowest statistical grouping over
the 31-year period; the past six years were in the lowest or second lowest mortality tier (Figure 11). This is a remarkable turnaround from 2002 when record-high disease levels devastated Maryland populations, resulting in a 58% observed mortality rate.

As with spatfall and oyster diseases, mortalities were patchy, with a general north-south gradient in observed mortality rates (Figure 12). Higher mortalities during 2015 were observed in upper Tangier Sound, upper St. Marys River, and the mouths of some tributaries, including the Choptank, Little Choptank, and Patuxent rivers and Bodkins Shoal bar in Eastern Bay. The highest mortality on an individual bar with more than 50 oysters/bu was 71% on Holland Straits East bar in the middle region of Tangier Sound.

**BIOMASS INDEX**

The 2015 Maryland Oyster Biomass Index dipped by 14% from the two previous years’ record highs, which had more than doubled the 2010 Index (Figure 13). Nonetheless, the 2015 Biomass Index of 1.77 was the third highest of the 26-year time series, reflecting the high oyster survivorship over the past few years, particularly of the strong 2010 and 2012 year classes.
The Biomass Index is a relative measure of how the oyster population is doing over time. It accounts for recruitment, individual growth, natural mortality, and harvesting in a single metric. In assessing the size of the population, the Biomass Index reflects both the abundance of oysters and their collective weight (another way of looking at how large they are). For example, when examining two groups of oysters with the same abundance, the group with the greater number of larger oysters would have the higher biomass.

The oyster population had been slow to recover since its nadir in 2002, the last year of the devastating 4-year epizootic. The Biomass Index remained below one for eight consecutive years despite low disease pressure and high oyster survivorship over this period. Spatfall during this timeframe was sufficient to maintain the population at this level but not increase it. It was not until the strong recruitment event in 2010 that the population began to grow, bolstered by another good spatset in 2012.

COMMERCIAL HARVEST

With reported harvests of 389,000 bushels during the 2014-15 season, commercial oyster landings decreased by 7% from the previous year (Table 6, Figure 14a). Nevertheless, this was the second highest total since the 1998-99 harvest season. At an average reported price of $44 per bushel, the dockside value of $17.1 million was an increase of $3.0 million over the previous year and the highest since 1982 (Table 7a).

Prior to the 2012-13 season, the fishery had been slow to recover from the devastating oyster blight of 2002, with a record low of 26,000 bu taken in 2003-04. The substantial harvest increases during the last three seasons over the average landings of the previous eight years were due to the strong 2010 and 2012 year-classes and subsequent good survivorship, allowing a large proportion of the cohorts to attain market size. This abundance of oysters led to an increase in harvesters and fishing effort, resulting in higher landings.

Figure 14a. Maryland oyster landings over the most recent 22 seasons.

Taken in context, the 2014-15 landings remain only a fraction of the harvests prior to the mid-1980s disease epizootics (Figure 14b). Since the heyday of the Maryland oyster fishery in the 19th century, annual landings below 100,000 bushels have been reported in only five seasons, all within the past 22 years (and four of these in the most recent 13 years). Nevertheless, the recent spikes in harvests are a welcome improvement from the dismal landings of the previous decade.

Figure 14b. Maryland seasonal oyster landings, 1976-77 to 2013-14.

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1 The baseline (Biomass Index = 1) year of 1993 was chosen because it had the lowest harvest on record up to that point.
Although the region’s share declined from the previous season, the Tangier Sound/Lower Mainstem region, including the Nanticoke, Wicomico and Honga rivers, Pocomoke Sound and Fishing Bay, was again the dominant harvest area, accounting for nearly 50% of the 2014-15 landings (Table 6). Outside of Tangier Sound proper, which contributed 20.3% of the landings, the highest percentage of the harvests (16.1%) came from Broad Creek, a tributary of the Choptank River with a much smaller area. The regions experiencing harvest increases or decreases were almost evenly split, but the losses in a given region were more substantial than the gains. The most substantial changes in Maryland landings between the 2013-14 and 2014-15 seasons were:

