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The Status of Virginia's Public Oyster Resource 2016

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The Status of Virginia's Public Oyster Resource 2016

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Part I. OYSTER RECRUITMENT IN VIRGINIA DURING 2016

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 recruitment 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 on both the public side (Virginia Marine Resources Commission (VMRC), Shellfish Replenishment Division) and private industry who are interested in potential timing and location of shell plantings in order to optimize recruitment of spat on bottom cultch (shell that is available for larvae to settle on).

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 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 various 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 2016 settlement season in three tributaries in the Virginia portion of the Chesapeake Bay.

METHODS

Settlement during 2016 was monitored in the James, Piankatank and Great Wicomico Rivers from the last week of May (all three rivers) through the last week of September (James River) and the first week of October (Piankatank and Great Wicomico Rivers). Settlement 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-five years whereas "modern" sites are sites that were added during 1998 to help 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. From 1993 through the early 2000s, VMRC built numerous artificial

oyster shell reefs in several tributaries of the western Chesapeake Bay as well as 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 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 provided 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 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 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 2015 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: $S = \sum \text{spat shell}^{-1} / \text{weeks}$ (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 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. Note this assumes that the shell would remain clean and relatively unfouled by other organisms, which is typically not the case when shells are planted on the bottom. Spat shell⁻¹ values were categorized for comparison purposes as follows: 0.10-1.00, light; 1.01-10.00, moderate; 10.01 to 100.0, heavy; 100.01 or more, extremely heavy. Unqualified references to diseases in this text imply the two oyster diseases found in the bay, *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (*Perkinsus*, or Dermo).

Water temperature (°C) and salinity measurements were taken approximately 0.5 m off the bottom at all sites on a weekly basis using a handheld electronic probe (YSI Pro2030).

James River

RESULTS

Settlement on shellstring collectors during 2016 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of settlement over the past twenty-five years (1991-2016) at the historical sites in all three-river systems and over the past eighteen years (1998-2016) for the modern sites (as discussed in the methods) 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 notable 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 2016 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 2016. Comparisons were made over the past eighteen years for the modern sites whereas the historical sites include twenty-five 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 (labeled Cranes Creek in reports prior to 1997).

Oyster settlement in the James River was first observed during the week of 10 June at four out of the eight sites monitored (Table S1). Settlement occurred throughout the rest of the recruitment period, with at least one spat settling every week at each site (with the exception of Deep Water Shoal during two weeks in mid-July). Settlement during the first two weeks of July accounted for around 69% of the total settlement observed in the river for the year (Figure S3). At both Dry Shoal and Wreck Shoal, settlement during this two-week period accounted for 83% of the total settlement observed in 2016. The largest peak in settlement at Deep Water Shoal occurred a little later than at the other sites, with 41% of the total for the year occurring during the week of 19 August.

Cumulative settlement in the James River during 2016 was heavy at Deep Water Shoal, Horsehead, Point of Shoal, Rock Wharf and Day’s Point and extremely heavy at Swash, Dry Shoal and Wreck Shoal. Settlement ranged from a low of 19.5 cumulative spat shell⁻¹ at Deep Water Shoal to a high of 149.3 cumulative spat shell⁻¹ at Wreck Shoal (Table S1; Figure S4). Settlement during 2016 was higher than the previous year (2015) at Deep Water Shoal, Horsehead, Swash, Dry Shoal and Wreck Shoal. Settlement in 2016 was higher than the five-year mean at seven out of the eight sites (the exception was Day’s Point) and higher than the ten-year mean at Horsehead, Swash, Dry Shoal and Wreck Shoal. Settlement was also higher than both the 20 and 25-yr mean at six and seven out of the eight sites, respectively. The exceptions were no change in settlement at Deep Water Shoal compared with the 20-yr mean and lower settlement at Day’s Point when compared with both the 20 and 25-yr means. Overall, settlement in the James River during 2016 was in the upper range of that observed during the past twenty-five years of monitoring (second highest at Swash and Wreck Shoal;

third highest at Horsehead; fourth highest at Deep Water Shoal; fifth highest at Point of Shoal and Rock Wharf; sixth highest at Dry Shoal). The long-term means are primarily driven by a few exceptionally high settlement years (1991, 1993, 2002, 2008, 2010 and 2012).

Average river water temperatures in the James River during the 2016 monitoring period ranged from a low of 20.2 to a high of 30.7°C (Figure S5A). Prior to reaching the maximum for the season in the third week of July, water temperature was similar to the long-term means (5, 10, 20 and 25-yr; Figure S5) for the system. The temperature maximum for the season was around 3°C higher than the long-term means and after reaching the maximum for the season water temperature remained 1 to 3°C higher than the long-term means throughout most of the rest of the sampling period (Figure S5A).

Average salinities in the James River ranged from 4.8 to 15.9, generally increasing over the course of the sampling period (Figure S5B). However, due to significant rain events there were several periods when average salinity decreased 1 to 2 from one week to the next, such that there was anywhere from a 3 to 5 difference in salinity when compared with the 5, 10, 20 and 25-yr means. The two most notable periods when this occurred was during the weeks of 3 June and 1 July (Figure S5B). Following the second rain event in early July, salinity in the James made a remarkable recovery increasing from an average of 7.0 on 1 July to an average of 14.7 by 22 July. However, salinity then decreased again and was 1 to 3 lower than the long-term means during the last week of July into the first part of August. Salinity increased toward the end of the sampling period such that it remained 1 to 2 higher than the long-term means during the last few weeks of the sampling period. Throughout the sampling period, the difference in salinity between the most upriver site (Deep Water Shoal) and the most downriver sites (Day's

Point and/or Wreck Shoal; Figure 1) ranged between 5 and 12.

Piankatank River

Settlement in the Piankatank River was first observed during the week of 10 June at Wilton Creek, Ginney Point and Bland Point (Table S1; Figure S6). Settlement was relatively consistent (at least one spat at each of the sites in any given week) throughout the system from the week of 24 June through the rest of the monitoring period. There was a large peak in settlement observed throughout the system, during the weeks of 1 July and 8 July. Settlement during this two-week period accounted for approximately 90% of the total settlement observed on the shellstrings during the monitoring period (Figure S6).

Cumulative spat shell⁻¹ for the year was heavy at Ginney Point and extremely heavy at the other seven sites, ranging from a low of 64.1 at Ginney Point to a high of 815.0 at Bland Point (Table S1). It should be noted that the shellstring at Ginney Point was lost during the week of 1 July, which as previously mentioned was one of two weeks in which peak settlement occurred in the system. This is most likely why settlement at this site in 2016, while heavy was not as heavy as what was observed throughout the rest of the system. Settlement during 2016 was higher than that observed during 2015 and higher than the 5-yr mean at every site except Ginney Point and Cape Toon and higher than the 10-yr mean at all eight sites monitored. Settlement at the three historical sites was also higher than the 20 and 25-yr means (Table S2; Figure S7A). Settlement during 2016 was the highest recorded over the past twenty-five years of monitoring at Burton Point. Settlement at Palace Bar was the second highest recorded over the past twenty-five years. Even at Ginney Point, despite missing the count from one of the two weeks when peak settlement occurred,

cumulative settlement during 2016 was the fourth highest recorded over the past twenty-five years of monitoring. At the modern sites, settlement during 2016 ranked the highest (Bland Point, Heron Rock and Stove Point), second highest (Wilton Creek) and fifth highest (Cape Toon) observed since monitoring began at those sites in 1998. Settlement in 2016 at Bland Point was twice as high as the next highest settlement year (2015).

The average water temperature during the 2016 sampling period in the Piankatank River ranged from 20.2 to 30.7°C (Figure S8A). Water temperature in the Piankatank River was similar (within 1°C) to the long-term means (5, 10, 20 and 25-yr) from late May through early July (Figure S8A). Similar to what was observed in the James River, the maximum for the season was 2 to 3°C higher than the long-term means and after reaching the maximum toward the end of July, temperature generally remained 1 to 3 °C above the long-term means for the rest of the monitoring period (Figure S8A).

Salinity in the Piankatank River during 2016 ranged from 13.3 to 18.7 generally increasing over the course of the sampling period. During the first few weeks of sampling, salinity was relatively variable. From the first week of June through the remainder of the sampling period, salinity generally remained 1 to 2 higher than the long-term (5, 10, 20 and 25-yr) means (Figure S8B). On average salinity was 1 higher throughout most of June and July, and 2 higher throughout most of August and September. In any given week, the difference recorded between the most upriver site (Wilton Creek) and the most down river site (Burton Point; see Figure S1) was less than 3.

Great Wicomico River

Settlement in the Great Wicomico River was first observed during the week of 3 June at Glebe Point and Shell Bar. Settlement was then consistent (at least one spat set during each week at most of the sites) from then through the end of the monitoring period (Table S1; Figure S9). Similar to the Piankatank River, the majority of settlement for the season occurred during a two-week period from 1 July through 8 July. Settlement during this two-week period accounted for 90% of the total settlement for the year in the system (Table S1; Figure S9). This peak in settlement was extended at Fleet Point to include the week of 15 July. This three-week period (1 July through 15 July) accounted for 93% of the total settlement observed at Fleet Point during 2016. Settlement for the rest of the sampling period was relatively light throughout the system.

Cumulative spat shell⁻¹ for the year was extremely heavy at all nine sites, ranging from a low of 525.6 at Hilly Wash to a high of 1,117.3 at Glebe Point (Table S1; Figure S10). Settlement in the Great Wicomico River in 2016 was higher than that observed in 2015 at all nine sites (Table S2; Figure S10). Settlement in 2016 was also higher than the 5 and 10-yr means at all nine sites and higher than the 20 and 25-yr means at all five historical sites. When compared with the past twenty-five years, settlement in 2016, was the highest recorded at Hudnall, Haynie Point, Whaley's East and Fleet Point and the second highest at Glebe Point. Settlement during 2016 at Whaley's East and Fleet Point was approximately 5 and 8 times higher, respectively, than the next highest observed during the previous twenty-five years. Settlement in 2016 at the modern sites ranked the highest (Shell Bar) and second highest (Hilly Wash, Harcum Flats and Rogue Point)

observed since monitoring began at those sites in 1998. Settlement at Shell Bar was approximately twice as high as that observed in 2012, the next highest year.

Average river water temperatures in the Great Wicomico River during the 2016 sampling period ranged from 21.0 to 30.9°C throughout the sampling period, reaching the maxima during the week of 22 July (Figure S11A). From late May, when sampling began through early July, water temperature in general was around 1°C lower than the long-term (5, 10 and 18-yr) means. Following the temperature max in late July, which was around 2°C higher than is typical for the system, temperature decreased for two weeks, before again increasing, and then remained 1 to 2°C higher than the long-term means through the end of August (Figure S11A).

Salinity in the Great Wicomico River during the 2016 sampling period ranged from 13.0 to 18.1, generally increasing over the course of the monitoring period (Figure S11B). Salinity throughout the entire sampling period was consistently higher than the long-term (5, 10 and 18-yr) means (Figure S11B). This difference ranged between 0.5 and 2.6. There was typically a 1 to 2 difference in salinity between the most upriver site (Glebe Point) and the most downriver site (Fleet Point: Figure S1) throughout the monitoring period.

DISCUSSION

During the fourteen-year period between 1994 and 2007, settlement on the shellstrings was low to moderate; with 83% of all of the year/site combinations having a seasonal cumulative total of less than 10 spat shell⁻¹. However, settlement on the shellstrings over the past nine years (2008-2016) has been on the rise such that 82% of all of the year/site combinations had heavy

spatfall (seasonal cumulative total of > 10 spat shell⁻¹) and 34% of all of the year/site combinations had extremely heavy spatfall (seasonal cumulative total of > 100 spat shell⁻¹; Table S2). This trend of increased spat set has been especially notable in the Great Wicomico River, where since 2006, 88% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell⁻¹) and 44% of the total year/site combinations had extremely heavy spatfall (seasonal cumulative total of > 100 spat shell⁻¹; Table S2). In 2016, for the second year in a row, settlement on the shellstrings was heavy to extremely heavy at all twenty-five sites monitored.

Overall, settlement on shellstrings in the James River during 2016 was heavy (five sites) to extremely heavy (three sites). Since 2008, the James River has had several very strong year classes (2008, 2010, 2012 and 2016). The mean cumulative spat shell⁻¹ over all eight sites from 1991 to 2007 was 12.7, whereas the mean for all eight sites over the past nine years (2008 to 2015) was 81.9. This translates to almost a seven-fold increase in settlement over the past nine years compared with the previous seventeen years. Since 2008, at least three out of the eight sites experienced heavy to extremely heavy settlement each year. The one exception was during 2009, when all eight sites monitored had moderate settlement (Table S2). In recent years, the timing of settlement in the James River has been getting progressively earlier (Southworth & Mann 2004). Once settlement began in late-June, at least some settlement occurred each week throughout the rest of the 2016 monitoring season. However, similar to what Southworth and Mann (2004) observed, the majority of this settlement occurred in the first half of the season, such that at six out of the eight sites monitored, at least 55% of the total settlement for the season had occurred by the week of 8 July. One exception to this was Deep Water Shoal. This may have been due to the significant rain events that occurred in the

watershed in the month of June. Due to its location in the river, Deep Water Shoal is especially susceptible to low salinity following large rain events and salinity at the site was less than 5 throughout June, into early July, potentially affecting settlement. The other exception was Point of Shoals. This was most likely due to continued issues at that site, such that the shellstring was unable to be collected from 8 July to 22 July, which was when the majority of the settlement was occurring throughout the rest of the system.

Overall, settlement on the shellstrings in the Piankatank River was heavy (one site) to extremely heavy (seven sites), with cumulative number of spat shell⁻¹ for the season at the three historical sites and at the five modern sites being among the highest observed over the past twenty-six and nineteen years of monitoring respectively. Similar to the James River, the Piankatank River has had several very strong year classes in recent years (2012, 2015 and 2016). From 1993 to 2006 (historical sites) and 1998 to 2006 (modern sites), settlement in the Piankatank River was consistently low to moderate at most of the sites monitored. At the three historical sites the mean from 1993 to 2006 was 2.8 cumulative spat shell⁻¹, whereas from 2007 to 2016 the mean at those three sites was 73.8 cumulative spat shell⁻¹, a 26-fold increase over the previous fourteen-year mean. Since the addition of the modern sites in 1998, the mean across the river increased from 4.6 cumulative spat shell⁻¹ (1998 to 2006) to 75.1 cumulative spat shell⁻¹ (2007 to 2015), a sixteen-fold increase. For the past several years potential broodstock (small plus market) in the system has been on the rise. At the three Piankatank River sites monitored during the fall dredge survey, the total number of small and market oysters combined during 2016 was among the highest observed over the past twenty-five years of monitoring (Part II of this report). Density and abundance of broodstock is an important factor in determining fertilization

success (Mann & Evans 1998) and the increase in small and market oysters in the system over the past few years may help to explain at least some of the spawning success observed in the system during that time.

Settlement on the shellstrings in the Great Wicomico has been especially good for the past eleven years, with 2016 marking the first year with extremely heavy (>100 cumulative spat shell⁻¹) settlement recorded at all nine sites monitored. Settlement at the two most downriver sites (Whaley's East and Fleet Point; Figure S1) was the highest recorded at those two sites since regular monitoring began in 1970 (http://www.vims.edu/research/units/labgroups/molluscan_ecology/publications/topic/shellstring/index.php). In contrast to what was observed during most of the 1990s and the early 2000s, settlement in the Great Wicomico River over the past eleven years has been especially good. For the five historical sites the mean cumulative spat shell⁻¹ from 1991 to 2005 ranged from 1.2 (Whaley's East) to 21.7 (Glebe Point), whereas the mean from 2006 and 2016 ranged from 76.1 (Fleet Point) to 434.4 (Glebe Point). This corresponds to a 20 (Glebe Point) to 83 (Whaley's East) fold increase in settlement at these sites during the past eleven years compared with the previous fifteen years. At the modern sites, the mean cumulative spat shell⁻¹ from 1998 to 2005 ranged from 3.2 (Shell Bar) to 5.4 (Harcum Flats), whereas the mean from 2006 to 2016 ranged from 226.4 (Shell Bar) to 265.0 (Rogue Point). This corresponds to a 49 (Harcum Flats) to 71 (Shell Bar) fold increase at these sites during the past eleven years compared with the previous eight years.

Table S1: Average number of spat shell¹ for standardized week beginning on the date shown. "D" indicates the date deployed and "-" denotes a week when a shellstring was not collected.

