The Status of Virginia's Public Oyster Resource 2021

MELISSA SOUTHWORTH
and ROGER MANN

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

February 2022

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Citation for this report:

Southworth, M. and R. Mann. 2022. The status of Virginia's public oyster resource, 2021. Molluscan Ecology Program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 52 pp. doi: 10.25773/6GB1-V305.

Part I. OYSTER RECRUITMENT IN VIRGINIA DURING 2021

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), Conservation Replenishment Department) 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 larval oysters 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 2021 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 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 2021 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 thirty 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 2021 ranged from 6 to 15 days. These periods do not always coincide among the different rivers or sites 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.

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[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 (ppt) 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 2021 is summarized in Table S1 and is discussed below for each river system monitored. Table S2 includes a summary of spatfall compared with 2021 during the previous thirty years (1991-2020) at the historical sites in all three-river systems and during the previous twenty-three years (1998-2020) 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 2021 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 2021. Comparisons were made over the past twenty-three years for the modern sites whereas the historical sites include thirty 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 Glebe Point, Hudnall, Haynie Point, Whaley's East (labeled Cranes Creek in reports prior to 1997), and Fleet Point.

James River

Oyster spatfall in the James River was first observed during the week of June 10 at Point of Shoal and Rock Wharf (Table S1). By the following week, there was spatfall at all eight sites, with at least some spatfall from then through the end of the monitoring period at each site every week. The largest overall peak in spatfall in 2021, occurred during the week of June 24, with 50% of the overall spatfall in the James occurring during that one week. Individually, the week of June 24 accounted for between 23 (Rock Wharf) to 67% (Horsehead) of the total spatfall for the year. There was also a small peak observed at Rock Wharf during the week of September 16, accounting for 28% of the total spatfall for the year (Table S1; Figure S3). At Day's Point, approximately 69% of the total spatfall for the year occurred during just three weeks (June 24, July 22, and August 26).

Cumulative spatfall in the James River during 2021 was extremely heavy at Wreck Shoal and heavy at the other seven sites monitored. Spatfall varied widely from one site to the next, from a low of 14.9 cumulative spat shell^{-1} at Day's Point to a high of 167.9 cumulative spat shell^{-1} at Wreck Shoal (Table S1; Figure S4). Spatfall during 2021 was higher than all previous reference points (2020, 5, 10, 20, and 30-yr means) at Horsehead, Point of Shoal, Swash and Wreck Shoal. At Deep Water Shoal, spatfall was higher than 2020 as well as the both the 5 and 10-yr means. Spatfall at Dry Shoal was higher than the 30-yr mean and at Rock Wharf, spatfall was higher in 2021 than the previous year (2020) as well as both the 10 and 30-yr means. Comparing 2021 to the previous thirty years, spatfall numbers at Horsehead, Point of Shoal, Swash, and Wreck Shoal were the fifth, fifth, fourth and third highest observed, respectively. Spatfall in 2021 at all sites except Day's Point, ranked in the 66th percentile or higher. Day's Point was in the 53rd percentile over the past thirty years. The long-term means are primarily driven by a few exceptionally high spatfall years (1991, 1993, 2008, 2010, 2012, 2016, 2018, and 2020). Since 2010, spatfall throughout the James River, has been consistently moderate to heavy (Table S2).

Average river water temperature in the James River during the 2021 monitoring period ranged from a low of 20.0 to a high of 29.4°C (Figure S5A). Water temperature was similar (difference of less than 0.5°C) to the long-term means (5, 10, 20, and 30-yr) from early-June through July, until water temperature dropped during the week of August 5. Average water temperature decreased by almost 2°C between the week of July 29 and August 5, but then increased, reaching a maximum for the year of 29.4°C during the week of August 26, a full month later than what is typical for the river. There were several weeks during September when water temperature was not collected, but in general average river water temperatures in September were higher (1 to 2°C) than the long-term means (Figure S5A).

Average salinities in the James River during 2021 ranged from 9.6 to 16.8 ppt, generally increasing from early June through late July, and then decreasing during August (Figure S5B). For most of June and July, salinity was 1 to 3 ppt higher than the long-term (5, 10, 20, and 30-yr) means for the river. From mid-August through mid-September, average river salinity in the James was similar to the long-term means, before salinity again increased, ending the monitoring period slightly higher than what is typical for the river. The difference in salinity between the most upriver site (Deep Water Shoal) and the two most downriver sites (Day's Point and/or Wreck Shoal; Figure S1) in any one week, ranged between 6 and 12 ppt.

Piankatank River

Spatfall in the Piankatank River was first observed during the week of June 10 at Bland Point (Table S1; Figure S6). By the week of June 24, spatfall was occurring at all eight sites and was consistent (spatfall at least six out of the eight sites), but highly variable in frequency (0.1 to 477.8

spat shell^{-1}) from then through the rest of the monitoring period. The largest overall peak in the system occurred from July 1 to July 15 (Figure S6A). This three-week period accounted for 86 (Wilton Creek) to 97% (Cape Toon) of the spatfall for the year. At Wilton Creek, 76% of the spatfall for the year was observed during the week of July 15.