Tangier Sound
- decreased 24,224 bushels (-23%)
Fishing Bay
- decreased 22,855 bushels (-37%)
Pocomoke Sound
- decreased 15,081 bushels (-45%)
Broad Creek
- decreased 13,689 bushels (-18%)
Lower Choptank River
- increased 13,074 bushels (+101%)
Patuxent River
- increased 25,797 bushels (+129%)

The combined harvests in the Tangier Sound region decreased by 55,631 bushels or 23.5%. The northern portion of the mainstem and associated tributaries continued to perform poorly due to a lack of recruitment and repletion activity. For example, the combined percentage of landings from the upper bay and Chester River, which in some years accounted for over half of Maryland’s total landings, was a mere 1.1% (Table 6).

For the seventh consecutive season, power dredging was the predominant method of harvesting, accounting for 42% of the total landings, a sharp decline from the previous year (Table 7b). This activity was mainly in the Lower Eastern Shore and Choptank regions. Hand tonging remained at 16% of the total harvests, primarily from Broad Creek, though still well below 74% of the landings during the 1996-97 season. Patent tonging showed a strong increase to 27% of the total, while sail dredging and diving trailed with single-digit percentages.

**OYSTER SANCTUARIES**

A total of 87 oyster bars within 33 sanctuaries were sampled during 2015 the Fall Survey (Table 8). Recruitment within sanctuaries generally followed the same pattern as adjacent harvest areas. The mean spatfall in the Manokin Sanctuary was higher than in the adjacent Tangier Sound, averaging 121 spat/bu despite relatively low counts on its two Key Bars (Figure 4, Table 2), and with a high count of 350 spat/bu on Marshy Island bar. This compares with 71 spat/bu in the open harvest area of Tangier Sound. Dermo disease levels in most of the sanctuaries increased somewhat from 2014 (Table 3). Of the 13 Disease Bars within oyster sanctuaries, dermo disease prevalences increased at eight bars and were above the 26-year average at six bars; intensities increased at 9 bars and were above the 26-year average at six bars. Most of the increases were modest, with a few exceptions (e.g. Bruffs Island, Sandy Hill, Oyster Shell Point). MSX disease was detected at only five of the Disease Index Bars within sanctuaries (Table 4), as well as three non-Index bars in sanctuaries. In two of the three sanctuary/restoration areas, Harris Creek and the Tred Avon River, there was no evidence of MSX. It was found at low prevalence in Broad Creek, which is an open harvest tributary located between those two sanctuaries. MSX was detected at an elevated prevalence level in the Little Choptank River, the third of the sanctuary/restoration areas. Mortality rates for the most part continue to be well below the long-term averages (Table 5), including in the Manokin River sanctuary, where anecdotal reports of high oyster mortalities were not confirmed. Overall, oysters in
sanctuaries that received strong spatfalls in 2010 and 2012 - including Harris Creek, Little Choptank, Manokin, and St. Marys - continued to do well.

**DISCUSSION**

*Present Conditions and Trends*

One striking aspect of environmental conditions during 2015 was that the annual mean monthly streamflow was the lowest since the 1999-2002 drought. Consequently, salinities during 2015 have been higher than average through most of the year, since freshwater input determines salinity in Chesapeake Bay. Salinity in turn is a key factor influencing oyster reproduction and recruitment, disease, and mortality (Tarnowski 2010).

Oyster recruitment is affected by salinity, both directly and indirectly (Kimmel & Newell 2007). If salinity is below a critical threshold the likelihood of a spatfall failure is assured. The timing and volume of streamflows (which modulate salinities) is important; the March – May period appears to be a good indicator of recruitment potential. However, favorable salinity is a necessary but not always sufficient condition to ensure a good spatfall (Tarnowski 2010).

