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The Status of Virginia's Public Oyster Resource 2010

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The Status of Virginia's Public Oyster Resource 2010

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Part I. OYSTER SPATFALL IN VIRGINIA DURING 2010

INTRODUCTION

The Virginia Institute of Marine Science (VIMS) monitors recruitment of the Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), annually from late spring through early fall, by deploying spatfall (settlement of larval oysters called spat) collectors (shellstrings) at various sites 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 in a given year. 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. 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 conditions, however, the relationship between settlement on shellstrings and recruitment to bottom cultch is expected to be commensurate.

This report summarizes data collected during the 2010 settlement season in the Virginia portion of the Chesapeake Bay.

METHODS

Spatfall during 2010 was monitored from the last week of May through the first week of October in the James, Piankatank and Great Wicomico Rivers. Spatfall sites included eight historical sites in the James River, three historical and five modern sites in the Piankatank River and five historical and four modern sites in the Great Wicomico River (Figure S1). In this report, "historical" sites refer to those that have been monitored annually for at least the past twenty years whereas "modern" sites are sites that were added during 1998 to monitor the effects of replenishment efforts by the

Commonwealth of Virginia. The modern 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 both Pocomoke and Tangier Sounds on the eastern side of the Chesapeake Bay as well as in several embayments on the Eastern Shore of Virginia (http://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 some of these reefs. In particular, broodstock oysters were planted on a reef in the Great Wicomico River during winter 1996-97 and on reefs in the Piankatank and Great Wicomico Rivers during winter 1997-98. The increase in the number of shellstring sites during 1998 in the two rivers coincided with areas of new shell plantings in spring 1998 and provides 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 reefs and shell plants on the bottom surrounding the reefs.

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 the 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 site. 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 sites were deployed for 7-day periods, there were some weather related deviations such that shellstring deployment periods ranged from 7 to 14 days. These periods do not always coincide among the different rivers monitored or in different years. Therefore, spat counts for different deployment dates and periods were standardized to correspond to the 7-day standard periods specified in Table 1 to allow for comparison among rivers and years. Standardized spat shell^{-1} (S) was computed using the formula: $S = \sum$ spat shell^{-1} / weeks (W) where W = number of days deployed / 7. Standardized weekly periods allow comparison of spatfall trends over the course of the season between various sites in a river as well as between data for different years.

The cumulative spatfall for each site was computed by adding the standardized weekly values of spat shell^{-1} for the entire sampling period. This value represents the average number of spat that would fall on any given shell if allowed to remain at that site for the entire sampling period. Spat shell^{-1} 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 weekly approximately 0.5 m off the bottom at all sites using a handheld electronic probe (YSI 85). Water temperature was recorded in degrees Celsius (°C) and salinity was recorded in parts per thousand (ppt).

RESULTS

Settlement on shellstring collectors during 2010 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of settlement for the past twenty years at the historical sites in all three river systems and the past twelve years for the modern sites 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 2010 data with historical data in the James River, all eight sites were used. All of the sites monitored in the James River are considered to be part of the traditional seed area. Historically seed oysters were transplanted from this area to other tributaries in the Chesapeake Bay where recruitment was low (Haven & Fritz 1985). Due to the addition of new (modern) 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 2010. Comparisons were made over the past twelve years for the modern sites whereas the historical sites include twenty 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 3 at Dry Shoal (Table S1). Settlement was intermittent in the river system throughout the month of June, becoming consistent in the first week of July. Settlement continued until late September, and possibly longer, but due to weather constraints we were unable to collect the final shellstrings in a time frame suitable for examination. The major peak in settlement occurred during the weeks of July 15 and 22. Settlement in this two-week period accounted for 78% of the total settlement in the system, with the largest proportion (61%), occurring during the week of July 15 (Figure S3). Settlement at the individual sites during this two-week period accounted for 32 (Deep Water Shoal) to 85% (Day's Point) of the total for the year.

Settlement in the James River during 2010 was high throughout the system ranging from a low of 19.7 (Deep Water Shoal) to a high of 335.0 (Day's Point) cumulative spat shell^{-1}. Settlement during 2010 in the James River was the highest observed in the past twenty years at Day's Point, the second highest at Horsehead, Dry Shoal, Rock Wharf and Wreck Shoal and the third highest at Deep Water Shoal, Point of Shoal and Swash (Table S2; Figure S4). Settlement during 2010 was higher than the previous year at all eight sites in the James River. Settlement was also higher than the 5 and 10-yr means at Horsehead, Point of Shoal, Dry Shoal, Rock Wharf and Day's Point and higher than the 20-yr mean at all of the sites except Deep Water Shoal (Table S2).

Average river water temperatures ranged from 23 to 29°C (Figure S5A). Water temperature reached the maximum of 29°C twice during the season, the first time at the end of June and again in mid August. Water temperature increased at a faster rate than the long-term means (5, 10 and 20-yr), such that temperature in 2010 was 3°C higher than the long-term means at the end of June, when temperature reached its first maximum of the season. Water temperature remained slightly higher (1 to 2°C) than the long-term means throughout most of the rest of sampling season.

At the beginning of the sampling period salinity was similar to the long-term means (5, 10 and 20-yr). From mid June onward, salinity was an average of 1 to 3 ppt higher than the 5-yr mean and 1 to 4 ppt higher than both the 10 and 20-yr means (Figure S5B). Salinity in the James River increased throughout most of the sampling season, reaching a peak high of 19 ppt, an almost 5 ppt difference from the 10 and 20-yr means. The difference in salinity in any given week between the most upriver site (Deep Water Shoal) and the most downriver sites (Day's Point and/or Wreck Shoal; Figure 1) ranged from 5 to 10 ppt.

Piankatank River

Settlement in the Piankatank River was first observed during the week of June 17 at Stove Point and Burton Point, the two sites located closest to the mouth of the system (Figure S1). Settlement was intermittent throughout the system from that time until the week of July 8 upon which time there was a three-week pulse (July 8, 15, and 22) in settlement in the system accounting for 90% of the total settlement observed during 2010 (Table S1; Figure S6). Approximately 82% of the spat that set at Cape Toon during 2010 settled during the week of July 8. Settlement from August 12 through the end of the monitoring period was light and intermittent throughout the Piankatank river system.

Cumulative spat shell^{-1} for the year was high ranging from a low of 19.0 at Burton Point to a high of 193.2 at Cape Toon. For the seventh year in a row, Cape Toon had the highest cumulative spat shell^{1} (Table S2) in the system. Spatfall at Cape Toon was the highest observed since monitoring began at the site in 1998, and was eight times higher than that observed in 2007, the next highest year. Spatfall during 2010 was higher than that observed in 2009 as well as higher than both the 5 and 10-yr means at all eight sites monitored (Table S2; Figure S7). Settlement during 2010 was also higher than the 20-yr mean at all three historical sites in the system.

The average water temperature ranged from 23 to 29°C throughout the sampling period. Similar to that observed in the James River, water temperature reached the maximum of 29°C twice during the sampling season, the first time toward the end of June and the second time in late July into early August. Water temperature was approximately 1°C higher than the long-term means (5, 10, and 20-yr) the week sampling began, and then increased approximately 5°C during the last two weeks of June at which time it was around 3°C higher than the long-term means (Figure S8A). This increase was followed by a sharp drop (2°C in one week) in water temperature after which it remained slightly higher (between 1 and 2°C) than the long-term means throughout most of the rest of the sampling period.

Salinity was similar to the 5, 10 and 20-yr means when sampling began and remained that way throughout most of June and July, with the exception of the week of July 1, when salinity was an average of 1.5 ppt higher than the long-term means (Figure S8B). From late July through the end of September, salinity was approximately 1 ppt higher than the previous 5-yr mean and 1.5 to 2 ppt higher than the 10 and 20-yr means. The difference recorded in any given week between Wilton Creek (the most upriver site) and Burton Point (the most downriver site: Figure S1) ranged between 1 and 3 ppt throughout most of the sampling period.

Great Wicomico River

Settlement was first observed during the week of June 10 at all sites except Glebe Point (Table S1) and was relatively consistent from then through the first week of July. Settlement was light and intermittent throughout the system for the rest of the monitoring period. The majority of settlement during 2010 occurred during the last three weeks of June and the first week of July, with a minor pulse observed during the week of June 17, accounting for 62% of the total settlement in the system for the year (Figure S9). Overall, this four-week period accounted for 96% of the total spatfall for the year, ranging from 89% of the total at Haynie Point to 97% of the total at Rogue Point, Hudnall, and Shell Bar.

Cumulative spat shell^{-1} for the year was high at all nine sites ranging from a low of 10.2 at Whaley's East to a high of 82.9 at Rogue Point. Similar to years past, settlement was lowest at the two sites downriver of Sandy Point. However, settlement during 2010 at these two sites was higher than that observed in 2009 as well as higher than the 5, 10 and 20-yr means (Table S2: Figure S10). This was the second highest settlement observed at Whaley's East and the third highest at Fleet Point in the past twenty years of monitoring. Settlement at Haynie Point was higher than 2009 as well as both the 10 and 20-yr means, and was the fourth highest observed since 1990. Settlement at Shell Bar was higher than 2009 as well as both the 5 and 10-yr means and was the second highest observed since monitoring began at that site in 1998. For the remaining five sites, settlement during 2010 was lower than the previous year (2009) and the 5-yr mean. Settlement was higher than the previous 10-yr mean at both Rogue Point and Hudnall and higher than the 20-yr mean at Hudnall.

Average river water temperatures ranged from 19 to 29°C throughout the sampling period reaching 29°C twice during the sampling season, the first time toward the end of June and the second time in late July (Figure S11A). Water temperature for the first two weeks of the sampling period was slightly higher (approximately 2°C) than the 5 and 12-year means, but was then similar to the long-term means for most of the rest of the sampling period (Figure S11A), reaching the maximum approximately a month earlier than is typical for that system. Water temperature increased relatively quickly during the month of June (approximately 5°C), such that there was a 2°C difference in 2010 when compared with the 12-year mean and a 3°C difference when compared with the 5-year mean.

Salinity ranged from 13 to 18 ppt, reaching a maximum toward the end of the sampling period in September (Figure S11B). For several weeks in late June, mid to late July and most the month of September salinity was at least 2 ppt higher than the long-term means (Figure S11B). There was a 1 to 2 ppt difference in salinity between the most upriver site (Glebe Point) and the most downriver site (Fleet Point: Figure S1) throughout most of the sampling period.

DISCUSSION

With some exceptions in each of the rivers during various years, low or moderate spatfall (seasonal cumulative total of less than 10 spat $shell^{-1}$) has been common in Virginia since 1993 (76% of all year/site combinations). Settlement was heavy in all areas monitored during 2010, among the highest observed in the past twenty years of monitoring at several sites. Settlement at the upriver Great Wicomico River sites, while low when compared to the past several years was still relatively high when compared with most of the 1990s and early 2000s.

Settlement in the James River during 2010 was heavy, similar to that observed in the early 1990s and in 2008, another exceptionally high year of settlement that occurred throughout the system. In recent years, the timing of settlement in the James River has been getting progressively earlier (Southworth & Mann 2004). This pattern was again observed in 2010, with greater than 67% of the set occurring by mid July at seven out of the eight sites monitored. Temperature is the single most important factor affecting both timing and magnitude of oyster spawning (Shumway 1996), and the relatively quick increase in temperature that was observed in mid June (5°C in two weeks) may have contributed to the early spawn.

Settlement throughout the Piankatank River was high, with cumulative number of spat $shell^{-1}$ for the season among the highest observed over the past thirteen (modern sites) to twenty (historical sites) years of monitoring. Settlement at most sites was either the highest observed or second only to spatset in the early 1990s. For the past several years potential broodstock (small plus market) in the system has been on the rise and the number of potential brookstock in the system during 2010 was among the highest observed during the past twenty years of monitoring (Part II, this report). Density of the broodstock is an important factor in determining fertilization success (Mann & Evans 1998) and size is important in that fecundity, the number of eggs produced per oyster, increases non-linearly with an increase in biomass (Cox & Mann 1992, Mann & Evans 1998). This may help explain why settlement in the Piankatank River has returned to moderate conditions over the past few years. The timing of the set in the Piankatank River was early with 67 to 97% of the total spat for the season having settled by the week of July 22. The Piankatank River, similar to the James River experienced a large temperature increase (5°C in two weeks) during mid June, which may have been a contributing factor to the timing of the spawn (Shumway, 1996)

Settlement in the Great Wicomico River, while not as high as has been observed over the past several years, was still relatively high when compared with the late 1990s and early 2000s. Settlement at the two most downriver sites ranked among the highest observed since the mid 1980s. Historically, settlement in the Great Wicomico River has occurred earlier than that in the James and Piankatank Rivers (Andrews 1951, Southworth & Mann 2004) and 2010 was no exception. The majority of the settlement occurred between mid June and early July.

Table S1: Average number of spat shell^{-1} for standardized week beginning on the date shown. "D" indicates the date deployed and "-" 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	10/7	YEAR
	147	154	161	168	175	182	189	196	203	210	217	224	231	238	245	252	259	266	273	280	TOTAL
JAMES RIVER																					
Deep Water Shoal	D	0	0	0	0	0.3	0.8	4.3	1.9	0.5	1.9	1.9	1.5	1.9	2.6	1.7	-	0.4			19.7
Horsehead	D	0	0	0	0.2	2.0	2.3	79.9	13.1	2.6	2.4	1.4	2.7	2.5	4.4	1.0	-	0.5			115.0
Point of Shoal	D	0	0	0	0	1.5	2.1	34.0	9.5	1.8	2.0	2.2	2.3	2.8	2.8	2.8	-	1.2			65.0
Swash	D	0	0	0.1	0	4.2	-	31.0	8.0	1.4	1.3	0.9	0.4	1.4	2.3	1.1	-	0.35			52.5
Dry Shoal	D	0.1	0	0.1	0.3	1.6	25.5	138.4	30.8	12.1	14.2	2.0	2.2	2.6	7.5	2.1	-	0.7			240.2
Rock Wharf	D	0	0	0.2	0	1.0	8.5	143.8	79.3	6.3	12	4.4	8.4	3.9	2.7	1.0	-	0.85			272.4
Wreck Shoal	D	0	-	0	0	3.0	4.8	45.8	3.7	2.7	1.4	0.6	0.7	0.4	0.9	0	-	0.05			64.1
Day's Point	D	0	0	0	0.1	0.7	16.2	236.5	49.4	9.0	3.2	0.4	4.1	2.8	10.8	1.6	-	0.15			335.0
PIANKATANK RIVER																					
Wilton Creek	D	0	0	0	0	0.2	2.4	-	11.6	1.1	2.7	0.2	0.7	0	0.9	0.2	0.2	0.6	-	0.05	20.9
Ginney Point	D	0	0	0	0	0.1	11.7	16.3	27.1	1.9	2.6	0.2	0.3	0.1	2.8	0.3	0.1	0	-	0.15	63.7
Palace Bar	D	0	0	0	0.3	0	6.3	3.2	16.7	1.6	0.9	0	0.3	0	0.6	0	0.2	0.2	-	0	30.3
Bland Point	D	0	0	0	0.4	0.3	12.4	4.4	13.6	0.8	1.3	0.1	0.2	-	0.15	0	0.1	0.9	-	0	34.7
Heron Rock	D	0	0	0	0.1	0.2	15.4	3.9	3.8	2.1	0.9	0.1	0.3	0.5	0.2	0	0.4	0.2	-	0.1	28.2
Cape Toon	D	0		0	0.3	0.2	157.9	16.4	12.5	0.8	2.6	0.1	0.1	1.0	0.3	0.3	0.2	0.5	-	0	193.2
Stove Point	D	0	0	0.1	0.1	0.1	12.0	3.1	3.7	0.8	1.2	0	0.6	0.1	0.6	0.3	0.2	0.2	-	0.05	23.2
Burton Point	D	0	0	0.1	0	0	11.0	3.6	2.0	0.2	0.6	0	0.2	0.1	0.1	0.4	0.2	0.4	-	0.05	19.0
GREAT WICOMICO																					
Glebe Point	D	0	0	15.2	14.0	7.8	0	0.2	0	0	1.1	0.5	0.4	0.1	0	0.11	0.1	0	-	0	39.5
Rogue Point	D	0	18.6	52.6	5.1	4.4	0	0.4	0	0	0.8	0.4	0.1	0	0	0	0.4	0.1	-	0	82.9
Hilly Wash	D	0	1.6	15.1	5.2	4.7	0.1	0.7	0	0	0.1	0.1	0	0	0	0	0	0	-	0	27.6
Harcum Flats	D	0	2.0	20.2	4.4	3.5	0.1	0.4	0.1	0	0	0	0.2	0.3	0.1	0	0	0	-	0	31.3
Hudnall	D	0	0.9	24.5	4.0	2.2	0.2	0.3	0	0	0.2	0	0.1	0	0	0.1	0	0	-	0	32.5
Shell Bar	D	0	1.2	31	5.1	7.7	0.3	0.5	0	0	0.2	0.1	0	0	0	0	0.1	0	-	0	46.2
Haynie Point	D	0	0.8	10.8	2.0	2.3	0.1	1.0	0	0.1	0.1	0	0.3	0	0	0.3	0	0	-	0	17.8
Whaley's East	D	0	0.4	12.3	1.2	1.6	0.3	0	0.1	0	0	0	0.4	0	0	0	0	0	-	0.05	16.4
Fleet Point	D	0	0.7	6.5	1.6	1.0	-	-	0	0	0.1	-	-	0	0	0.3	0	0	-	0	10.2

Table S2: Spatfall totals for historical sites (1990-2010) and for 1998-2010 at sites where historical data are not available. Values presented as the cumulative sum of spat shell^{-1} values for each year. "+" and "-" indicate the direction of change in 2010 in reference to 2009 and to the five, ten, and twenty-year means. Blank cells for a site indicate years where data are not available. NC indicates a change of less than 1 spat shell^{-1} in either direction.

