2012

The Status of Virginia's Public Oyster Resource 2011

Melissa Southworth
Virginia Institute of Marine Science

Roger L. Mann
Virginia Institute of Marine Science

Recommended Citation
Southworth, M., & Mann, R. L. (2012) The Status of Virginia's Public Oyster Resource 2011. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.21220/V5N309

The Status of Virginia's Public Oyster Resource 2011

MELISSA SOUTHWORTH
and ROGER MANN

Molluscan Ecology Program
Department of Fisheries Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, VA 23062

March, 2012

TABLE OF CONTENTS

PART I. OYSTER SPAT SETTLEMENT IN VIRGINIA DURING 2011
INTRODUCTION....3
METHODS....3
RESULTS....5
James River....5
Piankatank River....6
Great Wicomico River....7
DISCUSSION....8

PART II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2011
INTRODUCTION....24
METHODS....24
RESULTS....25
James River....26
York River....27
Mobjack Bay....27
Piankatank River....28
Rappahannock River....28
Great Wicomico River....29
DISCUSSION....30

ACKNOWLEDGEMENTS....50

REFERENCES....50

Citation for this report:

Southworth, M. and R. Mann. 2012. The status of Virginia's Public Oyster Resource, 2011. Molluscan Ecology Program, Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5N309

Part I. OYSTER SPAT SETTLEMENT IN VIRGINIA DURING 2011

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 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 settlement 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 settlement 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 spat settlement, which are evident in the data.

Data from settlement monitoring also serve as an indicator of potential oyster recruitment into a particular estuary. Settlement and subsequent survival of spat on bottom cultch (shell that is 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 2011 settlement season in the Virginia portion of the Chesapeake Bay.

METHODS

Spat settlement during 2011 was monitored from the last week of May through the last week of September in the James, Piankatank and Great Wicomico Rivers. Monitoring 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 and in both Pocomoke and Tangier Sounds on the eastern side of the Chesapeake Bay (http://www.vims.edu/research/units/labgroups/molluscan_ecology/restoration/va_restoration_atlas/index.php). The change in the number and location of shellstring sites during 1998 was implemented to provide a means of quantitatively monitoring oyster spat settlement 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 as well as shell plants on the bottom surrounding the reefs.

Oyster shellstrings were used to monitor oyster settlement. 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 oyster 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 during 2011 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 settlement trends over the course of the season between various sites in a river as well as between data for different years.

The cumulative spat settlement 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 2011 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 thirteen 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 2011 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 sites (modern) during 1998 in the Piankatank and Great Wicomico Rivers, any comparison made to historical data could not include data from all of the sites monitored during 2011. Comparisons were made over the past thirteen 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 (also traditionally termed spat settlement or spat set) in the James River was first observed during the week of July 1 at seven out of the eight sites monitored, settlement was not observed at Deep Water Shoal until the week of July 15; (Table S1). Once settlement began in early July, it was relatively consistent for the rest of the monitoring period, with the exception of the week of September 9 when there was settlement at only three out of the eight sites. There was a large peak in settlement observed at Day's Point during the week of August 5, accounting for 77% of the total settlement at that site for the year (Figure S3). Approximately 65% of the total settlement observed at Rock Wharf occurred during the weeks of July 29 and August 5 (Figure S3). For all of the sites in the James River the majority of spat settlement (> 68%) occurred between the weeks of July 1 and August 12.

Settlement in the James River during 2011 was moderate to heavy ranging from a low of 7.0 (Deep Water Shoal) to a high of 33.8 (Dry Shoal and Rock Wharf) cumulative spat $shell^{-1}$ (Table S1,

Figure S4). While spat shell^{-1} values throughout the James River during 2011 ranged in the middle of those observed over the past twenty years of observations, they were still lower than the previous year (2010) as well as the 5, 10 and 20-yr means at all eight sites monitored in the system (Table S2). It should be noted that the relatively high long-term means (5, 10 and 20-yr) are primarily being driven by a few exceptional years (1991, 1993, 2008 and 2010).

Average river water temperatures during the monitoring period ranged from 23 to 29°C (Figure S5A). Water temperature reached the maximum of 29°C in the beginning of August. Water temperature was approximately 3°C higher than the long-term means when sampling first began, but was within normal range by the middle of June (Figure S5A). With the exception of the week of August 12, water temperature during 2011 was similar (within 1°C) to the long-term (5, 10 and 20-yr) means throughout most of the rest of the sampling period.

During the first week of sampling, salinity was 3 to 4 ppt lower than the 5 and 10-yr mean (Figure S5B). Salinity was similar to the 5, 10 and 20-yr mean from the second week of June through the second week of August. From then until the end of the survey salinity was 2 to 6 ppt lower than the 5, 10 and 20-yr means for the system (Figure S5B). Between the week of September 2 and September 9, salinity in the James River decreased by approximately 5 ppt. This was most likely a result of an increase in run-off/stream flow from Hurricane Lee (Figure S5B). 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 6 to 10 ppt.

Piankatank River

Settlement in the Piankatank River was first observed during the week of June 3 at five out of the eight sites monitored (Table S1; Figure S6). Settlement was relatively consistent throughout the sampling season occurring at a majority of the sites each week. There were two notable peaks in setting in the Piankatank River during 2011. The first occurred during the week of July 1 and the second during the week of September 2, approximately 62% of the spat settlement observed in the system occurred during these two weeks, with a slightly higher proportion of it occurring during the July peak (Figure S6).

Cumulative spat shell^{-1} for the year was heavy ranging from a low of 14.1 at Palace Bar to a high of 32.0 at Ginney Point (Table S1). Settlement during 2011 was lower than that observed during 2010 (a notably exceptional year) at all of the sites monitored except Stove Point (Table S2). Settlement during 2011 was higher than the 10-yr mean at all eight sites and higher than the 5-yr mean at all of the sites except Cape Toon (Table S2). Settlement at the three historical sites was higher than the 20-yr mean at Palace Bar and Ginney Point, but lower than the 20-yr mean at Burton Point. Overall, settlement in the Piankatank River during 2011 was good, ranking the second (Wilton Creek, Heron Rock, Cape Toon and Stove Point) and third (Bland Point) highest recorded in thirteen years of monitoring at the modern sites and the second (Ginney Point and Burton Point) and fourth (Palace Bar) highest recorded in twenty years of monitoring at the historical sites (Figure S7).

The average water temperature during the 2011 sampling period in the Piankatank River ranged from 23 to 30°C. Water temperature was 4°C higher than the 5-yr mean during the first week of sampling and 6°C higher than the 5, 10 and 20-yr mean during the second week of sampling. (Figure S8A). Water temperature continued to be slightly higher (1 to 2°C) than the long term means throughout the first half of the sampling period, reaching a maximum of 30°C during the week of July 22, approximately one week earlier than when the seasonal maxima is typically reached (Figure S8A). Water temperature in the system was similar to the long-term means (5, 10 and 20-yr) throughout most of the months of August and September (Figure S8A).

Salinity in the Piankatank River during 2011 was an average of 3 ppt lower than the 5, 10 and 20-yr means throughout the majority of the sampling period, with the largest difference (5 ppt) occurring during the last two weeks of monitoring (Figure S8B). The only time salinity was similar to the long-term means (less than 2 ppt difference) was during the first three weeks of August (Figure S8B). The decrease in salinity observed during the last month and a half of sampling was most likely a result of Hurricane Irene, which directly impacted the Chesapeake Bay during the last week of August and Hurricane Lee which indirectly impacted the Chesapeake Bay in the middle of September with record flooding and run-off from the Susquehanna River into the main stem of the Chesapeake Bay. The difference recorded in any given week between Wilton Creek (the most upriver site) and Burton Point (the most downriver site: Figure S1) was 1 to 3 ppt throughout most of the sampling period.

Great Wicomico River

Settlement in the Great Wicomico River during 2011 was first observed during the week of June 10 at the five most downriver sites (due to adverse weather, we were unable to collect shellstrings at the four most upriver sites during that week). Settlement throughout the system was consistent from the middle of June through the second week of July, intermittent to absent from the middle of July through the end of August and then light and intermittent for the rest of the monitoring period (Table S1; Figure S9). There was a system-wide peak that occurred during the week of July 1 that accounted for approximately 61% of the total settlement for the season (Figure S9). The majority of spat in the Great Wicomico settled between the weeks of June 17 and July 8 Overall, this four-week period accounted for 95% of the total spat settlement in the system for the year, ranging from 67% of the total at Whaley's East to 99% of the total at Glebe Point

Cumulative spat shell^{-1} for the year was moderate at Fleet Point (5.5) and Whaley's East (6.5), the two sites downriver of Sandy Point (Figure S1). Settlement at the other seven sites was heavy ranging from a low of 22.7 spat shell^{-1} at Haynie Point to a high of 134.0 spat shell^{-1} at Glebe Point. Settlement during 2011 at Glebe Point, Hilly Wash, Harcum Flats, Hudnall and Haynie Point was higher than that observed during 2010. Settlement was either lower than or there was no change during 2011 when compared with the previous 5-yr mean at all nine sites monitored. During 2011 settlement was higher than the previous 10-yr mean at Glebe Point, Hudnall, Shell Bar, Haynie Point and Fleet Point and higher than the 20-yr mean at four out of the five historical sites (Glebe Point was the exception; Table S2). Overall settlement in the Great Wicomico River during 2011 was moderate ranking from the third to the sixth highest recorded over the past thirteen (modern sites) to twenty (historical sites) years of monitoring (Figure S10).

Average river water temperatures ranged from 23 to 30°C throughout the sampling period reaching the maximum during the week of July 22 (Figure S11A). Water temperature in the Great Wicomico River for the first two weeks of sampling was around 4°C higher than the long-term means for the system, similar to that observed in the James and Piankatank Rivers (Figure S11A). After this two week period, water temperature remained within 2°C of both the 5 and 13-yr means for the rest of the sampling season (Figure S11A). While temperature remained similar to the long-term means during this time, there was one notably sharp drop in temperature (4°C) observed between the week of September 9 and September 16 (Figure S11A).

Salinity ranged from 8 to 15 ppt, reaching a maximum in mid-August (Figure S11B). Similar to the observations in the Piankatank River, salinity in the Great Wicomico River was an average of 3 ppt lower than both the 5 and 13-yr means throughout most of the sampling period (Figure S11B). Salinity had started to rebound and return to normal by early to mid-August, but dropped once again following Hurricanes Irene and Lee, such that by the end of the sampling period, salinity in the system was 6 ppt lower than both the 5 and 13-yr 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 to moderate spat settlement (seasonal cumulative total of less than 10 spat $shell^{-1}$) has been common in Virginia since 1993 (69% of all year/site combinations). However, settlement on the shellstrings over the past five years (2007-20011) has been on the rise such that 69% of all of the year/site combinations had heavy settlement (seasonal cumulative total of > 10 spat $shell^{-1}$). Settlement was moderate to heavy in all areas monitored during 2011, among the highest observed in the past twenty years of monitoring at several sites. Settlement in the Piankatank River ranked the second to fourth highest over the past twenty years at the three historical sites and the second to third highest over the past thirteen years at the five modern 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.

Overall, settlement on shellstrings in the James River during 2011 was moderate to heavy. Comparison of 2011 settlement values with the long-terms means show that the 2011 values were less than the 5, 10 and 20-yr means, however as previously mentioned these long term means are dominated by four strong year classes (1991, 1993, 2008 and 2010). The average cumulative spat shell^{-1} across these four years ranged from 74.6 (Deep Water Shoal) to 215.3 (Day's Point), whereas the average across all of the other years (including 2011) ranged from 3.9 (Deep Water Shoal) to 9.4 (Day's Point). Excluding the four exceptional years of 1991, 1993, 2008 and 2010, the 2011 data indicate a relatively good year having the highest to fourth highest settlement out of the remaining seventeen years in the time series. Historically the bulk of the spat settlement in the James River occurred later in the season than in the Piankatank and Great Wicomico River systems (late August into September versus June and July; Haven & Fritz 1985). Since the late 1970s however, the timing of settlement in the James River has been more in line with the other two systems (Southworth & Mann 2004) and settlement during 2011 in the James River once again followed this more modern pattern with the bulk of spat settlement occurring by early August.

Despite salinity being 2 to 6 ppt lower than the long-term means throughout most of the sampling period, settlement on the shellstrings in the Piankatank River was heavy, with cumulative numbers of spat shell^{-1} for the season among the highest observed over the past thirteen (modern sites) to twenty (historical sites) years of monitoring. For the past several years broodstock oysters (small plus market) in the system has been on the rise. The number of brookstock oysters in the system during 2011 was 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, including 2011, despite the lower than normal salinities. Butler (1949) found that very low salinities (less than 5 to 6 ppt) may inhibit gametogenesis, but as long as salinities remain higher than that, salinity appears to have no effect. While salinity in the Piankatank was lower than normal, it remained well above the 6 ppt threshold suggested by Butler throughout the spawning season. The timing of settlement in the Piankatank River was early with 65% of the total spat for the season being recorded by the week of July 22.

Settlement in the Great Wicomico River, while not as high as has been observed over the past five years, was still relatively high when compared with the late 1990s and early 2000s. When compared with the previous eight (modern sites) and fifteen (historical sites) years, settlement over the past six years has been consistently high at all nine sites in the Great Wicomico River. For the five historical sites the average spat shell^{-1} between 1991 and 2005 ranged from 1.2 (Whaley's East) to 21.7 (Glebe Point), whereas the average between 2006 and 2011 ranged from 6.7 (Fleet Point) to 167.1 (Glebe Point). This was a five to eleven fold increase in settlement during the past six years over the previous fifteen years. For the modern sites, the average spat shell^{-1} between 1998 and 2005 ranged from 3.2 (Shell Bar) to 5.4 (Harcum Flats), whereas the average between 2006 and

2011 ranged from 40.5 (Shell Bar) to 119.0 (Harcum Flats). This was a twelve to twenty-two fold increase during the past six years when compared with the previous eight years.

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	5/27 147	6/3 154	6/10 161	6/17 168	6/24 175	7/1 182	7/8 189	7/15 196	7/22 203	7/29 210	8/5 217	8/12 224	8/19 231	8/26 238	9/2 245	9/9 252	9/16 259	9/23 266	YEAR TOTAL
JAMES RIVER																			
Deep Water Shoal	D	-	0	0	0	0	0	0.6	1.3	1.5	0.2	2.3	0.8	-	0.2	0	0.1	0	7.0
Horsehead	D	0	0	0	0	0.6	0.9	2.9	2.0	4.6	0.98	1.2	0.9	-	0.3	0	0.6	0	15.0
Point of Shoal	D	0	0	0	0	0.1	0.3	0.5	0.7	2.7	0.6	0.5	0.7	1.3	0.4	0	-	0.2	8.0
Swash	D	0	0	0	0	0.5	0.3	2.4	0.8	4.9	1.6	1.9	0.5	0.5	0.4	0	0	0.3	14.1
Dry Shoal	D	0	0	0	0	0.4	2.2	2.2	6.2	6.5	5.2	3.1	2.2	-	1.1	0.7	2.8	1.2	33.8
Rock Wharf	D	0	0	0	0	0.1	-	1.2	4.5	10.1	11.8	3.0	1.4	-	1.4	0	0.2	0.1	33.8
Wreck Shoal	D	0	0	0	0	0.4	1.0	4.3	1.3	7.2	0.8	0.7	0.8	-	0.5	0.1	0.4	-	17.5
Day's Point	D	0	0	0	0	0.2	1.0	0.2	0.4	1.7	19.8	-	1.0	-	0.1	0.1	1.1	0	25.6
PIANKATANK RIVER																			
Wilton Creek	D	0.2	0.6	2.0	3.8	5.4	1.6	0.2	0	0.1	0.9	0	0	0.2	2.5	0.4	0.2	0.3	18.4
Ginney Point	D	0.3	0.6	2.0	1.6	19.3	2.7	0.4	0	0.1	2.1	0.2	0	0.1	1.2	0.2	0.6	0.6	32.0
Palace Bar	D	0	0.4	0.7	1.8	7.0	0.8	0	0.1	0	0.3	0.3	0	0.3	1.2	0.7	0.5	0	14.1
Bland Point	D	0.1	0.5	0.6	0.6	4.9	0.5	0.2	0.2	0	0.5	0.1	0.2	6.1	6.8	0.4	0.6	0.2	22.5
Heron Rock	D	0	0.2	0.1	0.8	15.8	0.1	0.2	0	0	0.2	0.1	0.3	0.4	3.2	0.3	0.7	0.1	22.5
Cape Toon	D	0.1	0.2	0.9	3.0	13.7	1.6	0.4	0.6	0.2	0.1	1.5	0.7	0.5	8.2	-	1.2	0.2	33.1
Stove Point	D	0.2	0.5	0.2	2.7	10.9	1.6	0.1	0.1	0.1	0.3	0.1	0.1	2.7	4.5	0.3	0.9	0.7	26.0
Burton Point	D	0	0.3	0.4	1.3	5.7	0.2	0.3	0.8	0.1	0.4	0.4	0.2	0.7	4.9	1.2	0.6	0	17.5
GREAT WICOMICO																			
Glebe Point	D	0	-	1.7	8.0	69.6	54.1	0.1	0	0	0	0	0	0.2	0.3	0	0	0	134.0
Rogue Point	D	0	-	1.0	2.6	22.3	3.9	0	0.2	0	0	0	0.1	1.4	1.8	0.1	0.1	0	33.5
Hilly Wash	D	0	-	1.8	7.3	30.3	1.8	0.1	0	0	0	0	0	0.8	0.8	0	0.2	0.2	43.3
Harcum Flats	D	0	-	0.8	6.2	38.1	4.3	0.1	0	0.1	0	0	0	0.7	0.2	0.2	0.2	0.1	51.0
Hudnall	D	0	0.8	3.5	6.3	30.4	1.8	0.1	0	0	0	0	0	0.8	0.5	0.1	0.2	0	44.5
Shell Bar	D	0	0.7	3.8	4.6	27.1	1.5	0.1	0	0	0	0	0.1	1.4	0.2	0.3	0.3	0.1	40.2
Haynie Point	D	0	0.1	4.4	4.5	10.8	0.4	0	0	0	-	0	0.1	1.2	0.9	0.1	0.2	0	22.7
Whaley's East	D	-	0.2	0.3	0.9	2.3	0.2	0.3	0	0	0	0	0	0.2	0.7	0.1	0.1	0.2	5.5
Fleet Point	D	0	0.2	0.1	2.7	1.9	0.6	0.1	0	0	0	0.1	0.1	0.2	0.5	0	0	0	6.5

