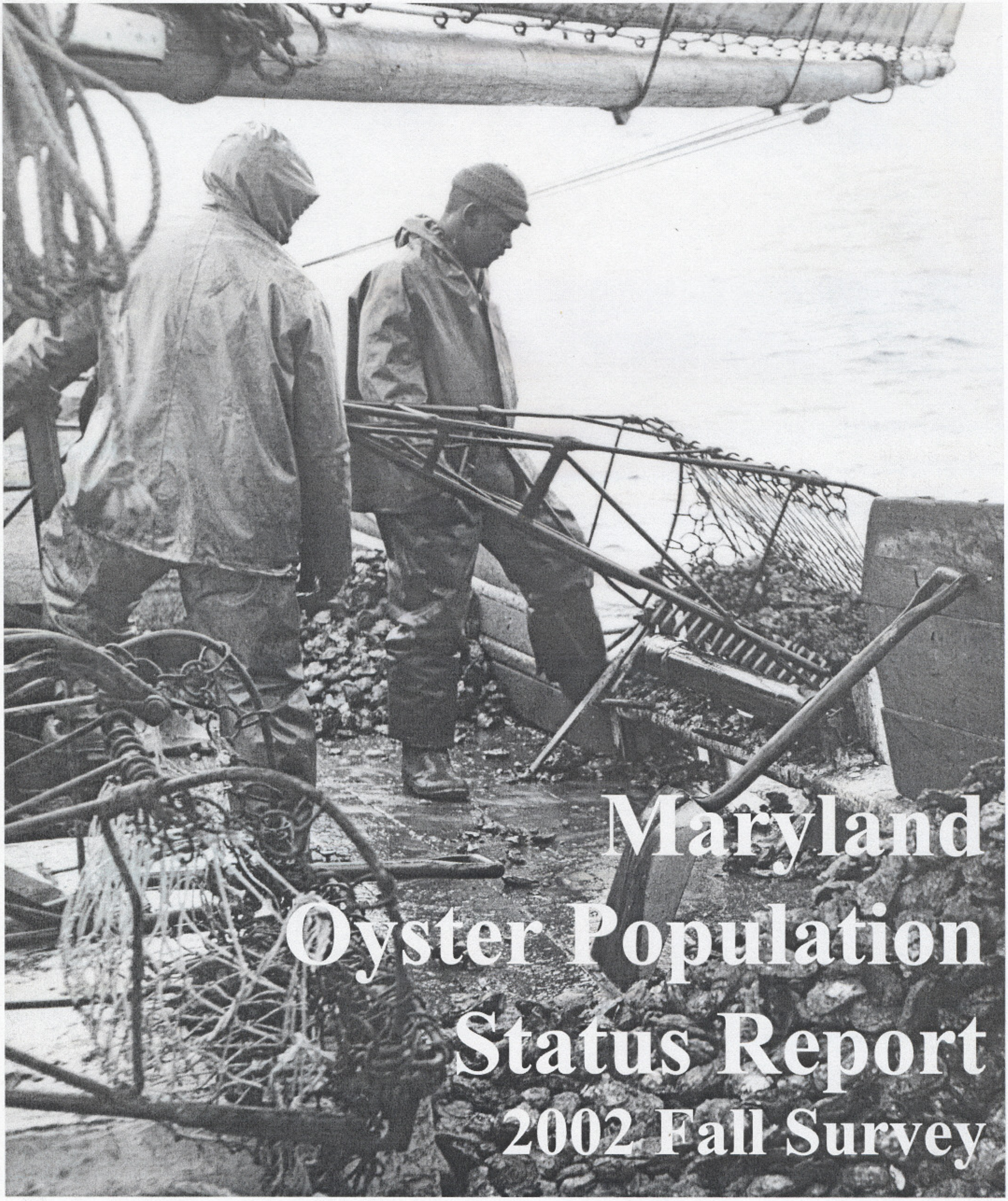

Maryland Oyster Population Status Report

2002 Fall Survey

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and
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Shellfish Program & Sarbanes Cooperative Oxford Laboratory

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EXECUTIVE SUMMARY

The Chesapeake watershed has been under drought conditions for four consecutive years. With 2002 freshwater input at only 80% of the 50-year mean, salinities were abnormally elevated throughout the bay and its tributaries. The consequent impact on the Maryland oyster populations has been substantial, with the higher salinities affecting reproduction, disease, and mortality.

Although the 2002 spat index was slightly below average, several areas received good and even greatly improved spatfall. Spat counts in the hundreds per bushel were found in Tangier Sound and adjacent eastern Chesapeake Bay, along with the St. Mary's River. Spat were also observed on most of the oyster bars above the Bay Bridge, a region which does not usually receive a set because the salinity regime is normally too low for successful reproduction and recruitment. In contrast, some formerly productive areas, including Eastern Bay, the Choptank River and its tributaries, and the Little Choptank River, experienced disappointingly poor spat sets.

As a result of the sustained high salinities, the two primary oyster diseases flourished, occurring at record levels of prevalence and geographic extent in 2002. *Perkinsus marinus*, the parasite that causes dermo disease, was found in every one of the oyster populations tested for the the disease, with a record 94% of all oysters infected. Even populations on remote upstream bars such as Beacon Bar in the Potomac River, which were previously believed to be naive to dermo disease, had infected oysters, suggesting that few if any refuges from this disease currently exist in Maryland.

Likewise, the current MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni* is the most severe on record. Nearly 90% of the examined populations tested positive for the disease, with 28% of the tested oysters infected. This disease, which requires higher salinities than dermo, has made incursions far upstream in many tributaries due to the drought, occurring as far upbay as Hackett Point (above the mouth of the Severn River) and the Chester River. Also, for the first time MSX was found in the Wicomico River, a tributary of the Potomac River, as well as on Long Point bar in the Miles River. In addition, oysters tested positive for MSX in the Choptank River as far upriver as Oyster Shell Point, which last occurred during the 1992 epizootic.

Oyster mortalities increased dramatically in 2002 to 58% of the Maryland populations, compared to the 18-year average of 30%. This jump in mortality rate is associated with the sharp increases in both MSX prevalences and geographic extent, with the most severe impacts occurring in the higher salinity tributaries. The Little Choptank River was particularly devastated, experiencing an average 93% total observed mortality. Some individual oyster bars such as Cooks Point in the Choptank River lost their entire oyster populations.

The 2001-02 commercial harvest of 148,000 bushels represents a 57% decline from the previous year. This marks the third consecutive year of harvest declines, reversing a half-decade trend of increasing catches. Over the past 15 or so years, harvesters have become increasingly dependent on the lower salinity zones such as the Chester River and upper bay, since the middle and higher salinity regions have become increasingly unreliable for oyster production.

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 and 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 2002 Annual Fall Dredge Survey was 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 Sarbanes Cooperative Oxford Laboratory (SCOL). A total of 375 samples were obtained to examine 269 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 (2002).

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 recorded from each sample appears in Table 1.

In past years, representative subsamples of 30 oysters, $40mm in shell height, were taken at each of the 43 Disease Bar sites. During 2001, results were obtained for only 42 sites because an adequate sample of oysters could not be caught at Flag Pond. Additional disease status samples were collected from seed production areas, seed planting areas, and areas of special interest. All oysters were transported to SCOL 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. 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 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.

