

The Status of Virginia's Public Oyster Resource 2015

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Part I. OYSTER RECRUITMENT IN VIRGINIA DURING 2015

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 2015 settlement season in three tributaries in the Virginia portion of the Chesapeake Bay.

METHODS

Settlement during 2015 was monitored from the last week of May through the first week of October in the James, 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 diseases caused by *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).

RESULTS

Settlement on shellstring collectors during 2015 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 (1990-2015) at the historical sites in all three-river systems and over the past seventeen years (1998-2015) 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 2015 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 2015. Comparisons were made over the past seventeen 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).

James River

Oyster settlement in the James River was first observed during the week of 17 June at five out of the eight sites monitored (Table S1). Settlement was consistently light to moderate throughout most of the rest of the recruitment period, with settlement occurring at 75 to 100% of the sites in any given week. Although there

were no obvious large peaks in settlement observed in the James River in 2015, 45% of the settlement observed throughout the system for the year occurred during the weeks of 24 June and 1 July (Figure S3). At Day’s Point, this two-week period accounted for 60% of the settlement observed for the year.

Settlement in the James River during 2015 was heavy at all eight sites monitored, ranging from a low of 18.0 cumulative spat shell¹ at Deep Water Shoal to a high of 93.1 cumulative spat shell¹ at Day’s Point (Table S1; Figure S4). Settlement during 2015 was higher than the previous year (2014) at all eight sites. Settlement in 2015 was higher than the five-year mean at Deep Water Shoal, Horsehead, Point of Shoal and Swash and higher than the ten-year mean at Day’s Point. Settlement was also higher than the 25-yr mean at six out of the eight sites (all except Swash and Wreck Shoal) and higher than the 20-yr mean at Horsehead, Point of Shoal, Dry Shoal, Rock Wharf and Day’s Point. Overall, settlement in the James River during 2015 was in the upper range of that observed during the past twenty-five years of monitoring (fourth highest at Deep Water Shoal, Horsehead and Rock Wharf; fifth highest at Point of Shoal and Wreck Shoal; sixth highest at Swash, Dry Shoal and Day’s Point), with the long term means being primarily driven by a few exceptionally high years (1991, 1993, 2002, 2008, 2010 and 2012).

Average river water temperatures in the James River during the 2015 monitoring period ranged from a low of 23.6 to a high of 28.7°C (Figure S5A). During the last two weeks of June, water temperature was 2 to 3°C higher than the long-term means (5, 10, 20 and 25-yr; Figure S5A), experiencing an almost 4°C increase between the weeks of 10 June and 24 June. Following this relatively rapid increase, water temperature reached its maximum of 28.7°C for the first time during the monitoring period. This first maximum occurred approximately one month

earlier than is typical for the system. Water temperature reached the maximum again during the week of 29 July, similar timing to the 5, 10, 20 and 25-yr long-term means (Figure S5A). Water temperature during 2015 was similar to the long-term means for the majority of the rest of the sampling season, although it should be noted that during the week of 9 September, temperature was around 27°C, approximately 2°C higher than the long-term (5, 10, 20 and 25-yr) means.

Average salinities in the James River ranged from 8.8 to 15.4, generally increasing over the course of the sampling period (Figure S5B). Salinity was similar to the long-term means (5, 10, 20 and 25-yr) throughout most of the monitoring period. The one exception was in mid-July when salinity was approximately 3 lower than the 5, 10, 20 and 25-yr means (Figure S5B). 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 4 and 11.

Piankatank River

Settlement in the Piankatank River was first observed during the week of 10 June at Bland Point and Stove 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 17 June through the rest of the monitoring period. There was a large peak in settlement observed throughout the system during the week of 24 June, accounting for 57% of settlement for the year, with 69% of the settlement occurring during the weeks of 24 June and 1 July (Figure S6). This two-week period (24 June and 1 July) accounted for 83% of the settlement observed at Burton Point.

Cumulative spat shell⁻¹ for the year was heavy (three sites) to extremely heavy (five sites), ranging from a low of 31.4 at Wilton Creek to a high of 379.5 at Burton Point (Table S1). Settlement during 2015 was higher than that observed during 2014 at every site except Cape Toon and Ginney Point (no change). Settlement at the three historical sites was higher than the 10, 20 and 25-yr means and higher than the 5-yr mean at Palace Bar and Burton Point (Table S2; Figure S7A). Settlement during 2015 was the highest recorded over the past twenty-five years of monitoring at Burton Point. Settlement at both Ginney Point and Palace Bar was the third highest recorded over the past twenty-five years. At the modern sites, settlement during 2015 was higher than both the 5 and 10-yr means at all of the sites except Wilton Creek (Table S2; Figure S7B). At the modern sites, settlement during 2015 ranked the highest (Bland Point, Heron Rock and Stove Point), second highest (Wilton Creek) and fourth highest (Cape Toon) observed since monitoring began at those sites in 1998.

The average water temperature during the 2015 sampling period in the Piankatank River ranged from 22.9 to 29.5°C (Figure S8A). Water temperature in the Piankatank River was similar to the long-term means (5, 10, 20 and 25-yr) throughout most of the sampling period (Figure S8A). Similar to what was observed in the James River, between the weeks of 10 June and 24 June, water temperature increased almost 4°C, during which time it was 2 to 3°C higher than the long-term means (Figure S8A). Water temperature was also 1 to 2°C higher than the 5, 10, 20 and 25-yr means throughout much of September.

Salinity in the Piankatank River during 2015 ranged from 15.4 to 17.5 generally increasing over the course of the sampling period. Salinity was higher (1 to 2) than the long-term (5, 10, 20 and 25-yr) means throughout most of June (Figure S8B). Salinity had become similar to the 5, 10, 20 and 25-yr means by the first week of

July and remained similar throughout the rest of the monitoring period. The difference recorded in any given week between the most upriver site (Wilton Creek) and the most down river site (Burton Point; see Figure S1) was typically less than 3.

Great Wicomico River

Settlement in the Great Wicomico River was first observed during the week of 17 June at eight out of the nine sites and was 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). The majority of settlement for the season occurred during a three-week period from 24 June through 8 July. Settlement during this three-week period accounted for 85 (Fleet Point) to 98% (Glebe Point) of the total settlement for the year, with 34 (Fleet Point) to 75% (Glebe Point) of the settlement occurring during the week of 1 July (Table S1; Figure S9). Settlement throughout the rest of the sampling period was light.

Cumulative spat shell⁻¹ for the year was heavy (Whaley's East and Fleet Point) to extremely heavy (remaining seven sites), ranging from a low of 36.8 at Fleet Point to a high of 437.7 at Shell Bar (Table S1; Figure S10). Settlement in the Great Wicomico River in 2015 was higher than that observed in 2014 at Harcum Flats, Shell Bar and Haynie Point with no change observed at Whaley's East (Table S2; Figure S10). Settlement in 2015 was higher than the 5, 10, 20 and 25-yr means at four out of the five historical sites. The one exception was Glebe Point where settlement was lower than the 5 and 10-yr means, but higher than the 20 and 25-yr means. When compared with the past twenty-five years, settlement in 2015, was the highest recorded at Haynie Point, the third highest at Hudnall, Whaley's East and Fleet Point and the fifth highest at Glebe Point. At the modern sites,

settlement was higher than both the 5 and 10-yr means at Shell Bar and higher than the 10-yr mean at Harcum Flats. Settlement in 2015 at the modern sites, ranked the second highest (Shell Bar), third highest (Hilly Wash and Harcum Flats) and fifth highest (Rogue Point) observed since monitoring began at those sites in 1998.

Average river water temperatures in the Great Wicomico River ranged from 23.1 to 29.3°C throughout the sampling period, reaching the maxima during the week of 29 July (Figure S11A). Temperature increased fairly quickly between the weeks of 3 June and 24 June from around 23°C on 3 June to 28.5°C by 24 June, at which time the water temperature was approximately 2°C higher than the 5, 10 and 17-yr means (Figure S11A). Water temperature during 2015 fluctuated a good bit from week to week (often changing 1 to 2°C), but remained similar to the long-term (5, 10 and 17-yr) means throughout the months of July, August and September. The one exception occurred in mid-September when the temperature increased (temperature typically is on the decline at this time of year), and was approximately 2°C higher than the 5, 10 and 17-yr means (Figure S11A).

Salinity in the Great Wicomico River during the 2015 sampling period ranged from 14.6 to 16.7, generally increasing over the course of the monitoring period (Figure S11B). Similar to what was observed in the Piankatank River, salinity in the Great Wicomico River was consistently 1 to 2 higher than the long-term (5, 10 and 17-yr) means throughout the month of June (Figure S11B), becoming similar to the long-term means in early July and remaining similar for the rest of the monitoring period. 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 eight years (2008-2015) has been on the rise such that 81% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell⁻¹) and 29% 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, 87% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell⁻¹) and 39% of the total year/site combinations had extremely heavy spatfall (seasonal cumulative total of > 100 spat shell⁻¹; Table S2). Settlement on the shellstrings in 2015 was heavy to extremely heavy at all twenty-five sites monitored.

Overall, settlement on shellstrings in the James River during 2015 was heavy. As has been the case for the past several years, settlement tended to be higher along the southern shore of the river (Day's Point, Rock Wharf and Dry Shoal). Since 2008, the James River has had several very strong year classes. The mean cumulative spat shell⁻¹ for all eight sites combined from 1990 to 2007 was 12.5, whereas the mean for all eight sites combined over the past eight years (2008 to 2015) was 83.0. This translates to almost a seven-fold increase in settlement over the past eight years compared with the previous eighteen 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 mid-June, at least some settlement occurred each week throughout the rest of the 2015 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 50% of the total settlement for the season had occurred by the end of July. At three of the more downriver sites (Dry Shoal, Wreck Shoal and Day's Point; Figure S1), at least 50% of the settlement for the season had occurred by mid-July.

Overall, settlement on the shellstrings in the Piankatank River was heavy to extremely heavy, 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 eighteen years of monitoring respectively. Similar to the James River, the Piankatank River has had several very strong year classes in recent years, including the 2015-year class. 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 combined the mean from 1993 to 2006 was 7.4 cumulative spat shell⁻¹, whereas from 2007 to 2015 the mean at those three sites was 170.2 cumulative spat shell⁻¹, a 23-fold increase over the previous fourteen-year mean. Since the addition of the modern sites in 1998, the mean combined cumulative spat shell⁻¹ across the river increased from 32.5 cumulative spat shell⁻¹ (1998 to 2006) to 505.7 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 2015 was 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.

For the tenth year in a row, overall settlement on the shellstrings in the Great Wicomico River was heavy to extremely heavy, especially when compared with most of the 1990s and the early 2000s. For the five historical sites the mean spat shell⁻¹ between 1991 and 2005 ranged from 1.2 (Whaley's East) to 21.7 (Glebe Point), whereas the mean between 2006 and 2015 ranged from 24.2 (Fleet Point) to 366.1 (Glebe Point). This was a 15 to 30-fold increase in settlement at these sites during the past ten years compared with the previous fifteen years. For the modern sites, the mean spat shell⁻¹ between 1998 and 2005 ranged from 3.2 (Shell Bar) to 5.4 (Harcum Flats), whereas the mean between 2006 and 2015 ranged from 149.9 (Shell Bar) to 229.8 (Harcum Flats). This was a 43 to 56 fold increase at these sites during the past ten years when 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	5/27	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
	147	154	161	168	175	182	189	196	203	210	217	224	231	238	245	252	259	266	273	
JAMES RIVER																				
Deep Water Shoal	D	-	0	0.2	1.3	2.3	0.2	0	0.7	0.3	-	1.2	2.9	1.7	3.2	3.3	0.7	-	-	18.0
Horsehead	D	-	0	0.2	9.0	11.5	1.4	0.8	6.0	1.1	-	2.3	3.2	1.5	4.9	2.1	2.0	-	0.4	46.4
Point of Shoal	D	-	0	-	3.1	13.7	0.4	0.9	1.4	0.9	-	1.7	3.1	2.7	3.5	3.7	1.4	-	0.2	36.7
Swash	D	-	0	0	6.0	7.0	0.9	0.5	2.1	0.8	-	0.7	2.9	0.8	4.7	2.2	3.9	-	-	32.5
Dry Shoal	D	-	0	0.1	12.5	14.8	3.8	3.0	13.6	3.1	-	0.8	3.7	1.2	5.4	1.1	0	-	0.5	63.6
Rock Wharf	D	-	0	0.2	10.6	7.0	1.9	1.0	1.9	0.8	-	1.5	4.9	0.5	12.5	7.0	2.3	-	0.2	52.3
Wreck Shoal	D	-	0	0.6	-	11.0	3.0	0	8.0	0.6	-	1.4	1.3	0.3	1.9	0.6	0.9	-	0.8	30.4
Day's Point	D	-	0	0	21.2	35.1	4.1	3.0	10.9	4.3	-	0.4	-	1.7	6.2	3.3	2.8	-	0.1	93.1
PIANKATANK RIVER																				
Wilton Creek	D	0	0	0.1	5.5	1.0	2.0	1.2	4.9	2.8	1.8	5.1	2.0	0.5	0.1	0.5	3.4	-	0.5	31.4
Ginney Point	D	0	0	0.4	17.7	2.5	5.6	0.6	6.9	2.8	6.7	6.3	3.0	1.4	1.0	1.1	13.8	-	0.6	70.4
Palace Bar	D	0	0	0.6	24.5	2.2	1.7	0.2	4.0	0.9	3.6	3.6	3.1	2.3	1.1	0.7	7.5	-	0.7	56.7
Bland Point	D	0	0.1	0.6	243.0	31.5	6.0	2.7	8.9	5.2	14.7	20.4	5.1	20.6	7.6	8.6	14.6	-	1.3	390.9
Heron Rock	D	0	0	0	64.2	1.7	5.9	0.9	3.9	0.3	3.0	7.1	4.3	2.8	5.9	0.7	4.4	-	-	105.1
Cape Toon	D	0	0	1.0	99.4	19.5	3.1	3.5	4.2	1.9	7.6	8.7	2.1	3.8	7.7	0.7	4.0	-	0.3	167.5
Stove Point	D	0	0.1	0.9	169.8	41.2	5.0	3.9	5.4	5.0	11.2	14.7	3.5	7.1	12.6	2.8	19.7	-	1.2	304.1
Burton Point	D	0	0	0.6	232.2	82.1	3.1	4.0	1.9	3.4	6.6	4.4	5.0	2.6	17.9	2.2	13.0	-	0.5	379.5
GREAT WICOMICO																				
Glebe Point	D	0	0	0	12.4	175.2	41.6	2.9	0.3	0	0.2	0.4	0.5	0	0	0.3	0.4	0.4	0.2	234.8
Rogue Point	D	0	0	0.5	32.0	50.7	9.9	1.7	0.7	0.1	0.2	0.8	0.5	0.3	1.6	1.1	1.0	0.8	0.8	102.7
Hilly Wash	D	0	0	0.4	41.5	96.8	5.8	3.5	0.2	0.2	0.3	0.5	0.1	0.5	0.2	0.2	0.3	0.5	0.4	151.4
Harcum Flats	D	0	0	0.2	65.7	155.7	31.2	2.0	1.1	0.7	0.2	0.4	0.1	0.3	0.2	1.2	1.0	0.2	0.7	260.9
Hudnall	D	0	0	0.2	36.2	78.8	15.5	1.2	0.5	0.4	0.6	0.2	0	0.2	0.7	0.3	1.1	0.2	0.3	136.4
Shell Bar	D	0	0	1.4	65.3	280.8	68.4	5.3	5.3	2.1	0.4	0.3	0.1	0.3	0.8	3.5	3.1	0.4	0.2	437.7
Haynie Point	D	0	0	0.7	82.8	133.1	36.9	2.2	1.1	0.5	0.3	0.2	0.1	0.7	0.5	1.3	0.7	0.5	0.3	261.9
Whaley's East	D	0	0	0.1	22.7	43.8	10.3	0.7	0.8	0.1	0.1	0.1	0.1	0.3	0.4	0.6	1.7	0.7	0	82.5
Fleet Point	D	0	0	0.1	14.1	12.6	4.6	0.4	1.0	-	0.1	0.3	0.1	0.4	1.1	1.9	0	0	0.1	36.8