The elevated salinities of 2015 should have resulted in a strong recruitment year. Indeed, the 2015 Spat Index was 50% higher than the 31-year median, but the average was due entirely to a high spatset on Chicken Cock bar in the St. Marys River. In fact, the lower Potomac River region, including the lower St. Marys River, experienced the best recruitment in 30 years, but aside from this region, spatset in Maryland was generally spotty and irregular. In Tangier Sound, the range of spatset was 0 to 518 spat/bu, with most of the results only reaching double digits at most. Further upbay some regions lacked spatsets altogether. As a result, despite the higher Spat Index, recruitment can be considered indifferent for the third year in a row, with a statistical ranking of only Tier Four (out of six) (Figure 3a). While southern waters may see an uptick in harvests in about three years, other areas, notably Eastern Bay, will continue to struggle.

The rapid and extensive range expansion of MSX disease during 2015 was likely facilitated by the elevated salinities, similar to past patterns in Maryland (Tarnowski 2010). Oyster parasites are salinity sensitive, particularly *H. nelsoni* (Ford 1985, Ragone & Burreson 1993). *Haplosporidium nelsoni* can exist in salinities as low as 10 ppt, but it becomes substantially more pathogenic in salinities greater than 15 ppt and temperatures greater than 20°C (Ford 1985). Mid-bay locations such as monitoring buoy CB4.2C, which typically experience lower salinities, consistently had salinities above this range, enabling the spread of MSX disease as far upbay as Eastern Bay, although often at low prevalences.

The highest prevalences of MSX disease were detected in several oyster populations in southern Maryland, where salinities in certain areas approached 20 ppt, although related mortalities have been low. There are two main hypotheses as to why mortalities have remained below average, which are more fully explained in Tarnowski (2010). Briefly, the first is that oysters have developed resistance or tolerance to the disease. Alternatively, the lower mortalities may be due to favorable environmental conditions, both short-term and extending over a decade, which have been well documented in past Fall Oyster Survey reports. The timely freshwater pulse in July 2015, which reduced mid-bay salinities to below 10 ppt, may have mitigated more serious negative impacts from MSX. Nevertheless, if the trend in elevated salinities continues well into 2016, it could test these hypotheses.

Dermo disease acquisition is influenced by thresholds of salinity and temperature, with infection prevalences and intensities
typically rising with increases in these conditions (McCollough et al. 2007). While dermo disease is considered enzootic in Chesapeake Bay, not all infections are lethal or progress to lethal intensities. Environmental conditions mitigate or promote infection intensities. Increasing salinities and temperatures create favorable conditions for infection intensification, particularly in areas where otherwise typically lower salinities hold the progress of the disease in check. Both the percentage of moderate to high infection intensities and the percentage of lethal infections increased in 2015. The sample collected from Stone Rock exhibited the highest mean infection intensity on record (Table 3). Should higher salinities persist into the summer of 2016, *P. marinus* may contribute significantly to oyster mortality throughout the bay. Those populations in higher salinity areas may well experience twin stresses from both dermo and MSX disease combined.

The positive trend in the Chesapeake oyster populations over the past dozen years likely can be attributed to the generally favorable salinities during this period. The record-high disease-related mortalities at the turn of the millennium subsided during the high streamflow years of 2003-2004, dropping to pre-disease levels and has remained below the long-term average up to the present (Figure 11, Table 5). This allowed oyster stocks to rebuild, slowly during the first few years then explosively, driven by strong year classes in 2010 and 2012 (Figure 13). The resulting increase in landings is likely short-lived due to indifferent spatsets following 2012 and a downturn is expected (Tarnowski 2015).

As already mentioned, one of the most critical physical factors influencing oyster populations is salinity. But salinity is dependent on highly variable circumstances, including the frequency, intensity and timing of storm systems as well as accumulated snowpack and the rate at which it melts. Therefore, offering reliable predictions about recruitment and disease-related mortality become more difficult the further into the future a projection is made. An additional complication is the variety of other factors, some probably unknown, that can account for successful recruitment when salinities are adequate (Tarnowski 2010). The relationship between salinity and oyster diseases is more straightforward, but a random event such as a well-timed tropical storm can lower salinities over a brief duration, lessening disease pressure on the oyster populations. Because of the highly variable nature of the conditions influencing these key population properties, the ability to predict them dwindles to nil over a relatively short period into the future.

