Maryland Oyster Population Status Report

2003 and 2004 Fall Surveys

Mitchell Tarnowski, Editor
Prepared by the Staff of the Maryland Department of Natural Resources
Shellfish Program and Cooperative Oxford Laboratory
MDNR Publ. No. 17-1072005-62

December 2005

FOR MORE INFORMATION PLEASE CONTACT
Maryland Department of Natural Resources
Fisheries Service
Tawes State Office Building
580 Taylor Avenue
Annapolis, MD 21401
1-800-688-FINS • 410-260-8258

MDNR GENERAL INFORMATION
1-877-620-8DNR
www.dnr.state.md.us
Fisheries Service Ext. - 8258

Robert L. Ehrlich, Jr., Governor
Michael S. Steele, Lt. Governor
C. Ronald Franks, Secretary, DNR

CONTRIBUTORS

Editor

Shellfish Program, MDNR

Mitchell Tarnowski, Shellfish Biologist

Technical Participants

Lead Scientist

Shellfish Program, MDNR

Roy Scott, Senior Shellfish Biologist (2003)
Mitchell Tarnowski, Shellfish Biologist (2004)

Field Operations

Deal Island Work Center, Shellfish Program, MDNR

John Hess, Manager
Mickey Astarb, Biologist
Stanley Daniels, Repletion Manager
David White, Captain R/V *Miss Kay*

Parasite Diagnostic Testing

Cooperative Oxford Laboratory, MDNR

Carol B. McCollough, Pathologist (2004)
Dr. Melba Reantaso, Pathologist (2003)
Rosalee Hamilton, Managing Histologist
Jud Blazek, Histotechnician
Sara Fegel, Histotechnician
Suzanne Tyler, Histotechnician
Leon Williams, Biologist
Kelly Greenhawk, Programmer Analyst

Statistical Analyses

Shellfish Program, MDNR

Dr. Mark Homer, Research Statistician

Graphics

Shellfish Program, MDNR

Robert Bussell, Biologist

Cover

Coastal Bays Fisheries Program, MDNR

Angel Bolinger, Fisheries Biologist

Text

Shellfish Program, MDNR

Mitchell Tarnowski, Shellfish Biologist
Dr. Mark Homer, Research Statistician

Sarbanes Cooperative Oxford Laboratory, MDNR

Carol B. McCollough, Senior Histologist/Pathologist
Christopher Dungan, Research Scientist

Reviewers

Cooperative Oxford Laboratory, MDNR

Christopher Dungan, Research Scientist
Carol B. McCollough, Senior Histologist/Pathologist

Shellfish Program, MDNR

Christopher Judy, Director
Dr. Mark Homer, Research Statistician

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The severe drought which afflicted the Chesapeake region for four consecutive years finally broke during the fall of 2002. Above average rainfall continued throughout 2003 and 2004, resulting in the second and third highest freshwater inputs, respectively, over the past two decades. The consequent drop in salinities had mixed impacts on Maryland oyster populations, affecting reproduction, disease, and survivorship.

The Maryland oyster spatfall was extremely poor in both 2003 and 2004, with meaningful quantities confined to a few discrete areas, notably Tangier Sound. No spat were observed in large portions of the bay and tributaries, particularly in 2004. The 2003 spat index was the third lowest over the past 20 years, while the 2004 index was only slightly higher.

Oyster diseases abated over the past two years following the record high levels of 2002. The MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni*, which in 2002 had ravaged oyster populations as far up bay as the Bay Bridge, ended in 2003. By 2004, MSX disease had retreated to lower Tangier Sound and a portion of the St. Mary's County bayshore. On the other hand, *Perkinsus marinus*, the parasite that causes dermo disease, continued to be found in almost every oyster sample tested for that disease, although at much lower prevalences and intensities than in 2002. *P. marinus* infections persisted at elevated levels in the Tangier Sound region and on Sandy Hill bar in the Choptank River. In contrast to MSX disease, which has been extirpated by low salinities in most Maryland waters, the sustained widespread distribution of *P. marinus*, even at low to moderate intensity levels, indicates that dermo disease is still enzootic throughout most of the tidal waters of the state.

Survivorship improved dramatically in 2003 and 2004 with the sharp decreases in the distribution and prevalences of oyster diseases. Observed mortalities in 2003 declined for the first time since 1997. This welcome relief to the oyster populations followed the record high mortalities observed in 2002. Observed mortalities in 2003 may have been overestimated due to the persistence of boxes more than a year old. Despite the large volumes of freshwater input during 2003 and 2004, no significant oyster mortalities were observed as a consequence. Areas in the bay that received notable spatfalls in 2001 and 2002, such as the Point Lookout Oyster Sanctuary, have benefited from good survivorship during the subsequent two years and now have flourishing oyster populations.

As a consequence of the elevated disease levels and mortalities during the drought years, oyster harvests continued to plummet over the past two seasons, marking five consecutive years of declines. The 2002-03 harvest of 56,000 bushels was the lowest since the early 19th century, representing a 62% drop from the previous year. This was followed by yet another decline to a paltry 26,000 bushels, making the 2003-04 harvest the lowest on record. In the short term, the spatfalls of 2001 and 2002, coupled with the good survivorship over the last two years, should result in an increase in harvests, at least in the 2004-05 season. However, with the exception of Tangier Sound, the spat failures in 2003 and 2004 does not bode well for the fishery, especially if freshwater flows return to normal levels and disease proliferates in southern Maryland waters.

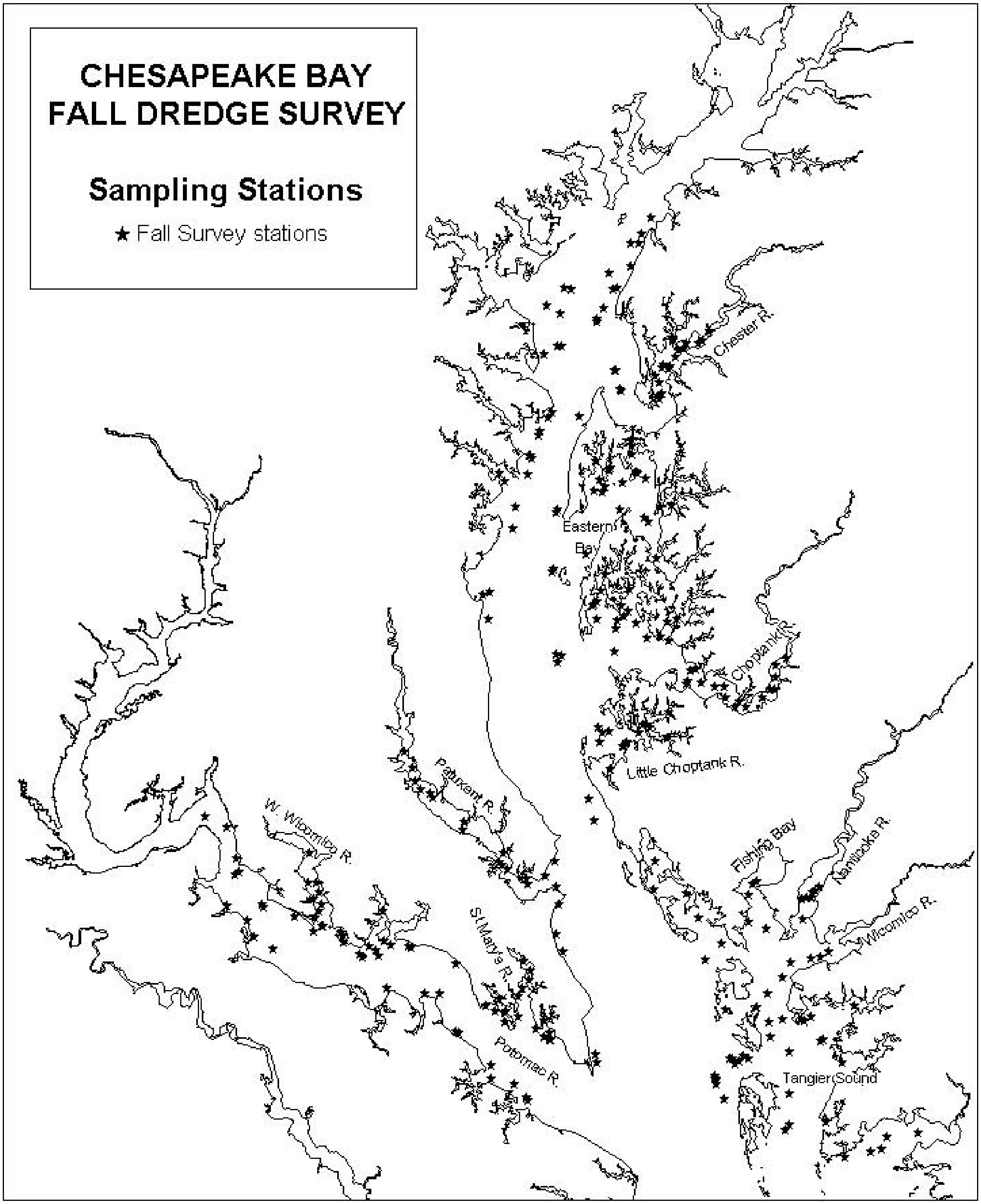

Figure 1a. Annual Maryland Fall Survey station locations, all bar types (standard, Key, Disease) included.

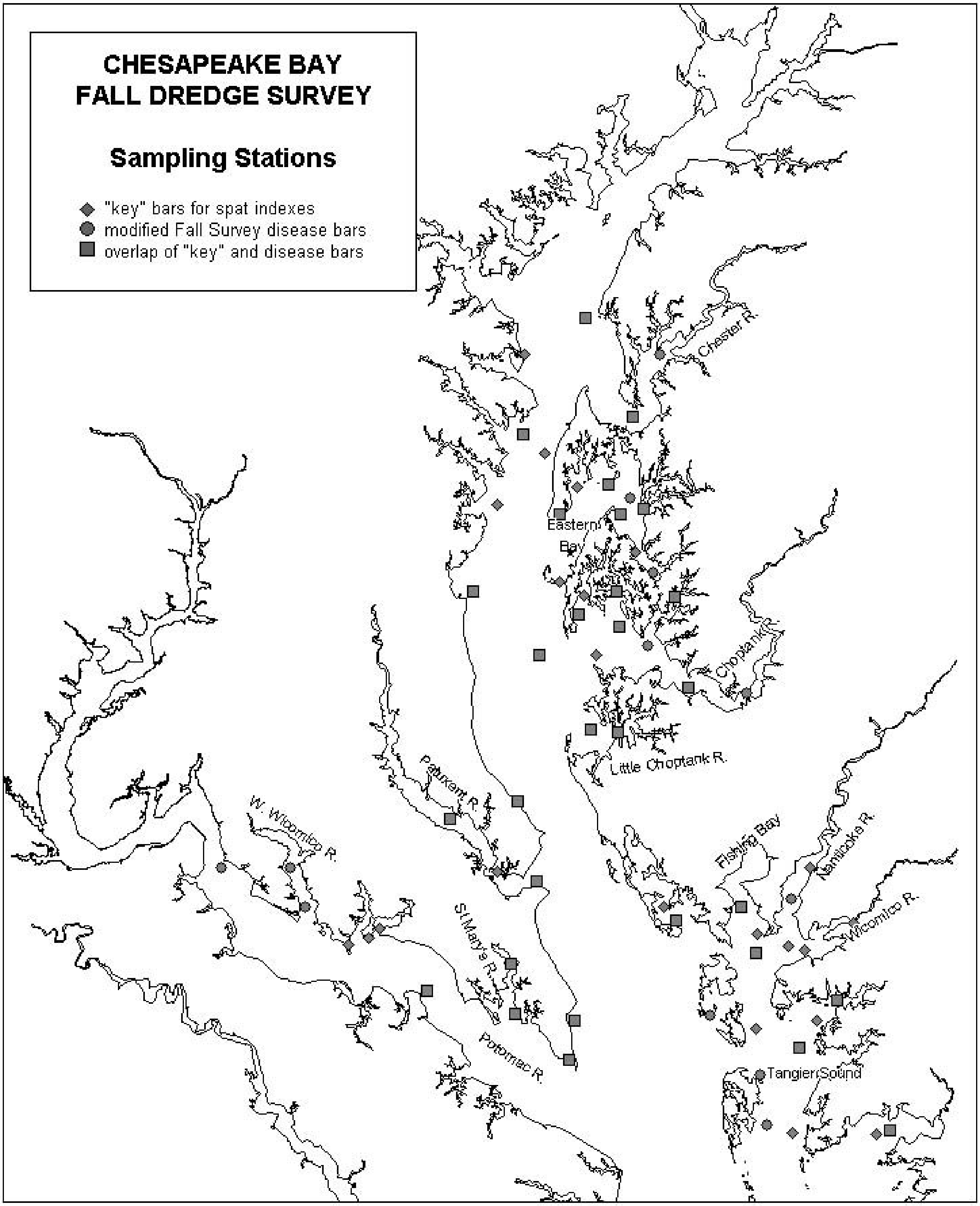

Figure 1b. Annual Maryland Fall Survey station locations for Key and Disease bars.

INTRODUCTION

Since 1939, various state agencies in Maryland have conducted annual dredge-based surveys of oyster bars. These assessments have provided biologists and managers with information on oyster spatfall intensity, observed mortality, and more recently, parasitic infection status 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 allows the discernment of trends in the oyster population. Monitored sites have included natural oyster bars, seed production areas, seed planting areas, dredged shell plantings, and fresh shell plantings. 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 1974, 53 sites referred to as the historical “Key Bar” set were fixed to form the basis of an annual spatfall intensity index (arithmetic mean) (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).

METHODS

The 2003 and 2004 Annual Fall Dredge Surveys were conducted by Shellfish Division staff from the Maryland Department of Natural Resources (MDNR) Fisheries Service between early October and mid-November. Oyster parasite diagnostic tests were performed by staff of the Cooperative Oxford Laboratory (COL). A total of 378 samples were obtained to examine 272 natural oyster bars, including Key Bar and Disease Bar sites, as well as contemporary seed oyster planting sites, shell planting locations, and seed production areas (Figures 1a and 1b). Data on seed and shell plantings are provided in Hess (2003, 2004).