Table S2: Spatfall totals for historical sites (1990-2014) and modern sites (1998-2014) 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 2015 in reference to 2014 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	1990	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	Mean 10-14	Mean 05-14	Mean 95-14	Mean 90-14	Ref 2014	Ref 5-yr	Ref 10-yr	Ref 20-yr	Ref 25-yr	
JAMES																																				
Deep Water Shoal	2.6	10.6	0.7	15.7	0.6	1.7	0.5	1.3	1.2	5.7	0.7	2.0	33.8	0.1	1.6	1.0	2.1	5.3	252.3	1.7	19.7	7.0	13.6	2.8	2.3	18.0	9.1	30.8	17.8	15.5	+	+	-	NC	+	
Horsehead	0.9	24.7	3.6	43.7	3.2	0.3	3.6	2.4	1.1	3.8	2.3	4.0	24.4	0.0	3.6	1.3	2.2	4.2	227.6	4.2	115.0	15.0	86.3	4.7	6.1	46.4	45.4	46.7	25.6	23.5	+	+	NC	+	+	
Point of Shoal	14.3	21.4	5.4	73.7	15.0	4.8	2.3	2.3	1.5	3.5	0.7	4.0	31.3	0.1	3.1	1.1	2.2	8.6	293.6	2.9	65.0	8.0	64.9	3.2	5.5	36.7	29.3	45.5	25.4	25.5	+	+	-	+	+	
Swash	3.3	68.7		46.2	4.8	1.8	2.2	1.7	1.6	6.8	2.6	3.5	26.0	0.5	11.9	1.4	1.8	6.3	481.5	5.2	52.5	14.1	56.8	4.0	12.8	32.5	28.0	63.6	34.7	34.1	+	+	-	-	-	
Dry Shoal	30.9	217.1	14.2	119.0	25.8	2.8	11.0	1.1	1.1	6.1	3.7	2.1	16.5	0.6	8.7	3.1	8.5	4.9	269.6	8.9	240.2	33.8	151.1	20.4	21.7	63.6	93.4	76.2	40.8	48.9	+	-	-	+	+	
Rock Wharf	1.8		11.4	34.3	10.7	0.2	2.4	5.6	2.1	8.0	1.0	8.5	22.7	0.1	10.0	4.4	1.9	19.8	347.5	5.0	272.4	33.8	106.5	10.9	11.5	52.3	87.0	81.4	43.7	38.8	+	-	-	+	+	
Wreck Shoal	4.0	35.3	3.3	15.5	2.2	2.6	10.0	0.7	0.7	3.1	0.9	3.2	8.3	1.3	21.6	3.1	4.1	4.1	584.3	7.1	64.1	17.5	66.4	3.3	12.3	30.4	32.7	76.6	40.9	35.2	+	-	-	-	-	
Day's Point	22.4	145.6	14.2	131.5	42.2	3.0	4.6	5.6	0.4	7.3	4.3	1.6	10.5	0.1	3.6	1.6	1.9	30.8	249.2	3.0	335.0	25.6	182.9	11.1	13.3	93.1	113.6	85.4	44.8	50.0	+	-	+	+	+	
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	65.6	35.1			+	-	-		
Ginney Point	62.6	25.4	11.4	1.7	0.0	0.5	1.3	0.0	2.2	6.4	6.8	1.2	5.9	0.2	0.2	0.3	3.9	7.1	18.3	4.5	63.7	32.0	232.0	29.3	70.5	70.4	85.5	46.1	24.3	23.5	NC	-	-	+	+	
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	48.3	26.2	14.4	19.1	+	+	+	+	+	
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	70.6	38.4			+	+	+			
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	35.8	20.3			+	+	+			
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	150.3	81.9			-	+	+	+		
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	48.8	29.3			+	+	+	+	+	
Burton Point	87.4	16.4	11.7	6.5	0.1	1.0	1.0	0.7	1.3	14.9	2.7	0.8	4.9	0.2	1.9	0.9	2.9	10.6	7.1	3.0	19.0	17.5	172.0	21.3	58.4	379.5	57.6	31.3	17.1	18.6	+	+	+	+	+	
GREAT WICOMICO																																				
Glebe Point	19.5	1.9	0.5	0.2	0.0	1.5	0.6	21.2	0.6	2.4	4.2	1.1	283.3	4.9	1.6	2.0	150.3	132.9	140.6	405.6	39.5	134.0	2122.5	49.4	251.4	234.8	519.4	342.8	187.5	150.9	-	-	-	+	+	
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	354.9	219.6			-	-	-			
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	325.2	201.8			-	-	-			
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	1128.3	38.6	156.6	260.9	281.2	203.9			+	-	+			
Hudnall	94.8	4.5	0.5	0.8	0.0	0.1	0.2	39.1	0.5	0.9	1.0	1.4	12.7	3.1	0.6	0.9	37.4	51.7	83.0	44.3	32.5	44.5	287.0	37.8	150.5	136.4	110.5	77.0	41.5	37.2	-	+	+	+	+	
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	181.1	106.3			+	+	+			
Haynie Point	68.2	12.4	0.6	1.4	0.0	1.0	3.7	4.4	0.7	1.1	1.1	0.9	15.4	1.6	0.3	0.8	17.1	24.8	43.1	8.6	17.8	22.7	213.5	16.1	220.4	261.9	98.1	58.5	30.8	27.9	+	+	+	+	+	
Whaley's East	39.1	7.9	0.1	0.2	0.0	0.3	2.1	1.0	0.4	1.8	0.2	0.7	2.4	0.9	0.1	0.4	6.0	21.6	1.9	2.3	16.4	5.5	144.7	4.1	83.0	82.5	50.7	28.6	14.8	13.7	NC	+	+	+	+	
Fleet Point	17.4	5.8	2.9	2.0	0.0	0.3	2.6	3.4	0.3	0.5	0.6	1.0	3.9	0.4	0.3	0.4	4.9	8.6	8.4	1.3	10.2	6.5	79.3	8.4	77.5	36.8	36.4	20.6	10.9	9.9	-	NC	+	+	+	

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 2015 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.

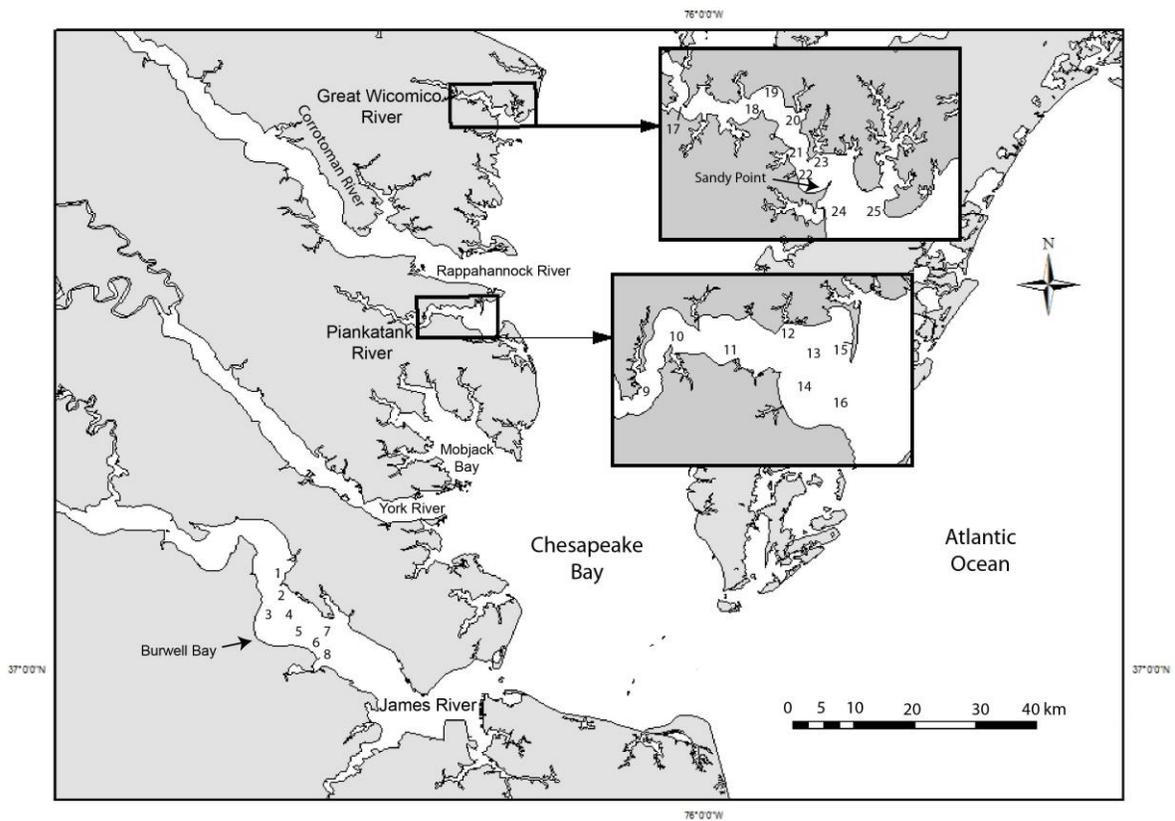


Figure S2: Diagram of shellstring setup on buoys with picture of a shellstring embedded.

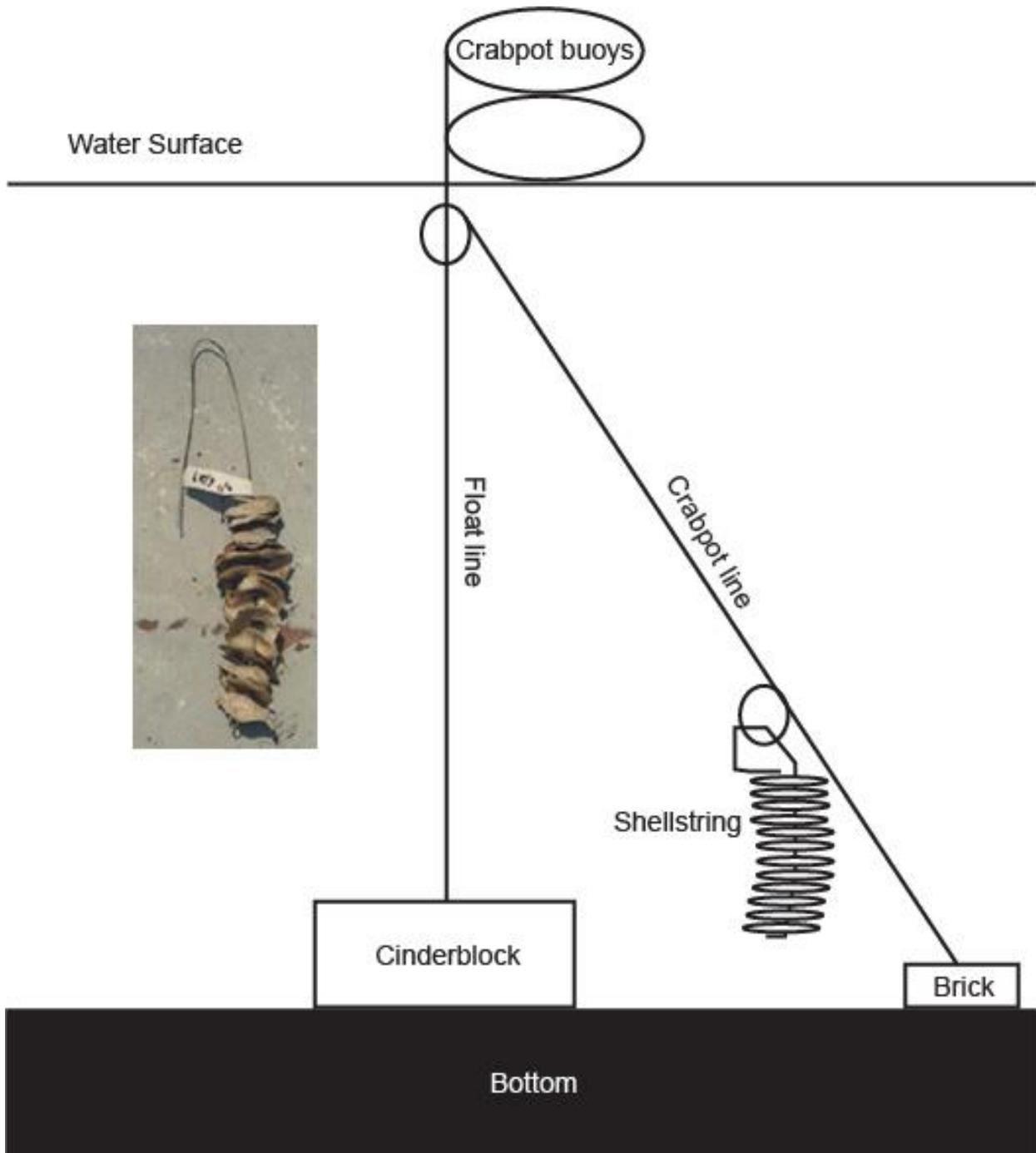


FIGURE S3: JAMES RIVER (2015) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹

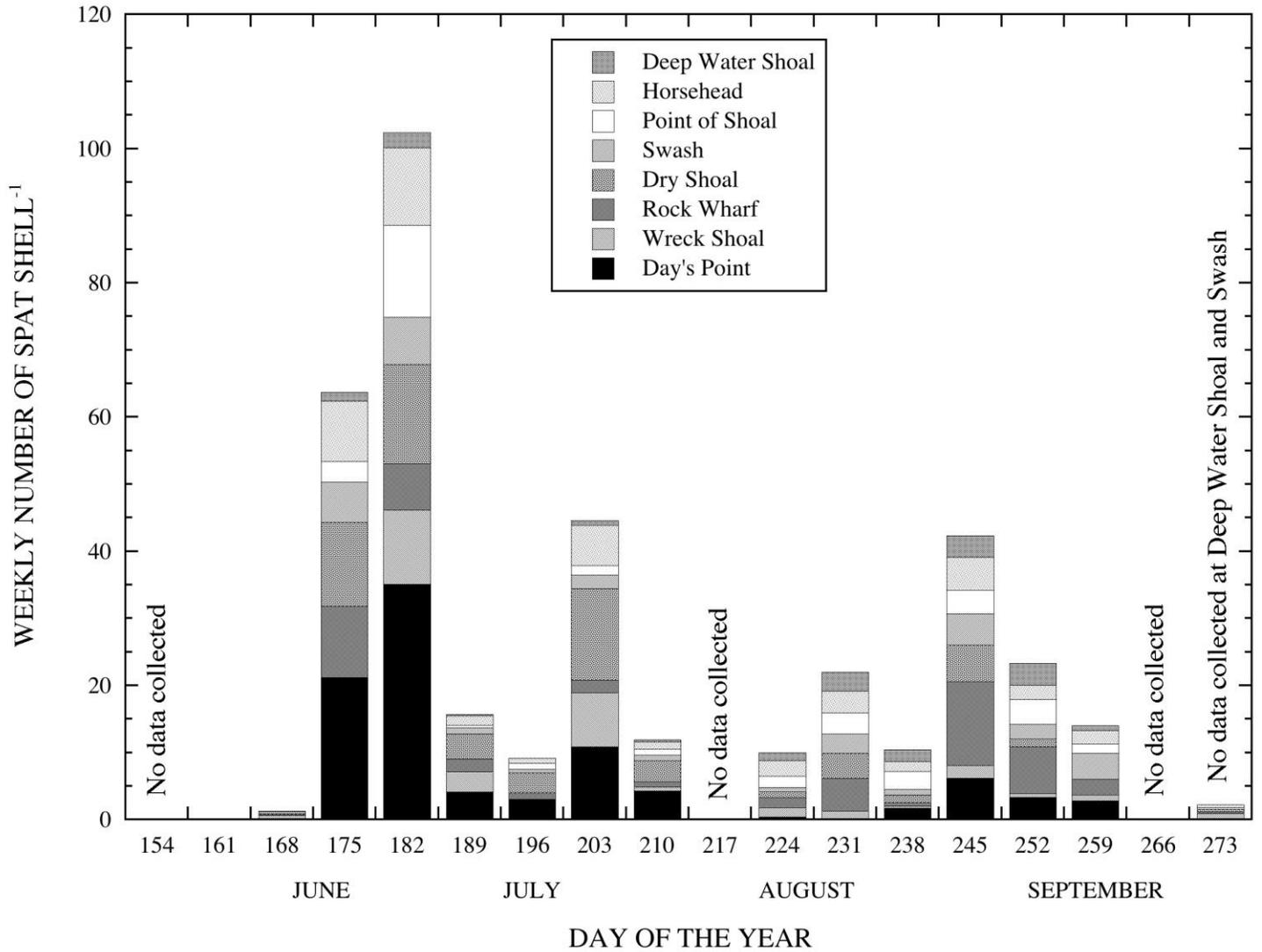


FIGURE S4: RECRUITMENT TRENDS OVER THE PAST 25 YEARS AT ALL EIGHT SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall)

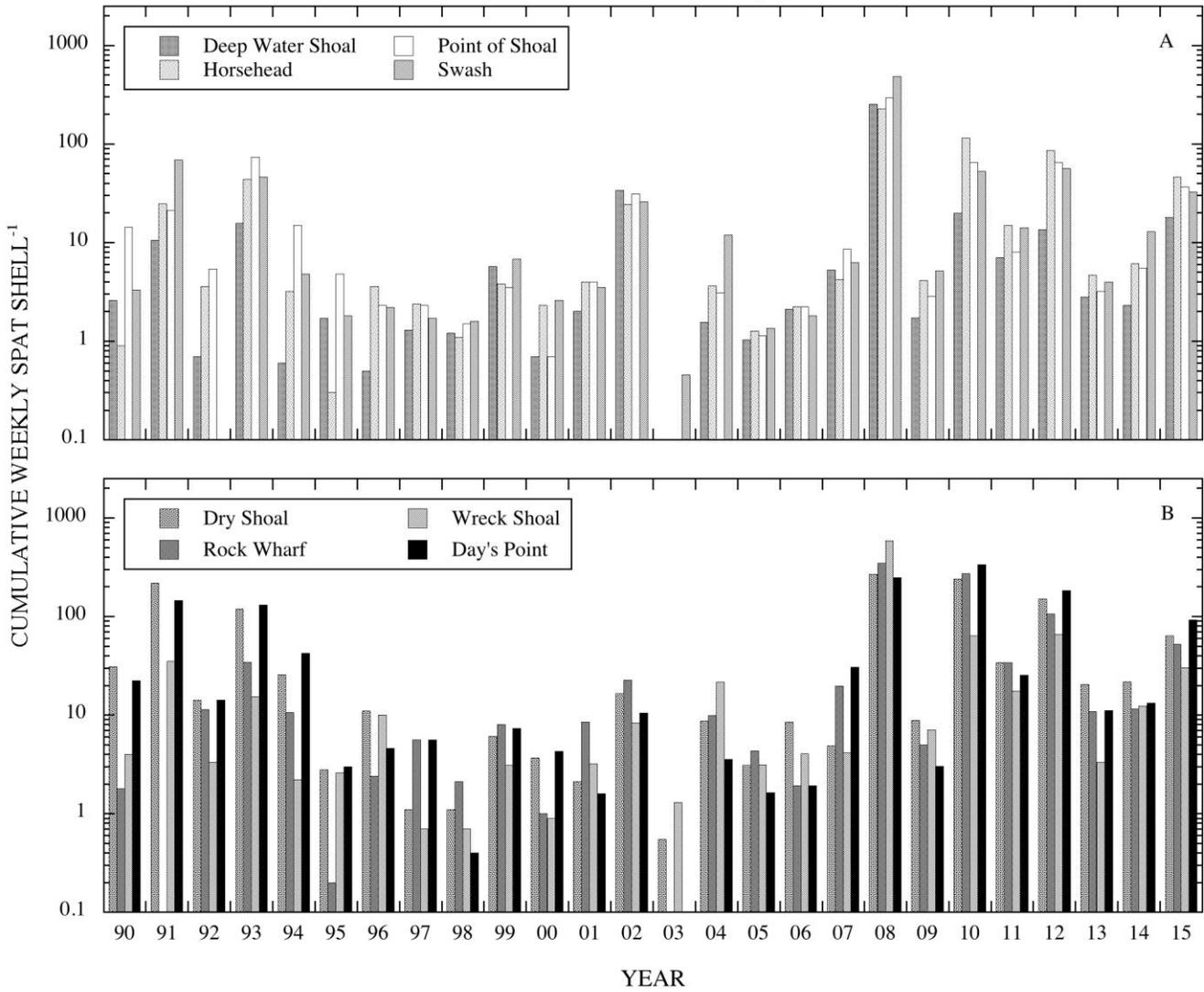


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 25-YEAR MEANS COMPARED WITH 2015 (Error bars represent standard error of the mean; shaded area represents the bulk of recruitment during 2015; n is the number of data points used to calculate the mean)