STATION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Mean 05-09	Mean 00-09	Mean 90-09	Ref. 2009	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr
JAMES																												
Deep Water Shoal	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	1.0	2.1	5.3	252.3	1.7	19.7	52.5	30.0	17.1	+	-	-	-
Horsehead	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	1.3	2.2	4.2	227.6	4.2	115.0	47.9	27.4	18.1	+	+	+	+
Point of Shoal	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	1.1	2.2	8.6	293.6	2.9	65.0	61.7	34.8	24.6	+	+	+	+
Swash	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	1.4	1.8	6.3	481.5	5.2	52.5	99.2	54.1	35.7	+	-	-	+
Dry Shoal	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	3.1	8.5	4.9	269.6	8.9	240.2	59.0	32.6	37.8	+	+	+	+
Rock Wharf	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	4.4	1.9	19.8	347.5	5.0	272.4	75.7	42.1	26.2	+	+	+	+
Wreck Shoal	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	3.1	4.1	4.1	584.3	7.1	64.1	120.5	63.8	35.8	+	-	NC	+
Day's Point	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	1.6	1.9	30.8	249.2	3.0	335.0	57.3	30.7	34.2	+	+	+	+
PIANKATANK																												
Wilton Creek									1.9	5.9	3.6	0.2	6.5	0.1	0.2	0.4	3.9	2.9	12.1	4.1	20.9	4.7	3.4		+	+	+	
Ginney Point	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	0.3	3.9	7.1	18.3	4.5	63.7	6.8	4.8	8.0	+	+	+	+
Palace Bar	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	0.2	2.1	4.6	7.5	5.9	30.3	4.1	2.8	11.7	+	+	+	+
Bland Point									2.3	44.1	2.7	1.3	6.7	0.2	0.4	1.0	3.7	11.0	11.1	4.7	34.7	6.3	4.3		+	+	+	
Heron Rock									10.1	9.3	3.2	0.6	5.1	0.2	0.7	0.4	1.1	9.9	7.4	5.4	28.2	4.8	3.4		+	+	+	
Cape Toon									4.5	12.3	1.2	1.8	9.1	0.1	2.0	2.6	8.2	23.5	23.4	9.9	193.2	13.5	8.2		+	+	+	
Stove Point									1.0	7.1	1.8	1.6	31.0	0.1	0.7	1.7	7.0	19.9	14.1	6.0	23.2	9.7	8.4		+	+	+	
Burton Point	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	0.9	2.9	10.6	7.1	3.0	19.0	4.9	3.5	8.8	+	+	+	+
GREAT WICOMICO																												
Glebe Point	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	2.0	150.3	132.9	140.6	405.6	39.5	166.3	112.6	58.7	-	-	-	-
Rogue Point									0.9	2.0	2.6	0.7	16.6	7.0	0.5	2.6	88.1	112.0	126.2	92.9	82.9	84.3	44.9		-	-	+	
Hilly Wash									0.6	1.6	3.2	0.8	24.1	2.9	0.5	1.9	43.9	126.9	137.7	81.7	27.6	78.4	42.4		-	-	-	
Harcum Flats									0.1	1.3	0.8	1.1	33.7	3.7	0.7	1.5	110.7	135.3	273.3	112.3	31.3	126.6	67.3		-	-	-	
Hudnall	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	0.9	37.4	51.7	83.0	44.3	32.5	43.5	23.6	18.9	-	-	+	+
Shell Bar									0.0	2.9	0.8	0.8	17.8	1.9	0.3	0.9	29.6	30.3	78.1	18.5	46.2	31.5	17.9		+	+	+	
Haynie Point	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	0.8	17.1	24.8	43.1	8.6	17.8	18.9	11.4	10.4	+	NC	+	+
Whaley's East	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	0.4	6.0	21.6	1.9	2.3	16.4	6.4	3.6	4.5	+	+	+	+
Fleet Point	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	0.4	4.9	8.6	8.4	1.3	10.2	4.7	3.0	3.2	+	+	+	+

Figure S1: Map showing the location of the 2010 shellstring sites. An M following the site name indicates a modern 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 (M), 10) Ginney Point, 11) Palace Bar, 12) Bland Point (M), 13) Heron Rock (M), 14) Cape Toon (M), 15) Stove Point (M), 16) Burton Point. Great Wicomico River: 17) Glebe Point, 18) Rogue Point, 19) Hilly Wash (M), 20) Harcum Flats (M), 21) Hudnall, 22) Shell Bar (M), 23) Haynie Point, 24) Whaley's East, 25) Fleet Point.

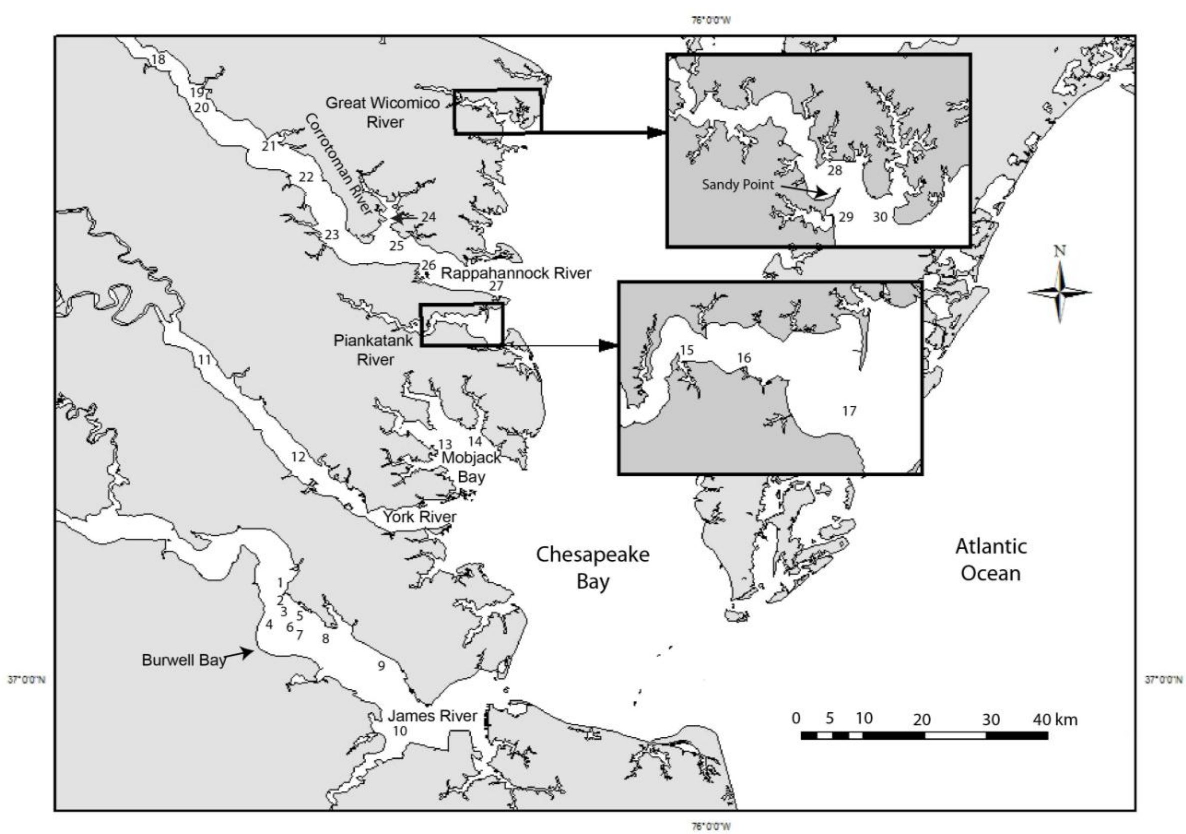


Figure S2: Diagram of shellstring setup on buoys.

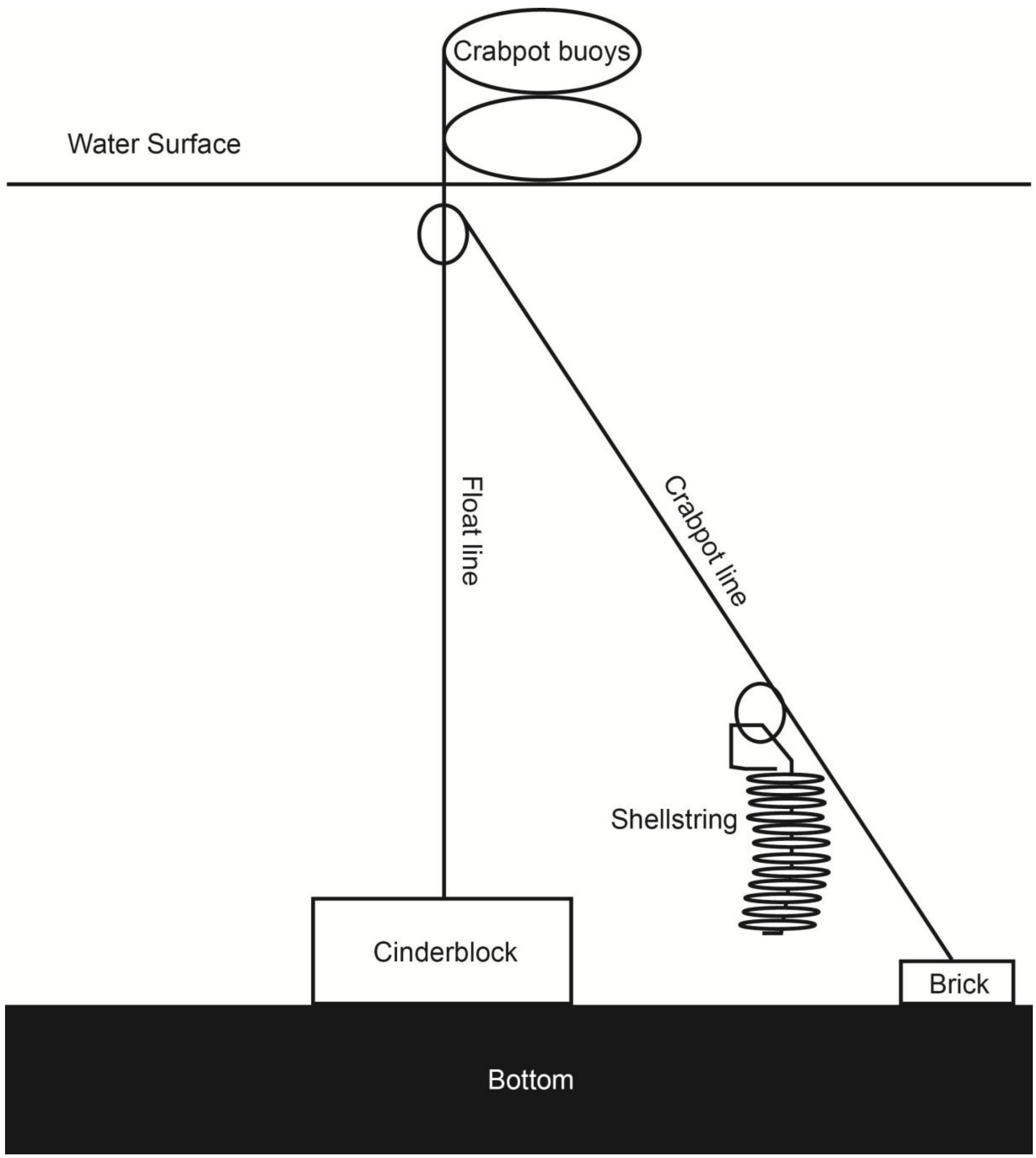


FIGURE S3: JAMES RIVER (2010) WEEKLY SPATFALL INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

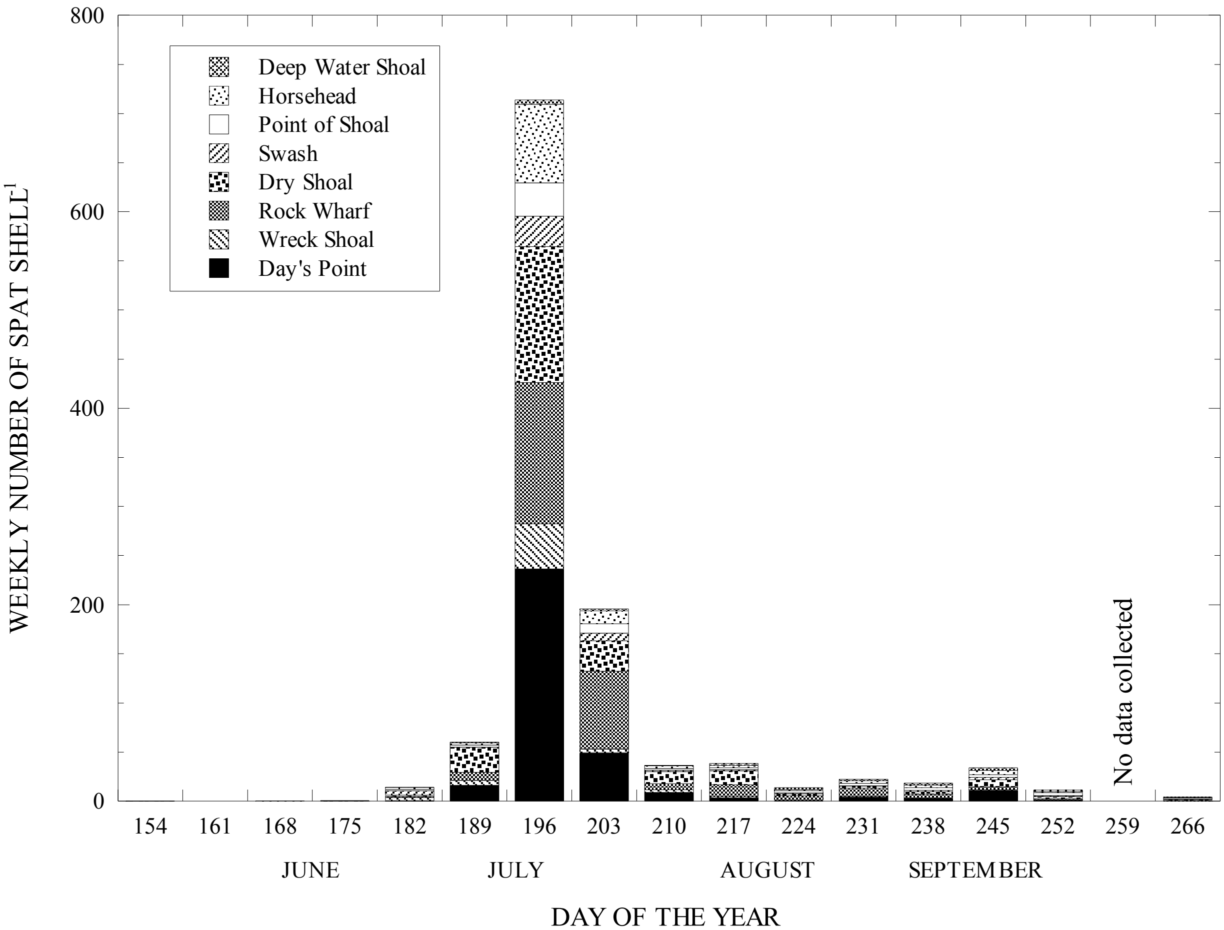


FIGURE S4: SPATFALL TRENDS OVER THE PAST 20 YEARS AT ALL 8 SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall)

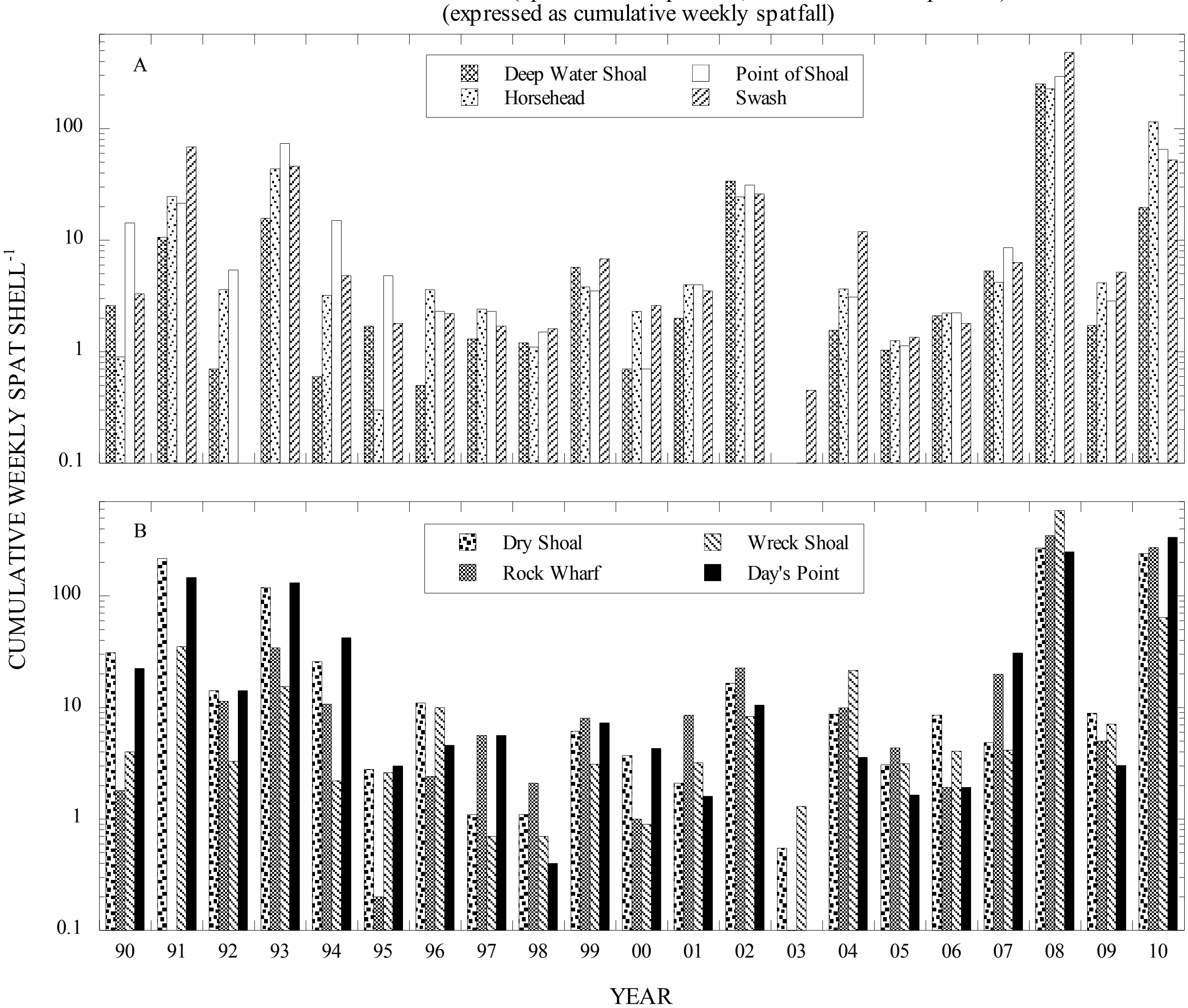


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2010
(Error bars represent standard error of the mean; shaded area represents the bulk of the settlement during 2010; n is the number of data points used to calculate the mean)