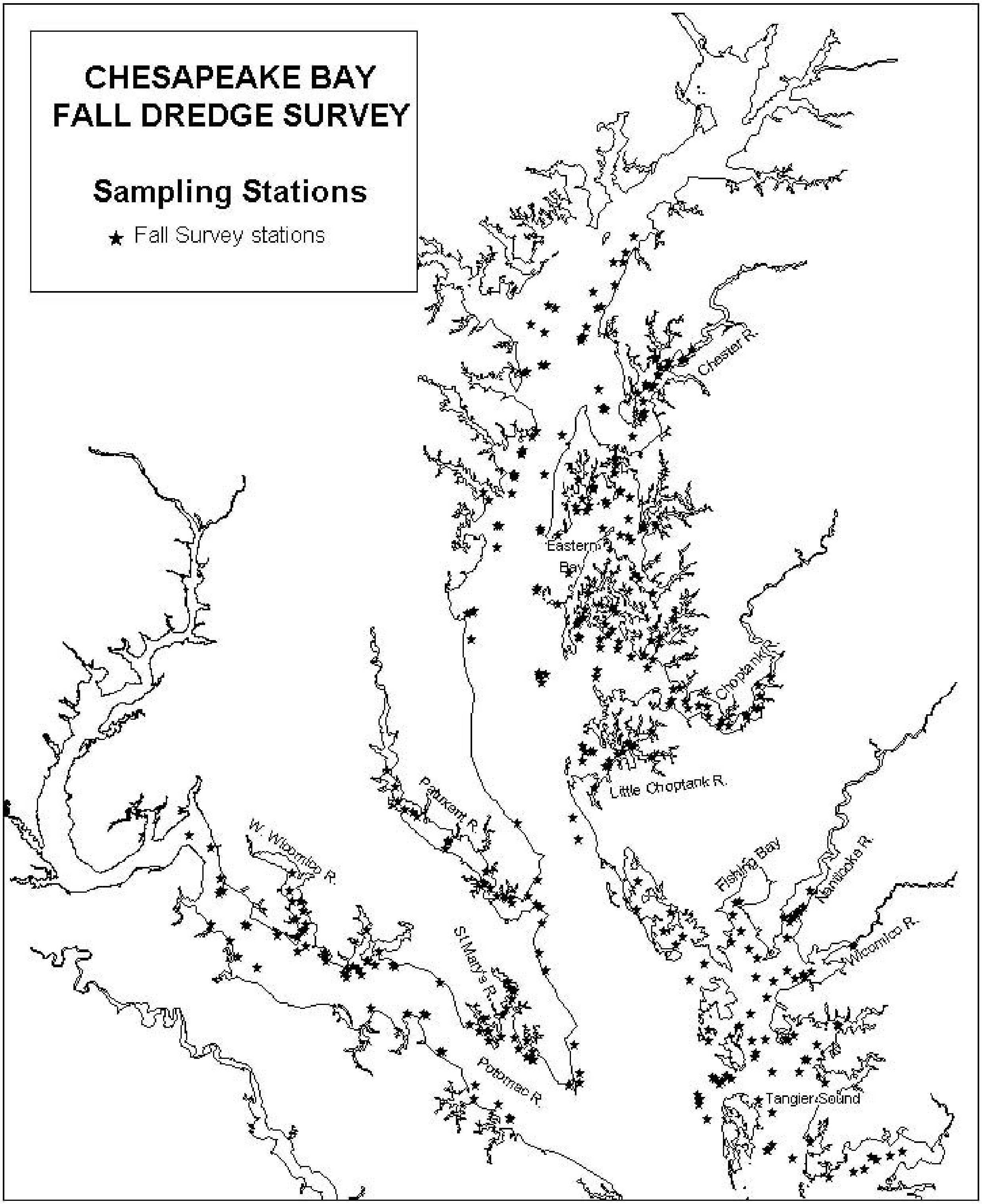

Figure 1a. Annual Maryland Fall Survey station locations, all bar types (standard, Key, Disease) included.

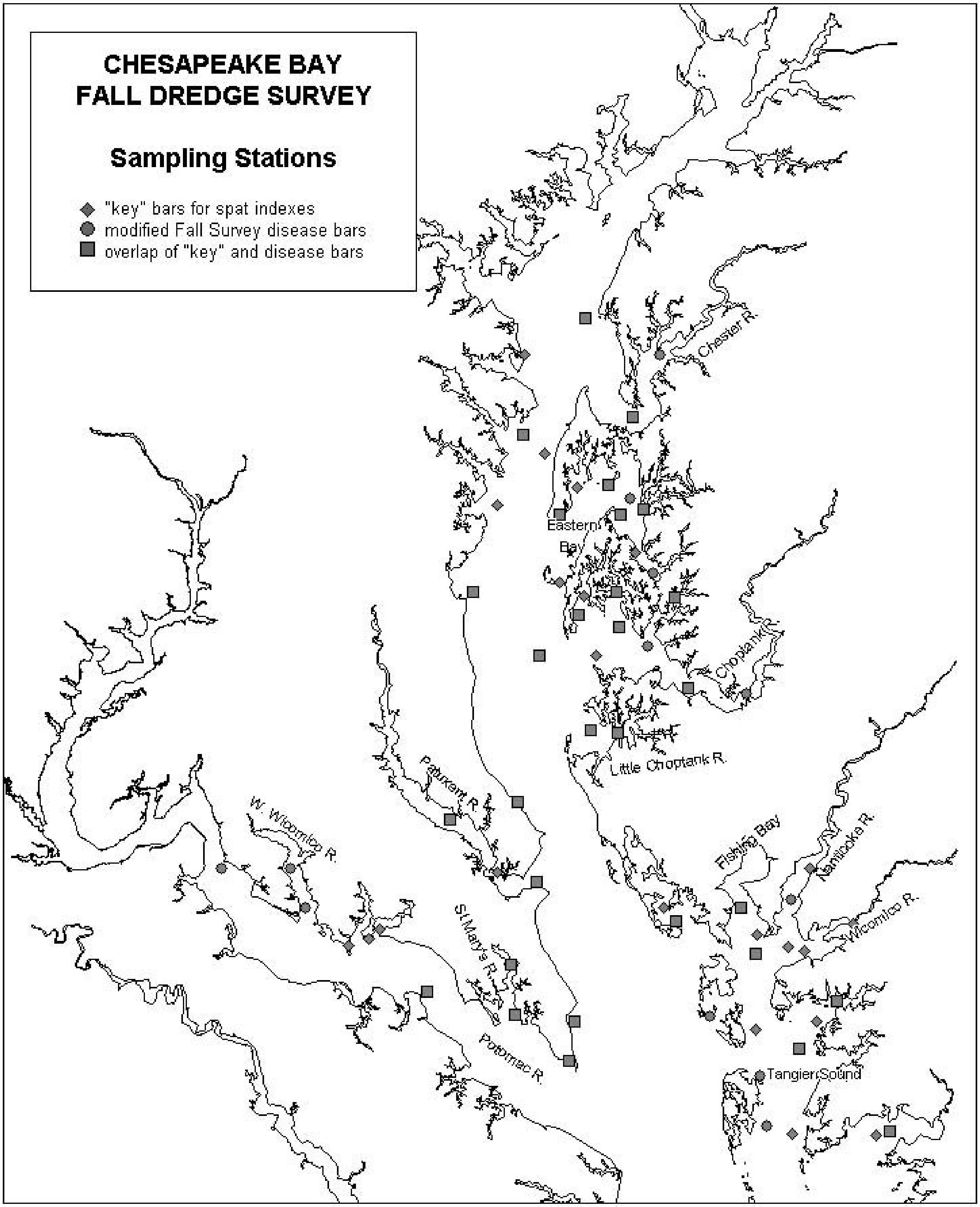

Figure 1b. Annual Maryland Fall Survey station locations for Key and Disease bars.

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, as 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 affects salinity, which is a key factor in oyster spatfall, disease, and mortality. During 2002, freshwater flow into the Maryland portion of Chesapeake Bay, including the Potomac River, was about 80% of the 50-year monthly mean (Sec. "C" in Bue 1968; USGS 2002) (Fig. 2). The drought situation was actually much more acute than the final figure indicates, with summer flows averaging less than 50% of the 65-year average (USGS 2002). This marks the fourth consecutive year and eight out of the past 12 years that flows were below average.

Over the 14-year period prior to this four year sustained drought, low flow years had alternated with high flow years on an annual or at most bi-annual basis. Going back to 1985, significant freshets occurred in 1990, 1993, 1994, 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 which persisted over the entire year (USGS 1993, 1994, 1996, 1998).

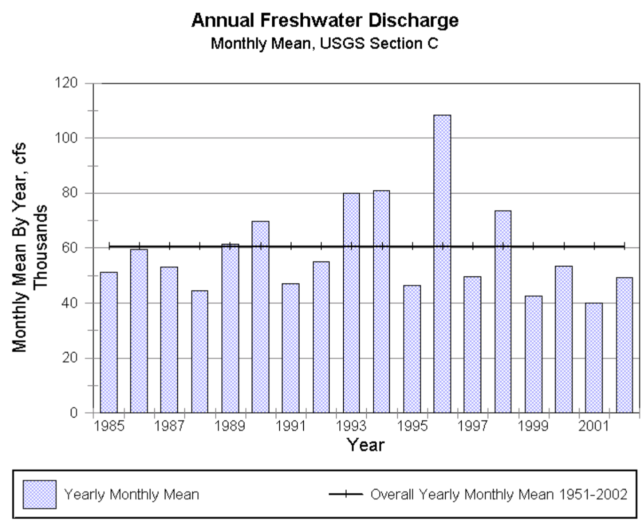

Figure 2. Mean monthly freshwater flow into Chesapeake Bay. Section C: all Md. tributaries and the Potomac River.

Moderate to severe low freshwater flows into the Chesapeake Bay resulted in elevated salinities during 1997, 1999, 2000, 2001 and 2002. Since 1985, low flows were particularly severe (#80% of the 50 year average) in 1988, 1991, 1995, 1997, 1999 and 2001.

Spatfall Intensity

The Maryland oyster spatfall distribution for 2002, as number of spat per bushel of shell, is mapped in Figure 3. Spatfall was highest in Tangier Sound and the adjacent southeastern mainstem of Chesapeake Bay, along with the St. Mary's River, with spat counts in the hundreds per bushel. Although densities were low, spat were also found on most of the bars examined in the above the Bay Bridge, a region which does not usually receive a set because the salinity regime is normally too low for successful reproduction and recruitment. The Kent Island shore also enjoyed a higher than usual spatfall.

Equally noteworthy was the generally poor spatfall in the central part of the bay and tributaries, including the Choptank, Little Choptank, and Patuxent Rivers, as well as Eastern Bay. In contrast, the Little Choptank River was once a source of seed for planting elsewhere, and Eastern Bay experienced one of the heaviest spat sets on record in 1997. The Potomac River also had very little spat set.