Table S2: Spatfall totals for historical sites (1991-2011) and for 1998-2011 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 2011 in reference to 2010 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	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean 06-10	Mean 01-10	Mean 91-10	Ref. 2010	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr
JAMES																												
Deep Water Shoal	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	7.0	56.2	31.9	17.9	-	-	-	-
Horsehead	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	15.0	70.6	38.7	23.8	-	-	-	-
Point of Shoal	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	8.0	74.5	41.2	27.1	-	-	-	-
Swash	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	14.1	109.4	59.0	38.3	-	-	-	-
Dry Shoal	217	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	33.8	106.4	56.3	48.2	-	-	-	-
Rock Wharf		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	33.8	129.3	69.2	40.4	-	-	-	-
Wreck Shoal	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	17.5	132.7	70.1	38.8	-	-	-	-
Day's Point	146	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	25.6	124.0	63.7	49.8	-	-	-	-
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	18.4	8.7	5.1		-	+	+	
Ginney Point	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	32.0	19.5	10.5	8.0	-	+	+	+
Palace Bar	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	14.1	10.1	5.4	7.3	-	+	+	+
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	22.5	13.0	7.5		-	+	+	
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	22.5	10.4	5.9		-	+	+	
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	33.1	51.6	27.4		-	-	+	
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	26.0	14.0	10.5		+	-	+	
Burton Point	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	17.5	8.5	5.1	5.4	-	+	+	-
GREAT WICOMICO																												
Glebe Point	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	134.0	173.8	116.2	59.7	+	-	+	-
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	33.5	100.4	52.9		-	-	-	
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	43.3	83.6	44.8		+	-	-	
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	51.0	132.6	70.3		+	-	-	
Hudnall	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	44.5	49.8	26.8	15.8	+	-	+	+
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	40.2	40.5	22.4		-	NC	+	
Haynie Point	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	22.7	22.3	13.0	7.8	+	NC	+	+
Whaley's East	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	5.5	9.6	5.2	3.3	-	-	NC	+
Fleet Point	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	6.5	6.7	3.9	2.9	-	NC	+	+

Figure S1: Map showing the location of the 2011 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.

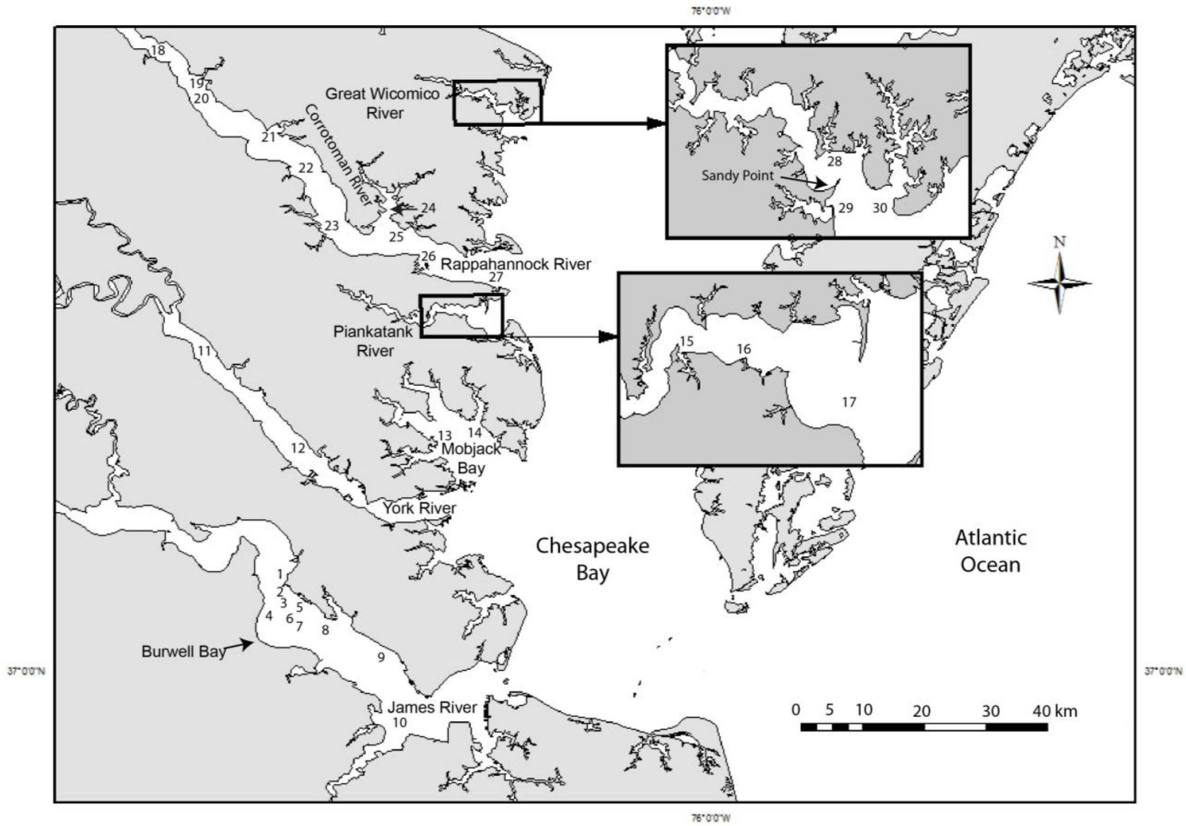


Figure S2: Diagram of shellstring setup on buoys.

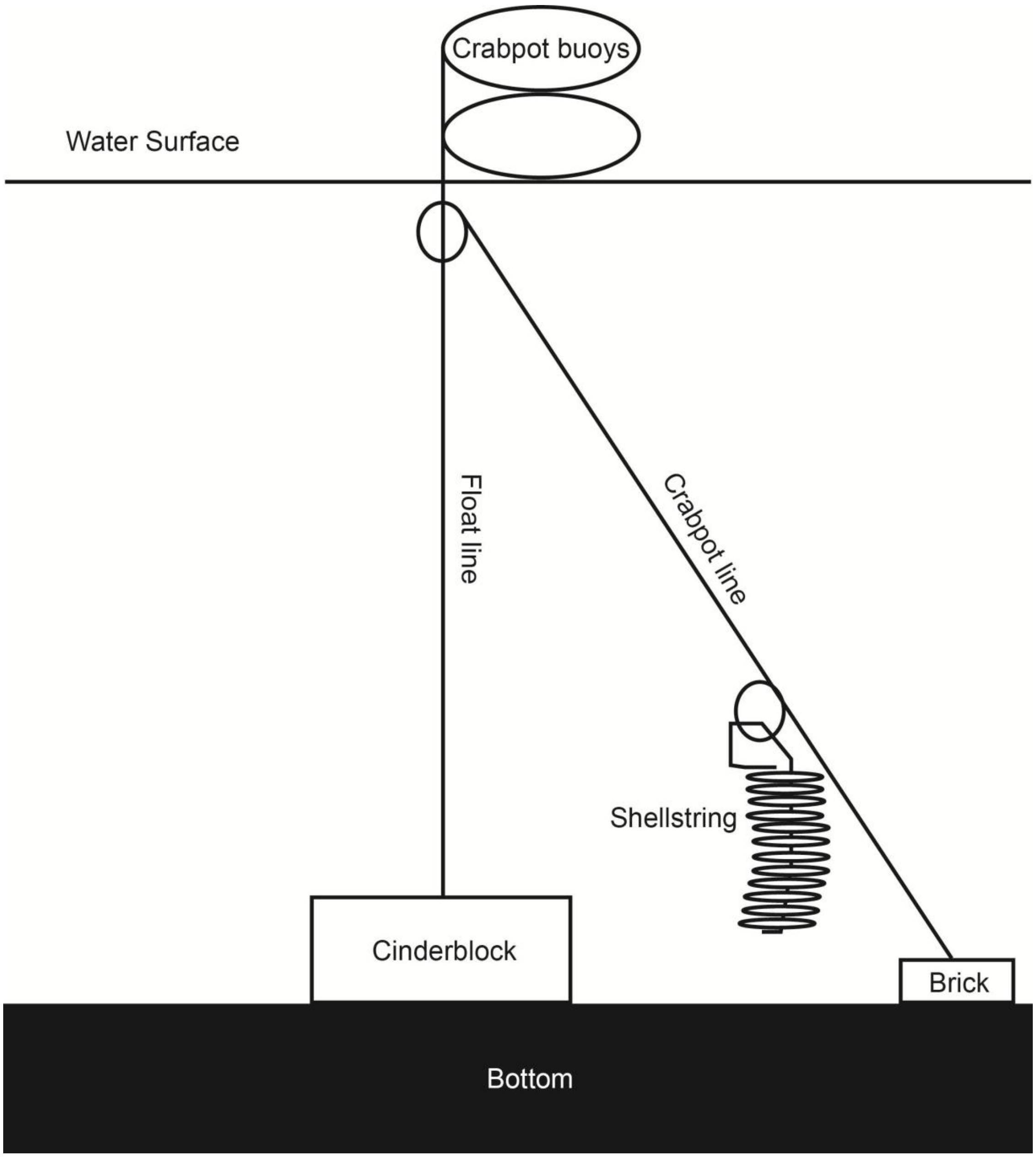


FIGURE S3: JAMES RIVER (2011) WEEKLY SPAT SETTLEMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

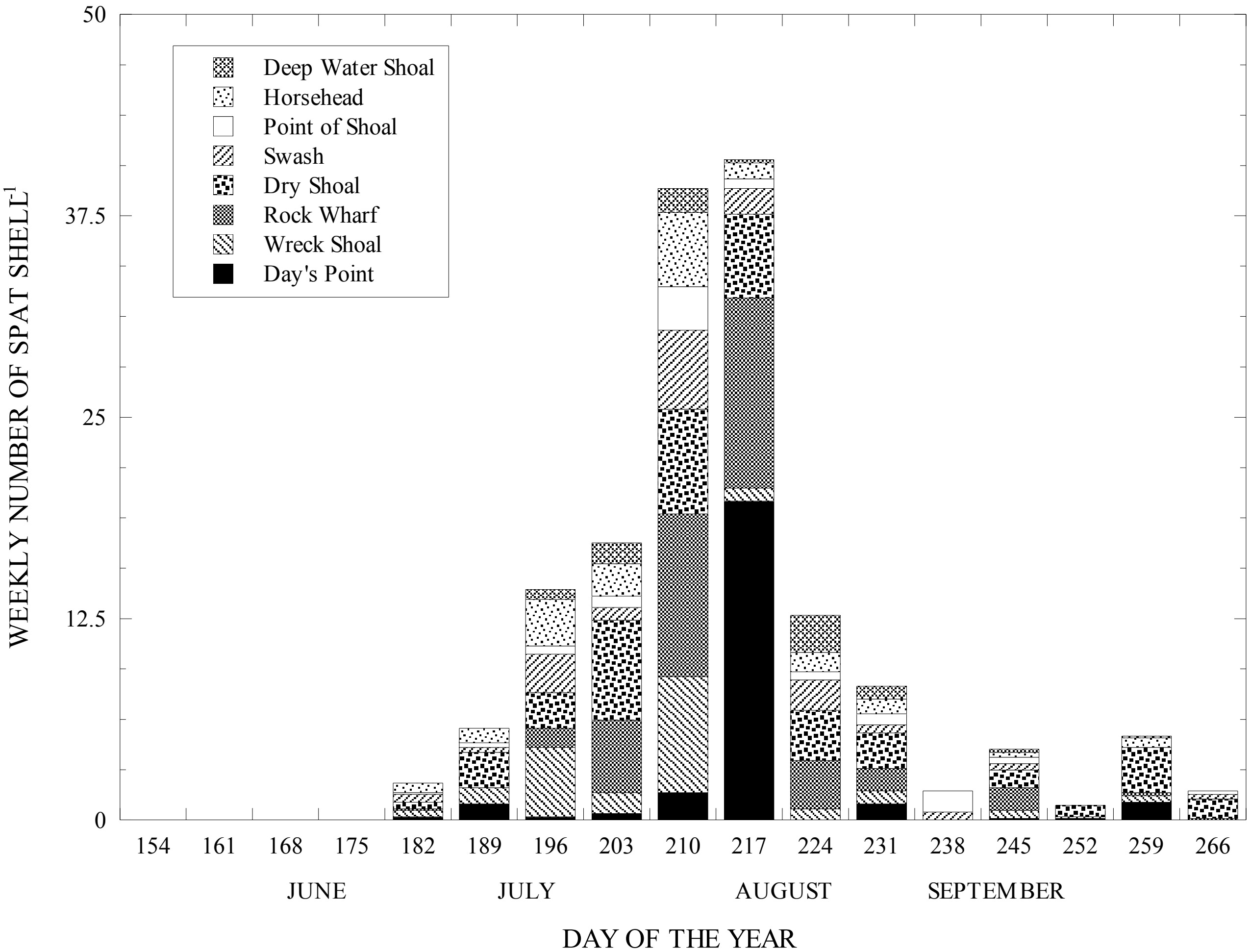


FIGURE S4: SETTLEMENT TRENDS OVER THE PAST 20 YEARS AT ALL 8 SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall)

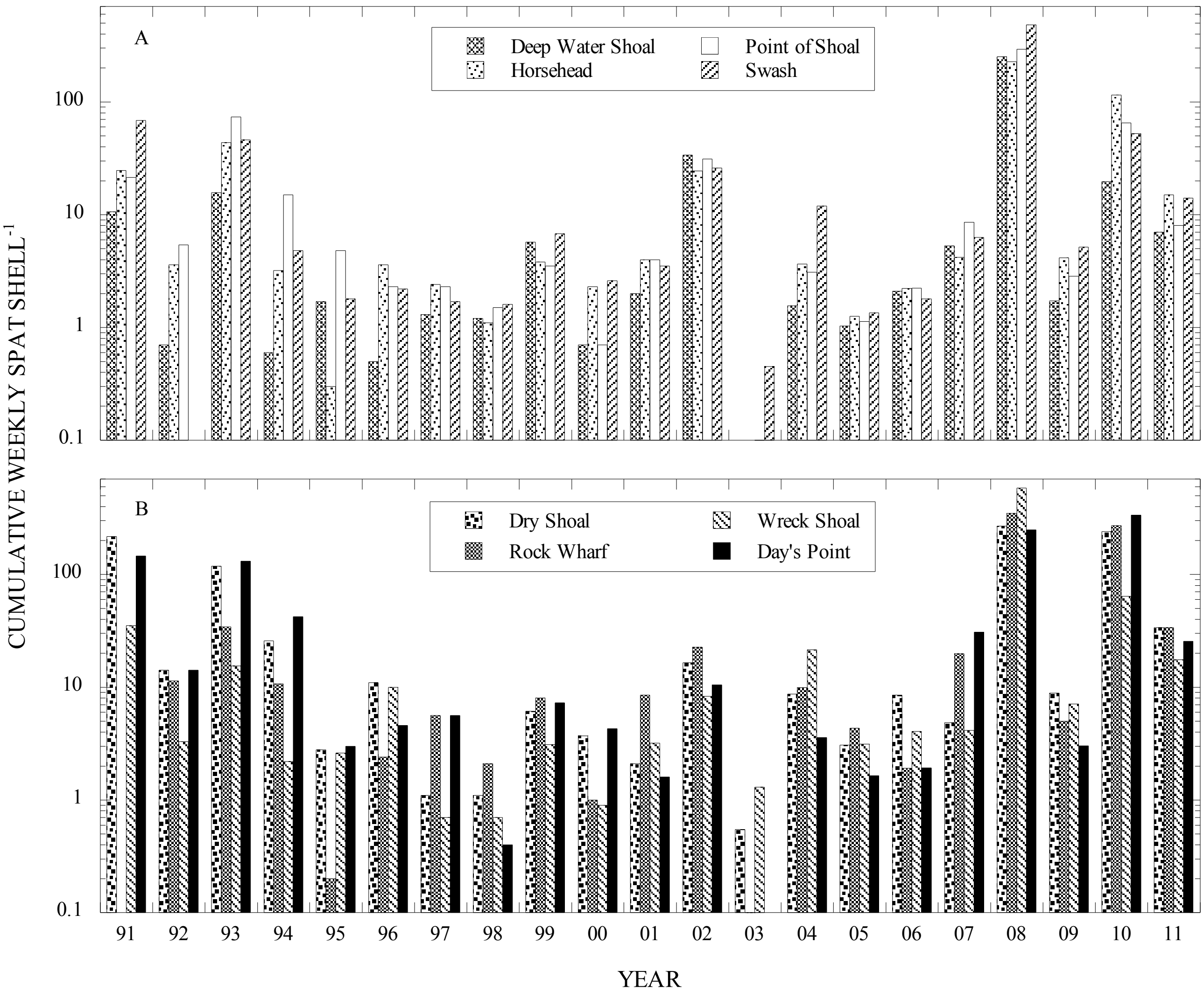


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2011
(Error bars represent standard error of the mean; shaded area represents the bulk of the settlement during 2011; n is the number of data points used to calculate the mean)

