The Status of Virginia's Public Oyster Resource 2019

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Part I. OYSTER RECRUITMENT IN VIRGINIA DURING 2019

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[1] (settlement and recruitment of larval oysters to the post metamorphic form termed spat) collectors (shellstrings) at various sites in three Virginia 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 recruitment 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. Survival of spat on bottom cultch is 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 the settlement process and survival of spat on the bottom. Therefore, spatfall on shellstrings may not directly correspond with recruitment on bottom cultch at all times or places.

This report summarizes data collected during the 2019 settlement season in three tributaries in the Virginia portion of the Chesapeake Bay.

[1] A number of terms are used to describe various stages of the settlement (behavior, larvae seeking the substrate), metamorphosis (irreversible change in morphology accompanying transition from larval to attached form), and subsequent growth to the juvenile (attached, small version of the adult) progression of oysters. Spat is commonly used to describe the early post metamorphic attached form. Spatfall "set" or "strike"is used commonly used to describe the continuum resulting in spat. For the current report we use the common term spatfall to reflect the end point of settlement and metamorphosis on shellstrings, and recruitment to reflect survival of juvenile oysters on bottom substrate (cultch) in the following fall surveys.

METHODS

Spatfall during 2019 was monitored in the James, Piankatank and Great Wicomico Rivers from the week of May 20 through the week of September 30. Spatfall sites included eight historical sites in the James River, three historical and five modern sites in the Piankatank River and five historical and four modern sites in the Great Wicomico River (Figure S1). In this report, "historical" sites refer to those that have been monitored annually for at least the past twenty-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[2]. The change in the number and location of shellstring sites during 1998 was implemented to provide a means of 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 and these "new" sites have become permanent oyster spatfall monitoring sites.

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

Although shellstring collectors at most sites were deployed for 7-day periods, there were some deviations such that shellstring deployment periods during 2019 ranged from 6 to 21 days. These periods do not always coincide among the different rivers monitored or in different years. Therefore, spat counts for different deployment dates and periods were standardized to correspond to the 7-day standard periods specified in Table 1 to allow for comparison among rivers and years. Standardized spat shell^{-1} (S) was computed using the formula: $S = \sum$ spat shell^{-1} / weeks (W) where W = number of days deployed / 7. Standardized weekly periods allow comparison of spatfall trends over the course of the season between various sites in a river as well as between data for different years.

[2] https://www.vims.edu/research/units/labgroups/molluscan_ecology/archive/restoration/va_restoration_atlas/indexmap/index.php

[3] https://www.vims.edu/research/units/labgroups/molluscan_ecology/_docs/Shellstring_manual.pdf

The cumulative spatfall for each site was computed by adding the standardized weekly values of spat shell^{-1} for the entire sampling period. This value represents the average number of spat that would fall on any given shell if allowed to remain at that site for the entire sampling period. Note that 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).

RESULTS

Spatfall on shellstring collectors during 2019 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of spatfall over the past twenty-five years (1994-2019) at the historical sites in all three-river systems and over the past twenty-one years (1998-2019) 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 spatfall 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 2019 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 typically 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 2019. Comparisons were made over the past twenty-one 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 spatfall in the James River was first observed during the week of May 27 at Rock Wharf (Table S1). From the week of June 17 to July 8, spatfall was light throughout the system. The bulk of spatfall in the James River in 2019 occurred from the third week of July through the end of the monitoring period (Table S1 and Figure S3). Spatfall during this period accounted for 92 (Point of Shoal) to 99% (Deep Water Shoal) of the spatfall for the year. There was a notable peak in spatfall during the weeks of August 5 and 12 at every site except Deep Water Shoal. Overall spatfall during these two weeks accounted for 47% of the spatfall in the system for the year (Figure S3). Spatfall at Deep Water Shoal was light to moderate throughout the monitoring period, with the bulk of spatfall (63%) occurring in September.

Cumulative spatfall in the James River during 2019 was heavy at all eight sites monitored. Spatfall ranged from a low of 20.2 cumulative spat shell^{-1} at Deep Water Shoal to a high of 82.7 cumulative spat shell^{-1} at Rock Wharf (Table S1; Figure S4). Spatfall during 2019 was higher than the previous year (2018) at Deep Water Shoal, Horsehead, Point of Shoal, Rock Wharf and Day's Point. Spatfall in 2019 was higher than the 5, 10, 20 and 25-year means at Deep Water Shoal, Horsehead, Point of Shoal and Rock Wharf (see Fig. S1) and higher than the twenty-five year mean at Dry Shoal, Wreck Shoal and Day's Point. Spatfall in 2019 at Deep Water Shoal, Point of Shoal and Rock Wharf was in the upper range of that observed during the past twenty-five years of monitoring (the 92nd percentile at Deep Water Shoal and the 88th percentile at Point of Shoal and Rock Wharf). Spatfall at all eight sites ranked in the 72nd percentile or higher. The long-term means are primarily driven by a few exceptionally high spatfall years (2002, 2008, 2010, 2012, 2016 and 2018), three of which have occurred in the past five years.

Average river water temperature in the James River during the 2019 monitoring period ranged from a low of 23.3 to a high of 28.9°C (Figure S5A). Water temperature was several degrees higher than normal (Figure S5A) several times during the monitoring period. The most notable times were in late May/early June when monitoring began, in early July, when temperature reached the max two weeks earlier than is typical, and again at the end of August into early September (Figure S5). After reaching the max for the year (28.9°C) during the week of July 8, temperature then decreased and was around 1°C less than the 5-yr mean during the week of July 22. It should be noted however, that there were several weeks in mid-June, a week in mid-July and several weeks during September when weather was such that samples were not able to be collected.

Average salinities in the James River during 2019 ranged from 6.5 to 16.9 (Figure S5B), generally increasing throughout the monitoring period. Salinity throughout the monitoring period was typically similar to or slightly higher than the long-term (5, 10, 20 and 30-yr) means. The one exception was in mid-June (week of June 17) when salinity was 3 less than the long-term means. Salinity quickly increased and by the following week was 2 to 3 greater than the long-term means. 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 6 and 12, with the largest differences occurring earlier in the season; by mid-July, the difference in any given week was typically less than 8.

Piankatank River

Spatfall in the Piankatank River was first observed during the week of June 10 at Ginney Point, Palace Bar, Heron Rock and Cape Toon (Table S1; Figure S6). Spatfall was variable for most of the monitoring period, with little to no spatfall during the weeks of July 15 and 22. Spatfall was heaviest during three separate weeks (June 24 and September 2 and 9), with 42 (Heron Rock) to 83% (Bland Point) of the total spatfall for the year settling during these three weeks. Spatfall throughout the Piankatank River was generally higher in August and September, with 63% of the spatfall for the year occurring during these two months.

Cumulative spat shell^{-1} for the year was heavy at all eight sites monitored in the Piankatank River in 2019, ranging from a low of 14.4 cumulative spat shell^{-1} at Palace Bar to a high of 92.0 cumulative spat shell^{-1} at Bland Point (Table S1; Figure S7). Spatfall during 2019 was higher than that observed during 2018 at Bland Point, Cape Toon, Stove Point and Burton Point. Spatfall was also higher than the 20-yr mean at Bland Point, Heron Rock, Cape Toon and Stove Point and higher than the 25-yr mean at Burton Point. Spatfall in 2019 was lower than both the 5 and 10-yr means at all eight sites monitored (Table S2; Figure S7A). Spatfall at the three historical sites was in the 64th (Ginney Point), 68th (Palace Bar) and 84th (Burton Point) percentile over the past twenty-five years. At the modern sites, spatfall was the fourth (Bland Point and Stove Point; 85th percentile), sixth (Heron Rock; 76th percentile), seventh (Cape Toon; 71st percentile) and tenth (Wilton Creek; 57th percentile) highest observed since monitoring began at those sites in 1998.

The average water temperature during the 2019 sampling period in the Piankatank River ranged from 22.8 to 29.8°C, reaching the maximum in late July, as is typical for the river system (Figure S8A). Water temperature in the Piankatank River was similar to the long-term means (5, 10, 20 and 30-yr) throughout much of the monitoring period. The two exceptions were in late May/early June when monitoring first began, and during the first few weeks of July. Water temperature was 1 to 2°C higher than the long-term means during both of these periods (Figure S8A). Water temperature in the Piankatank fluctuated a good bit from one week to the next in late August into early September and was slightly higher than the 5-yr mean at the end of the monitoring period.

Salinity in the Piankatank River during 2019 ranged from 10.9 to 18.4 (Figure S8B) and generally increased over the duration of the monitoring period. From late May, when monitoring began, through early August, salinity was anywhere from 1 to 3 less than the long-term means (5, 10, 20 and 30-yr). Salinity continued to increase throughout August and September, ending the monitoring period 2 to 3 higher than the long-term means (Figures S8B). In any given week, the difference recorded between the most upriver site (Wilton Creek) and the most downriver site (Burton Point; see Figure S1) ranged from a low of less than 1 to a high of 3.

Great Wicomico River

Spatfall in the Great Wicomico River was first observed during the week of June 3 at all nine sites monitored. Spatfall from the week of June 3 through the week of July 1, was moderate to heavy every week, with 94 (Glebe Point) to 99% (Harcum Flats and Haynie Point) of the spatfall for the year occurring during this five-week period. In particular, 88% of the spatfall overall occurred during the weeks of June 10, June 24 and July 1. Spatfall from July 8 through the rest of the monitoring period was light and variable (Table S1; Figure S9). Approximately 69% of the total spatfall for the year at Glebe Point occurred during the week of June 10.

Cumulative spat shell^{-1} for the year was extremely heavy, ranging from a low of 113.2 at Hilly Wash to a high of 298.8 at Shell Bar (Table S1; Figure S10). Spatfall in the Great Wicomico River in 2019 was higher than that observed in 2018, at all nine sites (Table S2; Figure S10). 2019 spatfall was also than the 5, 10, 20 and 25-yr means at Haynie Point and Fleet Point and higher than the 10, 20 and 25-yr means at Hudnall and Whaley's East. When compared with the past twenty-five years, spatfall in 2019, ranked in the 72nd (Glebe Point), 88th (Hudnall) and 96th (Haynie Point, Whaley's East and Fleet Point) percentile. When compared to the past twenty-one years, the four modern sites ranked in the 66th (Hilly Wash), 76th (Harcum Flats), 80th (Shell Bar) and 85th (Rogue Point) percentile. Spatfall in the Great Wicomico has been exceptionally consistent and heavy in almost every year since 2006. Spatfall numbers in 2019 ranked from the second (Haynie Point, Whaley's East and Fleet Point) to the eighth (Hilly Wash) highest within that smaller subset of fourteen (2006 to 2019) years.

The average river water temperature in the Great Wicomico River during the 2019 sampling period ranged from 22.1 to 30.1°C, reaching the maximum in late July, as is typical for the river system (Figure S11A). Water temperature in the Great Wicomico River fluctuated a good bit throughout the monitoring period. During the last week of May, water temperature was several °C higher than the 5, 10 and 20-yr means, but it then decreased and was slightly lower two weeks later. By the time water temperature reached the maximum for the year during the third week of July, it was again 1 to 2°C higher than the long-term means (Figure S11A). Water temperature in the Great Wicomico fluctuated a good bit from one week to the next in late August into early September and was slightly higher than the 5-yr mean at the end of the monitoring period.

Salinity in the Great Wicomico River during the 2019 sampling period ranged from 10.1 to 17.9 (Figure S11B). From late May, when monitoring began, through early August, salinity was anywhere from 1 to 3 less than the long-term means (5, 10 and 20-yr). Salinity continued to increase throughout August and September, ending the monitoring period 1 to 3 higher than the long-term means (Figures S8B). There was typically a 1 to 3 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, spatfall on the shellstrings was light to moderate; with 83% of all of the year/site combinations having a seasonal cumulative total of less than 10 spat shell^{-1}. However, spatfall on the shellstrings over the past twelve years (2008-2019) has been on the rise such that 88% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell^{-1}) and 35% 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 from 2006 to

2019, 87% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell^{-1}) and 49% of the total year/site combinations had extremely heavy spatfall (seasonal cumulative total of > 100 spat shell^{-1}; Table S2).

Overall, spatfall on shellstrings in the James River during 2019 was heavy at all eight sites monitored. Since 2008, the James River has had several very strong year classes (2008, 2010, 2012, 2016 and 2018). The mean cumulative spat shell^{-1} over all eight sites from 1994 to 2007 was 5.7, whereas the mean for all eight sites over the past twelve years (2008 to 2019) was 78.3. This translates to around a thirteen-fold increase in spatfall over the past twelve years compared with the previous fourteen years. Since 2008, at least three out of the eight sites experienced heavy to extremely heavy spatfall each year, with heavy or extremely heavy spatfall during 79% (76/96) of the year/site combinations with moderate spatfall during the remaining year/site combinations (20/96). The one exception was during 2009, when all eight sites monitored had moderate spatfall (Table S2). From 1994 to 2007 on the other hand, only 16% (18/112) of the year/site combinations had heavy or extremely heavy spatfall, with 16% (18/112) during that time period experiencing light spatfall. The majority of the spatfall in 2019 occurred in late July, August and September. This pattern of late recruitment has become rare in recent years (Southworth & Mann 2004), as the majority of spatfall throughout the Virginia portion of the Chesapeake Bay has tended to occur earlier in the season (late June, into early July).

Overall, spatfall in 2019 on the shellstrings in the Piankatank River was heavy on all eight sites monitored. Similar to the James River, the Piankatank River has had several very strong year classes in recent years (2012, 2015 and 2016). From 1994 to 2006 (historical sites) and 1998 to 2006 (modern sites), spatfall in the Piankatank River was consistently low to moderate at most of the sites monitored. Spatfall began to improve beginning around 2007 and has been consistently good since 2010. From 1994 to 2009, only 15% (16/108) of the year/site combinations experienced heavy spatfall and 32% (35/108) experienced light spatfall. However, since 2010, only one year/site combination had moderate spatfall, with extremely heavy spatfall at 28% (22/80) of the year/site combinations and heavy spatfall during the remaining year/site combinations. At the three historical sites the mean from 1994 to 2009 was 3.3 cumulative spat shell^{-1}, whereas from 2010 to 2019 the mean at those three sites was 80.4 cumulative spat shell^{-1}, a 24-fold increase over the previous sixteen-year mean. Since the addition of the modern sites in 1998, the mean across the river increased from 5.5 cumulative spat shell^{-1} (1998 to 2009) to 95.5 cumulative spat shell^{-1} (2010 to 2019), a 17-fold increase.

With the exception of 2018, spatfall on the shellstrings in the Great Wicomico has been especially good from 2006 through 2019, with 2019 marking the third year during that time period with extremely heavy (>100 cumulative spat shell^{-1}) spatfall recorded at all nine sites monitored. As has been typical in recent years (Southworth & Mann 2004), spatfall in the Great Wicomico has been getting progressively earlier, with the majority (greater than 94%) of spat settling on the shellstrings in 2019, having set by early July.

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

STATION	5/20 140	5/27 147	6/3 154	6/10 161	6/17 168	6/24 175	7/1 182	7/8 189	7/15 196	7/22 203	7/29 210	8/5 217	8/12 224	8/19 231	8/26 238	9/2 245	9/9 252	9/16 259	9/23 266	9/30 273	YEAR TOTAL
JAMES RIVER																					
Deep Water Shoal	D	0	-	-	0	0.1	0.2	0	-	0.3	1.0	2.8	0.2	2.8	-	4.5	1.4	-	6.3	0.6	20.2
Horsehead	D	0	-	-	0.2	1.2	0.5	0	-	0.2	9.2	10.1	2.5	9.8	-	3.4	4.9	-	5.2	0.6	47.8
Point of Shoal	D	0	-	-	0	1.2	2.2	0	-	1.2	7.8	9.0	2.5	4.1	-	6.2	5.0	-	3.9	0.4	43.5
Swash	D	0	-	-	0.1	1.4	0.6	0.4	-	3.0	6.0	14.0	1.1	4.9	-	-	2.4	-	4.2	0.5	38.6
Dry Shoal	D	0	-	-	0.3	3.1	0.1	0.4	-	0.3	10.4	20.2	6.1	10.4	-	1.6	1.6	-	7.4	1.1	63.0
Rock Wharf	D	0.1	-	-	0.2	0.8	1.2	0.4	-	3.1	10.0	28.7	7.9	6.9	-	12.1	4.8	-	3.9	2.7	82.7
Wreck Shoal	D	0	-	-	0.4	0.5	0.7	0.7	-	1.6	14.7	21.0	3.1	10.7	-	4.2	3.7	-	-	-	61.3
Day's Point	D	0	-	-	0	0.8	0.2	0.1	-	0.6	14.5	14.7	10.8	1.9	-	1.1	8.8	-	-	-	53.5
PIANKATANK RIVER																					
Wilton Creek	D	0	0	0	1.0	3.2	0.1	0.2	0	0	0	1.1	1.3	0.4	0.3	0.5	4.1	2.8	2.4	0.1	17.8
Ginney Point	D	0	0	0.1	2.4	3.5	0.2	0.2	-	0	0.1	2.2	0.7	0.2	0.8	3.8	7.1	1.6	1.0	0.4	24.3
Palace Bar	D	0	0	0.2	0	1.5	0.6	0	0	0	0	0.5	0.8	1.3	1.1	2.8	3.9	1.2	0.3	0.1	14.4
Bland Point	D	0	0	0	0.5	22.2	2.5	2.2	0.1	0	0	0.7	1.9	1.3	3.3	23.7	30.8	2.2	0.3	0	92.0
Heron Rock	D	0	0	0.2	0.7	6.7	5.3	1.2	0.3	0.1	0.2	2.8	3.2	1.6	2.6	3.5	4.5	1.2	0.6	0.4	35.3
Cape Toon	D	0	0	0.6	4.2	29.9	6.4	3.1	0	0	0.2	2.0	1.7	5.8	10.1	13.7	6.5	2.5	1.3	0	88.4
Stove Point	D	-	-	0	0.6	8.8	15.8	2.4	0	0	0.1	1.1	1.5	1.9	2.9	12.5	11.7	2.6	1.2	0.3	63.5
Burton Point	D	0	0	0	1.0	8.0	4.7	1.8	0	0	0.1	1.4	5.5	1.2	2.4	17.4	8.9	0.8	0.6	0.1	54.2
GREAT WICOMICO																					
Glebe Point	D	0	3.8	116.4	30.5	8.6	0.4	1.7	0	0	7.1	0.5	0	0	0	-	0	0.2	0	0	169.2
Rogue Point	D	0	10.2	91.7	10.3	49.5	20.9	0.2	0	0	0.7	0.4	0.1	0.2	0	-	0.8	1.5	0.6	1.4	188.5
Hilly Wash	D	0	11.8	48.9	7.0	29.7	12.3	0.7	0	0	1.5	0.1	0.2	0	0	-	0	0.4	0.4	0.2	113.2
Harcum Flats	D	0	9.9	70.9	21.0	78.1	45.9	0.7	0	0	0.6	0.5	0.1	0	0	-	0.2	0.6	0.4	0.2	229.1
Hudnall	D	0	4.2	30.1	6.9	98.2	41.4	1.1	0	0	1.7	0.5	0.3	0.1	0	-	0.1	0.9	0.4	0.2	186.1
Shell Bar	D	0	6.3	80.4	11.4	109.3	84.9	2.1	0	0	0.8	0.7	0.1	0	0.2	-	0.2	1.5	0.7	0.2	298.8
Haynie Point	D	0	6.6	49.6	5.7	72.8	135.2	1.5	0	0	0.2	0.4	0.1	0	0	-	0.4	0.3	0.6	0.2	273.6
Whaley's East	D	0	2.2	7.9	5.9	82.4	62.5	0.1	0	0	0.2	0.4	0.2	0	0.1	-	0.3	2.5	0.5	0.1	165.3
Fleet Point	D	0	4.6	17.7	12.4	81.6	117.5	-	-	0	0.1	0.4	0.3	-	-	-	0.2	2.9	0.5	0.9	239.1

Table S2: Spatfall totals for historical sites (1994-20019) and modern sites (1998-2019) as defined in the text. Values presented are the cumulative sum of spat shell^{-1} values for each year. "+" and "-" indicate the direction of change in 2019 in reference to 2018 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 shell^{-1} in either direction.