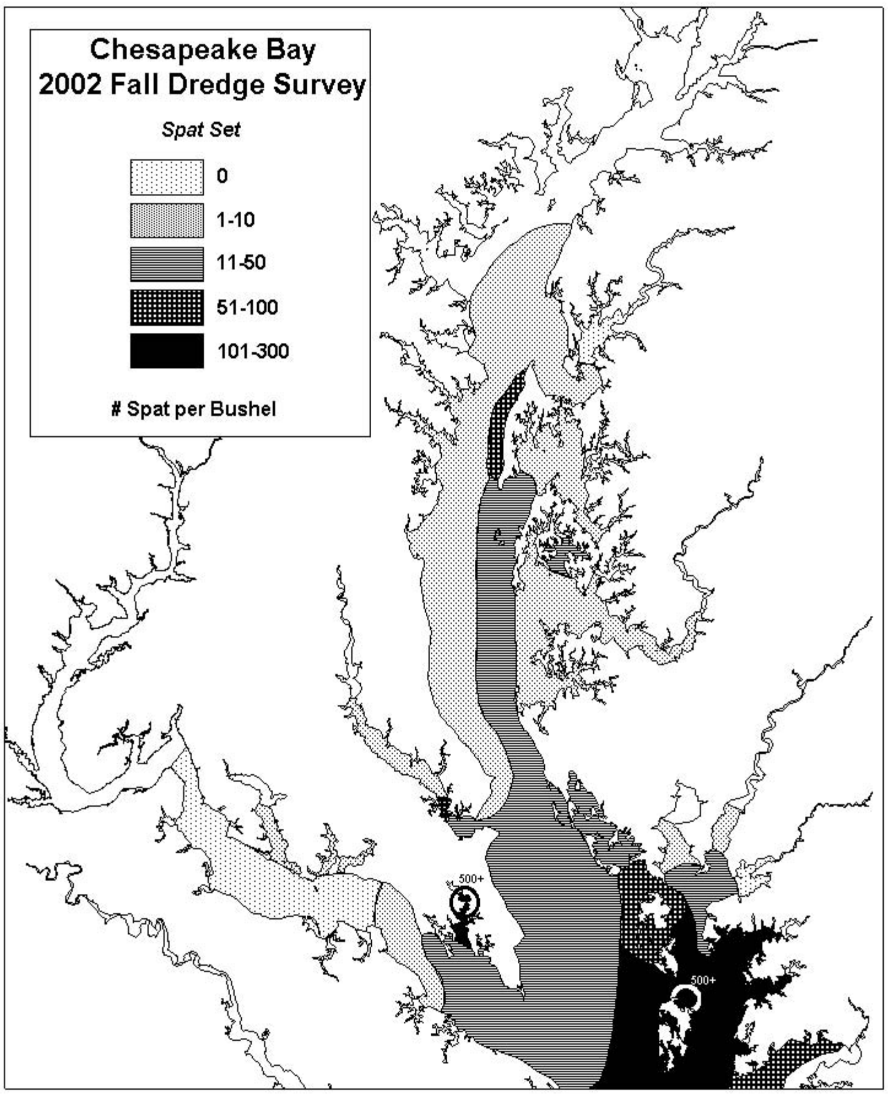

Figure 3. Spatfall intensity ranges, 2002. Areas with over 500 spat/bu. include the upper St. Mary's River and Tangier Sound adjacent to Smith Island.

The 2002 spatfall intensity index from the Key Bar set is compared with previous years through 1985 in Table 2. The overall spatfall intensity for 2002 was 40.3, a 2½ -fold improvement over the previous year but below the 18-year average of 54.7. Figure 4 charts the spatfall intensity index from 1985 through 2002, along with the 18-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. Despite the below average spatfall, 2002 fell into the middle tier of spatfall rankings.

The period from 1985-2002 (Figure 4; Table 2) included some of the

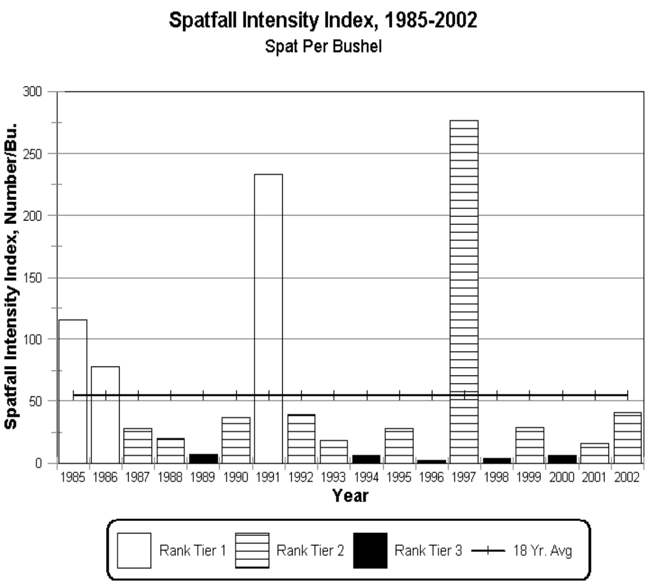

Figure 4. Spatfall intensity (spat per bushel of cultch) on Maryland "Key Bars" for spat monitoring.

lowest spatfall intensity indices (1989, 1994,
1996, 1998 and 2000) and two of the highest (1991 and 1997) over the 62- year history of the Annual Fall Survey (Krantz 1996). Spatfall intensity indices from 1996-2002 included the lowest on record (1996) and the second highest (1997).

The spatfall intensity index is an arithmetic mean which does not take into account 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. In 2002, eight of the 53 Key Bars totaled 75% of the index; however, the number of bars receiving a light set were more evenly distributed so that it took 19 bars to reach 95% of the total.

Oyster Parasites

Perkinsus marinus, the oyster parasite that causes dermo disease, was present in oyster populations from all 42 Disease Bars sampled in 2002, continuing and intensifying an epizootic that began in 1999. In addition, dermo disease was found in oyster populations from all 11 other bars sampled during the same time period. These results demonstrate that dermo disease occurs throughout Maryland's oyster grounds

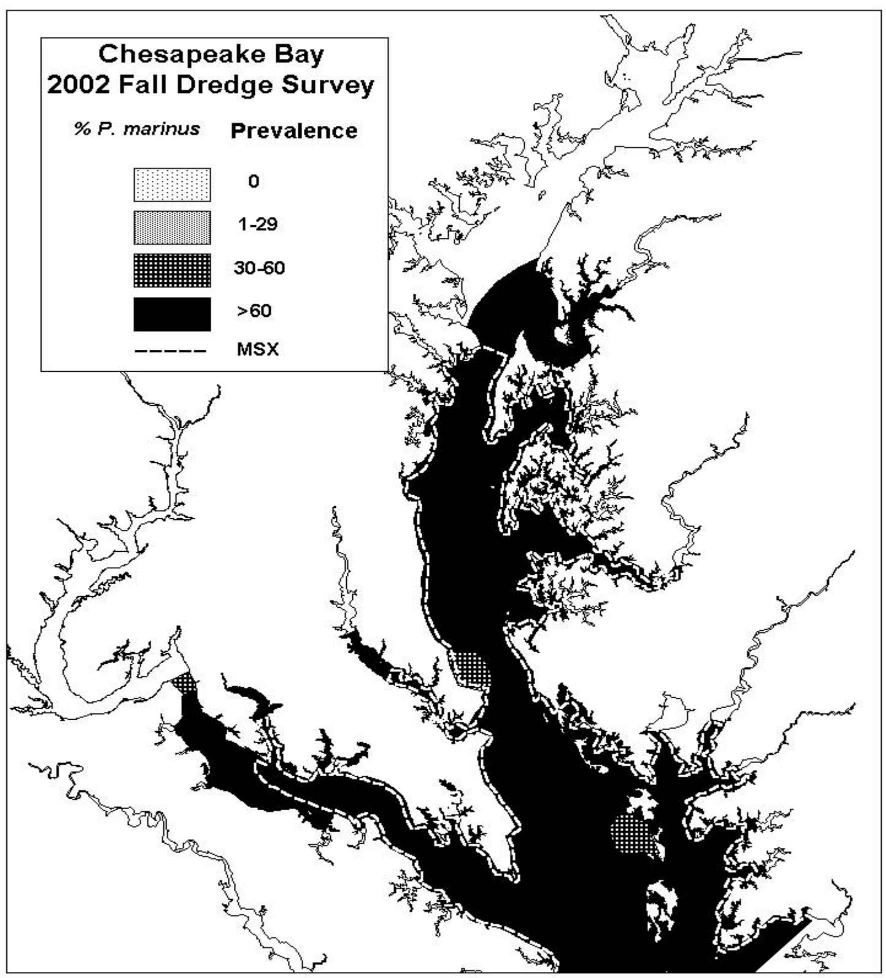

Figure 5. Geographic extent of oyster diseases, 2002.

(Figure 5). Furthermore, 94% of the tested oysters were infected with *P. marinus*, the highest prevalence recorded during the past 13 years (Figure 6). Only three Disease Bars had prevalences below 80%, while 38 Disease Bar populations had sample prevalences greater than or equal to 90% (Table 3). Even lower salinity bars such as Swan Point in the Upper Bay and Lower Cedar Point in the Potomac River had prevalences of 90% or greater. Statistical results rank 2002 in the top tier (grouping) for *P. marinus* prevalence since 1990 (Figure 6).

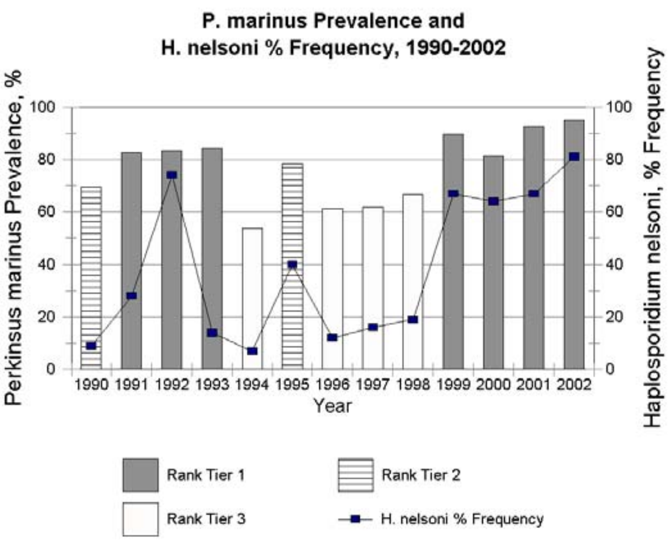

Figure 6. Statistical ranking and 13-year mean of *P. marinus* prevalence, and percent frequency of Disease Bars with *H. nelsoni* infected oysters.