A key role of the Fall Oyster Survey and associated reports such as this is to gather and disseminate data about Maryland’s oyster populations for informed, timely, and proactive management decisions. For example, based on the findings from the 2015 Survey, the Potomac River Fisheries Commission shut down the lower Potomac fishery to protect the exceptional spatset that year from dredging-related mortality. But no survey can predict what the future may bring, whether an abundance of oysters to harvest in a few years or a disease-ravaged population. This will be left to the vagaries of nature.

**LITERATURE CITED**


TABLES

Table 1. Listing of data recorded during the Annual Fall Dredge Survey.

**Physical Parameters**

- Latitude and longitude (deg., min., decmin.)
- Depth (ft.)
- Temperature (°C; surface at all stations, 1 ft. above bottom at Key & Disease Bars)
- Salinity (ppt; surface at all stations, 1 ft. above bottom at Key & Disease Bars)
- Tow distance (ft.) (2005-present)

**Biological Parameters**

- Total volume of material in dredge (Md. bu.) (2005-present)
- Counts of live and dead oysters by age/size classes (spat, smalls, markets) per Md. bushel of material
- Stage of oyster boxes (recent, old)
- Observed (estimated) average and range of shell heights of live and dead oysters by age/size classes (mm)
- Shell heights of oysters grouped into 5-mm intervals (Disease Bars, 1990-2009) or 1-mm intervals (Disease Bars and other locations totaling about 30% of all surveyed bars, 2010-present)
- Oyster condition index and meat quality
- Type and relative index of fouling and other associated organisms
- Type of sample and year of activity (e.g. 1997 seed planting, natural oyster bar, 1990 fresh shell planting, etc.)
Table 2. Spatfall intensity (spat per bushel of cultch) from the 53 “Key” spat monitoring bars, 1985-2015.

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Table 2 - Spat (continued).

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**Spat Index** | **34.2** | **41.4** |

(Return to Text)
Table 3. *Perkinsus marinus* prevalence and intensity (scale of 0-7) in oysters from the 43 disease monitoring bars, 1990-2015. NA = insufficient quantity of oysters for analytical sample. (S) = bar within an oyster sanctuary.

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| Annual Means | 68 | 2.3 | 56 | 1.8 | 59 | 2.0 | 57 | 1.8 | 38 | 1.2 | 59 | 2.0 |
| Bar Freq. (%) | 93 | 95 | 93 | 98 | 93 | 93 |
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(Return to Text)
Table 4. Prevalence of *Haplosporidium nelsoni* in oysters from the 43 disease monitoring bars, 1990-2015. NA=insufficient quantity of oysters for analytical sample. ND= sample collected but diagnostics not performed; prevalence assumed to be 0. (S) = bar within an oyster sanctuary.

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1 Includes harvests from unidentified regions. Not all harvest reports provided region information, but were included in the Md. total.
Table 6 - Landings (continued).

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¹ Includes harvests from unidentified regions.
Table 6 - Landings (continued).

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1 Includes harvests from unidentified regions.
Table 6 - Landings (continued).

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1 Includes harvests from unidentified regions.
Table 6 - Landings (continued).

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<td>22,933</td>
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<td>45,301</td>
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<td>5,551</td>
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<td><strong>Total Tangier Sound Region</strong></td>
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<td>137,317</td>
<td>341,232</td>
<td>416,578</td>
<td>388,658</td>
<td>298,755</td>
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</table>

¹ Includes harvests from unidentified regions.
Table 7a. Bushels of oyster harvest by gear type in Maryland, 1989-90 through 2014-15 seasons.
Dockside value is in millions of dollars.

<table>
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<tr>
<th>Season</th>
<th>Hand Tongs</th>
<th>Diver</th>
<th>Patent Tongs</th>
<th>Power Dredge</th>
<th>Skipjack</th>
<th>Total Harvest $</th>
<th>Dockside Value</th>
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<td>7,630</td>
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<td>347,968</td>
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1 Harvest reports without gear information were not included in harvest by gear type totals but were included in total harvest.

(Return to Text)
Table 7b. Percent of oyster harvest by gear type in Maryland, 1989-90 through 2014-15 seasons. Some years may not total 100% due to incomplete data.

