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The Status of Virginia's Public Oyster Resource 2013.

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Part I. OYSTER RECRUITMENT IN VIRGINIA DURING 2013

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 (recruitment of larval oysters called spat, where recruitment is the end point of the process of settlement and metamorphosis) 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 recruitment (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 interested in potential timing and location of shell plantings.

Results from spatfall monitoring reflect the abundance of ready-to-settle oyster larvae in an area, and thus, provide an index of oyster population reproduction as well as development and survival of larvae to the recruitment stage in an estuary. Environmental factors affecting these physiological activities may cause seasonal and annual fluctuations in recruitment, which are evident in the data.

Data from spatfall monitoring also serve as an indicator of potential oyster recruitment into a particular estuary. Recruitment and subsequent survival of spat on bottom cultch (shell that is available as substrate for recruitment) are affected by many factors, including physical and chemical environmental conditions, the physiological condition of the larvae when they begin the recruitment and metamorphic process, predators, disease, and the timing of these factors. Availability and condition of bottom cultch also affects recruitment and survival of spat on the bottom. Therefore, recruitment on shellstrings may not directly correspond with recruitment on bottom cultch at all times or places. Under most circumstances, however, the relationship between recruitment on shellstrings and recruitment to bottom cultch is expected to be commensurate.

This report summarizes data collected during the 2013 oyster recruitment season in the Virginia portion of the Chesapeake Bay.

METHODS

Oyster recruitment during 2013 was monitored from the last week of May through the last week of September in the James, Piankatank and Great Wicomico Rivers. Recruitment 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 monitor the effects of replenishment efforts by the Commonwealth of Virginia. The modern sites in both the Piankatank and Great Wicomico Rivers correspond to those sites that were considered "new" in the 1998 survey. Since 1993, the Virginia Marine Resources Commission (VMRC) has built numerous artificial oyster shell reefs in several tributaries of the western Chesapeake Bay and in both Pocomoke and Tangier Sounds located on the eastern side of the Chesapeake Bay (http://www.vims.edu/research/units/labgroups/molluscan_ecology/restoration/va_restoration_a

tlas/index.php). The change in the number and location of shellstring sites during 1998 was implemented to provide a means of quantitatively monitoring oyster recruitment 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 both broodstock oysters on the reefs as well as shell plants on the bottom surrounding the reefs.

Oyster shellstrings were used to monitor oyster recruitment. 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 on either a pole (if one was available at the site) or on a buoy set-up (Figure 2). 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 2013 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 between 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 recruitment trends over the course of the season between various sites in a river as well as between data for different years.

The cumulative recruitment for each site was computed by tallying the standardized weekly spat shell^{-1} values for the entire sampling period. This value represents the average number of spat that would fall on any given shell if allowed to remain at that site for the entire sampling period. Spat shell^{-1} values were categorized for comparison purposes as follows: 0.1-1.0, light; 1.1-10.0, moderate; and 10.1 or more, heavy. Unqualified references to diseases in this text imply diseases caused by *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (*Perkinsus*, or Dermo).

Water temperature (°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

Recruitment on shellstring collectors during 2013 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of recruitment over the past twenty-five years (1988-2013) at the historical sites in all three river systems and over the past fifteen years (1998-2013) for the modern sites in the Piankatank and Great Wicomico Rivers. Unless otherwise specified, the information presented

below refers to those two tables. In this report the term "peak" is used to define the period when there was a noticeable increase in recruitment 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 2013 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 2013. Comparisons were made over the past fifteen 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 (Cranes Creek in data reports prior to 1997).

James River

Oyster recruitment in the James River was first observed during the week of 17 June at Point of Shoal (Table S1). Recruitment was intermittent from then through mid-July, with the last two weeks of data collection missed at the end of July due to inclement weather. Recruitment was relatively light, but consistent throughout most of August and September, with no obvious peak in recruitment occurring during the season (Figure S3).

Recruitment in the James River was moderate (five sites) to heavy (three sites) ranging from a low of 2.8 cumulative spat shell^{-1} at Deep Water Shoal to a high of 20.4 cumulative spat shell^{-1} at Dry Shoal (Table S1; Figure S4). Recruitment during 2013 was lower than the previous year (2012), as well as the 5, 10, 20 and 25-yr means at all eight sites monitored. Overall recruitment in the James River during 2013 was in the middle of the range of that observed over the past twenty-five years of monitoring, with the long term means being primarily driven by a six exceptional years (1991, 1993, 2002, 2008, 2010 and 2012).

Average river water temperatures during the monitoring period ranged from 21.5 to 27.4°C (Figure S5A). Water temperature reached the maximum of 27.4°C in mid-July. This maximum was approximately 2°C less than what is typical for the James River, but this may have been due to the fact that inclement weather prevented data collection during the last two weeks of July, which is often when the James River reaches its summer temperature maxima. However, it should be noted that water temperature throughout a large portion of the 2013 sampling season was 1 to 2°C less than the long terms means (5, 10, 20 and 25-year; Figure S5A). This difference was especially prominent at the beginning of the sampling period and during the first few weeks of August.

Average salinities in the James River during the monitoring period ranged from 5.7 to 16.8, fluctuating a good deal throughout June into early July and generally increasing from mid-July onward. Salinity in the James River was highly variable throughout the month of June; changing as much as 6 from one week to the next (Figure S5B). During the weeks of 10 June and 24 June, salinity was between 4 and 4.5 lower than the long-term (5, 10, 20 and 25-yr) means. Salinity was similar (within 2) to the 5, 10, 20 and 25-yr means throughout the months of July, August and September. The one exception was during the week of 19 August when salinity was around 4 lower than the long-

term means (Figure S5B). The difference in salinity in any given week between the most upriver site (Deep Water Shoal) and the most downriver sites (Day's Point and/or Wreck Shoal; Figure 1) ranged from 7 to 15.

Piankatank River

Recruitment in the Piankatank River was first observed during the week of 17 June at three out of the eight sites monitored (Table S1; Figure S6). Recruitment was relatively consistent (at least one spat set during each week at each site) throughout July and early August. There was an approximate three-week peak in recruitment throughout the system between 22 July and 5 August. Recruitment during this period at the seven sites where data were available for all three weeks, accounted for between 91 (Wilton Creek, Ginney Point and Burton Point) and 97% (Cape Toon) of the total spat set observed for the year.

Cumulative spat shell^{-1} for the year was moderate to heavy ranging from a low of 4.3 at Heron Rock to a high of 62.9 at Cape Toon (Table S1). It should be noted that the relatively low recruitment observed at Heron Rock (when compared with the other sites in the system), might have been due to the absence of data at that site during two out of the three weeks in which the peak recruitment occurred. Recruitment during 2013 was lower than that observed during 2012 at all eight sites in the Piankatank River. Recruitment at the historical sites was higher than the 20-yr mean at all three sites and higher than the 25-yr mean at both Ginney Point and Burton Point (Table S2; Figure S7A). At the modern sites, recruitment during 2013 was higher than both the 5 and 10-yr means at Stove Point and higher than the 10-yr mean at Bland Point and Cape Toon (Table S2; Figure S7B). At the modern sites, recruitment during 2013 ranked the second (Stove Point and Wilton Creek) and third highest (Bland Point and Cape Toon) observed since monitoring began at those sites in 1998.

The average water temperature in the Piankatank River during the 2013 sampling period ranged from 21.4 to 30.2°C, reaching the maxima during the week of 15 July (Figure S8A). With only two exceptions, water temperature in the Piankatank River was similar (typically less than 2°C) to the 5, 10 and 20-yr means throughout the majority of the sampling period (Figure S8A). These two exceptions occurred in the very beginning of the sampling period during the week of 27 May when temperature was 2.2 and 2.9 °C less than the 5 and 10-year means respectively and during the week of 15 July when temperature was at its maxima and was 1.9 (5 and 10-year) and 2.4 °C (20-year) higher than the long-term means.

Salinity in the Piankatank River during 2013 ranged from 15.9 to 19.3. During the month of June and the first three weeks of July, the average salinity was between 2 and 4 higher than the 5, 10 and 20-year means (Figure S8B). Throughout most of the rest of the 2013 sampling season, salinity was similar to the long-term (5, 10 and 20-yr) means (Figure S8B), with the exception of the final week of sampling (September 23) when salinity once again increased and was around 2.5 higher than the long-term means. The difference recorded in any given week between Wilton Creek (the most upriver site) and Burton Point (the most downriver site: Figure S1) was between 1 and 6, but was typically less than 3. The few times that the difference was higher was following a heavy rainfall, which due to the shallowness of the Wilton Creek site, tends to experience large fluctuations in salinity following large influxes of fresh water.

Great Wicomico River

Recruitment in the Great Wicomico River was first observed during the week of 24 June at seven out of the nine sites and was consistent (at least one spat set during each week at each site) from 1 July through 12 August (Table S1; Figure S9). At all of the sites except Whaley's East, the majority (72 to 86%) of recruitment for the year occurred between 1 July and 22 July (Figure S9). At Whaley's East, 70% of the spat set for the year occurred during a two-week period in late July/early August (29 July to 5 August; Figure S9).

Cumulative spat shell^{-1} for the year at the two sites downriver of Sandy Point, Whaley's East and Fleet Point, was moderate, 4.1 and 8.4 spat shell^{-1} respectively. Recruitment at the seven upriver sites was heavy ranging from a low of 16.1 spat shell^{-1} at Haynie Point to a high of 79.5 spat shell^{-1} at Rogue Point (Table S1; Figure S10). Recruitment in the Great Wicomico River in 2013 was lower than that observed in 2012 and lower than both the 5 and 10-yr means at all nine stations monitored (Table S2; Figure S10). At the historical sites, recruitment in 2013 was higher than the 20 and 25-yr means at both Hudnall and Fleet Point.

During the 2013 sampling period, average river water temperatures ranged from 22.8 to 30.1°; reaching the maxima during the week of 15 July (Figure S11A). For the majority of the monitoring season, water temperatures in the Great Wicomico were typically less than 1°C different from the long-term (5, 10 and 15-yr) means (Figure S11A). However, during several weeks of August, water temperature was between 1.5 and 2°C lower than the long-term (5, 10 and 15-yr) means (Figure S11A).

Salinity in the Great Wicomico River during the 2013 sampling period ranged from 14.6 to 18.8 (Figure S11B). Similar to what was observed in the Piankatank River, throughout the month of June, into early July, salinity in the Great Wicomico River on average was 2.6 higher than the long-term (5, 10 and 15-yr) means (Figure S11B). There was a 1 to 4 difference in salinity between the most upriver site (Glebe Point) and the most downriver site (Fleet Point: Figure S1) throughout most of the sampling period.

DISCUSSION

With some exceptions in each of the rivers during various years, low or moderate recruitment (seasonal cumulative total of less than 10.0 spat shell^{-1}) has been common in Virginia since 1993 (61% of all year/site combinations). However, recruitment on the shellstrings over the past seven years (2007-2013) has been on the rise such that 73% of all of the year/site combinations had heavy recruitment (seasonal cumulative total of > 10.0 spat shell^{-1}). This trend of increased spat set has been especially notable in the Great Wicomico River, where since 2006, 85% of all of the year/site combinations had heavy recruitment (seasonal cumulative total of > 10 spat shell^{-1}) and 29% of the total year/site combinations had very heavy recruitment (seasonal cumulative total of > 100.0 spat shell^{-1};Table S2). Recruitment was moderate to heavy at all sites monitored during 2013.

Overall recruitment on shellstrings in the James River during 2013 was moderate (Deep Water Shoal, Horsehead, Point of Shoal, Swash and Wreck Shoal) to heavy (Dry Shoal, Rock Wharf, Day's Point). Recruitment tended to be higher along the southern shore of the river. Since 2008, the James River has had several very strong year classes. The average cumulative spat shell^{-1} for all eight sites combined from 1988 to 2007 was 12.3, whereas the average for all eight sites combined over the past six years (2008 to 2013) was 101.1. This

represents an eight-fold increase in recruitment over the past six years compared with the previous twenty years. In recent years, the timing of recruitment in the James River has been getting progressively earlier (Southworth & Mann 2004). The bulk of the recruitment in the James River system during 2013 however occurred later in the year, primarily during August and September, similar to historical recruitment patterns in the system (Haven & Fritz 1985).

Overall recruitment on the shellstrings in the Piankatank River was moderate to heavy, with cumulative number of spat shell^{-1} for the season at the modern sites among the highest observed over the past sixteen years of monitoring. Similar to the James River, in recent years the Piankatank River has had several very strong year classes including the 2013-year class. From 1993 to 2006 (historical sites) and 1998 to 2006 (modern sites), recruitment in the Piankatank River was consistently low to moderate at most of the sites monitored. At the three historical sites the average from 1993 to 2006 was 7.4 cumulative spat shell^{-1}, whereas from 2007 to 2013 the average at those three sites was 124.6 cumulative spat shell^{-1}, a seventeen-fold increase over the previous fourteen-year average. Since the addition of the modern sites in 1998, the average across the river increased from 32.5 cumulative spat shell^{-1} (1998 to 2006) to 354.2 cumulative spat shell^{-1} (2007 to 2013), an eleven-fold increase. For the past several years potential broodstock (small plus market) in the system has been on the rise. The number of potential brookstock in the system during 2013 was among the highest observed during the past twenty-five years of monitoring (Part II, this report). Density of the broodstock is an important factor in determining fertilization success (Mann & Evans 1998).

For the eighth year in a row, overall recruitment on the shellstrings in the Great Wicomico River was heavy, especially when compared with most of the 1990s and the early 2000s. For the five historical sites the average spat shell^{-1} between 1991 and 2005 ranged from 1.2 (Whaley's East) to 21.7 (Glebe Point), whereas the average between 2006 and 2013 ranged from 16.0 (Fleet Point) to 396.8 (Glebe Point). This was a 10 to 21-fold increase in recruitment during the past eight years over the previous fifteen years. For the modern sites, the average spat shell^{-1} between 1998 and 2005 ranged from 2.6 (Harcum Flats) to 5.4 (Hilly Wash), whereas the average between 2006 and 2013 ranged from 95.8 (Shell Bar) to 235.1 (Harcum Flats). This was a 35 to 89 fold increase during the past eight years when compared with the previous eight years.

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

STATION	5/27 147	6/3 154	6/10 161	6/17 168	6/24 175	7/1 182	7/8 189	7/15 196	7/22 203	7/29 210	8/5 217	8/12 224	8/19 231	8/26 238	9/2 245	9/9 252	9/16 259	9/23 266	YEAR TOTAL
JAMES RIVER																			
Deep Water Shoal	D	0	0	0	0	0	0	0	-	-	0.2	0.3	0.1	0.2	0.5	1.0	0.2	0.3	2.8
Horsehead	D	0	0	0	0	0.2	0	0.1	-	-	-	0.2	0.7	0.1	0.7	1.4	0.1	1.2	4.7
Point of Shoal	D	0	0	0.1	0	0.1	0.1	0	-	-	0.2	0.1	0.8	0	1.0	0.6	0	0.2	3.2
Swash	D	0	0	0	0	0	0.3	0.3	-	-	0.3	0.8	0.8	0.1	0.5	0.6	0.1	0.2	4.0
Dry Shoal	D	0	0	0	0.1	0.5	0.4	1.7	-	-	1.7	2.0	3.1	1.7	4.5	3.7	0.8	0.2	20.4
Rock Wharf	D	0	0	0	0	0.1	0.1	0.3	-	-	1.5	0.9	1.9	1.0	3.2	1.3	0.5	0.1	10.9
Wreck Shoal	D	0	0	0	0	0	0	0.1	-	-	0.1	0.2	0	0.4	0.7	1.2	0.5	0.1	3.3
Day's Point	D	0	0	0	0.1	0.4	0	0.1	-	-	2.4	0.8	0.4	0.8	2.4	2.9	0	0.8	11.1
PIANKATANK RIVER																			
Wilton Creek	D	0	0	0	0	0.5	0.1	1.3	6.6	10.8	2.4	1.5	0	0.1	0	0	0	0	23.3
Ginney Point	D	0	0	0.2	1.4	0.1	0.1	2.3	13.5	8.2	2.7	0.4	0.1	0.1	0	0	0.2	0	29.3
Palace Bar	D	0	0	0	0.1	0.1	-	2.4	3.1	6.8	3.2	0.7	0.2	0	0	0	0	0	16.6
Bland Point	D	0	0	0	0.2	0.1	0.1	4.8	23.2	10.1	1.6	0.8	0.5	0.1	0	0	0	0	41.5
Heron Rock	D	0	0	0	0.5	0.0	-	2.7	-	-	0.7	0.4	0.0	0	0	0	0	0	4.3
Cape Toon	D	-	0	0.1	0.3	0.1	0.1	2.8	29.7	22.1	6.4	0.1	0.5	0.1	0	0.4	0.2	0	62.9
Stove Point	D	0	0	0	0.1	0.4	0.2	7.0	26.8	5.2	1.5	0.5	0.3	0.2	0.1	0	0	0	42.3
Burton Point	D	-	0	0.1	0.5	0.5	0.2	3.2	4.8	3.9	7.4	0.6	0.1	0	0	0	0	0	21.3
																			241.50
GREAT WICOMICO																			
Glebe Point	D	0	0	0	0.9	6.8	4.7	0.1	24.7	5.1	5.3	1.2	0.3	0.2	0.1	0	0	0	49.4
Rogue Point	D	0	0	0	0.9	32.1	13.1	4.2	18.9	4.1	2.9	1.5	1.6	0.2	0	0	0	0	79.5
Hilly Wash	D	0	0	0	7.7	18.1	7.0	2.0	28.1	1.9	2.3	2.3	3.4	0.1	0.2	0.1	0	0	73.2
Harcum Flats	D	0	0	0	0.1	16.7	2.5	1.2	11.9	2.6	1.0	1.2	1.1	0	0.2	0	0.1	0	38.6
Hudnall	D	0	0	0	0.6	25.0	2.4	1.8	-	2.3	2.1	1.4	1.7	0.1	0.4	0	0	0	37.8
Shell Bar	D	0	0	0	0.8	15.6	4.3	5.1	11.9	4.0	3.6	4.1	1.1	0.1	0.5	0	0.1	0	51.2
Haynie Point	D	0	0	0	0.4	4.7	3.5	1.5	2.0	1.6	1.2	0.7	0.4	0	0	0	0	0.1	16.1
Whaley's East	D	0	0	0	0	0.1	0.2	0.5	0.3	1.1	1.8	0.1	0	0	0	0	0	0	4.1
Fleet Point	D	0	0	0	-	5.0	0.5	0.3	0.4	0.4	0.6	0.8	0.2	0.1	0.1	0	0	0	8.4

Table S2: Recruitment totals for historical sites (1988-2012) and modern sites (1998-2012) as defined in the text. Values are presented as the cumulative sum of spat shell^{-1} for each year. "+" and "-" indicate the direction of change in 2013 in reference to 2012 and to the five, ten, twenty and twenty-five year means. Blank cells for a site indicate years where data are not available.