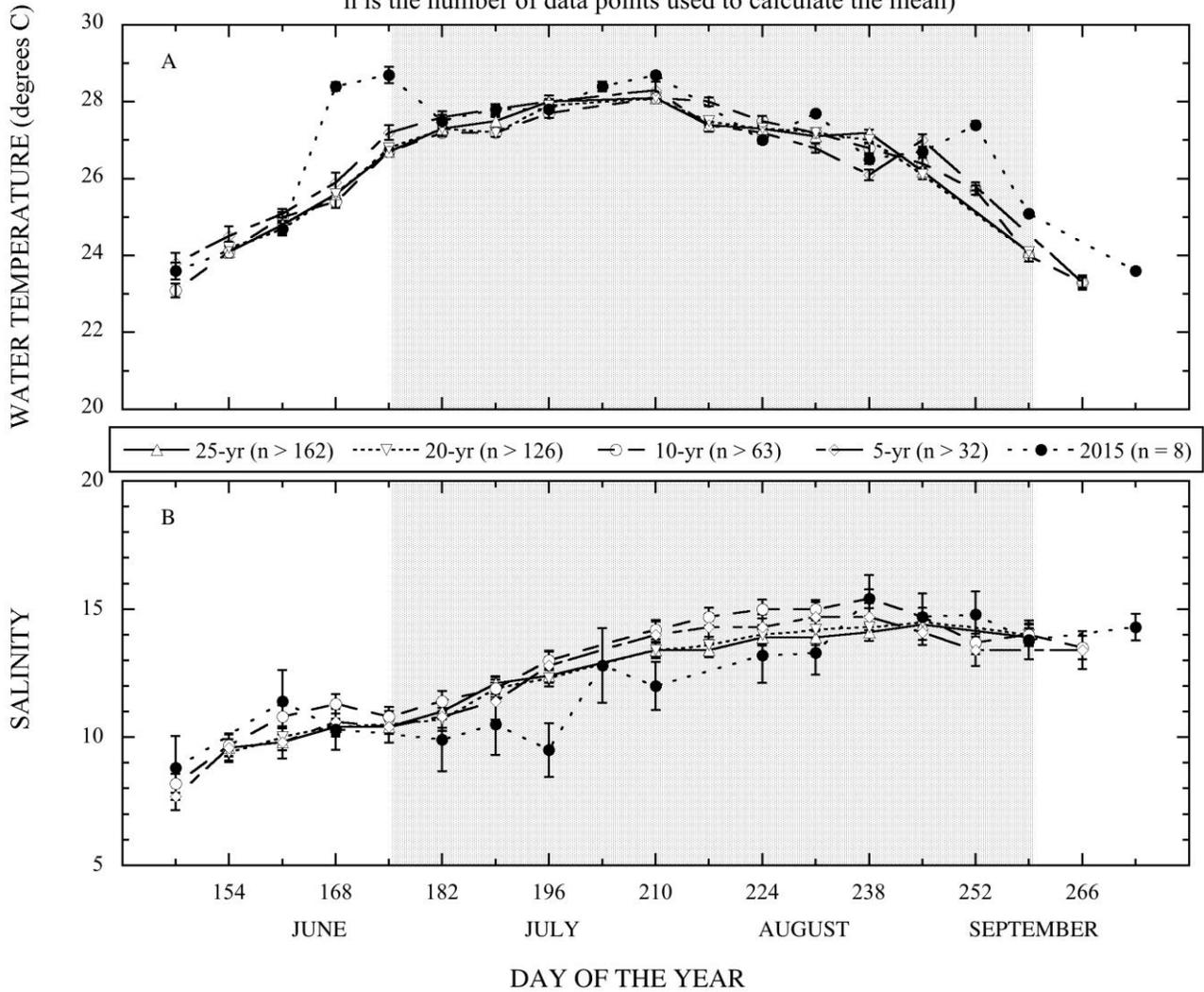


FIGURE S6: PIANKATANK RIVER (2015) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹
 (H = historical station: M = modern station as described in text)

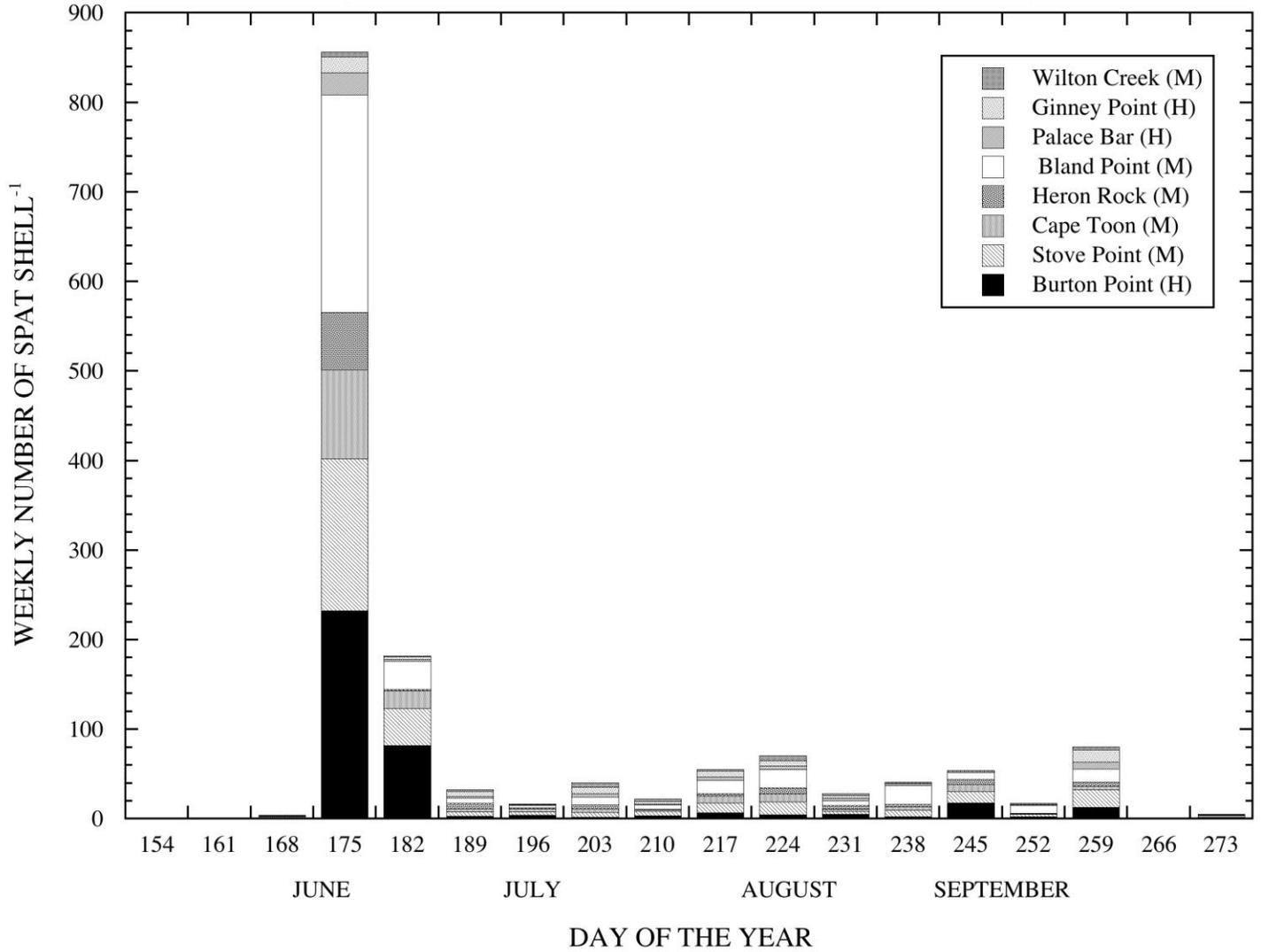


FIGURE S7: RECRUITMENT TRENDS IN THE PIANKATANK RIVER AT THE THREE HISTORICAL SITES (panel A: 25 years) AND THE FIVE MODERN SITES (panel B: 17 years) (Expressed as cumulative weekly spatfall)

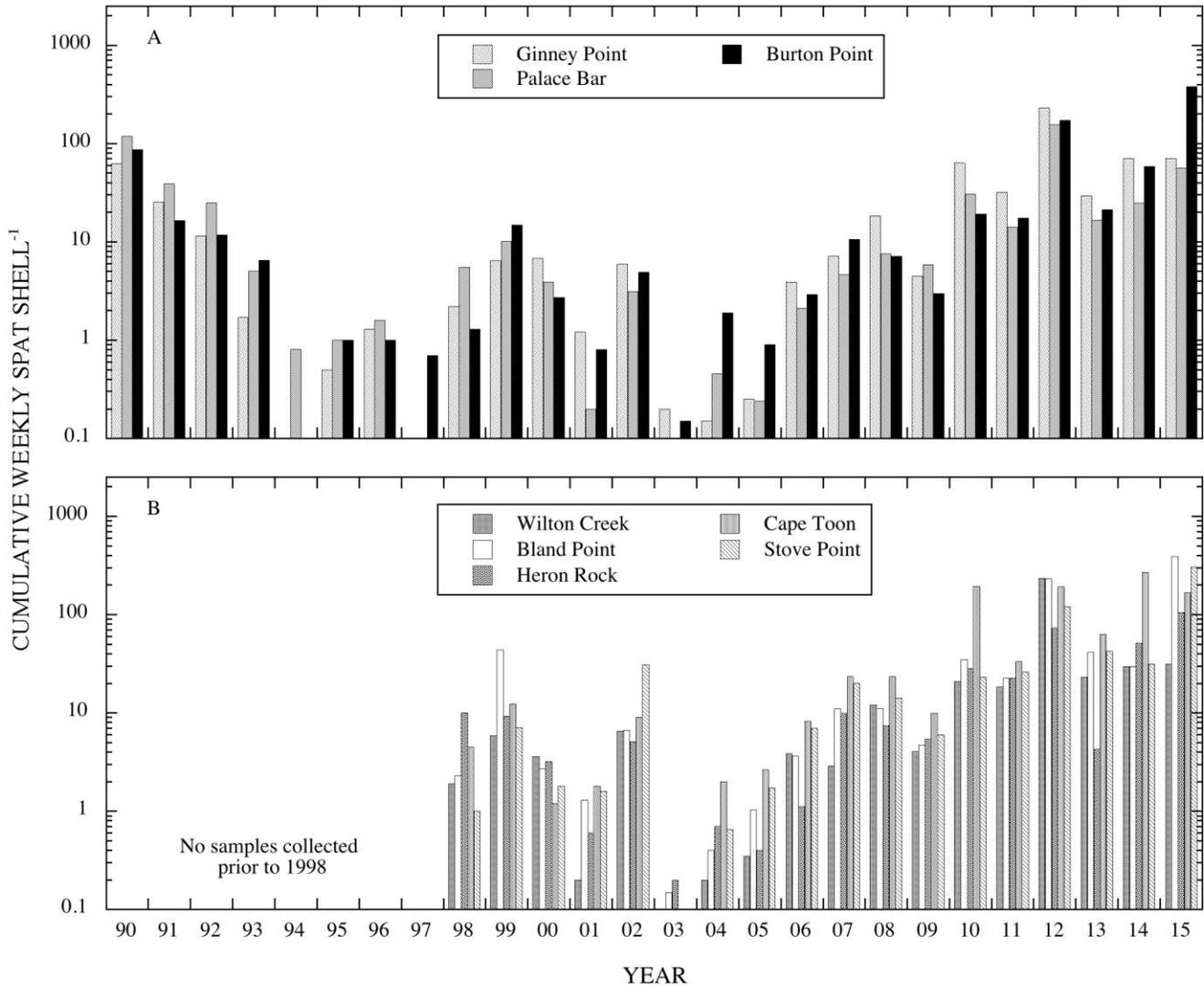


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 25-YEAR MEANS COMPARED WITH 2015 (Error bars represent standard error of the mean; darker shaded area = heavy recruitment; lighter shaded area = period of lighter recruitment; n is the number of data points used to calculate the mean)

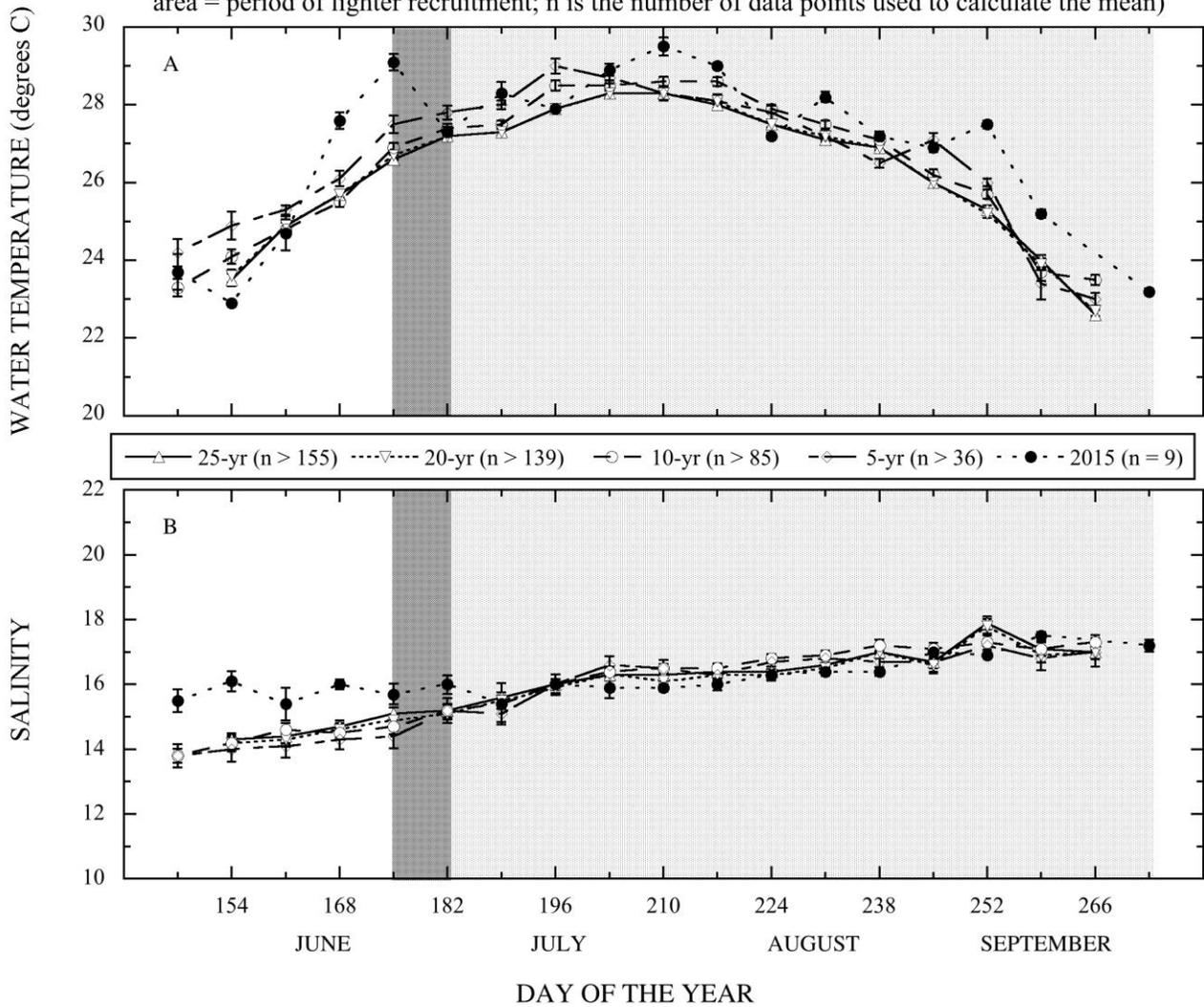


FIGURE S9: GREAT WICOMICO RIVER (2015) WEEKLY RECRUITMENT INTENSITY
 EXPRESSED AS NUMBER OF SPAT SHELL⁻¹
 (H = historical station: M = modern station as described in text)