Significantly, *P. marinus* was found in areas previously thought to be disease-free. Beacon, one of the most upriver bars in the Potomac River (above the Rt. 301 bridge), was always considered to have a naive population of oysters, that is, oysters that had never been exposed to disease, due to the low salinity and isolated location of the bar. In 2002, 43% of the oysters sampled from this bar were infected with *P. marinus*, despite the fact that the environment of Beacon normally is not conducive to dermo disease and the bar is remote from infective sources.

The infection levels of *P. marinus* remained high in 2002. The annual mean intensity of infection was 3.2 on a scale of 0-7,

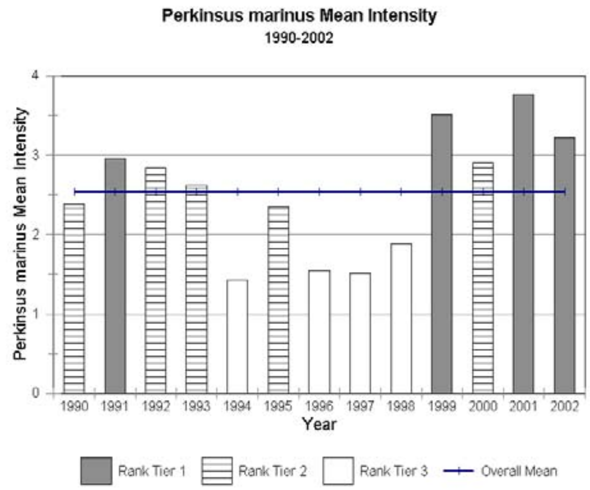

Figure 7a. Annual mean *P. marinus* infection intensity on a scale of 0-7 in oysters from Maryland disease monitoring bars. Overall mean is for the years 1990 to 2002.

which was a slight decline from the 2001 mean intensity of 3.8. This difference was not statistically significant, with 2002 the third highest year for *P. marinus* annual mean intensity since 1990, ranking it in the top statistical tier (Figure 7a). Lethal infection intensities ($5) were detected in 26 % of all sampled oysters and seven of 42 samples (17%) had lethal infection prevalences of 50% or more.

The period from 1996 to 2002 exhibited increases in both the overall level of infection intensity (Figure 7a) and the frequency of sample mean intensity levels of 3.0 or greater (Figure 7b). While about 40% to 50% of the Chesapeake Bay oyster bars (as represented by the Disease Bar set) from 1991-1993 had mean

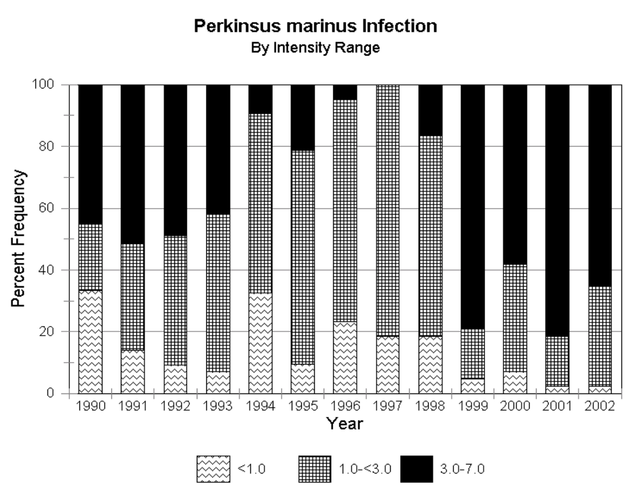

Figure 7b. *P. marinus* infection intensity ranges, percent frequency by year and range.

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.

Haplosporidium nelsoni, commonly referred to as MSX, is another potentially devastating oyster parasite. This parasite can cause rapid mortality in oysters and generally kills a wider range of oyster year classes, including younger oysters than does *P. marinus*.

Haplosporidium nelsoni continued to expand its range in Maryland during 2002, occurring as far up-bay as the Bay Bridge and Chester River, and up the Potomac River into the Wicomico River. The parasite was found in oysters from 38 of 42 Disease Bars (90%), a substantial increase from 2001 when 28 of 42 Disease Bars (67%) were infected (Table 4). In contrast, between 1996 and 1998 *H. nelsoni* was found in oysters from only eight or fewer (#19%) of the 43 Disease Bar set (Figure 8). Looking at it from the opposite perspective, only four 2002 Disease Bar samples, all from the lowest salinity regime, were MSX disease-free compared to 14 uninfected samples during 2001. For the first time on record, *H. nelsoni* was detected in oysters from Lancaster Bar in the western shore Wicomico River and Long Point Bar in the Miles River. In addition, the parasite returned to Hackett Point Bar in the Upper Bay, along with Sandy Hill and Oyster Shell Point Bars in the Choptank River, the farthest upstream incursions of the disease since 1992.

Also noteworthy was the discovery of *H. nelsoni* in the Chester River, a region where the disease rarely occurs. Examination of a sample collected from Blunt, an oyster reserve bar, revealed that the parasite has extended its range into this tributary as well. Although the Chester River has generally been considered to lie outside the range of *H. nelsoni*, a sample collected at Buoy Rock during the 1987 Fall Survey was positive for MSX at 10% prevalence. Furthermore, samples collected from Love Point at the mouth of the Chester River, well above the Bay Bridge, have tested positive for MSX in the past. *Haplosporidium nelsoni*

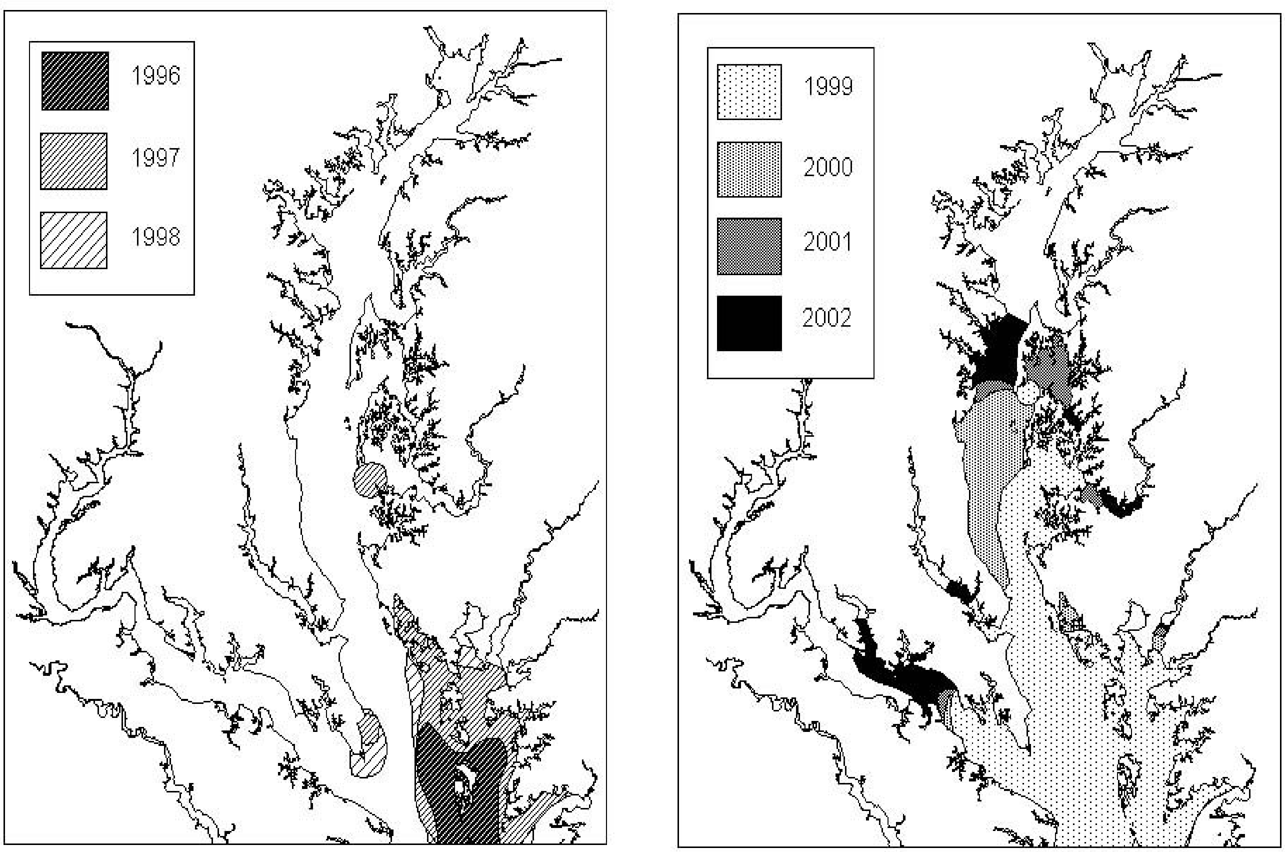

Figure 8. Expansion of the MSX geographical range in Maryland waters between 1996 and 2002.

was detected at this bar in 1975 and 1987 at 3% and 20% prevalence, respectively.

The 2002 prevalence of *H. nelsoni* among all tested oysters averaged 28%, more than double the 13% prevalence in 2001. There were 2.4 times as many sites with increased sample prevalences in 2002, with 29 samples showing higher prevalences than during 2001, while only 12 samples remained the same or decreased. Moreover, the 2002 increases in *H. nelsoni* prevalence were generally much larger in magnitude than were decreases. Among Disease Bars with infected populations, 16 (42%) had prevalences of 33% or greater and nine had prevalences exceeding 50%. In contrast, during 2001 only seven of the 28 affected Disease Bar samples (25%) had prevalences over 33% and none (0%) exceeded 50% (Table 4).