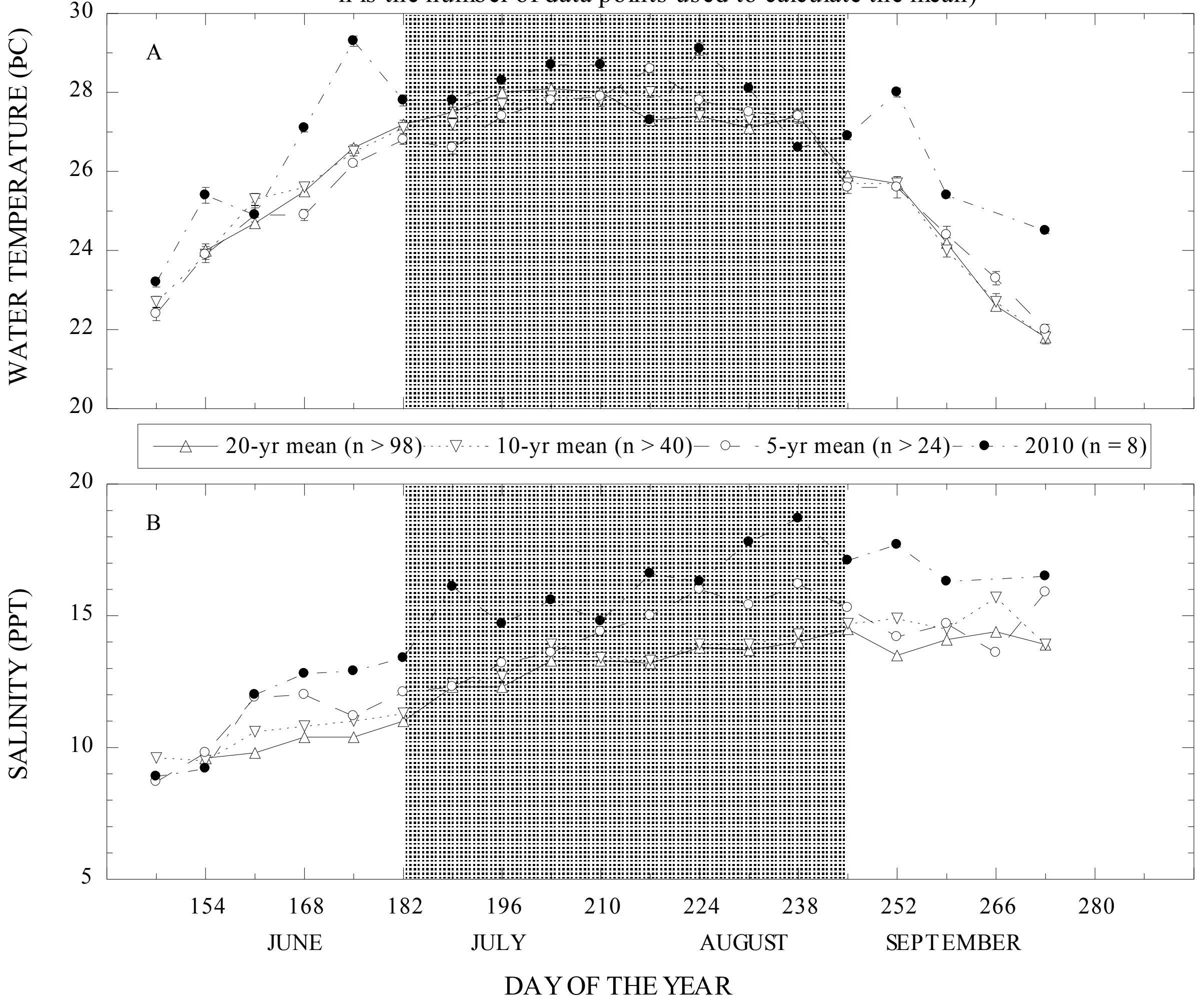


FIGURE S6: PIANKATANK RIVER (2010) WEEKLY SPATFALL INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: M = modern station as described in text)

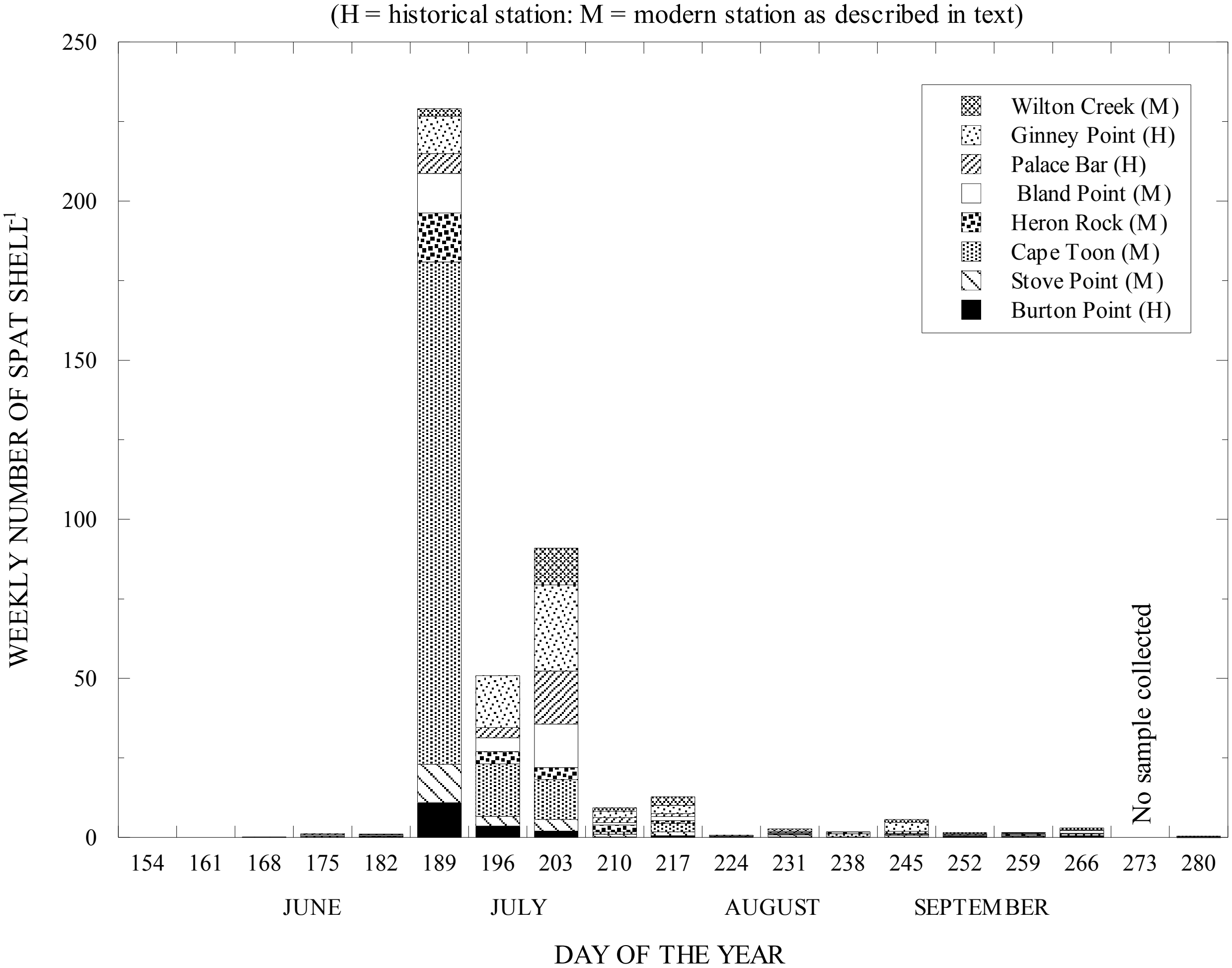


FIGURE S7: SPATFALL TRENDS IN THE PIANKATANK RIVER AT THE 3 HISTORICAL SITES (panel A: 20 years) AND THE 5 MODERN SITES (panel B: 12 years)
(Expressed as cumulative weekly spatfall)

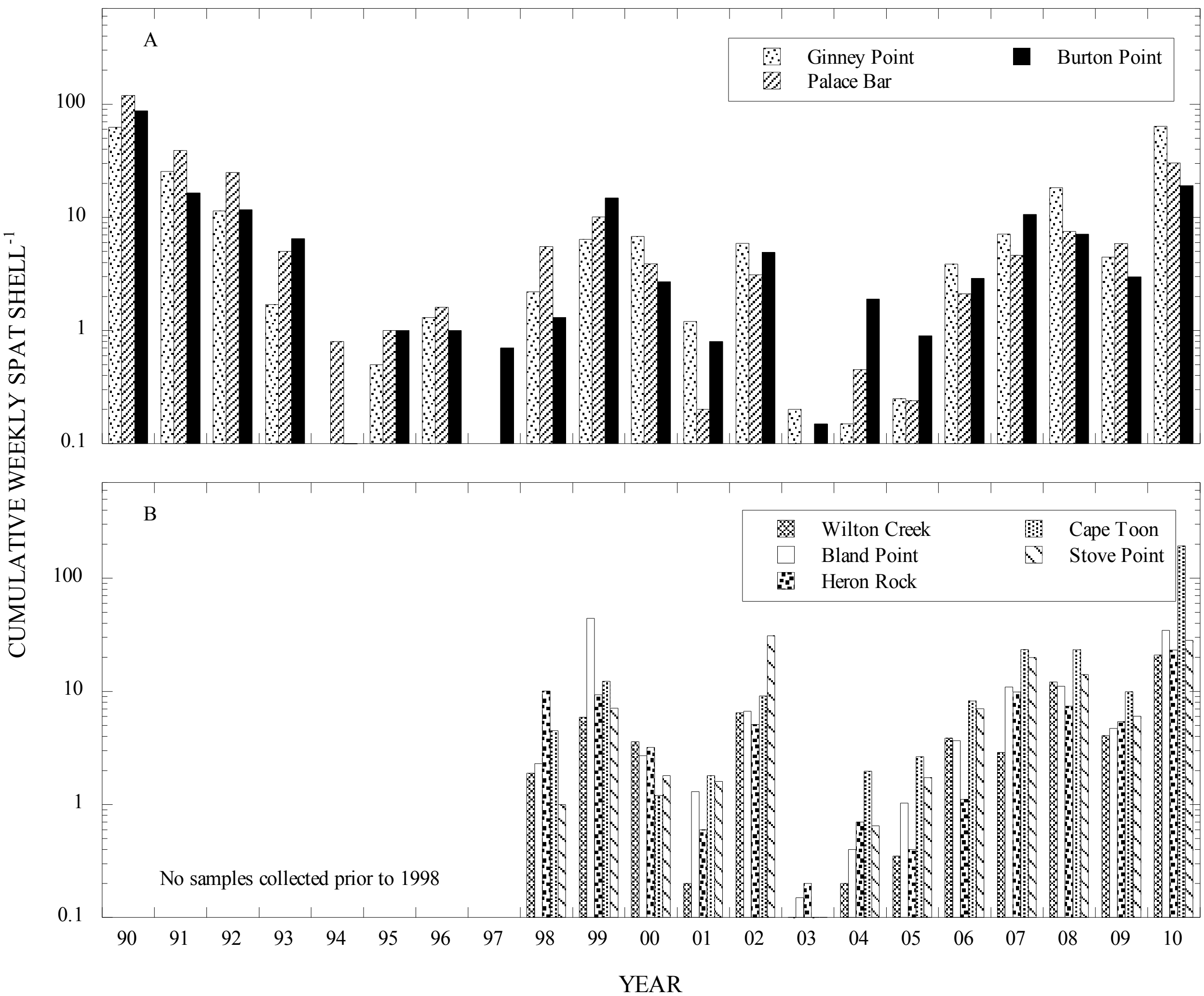


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2010
(Error bars represent standard error of the mean; shaded area represents the bulk of settlement during 2010; n is the number of data points used to calculate the mean)

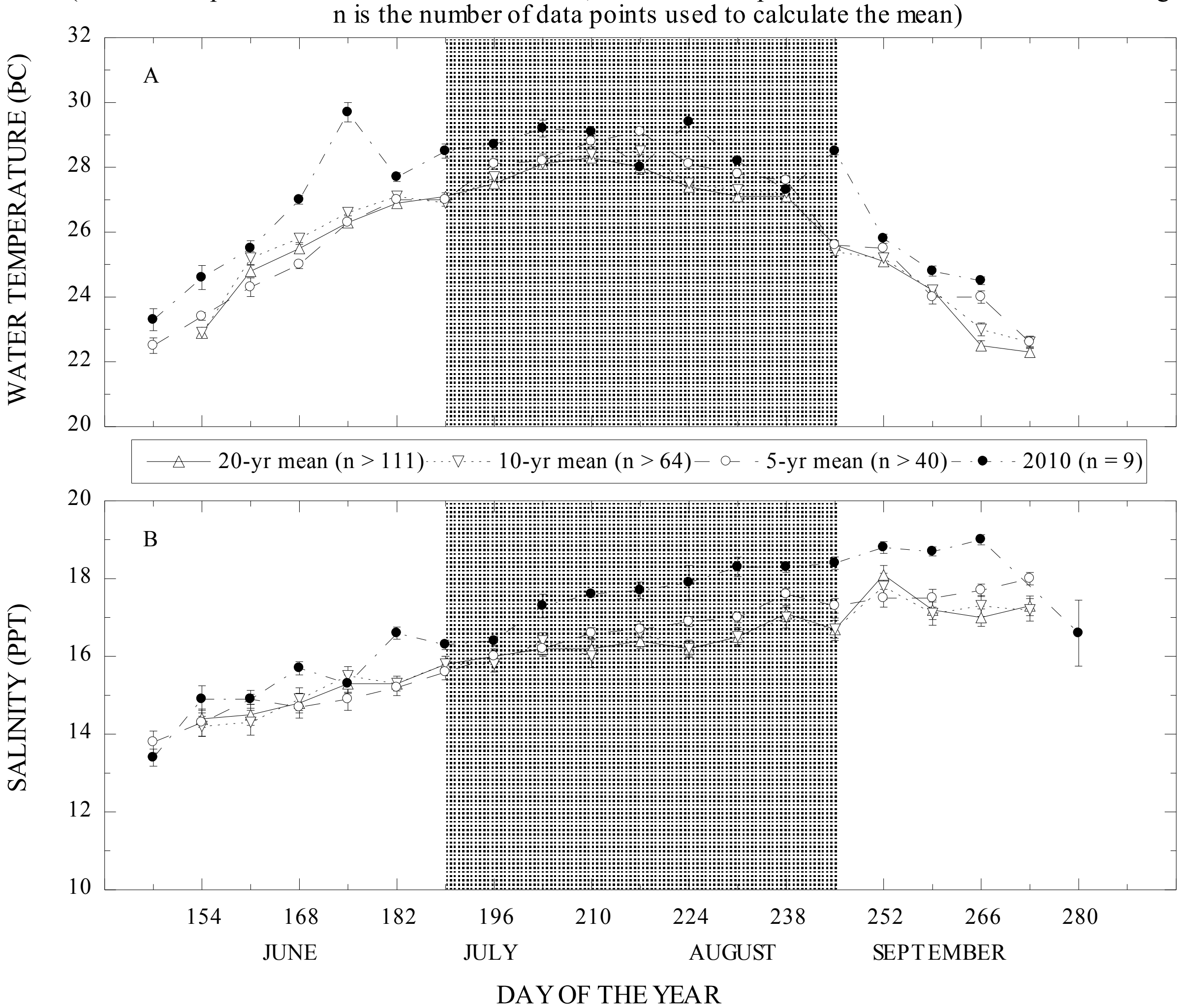


FIGURE S9: GREAT WICOMICO RIVER (2010) WEEKLY SPATFALL INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

(H = historical station: M = modern station as described in text)