A standard 36-inch-wide oyster dredge was used to collect the samples. At each of the 53 Key Bar sites and the 43 Disease Bars, two 0.5-bushel subsamples were collected from replicate dredge tows. On seed production areas, five 0.2-bushel subsamples were taken from replicate dredge tows. At all other sites, one 0.5-bushel subsample was collected per dredge tow. A list of data categories recorded from each sample appears in Table 1.

Representative subsamples 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, and areas of special interest. All oysters were transported to COL for parasite diagnostic tests. Data reported for *Perkinsus marinus* (dermo disease) are from rectal Ray’s fluid thioglycollate medium (RFTM) assays. Prior to 1999, the less sensitive hemolymph assays were performed. Data reported for *Haplosporidium nelsoni* (MSX disease) have been generated from tissue 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 are infected with a parasite, regardless of infection intensity (Appendix 2). Intensity refers to the mean infection stage or parasite concentration in sampled oysters. An index, ranging from zero to seven, based on pathogen concentration in hemolymph or solid tissue is used to classify dermo disease intensities. (See Gieseker 2001 for a complete description of parasite diagnostic techniques and calculations).

Total observed mortality (small and market oysters combined) was calculated as the number of boxes and gapers divided by the sum of live and dead oysters (Appendix 2).

To provide a statistical framework for some of the Annual Fall Survey data sets, a nonparametric 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 a variety of 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 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 not statistically different from 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 $\alpha=0.15$.

RESULTS

Freshwater Discharge Conditions

Freshwater flow into Chesapeake Bay affects salinity, which is a key factor influencing oyster spatfall, disease, and mortality. The severe drought, which afflicted the Chesapeake region for four successive years, finally broke during the fall of 2002. Above average rainfall continued through 2003 and 2004, resulting in the second and third highest freshwater discharges, respectively, over the past two decades (Sec. "C" in Bue 1968; USGS 2005) (Figure 2). The average monthly mean flows during these two years exceeded the 75th percentile for the 1937-2003 period, which USGS categorizes as wet years (USGS 2005).

Over the 14-year period prior to the four year sustained drought, low flow years had alternated with high flow years on an annual, or at most biennial, basis. Going back to 1985, significant freshets occurred in 1993, 1994,

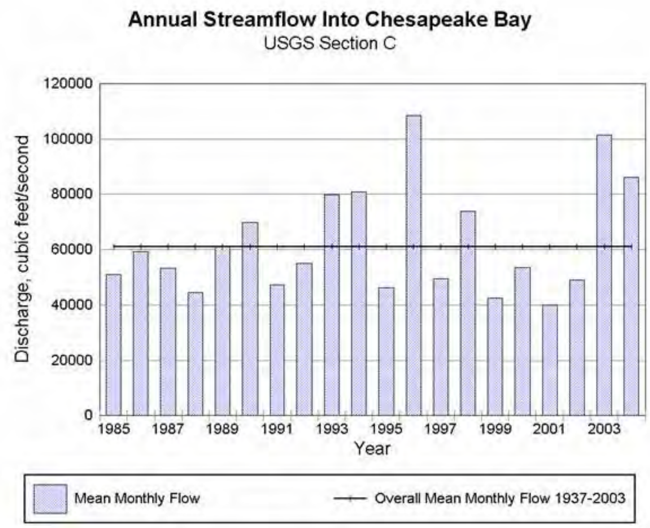

Figure 2. Mean monthly freshwater flow into Chesapeake Bay. Section C: all Maryland tributaries and the Potomac River.

1996, and 1998. These often resulted in substantial oyster mortalities, such as the 1993 event in the Potomac River drainage (MDNR 2001). The freshets of 1994, 1996, and 1998 had a more geographically widespread impact on oyster mortality. The freshets of 1993, 1994, and 1998 were winter/spring events unlike the 1996 high freshwater flows that persisted over the entire year (USGS 2005). Despite the high flows in 2003 and 2004, no significant oyster mortalities were observed as a consequence (see Mortality section below).

In recent years, moderately to severely low freshwater flows into the Chesapeake Bay resulted in elevated salinities during 1997 and 1999 - 2002. Since 1985, low flows were particularly severe (≤ 80% of the 50-year average) in 1988, 1991, 1995, 1997, 1999 and 2001 (USGS 2005).

Spatfall Intensity

Maryland oyster spatfall was extremely poor in both 2003 and 2004. The distribution of meaningful spatset, as number of spat per bushel of shell, was largely confined to a few discrete areas and in relatively low numbers (Figures 3a and 3b). Although spatfall was light throughout the bay in 2003, the highest concentrations were found in the area of Tangier Sound. Other pockets of spatfall occurred in lower Eastern Bay, the lower Patuxent River, and the lower St. Mary's County shore of the Potomac. No spat were observed in the upper bay, Anne Arundel and Calvert bayshores, Choptank River region, and the rest of the Potomac River and its

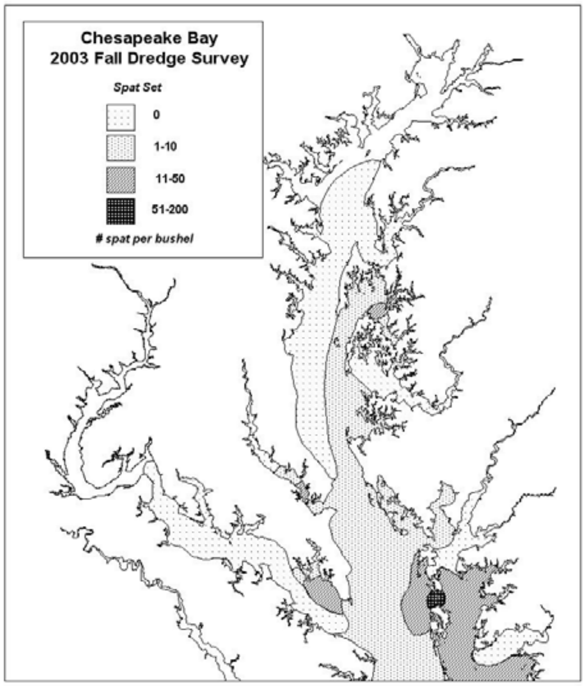

Figure 3a. Spatfall intensity ranges and distribution, 2003.

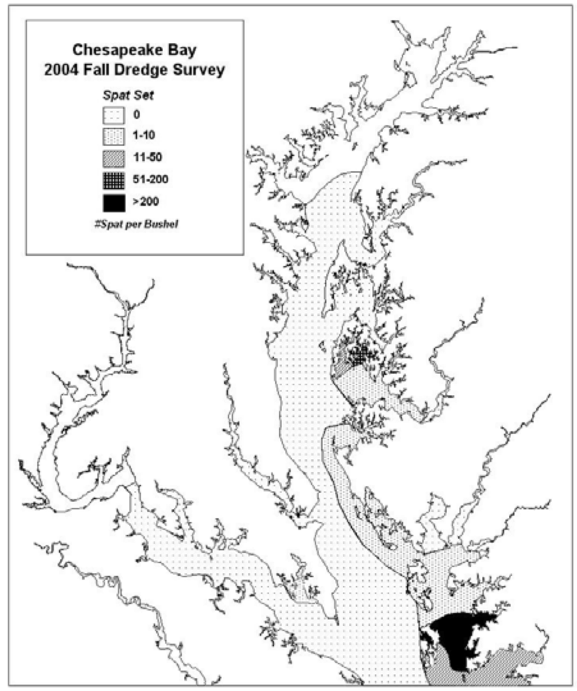

Figure 3b. Spatfall intensity ranges and distribution, 2004.

tributaries. In 2004, spatfall was highest in lower Tangier Sound, with lesser amounts in Broad and Harris Creeks and Pocomoke Sound. The remainder of the bay and tributaries had little or no spatfall, with large expanses recording zeroes, including the entire western shore of the mainstem, Patuxent River, Potomac River and its tributaries, and Eastern Bay.

The 2003 and 2004 spatfall intensity indices from the Key Bar set are compared with previous years through 1985 in Table 2. The overall spatfall intensity for 2003 was 4.8, an order of magnitude drop from the previous year and well below the 20-year average of 49.7. This was the third-lowest index recorded for this time period. Spatfall intensity in 2004 was almost as poor, with spat absent on 30 of the 53 Key Bars, contributing to an index of 6.5. Figure 4 charts the spatfall intensity index from 1985 through 2004, along with the 20-year mean, and gives three groupings of statistically similar years from greatest to least as determined from a multiple comparison procedure associated with Friedman's Two-Way Rank Sum Test. Both 2003 and 2004 fell into the lowest tier of spatfall rankings.

Oyster spatfall during the period from 1985 to 2004 (Figure 4; Table 2) has been extremely variable. These years included some of the lowest spatfall intensity indices (1989, 1994, 1996, 1998, 2000, 2003-04) and two of the highest (1991 and 1997) over the 65-year history of the Annual Fall Survey (Krantz 1996). Spatfall intensity indices from 1996-2004 included the lowest on record (1996) followed by the second highest (1997).

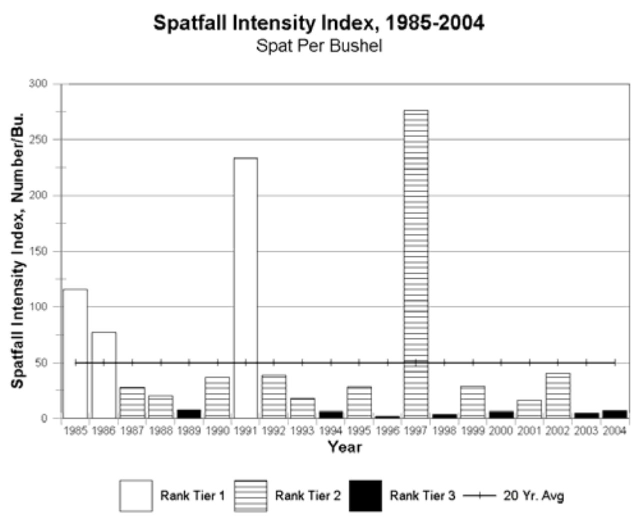

Figure 4. Spatfall intensity (spat per bushel of cultch) on Maryland "Key Bars" for spat monitoring.

The spatfall intensity index is an arithmetic mean that does not take into account

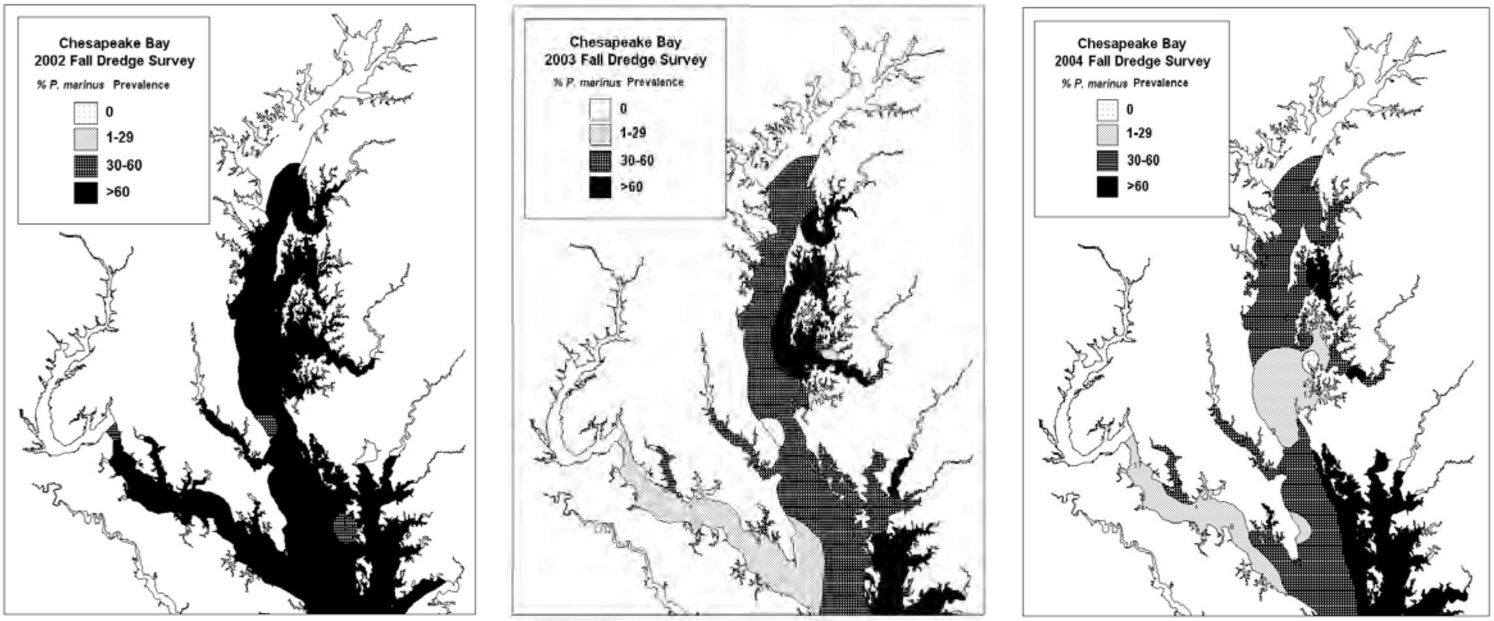

Figure 5. Geographic extent and prevalence of dermo disease.

geographic distribution. For example, the 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. Mary's Rivers (MDNR 2001). Over 75% of the 1997 index was accounted for by only five of the 53 Key Bars, while ten contributed nearly 95%. In contrast, the 1991 spatfall was far more widespread, with 15 Key Bars totaling 75% of the index (the 3rd highest on record), and 28 sites were needed to attain 95% of the spatfall intensity index. As mentioned, spatfall over the past two years has been geographically limited: in 2003, six bars comprised 75% of the index, while in 2004, 75% of the index was from five bars with one bar accounting for 48%.