The current epizootic is the most severe on record. Both the 2002 frequency of occurrence (88%) and mean annual prevalence (28%) of *H. nelsoni* represent record high levels in Maryland, demonstrating a continuing and increasing epizootic that began in 1999. Since 1990, there have been three *H. nelsoni* epizootics: 1991-1992, 1995, and 1999-2002. The previous maximum frequency of occurrence was 74% and maximum mean annual prevalence was 26%, both in 1992. Both of the earlier recent epizootics were followed closely by periods of unusually high freshwater input into parts of the Chesapeake Bay, in 1993 and in 1996. These freshet events were largely responsible for the dramatic contraction of the geographic distribution of *H. nelsoni* in 1993 and in 1996 (Table 4). Streamflows from November 2002 through March 2003 have been higher than average.

<u>Oyster Mortality</u>

The 58% annual fishery-independent mortality estimated during 2002 is the highest ever measured for the Maryland Disease Bar oyster populations. This compares with the 18-year average of 30%, or more dramatically with the pre-enzootic (prior to the mid-1980's) background mortality levels of 10% or less. The highest 2002 Disease Bar observed mortality was 100% on Cooks Point bar in the Choptank River (Table 5).

The range of observed mortality levels exceeding 50% expanded from the Potomac and Patuxent Rivers in 2001 to also include most of

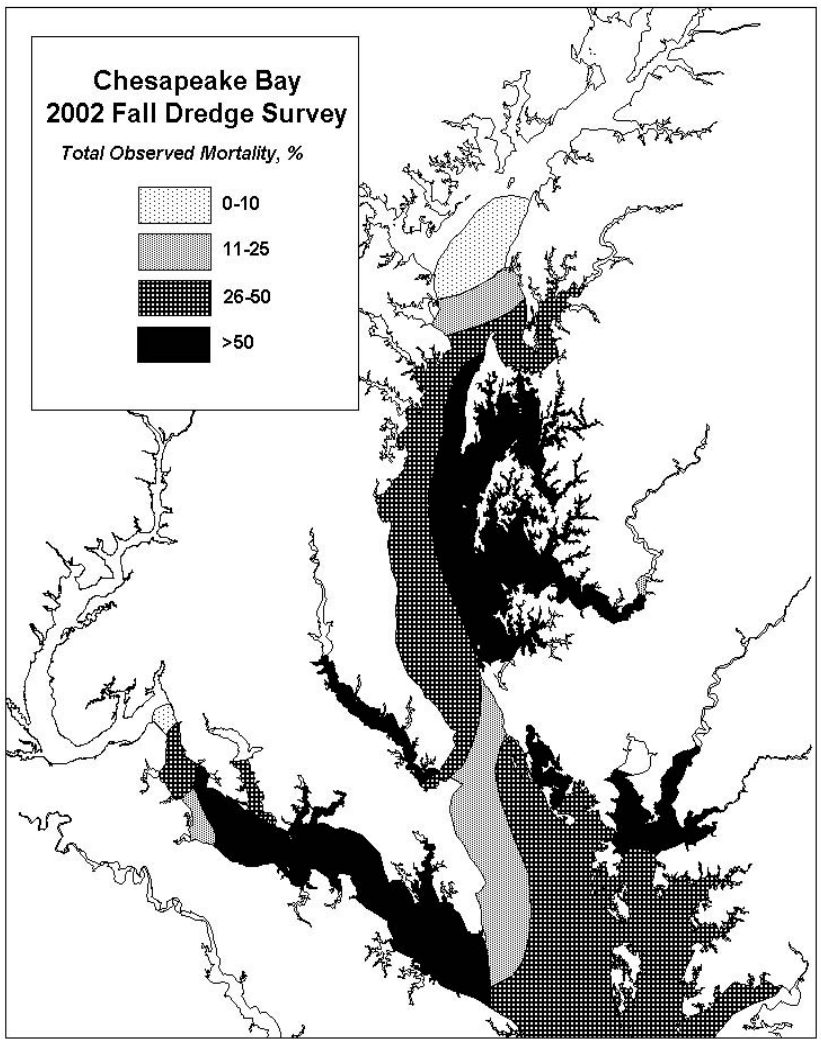

Figure 9. Total observed oyster mortality, 2002.

the Eastern Shore tributaries including Eastern Bay, the Choptank, Little Choptank, Honga, Nanticoke, and Wicomico Rivers, and Fishing Bay, as well as the eastern mainstem from the Kent Island shore to Taylors Island (Figure 9). The Little Choptank River was particularly devastated, with an average observed mortality of 93% on all examined bars and very little spat set to replace the oysters that had died. The Potomac River tributaries of St. Clements and Breton Bays, Smith Creek, and St. Mary's River also experienced heavy mortalities of up to 80%.

Since 1997 there has been a steady increase in observed mortality (Figure 10). In addition, the number of sites with total observed mortality of 30% or greater increased substantially between 1996 and 2002 (Table 5). From 1996 through 1998, only between eight to eleven of the 43 Disease Bars exhibited total observed mortality of 30% or more. In 1999 and 2000, respectively, 21 and 24 of the Disease Bar sites (out of 42 in 2000) had mortalities of 30% or greater, increasing to 34 bars in 2001 (Table 5). In 2002, 30% or greater total observed mortality was measured on 35 (84%) of the Disease Bars, and 50% or greater total observed mortality was measured on 28 (63%). In comparison, during 2001, another high mortality year, only 13 (30%) of samples showed mortalities greater than or equal to 50%. The recent jump in mortalities is strongly associated with increases in MSX prevalence since 2001, including the return of MSX to bars where it had long been absent (Figure 11).

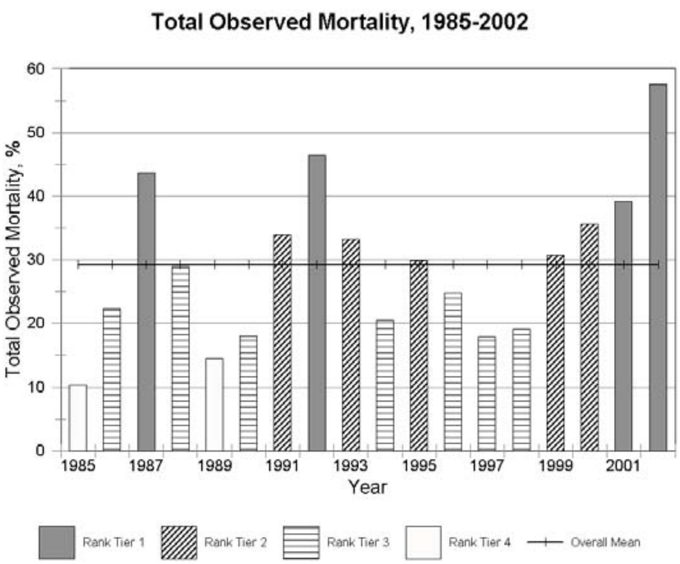

Figure 10. Mean annual total observed mortality, small and market oysters combined. Overall mean is for the period 1985 through 2002.

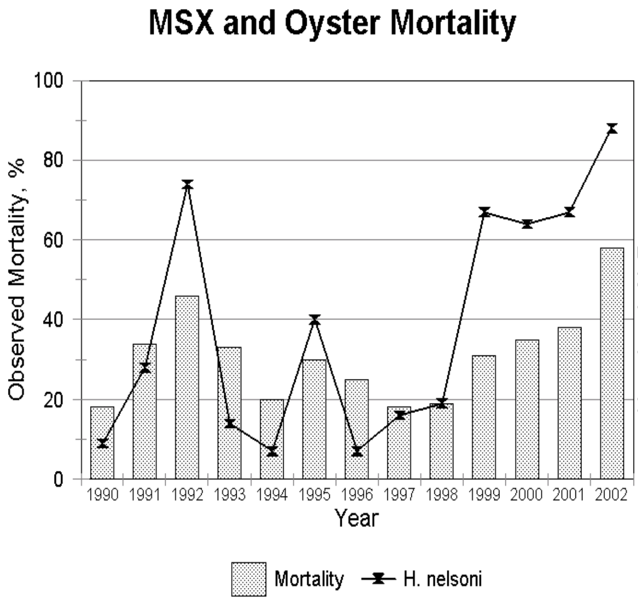

Figure 11. Changes in oyster mortalities and *H. nelsoni* prevalence from 1990 through 2002.

Annual total mortality averages and rank tiers are shown for 1985-2002 in Figure 10. Friedman's Two-way Rank Sum test results indicated four statistically related tiers (bar groupings) of observed mortality. This marks the second consecutive year that mortalities were ranked in the highest statistical grouping.

Commercial Harvest

The 2001-02 harvest of 148,000 bushels represents a 57% decline from the previous year (Figure 12). This marks the third consecutive year of harvest declines, reversing a half decade trend of increasing catches. Since the most recent peak of 423,000 bushels in 1998-99, harvests have plummeted by 65%, resulting in the third lowest oyster landings in over a century.