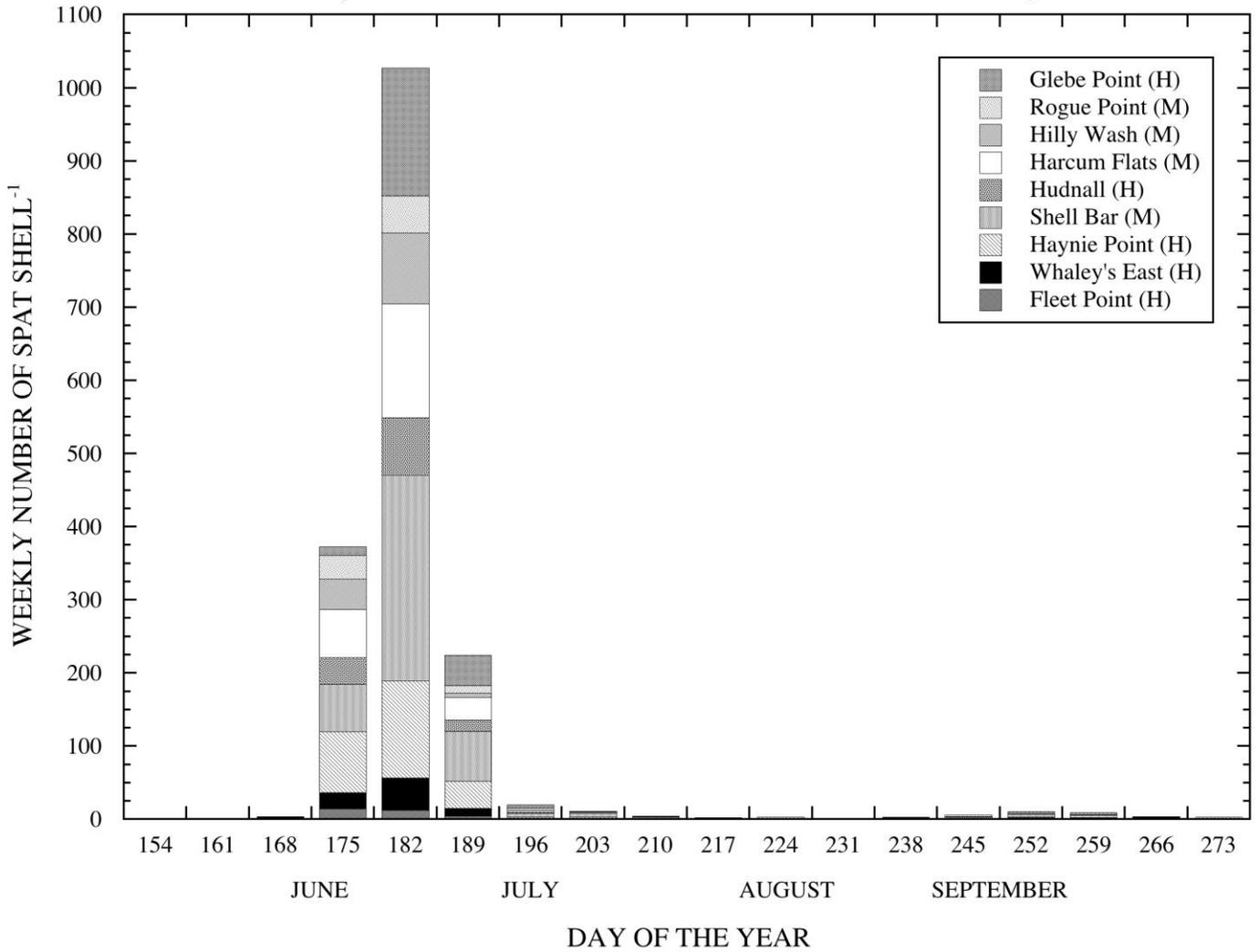


FIGURE S10: RECRUITMENT TRENDS IN THE GREAT WICOMICO RIVER AT THE FIVE HISTORICAL SITES (panel A: 25 years) AND THE FOUR MODERN SITES (panel B: 17 years) (Expressed as cumulative weekly spatfall)

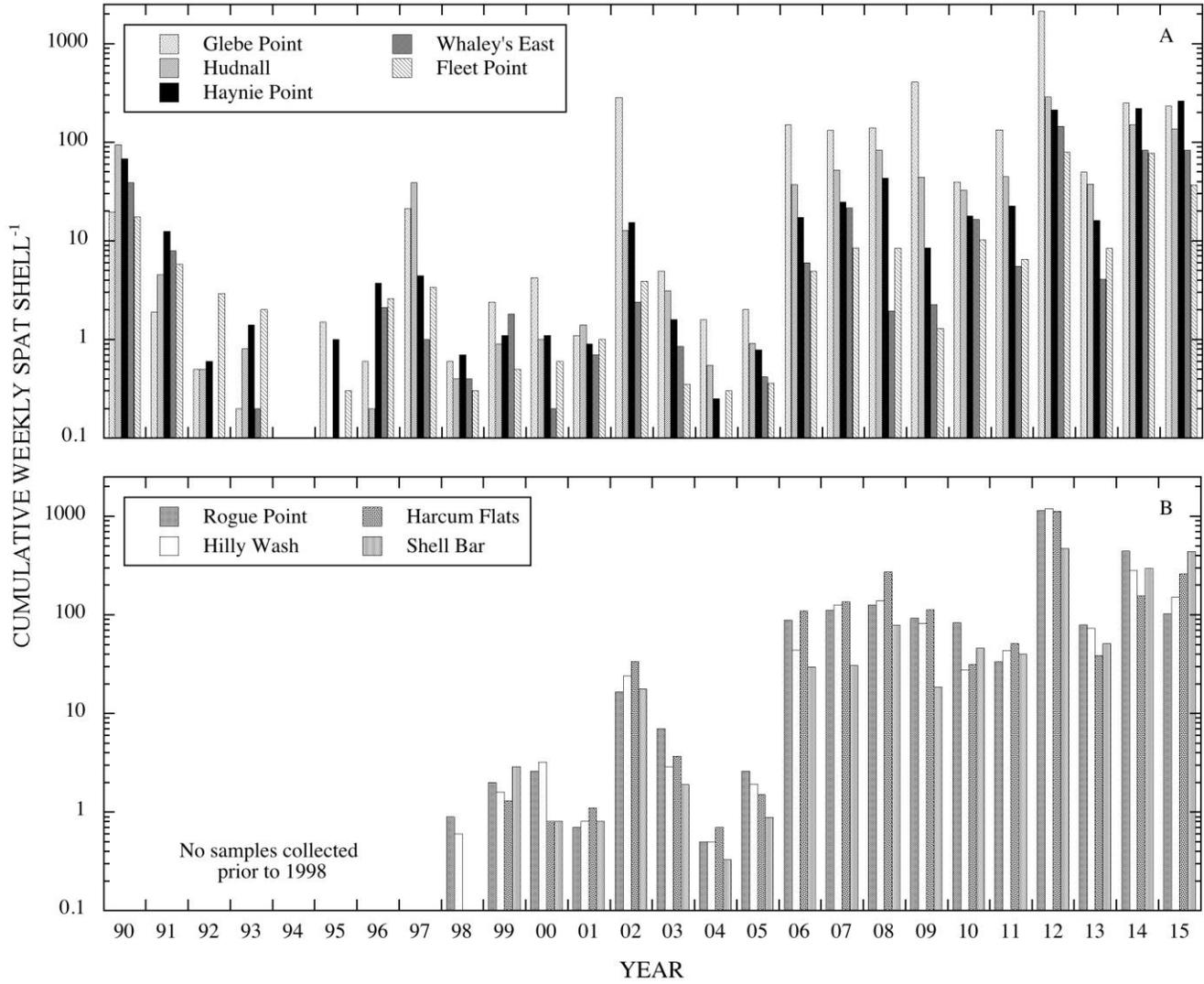
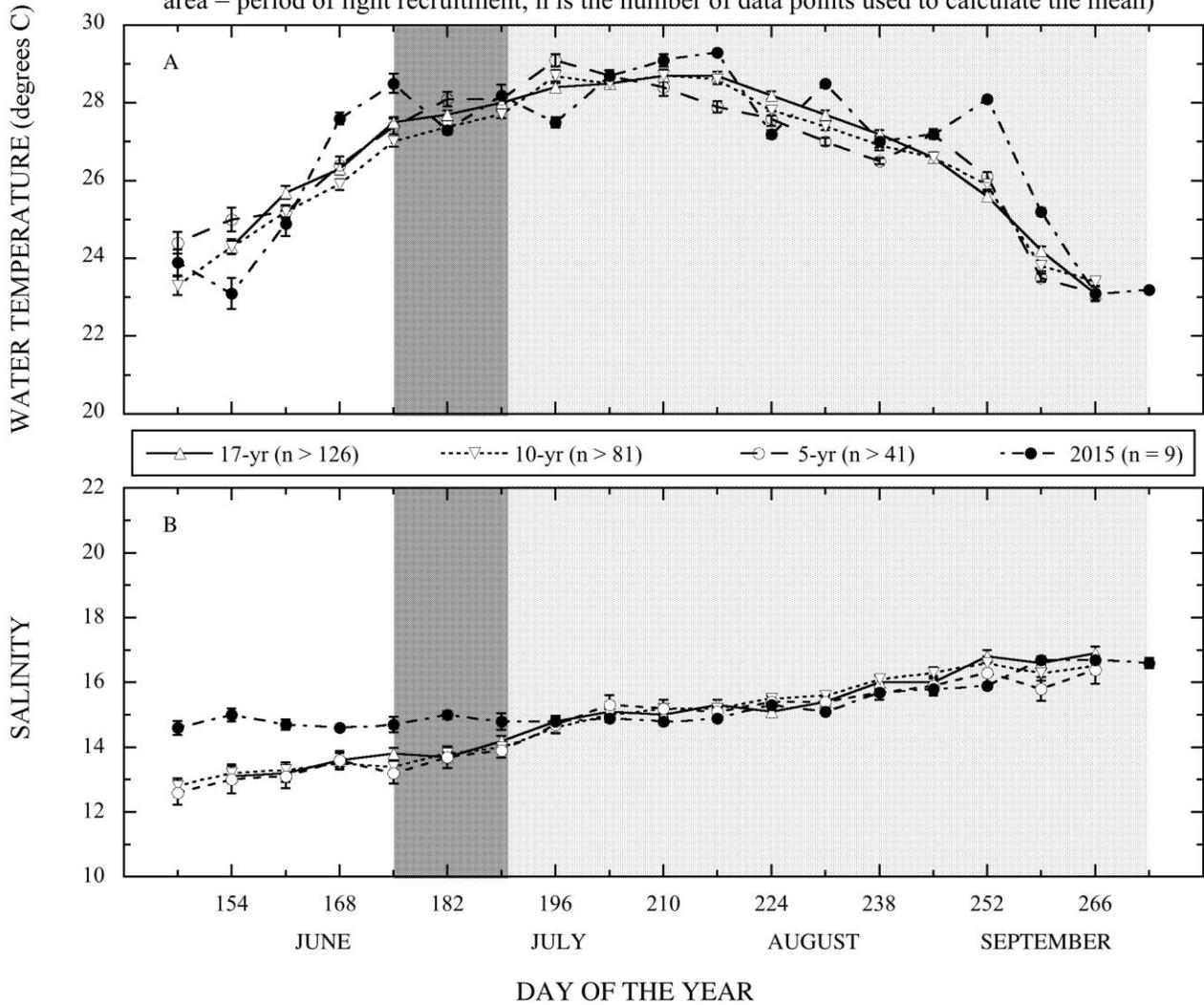


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE RECRUITMENT PERIOD: 5, 10 AND 17-YEAR MEANS COMPARED WITH 2015
 (Error bars represent standard error of the mean; darker shaded area = period of heavy recruitment; lighter shaded area = period of light recruitment; n is the number of data points used to calculate the mean)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2015

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 bar surveys conducted during October 2015.

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 this report 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 2015 are shown in Figure D1. Geographic coordinates of the bars are given in Table D1.

Four samples of bottom material were collected on each bar using an oyster scrape/dredge. In all surveys in the York River and Mobjack Bay (through 2015), in surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers in 1990 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 four samples collected at each bar for live oysters and box counts after conversion to a full bushel.

From each half-bushel sample, the number of market oysters (76 mm = 3-in. in length or larger), small oysters (< 76 mm, excluding spat), spat (recently settled, 2015 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 6 October and 21 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 168.5 bushel⁻¹ at Nansemond Ridge to a high of 2,669.5 bushel⁻¹ at Mulberry Point. The total number of live oysters at Mulberry Point was the highest observed over the past twenty-five years of monitoring. The total number of live oysters was the second highest observed at Deep Water Shoal, Horsehead, Swash, Dry Shoal, Wreck Shoal and Thomas Rock and the third highest observed at Point of Shoal since prior to 1990. When spat are excluded, the total number of small and market oysters combined was the second highest (Deep Water Shoal and Mulberry Point), third highest (Thomas Rock) and fourth highest (Point of Shoal and Long Shoal) observed over the past twenty-five years. At Swash the total number of small and market oysters combined was the highest observed since monitoring began at that site in 1996. 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 2015 was in the middle of that observed over the past twenty-

five years of monitoring, the majority of these were spat with the number of small and market oysters combined ranking the third lowest observed since prior to 1990.

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 several sites in the system. All of the sites monitored had low to moderate numbers of market oysters ranging from a low of 1.0 bushel⁻¹ at Nansemond Ridge to a high of 128.0 bushel⁻¹ at Point of Shoal. There was a notable increase (Figure D2) in the number of market oysters at Horsehead and Long Shoal when compared with 2014, and Long Shoal had the highest number of market oysters observed over the past twenty-five years of monitoring (Figure D3B). There was a notable decrease in the number of market oysters at Mulberry Point and Swash (Figure D2), and Mulberry Point had the lowest number observed over the past twenty-five years of monitoring (Figure D3A). The number of market oysters at Wreck Shoal has been steadily increasing since about 2009 (approximately a three-fold increase over the seven-year time period; Figure D3C) and while 2015 did not have a notable increase in the number of market oysters when compared with 2014, it still had the highest observed since prior to 1990.

The average number of small oysters bushel⁻¹ ranged from a low of 6.5 at Nansemond Ridge to a high of 1,291.5 at Mulberry Point. When compared with 2014, there was a notable decrease in the number of small oysters at Long Shoal (Figures D2 and D3). Despite this decrease the number of small oysters observed at Long Shoal still ranked the fourth highest over the past twenty-five years of monitoring. Comparing 2015 with the past twenty-five years, the number of small oysters was the third highest at Thomas Rock, the second highest at Mulberry Point and the highest at Swash, as well as the third lowest at Nansemond Ridge.

The number of small oysters at Nansemond Ridge was at very low levels (Figure D3C) for the seventh year in a row.

Overall, settlement in the James River in 2015 was relatively high with a relatively large increase when compared with 2014 numbers at all ten sites monitored (Figure D2 and D3). The average number of spat bushel⁻¹ ranged from a low of 161.0 at Nansemond Ridge to a high of 1,373.5 at Swash. Since 2008, settlement in the James River has had several strong year classes (2008, 2010 and 2012). Settlement in 2015 produced another strong year class, with the average number of spat bushel⁻¹ ranking among the highest (highest to fourth 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 mid-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 2015, the majority of the oysters at the eight most upriver sites were a split between small and market oysters whereas the majority of the oysters at the two most downriver sites (Thomas Rock and Nansemond Ridge) were primarily spat, somewhat similar to the historical patterns observed in the system (Figure D1 and D3).

The average number of boxes bushel⁻¹ was low, ranging from 5.5 at Nansemond Ridge to 62.0 at Swash. Boxes accounted for less than 6% of the total (live oysters plus boxes) at all ten sites. Greater than 20% of the boxes at Horsehead, Long Shoal, Dry Shoal and Wreck Shoal were new boxes, indicating some recent mortality at those four sites. At Deep Water Shoal and Mulberry Point 35 and 29% of the boxes respectively were spat boxes. Given the large number of spat observed at both of those sites,

this is not unexpected. There were very few boxes observed at Nansemond Ridge and the majority of these were spat boxes. Two out of the seven 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 14.9 and 17.2°C (Table D2). Salinity was variable depending on location in the river, increasing in a downriver direction, from 4.6 at Deep Water Shoal to 14.7 at Wreck Shoal. The salinities at both Thomas Rock and Nansemond Ridge were slightly lower (13.8 and 14.1 respectively) than at Wreck Shoal despite being located further downriver.

York River

In the York River, the average total number of live oysters bushel⁻¹ was 201.5 at Bell Rock and 296.5 at Aberdeen Rock. The live oysters at Bell Rock were primarily a 50/50 split of market and small oysters (approximately 85% of the total), with a small percentage of spat. When compared with 2014, there was a notable decrease in the number of small oysters and an increase in the number of spat observed at Bell Rock (Figure D4). At Aberdeen Rock there was a fairly large increase in the number of spat when compared with 2014 (Figure D4), such that 2015 had the highest number of spat observed over the past twenty-five years of monitoring, almost three times higher than the next highest year. (Figure D5). There was a small increase in the number of small oysters observed at Aberdeen Rock when compared with 2014 (Figure D4). The number of market oysters at Aberdeen Rock was the fourth highest observed since prior to 1990. The average number of boxes bushel⁻¹ was moderate (37.0 bushel⁻¹) at Bell Rock and low (19.5 bushel⁻¹) at Aberdeen Rock,

accounting for approximately 16 and 6% of the total oysters (live oysters plus boxes) at Bell Rock and Aberdeen Rock respectively. The majority (>75%) 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 3.0: 14.2 at Bell Rock and 17.2 at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 483.0 and 1,359.0 oysters bushel⁻¹ respectively. There was a very large increase in the number of spat observed at both bars when compared with 2014 (Figure D4). Settlement at Pultz Bar was the highest observed over the past twenty-five years of monitoring, seven times higher than the next highest year (Figure D6) and spat accounted for 91% of the oysters observed at that site. Settlement at Tow Stake was the second highest observed over the past twenty-five years of monitoring (Figure D6) with spat accounting for 63% of the live oysters observed at that site. The number of market oysters at Pultz Bar however, remains low (Figure D6). The number of market oysters observed at Tow Stake remained relatively stable between 2009 and 2014, but almost doubled in 2015, such that 2015 was the highest observed since prior to 1990. The total number of boxes observed in the system was low, accounting for 2 (Pultz Bar) and 6% (Tow Stake) of the total (live oysters plus boxes). The majority of boxes at Tow Stake were old boxes, whereas those at Pultz Bar were primarily a 50/50 split of old and spat boxes. This is not unexpected given that the majority of the live oysters at Pultz Bar were spat. All of the spat boxes observed at both sites 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 19 (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 789.0 at Ginney Point to a high of 1,068.5 at Burton Point. There was a notable increase in the number of small oysters at all three sites when compared with 2014 (Figures D7 and D8). This increase resulted in the highest number of small oysters observed over the past twenty-five years of monitoring at all three sites. While the number of market oysters was slightly lower when compared with the previous two years at Ginney Point and Palace Bar, the number of market oysters throughout the river has remained relatively stable since about 2008 (Figure D8). When compared with 2014, there was a notable increase in the number of spat at Burton Point (Figure D7) and 2015 had the highest settlement at that site in thirteen years (since 2002). The number of boxes observed was low, accounting for 1 (Palace Bar) to 3% (Burton Point) of the total (live oysters plus boxes). The majority (>70%) of boxes at all three sites were old. For the first time in several years, none of the observed 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 ranged between 18.9 (Burton Point) and 19.6°C (Ginney Point) and salinity was between 16.6 (Ginney Point) and 17.8 (Burton Point).