STATION	5/20	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/2	9/9	9/16	9/23	9/30	YEAR TOTAL
JAMES RIVER																					
Deep Water Shoal	D	0	0	0	-	0	0.6	4.0	0	0	0.6	3.0	0.1	8.1	1.3	-	1.0	-	0.8	-	19.5
Horsehead	D	0	0	0	-	0.5	12.9	34.2	1.2	1.5	1.4	7.7	1.3	10.7	4.0	7.4	2.8	-	1.5	-	87.1
Point of Shoal	D	0	0	0.1	-	0.2	12.8	-	-	-	1.3	1.7	0.9	10.1	1.6	4.5	3.2	-	0.9	-	37.3
Swash	D	0	0	0	-	0.6	20.4	59.6	0.9	2.4	1.0	5.1	1.9	9.7	1.2	4.6	2.5	-	1.7	-	111.6
Dry Shoal	D	0	0	0.1	-	0.8	24.6	63.6	0.9	0.9	0.6	3.1	3.1	1.8	1.8	2.9	-	-	2.0	-	106.2
Rock Wharf	D	0	0	0	-	0.4	15.1	12.2	0.8	0.8	3.8	1.2	1.4	1.3	4.9	3.5	2.6	-	-	-	48.0
Wreck Shoal	D	0	0	0.1	-	3.5	74.7	49.9	1.3	1.5	1.7	3.0	2.0	5.2	0.1	3.0	1.4	-	1.9	-	149.3
Day's Point	D	0	0	0.1	-	-	5.1	14.8	0.5	1.4	0.7	0.5	0.3	1.5	1.7	0.6	0.3	-	0.6	-	28.1
PIANKATANK RIVER																					
Wilton Creek	D	0	0	0.4	-	0.8	52.6	124.5	7.6	1.8	0.6	2.4	1.3	1.1	0.7	9.1	3.0	1.5	-	2.1	209.5
Ginney Point	D	0	0	0.1	-	-	-	28.5	5.8	1.3	1.5	0.9	1.4	1.4	3.3	9.9	5.5	3.2	-	1.3	64.1
Palace Bar	D	0	0	0	-	3.2	72.2	51.7	1.6	0.9	0.4	0.3	0.6	0.6	0.9	5.2	1.2	1.2	-	2.0	142.0
Bland Point	D	0	0	0.1	-	7.4	423.3	356.8	2.3	2.2	0.6	1.3	0.2	1.7	2.8	7.8	4.0	2.9	-	1.6	815.0
Heron Rock	D	0	0	0	-	1.5	107.3	21.6	7.9	-	0.5	1.1	0.1	2.2	2.3	6.3	4.4	2.9	-	1.3	159.4
Cape Toon	D	0	0	-	-	12.2	68.3	12.2	-	-	0.7	1.1	1.2	1.2	1.5	1.8	2.2	0.8	-	1.1	104.3
Stove Point	D	0	0	0	-	6.4	84.4	222.5	4.5	1.1	0.9	1.8	0.2	1.5	3.1	3.4	3.2	2.0	-	0.8	335.8
Burton Point	D	0	0	0	-	4.3	162.2	279.0	20.6	1.2	0.4	0.6	1.0	0.3	2.1	-	2.8	-	-	-	474.5
GREAT WICOMICO																					
Glebe Point	D	0	0.1	0.3	-	32.4	889.9	182.6	8.2	0.6	0.6	0.7	0.1	0.1	0	0.1	0.4	0.8	-	0.4	1117.3
Rogue Point	D	0	0	0.6	-	47.3	538.8	18.7	6.3	0.7	0.2	0.3	0.4	-	0.5	0.7	0.5	3.7	-	0.2	618.9
Hilly Wash	D	0	0	0.8	-	38.3	406.0	69.7	4.1	0.8	0.2	0.3	1.3	0.1	0.3	0.4	0.9	2.2	-	0.2	525.6
Harcum Flats	D	0	0	0.6	-	66.0	454.4	69.2	4.8	0.3	0.2	0.7	1.0	0	0.6	0.7	0.5	2.9	-	-	601.9
Hudnall	D	0	0	0.2	-	74.1	404.7	114.3	4.9	0.3	0.2	0.1	0.4	0	0.1	0.1	0.8	1.6	-	0.1	601.9
Shell Bar	D	0	0.1	1.5	-	98.7	628.6	235.6	16.7	0.2	0.1	1.9	1.4	0.3	0.1	0.2	1.9	3.1	-	0.7	991.1
Haynie Point	D	0	0	0.7	-	-	408.2	148.4	9.6	0.5	0.4	0.9	2.8	0.3	0.7	0.9	0.4	1.7	-	0.2	575.7
Whaley's East	D	0	0	0.1	-	15.9	480.2	241.2	7.9	0	0.4	0.3	0.4	0	0.2	0.5	0.2	0.5	-	0	747.8
Fleet Point	D	0	0	0	-	17.2	164.5	286.9	108.0	1.2	0.6	1.0	3.3	0.2	1.3	4.8	1.4	5.3	-	-	595.7

Table S2: Spatfall totals for historical sites (1991-2015) and modern sites (1998-2015) as defined in the text. Values presented as the cumulative sum of spat shell¹ values for each year. "+" and "-" indicate the direction of change in 2016 in reference to 2015 and to the five, ten, twenty and twenty-five year means. Blank cells for a site indicate years where data are not available. NC indicates a change of less than 1 spat shell¹ 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	2012	2013	2014	2015	2016	Mean 11-15	Mean 06-15	Mean 96-15	Mean 91-15	Ref. 2015	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr	Ref. 25-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	13.6	2.8	2.3	18.0	19.5	8.7	32.5	18.6	16.1	+	+	-	NC	+									
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	86.3	4.7	6.1	46.4	87.1	31.7	51.2	27.9	25.3	+	+	+	+	+									
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	64.9	3.2	5.5	36.7	37.3	23.7	49.1	27.0	26.4	NC	+	-	+	+									
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	56.8	4.0	12.8	32.5	111.6	24.0	66.7	36.3	35.3	+	+	+	+	+									
Dry Shoal	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	33.8	151.1	20.4	21.7	63.6	106.2	58.1	82.3	43.8	50.2	+	+	+	+	+									
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	106.5	10.9	11.5	52.3	48.0	43.0	86.2	46.3	41.0	-	+	-	+	+									
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	66.4	3.3	12.3	30.4	149.3	26.0	79.4	42.3	36.2	+	+	+	+	+									
Day's Point	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	25.6	182.9	11.1	13.3	93.1	28.1	65.2	94.6	49.3	52.9	-	-	-	-	-									
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	235.6	23.3	29.7	31.4	209.5	67.7	38.2					+	+	+		+						
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	232.0	29.3	70.5	70.4	64.1	86.8	53.2	27.8	23.8	-	-	+	+	+									
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	155.7	16.6	24.8	56.7	142.0	53.6	31.8	17.2	16.6	+	+	+	+	+									
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	224.5	41.5	29.6	390.9	815.0	141.8	77.4					+	+	+	+	+							
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	73.1	4.3	50.8	105.1	159.4	51.2	30.8					+	+	+		+							
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	191.2	62.9	271.0	167.5	104.3	145.1	98.4					-	-	+		+							
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	121.0	42.3	31.4	304.1	335.8	105.0	59.5					+	+	+		+							
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	172.0	21.3	58.4	379.5	474.5	129.7	69.1	36.0	30.2	+	+	+	+	+									
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	2122.5	49.4	251.4	234.8	1117.3	558.4	366.1	199.1	159.5	+	+	+	+	+									
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	1136.2	79.5	442.5	102.7	618.9	358.9	229.6					+	+	+	+	+							
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	1198.8	73.2	283.0	151.4	525.6	349.9	216.7					+	+	+	+	+							
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	1128.3	38.6	156.6	260.9	601.9	327.1	229.8					+	+	+	+	+							
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	287.0	37.8	150.5	136.4	601.9	131.2	90.5	48.3	38.9	+	+	+	+	+									
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	40.2	472.7	51.2	295.0	437.7	991.1	259.4	149.9					+	+	+	+	+							
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	213.5	16.1	220.4	261.9	575.7	146.9	84.6	43.8	35.7	+	+	+	+	+									
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	144.7	4.1	83.0	82.5	747.8	64.0	36.8	18.9	15.5	+	+	+	+	+									
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	79.3	8.4	77.5	36.8	595.7	41.7	24.2	12.8	10.7	+	+	+	+	+									

Light settlement (0.1 - 1.0 spat/shell)
Moderate settlement (1.01-10.0 spat/shell)
Heavy settlement (10.0-100.0 spat/shell)
Extremely heavy settlement (>100.0 spat/shell)

Figure S1: Map showing the location of the 2016 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 (M), 19) Hilly Wash (M), 20) Harcum Flats (M), 21) Hudnall, 22) Shell Bar (M), 23) Haynie Point, 24) Whaley's East, 25) Fleet Point.

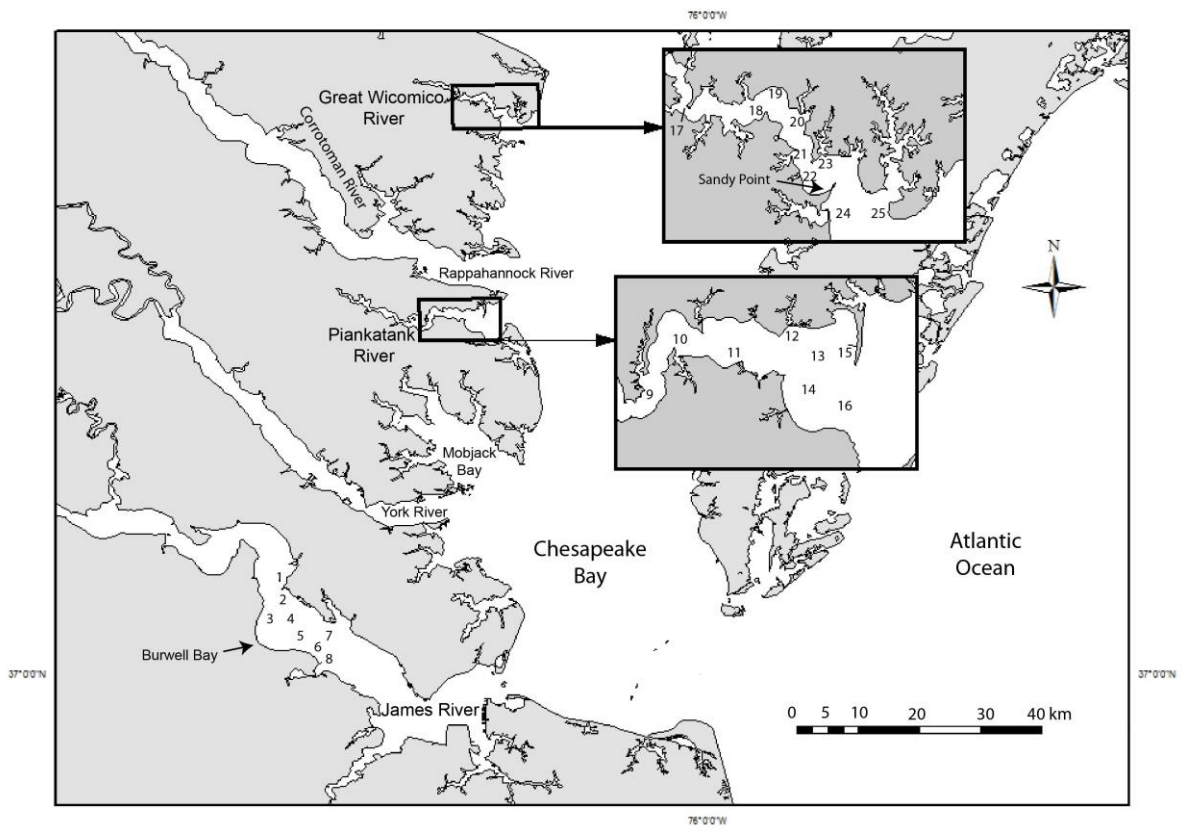


Figure S2: Diagram of shellstring setup on buoys with picture of a shellstring embedded.

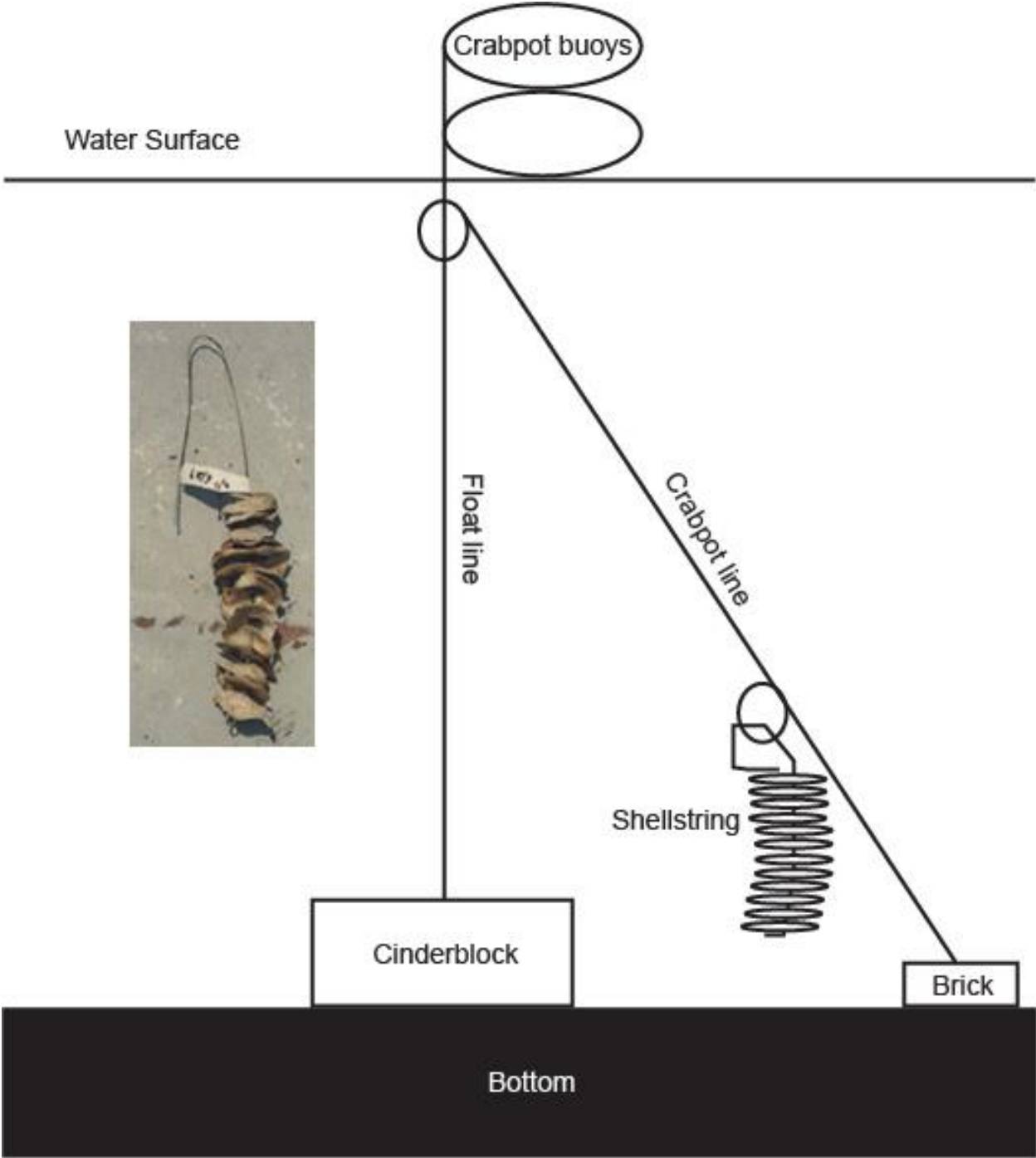


FIGURE S3: JAMES RIVER (2016) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹

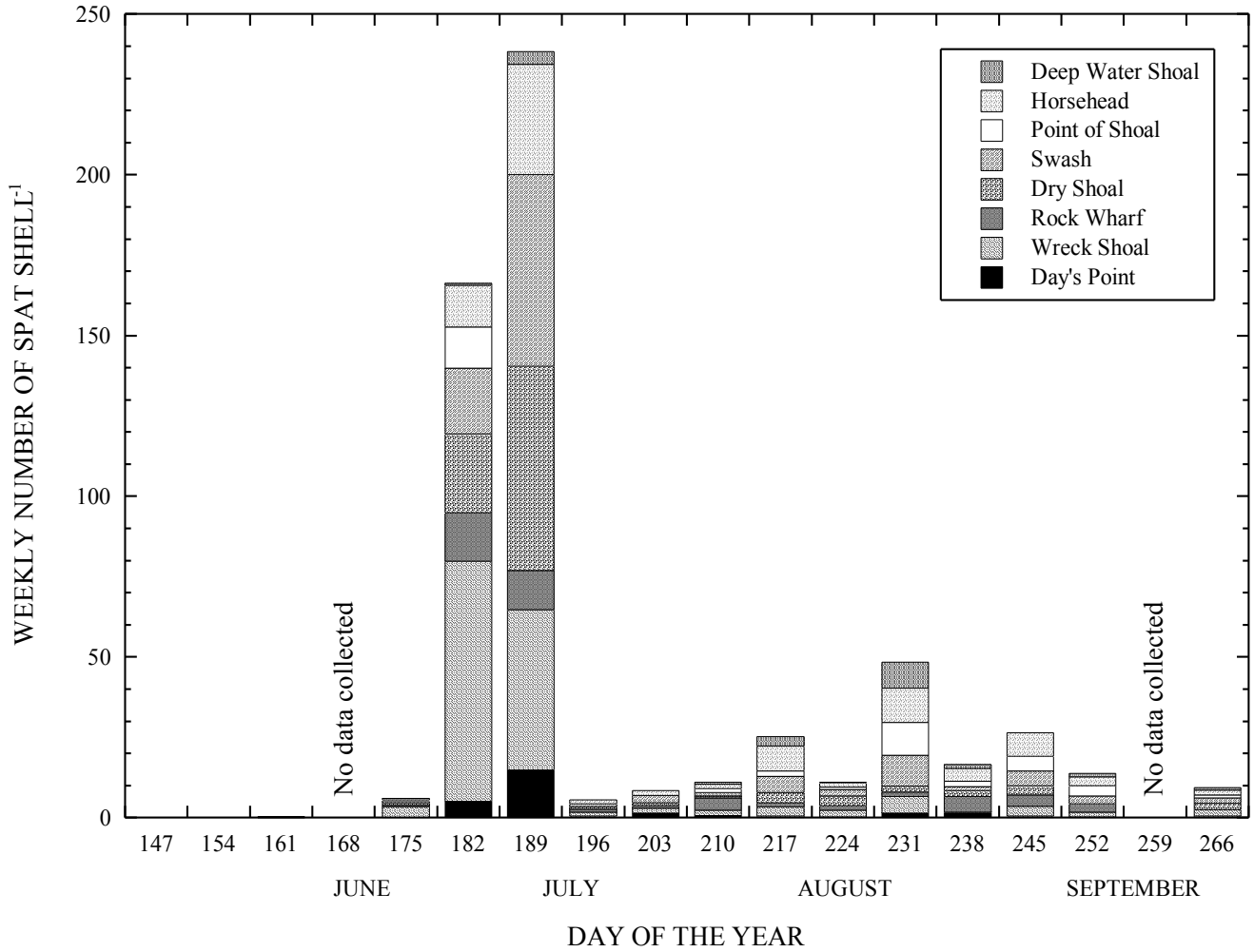


FIGURE S4: RECRUITMENT TRENDS OVER THE PAST 25 YEARS AT ALL EIGHT SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall)

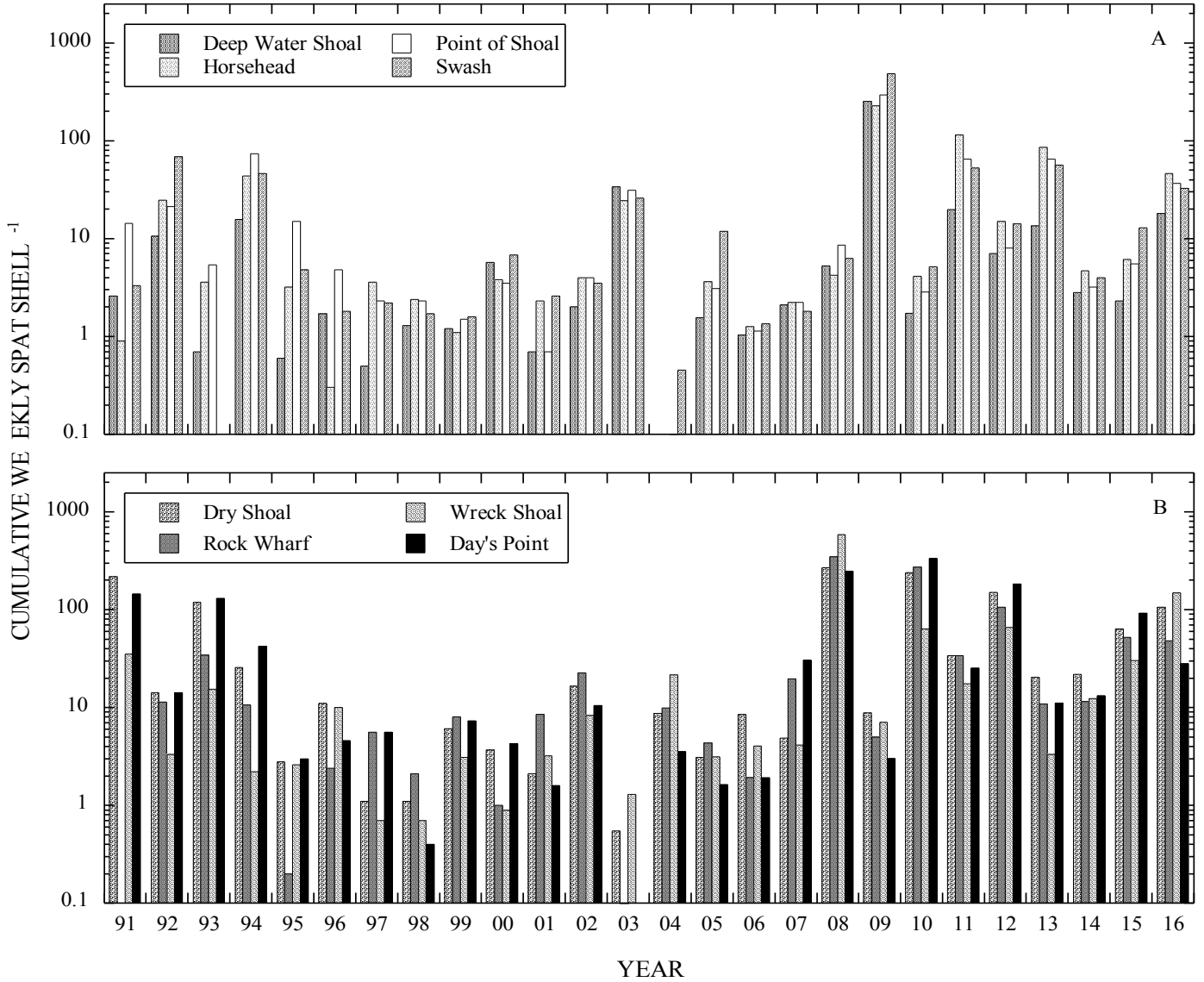


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 25-YEAR MEANS COMPARED WITH 2016 (Error bars represent standard error of the mean; darker shaded area = period of heavy recruitment; lighter shaded area = period of light recruitment; n is the number of data points used to calculate the mean)