The 2001-02 harvesting activity was focused in a few discrete areas, with five regions

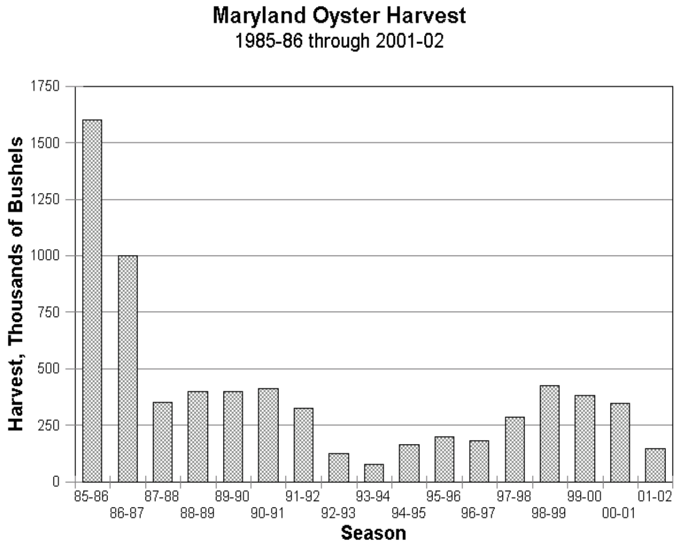

Figure 12. Maryland oyster landings in thousands of bushels.

accounting for 90% of the harvest (Table 6). Although Eastern Bay and its tributaries was still the leading harvest region, its share of the landings dropped sharply from 44% to 28%, reflecting the depletion of the previously dominant 1997 year class to disease and harvesting. Landings in this region dropped 72% (110,000 bushels) from the previous year. The Chester River landings actually increased modestly, ranking this region second. The Choptank River and its tributaries experienced a significant decline, especially in Broad and Harris Creeks, although the region still accounted for 16% of the total landings. While still low in general, Tangier Sound enjoyed a nearly ten-fold increase in harvests from the previous year. About 11% of the harvest came from the Upper Bay bars, ranking this region fifth in landings. The region of sharpest percent decline was the Little Choptank River, where landings plummeted by 91% from those of 2001, and a staggering 97% since the 1998-99 season, when it was the highest producing tributary in Maryland, contributing 20% of the total harvest.

Regional harvest summaries from the 1985-86 season through the 1999-2001 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. The middle to higher salinity areas have become increasingly less reliable for commercial oyster production.

DISCUSSION

Influence of Freshwater Discharge

It is clear that oyster mortality since the late 1980s has been strongly influenced by levels of freshwater discharge into the Chesapeake Bay, with freshets directly killing oysters and drought resulting in higher disease levels. Since oysters situated in 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 from the 1993, 1994, 1996, and 1998 freshets (MDNR 2001).

While freshets are short-term catastrophic events, the establishment of the oyster parasites in Chesapeake Bay has had severe long-term consequences on the oyster populations. Salinity is the enabling environmental factor for oyster diseases. *Perkinsus marinus* mean prevalence and infection intensity and *H. nelsoni* percent frequency of occurrence are inversely related to patterns of freshwater inflow. Given the enzootic and osmotically tolerant character of *P. marinus* (Dungan and Hamilton 1995), reduced freshwater discharges result in increasing infection prevalences, infection intensities, and mortalities. Even average discharges apparently cannot ameliorate the distribution and effects of *P. marinus* infection. In contrast, *H. nelsoni* is 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 produces a severe spike in mortality (Smith and Jordan 1993).

The Entrenchment of 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 *P. marinus* impact 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 protozoan 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 mortality levels. 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 some areas suffering over 80% total observed mortality.

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 past 4 years of drought this pattern has collapsed, and now Disease Bars in low-salinity areas exhibit dermo disease prevalences of 90% or more.

As an extreme example of disease taking hold in a low-salinity population, the occurrence of *P. marinus* on Beacon Bar in the Potomac River has profound implications for management and research. It demonstrates that remote oyster bars in low-salinity areas can be infected with dermo despite the miles-wide absence of repletion activity that may transplant infected seed oysters. That is, even bars far upstream can be infected through natural processes. It also suggests there is no refuge from dermo disease for oysters in most of Maryland waters. With the establishment of dermo disease in 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 is more devastating than the disease (freshets), and a very low rate of recruitment. The resulting limitations on management are obvious.

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 current *H. nelsoni* epizootic, the most severe on record, is strongly 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 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*. Recent conditions (through June 2003) of above-average streamflow (USGS 2003) may forecast similar results for 2003, if freshwater inflows remain high.

Spatfall

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. The impact of salinity was most evident in the Upper Bay, which received its first significant spat set since 1991. Despite the low counts, low disease pressure in this area should allow for good survivorship. 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. This pattern has been reflected in declining commercial fishery yields during this period, and in substantial changes and shifts in regional production.

Volatility in spatfall intensity has been, at least from 1939, a 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 (2^{nd} 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 (3^{rd} 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.

Mortality

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 the lower salinity areas. Since the 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 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. The combined effects of both parasites during a four-year drought has resulted in dramatically high oyster mortalities during 2002.

The Eastern oyster in the Maryland Chesapeake Bay has demonstrated modest levels of recruitment as compared to other regions along the East Coast of the United States. The hallmark of the Maryland population historically has been a high degree of survivorship 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

With the entrenchment of oyster diseases in the mid-1980's, annual 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 the 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 this effort, harvests have dropped for three successive years in the face of the recent inroads made by the two oyster diseases.

The impact of disease on the commercial fishery has not only been restricted to a severe decline in product availability, but also in product quality. Once prized throughout the East Coast, the Chesapeake Bay oyster is now marketable primarily because of memory. Anecdotally, Maryland oysters used to shuck 8-10 pints of meat from a bushel of shell stock, but in recent years shucking rates have declined to less than 4.5 pints to the bushel. This remarkable decrease may reflect the severity of disease effects on the ability of the oyster to physiologically function properly.

The continued onslaught of dermo disease and MSX epizootics have 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 a 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 could occur in the future is unlikely.

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

-Latitude and longitude

-Type of sample and date of action, ie. 1997 seed, natural, 1990 fresh shell planting, etc.

-Bottom type and depth

-Number and average and range of shell heights of live and dead spat, smalls, and markets

-Shell heights of oysters grouped into 5 mm intervals (Disease Bar sites 1990-2000)

-Stage of oyster boxes

-Relative volume of live and dead oysters

-Condition index and meat quality of live oysters

-Type and relative extent of fouling

-Relative volume of fouling organisms

-Temperature and salinity

Table 2. Spatfall intensity (spat per bushel of cultch) from the 53 "Key" spat monitoring bars, 1985-2002.

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

Table 2 (Continued).

Oyster Bar	Spatfall Intensity, Number Per Bushel								
	1994	1995	1996	1997	1998	1999	2000	2001	2002
Mountain Point	0	0	0	1	0	0	0	0	1
Swan Point	0	1	0	0	0	0	0	0	0
Brickhouse	0	5	0	0	0	1	1	3	97
Hacketts Point	0	0	0	0	0	0	1	0	13
Tolly Point	0	0	0	0	0	2	2	1	0
Three Sisters	0	1	0	0	0	0	0	1	0
Holland Point	0	1	0	0	0	0	0	1	4
Stone Rock	4	29	0	18	0	3	34	2	17
Flag Pond	0	10	0	7	0	1	5	5	7
Hog Island	0	24	0	5	2	6	1	28	10
Butlers	1	7	1	8	0	6	1	27	33
Buoy Rock	0	6	0	8	0	0	0	2	1
Parsons Island	0	57	0	3,375	3	6	6	6	5
Wild Ground	0	68	0	990	0	2	5	5	6
Hollicutts Noose	0	7	0	56	0	6	2	1	15
Bruffs Island	1	15	0	741	4	5	9	6	0
Ash Craft	0	60	1	2,248	0	14	2	10	0
Turtleback	0	194	0	3,368	5	13	4	45	9
Shell Hill	0	15	0	19	1	4	4	0	0
Sandy Hill	0	4	0	55	0	4	0	1	1
Royston	0	14	0	289	0	39	0	3	10
Cooks Point	2	16	0	20	0	1	5	5	3
Eagle Point	0	67	0	168	2	16	0	5	4
Tilghman Wharf	4	64	0	472	0	49	1	1	4
Deep Neck	12	294	3	788	1	211	3	11	31
Double Mills	0	15	0	40	0	1	0	0	0
Ragged Point	3	16	0	106	0	43	3	5	0
Cason	28	48	5	228	4	53	5	2	9
Windmill	19	13	2	5	1	37	0	21	9
Normans Addition	17	25	0	8	0	31	1	30	33
Goose Creek	27	3	0	5	0	0	0	0	1
Clay Island	31	11	1	20	2	5	4	8	16
Wetipquin	4	1	0	0	10	0	0	0	3
Middleground	28	2	6	27	0	9	1	0	24
Evans	30	2	1	5	0	1	0	0	12
Mt. Vernon Wharf	0	3	0	0	1	0	0	0	0
Georges	9	16	0	8	6	50	6	1	280
Drum Point	13	14	10	16	11	157	27	44	124
Sharkfin Shoal	11	6	0	7	0	9	5	0	57
Turtle Egg	31	7	35	70	3	180	33	33	207
Piney Island East	25	23	25	45	16	118	28	167	127
Great Rock	11	3	7	0	1	82	6	140	1
Gunby	7	35	9	0	24	54	32	6	108
Marumsco	5	6	0	0	57	27	27	4	89
Broomes Island	0	58	0	0	1	7	0	1	15
Back of Island	1	17	0	3	0	22	9	44	27
Chicken Cock	4	78	2	36	10	132	16	12	151
Pagan	7	54	0	1,390	6	95	42	117	535
Black Walnut	0	1	0	2	0	3	0	1	2
Blue Sow	0	5	0	0	0	11	0	2	4
Dukehart	0	0	0	0	0	1	0	0	1
Ragged Point	0	20	0	2	0	1	1	0	1
Cornfield Harbor	0	49	0	4	11	25	5	35	31
Spat Index	**6.3**	**28.1**	**2.0**	**276.7**	**3.5**	**29.1**	**6.4**	**15.9**	**40.5**

Table 3. *Perkinsus marinus* prevalence and intensity (scale of 0-7) in oysters from the 43 disease monitoring bars, 1990-2001. ND indicates insufficient quantity of oysters for analytical sample.

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

Table 3 (Continued).