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean 14-18	Mean 09-18	Mean 99-18	Mean 94-18	Ref. 2018	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr	Ref. 25-yr
JAMES																																			
Deep Water Shoal	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	7.6	4.3	20.2	10.3	9.7	20.0	16.3	+	+	+	NC	+
Horsehead	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	42.0	26.8	47.8	41.7	43.4	35.3	28.7	+	+	+	+	+
Point of Shoal	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	29.9	22.3	43.5	26.3	27.6	31.2	26.0	+	+	+	+	+
Swash	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	60.2	72.2	38.6	57.9	42.2	48.2	39.0	-	-	-	-	NC
Dry Shoal	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	133.3	188.7	63.0	102.7	96.8	64.6	53.3	-	-	-	-	+
Rock Wharf	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	77.2	58.3	82.7	49.5	67.6	55.0	44.8	+	+	+	+	+
Wreck Shoal	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	87.7	223.2	61.3	100.6	66.1	64.8	52.5	-	-	-	-	+
Day's Point	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	139.3	38.6	53.5	62.5	87.0	59.0	49.5	+	-	-	-	+
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	27.2	18.7	17.8	63.3	61.9	32.7		NC	-	-	-	
Ginney Point	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	27.9	35.8	24.3	53.7	63.0	34.0	27.4	-	-	-	-	-
Palace Bar	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	18.6	14.5	14.4	51.3	47.9	25.6	20.8	NC	-	-	-	-
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	62.1	39.3	92.0	267.4	166.5	87.3		+	-	-	+	
Heron Rock					10.1	9.3	3.2	0.6	5.1	0.2	0.7	0.4	1.1	9.9	7.4	5.4	28.2	22.5	73.1	4.3	50.8	105.1	159.4	31.3	36.1	35.3	76.5	51.6	27.7		NC	-	-	+	
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	112.0	75.9	88.4	146.1	122.1	65.3		+	-	-	+	
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	18.3	28.7	63.5	143.7	93.7	51.1		+	-	-	+	
Burton Point	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	43.7	34.6	54.2	198.1	122.3	63.5	51.0	+	-	-	-	+
GREAT WICOMICO																																			
Glebe Point	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	487.9	10.0	169.2	420.3	485.2	278.8	224.0	+	-	-	-	-
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	141.1	11.1	188.5	263.3	274.1	155.0		+	-	-	+	
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	281.6	9.9	113.2	250.3	267.6	151.0		+	-	-	-	
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	333.6	14.5	229.1	273.5	272.9	164.5		+	-	-	+	
Hudnall	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	200.7	9.7	186.1	219.8	154.5	86.9	71.1	+	-	+	+	+
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	336.7	12.8	298.8	414.7	270.2	143.3		+	-	+	+	
Haynie Point	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	106.9	8.8	273.6	234.7	145.2	77.9	62.7	+	+	+	+	+
Whaley's East	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	101.1	7.5	165.3	204.4	119.5	61.5	49.4	+	-	+	+	+
Fleet Point	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	224.1	21.9	239.1	191.2	106.2	54.5	43.9	+	+	+	+	+

Light settlement (0.1 - 1.0 spat/shell)
Moderate settlement (1.01-10.0 spat/shell)
Heavy settlement (10.1-100.0 spat/shell)
Extremely heavy settlement (>100.0 spat/shell)

Figure S1: Map showing the location of the 2019 shellstring deployment 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.

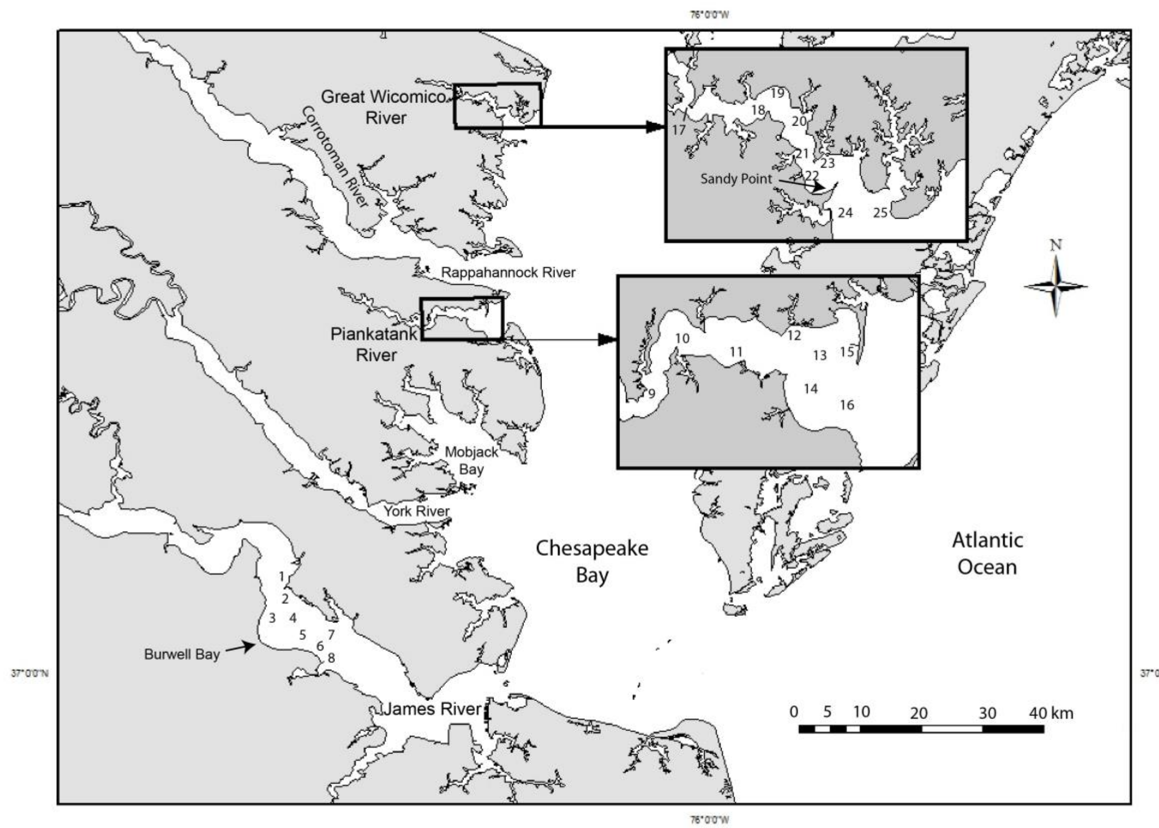


Figure S2: Diagram of shellstring setup on buoys with pictures of each step (see https://www.vims.edu/research/units/labgroups/molluscan_ecology/_docs/Shellstring_manual.pdf for a detailed description of shellstring survey methods).

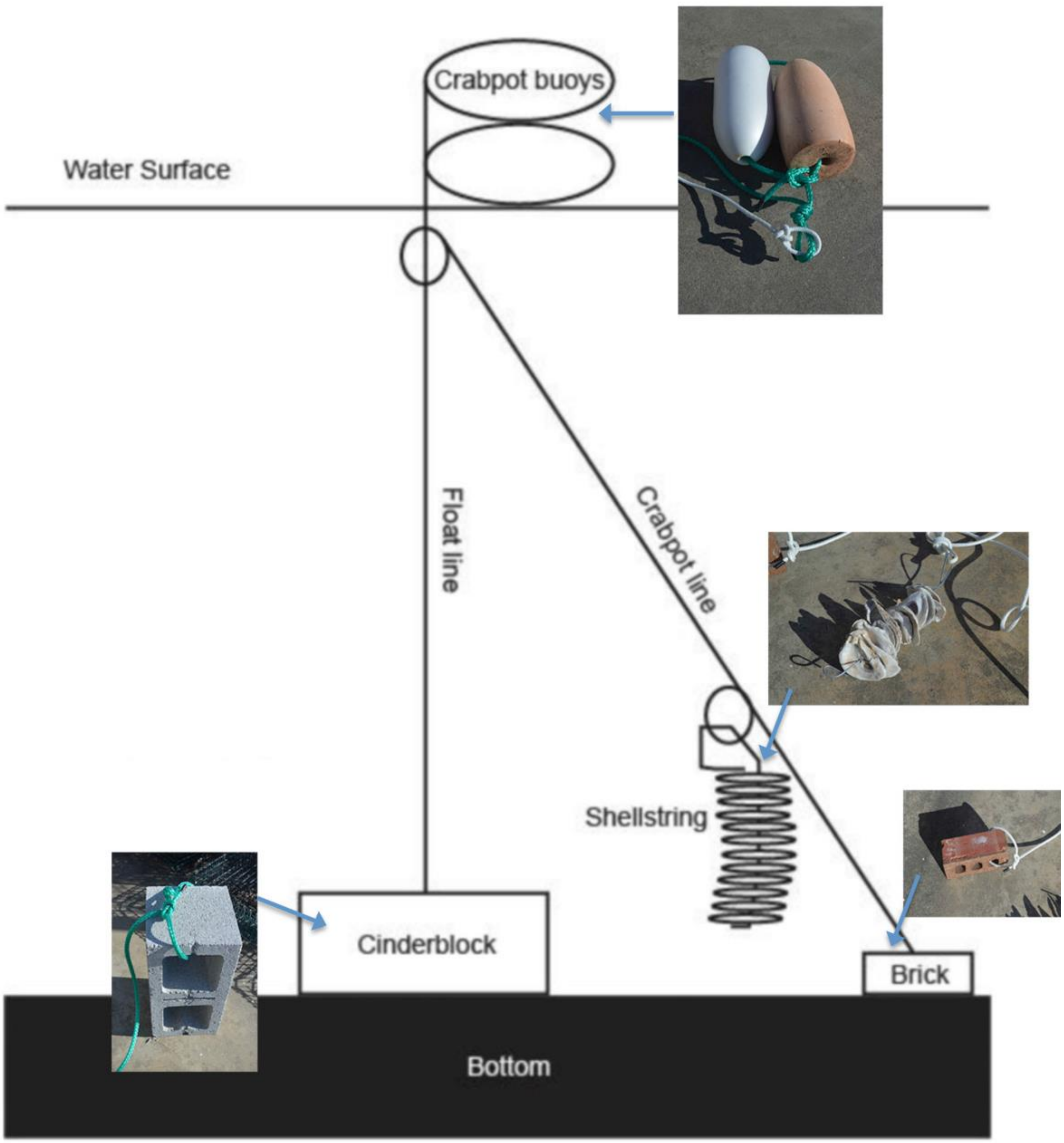


FIGURE S3: JAMES RIVER (2019) WEEKLY RECRUITMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(* no data collected in weeks 266 and 273)

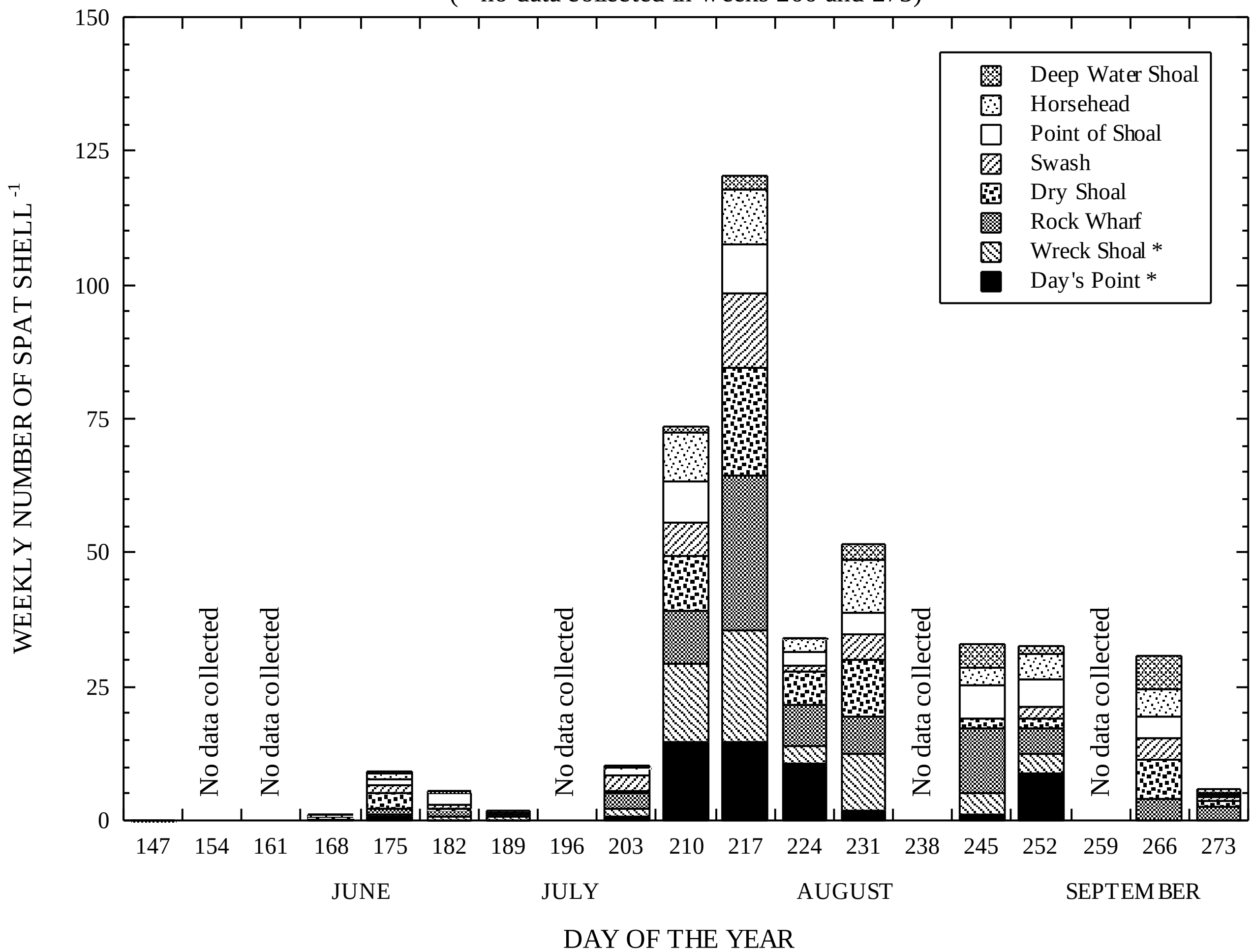


FIGURE S4: RECRUITMENT TRENDS OVER THE PAST 25 YEARS AT ALL EIGHT SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

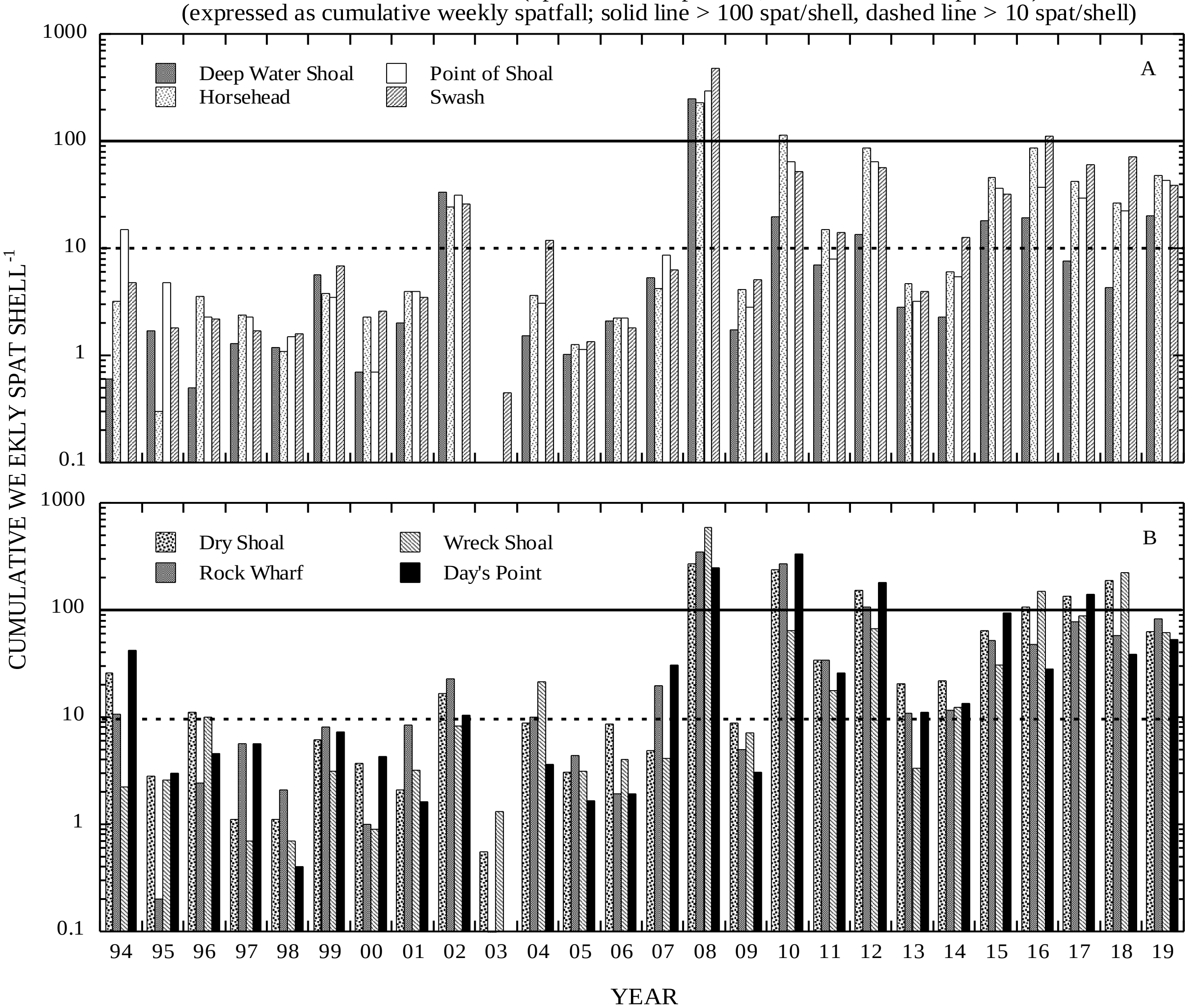


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 30-YEAR MEANS COMPARED WITH 2019
(Error bars represent standard error of the mean; shaded area is the period when most of the recruitment occurred in the river)