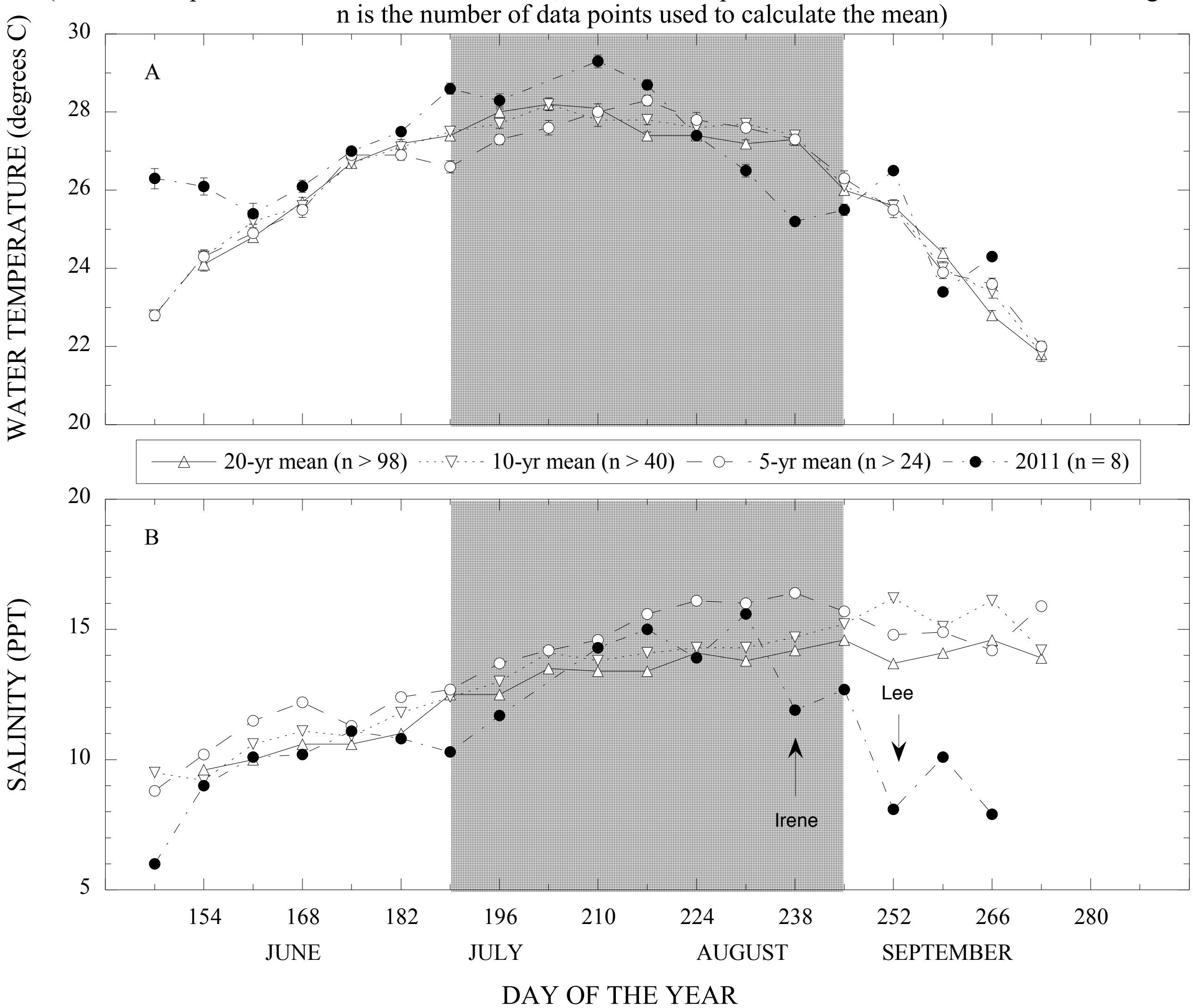


FIGURE S6: PIANKATANK RIVER (2011) WEEKLY SPAT SETTLEMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: M = modern station as described in text)

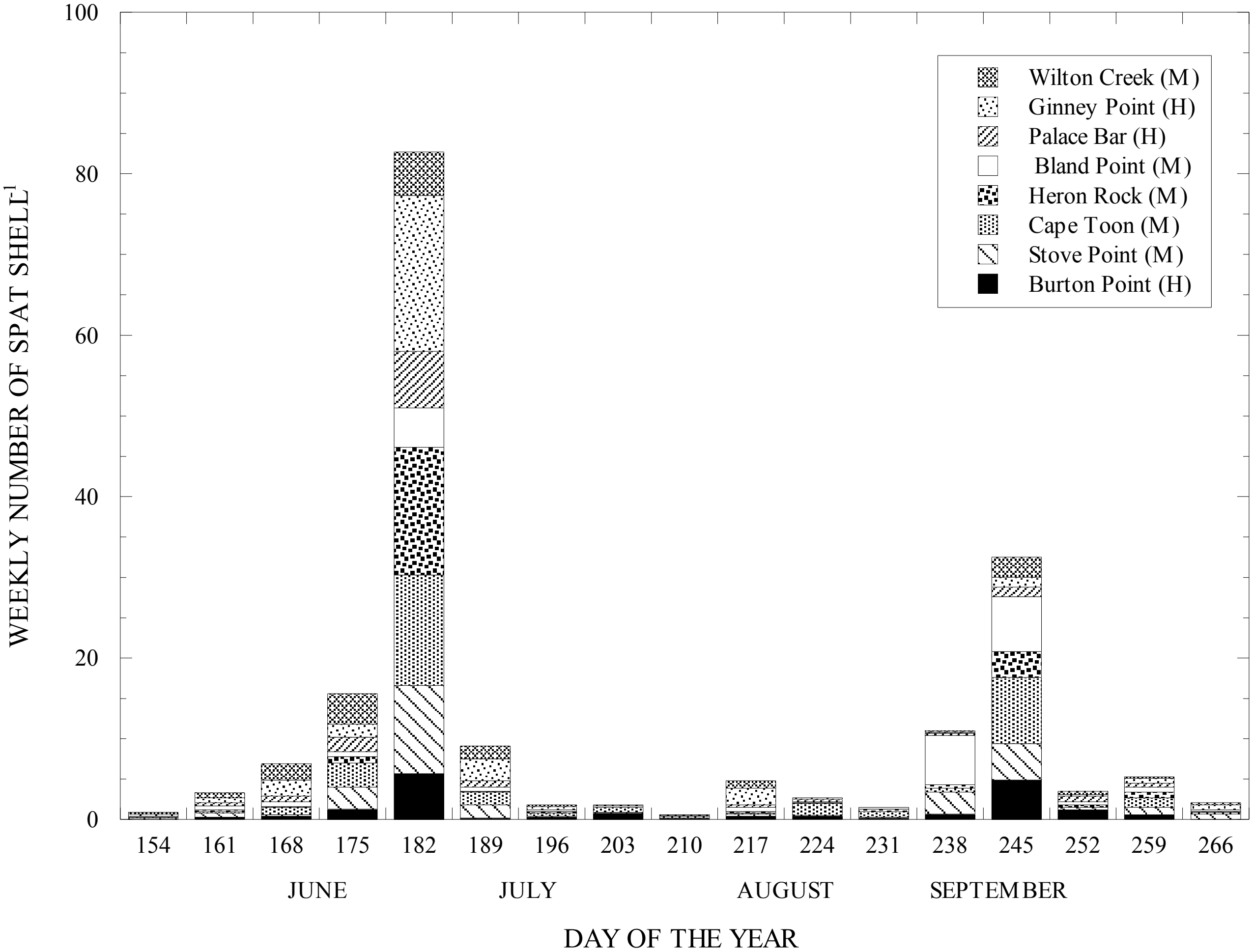


FIGURE S7: SETTLEMENT TRENDS IN THE PIANKATANK RIVER AT THE 3 HISTORICAL SITES (panel A: 20 years) AND THE 5 MODERN SITES (panel B: 12 years)
(Expressed as cumulative weekly spatfall)

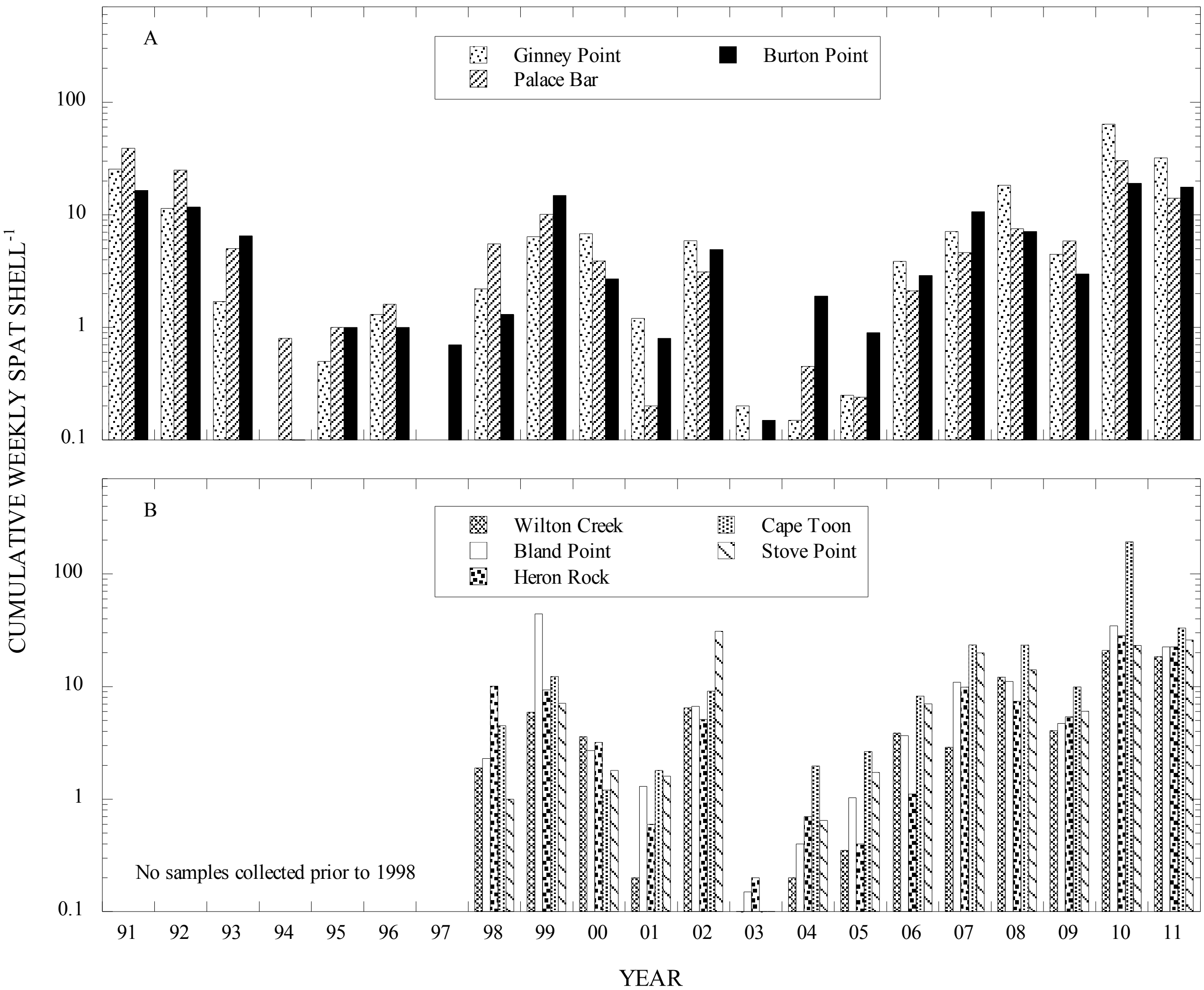


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2011
(Error bars represent standard error of the mean; shaded areas represent the two main pulses in settlement observed during 2011; n is the number of data points used to calculate the mean)

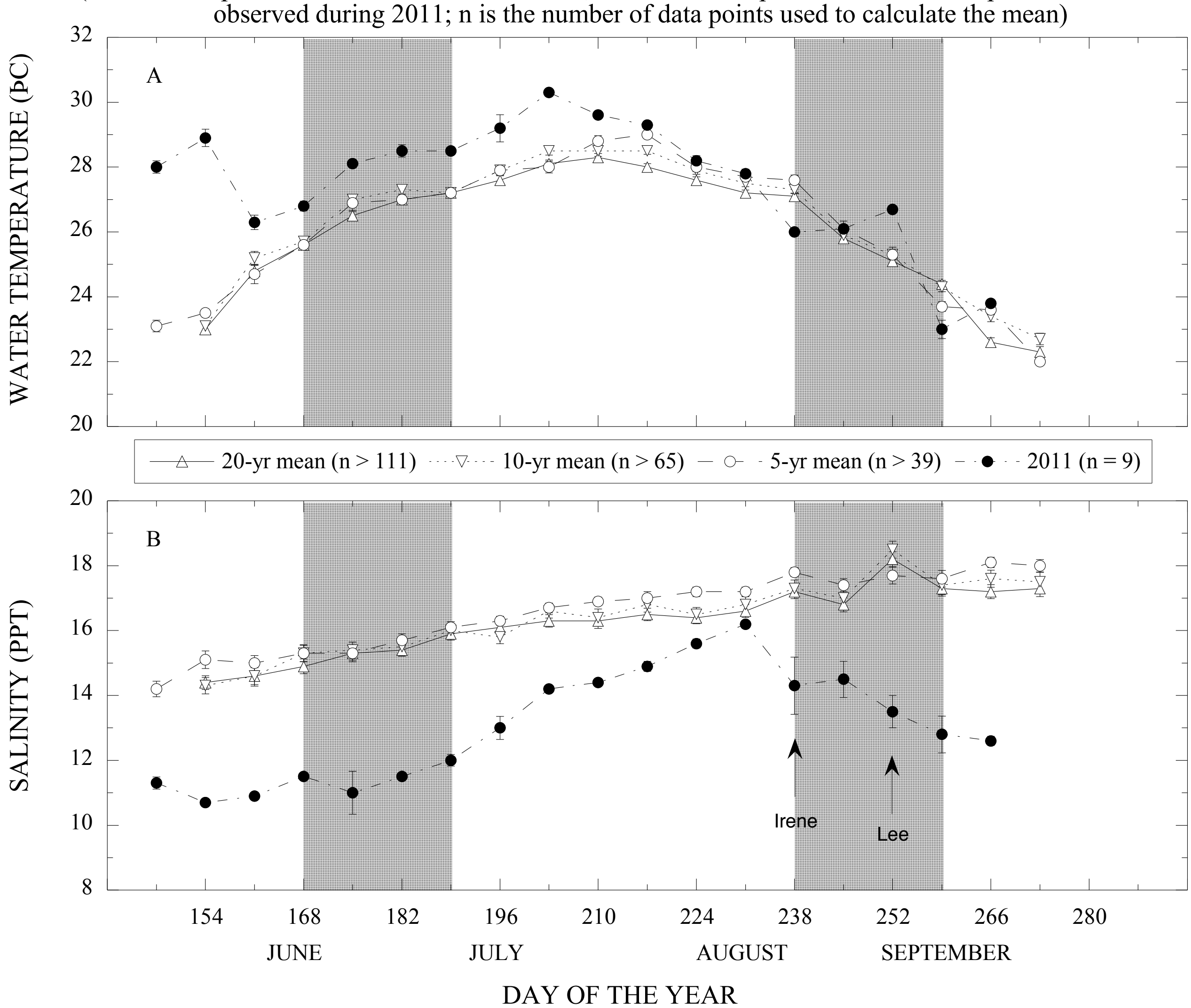


FIGURE S9: GREAT WICOMICO RIVER (2011) WEEKLY SPAT SETTLEMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

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

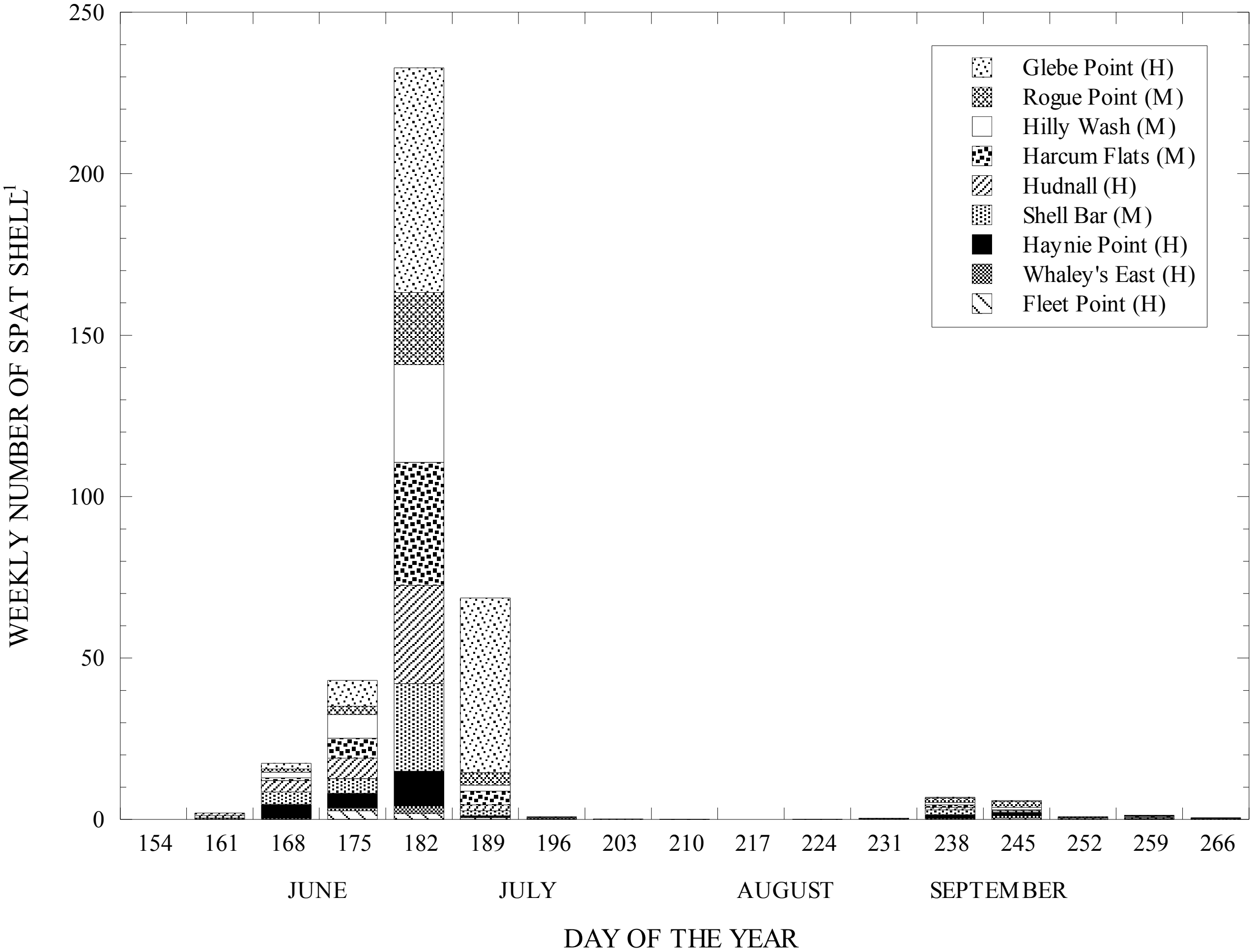


FIGURE S10: SETTLEMENT TRENDS IN THE GREAT WICOMICO RIVER AT THE 5 HISTORICAL SITES (panel A: 20 years) AND THE 4 MODERN SITES (panel B: 13 years)
(Expressed as cumulative weekly spatfall)

