3-1997

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Marine Resource Report 97-2

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EXECUTIVE SUMMARY

Weather. The winter of 1996 was unusually cold and water temperature was consistently below the long-term average. Water temperatures remained below 5°C for a period of ten weeks, two weeks longer than normal. The spring was also relatively cold while summer temperatures were fairly typical. With the exception of a few weeks in early October and early December, temperatures during October through December were generally above average. Above average rainfalls and atypical climatic events during 1996, including several winter storms and a hurricane in early September, resulted in record high streamflows in many of the Chesapeake Bay tributaries. Record high James River streamflows were recorded in January, September and December. High streamflows decreased salinities in upper river areas and subsequently had a significant impact on oyster diseases.

Haplosporidium nelsoni **(MSX).** For the first time in four years some abatement of *H. nelsoni* occurred in the James River Wreck Shoal seed area. Infections acquired in the summer of 1995 were present at a prevalence of 24% in January 1996, however prevalence declined to 0% by May. Infections were absent or rare the remainder of the year. Fall abundances of *H. nelsoni* in other Virginia tributaries were generally lower than in 1995. Low prevalences of *H. nelsoni* were observed in the Piankatank River at Burton's Point (4%) and in the Rappahannock River at Parrot Rock (8%). Prevalences and intensities of *H. nelsoni* were higher in bayside and seaside eastern shore oysters than in western shore oysters. On the bayside, *Haplosporidium nelsoni* was present at Byrd Rock (30%) in Pocomoke Sound and in Nasawadox Creek (16%). On the seaside *H. nelsoni* was present at relatively high prevalences in Bradford Bay (56%), Fishermans Island (36-64%), and in Quinby Channel (20-76%). Moderate and heavy infections were observed in some of these eastern shore areas and it is likely that disease associated oyster mortality occurred.

Haplosporidium nelsoni was also abundant in the lower York River. VIMS tray oysters, which were transplanted from Ross Rock to the lower York River site on 1 May 1995, had a high prevalence (52%) of *H. nelsoni* by 11 July 1995. Prevalence increased to 84% in August and remained between 60-70% for the remainder of the year. *Haplosporidium nelsoni* contributed to disease-associated mortality in the trays which was nearly 70% by 11 September. Once again, for the fifth consecutive year, *H. nelsoni* prevalence at VIMS was at a record high level.

Perkinsus marinus **(Dermo).** Our fall survey of Virginia oyster bars indicated that *P. marinus* was present at all western shore oyster bars. However, the unusually cold winter and

INTRODUCTION

The protozoan parasites *Haplosporidium nelsoni*, popularly known as MSX, and *Perkinsus marinus*, popularly known as Dermo, are serious pathogens of oysters in the Chesapeake Bay. MSX first appeared in Chesapeake Bay in 1959 and in the early 1960s killed millions of bushels of oysters on lower Bay oyster grounds. The continued presence of the parasite has discouraged use of these prime growing areas since that time.

The infection period for *H. nelsoni* begins in early May each year with peak mortality in the lower Bay from these early summer infections occurring during August and September. However, infections acquired during late summer and fall may overwinter if salinity remains high and develop as soon as water temperature increases in early spring. These overwintering infections may cause oyster mortality as early as June. In the major tributaries, normal spring runoff usually causes expulsion of overwintering *H. nelsoni* infections by May, but the pathogen may reinvade an area by fall if salinity is favorable during summer. Oyster mortality is reduced under these circumstances because *H. nelsoni* is present mainly during winter when cold water temperature slows development of the parasite.

Historically, *P. marinus* has been present at low levels in the lower portions of all Virginia rivers, but the parasite increased in abundance and spread throughout all public oyster beds during the late 1980s. Until that time *P. marinus* was not as serious a pathogen as *H. nelsoni* because *P. marinus* spread slowly within an oyster bed and between adjacent beds, and required three years to cause significant mortality. However, because of the increase in the distribution and abundance of *Perkinsus*, this parasite is now more important than *H. nelsoni* as an oyster pathogen in the Bay. The population dynamics of *P. marinus* are complex and not entirely understood. Most mortality occurs during late summer and early fall, but it may begin as early as June following warm winters that allow more overwintering infections.

The distribution and pathogenicity of both diseases are limited by salinity and, in a very general sense, neither parasite causes serious mortality in areas where the salinity remains below about 12 ppt. *Haplosporidium nelsoni* is eliminated from oysters after about 10 days below 10 ppt; however, *P. marinus* may persist for years at low salinity although it is not pathogenic.

Because of the detrimental effect of these diseases on the Virginia oyster industry, the Virginia Institute of Marine Science has been monitoring the prevalence of both parasites since 1960. Information on disease severity and distribution each year is provided to management agencies and the oyster industry through publications and special advisories of the Marine Advisory Service office. The results of disease monitoring for the calendar year 1996 are presented in this report.

***Perkinsus marinus* (Dermo).** Our fall survey of Virginia oyster bars indicated that *P marinus* was present at all western shore oyster bars. However, the unusually cold winter anc high streamflows of 1996 resulted in reduced *P. marinus* activity, compared to recent years, particularly in upper tributary areas. Fall prevalences and intensities of the parasite in areas located in the Great Wicomico River, Piankatank River, Pocomoke Sound and on the seaside of the eastern shore were generally above 90% and moderate to heavy infections were numerous. In the Rappahannock River prevalences were lower than observed in recent years but heavy and moderate infections were still numerous in oysters sampled below Long Rock and it is likely that some oyster mortality occurred in these areas.

In the James River, *P. marinus* disease pressure was significantly reduced at Deepwater Shoal and Horsehead Bar. Summer and fall prevalences and intensities of *P. marinus* at these two bars were the lowest recorded since 1989. Maximum summer/fall prevalences were only 8% at Deepwater Shoal and 52% at Horsehead Rock.

In comparison to the previous 4-5 years, the prevalence of *P. marinus* at Point of Shoals was 25-40% lower in 1996. Prevalence remained between 44 and 60% from September through December. Infection intensities were also significantly lower in 1996, advanced infections were observed in only 7 of the 300 oysters analyzed.

At Wreck Shoal prevalences of *P. marinus* in the late summer and fall fluctuated between 72 and 96%. This was the first year since the mid-1980s that Wreck Shoal summer/fall prevalences did not reach 100%. Despite lower prevalences infection intensities were still relatively high. Relatively high abundances, 12-20%, of moderate and heavy infections were observed from July through December. These advanced infections likely caused some oyster mortality in this area.

METHODS

Sampling.

The oyster disease monitoring program consists of three different sample types—tray samples, native oyster samples and samples provided from private oyster grounds.

Tray Samples. In late April each year, oysters are dredged from Ross Rock in the upper Rappahannock River, and placed in 2-foot by 4-foot legged trays in the York River at Gloucester Point. Oysters from the upper Rappahannock River are known to be highly susceptible to *H. nelsoni* and thus they serve as excellent indicators of annual abundance of this parasite when placed in an endemic area such as the lower York River just prior to the normal infection period for *H. nelsoni* that begins in May and continues through July. Historically, *P. marinus* has never invaded the trays during the first year of monitoring so the trays were a good measure of mortality resulting from MSX alone. However, because of the dramatic increase in *P. marinus* abundance since 1987, oysters in the monitoring trays have become infected with this pathogen in recent years. The presence of both *H. nelsoni* and *P. marinus* in the trays has made interpretation of the cause of mortality difficult. In addition, because of its widespread distribution, oysters from the upper Rappahannock River may now be infected with *P. marinus* when they are collected. Nonetheless, these oysters can still be used to monitor *H. nelsoni*, which normally does not occur in the upper reaches of the rivers.

Prior to establishing trays, a sample of 25 oysters is analyzed for *H. nelsoni* and *P. marinus* to determine the level of existing infections at the dredge site. No *H. nelsoni* infections have ever been encountered at these sites during April, but in recent years *P. marinus* has been present at low prevalence (<10%). At least 300 oysters are placed in each of the two York River trays on 1 May each year. Trays are cleaned every week and counts are periodically made of live and dead oysters in each tray. Samples of 25 oysters are removed on about 1 July, 1 August, 1 September, and 1 October for disease determination; final counts are made about 1 December and trays are removed from the river at that time. New trays are established each May to provide a record of disease prevalence and intensity for each year. Because oysters from the same source have been held at the same location each year since 1960 we have a long-term data base on *H. nelsoni* abundance and it is possible to compare years and to relate disease abundance and distribution to various environmental parameters.

Native Oyster Samples. In order to determine the annual distribution and severity of both *H. nelsoni* and *P. marinus;* samples of native oysters are collected periodically from most major public harvesting areas in Virginia. Samples of 25 oysters are collected in the fall, approximately 1 October, from many sites in Mobjack Bay, the Rappahannock River, the Great Wicomico River and from other tributaries of the western shore and the seaside of the Eastern

Shore. Since 1987 a more intensive survey has been conducted in the James River, samples are collected monthly at Wreck Shoal, Horsehead Rock and Deep Water Shoal and periodically at Point of Shoal.