Rappahannock River

In the Rappahannock River, the average total number of live oysters bushel⁻¹ ranged from a low of 34.5 at Morattico Bar to a high of 462.0

at Drumming Ground. As is typical for the Rappahannock River system, there appeared to be no relationship between the total number of live oysters and location in the river (i.e., upriver vs. downriver: Figure D1), temperature or salinity (Table D2). 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 2015. 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 2015 numbers were similar to those observed prior to the decrease in 2011.

The average number of market oysters bushel⁻¹ ranged from a low of 14.5 at Morattico Bar to a high of 108.0 at Drumming Ground. When compared with 2014, there was a relatively small increase in the number of market oysters observed at Bowler's Rock, Smokey Point and Middle Ground and a larger increase observed at Drumming Ground (Figure D9 and D10). There was a relatively small decrease in market oysters observed at Ross Rock and Morattico Bar (Figure D9 and D10). Overall the number of market oysters in the Rappahannock River in recent years has been on the rise and 2015 ranked among the highest to fourth highest over the past twenty-five years at eight out of the ten sites monitored. At the three most upriver sites (Ross Rock, Bowler's Rock and Long Rock) market oysters accounted for greater than 53% of the live oysters observed. The number of market oysters at Ross Rock steadily increased between 2008 and 2014 such that there were approximately twice as many market oysters observed in 2014 compared with 2008 (Figure D10A). However, the number of market oysters at Ross Rock decreased in 2015, essentially

eliminating the gain in numbers seen between 2008 and 2014.

As in previous years (with the exception of 2014), Drumming Ground had the highest number of small oysters bushel⁻¹ (Figure D9 and D10). When compared with 2014, there was a relatively small decrease in the number of small oysters observed at Ross Rock and Long Rock (Figure D9 and D10). The number of small oysters was the second highest observed at Hog House and the fifth lowest observed at Parrot Rock since prior to 1990 (Figure D10).

Overall, settlement in the Rappahannock River in 2015 was relatively high, ranging from 2.0 spat bushel⁻¹ at Bowler's Rock to 326.0 spat bushel⁻¹ at Broad Creek. There was at least one spat found at each of the ten sites. When compared to 2014, there was a notable increase in the number of spat observed at all ten sites (Figure D9). Settlement ranked among the highest to the fifth highest observed over the past twenty-five years of monitoring at nine out of the ten sites. The one exception was Ross Rock, which typically has very little to no settlement, so any settlement at that site is considered good.

The average total number of boxes bushel⁻¹ was low, accounting for less than 9% of the total (live oysters plus dead) at all ten sites monitored. Greater than 20% of the total boxes at Middle Ground and Broad Creek were new boxes, indicating some recent mortality at those sites.

Water temperature on the day of sampling ranged from 19.4 to 20.0°C. Salinity increased as one moved from the most upriver site (Ross Rock: 6.7) toward the mouth (Broad Creek: 17.6).

Great Wicomico River

In the Great Wicomico River, the average total number of live oysters bushel⁻¹ ranged from a low of 329.0 at Fleet Point to a high of 547.0 at Haynie Point. When compared with 2014, there was a fairly large increase in the number of market oysters observed at Whaley's East (Figure D11) and overall the number of market oysters at all three sites was among the highest observed over the past twenty-five years of monitoring (Figure D12). When compared with 2014 numbers, there was a notable decrease in small oysters and an increase in spat at all three sites (Figure D11). The increase in spat observed at Haynie Point and Fleet Point was much larger than that observed at Whaley's East. Overall, settlement in 2015 was relatively moderate, especially compared to the high numbers that have become more prevalent in the system over the past several years (since about 2006). The total number of boxes bushel⁻¹ was low to moderate accounting for 9, 8 and 11% of the total (live oysters plus boxes) at Haynie Point, Whaley's East and Fleet Point respectively. The majority (>76%) of the boxes at all three sites were old. Water temperature on the day of sampling was around 19°C and salinity was around 17 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 60.9 market oysters bushel⁻¹). However, over the past nine years, the number of market oysters on the thirty bars that are sampled annually has been slowly, but steadily increasing, 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.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2015, the largest majority of the oysters were spat accounting for approximately 52% of the population with approximately 39% small oysters and 8% market oysters. At fourteen of the thirty sites monitored, spat accounted for greater than 50% of the live oysters present, with small oysters dominating at five out of the thirty sites. The three most upriver sites in the Rappahannock River (Ross Rock, Bowler's Rock and Long Rock) were the only sites with greater than 50% market oysters. However, all of these sites have relatively low (less than 102 oysters bushel⁻¹) oyster populations. The oyster population in the Piankatank River has 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). The numbers of both small and market oysters at all three sites in the Piankatank River in 2015 were the highest observed over the past twenty-five years of monitoring.

Settlement during 2015 varied widely throughout the Virginia portion of the bay, but was moderate to high (greater than 100 spat bushel⁻¹) everywhere except at Bell Rock in the York River and at the more upriver sites (Hog House to Ross Rock; Figure D1) in the Rappahannock River. Settlement was exceptionally high (greater than 1,000 spat bushel⁻¹) at Deep Water Shoal, Mulberry Point and Horsehead in the James River and at Pultz

Bar in the Mobjack Bay. 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 2015, the highest settlement was again observed at the more downriver sites, but for the first time since 2010, at least one spat was observed at each of the ten sites in the system.

The average total number of boxes observed during 2015, was low to moderate at most sites, accounting for less than 16% of the total (live oysters plus boxes) oysters at all thirty sites and less than 10% of the total (live oysters plus boxes) at twenty-eight 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 2015 Nansemond Ridge and Broad Creek were the only sites that had a relatively large number of small and market size boxes (approximately 21% of the total, live and dead, at both sites). However, it should be noted that the oyster population at Nansemond Ridge has remained very low for several years. At the majority of the other sites (nineteen of twenty-eight), 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 2015, there were drill holes present in spat boxes at Nansemond Ridge in the James River and at Pultz Bar and Tow Stake in Mobjack Bay. 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 2015 were again marked with a fairly high number of spat boxes with drill holes in several 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 York River and Mobjack Bay during the patent tong survey in November and December of 2015 (Southworth, personal observation), so the predation of spat by oyster drills in these systems remains a concern.

Table D1: Station locations for the 2015 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 2015. 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	10/21	17.2	4.6	108.5	610.5	1033.5	1752.5	2.0	15.5	9.5	27.0
Mulberry Point	10/21	16.4	5.7	4.5	1291.5	1373.5	2669.5	5.0	18.5	9.5	33.0
Horsehead	10/21	16.7	6.9	56.5	980.5	1066.0	2103.0	13.5	32	4.5	50.0
Point of Shoal	10/21	16.5	7.9	128.0	657.5	689.0	1474.5	8.0	30.5	6.0	44.5
Swash	10/21	16.8	7.7	7.5	1094.0	982.5	2084.0	8.5	51.0	2.5	62.0
Long Shoal	10/21	16.3	8.5	76.0	696.5	492.0	1264.5	8.5	30.5	2.0	41.0
Dry Shoal	10/21	16.7	12.5	80.0	467.5	534.5	1082.0	10.0	27.5	2.5	40.0
Wreck Shoal	10/21	17.2	14.7	100.5	215.0	381.0	696.5	11.5	25.5	3.5	40.5
Thomas Rock	10/20	15.9	13.8	29.0	72.0	292.0	393.0	1.0	11.5	2.5	15.0
Nansemond Ridge	10/20	14.9	14.1	1.0	6.5	161.0	168.5	0.0	2.0	3.5	5.5
York River											
Bell Rock *	10/8	19.9	14.2	92.0	84.5	25.0	201.5	5.0	31.5	0.5	37.0
Aberdeen Rock	10/8	20.5	17.2	20.0	53.0	223.5	296.5	2.5	14.5	2.5	19.5
Mobjack Bay											
Tow Stake	10/8	19.7	19.0	113.0	66.5	303.5	483.0	0.5	20.5	9.0	30.0
Pultz Bar	10/8	19.9	19.0	9.0	115.0	1235.0	1359.0	2.0	9.5	10.0	21.5
Piankatank River											
Ginney Point	10/6	19.6	16.6	84.0	433.5	271.5	789.0	0.0	17.0	1.0	18.0
Palace Bar	10/6	19.4	17.2	21.0	577.0	305.0	903.0	0.5	8.0	3.0	11.5
Burton Point	10/6	18.9	17.8	117.0	262.5	689.0	1068.5	4.0	23.5	3.5	31.0
Rappahannock River											
Ross Rock	10/16	19.4	6.7	54.5	42.0	5.5	102.0	0.0	2.0	0.0	2.0
Bowler's Rock	10/16	19.4	9.3	69.5	20.5	2.0	92.0	0.0	4.0	1.0	5.0
Long Rock	10/16	19.5	9.4	69.0	10.5	3.5	83.0	1.0	5.0	0.0	6.0
Morattico Bar	10/16	19.6	12.1	14.5	12.0	8.0	34.5	0.0	2.0	0.0	2.0
Smokey Point	10/16	19.9	14.4	33.0	36.0	48.0	117.0	0.0	2.0	1.0	3.0
Hog House	10/16	20.0	16.2	26.5	43.0	81.5	151.0	0.0	5.0	6.0	11.0
Middle Ground #	10/16	20.0	15.5	23.0	125.0	154.5	302.5	3.0	8.0	2.0	13.0
Drumming Ground	10/16	19.9	14.9	108.0	156.0	198.0	462.0	2.5	17.5	5.0	25.0
Parrot Rock	10/16	19.9	16.8	66.5	28.0	175.5	270.0	4.5	13.5	8.0	26.0
Broad Creek	10/16	19.8	17.6	57.5	46.0	326.0	429.5	7.5	20.0	10.5	38.0
Great Wicomico River											
Haynie Point	10/14	19.0	16.8	117.0	169.0	261.0	547.0	4.0	45.5	3.0	52.5
Whaley's East	10/14	18.6	17.0	69.5	209.0	132.0	410.5	5.0	28.0	3.0	36.0
Fleet Point	10/14	18.7	16.9	70.5	118.5	140.0	329.0	4.5	30.0	5.0	39.5

Figure D1: Map showing the location of the oyster bars sampled during the 2015 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.

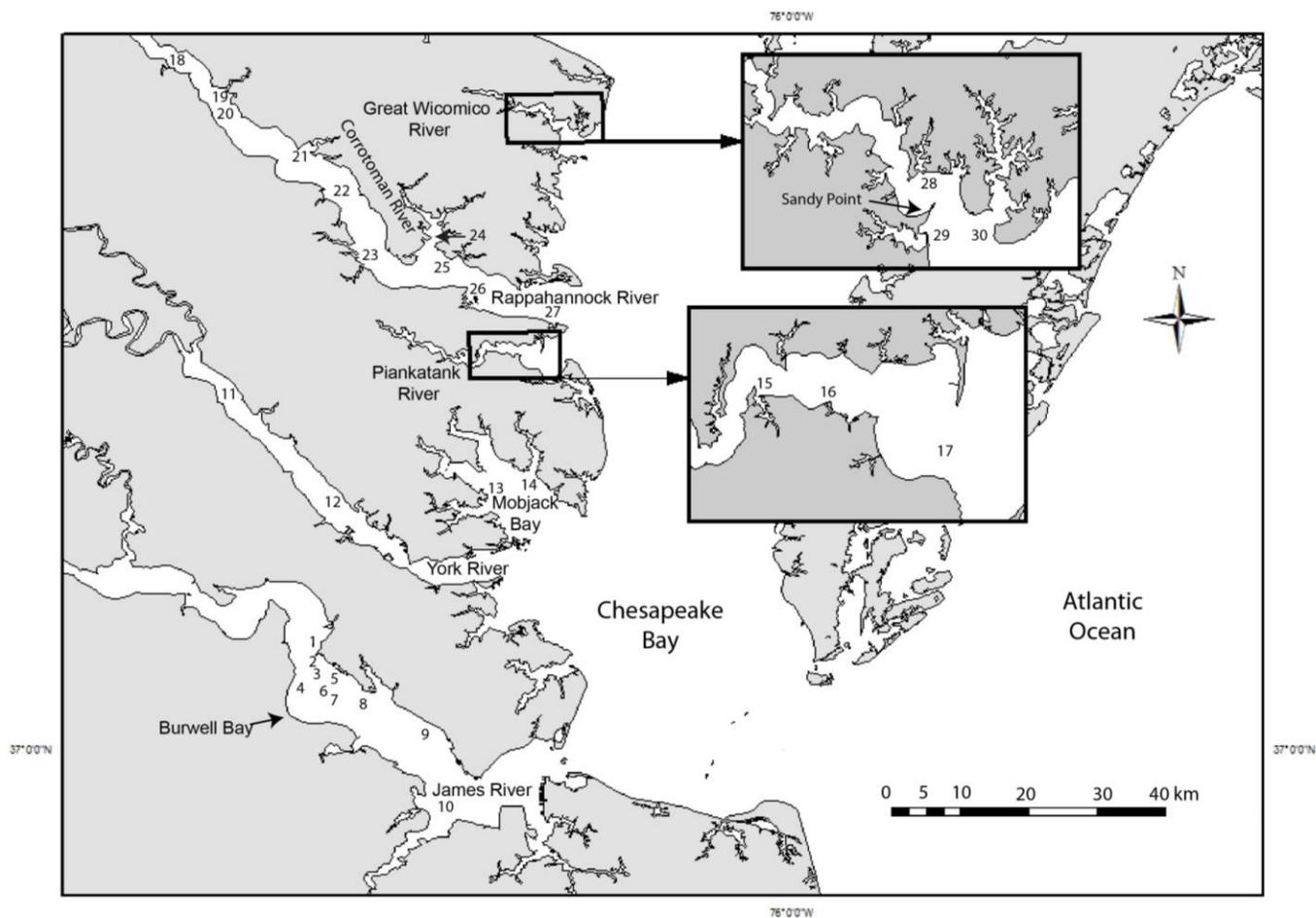


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE JAMES RIVER (2014-2015)
 (Error bars represent standard error of the mean)

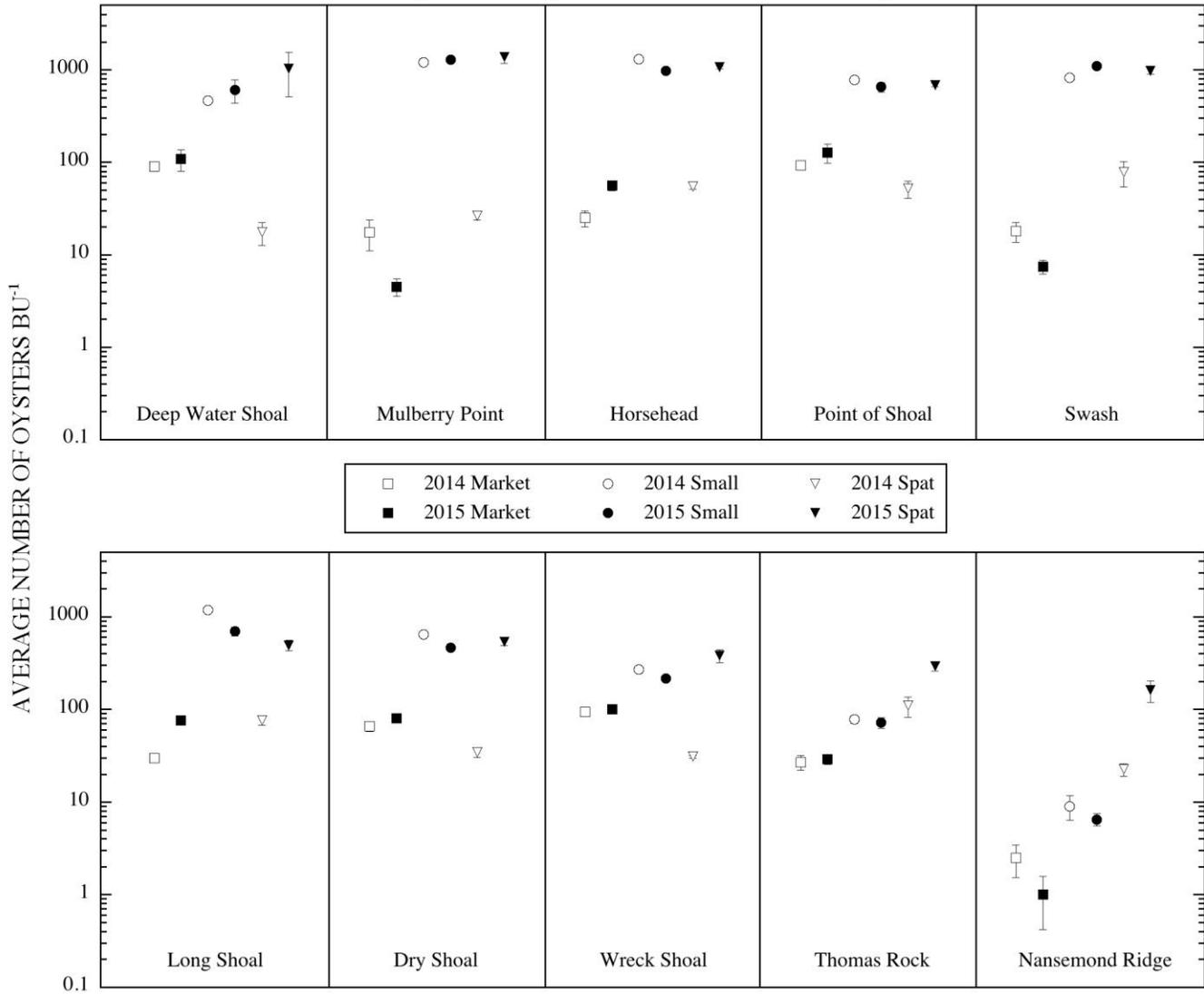
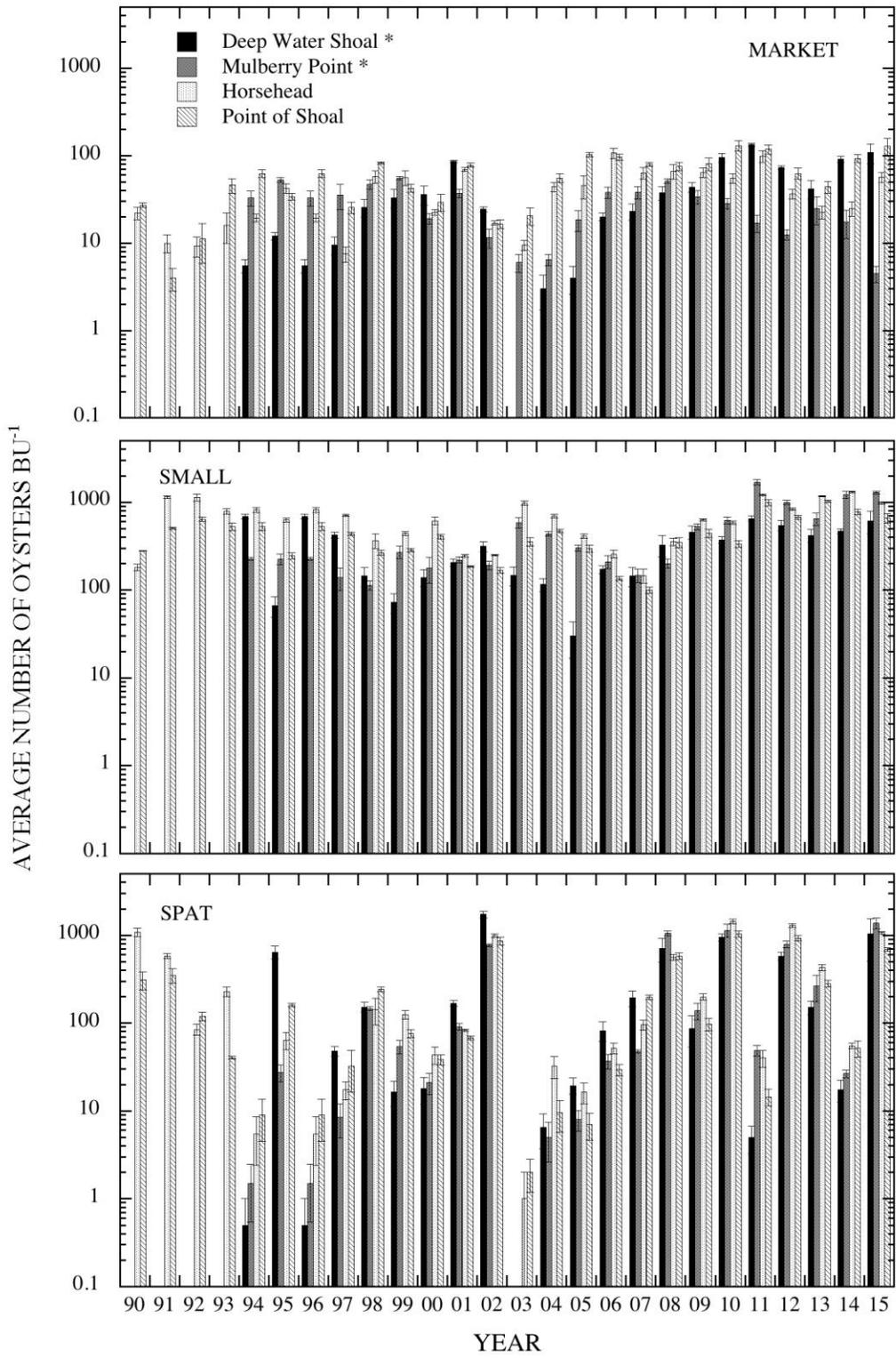