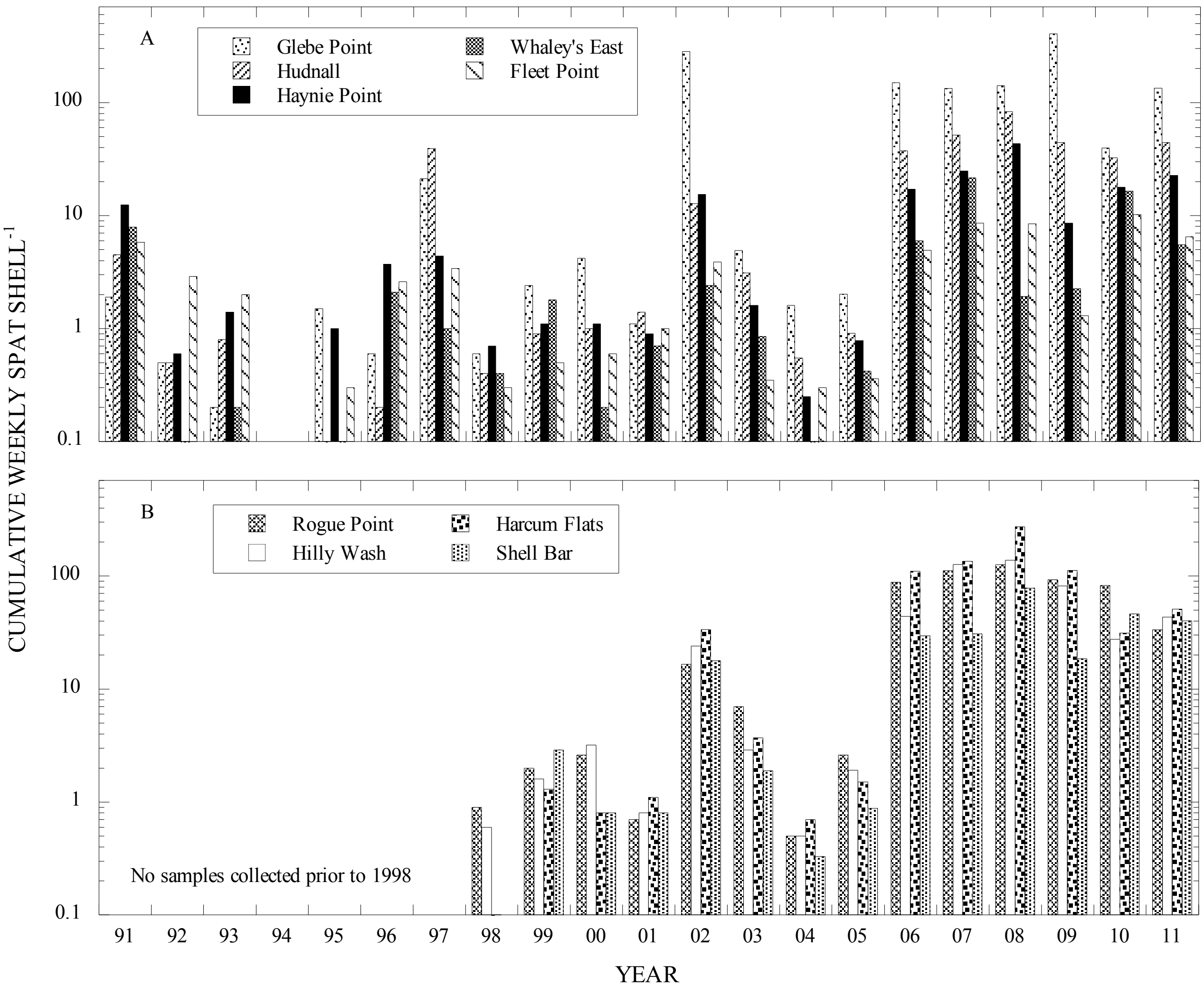
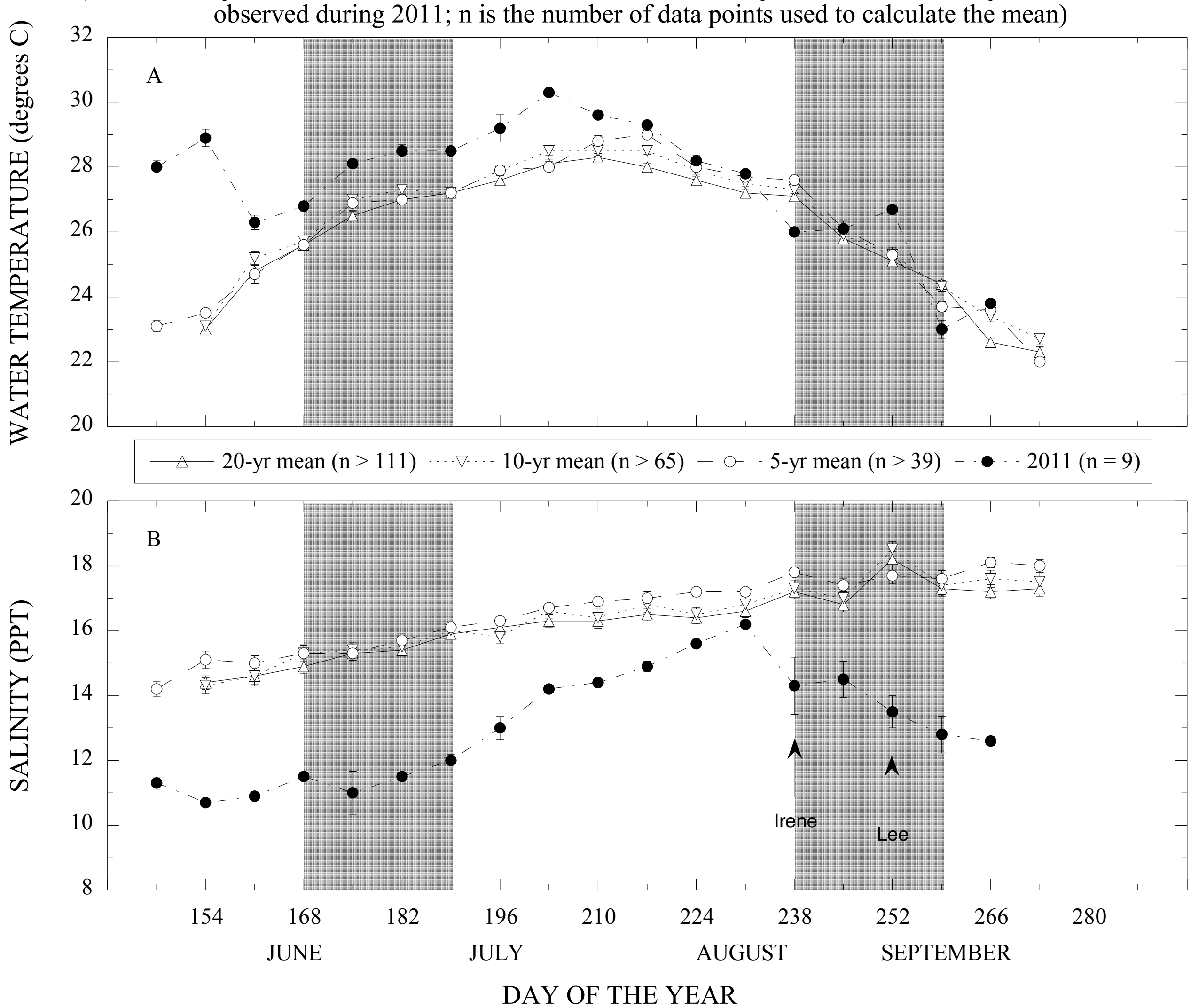


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE SETTLEMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2011
(Error bars represent standard error of the mean; shaded areas represent the two main pulses in settlement observed during 2011; n is the number of data points used to calculate the mean)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2011

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 spat settlement 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 2011.

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 are associated with well-documented physiological or environmental factors, then they may be considered a reflection of actual changes in abundance with time.

METHODS

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; they are presently under management by the Virginia Marine Resources Commission (VMRC) (http://www.vims.edu/mollusc/oyrestatlas/).

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 spat settlement 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 2011.

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.

RESULTS

Thirty oyster bars were sampled between October 11 and October 25, 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 on privately leased bottom 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 192.5 bushel^{-1} at Thomas Rock to a high of 1766.0 bushel^{-1} at Mulberry Point. The total number of live oysters at eight out of the ten sites monitored, ranked amongst the second to fourth highest observed over the past twenty years of observations.

The average number of market oysters bushel^{-1} in the James River remains low when compared with historical numbers, but has been on the rise in recent years at several sites in the system. All of the sites monitored had low to moderate numbers of market oysters bushel^{-1} ranging from 1.0 (Nansemond Ridge) to 133.5 (Deep Water Shoal). There was a notable increase in the number of market oysters bushel^{-1} at Horsehead when compared with 2011 (Figure D2 and D3). The number of market oysters bushel^{-1} at Deep Water Shoal, Dry Shoal and Wreck Shoal was the highest observed since prior to 1991 and the second highest observed since that time at Horsehead and Point of Shoal (Figure D3). The number of market oysters bushel^{-1} at Wreck Shoal was at an all time low in 2002, but by 2005 had steadily increased to the highest values observed in the past twenty years and has remained at similar levels since (Figure D3C). During 2011, the market oysters at Wreck Shoal accounted for around 20% of the total live oysters observed at that site.

The average number of small oysters bushel^{-1} ranged from a low of 10.0 at Nansemond Ridge to a high of 1700.0 at Mulberry Point. The number of small oysters bushel^{-1} increased when compared with 2010 at all of the sites except Thomas Rock and Nansemond Ridge (Figure D2). This increase in small oysters observed at the eight most upriver sites is to be expected given the large spat settlement that occurred at these sites during 2010. The number of small oysters bushel^{-1} at Nansemond Ridge remains at very low levels for the third year in a row (Figure D3C). This is somewhat surprising given that spat settlement at Nansemond Ridge was moderate to good during 2010, but this was not reflected by an increase in small oysters during 2011 as was seen at the eight most upriver sites.

The average number of spat bushel^{-1} ranged from a low of 5.0 at Deep Water Shoal to a high of 214.0 at Horsehead. There was a relatively large decrease in spat observed at the eight most upriver sites when compared with 2010 (Figure D2 and D3). The pattern historically observed in the James River was an increasing percentage of small oysters combined with a decreasing percentage of spat progressing from the most downriver site (Nansemond Ridge) to the most upriver site (Deep Water Shoal). This pattern was observed for the first time in several years during 2011. Greater than 66% of the oysters at the eight most upriver sites were in the small category and greater than 66% of the oysters at Thomas Rock and Nansemond Ridge were in the spat category.

The average number of boxes bushel^{-1} ranged from a low of 9.0 (Thomas Rock) to a high of 62.0 (Horsehead). Boxes accounted for less than 7% of the total (live and dead) at nine out of the ten sites monitored; the exception was Wreck Shoal where boxes accounted for 12% of the total (live and dead). More than 23% of the boxes were new boxes at seven out of the ten sites (Deep Water Shoal, Mulberry Point, Horsehead, Point of Shoal, Swash, Long Shoal and Dry Shoal) indicating some recent mortality at those sites. There was one drilled spat box observed at Nansemond Ridge. The presence of a drill hole is 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 during the two days of sampling ranged between 18.4 and 19.6°C (Table D2). Salinity was variable depending on location in the river, increasing in a downriver direction, from 4.0 ppt at Deep Water Shoal to 14.4 ppt at Nansemond Ridge.

York River

The average total number of live oysters bushel^{-1} in the York River was 203.0 at Bell Rock and 245.0 at Aberdeen Rock. The live oysters at both sites were primarily small (63% at Aberdeen Rock and 72% at Bell Rock). There was a notable (two-fold) decrease in market oysters at Bell Rock when compared with 2010, but the number of market oysters bushel^{-1} during 2011 was still the third highest observed at that site since prior to 1991 (Figure D4 and D5). When compared with 2010, there was a notable increase in small oysters and a decrease in spat observed at Bell Rock (Figure D4). At Aberdeen Rock, there was a notable increase in all size categories when compared with 2010 (Figure D4 and D5) and 2011 had the highest number of both small and market oysters over the past twenty years of monitoring. The average number of boxes bushel^{-1} was low at both sites (5.1 bushel^{-1} at Bell Rock; 13.6 bushel^{-1} at Aberdeen Rock) accounting for approximately 4.9 and 11.4% of the total oysters (live and boxes) at Bell Rock and Aberdeen Rock respectively. At both sites, the majority of the boxes (greater than 73% of the total) were old boxes. Due to boat issues, Bell Rock was sampled two weeks later in the season than Aberdeen Rock; water temperature was 17.9°C at Bell Rock and 20.4°C at Aberdeen Rock. There was a 2.7 ppt difference in salinity: 12.1 ppt at Bell Rock and 14.8 ppt at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 202.5 and 90.0 oysters bushel^{-1} respectively. For the second year in a row, there was a notable decrease in the number of small oysters bushel^{-1} observed at Pultz Bar when compared with the previous year (Figure D4 and D6). The number of market oysters bushel^{-1} at Pultz Bar however, was the second highest observed over the past twenty years of monitoring and has remained at a relatively stable level since 2008 (Figure D6). The number of market oysters bushel^{-1} observed at Tow Stake has also remained relatively stable during the past three years (Figure D6), ranking the third highest since prior to 1991. The number of spat bushel^{-1} at both sites was relatively low, and there was a notable decrease in spat observed at Tow Stake when compared with 2010. There was a low to moderate number of boxes observed in the system, accounting for

10% (Tow Stake) to 19% (Pultz Bar) respectively of the total (live and boxes). The majority of boxes at both sites were old. Water temperature was approximately 20°C and salinity was around 15 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 277.5 at Burton Point to 493.0 at Palace Bar. The number of market oysters bushel^{-1} in the river, had been on the rise since 2008, but 2011 showed the first small decrease in market oysters in four years at both Ginney Point and Palace Bar (Figure D7 and D8). The number of market oysters bushel^{-1} at Burton Point however, continued to increase and 2011 had the most market oysters since prior to 1991. There was a notable increase in the number of small oysters observed in 2011 at all three sites when compared with 2010, which is not surprising given the large spat settlement that occurred in the system in 2010. Despite the small decrease in the number of market oysters observed at Ginney Point and Palace Bar, the total number of small and market oysters combined (broodstock) was at its highest level since prior to 1991 at all three sites (Figure D8). There was a notable decrease in spat settlement at all three sites when compared with 2010, and spat settlement was considerable lower than it had been for the past several years (Figures D7 and D8). The number of boxes observed was low to moderate accounting for 5% (Palace Bar) to 16% (Palace Bar) respectively of the total (live and boxes). The majority of the boxes at all three sites were old (> 83%). Water temperature on the day of sampling was around 20ºC at all three sites. Salinity ranged between 11.8 (Ginney Point) and 12.5 ppt (Burton Point).

Rappahannock River

The average total number of live oysters bushel^{-1} in the Rappahannock River ranged from a low of 30.0 at Morattico Bar to a high of 293.0 at Drumming Ground. As is typical for the Rappahannock River system, there appeared to be no consistent 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). Typically, most of the oysters in the Rappahannock River system are found in the Corrotoman River (Middle Ground), just outside the mouth of the Corrotoman (Drumming Ground), and at the more downriver sites. With the exception of Middle Ground this pattern again held true during 2011. The total number of oysters at Middle Ground had been increasing over the past three years, but 2011, showed a sharp decline in oysters at that site in all size categories such that the total number of oysters was near the lowest levels observed during the past twenty years of monitoring.

The average number of market oysters bushel^{-1} ranged from 3.0 (Middle Ground) to 65.5 (Ross Rock). When compared with 2010, there was a small increase in the number of market oysters bushel^{-1} observed at Long Rock and a decrease at Middle Ground and Broad Creek (Figure D9 and D10). With the increase in market oysters observed at Long Rock, numbers were at the second highest observed at that site since prior to 1991. The number of market oysters bushel^{-1} at Ross Rock has been relatively stable over the past several years and 2011 had the highest numbers observed at that site over the past twenty years of monitoring (Figure D10A).

