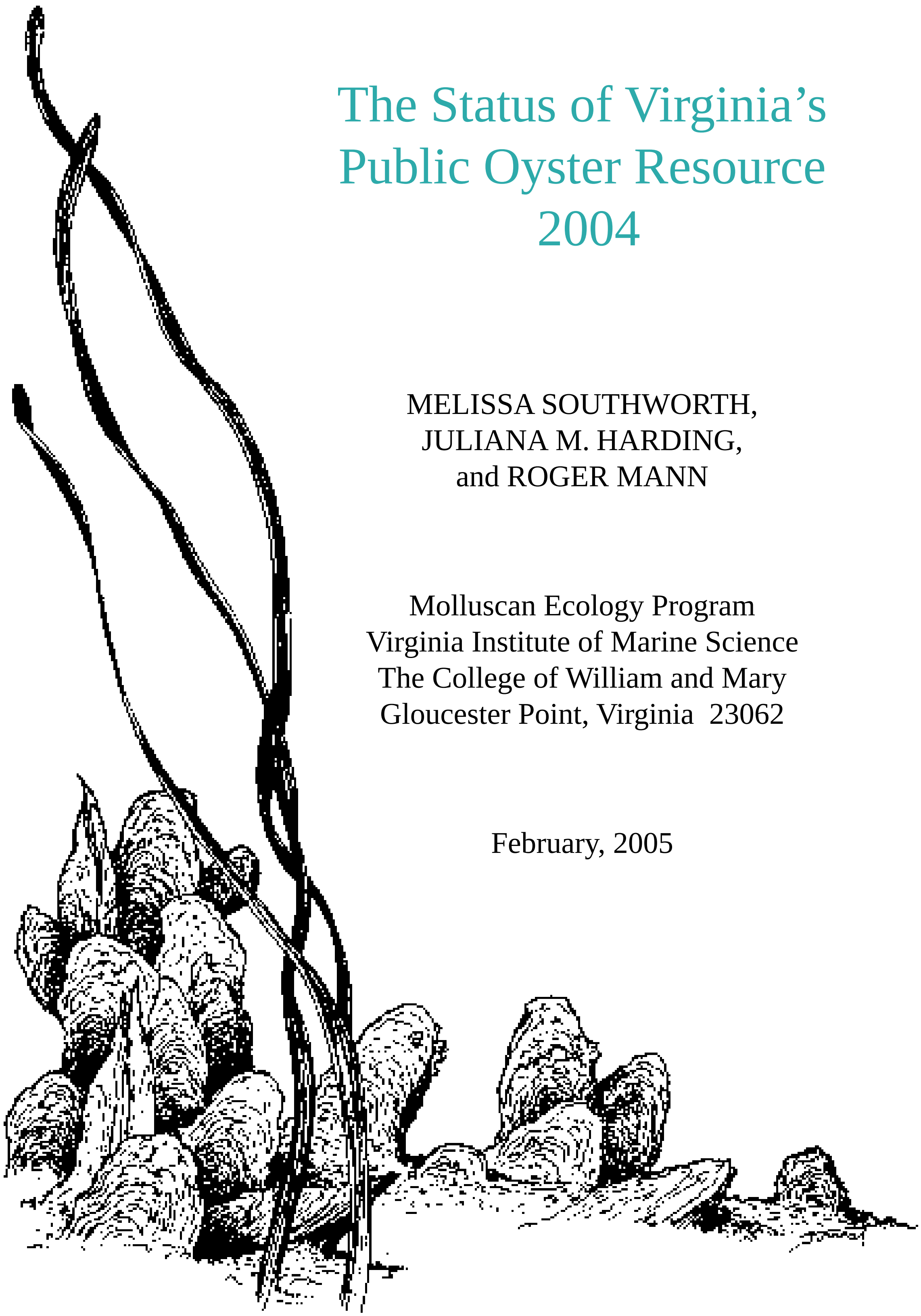
The Status of Virginia's Public Oyster Resource 2004



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Part I.

Oyster Spatfall In Virginia During 2004

INTRODUCTION

The Virginia Institute of Marine Science (VIMS) monitors the recruitment activity of the Eastern oyster, *Crassostrea virginica* (Gmelin), annually from late spring through early fall, by deploying spatfall (settlement of larval oysters or spat) collectors (shellstrings) at various stations throughout Virginia's western Chesapeake Bay tributaries. The survey provides an estimate of a particular area's potential for receiving a "strike" or settlement (set) of oysters on the bottom and helps describe the timing of settlement events. Information obtained from this monitoring effort provides an overview of long-term spatfall trends in the lower Chesapeake Bay and contributes to the assessment of the current oyster resource condition and the general health of the Bay system. These data are also valuable to parties interested in potential timing and location of shell plantings.

Results from spatfall monitoring reflect the abundance of ready-to-settle oyster larvae in an area, and thus, provide an index of oyster population reproduction as well as development and survival of larvae to the settlement stage in an estuary. Environmental factors affecting these physiological activities may cause seasonal and annual fluctuations in spatfall, which are evident in the data.

Data from spatfall monitoring also serve as an indicator of potential oyster recruitment into a particular estuary. Settlement and subsequent survival of spat on bottom cultch (shell available for larvae to settle on) are affected by many factors, including physical and chemical environmental conditions, the physiological condition of the larvae when they settle, predators, disease, and the timing of these factors. Abundance and condition of bottom cultch also affects settlement and survival of spat on the bottom. Therefore, settlement on shellstrings may not directly correspond with recruitment on bottom cultch at all times or places. Under most circumstances, however, the relationship between settlement on shellstrings and recruitment to bottom cultch is expected to be commensurate.

This report summarizes data collected during the 2004 settlement season in the Virginia portion of the Chesapeake Bay.

METHODS

Spatfall during 2004 was monitored from the first week of June through the last week of September in the James, Piankatank and Great Wicomico Rivers. Spatfall stations included eight historical sites in the James River, three historical and five new sites in the Piankatank River and five historical and four new sites in the Great Wicomico River (Figure S1). In this report, historical sites refer to those that have been monitored yearly for at least the past 15 years whereas "new" sites are stations that were added during 1998 to monitor the effects of replenishment efforts by the Commonwealth of Virginia. The new sites in both the Piankatank and Great Wicomico Rivers correspond to those sites that were considered "new" in the 1998 survey. Since 1993, the Virginia Marine Resources Commission (VMRC) has built numerous artificial oyster shell reefs in several tributaries of the western Chesapeake Bay, in Pocomoke and Tangier Sounds on the eastern side of the Chesapeake Bay as well as in several embayments on the Eastern Shore of Virginia (www.vims.edu/mollusc/monrestoration/restsitemaps/VArfrestsite.htm). The change in the number and location of shellstring sites during 1998 was implemented to provide a means of quantitatively monitoring oyster spatfall around these reefs. In particular, broodstock oysters were planted on a reef in the Great Wicomico River during winter 1996 and on reefs in the Piankatank and Great Wicomico Rivers during winter 1997. The increase in the number of shellstring sites during 1998 in the two rivers coincide with areas of new shell plantings in spring 1998 and provide a means of monitoring the reproductive activity of planted broodstock on the artificial oyster reefs. Since 1998, many of the reefs and bottom sites in the Piankatank and Great Wicomico Rivers have received both broodstock oysters on the reef and shell plants on the bottom surrounding the reefs. During 2004 (early summer) broodstock oysters were planted on Shell Bar Reef in the Great Wicomico River (www.vims.edu/mollusc/monrestoration/restoyreef.htm).

Oyster shellstrings were used to monitor oyster spatfall. A shellstring consists of twelve oyster shells of similar size (about 76 mm, (3-in) in length) drilled through the center and strung (inside of shell facing substrate) on heavy gauge wire (Figure S2). Throughout the monitoring period, shellstrings were deployed approximately 0.5 m (18-in) off the bottom at each station. Shellstrings were usually replaced after a one-week exposure and the number of spat that attached to the smooth underside of the middle ten shells was counted under a dissecting microscope. To obtain the mean number of spat shell^{-1} for the corresponding time interval, the total number of spat observed was divided by the number of shells examined (ten shells in most cases).

Although shellstring collectors at most stations were deployed for seven-day periods, there were some weather related deviations such that shellstring deployment periods ranged from six to fourteen days. These periods did not always coincide among the different rivers and areas monitored. Therefore, spat counts for different deployment dates and periods were standardized to correspond to the 7-day standard periods specified in Table 1. Standardized spat shell^{-1} (S) was computed using the formula:

$$S = \text{spat shell}^{-1} / \text{weeks } (W)$$

where W = number of days deployed / 7. Standardized weekly periods allow comparison of spatfall trends over the course of the season between the various stations in a river as well as between data for different years.

The cumulative spatfall for each station was computed by adding the standardized weekly values of spat shell^{-1} for the entire season. This value represents the average number of spat that would fall on any given shell if allowed to remain at that station for the entire sampling season. Spat shell^{-1} / week values were categorized for comparison purposes as follows: 0.10-1.00, light; 1.01-10.00, moderate; and 10.01 or more, heavy. Unqualified references to diseases in this text imply diseases caused by *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (*Perkinsus* or Dermo).

Water temperature and salinity measurements were taken at all stations. Water was collected each week from approximately 0.5 m off the bottom with a Niskin bottle. Temperature (degrees C) was then measured with an alcohol thermometer and salinity (in ppt, or parts per thousand) was measured with a hand-held refractometer.

RESULTS

Spatfall on shellstring collectors for 2004 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of settlement for the past 16 years at the historical stations in all three river systems and the past 7 years for the new stations in the Piankatank and Great Wicomico Rivers. Unless otherwise specified, the information presented below refers to those two tables. In this report the term peak is used to define the period when there was a noticeable increase in settlement at a particular site or area in the system compared with the other sites or when there was an increase at all sites throughout an entire river system. When comparing 2004 data with historical data in the James River, all eight stations were used. All of the stations monitored in the James River are considered to be part of the seed area, where traditionally, seed oysters were transplanted from this area to other tributaries in the Chesapeake Bay where recruitment was low (Haven and Fritz 1985). Due to the addition of new sites during 1998 in the Piankatank and Great Wicomico Rivers, any comparison made to historical data could not include data from all of the sites sampled during 2004. Comparisons were made over the past 5 years for the new sites whereas the historical sites include 15 years of data. Historical sites in the Piankatank River are Burton Point, Ginney Point and Palace Bar. Historical sites in the Great Wicomico River include Fleet Point, Glebe Point, Haynie Point, Hudnall and Whaley's East (Cranes Creek in data reports prior to 1997).

James River

Oyster settlement in the James River was first observed during the week of June 24 at Wreck Shoal (Table S1). Settlement began at five out of the other seven sites in early July. From mid-July through the end of the season, settlement was relatively heavy and consistent (at least one spat per week) at the more downriver sites whereas it was lighter and intermittent at the more upriver sites. There was a peak in settlement throughout the river in late July into early August, with a second peak at Wreck Shoal in mid September (Figure S3)

Overall settlement in the James River during 2004 was moderate to heavy with cumulative spat shell^{-1} / week ranging from a low of 1.55 at Deep Water Shoal to a high of 21.6 at Wreck Shoal. It should be noted that data were only available at Dry Shoal for nine out of the eighteen weeks of sampling, so caution should be used when interpreting data from that site. In years past, settlement in the James tended to be higher at the more southern downriver stations when compared with the more northern upriver stations (Figure S1 and Table S2). The past five to six years have been characterized with a relatively even spat set throughout the system, however during 2004 there was a slightly higher percentage of settlement at the more downriver sites when compared with the upriver sites.

Settlement in the James River during 2004 showed an order of magnitude increase from the previous year (2003) at all of the stations monitored (Table S2; Figure S4). Spatfall during 2004 was higher than the 5, 10 and 15-year means at both Rock Wharf and Wreck Shoal. It was also higher than both the 5 and 10-year means at Swash and Dry Shoal. The large number of spat recorded at Dry Shoal was surprising given the unavailability of data for half of the season as previously mentioned. Spatfall at the other four sites while higher than that observed during 2003, was lower than the previous 5, 10 and 15-year means.

Average river water temperatures reached a maximum in early July (30.0˚C: Figure S5A). Water temperature was similar to the 5, 10 and 15-year means (Figure S5A) throughout the sampling period. Beginning in mid-July salinity was anywhere from 3 to 8 ppt lower during 2004 than the 5, 10 and 15-year means (Figure S5B). The low salinity continued throughout the rest of the sampling period and never reached above 10 ppt at any of the sites monitored during the month of September. There was a 6 to 10 ppt salinity difference between Deep Water Shoal (the most upriver station) and Day's Point (the most downriver station: Figure S1), a slightly higher difference than in previous years.

Piankatank River

Settlement in the Piankatank River was first observed during the week of July 29 at four out of the eight stations monitored (Table S1). Settlement began at all stations the following week and was light and intermittent throughout the rest of the sampling period (Figure S6). There was a small peak in settlement at Burton Point during the week of August 5 (Figure S6). Overall settlement was moderate at Burton Point and Cape Toon and low at the remaining six stations.

Cumulative spat shell^{-1} / week for the year ranged from a low of 0.15 at Ginney Point to a high of 1.98 at Cape Toon.

Spatfall during 2004 showed a small increase when compared with 2003 at all stations monitored except Ginney Point where there was no observed difference between the 2 years (Table S2: Figure S7). At two of the historical stations (Ginney Point and Palace Bar), settlement was an order of magnitude lower than the previous 5, 10 and 15-year means. Settlement at the other five (new) stations was lower than the previous 5-year mean and was among the lowest observed since monitoring began at those sites in 1998.

The average water temperature ranged from 22 to 29˚C throughout the sampling period, reaching a maximum in mid July. Water temperature was similar to the average temperatures previously recorded in the river except during the first 2 weeks of sampling when it was 4 to 5 degrees higher than the 5, 10 and 15-year means (Figure S8A). Salinity ranged from 7 to 16 ppt throughout the sampling period. In early June, salinity was around 4 ppt lower than the previously recorded salinities in the river. Salinity then rose and was similar to the 5, 10 and 15-year means until mid July when salinity again dropped and remained 2 to 4 ppt lower than the average for the rest of the sampling period (Figure S8B). There were several weeks in July when the salinity changed 2 to 3 ppt on a weekly basis. The difference recorded between Wilton Creek (the most upriver station) and Burton Point (the most downriver station: Figure S1) ranged between 1 and 4 ppt throughout the sampling period.

Great Wicomico River

Settlement in the Great Wicomico River during 2004 began at Hudnall and Shell Bar during the week of July 15. Settlement throughout the river was intermittent and light from August 5 through September 23 (Figure S9). There was a small peak in settlement observed at Glebe Point during the week of August 19 (Figure S9).

Cumulative spat shell^{-1} / week for the year ranged from a low of 0.05 at Whaley's East to a high of 1.6 at Glebe Point. As has been observed in the past, settlement at the two stations downriver of Sandy Point, Whaley's East and Fleet Point, was among the lowest observed in the system. Settlement during 2004 was lower than the previous year (2003) at all of the stations sampled (Table S2: Figure S10). Settlement was lower during 2004 than the previous 5-year mean at all stations sampled and lower than both the 10 and 15-year means at the five historical stations (Table S2). The pattern of an increase in spatfall as one moves upriver was once again observed in the Great Wicomico, with the highest spatfall occurring at Glebe Point (the most upriver station).

Average river water temperatures ranged between 23 and 31˚C throughout the sampling period (Figure S11A). Water temperature reached a maximum in mid July. Given the lack of historical data for the Great Wicomico River, temperature and salinity during 2004 could only be compared with the previous 5-year mean instead of the 5, 10 and 15-year means as it was in the James and Piankatank Rivers. Water temperature throughout the sampling period was similar to the previous 5-year mean; excluding the first 2 weeks of June when similar to the Piankatank River it was several degrees higher than the average (Figure S11A). Salinity patterns in the Great Wicomico River were also similar to the patterns observed in the Piankatank River. Low salinities prevailed in early June, they returned to normal for several weeks until mid July when they dropped below the average and remained below average for the rest of the sampling period. Throughout the month of July and into early August, salinity in the Great Wicomico River experienced a 2 to 3 ppt difference between sampling weeks, such that if it were 10 ppt one week, it would increase to 13 ppt the next; then again decrease to 10 ppt the following week (Figure S11B). As typical in previous years, there was a 1 to 4 ppt difference in salinity between the most upriver station (Glebe Point) and the most downriver station (Fleet Point: Figure S1) throughout most the sampling period.

DISCUSSION

With few exceptions in each of the rivers during various years, low spatfall (< 10 spat shell^{-1}) has been common in Virginia since 1993. While settlement during 2004 in the Piankatank River was higher than that recorded during 2003, spatfall during 2004 in both the Piankatank and Great Wicomico Rivers was among the lowest observed over the last 15 years of monitoring (Table S2). Oyster settlement in the James River

was good (1.6 to 21.6 spat shell^{-1}) at all eight sites compared with 2004 and was among the highest recorded over the past 15 years of monitoring at several of the downriver sites (second highest at Wreck Shoal and fourth highest at Rock Wharf).
Overall oyster settlement in the Piankatank and Great Wicomico River systems was among the lowest observed during the past 15 years of monitoring, while settlement in parts of the James River system was among the highest observed during the past 15 years. There are several factors that may have contributed to this discrepancy between the three river systems. Both temperature and salinity in the James River were within normal ranges until mid way through the spawning season. In the Piankatank and Great Wicomico Rivers, temperature was higher than normal and salinity was lower than normal early in the season and while temperature reached within normal seasonal range by mid June, salinity was lower than average throughout the majority of the spawning season (from mid July onward). Factors such as gametogenesis or fecundity, larval survival and growth in the plankton, quantity and quality of food, and success of metamorphosis are all affected by salinity, and in turn could have had an effect on both the timing and size of oyster settlement during 2004.

While the relationship between salinity and gametogenesis and fecundity is not well described in the literature we can make some general observations. Butler (1949) showed that prolonged levels of decreased salinity could inhibit gametogenesis thus preventing normal development of the gonad until salinities increase. In oysters gametogenesis begins with rising water temperatures in the spring (Thompson et al. 1996). If salinity during the spring season was lower than the seasonal average as suggested by the low salinity measured in the first part of June, then the broodstock in both the Piankatank and Great Wicomico Rivers may have experienced decreased gonadal development early in the season. The salinity in both systems did increase in mid June, but dropped again within a month and continued to be lower than the seasonal average throughout the rest of the season. While Butler (1949) showed that normal gametogenesis will occur once salinity rises, the duration of the increased salinities in the Piankatank and Great Wicomico Rivers may not have been long enough to promote normal gonadal development. In contrast salinity in the James River was near the 5, 10 and 15-year means until well into July, salinity didn't decrease until after the gonads were most likely fully developed as evidenced by the presence of spat in late June and early July (indicating that the broodstock had developed and spawned). Salinity may also have a direct effect on fecundity. Mann et al. (1994) found fecundity varied significantly over a 3-year period and observed reduction in fecundity was correlated with declining salinities. Perhaps with the lower than normal salinity observed during 2004, the fecundity of broodstock throughout the Piankatank and Great Wicomico Rivers was reduced. In the James River, the lowered salinity occurred later in the season, so as with the gametogenesis, the drop in salinity didn't affect fecundity, as it would have had it occurred earlier in the spawning season.

Decreased salinity may also influence the quantity and quality of food available to larvae. Light and nutrients are the two major factors that limit primary productivity (Lalli and Parsons, 1995). The decreased salinities throughout the three systems were most likely caused by an increase in rainfall as evidenced by the increase in stream flow for most of the sampling period (USGS, water data http://nwis.waterdata.usgs.gov). An increase in water flow in a system can increase stratification, thereby decreasing the amount of vertical mixing that occurs. This in turn prevents the necessary nutrients from the bottom layer from being mixed into the surface layer where they need to be to be available for use by the phytoplankton.