Private Oyster Grounds. Private oyster planters submit samples for disease diagnosis and the results are used to make planting and harvesting decisions. In this report these samples are identified by location only and cannot be separated from native oyster samples.

Diagnostic Techniques.

Prevalence of *H. nelsoni* was determined by histological analysis of paraffin–embedded tissue sectioned at 6 μm and stained with hematoxylin and eosin; prevalence of *P. marinus* was determined by thioglycollate culture of mantle, gill and rectal tissue.

Monthly mortality in tray samples was determined by dividing the number of dead oysters by the number of live and dead oysters in the tray. This result was divided by the period in days since the last count to yield percent dead per day. This value was then multiplied by 30 to yield monthly mortality. Cumulative mortality in each tray was calculated using a complex formula that accounts for live oysters removed for disease diagnosis.

Environmental Parameters.

Water temperature for the determination of long-term averages and yearly anomalies is obtained from a continuous monitor at the VIMS pier in the lower York River. Water temperatures were also recorded at the various collection sites on each sample date. Salinity data for the James River is obtained from a variety of sources. The State Water Control Board takes biweekly samples at Wreck Shoal and at Deep Water Shoal from May through October and monthly samples from November through April. The VIMS shellstring survey obtains weekly data at these locations from May through October and the VIMS oyster disease monitoring program obtains monthly samples throughout the year. Riverflow data for the James River and for the entire Chesapeake Bay are obtained from the U. S. Geological Survey.

RESULTS

Temperature and streamflow/salinity.

During the winter and spring of 1996 water temperatures were generally below the long term average (Figure 1 and 2), continuing a trend that began in late October 1995. In late-December 1995 and in January and February 1996 average weekly water temperatures were consistently below 4°C. Weekly temperature averages less than 5°C were recorded for a period of ten weeks; typically water temperature remains below 5°C for a period of 8 weeks. Temperatures were continuously below average through early-May (Figure 2). Water temperature increased to about 20°C by the third week in May, as typical for the region. Temperatures increased to greater than 25°C in mid-June, about two weeks earlier than predicted based on the long-term average. Temperatures during the remainder of the summer were fairly typical. With the exception of a few weeks in early October and early December, temperatures during October through December were generally above average. A comparison of 1992-1996 temperature anomalies (deviations from long-term average temperatures) is shown in Figure 3.

Atypical climatic events during 1996, including severe winter storms and Hurricane Fran, resulted in periodic record high streamflows in Chesapeake Bay tributaries. In the James River, 45 year record high streamflows were recorded for the months of January, September and December (Figure 1). During January and February a series of winter storms produced unusually high snowfall in the region which ultimately yielded high runoffs as snow melted. March and April were relatively dry and streamflows were slightly below average. In May and June sporadic intensive rainfalls resulted in slightly above normal streamflows and then once again more typical conditions were observed in July and August. On September 5 hurricane Fran struck the region and intensive rainfalls associated with the storm caused extremely high streamflows. Streamflows remained above average throughout the remainder of the year with flow being particularly high in December. A comparison of 1992-1996 streamflow anomalies (deviations from long-term means) is shown in Figure 3. The extremely high streamflows observed in the James River in 1996 resulted in periodic declines in salinity to less than 5 ppt at Deepwater Shoal (DWS) (Figure 4), Horsehead Bar (HH) (Figure 5), Point of Shoals (PTS) (Figure 6) and Wreck Shoal (WS) (Figure 7). Average annual salinities were respectively, 3.3 ppt, 5.5 ppt, 6.1 ppt, and 11.2 ppt at Deepwater Shoal, Horsehead Bar, Point of Shoals, and Wreck Shoal. Salinity ranges were 0-9 at DWS, 0-12 at HH, 0-12 at PTS, and 3 to 16.6 ppt at WS. Immediately after Hurricane Fran salinity decreased to 0 at DWS, HH and PTS and to 3.0 ppt at WS. From August to October salinity ranged from 0-9 ppt at Deepwater Shoal (Figure 4), 0-11 ppt at Horsehead Rock (Figure 5), 0-12 at Point of Shoals (Figure 6) and 3-16 ppt at Wreck Shoal (Figure 7). The salinity depressions associated with Hurricane Fran were of a relatively short duration. At all stations salinity returned to near pre-storm levels within about a 2 week period.

Native Oyster Samples.

***Perkinsus marinus* (Dermo).** The occurrence of cold temperatures and high streamflow during the winter and summer of 1996 resulted in reductions in summer and fall prevalences and intensities of *P. marinus* baywide compared to recent years. Although the parasite was found on all beds sampled in the fall (the period of maximum abundance) (Table 1 and 2), prevalences were lower than in 1995. *Perkinsus marinus* prevalence and infection intensity varied with location, generally decreasing with decreasing salinities as one moves up river. Moderate to heavy infections were only observed in oysters from areas having salinities greater than 9 ppt. Prevalences and intensities of the parasite in the Great Wicomico River and the Piankatank River were generally above 90%. In the Rappahannock River prevalences were lower than observed in recent years but heavy and moderate infections were still numerous in oysters sampled below Long Rock and it is likely that some oyster mortality occurred in these areas. Prevalences exceeding 90% were also found bayside and seaside on the eastern shore. Infection levels were particularly high at Tangier and Pocomoke Sounds, Quinby Channel, and Fishermans Island (Table 2).

In the James River, *P. marinus* disease pressure was significantly reduced particularly at Deepwater Shoal and Horsehead Bar (Table 1). Summer and fall prevalences and intensities of *P. marinus* at these two bars were the lowest recorded since 1989. At Deepwater Shoal *P. marinus* was nearly eradicated as overwintering infection prevalence declined to a 4% in April and failed to increase appreciably in the summer and fall. The maximum prevalence in summer and fall was only 8%. This is extremely low in comparison to previous years in which yearly maximums in prevalence at Deepwater Shoal exceeded 40% (Figure 4).

At Horsehead Rock, *P. marinus* prevalence declined from 56% in January to 0% in April (Table 1, Figure 5 and 8). Prevalence gradually increased to a summer/fall maximum of 52% in August; however, a sharp decline was observed in early September in association with reduced salinities caused by Hurricane Fran. Prevalence remained below 30% from September through December. Advanced infections were rare and were observed in only 4% of the oysters sampled in September and November (Table 1).

The pattern of *P. marinus* prevalence at Point of Shoals was similar to that at Horsehead Rock (Table 1, Figure 6 and 8). Following a typical decline in prevalence from 64% in January to an annual minimum of 4% in April and May, prevalence gradually increased to a summer maximum of 52% in September. Prevalence remained between 44 and 60% from September through December. In comparison to the previous 4-5 years, prevalences at Point of Shoals in 1996 were down 25-40%. Infection intensities were also significantly lower in 1996, advanced infections were observed in only 7 (2%) of the 300 oysters examined.

At Wreck Shoal *P. marinus* prevalences in January and February were relatively high, 72% (Table 1, Figure 7 and 8). Prevalence decreased in April to an annual low of 4%. As typically observed at this site, prevalence increased to greater than 90% in July (Figure 8). During the late summer and fall, prevalence fluctuated between 72 and 96%. This was the first year since the mid-1980s that Wreck Shoal summer/fall prevalences did not reach 100%. Despite lower prevalences infection intensities were still relatively high. Moderate and heavy infections were common from July through December (Table 1). The high abundance, 12-20%, of advanced infections from July to September likely caused some oyster mortality in this area.

***Haplosporidium nelsoni* (MSX).** For the first time in four years some abatement of *H. nelsoni* occurred in the James River Wreck Shoal seed area (Table 1, Figure 7 and 8). Infections acquired in the summer of 1995 were present at a prevalence of 24% in January 1996, however prevalence declined to 0% by May. Infections were absent or rare the remainder of the year. This is in sharp contrast to previous years in which prevalences exceeding 50% were observed. *Haplosporidium nelsoni* was not detected in Horsehead Rock oysters sampled in 1996 (Table 1).

Haplosporidium nelsoni was also observed at relatively low prevalences in oysters sampled in the fall from public oyster beds in other Virginia tributaries (Table 2). Low prevalences of *H. nelsoni* were observed in the Piankatank River at Burton's Point (4%) and in the Rappahannock River at Parrot Rock (8%). The abundance of the pathogen in these areas was lower than in 1995. Prevalences and intensities of *H. nelsoni* were higher in bayside and seaside eastern shore oysters than in western shore oysters. On the bayside, *Haplosporidium nelsoni* was present at Byrd Rock (30%) in Pocomoke Sound and in Nasawadox Creek (16%). On the seaside *H. nelsoni* was present at relatively high prevalences in Bradford Bay (56%), Fishermans Island (36-64%), and in Quinby Channel (20-76%) (Table 2).