For the tenth year in a row, Drumming Ground near the mouth of the Corrotoman River had the highest average number of small oysters bushel^{-1} with 211.5, which was a small increase when compared with 2010 (Figure D9 and D10C). There was also a small increase in the number small oysters observed at all of the sites except Middle Ground, which as previously mentioned had a decrease in the numbers of oysters in all size categories during 2011. The number of both market and small oysters bushel^{-1} at Parrot Rock was the highest levels observed in the past twenty years of monitoring (Figure D10C).

While there was at least one spat found at all of the sites except Bowler's Rock and Long Rock, there was still a notable decrease in spat settlement at all ten sites when compared with 2010 (Figure D9). Settlement throughout the system was among the lowest recorded in the system over the past twenty years, ranging from 0 (Bowler's Rock and Long Rock) to 37.5 (Drumming Ground) spat bushel^{-1}. The low spat settlement numbers were especially evident at the three most downriver sites (Drumming Ground, Parrot Rock and Broad Creek), which typically have the highest spat settlement in the system (Figure D10C).

The average total number of boxes bushel^{-1} was low, accounting for less than 11% of the total (live and dead) at eight out of the ten sites. The number of boxes bushel^{-1} observed at Hog House and Middle Ground was high accounting for 57% and 74% respectively of the total (live and dead) respectively. At all of the sites, the majority of the boxes (greater than 89%) were old boxes.

Water temperature on the day of sampling ranged from 19.9 to 20.6°C. Salinity increased as one moved from the most upriver site (Ross Rock: 6.0 ppt) toward the mouth (Broad Creek: 12.1 ppt).

Great Wicomico River

The average total number of live oysters bushel^{-1} in the Great Wicomico River ranged from a low of 160.5 at Fleet Point to a high of 325.5 at Haynie Point. Over the past several years, there has been a steady increase in the number of market oysters at Haynie Point (Figure D12). While there was a small decrease in the number of market oysters bushel^{-1} at Haynie Point when compared with 2010, the number of market oysters at Haynie Point was still the second highest observed over the past twenty years of monitoring (Figure D11 and D12). There was a notable increase in the number of market oysters bushel^{-1} at both Whaley's East and Fleet Point when compared with 2010 and an increase in small oysters at Fleet Point (Figure D11). The number of market oysters during 2011 was at its highest level observed since prior to 1991 at Whaley's East and the second highest at Fleet Point. Settlement in more recent years in the Great Wicomico River has been on high when compared to that observed in the late 1980s and early 1990s, however, settlement for the past three years has been more moderate (Figure D12) with a small decrease observed at both Whaley's East and Fleet Point during 2011. The total number of boxes bushel^{-1} was low ranging from 17.5 (Fleet Point) to 25.5 (Whaley's

East). This accounted for less than 10% of the total (live and dead) at all three sites. Water temperature on the day of sampling was around 20°C and salinity was between 10.6 (Fleet Point) and 11.0 ppt (Haynie Point).

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 remains low (average of 39.2 market oysters $bushel^{-1}$), but slightly higher than that observed during 2010, marking the fourth year in a row with a small overall increase. Over the past five years, the number of market oysters on the thirty bars that are sampled annually has more than doubled increasing from an average of 16.5 $bushel^{-1}$ in 2007 to an average of 39.2 $bushel^{-1}$ in 2011.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. Following the large spat settlement in 2010, the majority of the oysters observed during 2011 were again primarily small, with twenty-four of the thirty sites consisting of greater than 50% small oysters. 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 density (< 60 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 during 2011, the number of small and market oysters combined were the highest observed during the past twenty years and while this suggests 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 determine if these increases in the number of oysters will persist.

Overall, settlement during 2011 was low to moderate throughout most of the Virginia portion of the bay with most sites falling within the middle of the range that has been typical over the past twenty years. Two out of the ten sites in the Rappahannock River had zero spat settlement. Settlement in the James River was similar to historic patterns (Haven & Fritz 1985) with higher settlement at the two most downriver sites, and decreasing settlement in an upriver direction from Nansemond Ridge.

The average total number of boxes observed during 2011 was low to moderate at most sites accounting for less than 18% of the total (live and dead) oysters. The exceptions were Hog House and Middle Ground in the Rappahannock River system, which had a high number of boxes accounting for 57 and 74% of the total respectively. The boxes at these two sites included all size categories, suggesting a potential die-off due to a low oxygen event, rather than a disease related event, which typically affects only the larger, older oysters (Andrews 1988). Over the past several years the four most downriver sites in the James River (Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge) have had a large number of small and market boxes, indicating some increased mortality caused by disease. 2011 was the first year in the past five that there was not a large number of small and market boxes at the downriver sites in the James River. Both oyster diseases in the Chesapeake Bay (*Perkinsus marinus* and *Haplosporidium nelson*) experience reduced pathogenicity at lower salinities (Ford & Tripp 1996), as was the case throughout most of the Bay.

In general, drill holes have become more prevalent in spat boxes since the early 2000s. During 2011, there were drill holes present in spat boxes at Nansemond Ridge in the James 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 extirpated them from 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 2011 dredge survey, it should be noted that drill holes were observed at multiple sites in the James and Piankatank Rivers and Mobjack Bay during the patent tong survey in November of 2011 (Southworth, personal observation), so the predation of spat by oyster drills in these systems remains a concern.

Table D1: Station locations for the 2011 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 2011. 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	10/18	19.6	4.0	133.5	654.5	5.0	793.0	8.5	10.5	0.0	19.0
Mulberry Point	10/18	19.4	5.3	17.0	1700.0	49.0	1766.0	10.0	26.5	0.0	36.5
Horsehead	10/18	19.6	5.1	98.5	1212.5	40.0	1351.0	18.0	44.0	0.0	62.0
Point of Shoal	10/18	19.6	6.1	118.5	994.0	14.5	1127.0	14.5	25.0	0.0	39.5
Swash	10/18	19.3	6.9	20.5	991.0	54.5	1066.0	12.5	20.5	1.5	34.5
Long Shoal	10/18	19.3	7.5	54.5	913.0	94.0	1061.5	21.0	29.0	1.0	51.0
Dry Shoal	10/18	19.3	9.9	59.5	551.0	44.5	655.0	12.0	40.0	0.5	52.5
Wreck Shoal	10/17	19.2	10.9	58.5	197.5	43.0	299.0	5.5	32.0	2.0	39.5
Thomas Rock	10/17	19.0	10.7	12.5	53.0	127.0	192.5	1.0	6.5	1.5	9.0
Nansemond Ridge	10/17	18.4	14.4	1.0	10.0	214.0	225.0	1.5	5.0	6.0	12.5
York River											
Bell Rock *	10/25	17.9	12.1	20.0	146.5	36.5	203.0	1.0	8.0	1.5	10.5
Aberdeen Rock	10/11	20.4	14.8	26.0	155.0	64.0	245.0	5.5	23.0	3.0	31.5
Mobjack Bay											
Tow Stake	10/11	19.9	15.4	29.0	156.5	17.0	202.5	2.0	18.5	2.0	22.5
Pultz Bar	10/11	20.0	15.3	44.5	39.0	6.5	90.0	4.0	15.5	0.5	20.0
Piankatank River											
Ginney Point	10/12	20.4	11.8	31.0	356.5	25.5	413.0	4.5	69.5	1.5	75.5
Palace Bar	10/12	20.3	12.4	19.0	364.0	110.0	493.0	3.0	21.5	1.5	26.0
Burton Point	10/12	20.3	12.5	44.0	185.5	48.0	277.5	2.0	27.0	1.0	30.0
Rappahannock River											
Ross Rock	10/13	19.9	6.0	65.5	76.0	0.5	142.0	1.5	14.5	0.0	16.0
Bowler's Rock	10/13	20.1	8.0	32.0	26.5	0.0	58.5	0.5	4.0	0.0	4.5
Long Rock	10/13	20.2	8.7	39.5	21.0	0.0	60.5	0.0	4.0	0.0	4.0
Morattico Bar	10/13	20.3	10.0	8.5	21.0	0.5	30.0	0.0	0.5	0.0	0.5
Smokey Point	10/13	20.3	10.8	20.5	70.0	2.5	93.0	0.0	10.5	0.0	10.5
Hog House	10/13	20.3	11.3	10.5	18.0	17.5	46.0	0.0	61.0	0.0	61.0
Middle Ground #	10/13	20.6	11.3	3.0	29.0	25.0	57.0	13.0	150.0	0.5	163.5
Drumming Ground	10/13	20.3	11.7	44.0	211.5	37.5	293.0	1.0	38.0	1.0	40.0
Parrot Rock	10/13	20.1	11.8	51.0	132.0	20.5	203.5	0.5	17.5	0.0	18.0
Broad Creek	10/13	20.3	12.1	14.0	146.0	16.0	176.0	0.5	12.0	0.5	13.0
Great Wicomico River											
Haynie Point	10/12	20.5	11.0	38.0	99.5	188.0	325.5	1.5	16.0	3.5	21.0
Whaley's East	10/12	20.4	10.7	32.0	178.5	53.0	263.5	0.0	25.0	0.5	25.5
Fleet Point	10/12	20.3	10.6	28.5	112.0	20.0	160.5	2.0	15.5	0.0	17.5

Figure D1: Map showing the location of the oyster bars sampled during the 2011 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.

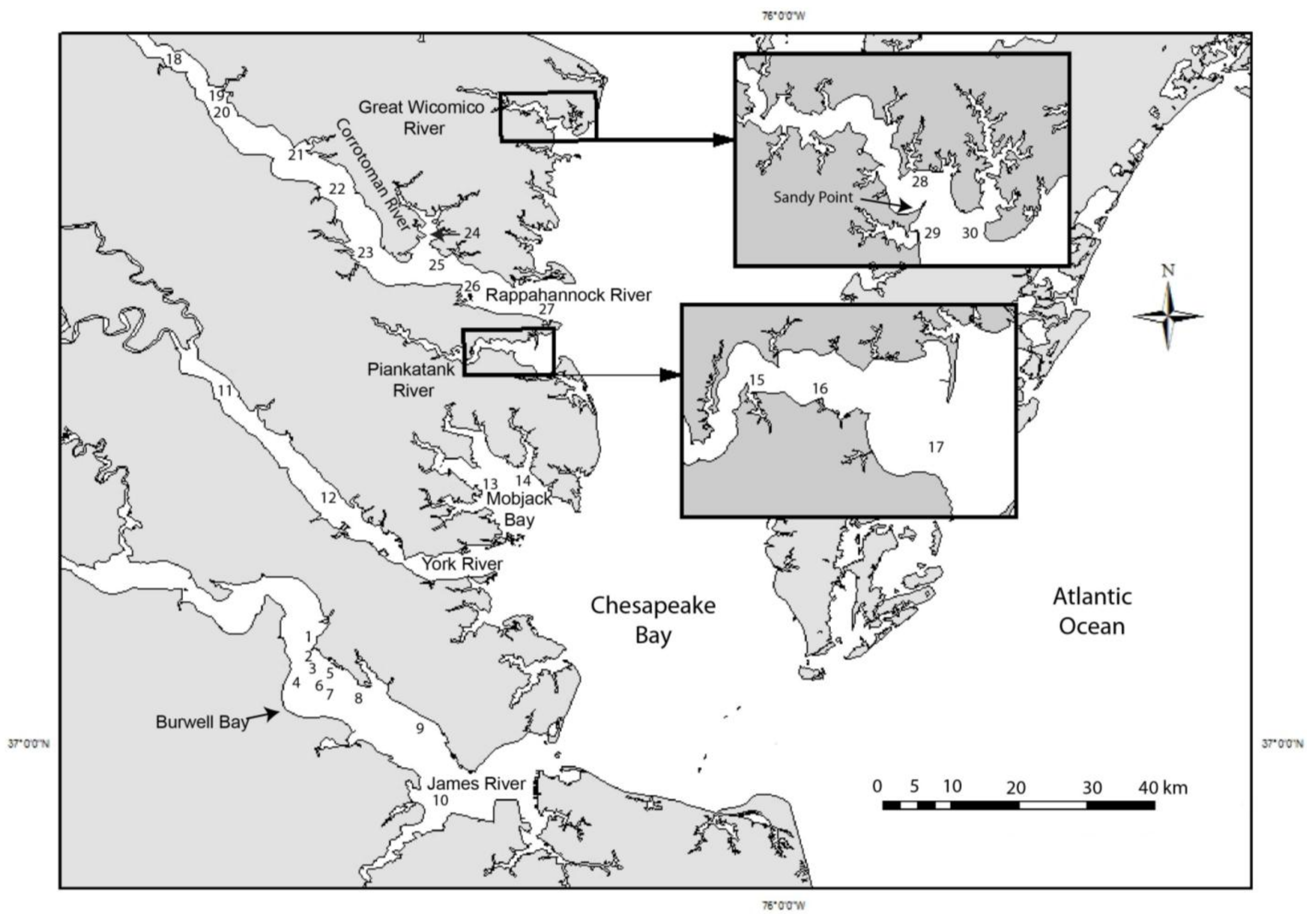


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2010-2011)
(Error bars represent standard error of the mean)