Historically, oyster settlement in the James River tended to be greater at stations in the lower part of the seed area with the majority of the larvae being supplied by broodstock in the lower estuary (Haven and Fritz 1985, Ruzecki and Hargis 1989). With the onset of the two oyster diseases (MSX and Perkinsus) in the1960s, the available broodstock has been slowly making an up-estuary progression primarily due to a die-off of oysters in the lower estuary caused by the diseases (Southworth and Mann 2004). This has resulted in an up-estuary progression of oyster settlement such that for the past several decades the difference between spatfall numbers at the more downriver sites versus the more upriver sites in the seed area have decreased. However, in the past 2 to 3 years due to decreased salinities both MSX and *Perkinsus* prevalence have decreased throughout the James River (Carnegie, VIMS, personal communication). This, in turn has resulted in an increase in the number of broodstock oysters in the lower portion of the estuary (Part II of this report). While continued low salinities over the past 2 years has caused a decrease in the number of oysters in the upper James (Southworth et al. 2004), the same low salinities have allowed an increase in oyster populations in the lower James, creating conditions more similar to the historic conditions observed by Andrews (1951) and Haven and Fritz (1985). This may be one reason for the increase in spatfall observed at the more downriver sites in the James River during 2004.

Table S1: Average number of spat shell^{-1} for standardized week beginning on the date shown. "D" indicates the date deployed. "-" denotes a week when a shellstring was not collected.

STATION	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/2	9/9	9/16	9/23	9/30	YEAR
	147	154	161	168	175	182	189	196	203	210	217	224	231	238	245	252	259	266	273	TOTAL
James River																				
Deep Water Shoal	D	0	0	0	0	0	0.2	0.15	0.95	0.05	0	0.15	0.05	0	0	-	0	-	0	1.55
Horsehead	D	0	0	0	0	0	0	0	1.45	0.3	0.7	0.3	0.1	0.6	0	-	0.15	-	0.04	3.64
Point of Shoal	D	0	0	0	0	0	0.05	0.05	1.15	0.2	0.45	0.75	0	0.4	0	-	0	-	0.04	3.09
Swash	D	0	0	0	0	0	0.8	0	3.5	1.25	3.3	1.0	0.2	0.85	0.5	-	0.33	-	0.18	11.91
Dry Shoal	D	0	0	N	N	0	0.65	0.1	2.7	2.15	1.1	2.0	N	N	N	-	N	-	N	8.70
Rock Wharf	D	0	0	0	0	0	0	0.1	3.05	0.9	2.95	0.55	0.5	0.9	0.3	-	0.28	-	0.44	9.97
Wreck Shoal	D	0	0	0	0.05	0	0.55	0.4	4.0	5.65	3.5	2.2	0.8	0.75	2.65	-	0.7	-	0.35	21.6
Day's Point	D	0	0	0	0	0	0.1	0.05	0.45	0.3	1.2	0.45	0.1	0.2	0.35	-	0.25	-	0.13	3.58
Piankatank River																				
Wilton Creek		D	0	0	0	0	0	0	0	0	0.1	0	0	0	0	-	0.05	0.05	0	0.20
Ginney Point		D	0	0	0	0	0	0	0	0	0.1	0	0	0	0	-	0	0.05	0	0.15
Palace Bar		D	0	0	0	0	0	0	0	0	0.2	0	0.2	0	0	-	0	0.05	0	0.45
Bland Point		D	0	0	0	0	0	0	0	0.05	0.2	0	0.05	0.05	0	-	0	0.05	0	0.40
Heron Rock		D	0	0	0	0	0	0	0	0	0.1	0.1	0.15	0.05	0	-	0.2	0.1	0	0.70
Cape Toon		D	0	0	0	0	0	0	0	0.2	0.5	0.15	0.25	0.2	0.15	-	0.28	0.25	0	1.98
Stove Point		D	0	0	0	0	0	0	0	0.05	0.2	0.05	0.15	0	0.05	-	0.05	0.05	0.05	0.65
Burton Point		D	0	0	0	0	0	0	0	0.1	1.4	0	0.05	0.1	0.05	-	0.1	0	0.1	1.90
Great Wicomico River																				
Glebe Point		D	0	0	0	0	0	0	0	0	0.25	0	1.0	0	0	-	0.05	0.3	0	1.60
Rogue Point		D	0	0	0	0	0	0	0	0	0	0	0	0	0.05	-	0.05	0.4	0	0.50
Hilly Wash		D	0	0	0	0	0	0	0	0	0.25	0	0.05	0	0.1	-	0	0.1	0	0.50
Harcum Flats		D	0	0	0	0	0	0	0	0	0	0	0.1	0	0.2	-	0	0.4	0	0.70
Hudnall		D	0	0	0	0	0	0.1	0	0	0.05	0.05	0.05	0.05	0	-	0	0.25	0	0.55
Shell Bar		D	0	0	0	0	0	0.05	0	0	0.15	0	0.05	0	0.05	-	0.03	0	0	0.33
Haynie Point		D	0	0	0	0	0	0	0	0	0.05	0	0.1	0	0	-	0	0.1	0	0.25
Whaley's East		D	0	0	0	0	0	0	0	0	0	0	0.05	0	0	-	0	0	0	0.05
Fleet Point		D	0	0	0	0	0	0	0	0	0	0.15	0	0	0	-	N	0.15	0	0.30

Table S2: Spatfall totals for historical sites (1988-2004) and for 1998-2004 at sites where historical data are not available. Values are presented as the cumulative sum of spat shell^{-1} values for each year. "+" and "-" indicate direction of change in 2004 in reference to 2003 and to the five, ten, and fifteen-year means. Blank cells for a site indicate years where data are not available.

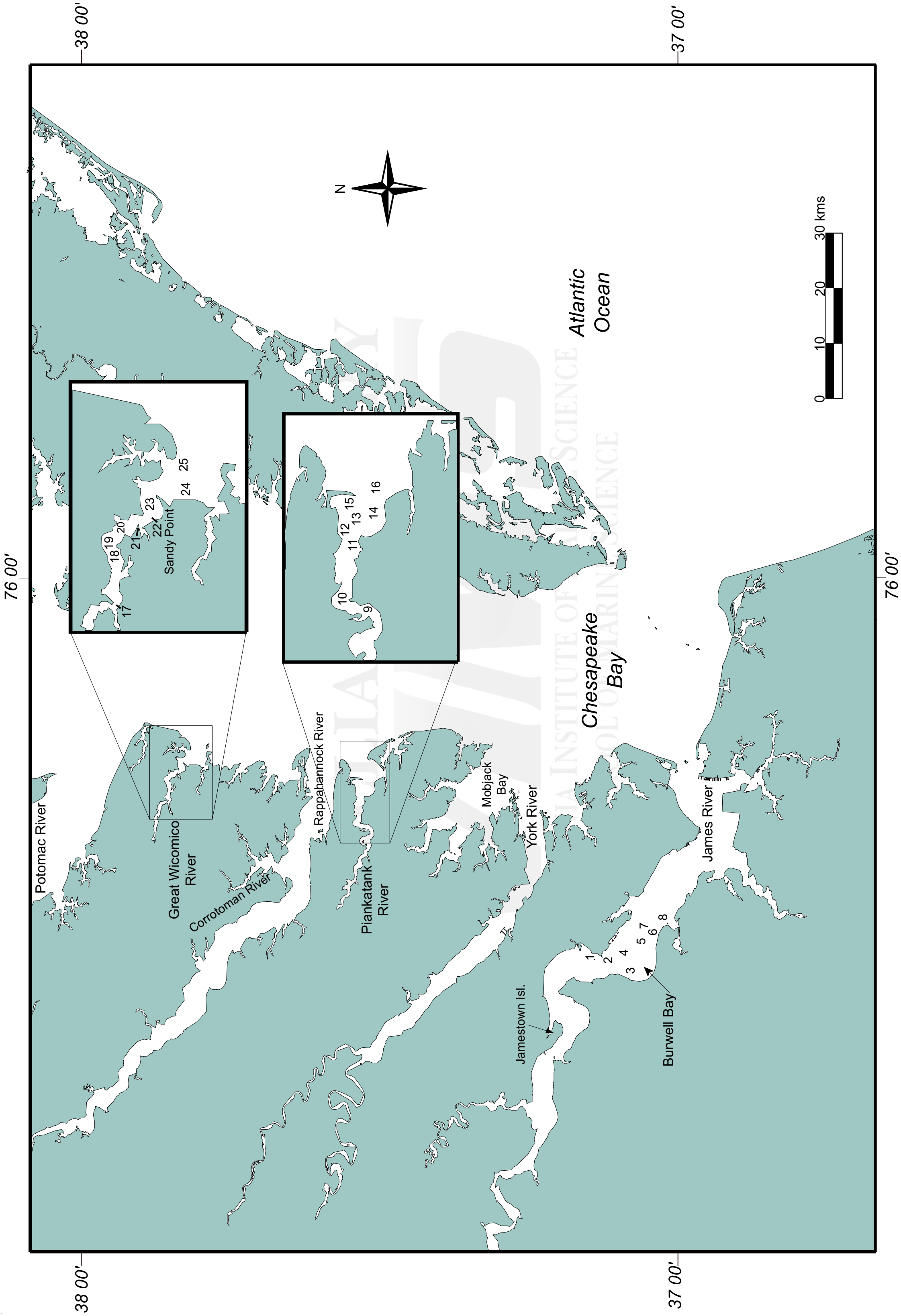
STATION	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Mean 99-03	Mean 94-03	Mean 89-03	Ref. 2003	Ref. 5-yr	Ref. 10-yr	Ref. 15-yr
James River																							
Deep Water Shoal	2.0	2.6	10.6	0.7	15.7	0.6	1.7	0.5	1.3	1.2	5.7	0.7	2.0	33.8	0.1	1.6	8.5	4.8	5.3	+	-	-	-
Horsehead	1.5	0.9	24.7	3.6	43.7	3.2	0.3	3.6	2.4	1.1	3.8	2.3	4.0	24.4	0.0	3.6	6.9	4.5	8.0	+	-	-	-
Point of Shoal	3.7	14.3	21.4	5.4	73.7	15.0	4.8	2.3	2.3	1.5	3.5	0.7	4.0	31.3	0.1	3.1	7.9	6.6	12.3	+	-	-	-
Swash	3.8	3.3	68.7		46.2	4.8	1.8	2.2	1.7	1.6	6.8	2.6	3.5	26.0	0.5	11.9	7.9	5.1	12.4	+	+	+	-
Dry Shoal	10.0	30.9	217.1	14.2	119.0	25.8	2.8	11.0	1.1	1.1	6.1	3.7	2.1	16.5	0.6	8.7	5.8	7.1	30.8	+	+	+	-
Rock Wharf	2.1	1.8		11.4	34.3	10.7	0.2	2.4	5.6	2.1	8.0	1.0	8.5	22.7	0.1	10.0	8.1	6.1	7.9	+	+	+	+
Wreck Shoal	10.2	4.0	35.3	3.3	15.5	2.2	2.6	10.0	0.7	0.7	3.1	0.9	3.2	8.3	1.3	21.6	3.4	3.3	6.8	+	+	+	+
Day's Point	26.1	22.4	145.6	14.2	131.5	42.2	3.0	4.6	5.6	0.4	7.3	4.3	1.6	10.5	0.1	3.6	4.8	8.0	28.0	+	-	-	-
Piankatank River																							
Wilton Creek										1.9	5.9	3.6	0.2	6.5	0.1	0.2	3.3			+	-		
Ginney Point	29.9	62.6	25.4	11.4	1.7	0.0	0.5	1.3	0.0	2.2	6.4	6.8	1.2	5.9	0.2	0.2	4.1	2.5	10.4	NC	-	-	-
Palace Bar	42.4	119.2	38.9	24.9	5.0	0.8	1.0	1.6	0.0	5.5	10.1	3.9	0.2	3.1	0.1	0.5	3.5	2.6	17.1	+	-	-	-
Bland Point										2.3	44.1	2.7	1.3	6.7	0.2	0.4	11.0			+	-		
Heron Rock										10.1	9.3	3.2	0.6	5.1	0.2	0.7	3.7			+	-		
Cape Toon										4.5	12.3	1.2	1.8	9.1	0.1	2.0	4.9			+	-		
Stove Point										1.0	7.1	1.8	1.6	31.0	0.1	0.7	8.3			+	-		
Burton Point	31.6	87.4	16.4	11.7	6.5	0.1	1.0	1.0	0.7	1.3	14.9	2.7	0.8	4.9	0.2	1.9	4.7	2.4	12.1	+	-	-	-
Great Wicomico River																							
Glebe Point	8.2	19.5	1.9	0.5	0.2	0.0	1.5	0.6	21.2	0.6	2.4	4.2	1.1	283.3	4.9	1.6	59.2	32.0	23.3	-	-	-	-
Rogue Point										0.9	2.0	2.6	0.7	16.6	7.0	0.5	5.8			-	-		
Hilly Wash										0.6	1.6	3.2	0.8	24.1	2.9	0.5	6.5			-	-		
Harcum Flats										0.1	1.3	0.8	1.1	33.7	3.7	0.7	8.1			-	-		
Hudnall	26.4	94.8	4.5	0.5	0.8	0.0	0.1	0.2	39.1	0.5	0.9	1.0	1.4	12.7	3.1	0.6	3.8	5.9	12.4	-	-	-	-
Shell Bar										0	2.9	0.8	0.8	17.8	1.9	0.3	4.8			-	-		
Haynie Point	17.0	68.2	12.4	0.6	1.4	0.0	1.0	3.7	4.4	0.7	1.1	1.1	0.9	15.4	1.6	0.3	4.0	3.0	8.6	-	-	-	-
Whaley's East	8.4	39.1	7.9	0.1	0.2	0.0	0.3	2.1	1.0	0.4	1.8	0.2	0.7	2.4	0.9	0.1	1.2	1.0	4.4	-	-	-	-
Fleet Point	7.9	17.4	5.8	2.9	2.0	0.0	0.3	2.6	3.4	0.3	0.5	0.6	1.0	3.9	0.4	0.3	1.3	1.3	3.3	-	-	-	-

Figure S1: Map showing the location of the 2004 shellstring sites. An N following the site name indicates a new site as specified in the text; all other sites are historical.

James River: 1) Deep Water Shoal, 2) Horsehead, 3) Point of Shoal, 4) Swash, 5) Dry Shoal, 6) Rock Wharf, 7) Wreck Shoal, 8) Day's Point.

Piankatank River: 9) Wilton Creek (N), 10) Ginney Point, 11) Palace Bar, 12) Bland Point (N), 13) Heron Rock (N), 14) Cape Toon (N), 15) Stove Point (N), 16) Burton Point.

Great Wicomico River: 17) Glebe Point, 18) Rogue Point, 19) Hilly Wash (N), 20) Harcum Flats (N), 21) Hudnall, 22) Shell Bar (N), 23) Haynie Point, 24) Whaley's East, 25) Fleet Point.


38 00'
37 00'
76 00'
N
Atlantic
Ocean
Chesapeake
Bay
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20
30 kms
Potomac River
Great Wicomico
River
Corrotoman River
Rappahannock River
Piankatank
River
Mobjack
Bay
York River
James River
Jamestown Isl.
Burwell Bay
Sandy Point
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Figure S2: Diagram of shellstring setup on buoys.

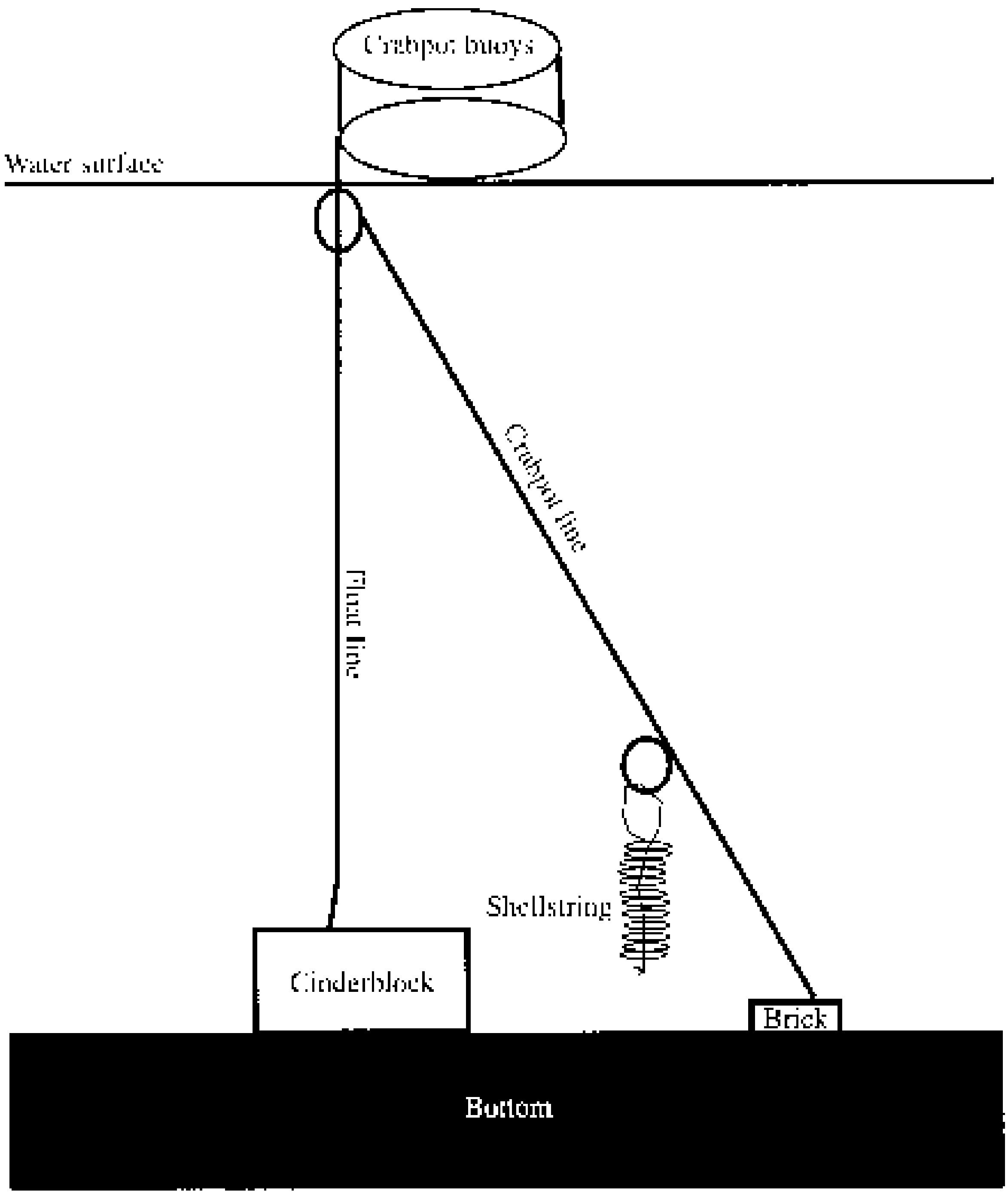


FIGURE S3: JAMES RIVER (2004) WEEKLY SPATFALL INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