Oyster Parasites

Perkinsus marinus, the oyster parasite that causes dermo disease, continued to be present in oyster populations from almost all of the Disease Bars sampled in 2003 and 2004, although at much lower infection intensities than during the drought-related epizootic of 1999 – 2002. Whereas prevalences greater than 60% occurred throughout the bay and tributaries in 2002, these high prevalences were limited mainly to eastern shore tributaries in 2003 (Figure 5). By 2004, these areas had contracted even further in the upper half of the bay, especially in the Chester and Choptank Rivers and parts of Eastern Bay, but expanded again in the lower half of the of the bay, including upper Tangier Sound and adjacent bay mainstem, Fishing Bay, and Honga River on the eastern shore, and St. Mary's River (Figure 5).

Average *P. marinus* prevalence on the Disease Bars dropped from 94% in 2002 to 60% in 2003 (Table 3). Despite the increase of high-prevalence samples in the southern portion of Maryland, overall prevalences continued to decline in 2004 to 53%, the lowest average since the Disease Bars were established in 1990. Statistical results rank 2003 and 2004 in the lowest tier (grouping) for *P. marinus* prevalence since 1990 (Figure 6).

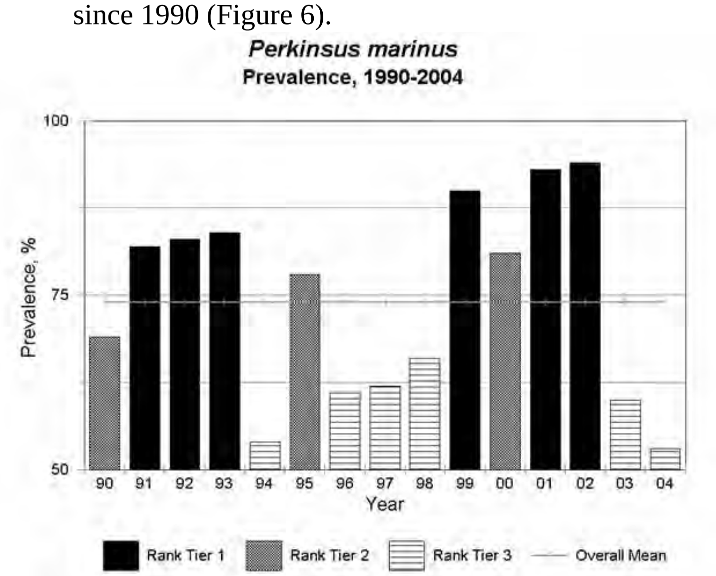

Figure 6. Statistical ranking and 15-year mean of *P. marinus* prevalence.

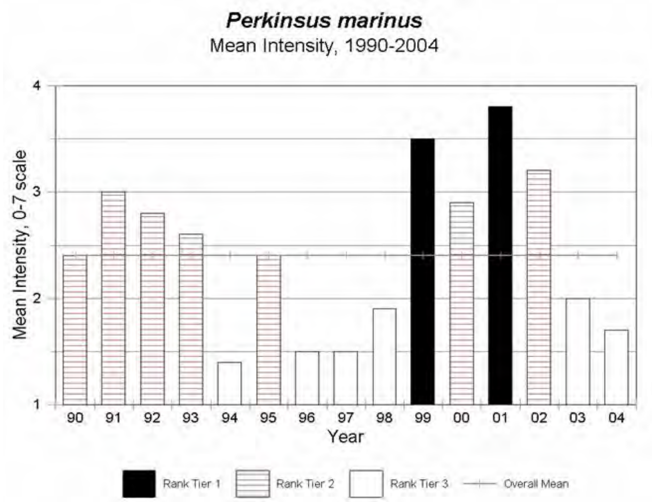

Figure 7a. Annual mean *P. marinus* infection intensity on a scale of 0-7 in oysters from Maryland disease monitoring bars. Overall mean is for the vears 1990 to 2002.

The infection intensities of *P. marinus* also declined sharply over the past two years. The 2003 annual mean intensity of infection was 2.0 on a scale of 0-7, compared with the 2002 mean intensity of 3.2 (the record high mean intensity was 3.8 in 2001). This difference was statistically significant, ranking 2003 in the lowest statistical tier (Figure 7a). Infection intensities dropped slightly in 2004 to an average index of 1.7. However, high mean infection intensities persisted in Tangier Sound and Manokin River samples, along with a higher percentage of lethal infections (≥5.0). Overall, the average percentage of lethal infections in 2004 was 11%, compared to 26% in 2002. The mean infection intensity level for 2004 was statistically ranked in the bottom tier (Fig. 7a).

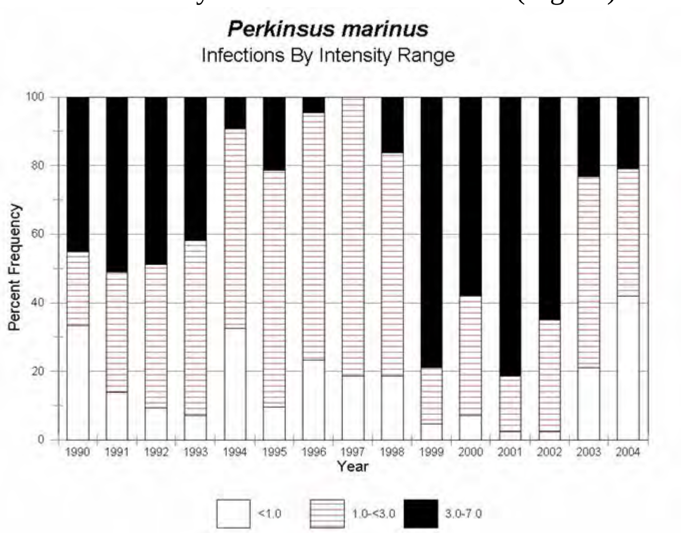

Figure 7b. *P. marinus* infection intensity ranges, percent frequency by year and range.

The frequency of sample mean intensity levels of 3.0 or greater in 2003 and 2004 fell by about two-thirds from the previous four years, marking the end of the most acute *P. marinus* epizootic to afflict the Maryland oyster population (Figure 7b). While about 40-50% of the Chesapeake Bay oyster bars (as represented by the Disease Bar set) from 1991-1993 had mean *P. marinus* infection intensities of 3.0 or greater, over 67% of oyster bars had mean infection intensities of 3.0 or greater during 1999-2002. Nevertheless, the continued widespread distribution of *P. marinus*, even though at low to moderate infection intensities, indicates that dermo disease remains enzootic in Maryland waters.

♠

Haplosporidium nelsoni, the protozoan that causes MSX disease, is another potentially devastating oyster parasite. This parasite can cause rapid mortality in oysters and generally kills a wider range of year classes, specifically younger oysters, over a wider seasonal period. Specifically, MSX disease kills young oysters and does so during both spring and fall; whereas *P. marinus* typically kills older Chesapeake Bay oysters during late summer and fall.

The geographic distribution of *H. nelsoni* contracted dramatically over the past two years. In 2002 the parasite occurred throughout Chesapeake Bay and tributaries as far up bay as the Bay Bridge and Chester River; only the upper reaches of the tributaries were free of MSX disease (Figure 8). By 2003 the parasite's range had collapsed to southern Maryland and in 2004 was further confined to pockets in lower Tangier Sound and the St. Mary's County bayshore (Figure 8). Whereas *H. nelsoni* was detected in oysters from 90% of the Disease Bars in 2002, during 2003 it was found on only 23% of the bars, while in 2004 infected oysters were found on a mere 7% of the bars (Table 4).

The 2003 mean annual prevalence of *H. nelsoni* among all tested oysters averaged 1.4%, substantially lower than the record 28% prevalence in 2002. The following year was even lower, with an average prevalence of just 0.2%, or a total of three infected oysters of the

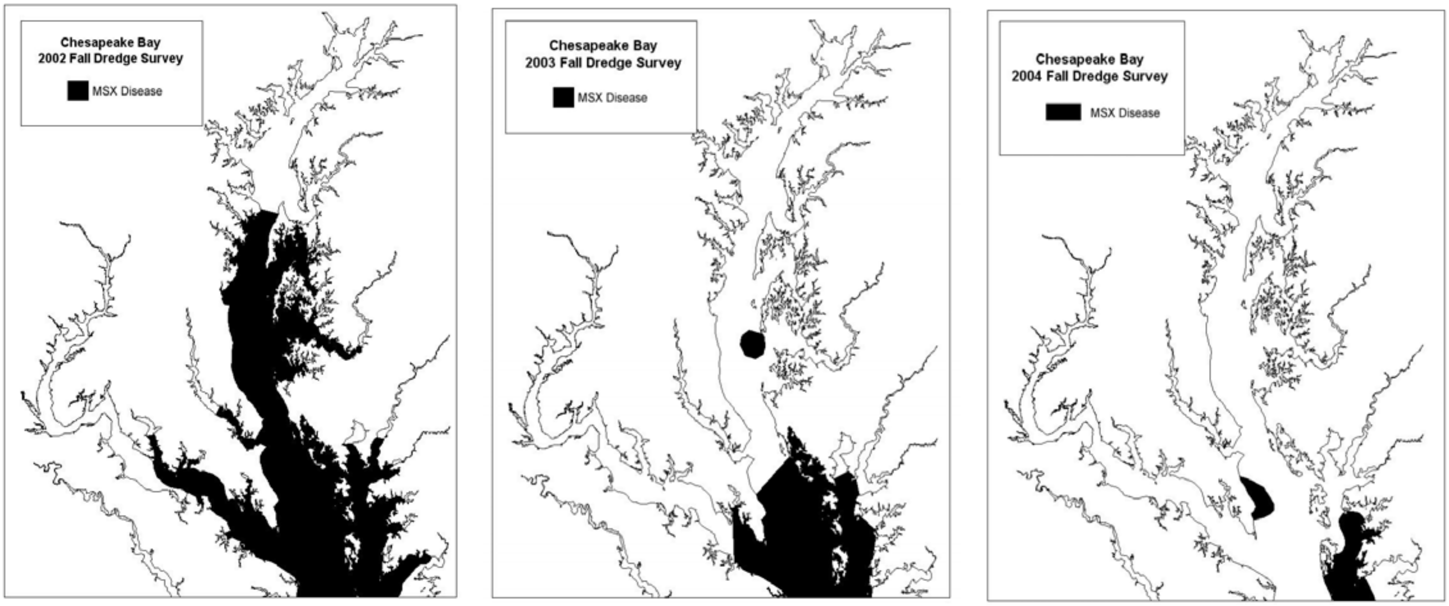

Figure 8. Contraction of the geographic range of MSX disease in Maryland waters between 2002 and 2004.

over 1,200 oysters examined. MSX disease was found on only three of the Disease Bars sampled in 2004, averaging 3% prevalence on the infected bars.

The abatement of MSX disease in 2003-04 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 occurrence (88%) and mean annual prevalence (28%) of *H. nelsoni*, leaving in its wake observed oyster mortalities approaching 60% (see following section). Since 1990, there have been three *H. nelsoni* epizootics: 1991-1992, 1995, and 1999-2002. These epizootics were followed closely by periods of unusually high freshwater input into parts of the Chesapeake Bay, which resulted in the purging of *H. nelsoni* infections from most Maryland oyster populations.

<u>Observed Mortality</u>

Mortalities plummeted in the two years following the record high 58% annual fishery-independent mortality estimated during 2002. The 35% observed mortality estimate in 2003 fell even lower, to 20% in 2004. These compare with the 20-year average of 30%, but are still well above the former (prior to the mid-1980's) background mortality levels of 10% or less (MDNR, unpubl. data). The highest Disease Bar observed mortalities in 2003 were 89% on Lighthouse bar and 88% on Sandy Hill bar, both in the Choptank River (Table 5). Cook Point bar, also in the Choptank River, had mortalities drop from 100% in 2002 to 21% in 2003 and 0% in 2004, primarily because the older, heavily infected oysters died, leaving behind younger, lightly infected individuals. The highest mortality observed in 2004 was 59%, both on Sandy Hill and on Goose Creek in Fishing Bay.

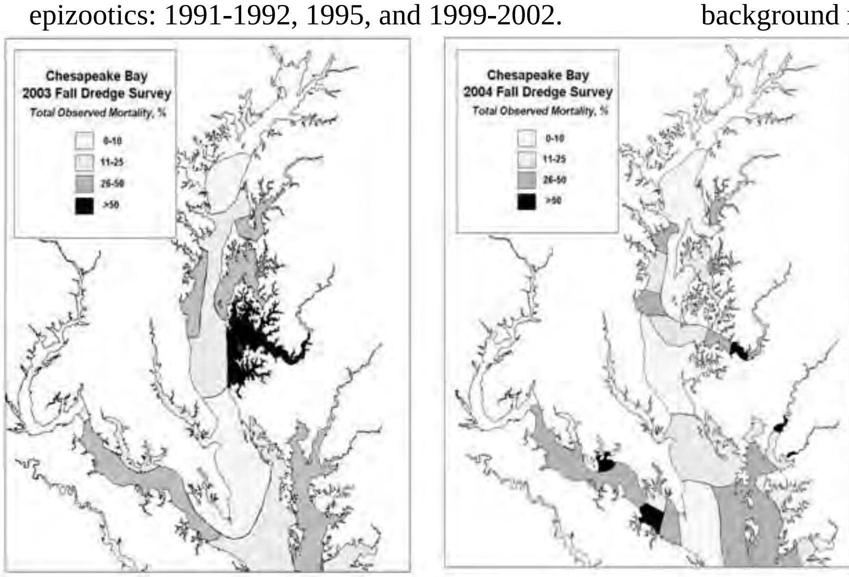

Figure 9. Total observed oyster mortality, 2003 and 2004.

The geographic range of observed mortality levels exceeding 50% was confined to the Choptank and Little Choptank Rivers and associated tributaries in 2003 (Figure 9). By 2004, such areas had fragmented into a handful of small pockets in the Potomac, Choptank, Nanticoke, and Wicomico Rivers.