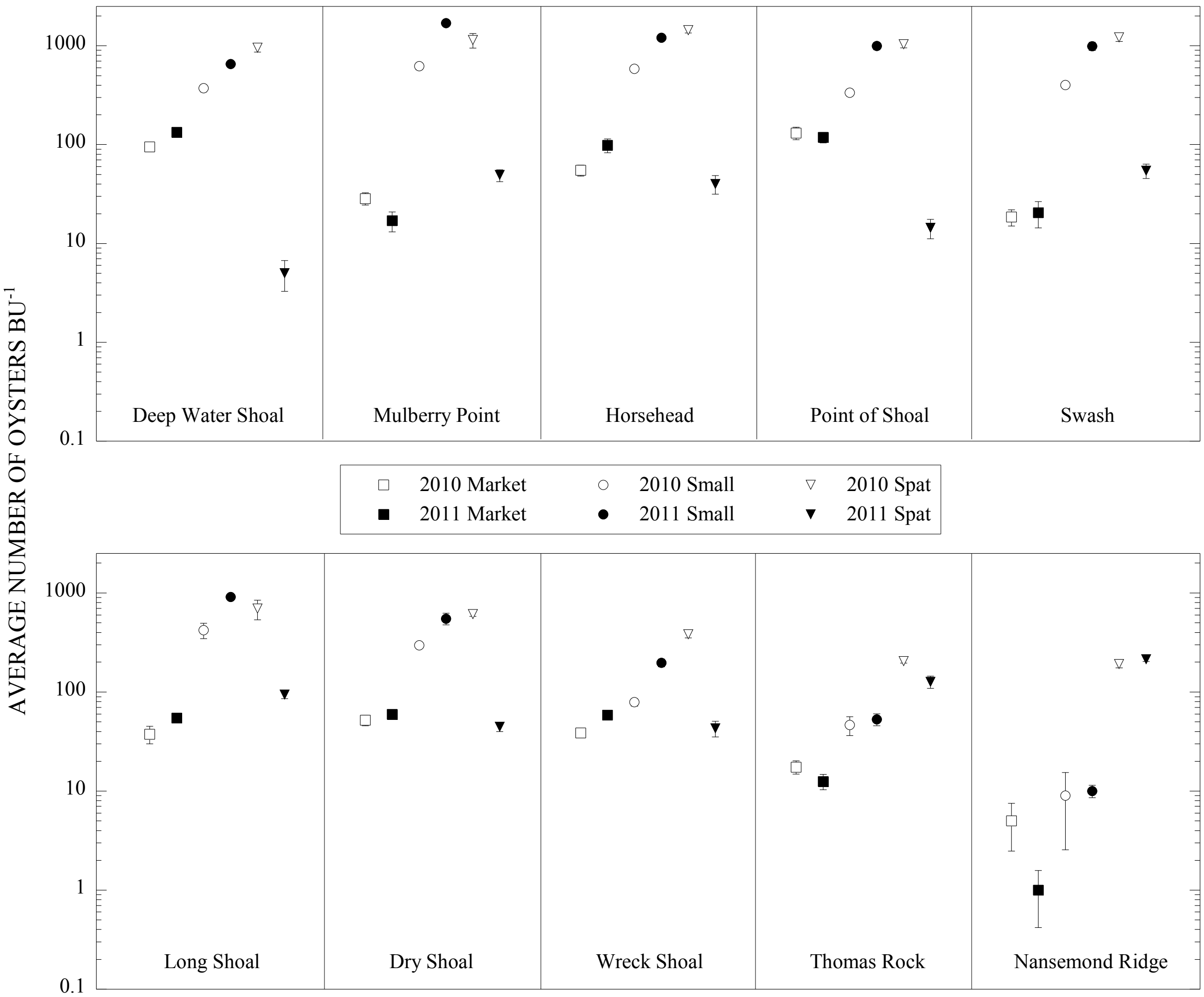
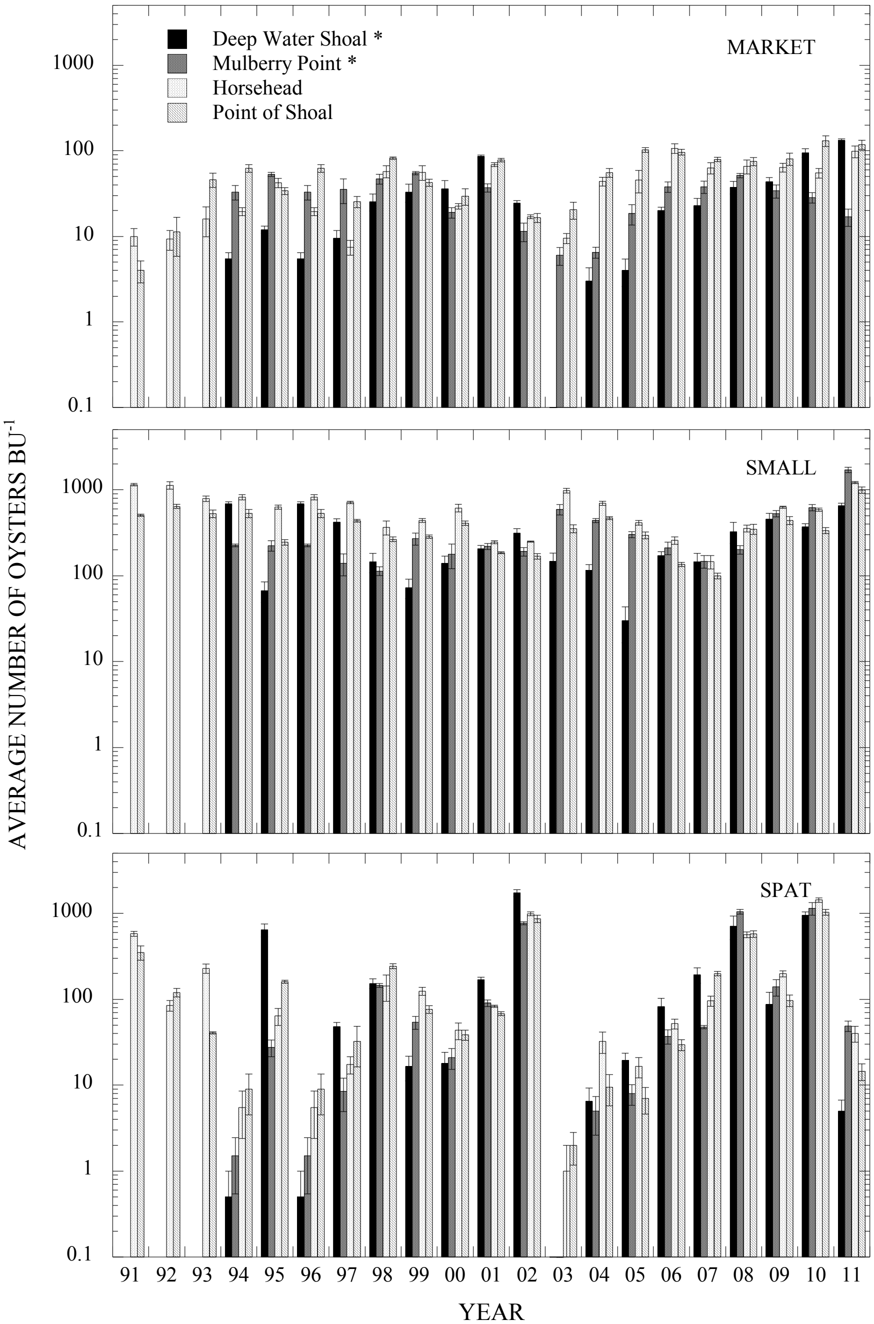
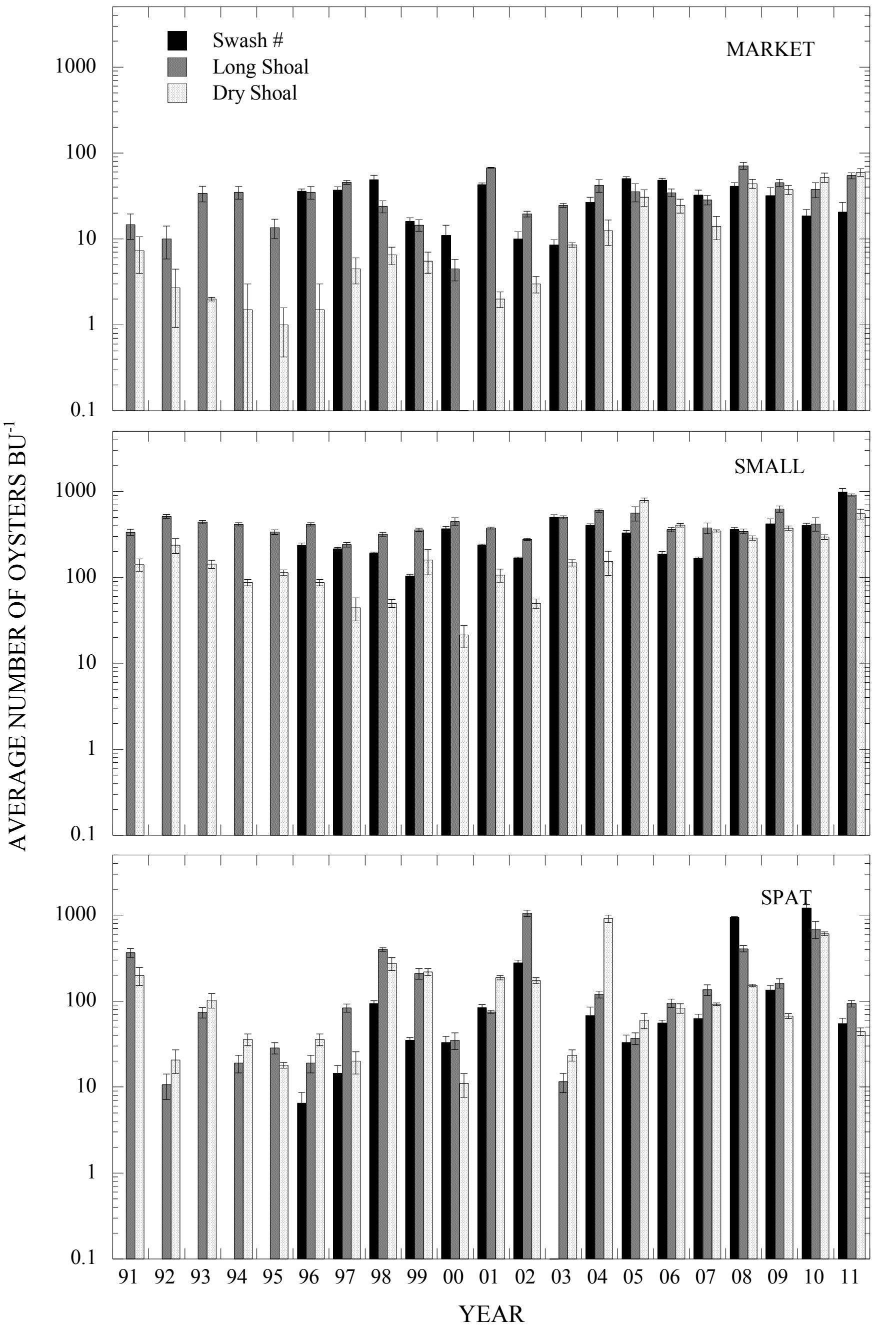


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* 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)

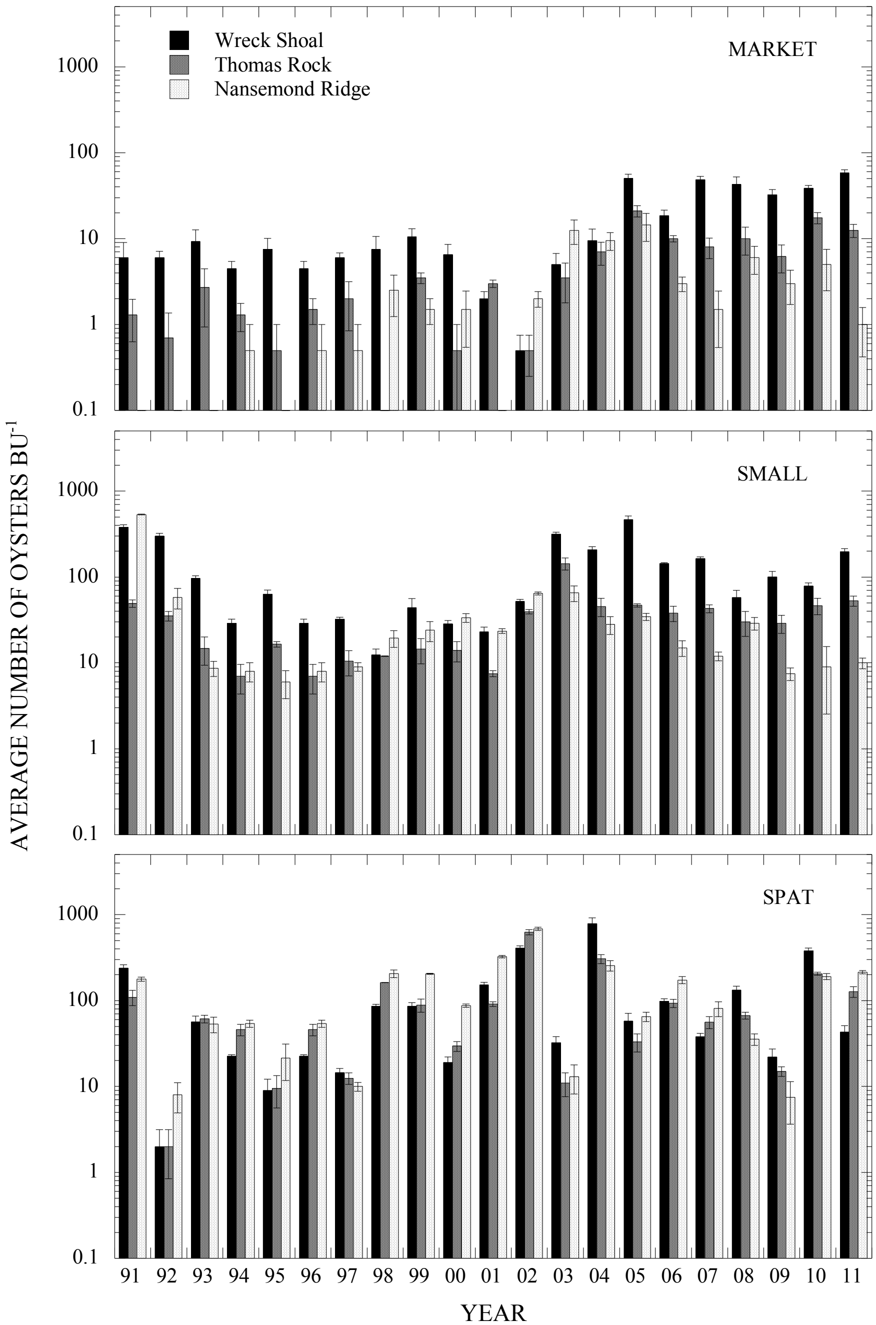


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE YORK RIVER AND MOBJACK BAY (2010-2011)
(Error bars represent standard error of the mean)

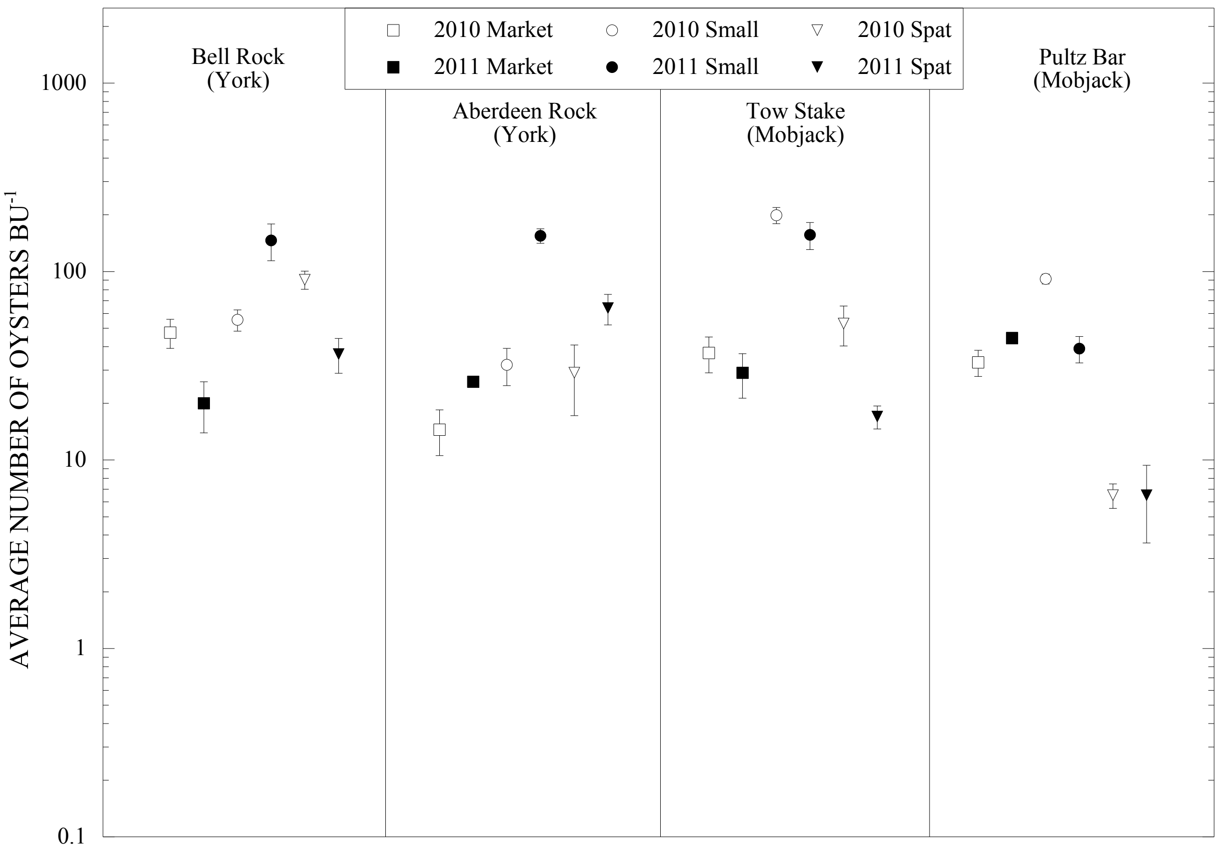


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)

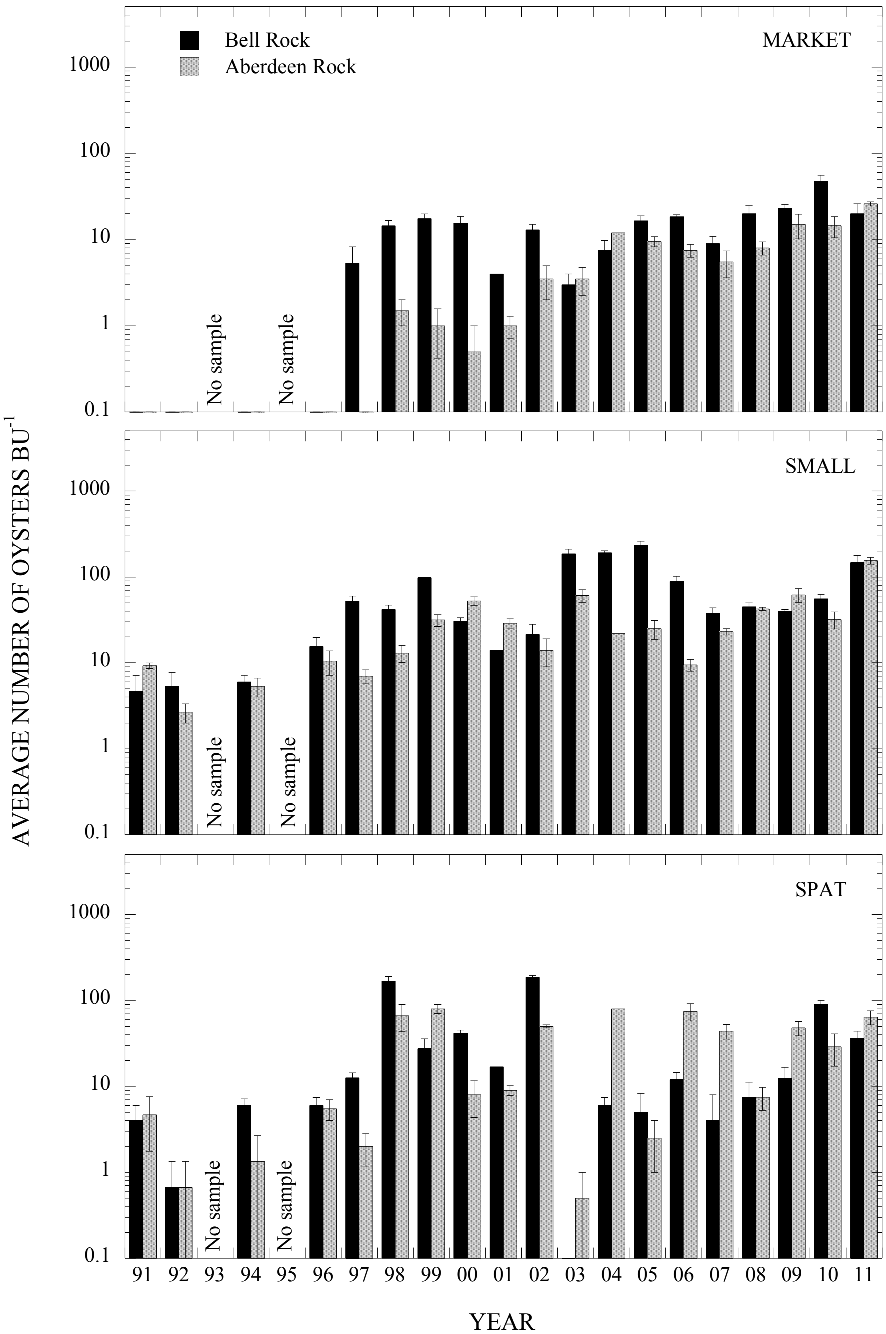


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)