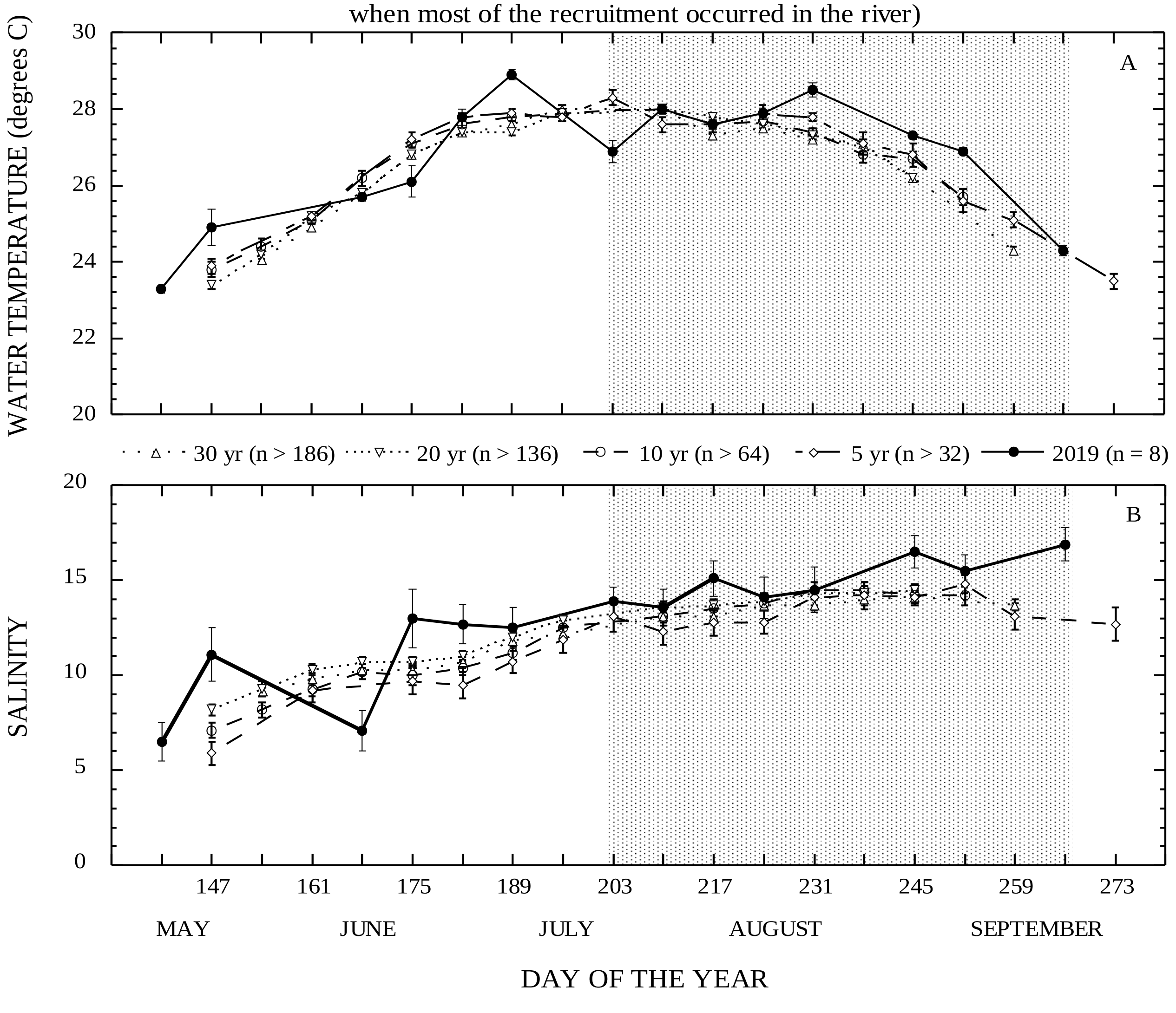


FIGURE S6: PIANKATANK RIVER (2019) WEEKLY RECRUITMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$

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

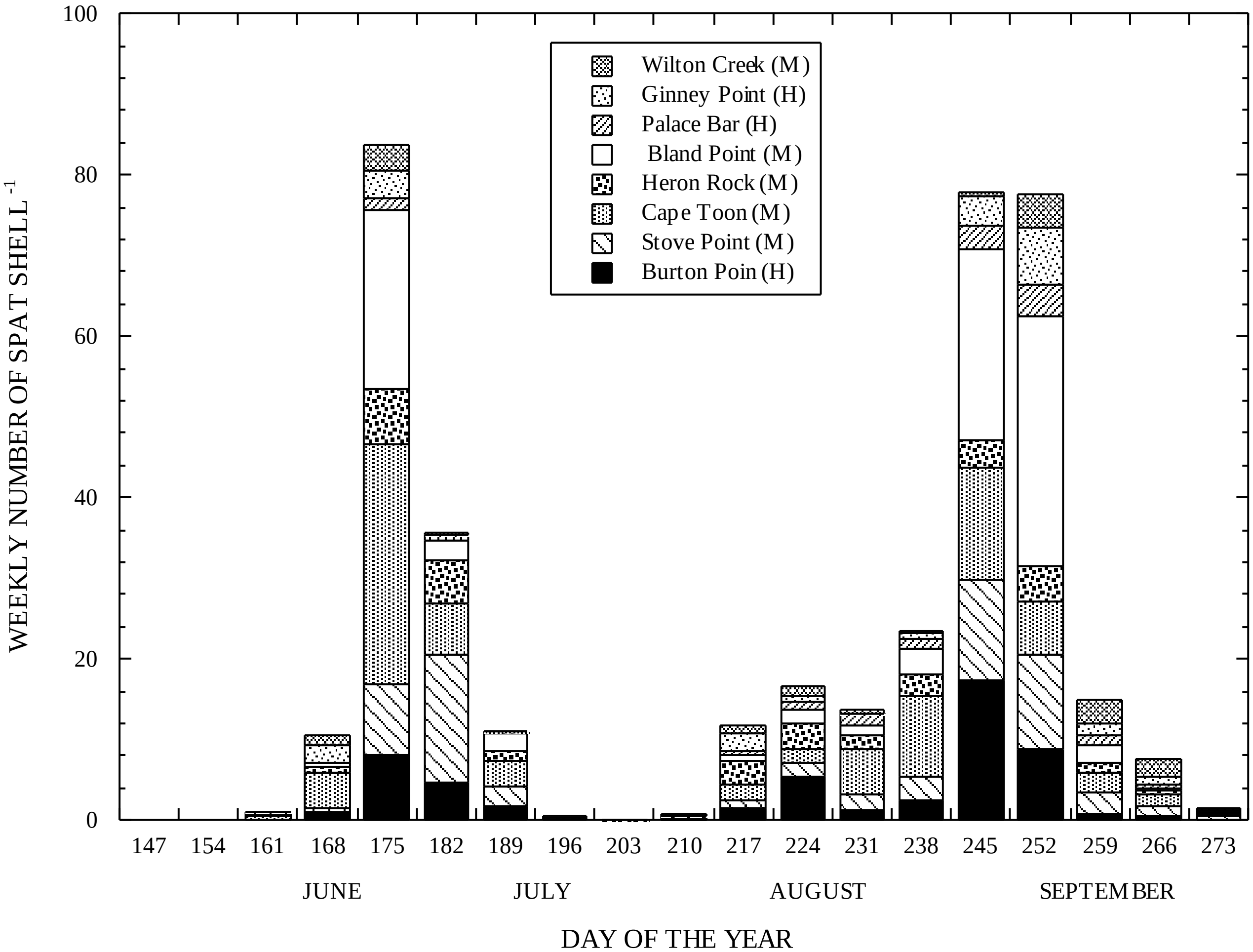


FIGURE S7: RECRUITMENT TRENDS IN THE PIANKATANK RIVER AT THE THREE HISTORICAL SITES (panel A: 25 years) AND THE FIVE MODERN SITES (panel B: 21 years)
(expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

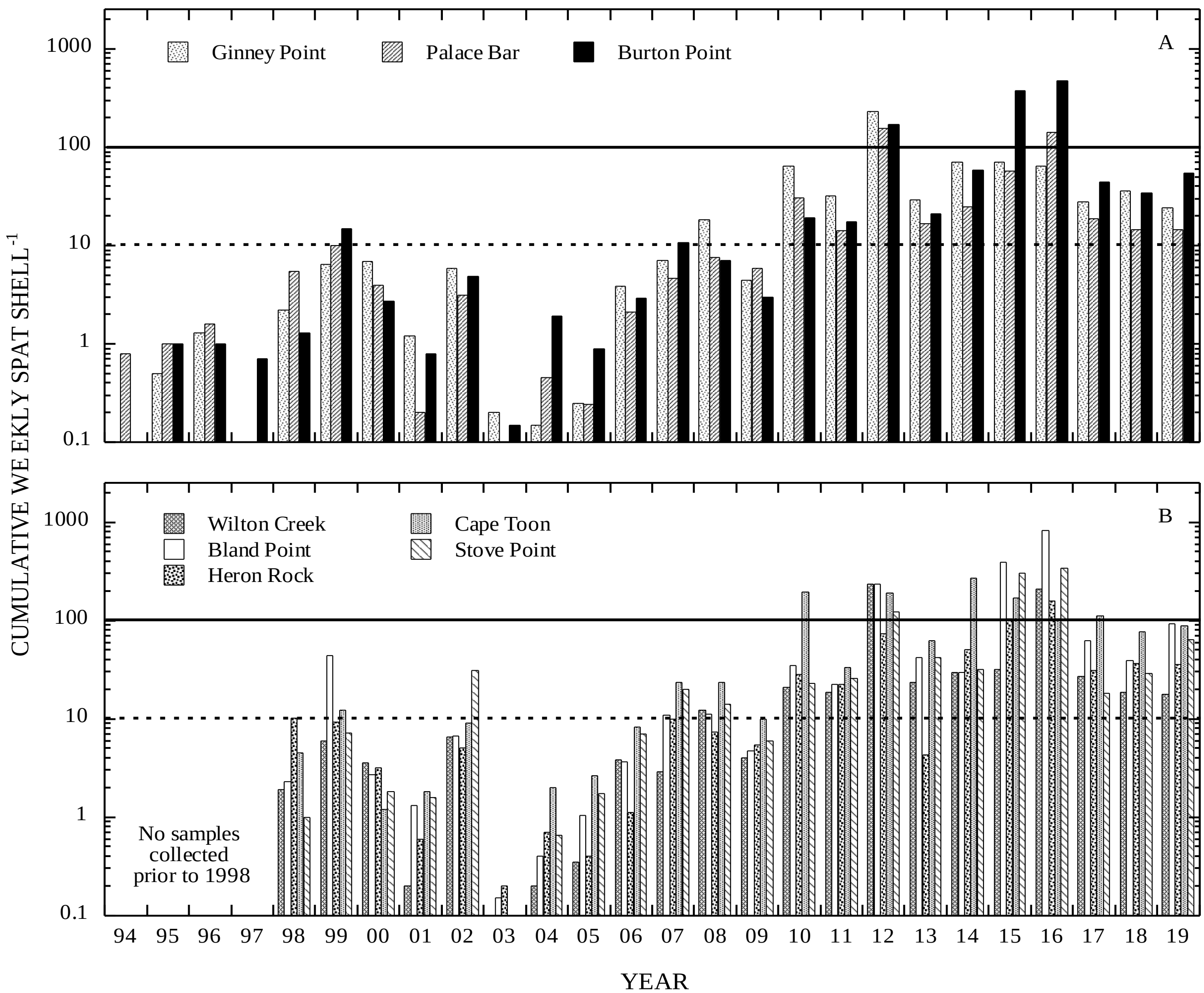


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 30-YEAR MEANS COMPARED WITH 2019
(Error bars represent standard error of the mean; shaded area is the period when most of the recruitment occurred in the river)

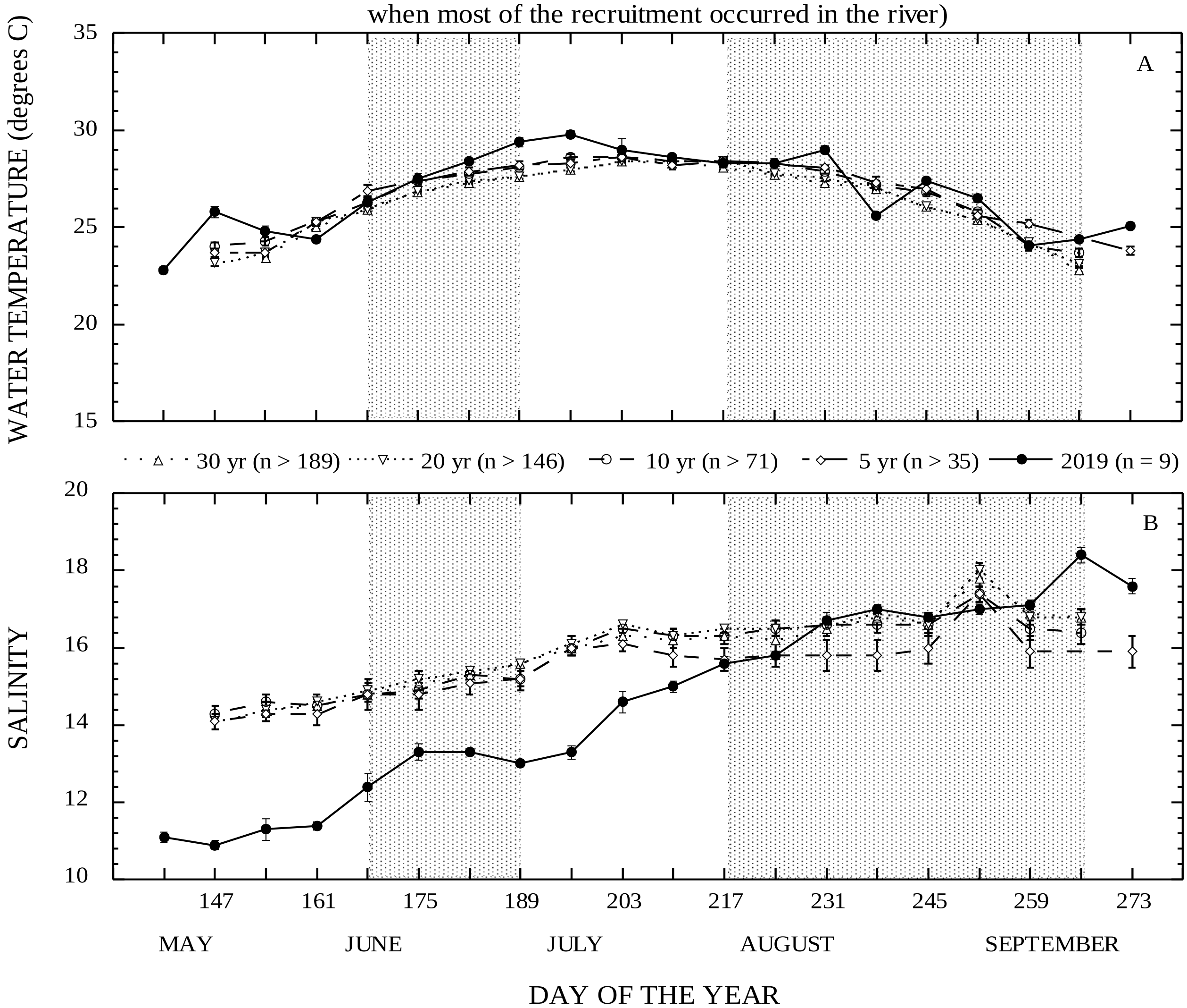


FIGURE S9: GREAT WICOMICO RIVER (2019) WEEKLY RECRUITMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: M = modern station as described in text;
* no data collected in weeks 189, 196, 231 and 238)