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



* No data prior to 1994

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

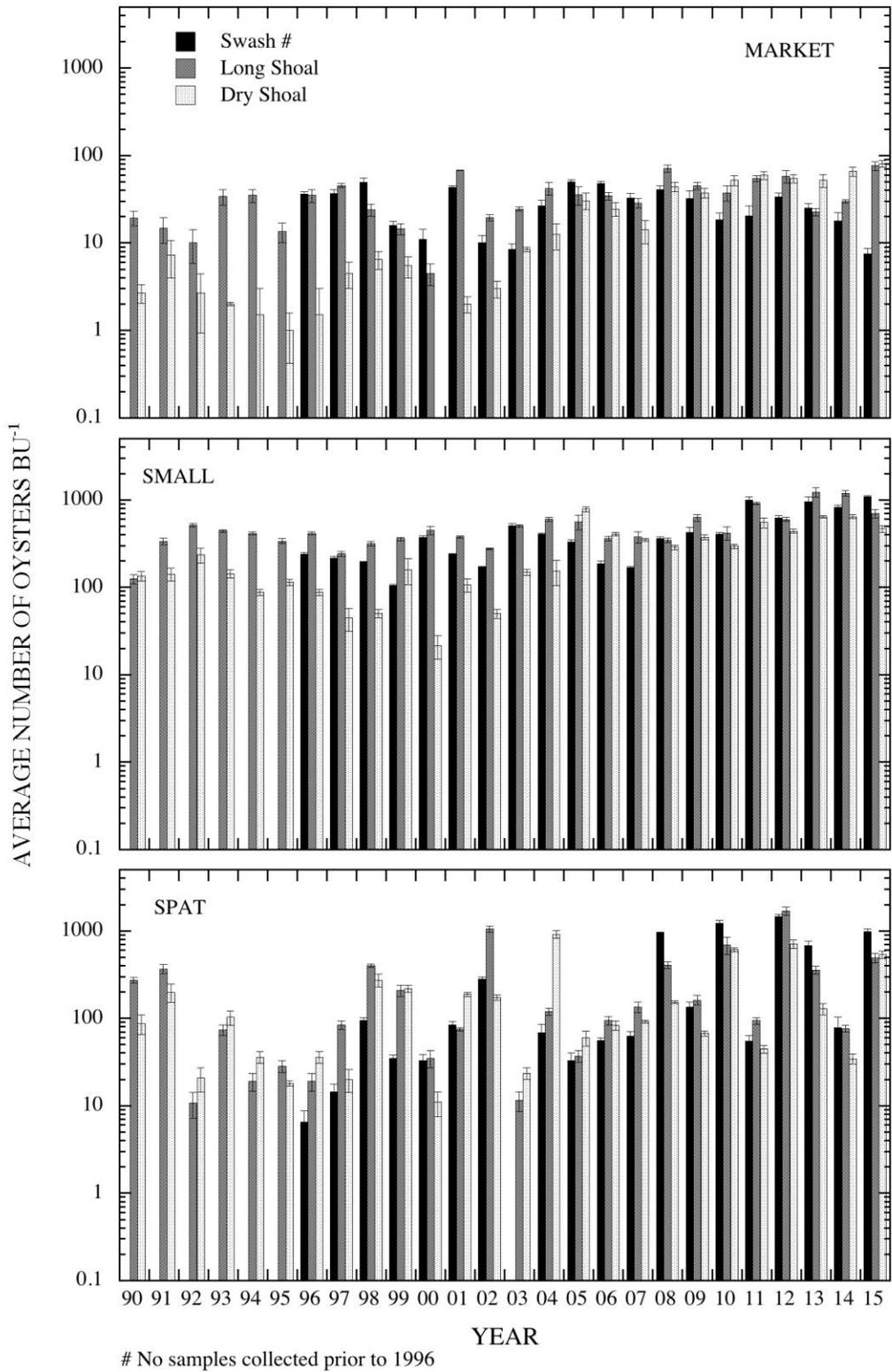


FIGURE D3C: JAMES RIVER OYSTER TRENDS
 OVER THE PAST 25 YEARS
 (Error bars represent standard error of the mean)

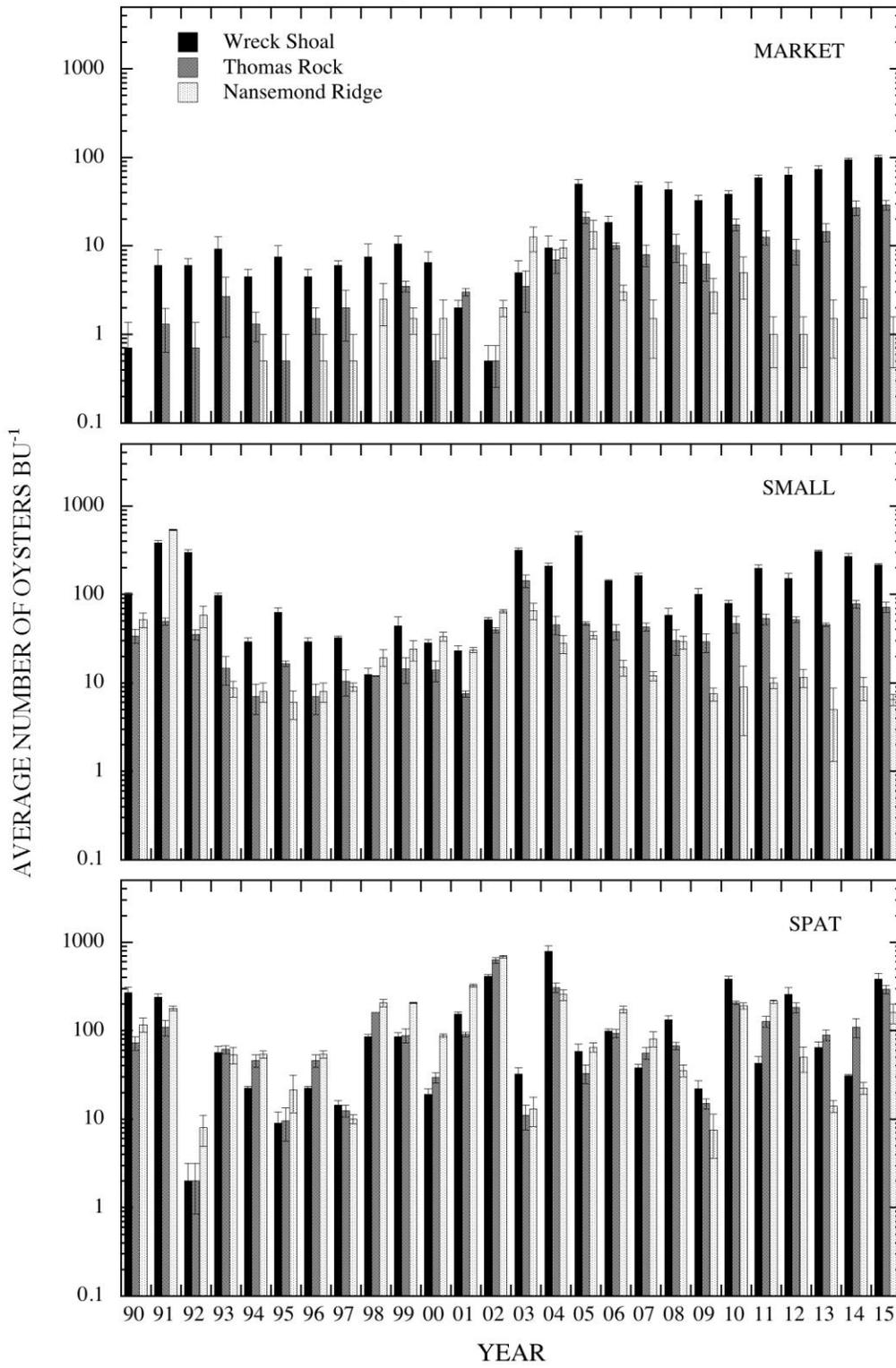


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE YORK RIVER AND MOBJACK BAY (2014-2015)
 (Error bars represent standard error of the mean)