Cumulative spat shell^{-1} for the year was heavy at Wilton Creek and extremely heavy at the other seven sites monitored in the Piankatank River. Spatfall ranged from a low of 63.2 cumulative spat shell^{-1} at Heron Rock to a high of 704.3 cumulative spat shell^{-1} at Stove Point (Table S1; Figure S7). Spatfall during 2021 was higher than all previous reference points (2020, 5, 10, 20, and 30-yr means) at every site monitored. At the three historical sites, spatfall in 2021 was in the 93rd (Palace Bar and Burton Point) and 96th (Ginney Point) percentile over the past thirty years. At the modern sites, spatfall ranged from the 91st (Wilton Creek and Bland Point) to the 100th (Cape Toon and Stove Point) percentile since monitoring began at those sites in 1998.

The average water temperature during the 2021 sampling period in the Piankatank River ranged from 21.4 to 29.1°C (Figure S8A). Water temperature in the Piankatank River was similar to the long-term (5, 10, 20, and 30-yr) means throughout most of June, July and August. The few exceptions occurred during the weeks of June 3 (2 to 3°C lower), June 24 (1 to 2°C lower) and August 5 (2 to 3°C lower). After the week of August 5, water temperature steadily increased, reaching the maximum for the year (29.1°C) during the last two weeks of August, approximately a month later than is typical for the river. After reaching the maximum, water temperature decreased throughout the rest of the monitoring period, but remained 1 to 2°C higher than the long-term means throughout most of September (Figure S8A).

Salinity in the Piankatank River during 2021 ranged from 13.7 to 18.2 ppt, steadily increasing from early June through mid-July before leveling off and remaining between 17 and 18 ppt for the rest of the monitoring period (Figure S8B). From the week of July 8 onward, salinity during 2021 was 1 to 2 ppt higher than the long-term means (5, 10, 20, and 30-yr) in any given week. The one exception occurred during the week of September 9, when salinity was similar (less than 0.5 ppt) to the long-term means. There was typically a 1 to 3 ppt difference in salinity between the most upriver site (Wilton Creek) and the most downriver site (Burton Point: Figure S1).

Great Wicomico River

Spatfall in the Great Wicomico River was first observed during the week of June 3 at Haynie Point, June 10 at Rogue Point, and June 17 at all nine sites monitored. There was a very large pulse in spatfall during the three-week period between June 24 and July 8. Settlement during these three weeks accounted for 75 to 95% of the total for the year at every site except Fleet Point (Table S1; Figure S9). At Fleet Point, this period accounted for 46% of the total, with an additional 40% occurring during the week of July 15 (Table S1; Figure S9). At Glebe Point, the week of July 8 accounted for 58% of the total spatfall for the year.

Cumulative spat shell^{-1} for the year was highly variable across the river system. It was heavy at the five most upriver sites (see Figure S1 for specific locations) and Fleet Point, with the cumulative spat shell^{-1} at those six sites ranging from a low of 13.0 at Glebe Point to a high of 87.3

at Harcum Flats. Spatfall was extremely heavy at the remaining three sites (Shell Bar, Haynie Point, and Whaley's East), with cumulative spat shell^{-1} for the year of 194.0, 142.7, and 125.2, respectively (Table S1; Figure S10). Spatfall in the Great Wicomico River in 2021 at the five most upriver sites was lower than that observed at all previous reference points; 2020, 5, 10, and 20-yr means at all five sites and the 30-yr mean at Glebe Point and Hudnall. Spatfall at Haynie Point and Whaley's East was lower than that observed in 2020, as well as the 5 and 10-yr means, but was higher than both the 20 and 30-yr means. At Shell Bar, spatfall in 2021 was higher than the 20-yr mean, but lower than all other reference points. Spatfall at Fleet Point was higher than the previous year, but lower than all of the other reference points (5, 10, 20, and 30-yr mean). When compared with the previous thirty years, spatfall in 2021 was in the 73rd percentile or greater at all of the historical sites except Glebe Point. Spatfall at Glebe Point was in the 46th percentile over the past thirty years. When compared to the previous twenty-three years, spatfall in 2021 at the four modern sites ranked in the 43rd percentile at Rogue Point, the 52nd percentile at Hilly Wash and Harcum Flats and in the 69th percentile at Shell Bar. Spatfall on the shellstring collectors in the Great Wicomico River has been consistent and heavy in almost every year since 2006 (Table S2).

The average river water temperature in the Great Wicomico River during the 2021 sampling period ranged from 21.6 to 29.4°C (Figure S11A). Throughout most of June, water temperature in the Great Wicomico River was 1 to 2°C lower than the long-term (5, 10, and 20-year) means. Similar to what was observed in the James and Piankatank Rivers, temperature decreased by almost 2°C between the weeks of July 29 and August 5, then increased for several weeks, reaching the maximum for the year (29.4°C) during the week of August 26, approximately a month later than is typical for the river. After reaching the maximum, water temperature decreased throughout the rest of the monitoring period, but remained 1 to 2°C higher than the long-term means throughout most of September (Figure S11A).