Bar	*Perkinsus marinus* Prevalence (%) and Intensity (I)							
	1994		1995		1996		1997	
	%	I	%	I	%	I	%	I
Swan Point	3	0.1	20	0.2	0	0.0	3	0.1
Hacketts Point	23	0.5	90	2.5	30	0.7	43	1.3
Holland Point	36	1.1	87	2.9	47	1.4	37	1.1
Stone Rock	90	2.5	87	2.2	93	2.7	90	2.3
Flag Pond	30	0.8	87	3.3	63	2.0	53	1.2
Hog Island	37	1.0	93	2.7	43	1.2	47	1.3
Butlers	80	2.1	87	2.5	60	1.6	57	1.0
Buoy Rock	10	0.3	67	1.7	13	0.4	7	0.7
Oldfield	20	0.6	83	2.3	0	0.0	10	0.2
Bugby	43	0.8	83	2.6	80	2.0	70	1.8
Parsons Island	93	3.1	70	2.1	73	2.8	63	1.4
Hollicutts Noose	70	1.7	90	2.8	60	1.4	50	1.0
Bruffs Island	63	1.3	73	2.1	67	1.4	17	0.2
Turtleback	60	1.2	100	2.8	83	2.1	83	1.8
Long Point	60	2.0	67	2.2	20	0.4	23	0.6
Cooks Point	90	3.0	ND	---	60	1.5	70	2.4
Royston	80	2.0	63	2.0	50	1.1	67	1.5
Lighthouse	47	1.2	90	3.3	77	1.8	57	1.5
Sandy Hill	83	2.3	89	3.4	30	0.7	60	1.3
Oyster Shell Pt	10	0.3	68	1.8	13	0.2	50	0.9
Tilghman Wharf	63	1.9	93	2.5	67	1.3	60	1.0
Deep Neck	67	2.3	97	3.0	83	2.1	100	2.6
Double Mills	90	2.0	75	2.5	70	1.2	83	2.0
Cason	83	2.2	93	2.3	87	1.9	93	2.4
Ragged Point	87	2.3	93	2.5	97	2.6	97	2.1
Normans Add.	93	3.3	87	2.8	93	2.4	73	1.6
Goose Creek	53	1.1	87	2.5	97	4.0	83	2.0
Wilson Shoals	40	0.9	63	1.1	83	1.8	80	1.9
Georges	50	1.2	87	2.8	93	2.0	93	2.2
Holland Straits	57	1.6	93	3.1	83	2.0	67	1.8
Sharkfin Shoal	63	1.4	90	3.0	97	2.1	93	2.6
Back Cove	80	2.2	83	3.0	97	3.2	93	2.9
Piney Isl East	87	3.1	93	2.5	63	1.7	73	2.2
Old Woman's Leg	73	2.1	100	4.2	80	2.3	57	1.3
Marumsco	72	1.6	100	4.2	90	2.4	61	2.1
Broomes Island	40	0.6	43	1.0	17	0.4	83	2.1
Chicken Cock	40	1.0	83	1.9	77	1.4	73	1.7
Pagan	10	0.3	93	2.2	82	1.4	86	1.7
Lancaster	20	0.2	27	0.6	56	1.2	80	1.6
Mills West	20	0.2	57	1.4	60	1.2	60	1.2
Cornfield Harbor	77	1.9	93	2.5	87	2.0	83	1.8
Ragged Point	10	0.2	33	0.8	7	0.2	0	0.0
Lower Cedar Pt.	7	0.1	13	0.2	3	0.3	0	0.0
***P. marinus* Indices**	**54**	**1.4**	**78**	**2.3**	**61**	**1.5**	**62**	**1.5**

Table 3 (Continued).

Bar	*Perkinsus marinus* Prevalence (%) and Intensity (I)									
	1998		1999		2000		2001		2002	
	%	I	%	I	%	I	%	I	%	I
Swan Point	43	1.2	97	3.4	80	1.2	93	3.3	97	2.7
Hacketts Point	43	1.1	97	3.3	97	3.7	97	3.4	100	3.3
Holland Point	37	0.9	93	2.8	87	3.4	93	3.2	100	3.6
Stone Rock	100	3.5	100	4.0	93	3.6	83	2.8	100	2.3
Flag Pond	73	2.3	NA	NA	NA	NA	NA	NA	37	0.5
Hog Island	97	3.2	93	5.5	83	3.9	93	3.4	87	2.9
Butlers	97	3.3	93	3.2	83	2.7	80	2.4	80	1.4
Buoy Rock	33	0.9	93	3.0	97	3.5	93	3.5	100	2.6
Oldfield	33	0.8	97	3.0	93	3.0	100	3.3	97	2.5
Bugby	60	1.4	100	3.9	100	4.0	100	4.6	97	3.1
Parsons Island	80	2.5	100	4.7	100	3.5	100	4.5	100	4.4
Hollicutts Noose	83	2.5	90	3.0	100	4.1	100	4.8	100	3.6
Bruffs Island	57	1.6	100	3.7	97	3.2	100	3.8	100	3.6
Turtleback	50	1.6	100	4.3	97	3.1	100	4.2	100	4.7
Long Point	100	2.7	100	3.6	97	3.3	100	4.2	100	3.1
Cooks Point	87	2.8	93	3.4	40	1.2	77	2.2	NA	NA
Royston	90	2.5	97	3.5	97	4.7	100	5.2	100	4.2
Lighthouse	43	1.5	87	2.3	100	3.4	100	3.3	100	4.6
Sandy Hill	40	1.0	97	3.4	87	3.6	100	4.5	100	5.0
Oyster Shell Pt	20	0.3	83	2.3	73	2.2	100	3.6	100	3.0
Tilghman Wharf	67	2.0	87	2.5	93	3.4	100	3.5	90	3.2
Deep Neck	97	2.9	97	4.5	100	4.0	97	4.8	100	3.2
Double Mills	100	3.0	100	4.8	100	4.7	100	5.5	97	2.9
Cason	50	1.4	97	3.8	100	3.6	100	4.3	94	4.4
Ragged Point	87	1.4	100	4.0	97	3.7	100	4.3	100	3.5
Normans Add.	73	2.3	93	3.5	80	3.4	90	3.0	67	1.9
Goose Creek	100	3.0	100	5.4	97	3.1	100	4.1	93	4.0
Wilson Shoals	70	1.6	100	4.3	70	2.1	100	4.0	100	3.6
Georges	83	2.4	93	3.5	80	2.3	100	5.2	100	4.0
Holland Straits	57	1.2	80	2.5	30	0.9	43	1.4	50	1.1
Sharkfin Shoal	80	2.7	100	4.3	80	2.3	90	3.7	97	3.6
Back Cove	90	2.3	100	5.5	40	1.2	100	5.0	97	3.8
Piney Isl East	83	1.9	63	2.4	86	2.3	60	1.5	100	3.1
Old Woman's Leg	90	3.2	87	3.9	70	1.7	100	5.0	100	3.7
Marumsco	80	2.8	90	3.4	93	2.7	100	5.0	97	4.1
Broomes Island	83	3.0	100	4.6	93	4.0	100	4.8	97	3.8
Chicken Cock	80	1.7	100	5.0	63	1.8	93	3.6	100	2.9
Pagan	73	1.7	97	3.4	68	1.6	100	4.6	93	4.0
Lancaster	37	0.7	83	2.5	90	2.7	100	4.5	97	2.7
Mills West	20	0.4	90	3.2	97	3.6	100	4.8	93	3.1
Cornfield Harbor	83	2.0	97	3.9	80	2.1	80	2.9	97	1.7
Ragged Point	0	0.0	17	0.5	13	0.7	33	0.5	93	2.6
Lower Cedar Pt.	0	0.0	0	0.0	17	0.5	90	2.3	97	2.5
***P. marinus* Indices**	**67**	**1.9**	**90**	**3.5**	**81**	**2.9**	**93**	**3.8**	**94**	**3.2**

Table 4. Prevalence of *Haplosporidium nelsoni* in oysters from the 43 disease monitoring bars, 1990-2002.

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

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

Table 4 (Continued).

Bar	*Haplosporidium nelsoni* Prevalence (%)						
	1996	1997	1998	1999	2000	2001	2002
Swan Point	0	0	0	0	0	0	0
Hacketts Point	0	0	0	0	0	0	13
Holland Point	0	0	0	0	3	7	40
Stone Rock	0	0	0	30	47	40	30
Flag Pond	0	0	0	NA	NA	NA	20
Hog Island	0	0	0	60	27	27	20
Butlers	0	7	3	47	17	27	20
Buoy Rock	0	0	0	0	0	0	0
Oldfield	0	0	0	0	0	0	0
Bugby	0	0	0	0	0	0	27
Parsons Island	0	0	0	0	0	3	17
Hollicutts Noose	0	0	0	7	10	17	37
Bruffs Island	0	0	0	0	0	3	17
Turtleback	0	0	0	0	0	7	33
Long Point	0	0	0	0	0	0	3
Cooks Point	0	3	0	13	33	37	NA
Royston	0	0	0	3	7	0	60
Lighthouse	0	0	0	13	7	3	67
Sandy Hill	0	0	0	0	0	10	53
Oyster Shell Pt	0	0	0	0	0	0	7
Tilghman Wharf	0	0	0	3	27	7	60
Deep Neck	0	0	0	3	7	0	63
Double Mills	0	0	0	3	0	0	33
Cason	0	0	0	7	27	33	59
Ragged Point	0	0	0	20	47	40	30
Normans Add	0	0	3	63	37	37	20
Goose Creek	0	0	0	47	17	13	33
Wilson Shoals	0	0	0	4	10	10	27
Georges	0	0	0	40	20	13	30
Holland Straits	0	10	3	73	40	47	57
Sharkfin Shoal	0	0	20	53	37	20	27
Back Cove	3	3	10	33	37	10	7
Piney Isl East	7	13	17	43	53	40	17
Old Woman's Leg	20	4	23	53	30	13	13
Marumsco	0	11	7	37	30	17	30
Broomes Island	0	0	0	3	10	0	13
Chicken Cock	0	0	0	77	7	17	30
Pagan	0	0	0	3	13	10	40
Lancaster	0	0	0	0	0	0	10
Mills West	0	0	0	3	0	0	43
Cornfield Harbor	0	0	3	53	17	33	50
Ragged Pt. (Potomac)	0	0	0	13	10	7	60
Lower Cedar Pt.	0	0	0	0	0	0	0
Percent Frequency[2]	**7**	**16**	**19**	**67**	**64**	**67**	**88**

[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, 1985-2002.