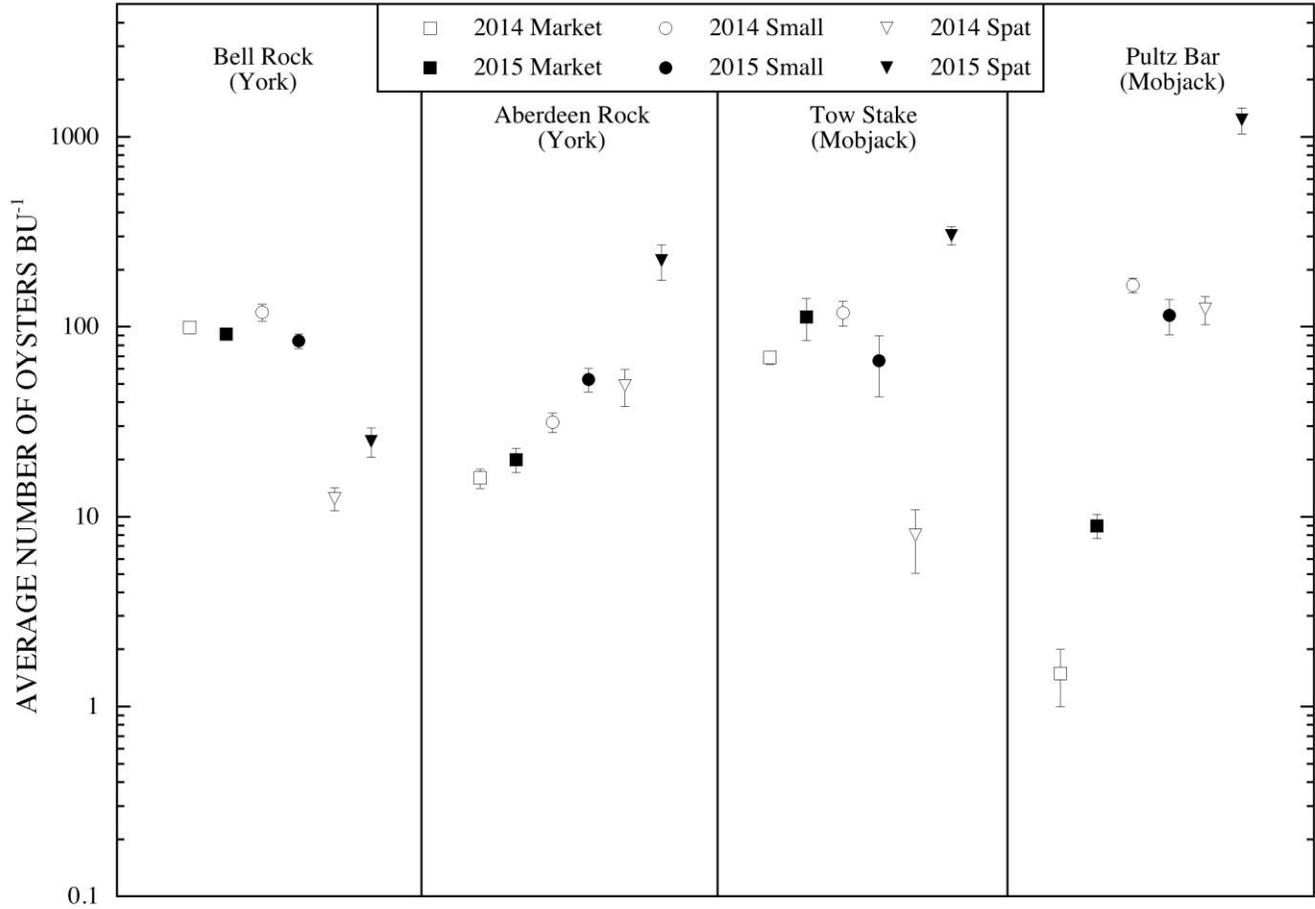


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

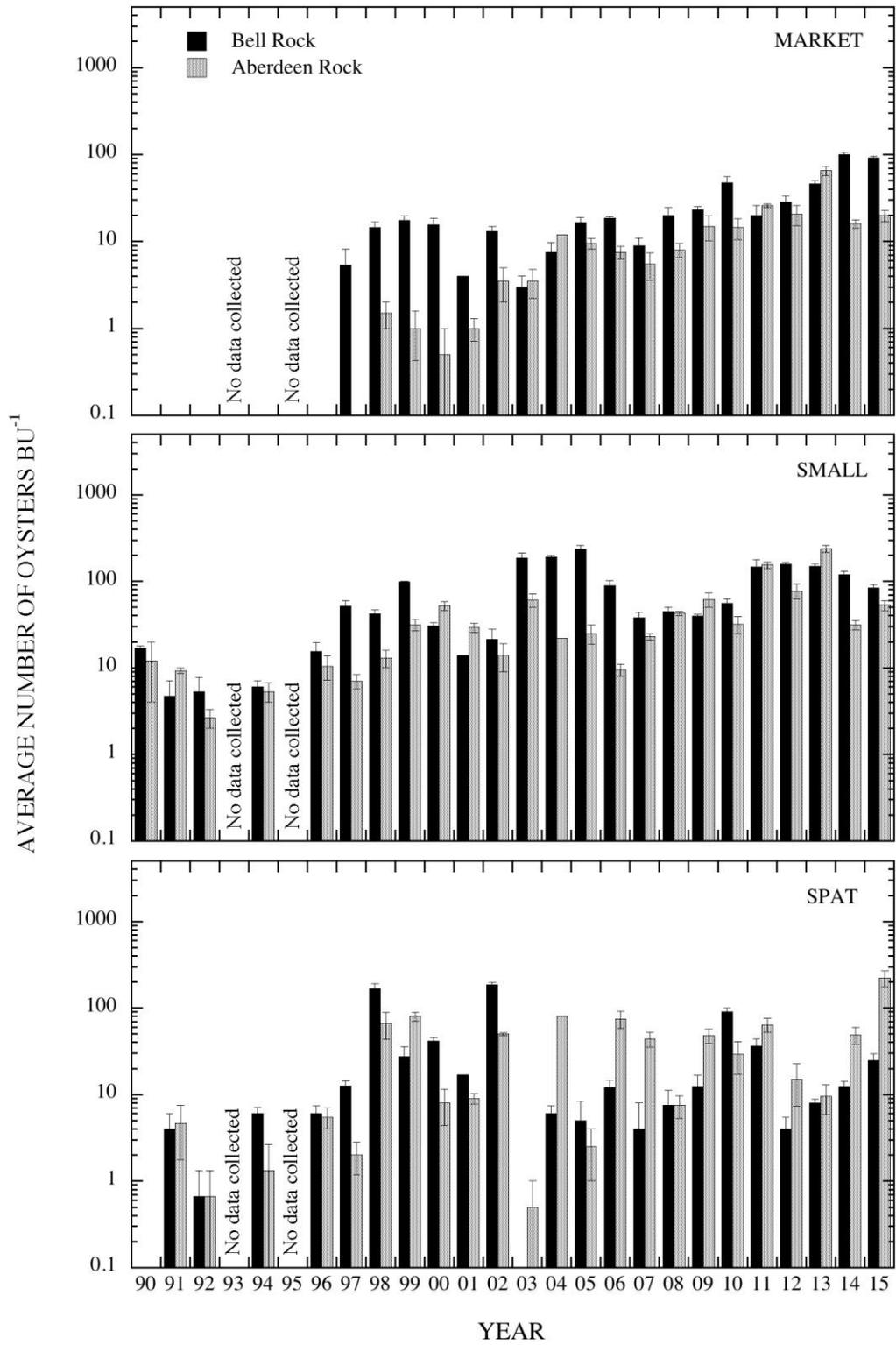


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

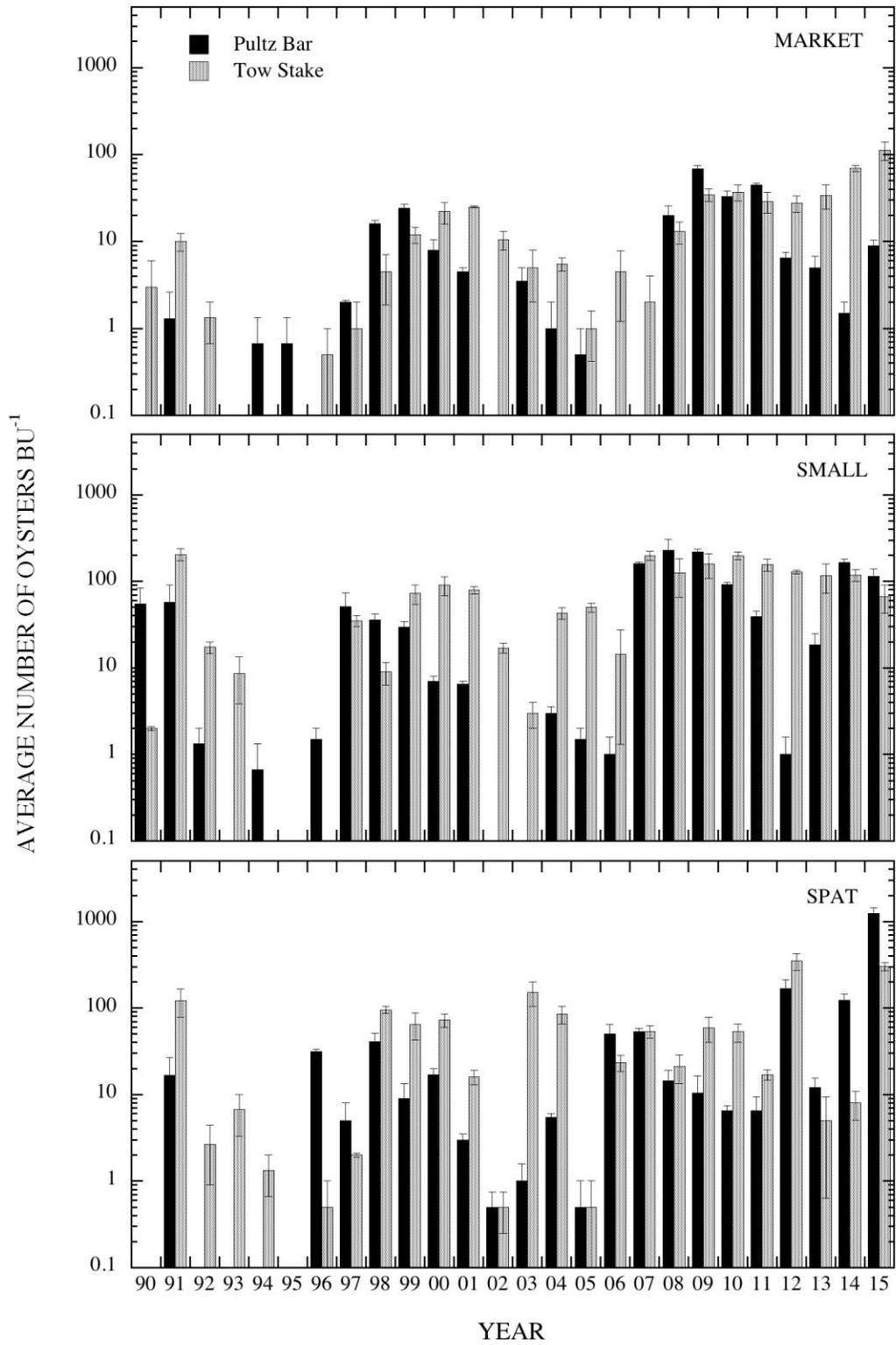


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE PIANKATANK RIVER (2014-2015)
 (Error bars represent standard error of the mean)

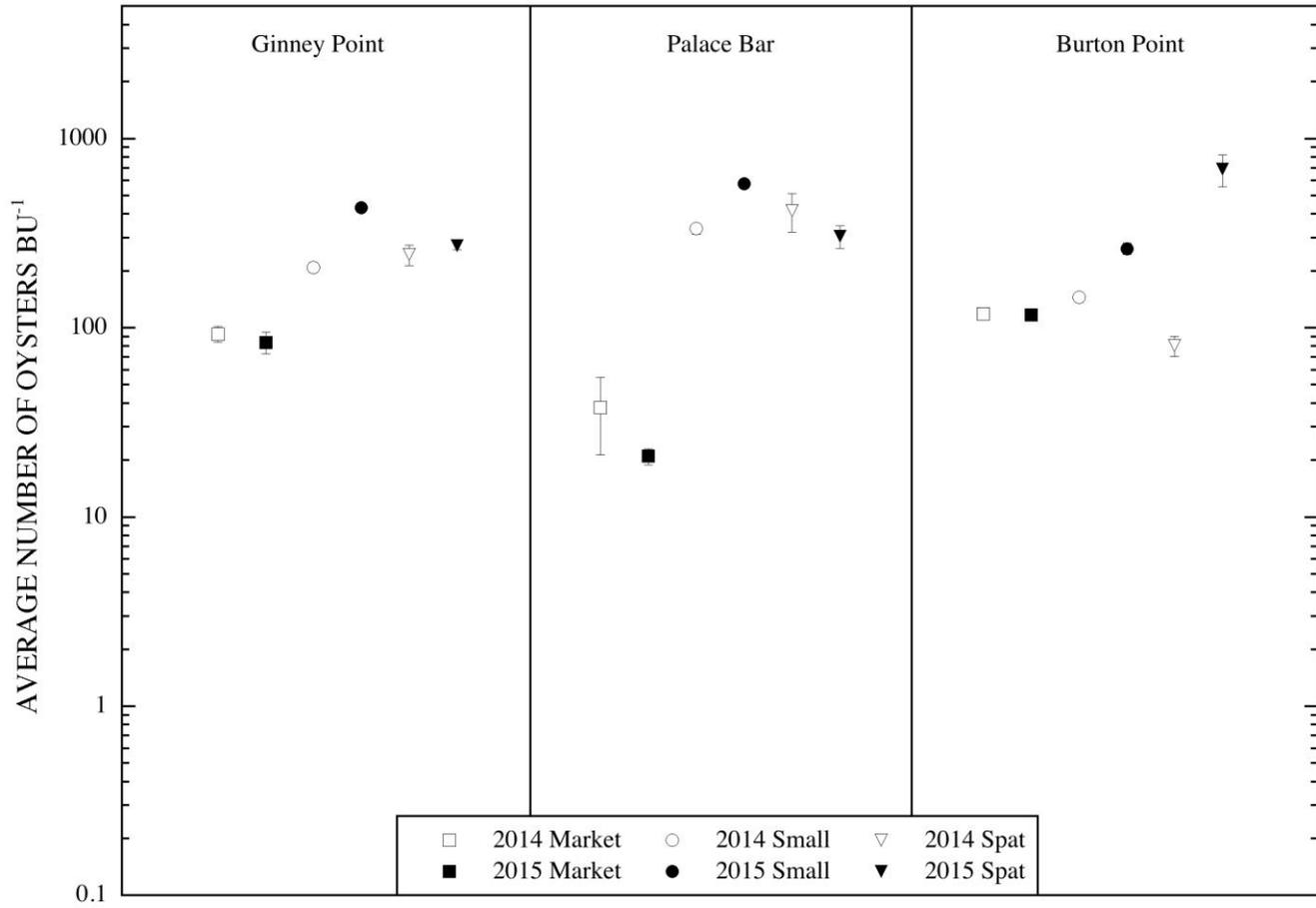


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
 OVER THE PAST 25 YEARS
 (Error bars represent standard error of the mean)

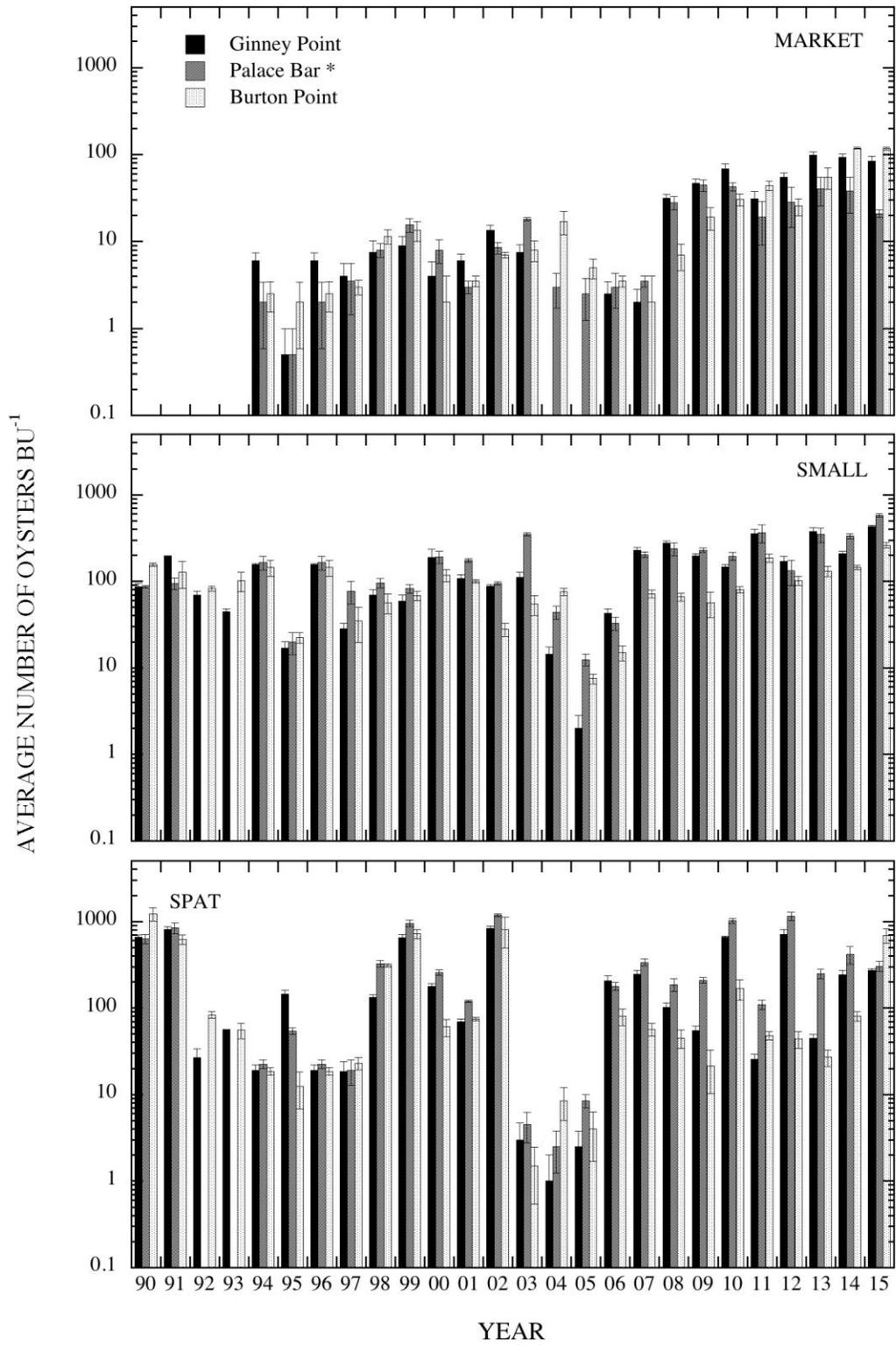


FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2014-2015)
 (Error bars represent standard error of the mean)

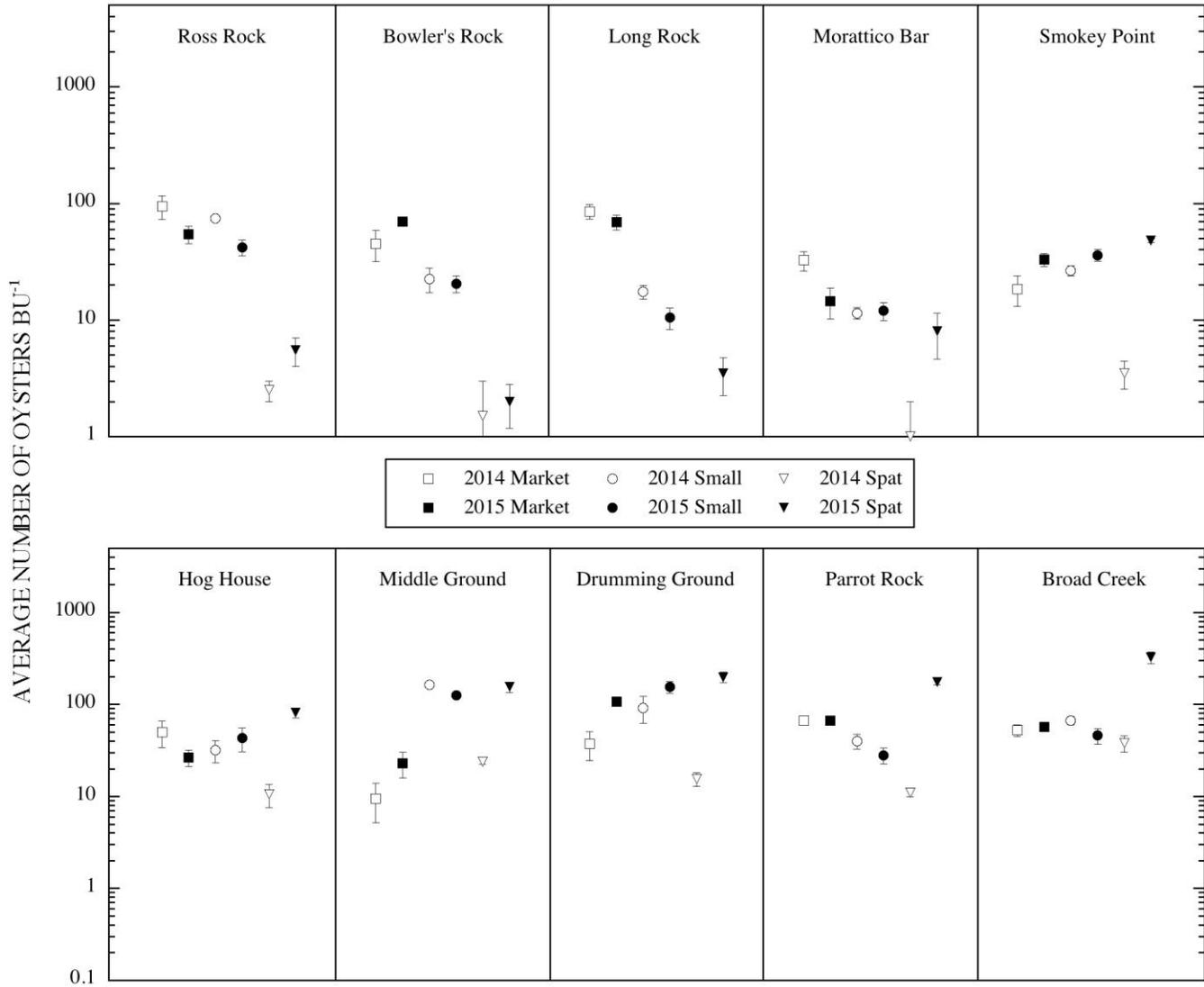


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

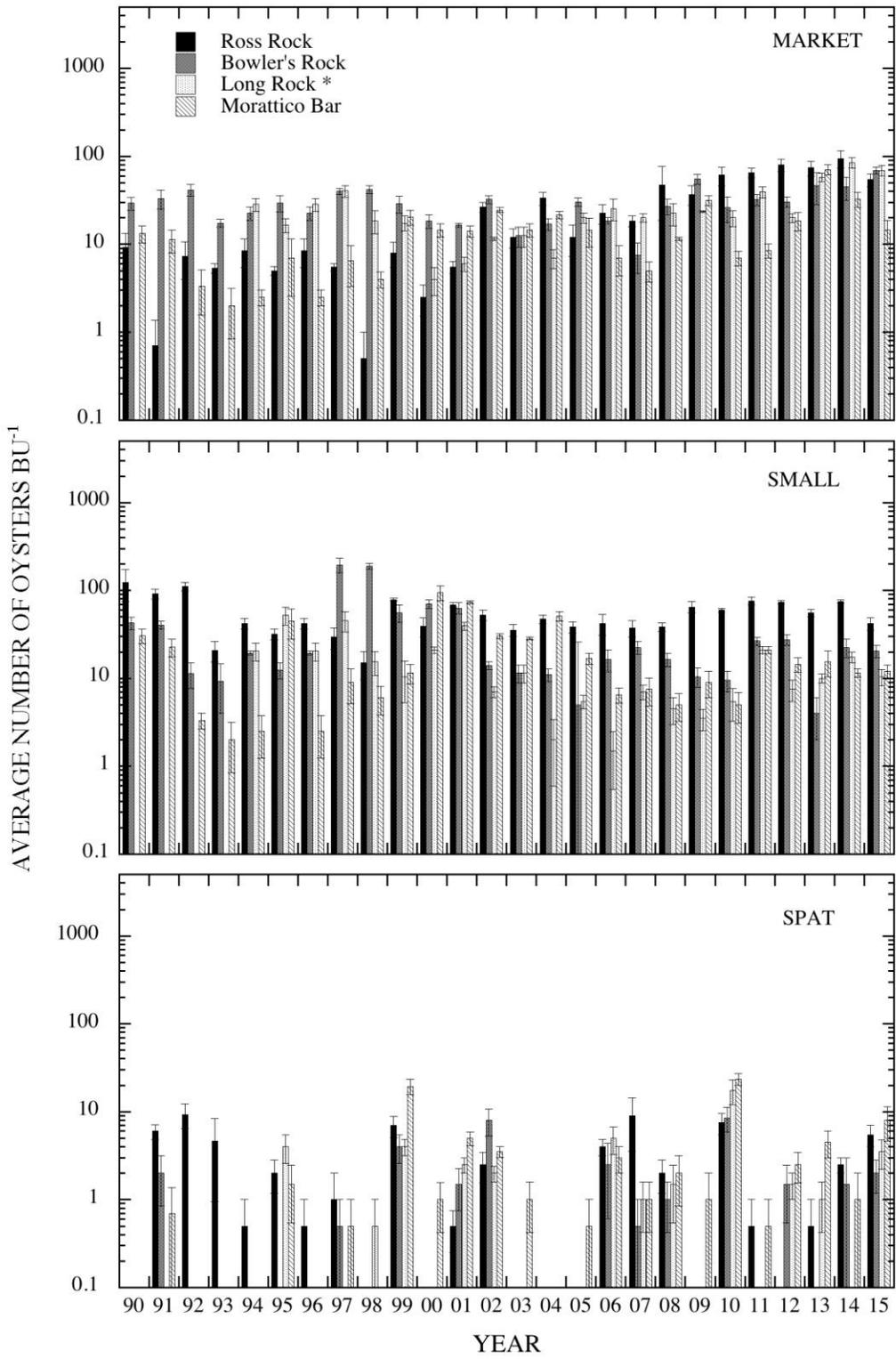


FIGURE D10B: RAPPAHANNOCK RIVER OYSTER TRENDS
 OVER THE PAST 25 YEARS
 (Error bars represent standard error of the mean)