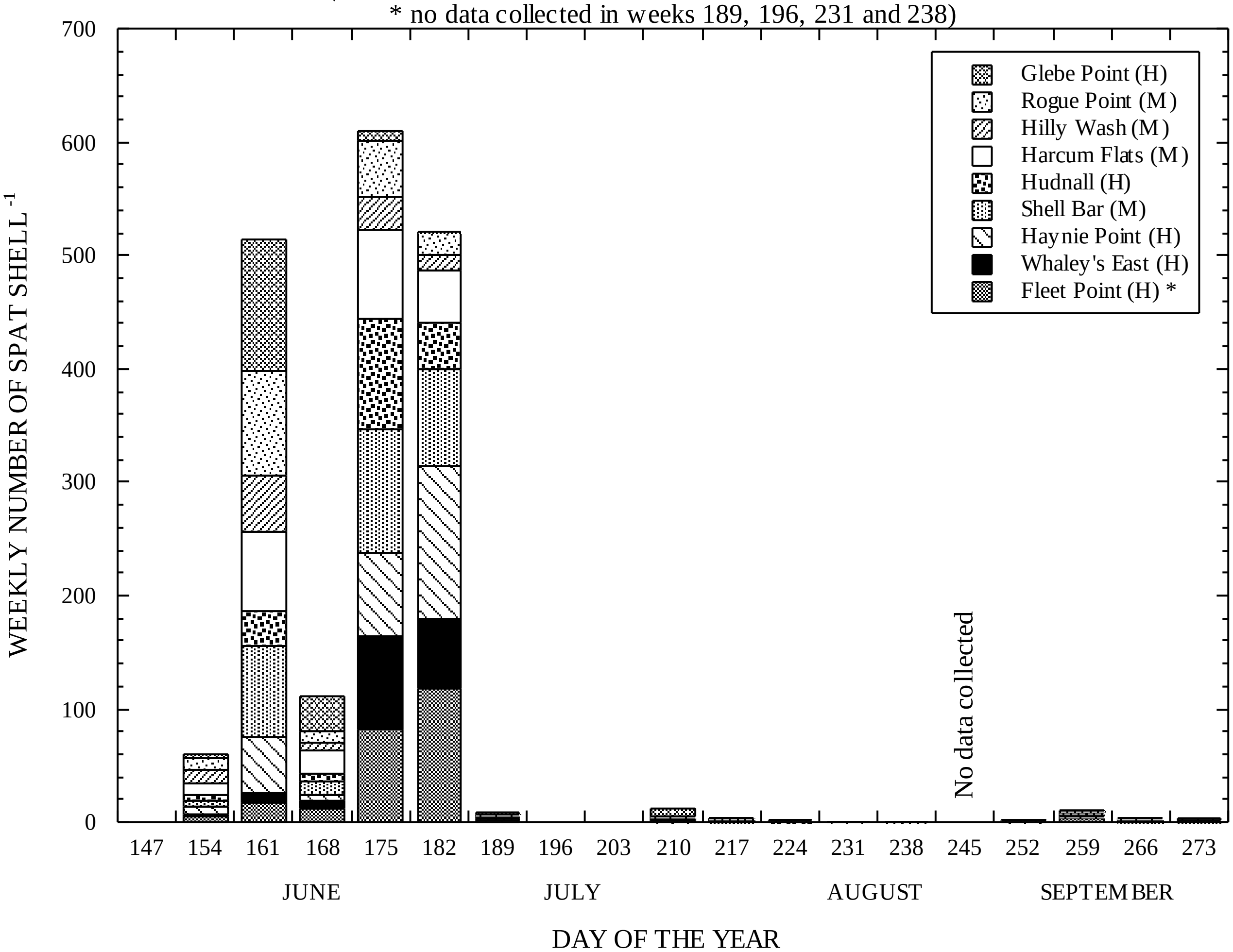


FIGURE S10: RECRUITMENT TRENDS IN THE GREAT WICOMICO RIVER AT THE FIVE HISTORICAL SITES (panel A: 25 years) AND THE FOUR MODERN SITES (panel B: 21 years) (expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

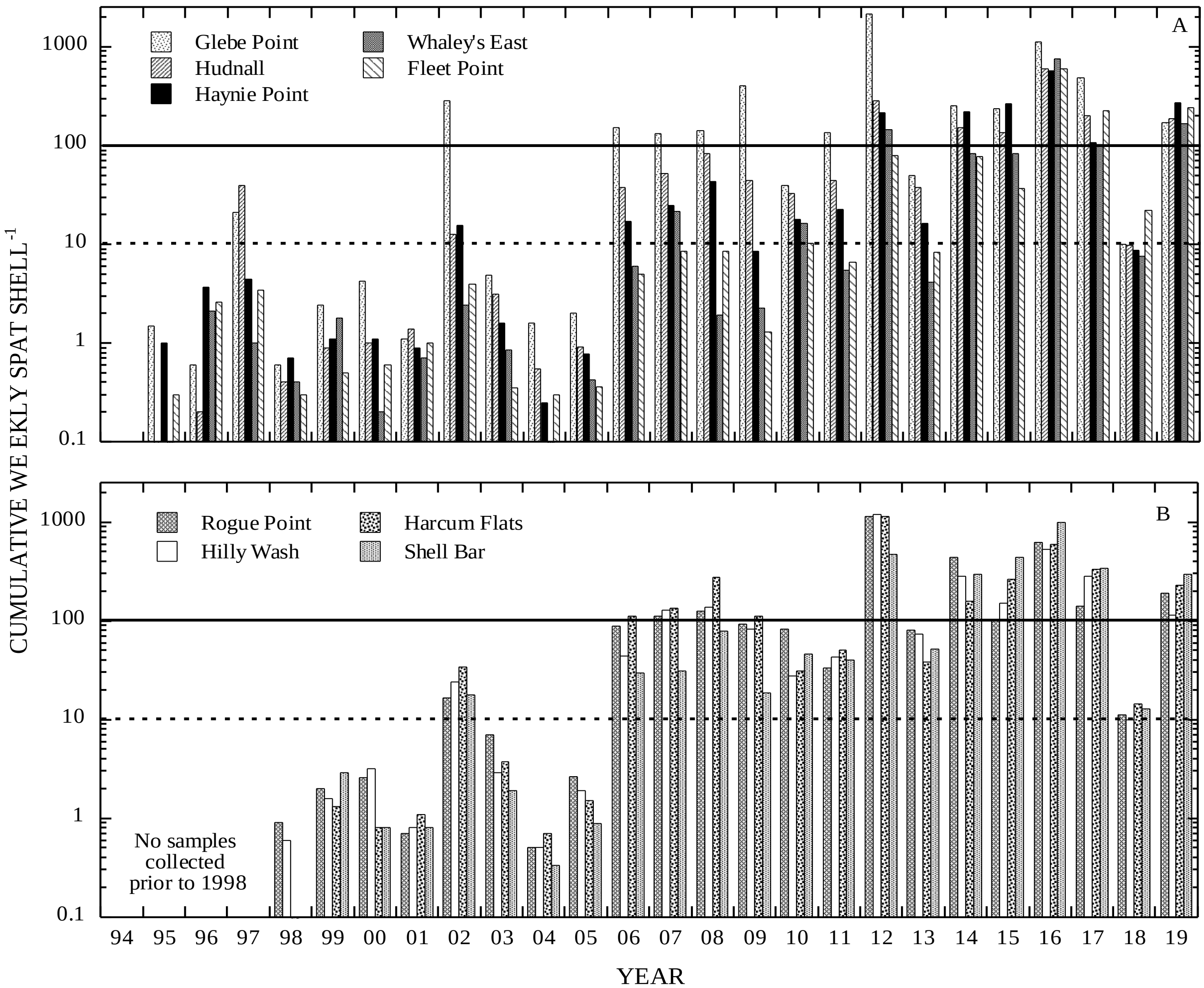
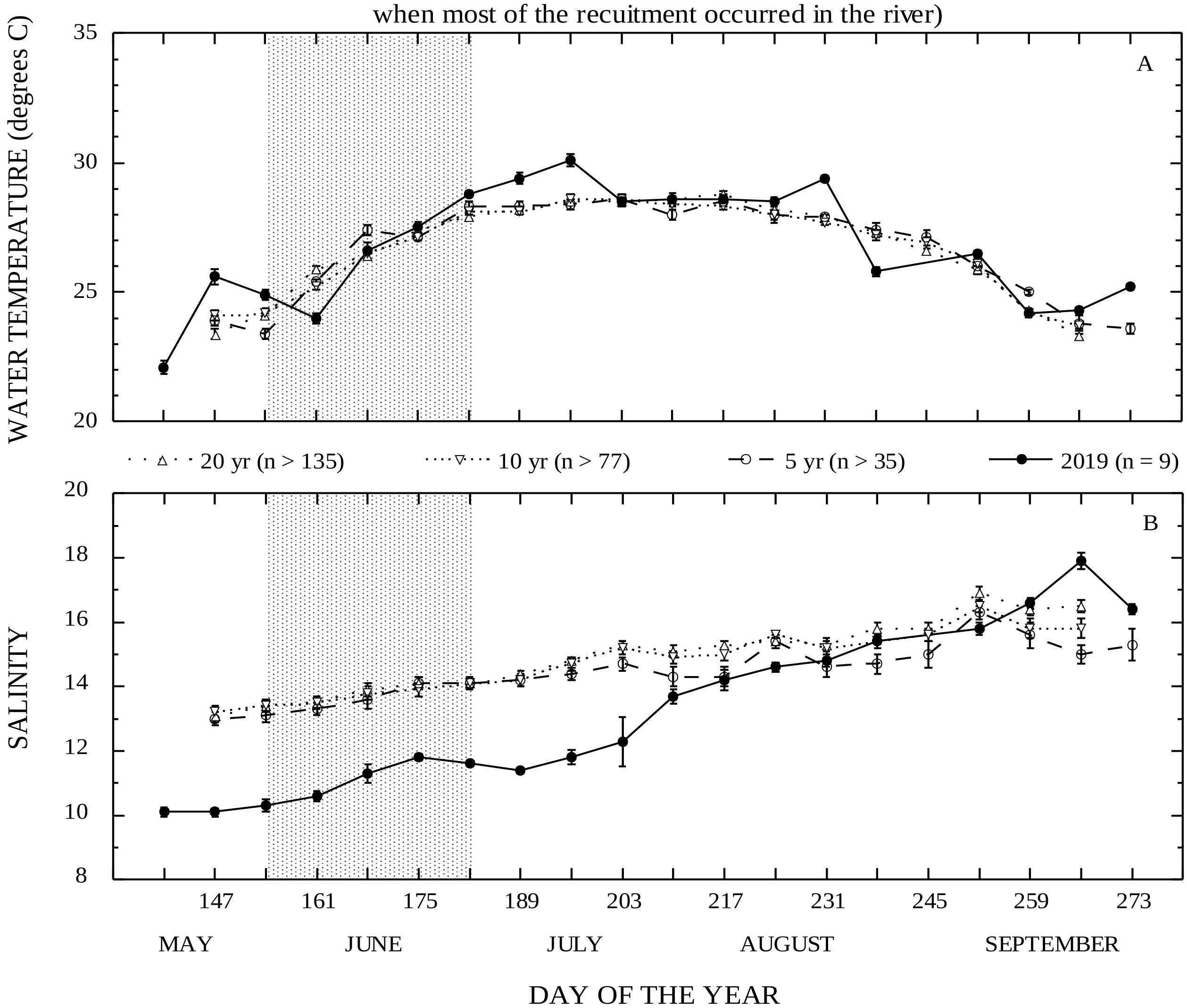


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE RECRUITMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2019
(Error bars represent standard error of the mean; shaded area was the period when most of the recuitment occurred in the river)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2019

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[4]. 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 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 2019.

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 annual 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.

[4] https://webapps.mrc.virginia.gov/public/maps/chesapeakebay_map.php

METHODS

Locations of the oyster bars sampled during Fall 2019 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 2019), in surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers in 1993 and 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 inches^3), which differs from a US bushel (2150.4 inches^3) and a Maryland bushel (2800.7 inches^3). Beginning in 1995, James, Piankatank, Rappahannock, and Great Wicomico River samples (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 2019 samples in the James River, the number of samples was reduced (n = 3) at all but the most downriver (Nansemond Ridge) site (see Figure D1) to facilitate sample processing in a timelier manner. The number of samples was also reduced at both Mobjack Bay sites (n = 2 at Pultz Bar; n = 3 at Tow Stake).

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 (recent 2019 recruits), new boxes[5] (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).

[5] The term box is commonly used to describe the articulated valves of a dead oyster. A "new" box may contain tissue from a recent mortality or simply be a set of valves with clean interior. An "old" box" is typically fouled internally. Boxes are a proxy of recent mortality, but the rates at which paired shells disarticulate is poorly understood and probably varies with size and time of year.

RESULTS

Thirty oyster bars were sampled between October 4 and October 16, 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 472.0 bushel^{-1} at Nansemond Ridge to a high of 3,536.7 bushel^{-1} at Swash. 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 and Long Shoal, the second highest observed at Dry Shoal, Wreck Shoal and Thomas Rock, the third highest at Nansemond Ridge and the fourth highest at Swash. When spat are excluded, the total number of small and market oysters combined was the highest (Swash, Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge), second highest (Deep Water Shoal and Long Shoal), fourth highest (Horsehead) and fifth highest (Point of Shoal) observed over the past twenty-five years. The number of oysters at Nansemond Ridge had been at fairly low levels for several years, but has generally been increasing, such that 2019 was the highest observed over the past twenty-five years in small oysters, the second highest in market size oysters and the third highest in spat.

The average number of market oysters in the James River remains low when compared with historical numbers. The number of market oysters in 2019 ranged from a low of 0 bushel^{-1} at Swash to a high of 62.0 bushel^{-1} at Point of Shoal. There was a notable decrease in the number of market oysters at Deep Water Shoal and Swash when compared with 2018 (Figure D2). The number of market oysters at Point of Shoal has fluctuated from one year to the next for the past several years, it was up in 2015, down in 2016 and 2017, then back up in 2018 and 2019. This reef has been heavily targeted for seed harvest over the past few years and this fluctuation may reflect that activity. The number of market oysters at Wreck Shoal steadily increased between 2009 and 2014, then remained relatively stable (between 90 and 100 bushel^{-1}) from 2014 to 2016 (Figure D3C). The numbers of market oysters on Dry Shoal, Wreck Shoal and Thomas Rock have remained relatively stable for the past three years, ranging between 43 and 47 bushel^{-1} on Dry Shoal, between 43 and 56 bushel^{-1} on Wreck Shoal and between 51 and 64 bushel^{-1} on Thomas Rock (Figures D3B and D3C). For the fourth year in a row, the number of market oysters at Swash and Mulberry Point were among the lowest observed (the lowest and 4th lowest respectively) since monitoring began at those sites in the early 1990s (Figure D3A and D3B). The number of market oysters on Deep Water Shoal, remained low (second lowest over the past twenty-five years), following the 2018 low salinity mortality event.

The average number of small oysters bushel^{-1} ranged from a low of 129.5 at Nansemond Ridge to a high of 2,391.7 at Deep Water Shoal. When compared with 2018, there was a notable increase in the number of small oysters at Deep Water Shoal, Swash, Long Shoal, Dry Shoal, Wreck Shoal and Thomas Rock (Figure D2 and D3). With these increases, 2019 had the highest number of small oysters over the past twenty-five years at Swash, Dry Shoal, Wreck Shoal and Thomas Rock and the second highest at Deep Water Shoal and Long Shoal. While the number of small oysters observed at Nansemond Ridge was the lowest of the ten sites, 2019 numbers were similar to those observed in 2018, which were twice as high as any of the previous twenty-four years (Figure D3C).

Overall, recruitment in the James River in 2019 was high, comparable to the past few years (Figure D2 and D3), although there was a notable decrease observed when compared to 2018 at the four most downriver (Dry Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge) sites (Figure D2 and D3). The average number of spat bushel^{-1} ranged from a low of 324.5 at Nansemond Ridge to a high of 1,791.7 at Horsehead. Since 2008, recruitment in the James River has had several strong year classes (2008, 2010, 2012, 2016, 2018 and 2019), with 2019 being among the strongest. Recruitment in 2019 was the highest observed over the past twenty-five years at Mulberry Point, Horsehead, Point of Shoal and Swash and the third highest at Deep Water Shoal, Long Shoal, Wreck Shoal, Thomas Rock and Nansemond Ridge (Figure D3).

The average number of boxes bushel^{-1} was low to moderate, ranging from 11.0 at Nansemond Ridge to 79.3 at Long Shoal, and was generally higher at the mid-river sites. Boxes accounted for less 4% of the total (live oysters plus boxes) at all ten sites, with the majority (greater than 67%) old boxes. At Deep Water Shoal, Thomas Rock and Nansemond Ridge, between 23 and 28% of the boxes were spat boxes. Around 11 and 12% of the total boxes at Wreck Shoal and Dry Shoal respectively were new boxes, indicating some recent mortality at these two sites, but overall these were a small percentage of the total (live oysters plus boxes).

Water temperature during the two days of sampling ranged between 20.9 and 21.3°C (Table D2). Salinity generally increased in a downriver direction (see Figure D1), from a low of 13.7 at Deep Water Shoal to a high of 20.1 at Nansemond Ridge.

York River

In the York River, the average total number of live oysters bushel^{-1} was 164.0 at Bell Rock and 322.5 at Aberdeen Rock. When compared with 2018, there was a notable decrease in the number of market oysters observed at Bell Rock (Figures D4 and D5) and a notable increase in the number of spat at both sites. The number of market oysters at Aberdeen Rock has been steadily increasing over the past five years (Figure D5) such that 2019 had the second highest number observed over the past twenty-five years. Recruitment was the fourth highest observed over the past twenty-five years at Bell Rock and the second highest observed at Aberdeen Rock. For the fourth year in a row, the average number of boxes bushel^{-1} was moderate (31.0 bushel^{-1}) at Bell Rock and low (15.0 bushel^{-1}) at Aberdeen Rock, accounting for approximately 16 and 4% of the total oysters (live oysters plus boxes) at Bell Rock and Aberdeen Rock respectively. The majority (>90%) of the boxes at both sites were old. Water temperature on the day of sampling was around 23°C at both sites. Salinity was 15.4 at Bell Rock and 18.6 at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 539.3 and 4,526.0 oysters bushel^{-1} respectively. When compared with 2019, there was a notable increase in the number of oysters in all size categories observed at Tow Stake (Figure D4) and a very large increase in the number of spat observed at Pultz Bar. There was also a notable decrease in the number of small and market oysters observed at Pultz Bar, a four and five fold decrease respectively. Recruitment in 2019 at Pultz Bar was almost four times higher than the next highest observed during the past twenty-five years of monitoring. (Figure D6). Recruitment at Tow Stake was the second highest observed over the past twenty-five years. The total number of boxes observed in the system was low, accounting for 4 (Tow Stake) and 1% (Pultz Bar) of the total (live oysters plus boxes). Approximately 86% of the boxes observed at Pultz Bar were spat boxes, which is not surprising given that over 99% of the oysters on Pultz Bar were spat. Five out of the 6 total spat (83%) boxes observed at Tow Stake and 17 out of the 37 total spat boxes (46%) at Pultz Bar 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 22°C at Pultz Bar and 23°C at Tow Stake. Salinity was 20.4 at Pultz Bar and 19.6 at Tow Stake.