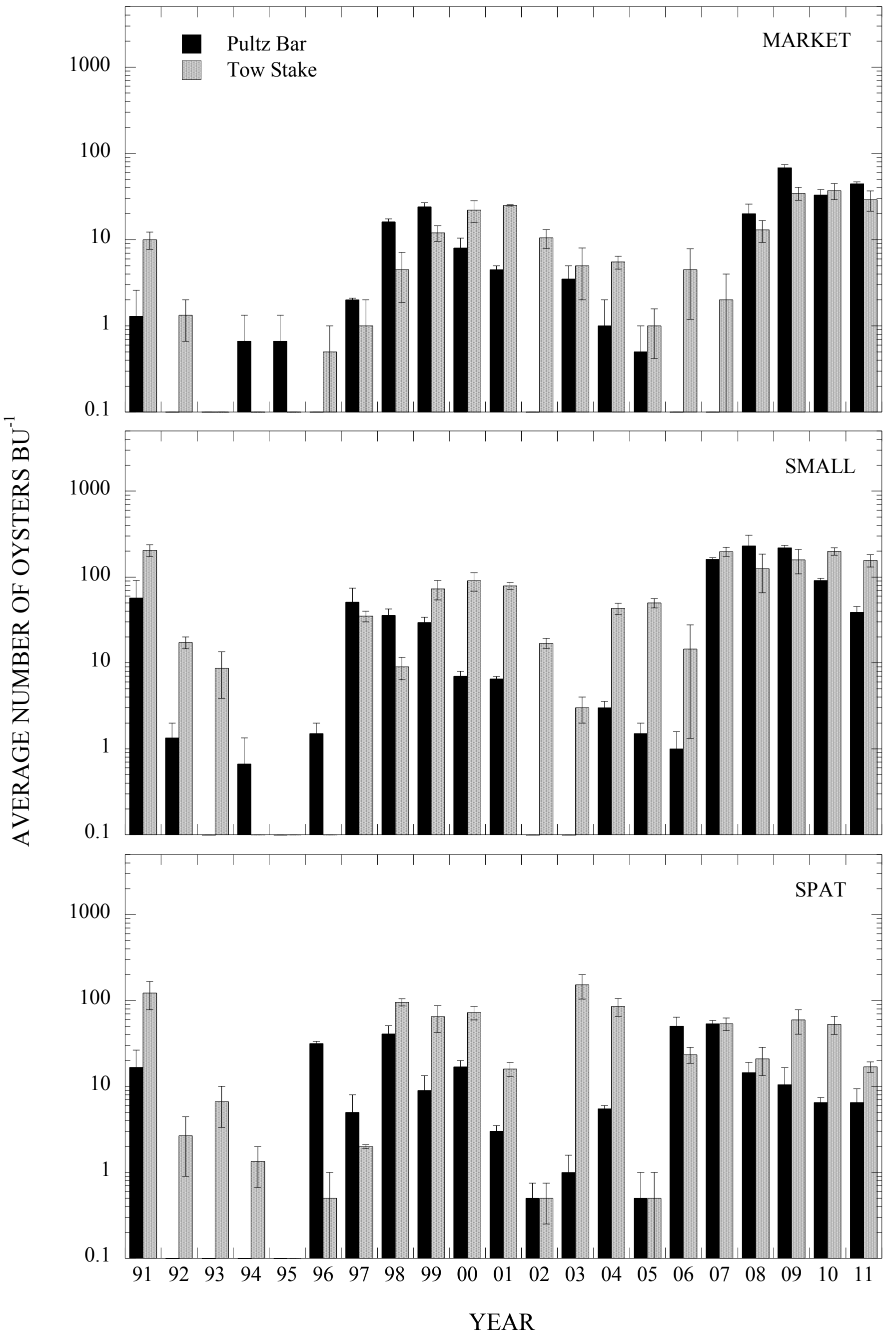


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2010-2011)
(Error bars represent standard error of the mean)

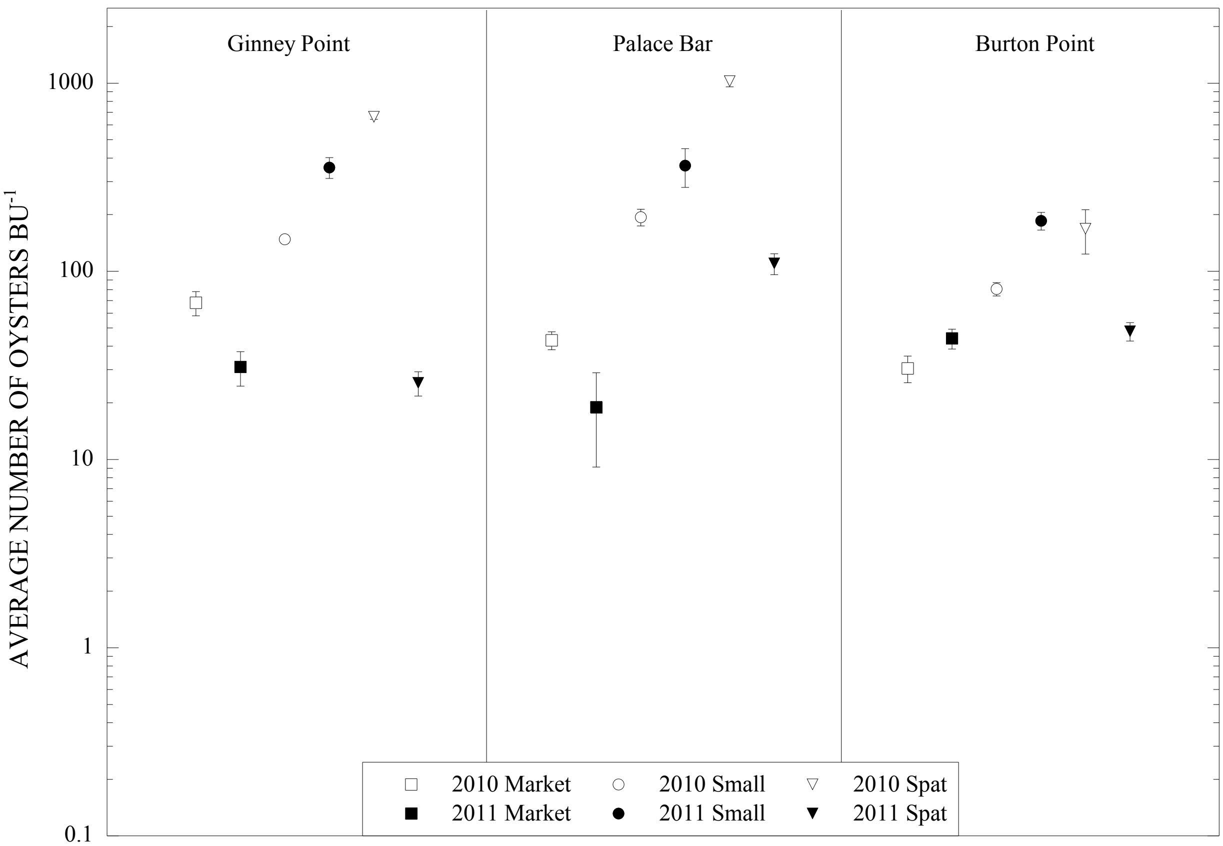
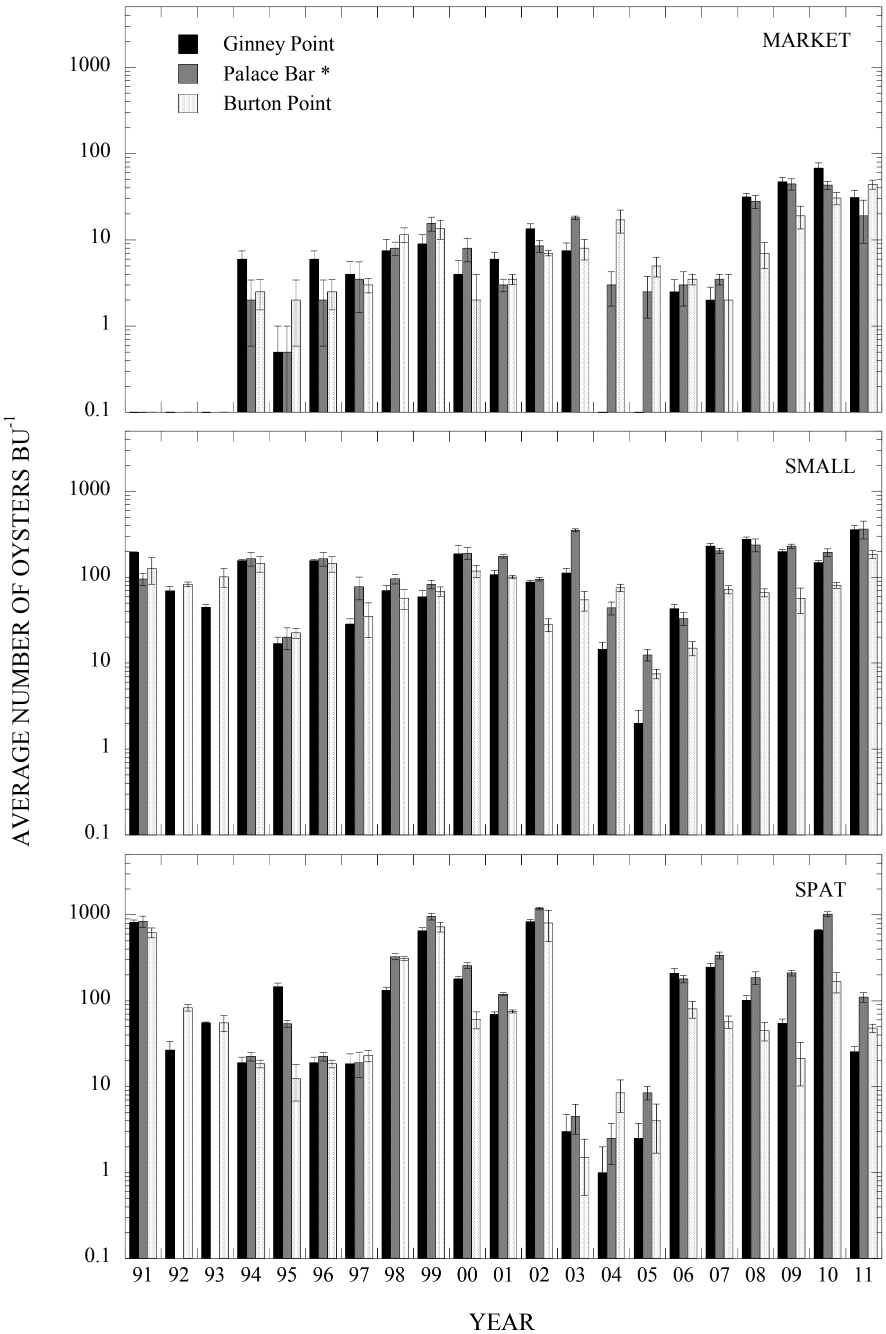


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 1992 and 1993

FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2010-2011)
(Error bars represent standard error of the mean)

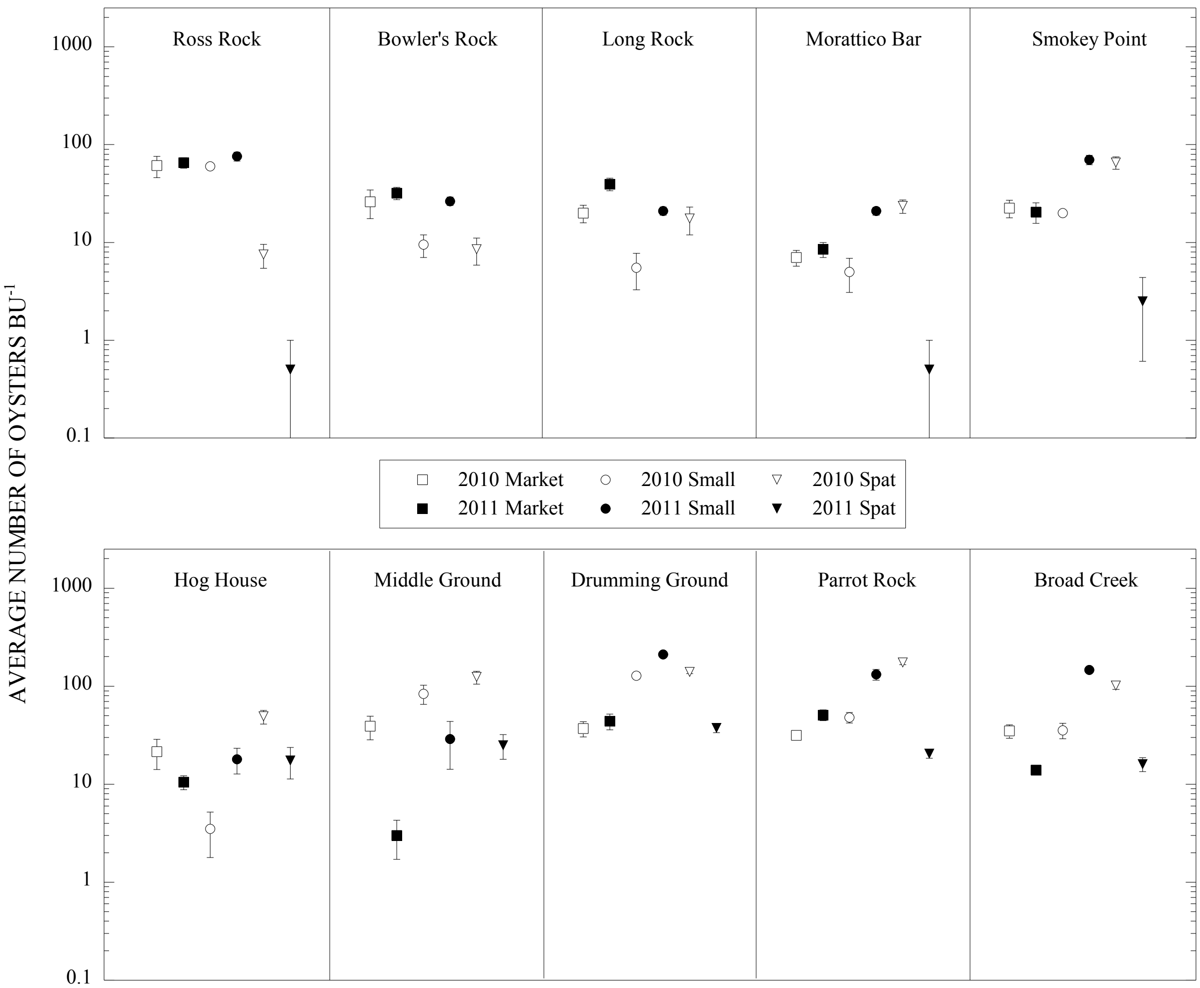
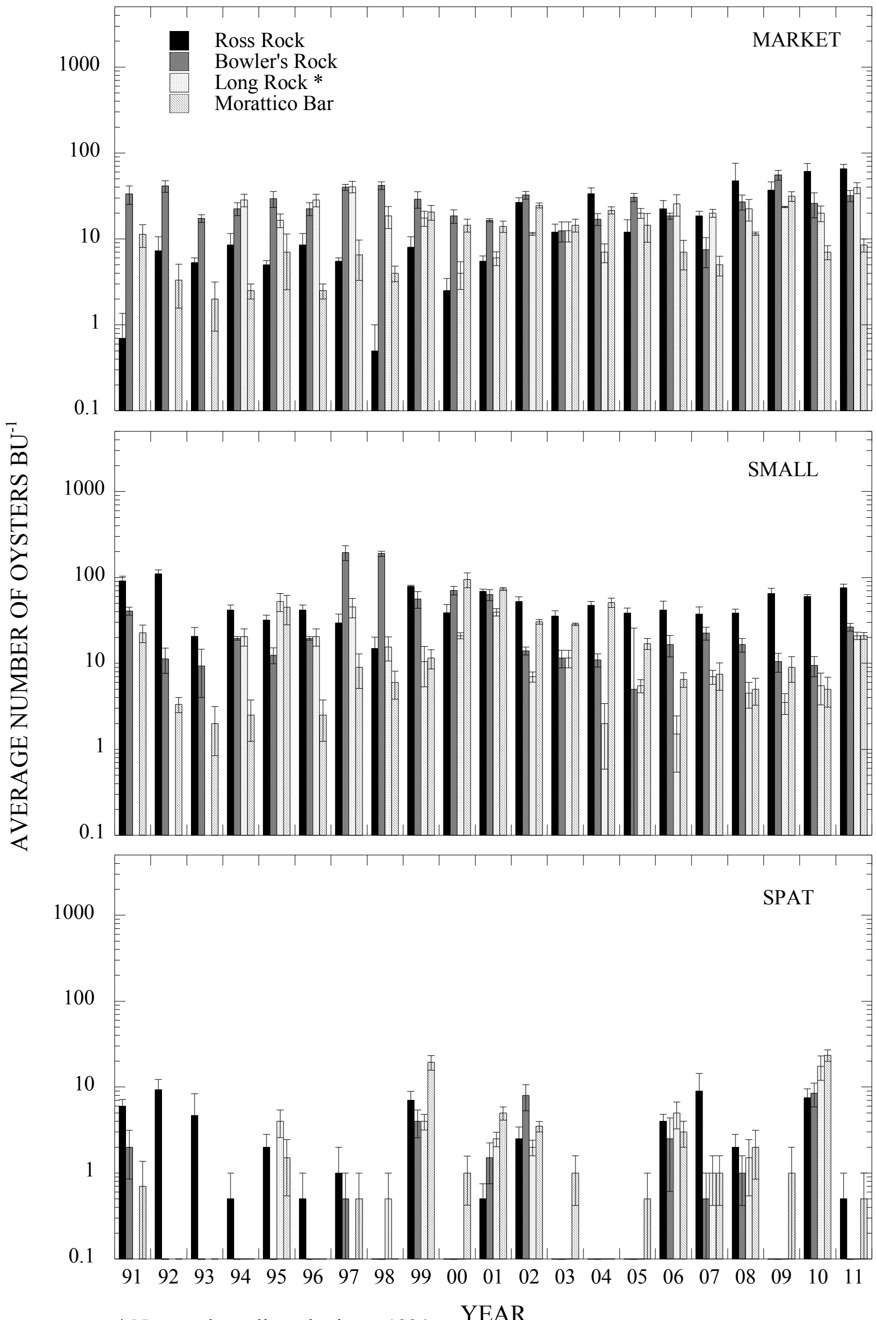