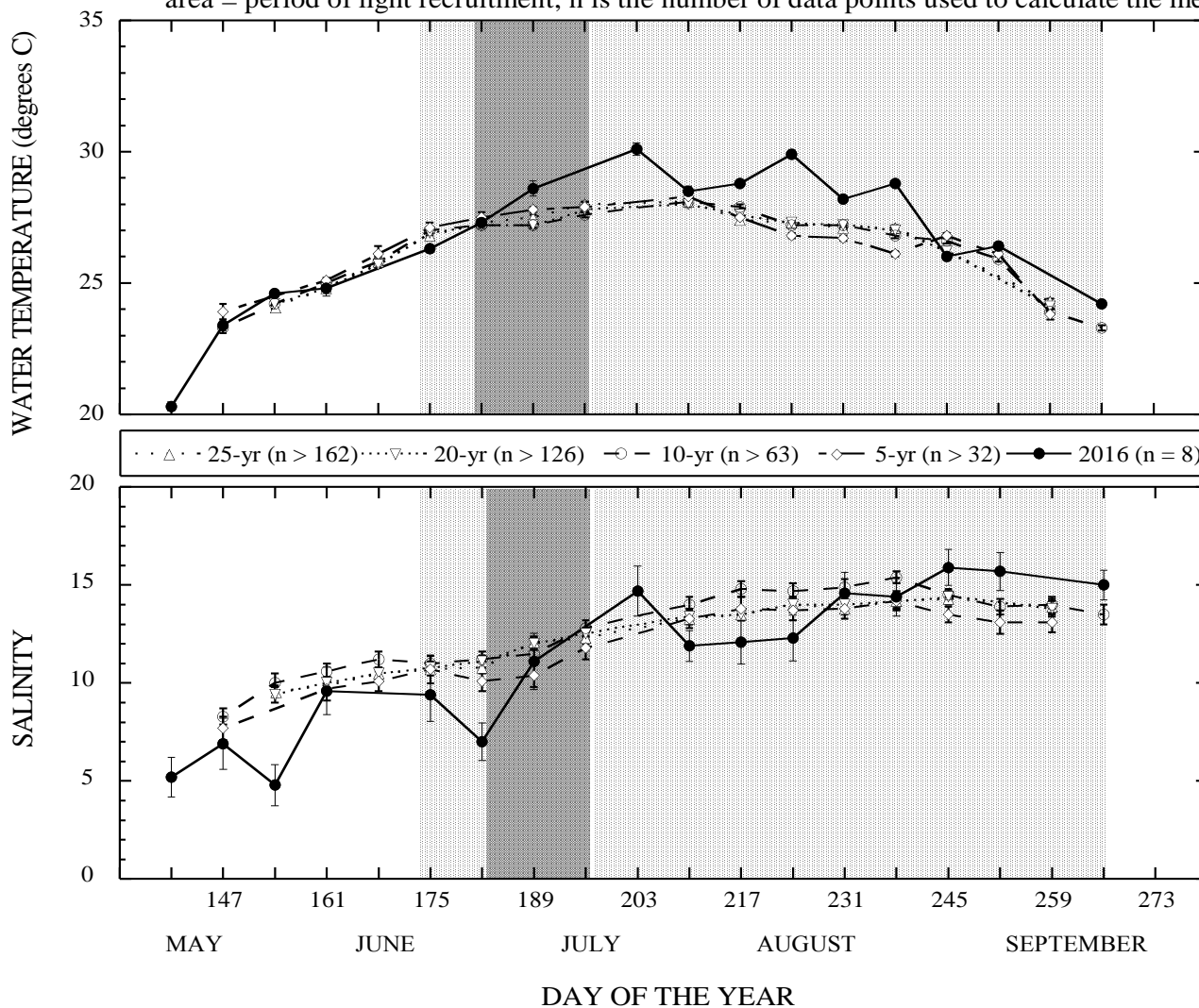


FIGURE S6: PIANKATANK RIVER (2016) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹
 (H = historical station: M = modern station as described in text)

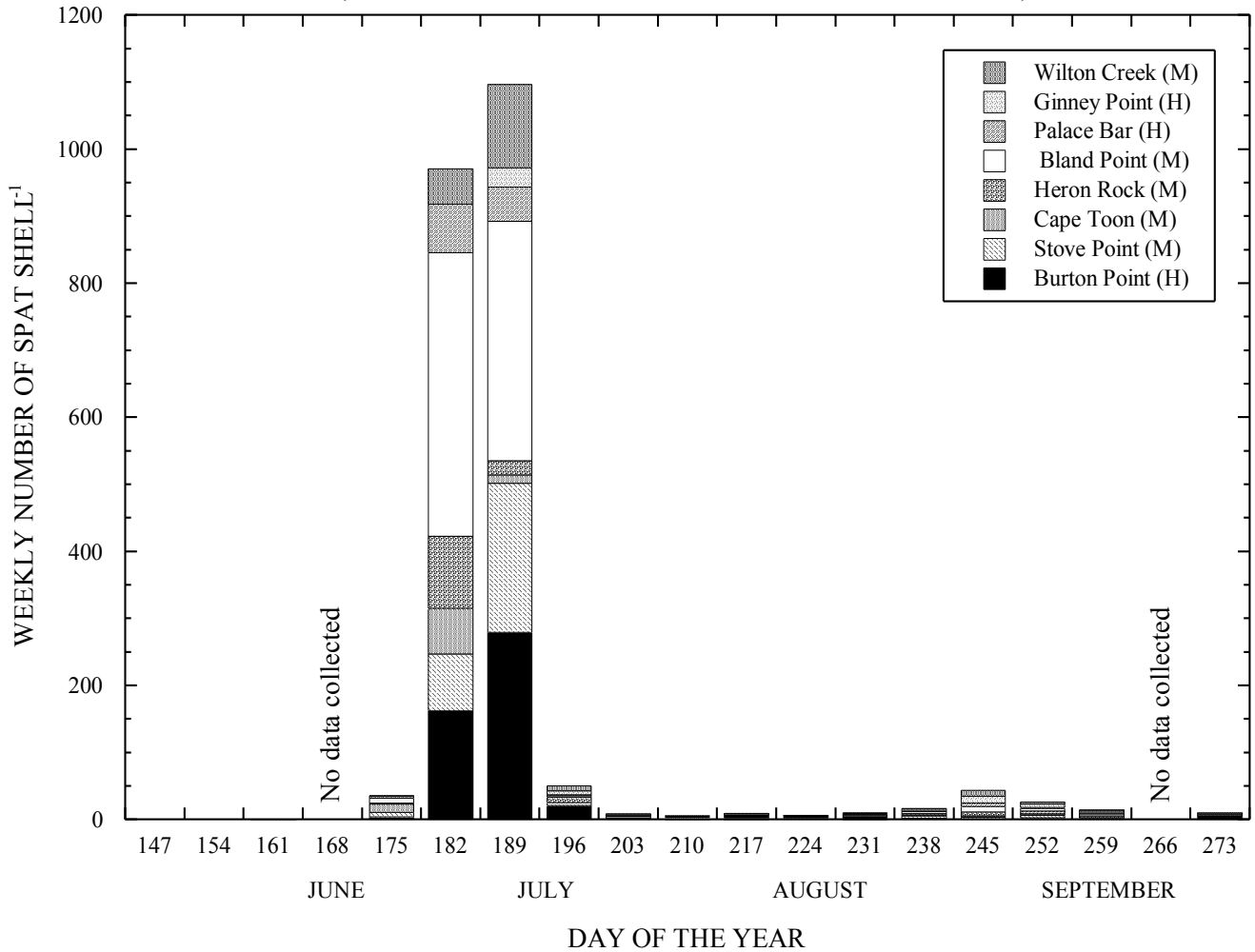


FIGURE S7: RECRUITMENT TRENDS IN THE PIANKATANK RIVER AT THE THREE HISTORICAL SITES (panel A: 25 years) AND THE FIVE MODERN SITES (panel B: 18 years) (Expressed as cumulative weekly spatfall)

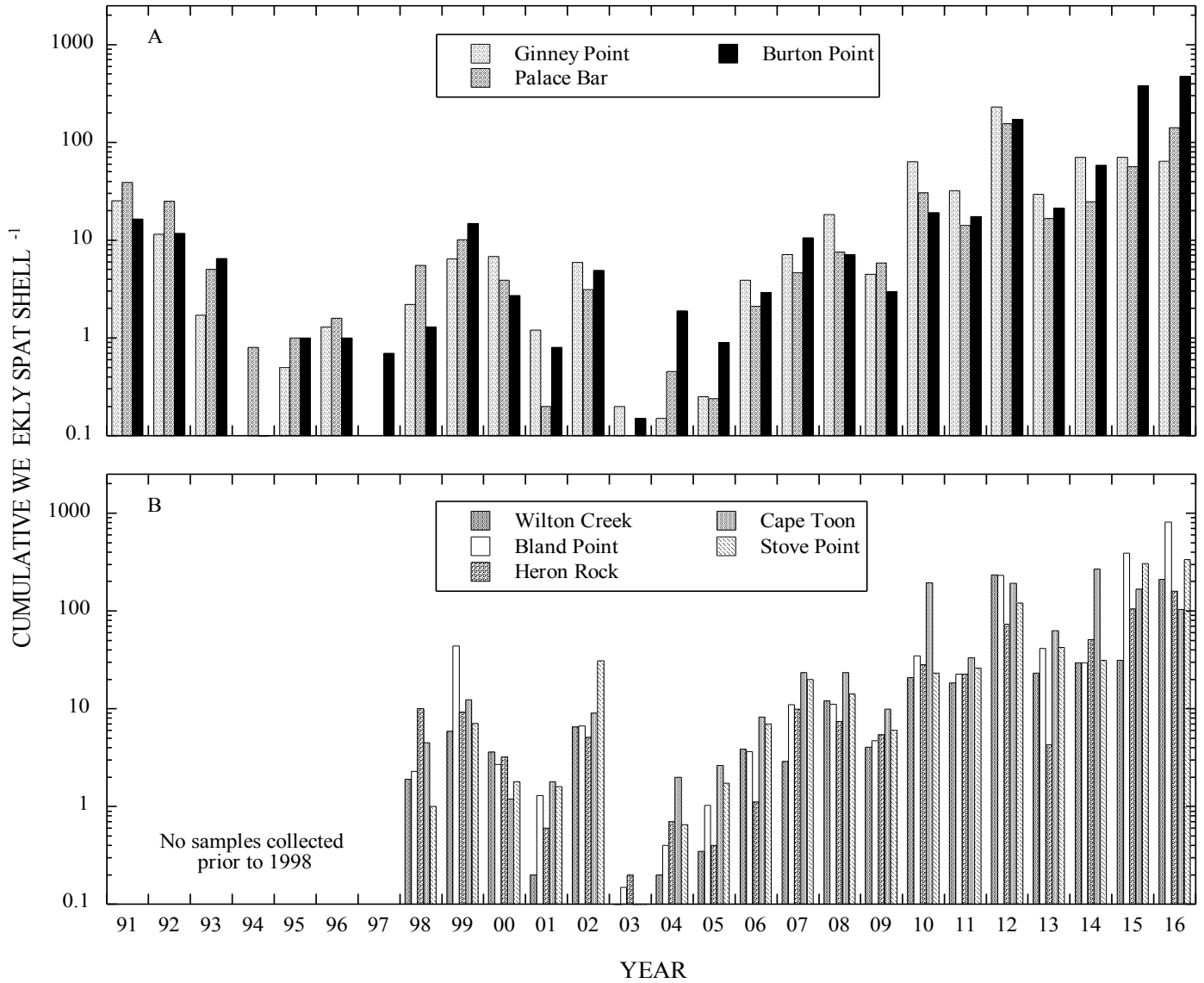


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 25-YEAR MEANS COMPARED WITH 2016 (Error bars represent standard error of the mean; darker shaded area = period of heavy recruitment; lighter shaded area = period of light recruitment; n is the number of data points used to calculate the mean)

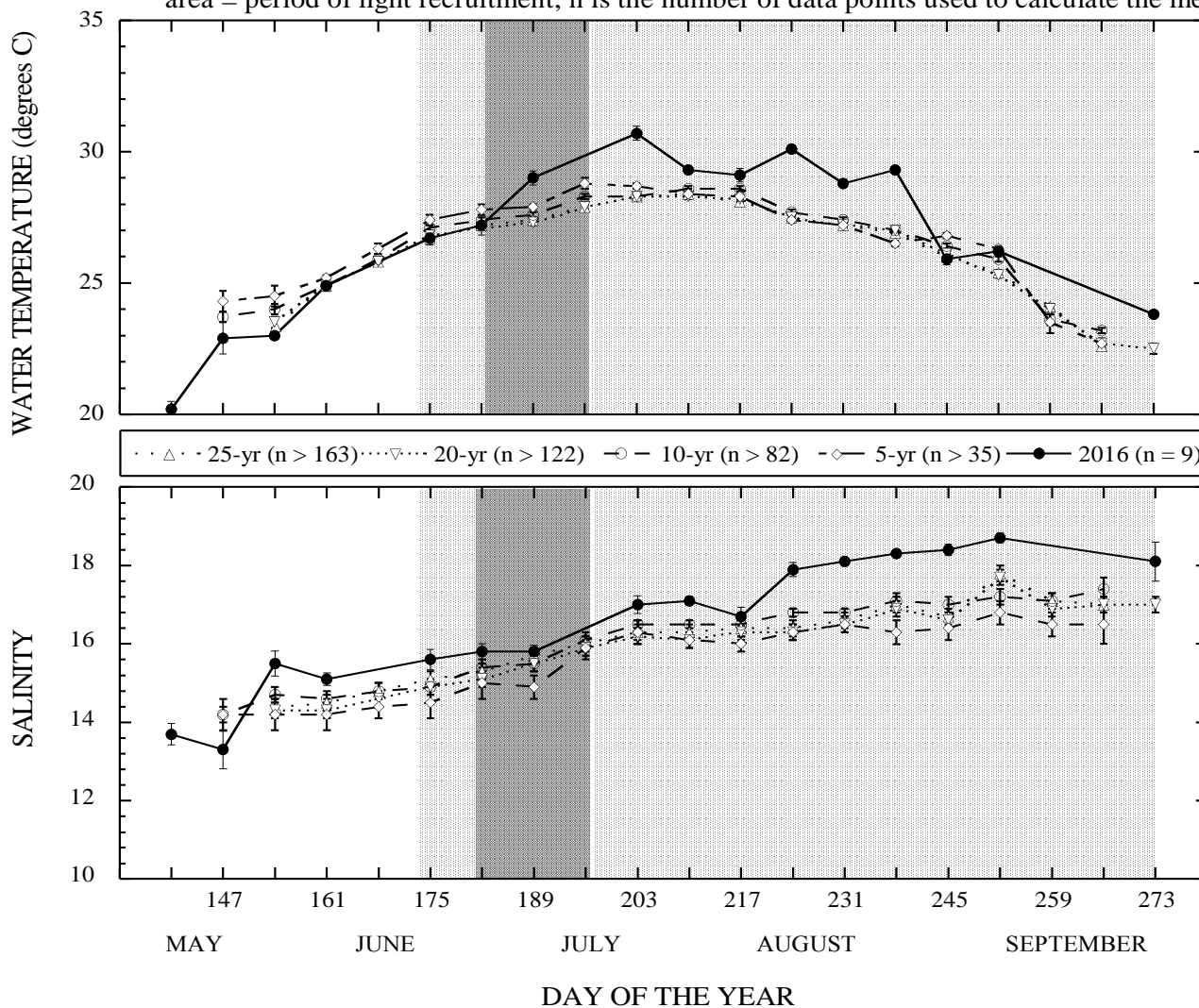


FIGURE S9: GREAT WICOMICO RIVER (2016) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹
 (H = historical station: M = modern station as described in text)