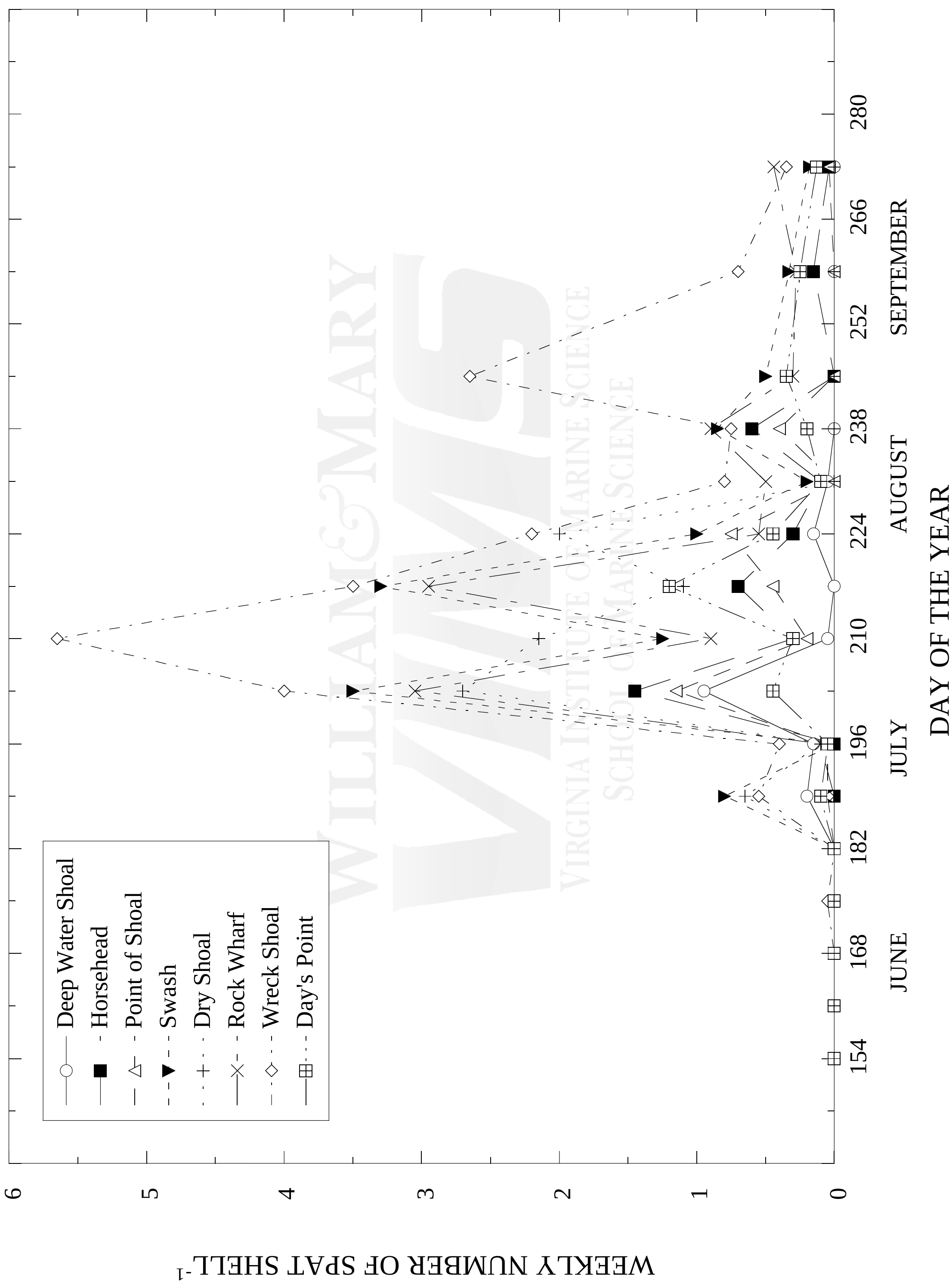


FIGURE S4: SPATFALL TRENDS OVER THE PAST 15 YEARS AT ALL 8 SITES IN THE JAMES RIVER (upriver sites in top panel; downriver sites in bottom panel) (expressed as cumulative weekly spatfall)

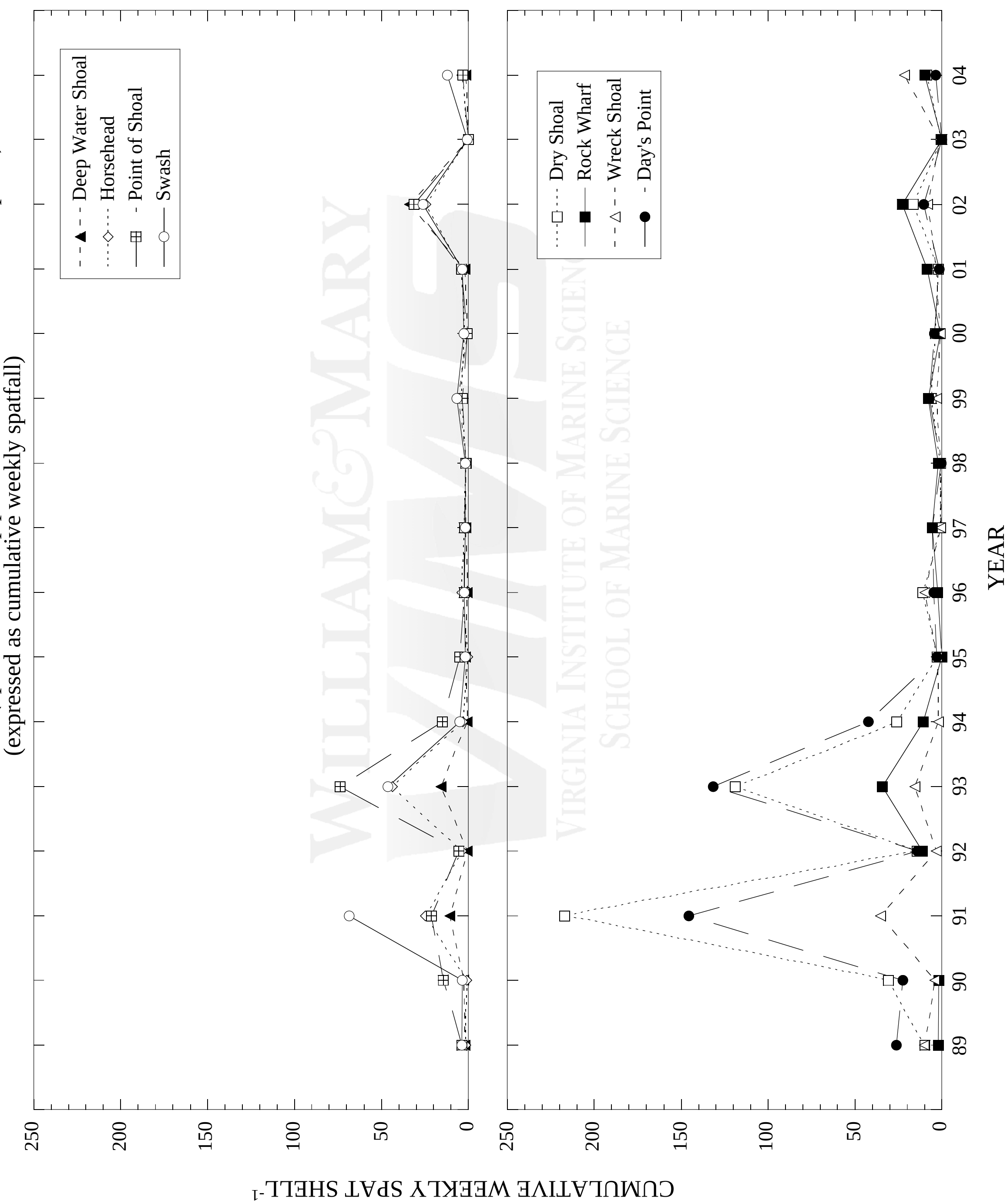


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 15-YEAR MEANS COMPARED WITH 2004
(Error bars represent standard error of the mean; shaded area represents settlement during 2004)

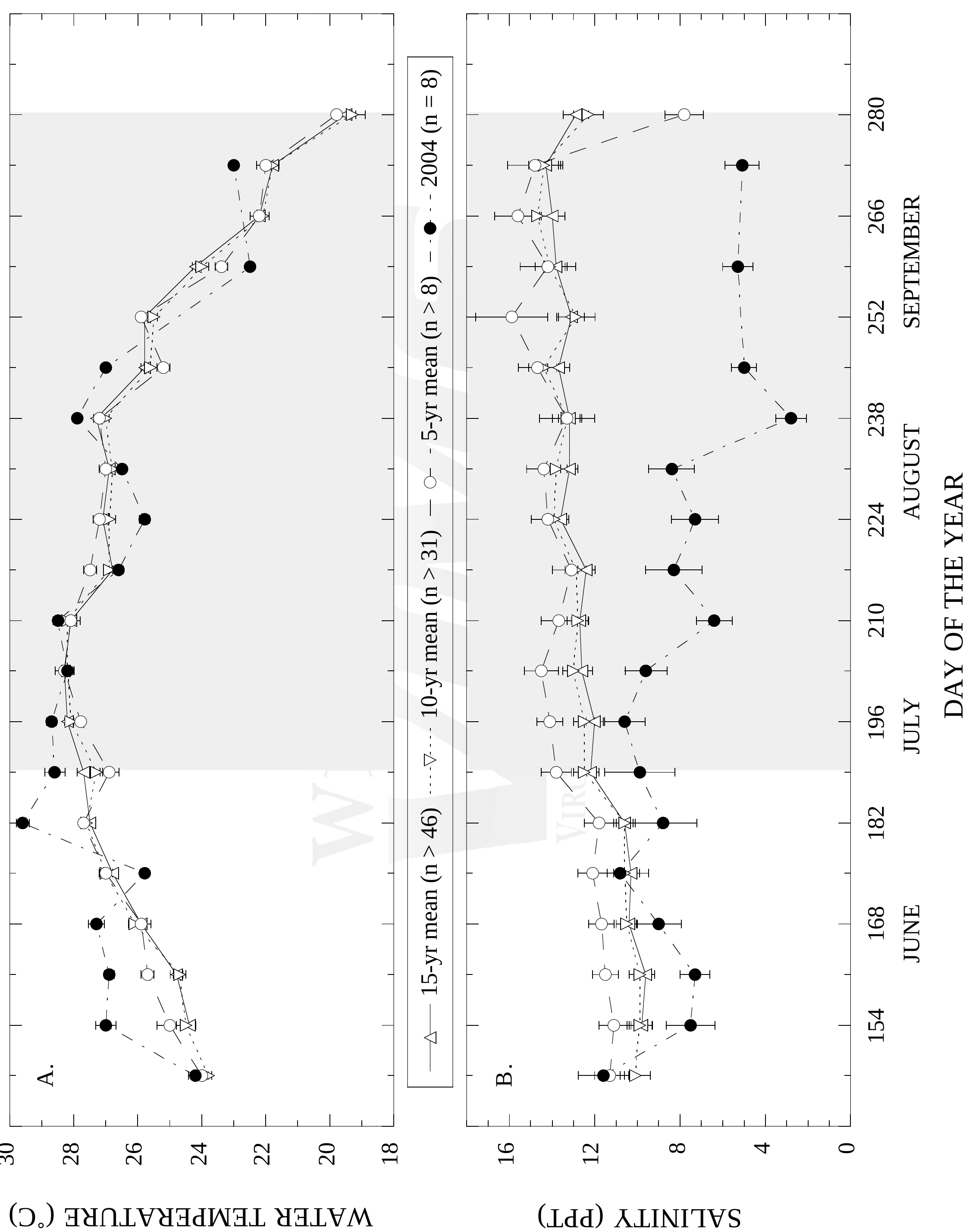


FIGURE S6: PIANKATANK RIVER (2004) WEEKLY SPATFALL INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: N = new station as described in text)

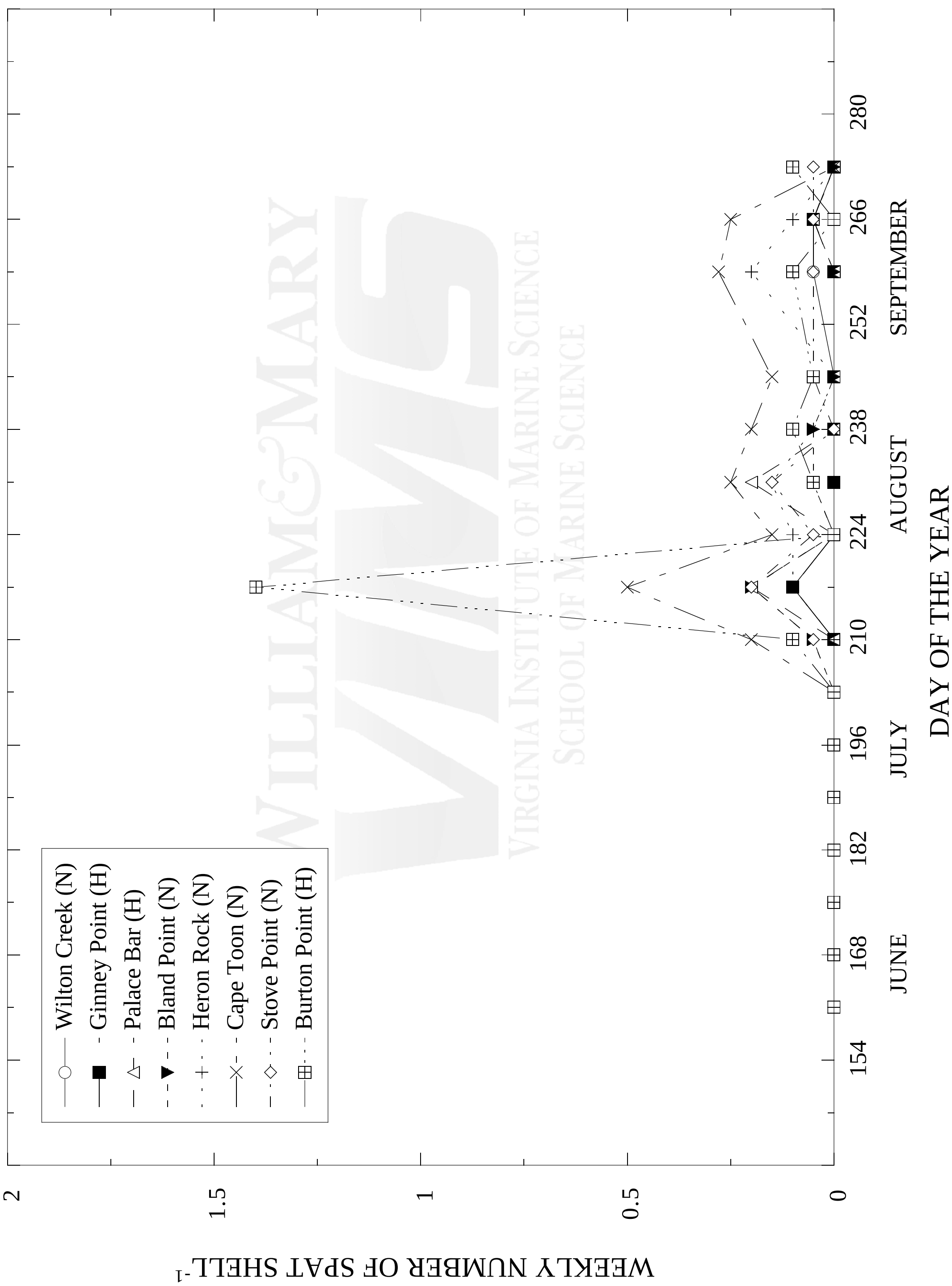


FIGURE S7: SPATFALL TRENDS IN THE PIANKATANK RIVER AT THE 3 HISTORICAL SITES (panel A: 15 years) AND THE 5 NEW SITES (panel B: 5 years)
(Expressed as cumulative weekly spatfall)

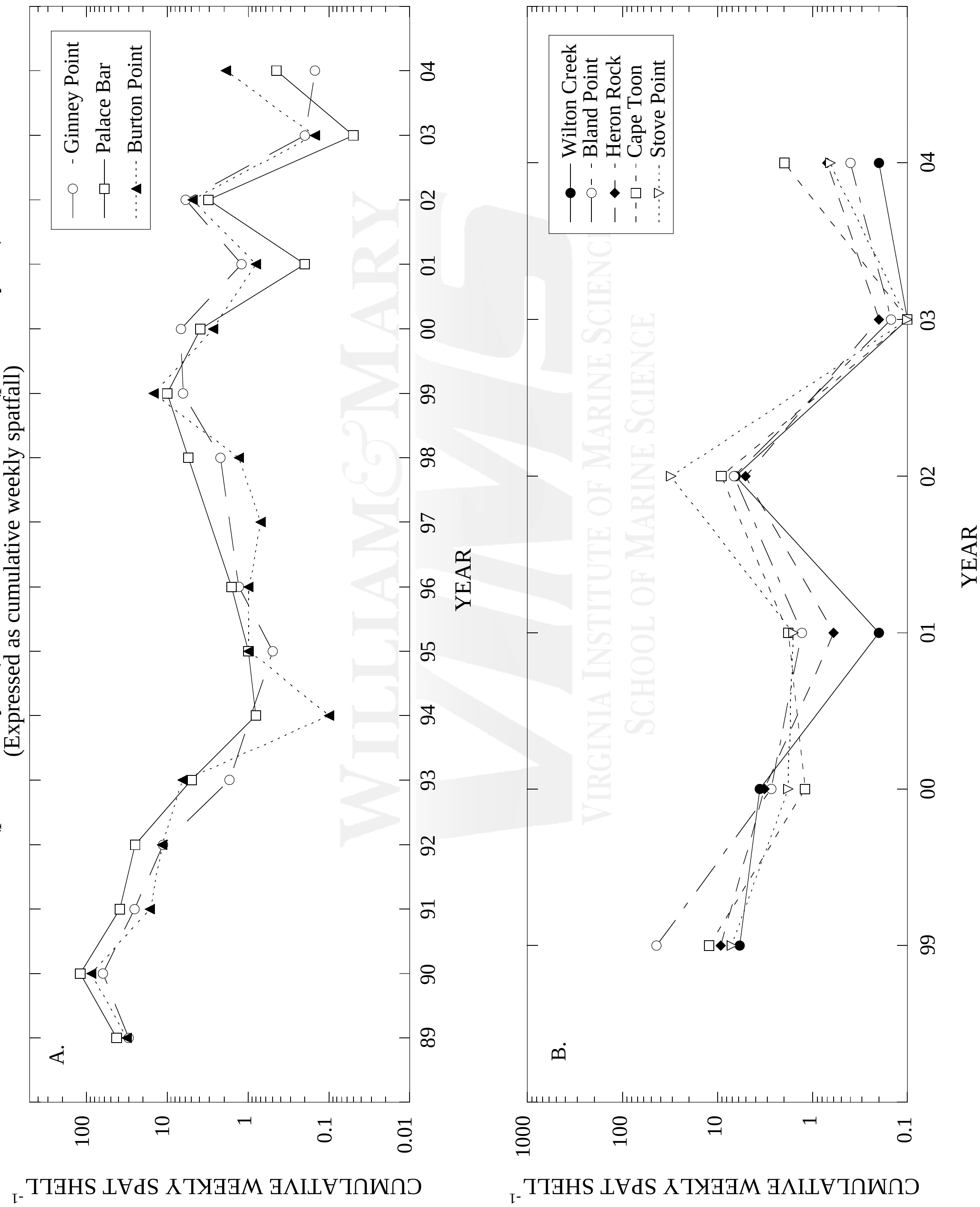


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 15-YEAR MEANS COMPARED WITH 2004
(Error bars represent standard error of the mean; shaded area represents settlement during 2004)