Piankatank River

In the Piankatank River, the average total number of live oysters bushel^{-1} ranged from a low of 395.0 at Ginney Point to a high of 627.0 at Burton Point. When compared with 2018, there was a notable increase in the number of spat at all three sites (Figures D7 and D8). From 2013 to 2017, the number of market oysters at Ginney Point had remained relatively high and stable (between 72 and 99 bushel^{-1}). There was a decrease observed in 2018, with similar numbers in 2019. Since reaching a twenty-five year high in 2014/2015, the number of market oysters at Burton Point had been in decline for the past several years (Figure D8), with similar numbers in 2017 through 2019. Overall, the number of market oysters in the river was low from 1993 through 2008, but generally increased between 2008 and 2014. Since 2014 however, market oysters in the Piankatank River have been steadily declining, although 2019 numbers were still higher than pre-2008 numbers, and in general small and market oysters combined, while variable from one year to the next have remained at a higher level throughout the system since 2008 (compared with numbers observed from 1993 through 2007). Recruitment in 2019 was moderately high at all three sites, with the overall average across the three sites ranking in the 76th percentile over the past twenty-five years. The number of boxes observed was low at all three sites, accounting for 1 (Palace Bar) to 6% (Ginney Point) of the total (live plus dead). The majority (>92%) of boxes at all three sites were old. One out of the 3 total spat (33%) boxes observed 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 25ºC at all three sites and salinity was 16.5 at both Ginney Point and Palace Bar and 17.4 at Burton Point.

Rappahannock River

In the Rappahannock River, the average total number of live oysters bushel^{-1} ranged from a low of 0 at Ross Rock (which experienced 100% mortality during the summer of 2018 due to a freshet) to a high of 583.0 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 2019. At Ross Rock, the oyster population had been steadily increasing since about 2009, but following a freshet event in 2018, all of the oysters at Ross Rock died and as of fall 2019 there was no sign of recovery. 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 greater than or similar to those observed prior to the decrease in 2011, such that the oyster population on Middle Ground in 2019 was at the highest level observed over the past twenty-five years of monitoring. Given that Ross Rock experienced 100% mortality in 2018, and the population remains at zero, the rest of the discussion of the Rappahannock River oyster population will not include Ross Rock.

The average number of market oysters bushel^{-1} ranged from a low of 21.0 at Morattico Bar to a high of 77.5 at Broad Creek. When compared with 2018, there was a notable decrease in the number of market oysters at Bowler's Rock and Morattico Bar and a modest increase observed at Drumming Ground and Broad Creek (Figure D9 and D10). Market oysters increased at Drumming Ground for the second year in a row, such that 2019 was in the 91st percentile over the past twenty-five years. Despite the decrease in market oysters at several sites in the Rappahannock River, overall the number of market oysters has been higher since about 2008 (Figure D10). From 1994 to 2007, the average over all ten sites in any given year was less than 20 market oysters bushel^{-1}, whereas from 2008 to 2019 the average over all ten sites ranged between 22 (2008) and 70 (2016) market oysters bushel^{-1} (Figure D10). The average over all nine sites (Ross Rock was not included) in 2019 was 37.6 market oysters bushel^{-1}.

For the second year in a row, Drumming Ground had the highest number of small oysters, with 349.0 bushel^{-1} (Figure D9 and D10). When compared with 2018, there was a notable increase in the number of small oysters observed at Long Rock, Morattico Bar, Smokey Point, Drumming Ground and Broad Creek (Figure D9 and D10). It should be noted that Morattico Bar, Smokey Point and Hog House all received a seed plant in the spring of 2019 and the numbers of small oysters on those reefs in 2019 ranked the highest observed over the past twenty-five years at Morattico Bar and Smokey Point and the second highest observed at Hog House.

Overall, recruitment in the Rappahannock River in 2019 was light to moderate, ranging from 4 spat bushel^{-1} at Morattico Bar to 191.5 spat bushel^{-1} at Broad Creek. In more recent years, recruitment has become more common at the more upriver sites (Figures D9 and D10) and overall 2019 ranked the fourth highest (88th percentile) over the past twenty-five years of monitoring. In general, since 2010, higher recruitment years have become more common. In the sixteen-year period from 1994 to 2009, there were only four years (1995, 1999, 2002 and 2006) with an overall average recruitment greater than 50 spat bushel^{-1}, whereas in the ten-year period from 2010 to 2019 there were five years (2010, 2012, 2015, 2017 and 2019) with an overall average recruitment greater than 50 spat bushel^{-1}.

The average total number of boxes bushel^{-1} was low to moderate, accounting for 2 (Smokey Point) to 25% (Bowler's Rock) of the total (live oysters plus dead). Around 18% of the total boxes at Broad Creek were new boxes, indicating some recent mortality at that site. At the other eight sites, greater than 88% of the total boxes were old. There were no boxes with drill holes, indicative of predation by one of the two native oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*, observed at any of the sites.

Water temperature on the two days of sampling ranged from 20.5 to 21.7°C. Salinity generally increased as one moved from the most upriver site (Ross Rock: 11.3) toward the mouth (Broad Creek: 17.8).

Great Wicomico River

In the Great Wicomico River, the average total number of live oysters bushel^{-1} ranged from a low of 224.0 at Fleet Point to a high of 881.5 at Haynie Point. When compared with 2018, there was a notable increase in the number of market oysters at Haynie Point. There was a notable increase in the number of small oysters at Fleet Point and a notable decrease at Whaley's East. The number of spat increased at all three sites when compared with 2018 (Figure D11 and D12). The number of market oysters at Whaley's East has remained at similar numbers for the past two years, ranking among the highest observed at Whaley's East since prior to the early 1990s. Recruitment in the Great Wicomico River in 2019 was moderate to good, with an average over the three sites ranking in the 84th percentile of spatfall over the past twenty-five years. The total number of boxes bushel^{-1} was low at all three sites, accounting for less than 6% of the total (live oysters plus boxes). Around 26% of the boxes at Haynie Point were spat boxes. The majority (>87%) of the boxes at Fleet Point and Whaley's East were old. Water temperature on the day of sampling was between 19 and 20°C and salinity was 16.9 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 several 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 33.6 market oysters bushel^{-1}). From 2007 to 2015, the number of market oysters on the thirty bars that are sampled annually slowly increased, 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-fold increase over the nine-year period. However, over the past several years, the overall number of market oysters on the thirty bars has been slowly declining.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2019, the overall oyster population was composed of 53% spat, 44% small oysters and 3% market oysters. At twelve of the thirty sites monitored, small oysters accounted for greater than 50% of the live oysters present, with spat dominating at nine out of the thirty sites. There was a large die-off of broodstock oysters that occurred in the Piankatank River in late 2003/early 2004 (Southworth et al. 2005). Following that die-off, the oyster population in the river started to increase and remained at higher levels from 2010 through 2017; the average number of small and market oysters combined over the three sites monitored consistently remained above 300 bushel^{-1} from 2013 to 2017. In 2018, the average small and market oysters bushel^{-1} dipped to 298 bushel^{-1}, with a further decrease to 238 bushel^{-1} in 2019.

Recruitment during 2019 varied a good bit throughout the Virginia portion of the bay, but overall was moderate to good. There were less than 20 spat bushel^{-1} at only six out of the thirty sites (all in the upper Rappahannock River), and greater than 100 spat bushel^{-1} at twenty-one out of the thirty sites (all ten sites in the James River), with greater than 500 spat bushel^{-1} at eleven sites, including every site in the James River except Nansemond Ridge. In the Rappahannock River, recruitment tends to be highest at the more downriver sites (see Figure D1), with often no recruitment at the upriver sites. In 2019, the highest recruitment was again observed at the more downriver sites, but every site except Ross Rock received at least some recruitment.

The average total number of boxes observed during 2019, was low to moderate at most sites, accounting for less than 15% of the total (live oysters plus boxes) oysters at every site except Bell Rock and Bowler's Rock and less than 10% of the total (live oysters plus boxes) at twenty-six out of the twenty-nine (excluding Ross Rock) 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 2019 Bell Rock (for the fourth year in a row) had a relatively large number of small and market size boxes (approximately 21% of the total, live small and market oysters plus new and old boxes, respectively). There was also a large percentage (25%) observed at Bowler's Rock. At the majority of the other sites (twenty-five out of twenty-seven), 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 2019, there were drill holes present in spat boxes at Tow Stake and Pultz Bar in Mobjack Bay and at Burton Point in the Piankatank River. The presence of a drill hole 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 since the mid-2000s in the lower James River, in the lower York River, in the mouths of the Piankatank and Rappahannock Rivers, and in Mobjack Bay. In addition, both species of oyster drills as well as evidence of their predation were observed on various reefs in the James and York Rivers, in Mobjack Bay and in both Pocomoke and Tangier Sounds (Southworth, unpublished data).

Table D1: Station locations for the 2019 VIMS fall dredge survey.

Station	Latitude	Longitude
James River		
Deep Water Shoal	37 08.933	76 38.133
Mulberry Point	37 07.150	76 37.917
Horsehead	37 06.413	76 38.056
Point of Shoal	37 04.617	76 38.600
Swash	37 05.533	76 36.733
Long Shoal	37 04.581	76 37.028
Dry Shoal	37 03.683	76 36.233
Wreck Shoal	37 03.617	76 34.333
Thomas Rock	37 01.766	76 29.597
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 49.642	76 44.180
Long Rock	37 48.810	76 42.504
Morattico Bar	37 46.917	76 39.550
Smokey Point	37 43.150	76 34.933
Hog House	37 38.171	76 32.553
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 2019. 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	10/16	21.1	13.7	1.7	2391.7	968.3	3361.7	1.7	20.0	8.3	30.0
Mulberry Point	10/16	21.0	14.5	5.0	965.0	1420.0	2390.0	0.0	25.0	3.3	28.3
Horsehead	10/16	21.0	14.8	26.7	1340.0	1791.7	3158.4	5.0	45.0	6.7	56.7
Point of Shoal	10/16	20.9	14.7	62.0	950.0	1358.0	2370.0	3.3	60.0	4.0	67.3
Swash	10/16	20.9	15.2	0.0	1895.0	1641.7	3536.7	3.3	55.0	3.3	61.6
Long Shoal	10/16	20.9	15.2	20.0	1644.7	1193.3	2858.0	5.3	72.0	2.0	79.3
Dry Shoal	10/16	20.9	15.9	42.7	1116.0	562.7	1721.4	7.3	51.3	0.7	59.3
Wreck Shoal	10/15	21.2	18.8	56.0	912.0	509.3	1477.3	4.7	37.3	2.0	44.0
Thomas Rock	10/15	21.3	20.0	51.3	800.0	616.7	1468.0	1.3	9.3	3.3	13.9
Nansemond Ridge	10/15	21.0	20.1	18.0	129.5	324.5	472.0	0.5	8.0	2.5	11.0
York River											
Bell Rock *	10/7	23.3	15.4	30.0	80.0	54.0	164.0	0.5	29.5	1.0	31.0
Aberdeen Rock	10/7	23.4	18.6	44.0	93.5	185.0	322.5	1.5	13.5	0.0	15.0
Mobjack Bay											
Tow Stake	10/7	22.9	19.6	29.3	169.3	340.7	539.3	2.7	17.3	4.0	24.0
Pultz Bar	10/7	22.2	20.4	20.0	43.0	4463.0	4526.0	0.0	6.0	37.0	43.0
Piankatank River											
Ginney Point	10/4	25.1	16.5	39.5	197.5	158.0	395.0	0.5	23.5	0.0	24.0
Palace Bar	10/4	25.1	16.5	3.5	241.5	242.5	487.5	0.0	6.0	0.0	6.0
Burton Point	10/4	24.9	17.4	42.5	197.0	387.5	627.0	0.0	18.0	1.5	19.5
Rappahannock River											
Ross Rock	10/10	20.5	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bowler's Rock	10/10	20.7	13.7	25.0	44.5	4.5	74.0	0.0	24.0	0.0	24.0
Long Rock	10/10	21.1	14.5	28.0	32.5	6.0	66.5	0.0	10.0	0.0	10.0
Morattico Bar	10/10	21.3	15.5	21.0	117.0	4.0	142.0	0.0	7.0	0.0	7.0
Smokey Point	10/10	21.5	15.9	35.5	229.0	7.0	271.5	0.5	5.5	0.0	6.0
Hog House	10/10	21.0	16.0	31.5	51.0	7.0	89.5	0.0	5.5	0.0	5.5
Middle Ground #	10/10	21.4	16.4	37.5	141.0	139.0	317.5	2.5	24.5	1.0	28.0
Drumming Ground	10/10	21.7	17.1	68.0	349.0	166.0	583.0	0.0	37.0	0.0	37.0
Parrot Rock	10/10	21.6	16.9	52.0	76.5	57.0	185.5	1.0	11.5	0.0	12.5
Broad Creek	10/10	21.2	17.8	77.5	199.0	191.5	468.0	3.0	13.0	0.5	16.5
Great Wicomico River											
Haynie Point	10/11	19.8	16.9	43.5	211.5	626.5	881.5	1.0	12.0	4.5	17.5
Whaley's East	10/11	19.4	16.9	55.0	104.5	120.0	279.5	1.0	14.0	0.5	15.5
Fleet Point	10/11	19.4	16.9	42.0	101.5	80.5	224.0	0.0	6.5	1.0	7.5

Figure D1: Map showing the location of the oyster bars sampled during the 2019 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.

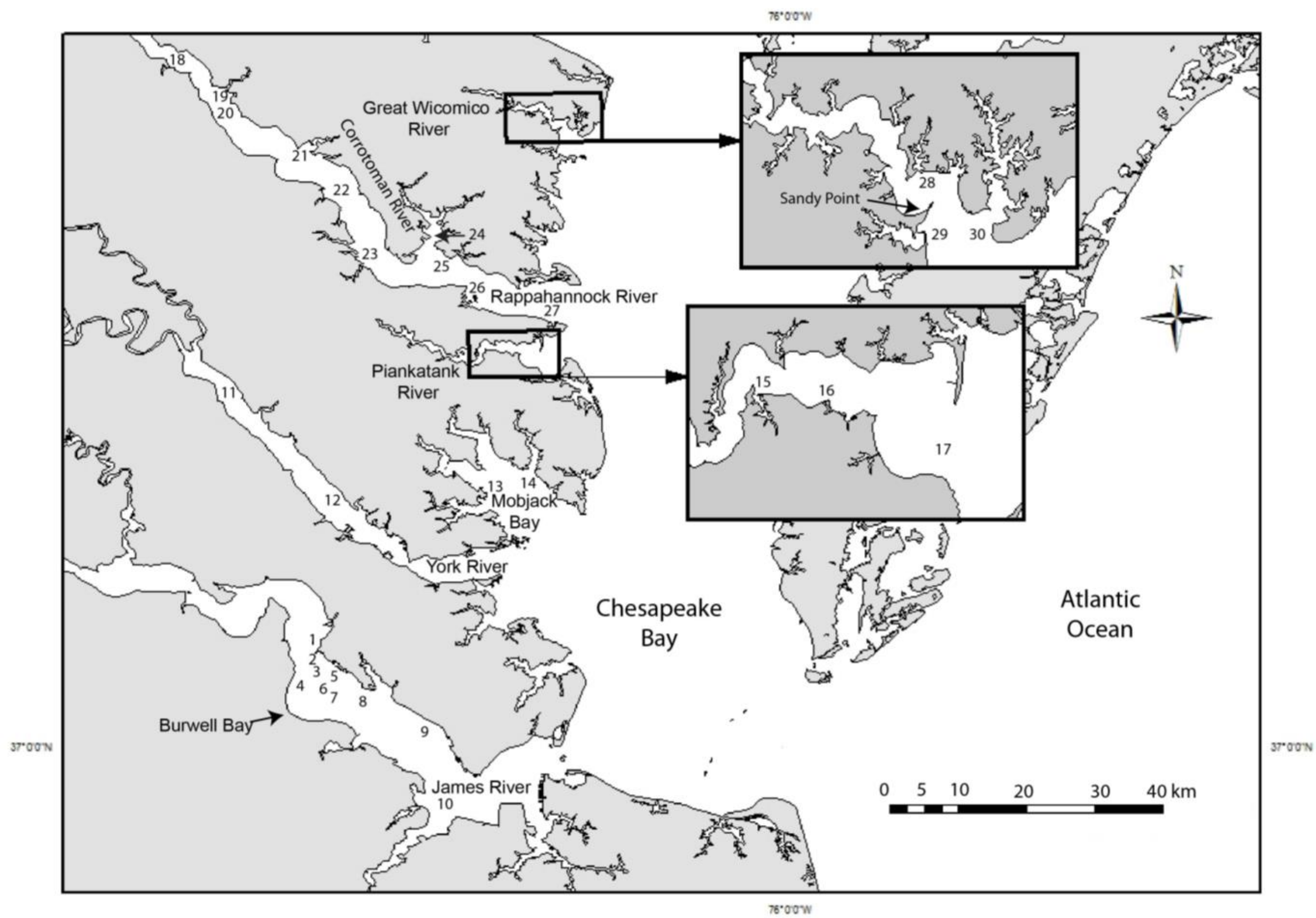


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2018-2019)
(Error bars represent standard error of the mean)