Observed mortalities in 2003 declined for the first time since 1997. From 1997 to 2002 there had been a steady increase in observed mortality (Figure 10). In addition, the number of sites with total observed mortality of 30% or greater peaked in 2002 to include 84% of the Disease Bars, while 50% or greater total observed mortality was measured on a staggering 63% of the bars. In comparison, by 2003, the number of bars with mortalities of 30% or more had dropped to 23, further falling to only seven in 2004. The recent jump and subsequent decline in mortalities is strongly associated with the rise and fall in MSX disease prevalences since 2001 (Figure 11). No freshet related mortalities were observed during the high freshwater flow years of 2003 and 2004.

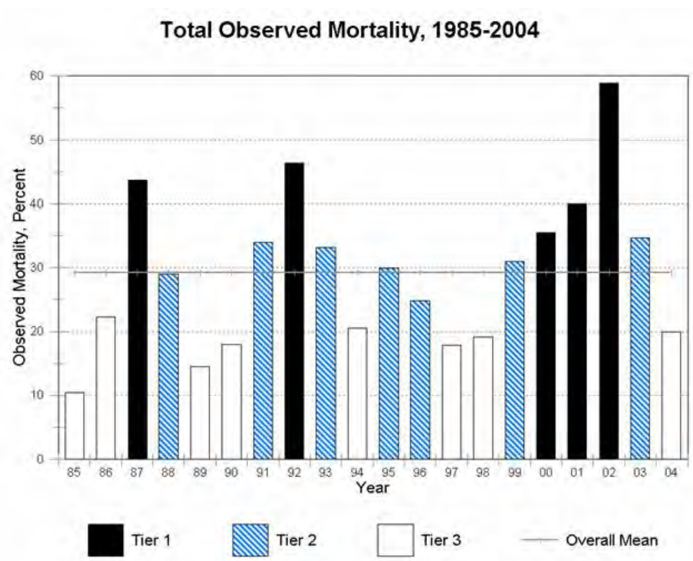

Figure 10. Mean annual total observed mortality, small and market oysters combined. Overall mean is for the period 1985 through 2004.

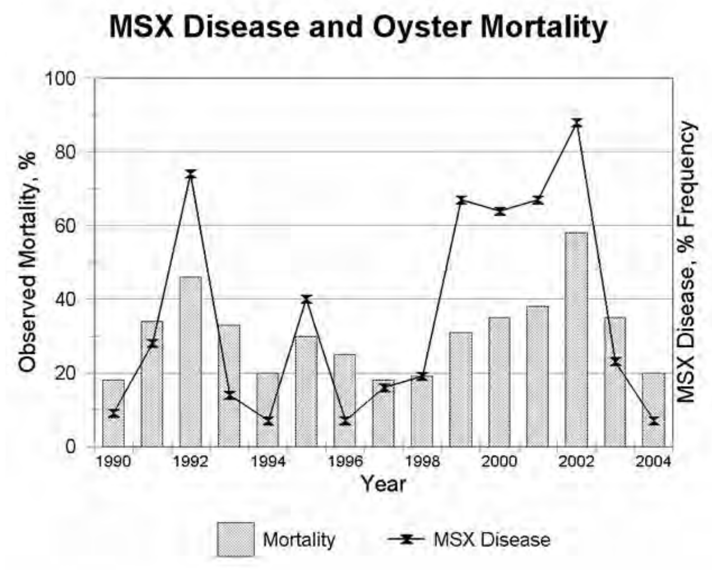

Figure 11. Changes in oyster mortalities and *H nelsoni* prevalence.

Annual total mortality averages and rank tiers are shown for 1985-2004 in Figure 10. Friedman's Two-way Rank Sum test results indicated three statistically related tiers (bar groupings) of observed mortality, with 2003 falling in the middle tier and 2004 ranked in the lowest tier, following three successive years of mortalities in the highest grouping.

Commercial Harvest

Oyster harvests continued to plummet over the past two seasons, marking five consecutive years of declines. The 2002-03 harvest of 56,000 bushels was the lowest since the early 19th century, representing a 62% drop from the previous year. This was followed by a 54% decline to a paltry 26,000 bushels, making the 2003-04 harvest the lowest on record.

Harvesting activity in 2002-03 contracted to three primary areas that accounted for 76% of the reported catch (Table 6). The upper bay was the leading region with one-third of the total harvest, which actually increased slightly over the previous year. This was followed by Tangier Sound and Chester River, although both experienced severe declines from the 2001-02 season. The most dramatic decrease occurred in the Eastern Bay region, which had been the leading producer over the previous three years. Harvests plunged by an order of magnitude, reflecting the depletion of the previously dominant 1997 year-class by disease and harvesting. Harvests from other previously productive areas such as the Choptank and Little

Choptank Rivers were fully two orders of magnitude lower than just a few years earlier.

Production areas contracted even further in the 2003-04 season, with only two regions supplying 79% of the reported harvest. Tangier Sound was the primary harvest region with over half of the Maryland total, even though landings from there had increased only modestly from the previous year. Eastern Bay was second with a fifth of the landings. Harvests from the upper bay declined dramatically, with an 86% drop from the previous year, especially in the Chester River, which supplied a negligible 557 bushels compared to 70,000 bushels only four years earlier.

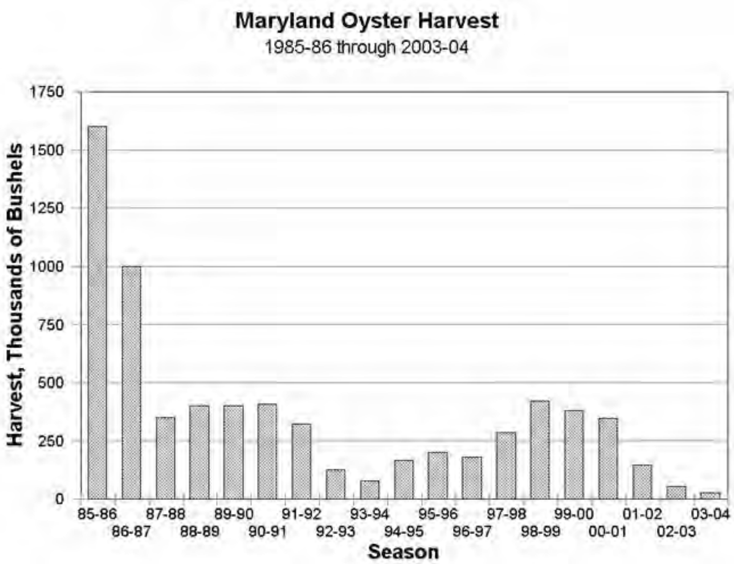

Figure 12. Maryland seasonal oyster landings.

Regional harvest summaries from the 1985-86 season through the 2003-04 season are given in Table 6. Over this period, harvesters have become increasingly dependent on the lower salinity zones such as the Chester River and the upper bay, since the middle- to higher-salinity areas have become increasingly less reliable for commercial oyster production. However, due to the good oyster survivorship over the last two years, more consistent recruitment, a shift to more efficient harvesting gear (power dredging), and harvest declines in other regions, Tangier Sound was the leading production area in 2004.

DISCUSSION

Influence of Freshwater Discharge

It is clear that oyster mortality since the late 1980s has been strongly influenced by the volume of freshwater discharge into the Chesapeake Bay, with freshets directly killing oysters and drought resulting in higher disease levels. Since oysters inhabiting the lower salinity zones have been relatively safe from parasite-induced mortality, these areas have become increasingly important to the commercial fishery. However, these lower salinity populations receive only sporadic recruitment on the order of once per decade, increasing the fishery's reliance on the State Repletion Program. Furthermore, they are at risk from high freshwater discharges as evidenced by mortalities attributed to the 1993, 1994, 1996, and 1998 freshets (MDNR 2001).

Despite the large volumes of freshwater input during 2003 and 2004, no significant oyster mortalities were observed as a consequence. Potentially adverse impacts due to the exceptionally high flows of 2003 were likely buffered by the elevated salinities of the preceding year.

While freshets may be short-term catastrophic events, the establishment of salinity-regulated oyster parasites in Chesapeake Bay has had severe long-term consequences on the oyster populations. Salinity is one of the principal environmental factors controlling oyster diseases. *Perkinsus marinus* mean prevalence and infection intensity and *H. nelsoni* percent frequency of occurrence are inversely related to freshwater inflow. Given the osmotically tolerant character of enzootic *P. marinus* (Dungan and Hamilton 1995), reduced freshwater discharges result in increasing infection prevalences, infection intensities, and mortalities. Even average discharges do not appear to ameliorate the distribution and effects of *P. marinus* infections. *Haplosporidium nelsoni* is even more strongly controlled by freshwater influences than *P. marinus*. Accordingly, low flow conditions have generally resulted in *H. nelsoni* epizootics. This parasite can cause rapid mortality in oysters, kills a wider range of oyster year-classes than does *P. marinus*, and typically contributes to a severe spike in mortality during drought conditions (Smith and Jordan 1993).

The Entrenchment of Dermo Disease

Since the mid-1980's, the pattern of *P. marinus* infection changed from acute (epizootic) to chronic (enzootic) on the majority of oyster bars in Maryland (Table 7). This profoundly changed the nature of the impact of *P. marinus* on oyster populations. Before chronic conditions occurred, *P. marinus* infections would build up over a one to three year period. After an intense outbreak, the parasite would then become undetectable in all but a few of the regional oyster populations. Once chronic infections became established in oyster populations, however, intense outbreaks became more frequent, with their periodicity largely controlled by freshwater discharge into the bay (Ford and Tripp 1996). This shift in infection pattern is reflected in a dramatic change in oyster mortalities. Prior to the widespread establishment of *P. marinus* in the mid-1980's, annual mortality averages ranged between 5% and 10%. Since then, bay-wide annual mortalities have averaged about 30%, with many areas suffering over 50% and some even 80% total observed mortality during high-salinity periods.

The establishment of enzootic conditions for dermo disease is evidenced by increased prevalences over a wide geographic extent for a sustained time period. Each year since 1990, *P. marinus* has been detected on at least 95% of all Disease Bars sampled. However, there were refuges where prevalences were lower than average. From 1990 to 1998, low prevalences typically occurred in samples from low-salinity bars in the upper Chesapeake Bay and the low-salinity reaches of the tributaries, where freshets could exert some controlling influence on the parasite. During the 1999-2002 drought this pattern broke down, with Disease Bars in low-salinity areas exhibiting dermo disease prevalences of 90% or more. After two years of above average freshwater flows, the sustained widespread distribution of *P. marinus*, even though at low to moderate infection intensities, indicates that dermo disease is still enzootic throughout most of the tidal waters of the state as of November 2004.

As an extreme example of disease taking hold in a normally low-salinity population, the occurrence of *P. marinus* on Beacon Bar in the Potomac River in 2002 has profound implications for management and research. It demonstrates that remote oyster bars in low-salinity areas can be infected by dermo disease despite the miles-wide absence of repletion activity that may transplant potentially infected seed oysters. That is, even oysters on far upstream bars can be infected through natural processes during high-salinity periods. It also suggests there is no consistent refuge from dermo disease for oysters in most Maryland waters. With the establishment of dermo disease in upstream areas previously thought to be safe from infection, these oyster populations are now subject to three problems: the potential for dermo disease-related mortality, the “cure” for parasite infection (freshets) that can be more devastating than the disease, and a low frequency and rate of recruitment. The resulting limitations on management will certainly confound efforts to enhance oyster populations in these areas.

The Advance and Retreat of MSX Disease

Since the mid-1980s, both the geographic range of *H. nelsoni* epizootics and associated mortalities have substantively increased in Maryland (MDNR 1988; Krantz 1990). The last *H. nelsoni* epizootic, the most severe on record, was associated with a four-year period of drought and low freshwater inflows to Chesapeake Bay (Figure 2). Similarly, the 1987, 1991-92, and 1995 epizootics were associated with below-average freshwater discharges. On the other hand, no MSX disease epizootic occurred in 1997 despite low annual average freshwater inflow. Due to the relatively high flows that occurred during the spring period, drought conditions did not prevail until mid-summer. Both the 1991-1992 and the 1995 epizootics were followed by unusually high freshwater inputs into the Chesapeake Bay during 1993-94 and 1996. These freshets were largely responsible for subsequent dramatic contractions in the distribution of *H. nelsoni*. Similarly, by Fall 2004 MSX disease had been purged from much of Maryland by two years of consistently high freshwater flows.

Spatfall

The poor spatfall indices in 2003 and 2004 were not surprising, given the high freshwater flows during those years. Because of the proximity of the two primary sources of freshwater input for the bay, the Susquehanna and Potomac Rivers, and the large distance to the Atlantic Ocean with its high-salinity waters, spatfall in Maryland is extremely sensitive to river flows.

Although oyster reproduction and settlement have minimum salinity requirements, elevated salinities do not necessarily guarantee a good spat set. As the 2002 data demonstrate, only a few areas experienced a noteworthy spat set, while other formerly productive areas received little if any. On a speculative note, while a stock-recruitment relationship has yet to be demonstrated for oysters, it might be that in 2002 some areas were so devastated by disease mortalities that broodstock densities fell below a minimum threshold required for successful reproduction.

Extreme variability in spatfall intensity is a historic characteristic of larval settlement in Maryland waters. The 1991-2002 period included four of the lowest annual spatfall intensity indices on record as well as the second and third highest since 1939, the year to which this index was back-calculated (Krantz 1996). However, Friedman's Two-Way Rank Sum Test produced what appears to be an anomaly, with the extremely strong index year of 1997 (second-highest on record) grouped only in the middle tier of yearly spatfall rankings. This index was exceptionally high because of the influence of a few bars with high spat counts. In contrast, the 1991 spatfall (third-highest on record) was far more widespread. Since the spatfall intensity index is calculated as an arithmetic mean, a few Key Bar sites with unusually high spatfall intensities can unduly influence the index. In contrast, Friedman's Test incorporates a geographic component by ranking the yearly spatfall intensities of each Key Bar. Rankings eliminate the problem of bias to the index resulting from unusually high spat counts on a small number of bars. The data from 1991 and 1997 clearly indicate the utility of a statistically-based ranking index, such as Friedman's Test, that more accurately defines spatfall intensity on a bay-wide basis.