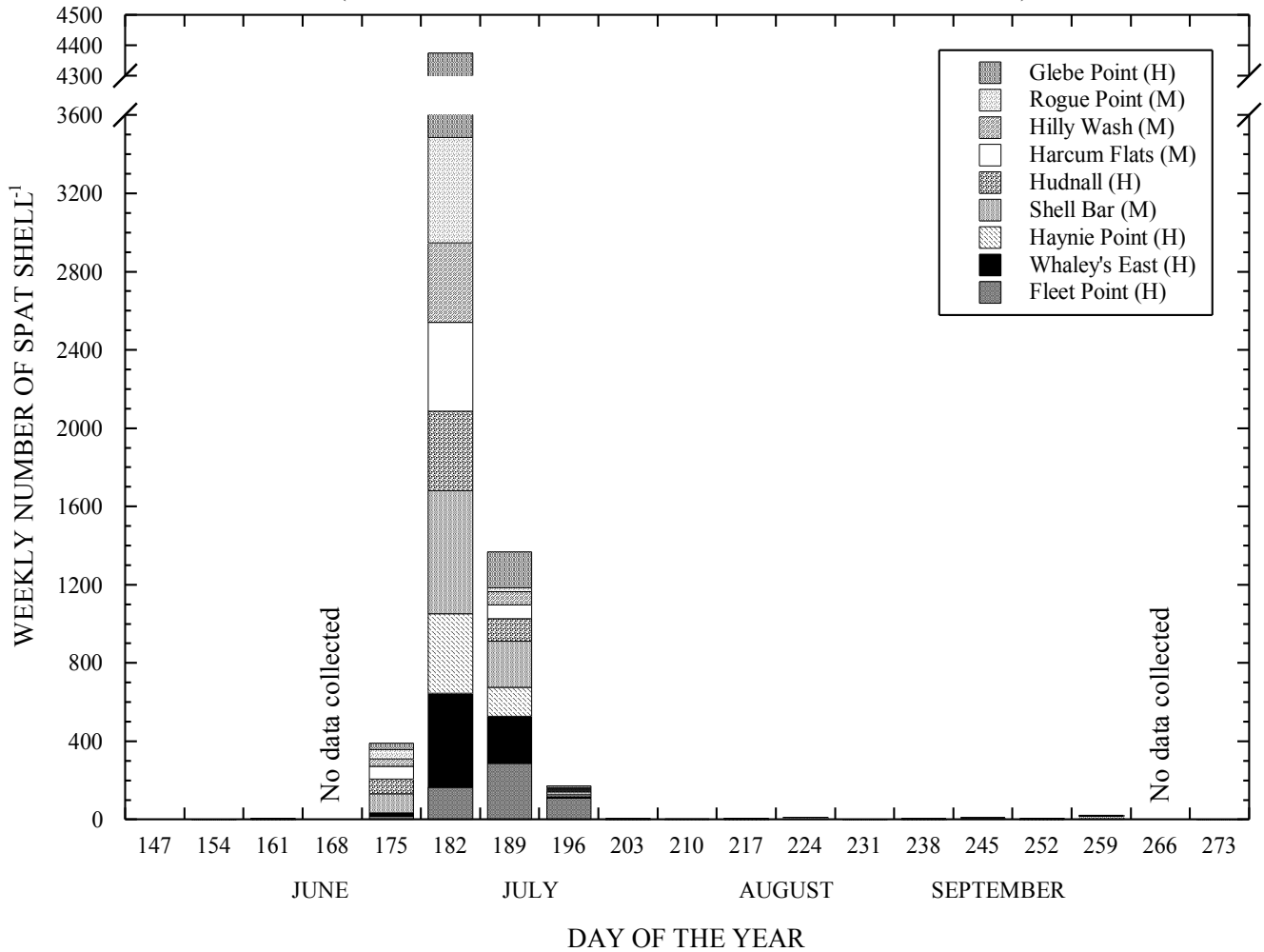


FIGURE S10: RECRUITMENT TRENDS IN THE GREAT WICOMICO RIVER AT THE FIVE HISTORICAL SITES (panel A: 25 years) AND THE FOUR MODERN SITES (panel B: 18 years) (Expressed as cumulative weekly spatfall)

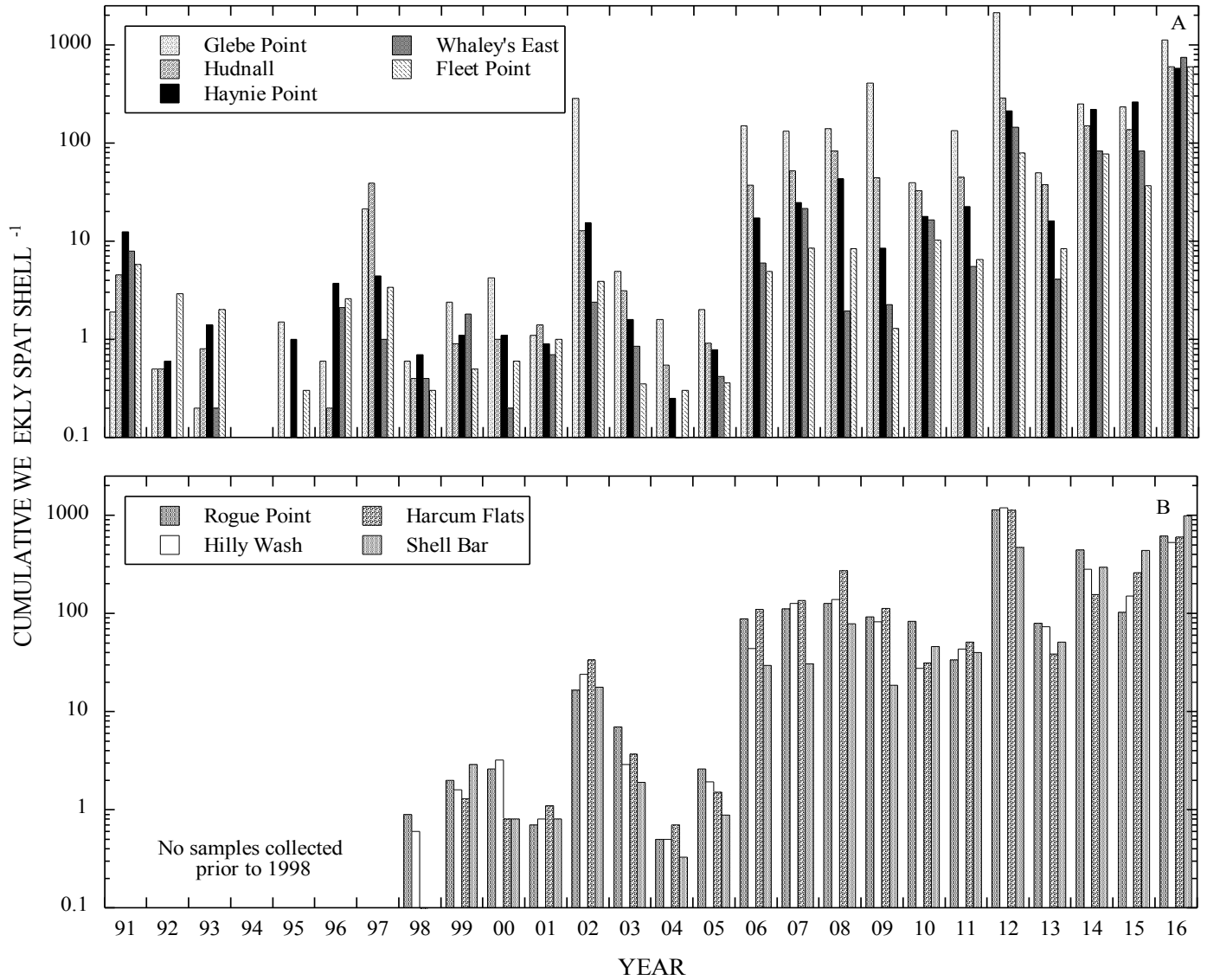
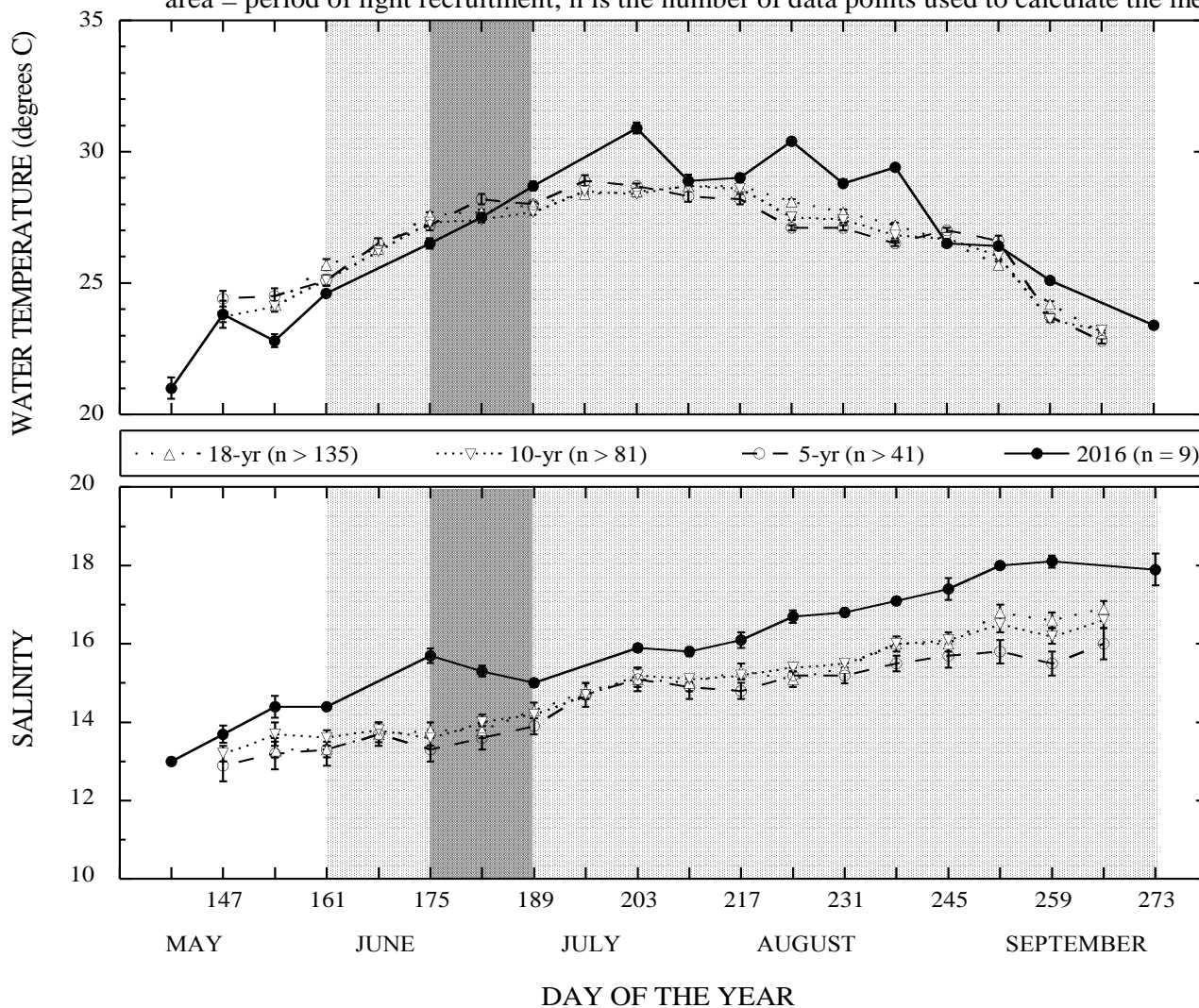


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE RECRUITMENT PERIOD: 5, 10 AND 18-YEAR MEANS COMPARED WITH 2016 (Error bars represent standard error of the mean; darker shaded area = period of heavy recruitment; lighter shaded area = period of light recruitment; n is the number of data points used to calculate the mean)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2016

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 was 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/research/units/labgroups/molluscan_ecology/restoration/va_restoration_atlas/index.php or https://webapps.mrc.virginia.gov/public/maps/c_hesapeakebay_map.php). These areas 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 oyster 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 oyster bar surveys conducted during October 2016.

Spatial variability in the 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 Figure D2 of the 2015 report (Southworth & Mann 2016) by the width of the confidence interval around the average count of spat (average spat count = 1033.5, CI = 524.0) at Deep Water Shoal (James River, VA). Dredges provide semi-quantitative data, have been used with consistency over extended periods of time (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 and/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 2016 are shown in Figure D1. Geographic coordinates of the bars are given in Table D1.

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 2016), in surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers in 1991 to 1994 and in the Great

Wicomico River in 2015, 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 inches³), which differs from a US bushel (2150.4 inches³) and a Maryland bushel (2800.7 inches³). Beginning in 1995, James, Piankatank, Rappahannock, and Great Wicomico River samples (with the exception of 2015 in the Great Wicomico River as previously mentioned) were collected using a 4-ft oyster 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 was 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 samples collected at each bar for live oysters and box counts after conversion to a full bushel. In most years, four samples (n = 4) were collected and processed at each sampling site, however, some derivation did occur such that fewer samples (n = 3) were collected. Due to the large number of oysters observed in the 2016 samples in the upper James River, the number of samples was reduced (n = 3) at the seven most upriver sites (see Figure D1) to facilitate sample processing in a timelier manner.

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, 2016 recruits), new boxes (inside of shells perfectly clean; presumed dead for approximately < 1 week), old boxes, spat boxes and drill boxes (spat box with a drill hole, 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) 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 were recorded approximately 0.5 meters off the bottom on the day of sampling at each of the oyster bars using a handheld electronic probe (YSI 30).

RESULTS

Thirty oyster bars were sampled between 5 October and 13 October, 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 located on a private lease 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 115 bushel⁻¹ at Nansemond Ridge to a high of 3,085.3 bushel⁻¹ at Deep Water Shoal. The total number of live oysters was the highest observed over the past twenty-five years of monitoring at Deep Water Shoal, Horsehead, Point of Shoal, Swash, Dry Shoal and Thomas Rock and the second highest observed at Long Shoal and Wreck Shoal. When spat are excluded, the total number of small and market oysters combined was the highest (Deep Water Shoal, Horsehead, Point of Shoal, Swash, Long Shoal, Dry Shoal and Thomas Rock), second highest (Wreck Shoal) and third highest (Nansemond Ridge) observed over the past

twenty-five years. The number of oysters at Nansemond Ridge has been at fairly low levels for the past several years and while the total number of oysters on Nansemond Ridge during 2016 was in the middle of that observed over the past twenty-five years of monitoring, the number of small and market oysters combined was among the highest observed since prior to 1992.

The average number of market oysters in the James River remains low when compared with historical numbers, but in recent years has been on the rise at the more downriver sites in the system. All of the sites monitored had low to moderate numbers of market oysters ranging from a low of 10.0 bushel⁻¹ at Nansemond Ridge to a high of 93.0 bushel⁻¹ at Wreck Shoal. There was a notable increase (Figure D2) in the number of market oysters at Thomas Rock and Nansemond Ridge when compared with 2015, and Wreck Shoal and Nansemond Ridge had the third highest number of market oysters observed over the past twenty-five years of monitoring (Figure D3C). There was a notable decrease in the number of market oysters at Deep Water Shoal and Long Shoal (Figure D2), and Deep Water Shoal, Mulberry Point and Swash has among the lowest number of market oysters observed since monitoring began at those sites in the early 1990s (Figure D3A and D3B). The number of market oysters at Wreck Shoal steadily increased from 2009 to 2014 and has remained relatively stable, between 90 and 100 bushel⁻¹ for the past three years. (Figure D3C).

The average number of small oysters bushel⁻¹ ranged from a low of 56.5 at Nansemond Ridge to a high of 2,493.3 at Deep Water Shoal. When compared with 2015, there was a notable increase in the number of small oysters at eight out of the ten sites (Deep Water Shoal, Horsehead, Point of Shoal, Long Shoal, Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge; Figures D2 and D3). This increase resulted in 2016 having the highest

number of small oysters observed in the past twenty-five years of monitoring at Deep Water Shoal, Horsehead, Point of Shoal, Long Shoal, Dry Shoal and Thomas Rock and the second highest observed at Wreck Shoal. The number of small oysters at Nansemond Ridge has been relatively low for the past seven years, but the increase observed during 2016, put the numbers near the highest observed since prior to 1992.

Overall, settlement in the James River in 2016 was relatively high, comparable to 2015 numbers at eight out of the ten sites (Figure D2 and D3). There was a small, but notable decrease observed when compared to 2015 at the remaining two sites (Mulberry Point and Nansemond Ridge; Figure D2 and D3). The average number of spat bushel⁻¹ ranged from a low of 48.5 at Nansemond Ridge to a high of 955.3 at Swash. Since 2008, settlement in the James River has had several strong year classes (2008, 2010, 2012 and 2015). Settlement in 2016 produced another relatively strong year class, with the average number of spat bushel⁻¹ ranking among the highest (fourth to sixth highest) observed over the past twenty-five years of monitoring at nine out of the ten sites. The one exception was Nansemond Ridge, where settlement was in the lower range of that observed over the past twenty-five years. Settlement patterns in the James River historically showed a trend of an increasing percentage of small oysters combined with a decreasing percentage of spat as one moved from the most downriver site (Nansemond Ridge) to the most upriver site (Deep Water Shoal). In general this pattern was again observed in 2016, with an increase in the percentage of small oysters and a decrease in the percentage of spat when moving from downriver to upriver (Figure D1 and D3).

The average number of boxes bushel⁻¹ was low, ranging from 12.0 at Nansemond Ridge to 78.6 at Long Shoal. Boxes accounted for less than 6% of the total (live oysters plus boxes) at every

site except Nansemond Ridge. Greater than 20% of the boxes at Deep Water Shoal, Horsehead, Dry Shoal and Wreck Shoal were new boxes, indicating some recent mortality at those four sites. At Mulberry Point and Nansemond Ridge 49 and 29% of the boxes respectively were spat boxes. Four out of seven of the spat boxes observed at Nansemond Ridge, contained a drill hole. 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 19.2 and 20.3°C (Table D2). Salinity was variable depending on location in the river, generally increasing in a downriver direction, from 6.7 at Deep Water Shoal to 14.6 at Thomas Rock. The salinity at Nansemond Ridge was slightly lower (12.5) than at Thomas Rock despite being located further downriver.

York River

In the York River, the average total number of live oysters bushel⁻¹ was 145.5 at Bell Rock and 172.5 at Aberdeen Rock. The live oysters at Bell Rock were primarily a 50/50 split of market and small oysters (approximately 97% of the total), with a very small percentage of spat. At Aberdeen Rock, approximately 73% of the oysters were small, with the remaining 27% being a 50/50 split of spat and market oysters. When compared with 2015, there was a notable decrease in the number of spat observed at both sites and an increase in small oysters at Aberdeen Rock (Figures D4 and D5). Overall, the number of oysters at Aberdeen Rock ranked among the highest observed over the past twenty-five years of monitoring, with 2016 having the second highest number of market oysters and the third highest number of small oysters (Figure D5). For the past three years, the number of market oysters at Bell Rock has

remained relatively stable (between 76 and 100 bushel⁻¹), at least twice as high as observed in any year from 1991 through 2013 (Figure D5). The average number of boxes bushel⁻¹ was moderate (53.0 bushel⁻¹) at Bell Rock and low (20.0 bushel⁻¹) at Aberdeen Rock, accounting for approximately 27 and 10% of the total oysters (live oysters plus boxes) at Bell Rock and Aberdeen Rock respectively. The majority (>88%) of the boxes at both sites were old. Water temperature on the day of sampling was around 20°C at both sites. The difference in salinity between the two sites was 5.9: 10.4 at Bell Rock and 16.3 at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 306.5 and 1,343.5 oysters bushel⁻¹ respectively. Settlement at Pultz Bar was the second highest observed since prior to 1991, despite the notable decrease when compared with 2015 (Figure D4 and D6). Following the good recruitment event at Pultz Bar in 2015, the number of small oysters in 2016 was the highest observed since prior to 1991, approximately five times higher than the next highest year (Figure D6). At Tow Stake, 2016 had the highest number of small oysters observed over the past twenty-five years, with moderate numbers of spat and market oysters, and a notable decrease in the number of market oysters when compared with 2015. At Pultz Bar, there was a notable increase in market oysters when compared with 2015, with 2016 having the second highest number observed since 1991 (Figure D6). The total number of boxes observed in the system was low, accounting for 2 (Pultz Bar) and 7% (Tow Stake) of the total (live oysters plus boxes). At Pultz Bar, around 29% of the total boxes were spat boxes. Approximately 57% (Tow Stake) and 35% (Pultz Bar) of the spat boxes contained a drill hole. 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. On the day of sampling, water temperature was around 20°C and salinity was 20.5 (Table D2) at both sites.