VIMS Tray Samples

Two trays of Ross Rock, Rappahannock River oysters were established at the VIMS, Gloucester Point, York River site on 1 May 1995. Analyses of a sample of the Ross Rock oysters prior to transplantation indicated that *P. marinus* prevalence was 0% and that the oysters were also free of detectable *H. nelsoni* infections. The number of live and dead oysters in each tray was assessed at the beginning of each month from June to November and the resulting determinations of percent monthly and percent cumulative mortalities are shown in Table 3. Fewer than 5% of the oysters died between May and the beginning of July, but cumulative mortality increased to 66% by early September and was 89% in November (Table 3). Samples for disease diagnoses were also taken at the beginning of each month. *Haplosporidium nelsoni* was not detected in oysters sampled on 1 June but by 8 July 52% of the oysters were infected, 54% of which had advanced infections. Prevalence of *H. nelsoni* increased to 84% in August, the maximum prevalence for the year, and remained above 60%

through December. Moderate and heavy infections were numerous and continually present from July to December (Table 3). *Haplosporidium nelsoni* prevalence and intensity in 1996 were higher than in 1995. Maximum summer/fall prevalences of MSX in VIMS tray oysters over a 36 year period are shown in Figure 9. Once again for the fifth consecutive year, *H. nelsoni* prevalence at the VIMS site was at or near the highest prevalence ever recorded at the site.

Perkinsus marinus infections first appeared in July and remained low until September. Prevalence of *P. marinus* increased from 12% on 1 August to 70% on 11 September (Table 3). Prevalence continued to be high (88-92%) in subsequent samples and advanced infections of *P. marinus* were numerous (28-44%) in oysters sampled in October and November.

Mortality occurring prior to 1 August may be attributed to MSX. Later mortality was probably caused by a combination of both parasites.

DISCUSSION

***Perkinsus marinus* (Dermo).** *Perkinsus marinus* continues to be present on all oyster beds in Virginia; however, prevalences and intensities in 1996 were relatively low compared to previous years, particularly in the uppermost James River seed areas. The typical annual cycle of *P. marinus* activity exhibits a pattern in which prevalence and intensity decline during the winter and early spring to an annual minimum in April or May. Prevalence and intensity once again increase in the summer and maximum prevalences are observed in September or October. This cyclic pattern is primarily driven by seasonal temperature changes, but it is also greatly influenced by salinity. Generally, prevalence and intensity rise more rapidly and to a greater degree in high salinity (>15 ppt) areas than in areas with lower salinity. Conversely, prevalence and intensity regress faster and more extensively in low salinity areas than in high salinity areas. Extremes in temperature may also influence this cycle. In 1996 the effect of high streamflow (abnormally low salinities) and cold winter temperatures on *P. marinus* levels in the upper James River seed areas was clearly evident. Unusually cold winter temperatures and high streamflows resulting from severe winter storms caused infections to decline to relatively low levels during the spring. The scarcity of overwintering infections combined with relatively wet summer conditions resulted in the lowest prevalences of *P. marinus* at Deepwater Shoal and Horsehead Rock in nearly a decade. Hurricane Fran, which struck the region on 5 September 1996, caused a sharp decline in salinity which greatly depressed *P. marinus* activity and retarded *P. marinus* infection progression in oysters in most upper tributary areas. Prevalences and intensities of *P. marinus* in more down river locations were also reduced relative to previous years; however, the impact of Hurricane Fran was less dramatic in these areas. For instance, after the hurricane, salinity at Wreck Shoal rebounded to pre-hurricane levels fairly quickly and infections progressed to moderate and heavy intensity in late September and October. However, monthly prevalences at Wreck Shoal were still reduced compared to previous years. The decline of *P. marinus* prevalence in the upper most seed areas is the first indication that the parasite may eventually be eradicated from these areas given the appropriate climatic conditions; however, as long as high disease levels persist at Wreck Shoal, the upper river bars are vulnerable to reinfection during dry years.

***Haplosporidium nelsoni* (MSX).** In recent years, 1993 through 1995, the parasite persisted at record high prevalences and intensities in the James River at Wreck Shoal, in the down river populated beds of Virginia's other major western shore tributaries, and in the sounds of Virginia's eastern shore. In 1996, *H. nelsoni* was once again observed in these areas; however, prevalences were generally lower, particularly in the James River. In the James River at Wreck Shoal prevalence declined from 24% in January to 0% in May and few infections were observed the remainder of the year. Generally, *H. nelsoni* is eliminated in spring and then reappears in the late summer and fall. Since the parasite is intolerant of salinities at or below 10 ppt, high streamflows which reduce salinity below 10 ppt usually result in parasite expulsion. At Wreck Shoal salinities at or below 10 ppt persisted through the late-winter and spring and then again in September following Hurricane Fran. In contrast, salinities in lower river areas and in the bays of the eastern shore remained relatively high and *H. nelsoni* persisted.

Susceptible oysters that were transplanted to VIMS in May also acquired *H. nelsoni* infections at a relatively high prevalence. The transplanted oysters exhibited one of the highest prevalences of *H. nelsoni* ever recorded at the site. Infections were detected in the tray oysters in July and a maximum prevalence of 84% was observed in August. Prevalence gradually declined from the mid-summer peak to 64% in December. Overall, *H. nelsoni* infections were severe and caused extensive mortality of the transplanted oysters. Although record high streamflows occurred periodically baywide, salinity at the lower York River site remained above 14.5 ppt, well within the tolerance of this parasite. Hence, it is not surprising that *H. nelsoni* infection pressure remained high at the York River site. Clearly, *H. nelsoni* continues to be a significant threat to the health and survival of Virginia's natural oyster resource, but at least some relief occurred in the upper James River seed beds.

ACKNOWLEDGMENTS

The oyster disease monitoring program could not be conducted without the help of many VIMS scientists and staff. Juanita Walker was responsible for sample processing and diagnoses for both *H. nelsoni* and *P. marinus*. Rita Crockett, Caitlin Robertson, Christine Scanlon, and Heather Yarnall assisted with sample processing and with cleaning and counting of oysters in the monitoring trays. Ray Morales, Kenny Walker, George Pongonis and various members of VIMS vessel operations staff assisted with monthly sample collection in the James River and with semi-annual sampling from other areas. Gary Anderson provided hydrographic data from the VIMS pier monitoring station. Mike Oesterling of the Marine Advisory Service staff coordinated sample collection from private oyster growers.

Table 1. Monthly survey of prevalence and intensity of *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* in oysters from James River harvesting areas in 1996. See accompanying figure for station locations. NA=not analyzed for MSX. NS=not sampled.

Location	Date	Temp. (°C)	Sal. (ppt)	MSX Infect./exam. -%infected	H–M–L*	*Perkinsus* Infect./exam. -%infected	H–M–L*
Deep Water Shoal	17 Jan	3.0	9.0	NA		7/25 (28%)	0-0-7
	21 Feb		2.0	NA		8/25 (32%)	0-0-8
	14 Mar	9.0	2.0	NA		3/25 (12%)	0-0-3
	21 Apr		0	NA		1/25 (4%)	0-0-1
	16 May	18.5	2.0	NA		3/25 (12%)	0-0-3
	12 Jun	25.8	0.5	NA		1/25 (4%)	0-0-1
	17 Jul		4.0	NA		2/25 (8%)	0-0-2
	14 Aug		8.5	NA		0/25 (0%)	0-0-0
	11 Sep		0	NA		0/25 (0%)	0-0-0
	14 Oct	17.7	0	NA		0/25 (0%)	0-0-0
	14 Nov		4.0	NA		1/25 (4%)	0-0-1
	11 Dec	9.0	0	NA		2/25 (8%)	0-0-2
Horsehead Rock	17 Jan	3.0	12.0	0/25 (0%)		14/25 (56%)	0-0-14
	21 Feb		4.0	0/25 (0%)		10/25 (40%)	0-0-10
	14 Mar	8.0	6.0	0/25 (0%)		4/25 (16%)	0-0-4
	21 Apr	18.0	0.5	0/25 (0%)		0/25 (0%)	0-0-0
	16 May	18.2	4.5	0/25 (0%)		2/25 (8%)	0-0-2
	12 Jun	25.4	2.0	0/25 (0%)		2/25 (8%)	0-0-2
	17 Jul		5.0	0/25 (0%)		7/25 (28%)	0-0-7
	14 Aug		9.0	0/25 (0%)		13/25 (52%)	0-0-13
	11 Sep		0	0/24 (0%)		6/25 (24%)	1-0-5
	14 Oct	17.5	1.0	0/24 (0%)		7/25 (28%)	0-0-7
	14 Nov		6.0	0/25 (0%)		7/25 (28%)	1-0-6
	11 Dec	8.0	1.0	0/25 (0%)		5/25 (20%)	0-1-4
Point of Shoals	17 Jan		9.0	NA		16/25 (64%)	1-0-15
	21 Feb			NA		13/25 (52%)	0-0-13
	14 Mar	6.9	8.0	NA		4/25 (16%)	0-0-4
	21 Apr	18.0	0.5	NA		1/25 (4%)	0-0-1
	16 May	17.7	5.0	NA		1/25 (4%)	0-0-1
	12 Jun	25.1	3.0	NA		2/25 (8%)	0-0-2
	17 Jul		6.0	NA		3/25 (12%)	0-0-3
	14 Aug		10.5	NA		5/25 (20%)	0-0-5
	11 Sep		0	NA		13/25 (52%)	1-0-12
	14 Oct	17.4	2.0	NA		11/25 (44%)	0-1-10
	14 Nov		5.0	NA		15/25 (60%)	3-0-12
	11 Dec	8.0	1.0	NA		11/25 (44%)	0-1-10
Wreck Shoal	17 Jan		16.0	6/25 (24%)	1-0-5	18/25 (72%)	1-1-16
	21 Feb		10.0	1/25 (4%)	0-0-1	18/25 (72%)	1-0-17
	14 Mar	7.0	10.0	3/25 (12%)	0-0-3	6/25 (24%)	0-0-6
	21 Apr	17.0	5.5	4/25 (16%)	1-0-3	1/25 (4%)	0-0-1
	16 May	17.8	10.0	0/25 (0%)	0-0-0	3/25 (12%)	0-0-3
	12 Jun	25.9	5.0	0/25 (0%)	0-0-0	7/25 (28%)	0-0-7
	17 Jul		12.0	2/25 (8%)	0-1-1	23/25 (92%)	2-1-20
	14 Aug		15.0	1/25 (4%)	0-0-1	18/25 (72%)	1-3-14
	11 Sep		3.0	4/25 (16%)	0-0-4	19/25 (76%)	3-2-14
	14 Oct	17.0	6.0	0/25 (0%)	0-0-0	24/25 (96%)	3-0-21
	14 Nov		12.0	0/25 (0%)	0-0-0	19/25 (76%)	3-1-15
	11 Dec	8.0	6.0	0/25 (0%)	0-0-0	24/25 (96%)	1-2-21