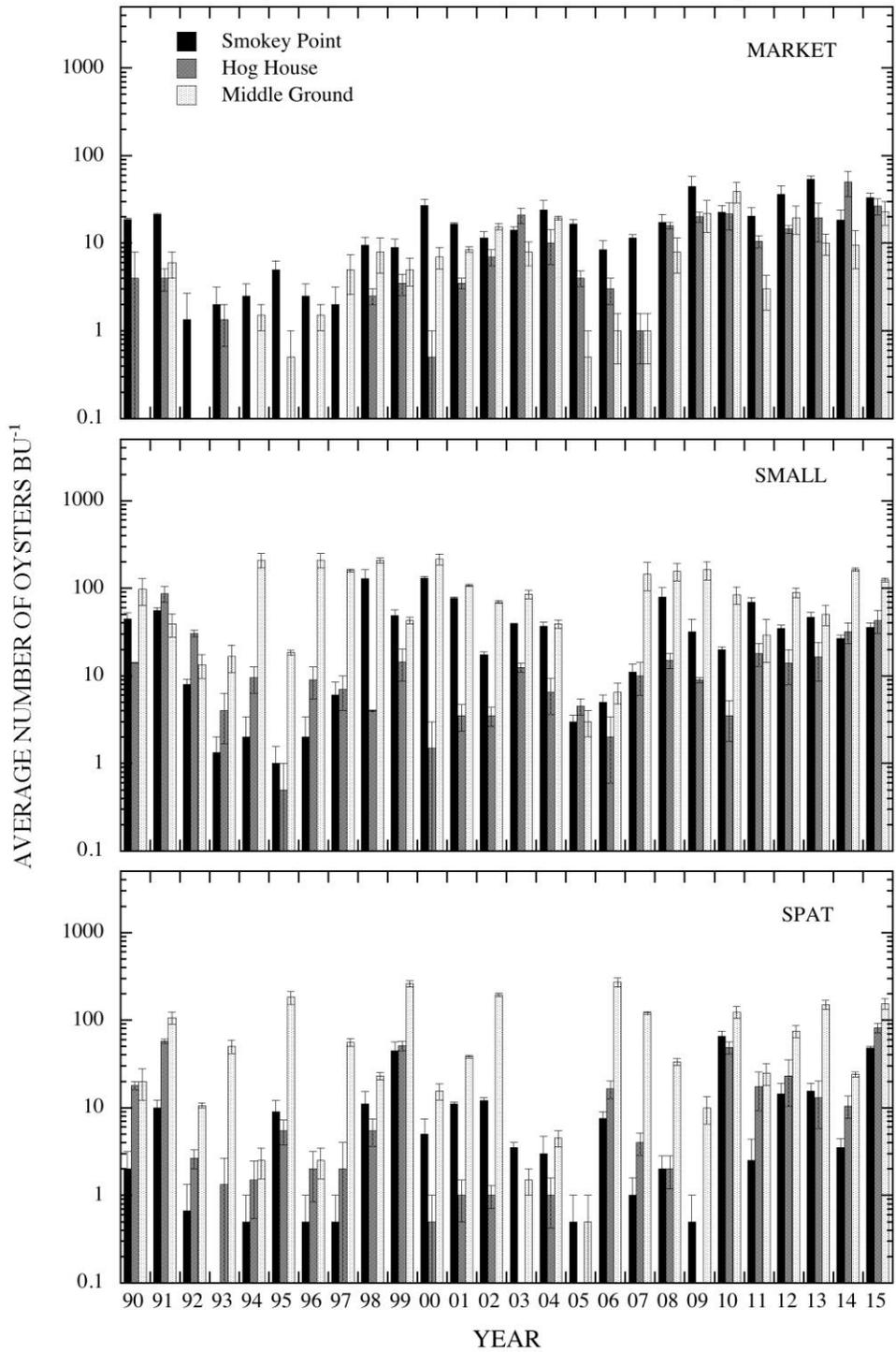


FIGURE D10C: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

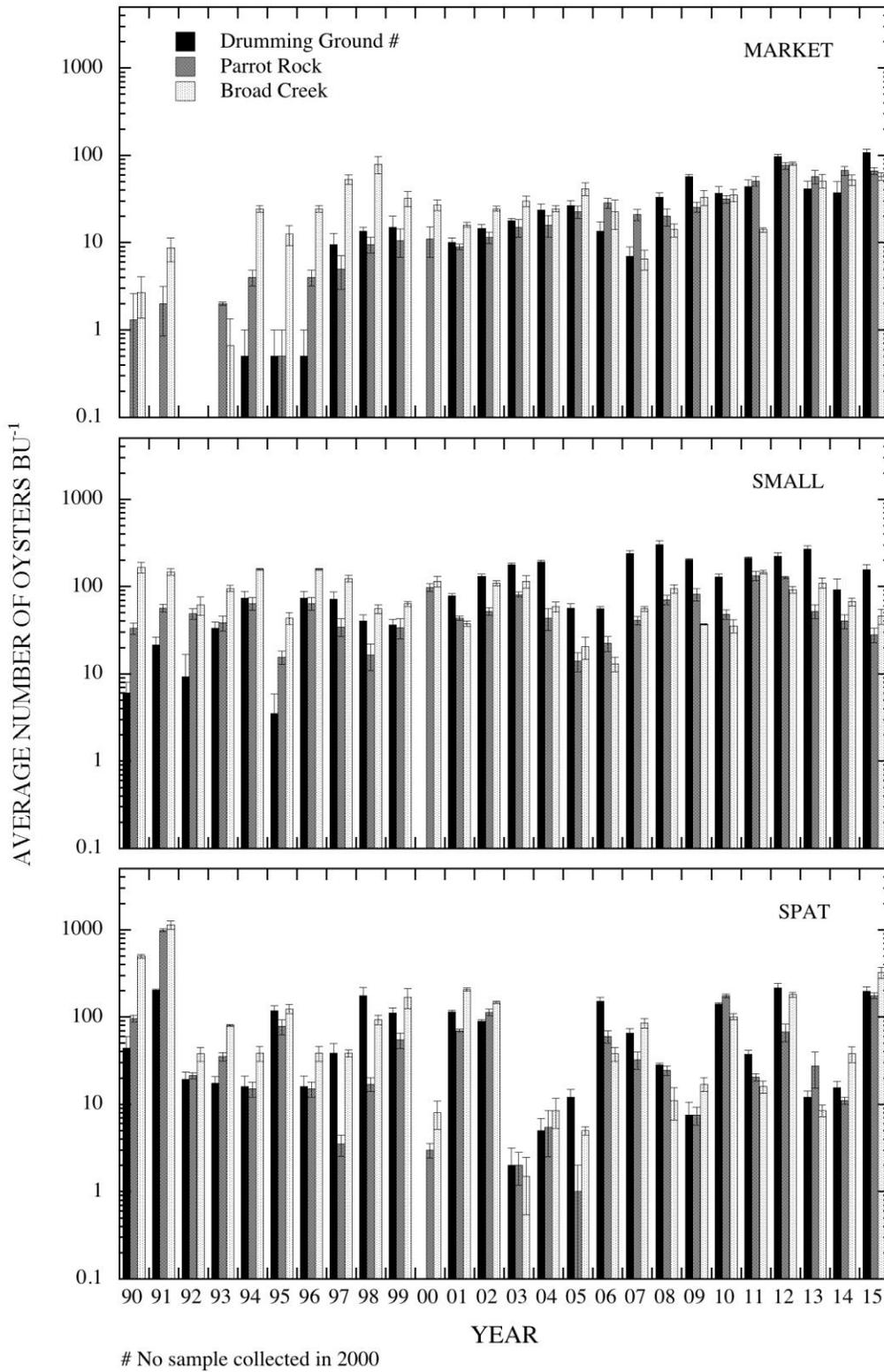


FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
 IN THE GREAT WICOMICO RIVER (2014-2015)
 (Error bars represent standard error of the mean)

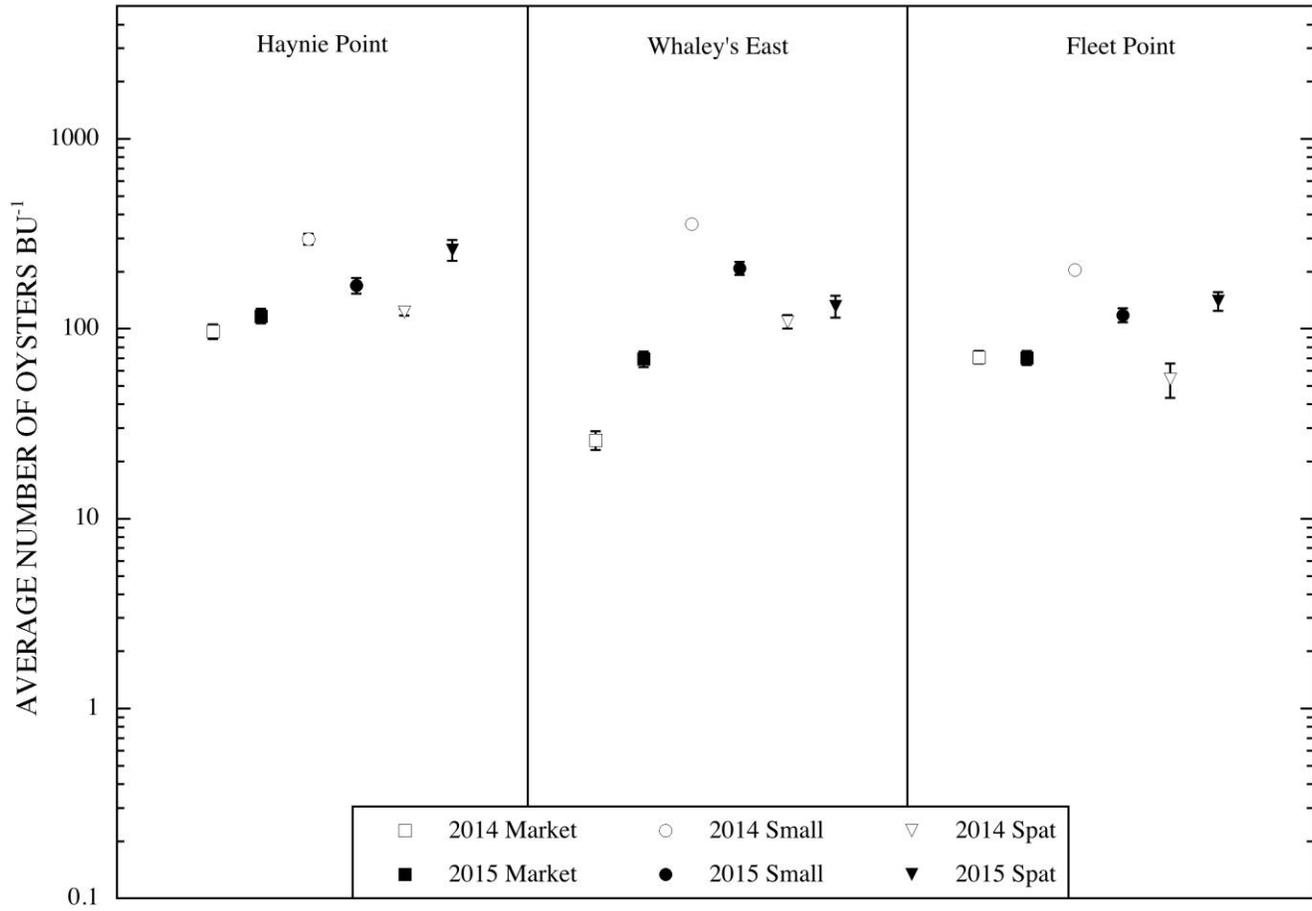
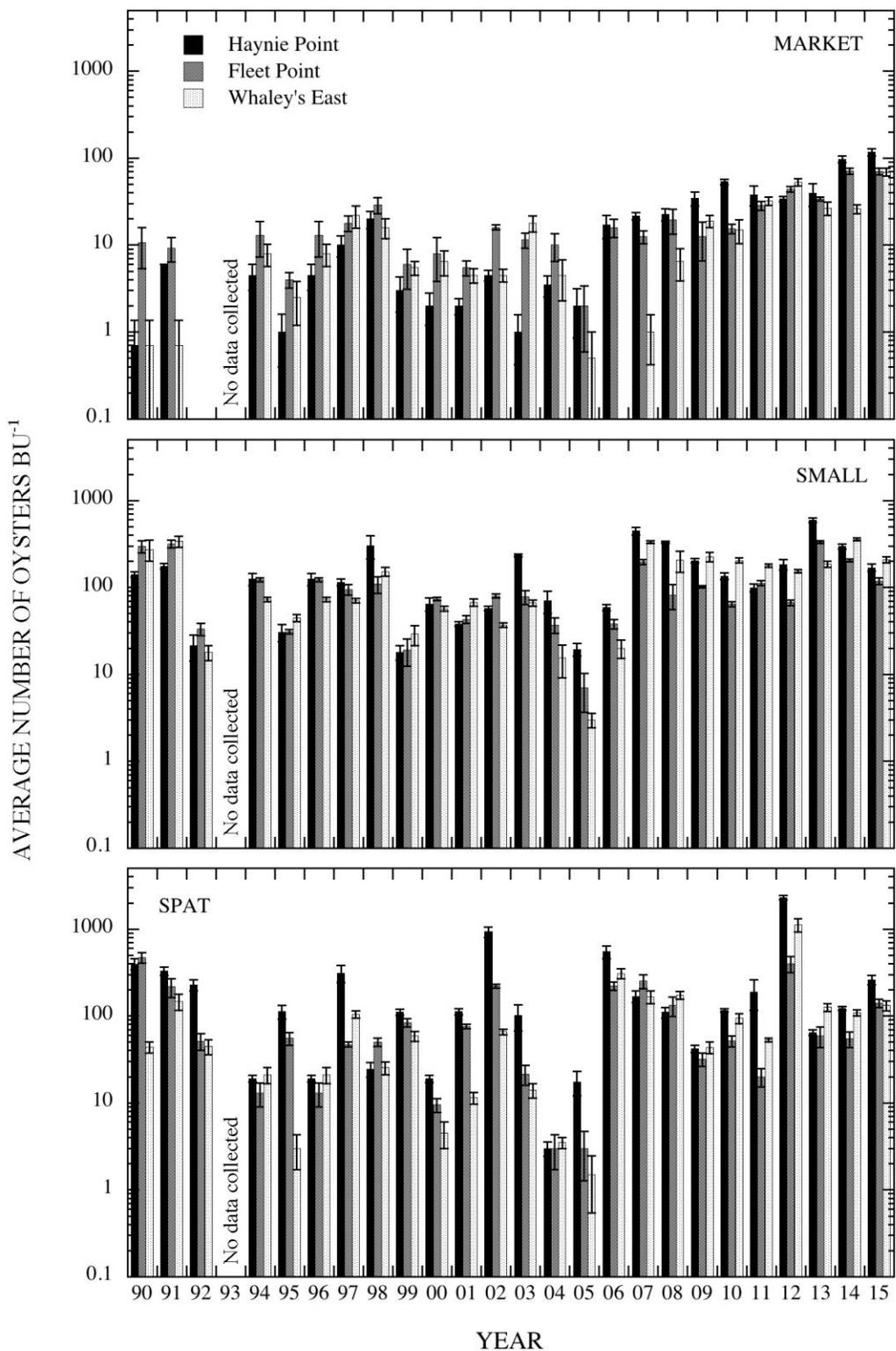


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



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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 and Wayne Reisner (VIMS Field Operations) for help with vessel operations. Patricia McGrath (VIMS Fisheries Science) assisted in making the shellstrings and in field collection. Matthew Long and Steven Cantara assisted in field collection. Cindy Forrester (Department of Fisheries Science, Budget Manager) and Grace Tisdale (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, Jim Goins and Terri Major. Roland Billups and Robin Rennie 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. Vernon Rowe, John Ericson and Kyle Jones of the VMRC provided assistance during the fall 2015 dredge survey.

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