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* 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)

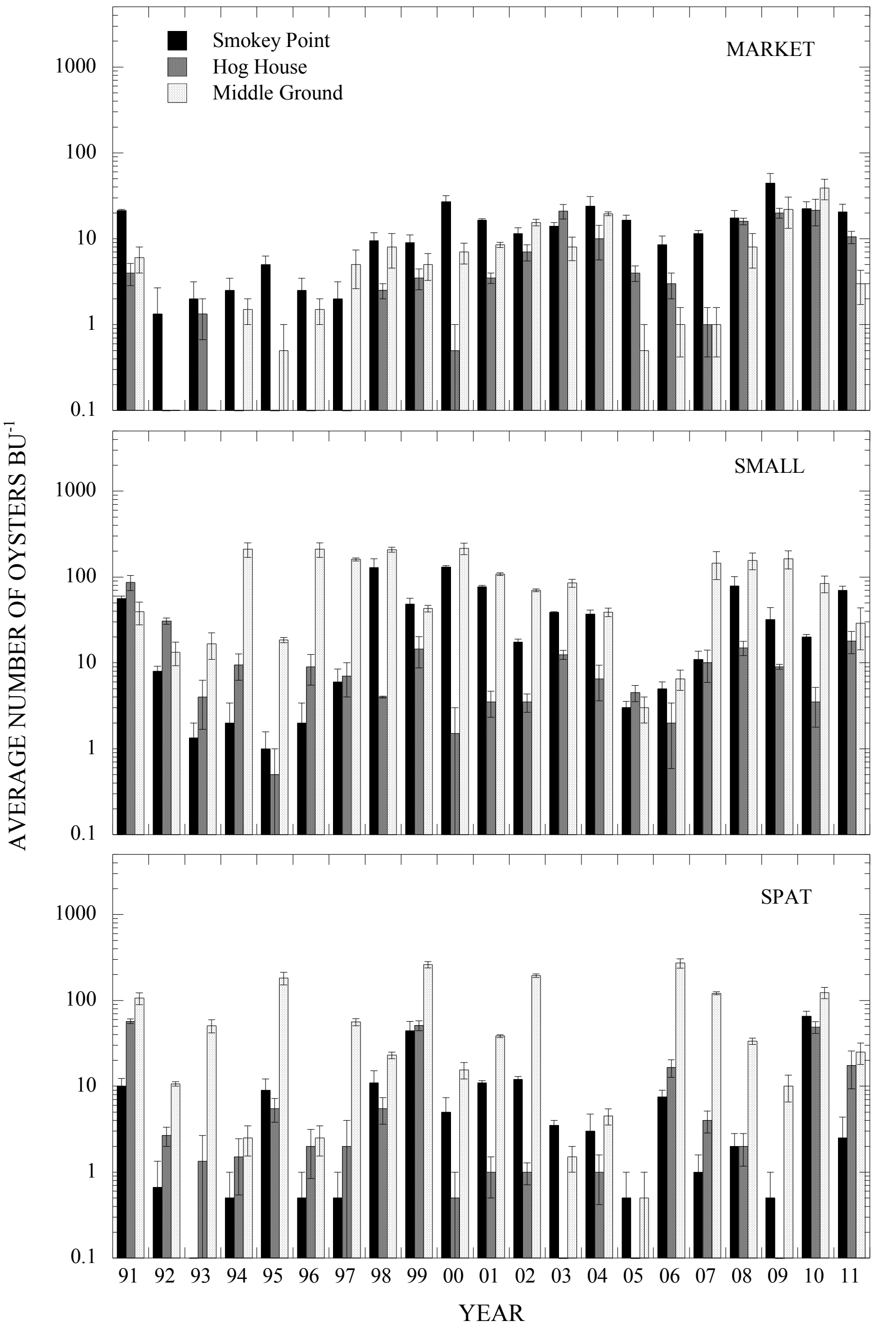
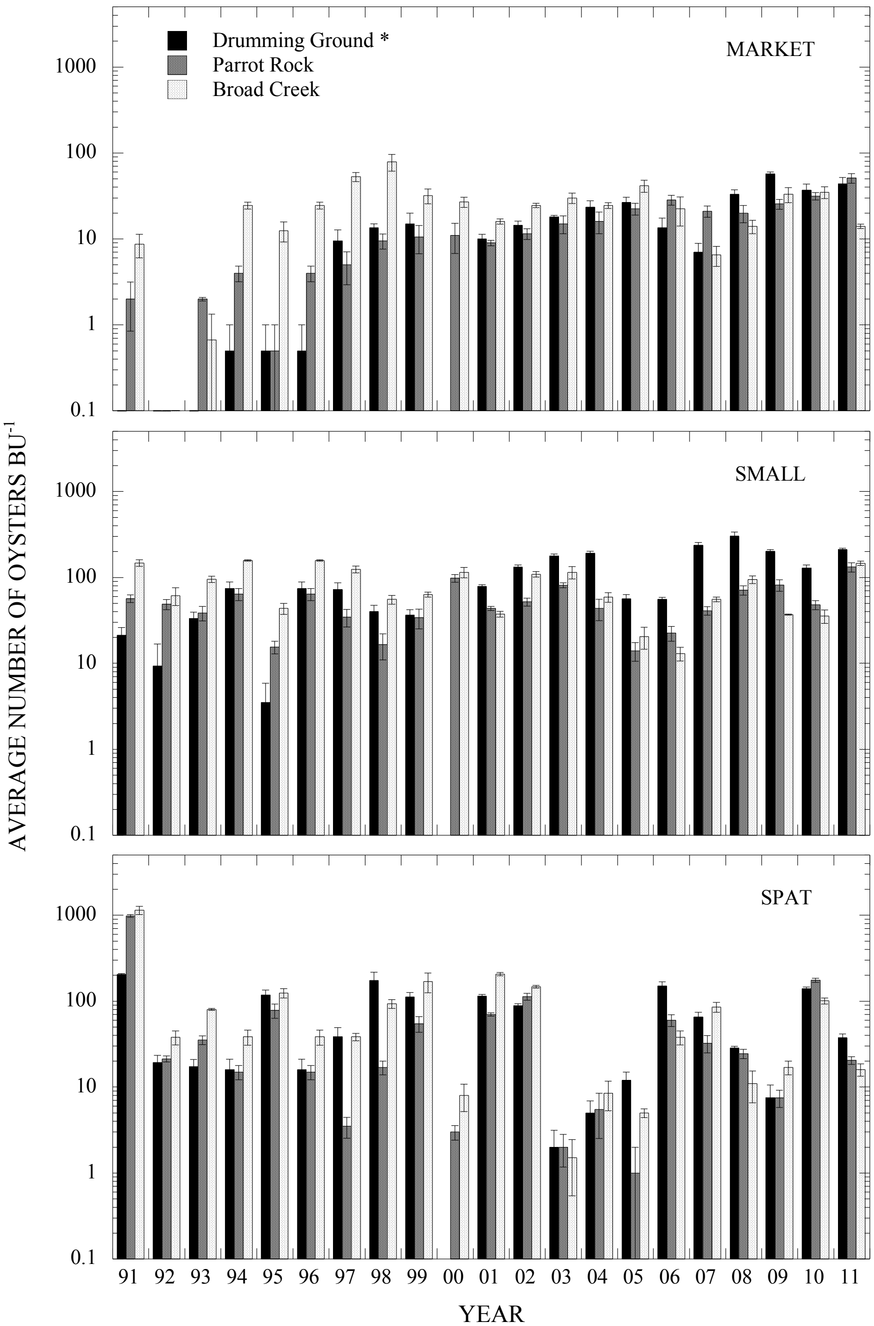


FIGURE D10C: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 2000

FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE GREAT WICOMICO RIVER (2010-2011)
(Error bars represent standard error of the mean)

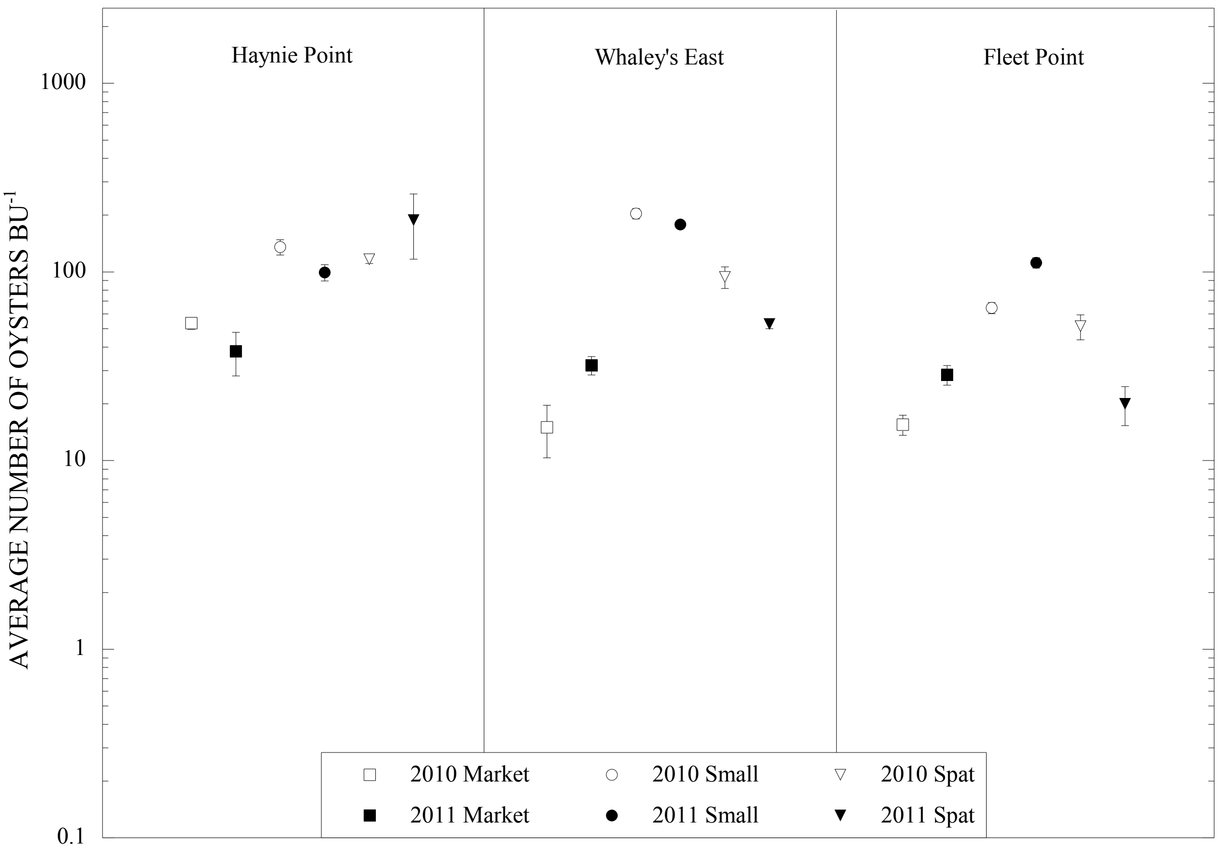
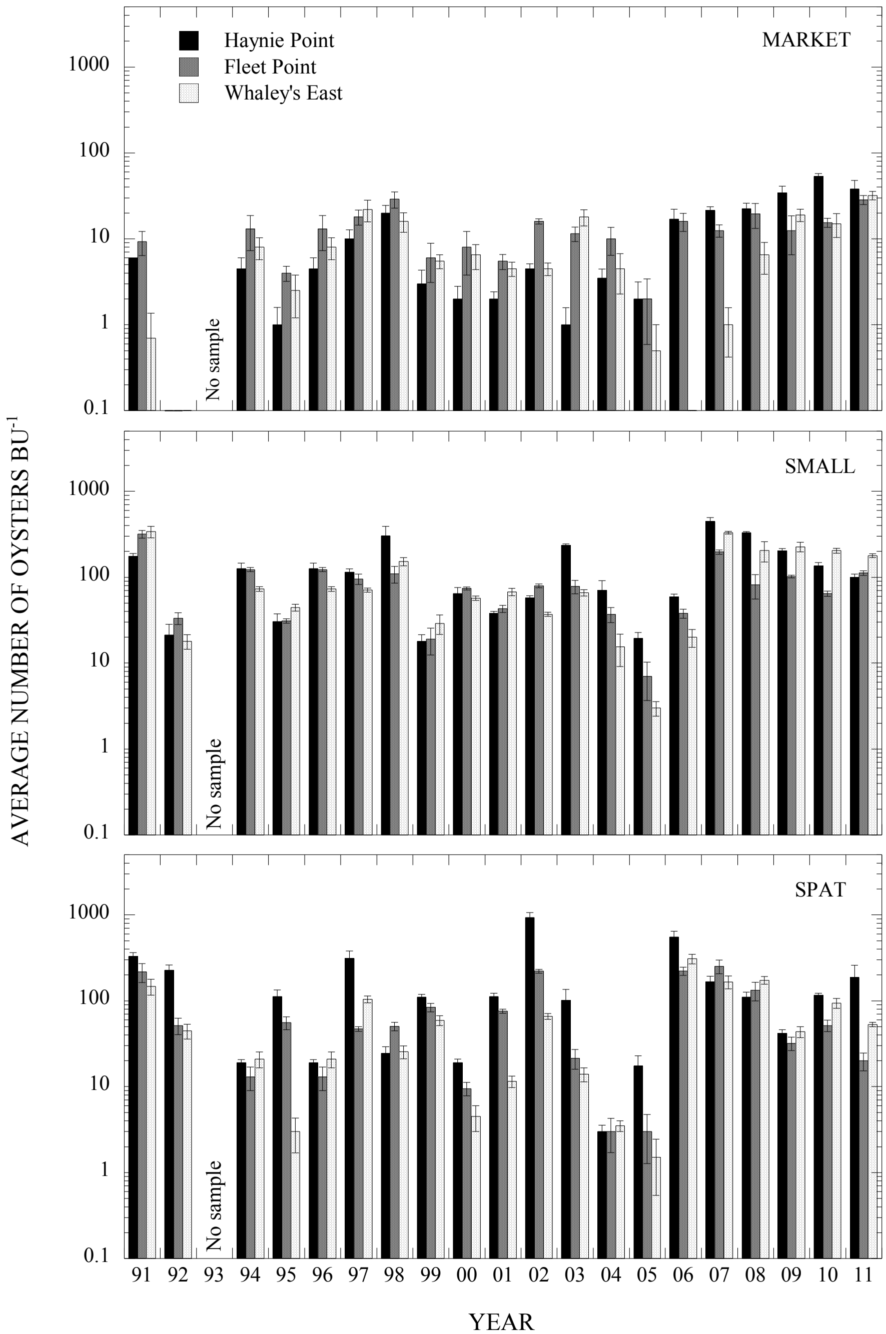


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



ACKNOWLEDGMENTS

These monitoring programs required the assistance of many people, without whose contributions they could not have been successfully completed. We are deeply grateful to the following: Tim Gass, Wayne Reisner and Matthew West (VIMS Field Operations) for help with vessel operations. Patricia McGrath (VIMS Fisheries Science) assisted in making the shellstrings and field collection. Cindy Forrester (Department of Fisheries Science, Budget Manager) and Grace Newbill (Department of Fisheries Science, Purchasing Agents) helped with purchasing field equipment and materials. VIMS Field Operations Department provided assistance with boat scheduling and operation throughout the year, namely Raymond Forrest and Susan Rollins. Roland Billups and Christine Bata from VIMS Vehicle Operations Department provided assistance with truck scheduling and operation. Dr. James A. Wesson, Division Head, Conservation and Replenishment Division of the Virginia Marine Resources Commission provided the *J. B. Baylor* vessel for use during the dredge survey and assisted with data collection during the dredge survey. Adam Crocket, John Ericson and Vernon Rowe of the VMRC provided assistance during the fall 2011 dredge survey.

REFERENCES

Andrews, J.D., 1988. Epizootiology of the disease caused by the oyster pathogen *Perkinsus marinus* and its effects on the oyster industry. Amer. Fish. Soc. Spec. Pub. 18:47-63.

Baylor, J.B. 1896. Method of defining and locating natural oyster beds, rocks and shoals. Oyster Records (pamphlets, one for each Tidewater, Virginia county, that listed the precise boundaries of the Baylor Survey). Board of Fisheries of Virginia.

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

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

Cox, C. & R. Mann. 1992. Temporal and spatial changes in fecundity of eastern oysters, *Crassostrea virginica* (Gmelin, 1791) in the James River, Virginia. J. Shellfish Res. 11:49-54.

Ford, S.E. & M.R. Tripp. 1996. Diseases and defense mechanisms In: V.S. Kennedy, R.I.E. Newell & A.F. Eble editors. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant Publications. pp. 581-660.

Hargis, W.J., Jr. & 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.

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. & 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. & 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.

Mann, R. and D.A. Evans. 1998. Estimation of oyster, *Crassostrea virginica*, standing stock, larval production, and advective loss in relation to observed recruitment in the James River, Virginia. J. Shellfish Res. 17(1):239-254.

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

Rothschild, B.J., J.S. Ault, P. Goulletquer & M. Heral. 1994. Decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. Mar. Ecol. Prog. Ser. 111(1-2):22-39.

Southworth, M., J.M. Harding & 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 & R. Mann. 2005. The status of Virginia's public oyster resource 2004. Molluscan Ecology Program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 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.