Mortality

Observed mortalities in 2003 may have been overestimated due to the persistence of boxes greater than a year old. Despite the fact that prevalences and intensities of *P. marinus* infections were both statistically ranked in the lowest level tiers, the average observed mortality for 2003 fell to the middle group. In fact, the 2003 mortality estimate was higher than the 20-year average. This suggests there was a residual from the large death assemblage of 2002 that remained as boxes through the 2003 survey, well beyond the assumed shell-articulation span of one year.

Areas in the bay that received notable spatfalls in 2001 and 2002, such as the Point Lookout Oyster Sanctuary, have benefited from good survivorship during the subsequent two years and now have flourishing oyster populations. In contrast, since the mid-1980's high spatfall intensity years in elevated salinity areas have generally been followed by periods of high *P. marinus* infection pressure and *H. nelsoni* epizootics, resulting in substantial year class losses.

Prior to the introduction of *H. nelsoni* and impacts from *P. marinus* outbreaks, mass natural mortality of oysters in Maryland's Chesapeake Bay was generally associated with freshets and occurred in lower-salinity areas. Since the wholesale onset of parasitic infections, mass mortalities have become more common, severe, and increasingly widespread. Both the geographic ranges of *H. nelsoni* epizootics and their associated mortalities have substantially increased in Maryland waters (MDNR 1988; Krantz 1990). Increasing frequency of *P. marinus* lethal sample infection prevalences is also associated with widespread mortalities. This trend is clearly reflected in both the historical records of the Annual Fall Survey and the commercial harvest yields. The period from 1999 through 2002 indicated a strengthening of this pattern. Similarly, as infection levels of both parasites dropped in 2003 and 2004, so too did mortalities.

The Eastern oyster in the Maryland Chesapeake Bay has demonstrated modest and variable levels of recruitment in comparison to other regions along the East Coast of the United States. Historically, this sporadic recruitment had been compensated for by the high degree of survivorship in the Maryland population relative to other regions. With bay-wide annual total observed mortalities averaging over 30% since 1990, the resilience of the population has been severely compromised.

Commercial Fishery

This pattern of sporadic recruitment and elevated mortalities has been reflected in declining commercial fishery yields during the past two decades, and in substantial changes and shifts in regional production. With the entrenchment of oyster diseases in the mid-1980's, annual Maryland oyster landings fell below one million bushels for the first time in well over a century and have yet to recover. As a consequence of high parasite-related oyster mortalities, most of the fishery has been pushed into lower-salinity areas where survivorship is good but natural recruitment is poor. This has resulted in an increased reliance on the State Repletion Program. Despite these repletion efforts, harvests have dropped for five successive years in the face of the recent inroads made by the two oyster diseases.

The impact of disease on the commercial fishery may not only been restricted to a severe decline in product availability, but also in product quality. Anecdotally, the volume of meat from a bushel of shucked Maryland oysters has declined in recent times. This decrease may reflect either the severity of disease effects on the ability of the oyster to physiologically function properly, resulting in diminished meat quality; reduced meat yields from smaller oysters that have not yet been cropped by disease; or both.

The continued onslaught of dermo and MSX disease epizootics has caused a notable shrinking of the industry infrastructure. Shucking houses are closing at an alarming rate, from 58 in 1974 to about 10 today (MDNR unpubl. data). Furthermore, the number of harvest participants is in steep decline. From 1987 to 2002 the number of licensed harvesters reporting catches of more than 50 bushels of oysters in a season has plummeted from 2,010 to 396 (MDNR unpubl. data). As infrastructure disappears and its valuable waterfront properties are used for other purposes such as expensive housing, the likelihood that re-capitalization will occur in the future is unlikely.

LITERATURE CITED

Bue, C.D. 1968. Monthly surface-water inflow to Chesapeake Bay: U.S. Geological Survey Open-File Report, Arlington, Va, October 1968, 45p.

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

Ford, S, and M.R. Tripp. 1996. Chapter 17. Diseases and defense mechanisms, p. 581-660. *In* V.S. Kennedy, R.I.E. Newell, and A.F. Eble (eds.), The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant Publ. UM-SG-TS-96-01.

Gieseker, C.M. 2001. Year 2000 Maryland Oyster Disease Status Report. MDNR, Fisheries Service, Sarbanes Cooperative Oxford Lab. FS-SCOL-01-1. Oxford, Md.

Hájek, J. and Z. Šidák. 1967. Theory of Rank Tests. Academic Press, New York.

Hess, J. 2003. Seed oyster and shell activity reports. MDNR, Shellfish Program, Annapolis, Md.

Hess, J. 2004. Seed oyster and shell activity reports. MDNR, Shellfish Program, Annapolis, Md.

Hollander, M. and D.A. Wolfe. 1973. Nonparametric Statistical Methods. John Wiley and Sons, New York, N.Y.

Krantz, G.E. 1990. Maryland Oyster Population Status Report, 1989 Fall Survey. MDNR, Ches. Bay Res. Monitoring Div., CBRM-OX-90-1. Oxford, Md.

Krantz, G.E. 1996. Oyster Recruitment in the Chesapeake Bay, 1939 to 1993. MDNR, Fish. Serv. Spec. Publ. Oxford, Md.

Krantz, G.E. and D.W. Webster. 1980. Maryland Oyster Spat Survey Fall 1979. Tech. Rep. Md. Sea Grant Prog. No. UM-SG-TS-80-01. College Park, Md.

Lehman, E.L. 1963. Asymptotically nonparametric inference in some linear models with one observation per cell. Ann. Math. Statist. **34**: 1494-1506.

McDonald, B.J. and W.A. Thompson, Jr. 1967. Rank sum multiple comparisons in one- and two-way classifications. Biometrika **54**: 487-497.

MDNR.1975-1984. Unpublished data, Bay-wide Bottom Survey and Annual Fall Dredge Surveys.

MDNR. 1988. Status and trends, Maryland’s oyster resources. Tidewater Admin., Fish. Div., 61pp.

MDNR. 2001. Maryland Oyster Population Status Report: 1996-2000 Fall Surveys. Sarbanes Coop. Lab. and Shellfish Prog.

Smith, G. and S. Jordan. 1993. Monitoring Maryland's Chesapeake Bay Oysters. MDNR, Ches. Bay Res. and Monitor. Div. Rep. No. CBRM-OX-93-3. Oxford, Md.

USGS. 2005. Estimated Streamflow Entering Chesapeake Bay Above Selected Cross Sections. United States Geological Survey Inflow Database.

TABLES

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

Physical Parameters

-Latitude and longitude

-Bottom type

-Depth

-Temperature

-Salinity

Biological Parameters

-Counts of live and dead oysters by age/size classes (spat, smalls, markets)

-Stage of oyster boxes (recent, old)

-Average and range of shell heights of live and dead oysters by age/size classes

-Shell heights of oysters grouped into 5 mm intervals (Disease Bar sites, 1990-present)

-Condition index and meat quality of live oysters

-Type and relative extent of fouling

-Type of sample and year of action (e.g. 1997 seed, natural, 1990 fresh shell planting, etc.)

Table 2. Spatfall intensity (spat per bushel of cultch) from the 53 "Key" spat monitoring bars, 1985-2004.

Oyster Bar	Spatfall Intensity, Number Per Bushel									
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Mountain Point	6	0	0	0	0	0	0	0	13	0
Swan Point	4	0	2	2	0	0	2	0	3	0
Brickhouse	78	0	4	8	0	3	0	0	0	0
Hacketts Point	0	4	0	0	0	0	0	0	1	0
Tolly Point	2	2	2	0	0	0	0	0	0	0
Three Sisters	10	2	8	0	0	0	0	0	0	0
Holland Point	6	2	0	0	0	0	0	2	0	0
Stone Rock	136	150	20	30	5	37	355	15	4	4
Flag Pond	98	306	128	98	0	4	330	8	0	0
Hog Island	116	32	58	35	2	7	169	2	2	0
Butlers	418	196	171	16	2	24	617	3	2	1
Buoy Rock	16	0	6	0	0	1	0	0	0	0
Parsons Island	78	2	4	2	0	7	127	18	2	0
Wild Ground	46	8	4	8	0	18	205	8	4	0
Hollicutts Noose	24	8	12	6	0	1	11	1	0	0
Bruffs Island	82	0	0	2	0	1	12	8	0	1
Ash Craft	10	2	0	10	0	2	12	0	0	0
Turtleback	382	40	12	34	6	11	168	15	0	0
Shell Hill	50	10	0	6	0	0	79	0	0	0
Sandy Hill	74	16	2	0	0	28	179	2	0	0
Royston	440	8	8	0	0	57	595	10	8	0
Cooks Point	64	82	4	28	0	17	171	1	0	2
Eagle Point	255	28	2	6	6	18	387	4	15	0
Tilghman Wharf	156	128	38	4	2	109	719	10	59	4
Deep Neck	566	114	6	22	4	48	468	22	94	12
Double Mills	332	24	2	0	0	1	129	0	13	0
Ragged Point	134	118	34	112	0	65	1036	53	10	3
Cason	400	24	46	50	0	143	1839	43	37	28
Windmill	34	112	43	22	16	155	740	46	20	19
Normans Addition	56	214	38	17	34	82	1159	53	33	17
Goose Creek	34	79	16	18	4	4	153	41	43	27
Clay Island	4	78	14	48	18	12	256	46	58	31
Wetipquin	34	10	0	0	0	3	3	6	1	4
Middleground	18	12	26	9	14	40	107	63	14	28
Evans	16	10	12	14	9	2	20	27	7	30
Mt. Vernon Wharf	0	0	0	0	0	0	15	0	18	0
Georges	26	97	14	4	16	4	52	42	19	9
Drum Point	48	186	48	90	72	16	140	185	45	13
Sharkfin Shoal	18	44	22	24	2	16	43	97	18	11
Turtle Egg	160	90	12	26	26	204	289	591	37	31
Piney Island East	182	384	50	160	74	64	429	329	22	25
Great Rock	2	6	4	6	10	12	208	44	27	11
Gunby	124	88	50	9	8	21	302	156	176	7
Marumsco	29	50	18	3	12	6	142	34	55	5
Broomes Island	34	0	0	0	0	3	12	0	0	0
Back of Island	42	0	8	4	4	15	49	5	0	1
Chicken Cock	620	298	96	62	18	29	182	5	45	4
Pagan	140	34	52	36	6	613	190	62	15	7
Black Walnut	16	6	0	0	0	1	6	0	1	0
Blue Sow	34	35	0	0	0	1	22	0	1	0
Dukehart	21	4	2	0	0	2	19	0	2	0
Ragged Point	69	66	4	0	0	2	14	0	3	0
Cornfield Harbor	383	908	362	28	14	26	212	2	29	0
Spat Index	**115.6**	**77.7**	**27.6**	**20.0**	**7.2**	**36.7**	**233.5**	**38.8**	**18.0**	**6.3**

Table 2 (Continued).

Oyster Bar	Spatfall Intensity, Number Per Bushel									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Mountain Point	0	0	1	0	0	0	0	1	0	0
Swan Point	1	0	0	0	0	0	0	0	0	0
Brickhouse	5	0	0	0	1	1	3	97	0	0
Hacketts Point	0	0	0	0	0	1	0	13	0	0
Tolly Point	0	0	0	0	2	2	1	0	0	0
Three Sisters	1	0	0	0	0	0	1	0	0	0
Holland Point	1	0	0	0	0	0	1	4	0	0
Stone Rock	29	0	18	0	3	34	2	17	1	0
Flag Pond	10	0	7	0	1	5	5	7	0	0
Hog Island	24	0	5	2	6	1	28	10	5	1
Butlers	7	1	8	0	6	1	27	33	3	0
Buoy Rock	6	0	8	0	0	0	2	1	1	1
Parsons Island	57	0	3,375	3	6	6	6	5	2	0
Wild Ground	68	0	990	0	2	5	5	6	4	0
Hollicutts Noose	7	0	56	0	6	2	1	15	3	0
Bruffs Island	15	0	741	4	5	9	6	0	4	0
Ash Craft	60	1	2,248	0	14	2	10	0	8	0
Turtleback	194	0	3,368	5	13	4	45	9	72	1
Shell Hill	15	0	19	1	4	4	0	0	0	0
Sandy Hill	4	0	55	0	4	0	1	1	0	2
Royston	14	0	289	0	39	0	3	10	0	14
Cooks Point	16	0	20	0	1	5	5	3	1	4
Eagle Point	67	0	168	2	16	0	5	4	1	12
Tilghman Wharf	64	0	472	0	49	1	1	4	0	15
Deep Neck	294	3	788	1	211	3	11	31	1	167
Double Mills	15	0	40	0	1	0	0	0	0	3
Ragged Point	16	0	106	0	43	3	5	0	1	2
Cason	48	5	228	4	53	5	2	9	1	5
Windmill	13	2	5	1	37	0	21	9	0	0
Normans Addition	25	0	8	0	31	1	30	33	2	0
Goose Creek	3	0	5	0	0	0	0	1	0	0
Clay Island	11	1	20	2	5	4	8	16	0	0
Wetipquin	1	0	0	10	0	0	0	3	1	0
Middleground	2	6	27	0	9	1	0	24	0	0
Evans	2	1	5	0	1	0	0	12	0	1
Mt. Vernon Wharf	3	0	0	1	0	0	0	0	0	0
Georges	16	0	8	6	50	6	1	280	15	4
Drum Point	14	10	16	11	157	27	44	124	13	8
Sharkfin Shoal	6	0	7	0	9	5	0	57	0	2
Turtle Egg	7	35	70	3	180	33	33	207	25	7
Piney Island East	23	25	45	16	118	28	167	127	1	27
Great Rock	3	7	0	1	82	6	140	1	3	19
Gunby	35	9	0	24	54	32	6	108	0	29
Marumsco	6	0	0	57	27	27	4	89	0	14
Broomes Island	58	0	0	1	7	0	1	15	1	0
Back of Island	17	0	3	0	22	9	44	27	11	0
Chicken Cock	78	2	36	10	132	16	12	151	56	2
Pagan	54	0	1,390	6	95	42	117	535	9	6
Black Walnut	1	0	2	0	3	0	1	2	0	0
Blue Sow	5	0	0	0	11	0	2	4	1	0
Dukehart	0	0	0	0	1	0	0	1	0	0
Ragged Point	20	0	2	0	1	1	0	1	0	0
Cornfield Harbor	49	0	4	11	25	5	35	31	9	0
Spat Index	**28.1**	**2.0**	**276.7**	**3.5**	**29.1**	**6.4**	**15.9**	**40.5**	**4.8**	**6.5**

Table 3. *Perkinsus marinus* prevalence and intensity (scale of 0-7) in oysters from the 43 disease monitoring bars, 1990-2004. ND indicates insufficient quantity of oysters for analytical sample.