STATION	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean 08-12	Mean 03-12	Mean 93-12	Mean 88-12	Ref. 2012	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr	Ref. 25-yr
JAMES																																			
Deep Water Shoal	4.3	2.0	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	58.9	30.4	18.4	15.5	-	-	-	-	-
Horsehead	3.5	1.5	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	89.6	45.9	27.4	23.3	-	-	-	-	-
Point of Shoal	41.7	3.7	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	86.9	44.9	29.4	27.0	-	-	-	-	-
Swash	7.6	3.8	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	122.0	63.2	36.5	33.9	-	-	-	-	-
Dry Shoal	13.2	10.0	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	140.7	72.9	45.9	48.2	-	-	-	-	-
Rock Wharf	9.9	2.1	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	153.0	80.1	44.8	38.4	-	-	-	-	-
Wreck Shoal	6.4	10.2	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	147.9	77.4	41.0	35.2	-	-	-	-	-
Day's Point	17.3	26.1	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	159.1	83.4	52.2	50.8	-	-	-	-	-
PIANKATANK																																			
Wilton Creek											1.9	5.9	3.6	0.2	6.5	0.1	0.2	0.4	3.9	2.9	12.1	4.1	20.9	18.4	235.6	23.3	58.2	29.8			-	-	-		
Ginney Point	3.3	29.9	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	70.1	36.2	19.4	20.8	-	-	-	+	+
Palace Bar	3.6	42.4	119.2	38.9	24.9	5.0	0.8	1.0	1.6	0.0	5.5	10.1	3.9	0.2	3.1	0.1	0.5	0.2	2.1	4.6	7.5	5.9	30.3	14.1	155.7	16.6	42.7	22.1	12.6	19.2	-	-	-	+	-
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	59.5	31.4			-	-	+		
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	27.3	14.9			-	-	-		
Cape Toon											4.5	12.3	1.2	1.8	9.1	0.1	2.0	2.6	8.2	23.5	23.4	9.9	193.2	33.1	191.2	62.9	90.2	48.7			-	-	+		
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	38.0	22.0			-	+	+		
Burton Point	2.0	31.6	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	43.7	23.5	13.4	16.7	-	-	-	+	+
GREAT WICOMICO																																			
Glebe Point	23.9	8.2	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	568.4	313.4	172.4	140.1	-	-	-	-	-
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	294.3	168.2			-	-	-		
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	297.8	166.5			-	-	-		
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	319.2	184.8			-	-	-		
Hudnall	51.3	26.4	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	98.3	58.5	32.1	32.8	-	-	-	+	+
Shell Bar											0.0	2.9	0.8	0.8	17.8	1.9	0.3	0.9	29.6	30.3	78.1	18.5	46.2	40.2	472.7	51.2	131.1	71.9			-	-	-		
Haynie Point	38.5	17.0	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	61.1	35.0	19.0	20.7	-	-	-	-	-
Whaley's East	14.6	8.4	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	34.1	20.0	10.4	11.2	-	-	-	-	-
Fleet Point	8.7	7.9	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	21.1	12.0	6.7	7.1	-	-	-	+	+

Figure S1: Map showing the location of the 2013 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.

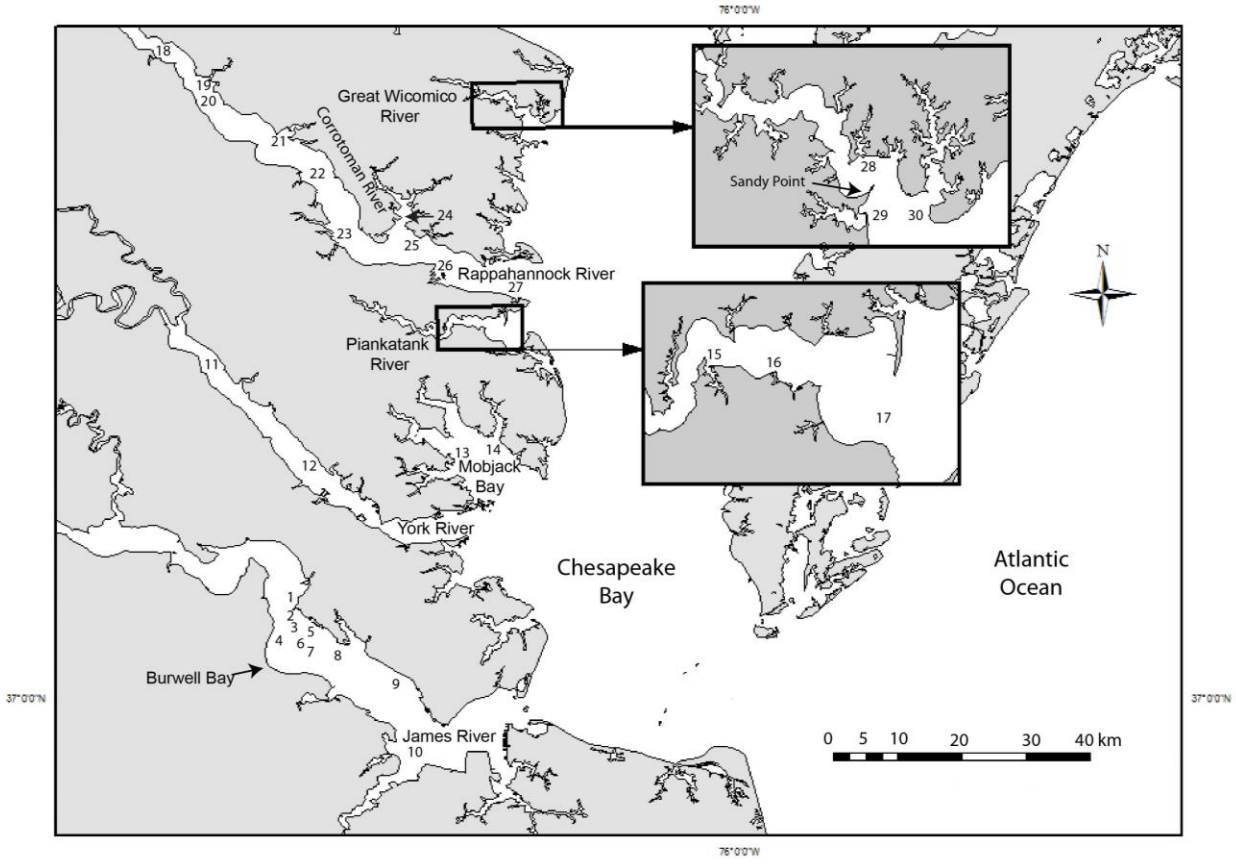


Figure S2: Diagram of shellstring setup on buoys with picture of a shellstring embedded.

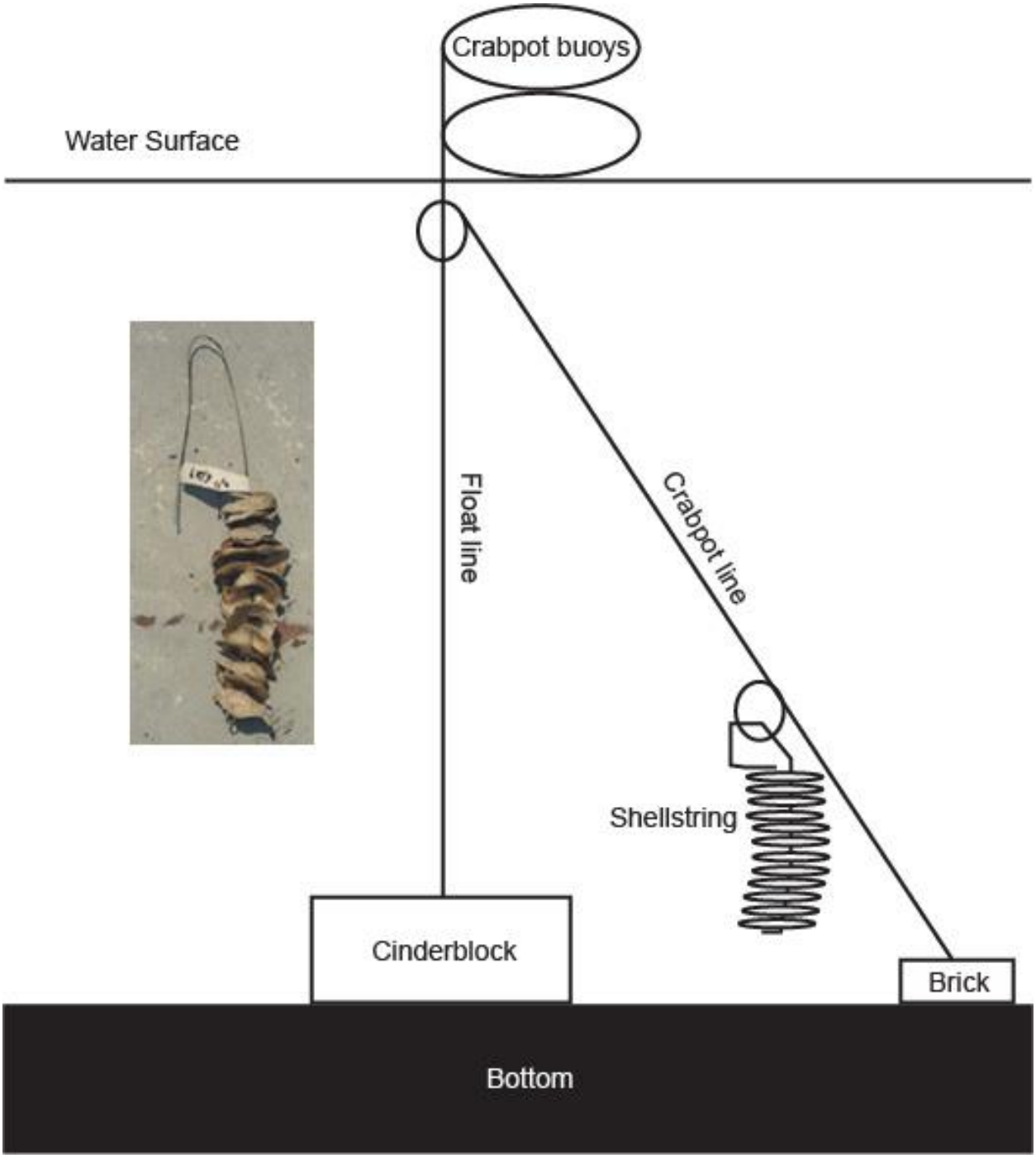


FIGURE S3: JAMES RIVER (2013) WEEKLY RECRUITMENT INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL^{-1}

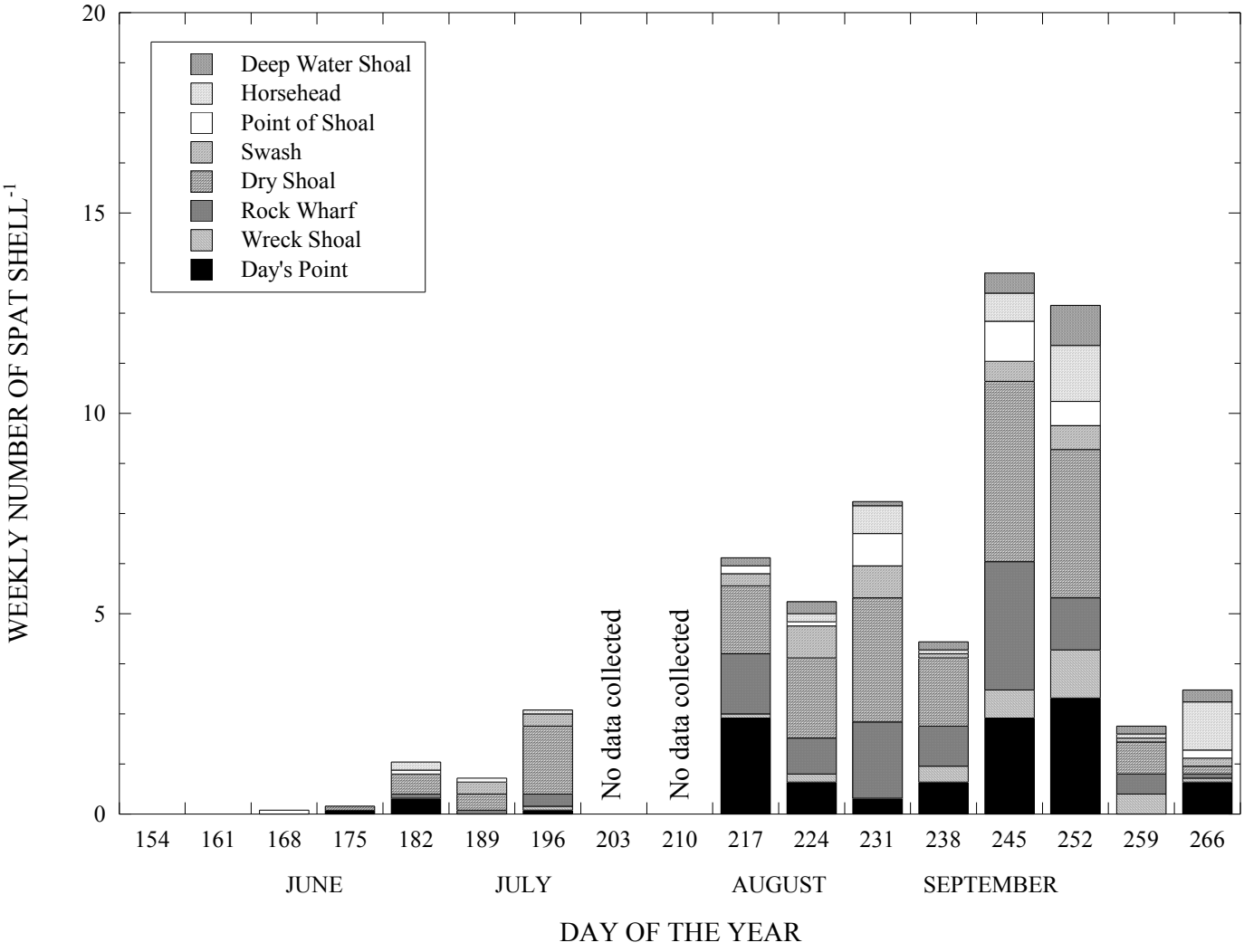


FIGURE S4: RECRUITMENT TRENDS OVER THE PAST 25 YEARS AT ALL EIGHT SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall)

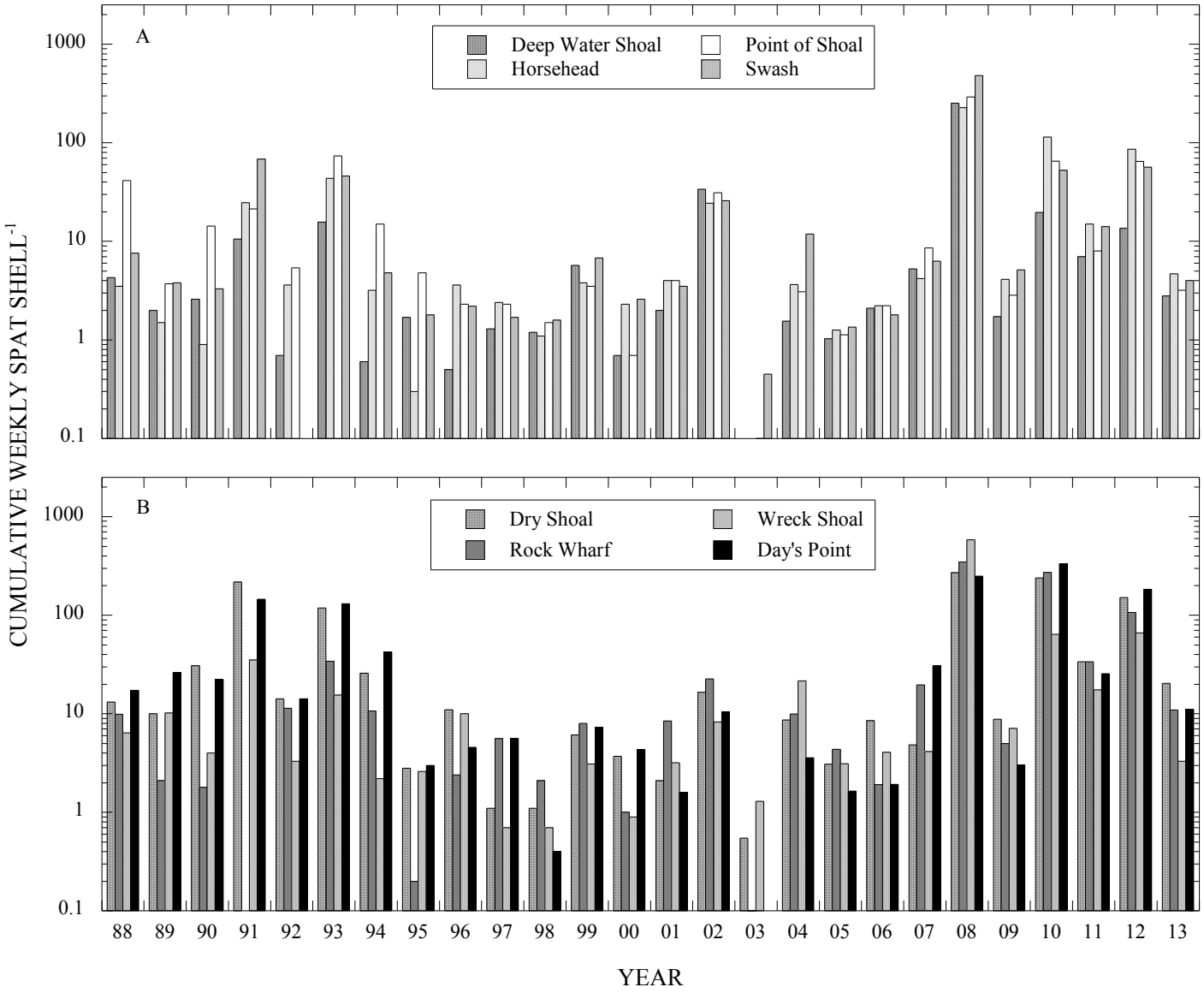


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE RECRUITMENT PERIOD: 5, 10, 20 AND 25-YEAR MEANS COMPARED WITH 2013
(Error bars represent standard error of the mean; shaded area represents the bulk of recruitment during 2013; n is the number of data points used to calculate the mean)