*H=number of heavy infections, M=moderate infections, L=light infections.

Table 2. Fall survey of prevalence and intensity of *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* in oysters from Virginia oyster beds in 1996. See accompanying figures for station locations. NA=not analyzed for MSX.

Location	Date	Temp. (°C)	Sal. (ppt)	MSX Infect./exam. -%infected	H–M–L*	*Perkinsus* Infect./exam. -%infected	H–M
James River							
Deep Water Shoal	14 Oct	17.7	0	NA		0/25 (0%)	0-0-
Horsehead Rock	14 Oct	17.5	1.0	0/24 (0%)	0-0-0	7/25 (28%)	0-0-
Point of Shoals	14 Oct	17.4	2.0	NA		11/25 (44%)	0-1-
Wreck Shoal	14 Oct	17.0	6.0	0/25 (0%)	0-0-0	24/25 (96%)	3-0-
White Shoal	30 Oct	17.9	10.8	0/25 (0%)	0-0-0	23/25 (92%)	1-1-
Long Rock	30 Oct	17.4	8.2	0/25 (0%)	0-0-0	25/25 (100%)	3-0-
Dry Shoals	30 Oct	16.8	8.2	0/25 (0%)	0-0-0	25/25 (100%)	2-2-
Jail Island	31 Oct	17.1	6.7	0/25 (0%)	0-0-0	24/25 (96%)	1-2-
York River							
Cedar Bush Creek	11 Jul			NA		25/25 (100%)	12-3-
Piankatank River							
Ginney Point	22 Oct	16.3	11.4	NA		25/25 (100%)	4-4-
Burton's Point	22 Oct	16.2	12.1	1/25 (4%)	0-1-0	23/25 (92%)	4-6-
Palace Bar	21 Oct	16.3	10.1	NA		25/25 (100%)	2-10-
Bland Point	12 Oct			0/25 (0%)	0-0-0	24/25 (96%)	4-1-1
Rappahannock River							
Ross Rock	23 Oct	16.8	3.7	0/25 (0%)	0-0-0	1/25 (4%)	0-0-
Bowlers Rock	23 Oct	16.5	5.7	NA		2/25 (8%)	0-0-
Long Rock	23 Oct	16.3	7.0	NA		17/25 (68%)	1-1-1
Parrot Rock	21 Oct	16.5	11.4	2/24 (8%)	0-0-2	17/25 (68%)	2-2-1
Broad Creek	21 Oct	15.9	12.2	0/25 (0%)	0-0-0	21/25 (84%)	1-1-1
Drummond Ground	23 Oct	16.6	10.8	NA		16/25 (64%)	3-1-1
Spike	19 Aug		12.1	1/24	0-0-1	25/25 (100%)	1-2-2
Corrotoman River							
Middle Ground	23 Oct	16.4	11.0	NA		21/25 (84%)	4-4-1
Great Wicomico River							
Haynies Bar	22 Oct	16.2	12.7	NA		22/25 (88%)	2-1-1
Whaley's East	22 Oct	15.8	12.8	NA		19/25 (76%)	0-1-1
Fleeton Point	22 Oct	15.8	12.7	1/25 (4%)	0-1-0	23/25 (92%)	1-1-2
Coan River							
Big Bar	5 Aug		9.2	NA		22/25 (88%)	2-1-1
Yeocomico River							
Palmers Creek	5 Aug		9.6	0/25 (0%)	0-0-0	10/25 (40%)	2-0-8

*H=number of heavy infections, M=moderate infections, L=light infections.

Table continued on following page.

Table 2 cont.

Location	Date	Temp. (°C)	Sal. (ppt)	MSX Infect./exam. -%infected	H–M–L*	*Perkinsus* Infect./exam. -%infected	H–M–L*
Eastern Shore							
Bayside							
Tangier Island	25 Nov			1/25 (4%)	0-0-1	25/25 (100%)	5-3-17
Tangier Sound							
California Rock	6 Aug	27.3	13.9	0/25 (0%)	0-0-0	23/25 (92%)	2-2-19
Pocomoke Sound							
Byrd Rock	6 Aug	26.8	12.8	3/10 (30%)	0-0-3	4/10 (40%)	0-1-3
Pocomoke Sound	6 Aug	25.8	13.9	0/25 (0%)	0-0-0	24/25 (96%)	3-5-16
Hurley Rock							
Nassawadox Creek	10 Oct			4/24 (16%)	1-1-2	22/24 (92%)	5-2-15
Seaside							
Bradford Bay	19 Nov			14/25 (56%)	9-3-2	25/25 (100%)	2-6-17
Watts Bay	18 Nov			0/25 (0%)	0-0-0	23/25 (92%)	0-2-21
Cockle Creek	18 Nov			3/25 (12%)	2-0-1	13/25 (52%)	1-0-12
Fishermans Is (VMRC) - 1	24 Sept			7/25 (28%)	2-1-4	25/25 (100%)	3-6-16
Fishermans Is (VMRC) - 2	24 Sept			11/25 (44%)	7-0-4	23/25 (92%)	2-1-20
Fishermans Is (VMRC) - 3	24 Sept			9/25 (36%)	5-2-2	25/25 (100%)	7-4-14
Fishermans Is (VMRC) - 1	12 Dec			10/23 (43%)	7-0-3	10/23 (43%)	0-1-9
Fishermans Is (VMRC) - 2	12 Dec			16/25 (64%)	6-3-7	8/25 (32%)	0-1-7
Fishermans Is (VMRC) - 3	12 Dec			12/25 (48%)	6-3-3	17/25 (68%0	2-1-14
Quinby Ch (VMRC) -1	22 Oct			15/25 (60%)	8-1-6	9/25 (36%)	1-1-7
Quinby Ch (VMRC) -2	22 Oct			19/25 (76%)	13-2-4	25/25 (100%)	5-3-17
Quinby Ch (VMRC) -3	22 Oct			5/25 (20%)	3-0-2	25/25 (100%)	4-6-15

*H=number of heavy infections, M=moderate infections, L=light infections.

Table 3. Mean mortality and disease prevalence in upper Rappahannock River seed oysters transplanted to trays at the lower York River, Gloucester Point, VA in May, 1996.

Date–1995	Monthly mortality–%	Cumulative mortality-%	*H. nelsoni* prevalence	Intensity H-M-L*	*P. marinus* prevalence	Intensit H–M–L
1 May	0.0	0.0	0/25 (0%)		0/25 (0%)	
5 Jun	1.0	1.2	0/25 (0%)		0/25 (0%)	
8 Jul	3.4	4.8	13/25 (52%)	3-4-6	1/25 (4%)	0-0-1
1 Aug	25.1	18.4	21/25 (84%)	11-3-7	3/25 (12%)	0-0-3
11 Sep	39.8	66.0	16/23 (70%)	7-2-7	16/23 (70%)	3-0-13
10 Oct	43.1	81.2	17/25 (68%)	9-4-4	22/25 (88%)	6-1-15
5 Nov	47.1	88.6	16/25 (64%)	5-6-5	23/25 (92%)	7-4-12

*H = number of heavy infections, M = moderate infections, L = light infections.