Oyster Bar	*Perkinsus marinus* Prevalence (%) and Intensity (I)									
	1990		1991		1992		1993		1994	
	%	I	%	I	%	I	%	I	%	I
Swan Point	7	0.1	27	0.7	23	0.4	37	0.8	3	0.1
Hacketts Point	0	0.0	27	0.8	57	1.2	97	3.2	23	0.5
Holland Point	20	0.5	47	1.1	80	2.4	93	3.0	36	1.1
Stone Rock	47	0.5	27	0.9	100	4.4	100	3.5	90	2.5
Flag Pond	30	0.8	97	2.6	97	5.7	88	2.7	30	0.8
Hog Island	90	3.0	97	4.5	100	4.2	93	2.4	37	1.0
Butlers	100	4.0	100	4.0	81	2.4	97	3.3	80	2.1
Buoy Rock	23	0.5	80	2.5	97	2.8	93	3.3	10	0.3
Oldfield	17	0.2	20	0.5	37	0.9	83	2.4	20	0.6
Bugby	100	3.4	100	4.0	73	1.8	100	3.0	43	0.8
Parsons Island	20	0.5	97	3.6	80	2.1	100	3.3	93	3.1
Hollicutts Noose	30	0.3	73	2.0	82	2.1	97	2.7	70	1.7
Bruffs Island	83	2.8	83	2.8	93	3.0	83	2.6	63	1.3
Turtleback	100	3.8	100	3.3	77	1.6	100	3.3	60	1.2
Long Point	73	2.3	94	4.3	86	3.0	77	2.6	60	2.0
Cooks Point	17	0.2	23	0.3	87	3.7	97	4.2	90	3.0
Royston	--	---	100	4.5	97	4.8	100	3.3	80	2.0
Lighthouse	90	2.3	100	4.0	100	4.6	93	3.2	47	1.2
Sandy Hill	100	5.0	100	5.7	100	4.2	100	3.8	83	2.3
Oyster Shell Point	3	0.1	60	1.7	100	3.9	93	2.8	10	0.3
Tilghman Wharf	100	3.2	97	3.0	100	3.4	100	3.2	63	1.9
Deep Neck	100	4.9	100	5.6	100	3.7	100	3.8	67	2.3
Double Mills	97	3.6	100	4.9	100	4.1	100	3.8	90	2.0
Cason	100	3.4	100	4.4	90	2.6	93	2.8	83	2.2
Ragged Point	100	4.8	100	4.6	100	5.0	100	3.9	87	2.3
Normans Addition	100	4.2	100	3.4	83	2.0	96	3.6	93	3.3
Goose Creek	60	1.8	100	3.1	100	3.6	87	2.1	53	1.1
Wilson Shoals	93	2.9	100	2.8	90	2.5	83	1.6	40	0.9
Georges	83	1.9	93	2.9	58	1.4	30	0.7	50	1.2
Holland Straits	100	4.2	100	4.0	100	3.4	76	2.3	57	1.6
Sharkfin Shoal	23	0.3	60	1.2	97	2.8	93	2.2	63	1.4
Back Cove	100	2.7	100	4.2	97	3.3	36	1.0	80	2.2
Piney Island East	93	2.7	97	3.1	87	2.7	83	2.2	87	3.1
Old Woman's Leg	57	1.1	100	4.5	100	4.0	82	2.0	73	2.1
Marumsco	97	3.5	93	3.3	60	1.3	87	2.5	72	1.6
Broomes Island	97	3.4	100	2.8	63	1.5	87	3.0	40	0.6
Chicken Cock	100	4.2	97	3.1	93	3.2	96	2.6	40	1.0
Pagan	93	3.3	97	2.3	100	3.0	93	2.1	10	0.3
Lancaster	97	3.6	97	2.8	67	1.4	67	1.6	20	0.2
Mills West	13	0.2	80	2.0	90	2.9	63	1.8	20	0.2
Cornfield Harbor	97	3.4	83	2.3	100	3.8	93	2.9	77	1.9
Ragged Point	97	3.8	90	2.8	40	0.9	50	1.4	10	0.2
Lower Cedar Point	40	0.7	10	0.3	23	0.6	7	0.1	7	0.1
***P. marinus* Indices**	**70**	**2.3**	**83**	**3.0**	**83**	**2.8**	**84**	**2.6**	**54**	**1.4**

Table 3 (Continued).

Oyster Bar	*Perkinsus marinus* Prevalence (%) and Intensity (I)									
	1995		1996		1997		1998		1999	
	%	I	%	I	%	I	%	I	%	I
Swan Point	20	0.2	0	0.0	3	0.1	43	1.2	97	3.4
Hacketts Point	90	2.5	30	0.7	43	1.3	43	1.1	97	3.3
Holland Point	87	2.9	47	1.4	37	1.1	37	0.9	93	2.8
Stone Rock	87	2.2	93	2.7	90	2.3	100	3.5	100	4.0
Flag Pond	87	3.3	63	2.0	53	1.2	73	2.3	NA	NA
Hog Island	93	2.7	43	1.2	47	1.3	97	3.2	93	5.5
Butlers	87	2.5	60	1.6	57	1.0	97	3.3	93	3.2
Buoy Rock	67	1.7	13	0.4	7	0.7	33	0.9	93	3.0
Oldfield	83	2.3	0	0.0	10	0.2	33	0.8	97	3.0
Bugby	83	2.6	80	2.0	70	1.8	60	1.4	100	3.9
Parsons Island	70	2.1	73	2.8	63	1.4	80	2.5	100	4.7
Hollicutts Noose	90	2.8	60	1.4	50	1.0	83	2.5	90	3.0
Bruffs Island	73	2.1	67	1.4	17	0.2	57	1.6	100	3.7
Turtleback	100	2.8	83	2.1	83	1.8	50	1.6	100	4.3
Long Point	67	2.2	20	0.4	23	0.6	100	2.7	100	3.6
Cooks Point	ND	---	60	1.5	70	2.4	87	2.8	93	3.4
Royston	63	2.0	50	1.1	67	1.5	90	2.5	97	3.5
Lighthouse	90	3.3	77	1.8	57	1.5	43	1.5	87	2.3
Sandy Hill	89	3.4	30	0.7	60	1.3	40	1.0	97	3.4
Oyster Shell Pt	68	1.8	13	0.2	50	0.9	20	0.3	83	2.3
Tilghman Wharf	93	2.5	67	1.3	60	1.0	67	2.0	87	2.5
Deep Neck	97	3.0	83	2.1	100	2.6	97	2.9	97	4.5
Double Mills	75	2.5	70	1.2	83	2.0	100	3.0	100	4.8
Cason	93	2.3	87	1.9	93	2.4	50	1.4	97	3.8
Ragged Point	93	2.5	97	2.6	97	2.1	87	1.4	100	4.0
Normans Add.	87	2.8	93	2.4	73	1.6	73	2.3	93	3.5
Goose Creek	87	2.5	97	4.0	83	2.0	100	3.0	100	5.4
Wilson Shoals	63	1.1	83	1.8	80	1.9	70	1.6	100	4.3
Georges	87	2.8	93	2.0	93	2.2	83	2.4	93	3.5
Holland Straits	93	3.1	83	2.0	67	1.8	57	1.2	80	2.5
Sharkfin Shoal	90	3.0	97	2.1	93	2.6	80	2.7	100	4.3
Back Cove	83	3.0	97	3.2	93	2.9	90	2.3	100	5.5
Piney Isl East	93	2.5	63	1.7	73	2.2	83	1.9	63	2.4
Old Woman’s Leg	100	4.2	80	2.3	57	1.3	90	3.2	87	3.9
Marumsco	100	4.2	90	2.4	61	2.1	80	2.8	90	3.4
Broomes Island	43	1.0	17	0.4	83	2.1	83	3.0	100	4.6
Chicken Cock	83	1.9	77	1.4	73	1.7	80	1.7	100	5.0
Pagan	93	2.2	82	1.4	86	1.7	73	1.7	97	3.4
Lancaster	27	0.6	56	1.2	80	1.6	37	0.7	83	2.5
Mills West	57	1.4	60	1.2	60	1.2	20	0.4	90	3.2
Cornfield Harbor	93	2.5	87	2.0	83	1.8	83	2.0	97	3.9
Ragged Point	33	0.8	7	0.2	0	0.0	0	0.0	17	0.5
Lower Cedar Pt.	13	0.2	3	0.3	0	0.0	0	0.0	0	0.0
***P. marinus* Indices**	**78**	**2.3**	**61**	**1.5**	**62**	**1.5**	**67**	**1.9**	**90**	**3.5**

Table 3 (Continued).

Oyster Bar	*Perkinsus marinus* Prevalence (%) and Intensity (I)									
	2000		2001		2002		2003		2004	
	%	I	%	I	%	I	%	I	%	I
Swan Point	80	1.2	93	3.3	97	2.7	33	1.0	33	0.7
Hacketts Point	97	3.7	97	3.4	100	3.3	33	1.1	30	0.8
Holland Point	87	3.4	93	3.2	100	3.6	33	1.1	30	0.6
Stone Rock	93	3.6	83	2.8	100	2.3	77	2.4	10	0.2
Flag Pond	NA	NA	NA	NA	37	0.5	0	0.0	3	0.3
Hog Island	83	3.9	93	3.4	87	2.9	53	2.3	53	1.4
Butlers	83	2.7	80	2.4	80	1.4	10	0.3	7	0.1
Buoy Rock	97	3.5	93	3.5	100	2.6	97	3.7	50	1.5
Oldfield	93	3.0	100	3.3	97	2.5	80	2.5	33	0.7
Bugby	100	4.0	100	4.6	97	3.1	97	3.4	63	1.7
Parsons Island	100	3.5	100	4.5	100	4.4	90	3.3	93	2.8
Hollicutts Noose	100	4.1	100	4.8	100	3.6	80	2.7	40	1.5
Bruffs Island	97	3.2	100	3.8	100	3.6	73	1.8	80	2.5
Turtleback	97	3.1	100	4.2	100	4.7	100	3.6	80	2.8
Long Point	97	3.3	100	4.2	100	3.1	97	2.8	97	3.2
Cooks Point	40	1.2	77	2.2	NA	NA	66	2.1	0	0.0
Royston	97	4.7	100	5.2	100	4.2	48	1.8	13	0.3
Lighthouse	100	3.4	100	3.3	100	4.6	20	0.6	43	1.2
Sandy Hill	87	3.6	100	4.5	100	5.0	93	3.5	87	3.3
Oyster Shell Pt	73	2.2	100	3.6	100	3.0	43	1.0	43	0.8
Tilghman Wharf	93	3.4	100	3.5	90	3.2	87	2.4	43	0.8
Deep Neck	100	4.0	97	4.8	100	3.2	97	3.7	27	0.5
Double Mills	100	4.7	100	5.5	97	2.9	53	1.7	53	2.1
Cason	100	3.6	100	4.3	94	4.4	17	0.4	3	3.3
Ragged Point	97	3.7	100	4.3	100	3.5	43	1.0	13	0.2
Normans Add.	80	3.4	90	3.0	67	1.9	37	1.3	93	3.3
Goose Creek	97	3.1	100	4.1	93	4.0	57	2.0	77	2.0
Wilson Shoals	70	2.1	100	4.0	100	3.6	83	2.3	97	2.3
Georges	80	2.3	100	5.2	100	4.0	83	2.6	100	4.2
Holland Straits	30	0.9	43	1.4	50	1.1	40	0.7	70	1.7
Sharkfin Shoal	80	2.3	90	3.7	97	3.6	47	3.4	100	4.4
Back Cove	40	1.2	100	5.0	97	3.8	100	4.6	97	3.7
Piney Isl East	86	2.3	60	1.5	100	3.1	100	3.9	100	3.9
Old Woman's Leg	70	1.7	100	5.0	100	3.7	100	4.4	93	3.7
Marumsco	93	2.7	100	5.0	97	4.1	90	2.3	87	2.8
Broomes Island	93	4.0	100	4.8	97	3.8	47	1.3	47	1.4
Chicken Cock	63	1.8	93	3.6	100	2.9	23	0.7	40	0.9
Pagan	68	1.6	100	4.6	93	4.0	60	1.3	83	2.3
Lancaster	90	2.7	100	4.5	97	2.7	50	1.5	37	0.9
Mills West	97	3.6	100	4.8	93	3.1	60	1.6	57	1.5
Cornfield Harbor	80	2.1	80	2.9	97	1.7	27	0.7	30	0.5
Ragged Point	13	0.7	33	0.5	93	2.6	24	0.7	9	0.1
Lower Cedar Pt.	17	0.5	90	2.3	97	2.5	13	0.5	17	0.4
***P. marinus* Indices**	**81**	**2.9**	**93**	**3.8**	**94**	**3.2**	**60**	**2.0**	**53**	**1.7**

Table 4. Prevalence of *Haplosporidium nelsoni* in oysters from the 43 disease monitoring bars, 1990-2004.