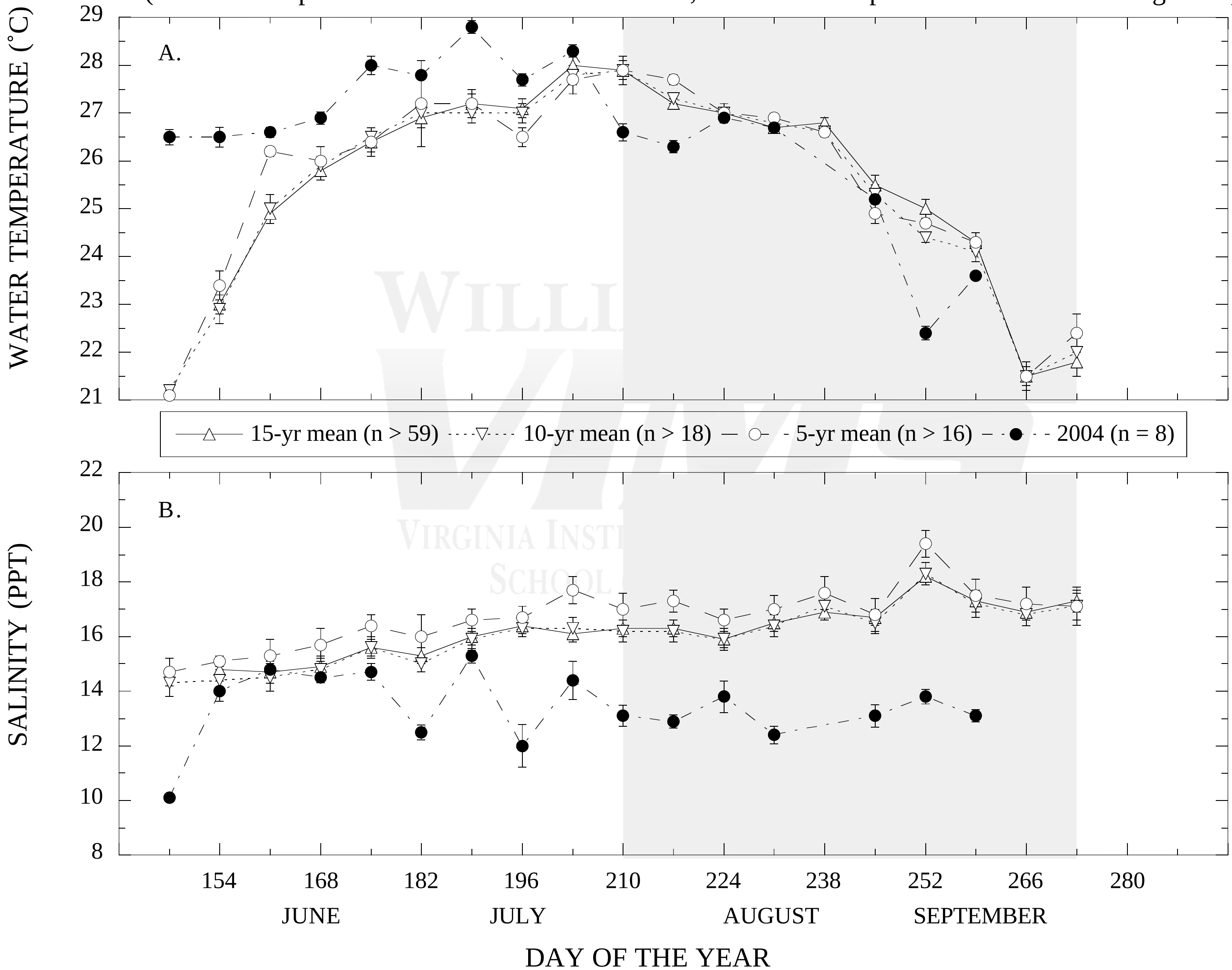


FIGURE S9: GREAT WICOMICO RIVER (2004) WEEKLY SPATFALL INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: N = new station as described in text)

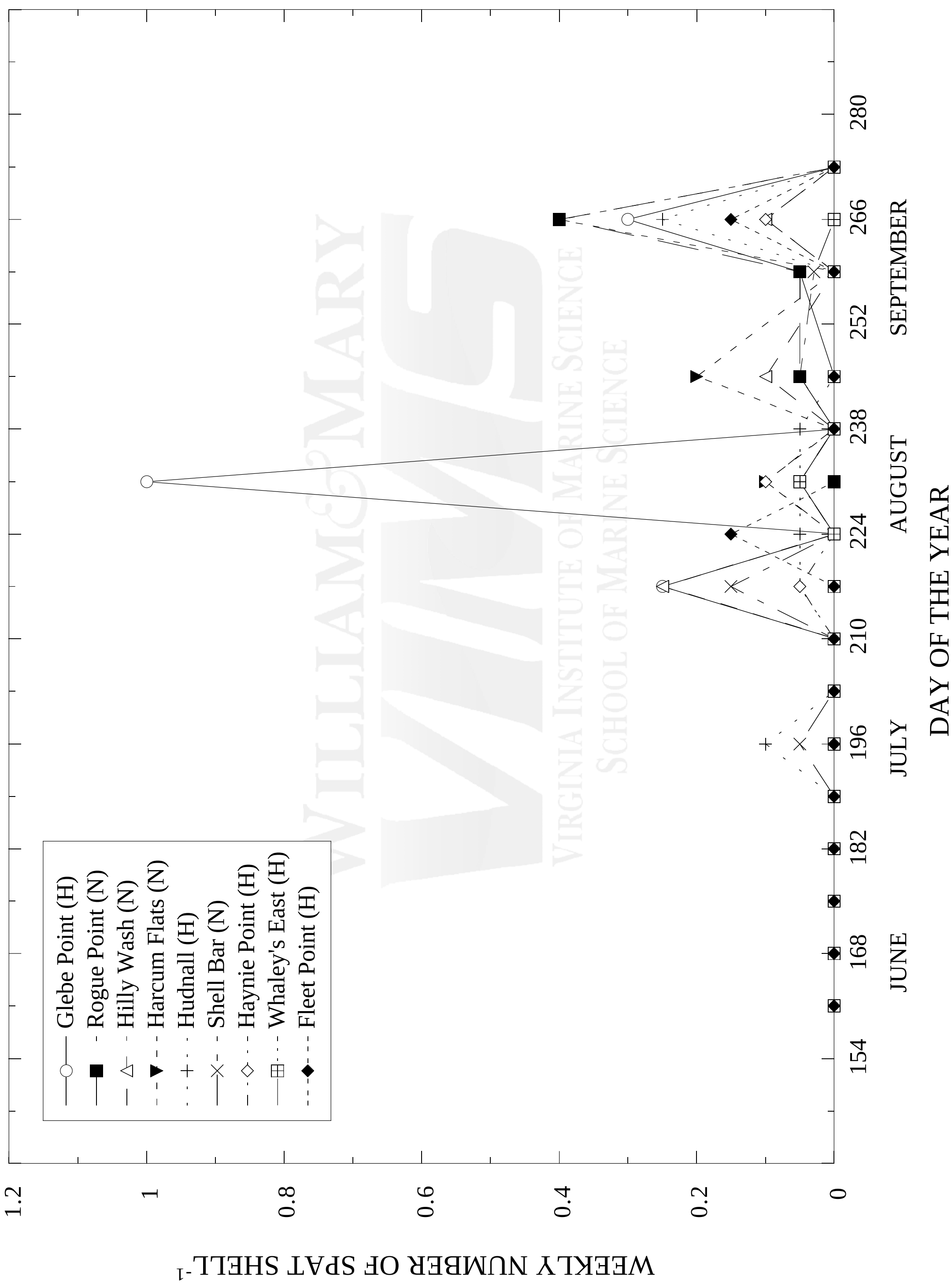


FIGURE S10: SPATFALL TRENDS IN THE GREAT WICOMICO RIVER AT THE 5 HISTORICAL SITES (panel A: 15 years) AND THE 4 NEW SITES (panel B: 5 years) (Expressed as cumulative weekly spatfall)

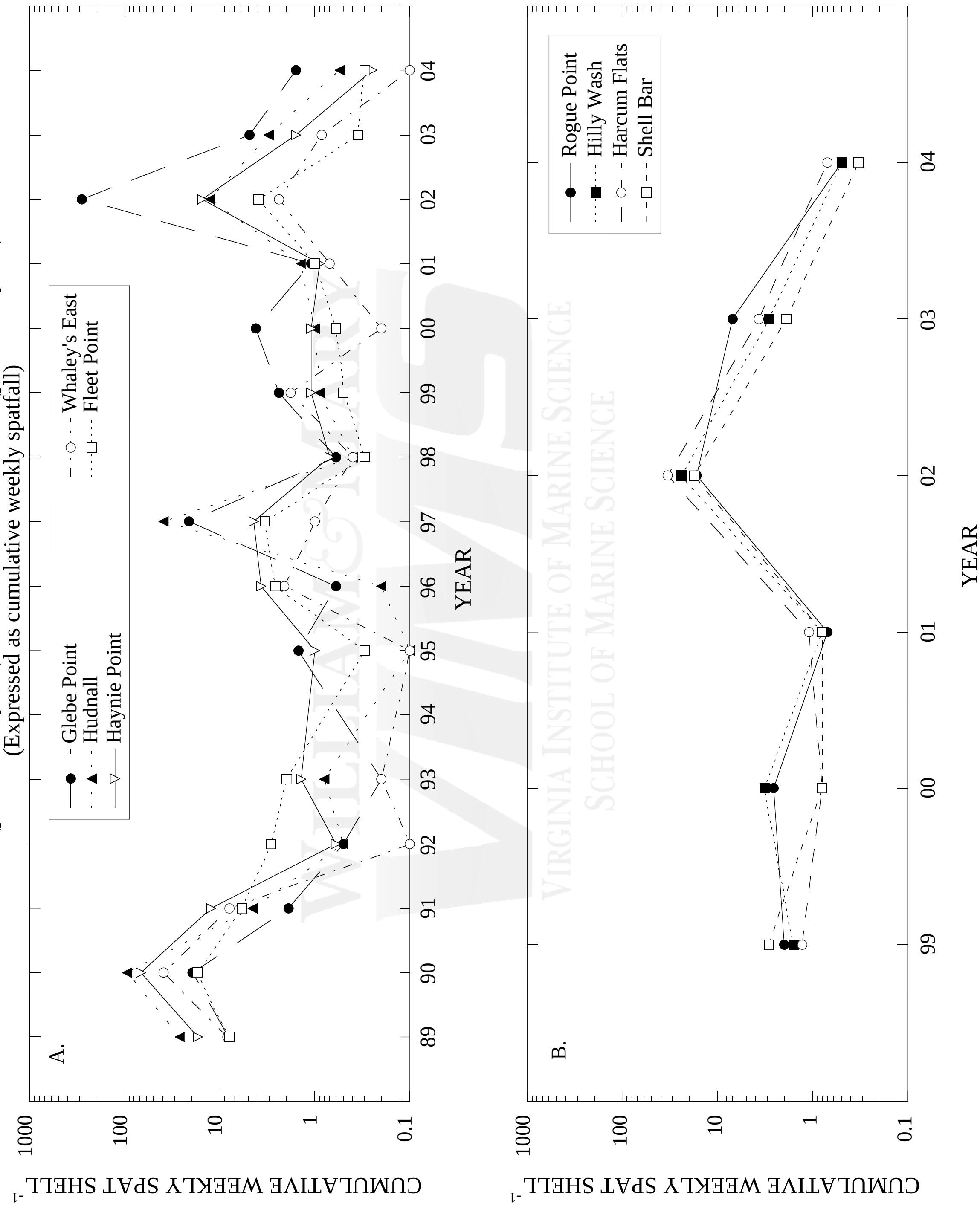
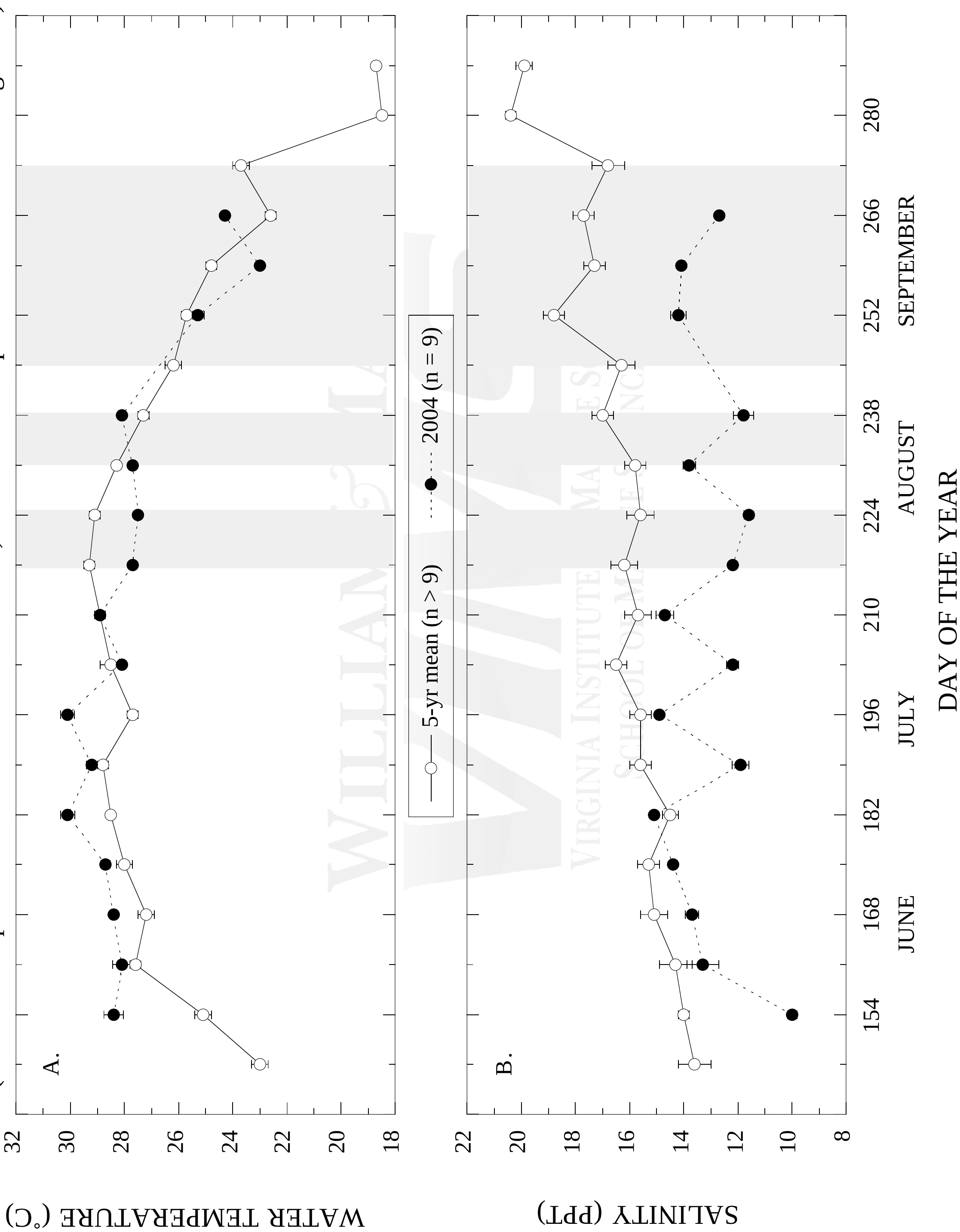


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE SETTLEMENT PERIOD: 5 -YEAR MEAN COMPARED WITH 2004

(Error bars represent standard error of the mean; shaded areas represent settlement during 2004)



Part II. Dredge Survey of Selected Oyster Bars in Virginia During 2004

INTRODUCTION

The Eastern oyster, *Crassostrea virginica* (Gmelin), has been harvested from Virginia waters as long as humans have inhabited the area. Accelerating depletion of natural stocks during the late 1880s led to the establishment of oyster harvesting regulations by public fisheries agencies. A survey of bottom areas in which oysters grew naturally was completed in 1896 under the direction of Lt. J. B. Baylor, U.S. Coast and Geodetic Survey and later updated by Haven et al. (1981). These areas (over 243,000 acres) were set aside by legislative action for public use and have come to be known as the Baylor Survey Grounds or Public Oyster Grounds of Virginia (http://www.vims.edu/mollusc/oyrestatlas/); they are presently under management by the Virginia Marine Resources Commission (VMRC).

Every year the Virginia Institute of Marine Science (VIMS) conducts a dredge survey of selected public oyster bars in Virginia tributaries of the western Chesapeake Bay to assess the status of the existing oyster resource. These surveys provide information about spatfall and recruitment, mortality and changes in abundance of seed and market-size oysters from one year to the next. This section summarizes data collected during bar surveys conducted during September and October 2004.

Spatial variability in distribution of oysters over the bottom can result in wide differences among dredge samples. Large differences among samples collected on the same day from one bar are an indication that distribution of oysters over the bottom is highly variable. An extreme example of that variability can be found in Southworth et al. (1999) by the width of the confidence interval around the average count of spat at Horsehead (James River, VA) during 1998. Dredges provide semi-quantitative data, have been used with consistency over extended periods (decades) in Virginia, and provide data on population trends. However, absolute quantification of dredge data is difficult in that dredges accumulate organisms as they move over the bottom, may not sample with constancy throughout a single dredge haul, and may fill before completion of the haul thereby providing biased sampling (Mann et al. 2004). Therefore, in the context of the present sampling protocol, differences in average counts found at one bar between seasons in the same year or between counts for the same season in different years may be the result of sampling variation rather than actual short-term changes in abundance. If the observed changes persist for several years or can be attributed to well-documented physiological or environmental factors, then they may be considered a reflection of actual changes in abundance with time.

METHODS

Locations of the oyster bars sampled by VIMS during October 2004 are shown in Figure D1. Geographic coordinates of the bars are given in Table D1.

Four samples of bottom material were collected at a single station on each bar using an oyster scrape dredge. In all surveys in the York River and Mobjack Bay (through 2004) and in all surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers preceding 1995, sampling was effected using a 2-ft wide dredge with 4-in teeth towed from a 21-ft boat; volume collected in the dredge bag was 1.5 bushels. For clarification all bushels mentioned in this report refer to a Virginia bushel (3003.9 inches^3), which differs from a US bushel (2150.4 inches^3) and a Maryland bushel (2800.7 inches^3). Beginning in 1995, samples were collected using a 4-ft dredge with 4-in teeth towed from the 43-ft long VMRC vessel J. B. Baylor; volume collected in the bag of that dredge is 3 bushels. In all surveys a half-bushel (25 liters) subsample was taken from each tow for examination. Data presented give the average of the four samples collected at each station for live oyster and box counts after conversion to a full bushel.

From each half-bushel sample, the number of market oysters (76 mm = 3-in. in length or larger), small oysters (< 76 mm, excluding spat), spat (recently settled, 2004 recruits), new boxes (inside of shells perfectly clean; presumed dead for approximately < 1 week), old boxes and spat boxes were counted. The presumed time period since death of an oyster associated with the two categories of boxes is a qualitative description based on visual observations. Water temperature (in ˚C) and salinity (in ppt, parts per thousand) were recorded at each of the dredge stations at the time of sampling using an alcohol thermometer and a hand-held refractometer.

During spring and early summer 2004, the following changes that may have had some effect on settlement and oyster abundance were made (Figure D1 and www.vims.edu/mollusc/monrestoration/restsitemaps/VArfrestsite.htm). Broodstock oysters were planted on Shell Bar Reef in the Great Wicomico River during June. Clean oyster shell (cultch) was planted on Haynie Point in the Great Wicomico River and on Palace Bar and Ginney Point on the Piankatank River.

RESULTS

Thirty oyster bars were sampled between September 27 and October 19, in six of the major Virginia tributaries on the western shore of the Chesapeake Bay. Bar locations are shown in Figure D1 and Table D1 (www.vims.edu/mollusc/oyrestatlas/index.htm). It should be noted that Bell Rock in the York River is a private bar and is included in this report for historical reasons. Results of this survey are summarized in Table D2 and, unless otherwise indicated, the numbers presented below refer to that table.

James River

Ten bars were sampled in the James River, between Nansemond Ridge at the lower end of the river and Deep Water Shoal near the uppermost limit of oyster distribution in the system. The average number of live oysters ranged from a low of 125 bushel^{-1} at Deep Water Shoal to a high of 1081 bushel^{-1} at Dry Shoal.

The overall number of market oysters in the James River remains low when compared with historical numbers. Horsehead, Point of Shoal, Swash and Long Shoal all had a moderate number of market oysters, ranging between 27 (Swash) and 56 (Point of Shoal) bushel^{-1}. There was a slight increase in the number of market oysters at these four sites when compared with 2003 (Figure D2). As was observed during 2003, the number of market oysters at Deep Water Shoal and Mulberry Point, the two most upriver stations, was low (Figure D3A). The number of market oysters at the remaining four sites, Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge, was low with no change when compared to 2003.

When compared with 2003 numbers, the number of small oysters at all ten sites in the James River was relatively similar except at the two most downriver sites (Nansemond Ridge and Thomas Rock) which both showed a slight decrease. Overall, the number of market and small oysters combined at Nansemond Ridge, Thomas Rock and Wreck Shoal has been on the rise for the past several years and are similar to population levels that were observed in the early 1990s after several years of very low numbers throughout the mid 1990s (Figure D4). Numbers of small oysters bushel^{-1} ranged from a low of 28 at Nansemond Ridge to a high of 697 at Horsehead.