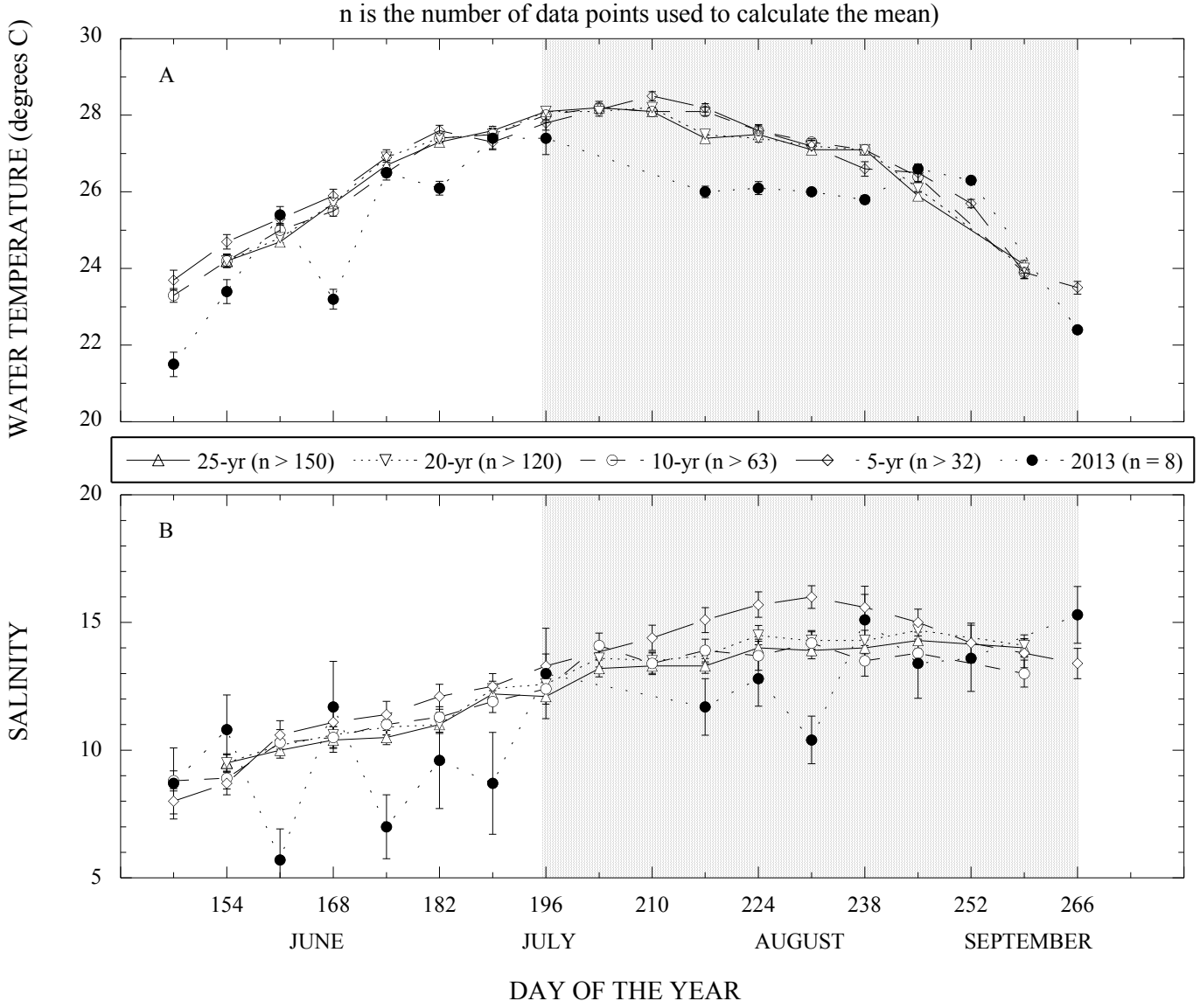


FIGURE S6: PIANKATANK RIVER (2013) WEEKLY RECRUITMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL^{-1}
(H = historical station: M = modern station as described in text)

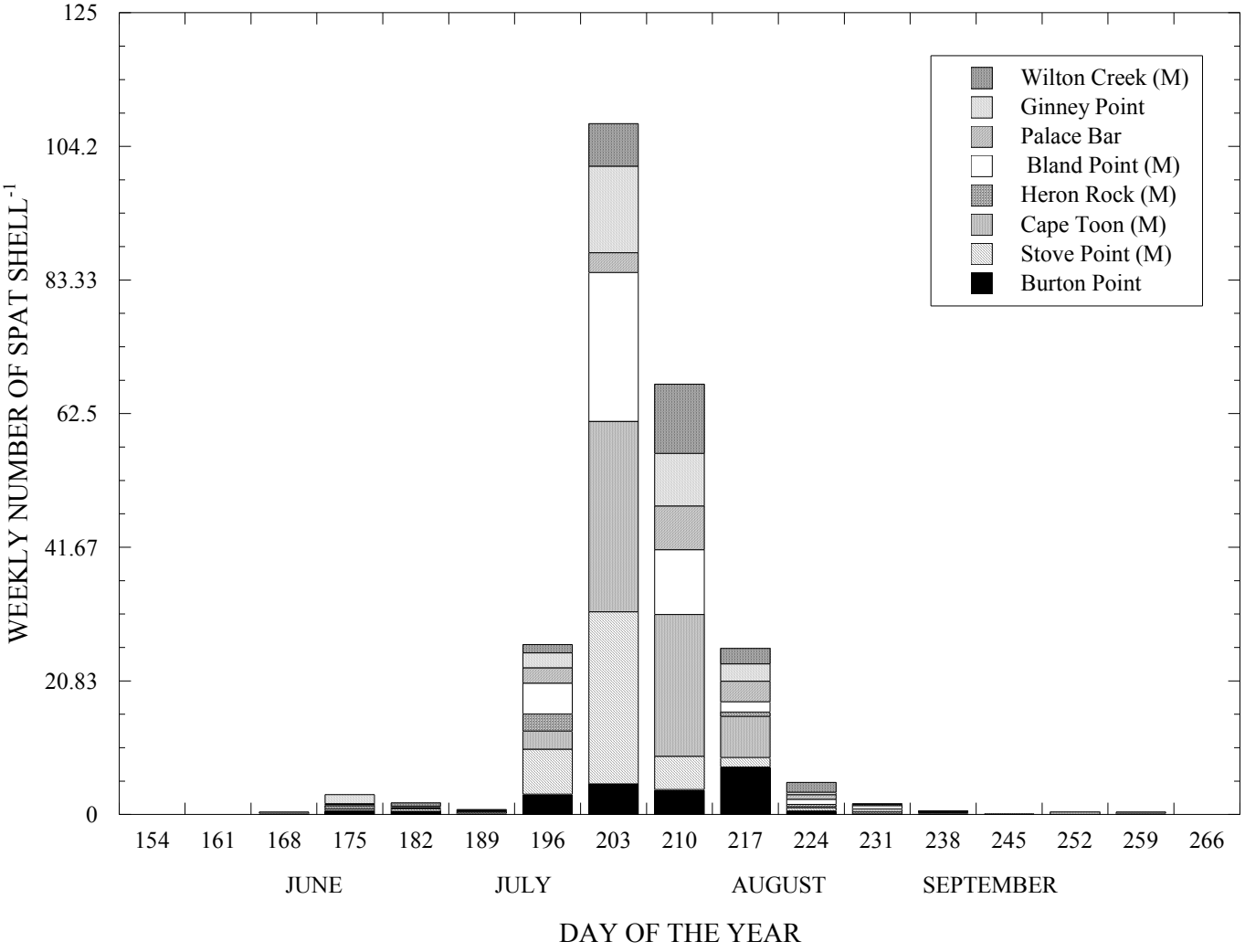


FIGURE S7: RECRUITMENT TRENDS IN THE PIANKATANK RIVER AT THE THREE HISTORICAL SITES (panel A: 25 years) AND THE FIVE MODERN SITES (panel B: 15 years)
(Expressed as cumulative weekly spatfall)

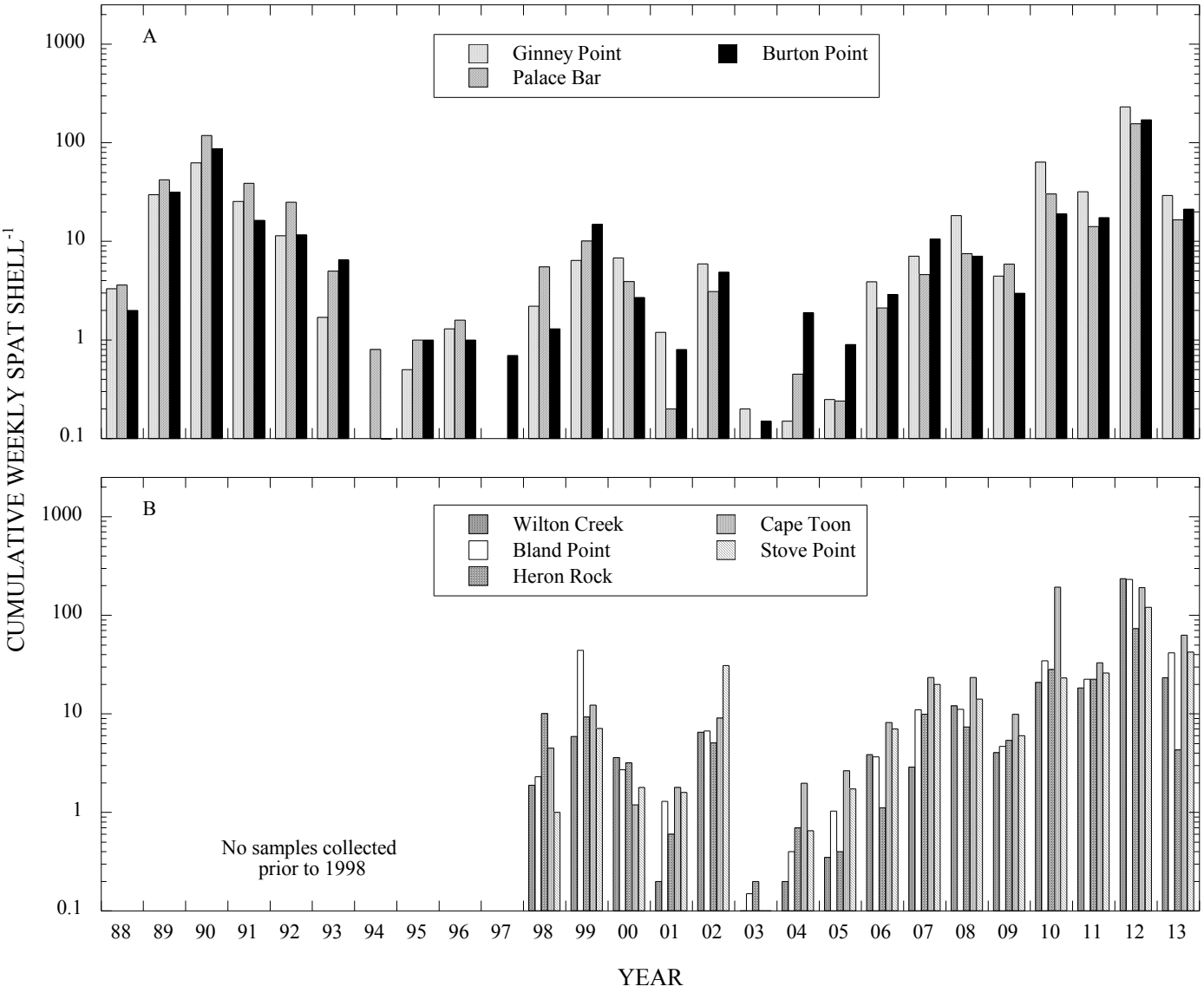


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE RECRUITMENT PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2013
(Error bars represent standard error of the mean; shaded area represents the bulk of recruitment during 2013; n is the number of data points used to calculate the mean)

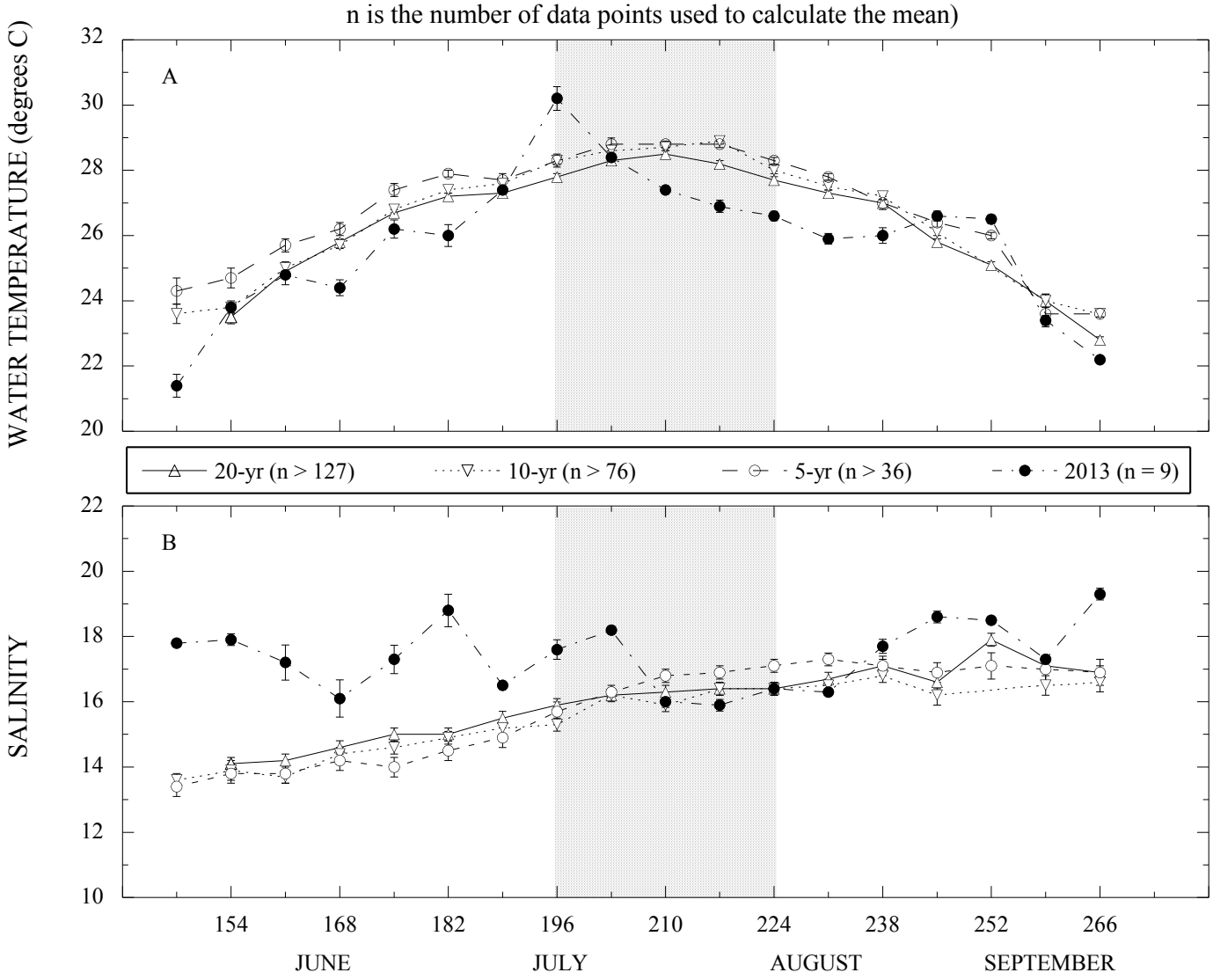


FIGURE S9: GREAT WICOMICO RIVER (2013) WEEKLY RECRUITMENT INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL $^{-1}$
(H = historical station: M = modern station as described in text)

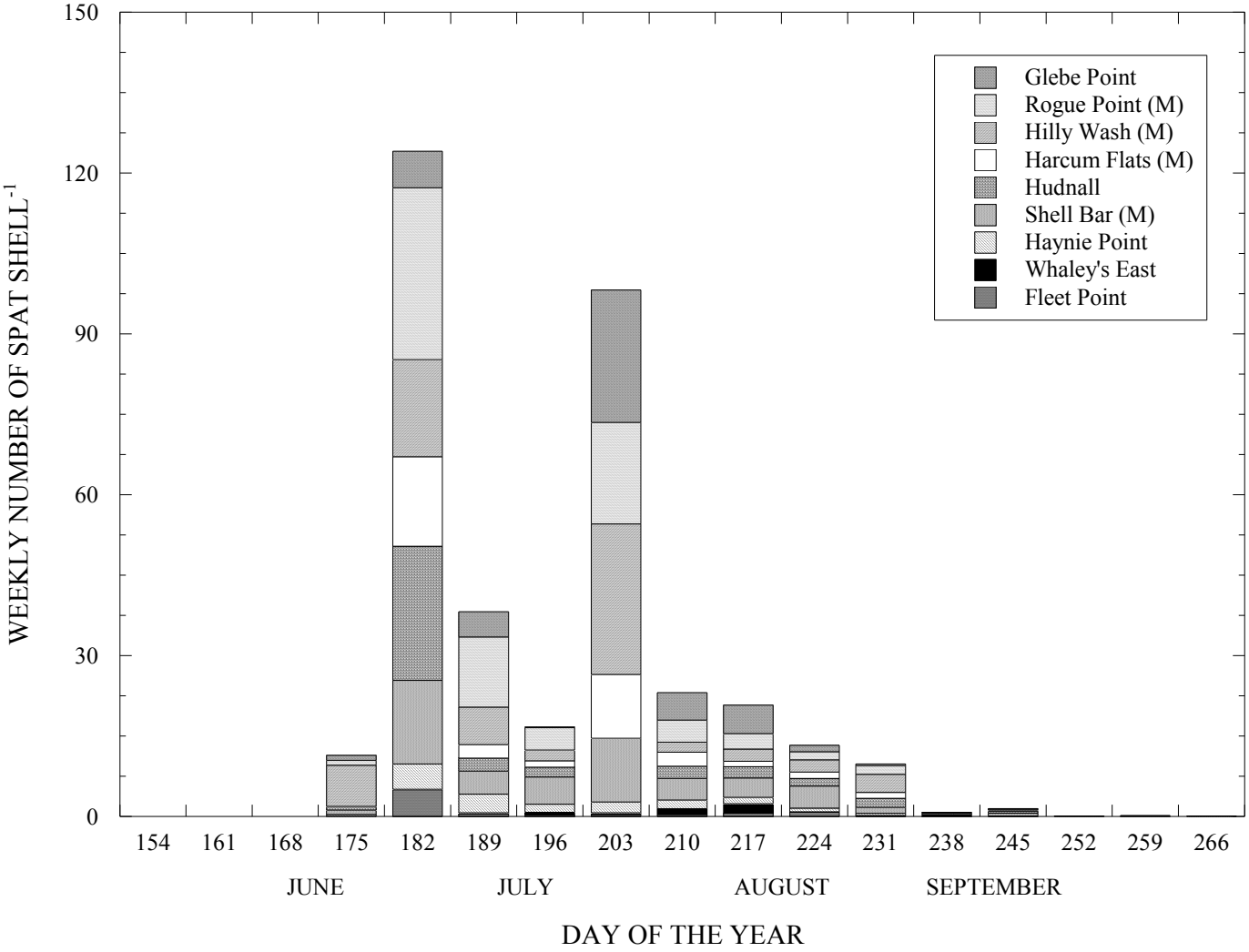


FIGURE S10: RECRUITMENT TRENDS IN THE GREAT WICOMICO RIVER AT THE FIVE HISTORICAL SITES (panel A: 25 years) AND THE FOUR MODERN SITES (panel B: 15 years) (Expressed as cumulative weekly spatfall)