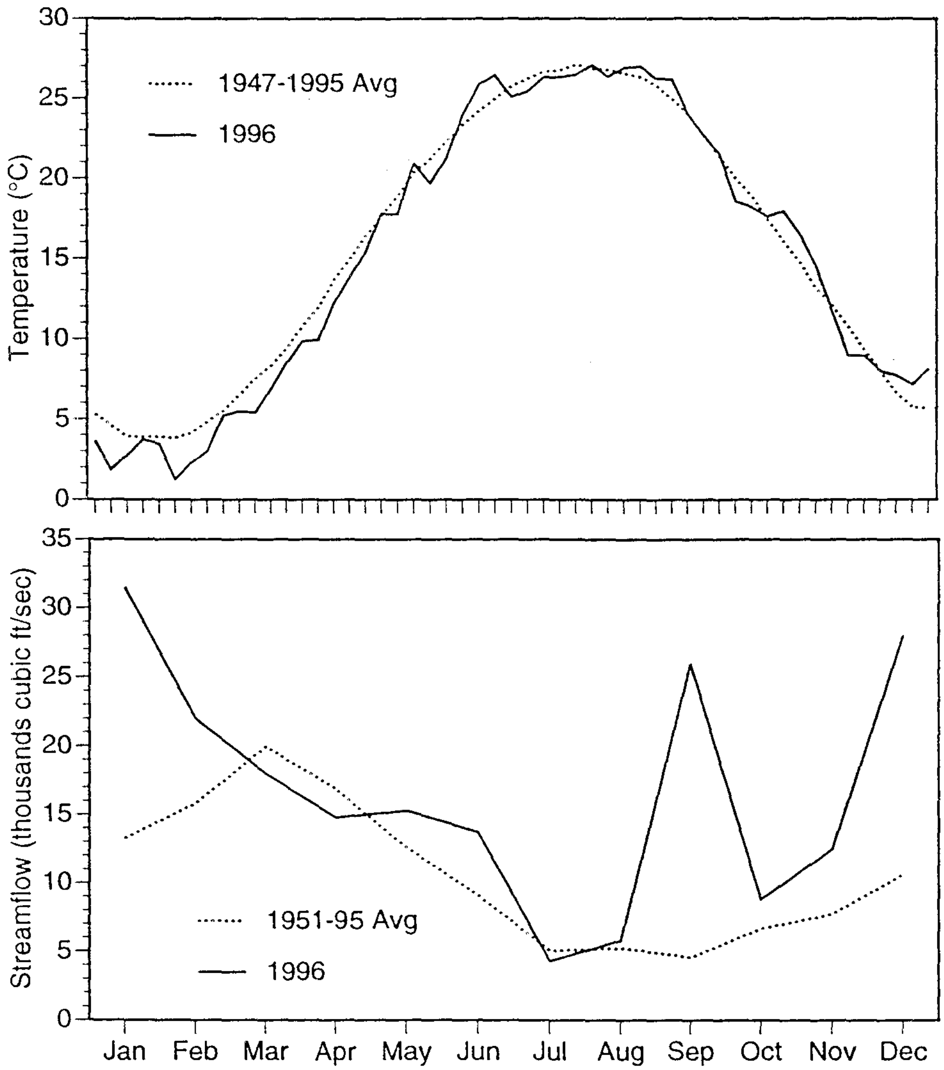


Figure 1. Average weekly water temperature at VIMS, Gloucester Point, VA (top) and monthly James River, VA streamflow (bottom). Long-term averages (dashed lines) are contrasted with 1996 values (solid lines). Long-term temperatures are for years 1947-1995 and long-term streamflows are for 1951-1995.

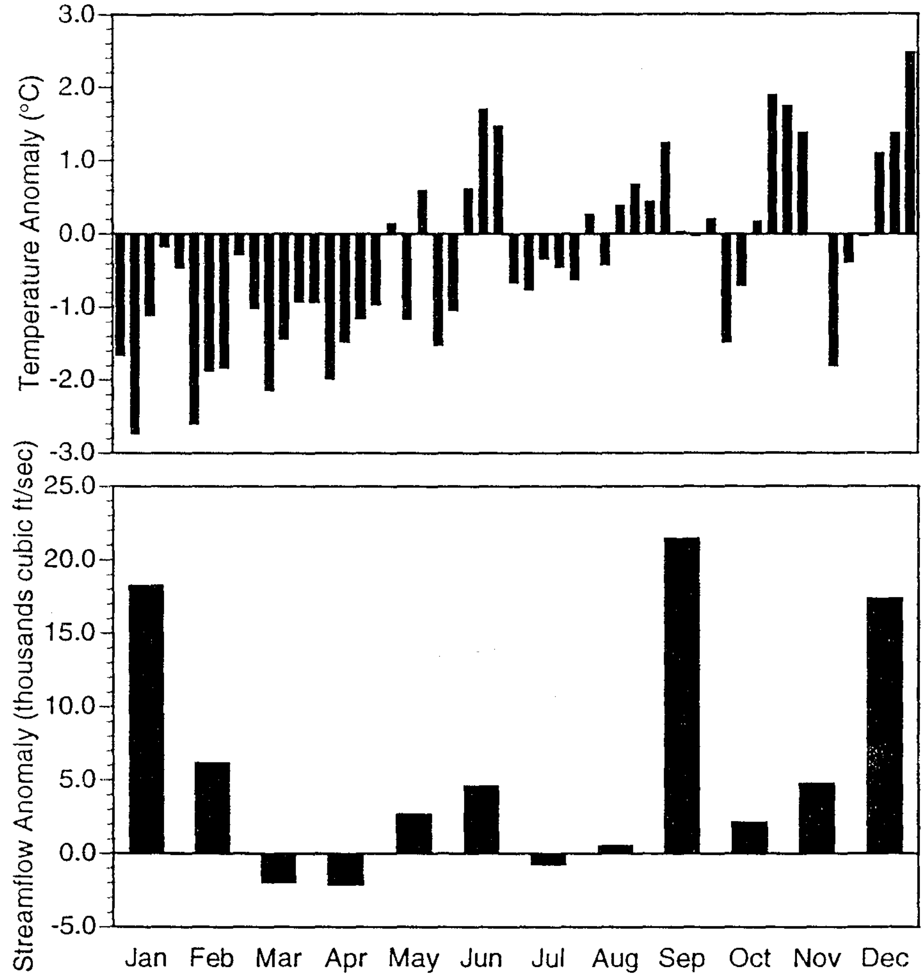


Figure 2. Weekly water temperature anomaly at the VIMS pier, Gloucester Point, VA based on average weekly water temperature from 1947-1995 (top) and monthly James River streamflow anomaly based on average discharge from 1951-1995 (bottom) for the calendar year 1996. Anomalies were calculated by subtracting the long term average from the value observed in 1996.