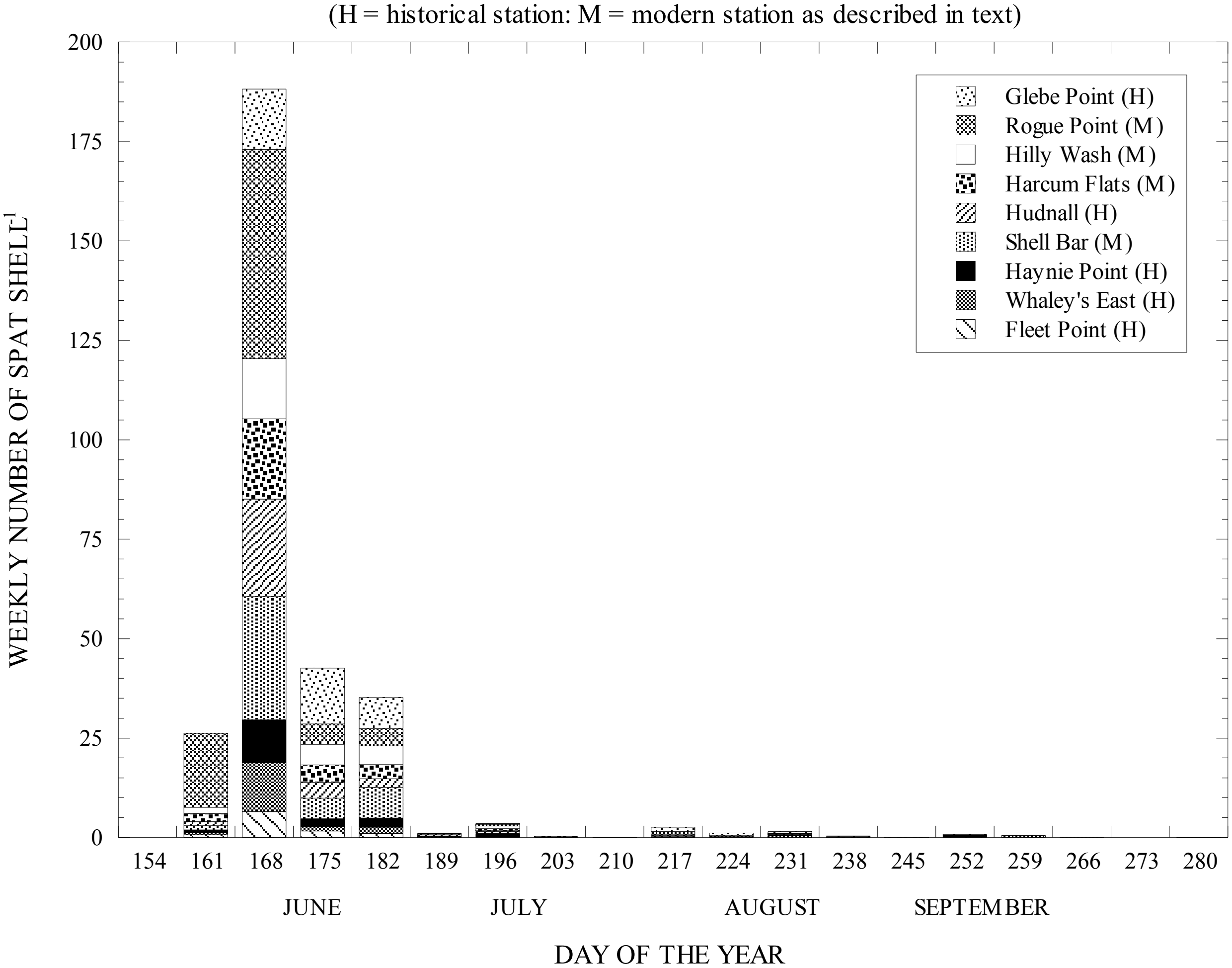


FIGURE S10: SPATFALL TRENDS IN THE GREAT WICOMICO RIVER AT THE 5 HISTORICAL SITES (panel A: 20 years) AND THE 4 MODERN SITES (panel B: 12 years)
(Expressed as cumulative weekly spatfall)

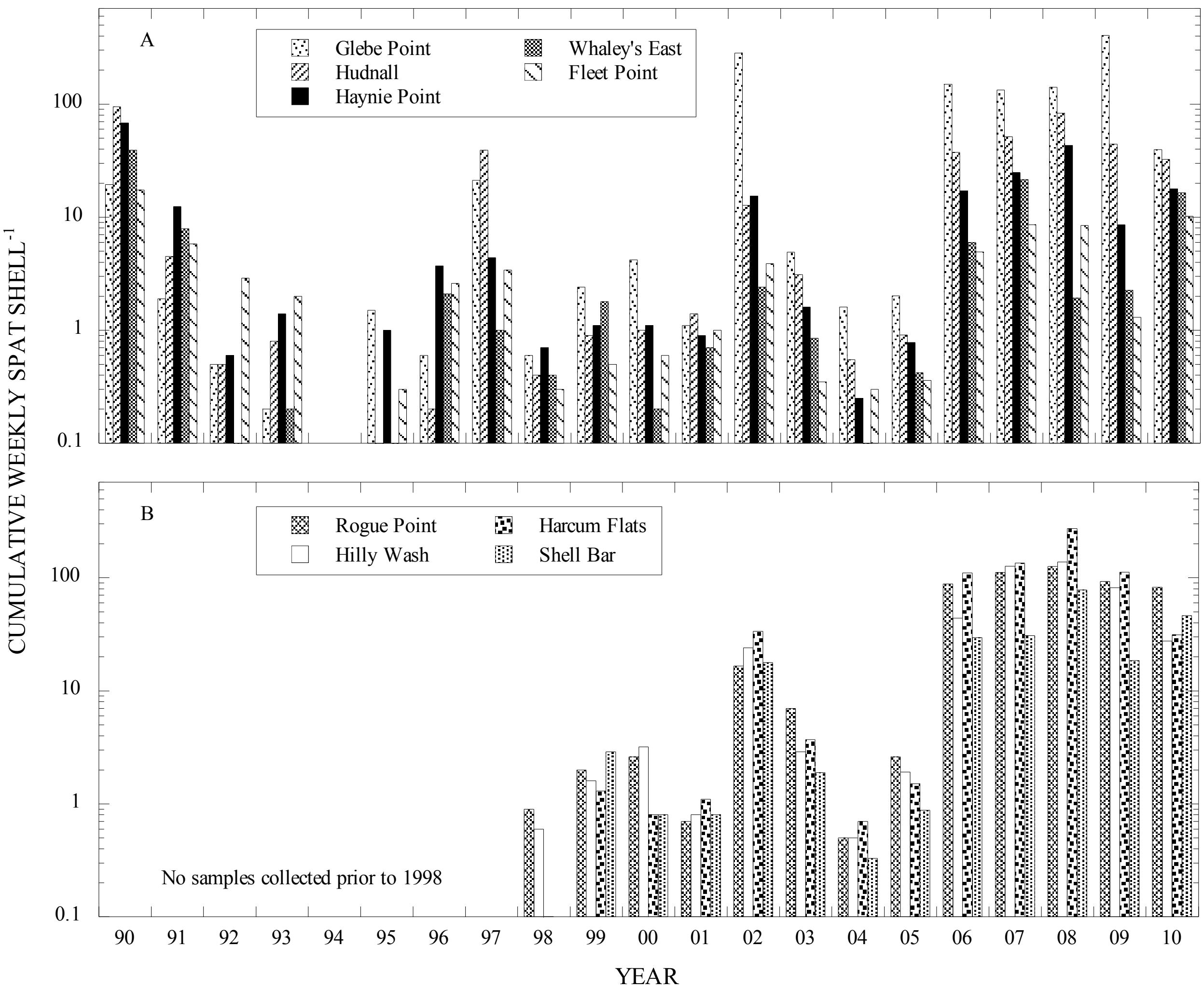
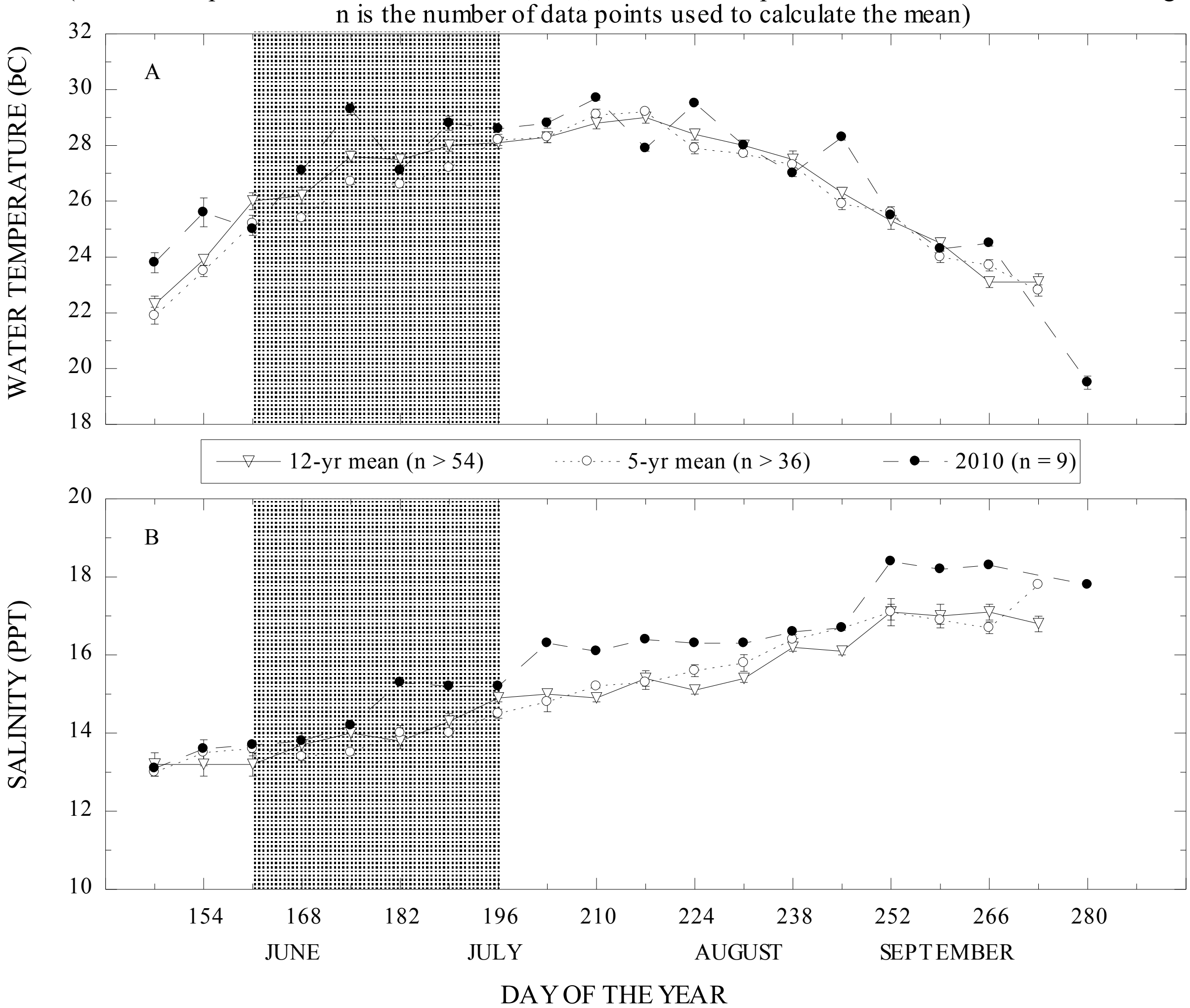


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE SETTLEMENT PERIOD: 5 AND 12-YEAR MEANS COMPARED WITH 2010
(Error bars represent standard error of the mean; shaded area represents the bulk of settlement during 2010; n is the number of data points used to calculate the mean)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2010

INTRODUCTION

The Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), 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 (Baylor 1896) 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) in collaboration with VMRC 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 relative 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 October 2010.

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 a particular bar 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 during fall 2010 are shown in Figure D1. Geographic coordinates of the bars are given in Table D1.

Four samples of bottom material were collected on each bar using an oyster scrape/dredge. In all surveys in the York River and Mobjack Bay (through 2010) and in all surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers preceding 1995, sampling was effected using a 2-ft wide oyster scrape with 4-in teeth towed from a 21-ft boat; volume collected in the scrape 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, James, Piankatank, Rappahannock, and Great Wicomico River samples were collected using a 4-ft dredge with 4-in teeth towed from the 43-ft long VMRC research 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 bar for live oysters 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, 2010 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 new and old box categories is a qualitative description based on visual observations. Water temperature (°C) and salinity (ppt, parts per thousand) were recorded approximately 0.5 meters off the bottom at each of the oyster bars using a handheld electronic probe (YSI 30).

RESULTS

Thirty oyster bars were sampled between October 13 and October 22, 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. 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. In years where data was not collected for a specific site, it has been indicated on the graph for that particular site/system. All other blanks on the graphs are where the population levels for a particular site/oyster category were zero.

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 205.0 bushel^{-1} at Nansemond Ridge to a high of 2078.5 bushel^{-1} at Horsehead. Overall, the number of live oysters was among the highest observed at Dry Shoal (third highest) and Thomas Rock (second highest) since prior to 1990.

The average number of market oysters in the James River remains low when compared with historical numbers, but has been on the rise at a few of the sites in recent years. All of the sites monitored had low to moderate numbers of market oysters ranging from 5.0 (Nansemond Ridge) to 131.0 $bushel^{-1}$ (Point of Shoal). There was a small increase in the number of market oysters at Deep Water Shoal, Point of Shoal, Dry Shoal and Thomas rock when compared with 2009 (Figure D2 and D3). The number of market oysters at Deep Water Shoal, Point of Shoal and Dry Shoal was the highest observed since prior to 1990 and the second highest observed since that time at Thomas Rock. The number of market oysters at Wreck Shoal was at an all time low in 2002, but by 2005 had steadily increased to the highest numbers observed in the past twenty years and has remained at similar levels since (Figure D3C).

The average number of small oysters $bushel^{-1}$ ranged from a low of 9.0 at Nansemond Ridge to a high of 622.5 at Mulberry Point. When compared with 2009, the number of small oysters remained relatively stable at all ten sites in the James River (Figure D2). The number of small oysters at Nansemond Ridge remains at very low levels for the second year in a row (Figure D3C), which is not surprising given the almost complete lack of settlement observed at that site in 2009.

The average number of spat $bushel^{-1}$ ranged from a low of 191.0 at Nansemond Ridge to a high of 1,436.0 at Horsehead. There was a relatively large increase in spat observed at all ten sites when compared with 2009 and the number of spat observed was among the highest recorded in the past twenty years at nine out of the ten sites (highest at Horsehead, Point of Shoal, Mulberry Point and Swash, second highest at Deep Water Shoal, Long Shoal and Dry Shoal and third highest at Wreck Shoal and Thomas Rock; Figure D3). The James River has experienced exceptionally high spat set in two out of the past three year (2008 and 2010). Historically, the typical pattern observed in the James River was an increasing percentage of small oysters and a decreasing percentage of spat as one moved from the most downriver site (Nansemond Ridge) to the most upriver site (Deep Water Shoal). In more recent years, this pattern has not been observed as often as spatfall over the past decade has been increasing at the more upriver sites while decreasing at the more downriver sites and 2010 was no exception. The highest percentage of oysters occurred in the spat oyster category at all ten sites monitored during 2010.

The average number of boxes $bushel^{-1}$ ranged from a low of 11.0 (Nansemond Ridge) to a high of 75.0 (Dry Shoal). Boxes accounted for less than 10% of the total (live and dead) at all ten sites. A large percentage of the boxes observed were spat boxes, which is not surprising given the large number of spat. At least 21% of the boxes were new boxes at seven out of the ten sites (Horsehead, Point of Shoal, Swash, Long Shoal, Dry Shoal, Wreck Shoal and Thomas Rock) indicating some recent mortality. An average of 22% of the total larger oysters (includes all categories except spat and spat boxes) were boxes at the four most downriver sites (Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge), indicating some disease mortality.

Water temperature during the two days of sampling was approximately 18°C (Table

D2) at all sites. Salinity was variable depending on location in the river, increasing in a downriver direction, from 12.9 ppt at Deep Water Shoal to 18.5 ppt at Nansemond Ridge.

York River

The average total number of live oysters $bushel^{-1}$ in the York River was 193.5 at Bell Rock and 75.5 at Aberdeen Rock. The live oysters at Bell Rock were approximately 50% spat with the other 50% being equally split between market and small oysters. There was a notable increase in all size ranges observed at Bell Rock when compared with 2009 (Figure D4). The number of market oysters at Bell Rock has been increasing since 2008, and 2010 had the highest number of market oysters observed over the past twenty years of monitoring, twice as many as that observed in 2009, the next highest year (Figure D5). The live oysters at Aberdeen Rock were a split between small and spat, with about 20% market oysters. There was a notable decrease in the small oysters observed when compared with 2009 (Figure D4). The average number of boxes $bushel^{-1}$ was low (16 $bushel^{-1}$ at both sites), accounting for approximately 7.6 and 17.5% of the total oysters (live and boxes) at Bell Rock and Aberdeen Rock respectively. At both sites, the majority of the boxes (greater than 88% of the total) were old boxes. Water temperature on the day of sampling was approximately 17.5°C at both sites. There was a 3.7 ppt difference in salinity: 15.1 ppt at Bell Rock and 18.8 ppt at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 289.0 and 131.0 oysters $bushel^{-1}$ respectively. There was a notable decrease in the number of market and small oysters observed at Pultz Bar (Figure D4 and D6). This decrease in the number of market oysters was a two-fold decrease (Figure D6). The number of market and small oysters observed at Tow Stake were among the highest observed during the past twenty years of monitoring (second highest number of markets, the highest number of smalls; Figure D6). The number of spat at both sites was relatively low. There were a relatively low number of boxes observed at Tow Stake accounting for approximately 13% of the total (live and boxes). The number of boxes at Pultz Bar however was relatively high (52.5 $bushel^{-1}$), accounting for almost 29% of the total (live and boxes), which is reflected in the large decrease in the number of oysters observed at that site as previously mentioned. Water temperature was 17.4°C and salinity was approximately 21 ppt at both sites (Table D2) on the day of sampling.