The overall number of spat varied depending on location in the river. The five most upriver sites all had less than 70 spat bushel^{-1} ranging from a low of 5 bushel^{-1} at Mulberry Point to a high of 68 bushel^{-1} at Swash. The five most downriver sites had a relatively large number of spat ranging from 120 bushel^{-1} at Long Shoal to 914 bushel^{-1} at Dry Shoal. Spatfall at the five most downriver sites was among the highest observed during the past 15 years. There was an increase in the number of spat at all ten sites during 2004 when compared with 2003, but given the recruitment failure in the upper James River during 2003, this translated into a relatively small increase at Deep Water Shoal, Mulberry Point, Horsehead and Point of Shoal with a much larger increase at the other six sites monitored. In the past, there has been a relationship between location in the river and the composition of live oysters in terms of size distribution. As one moves from the most upriver station (Deep Water Shoal) to the most downriver station (Nansemond Ridge: Figure D1), the percentage of small oysters tends to decrease while the percentage of spat tends to increase. This pattern was once again observed during 2004. Greater than 75% of the total number of oysters were small at the six most upriver sites whereas at the four most downriver sites greater than 75% of the total number of oysters were spat.

The average number of boxes bushel^{-1} ranged from a low of 14 (Nansemond Ridge) to a high of 74 (Mulberry Point). Boxes accounted for a much smaller percentage of the total (live and dead) during 2004 than during 2003. During 2003, boxes accounted for as much as 68% of the total (live and dead) whereas during 2004 they accounted for less than 6% at all of the sites monitored except Deep Water Shoal. At Horsehead and Point of Shoal there was a 50/50 split of new boxes and old boxes. At Thomas Rock and Nansemond Ridge there was a 50/50 split of old boxes and spat boxes. The boxes observed at the other six sites were predominately old boxes.

Water temperature during the sampling period ranged from 20 to 23˚C (Table D2). Salinity was variable depending on location in the river, increasing in a downriver direction, from 2 ppt at Deep Water Shoal to 12 ppt at Thomas Rock and 13 ppt at Nansemond Ridge.

York River

The average total number of live oysters per bushel in the York River was 114 at Aberdeen Rock and 206 at Bell Rock. The live oysters at Bell Rock were predominately small accounting for 93% of the total and predominately spat at Aberdeen Rock accounting for 70% of the total. There was a notable increase in both market oysters and spat compared with 2003 numbers at both bars sampled (Figure D5 and D6). The increase in market oysters at Aberdeen Rock was coupled with a decrease in small oysters. The total number of boxes (new and old) bushel^{-1} was low at Bell Rock (15 bushel^{-1}) and moderate at Aberdeen Rock (46 bushel^{-1}) accounting for 7 and 29% of the total oysters (live and dead) respectively. Water temperature on the day of sampling was 22˚C at Bell Rock and 21.5˚C at Aberdeen Rock. There was a 2 ppt difference in salinity observed: 6 ppt at Bell Rock and 8 ppt at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters per bushel in Mobjack Bay was low. The total number of live oysters bushel^{-1} at Pultz Bar was 10 with slightly higher than 50% spat. There was a small increase in the number of small oysters and spat, but 2004 marked the 6th year in a row with exceptionally low numbers of oysters at Pultz Bar (Figure D5 and D6). There were a total of 3 boxes observed at Pultz Bar and all of these were spat boxes with drill holes (indicative of predation by oyster drills). At Tow Stake there were 134 live oysters bushel^{-1} with a mixture of small oysters and spat. The only notable change from 2003 at Tow Stake was an increase in the number of small oysters (Figure D5 and D6). The total number of boxes was low at Tow Stake (19 bushel^{-1}) accounting for 12% of the total oysters (live and dead) observed. Of these boxes 87% were spat boxes and 18 out of the 32 spat boxes observed appeared to have been caused by oyster drills (presence of drill hole). Water temperature was 25˚C and salinity was 16 ppt at Tow Stake and 17 ppt at Pultz Bar (Table D2) on the day of sampling.

Piankatank River

The average total number of live oysters per bushel in the Piankatank River was low at all three stations ranging from 16 at Ginney Point to 101 at Burton Point. The number of market oysters throughout the system had been on a steady, but slow increase since the mid 1990s, however, 2004 showed a sharp decrease in numbers at Palace Bar and Ginney Point, the two most upriver sites with a small increase at Burton

Point (Figure D7 and D8). The majority of live oysters observed were small, accounting for greater than 75% of the total live oysters at all three stations. There was a substantial decrease in the number of small oysters at Palace Bar and Ginney Point and relatively no change at Burton Point when compared with 2004 numbers (Figure D7). For the second year in a row, there was a relatively low number of spat throughout the system, among the lowest observed over the past 15 years (Figure D8). There were a moderate number of boxes bushel^{-1} observed at all three sites ranging from 33 (Palace Bar) to 65 (Burton Point). Given that there was a small increase observed in both market and small oysters at Burton Point, the large number of boxes at that site is surprising. The observed boxes were approximately 90% old and 10% new. There was 1 spat box observed at Burton Point and this had a drill hole (indicative of oyster drill predation). Water temperature on the day of sampling was 22˚C at all three sites. Salinity ranged between 11 (Ginney Point) and 13 ppt (Burton Point; Table D2).

Rappahannock River

The average total number of live oysters per bushel in the Rappahannock River was low at all 10 stations sampled ranging from 11 (Long Rock) to 221 (Drumming Ground). There appeared to be no relationship between the total number of live oysters and location in the river (i.e., upriver vs. downriver: Figure D1), temperature, or salinity (Table D2) as seen in the James River. Seven out of the ten stations sampled had some spatfall, with an average of 4.1 spat bushel^{-1} while the other three stations sampled had no spat.

The number of market oysters bushel^{-1} ranged from 7 (Long Rock) to 34 (Ross Rock). For the third year in a row, Drumming Ground near the mouth of the Corrotoman River had the highest number of small oysters bushel^{-1} with 193. There was a notable, but small increase in market oysters at Ross Rock and Middle Ground when compared with 2003 numbers (Figures D9, D10 and D10B). The increase in market oysters at Middle Ground was coupled with a small decrease in the number of small oysters. The number of market oysters at Ross Rock has been slowly increasing since about 1998 and the number of market oysters at Broad Creek has remained relatively steady since about 1994 (Figures D10A and D10B). Numbers of market oysters at the other four downriver stations, Hog House, Middle Ground, Drumming Ground and Parrot Rock, have slowly been increasing for the past several years (Figure D10B). There was a slight decrease in the number of small oysters during 2004 at Broad Creek and Long Rock, and an increase at Morratico Bar. While there was a small increase in spat at Hog House, Middle Ground and Drumming Ground, recruitment throughout the Rappahannock River remains at a very low level. Settlement at the five most upriver stations, while low or absent during 2004, was typical for those sites (historically characterized by low spatfall), whereas settlement at the five most downriver stations (which were historically higher) was among the lowest observed during the past 15 years of monitoring (Figures D10A and D10B).

The total number of boxes bushel^{-1} ranged from 2 (Long Rock) to 64 (Drumming Ground). Boxes accounted for less than 25% of the total (live and dead) at all of the stations except Broad Creek where 35% of the total oysters were boxes. At all ten sites, at least 75% of the boxes observed were old. There were no spat boxes observed in any of the samples.

Water temperature on the day of sampling ranged from 21 to 21.5˚C. Salinity increased moving from the most upriver station (Ross Rock: 4.5 ppt) toward mouth (Broad Creek: 11 ppt).

Great Wicomico River

The total number of live oysters per bushel in the Great Wicomico River was very low averaging 24 (Whaley's East), 50 (Fleet Point) and 77 (Haynie Point). The live oysters found were predominately small (greater than 66%) at all three stations sampled. There was a notable decrease in the number of small oysters and spat at all three stations when compared with 2003 numbers (Figures D11 and D12). There was an increase in market oysters at Haynie Point and a decrease at Whaley's East, but both were small and the number of market oysters throughout the system remains low. Settlement in the Great Wicomico River during 2004 was extremely low; the lowest observed during the past 15 years of monitoring (Figure D12). As in the Piankatank River there was a large number of boxes accounting for 23 (Haynie Point) to 55% (Whaley's East) of the total number of oysters, live and dead. These were predominately old boxes (greater than 80%) at all three stations. There was only 1 spat box observed in any of the samples taken from the Great Wicomico River. This was at Whaley's East and it did not appear to have any drill holes (indicative of oyster drill predation). Water temperature was around 20˚C and salinity was 10 ppt at all three stations on the day of sampling.

DISCUSSION

The abundance of market oysters throughout the Chesapeake Bay region has been in serious decline since the turn of the century (Hargis and Haven 1995). In recent years the greatest concentration of market oysters on Virginia public grounds has been found at the upper limits of oyster distribution (lower salinity areas) in the James River and Rappahannock River, with the exclusion of Broad Creek in the mouth of the Rappahannock River. Presently, the abundance of market oysters in the Virginia tributaries of the Chesapeake remains low (mean of 15.9 market oysters bushel^{-1}).

For the past 15 to 20 years, the bulk of Virginia's oyster population has been composed primarily of small oysters (> 65%). This trend was not as apparent during 2004. Greater than 65% of the total oysters counted were small oysters at only 16 out of the 30 stations monitored. Both stations in Mobjack Bay were composed of approximately a 60/30 split of spat and small oysters with the other 10% markets. The oyster populations at the four most downriver sites in the James River and Aberdeen Rock in the York River were composed of greater than 70% spat. In the Rappahannock River market oysters dominated at some sites and small oysters dominated at others, with no clear pattern based on location in the system.

Circulation in the James River is such that larvae from the lower reaches are swept upriver and retained in a gyre from Wreck Shoal to Burwell Bay (Haven and Fritz 1985, Ruzecki and Hargis 1989). Historically the area between Wreck Shoal and Hampton Flats (located downriver of the seed area) provided the most larvae to the seed area, which is defined as the area between Nansemond Ridge and Deep Water Shoal (Figure D1); thus it covers the entire area that is currently sampled (Haven and Fritz 1985). With the onset of MSX and *Perkinsus*, many of these downriver oyster populations, those downriver of the seed area as well as those in the lower reaches of the seed area, disappeared such that the majority of the broodstock for the past several decades have been located in the mid to upper section of the seed area (the Burwell Bay region). As such over the past several decades, the majority of the spatfall has occurred in the more mid to upriver section of the seed area. However, there were several years during the early 1990s when spatfall was higher downriver (between Dry Shoal and Wreck Shoal; Part I of this report, Table S2) and this coincided with a period of low (3 to 4 ppt below average) salinity and an increase in the populations of the adults located in the more downriver seed area (Figure D4). This pattern was once again observed during 2004; low salinities (4 to 5 ppt below average) over the past 2 years with an increase in downriver populations, combined with an increase in spat in the lower portion of the seed area.

Spatfall during 2004 was low throughout the Piankatank, Rappahannock and Great Wicomico Rivers with an average of 3.2 spat bushel^{-1}. In all three of the river systems, spatfall was among the lowest observed during the past 15 years of monitoring. As previously mentioned oyster recruitment in the upper Rappahannock has been extremely low for the past 15 years, while recruitment in the lower Rappahannock has been steadily decreasing to the levels observed in the upper part of the estuary. Despite the apparent lack of recruitment in the upper Rappahannock, the adult populations appear to be relatively stable. There was almost total recruitment failure in both the Piankatank and Great Wicomico Rivers during 2004. This is despite what appears to be relatively stable broodstock populations in the two systems. One possible explanation could be food limitation or an algal bloom issue. For a large portion of the spawning season (late June through late July) the upper reaches of both rivers were dominated by tea-colored water (personal observation), which may have been the result of an algal bloom or high amounts of less than desirable run-off. This may also explain the relatively large number of boxes observed for the second year in a row combined with the absence of live market size oysters at Ginney Point (the most upriver station in the Piankatank) when there were 11 market oysters bushel^{-1} the previous year.

In Mobjack Bay, despite low oyster populations, settlement at Tow Stake was among the highest observed over the past 15 years. This can most likely be attributed to a broodstock source located elsewhere in the system. There was an increase in the number of small oysters at Tow Stake during 2004, which is what one expect given the high number of spat that settled during 2003.

For the first time in 2 years the number of boxes observed was relatively low, less than 35% of the total (live and dead) at all of the stations except Deep Water Shoal in the James River, all three sites in the Piankatank River and Whaley's East in the Great Wicomico River. The boxes at Deep Water Shoal were most likely either left over from the previous 2 years of die-off caused by disease (2002) and low salinities (2003) or newer boxes caused by the low salinity conditions encountered during the latter half of the spawning season during 2004 (Part I of this report). Given that disease prevalence tends to increase as salinity increases (Calvo and Burreson, 2000), disease was most likely the reason behind the large number of boxes during 2002. Low salinities, while good for purging MSX (Haskin and Ford 1982) and suppressing Perkinsus (Burreson and Andrews 1988) from the oysters can often itself be detrimental to the oyster. When coupled with temperatures greater than 23˚C, high mortality of oysters occurs at salinities at or below 5 ppt (Loosanoff 1952). Salinities in the upper part of the James River were quite low during the latter half of the season (less than 8 ppt), reaching near zero at Deep Water Shoal twice during the month of September when water temperatures were still in the mid 20s. Low salinity for a large portion of the season in the Piankatank combined with a possible algal bloom or less than desirable run-off was most likely the cause of the large number of boxes in that system.

There were a relatively low number of spat boxes observed at all of the sites monitored (including those in the lower James that had a large number of spat) except at the 2 stations in the Mobjack Bay. At Tow Stake there were a total of 32 spat boxes and of these 18 of them had drill holes. All 3 spat boxes found at Pultz Bar had drill holes in them, as did the 1 spat box found at Burton Point in the Piankatank River. These holes were most likely caused by the oyster drills *Urosalpinx cinerea* or *Eupleura caudata* which are often found in the lower Chesapeake Bay. Both of these species have been shown to be voracious predators of oyster spat causing mortality throughout most of the Chesapeake Bay (Carriker 1955) up until the occurrence of Hurricane Agnes (1972) which wiped them out in all but the lower reaches of the James River and mainstem Bay (Haven 1974). However, individuals of both of these species and drill eggmasses have been found in recent years in the mouths of the Piankatank and Rappahannock Rivers, and in Mobjack Bay including live specimens of *Urosalpinx cinerea* at Tow Stake during the 2004 dredge survey.

Table D1: Station locations for the VIMS Fall dredge survey.

STATION	LATITUDE	LONGITUDE
James River		
Deep Water Shoal	37 08 56	76 38 08
Mulberry Point	37 07 09	76 37 55
Horsehead	37 06 24	76 38 02
Point of Shoal	37 04 37	76 38 36
Swash	37 05 52	76 36 44
Long Shoal	37 04 35	76 37 01
Dry Shoal	37 03 41	76 36 14
Wreck Shoal	37 03 37	76 34 20
Thomas Rock	37 01 32	76 29 33
Nansemond Ridge	36 55 20	76 27 10
York River		
Bell Rock	37 29 05	76 44 58
Aberdeen Rock	37 20 00	76 36 06
Mobjack Bay		
Tow Stake	37 20 18	76 23 28
Pultz Bar	37 20 22	76 23 16
Piankatank River		
Ginney Point	37 32 00	76 24 12
Palace Bar	37 31 36	76 22 12
Burton Point	37 30 54	76 19 42
Rappahannock River		
Ross Rock	37 54 04	76 47 21
Bowler's Rock	37 49 35	76 44 08
Long Rock	37 48 59	76 42 50
Morattico Bar	37 46 55	76 39 33
Smokey Point	37 43 07	76 34 48
Hog House	37 38 30	76 33 04
Middle Ground	37 41 00	76 28 24
Drumming Ground	37 38 38	76 27 59
Parrot Rock	37 36 21	76 25 20
Broad Creek	37 34 37	76 18 03
Great Wicomico River		
Haynie Point	37 49 47	76 18 33
Whaley's East	37 48 31	76 18 00
Fleet Point	37 48 35	76 17 19

Table D2: Results of the Virginia public oyster grounds survey, Fall 2004.York River station numbers (*) are based on two 1 bushel samples. Note that the bushel measure used is a Virginia bushel which is equivalent to 3003.9 cubic inches. A Virginia bushel differs in volume from both a U.S. bushel (2150.4 cubic inches) and a Maryland bushel (2800.7 cubic inches). "**" indicates a private bar. Middle Ground (#) is located in the Corrotoman River, a subestuary of the Rappahannock River system.

Station	Date	Water temp. (deg C)	Salinity (ppt)	Average number of oysters per bushel				Average number of boxes per bushel			
				Market	Small	Spat	Total	New	Old	Spat	Total
James River											
Deep Water Shoal	10/19	23.0	2.0	3.0	115.5	6.5	125.0	4.0	69.5	0	73.5
Mulberry Point	10/19	23.0	3.0	6.5	438.5	5.0	450.0	4.5	22.0	0	26.5
Horsehead	10/19	23.0	3.0	44.0	697.0	32.5	773.5	7.0	6.5	2.0	15.5
Point of Shoal	10/19	20.0	5.0	55.5	468.5	9.5	533.5	8.0	8.5	0	16.0
Swash	10/19	23.0	5.0	26.5	406.5	68.0	501.0	3.5	12.0	0	15.5
Long Shoal	10/19	23.0	4.5	42.0	601.0	120.0	763.0	4.0	15.0	0	19.0
Dry Shoal	10/18	20.0	6.5	12.5	154.0	914.0	1080.0	2.0	18.0	4.0	24.0
Wreck Shoal	10/18	20.0	10.0	9.5	208.5	785.5	1003.5	2.5	6.5	6.5	15.5
Thomas Rock	10/18	20.0	12.0	7.0	45.5	306.5	359.0	1.0	11.0	8.0	20.0
Nansemond Ridge	10/18	20.0	13.0	9.5	28.0	355.5	393.0	0	7.5	6.5	14.0
York River*											
Bell Rock **	10/8	22.0	6.0	7.5	192.0	6.0	205.5	2.5	12.5	0	15.0
Aberdeen Rock	10/8	21.5	8.0	12.0	22.0	80.0	114.0	10.0	32.0	4.0	46.0
Mobjack Bay											
Tow Stake	9/27	25.0	16.0	5.5	43.0	85.5	134.0	0	2.5	16.0	18.5
Pultz Bar	9/27	25.0	17.0	1.0	3.0	5.5	9.5	0	0	1.5	1.5
Piankatank River											
Ginney Point	10/12	22.0	11.0	0	14.5	1.0	15.5	3.5	41.0	0	44.5
Palace Bar	10/12	22.0	12.0	3.0	44.0	2.5	49.5	4.0	28.5	0	32.5
Burton Point	10/12	22.0	13.0	17.0	75.5	8.5	101.0	7.0	57.0	0.5	64.5
Rappahannock River											
Ross Rock	10/15	21.5	4.5	33.5	47.5	0	81.0	0.5	13.5	0	14.0
Bowler's Rock	10/15	21.5	7.0	17.0	11.0	0	28.0	0	5.0	0	5.0
Long Rock	10/15	21.5	7.0	7.0	2.0	1.5	10.5	0	1.5	0	1.5
Morattico Bar	10/15	21.5	9.0	21.5	51.0	0	72.5	1.0	3.5	0	4.5
Smokey Point	10/15	21.5	9.5	24.0	37.0	3.0	64.0	0	10.5	0	10.5
Hog House	10/15	21.5	10.0	10.0	6.5	1.0	17.5	1.0	3.5	0	4.5
Middle Ground #	10/15	21.0	10.0	19.5	39.0	4.5	63.0	2.5	15.5	0	18.0
Drumming Ground	10/15	21.0	10.0	23.5	192.5	5.0	221.0	13.0	50.5	0	63.5
Parrot Rock	10/15	21.0	10.0	16.0	43.5	5.5	65.0	3.5	13.0	0	16.5
Broad Creek	10/15	21.0	11.0	24.5	59.0	8.5	92.0	3.5	45.0	0	48.5
Great Wicomico River											
Haynie Point	10/12	20.0	10.0	3.5	70.5	3.0	77.0	4.5	18.0	0	22.5
Whaley's East	10/12	20.0	10.0	4.5	15.5	3.5	23.5	1.5	27.0	0.5	29.0
Fleet Point	10/12	20.5	10.0	10.0	37.0	3.0	50.0	1.5	22.0	0	23.5

Figure D1: Map showing the location of the oyster bars sampled during the 2004 dredge survey.