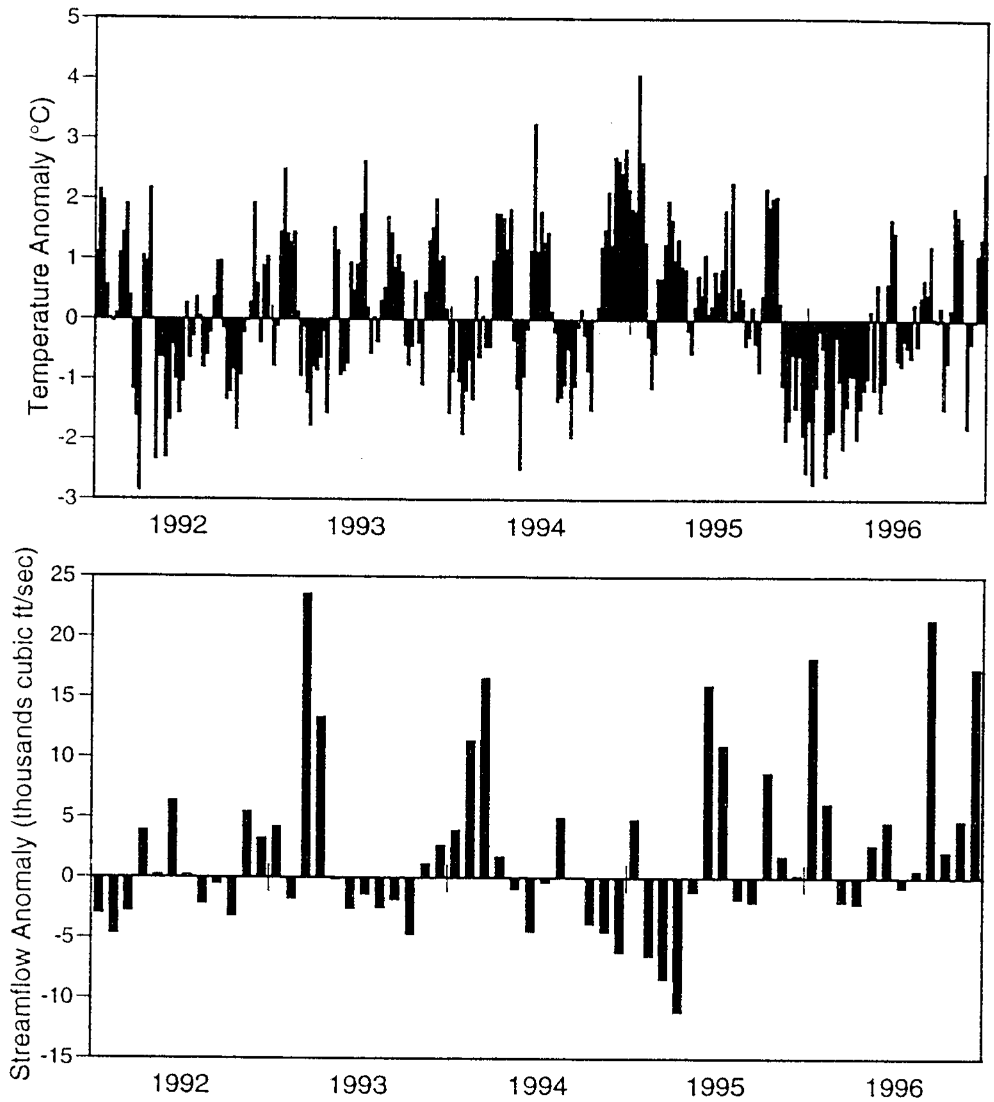


Figure 3. Mean weekly VIMS pier water temperature anomaly from long-term (1947-1995) average (top). Mean monthly James River streamflow anomaly from long-term (1951-1995) average (bottom).

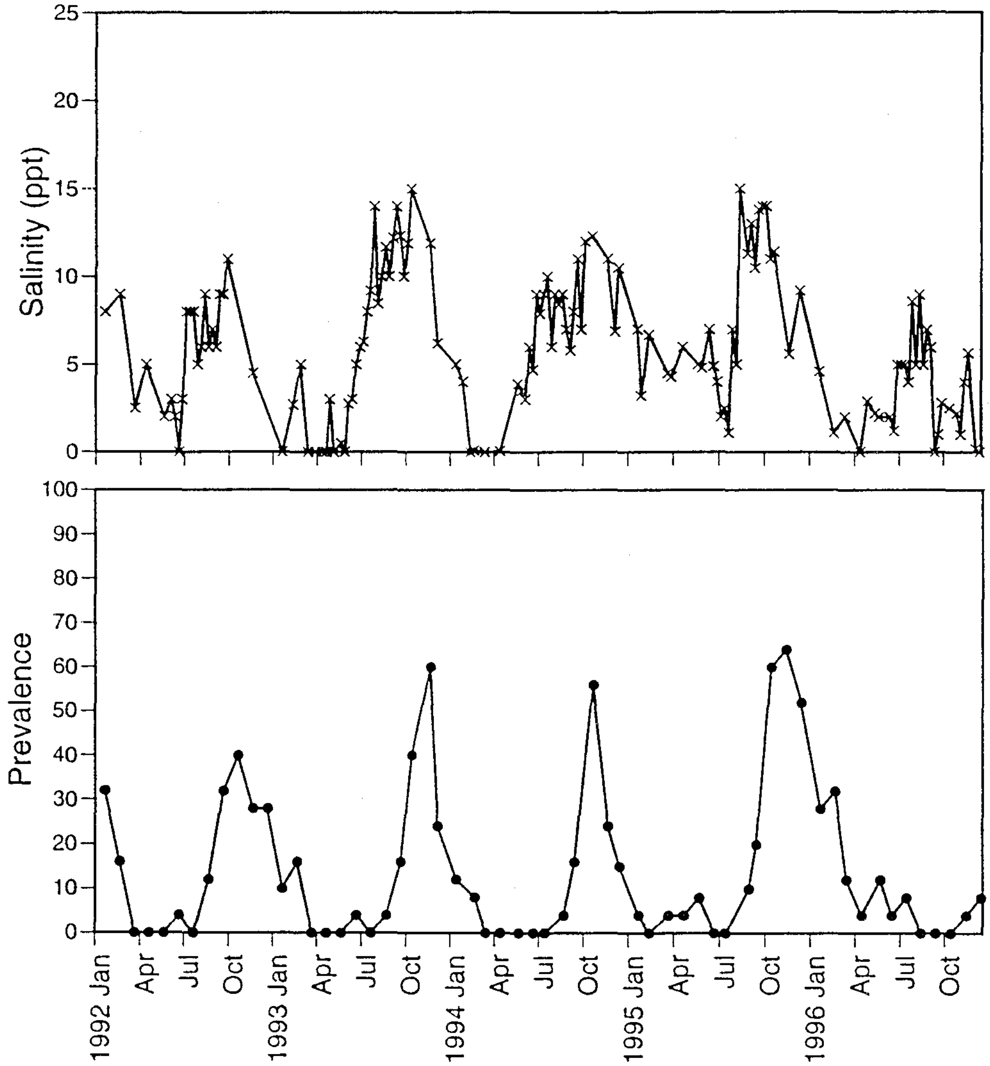


Figure 4. Salinity (top) and *P. marinus* prevalence (bottom) at Deepwater Shoal, James River, VA for the years 1992-1996.

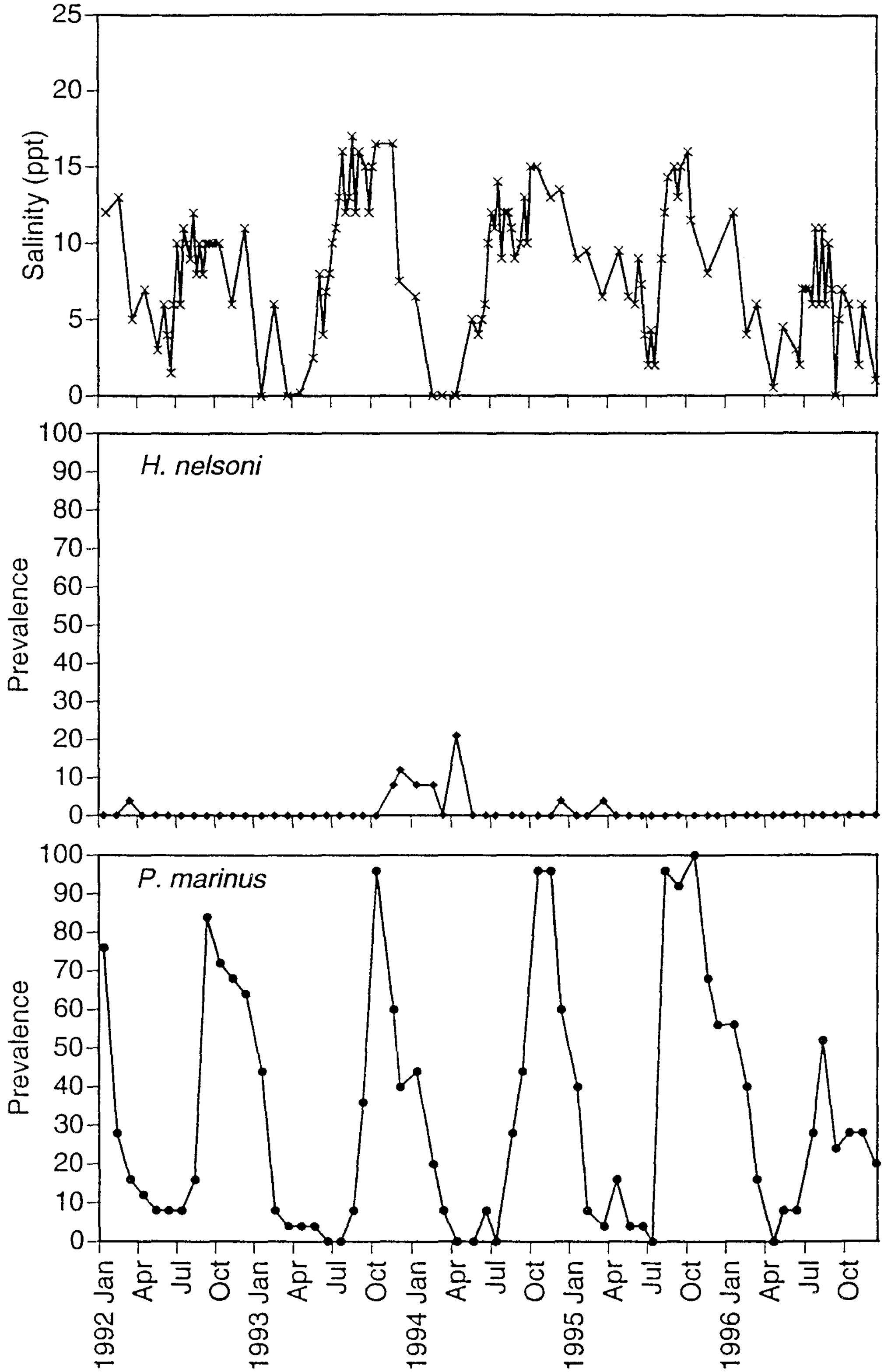


Figure 5. Salinity (top) and prevalence of *P. marinus* (bottom) and *H. nelsoni* (middle) at Horsehead Rock, James River, VA for the years 1992-1996.