Piankatank River

The average total number of live oysters $bushel^{-1}$ in the Piankatank River ranged from 279.0 at Burton Point to 1285.5 at Palace Bar. The number of market oysters in the river, while similar to that observed in 2009, has been on the rise for the past several years, and the numbers observed during 2010 represent the highest numbers observed over the past twenty years of monitoring at Burton Point and Ginney Point and the second highest at Palace Bar (Figure D7 and D8). Spat set was good for the fifth year in a row at all three sites following three years (2003-2005) of record low settlement (Figure D8). There was a notable increase in spat at all three stations when compared with 2009 and this represented some of the highest settlement in the past twenty years at Ginney Point and Palace Bar. The number of boxes observed was low, less than 5% of the total (live and boxes) at Palace Bar and Ginney Point and 13% of the total (live and boxes) at Burton Point. The majority of the boxes at all three sites were old (> 71%), with about 15% of the remaining being spat boxes. Similar to recent years, several (20% of the total observed) of the spat boxes at Burton Point had drill holes, indicative of predation by one of the two native oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*, both of which are found in the Chesapeake Bay. Water temperature on the day of sampling was around 20ºC at all three sites. Salinity ranged between 17.5 (Ginney Point) and 18.0 ppt (Burton Point).

Rappahannock River

The average total number of live oysters bushel^{-1} in the Rappahannock River ranged from a low of 35.5 at Morattico Bar to a high of 305.5 at Drumming Ground. As is typical for the Rappahannock River system, 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 has been observed in the past, the sites with the highest number of oysters were located in the Corrotoman River (Middle Ground), just outside the mouth of the Corrotoman River (Drumming Ground) and at the two most downriver sites (Parrot Rock and Broad Creek) in the system. For the third year in a row, the total number of oysters at Middle Ground has increased. This suggests that the population at Middle Ground is rebounding after the almost 100% die-off that occurred at the site in 2005 (Southworth et al. 2006).

The average number of market oysters bushel^{-1} ranged from 7.0 (Morattico Bar) to 61.0 (Ross Rock). There was a decrease in the number of market oysters observed at Bowler's Rock, Morattico Bar, Smokey Point and Drumming Ground (Figure D9 and D10) when compared with 2009. The number of market oysters was the highest observed in the past twenty years at Ross Rock, Hog House, Middle Ground and Parrot Rock and the second highest at Drumming Ground, despite the decrease. It should be noted that the decrease observed at both Smokey Point and Morattico Bar may have been a result of harvesting of seed oysters that were planted on those sites in 2008 and harvested in the spring of 2010 (VMRC, unpublished data).

For the ninth year in a row, Drumming Ground near the mouth of the Corrotoman River had the highest number of small oysters bushel^{-1} with 128.5, although this was a small decrease when compared with 2009. There was also a decrease in the number of small oysters observed at Hog House, Middle Ground and Parrot Rock (Figure D9). The number of small oysters at Bowler's Rock, Morattico Bar, Hog House and Broad Creek was among the lowest observed over the past twenty years of monitoring (Figure D10).

Similar to more recent years (with the exception of 2009), there was spatset at all ten stations in the Rappahannock River. This represented an increase when compared with 2009 at all ten sites (Figure D9). Settlement was among the highest observed over the past twenty years, especially at the more upriver sites (highest at Bowler's Rock, Long Rock, Morattico Bar and Smokey Point; Figure D10A and D10B). Settlement throughout the system has been low (typically less than 100 spat bushel^{-1}) since the mid 1990s but in 2010 the four most downriver sites (Middle Ground, Drumming Ground, Parrot Rock and Broad Creek) all had greater than 100 spat bushel^{-1} (Figure D10B and D10C).

Overall the average total number of boxes bushel^{-1} was low, accounting for less than 14% of the total (live and dead) at all ten sites. At six out of the ten sites greater than 86% of the boxes were old. Middle Ground, Drumming Ground and Parrot Rock all had about 75% old boxes and 25% new boxes indicating some recent mortality at those sites.

Water temperature on the day of sampling ranged from 17.2 to 18.6°C, generally increasing as one moved toward the mouth of the system. Salinity also increased as one moved from the most upriver site (Ross Rock: 10.8 ppt) toward the mouth (Broad Creek: 17.6 ppt).

Great Wicomico River

The average total number of live oysters bushel^{-1} in the Great Wicomico River ranged from a low of 131.5 at Fleet Point to a high of 313.0 at Whaley's East. Over the past several years, there has been a steady increase in the number of market oysters at Haynie Point and 2010 had the highest number of market oysters since prior to 1990 (Figure D11 and Figure D12). There was a small decrease in the number of small oysters observed at Haynie Point and Fleet Point and an increase in spat at all three sites when compared with 2009 (Figure D11). Settlement in more recent years in the Great Wicomico River has been on the high side (comparable to that observed in the late 1980s and early 1990s, however, despite the increase observed in 2010 when compared to 2009, settlement for the past two years has been more moderate (Figure D12). The total number of boxes bushel^{-1} was moderate ranging from 23.5 (Fleet Point) to 76.5 (Haynie Point). This accounted for 13 (Whaley's East) to 20% (Haynie Point) of the total (live and dead) number of oysters observed. At Whaley's East and Fleet Point, greater than 25% of these were new boxes, indicating some recent mortality at those sites. Water temperature on the day of sampling was approximately 20°C and salinity was approximately 17.5 ppt at all three sites monitored.

DISCUSSION

The abundance of market oysters throughout the Chesapeake Bay region has been in serious decline since the beginning of the 20th century (Hargis & Haven 1995, Rothschild et al. 1994). For the past few decades, 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 and Rappahannock Rivers, 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 Bay remains low (average of 37.9 market oysters $bushel^{-1}$), but the average observed in 2010 was slightly higher than that observed during 2009, marking the third year in a row with a small overall increase.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2010, the overwhelming number of spat dwarfed this trend, such that only three out of the thirty sites had greater than 50% small oysters, whereas nineteen of them had greater than 50% spat. There were only two sites (Bowler's Rock and Long Rock) that had predominately market oysters, but it should be noted that these both have extremely low (< 50 oysters $bushel^{-1}$) oyster populations. The oyster populations in the mesohaline reaches of the Piankatank River (on Ginney Point and Palace Bar) have been steadily increasing since 2004. This increase has followed a large die-off of broodstock oysters that occurred in late 2003 early 2004 (Southworth et al. 2005). At both of these sites the number of small and market oysters combined are the fourth highest observed during the past twenty years and while this seems to suggest that the oyster population at these sites is increasing, several more years of consistent numbers of small and market oysters along with good settlement is needed to know if these increases in the number of oysters will persist, but the large spatset that occurred in this system during 2010 is promising.

Overall, settlement during 2010 was moderate to high throughout most of the Virginia portion of the bay. There was at least one spat observed at all ten stations in the Rappahannock River, and settlement during 2010 was the highest observed at four of the sites since prior to 1990. Settlement in the James River was similar to the patterns that have been observed in more recent years, with higher settlement at the eight most upriver sites when compared with the two most downriver sites. This is in contrast to the historical settlement pattern where settlement tended to increase as one moved upriver (Haven & Fritz 1985).

The average total number of boxes observed during 2010 was low to moderate accounting for 2 to 29% of the total (live and dead) oysters. On a system basis, the Mobjack Bay and Great Wicomico Rivers had the highest number of boxes. After four years in a row of consistently high number of boxes in the James River, this system had a relatively low number of boxes during 2010. However, when spat were excluded from the live count, the four most downriver sites in the James River (Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge) all had a fairly high percentage of boxes (between 16 and 32%). This pattern has been observed for several years and may be indicative of increased mortality caused by disease. Nine out of the remaining twenty sites also experienced an elevated (greater than 20%) number of boxes when spat were excluded from the live count, this included at least one site in each of the other five systems monitored.

In general, drill holes have become more prevalent in spat boxes since the early 2000s. During 2010, there were drill holes present in spat boxes at Burton Point in the Piankatank River. The presence of drill holes is indicative of predation by one of the two oyster drill species, *Urosalpinx cinerea* or *Eupleura caudata,* which are 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 their corresponding egg masses have become more common during recent years in the mouths of the Piankatank and Rappahannock Rivers, and in Mobjack Bay. While there were very few spat boxes with drill holes observed during the 2010 dredge survey, it should be noted that drill holes were observed at multiple sites in both the Piankatank River and Mobjack Bay during the patent tong survey in November of 2010 (Southworth, personal observation), so the predation of spat by oyster drills in these systems remains a concern.

Table D1: Station locations for the 2010 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 32	76 36 44
Long Shoal	37 04 35	76 36 14
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 03	76 44 59
Aberdeen Rock	37 20 07	76 36 02
Mobjack Bay		
Tow Stake	37 20 20	76 23 10
Pultz Bar	37 21 11	76 21 10
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 36	76 44 07
Long Rock	37 48 59	76 42 50
Morattico Bar	37 46 55	76 39 33
Smokey Point	37 43 09	76 34 56
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 2010. Note that the bushel measure used is a VA bushel which is equivalent to 3003.9 in^{-3}. A VA bushel differs in volume from both a U.S. bushel (2150.4 in^{-3}) and a MD bushel (2800.7 in^{-3}). "*" indicates a private bar. Middle Ground (#) is located in the Corrotoman River, a subestuary of the Rappahannock River system.

Station	Date	Temp (˚C)	Sal. (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	10/20	18.4	12.9	95.0	373.0	953.5	1421.5	7.0	17.0	27.0	51.0
Mulberry Point	10/20	18.3	14.1	28.5	622.5	1141.5	1792.5	4.0	29.0	15.5	48.5
Horsehead	10/20	18.4	15.1	55.0	587.5	1436.0	2078.5	15.0	41.5	15.0	71.5
Point of Shoal	10/20	18.4	14.6	131.0	336.5	1034.0	1501.5	13.5	33.0	9.5	56.0
Swash	10/20	18.3	15.8	18.5	402.5	1216.5	1637.5	23.0	38.5	3.0	64.5
Long Shoal	10/20	18.3	16.8	37.5	419.5	692.5	1149.5	16.5	51.5	7.0	75.0
Dry Shoal	10/20	18.4	17.3	52.0	295.5	610.0	957.5	25.0	40.0	4.0	69.0
Wreck Shoal	10/20	18.4	18.1	38.5	79.0	381.0	498.5	7.5	14.0	5.0	26.5
Thomas Rock	10/19	18.4	17.0	17.5	46.5	205.5	269.5	7.5	23.0	1.5	32.0
Nansemond Ridge	10/19	18.1	18.5	5.0	9.0	191.0	205.0	0.5	4.0	6.5	10.5
York River											
Bell Rock *	10/22	17.3	15.1	47.5	55.5	90.5	193.5	1.5	14.0	0.5	16.0
Aberdeen Rock	10/22	17.6	18.8	14.5	32.0	29.0	75.5	1.5	14.5	0.0	16.0
Mobjack Bay											
Tow Stake	10/21	17.4	21.1	37.0	199.0	53.0	289.0	11.0	27.5	4.0	42.5
Pultz Bar	10/21	17.4	21.2	33.0	91.5	6.5	131.0	8.5	43.5	0.5	52.5
Piankatank River											
Ginney Point	10/13	19.8	17.5	68.0	148.0	661.0	877.0	8.0	32.5	5.5	46.0
Palace Bar	10/13	20.0	17.6	43.0	194.0	1021.5	1258.5	2.5	21.5	5.0	29.0
Burton Point	10/13	20.0	18.0	30.5	80.5	168.0	279.0	4.5	32.5	5.0	42.0
Rappahannock River											
Ross Rock	10/18	17.2	10.8	61.0	60.0	7.5	128.5	0.0	2.0	0.0	2.0
Bowler's Rock	10/18	17.3	12.9	26.0	9.5	8.5	44.0	0.5	4.5	0.0	5.0
Long Rock	10/18	17.7	14.5	20.0	5.5	17.5	43.0	0.5	2.5	0.5	3.5
Morattico Bar	10/18	17.6	15.0	7.0	5.0	23.5	35.5	0.0	1.5	0.0	1.5
Smokey Point	10/18	17.5	15.6	22.5	20.0	65.5	108.0	2.5	12.0	0.5	15.0
Hog House	10/18	17.9	16.6	21.5	3.5	49.0	74.0	0.0	3.5	0.0	3.5
Middle Ground #	10/18	18.2	16.8	39.0	84.0	123.5	246.5	9.0	25.5	2.5	37.0
Drumming Ground	10/18	18.6	17.2	37.0	128.5	140.0	305.5	10.0	30.0	1.0	41.0
Parrot Rock	10/18	17.6	17.2	31.5	48.0	175.0	254.5	6.0	18.5	0.5	25.0
Broad Creek	10/18	18.2	17.6	35.0	35.5	101.0	171.5	4.0	24.5	0.0	28.5
Great Wicomico River											
Haynie Point	10/14	20.2	17.4	53.5	135.5	116.5	305.5	12.5	64.0	0.0	76.5
Whaley's East	10/14	20.0	17.6	15.0	204.0	94.0	313.0	11.5	33.5	0.5	45.5
Fleet Point	10/14	20.2	17.8	15.5	64.5	51.5	131.5	7.0	16.5	0.0	23.5

Figure D1: Map showing the location of the oyster bars sampled during the 2010 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.

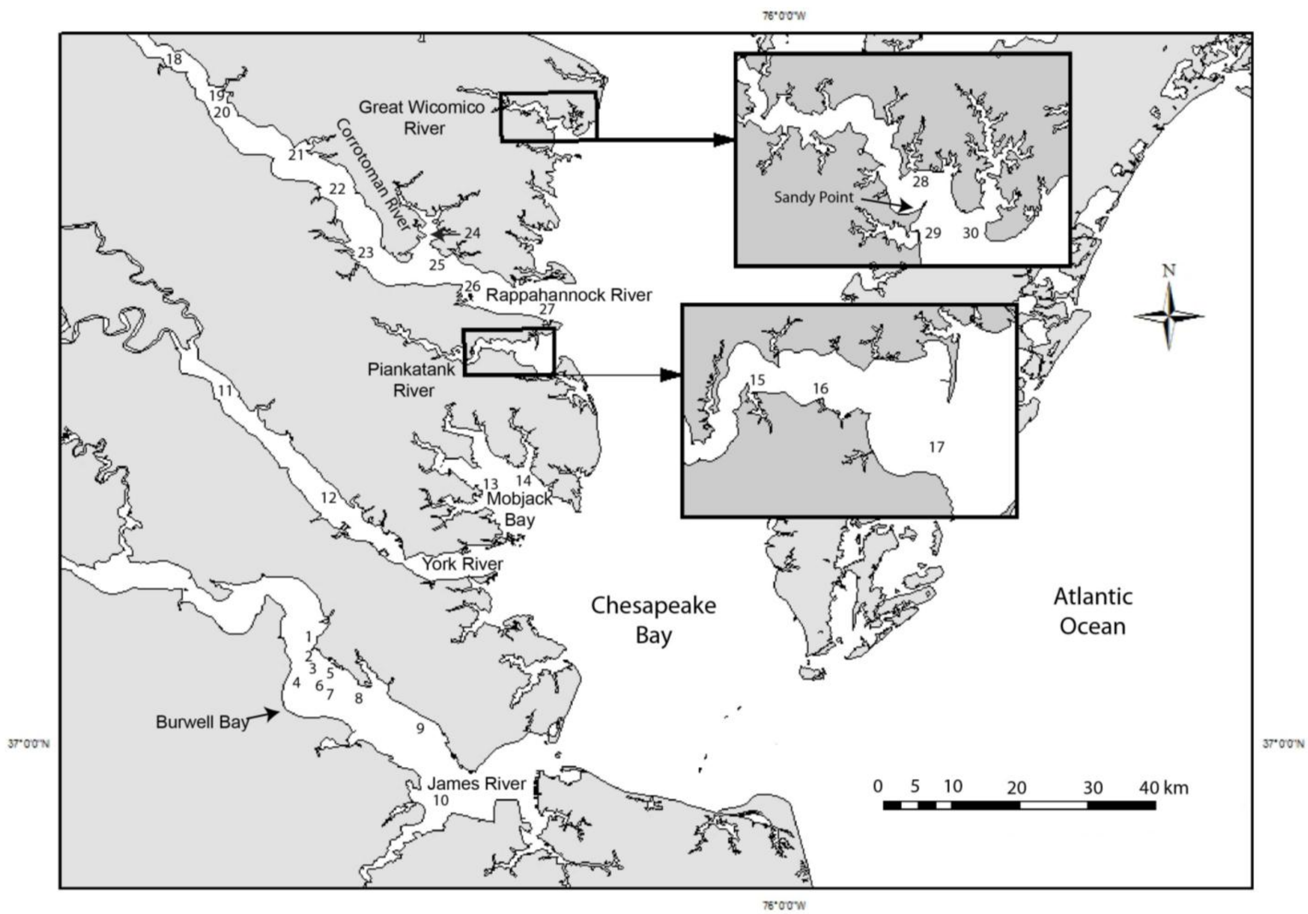


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2009-2010)
(Error bars represent standard error of the mean)