James River: 1) Deep Water Shoal, 2) Mulberry Point, 3) Horsehead, 4) Point of Shoal, 5) Swash, 6) Long Shoal, 7) Dry Shoal, 8) Wreck Shoal, 9) Thomas Rock, 10) Nansemond Ridge.

York River: 11) Bell Rock, 12) Aberdeen Rock.

Mobjack Bay: 13) Tow Stake, 14) Pultz Bar.

Piankatank River: 15) Ginney Point, 16) Palace Bar, 17) Burton Point.

Rappahannock River: 18) Ross Rock, 19) Bowler's Rock, 20) Long Rock, 21) Morattico Bar, 22) Smokey Point, 23) Hog House, 24) Middle Ground, 25) Drumming Ground, 26) Parrot Rock, 27) Broad Creek.

Great Wicomico River: 28) Haynie Point, 29) Whaley's East, 30) Fleet Point.

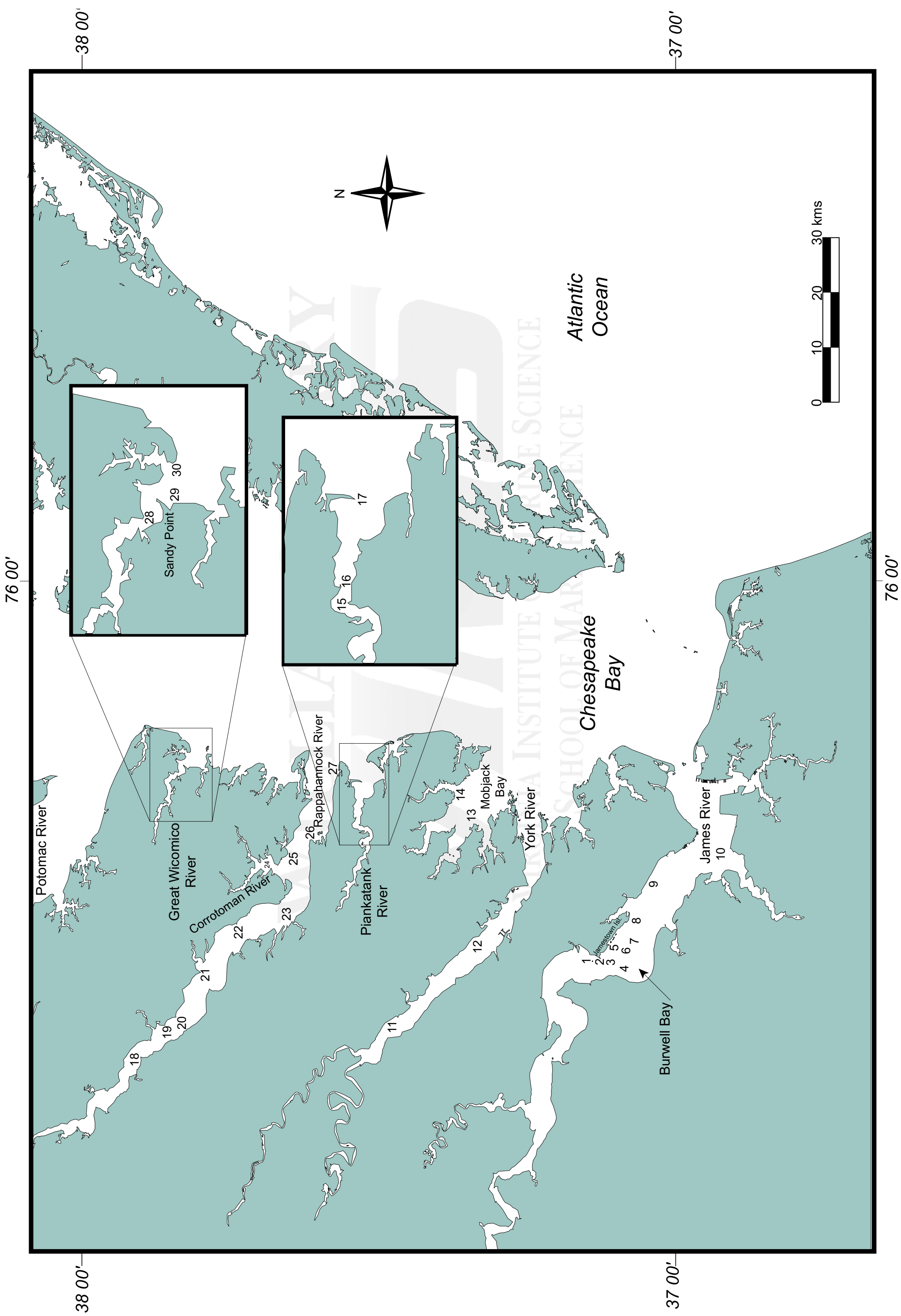

38 00'
37 00'
76 00'
N
Atlantic Ocean
Chesapeake Bay
Potomac River
Great Wicomico River
Corrotoman River
Rappahannock River
Piankatank River
Mobjack Bay
York River
James River
Burwell Bay
Sandy Point
0 10 20 30 kms

FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2003-2004)
(Error bars represent standard error of the mean)

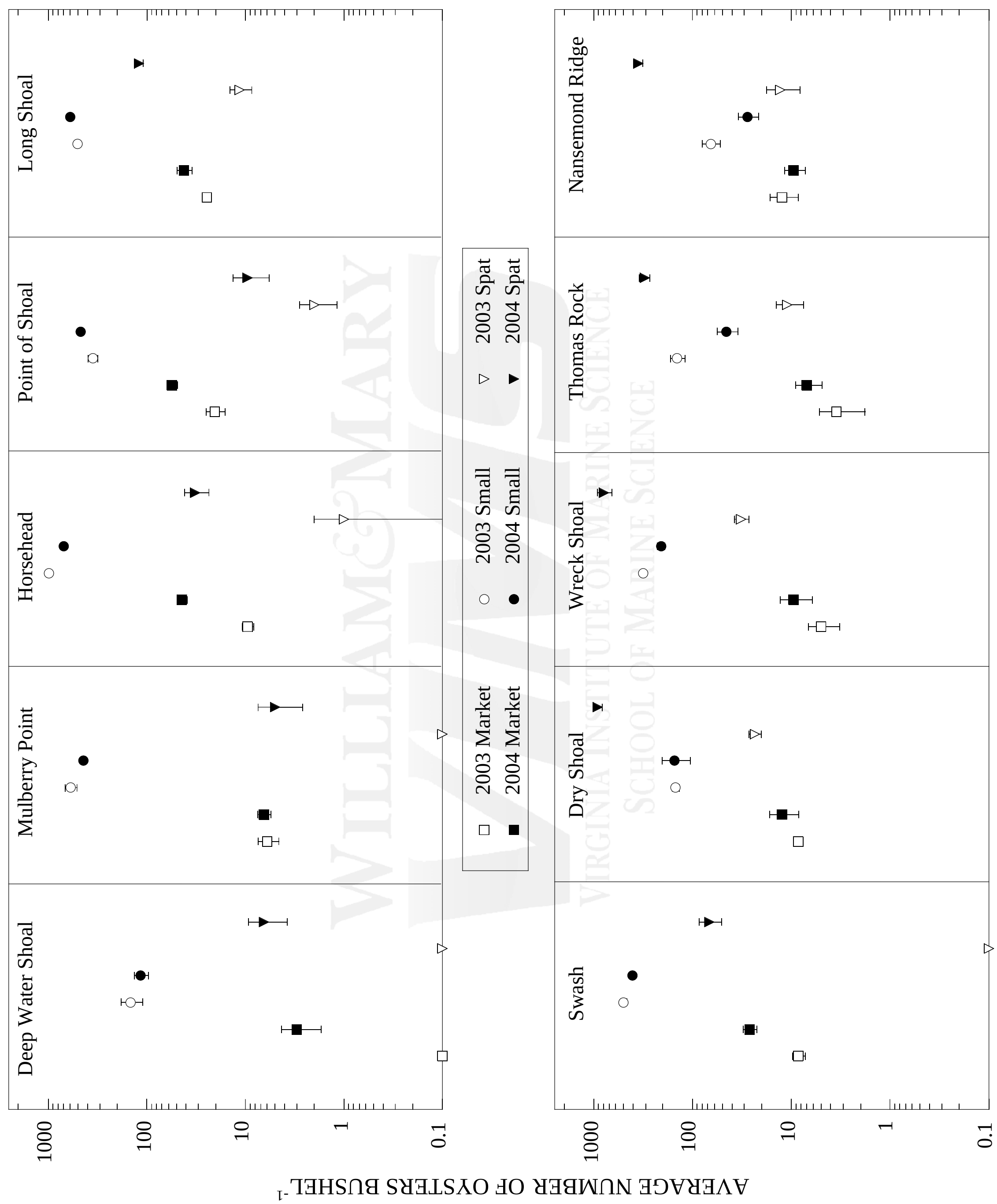


FIGURE D3A: JAMES RIVER OYSTER TRENDS OVER THE PAST 15 YEARS (10 WHERE DATA ARE NOT AVAILABLE)
(Error bars represent standard error of the mean)

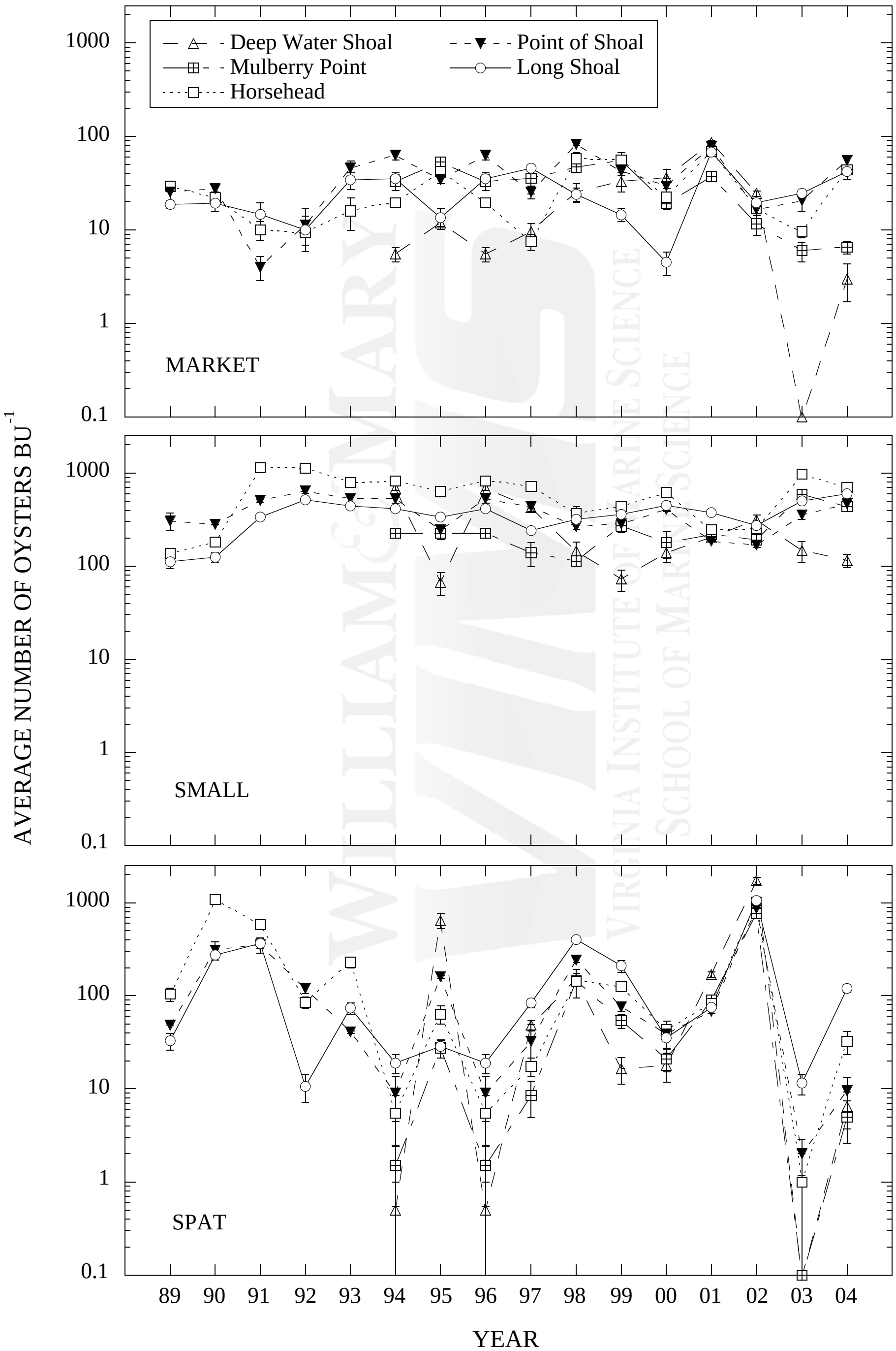


FIGURE D3B: JAMES RIVER OYSTER TRENDS
OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)