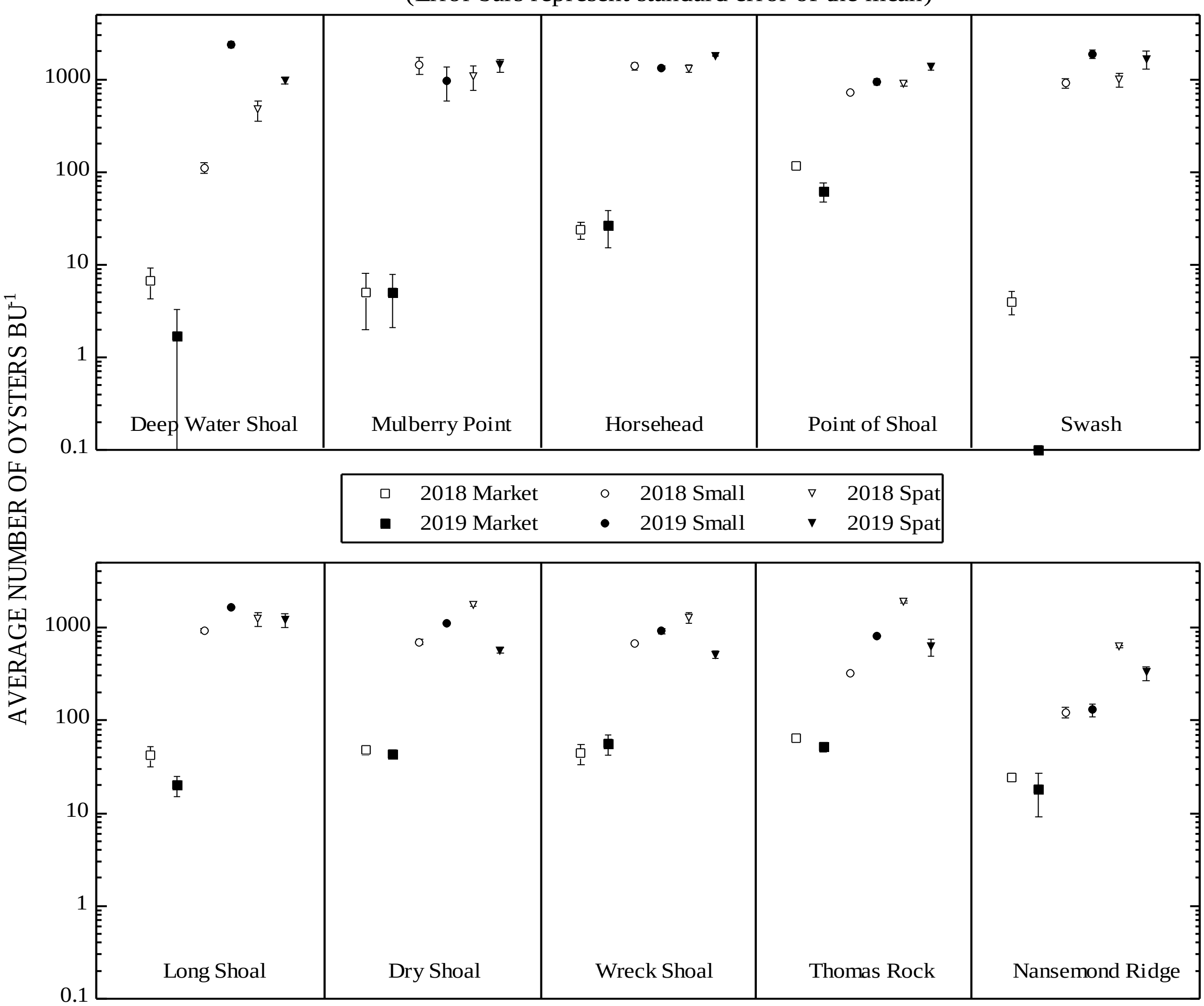


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

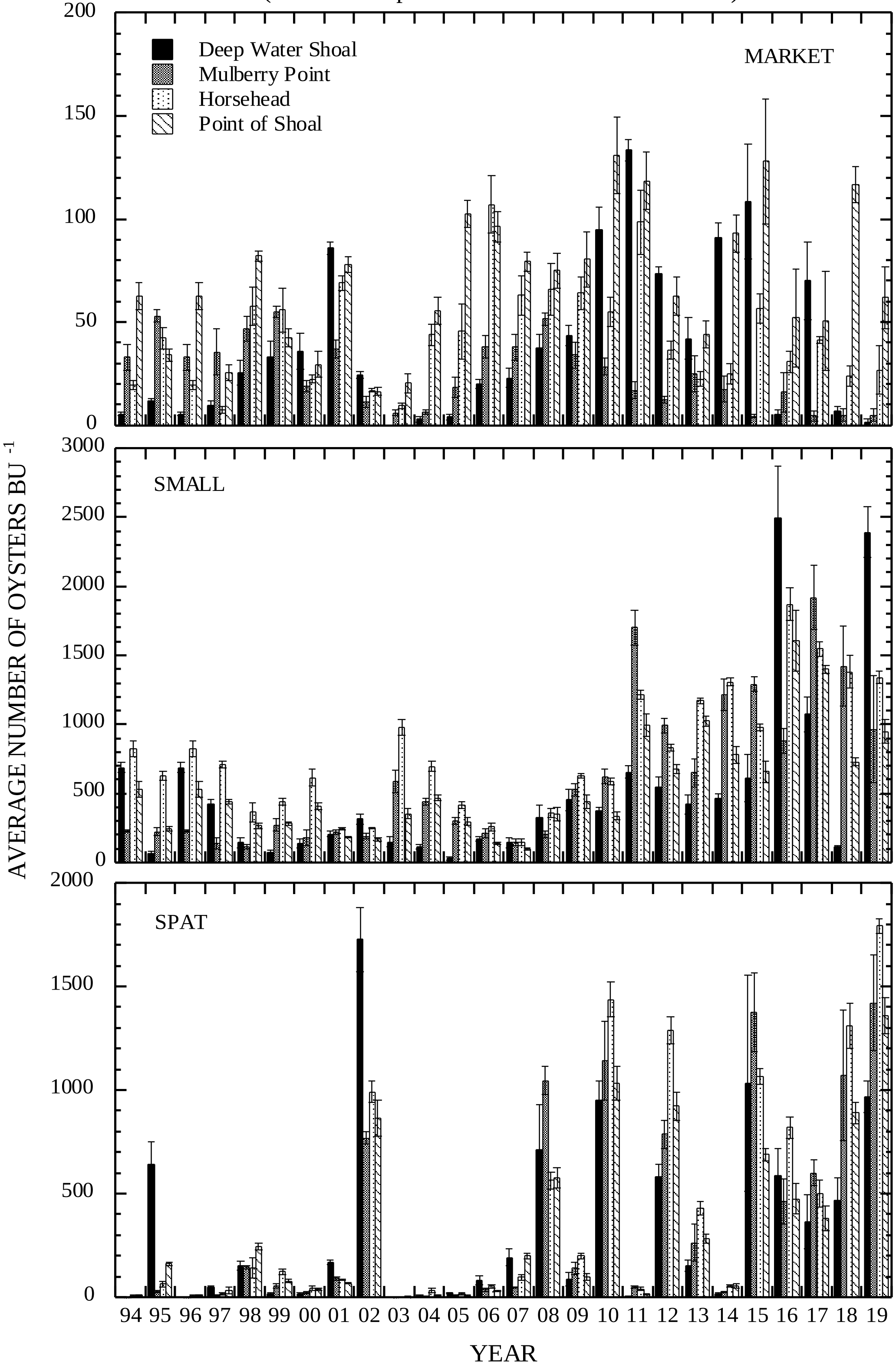
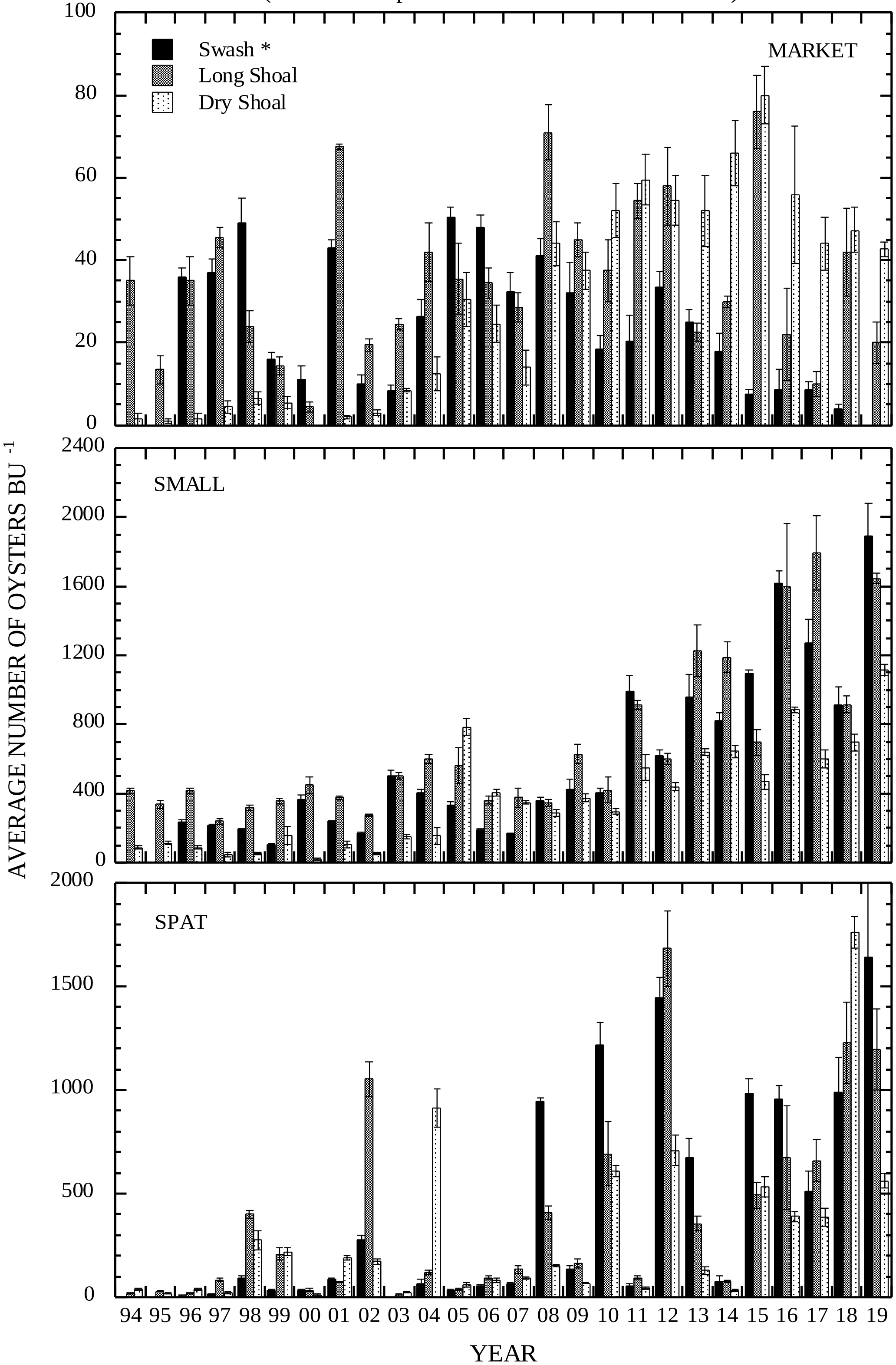


FIGURE D3B: JAMES RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1996

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

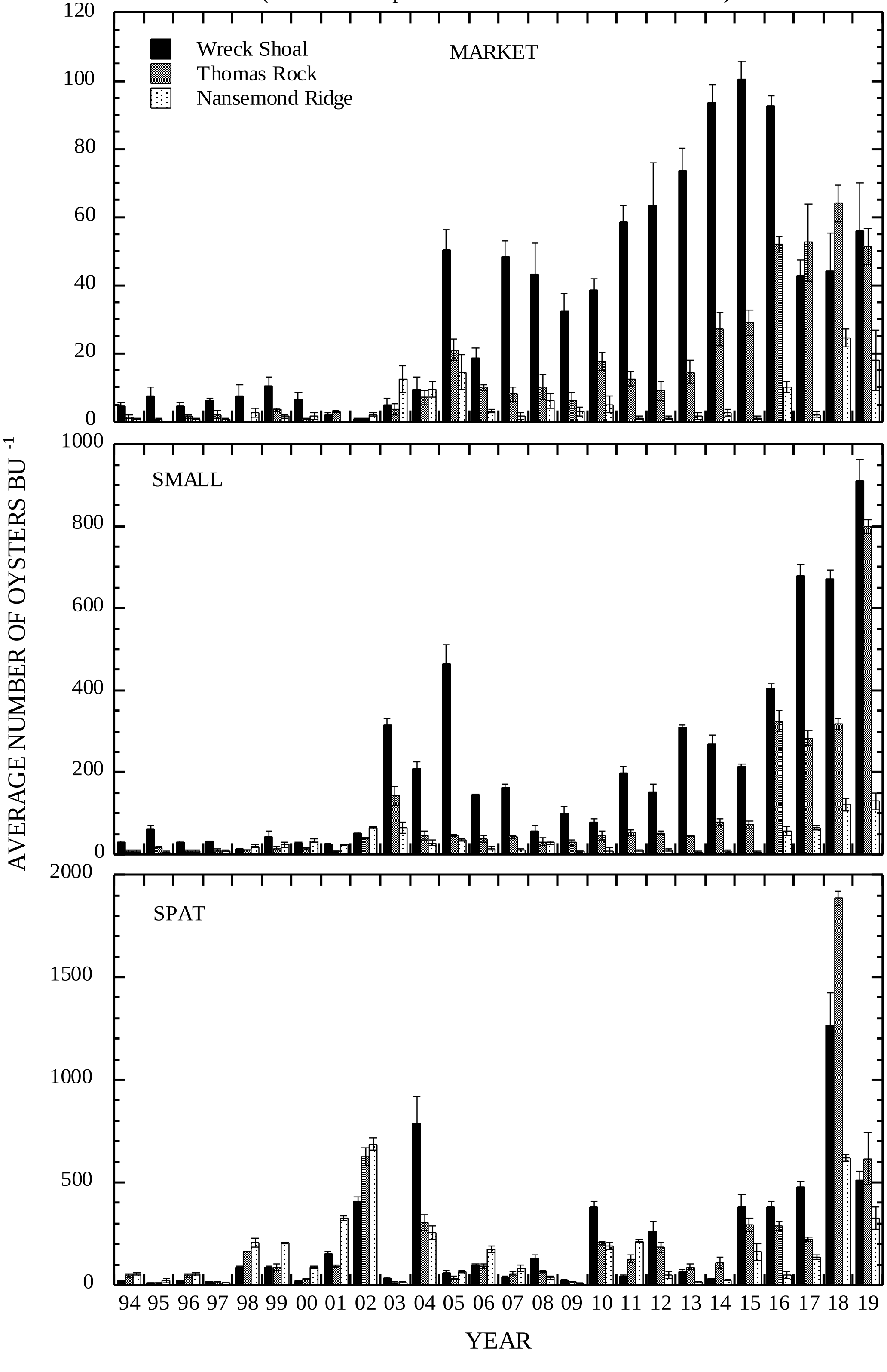


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE YORK RIVER AND MOBJACK BAY (2018-2019)
(Error bars represent standard error of the mean)