Piankatank River

In the Piankatank River, the average total number of live oysters bushel⁻¹ ranged from a low of 636.0 at Burton Point to a high of 916.5 at Palace Bar. When compared with 2015, there was a notable decrease in the number of small oysters at Palace Bar and in the number of market oysters and spat at Burton Point (Figures D7 and D8). The decrease in market oysters at Burton Point followed two years of relatively stable market oyster numbers. Despite this decrease, the number of market oysters at Burton Point in 2016 was the third highest observed over the past twenty-five years (Figure D8). The oyster population at Ginney Point was similar to 2015 in all size categories (Figure D7) and the number of market oysters has remained relatively high (first through fourth highest) and stable (between 72 and 99 bushel⁻¹) for the past four years. The number of market oysters throughout the river increased in 2008 and has remained at higher levels since. From 1991 to 2007, the average over the three sites ranged from less than 1 to 13 market oysters bushel⁻¹, whereas from 2008 to 2016 there were between 22 and 83 market oysters bushel⁻¹ (Figure D8). The average over the three sites in the Piankatank River in 2016 was 58 market oysters bushel⁻¹. The number of boxes observed was low, accounting for 3 (Palace Bar) to 5% (Burton Point) of the total (live oysters plus boxes). The majority (>71%) of boxes at all three sites were old. Approximately 15% of the spat boxes at Burton Point contained a drill hole. 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. On

the day of sampling, water temperature was around 23°C (Ginney Point) and salinity was between 17.6 (Ginney Point) and 19.4 (Burton Point).

Rappahannock River

In the Rappahannock River, the average total number of live oysters bushel⁻¹ ranged from a low of 60.0 at Morattico Bar to a high of 540.5 at Broad Creek. 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). 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. This pattern again held true during 2016. The total number of oysters at Middle Ground showed a relatively large decrease in 2011, following several good years of growth between 2008 and 2010. Since then, the total number of oysters at Middle Ground has increased, such that numbers over the past few years have been similar to those observed prior to the decrease in 2011.

The average number of market oysters bushel⁻¹ ranged from a low of 30.5 at Broad Creek to a high of 115.0 at Ross Rock. When compared with 2015, there was a notable increase in the number of market oysters observed at Ross Rock, Morattico Bar, Smokey Point, Hog House and Middle Ground and a decrease observed at Drumming Ground and Broad Creek (Figure D9 and D10). Overall the number of market oysters in the Rappahannock River in recent years (since 2008) has been on the rise and 2016 ranked among the highest to third highest over the past twenty-five years at seven out of the ten sites monitored. From 1991 to 2007, the average over all ten sites in any given year was less than

20 market oysters bushel⁻¹, whereas from 2008 to 2016 the average over all ten sites ranged between 21 (2008) and 70 (2016) market oysters bushel⁻¹ (Figure D10). At the four most upriver sites (Figure D1; Ross Rock, Bowler's Rock, Long Rock and Morattico Bar) market oysters accounted for greater than 61% of the live oysters observed.

As in previous years (with the exception of 2014), Drumming Ground had the highest number (307.5 bushel⁻¹) of small oysters (Figure D9 and D10). When compared with 2015, there was a notable increase in the number of small oysters observed at Bowler's Rock, Hog House, Middle Ground, Drumming Ground, Parrot Rock and Broad Creek (Figure D9 and D10). Small oysters in 2016, were the highest observed over the past twenty-five years at Drumming Ground and Broad Creek, the second highest at Hog House and the third highest at Parrot Rock. The number of small oysters at Morattico Bar in 2016 was among the lowest observed at that site since prior to 1991 (Figure D10A).

Overall, settlement in the Rappahannock River in 2015 was moderate, ranging from 0 spat bushel⁻¹ at Bowler's Rock to 210.5 spat bushel⁻¹ at Broad Creek. There was at least one spat found at nine out of the ten sites (the one exception was Bowler's Rock). When compared to 2015 (a notably good recruitment year), there was a decrease in the number of spat observed at all ten sites (Figure D9).

The average total number of boxes bushel⁻¹ was low to moderate, accounting for less than 13% of the total (live oysters plus dead) at all ten sites monitored. Greater than 20% of the total boxes at Morattico Bar, Hog House, Middle Ground, Drumming Ground and Broad Creek were new boxes, indicating some recent mortality at those sites. Broad Creek, the site with the highest settlement also had the highest percent of spat boxes (around 14% of the total

boxes) and one out of the eleven spat boxes contained a drill hole. 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 on the day of sampling ranged from 19.3 to 22.8°C. Salinity generally increased as one moved from the most upriver site (Ross Rock: 9.6) toward the mouth (Parrot Rock: 18.9). Salinity at Broad Creek was 17.1, slightly lower than at Parrot Rock, despite being located further downriver.

Great Wicomico River

In the Great Wicomico River, the average total number of live oysters bushel⁻¹ ranged from a low of 532.5 at Fleet Point to a high of 1,570.5 at Haynie Point. When compared with 2015, there was a notable decrease in the number of market oysters observed at all three sites (Figure D11), but the number of market oysters at Haynie Point and Whaley's East were still the third highest observed since prior to 1991 (Figure D12). When compared with 2015 numbers, there was a notable increase in both small oysters and spat at all three sites (Figure D11). Overall, settlement in 2016 was relatively high, the second highest observed over the past twenty-five years at all three sites, and spat accounted for the majority (>66% of total) of the oysters (Figure D12). The total number of boxes bushel⁻¹ was low accounting for less than 8% of the total (live oysters plus boxes) at all three sites. The majority (>66%) of the boxes at all three sites were old. Water temperature on the day of sampling was around 19°C and salinity was around 18 at all three sites.

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 50.5 market oysters bushel⁻¹). From 2007 to 2015, the number of market oysters on the thirty bars that are sampled annually slowly increased, going from an average of 16.5 bushel⁻¹ in 2007 to an average of 60.9 bushel⁻¹ in 2015, a little over a 3.5 fold increase over the nine year period. While the number of market oysters on the thirty bars in 2016 slightly decreased when compared to 2015, several more years are needed to see if this decrease will prevail.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2016, the largest majority of the oysters were small, accounting for approximately 60% of the population with approximately 34% spat and 6% market oysters. At half of the sites (fifteen out of thirty) monitored, small oysters accounted for greater than 50% of the live oysters present, with spat dominating at four out of the thirty sites. Bell Rock in the York River and the five most upriver sites in the Rappahannock River (Ross Rock, Bowler's Rock, Long Rock, Morattico Bar and Smokey Point) were the only sites with greater than 50% market oysters. The oyster population in the Piankatank River has been steadily increasing since 2004. This increase followed a large die-off of broodstock oysters that occurred in late

2003 early 2004 (Southworth et al. 2005). The number of small and market oysters combined in the Piankatank River in 2016 was among the highest observed over the past twenty-five years of monitoring.

Settlement during 2016 varied widely throughout the Virginia portion of the bay, with less than 20 spat bushel⁻¹ at eight out of the thirty sites and greater than 100 spat bushel⁻¹ at nineteen out of the thirty sites. Settlement was exceptionally high (greater than 1,000 spat bushel⁻¹) at Haynie Point in the Great Wicomico River. In the Rappahannock River, settlement tends to be highest at the more downriver sites (see Figure D1), with often no settlement at the upriver sites. In 2016, the highest settlement was again observed at the more downriver sites, and with the exception of Bowler's Rock, at least one spat was observed at every site in the system.

The average total number of boxes observed during 2016, was low to moderate at most sites, accounting for less than 13% of the total (live oysters plus boxes) oysters at every site except Bell Rock and less than 10% of the total (live oysters plus boxes) at twenty-four of the sites. Over the past few years several sites have had a large number of small and market boxes, indicating some increased mortality caused by disease. In 2016 Bell Rock was the only site that had a relatively large number of small and market size boxes (approximately 27% of the total, live small and market oysters plus new and old boxes). At the majority of the other sites (twenty of twenty-nine), less than 10% of the total (live small and market oysters plus new and old boxes) small and market oysters were boxes.

In general, drill holes have become more prevalent in spat boxes since the early 2000s. During 2016, there were drill holes present in spat boxes at Nansemond Ridge in the James River, at Pultz Bar and Tow Stake in Mobjack

Bay, at Burton Point in the Piankatank River and at Broad Creek in the Rappahannock 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 lower James River, in the lower York River, in the mouths of the Piankatank and Rappahannock Rivers, and in Mobjack Bay. The dredge samples taken in 2016 were again marked with a fairly high number of spat boxes with drill holes in most of these areas. It should also be noted that drill holes as well as live animals of both drill species were observed at multiple sites in the James, York, Piankatank and Rappahannock Rivers and in Mobjack Bay during the patent tong survey in November and December of 2016 (Southworth, personal observation), so the predation of spat by oyster drills in these systems remains a concern.

Table D1: Station locations for the 2016 VIMS fall dredge survey.

Station	Latitude	Longitude
James River		
Deep Water Shoal	37 8.933	76 38.133
Mulberry Point	37 7.150	76 37.917
Horsehead	37 6.400	76 38.033
Point of Shoal	37 4.617	76 38.600
Swash	37 5.533	76 36.733
Long Shoal	37 4.583	76 36.117
Dry Shoal	37 3.683	76 36.233
Wreck Shoal	37 3.617	76 34.333
Thomas Rock	37 1.533	76 29.550
Nansemond Ridge	36 55.333	76 27.167
York River		
Bell Rock	37 29.050	76 44.983
Aberdeen Rock	37 20.117	76 36.033
Mobjack Bay		
Tow Stake	37 20.333	76 23.167
Pultz Bar	37 21.183	76 21.167
Piankatank River		
Ginney Point	37 32.000	76 24.200
Palace Bar	37 31.600	76 22.200
Burton Point	37 30.900	76 19.700
Rappahannock River		
Ross Rock	37 54.067	76 47.350
Bowler's Rock	37 49.600	76 44.117
Long Rock	37 48.983	76 42.833
Morattico Bar	37 46.917	76 39.550
Smokey Point	37 43.150	76 34.933
Hog House	37 38.500	76 33.067
Middle Ground	37 41.000	76 28.400
Drumming Ground	37 38.633	76 27.983
Parrot Rock	37 36.350	76 25.333
Broad Creek	37 34.617	76 18.050
Great Wicomico River		
Haynie Point	37 49.783	76 18.550
Whaley's East	37 48.517	76 18.000
Fleet Point	37 48.583	76 17.317

Table D2: Results of the Virginia public oyster grounds survey, Fall 2016. Note that the bushel measure used is a VA bushel which is equivalent to 3003.9 in⁻³ (50 liters). A VA bushel differs in volume from both a U.S. bushel (2150.4 in⁻³; 35 liters) and a MD bushel (2800.7 in⁻³; 46 liters). "*" 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	10/13	20.3	6.7	5.3	2493.3	586.7	3085.3	17.3	18.0	4.7	40.0
Mulberry Point	10/13	20.2	8.3	16.0	879.3	461.3	1356.6	4.0	9.3	12.7	26.0
Horsehead	10/13	20.2	9.3	30.7	1870.7	819.3	2720.7	22.0	37.3	4.7	64.0
Point of Shoal	10/13	20.1	8.2	52.0	1606.7	475.3	2134.0	8.7	27.3	2.7	38.7
Swash	10/13	20.2	9.7	8.7	1614.7	955.3	2578.7	11.3	62.0	5.3	78.6
Long Shoal	10/13	20.3	9.1	22.0	1602.0	674.7	2298.7	4.0	39.3	3.3	46.6
Dry Shoal	10/13	20.2	11.3	56.0	884.7	390.7	1331.4	10.7	18.0	4.0	32.7
Wreck Shoal	10/12	19.9	11.5	92.5	406.0	380.5	879.0	12.5	39.5	2.0	54.0
Thomas Rock	10/12	19.7	14.6	52.0	324.5	289.5	666.0	7.5	30.5	1.5	39.5
Nansemond Ridge	10/12	19.2	12.5	10.0	56.5	48.5	115.0	2.0	6.5	3.5	12.0
York River											
Bell Rock *	10/17	20.1	10.4	75.5	66.0	4.0	145.5	5.5	47.0	0.5	53.0
Aberdeen Rock	10/17	20.2	16.3	27.0	126.0	19.5	172.5	2.0	17.5	0.5	20.0
Mobjack Bay											
Tow Stake	10/17	19.5	20.5	24.5	242.0	40.0	306.5	5.0	13.0	3.5	21.5
Pultz Bar	10/17	19.8	20.5	45.5	1068.5	229.5	1343.5	6.5	14.5	8.5	29.5
Piankatank River											
Ginney Point	10/5	23.3	17.6	71.5	433.5	256.0	761.0	7.5	25.0	1.5	34.0
Palace Bar	10/5	23.0	18.5	35.5	275.5	605.5	916.5	3.0	17.5	4.0	24.5
Burton Point	10/5	23.2	19.4	67.5	341.5	227.0	636.0	2.0	24.0	6.5	32.5
Rappahannock River											
Ross Rock	10/7	21.8	9.6	115.0	42.0	0.5	157.5	0.5	4.5	0.0	5.0
Bowler's Rock	10/7	21.8	11.6	87.0	56.5	0.0	143.5	1.0	5.0	0.0	6.0
Long Rock	10/7	22.4	14.7	88.0	10.5	1.5	100.0	2.5	12.5	0.0	15.0
Morattico Bar	10/7	22.8	16.4	39.5	20.0	0.5	60.0	0.5	0.5	0.0	1.0
Smokey Point	10/7	23.3	17.7	61.0	55.0	3.0	119.0	0.5	17.0	0.0	17.5
Hog House	10/7	22.2	16.3	84.0	80.5	20.0	184.5	5.5	19.0	0.0	24.5
Middle Ground #	10/7	22.7	17.7	74.0	190.0	5.0	269.0	9.5	17.5	0.0	27.0
Drumming Ground	10/7	22.4	17.2	65.5	307.5	108.0	481.0	4.5	17.0	0.5	22.0
Parrot Rock	10/7	22.2	18.9	56.5	114.5	101.5	272.5	3.5	30.0	1.0	34.5
Broad Creek	10/11	19.3	17.1	30.5	299.5	210.5	540.5	11.0	22.0	5.5	38.5
Great Wicomico River											
Haynie Point	10/11	19.4	18.1	58.5	268.5	1243.5	1570.5	6.5	42.5	15.0	64.0
Whaley's East	10/11	18.5	17.8	40.5	253.5	699.5	993.5	7.5	48.0	6.5	62.0
Fleet Point	10/11	18.9	18.5	21.5	194.5	316.5	532.5	4.0	33.0	6.0	43.0

Figure D1: Map showing the location of the oyster bars sampled during the 2016 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.

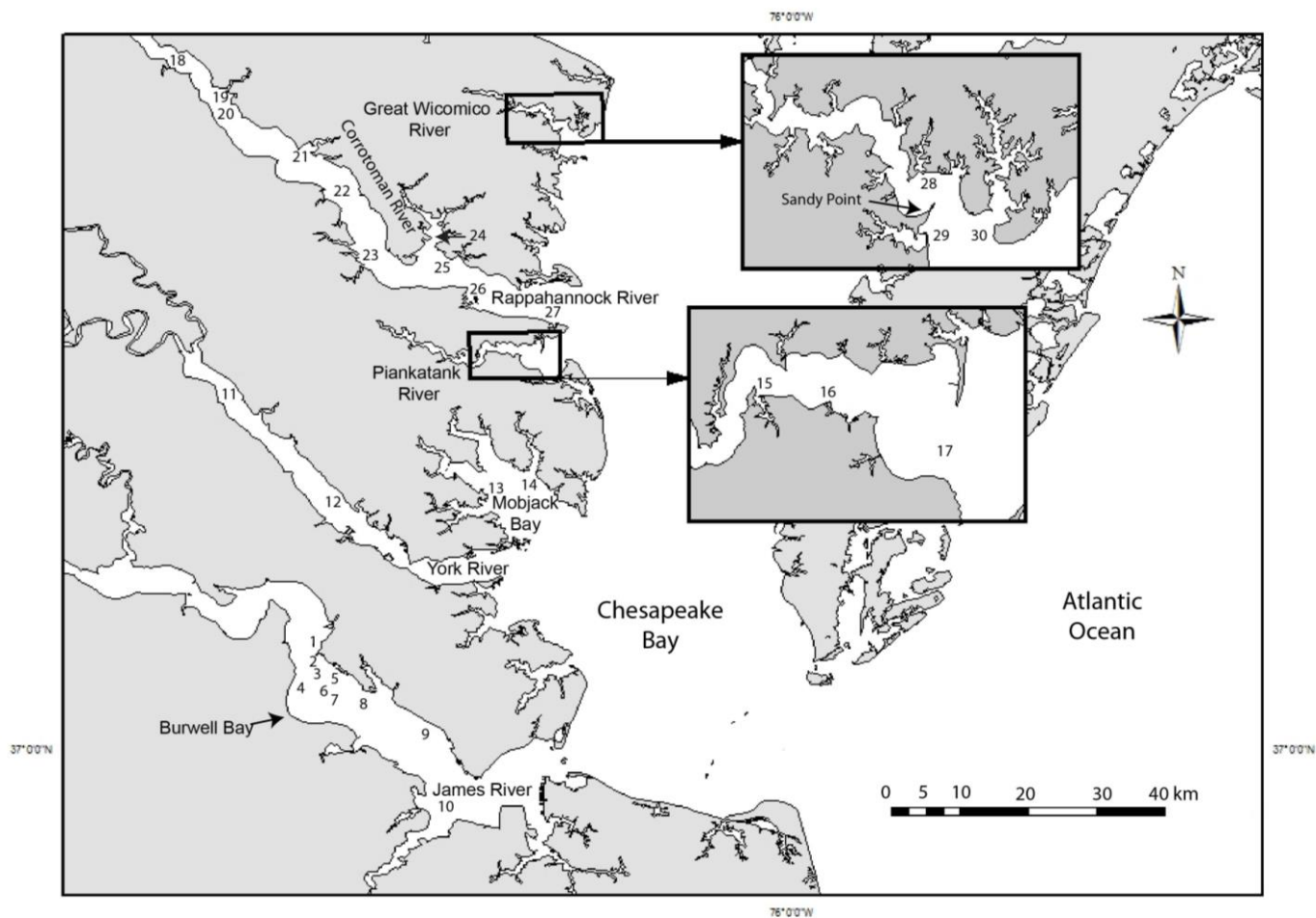


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE JAMES RIVER (2015-2016)
 (Error bars represent standard error of the mean)