<table>
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<th>Season</th>
<th>Hand Tongs</th>
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<th>Patent Tongs</th>
<th>Power Dredge</th>
<th>Skipjack</th>
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<td>&lt;1</td>
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<td>2008-09</td>
<td>12</td>
<td>11</td>
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<td>2010-11</td>
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<td>23</td>
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</tr>
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<td>14</td>
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<td>5</td>
<td>18</td>
<td>58</td>
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</tr>
<tr>
<td>2014-15</td>
<td>16</td>
<td>7</td>
<td>27</td>
<td>42</td>
<td>9</td>
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Table 8. Oyster bars within sanctuaries sampled during the 2015 Fall Survey.

<table>
<thead>
<tr>
<th>Region</th>
<th>Oyster Sanctuary</th>
<th>Surveyed Bars Within Sanctuary</th>
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</thead>
<tbody>
<tr>
<td>Upper Bay</td>
<td>Man O War/Gales Lump</td>
<td>Man O War Shoals</td>
</tr>
<tr>
<td></td>
<td>Poplar Island</td>
<td>Poplar I.</td>
</tr>
<tr>
<td></td>
<td>Herring Bay</td>
<td>Holland Pt.1,2</td>
</tr>
<tr>
<td></td>
<td>Calvert Shore</td>
<td>Flag Pond1,2</td>
</tr>
<tr>
<td>Middle Bay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Bay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Mainstem East</td>
<td>Northwest Middleground</td>
</tr>
<tr>
<td></td>
<td>Cedar Point</td>
<td>Cedar Point Hollow</td>
</tr>
<tr>
<td></td>
<td>Point Lookout</td>
<td>Pt. Lookout</td>
</tr>
<tr>
<td></td>
<td>Upper Chester River</td>
<td>Love Pt., Strong Bay, Wickes Beach</td>
</tr>
<tr>
<td></td>
<td>Upper Chester River</td>
<td>Boathouse, Cliff, Drum Pt., Ebb Pt., Emory Hollow, Old Field2, Sheep</td>
</tr>
<tr>
<td></td>
<td>Chester ORA Zone A</td>
<td>Shippen Creek</td>
</tr>
<tr>
<td></td>
<td>Eastern Bay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mill Hill</td>
<td>Mill Hill</td>
</tr>
<tr>
<td></td>
<td>Cox Creek</td>
<td>Ringold Middleground</td>
</tr>
<tr>
<td></td>
<td>Wye River</td>
<td></td>
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<tr>
<td></td>
<td>Wye River</td>
<td>Bruffs I.1,2, Mills, Race Horse, Whetstone, Wye River Middleground</td>
</tr>
<tr>
<td>Miles River</td>
<td>Miles River</td>
<td>Long Pt.2</td>
</tr>
<tr>
<td>Choptank River</td>
<td>Cook Point</td>
<td>Cook Pt.1,2</td>
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<td>Lower Choptank River</td>
<td>Chlora Pt.</td>
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<td></td>
<td>Sandy Hill</td>
<td>Hambrooks, Sandy Hill1,2</td>
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<td></td>
<td>Howell Point - Beacons</td>
<td>Beacons</td>
</tr>
<tr>
<td></td>
<td>States Bank</td>
<td>Green Marsh, Shoal Creek</td>
</tr>
<tr>
<td></td>
<td>Upper Choptank River</td>
<td>Bolingbrooke Sand, The Black Buoy, Oyster Shell Pt.2</td>
</tr>
<tr>
<td></td>
<td>Choptank ORA Zone A</td>
<td>Dixon, Mill Dam, Tanners Patch, Cabin Creek, Drum Pt.</td>
</tr>
<tr>
<td>Harris Creek</td>
<td>Harris Creek</td>
<td>Change, Mill Pt.1, Seths Pt., Walnut, Little Neck, Rabbit I.</td>
</tr>
<tr>
<td>Tred Avon River</td>
<td>Tred Avon River</td>
<td>Pecks Pt., Mares Pt., Louis Cove, Orem, Double Mills1,2, Maxmore Add. 1</td>
</tr>
<tr>
<td>Little Choptank River</td>
<td>Little Choptank River</td>
<td>Susquehanna, Cason1,2, Butterpot, McKeils Pt., Grapevine, Town, Pattison</td>
</tr>
<tr>
<td>Hooper Straits</td>
<td>Hooper Straits</td>
<td>Applegarth, Lighthouse</td>
</tr>
<tr>
<td>Nanticoke River</td>
<td>Nanticoke River</td>
<td>Roaring Pt. East, Wilson Shoals2, Bean Shoal, Cherry Tree, Cedar Shoal, Old Woman’s Patch, Hickory Nut, Wetipquin1</td>
</tr>
<tr>
<td>Manokin River</td>
<td>Manokin River</td>
<td>Piney I. Swash, Mine Creek, Marshy I., Drum Pt.1, Georges1,2</td>
</tr>
<tr>
<td>Tangier Sound</td>
<td>Somerset</td>
<td>Piney I. East Add. 1</td>
</tr>
<tr>
<td>Severn River</td>
<td>Severn River</td>
<td>Chinks Pt.</td>
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<tr>
<td>Patuxent River</td>
<td>Upper Patuxent</td>
<td>Thomas, Broad Neck, Trent Hall, Buzzard I., Holland Pt.</td>
</tr>
<tr>
<td></td>
<td>Neal Addition</td>
<td>Neale</td>
</tr>
<tr>
<td>St. Marys River</td>
<td>St. Marys River</td>
<td>Pagan1,2, Horseshoe</td>
</tr>
<tr>
<td>Breton Bay</td>
<td>Breton Bay</td>
<td>Black Walnut1, Blue Sow1</td>
</tr>
</tbody>
</table>