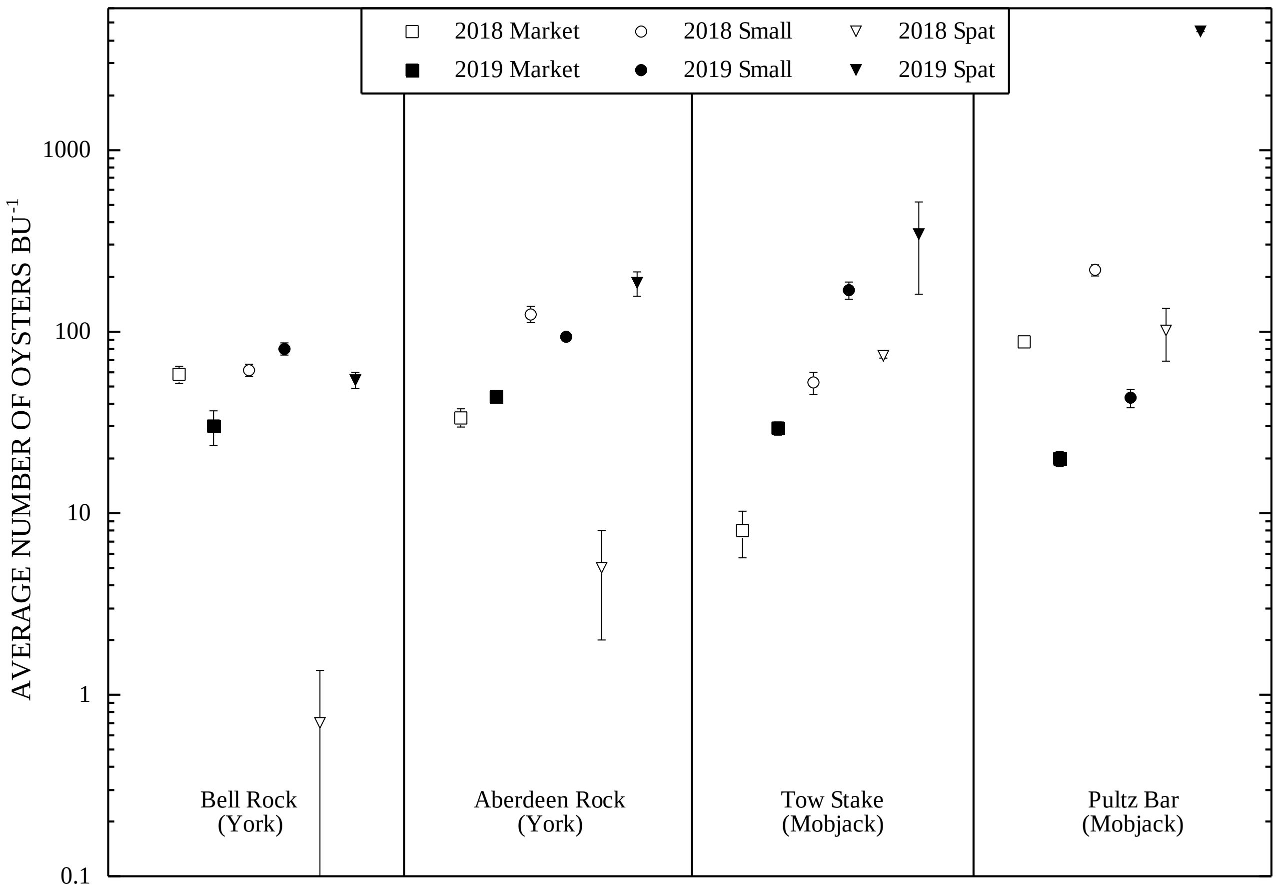


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

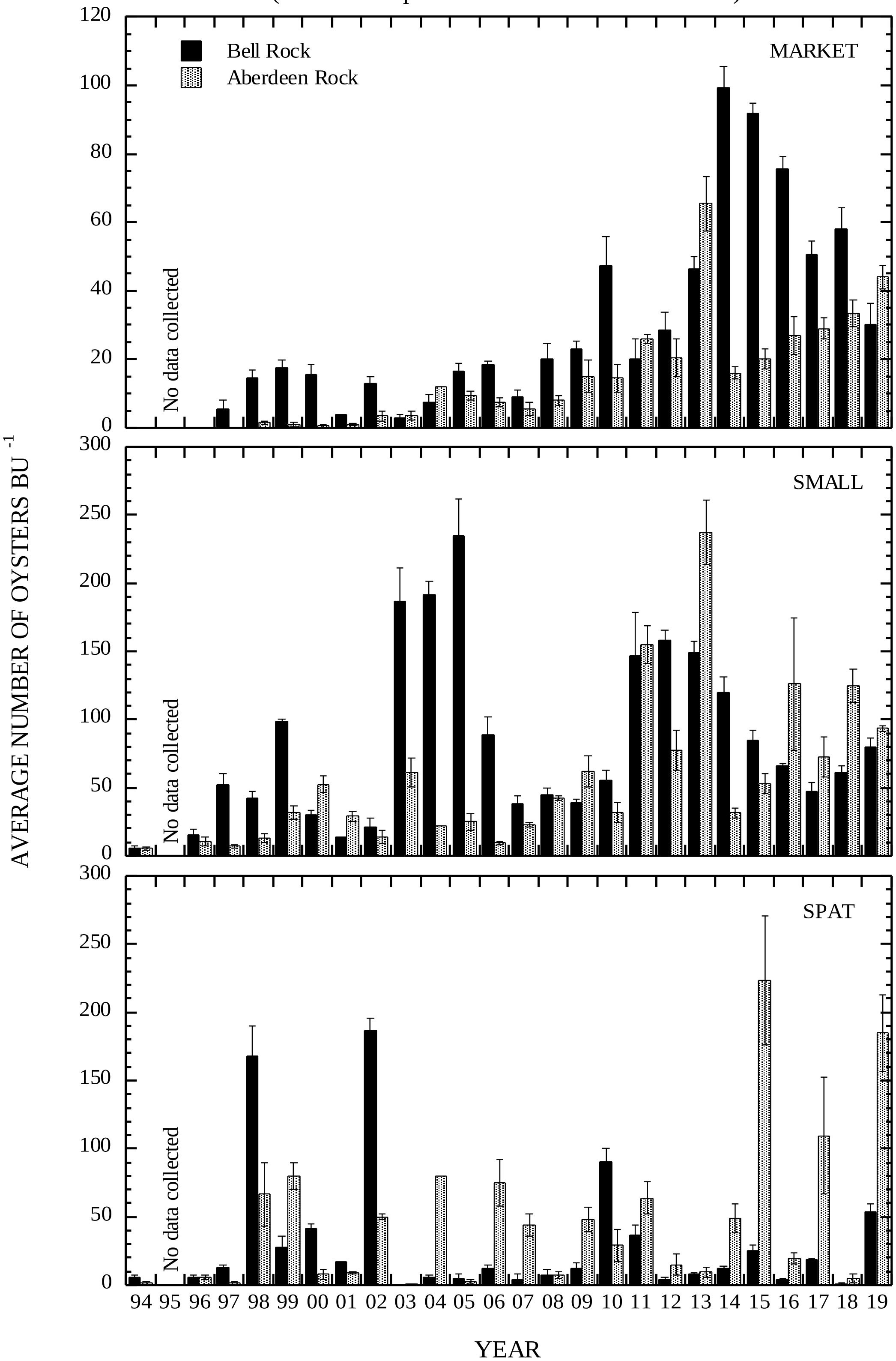


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

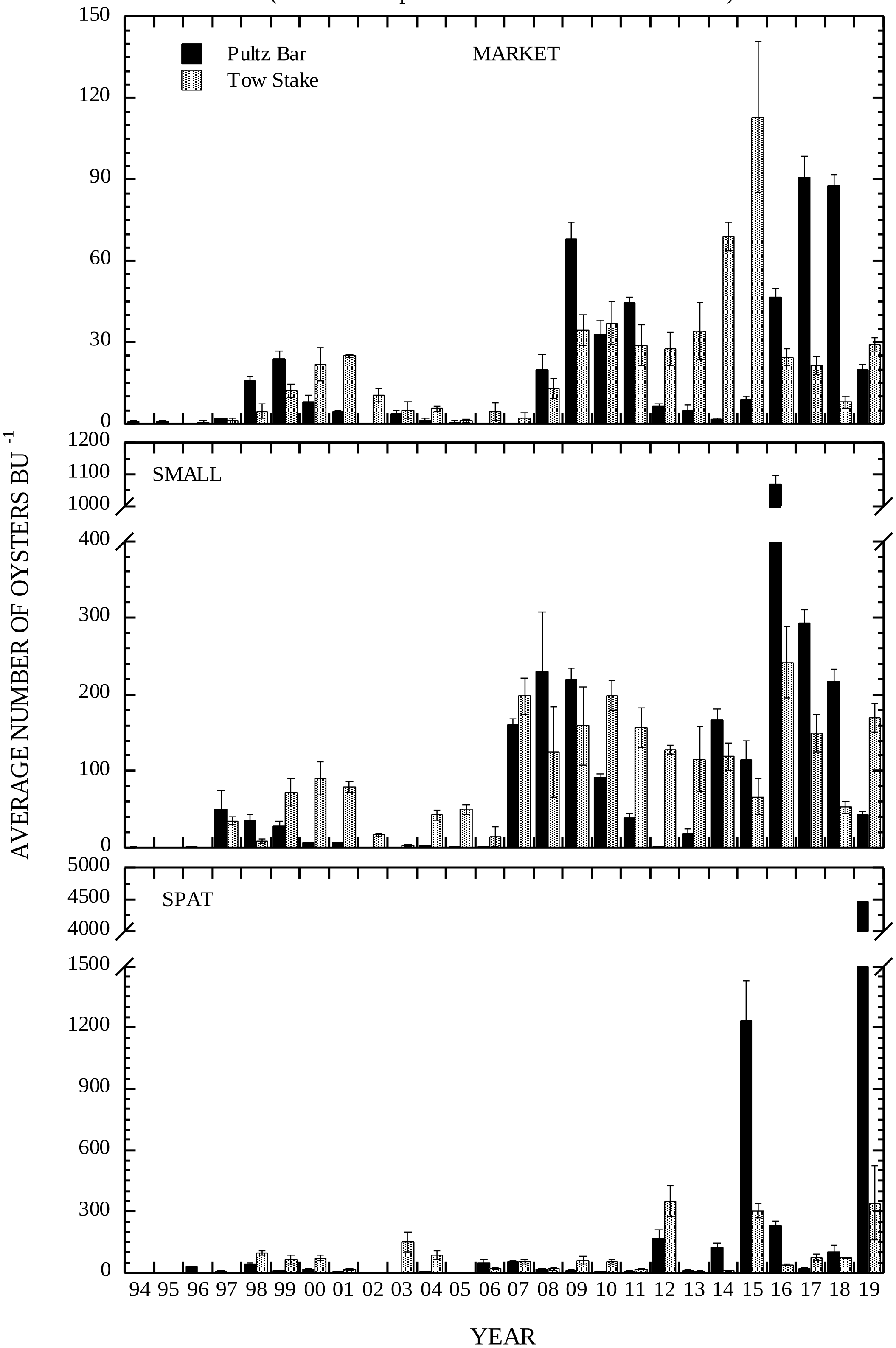


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2018-2019)
(Error bars represent standard error of the mean)

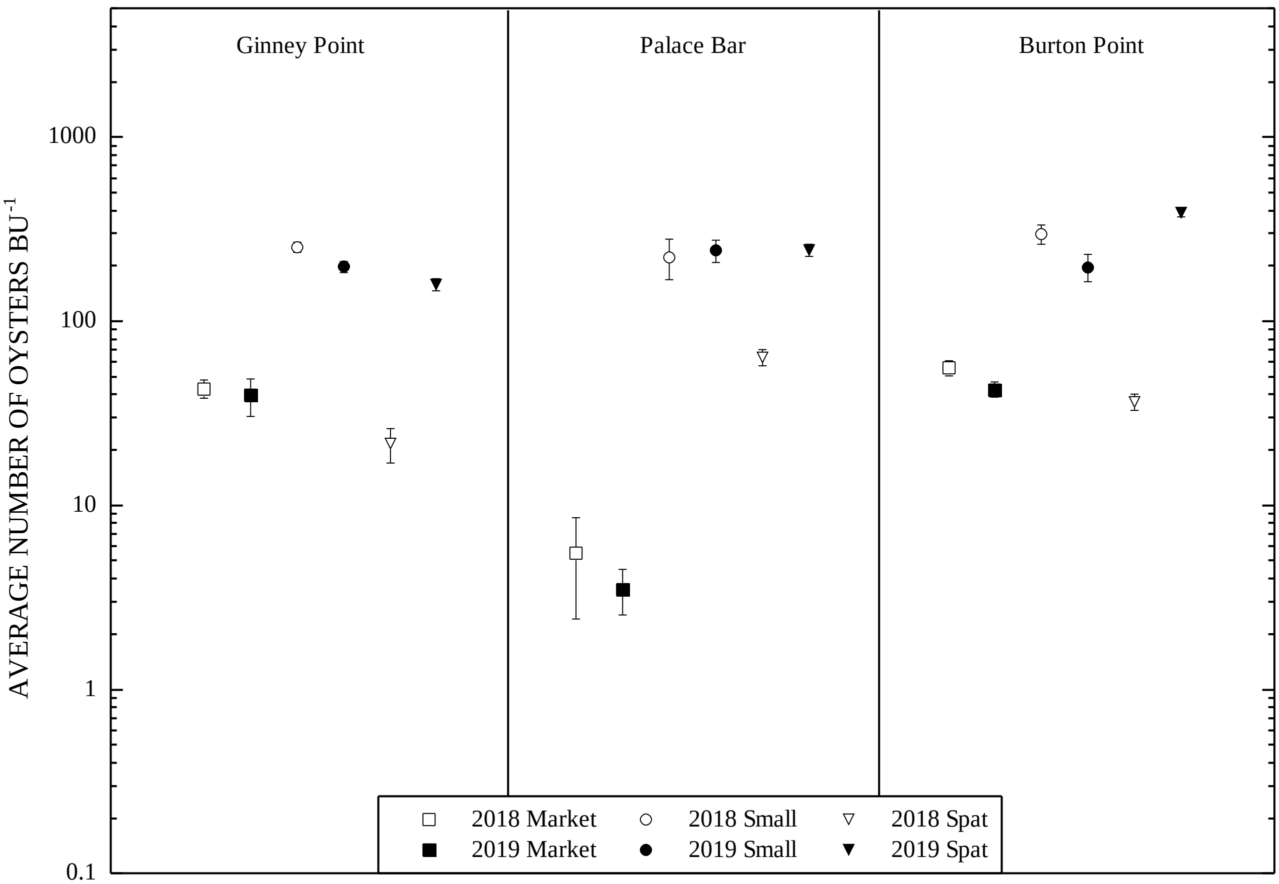


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)

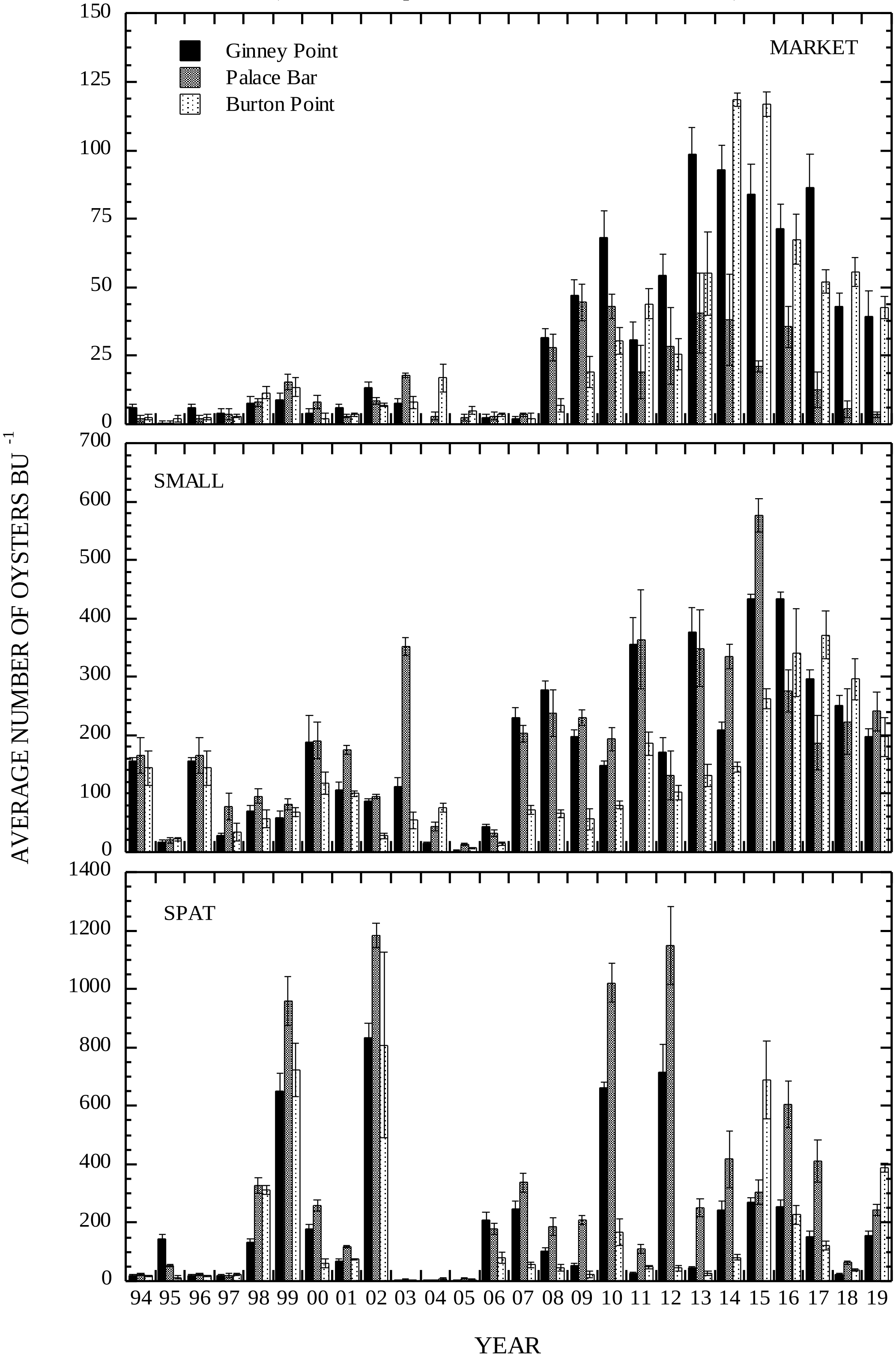


FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2018-2019)
(Error bars represent standard error of the mean; * recieved a seed plant in Spring 2019)