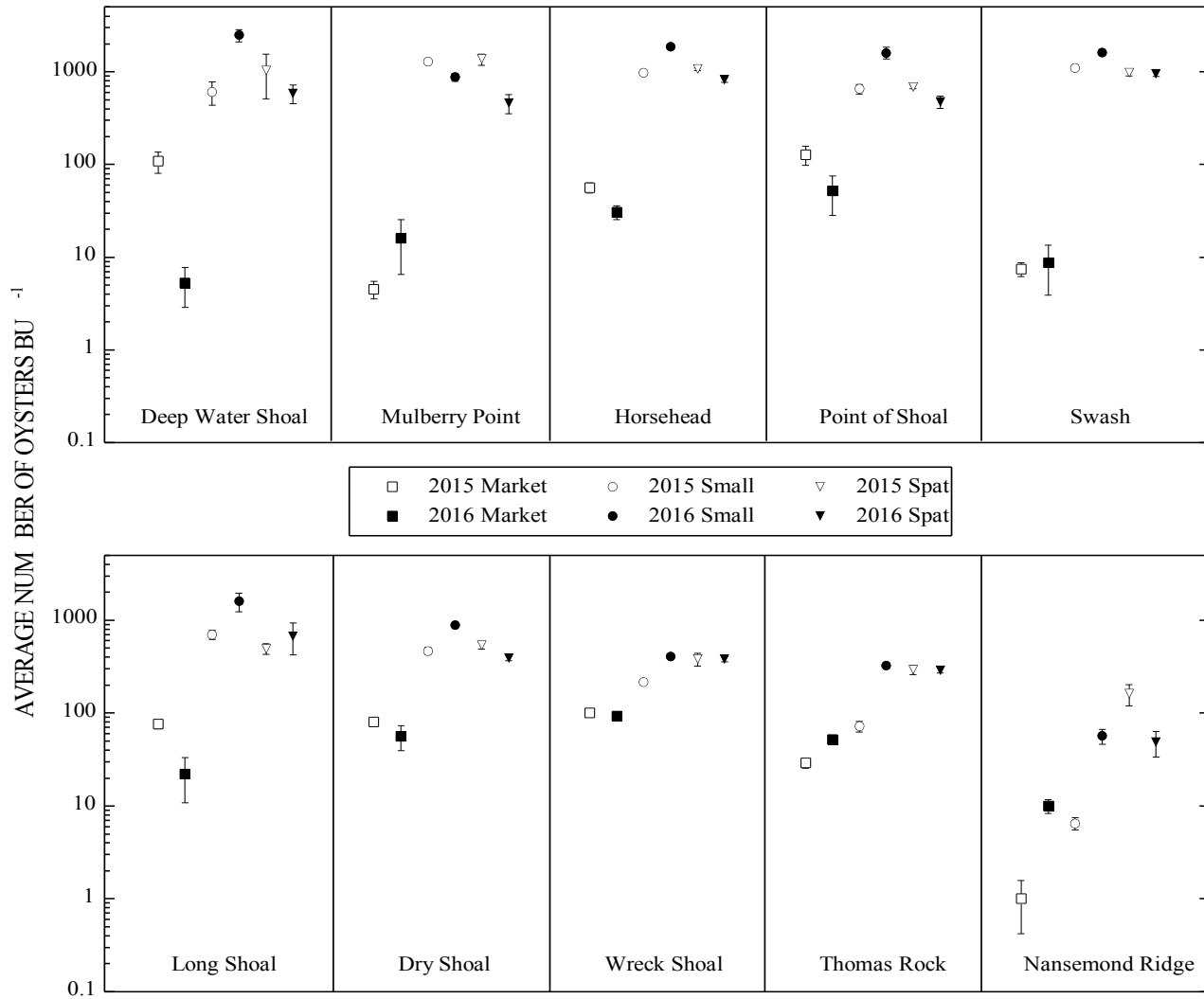
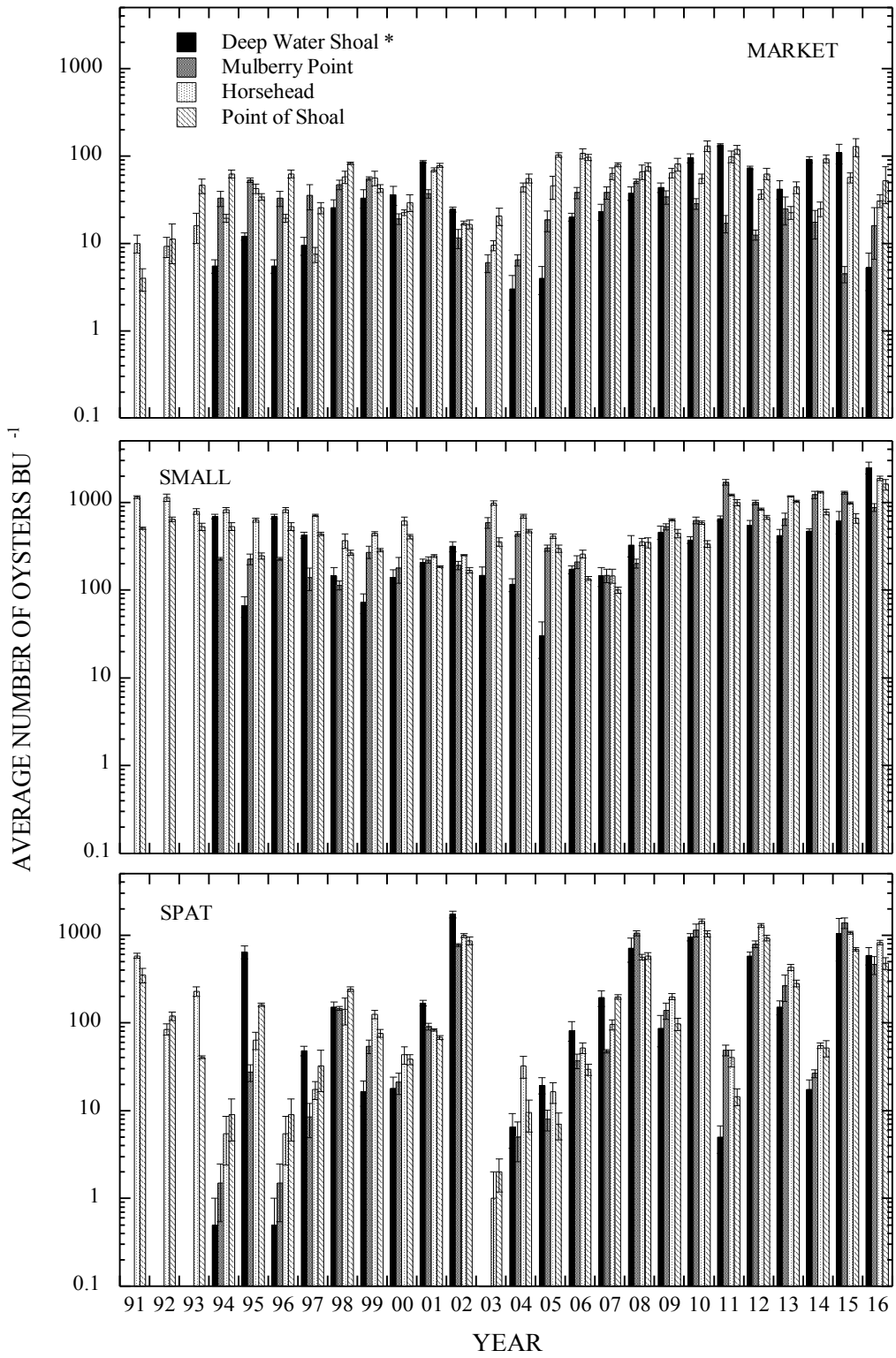


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



* No data prior to 1994

FIGURE D3B: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

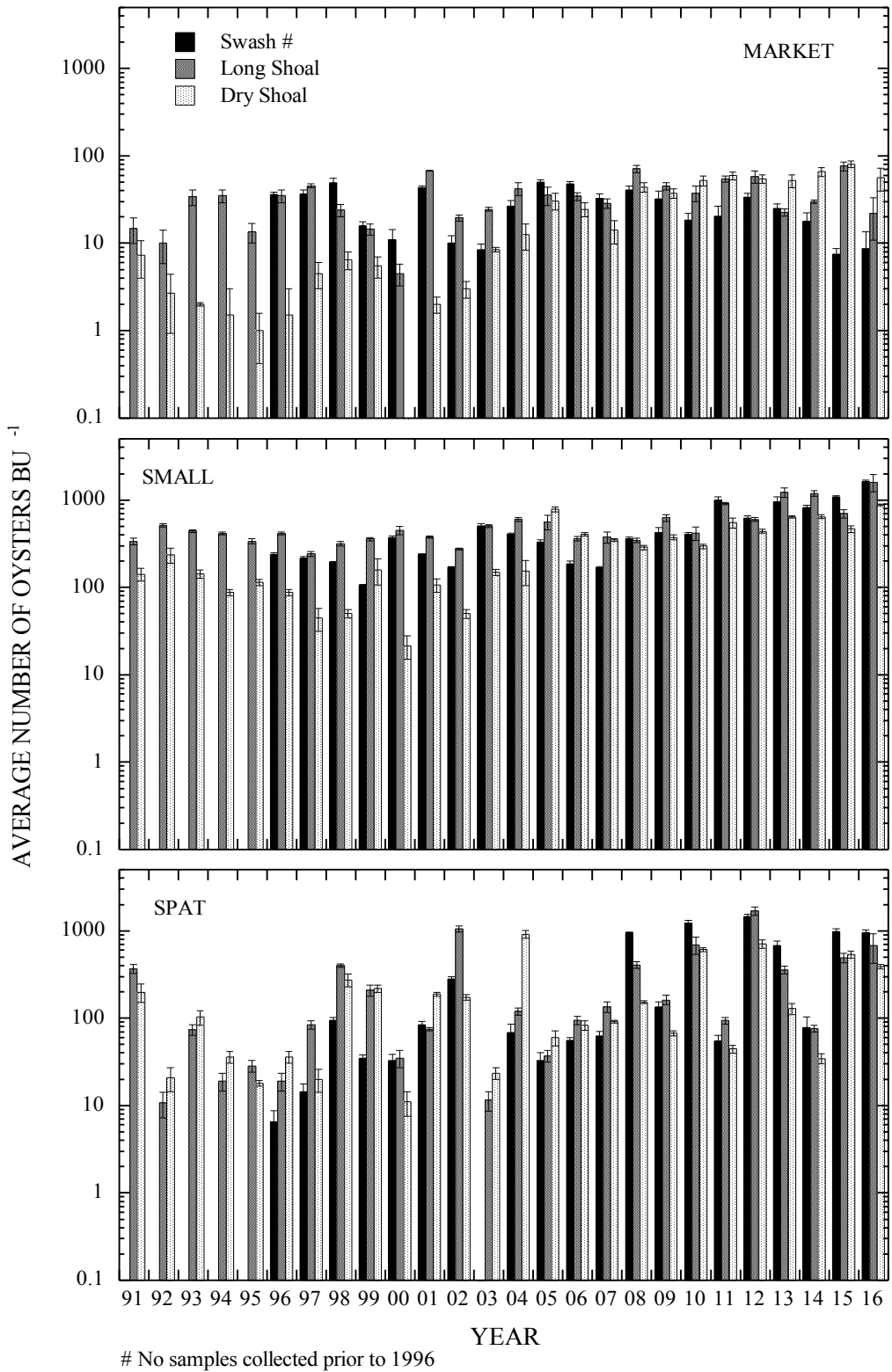


FIGURE D3C: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

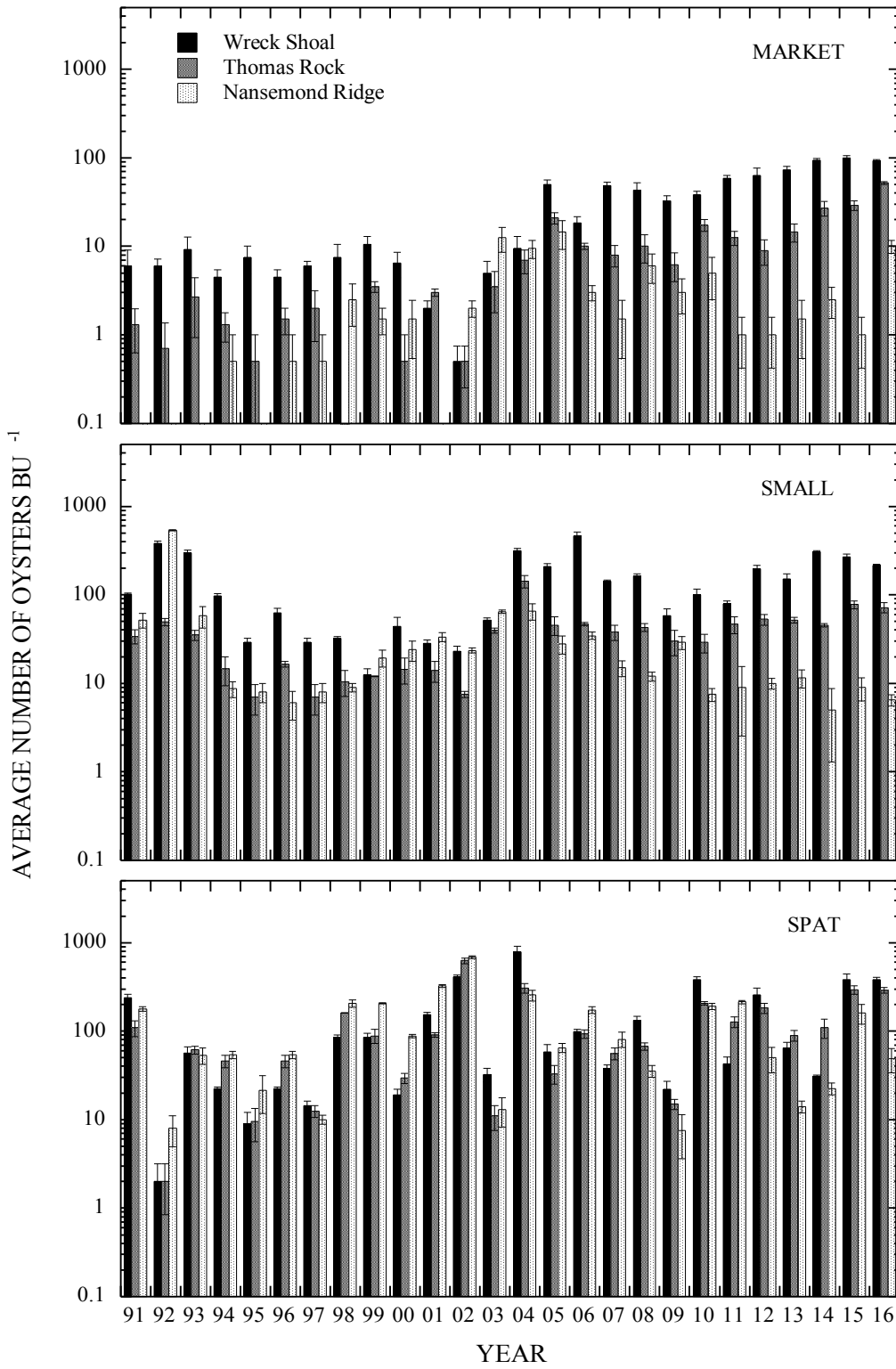


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE YORK RIVER AND MOBJACK BAY (2015-2016)
 (Error bars represent standard error of the mean)