1 Key Spat Bar  2 Disease Bar

(Return to Text)
Oysters

The eastern oyster *Crassostrea virginica* is found in waters with temperatures of -2°C to 36°C (28-97°F) and sustained salinities of 4‰ to 40‰ (ppt), where ocean water has 35‰ salinity. Oysters reproduce when both sexes simultaneously spawn their gametes into Chesapeake Bay waters. Spawning occurs from May - September, and peaks during June - July. Externally fertilized eggs develop into swimming planktonic larvae that are transported by water currents for 2-3 weeks, while feeding on phytoplankton as they grow and develop. Mature larvae seek solid benthic substrates, preferably oyster shells, to which they attach as they metamorphose to become sessile juvenile oysters. Unlike fishes and other vertebrates, oysters do not regulate the salt content of their tissues; instead, the salt content of oyster tissues conforms to the broad and variable range of salinities in oyster habitats. Thus, oyster parasites with narrow salinity requirements may be exposed to low environmental salinities when shed into environmental waters, as well as while infecting oysters in low-salinity waters. At death, an oyster’s shell valves spring open passively, exposing its tissues to predators and scavengers. However, the resilient hinge ligament holds the articulated valves together for months after death. Vacant, articulated oyster shells (boxes) in our samples are interpreted to represent oysters that died during the previous year, and the numbers of dead and dying (gaper) oysters are compared to those of live oysters in dredge samples, to estimate proportions for natural mortalities in oyster samples and populations.

Dermo disease

Although the protozoan parasite that causes dermo disease is now known as *Perkinsus marinus*, it was first described as *Dermocystidium marinum* in Gulf of Mexico oysters (Mackin, Owen & Collier 1950), and its name was colloquially abbreviated then as ‘dermo’. Almost immediately, dermo disease was also reported in Chesapeake Bay oysters (Mackin 1951). *Perkinsus marinus* is transmitted through the water to uninfected oysters in as few as three days, and such infections may prove fatal in as few as 18 days. Heavily infected oysters are emaciated; showing reduced growth and reproduction (Ray & Chandler 1955).