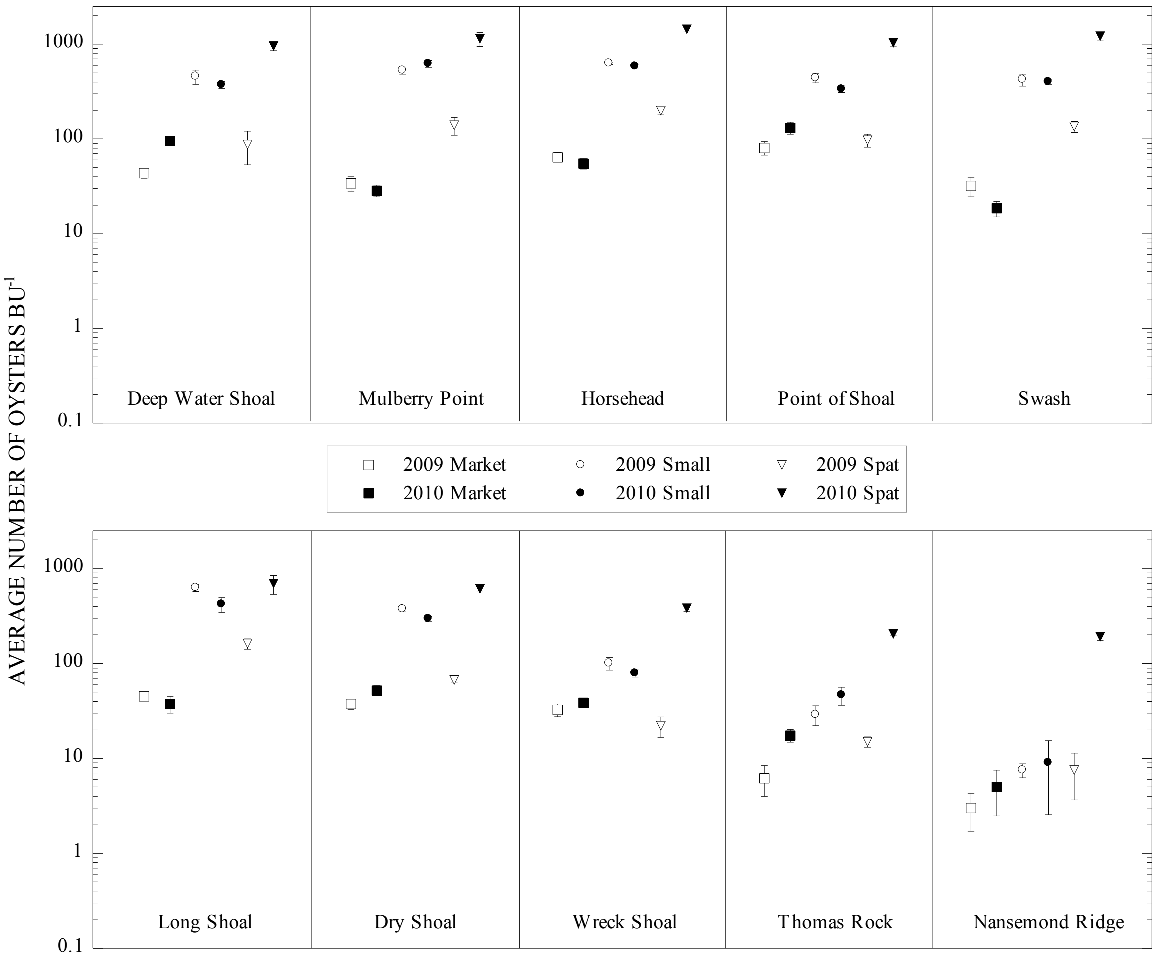
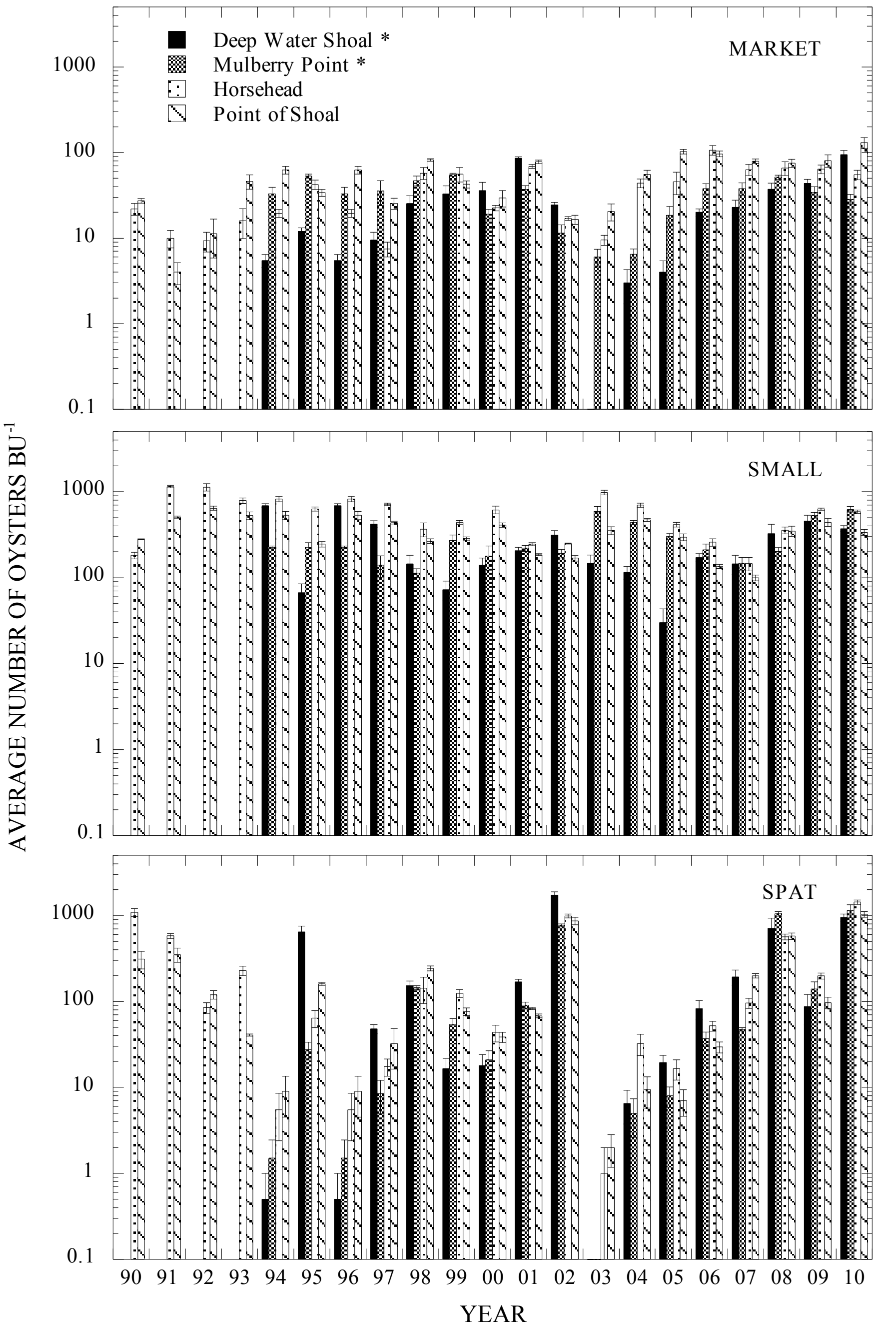
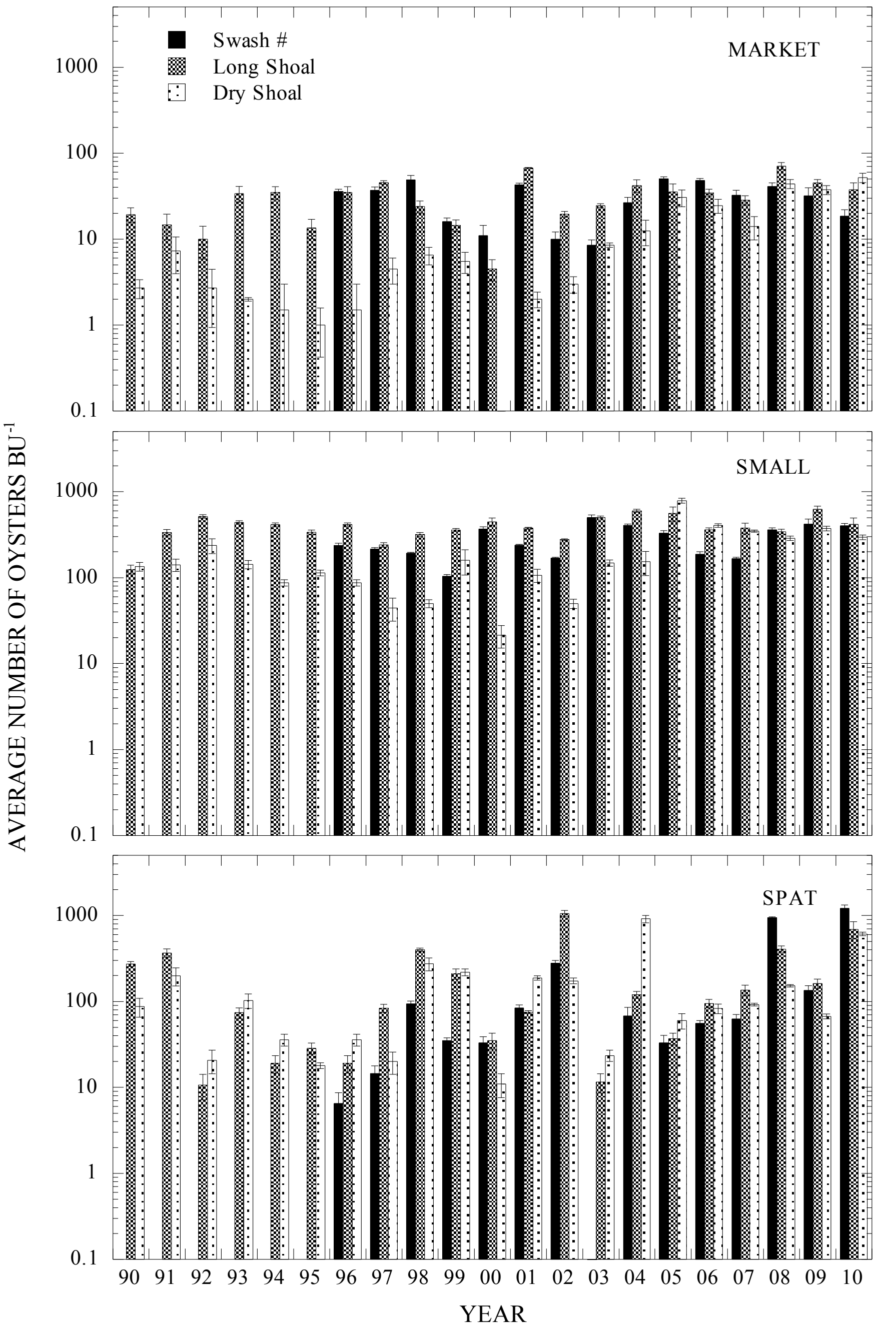


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1994

FIGURE D3B: JAMES RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



No samples collected prior to 1996

FIGURE D3C: JAMES RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)

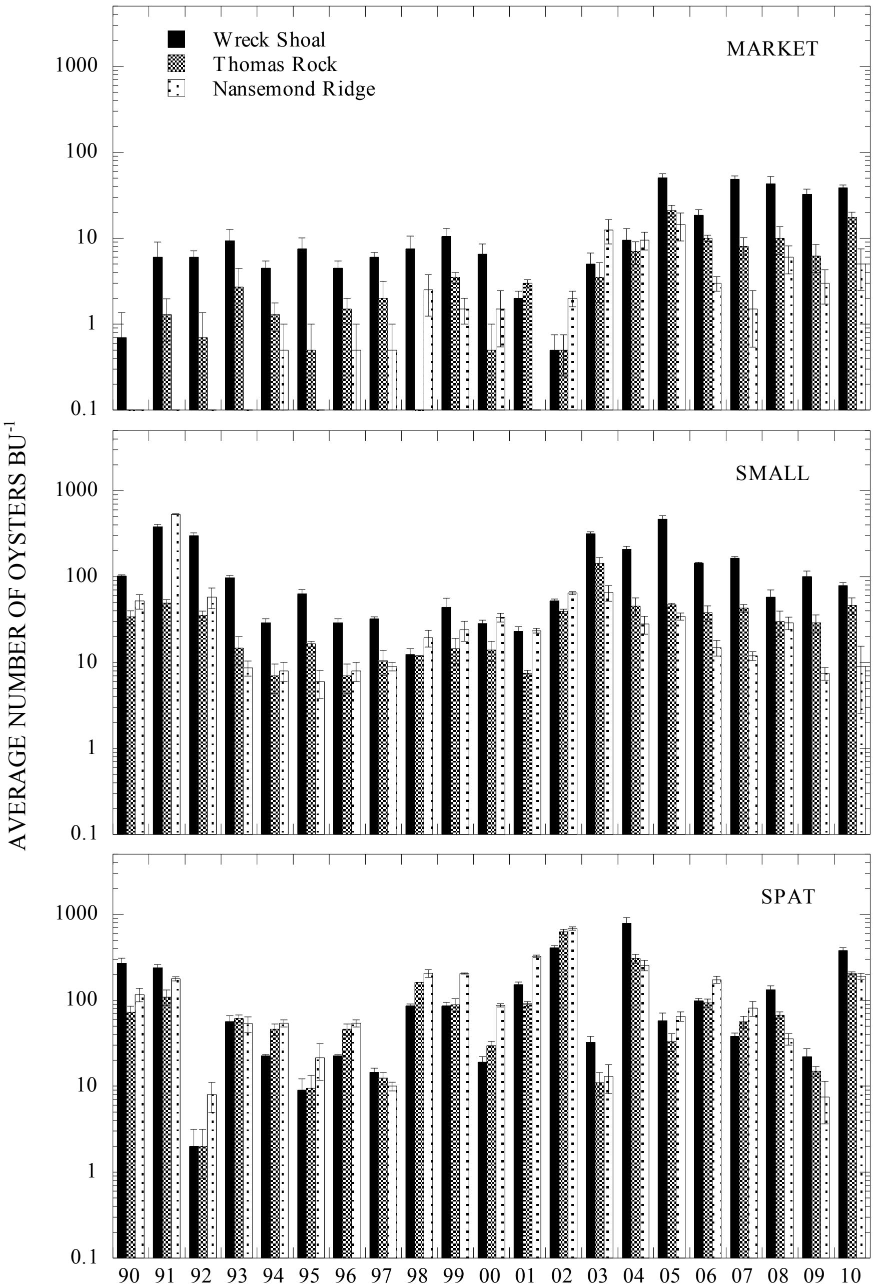


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE YORK RIVER AND MOBJACK BAY (2009-2010)
(Error bars represent standard error of the mean)

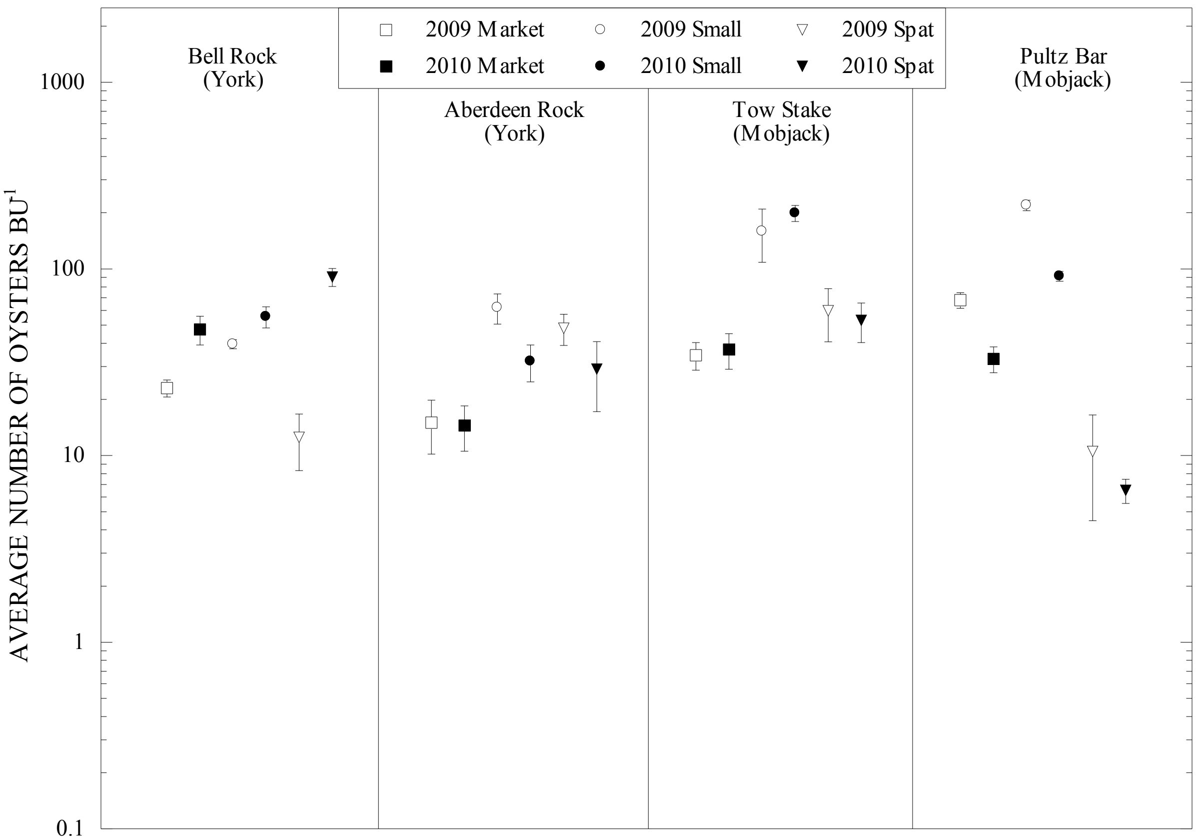


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)