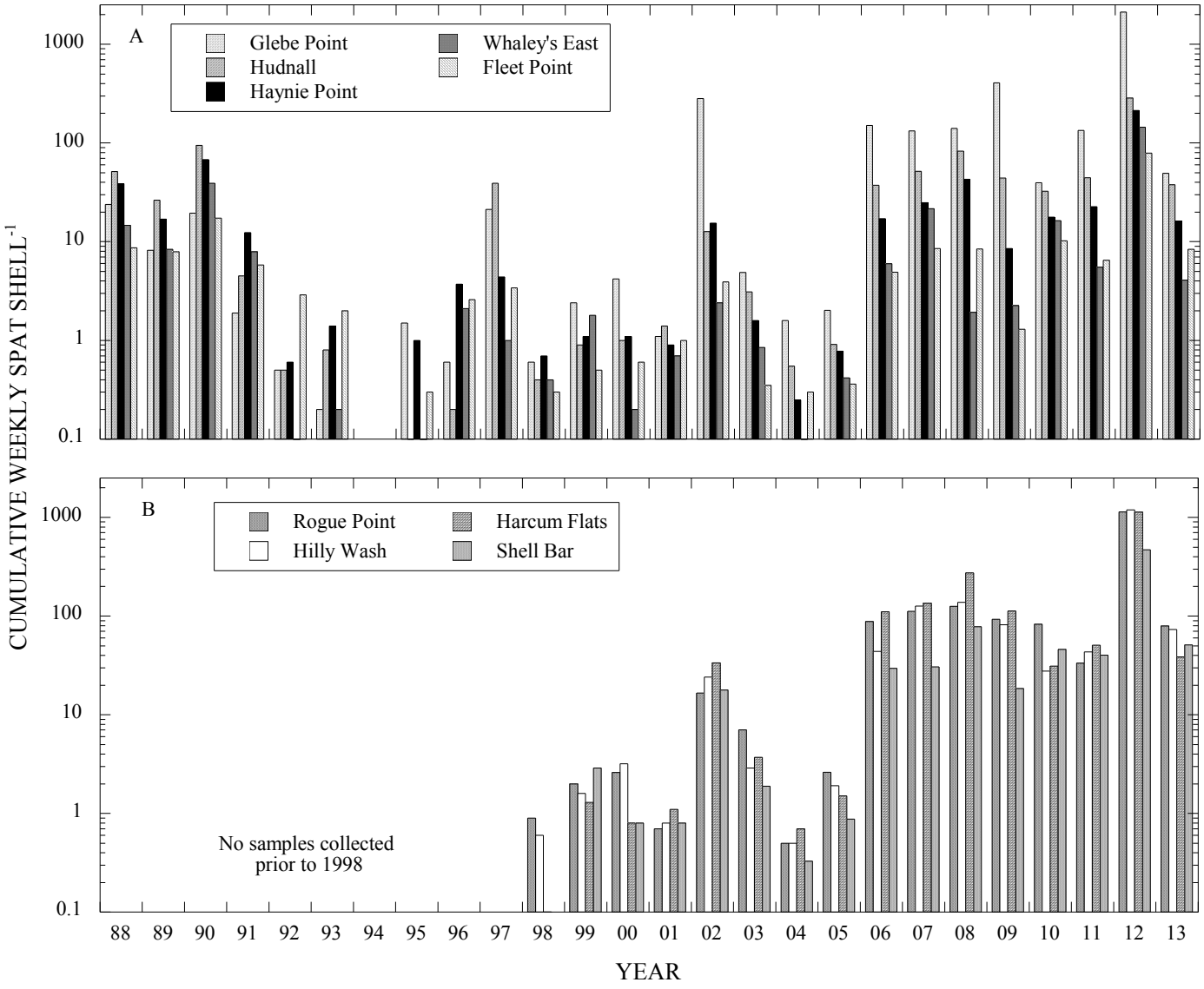
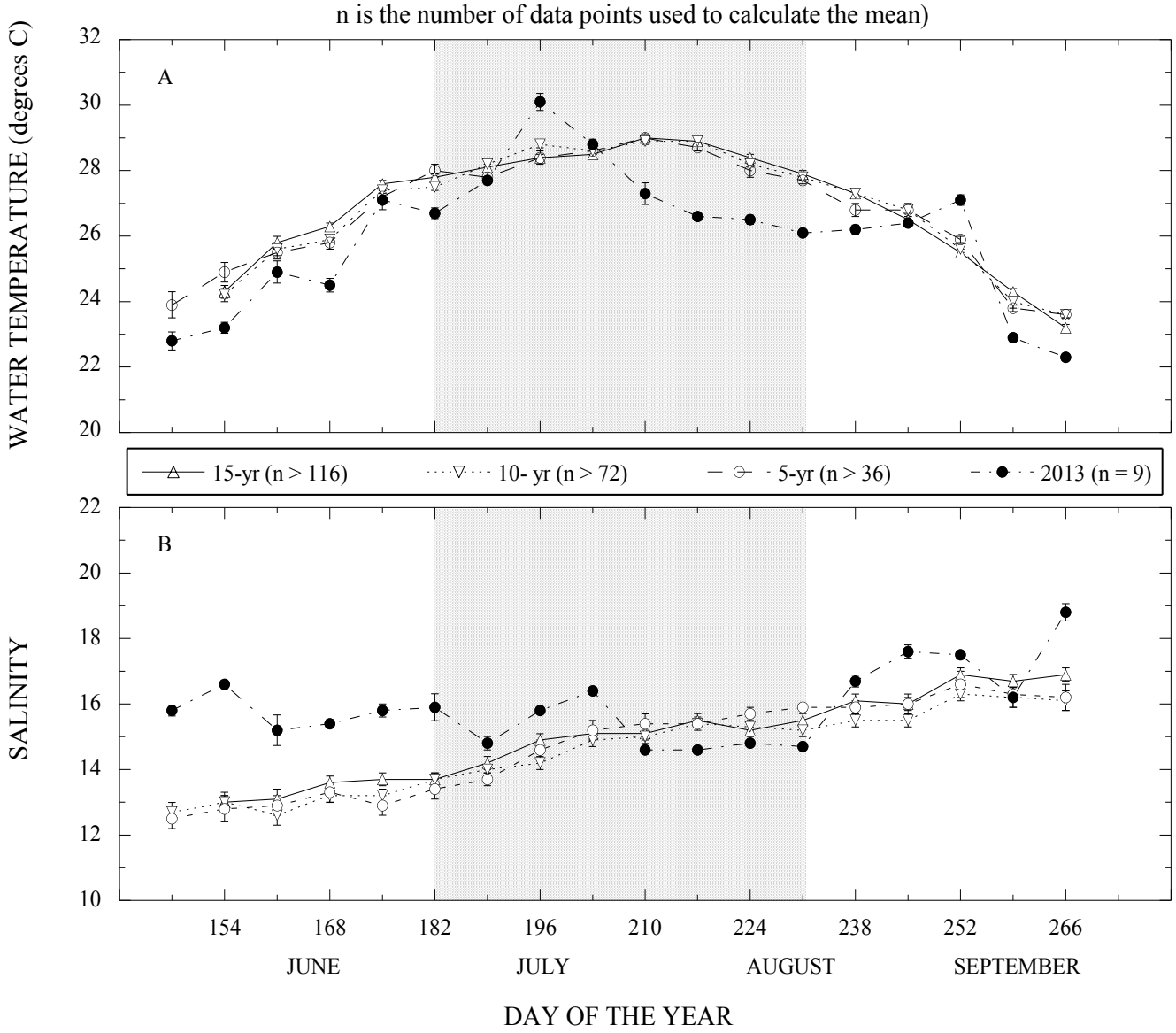


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE RECRUITMENT PERIOD: 5, 10 AND 15-YEAR MEANS COMPARED WITH 2013
(Error bars represent standard error of the mean; shaded area represents the bulk of recruitment during 2013; n is the number of data points used to calculate the mean)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2013

INTRODUCTION

The Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), has been harvested from Virginia waters as long as humans have inhabited the area. Accelerating depletion of natural stocks during the late 1880s led to the establishment of oyster harvesting regulations by public fisheries agencies. A survey of bottom areas in which oysters grew naturally was completed in 1896 under the direction of Lt. J. B. Baylor, U.S. Coast and Geodetic Survey (Baylor 1896) and later updated by Haven et al. (1981). These areas (over 243,000 acres) were set aside by legislative action for public use and have come to be known as the Baylor Survey Grounds or Public Oyster Grounds of Virginia (http://www.vims.edu/research/units/labgroups/molluscan_ecology/restoration/va_restoration_atlas/index.php); they are presently under management by the Virginia Marine Resources Commission (VMRC).

Every year the Virginia Institute of Marine Science (VIMS) in collaboration with VMRC, conducts a dredge survey of selected public oyster bars in Virginia tributaries of the western Chesapeake Bay to assess the status of the existing oyster resource. These surveys provide information about 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 bar surveys conducted during October 2013.

Spatial variability in distribution of oysters over the bottom can result in wide differences among dredge samples. Large differences among samples collected on the same day from one bar are an indication that distribution of oysters over the bottom is highly variable. An extreme example of that variability can be found in Southworth et al. (1999) by the width of the confidence interval around the average count of spat at Horsehead (James River, VA) during 1998. Dredges provide semi-quantitative data, have been used with consistency over extended periods (decades) in Virginia, and provide data on population trends. However, absolute quantification of dredge data is difficult in that dredges accumulate organisms as they move over the bottom, may not sample with constancy throughout a single dredge haul, and may fill before completion of the haul thereby providing biased sampling (Mann et al. 2004). Therefore, in the context of the present sampling protocol, differences in average counts found at a particular bar in different years may be the result of sampling variation rather than actual short-term changes in abundance. If the observed changes persist for several years or can be attributed to well-documented physiological or environmental factors, then they may be considered a reflection of actual changes in abundance with time.

METHODS

Locations of the oyster bars sampled during fall 2013 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 2013) and in all surveys in the James, Piankatank, Rappahannock and Great Wicomico Rivers preceding 1995, sampling was effected using a 2-ft wide oyster scrape with 4-in teeth towed from a 21-ft boat; volume collected in the scrape bag was 1.5 bushels. For clarification all bushels mentioned in this report refer to a Virginia bushel (3003.9 inches^3), which differs from a US bushel (2150.4 inches^3) and a Maryland bushel (2800.7 inches^3). Beginning in

1995, James, Piankatank, Rappahannock, and Great Wicomico River samples were collected using a 4-ft dredge with 4-in teeth towed from the 43-ft long VMRC research vessel *J. B. Baylor*; volume collected in the bag of that dredge 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, 2013 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 at each of the oyster bars using a handheld electronic probe (YSI 30).

RESULTS

Thirty oyster bars were sampled between 9 October and 22 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 20.5 bushel^{-1} at Nansemond Ridge to a high of 1,658.0 bushel^{-1} at Swash. The total number of live oysters at nine out of the ten sites (all except Nansemond Ridge), ranked among the first to fourth highest observed during the past twenty years of observations. The number of oysters at Nansemond Ridge has been in decline for the past several years and during 2013, the total number of oysters on Nansemond Ridge was the third lowest observed during the past twenty years of monitoring.

The average number of market oysters in the James River remains low when compared with historical numbers, but has been on the rise in recent years at several sites in the system. All of the sites monitored had low to moderate numbers of market oysters ranging from 1.5 (Nansemond Ridge) to 73.5 bushel^{-1} (Wreck Shoal). There was a notable decrease in the number of market oysters at Deep Water Shoal, Horsehead and Long Shoal when compared with 2012 and a small increase at Mulberry Point with no change in the number of market oysters observed at the other six sites (Figures D2 and D3). The number of market oysters at Wreck Shoal has been steadily increasing since about 2009 and 2013 had the highest number of market oysters observed since prior to 1993. The number of market oyster at Dry Shoal and Thomas Rock was the third highest observed over the past twenty years of monitoring (Figure D3).

The average number of small oysters bushel^{-1} ranged from a low of 5.0 at Nansemond Ridge to a high of 1126.0 at Long Shoal. When compared with 2012, there was a relatively small, but notable decrease in the number of small oysters at Mulberry Point and a notable increase at Horsehead, Point of Shoal, Swash, Long Shoal, Dry Shoal and Wreck Shoal (Figures D2 and D3). Comparing 2013 with the past twenty years, the number of small oysters during 2013 was the third highest (Mulberry Point and Wreck Shoal), second highest (Horsehead, Swash and Dry Shoal) and highest (Point of Shoal and Long Shoal) observed during that time. For the fifth year in a row, the number of small oysters at Nansemond Ridge was at very low levels (Figure D3C). This is somewhat surprising given that recruitment at Nansemond Ridge was moderate during both 2010 and 2011, yet the number of small oysters at Nansemond Ridge in 2013 was at its lowest numbers since prior to 1993.

The average number of spat bushel^{-1} ranged from a low of 14.0 at Nansemond Ridge to a high of 676.5 at Swash. When compared with 2012, there was a large decrease in spat observed at all ten sites (Figure D2 and D3). This was not unexpected given that 2012 was an exceptional recruitment year. It should be noted that given the large number of spat in 2012, some slow growing small oysters from the 2012-year class may have been mis-categorized as spat in 2013. The pattern historically observed in the James River was 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). As has been common in most recent years, this pattern was not observed in 2013. With the exception of Nansemond Ridge, which had relatively low numbers of spat, overall recruitment in the James River during 2013 was moderate (falling in the middle of the range) when compared with observed numbers over the past twenty years.

The average number of boxes bushel^{-1} ranged from a low of 5.0 (Nansemond Ridge) to a high of 94.0 (Deep Water Shoal). Boxes accounted for 12, 13 and 20% of the total (live and dead) at Deep Water Shoal, Thomas Rock and Nansemond Ridge respectively. At the other seven sites, boxes accounted for less than 6% of the total (live and dead). At Horsehead, Point of Shoal, Swash, Dry Shoal and Wreck Shoal, greater than 20% of the boxes were new boxes, indicating some recent mortality at those sites. The majority of the boxes however, (greater than 62% at all ten sites) were old boxes. At Nansemond Ridge 67% of the observed spat boxes contained a drill hole. The presence of a drill hole is indicative of predation by one of the two native oyster drills, *Eupleura caudata* and *Urosalpinx cinera*, both of which are found in the Chesapeake Bay.

Water temperature during the two days of sampling ranged between 18.6 and 19.7°C (Table D2). Salinity was variable depending on location in the river, increasing in a downriver direction, from 8.3 at Deep Water Shoal to 18.9 at Nansemond Ridge.

York River

In the York River, the average total number of live oysters bushel^{-1} was 204.0 at Bell Rock and 312.5 at Aberdeen Rock. The total number of oysters at Bell Rock was at the highest level observed since prior to 1994 (Figure D5). The live oysters at both sites were primarily small (73% at Bell Rock and 76% at Aberdeen Rock). When compared with 2012, there was a notable increase in both market and small oysters at Aberdeen Rock (Figure D4) and 2013 had the highest numbers over the past twenty years in both size categories. At Bell Rock, there was a notable increase in the number of market oysters

and spat when compared with 2012 (Figure D4). Despite the small increase in spat at Bell Rock, recruitment at both sites was relatively low. The average number of boxes bushel^{-1} was moderate at both sites (32.5 bushel^{-1} at Bell Rock; 57.0 bushel^{-1} at Aberdeen Rock) accounting for approximately 14 and 15% of the total oysters (live and boxes) at Bell Rock and Aberdeen Rock respectively. At Bell Rock 81% of the boxes were old boxes, but at Aberdeen, 36% of the total boxes were new boxes, indicating some recent mortality at that site. Water temperature on the day of sampling was 19.5°C at Bell Rock and 20.0°C at Aberdeen Rock. The difference in salinity between the two sites was 3.3: 16.6 at Bell Rock and 19.9 at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 154.5 and 35.5 oysters bushel^{-1} respectively. This was a fairly large decrease in total oysters at both sites when compared with 2012 (Figures D4 and D6). Despite a slight increase in the number of small oysters at Pultz Bar when compared with 2012, the population at that site remains relatively low (Figures D4 and D6). The number of market oysters observed at Tow Stake has remained relatively stable during the past five years (Figure D6), accounting for approximately 22% of the oysters at that site in 2013. There was a large decrease in the number of spat observed at both sites when compared with 2012 (Figure D4), which is not unexpected given that recruitment in 2012 was the highest observed at both sites over the past twenty years (Figure D6). There was a low to moderate number of boxes observed in the system, accounting for 6 (Tow Stake) to 10% (Pultz Bar) of the total (live and boxes). The majority of boxes at both sites were old boxes. Of the few spat boxes that were observed, 100% at Pultz Bar and 25% at Tow Stake had 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 cinera*, both of which are found in the Chesapeake Bay. On the day of sampling, water temperature was 19.6°C and salinity was approximately 21.0 at both sites (Table D2).

Piankatank River

The average total number of live oysters in the Piankatank River ranged from 213.5 bushel^{-1} at Burton Point to 639.5 bushel^{-1} at Palace Bar. When compared with 2012, there was a small increase in the number of market oysters at Ginney Point and Burton Point (Figure D7). The number of market oysters at all three sites was relatively stable between 2008 and 2012, but the increase observed at Ginney Point during 2013 almost doubled the number, such that 2013 had the highest number of market oysters over the past twenty years (Figure D8A) and accounted for almost 20% of the total oysters at that site. At Burton Point and Palace Bar, the number of market oysters remains relatively stable and 2013 ranked the highest (Burton Point) and third highest (Palace Bar) over the past twenty years of monitoring (Figure D8A). There was a notable increase in the number of small oysters and a decrease in the number of spat at Ginney Point and Palace Bar when compared with 2012 (Figures D7 and D8). The number of small oysters at all three sites was relatively high, ranking the fourth highest (Burton Point), third highest (Palace Bar) and highest (Ginney Point) over the past twenty years of monitoring (Figure D8B). The number of boxes observed was low to moderate accounting for 3 (Palace Bar) to 11% (Burton Point) of the total (live and boxes). At Palace Bar, 31% of the boxes were new boxes, indicating some recent mortality at that site. At Burton Point, 100% of the observed spat boxes contained a drill hole. The presence of a drill hole is indicative of predation by one of the two native oyster drills, *Eupleura caudata* and *Urosalpinx cinera*, both of which are found in the Chesapeake Bay. Water temperature on the

day of sampling ranged between 21.1 (Burton Point) and 21.6ºC (Ginney Point and Palace Bar). Salinity ranged between 17.4 (Ginney Point) and 18.0 (Burton Point).