Although *P. marinus* survives low temperatures and low salinities, its proliferation is highest in the broad range of temperatures (15-35°C) and salinities (10-30‰) that are typical of Chesapeake Bay waters during oyster dermo disease mortality peaks (Dungan & Hamilton 1995). Over several years of drought during the 1980s, *P. marinus* expanded its Chesapeake Bay distribution into upstream areas where it had been previously rare or absent (Burreson & Ragone Calvo 1996). Since 1990, at least some oysters in 93-100% of all regularly tested Maryland populations have been infected. Annual mean prevalences for dermo disease have ranged at 38-94% of all tested oysters, with a 26-year average of 68%.
MSX disease

The high-salinity protozoan oyster pathogen *Haplosporidium nelsoni* was first detected and described as a *multinucleated sphere unknown* (MSX) from diseased and dying Delaware Bay oysters during 1957 (Haskin et al. 1966), and it also infected oysters in lower Chesapeake Bay during 1959 (Andrews 1968). Although the common location of lightest *H. nelsoni* infections in oyster gill tissues suggests waterborne transmission of infectious pathogen cells, the complete life cycle and actual infection mechanism of the MSX parasite remain unknown.

Despite numerous experimental attempts, MSX disease has rarely been transmitted to uninfected oysters in laboratories. However, captive experimental oysters reared in enzootic waters above 14‰ salinity are frequently infected, and may die within 3-6 weeks. In Chesapeake Bay, MSX disease is most active in higher salinity waters with temperatures of 5-20°C (Ewart & Ford 1993). MSX disease prevalences typically peak during June, and deaths from such infections peak during August. In Maryland waters, annual average prevalences for MSX disease have ranged at 0.1-28%, with a 26-year mean of 6%.

Since MSX disease is rare in oysters from waters below 9‰ salinity, the distribution of *H. nelsoni* in Chesapeake Bay varies as salinities change with variable freshwater inflows. During a recent 1999-2002 drought, consistently low freshwater inflows raised salinities of Chesapeake Bay waters to foster upstream range expansions by MSX disease during each successive drought year (Tarnowski 2003). The geographic range for MSX disease also expanded widely during a recent 2009 epizootic. During 2003-2008 and 2010-2012, freshwater inflows near or above historic averages reduced salinities of upstream Chesapeake Bay waters to dramatically limit the geographic range and effects of MSX disease (Tarnowski 2014). Since 2013, the geographic range of MSX disease has expanded further upstream each year, and its mean annual prevalence has approximately doubled during successive years.

References


### APPENDIX 2

**GLOSSARY**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>box oyster</td>
<td>Pairs of empty shells joined together by their hinge ligaments. These remain articulated for months after the death of an oyster, providing a durable estimator of recent oyster mortality (see gaper). Recent boxes are those with no or little fouling or sedimentation inside the shells, generally considered to have died within the previous two to four weeks. Old boxes have heavier fouling or sedimentation inside the shells and the hinge ligament is generally weaker.</td>
</tr>
<tr>
<td>bushel</td>
<td>Unit of volume used to measure oyster catches. The official Maryland bushel is equal to 2,800.9 cu. in., or 1.0194 times the U.S. standard bushel (heaped) and 1.3025 times the U.S. standard bushel (level).</td>
</tr>
<tr>
<td>cultch</td>
<td>Hard substrate, such as oyster shells, spread on oyster grounds for the attachment of spat.</td>
</tr>
<tr>
<td>dermo disease</td>
<td>The oyster disease caused by the protozoan pathogen <em>Perkinsus marinus</em>.</td>
</tr>
<tr>
<td>dredged shell</td>
<td>Oyster shell dredged from buried ancient (3000+ years old) shell deposits. Since 1960 this shell has been the backbone of the Maryland shell planting efforts to produce seed oysters and restore oyster bars.</td>
</tr>
<tr>
<td>fresh shell</td>
<td>Oyster shells from shucked oysters. It is used to supplement the dredged shell plantings.</td>
</tr>
<tr>
<td>gaper</td>
<td>Dead or moribund oyster with gaping valves and tissue still present (see box oyster).</td>
</tr>
<tr>
<td>Haplosporidium nelsoni</td>
<td>The protozoan oyster parasite that causes MSX disease.</td>
</tr>
<tr>
<td>infection intensity, individual</td>
<td><em>Perkinsus</em> sp. parasite burdens of individual oysters, estimated by RFTM assays and categorized on an eight-point scale. Uninfected oysters are ranked 0, heaviest infections are ranked 7, and intermediate-intensity infections are ranked 1-6. Oysters with infection intensities of 5 or greater are predicted to die imminently.</td>
</tr>
</tbody>
</table>
| infection intensity, mean sample | Averaged categorical infection intensity for all oysters in a sample:  
\[
\text{mean sample} = \frac{\text{sum of all categorical infection intensities (0-7)}}{\text{number of sample oysters}}
\]  
Oyster populations whose samples show mean infection intensities of 3.0 or greater are predicted to experience significant near-term mortalities. |
| infection intensity, annual | Average of mean intensities for annual survey samples from constant mean sites:  
\[
\text{mean annual} = \frac{\text{sum of all sample mean intensities}}{\text{number of annual samples}}
\]  
Oyster populations whose samples show mean infection intensities of 3.0 or greater are predicted to experience significant near-term mortalities. |
| intensity index, sample | Categorical infection intensities averaged only for infected oysters:  
\[
\text{sample} = \frac{\text{sum of individual infection intensities(1-7)}}{\text{number of infected oysters}}
\]  
Oyster populations whose samples show mean infection intensities of 3.0 or greater are predicted to experience significant near-term mortalities. |
intensity index, annual
Categorical infection intensities averaged for all infected survey oysters:

\[
\text{sum of all sample intensity indices ÷ number of annual samples}
\]

market oyster
An oyster measuring 3 inches or more from hinge to mouth (ventral margin).

mortality (observed), sample
Percent proportion of annual, natural oyster population mortality estimated by dividing the number of dead oysters (boxes and gapers) by the sum of live and dead oysters in a sample:

\[
100 \times \left( \frac{\text{number of boxes and gapers}}{\text{(number of boxes and gapers + number of live)}} \right)
\]

mortality (observed), annual
Percent proportion of annual, bay-wide, natural oyster mortality estimated by averaging population mortality estimates from the 43 Disease Bar (DB) samples collected during an annual survey:

\[
\text{sum of sample mortality estimates ÷ 43 DB samples}
\]

MSX disease
The oyster disease caused by the protozoan pathogen *Haplorasporidium nelsoni*.

MSX % frequency, annual
Percent proportion of sampled populations infected by *H. nelsoni* (MSX):

\[
100 \times \left( \frac{\text{number of sample with MSX infections}}{\text{total sample number}} \right)
\]

Perkinsus marinus
The protozoan oyster parasite that causes dermo disease.

prevalence, sample
Percent proportion of infected oysters in a sample:

\[
100 \times \left( \frac{\text{number infected}}{\text{number examined}} \right)
\]

prevalence, mean annual
Percent proportion of infected oysters in an annual survey:

\[
\text{sum of sample percent prevalences ÷ number of samples}
\]

RFTM assay
Ray’s fluid thioglycollate medium assay. Method for enlargement, detection, and enumeration of *Perkinsus marinus* cells in oyster tissue samples. This diagnostic assay for dermo disease has been widely used and refined for over sixty years to date.

seed oysters
Young oysters produced by planting shell as a substrate for oyster larvae to settle on in historically productive areas. If the spatfall is adequate, the seed oysters are subsequently transplanted to growout (seed planting) areas, generally during the following spring.

small oyster
An oyster equal to or greater than one year old but less than 3 inches (see market oyster, spat).

spat
Oysters younger than one year old.

spatfall, spatset, set
The process by which swimming oyster larvae attach to a hard substrate such as oyster shell. During this process the larvae undergo metamorphosis, adopting the adult form and habit.

spatfall intensity, sample site
The number of spat per bushel of cultch. This is a relative measure of density used to calculate the spat index.
spatfall intensity index  The arithmetic mean of spatfall intensities from 53 fixed reference sites or Key Bars:

\[
\text{sum of Key Bar spatfall intensities} \div \text{number of Key Bars}
\]

(Return to Text)

Power dredging in the Choptank River, November 2015. (Photo: Robert Bussell)