Oyster Bar	*Haplosporidium nelsoni* Prevalence (%)						
	1990	1991	1992	1993	1994	1995	1996
Swan Point	0	0	0	0	ND	0	0
Hacketts Point	0	0	3	0	0	0	0
Holland Point	0	3	13	0	0	0	0
Stone Rock	0	0	43	0	0	3	0
Flag Pond	0	0	53	0	0	27	0
Hog Island	0	0	43	0	0	14	0
Butlers	0	0	50	0	0	23	0
Buoy Rock	ND	0	0	0	ND	0	0
Oldfield	ND	0	0	0	ND	0	0
Bugby	0	7	3	0	0	0	0
Parsons Island	ND	0	7	0	0	0	0
Hollicutts Noose	0	0	17	0	0	0	0
Bruffs Island	0	0	0	0	0	0	0
Turtleback	0	0	0	0	0	23	0
Long Point	0	0	0	0	0	0	0
Cooks Point	0	7	73	0	0	ND	0
Royston	ND	0	33	0	0	0	0
Lighthouse	0	0	53	0	0	0	0
Sandy Hill	0	0	13	0	ND	0	0
Oyster Shell Pt	0	0	30	0	ND	0	0
Tilghman Wharf	0	0	40	0	0	0	0
Deep Neck	0	0	30	0	0	0	0
Double Mills	0	0	17	0	0	0	0
Cason	0	0	43	0	0	0	0
Ragged Point	0	20	57	0	0	0	0
Normans Add	3	0	53	0	0	33	0
Goose Creek	0	10	27	7	0	20	0
Wilson Shoals	0	0	57	0	ND	7	0
Georges	10	7	23	0	0	33	0
Holland Straits	0	20	13	13	0	52	0
Sharkfin Shoal	20	43	40	17	0	33	0
Back Cove	0	17	27	33	7	20	3
Piney Isl East	7	23	17	20	13	10	7
Old Woman's Leg	0	33	23	30	10	43	20
Marumsco	0	20	20	0	0	20	0
Broomes Island	0	ND	20	0	0	0	0
Chicken Cock	0	0	57	0	ND	0	0
Pagan	0	0	0	0	ND	0	0
Lancaster	0	0	0	0	ND	0	0
Mills West	0	0	0	0	ND	0	0
Cornfield Harbor	0	0	57	0	0	37	0
Ragged Pt. (Potomac)	0	0	0	0	0	0	0
Lower Cedar Pt.	ND	ND	0	0	ND	0	0
Percent Frequency[1]	**9**	**28**	**74**	**14**	**7**	**40**	**7**

[1]ND=No samples taken; prevalence assumed to be 0. NA=unable to obtain a sufficient sample size.

Table 4 (Continued).

Oyster Bar	*Haplosporidium nelsoni* Prevalence (%)							
	1997	1998	1999	2000	2001	2002	2003	2004
Swan Point	0	0	0	0	0	0	0	0
Hacketts Point	0	0	0	0	0	13	0	0
Holland Point	0	0	0	3	7	40	0	0
Stone Rock	0	0	30	47	40	30	3	0
Flag Pond	0	0	NA	NA	NA	20	0	0
Hog Island	0	0	60	27	27	20	0	0
Butlers	7	3	47	17	27	20	3	3
Buoy Rock	0	0	0	0	0	0	0	0
Oldfield	0	0	0	0	0	0	0	0
Bugby	0	0	0	0	0	27	0	0
Parsons Island	0	0	0	0	3	17	0	0
Hollicutts Noose	0	0	7	10	17	37	0	0
Bruffs Island	0	0	0	0	3	17	0	0
Turtleback	0	0	0	0	7	33	0	0
Long Point	0	0	0	0	0	3	0	0
Cooks Point	3	0	13	33	37	NA	0	0
Royston	0	0	3	7	0	60	0	0
Lighthouse	0	0	13	7	3	67	0	0
Sandy Hill	0	0	0	0	10	53	0	0
Oyster Shell Pt	0	0	0	0	0	7	0	0
Tilghman Wharf	0	0	3	27	7	60	0	0
Deep Neck	0	0	3	7	0	63	0	0
Double Mills	0	0	3	0	0	33	0	0
Cason	0	0	7	27	33	59	0	0
Ragged Point	0	0	20	47	40	30	0	0
Normans Add	0	3	63	37	37	20	7	0
Goose Creek	0	0	47	17	13	33	0	0
Wilson Shoals	0	0	4	10	10	27	0	0
Georges	0	0	40	20	13	30	0	0
Holland Straits	10	3	73	40	47	57	7	0
Sharkfin Shoal	0	20	53	37	20	27	7	0
Back Cove	3	10	33	37	10	7	7	0
Piney Isl East	13	17	43	53	40	17	10	3
Old Woman's Leg	4	23	53	30	13	13	3	3
Marumsco	11	7	37	30	17	30	0	0
Broomes Island	0	0	3	10	0	13	0	0
Chicken Cock	0	0	77	7	17	30	3	0
Pagan	0	0	3	13	10	40	0	0
Lancaster	0	0	0	0	0	10	0	0
Mills West	0	0	3	0	0	43	0	0
Cornfield Harbor	0	3	53	17	33	50	10	0
Ragged Pt. (Potomac)	0	0	13	10	7	60	0	0
Lower Cedar Pt.	0	0	0	0	0	0	0	0
Percent Frequency[2]	**16**	**19**	**67**	**64**	**67**	**90**	**23**	**7**

[2]ND=No samples taken; prevalence assumed to be 0. NA=unable to obtain a sufficient sample size.

Table 5. Oyster population mortality estimates from the 43 disease monitoring bars, 1985-2004.

Oyster Bar	Total Observed Mortality (%)									
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Swan Point	14	1	2	1	9	4	4	3	5	35
Hacketts Point	7	0	10	9	5	2	2	12	18	30
Holland Point	4	21	19	3	19	3	14	45	43	42
Stone Rock	6	ND	ND	ND	ND	2	9	45	30	29
Flag Pond	ND	48	30	39	37	10	35	77	43	28
Hog Island	ND	26	47	25	6	19	73	85	76	16
Butlers	ND	23	84	15	7	30	58	84	66	37
Buoy Rock	10	0	0	1	10	5	11	16	51	33
Oldfield	8	3	3	4	2	7	3	9	8	12
Bugby	8	25	46	33	25	39	53	18	29	18
Parsons Island	19	1	26	13	2	7	43	27	29	18
Hollicutts Noose	2	32	42	25	14	1	7	9	29	32
Bruffs Island	2	1	45	12	9	12	50	77	47	47
Turtleback	ND	1	19	27	15	27	51	23	24	40
Long Point	17	8	23	8	12	11	53	73	44	8
Cooks Point	40	20	45	63	6	11	2	88	63	40
Royston	4	21	19	11	14	14	33	43	37	10
Lighthouse	3	14	59	14	8	8	45	52	57	27
Sandy Hill	12	6	29	34	7	11	75	48	45	36
Oyster Shell Point	9	0	1	2	2	3	2	19	20	14
Tilghman Wharf	2	36	57	ND	20	30	34	26	36	6
Deep Neck	2	25	37	32	47	66	48	40	32	1
Double Mills	4	7	13	9	6	28	82	50	24	10
Cason	4	22	60	37	40	63	25	48	53	6
Ragged Point	5	31	84	38	7	23	53	49	71	17
Normans Addition	15	53	82	ND	11	11	48	49	51	28
Goose Creek	6	26	84	59	19	7	23	63	38	7
Wilson Shoals	23	65	51	41	38	10	29	60	23	10
Georges	5	24	84	55	23	31	50	55	16	0
Holland Straits	19	51	85	90	15	27	35	71	18	16
Sharkfin Shoal	25	61	94	80	8	0	10	63	16	7
Back Cove	ND	ND	ND	ND	ND	11	49	88	4	6
Piney Island East	21	16	88	11	5	23	57	55	13	20
Old Woman's Leg	4	17	79	21	8	5	50	80	15	25
Marumsco	3	27	77	ND	20	8	31	44	21	8
Broomes Island	10	29	31	6	4	24	53	70	53	27
Chicken Cock	18	43	63	43	24	27	31	51	33	28
Pagan	9	30	27	13	20	39	24	19	17	11
Lancaster	13	6	4	4	6	28	20	8	7	4
Mills West	18	0	2	1	1	2	11	9	2	4
Cornfield Harbor	17	59	92	51	11	16	29	77	47	25
Ragged Point	10	14	29	79	54	63	34	63	28	35
Lower Cedar Point	6	9	2	1	6	6	7	5	47	28
Mortality Index	**10**	**22**	**44**	**29**	**14**	**18**	**34**	**46**	**33**	**20**

Table 5 (Continued).

Oyster Bar	Total Observed Mortality (%)									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Swan Point	18	43	20	3	7	13	12	14	13	10
Hacketts Point	30	16	10	26	22	13	30	60	17	10
Holland Point	35	49	36	36	8	33	42	67	50	29
Stone Rock	40	25	15	33	46	66	30	86	13	5
Flag Pond	24	16	13	33	50	ND	ND	23	0	0
Hog Island	45	20	16	33	67	67	14	31	11	6
Butlers	63	17	20	20	48	67	32	11	9	2
Buoy Rock	22	17	7	7	6	25	43	61	41	28
Oldfield	8	17	8	5	8	21	36	47	34	10
Bugby	18	27	15	8	5	29	48	63	50	14
Parsons Island	36	22	25	8	16	29	60	59	37	11
Hollicutts Noose	30	13	15	14	13	38	55	85	25	3
Bruffs Island	33	6	6	11	16	33	44	50	50	12
Turtleback	51	21	9	9	26	38	48	54	43	11
Long Point	28	8	3	9	14	33	34	66	54	10
Cooks Point	22	16	11	20	35	63	28	100	21	0
Royston	17	9	9	6	32	31	51	91	69	14
Lighthouse	18	15	5	6	20	33	44	92	89	47
Sandy Hill	29	23	22	4	15	27	50	77	88	59
Oyster Shell Point	18	25	6	2	1	15	28	55	48	20
Tilghman Wharf	10	9	15	6	12	19	34	85	62	17
Deep Neck	23	14	8	13	37	23	37	85	54	14
Double Mills	20	9	8	10	38	40	50	85	59	23
Cason	7	12	11	18	28	32	62	98	57	4
Ragged Point	16	12	13	19	34	37	70	94	52	5
Normans Addition	39	55	31	54	35	38	29	29	9	14
Goose Creek	38	69	64	20	64	63	81	85	53	59
Wilson Shoals	17	11	11	9	29	25	26	52	19	27
Georges	55	33	36	12	32	60	50	44	4	24
Holland Straits	45	43	20	18	35	35	17	12	11	18
Sharkfin Shoal	66	59	47	28	62	61	39	61	23	32
Back Cove	46	33	29	50	59	20	46	38	22	23
Piney Island East	65	56	49	67	38	27	12	20	28	48
Old Woman's Leg	63	46	33	38	42	15	53	27	35	56
Marumsco	78	53	49	26	40	22	35	45	4	11
Broomes Island	8	0	13	11	44	25	59	72	14	19
Chicken Cock	15	10	7	24	82	63	28	63	2	38
Pagan	9	27	15	3	14	35	51	84	7	29
Lancaster	19	25	8	8	18	48	58	52	35	27
Mills West	21	18	17	16	24	36	40	75	48	11
Cornfield Harbor	56	24	7	27	78	62	44	33	1	7
Ragged Point	8	11	4	25	10	8	33	ND	76	ND
Lower Cedar Point	5	23	3	26	8	0	3	44	55	22
Mortality Index	**30**	**25**	**18**	**19**	**31**	**35**	**38**	**58**	**35**	**20**

Table 6. Regional summary of oyster harvests (bu.) in Maryland, 1985-86 through 2003-04 seasons.

Region/Tributary	1985-86	1986-87	1987-88	1988-89	1989-90
Upper Bay	5,600	30,800	19,100	17,700	15,700
Middle Bay	73,400	37,900	42,500	10,500	15,900
Lower Bay	32,500	5,900	70	0	3,600
Total Bay Mainstem	111,500	74,600	61,700	28,200	35,200
Chester River	21,300	20,600	30,900	49,900	54,000
Eastern Bay	216,100	149,100	28,700	15,700	20,400
Miles R.	40,400	20,600	17,100	13,600	1,400
Wye R.	20,100	2,200	700	3,800	8,000
Total Eastern Bay Region	276,600	171,900	46,500	33,100	29,800
Upper Choptank River	29,000	42,400	36,500	51,900	27,700
Middle Choptank R.	144,500	89,700	66,400	66,400	71,000
Lower Choptank R.	225,100	52,500	26,200	9,100	32,100
Tred Avon R.	67,700	60,900	13,700	42,400	92,100
Broad Creek	12,900	58,700	8,500	13,500	8,100
Harris Cr.	3,500	16,700	6,900	7,800	8,800
Total Choptank R. Region	482,700	320,900	158,200	191,100	239,800
Little Choptank River	27,100	10,500	21,500	15,000	19,000
Upper Tangier Sound	84,000	30,400	40	0	0
Lower Tangier S.	64,400	22,200	90	0	0
Honga River	29,400	49,300	7,700	300	1,100
Fishing Bay	107,600	87,300	90	20	20
Nanticoke R.	21,300	5,100	1,500	900	2,600
Wicomico R.	3,600	200	100	40	20
Manokin R.	40,800	47,400	500	70	10
Annemesex R.	90	10	10	0	40
Pocomoke S.	32,700	22,300	0	0	0
Total Tangier Sound Region	383,900	264,200	10,000	1,300	3,800
Patuxent River	96,300	16,800	1,400	3,700	8,900
Wicomico R., St. Clement's and Breton Bays	16,000	23,400	23,000	47,600	22,200
St. Mary's River and Smith Cr.	80,700	30,700	2,300	500	1,100
Total Potomac Md Tributaries	96,700	54,100	25,300	48,100	23,300
Total Maryland (bu.)	**1,500,000**	**1,000,000**	**360,000**	**390,000**	**413,000**

Table 6 (continued).