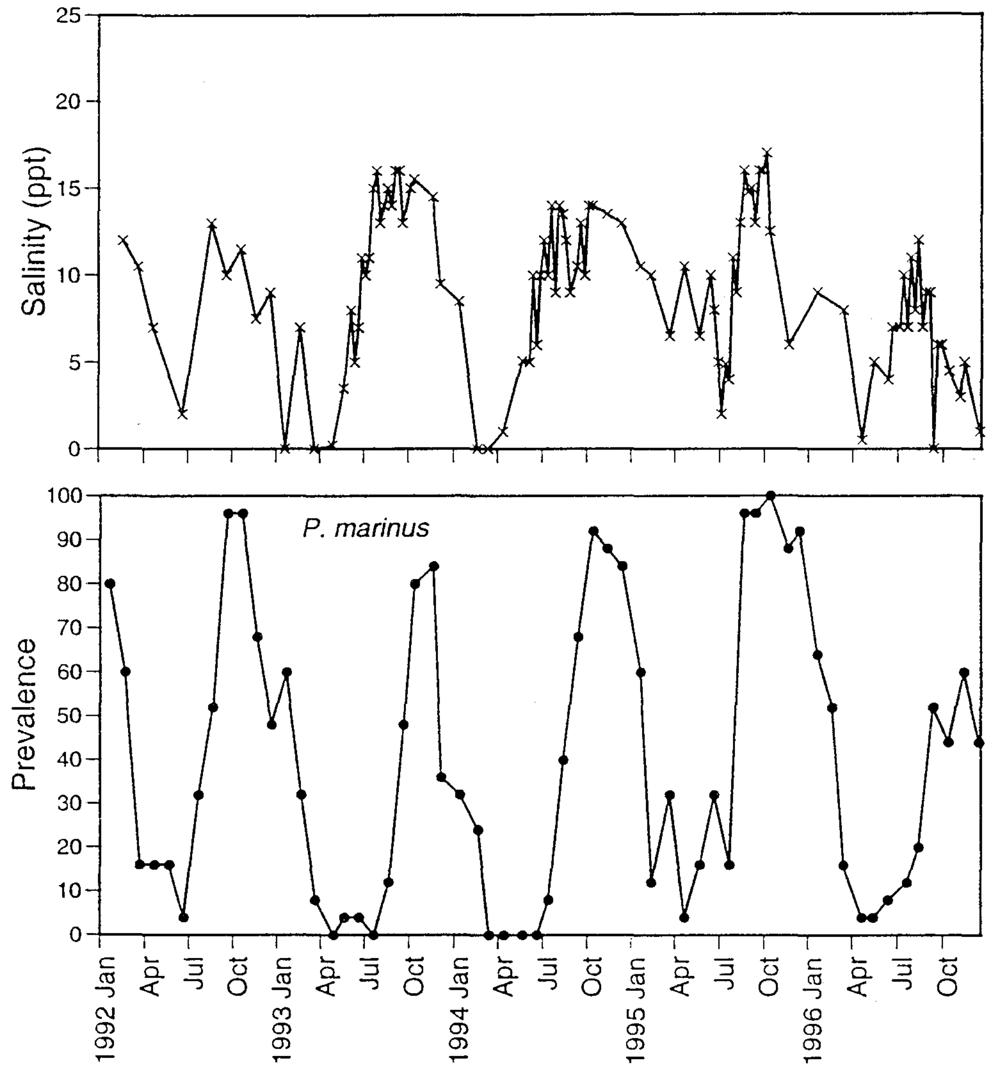


Figure 6. Salinity (top) and prevalence of *P. marinus* (bottom) at Point of Shoals, James River, VA for the years 1992-1996.

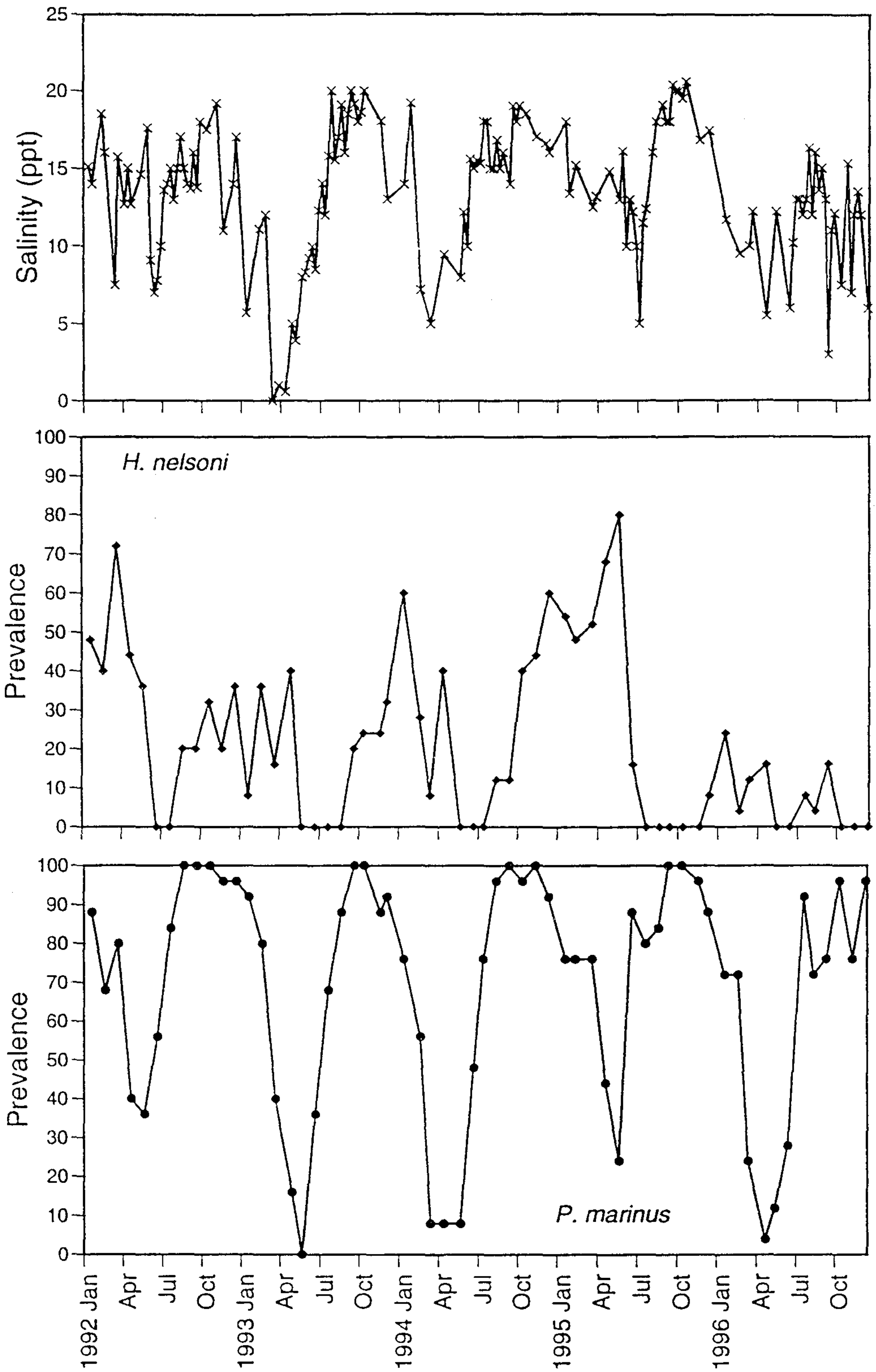


Figure 7. Salinity (top) and prevalence of *P. marinus* (bottom) and *H. nelsoni* (middle) at Wreck Shoal, James River, VA for the years 1992-1996.