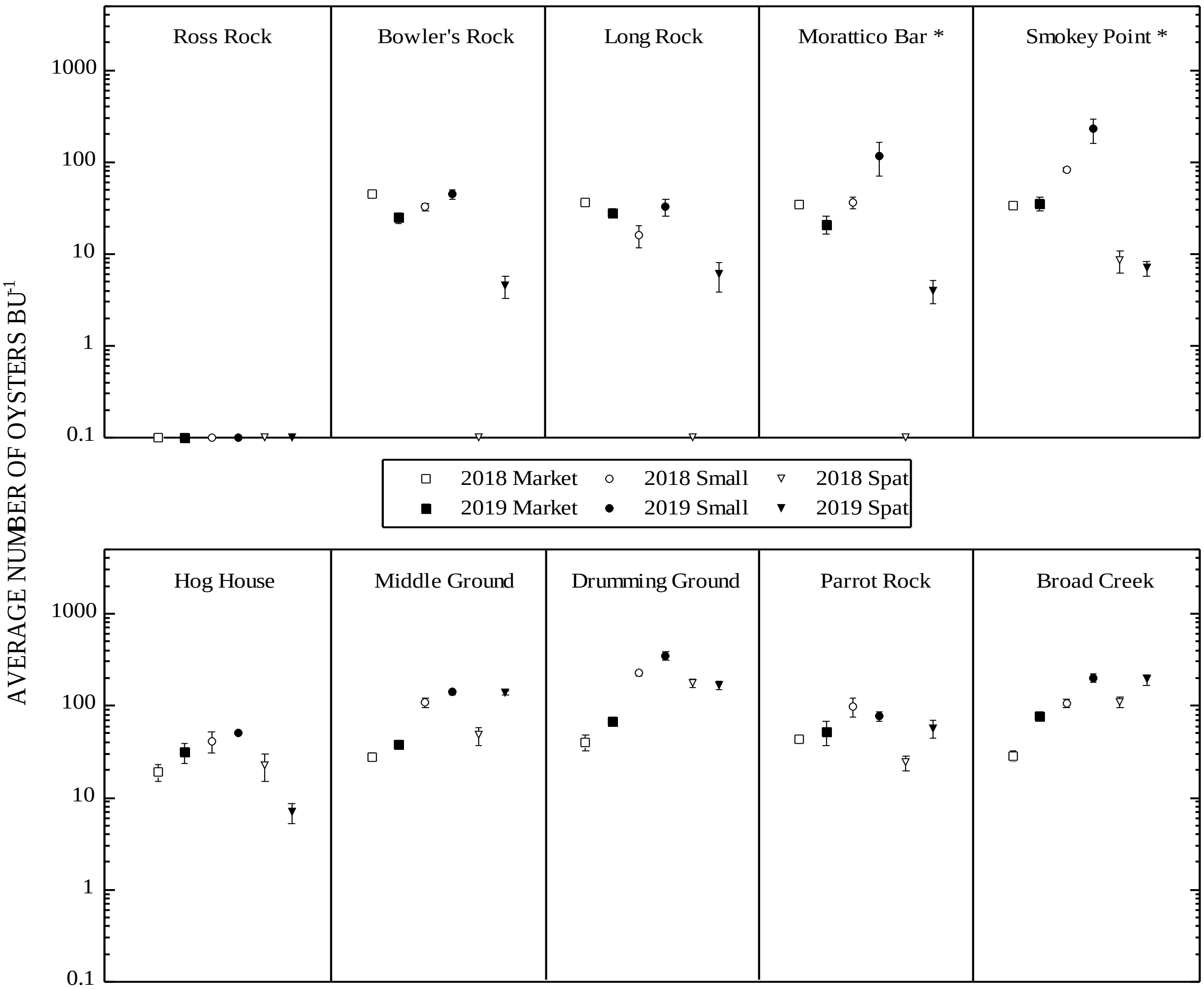
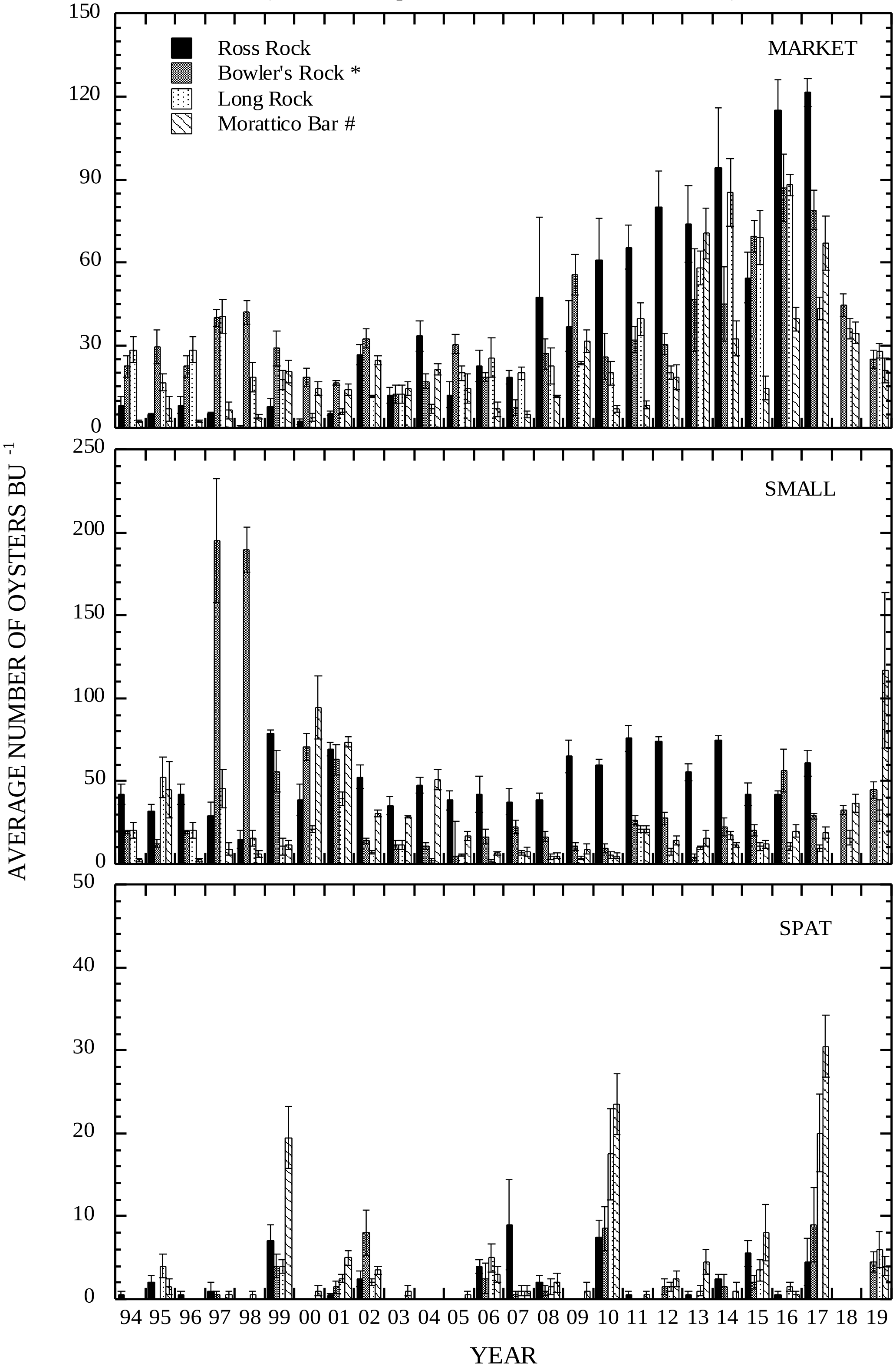
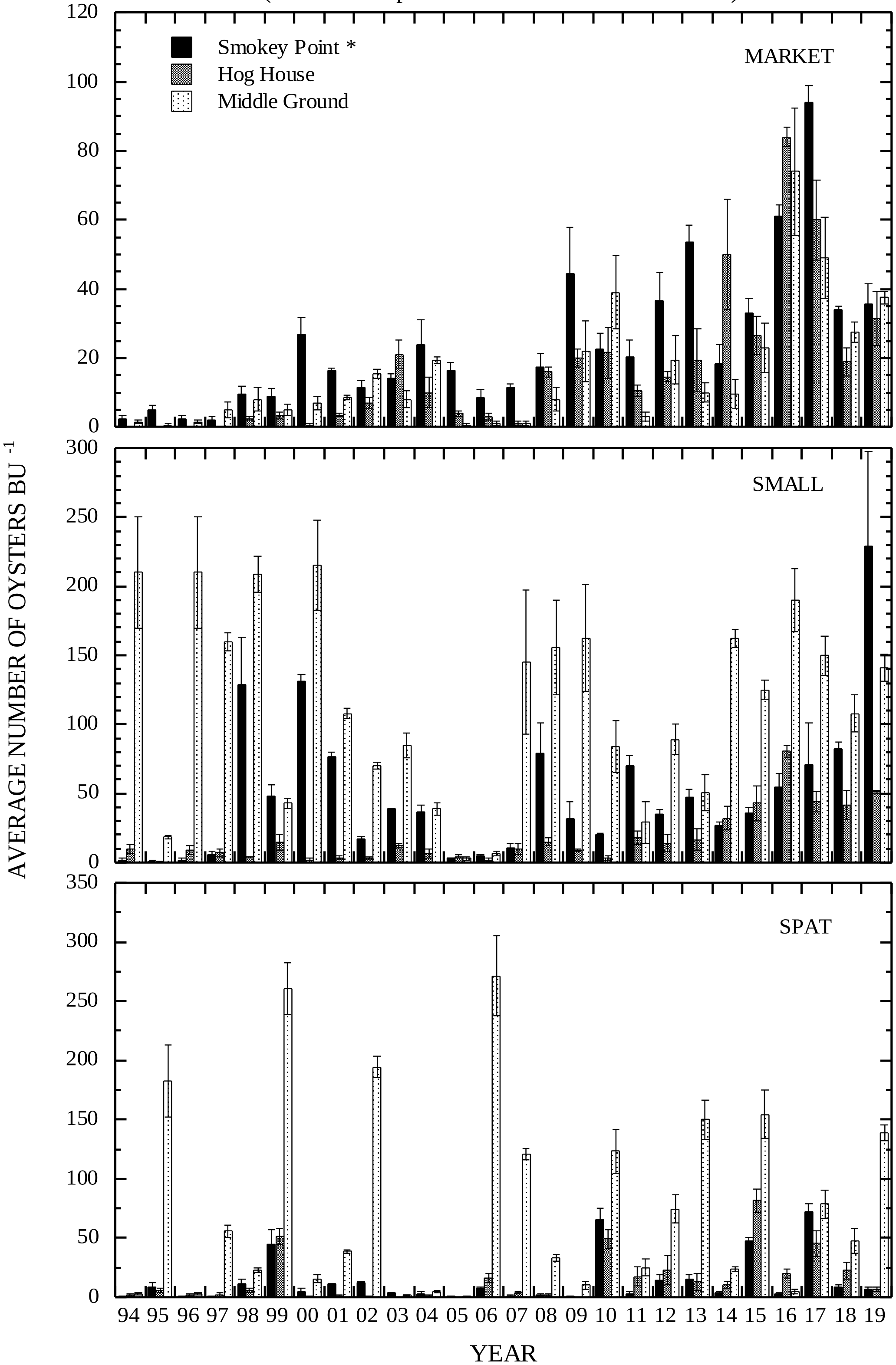


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



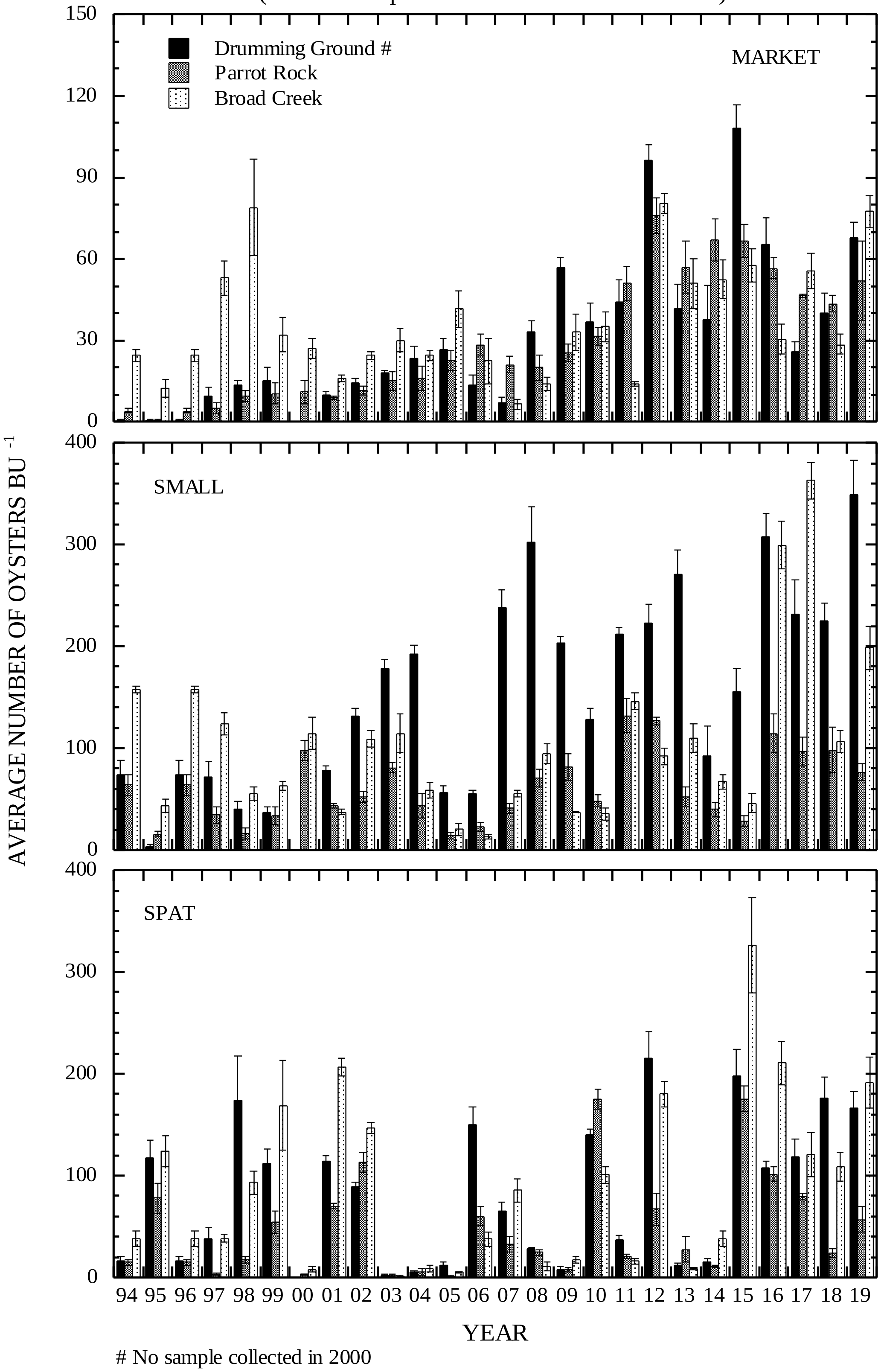
* Seed plant in 1997: # seed plant in 2019

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



* Seed plant in 2019

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



No sample collected in 2000

FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE GREAT WICOMICO RIVER (2018-2019)
(Error bars represent standard error of the mean)

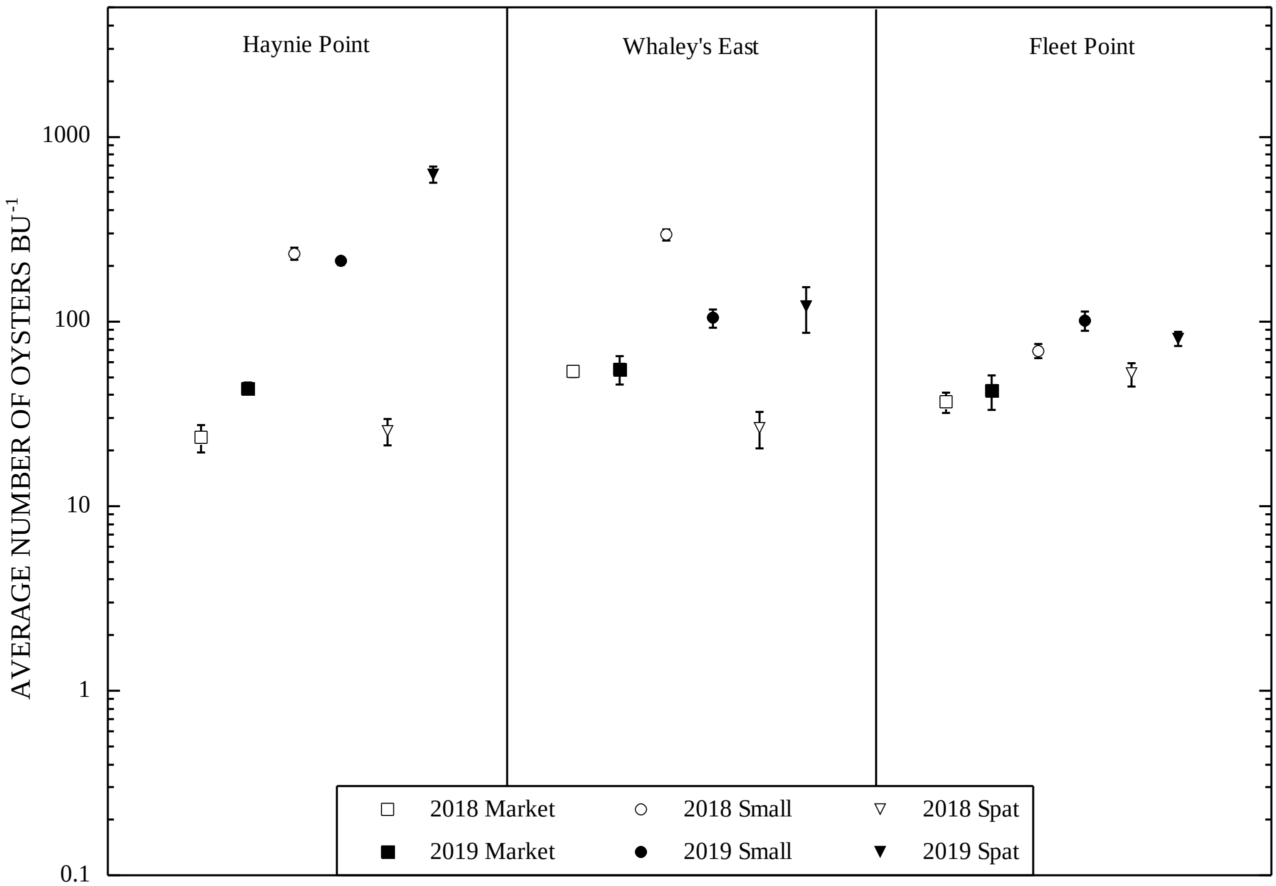
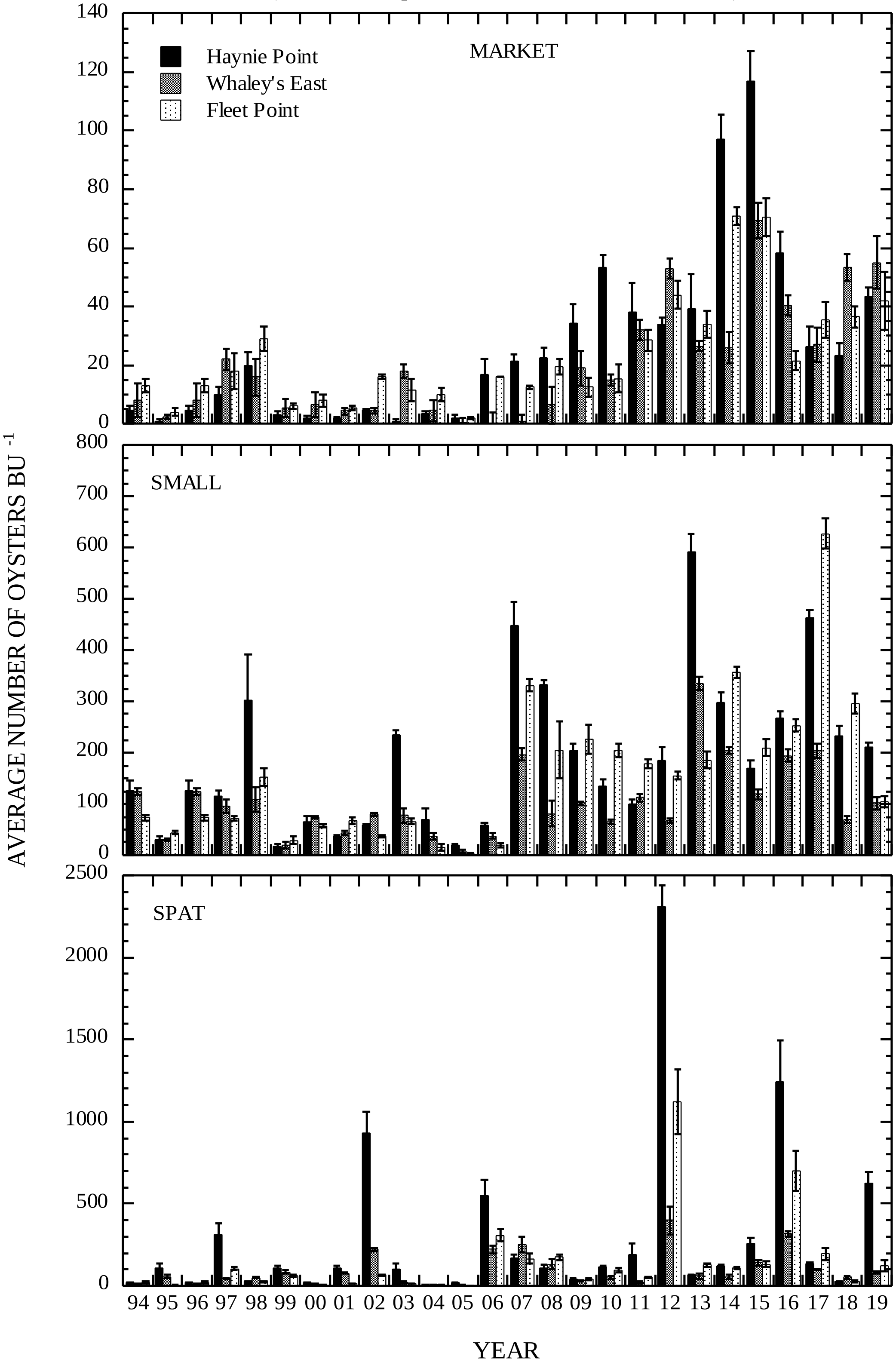


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 25 YEARS
(Error bars represent standard error of the mean)



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