Rappahannock River

In the Rappahannock River, the average total number of live oysters bushel^{-1} ranged from a low of 49.0 at Hog House to a high of 324.5 at Drumming Ground. As is typical for the Rappahannock River system, there appeared to be no relationship between the total number of live oysters and location in the river (i.e., upriver vs. downriver: Figure D1), temperature or salinity (Table D2). 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 2013. The total number of oysters at Middle Ground showed a relatively large decrease in 2011, following three good years of growth. The 2013 monitoring results suggest the population is beginning to rebound, but several more years of observation are needed to see if the upward trend will continue.

The average number of market oysters bushel^{-1} ranged from a low of 10.0 (Middle Ground) to a high of 74.0 (Ross Rock). When compared with 2012, there was a small increase in the number of market oysters observed at Long Rock and Morattico Bar and a small decrease at Drumming Ground (Figure D9 and D10). Overall the number of market oysters in the Rappahannock River has been on the rise and 2013 ranked among the highest to fourth highest over the past twenty years at eight out of the ten sites monitored. At the four most upriver sites, market oysters accounted for 57 (Ross Rock) to 92% (Bowler's Rock) of the total oysters observed and greater than 30% at four out of the other six sites. Since 2008, the number of market oysters at Ross Rock has been slowly but steadily increasing and 2013 had similar numbers to those observed in 2012 (Figure D10A).

For the twelfth year in a row, Drumming Ground, near the mouth of the Corrotoman River, had the highest average number of small oysters bushel^{-1} with 271.0 and 2013 had the second highest number of small oysters observed at that site since prior to 1993. There was a slight decrease in the number of small oysters observed at Middle Ground and Parrot Rock and a larger decrease at Bowler's Rock, such that the number of small oysters at Bowler's Rock in 2013 was at its lowest level during the past twenty years (Figures D9 and D10). At Hog House, Drumming Ground and Parrot Rock, the number of small oysters during 2013 ranked the second highest observed since prior to 1993.

As is typical for the Rappahannock, spat recruitment varied widely among the sites, ranging from a complete lack of recruitment at Bowler's Rock to a high of 150.5 spat bushel^{-1} at Middle Ground. There was at least one spat found at all of the sites except Bowler's Rock When compared with 2012, there was an increase in the number of spat found on Middle Ground and a large decrease at Drumming Ground and Broad Creek (Figures D9 and D10). Recruitment at both Drumming Ground and Broad Creek was among the lowest observed at those sites during the past twenty years of monitoring (Figure D10C).

The average total number of boxes bushel^{-1} was low to moderate, accounting for 3 to 15% of the total (live and dead) at nine out of the ten sites. The one exception, Broad Creek, had 64.0 boxes bushel^{-1} accounting for 27% of the total (live and dead). Greater than 22% of the total boxes at Ross Rock, Drumming Ground and Parrot Rock were new boxes, indicating some recent mortality at those sites.

Water temperature on the day of sampling ranged from 19.3 to 20.2°C. Salinity increased as one moved from the most upriver site (Ross Rock: 9.7) toward the mouth (Broad Creek: 17.7).

Great Wicomico River

In the Great Wicomico River, the average total number of live oysters bushel^{-1} ranged from a low of 338.0 at Whaley's East to a high of 695.5 at Haynie Point. Overall the total number of oysters at all three sites was relatively high, ranking the fourth highest (Whaley's East) and third highest (Haynie Point and Fleet Point) over the past twenty years of monitoring (Figure D12). Despite a small decrease in the number of market oysters observed when compared with 2012, the number of market oysters at both Whaley's East and Fleet Point remain among the highest observed over the past twenty years (Figures D11 and D12). The number of market oysters at Haynie Point has remained relatively stable since 2006 (Figure D12). There was a notable increase in the number of small oysters at Haynie Point and Fleet Point when compared with 2012 (Figure D11). Overall, recruitment in 2013 was relatively moderate, especially compared to the high numbers that have become more prevalent in the system over the past few years. Recruitment in 2012 was the highest observed in twenty years of monitoring, so not unexpectedly there was a large decrease in recruitment in 2013 when compared with 2012 numbers (Figure D11). The total number of boxes bushel^{-1} was low, accounting for less than 5% of the total (live and dead) at all three sites. Between 20 and 25% of the total boxes at all three sites were new boxes, indicating some recent mortality throughout the river system. Water temperature on the day of sampling was between 19.2 and 19.7°C and salinity was between 16.9 (Haynie Point) and 17.7 (Fleet Point).

DISCUSSION

The abundance of market oysters throughout the Chesapeake Bay region has been in serious decline since the beginning of the 20th century (Hargis & Haven 1995, Rothschild et al. 1994). For the past few decades, the greatest concentration of market oysters on Virginia public grounds has been found at the upper limits of oyster distribution (lower salinity areas) in the James and Rappahannock Rivers, with the exclusion of Broad Creek in the mouth of the Rappahannock River. Presently, the abundance of market oysters in the Virginia tributaries of the Chesapeake remains low (average of 41.6 market oysters bushel^{-1}). However, over the past seven years, the number of market oysters on the thirty bars that are sampled annually has more than doubled going from an average of 16.5 bushel^{-1} in 2007 to an average of 41.6 bushel^{-1} in 2013, remaining relatively stable over the past two years.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2013, following the large recruitment event that occurred in several of the systems in 2012, the majority of the oysters were primarily small, making up approximately 68% of the total oysters observed across all of the river systems. The four most upriver sites in the Rappahannock River were the only sites with greater than 50% market oysters, but with the exception of Ross Rock these sites all had relatively low (< 91 oysters bushel^{-1}) oyster populations. The oyster populations in the mesohaline reaches of the Piankatank River (Ginney Point and Palace Bar) have been steadily increasing since 2004. This increase has followed a large die-off of broodstock oysters that occurred in late 2003 early 2004 (Southworth et al. 2005). Both of these sites experienced an increase in the number of small

oysters in 2013, and the overall oyster population at these sites remains relatively stable.

Recruitment during 2013 varied widely throughout the Virginia portion of the bay. While recruitment during 2013 was not as exceptional as it was in 2012, overall it was moderate at a majority of the sites monitored. However, at Nansemond Ridge in the lower James River, at Drumming Ground and Broad Creek in the Rappahannock River and at all four sites in the York River and Mobjack Bay, recruitment during 2013 was among the lowest recorded during the past twenty years of monitoring. Only one site, Bowler's Rock in the Rappahannock River, had a complete lack of recruitment. Similar to more recent years, recruitment in the James River was highest in the middle part of the river, which is in contrast to the historical pattern of increasing recruitment as one moves downriver towards the mouth (Haven & Fritz 1985).

The average total number of boxes observed during 2013, was low to moderate at most sites accounting for less than 20% of the total (live and dead) oysters at twenty-nine out of the thirty sites and less than 10% at twenty out of the thirty 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 2013, several sites (Thomas Rock, Nansemond Ridge, Middle Ground, Parrot Rock and Broad Creek) again had increased small and market size boxes (greater than 18% of the total).

In general, drill holes have become more prevalent in spat boxes since the early 2000s. During 2013, there were drill holes present in spat boxes at Nansemond Ridge in the James River, at Pultz Bar and Tow Stake in Mobjack Bay and at Burton Point in the Piankatank River. The presence of drill holes is indicative of predation by one of the two oyster drill species, *Urosalpinx cinerea* or *Eupleura caudata,* which are found in the lower Chesapeake Bay. Both of these species have been shown to be voracious predators of oyster spat causing mortality throughout most of the Chesapeake Bay (Carriker 1955) up until the occurrence of Hurricane Agnes (1972) which wiped them out in all but the lower reaches of the James River and mainstem Bay (Haven 1974). However, individuals of both of these species and their corresponding egg masses have become more common during recent years in the lower James River, in the mouths of the Piankatank and Rappahannock Rivers, and in Mobjack Bay. The dredge samples taken in 2013 were again marked with a fairly high number of spat boxes with drill holes in these areas. It should also be noted that drill holes as well as live animals of both drill species were observed at multiple sites in the James, Piankatank and Rappahannock Rivers and Mobjack Bay during the patent tong survey in November and December of 2013 (Southworth, personal observation), so the predation of spat by oyster drills in these systems remains a concern.

Table D1: Station locations for the 2013 VIMS fall dredge survey.

Station	Latitude	Longitude
James River		
Deep Water Shoal	37 08 06	76 38 08
Mulberry Point	37 07 09	76 37 55
Horsehead	37 06 24	76 38 02
Point of Shoal	37 04 33	76 38 32
Swash	37 05 32	76 36 44
Long Shoal	37 04 31	76 36 07
Dry Shoal	37 03 41	76 36 14
Wreck Shoal	37 03 37	76 34 20
Thomas Rock	37 01 32	76 29 33
Nansemond Ridge	36 55 20	76 27 10
York River		
Bell Rock	37 29 03	76 44 59
Aberdeen Rock	37 20 07	76 36 02
Mobjack Bay		
Tow Stake	37 20 20	76 23 10
Pultz Bar	37 21 11	76 21 10
Piankatank River		
Ginney Point	37 32 00	76 24 12
Palace Bar	37 31 36	76 22 12
Burton Point	37 30 54	76 19 42
Rappahannock River		
Ross Rock	37 54 04	76 47 21
Bowler's Rock	37 49 36	76 44 07
Long Rock	37 48 59	76 42 50
Morattico Bar	37 46 55	76 39 33
Smokey Point	37 43 09	76 34 56
Hog House	37 38 21	76 32 37
Middle Ground	37 41 00	76 28 24
Drumming Ground	37 38 38	76 27 59
Parrot Rock	37 36 21	76 25 20
Broad Creek	37 34 37	76 18 03
Great Wicomico River		
Haynie Point	37 49 47	76 18 33
Whaley's East	37 48 31	76 18 00
Fleet Point	37 48 35	76 17 19

Table D2: Results of the Virginia public oyster grounds survey, Fall 2013. 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	10/22	19.5	8.3	42.0	420.0	150.5	612.5	4.5	84.0	5.5	94.0
Mulberry Point	10/22	19.0	9.7	25.0	650.0	264.0	939.0	3.0	50.5	2.0	55.5
Horsehead	10/22	19.3	10.8	22.5	1170.5	428.5	1621.5	16.5	62.0	4.5	83.0
Point of Shoal	10/22	18.6	11.5	44.0	1025.5	282.0	1351.5	15.5	41.5	10.0	67.0
Swash	10/22	19.0	11.1	25.0	956.5	676.5	1658.0	19.5	51.0	7.0	77.5
Long Shoal	10/22	19.2	14.6	22.5	1226.0	355.0	1603.5	9.0	46.5	8.5	64.0
Dry Shoal	10/22	19.3	15.9	52.0	639.5	129.0	820.5	11.5	38.0	5.0	54.5
Wreck Shoal	10/21	19.7	16.8	73.5	309.5	64.5	447.5	6.0	19.5	2.5	28.0
Thomas Rock	10/21	19.4	18.2	14.5	45.5	89.5	149.5	2.5	15.5	3.5	21.5
Nansemond Ridge	10/21	19.5	18.9	1.5	5.0	14.0	20.5	0.5	3.0	1.5	5.0
York River											
Bell Rock *	10/15	19.5	16.6	46.5	149.5	8.0	204.0	6.0	26.5	0.0	32.5
Aberdeen Rock	10/15	20.0	19.9	65.5	237.5	9.5	312.5	20.5	36.0	0.5	57.0
Mobjack Bay											
Tow Stake	10/15	19.6	21.0	34.0	115.5	5.0	154.5	0.5	8.5	2.0	11.0
Pultz Bar	10/15	19.6	20.9	5.0	18.5	12.0	35.5	0.5	2.5	1.0	4.0
Piankatank River											
Ginney Point	10/9	21.6	17.4	98.5	377.5	45.0	521.0	5.0	22.5	0.0	27.5
Palace Bar	10/9	21.6	17.6	40.5	348.5	250.5	639.5	7.0	13.5	2.0	22.5
Burton Point	10/9	21.1	18.0	55.0	131.5	27.0	213.5	3.5	21.0	1.0	25.5
Rappahannock River											
Ross Rock	10/17	19.7	9.7	74.0	55.5	0.5	130.0	1.5	3.0	0.0	4.5
Bowler's Rock	10/17	19.3	12.8	46.5	4.0	0.0	50.5	0.0	2.5	0.0	2.5
Long Rock	10/17	19.5	13.7	58.0	10.0	1.0	69.0	0.0	3.5	0.0	3.5
Morattico Bar	10/17	19.9	15.8	70.5	15.5	4.5	90.5	0.5	2.5	0.0	3.0
Smokey Point	10/17	19.8	16.5	53.5	47.0	15.5	116.0	2.0	8.5	0.5	11.0
Hog House	10/17	19.8	16.8	19.5	16.5	13.0	49.0	0.0	2.0	0.5	2.5
Middle Ground #	10/17	20.2	16.8	10.0	50.5	150.0	210.5	2.0	27.0	1.0	30.0
Drumming Ground	10/17	20.1	17.4	41.5	271.0	12.0	324.5	7.5	16.0	0.0	23.5
Parrot Rock	10/17	19.7	17.0	57.0	52.0	27.5	136.5	5.5	19.0	0.0	24.5
Broad Creek	10/17	19.7	17.7	51.0	110.0	8.5	169.5	5.5	58.0	0.5	64.0
Great Wicomico River											
Haynie Point	10/18	19.3	16.9	39.5	591.0	65.0	695.5	9.5	28.0	0.5	38.0
Whaley's East	10/18	19.7	17.4	26.5	185.5	126.0	338.0	2.5	10.0	0.5	13.0
Fleet Point	10/18	19.2	17.7	34.0	334.5	59.0	427.5	2.5	9.0	1.0	12.5

Figure D1: Map showing the location of the oyster bars sampled during the 2013 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.

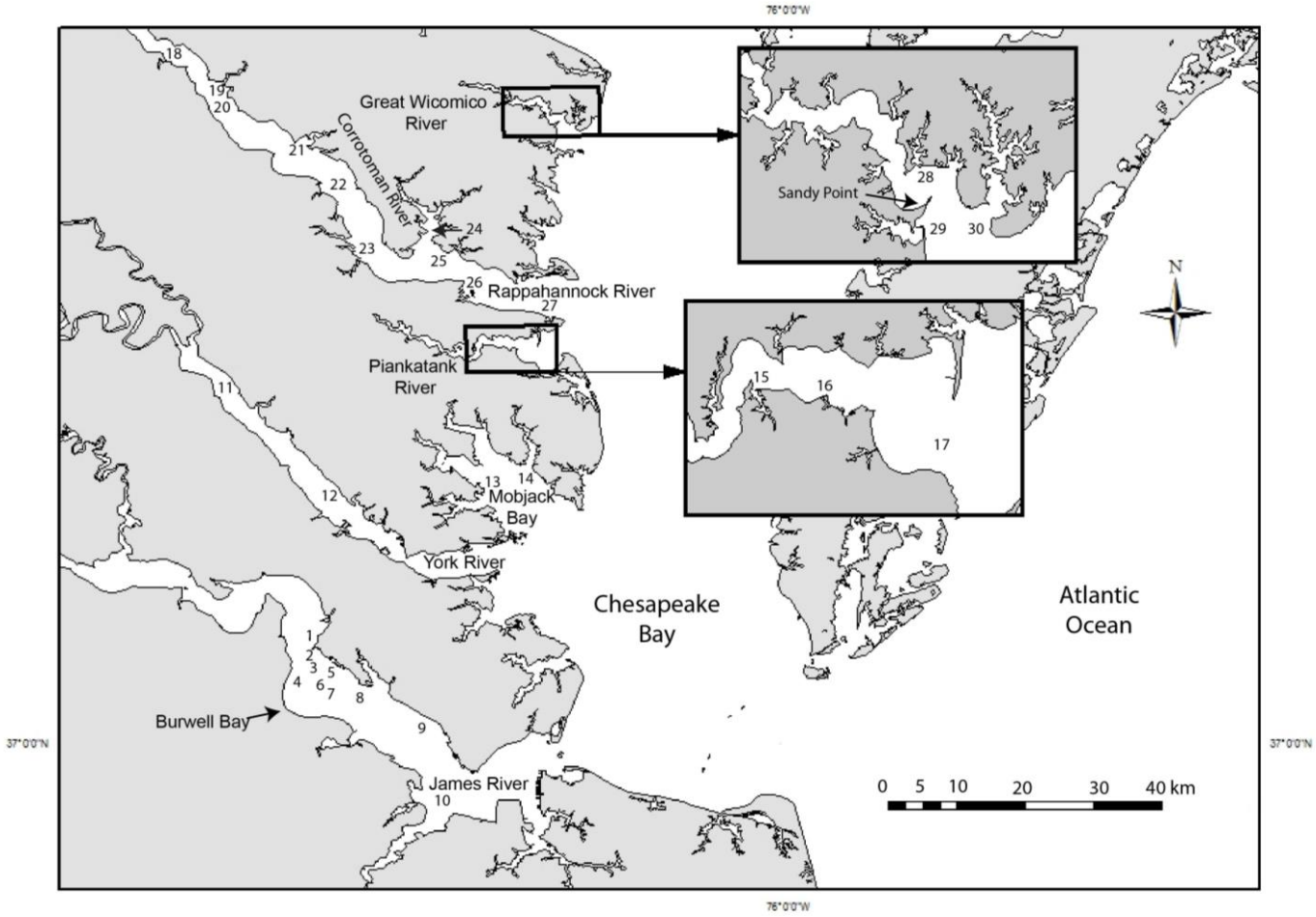


FIGURE D2: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2012-2013)
(Error bars represent standard error of the mean)