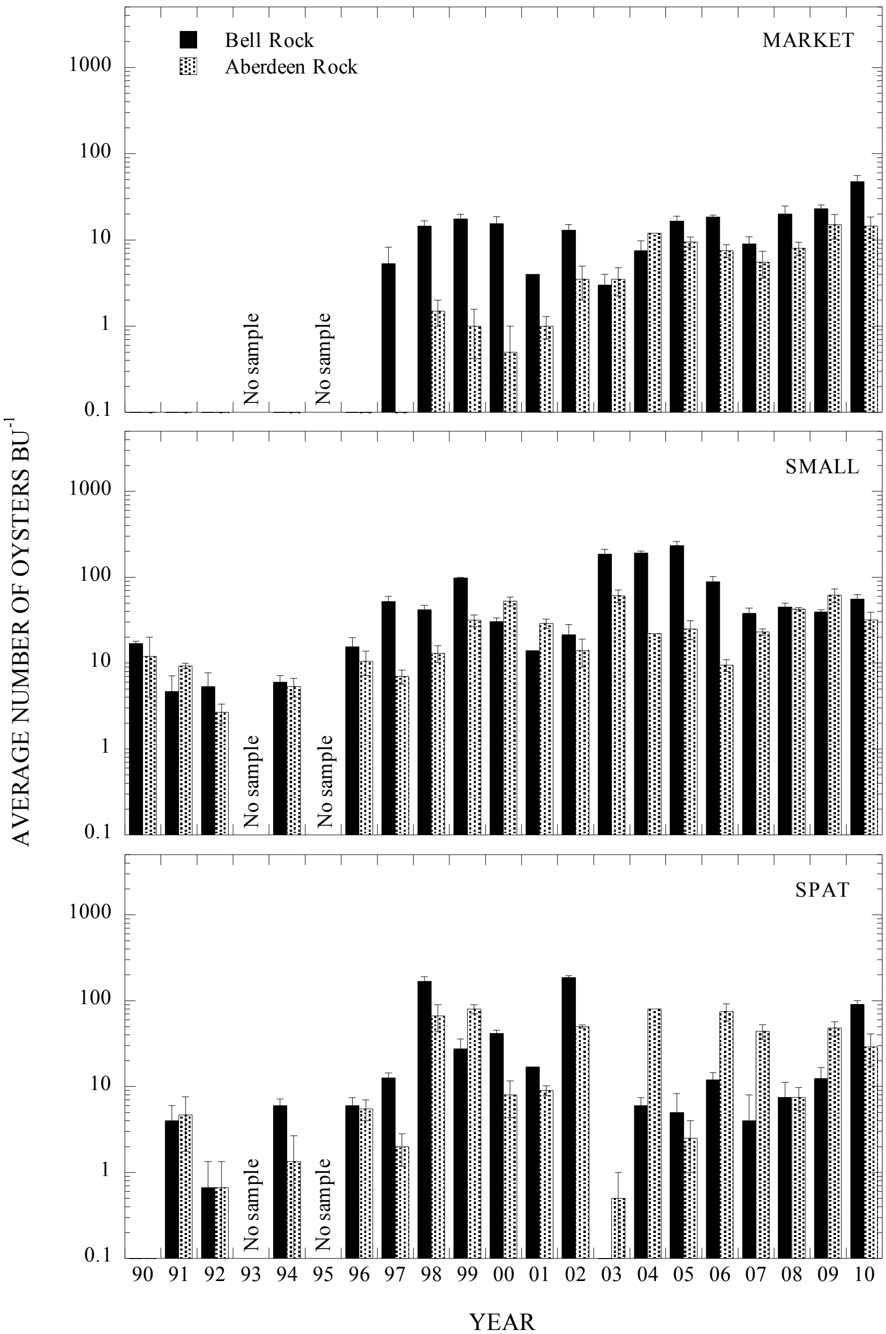


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER
THE PAST 20 YEARS
(Error bars represent standard error of the mean)

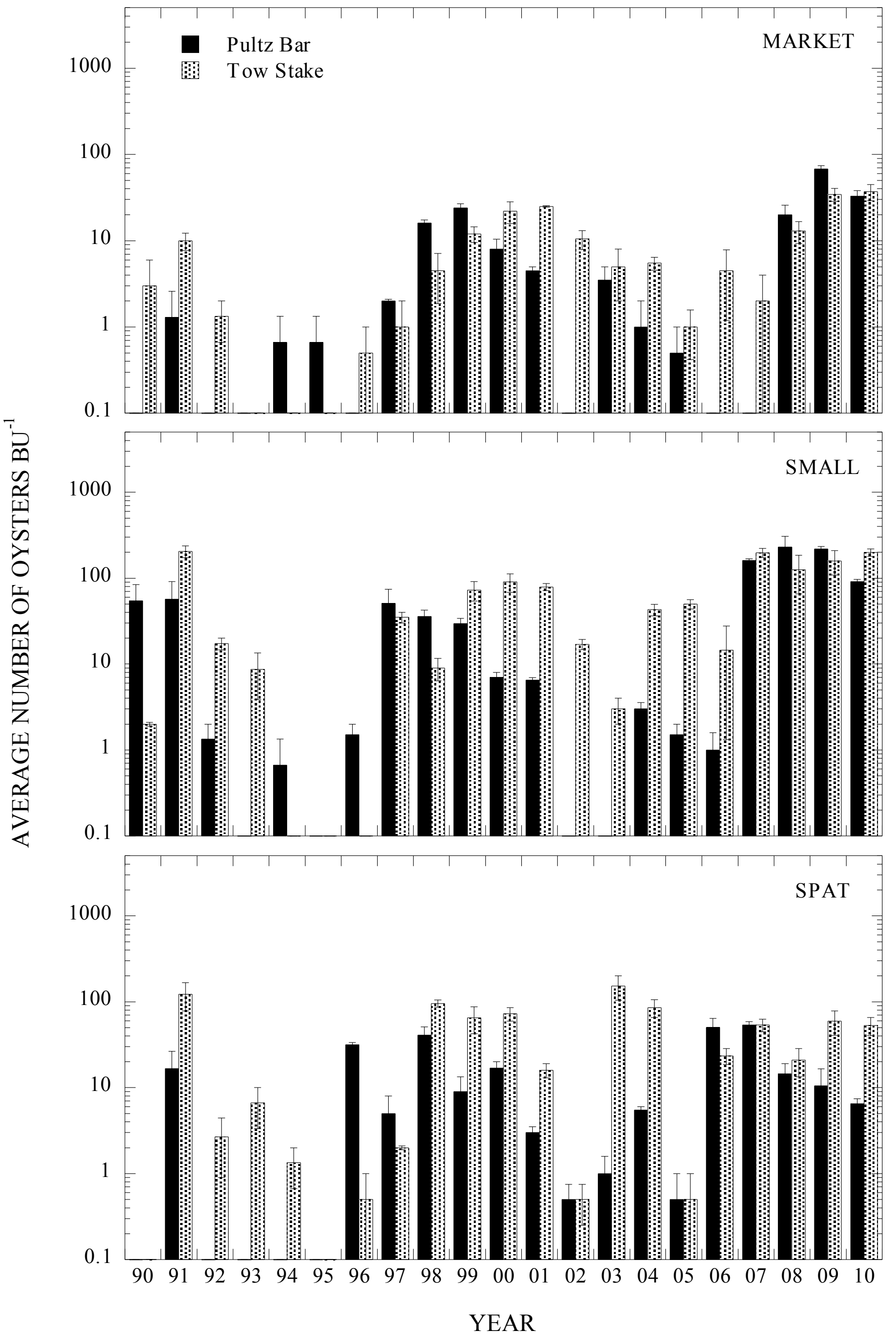


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2009-2010)
(Error bars represent standard error of the mean)

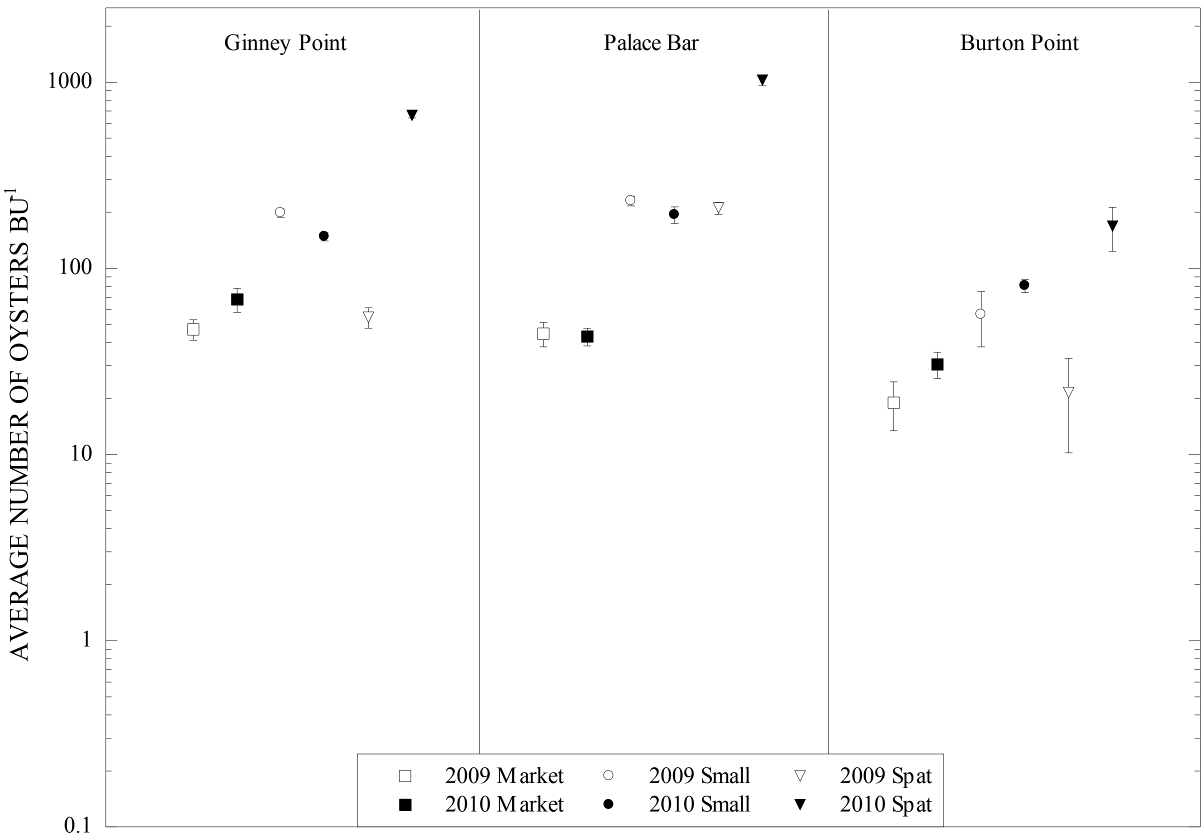
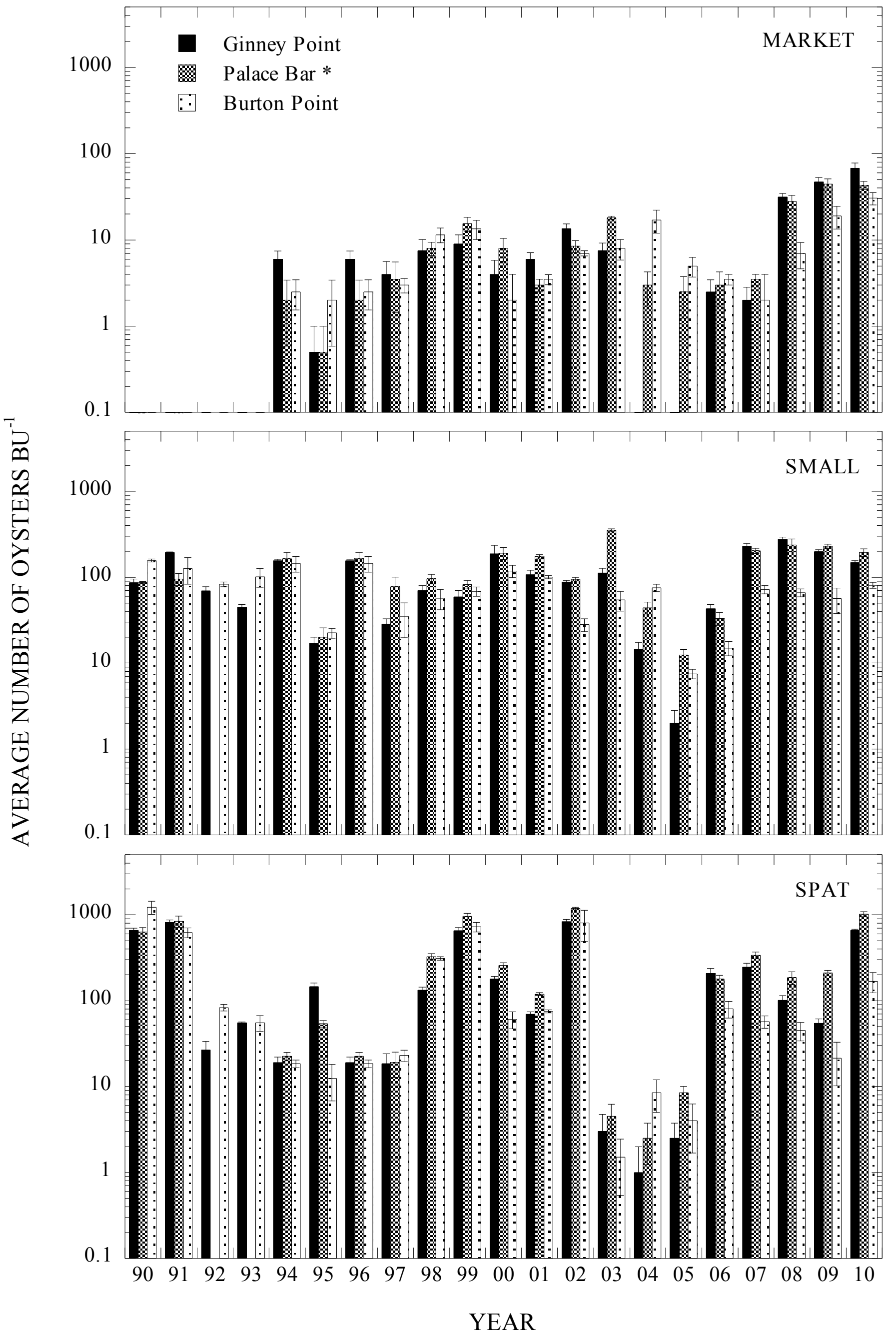


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 1992 and 1993

FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2009-2010)
(Error bars represent standard error of the mean)

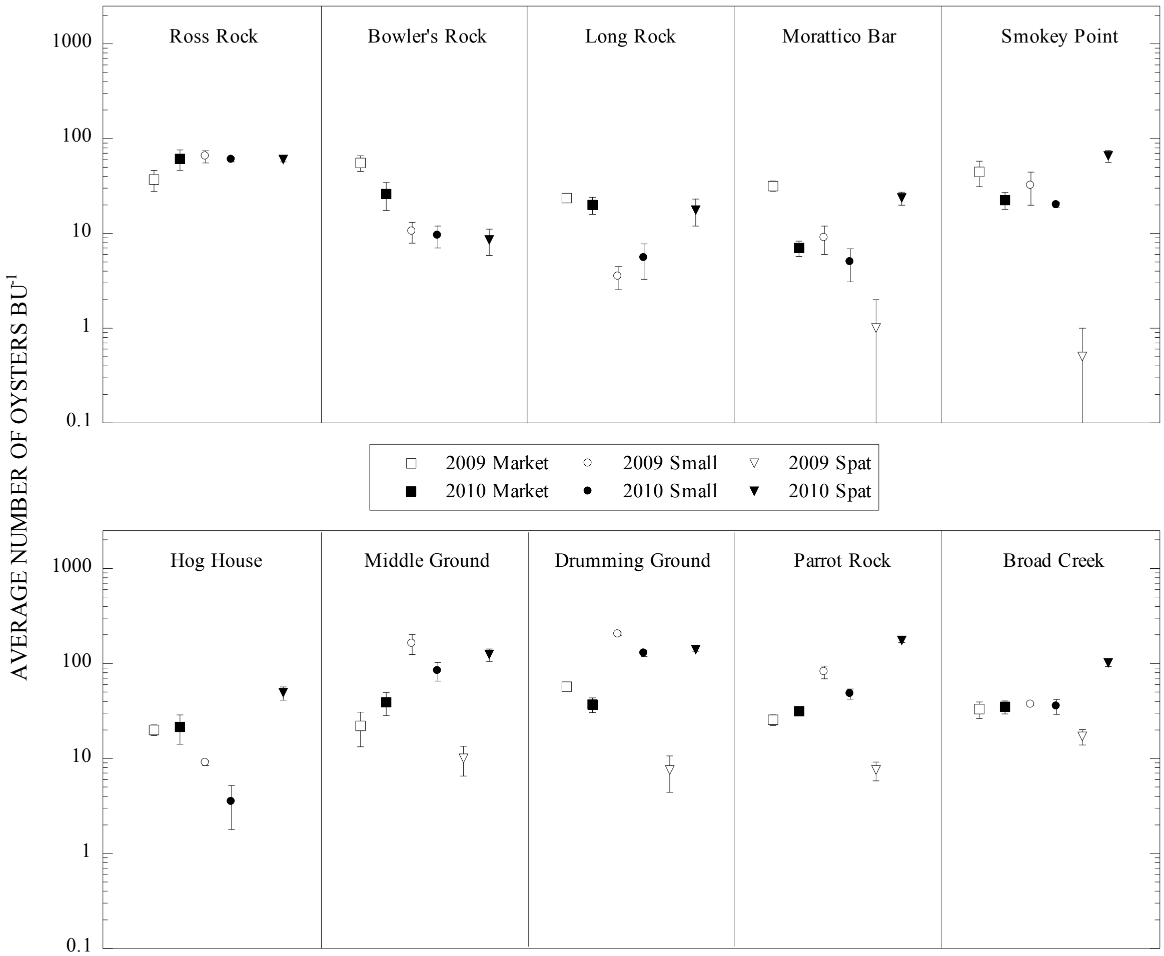
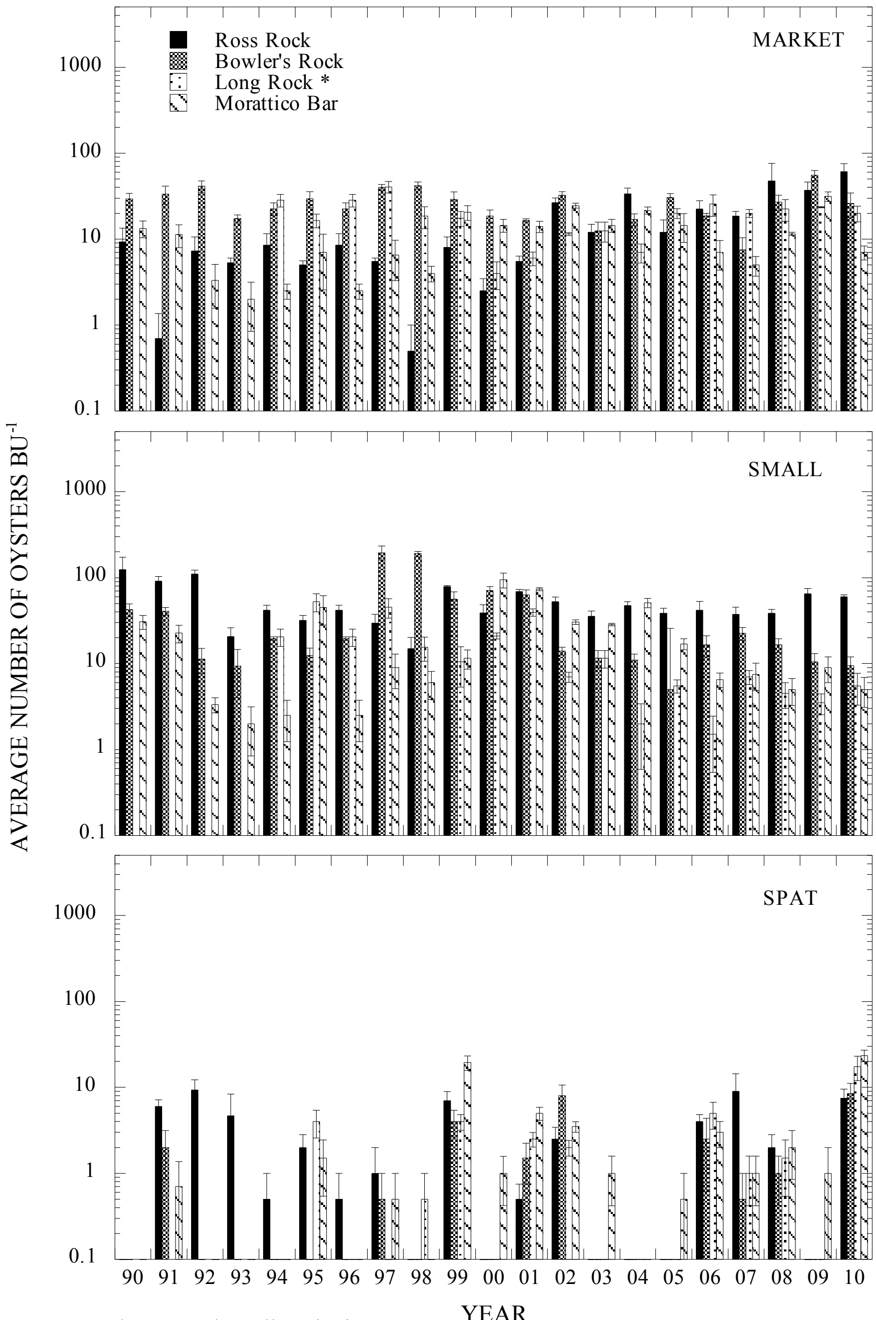