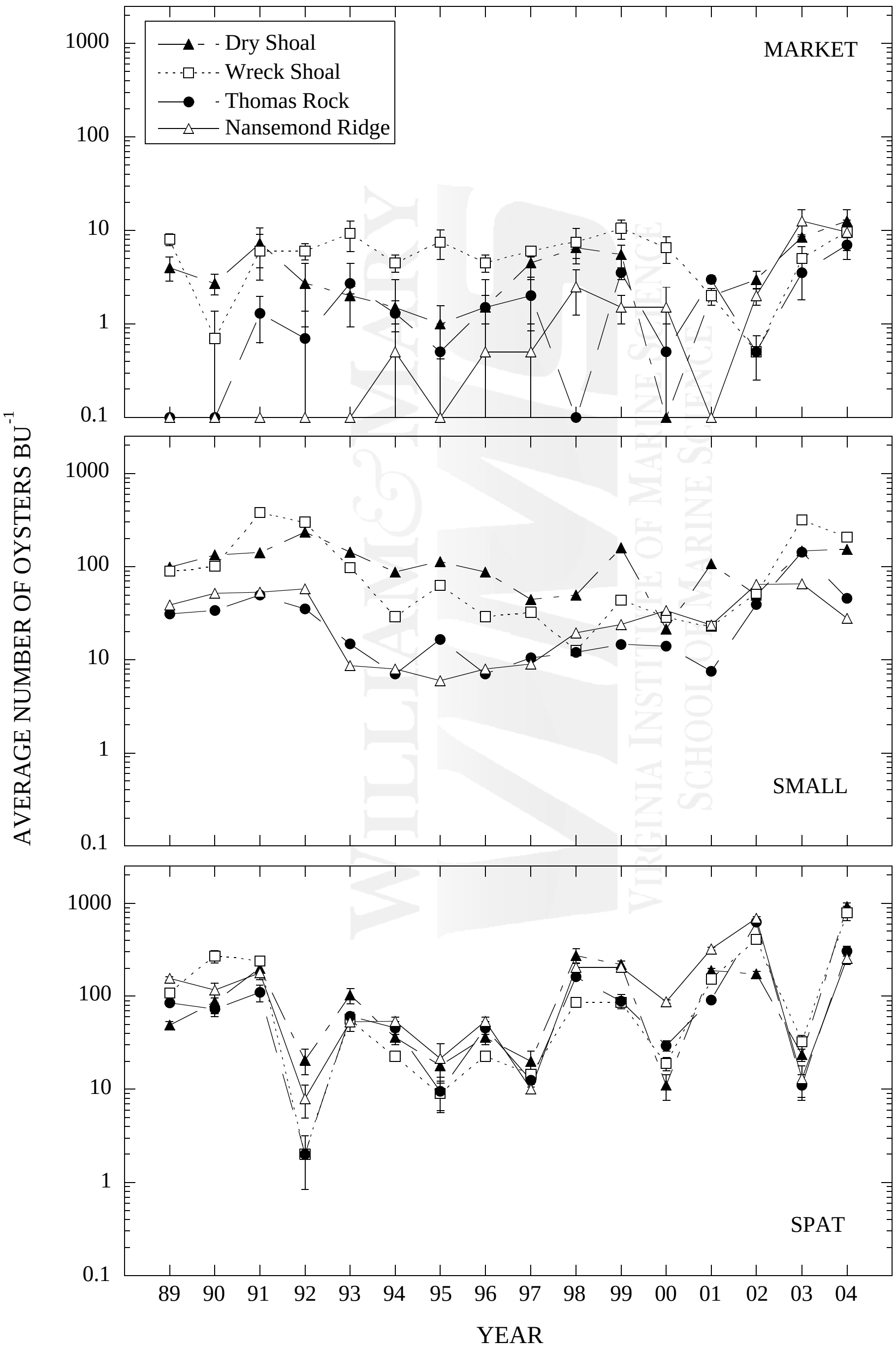


FIGURE D4: AVERAGE NUMBER OF MARKET AND SMALL OYSTERS COMBINED AT THE 3 MOST DOWNRIVER SITES IN THE JAMES RIVER

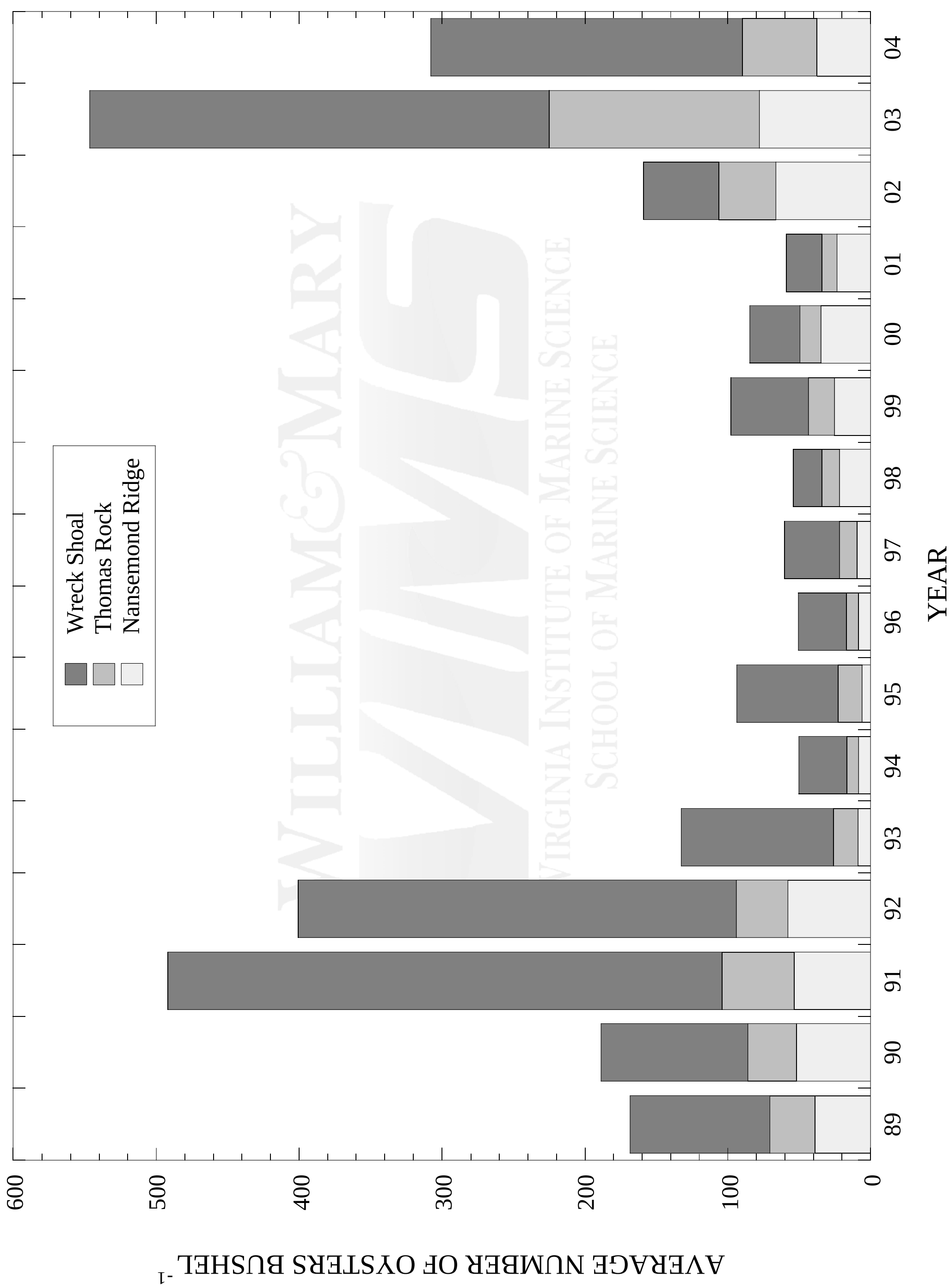
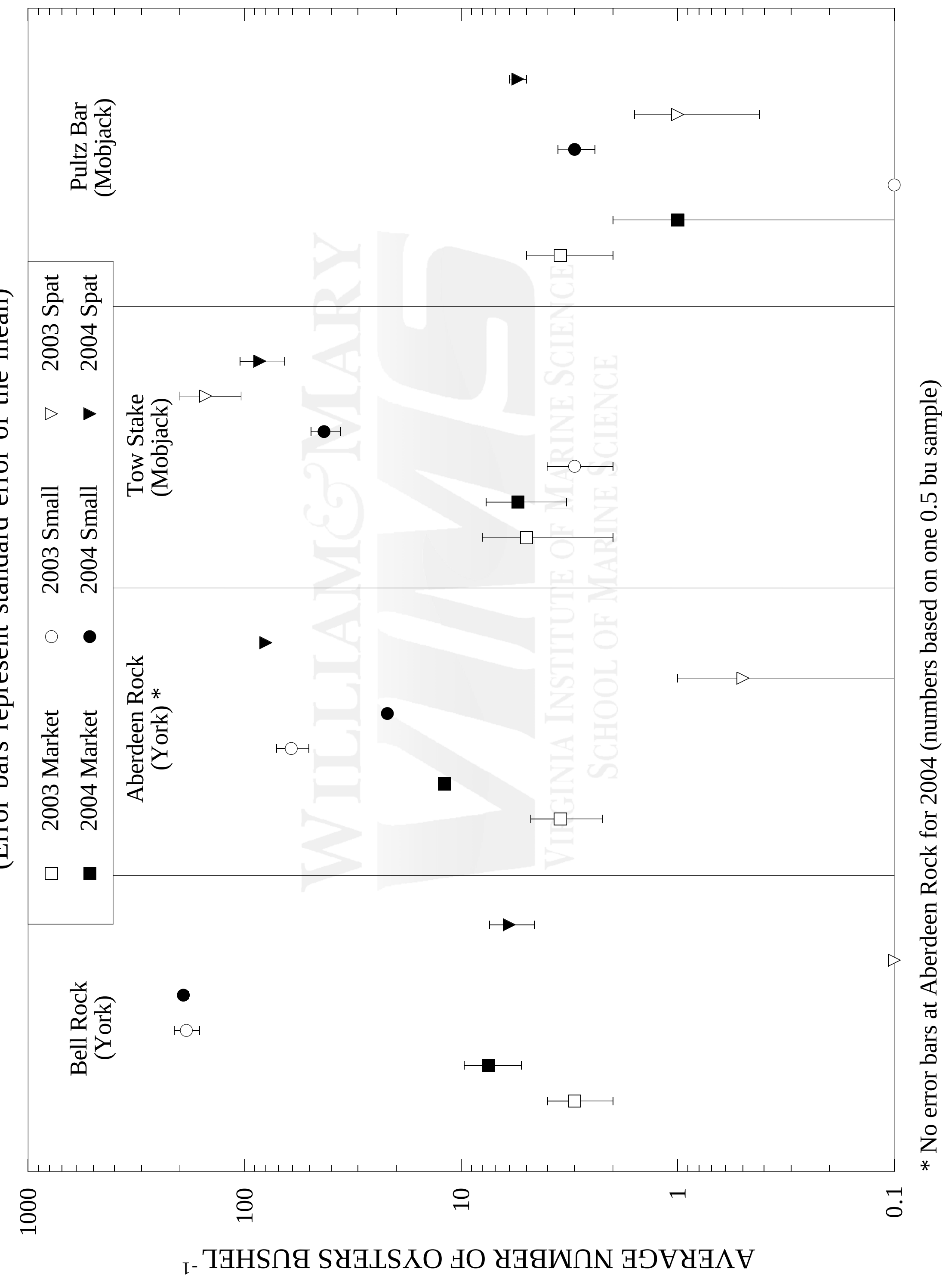


FIGURE D5: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE YORK RIVER AND MOBJACK BAY (2003-2004)
(Error bars represent standard error of the mean)



* No error bars at Aberdeen Rock for 2004 (numbers based on one 0.5 bu sample)

FIGURE D6: YORK RIVER AND MOBJACK BAY OYSTER TRENDS OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)

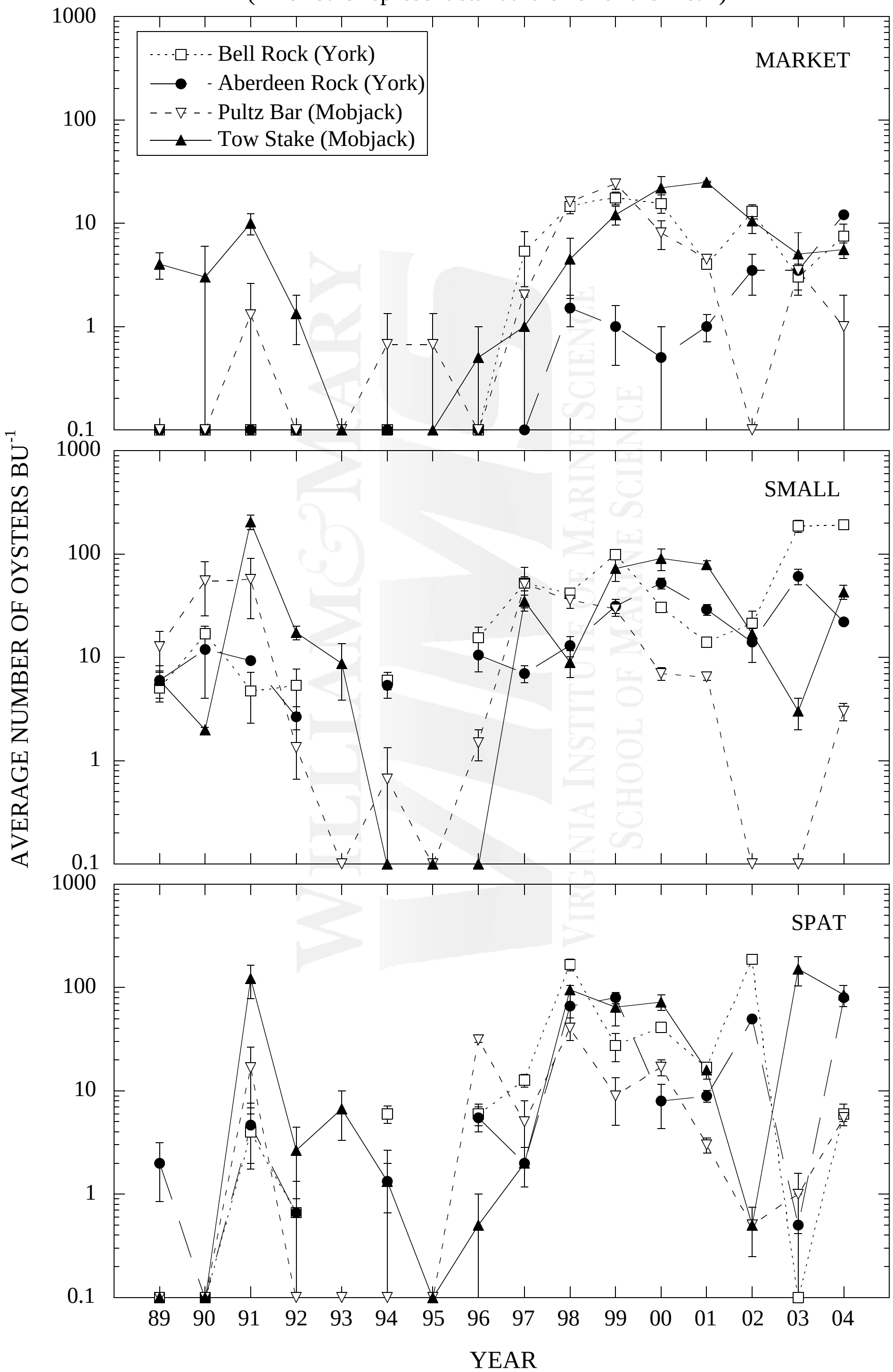


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2003-2004)
(Error bars represent standard error of the mean)

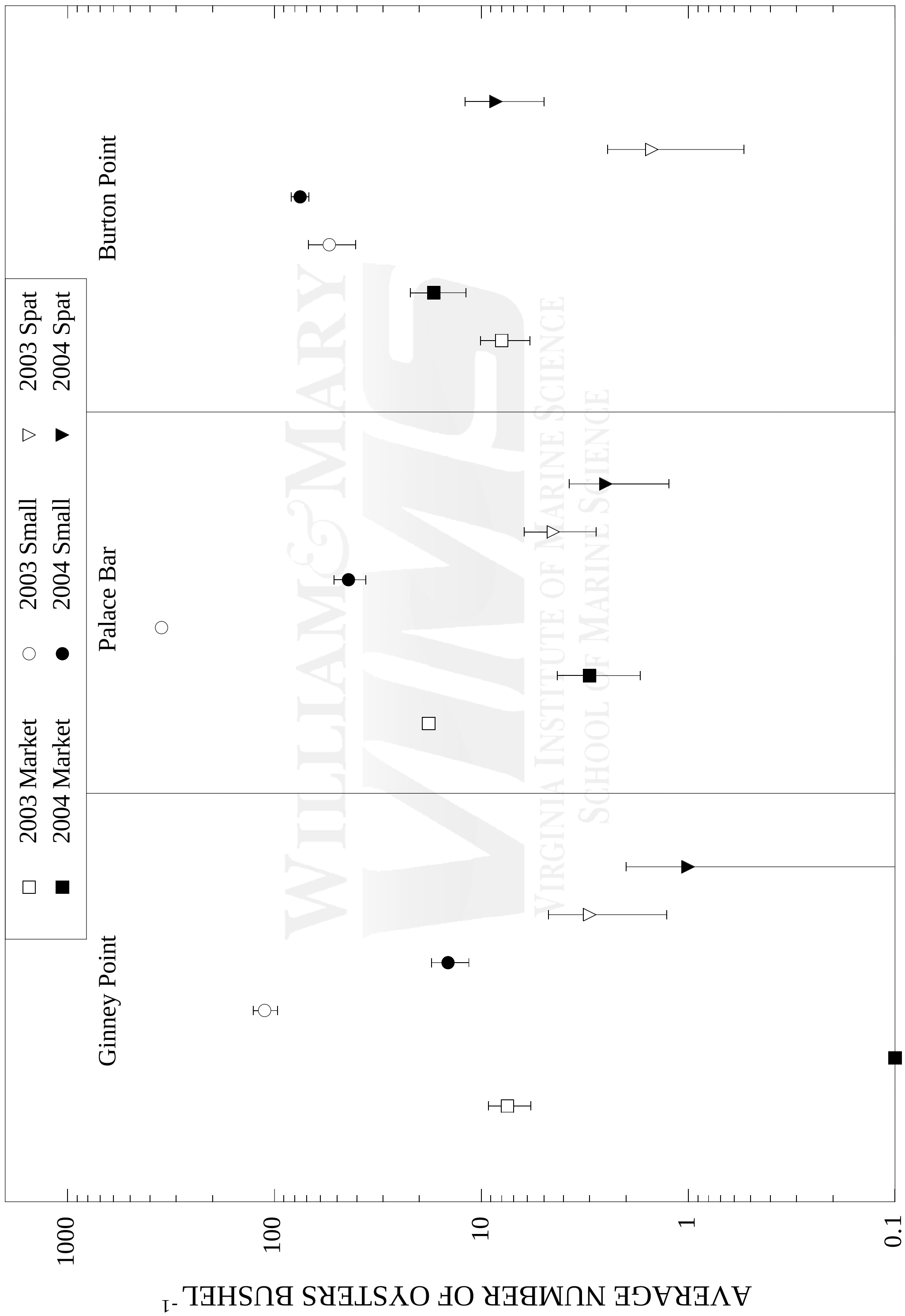


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)

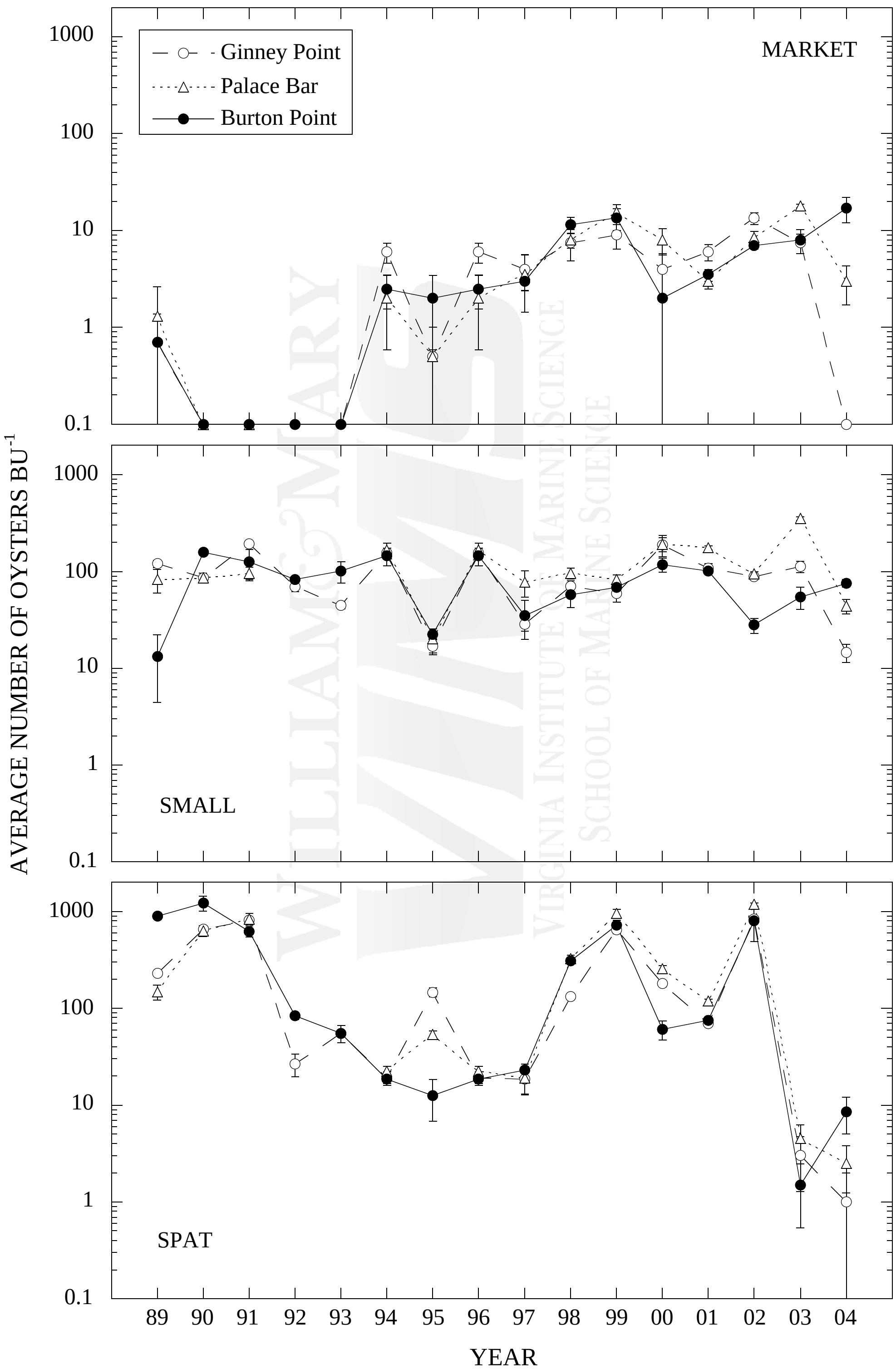


FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2003-2004)
(Error bars represent standard error of the mean)

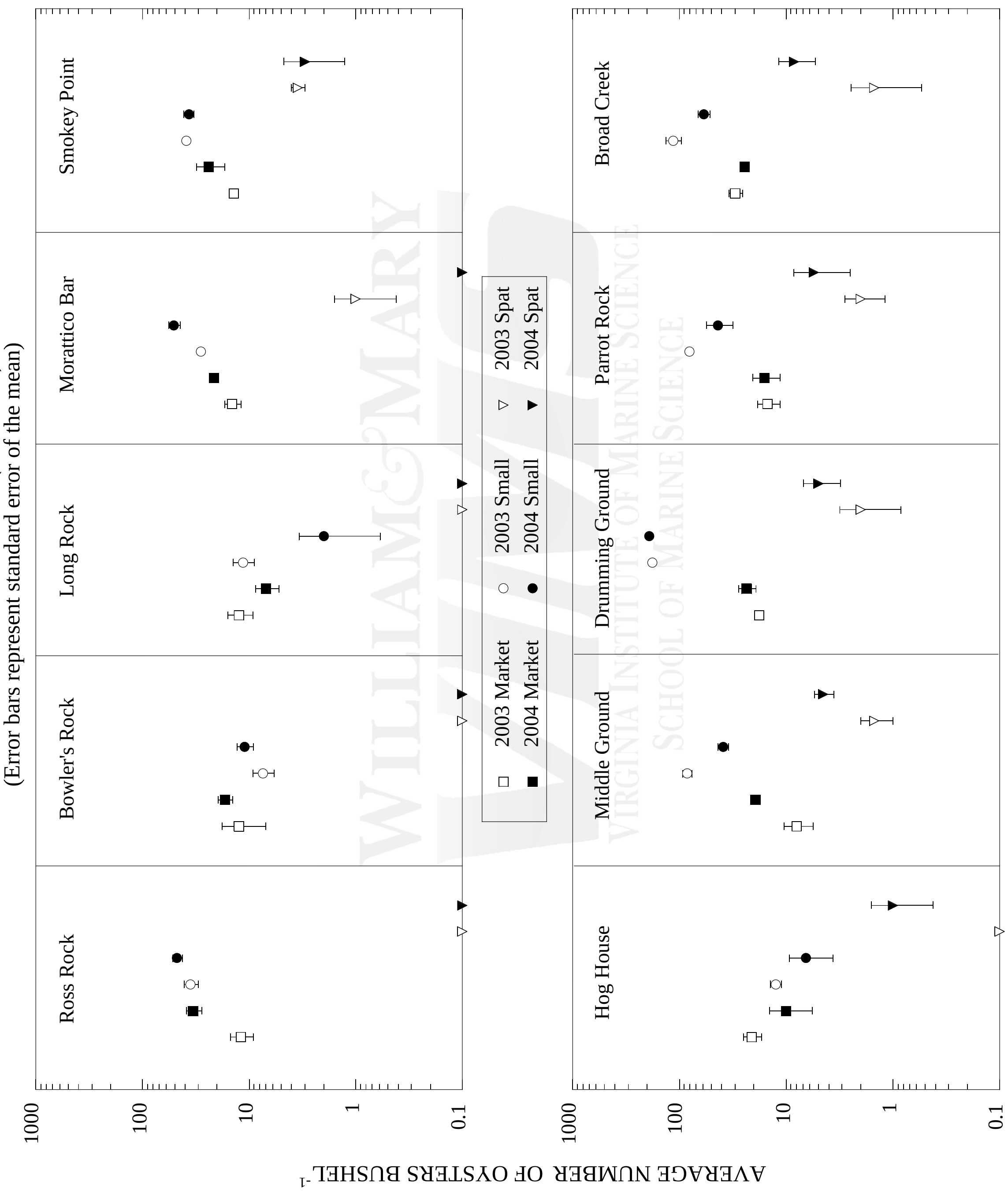


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)