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

Table 5 (Continued).

Bar	Total Observed Mortality, Percent								
	1994	1995	1996	1997	1998	1999	2000	2001	2002
Swan Point	35	18	43	20	3	7	13	12	14
Hacketts Point	30	30	16	10	26	22	13	30	60
Holland Point	42	35	49	36	36	8	33	42	67
Stone Rock	29	40	25	15	33	46	66	30	86
Flag Pond	28	24	16	13	33	50	ND	ND	23
Hog Island	16	45	20	16	33	67	67	14	31
Butlers	37	63	17	20	20	48	67	32	11
Buoy Rock	33	22	17	7	7	6	25	43	61
Oldfield	12	8	17	8	5	8	21	36	47
Bugby	18	18	27	15	8	5	29	48	63
Parsons Island	18	36	22	25	8	16	29	60	59
Hollicutts Noose	32	30	13	15	14	13	38	55	85
Bruffs Island	47	33	6	6	11	16	33	44	50
Turtleback	40	51	21	9	9	26	38	48	54
Long Point	8	28	8	3	9	14	33	34	66
Cooks Point	40	22	16	11	20	35	63	28	100
Royston	10	17	9	9	6	32	31	51	91
Lighthouse	27	18	15	5	6	20	33	44	92
Sandy Hill	36	29	23	22	4	15	27	50	77
Oyster Shell Point	14	18	25	6	2	1	15	28	55
Tilghman Wharf	6	10	9	15	6	12	19	34	85
Deep Neck	1	23	14	8	13	37	23	37	85
Double Mills	10	20	9	8	10	38	40	50	85
Cason	6	7	12	11	18	28	32	62	98
Ragged Point	17	16	12	13	19	34	37	70	94
Normans Addition	28	39	55	31	54	35	38	29	29
Goose Creek	7	38	69	64	20	64	63	81	85
Wilson Shoals	10	17	11	11	9	29	25	26	52
Georges	0	55	33	36	12	32	60	50	44
Holland Straits	16	45	43	20	18	35	35	17	12
Sharkfin Shoal	7	66	59	47	28	62	61	39	61
Back Cove	6	46	33	29	50	59	20	46	38
Piney Island East	20	65	56	49	67	38	27	12	20
Old Woman's Leg	25	63	46	33	38	42	15	53	27
Marumsco	8	78	53	49	26	40	22	35	45
Broomes Island	27	8	0	13	11	44	25	59	72
Chicken Cock	28	15	10	7	24	82	63	28	63
Pagan	11	9	27	15	3	14	35	51	84
Lancaster	4	19	25	8	8	18	48	58	52
Mills West	4	21	18	17	16	24	36	40	75
Cornfield Harbor	25	56	24	7	27	78	62	44	33
Ragged Point	35	8	11	4	25	10	8	33	ND
Lower Cedar Point	28	5	23	3	26	8	0	3	44
Mortality Index	**20**	**30**	**25**	**18**	**19**	**31**	**35**	**38**	**58**

Table 6. Regional summary of oyster harvests in Maryland, 1985-86 season through the 2001-02 season.

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	**1,500,000**	**1,000,000**	**360,000**	**390,000**	**413,000**

Table 6 (continued).

Region/Tributary	1990-	1991-	1992-	1993-	1994-	1995-
Upper Bay	19,800	35,200	18,200	8,900	7,800	26,600
Middle Bay	17,700	39,200	9,000	4,400	4,900	12,600
Lower Bay	37,900	9,300	90	0	1,100	800
Total Bay Mainstem	75,400	83,800	27,300	13,300	13,800	40,000
Chester River	60,400	55,100	53,800	51,300	29,100	42,600
Eastern Bay	33,200	20,600	3,600	2,400	3,700	1,500
Miles R.	1,700	100	300	0	200	200
Wye R.	2,300	300	20	30	50	0
Total Eastern Bay Region	37,200	21,000	3,900	2,700	4,000	1,700
Upper Choptank River	42,200	29,200	9,500	2,600	2,500	11,600
Middle Choptank R.	49,700	25,000	3,100	1,600	4,900	15,000
Lower Choptank R.	9,000	14,200	1,700	900	600	900
Tred Avon R.	22,000	800	0	0	5,900	1,300
Broad Creek	4,300	40	50	10	400	1,000
Harris Cr.	3,300	100	20	0	14,200	5,000
Total Choptank R. Region	130,500	69,300	14,400	5,100	28,500	34,800
Little Choptank River	8,800	3,800	50	300	19,300	1,900
Upper Tangier Sound	1,000	11,300	70	0	17,600	12,100
Lower Tangier S.	1,600	1,700	40	0	5,400	500
Honga River	5,600	600	20	100	1,700	400
Fishing Bay	900	6,400	500	30	11,900	20,900
Nanticoke R.	3,000	12,500	7,700	2,500	10,500	15,200
Wicomico R.	60	600	500	500	80	100
Manokin R.	60	200	40	10	100	0
Annemesex R.	0	10	0	0	0	0
Pocomoke S.	300	500	0	0	100	0
Total Tangier Sound Region	12,500	33,800	8,900	3,100	47,400	49,200
Patuxent River	48,400	24,500	0	0	30	100
Wicomico R., St. Clement's and Breton Bays	36,000	29,600	14,900	4,000	18,200	27,500
St. Mary's River and Smith Cr.	1,700	100	60	30	3,900	900
Total Potomac Md Tributaries	37,700	29,000	15,000	4,000	22,100	28,400
Total Maryland	**411,000**	**323,000**	**123,000**	**80,000**	**164,000**	**199,00**

Table 6 (continued).

Region/Tributary	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02
Upper Bay	2,600	18,800	13,100	28,100	31,150	16,100
Middle Bay	20,000	15,300	55,800	31,500	16,400	4,550
Lower Bay	300	4,800	8,300	3,800	2,050	600
Total Bay Mainstem	22,800	38,900	77,200	63,400	49,600	21,250
Chester River	5,400	43,000	21,000	70,100	20,800	29,450
Eastern Bay	1,100	3,800	30,900	75,800	120,500	33,400
Miles R.	500	30	800	35,700	20,150	6,600
Wye R.	0	400	900	9,400	11,300	1,800
Total Eastern Bay Region	1,600	4,200	32,600	120,900	151,950	41,800
Upper Choptank River	3,200	4,800	3,100	7,100	1,100	7,450
Middle Choptank R.	4,700	5,600	2,800	1,900	8,150	5,600
Lower Choptank R.	300	200	2,400	8,300	350	1,500
Tred Avon R.	3,800	6,900	11,700	3,700	8,950	1,000
Broad Creek	4,000	27,600	46,200	18,200	36,850	4,900
Harris Cr.	13,600	21,400	67,000	18,200	26,200	3,300
Total Choptank R. Region	29,600	66,500	133,200	57,400	81,600	23,750
Little Choptank River	40,800	36,100	84,100	33,600	27,850	2,400
Upper Tangier Sound	8,100	6,000	3,500	1,500	100	5,050
Lower Tangier S.	10,100	4,200	8,500	2,800	1,450	13,200
Honga River	200	1,300	300	50	0	50
Fishing Bay	8,800	3,800	700	90	0	0
Nanticoke R.	23,000	30,300	21,700	8,800	600	2,700
Wicomico R.	1,400	2,200	1,400	500	50	50
Manokin R.	900	600	300	90	200	1,850
Annemesex R.	0	0	0	200	0	0
Pocomoke S.	300	400	80	100	10	20
Total Tangier Sound Region	52,800	48,800	36,500	14,100	2,400	22,920
Patuxent River	20	60	5,600	2,000	10	0
Wicomico R., St. Clement's and Breton Bays	7,300	10,200	13,700	8,800	2,600	1,400
St. Mary's River and Smith Cr.	16,200	36,700	16,400	4,500	6,150	1,650
Total Potomac Md Tributaries	23,500	46,900	30,100	13,300	8,750	3,050
Total Maryland	**178,000**	**285,000**	**423,000**	**380,700**	**348,000**	**148,200**

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 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 name was abbreviated accordingly. Once described, 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 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 been 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 have fostered upstream range extensions by *H. nelsoni*, and MSX disease mortalities, during each successive drought year.

Appendix 1 References

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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 1.0194 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 immenently.
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*. 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, percent sample	Percent proportion of annual, non-fishing oyster population mortality estimated by dividing the number of recent-dead (box) oysters by the sum of live and recent-dead oysters in replicate samples: *[number of boxes ÷ (number of boxes + number of live oysters)] x 100*.
mortality, percent annual	Percent proportion of annual, Bay-wide, non-fishing oyster mortality estimated by averaging population mortality estimates from all samples collected during an annual survey: *sum of sample mortality estimates ÷ number of survey samples*.

MSX disease	The oyster disease caused by the protozoan pathogen, *Haplosporidium nelsoni*.
MSX frequency, percent 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 (alveolate) 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, the seed are subsequently 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 a swimming oyster larva attaches to a hard substrate such as oyster shell. During this process the larva undergoes metamorphosis, adopting the adult form and habit.