Region/Tributary	1990-91	1991-92	1992-93	1993-94	1994-95
Upper Bay	19,800	35,200	18,200	8,900	7,800
Middle Bay	17,700	39,200	9,000	4,400	4,900
Lower Bay	37,900	9,300	90	0	1,100
Total Bay Mainstem	75,400	83,800	27,300	13,300	13,800
Chester River	60,400	55,100	53,800	51,300	29,100
Eastern Bay	33,200	20,600	3,600	2,400	3,700
Miles R.	1,700	100	300	0	200
Wye R.	2,300	300	20	30	50
Total Eastern Bay Region	37,200	21,000	3,900	2,700	4,000
Upper Choptank River	42,200	29,200	9,500	2,600	2,500
Middle Choptank R.	49,700	25,000	3,100	1,600	4,900
Lower Choptank R.	9,000	14,200	1,700	900	600
Tred Avon R.	22,000	800	0	0	5,900
Broad Creek	4,300	40	50	10	400
Harris Cr.	3,300	100	20	0	14,200
Total Choptank R. Region	130,500	69,300	14,400	5,100	28,500
Little Choptank River	8,800	3,800	50	300	19,300
Upper Tangier Sound	1,000	11,300	70	0	17,600
Lower Tangier S.	1,600	1,700	40	0	5,400
Honga River	5,600	600	20	100	1,700
Fishing Bay	900	6,400	500	30	11,900
Nanticoke R.	3,000	12,500	7,700	2,500	10,500
Wicomico R.	60	600	500	500	80
Manokin R.	60	200	40	10	100
Annemesex R.	0	10	0	0	0
Pocomoke S.	300	500	0	0	100
Total Tangier Sound Region	12,500	33,800	8,900	3,100	47,400
Patuxent River	48,400	24,500	0	0	30
Wicomico R., St. Clement’s and Breton Bays	36,000	29,600	14,900	4,000	18,200
St. Mary’s River and Smith Cr.	1,700	100	60	30	3,900
Total Potomac Md Tributaries	37,700	29,000	15,000	4,000	22,100
Total Maryland (bu.)	**411,000**	**323,000**	**123,000**	**80,000**	**164,000**

Table 6 (continued).

Region/Tributary	1995-96	1996-97	1997-98	1998-99	1999-00
Upper Bay	26,600	2,600	18,800	13,100	28,100
Middle Bay	12,600	20,000	15,300	55,800	31,500
Lower Bay	800	300	4,800	8,300	3,800
Total Bay Mainstem	40,000	22,800	38,900	77,200	63,400
Chester River	42,600	5,400	43,000	21,000	70,100
Eastern Bay	1,500	1,100	3,800	30,900	75,800
Miles R.	200	500	30	800	35,700
Wye R.	0	0	400	900	9,400
Total Eastern Bay Region	1,700	1,600	4,200	32,600	120,900
Upper Choptank River	11,600	3,200	4,800	3,100	7,100
Middle Choptank R.	15,000	4,700	5,600	2,800	1,900
Lower Choptank R.	900	300	200	2,400	8,300
Tred Avon R.	1,300	3,800	6,900	11,700	3,700
Broad Creek	1,000	4,000	27,600	46,200	18,200
Harris Cr.	5,000	13,600	21,400	67,000	18,200
Total Choptank R. Region	34,800	29,600	66,500	133,200	57,400
Little Choptank River	1,900	40,800	36,100	84,100	33,600
Upper Tangier Sound	12,100	8,100	6,000	3,500	1,500
Lower Tangier S.	500	10,100	4,200	8,500	2,800
Honga River	400	200	1,300	300	50
Fishing Bay	20,900	8,800	3,800	700	90
Nanticoke R.	15,200	23,000	30,300	21,700	8,800
Wicomico R.	100	1,400	2,200	1,400	500
Manokin R.	0	900	600	300	90
Annemesex R.	0	0	0	0	200
Pocomoke S.	0	300	400	80	100
Total Tangier Sound Region	49,200	52,800	48,800	36,500	14,100
Patuxent River	100	20	60	5,600	2,000
Wicomico R., St. Clement’s and Breton Bays	27,500	7,300	10,200	13,700	8,800
St. Mary’s River and Smith Cr.	900	16,200	36,700	16,400	4,500
Total Potomac Md Tributaries	28,400	23,500	46,900	30,100	13,300
Total Maryland (bu.)	**199,000**	**178,000**	**285,000**	**423,000**	**380,700**

Table 6 (continued).

Region/Tributary	2000-01	2001-02	2002-03	2003-04
Upper Bay	31,150	16,100	18,930	2,210
Middle Bay	16,400	4,550	2,410	750
Lower Bay	2,050	600	50	187
Total Bay Mainstem	49,600	21,250	21,390	3,147
Chester River	20,800	29,450	11,830	557
Eastern Bay	120,500	33,400	4,650	5,446
Miles R.	20,150	6,600	50	56
Wye R.	11,300	1,800	60	0
Total Eastern Bay Region	151,950	41,800	4,760	5,502
Upper Choptank River	1,100	7,450	10	0
Middle Choptank R.	8,150	5,600	520	30
Lower Choptank R.	350	1,500	40	0
Tred Avon R.	8,950	1,000	40	0
Broad Creek	36,850	4,900	700	954
Harris Cr.	26,200	3,300	30	12
Total Choptank R. Region	81,600	23,750	1,340	996
Little Choptank River	27,850	2,400	190	1,150
Upper Tangier Sound	100	5,050	3,570	7,630
Lower Tangier S.	1,450	13,200	5,960	5,162
Honga River	0	50	590	378
Fishing Bay	0	0	390	24
Nanticoke R.	600	2,700	540	57
Wicomico R.	50	50	10	0
Manokin R.	200	1,850	970	1,638
Annemesex R.	0	0	0	0
Pocomoke S.	10	20	0	0
Total Tangier Sound Region	2,400	22,920	12,030	14,889
Patuxent River	10	0	0	0
Wicomico R., St. Clement's and Breton Bays	2,600	1,400	220	13
St. Mary's River and Smith Cr.	6,150	1,650	0	0
Total Potomac Md Tributaries	8,750	3,050	220	13
Total Maryland (bu.)	**348,000**	**148,200**	**55,840**	**26,471**

APPENDIX 1
OYSTER HOST and OYSTER PARASITES

Oysters

The eastern oyster, *Crassostrea virginica*, tolerates water temperatures of 0-36 °C and salinities of 3-35 ppt, where ocean water has 35 ppt salinity. Oysters reproduce when sexes simultaneously spawn their gametes into Chesapeake Bay waters during June and July. Externally fertilized eggs develop into planktonic larvae, which are transported in Chesapeake Bay waters for several weeks while feeding on phytoplankton as they grow and develop. Mature larvae seek solid substrates, preferably oyster shells (valves), to which they attach as they metamorphose to become sessile juvenile oysters. Unlike fishes and other vertebrates, oysters do not strictly regulate the salt content of their tissues. Instead, the salt content of functioning oyster tissues conforms to the broad and variable range of salinities in oyster habitats. Thus, oyster parasites with high or narrow salinity requirements may be exposed to low environmental salinities when shed into the environment and while infecting oysters whose habitat salinity is diluted by precipitation. Upon its death, an oyster's shell springs open by default and its tissues are consumed by predators and scavengers. However, the resilient hinge ligament holds its articulated valves together for months. Vacant, articulated oyster shells in our samples are interpreted to represent oysters that died during the previous year, and their relative numbers are used to estimate fisheries-independent mortality rates.

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, and Collier 1950), and its disease name was abbreviated to "dermo" accordingly. Once described, dermo disease was soon 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 by 18 days. Heavily infected oysters are emaciated; showing reduced growth and reproduction (Ray and Chandler 1955). Although *P. marinus* survives both low temperatures and low salinities, its proliferation is high in the broad range of temperatures (15-35 °C) and salinities (17-34 ppt) that are typical of Chesapeake Bay waters during oyster dermo disease mortality peaks (Dungan and Hamilton 1995). Over several years of drought during the 1980s, *P. marinus* expanded its Chesapeake Bay distribution into upstream areas where it had been rare or absent, and became prevalent in newly infected oyster populations (Burreson and Ragone Calvo 1996). Since 1990, oysters in most Maryland populations have become infected.

MSX disease

The high-salinity, protozoan oyster pathogen *Haplosporidium nelsoni* was first detected and described as a *multinucleated sphere X* (MSX) from diseased and dying Delaware Bay oysters during 1957 (Haskin et al. 1966) and was found infecting oysters from lower Chesapeake Bay during 1959 (Andrews 1968). Although the location of early *H. nelsoni* infections in oyster gill tissues suggests waterborne transmission, the complete life cycle and infection mechanism of this parasite remain unknown. Despite many attempts, MSX disease has never been experimentally transmitted in the laboratory; although experimental oysters deployed in affected waters above 14 ppt salinity may acquire infections and die within three to five weeks. In Chesapeake Bay, *H. nelsoni* infection rates peak during May and deaths from *H. nelsoni* infections peak during August, when MSX disease is most active at water temperatures of 5-20 °C (Ewart and Ford 1993). Since MSX disease is rare in oysters from waters below 9 ppt salinity, the distribution of *H. nelsoni* in Chesapeake Bay varies as salinities change with freshwater inflows. During 1999 through 2002, consistently low freshwater inflows to Chesapeake Bay fostered large upstream range extensions by *H. nelsoni*, and resulting MSX disease mortalities, during each successive drought year. Subsequent above-average freshwater inflows throughout 2003 and 2004 have resulted in a strong contraction in the range of MSX disease occurrence and associated mortalities.

Appendix 1 References

Andrews, J.D. 1968. Oyster mortality studies in Virginia VII. Review of epizootiology and origin of *Minchinia nelsoni*. Proc. Natl. Shellfish. Assn. **58**: 23-36.

Burreson, E.M and L.M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* disease in Chesapeake Bay, with emphasis on data since 1985. J. Shellfish Res. **15**: 17-34.

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

Ewart, J.W. and S.E. Ford. 1993. History and impact of MSX and dermo diseases on oyster stocks in the Northeast region. NRAC Fact Sheet No. 200, 8pp. Univ. of Massachusetts, North Dartmouth, MA.

Haskin, H.H., L.A. Stauber, and J.G. Mackin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): causative agent of the Delaware Bay Oyster epizootic. Science **153**: 1414-1416.

Ray, S.M. and A.C. Chandler. 1955. Parasitological reviews: *Dermocystidium marinum*, a parasite of oysters. Exptl. Parasitol. **4**: 172-200.

Mackin, J.G, H.M. Owen, and A. Collier. 1950. Preliminary note on the occurrence of a new protistan parasite, *Dermocystidium marinum* n. sp. in *Crassostrea virginica* (Gmelin). Science **111**: 328-329.

Mackin J.G. 1951. Histopathology of infection of *Crassostrea virginica* (Gmelin) by *Dermocystidium marinum* Mackin, Owen, and Collier. Bull. Mar. Sci. Gulf and Caribbean **1**: 72-87.

APPENDIX 2
GLOSSARY

box oyster	Pairs of empty oyster shells attached by their hinge ligaments. These remain articulated for months after the death of an oyster, providing a durable estimator of recent oyster mortality.
bushel	Unit of volume used to measure oyster catches. The official Maryland bushel is equal to 2,800.9 cu. in., or 1.302 times the U.S. Standard bushel.
dermo disease	Oyster disease caused by the protozoan pathogen, *Perkinsus marinus*.
dredged shell	Oyster shell dredged from buried ancient (3000+ years old) shell deposits. Since 1960 this shell has been the backbone of the Maryland shell planting effort to produce seed oysters and restore oyster bars.
fresh shell	Oyster shell from shucked oysters. It is used to supplement the dredged shell plantings.
Haplosporidium nelsoni	The (haplosporidian) protozoan oyster parasite that causes MSX disease.
infection intensity, individual	*Perkinsus* 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.
infection intensity, mean sample	Averaged categorical infection intensities for all oysters in a sample: *sum of all categorical infection intensities (0--7) ÷ number of sample oysters* This term is synonymous and identically calculated with the historic term “weighted prevalence”. Oyster populations whose samples show mean infection intensities of 3.0 or greater are predicted to experience significant near-term mortalities.
infection intensity, mean annual	Averaged categorical infection intensities for all annual survey oysters: *sum of all sample mean intensities ÷ number of annual samples*
intensity index, sample	Categorical infection intensities averaged only for infected sample oysters: *sum of individual infection intensities (1--7) ÷ number of infected oysters*
intensity index, annual	Categorical infection intensities averaged for all infected annual survey oysters: *sum of all sample intensity indices ÷ number of annual samples*
mortality (observed), % sample	Percent proportion of annual, non-fishing oyster population mortality: *[number of boxes ÷ (number of boxes + number of live oysters)] x 100*.

MSX disease	The oyster disease caused by the protozoan pathogen, *Haplosporidium nelsoni*.
MSX frequency, % annual	Percent proportion of sampled populations infected by *H. nelsoni* (MSX): *(number of samples with MSX infections ÷ total sample number) x 100.*
Perkinsus marinus	The protozoan oyster parasite that causes dermo disease.
prevalence, sample infection	The percent proportion of infected oysters in a sample: *(number infected ÷ number examined) x 100*.
prevalence, mean annual	Percent proportion of infected oysters in an annual survey: *sum of sample percent prevalences ÷ number of samples*.
RFTM assay	Ray's fluid thioglycollate medium assay. Microbiological assay described in 1952 [*Science* **116**:360-361] 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 fifty years to date.
seed	Young oysters produced by planting shell in naturally productive (seed production) areas. If the spatfall is adequate, seed oysters may be transplanted to growout (seed planting) areas, generally during the following spring.
spat	Oysters less than one year old.
spatfall, spatset, set	The process by which swimming oyster larvae attach to hard substrate such as oyster shell. Once a suitable substrate is found, the larvae metamorphose into the adult form, adopting a benthic, sessile habit.
spatfall intensity	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.