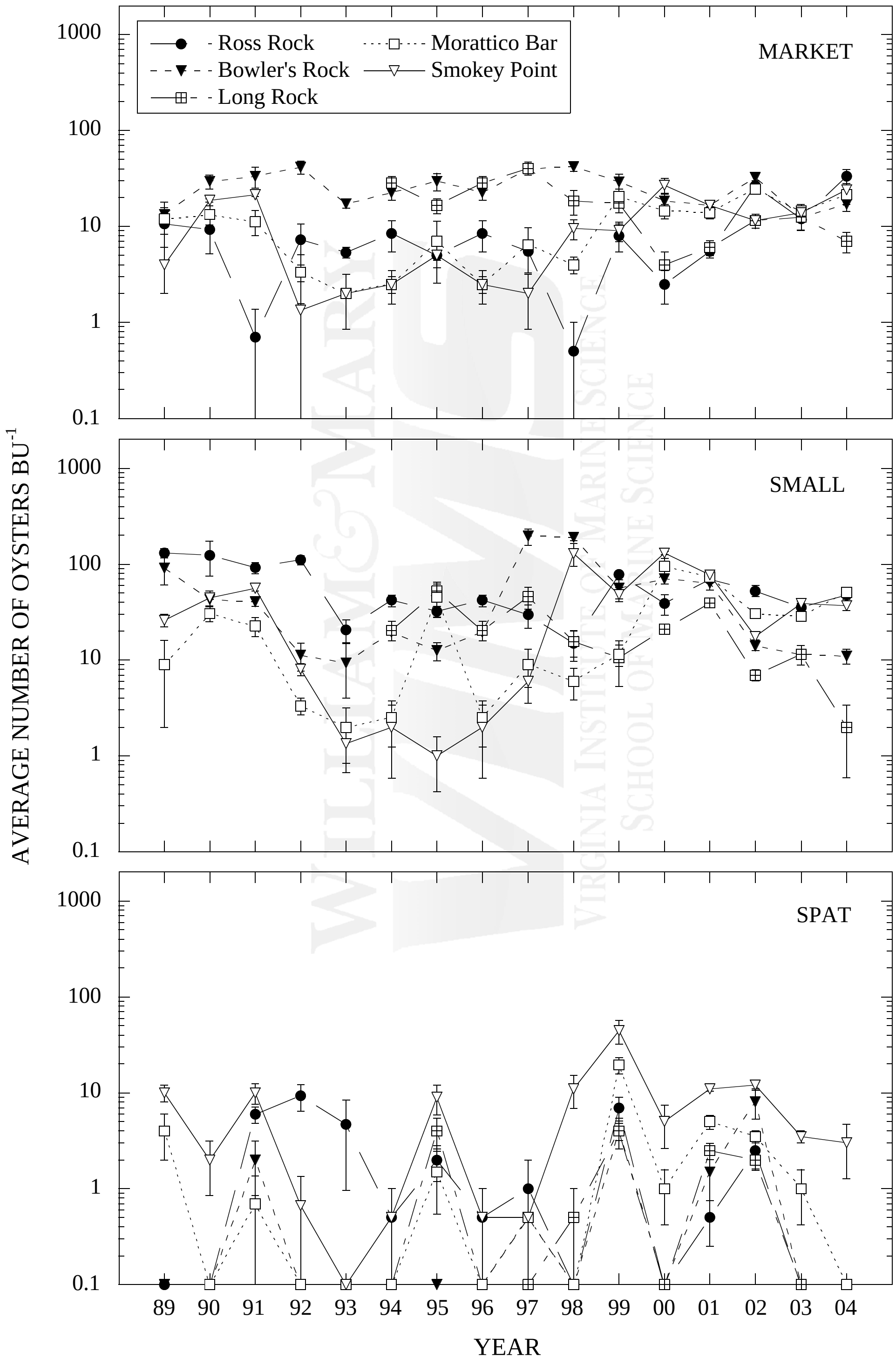


FIGURE D10B: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)

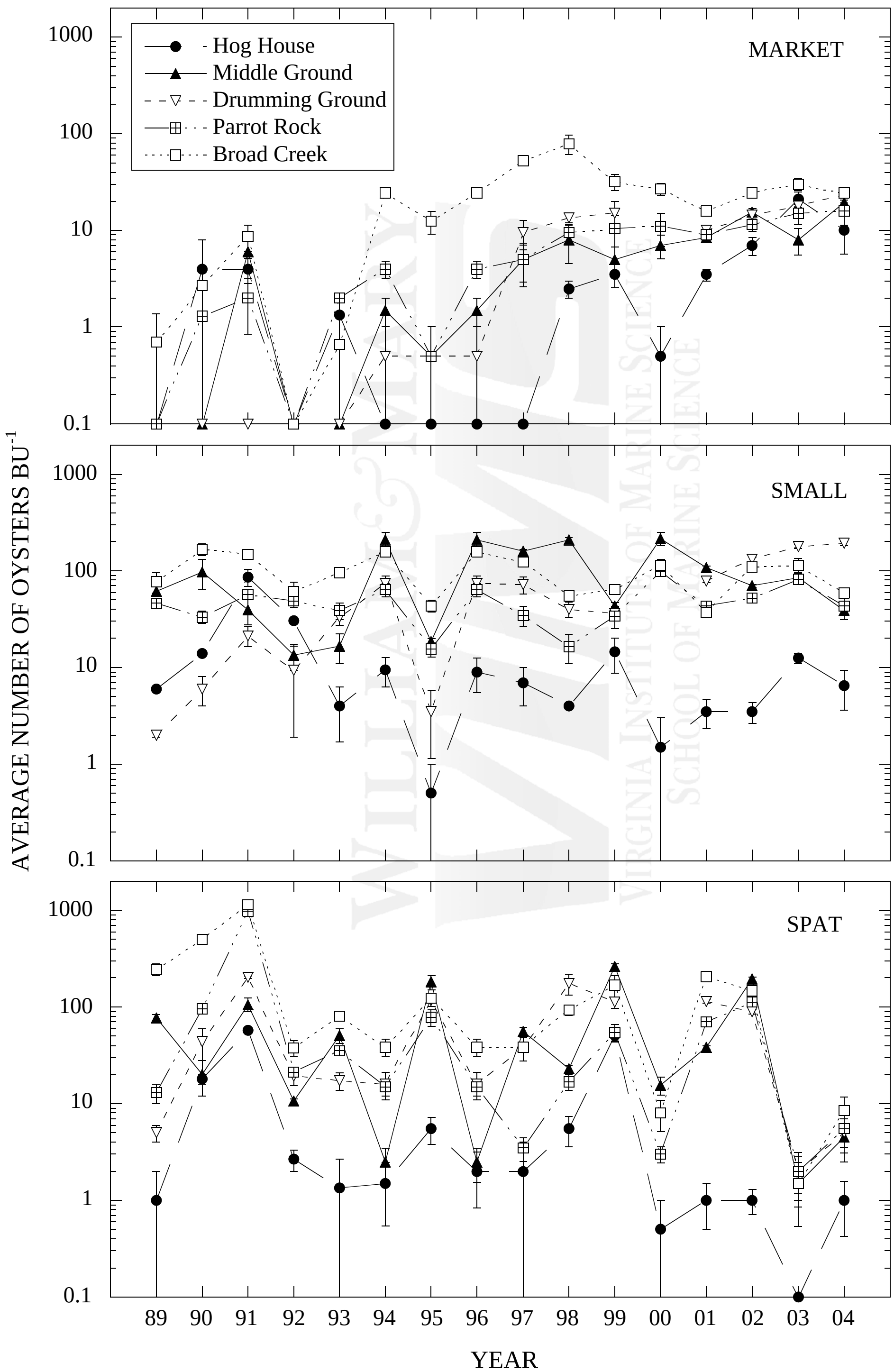


FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE GREAT WICOMICO RIVER (2003-2004)
(Error bars represent standard error of the mean)

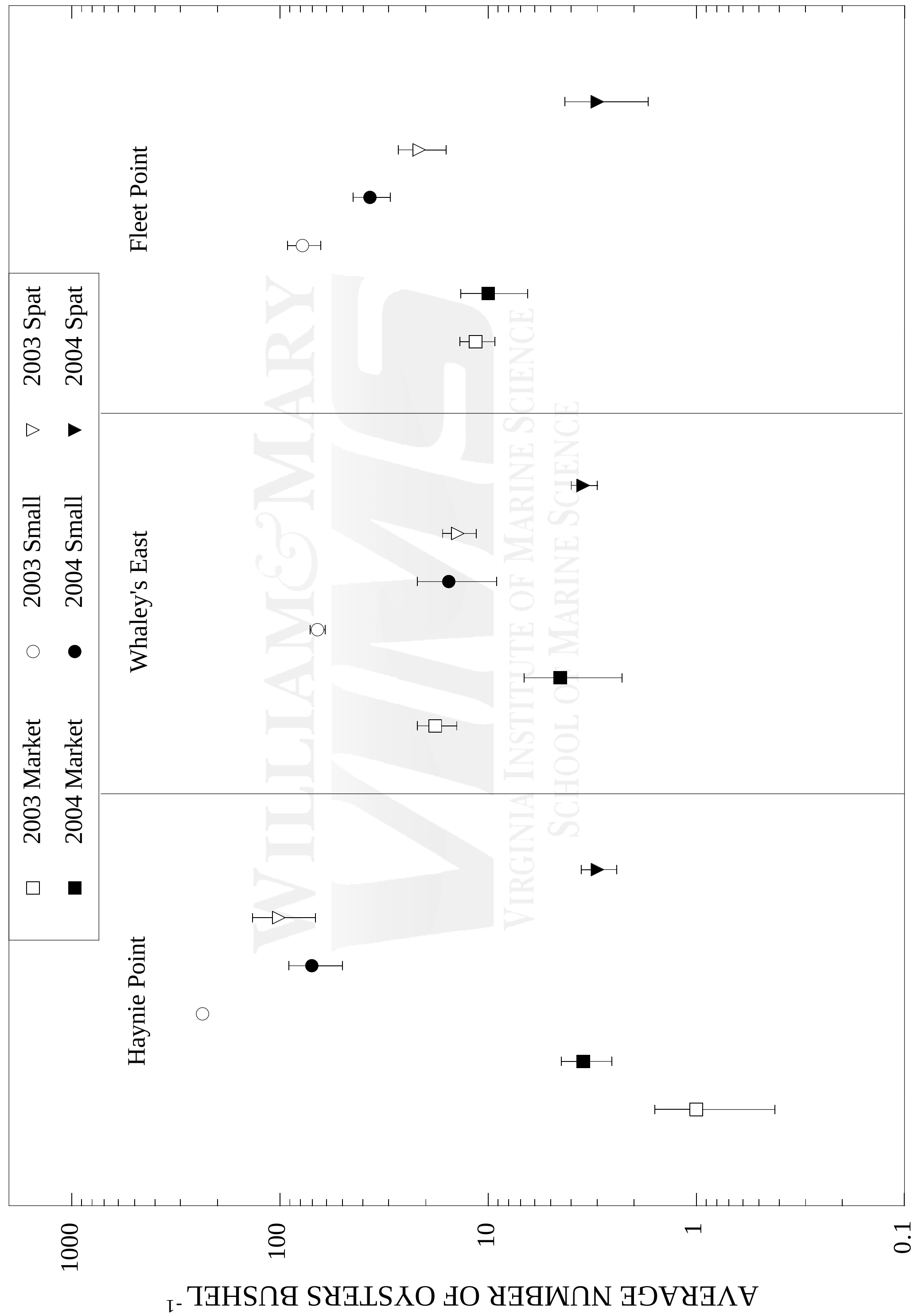
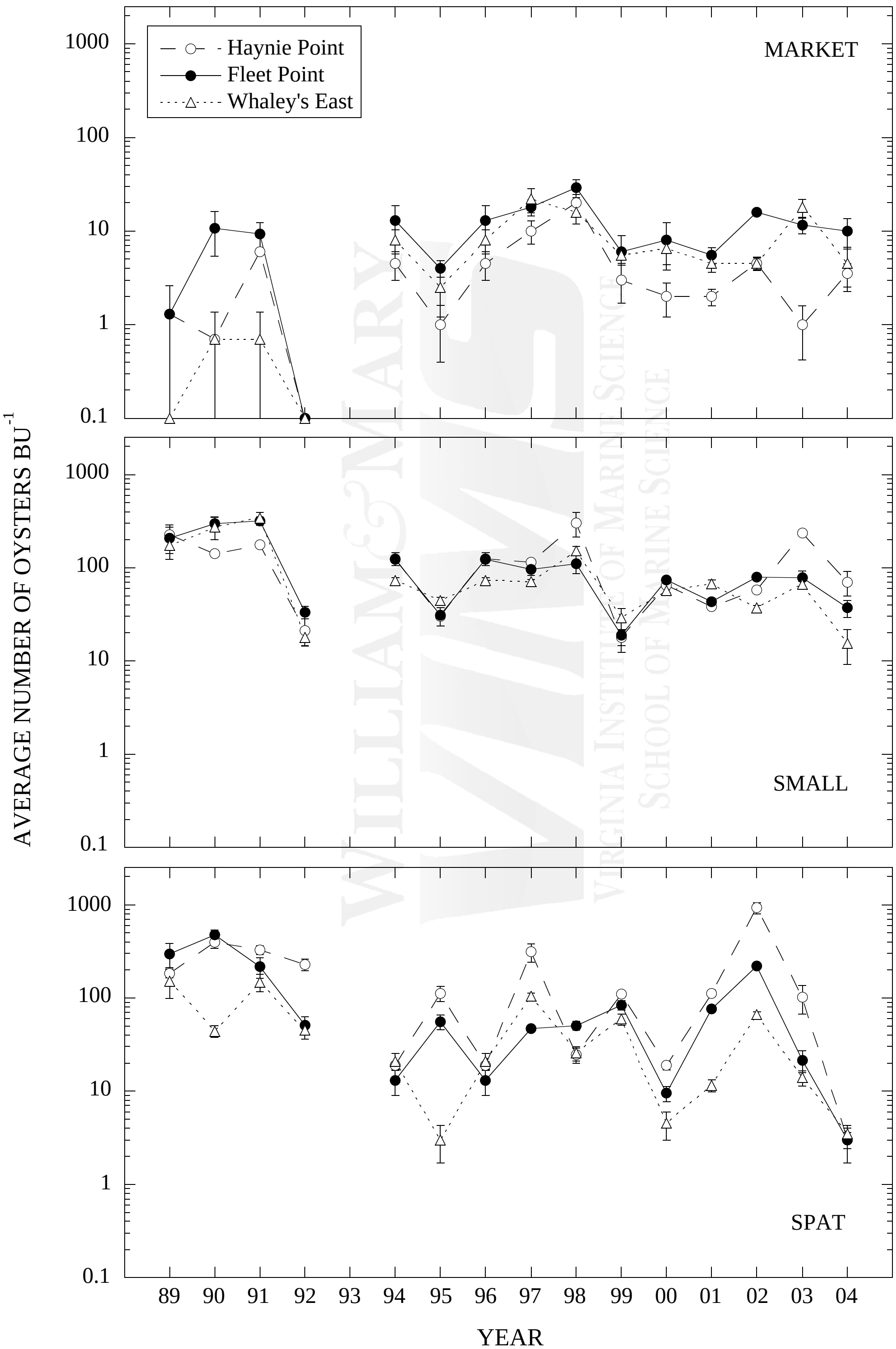


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 15 YEARS
(Error bars represent standard error of the mean)



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REFERENCES

Andrews, J.D. 1951. Seasonal patterns of oyster setting in the James River and Chesapeake Bay. Ecology. 32(4):752-758.

Burreson, E.M. and J.D. Andrews. 1988. Unusual intensification of Chesapeake Bay oyster diseases during recent drought conditions. Proc. Oceans 88:799-802.

Butler, P.A. 1949. Gametogenesis in the oyster under conditions of depressed salinity. Biol. Bull. 96:263-269.

Calvo, L.M. and E.M. Burreson. 2000. Status of the major oyster diseases in Virginia 1999: A summary of the annual monitoring program. Virginia Marine Resource Report No. 00-2. 23 pp.

Carriker, M.R. 1955. Critical review of biology and control of oyster drills *Urosalpinx* and *Eupleura*. U.S. Fish and Wildlife Service Special Scientific Report: Fisheries No. 148. 150 pp.

Hargis, W.J., Jr. and D.S. Haven. 1995. The precarious state of the Chesapeake public oyster resource. In: P. Hill and S. Nelson, editors. Proceedings of the 1994 Chesapeake Research Conference. Toward a sustainable coastal watershed: The Chesapeake experiment. June 1-3, 1994, Norfolk, VA. Chesapeake Research Consortium Publication No. 149. pp. 559-584.

Haskin, H.H. and S.E. Ford. 1982. *Haplosporidium nelsoni* (MSX) on Delaware Bay seed oyster beds: a host-parasite relationship along a salinity gradient. J. Invert. Pathol. 40:388-405.

Haven, D.S. 1974. Effect of Tropical Storm Agnes on oysters, hard clams, and oyster drills. In: The effects of Tropical Storm Agnes on the Chesapeake Bay estuarine system. Chesapeake Research Consortium Publication No. 27. 28 pp.

Haven, D.S. and L.W. Fritz. 1985. Setting of the American oyster *Crassostrea virginica* in the

James River, Virginia, USA: temporal and spatial distribution. Mar. Biol. 86:271-282.

Haven, D.S., W.J. Hargis Jr. and P. Kendall. 1981. The present and potential productivity of the Baylor Grounds in Virginia. Va. Inst. Mar. Sci., Spec. Rep. Appl. Mar Sci. & Ocean Eng. No 243. 154 pp.

Lalli, C.M. and T.R. Parsons. 1995. Biological Oceanography: an introduction. Pergamon Press, Oxford. 301 pp.

Loosanoff, V.L. 1952. Behavior of oysters in water of low salinities. Proc. Natl. Shellfish. Assoc. 43:135-151.

Mann, R., J.S. Rainer and R. Morales-Alamo. 1994. Reproductive activity of oysters, *Crassostrea virginica* (Gmelin, 1791) in the James River, Virginia, during 1987-1988. J. Shellfish Res. 13:157-164.

Mann, R., M. Southworth, J.M. Harding and J. Wesson. 2004. A comparison of dredge and patent tongs for estimation of oyster populations. J. Shellfish Res. 23(2):387-390.

Ruzecki, E.P. and W.J. Hargis Jr. 1989. Interaction between circulation of the estuary of the James River and transport of oyster larvae. In: B.J. Neilson, J. Brubaker and A Kuo, editors. Estuarine Circulation. Humana Press, Clifton, NJ. pp. 253-278.

Southworth, M., J.M. Harding and R. Mann. 1999. The status of Virginia's public oyster resource 1998. Virginia Marine Resources Report No. 99-6. 37 pp.

Southworth, M., J.M. Harding and R. Mann. 2004. The status of Virginia's public oyster resource 2003. Molluscan Ecology Program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 55 pp.

Southworth, M. and R. Mann. 2004. Decadal scale changes in seasonal patterns of oyster recruitment in the Virginia sub estuaries of the Chesapeake Bay. J. Shellfish. Res. 23(2):391-402.

Thompson, R.J., R.I.E. Newell, V.S. Kennedy and R. Mann. 1996. Reproductive processes and early development. In: V.S. Kennedy, R.I.E. Newell and A.F. Eble, editors. The Eastern Oyster: *Crassostrea virginica*. Maryland: Maryland Sea Grant Publications. pp. 335-370.