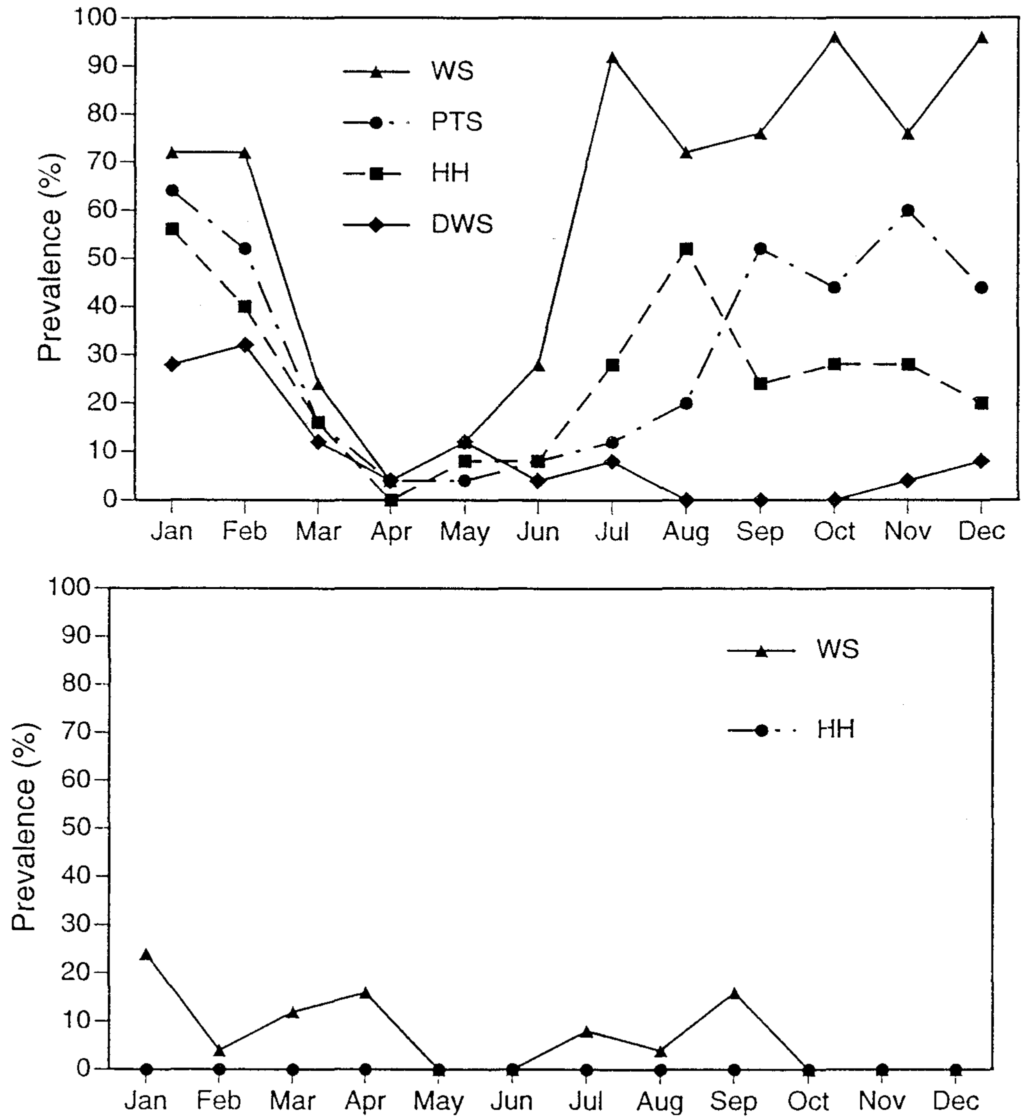


Figure 8. Prevalence of *P. marinus* (top) and *H. nelsoni* (MSX) (bottom) in James River oysters from Wreck Shoal (WS), Horsehead Rock (HH), Point of Shoals (PTS) and Deepwater Shoal (DWS) in 1996. DWS and PTS oysters were not analyzed for MSX.

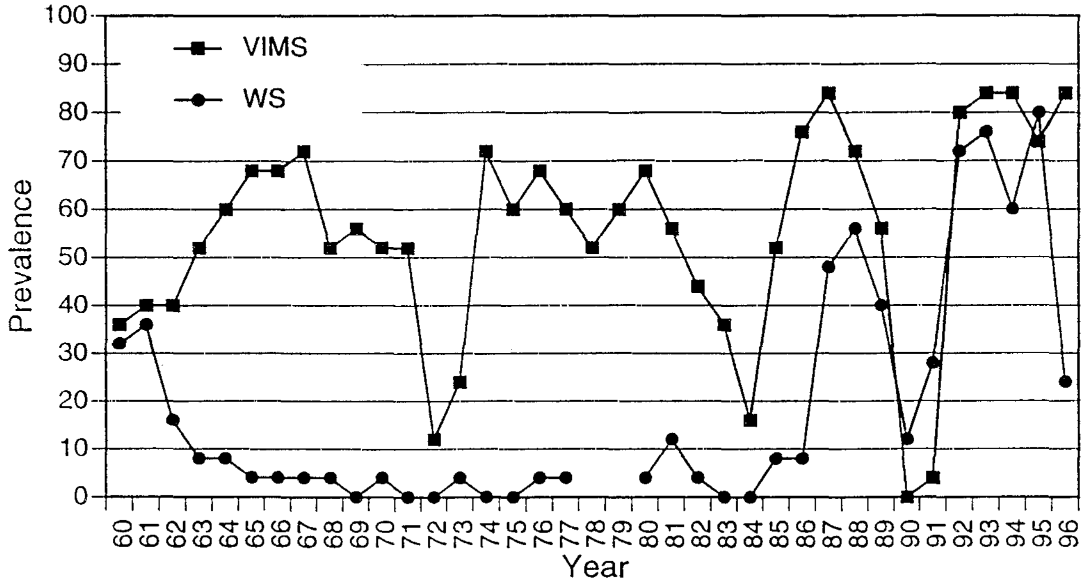
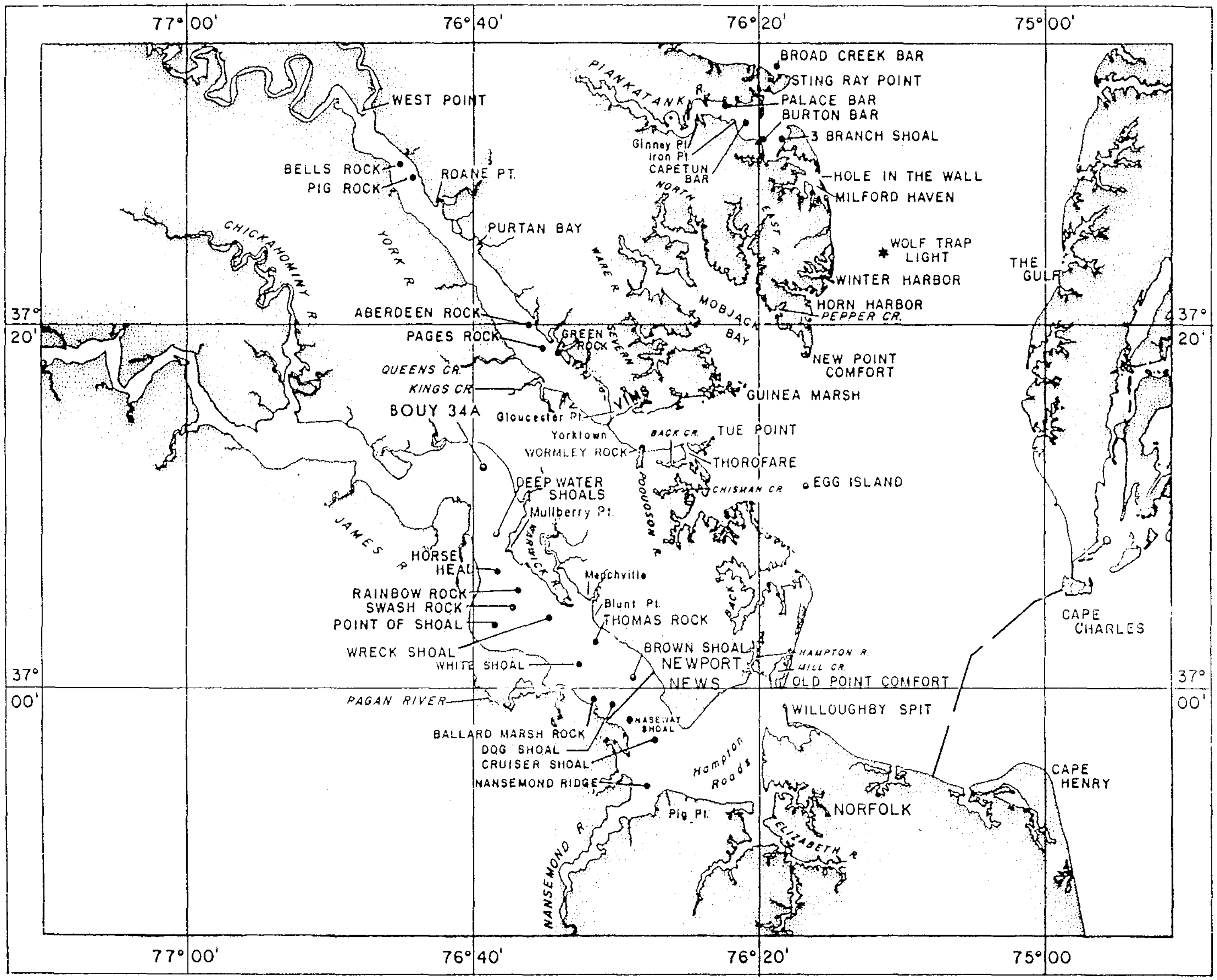


Figure 9. Maximum annual prevalence of *Haplosporidium nelsoni* (MSX) in imported monitoring tray oysters at VIMS and in native oysters at Wreck Shoal (WS), James River, 1960-1996.



Names of oyster rocks, geographical points, towns and bodies of water in James and York rivers