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1994

FIGURE D10B: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)

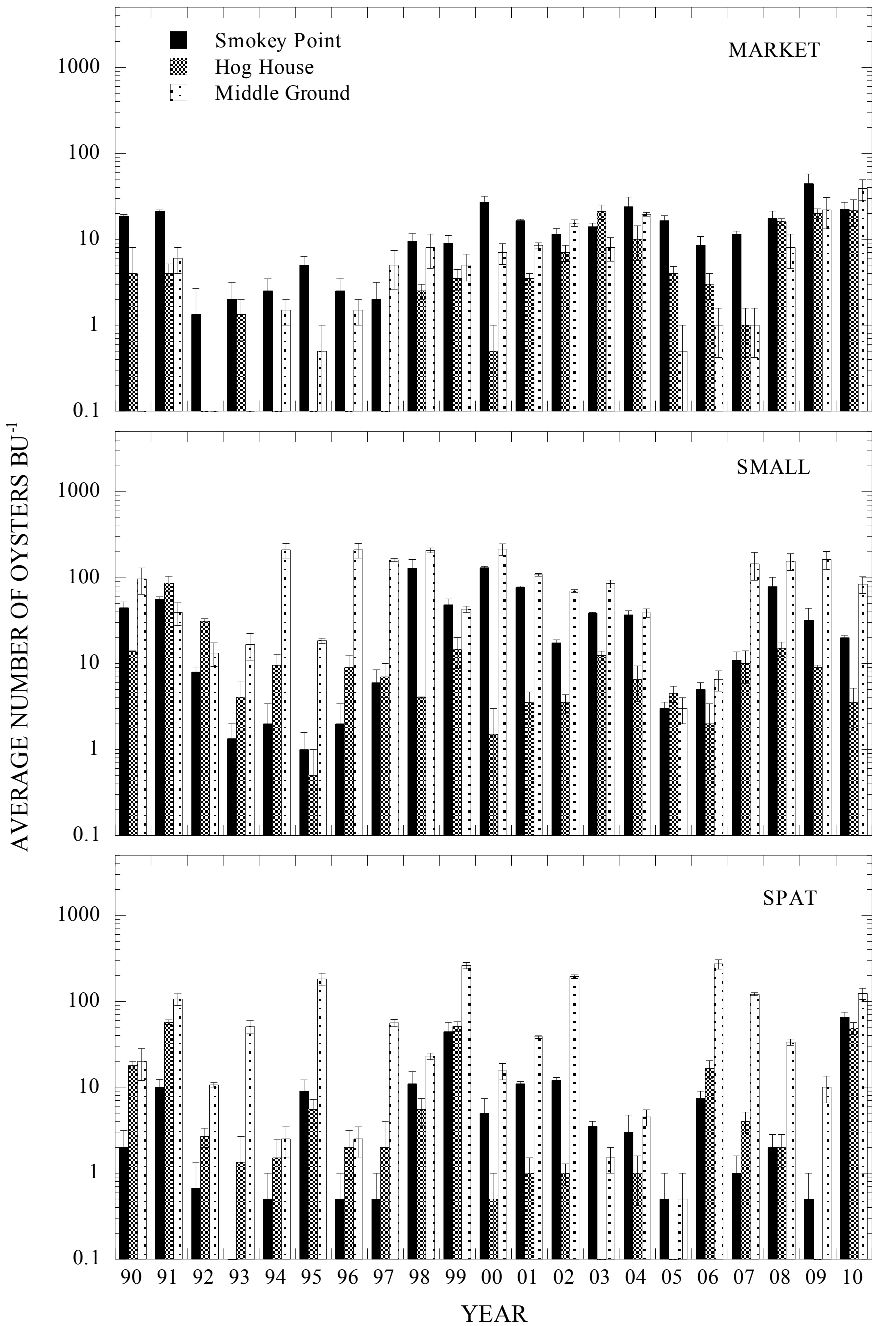
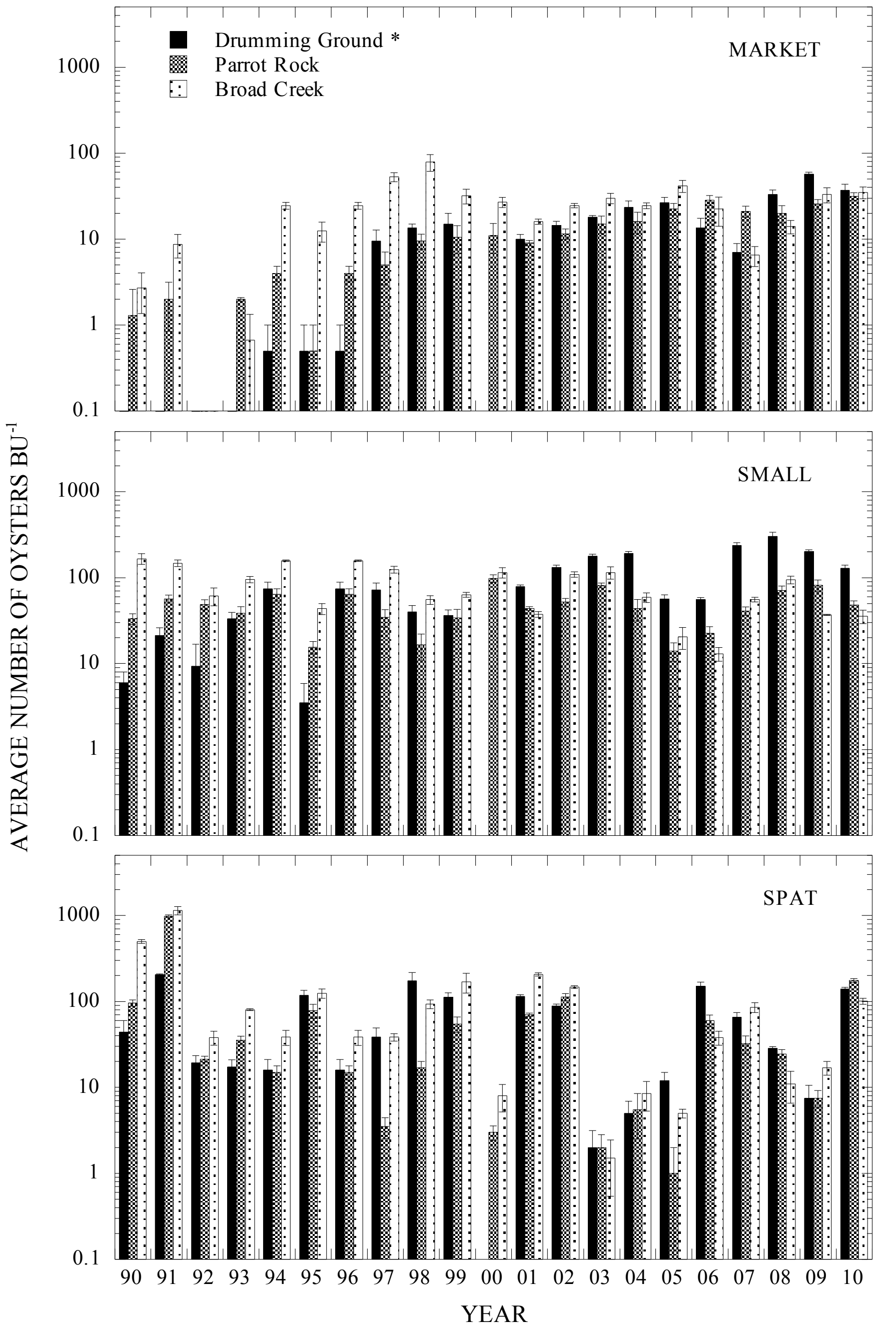


FIGURE D10C: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 2000

FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE GREAT WICOMICO RIVER (2009-2010)
(Error bars represent standard error of the mean)

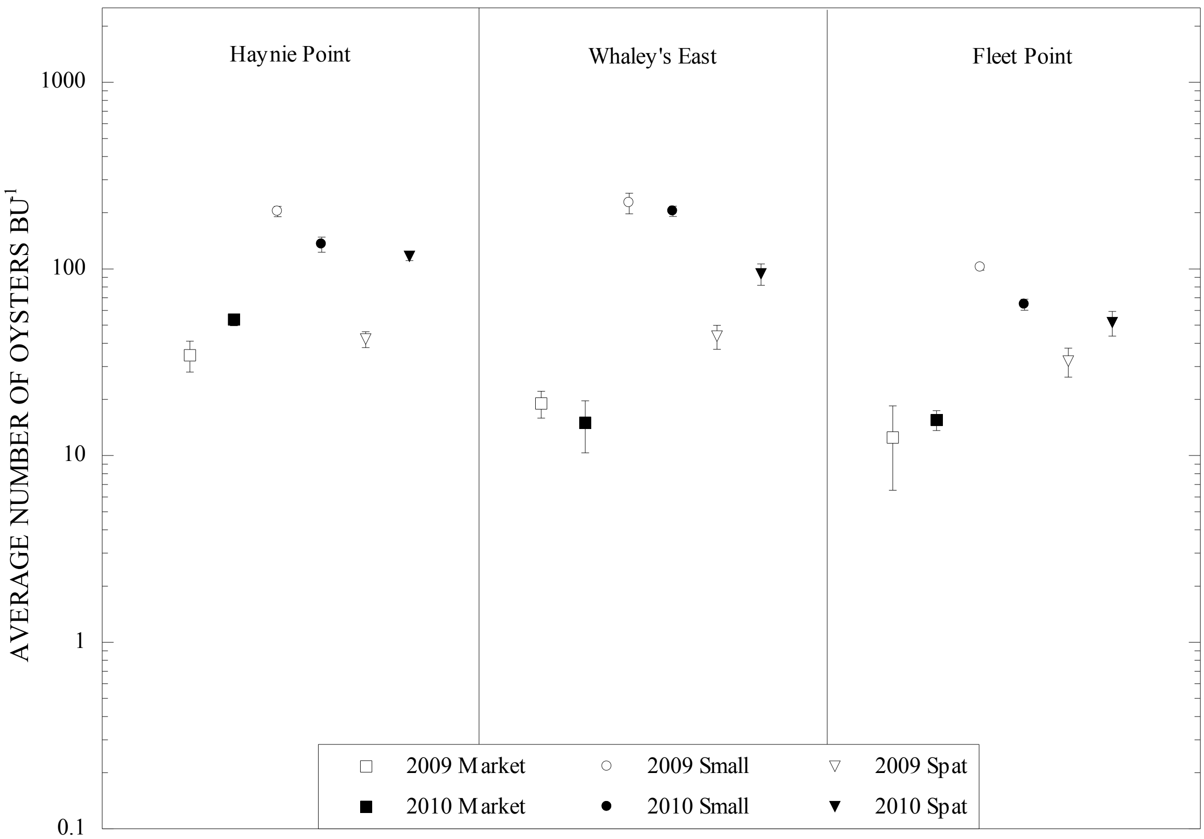
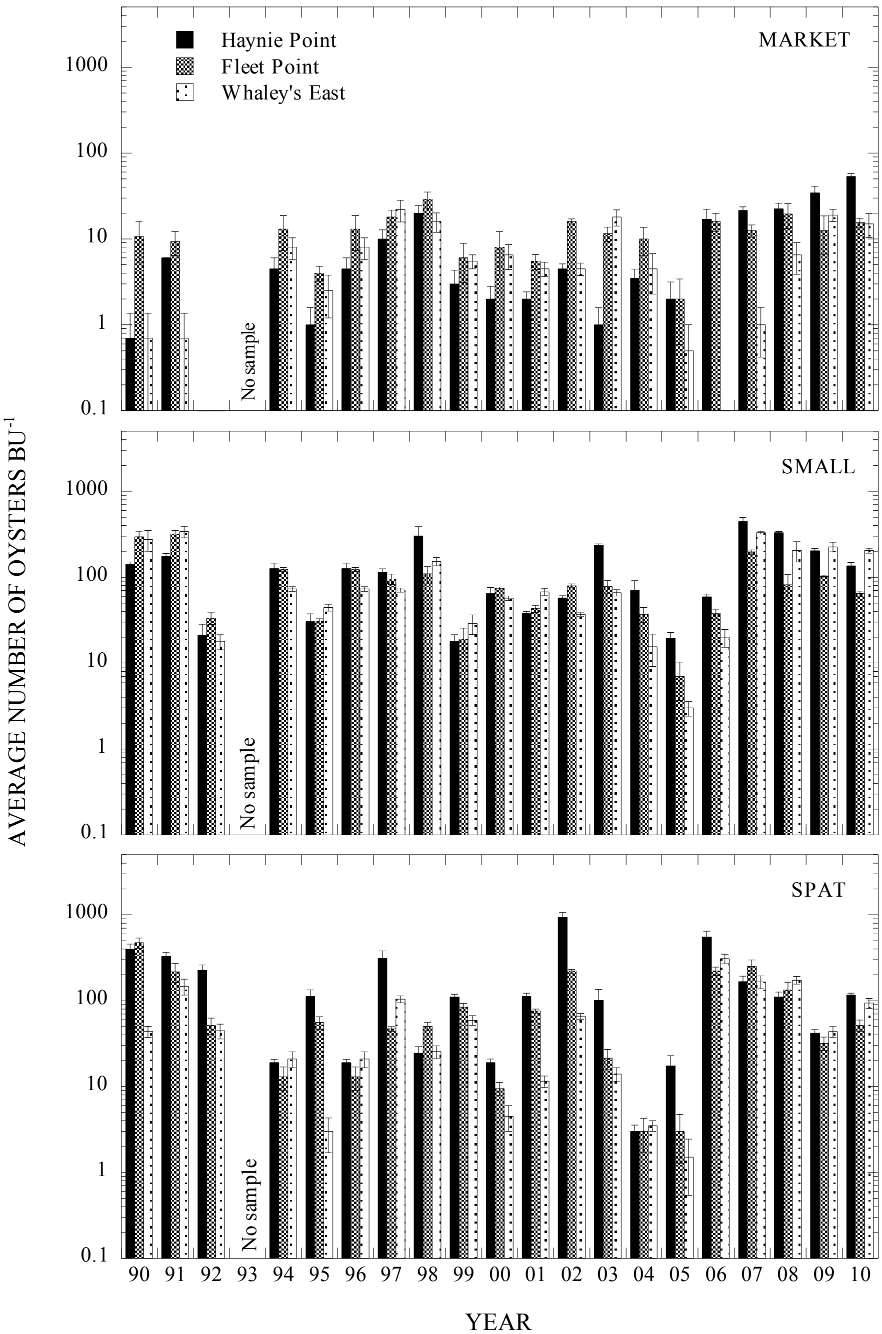


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



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