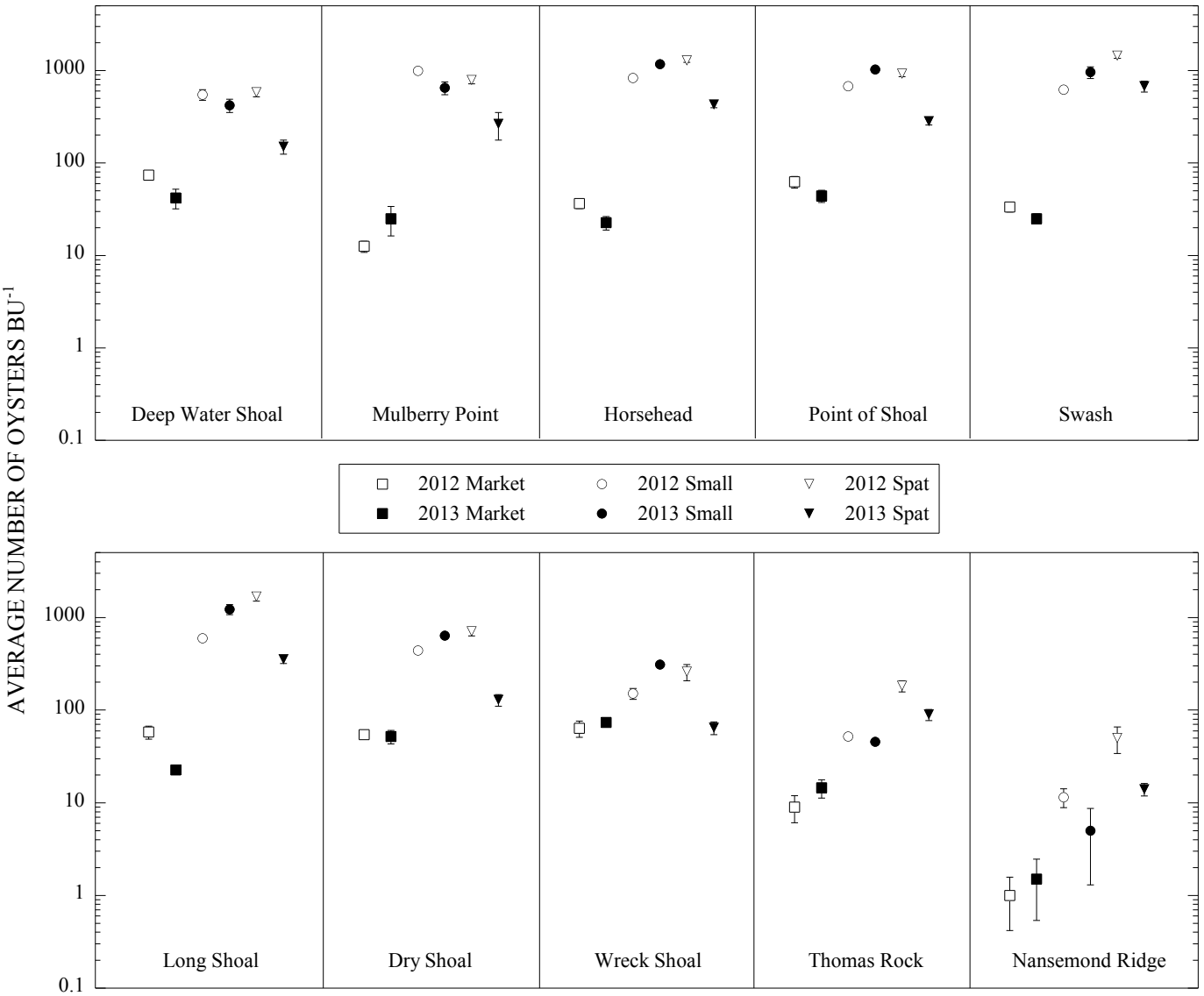
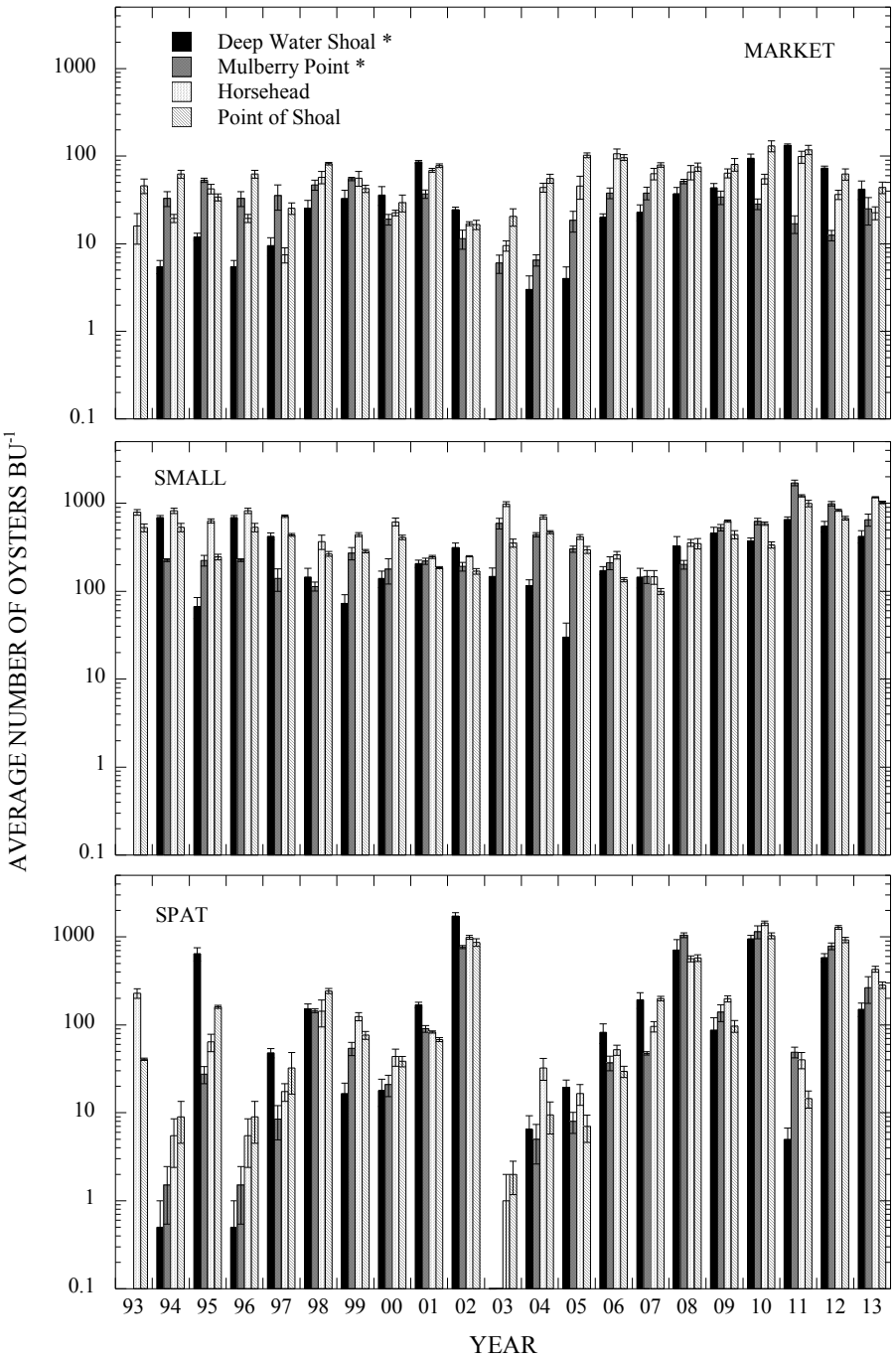
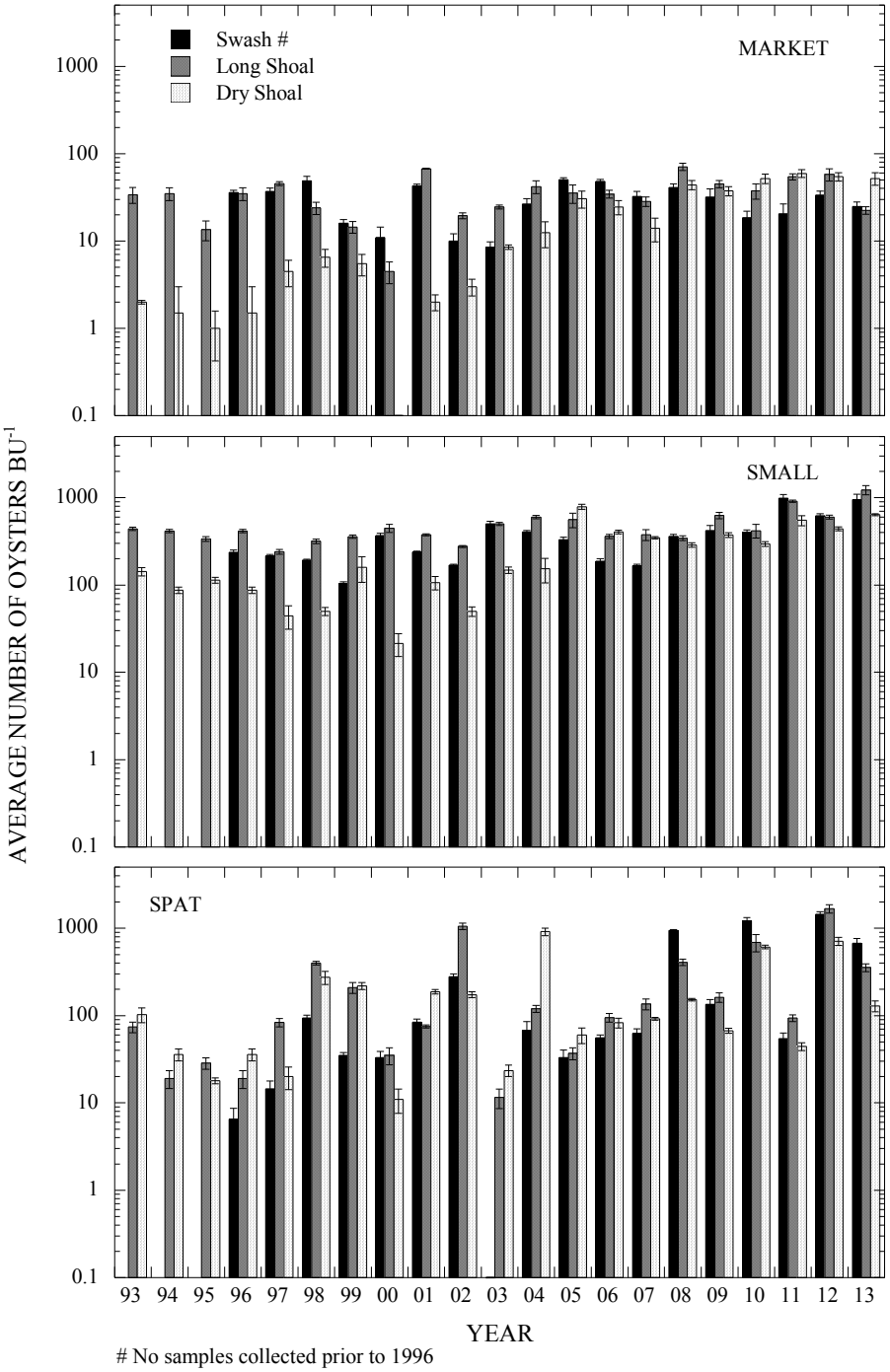


FIGURE D3A: JAMES RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1994

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



No samples collected prior to 1996

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

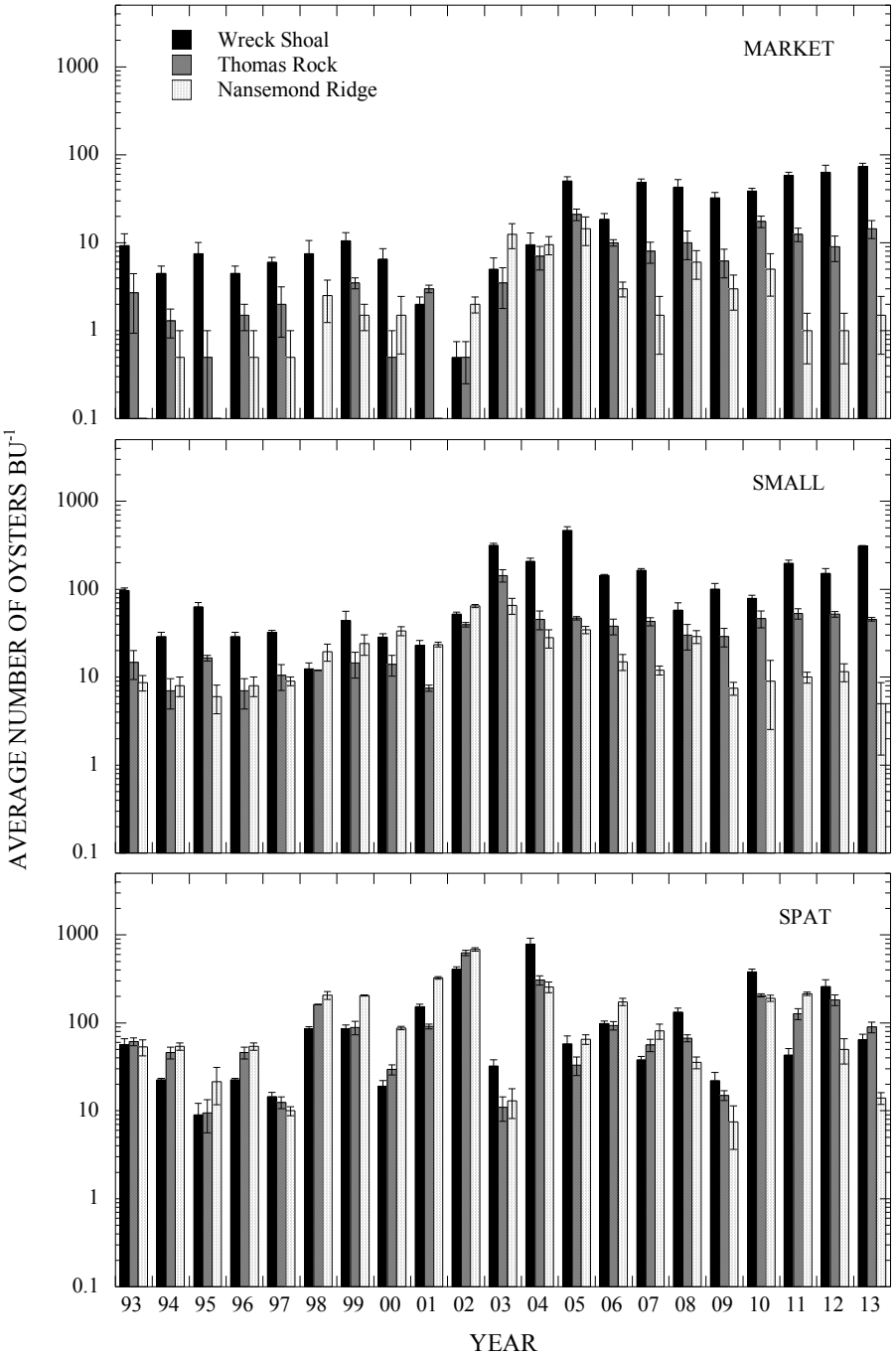


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE YORK RIVER AND MOBJACK BAY (2012-2013)
(Error bars represent standard error of the mean)

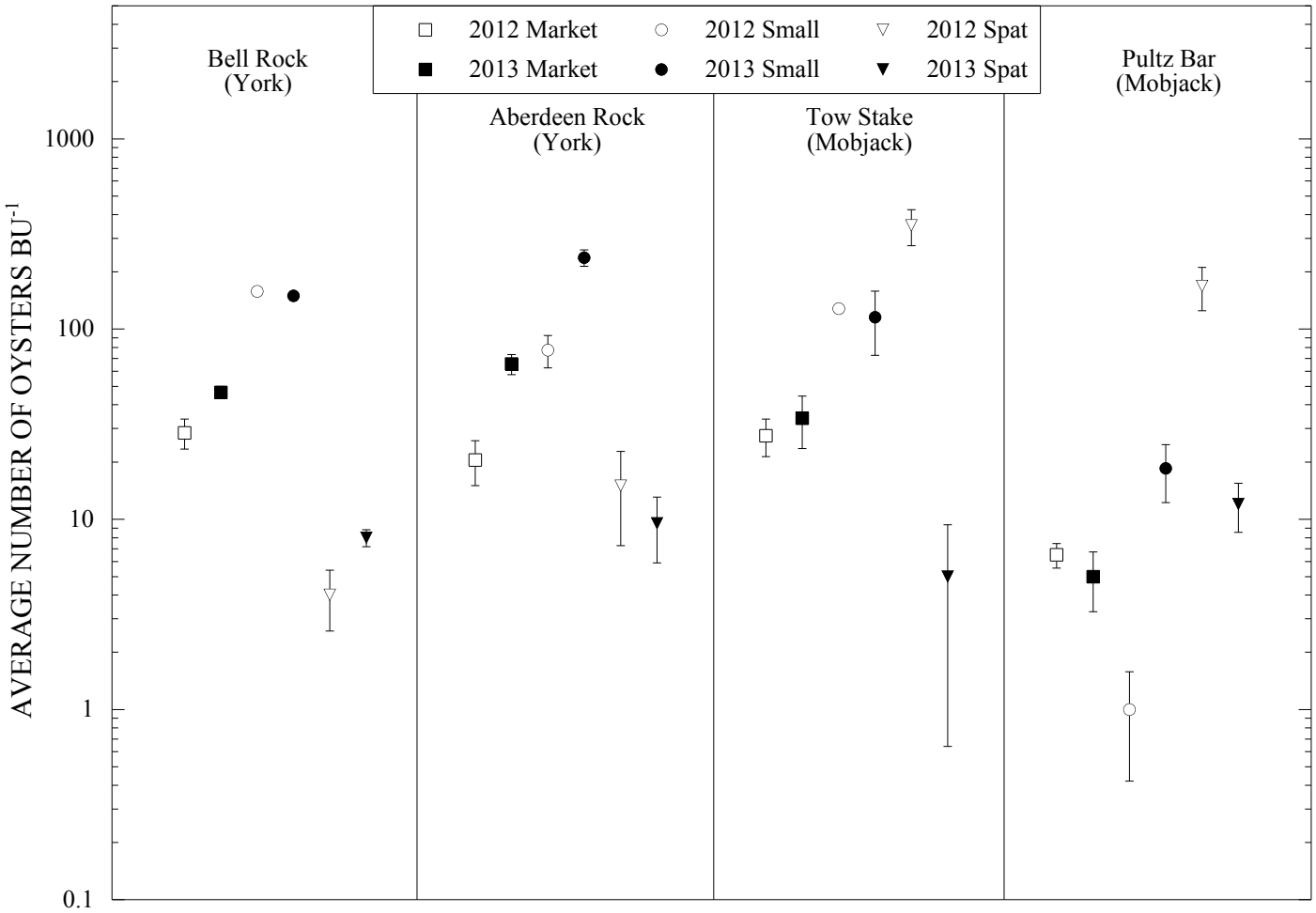


FIGURE D5: YORK RIVER OYSTER TRENDS OVER
THE PAST 20 YEARS
(Error bars represent standard error of the mean)