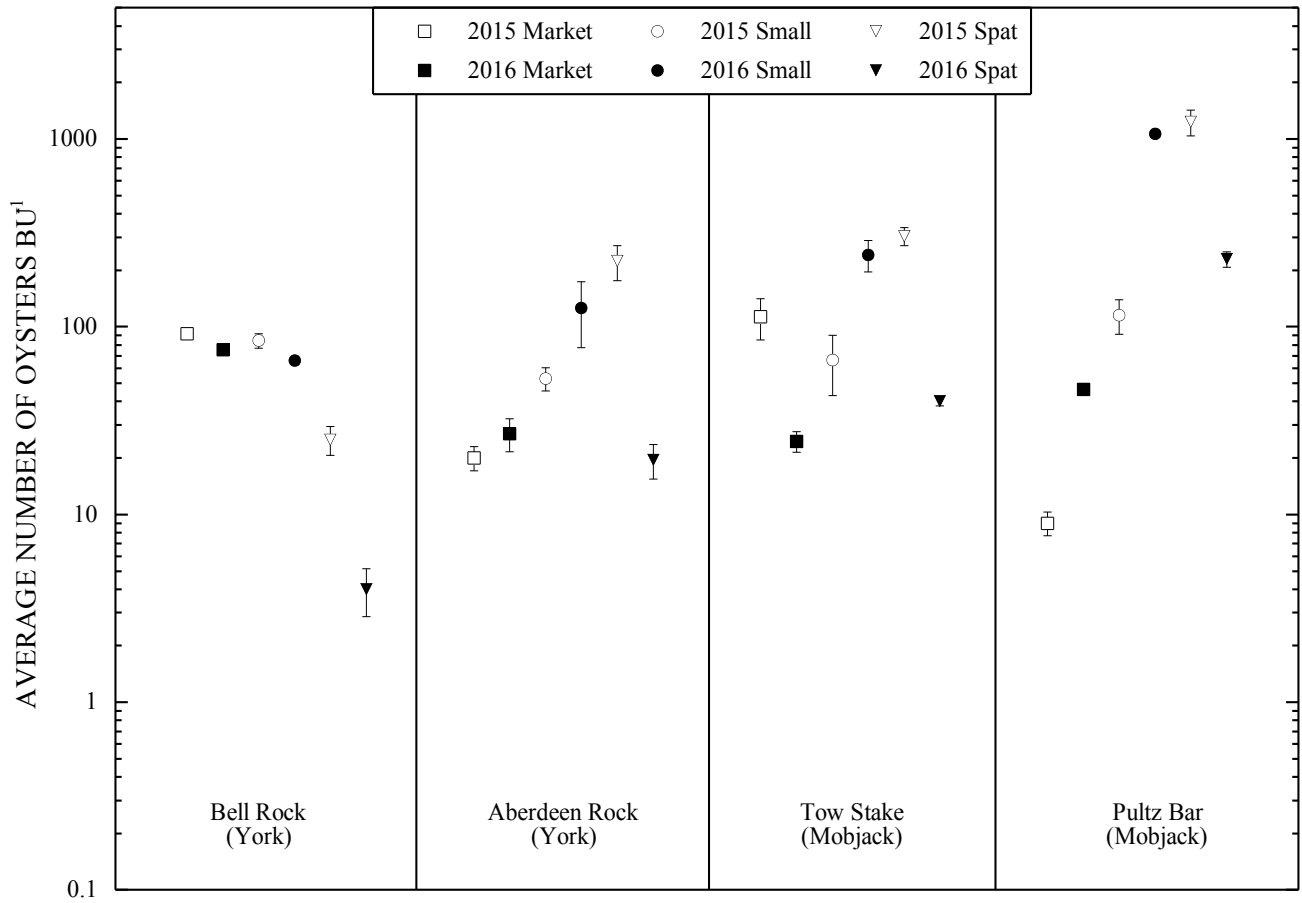


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

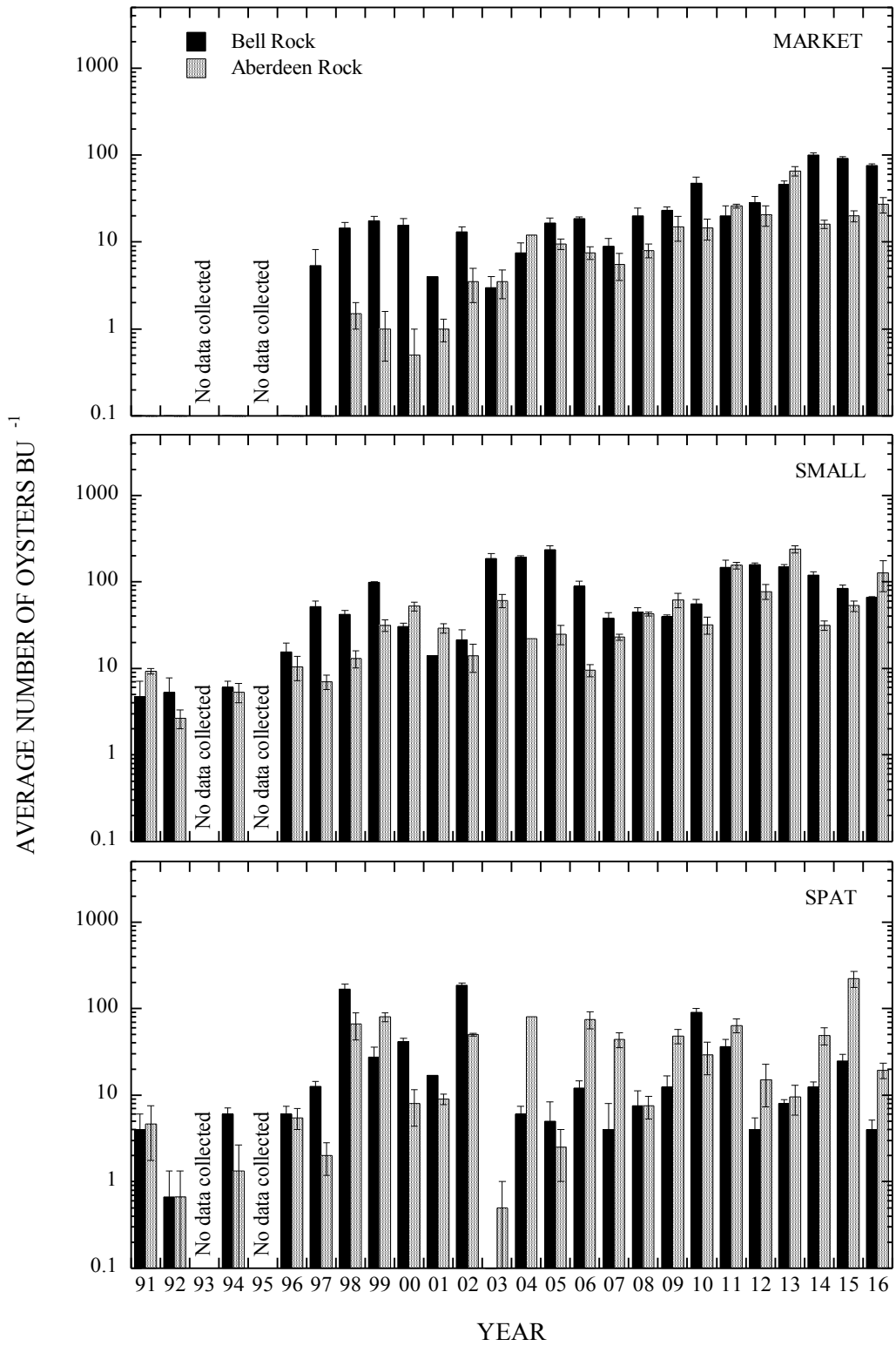


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

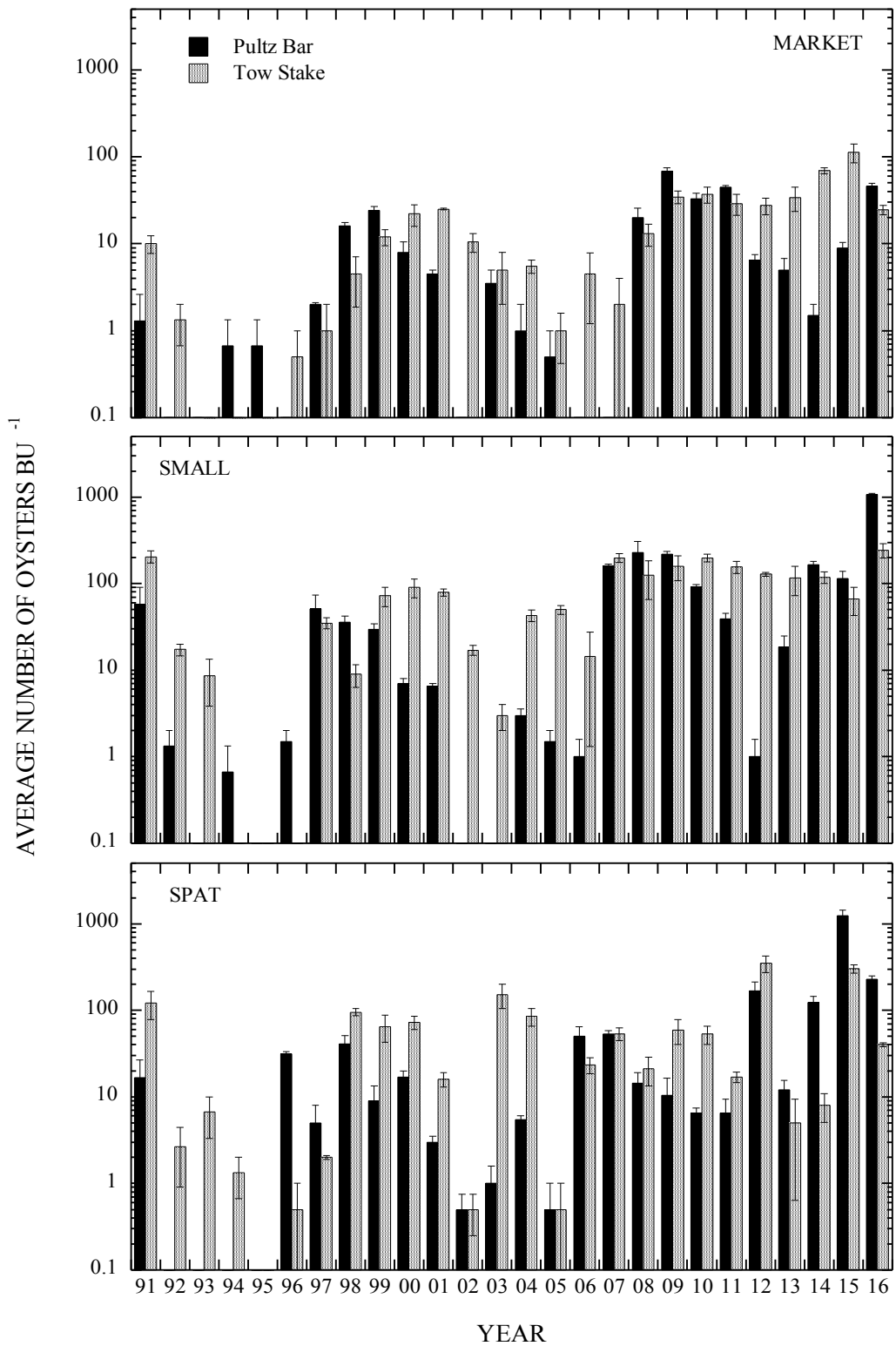


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE PIANKATANK RIVER (2015-2016)
 (Error bars represent standard error of the mean)

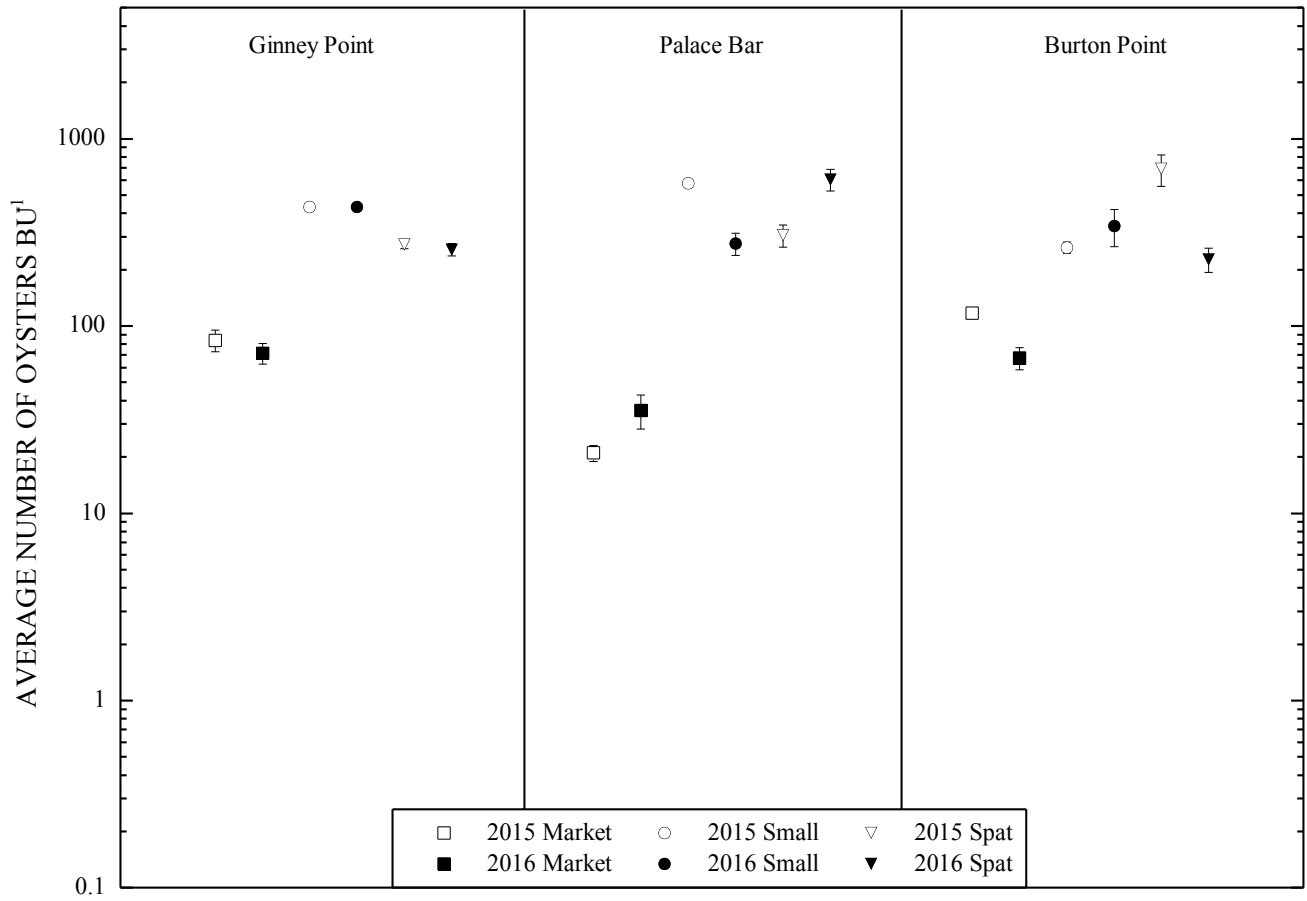
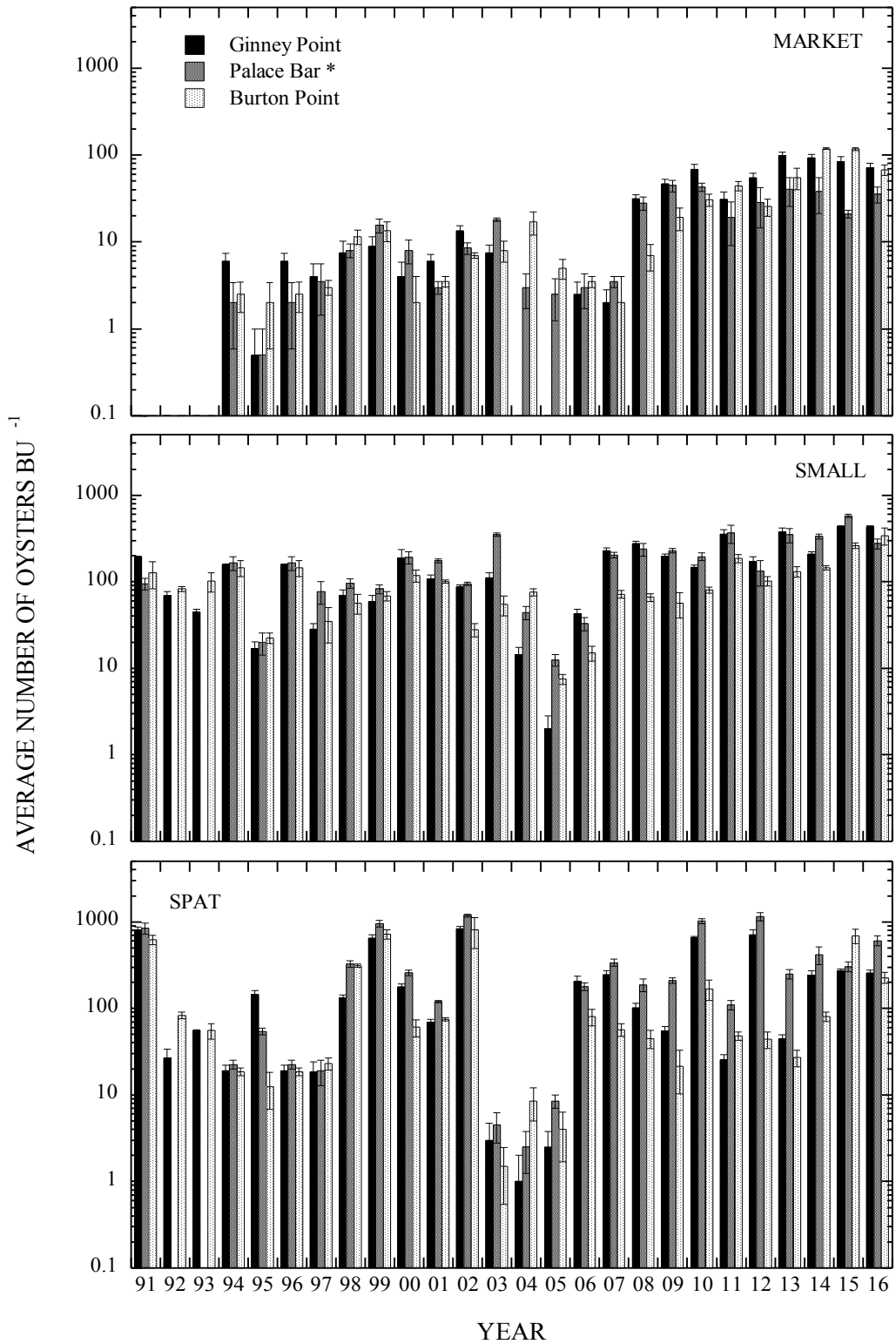


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



* No data in 1992 and 1993

FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2015-2016)
 (Error bars represent standard error of the mean)

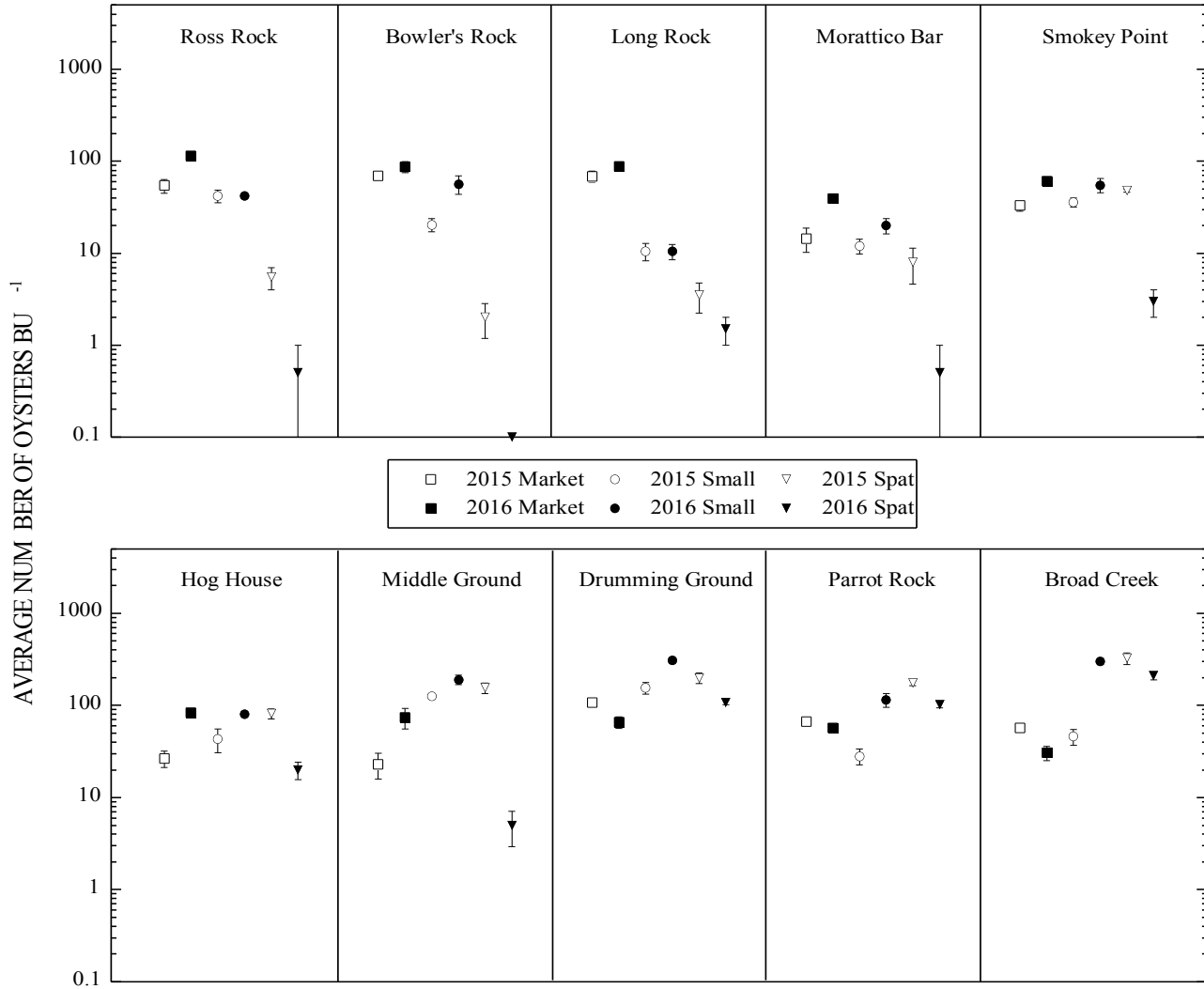
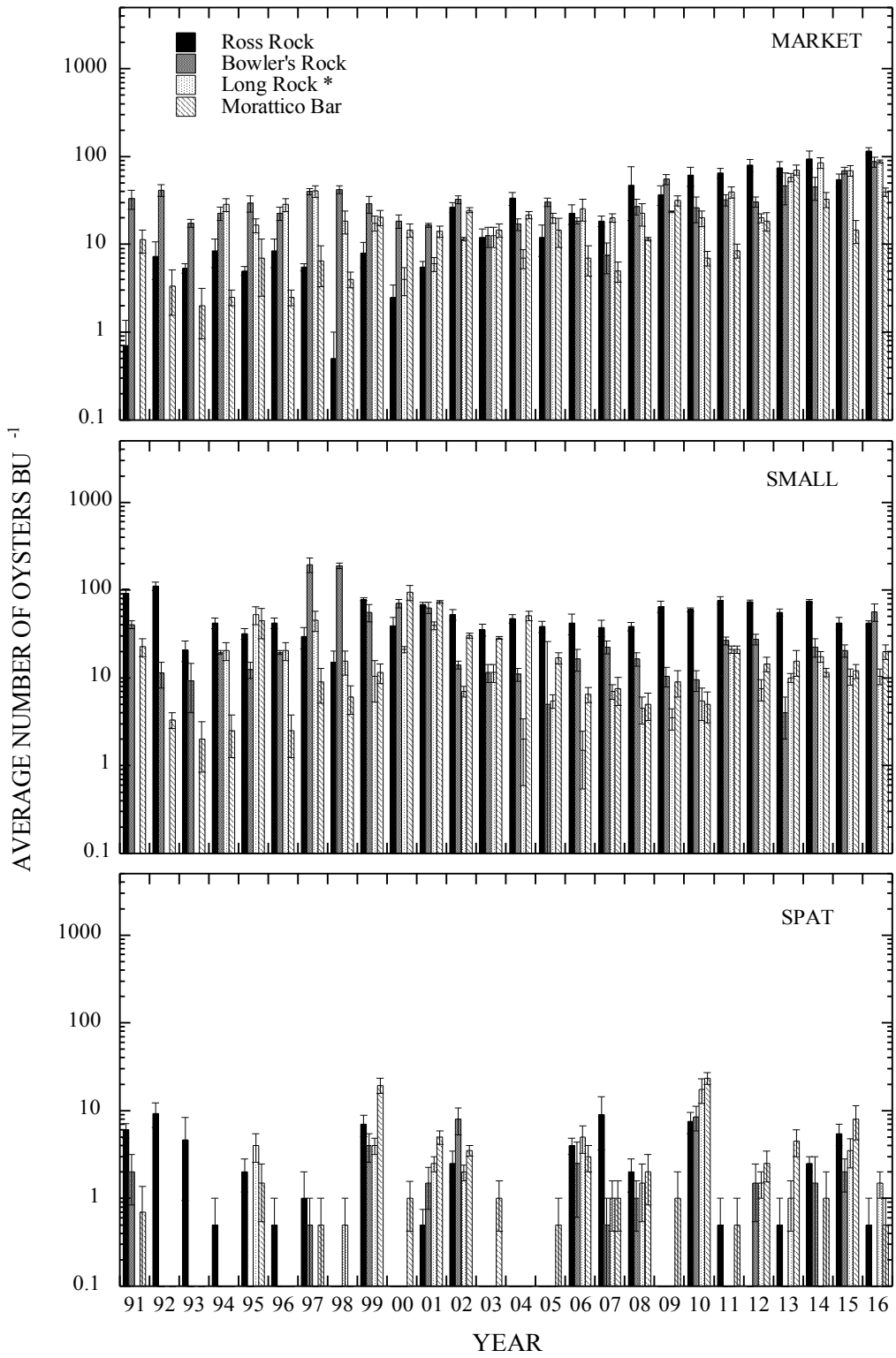