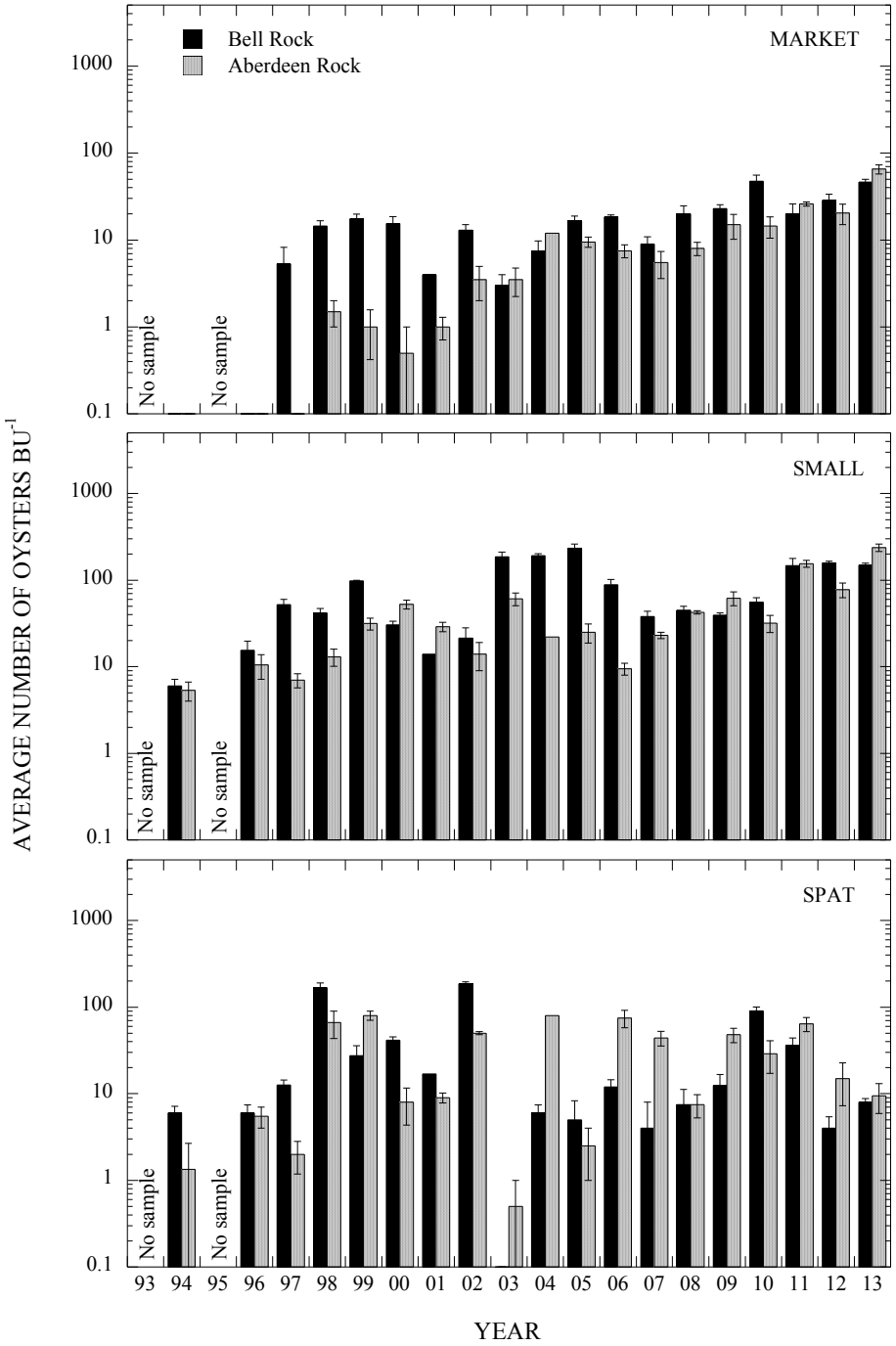


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER
THE PAST 20 YEARS
(Error bars represent standard error of the mean)

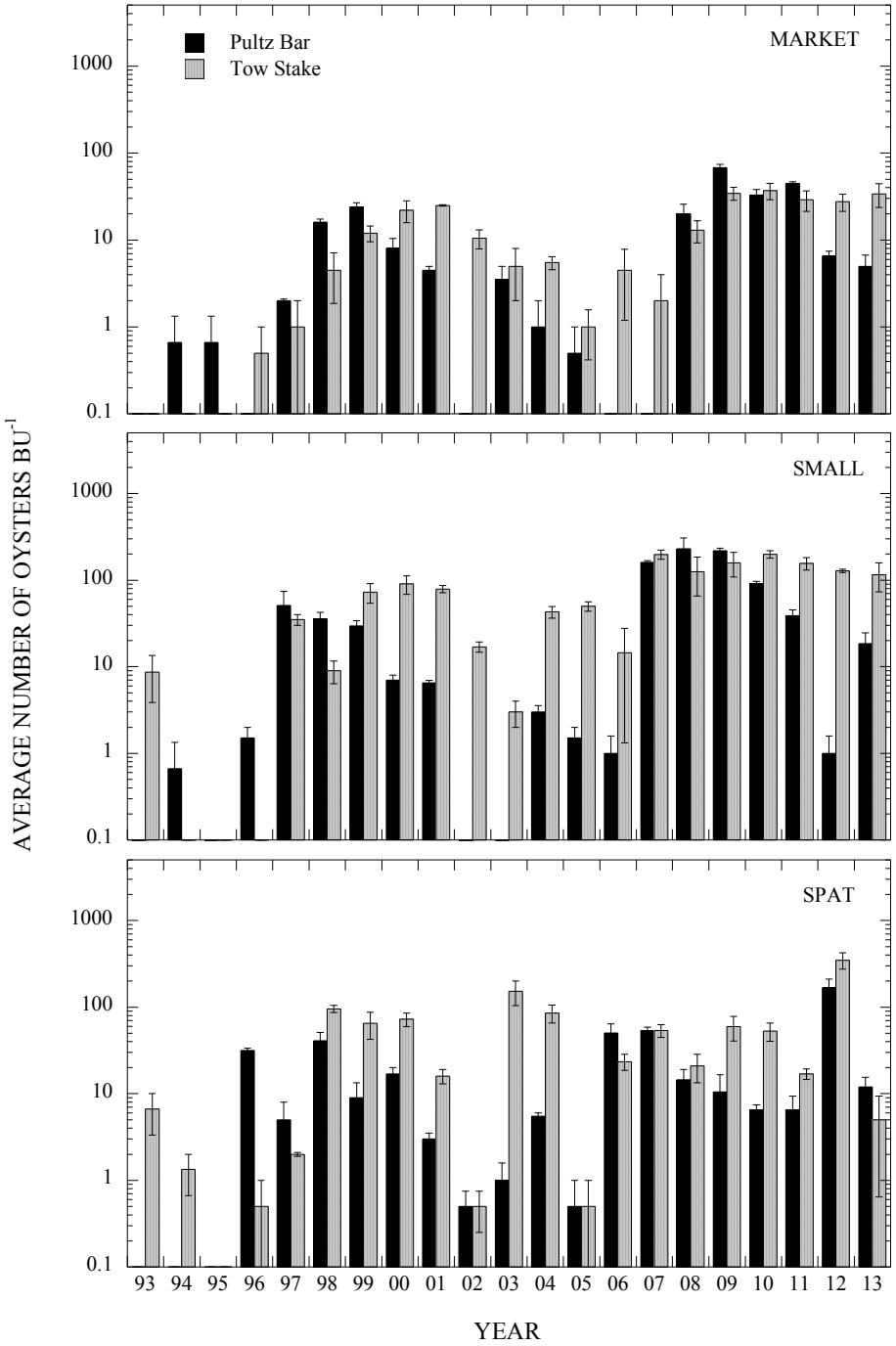


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2012-2013)
(Error bars represent standard error of the mean)

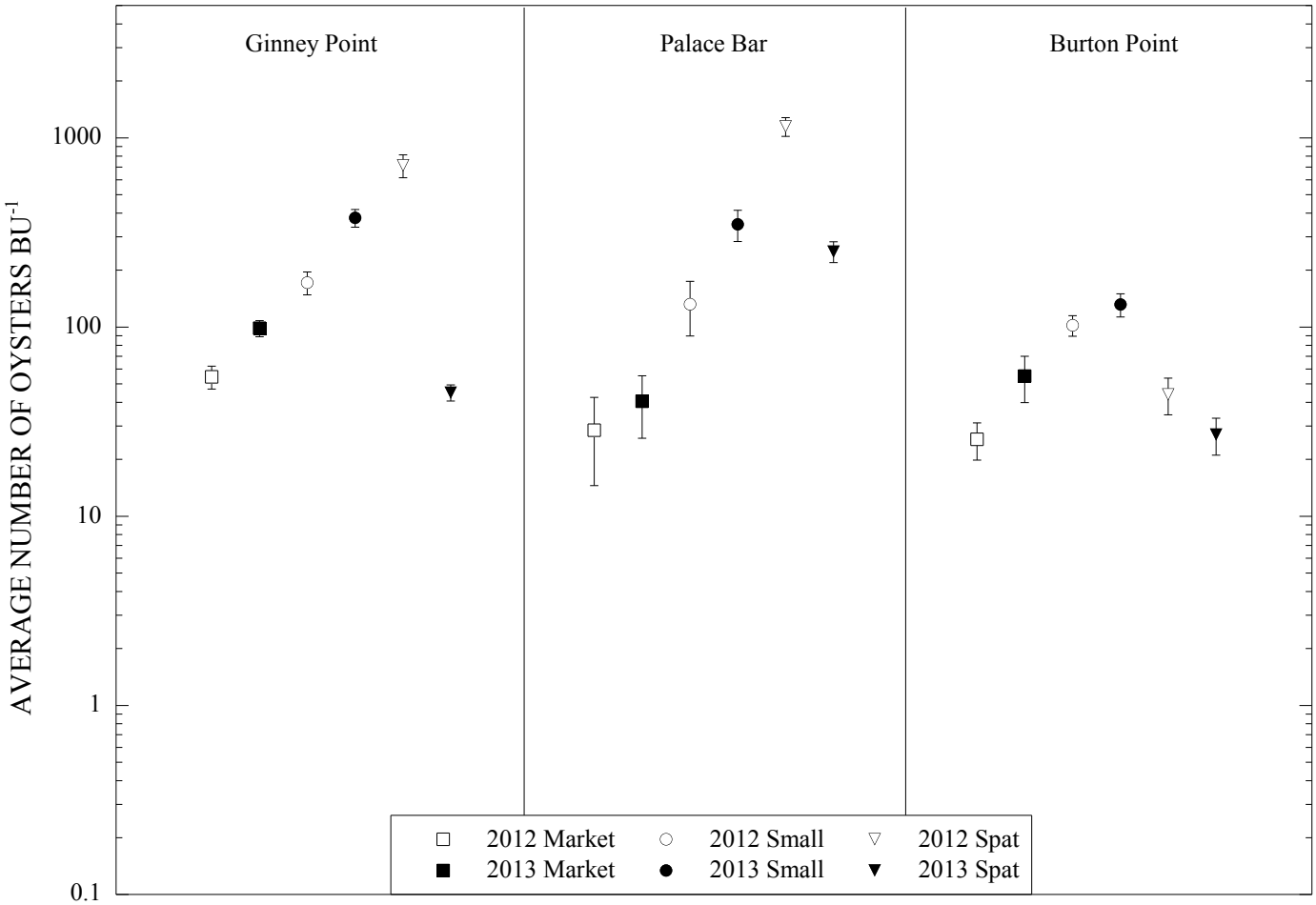
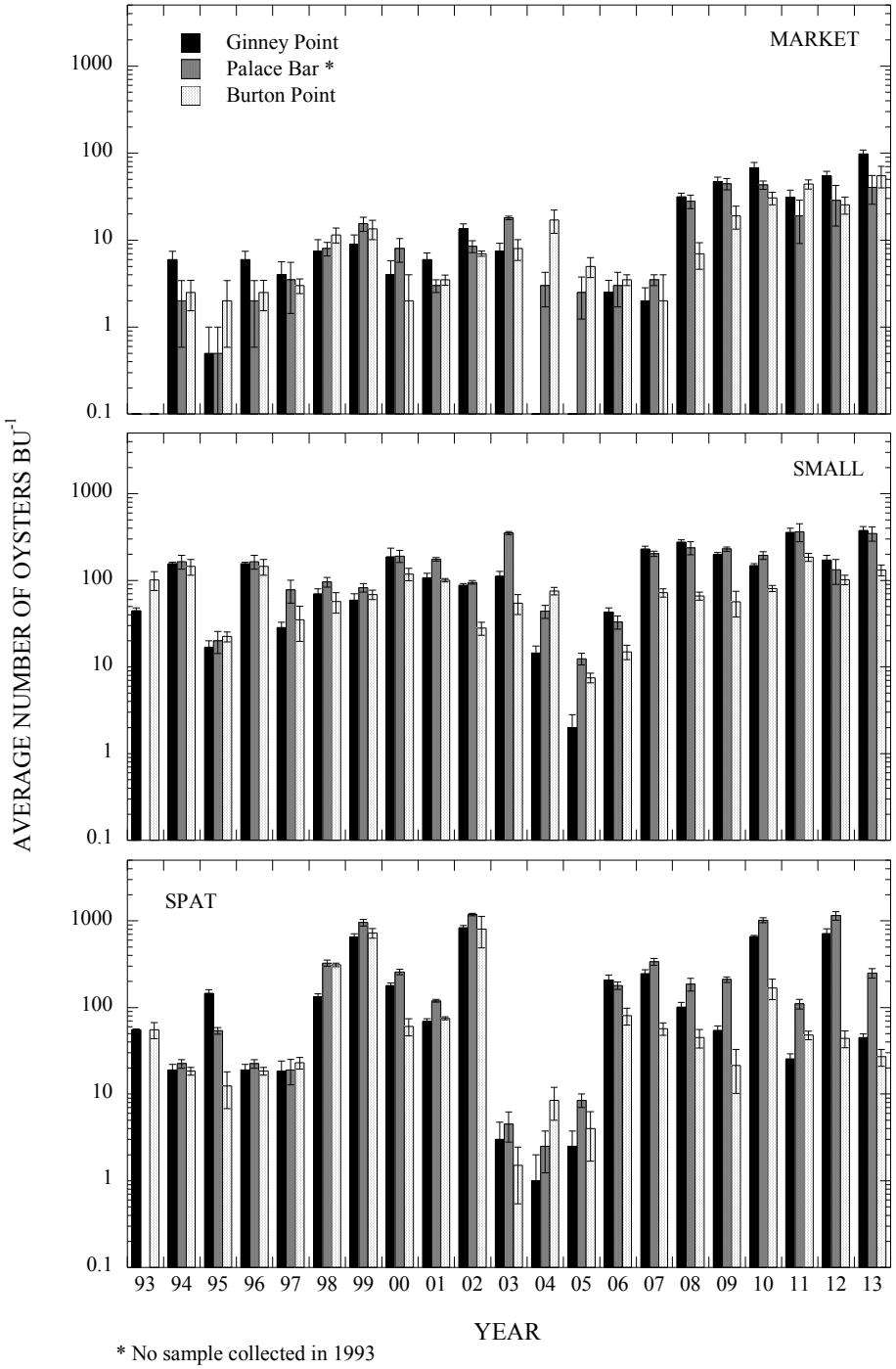


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 1993

FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2012-2013)
(Error bars represent standard error of the mean)

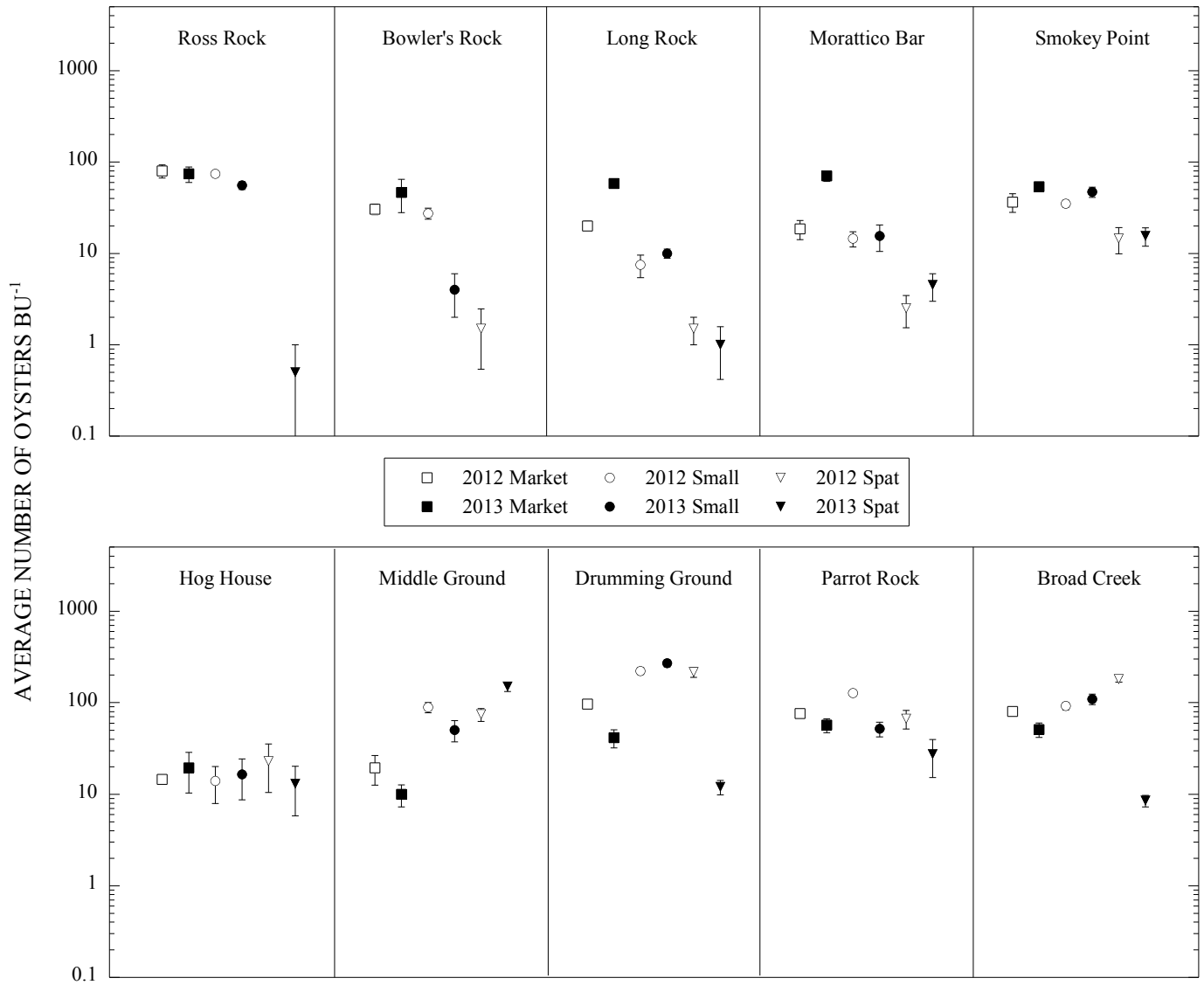
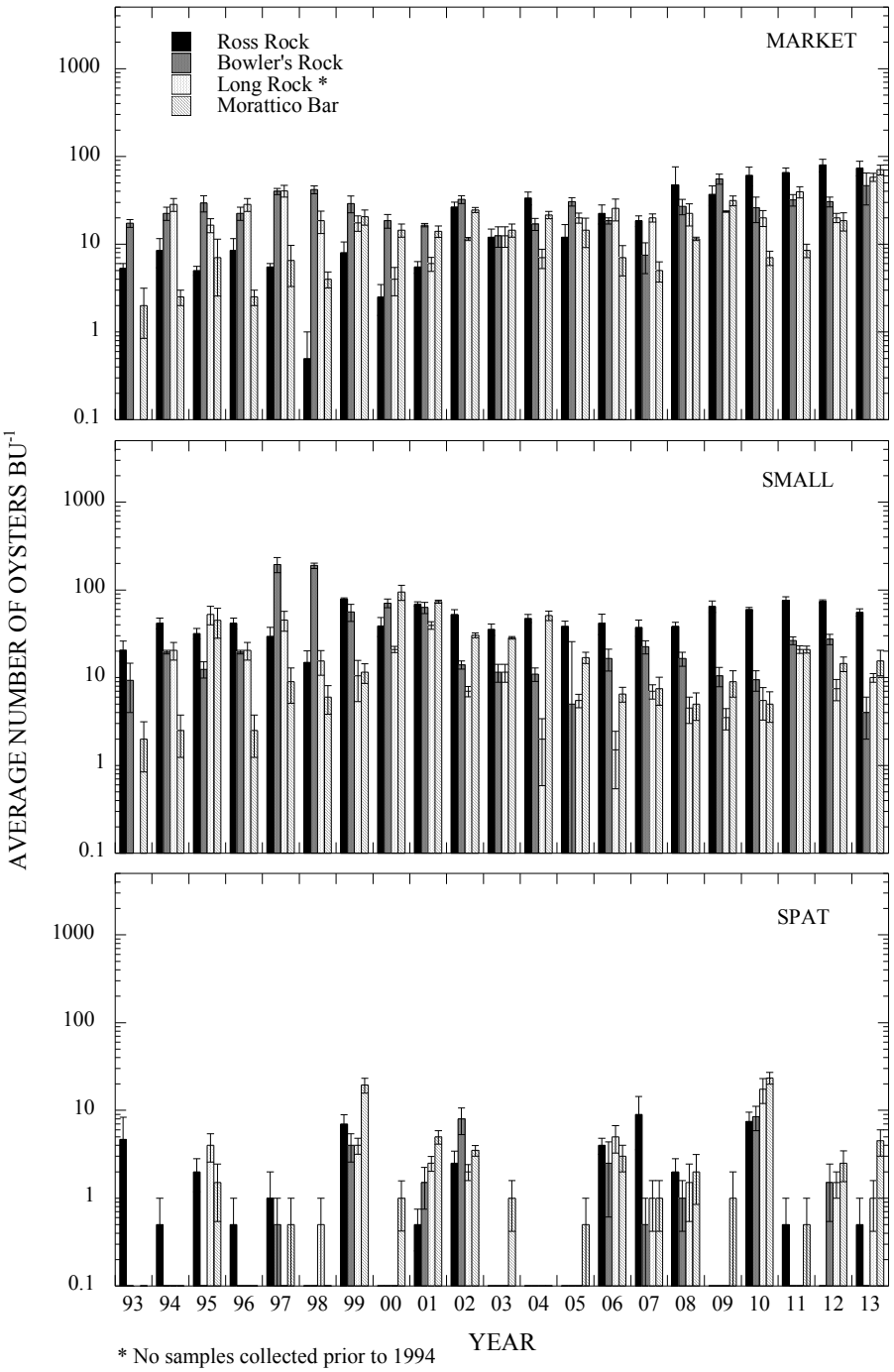


FIGURE D10A: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1994

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

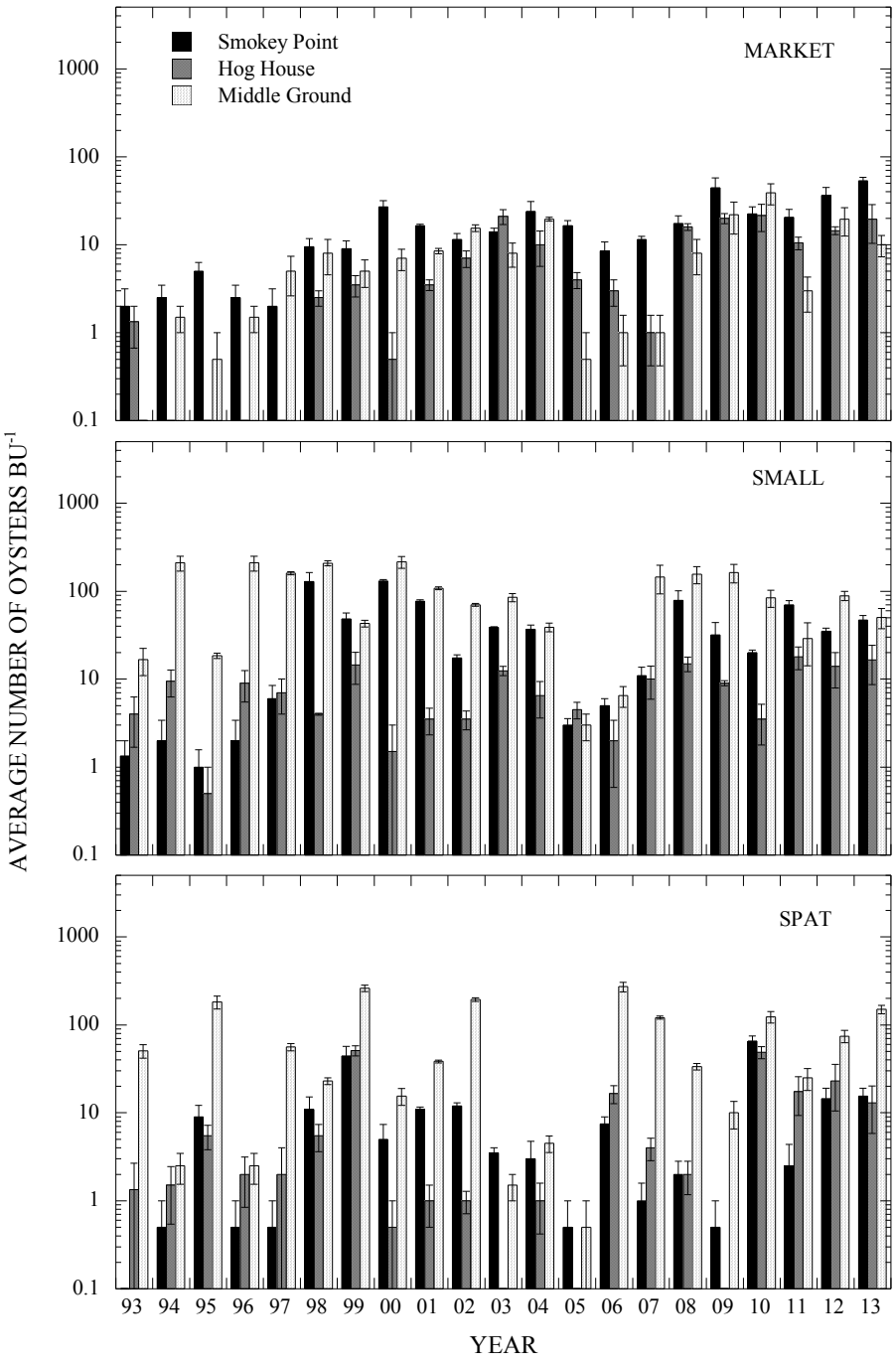
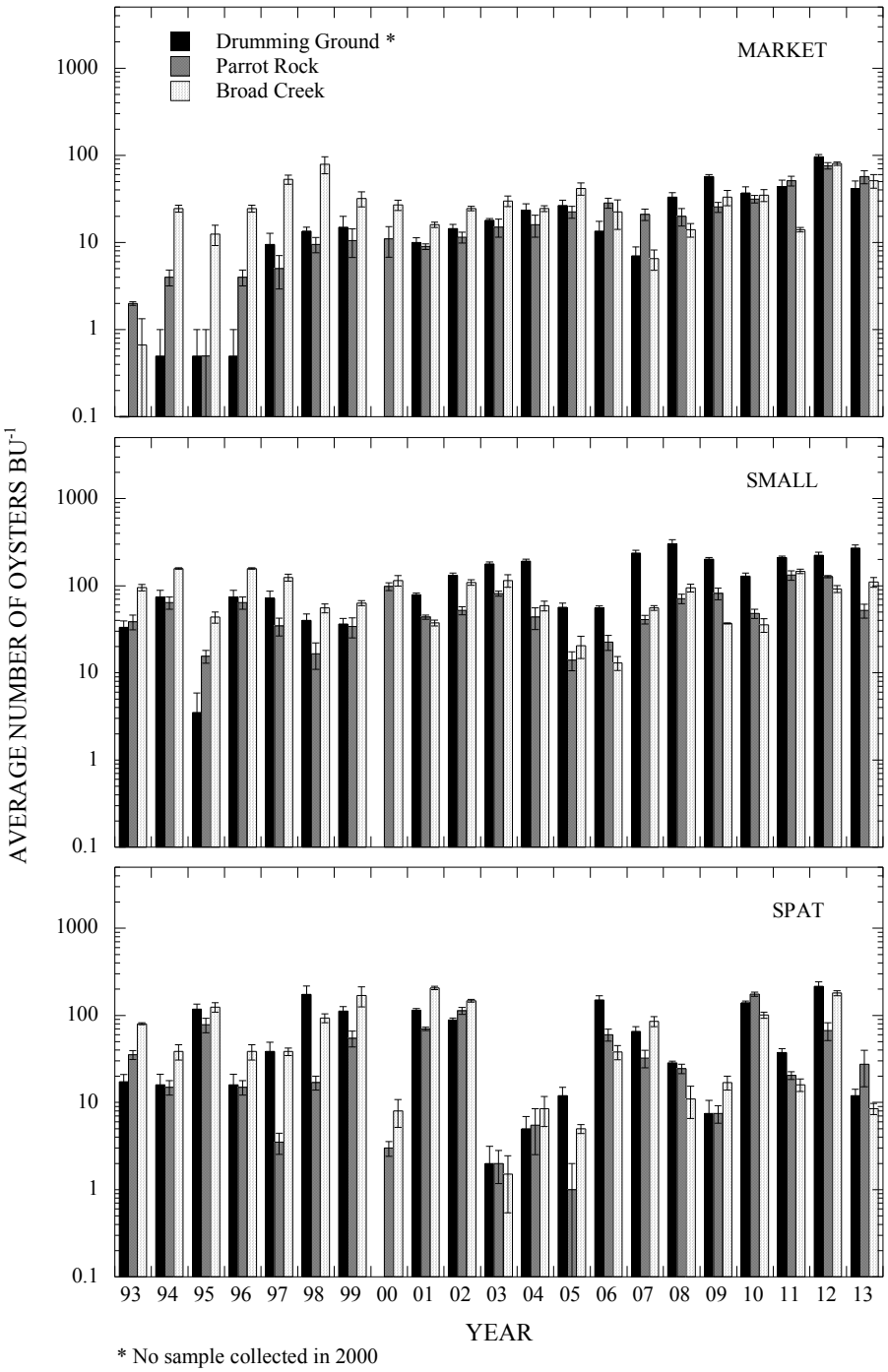


FIGURE D10C: RAPPAHANNOCK RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



* No sample collected in 2000

FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE GREAT WICOMICO RIVER (2012-2013)
(Error bars represent standard error of the mean)

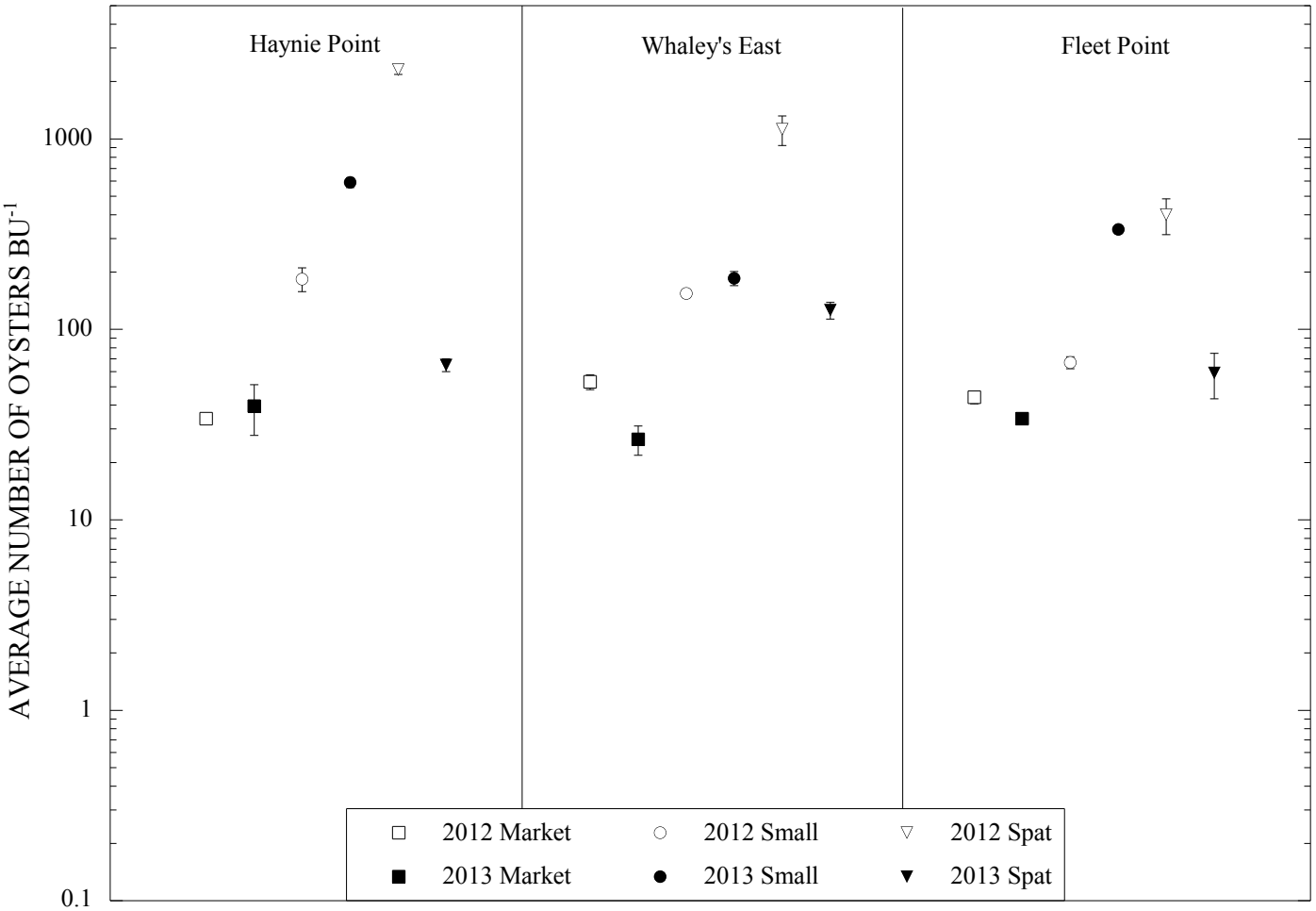
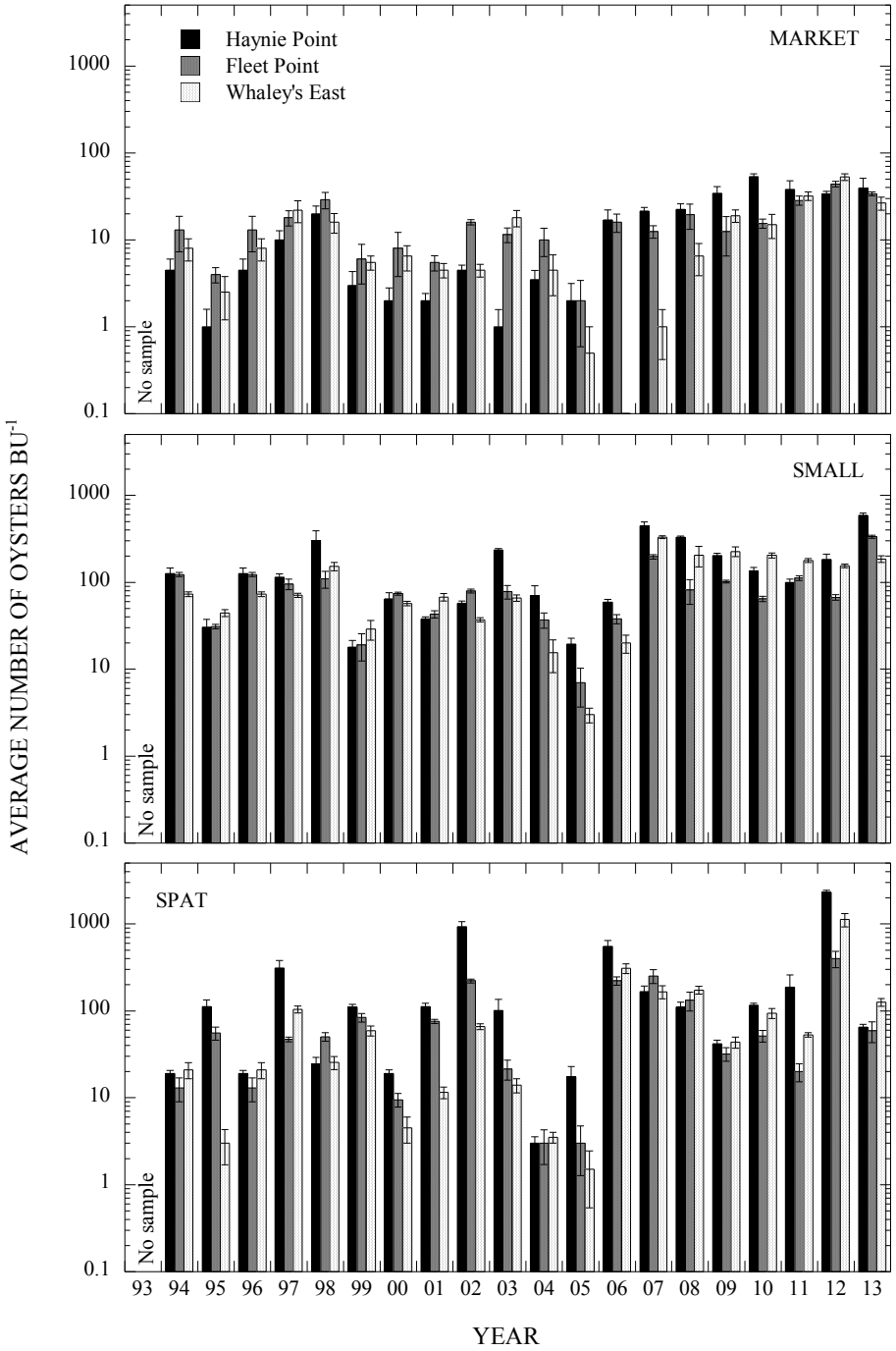


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS
OVER THE PAST 20 YEARS
(Error bars represent standard error of the mean)



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