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



* No data prior to 1993

FIGURE D10B: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

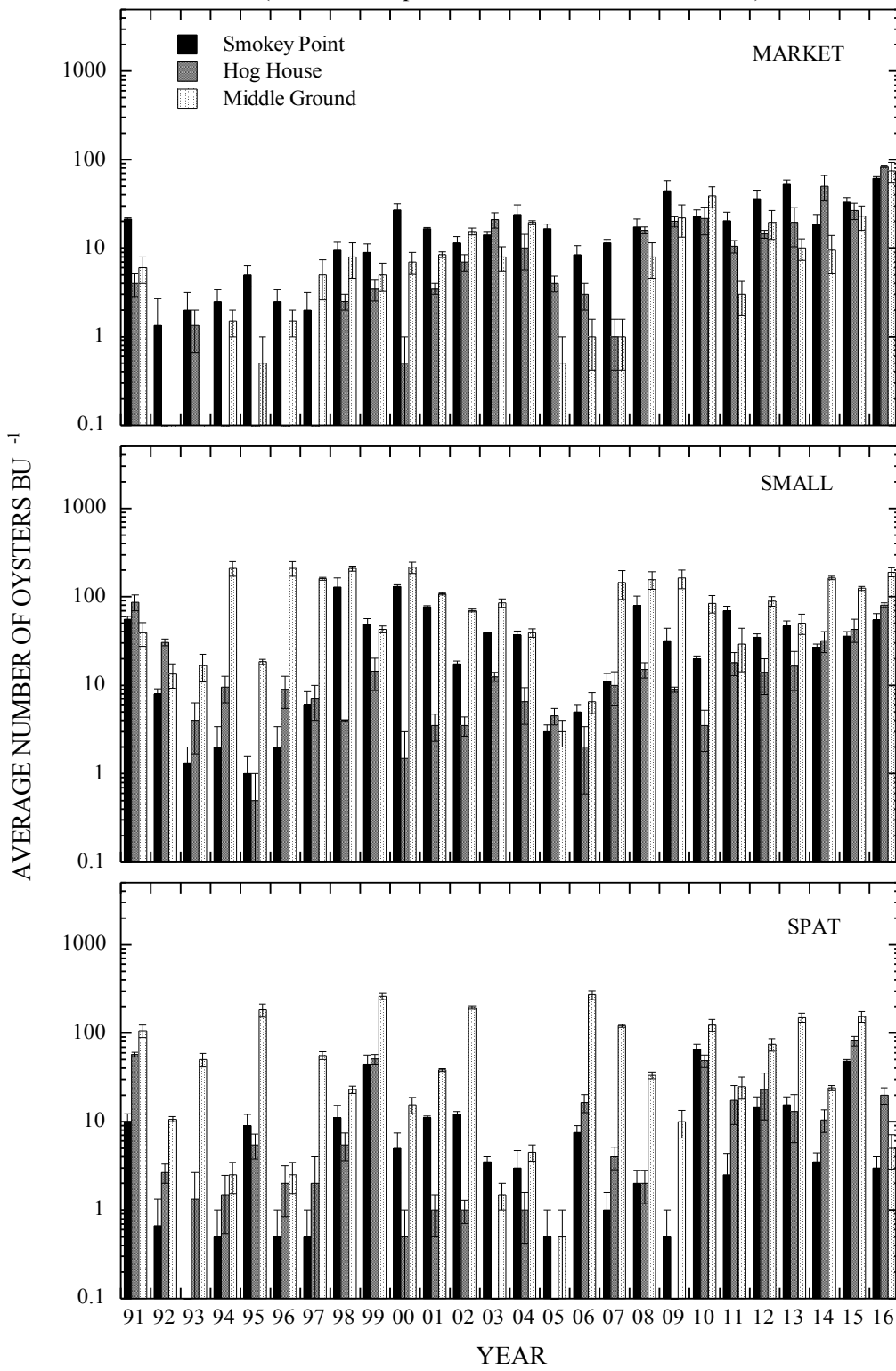


FIGURE D10C: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

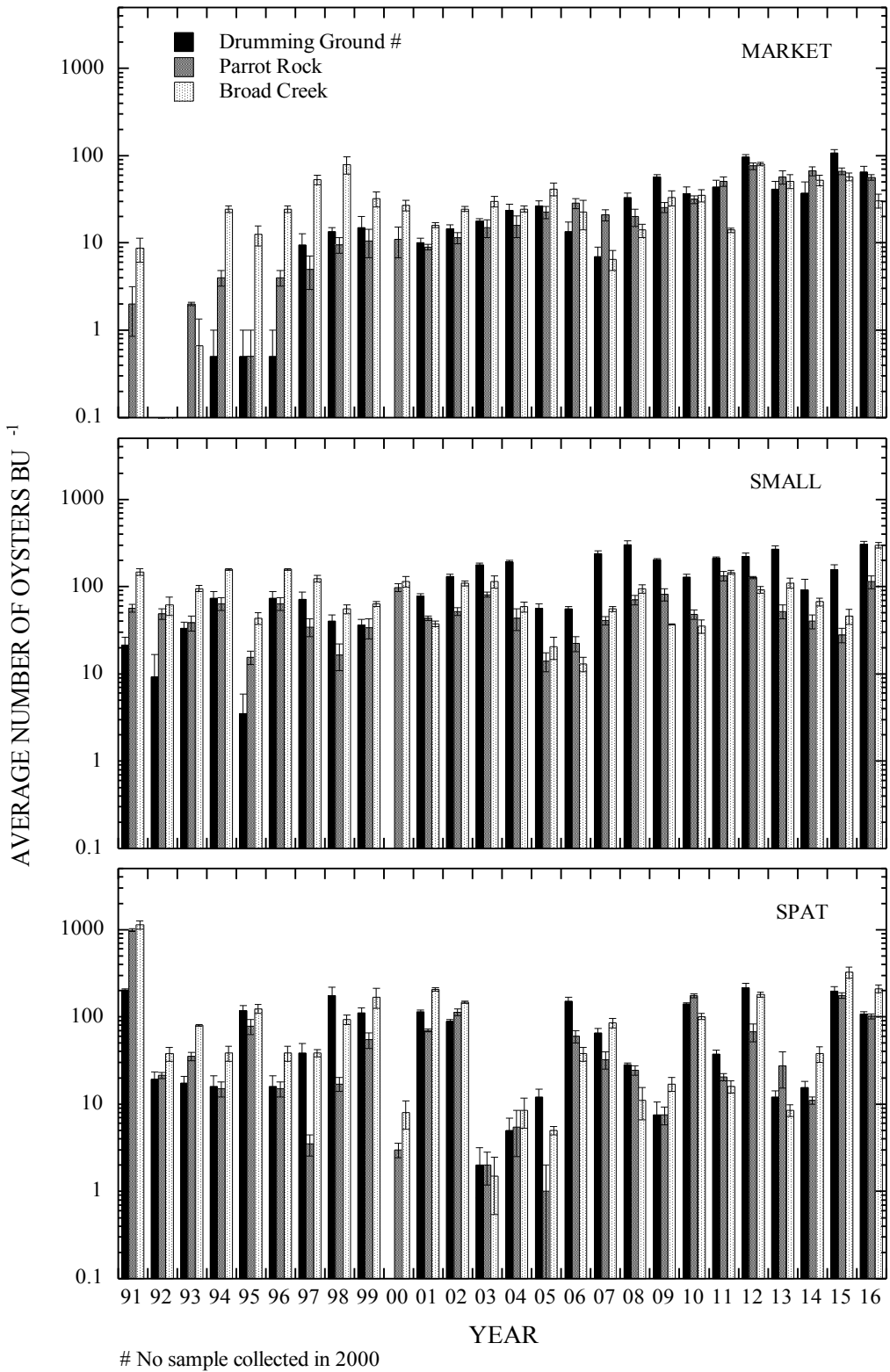


FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE GREAT WICOMICO RIVER (2015-2016)
 (Error bars represent standard error of the mean)

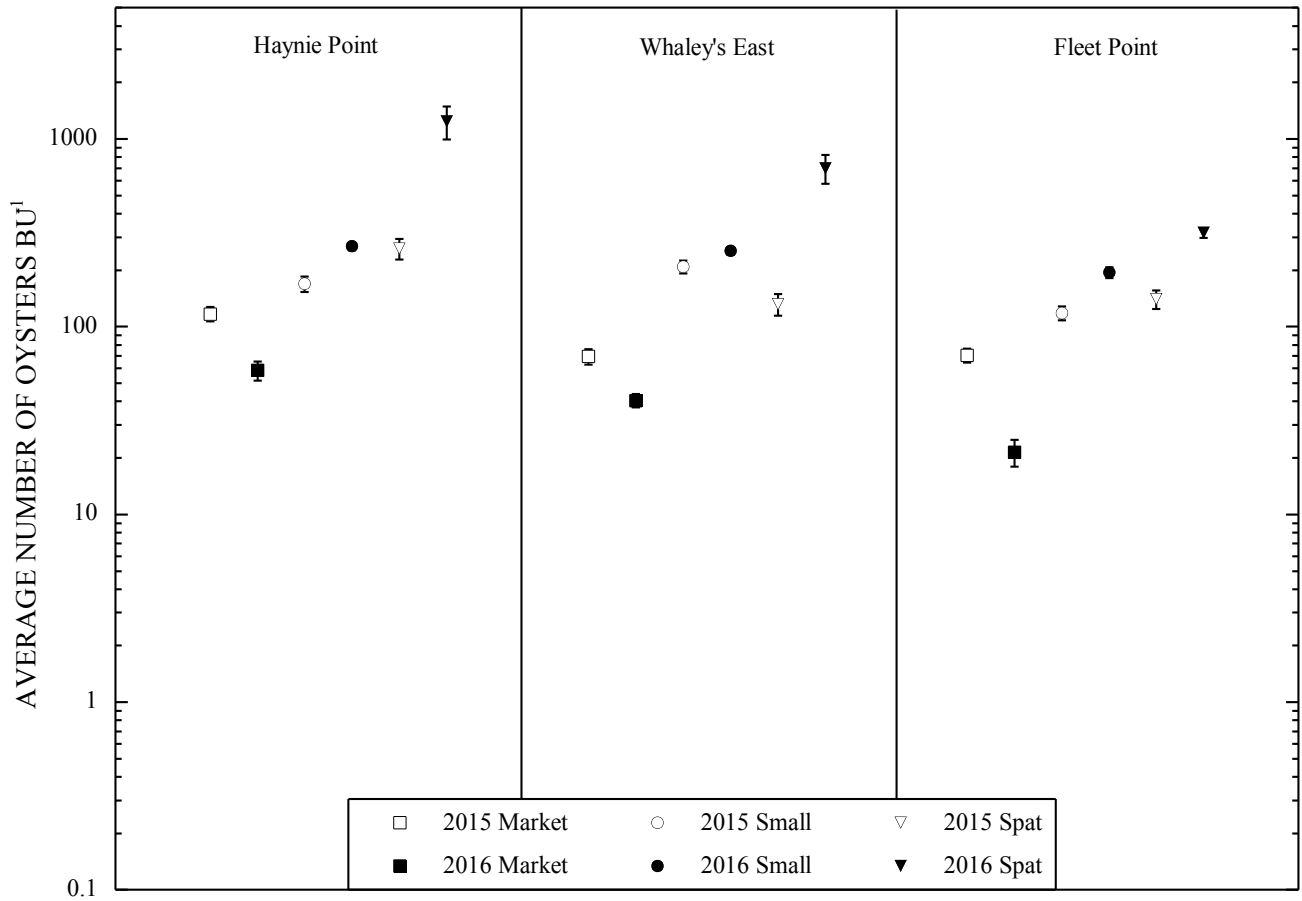
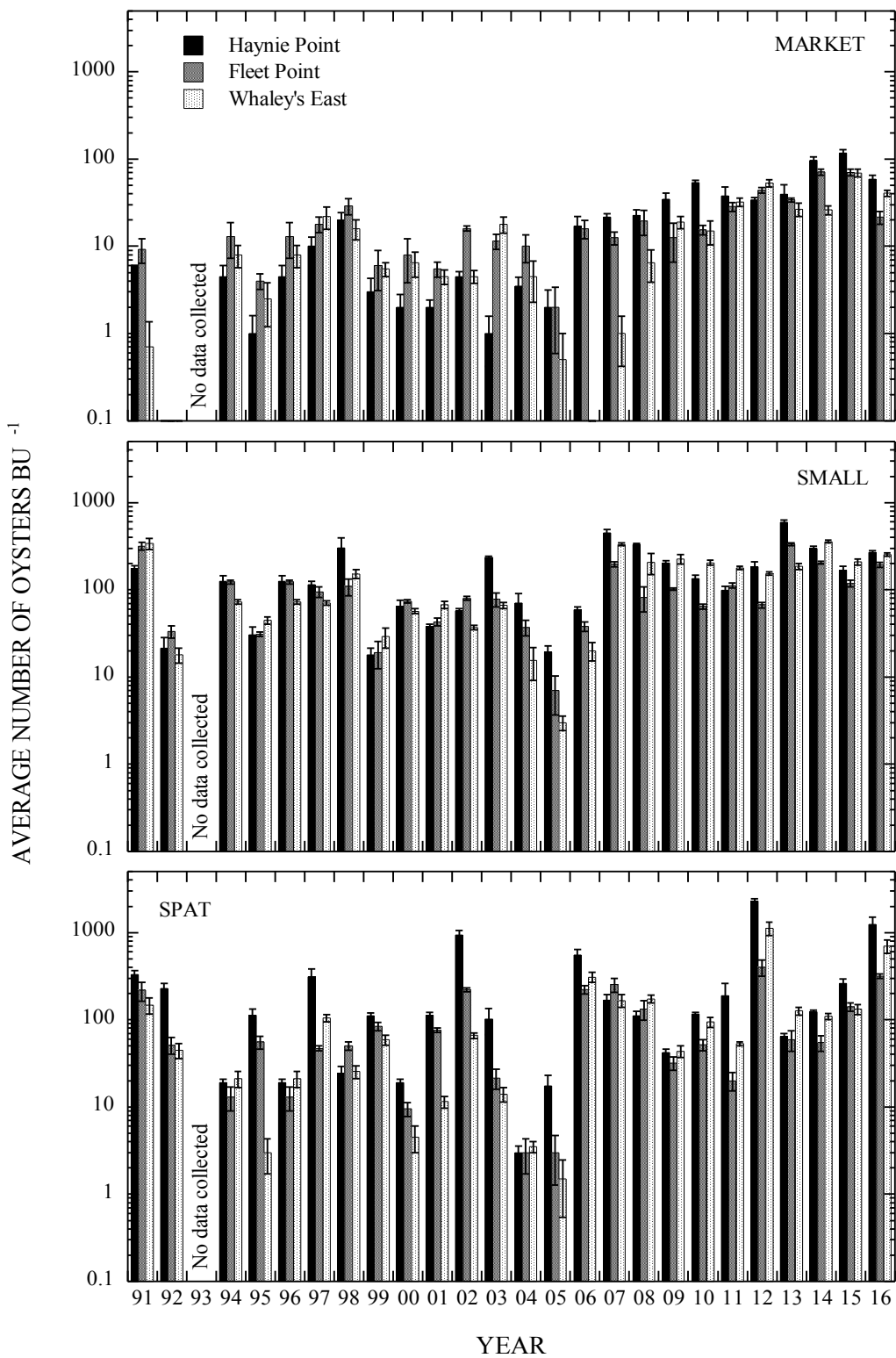


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



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