Salinity in the Great Wicomico River during 2021 ranged from 12.8 to 16.6 ppt, generally increasing throughout the monitoring period (Figure S11B). Salinity in 2021 was similar (less than 1 ppt difference) to the long-term means (5, 10, and 20-year) throughout the majority of the season (Figure S11B). The few exceptions occurred during the weeks of July 15 (1 ppt higher) and August 19 and 26 (1 to 2 ppt higher). In any given week, there was typically a 1 to 3 ppt difference in salinity between the most upriver site (Glebe Point) and the most downriver site (Fleet Point: Figure S1).

DISCUSSION

During the seventeen-year period between 1991 and 2007, spatfall on the shellstrings was light to moderate; with 78% 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 fourteen years (2008-2021) has been on the rise such that 86% 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 through 2021, 86% of all of the year/site combinations had heavy spatfall (seasonal cumulative total of > 10 spat shell^{-1}) and 51% of the total year/site combinations had extremely heavy spatfall (seasonal cumulative total of > 100 spat shell^{-1}; Table S2).

During 2021, water temperature in all three river systems, decreased by a notable amount during the week of August 5. Following this decrease, water temperature quickly increased and the maximum for the year was reached in all three river systems between August 19 and August 26. This is approximately one month later than what is typical for these rivers; in most previous years, the water temperature max has occurred at the end of July. There was a slight uptick in spatfall observed in both the James and Piankatank Rivers, approximately 2 to 3 weeks after this temperature increase. Changes in water temperature (both increases and decreases) have been indicated in stimulating oysters to spawn (Nelson 1928).

Overall, spatfall on shellstrings in the James River during 2021 was heavy to extremely heavy. Since 2008, the James River has had several very strong year classes on the shellstrings; 2008, 2010, 2012, 2016, 2017, and 2018, with 2020 and 2021 being notable as well. The mean cumulative spat shell^{-1} over all eight sites from 1991 to 2007 was 12.7, whereas the mean for all eight sites over the past fourteen years (2008 to 2021) was 76.0. This translates to around a six-fold increase in spatfall over the past fourteen years compared with the previous seventeen 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 81% (91/112) of the year/site combinations and moderate spatfall during the remaining year/site combinations (21/112). The one exception was during 2009, when all eight sites monitored had moderate spatfall (Table S2). From 1991 to 2007 on the other hand, only 27% (36/134) of the year/site combinations had heavy or extremely heavy spatfall, with 14% (19/134) during that time period experiencing light spatfall. In 2021, the largest peak in spatfall in the James River occurred during the week of June 24, accounting for approximately 50% of the spatfall for the year.

Overall, spatfall in 2021 on the shellstrings in the Piankatank River was heavy (one site) to extremely heavy (seven sites). Similar to the James River, the Piankatank River has had several very strong year classes on the shellstrings in recent years (2012, 2014, 2015, 2016, and now 2021). From 1991 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 1991 to 2009, only 19% (22/117) of the year/site combinations experienced heavy spatfall and 30% (35/117) experienced light spatfall. However, since 2010, only four year/site combinations have had moderate spatfall, with extremely heavy spatfall at 30% (29/96) of the year/site combinations and heavy spatfall during the remaining year/site combinations. At the three historical sites the mean from 1991 to 2009 was 5.3 cumulative spat shell^{-1}, whereas from 2010 to 2021 the mean at those three sites was 84.1 cumulative spat shell^{-1}, a 16-fold increase over the previous nineteen-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 103.7 cumulative spat shell^{-1} (2010 to 2021), a 19-fold increase.

With the exception of 2018, spatfall on the shellstrings in the Great Wicomico River has been especially good since 2006. Three out of the last six years (2016, 2017 and 2019) saw extremely heavy spatfall at all nine sites monitored in the Great Wicomico River. In seven out of the ten years between 2012 and 2021, at least seven of the sites monitored in the Great Wicomico had extremely heavy spatfall each year. During that time only 15% of the year/site combinations had moderate spatfall, with the remaining year/site combinations having either heavy or extremely heavy spatfall. As has been typical in recent years (Southworth & Mann 2004), spatfall in the Great Wicomico River has been getting progressively earlier, with the majority (greater than 98%) of spat settling on the shellstrings in 2021, 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	0.5	6.6	-	-	0.7	0.4	0.3	0.9	0.7	1.2	0.7	-	1.2	1.2	-	1.4	15.8
Horsehead	D	0	-	0	0.9	44.2	-	-	6.3	1.4	1.5	3.2	2.7	1.1	1.6	-	0.7	2.4	-	0.4	66.4
Point of Shoal	D	0	-	0.1	0.9	16.9	-	-	4.2	-	1.4	2.9	3.0	5.3	-	-	4.7	4.1	-	1.5	45.0
Swash	D	0	-	0	0.6	34.0	-	-	5.4	5.6	1.3	3.9	3.9	2.7	2.0	-	3.6	3.5	-	2.8	69.3
Dry Shoal	D	0	-	0	1.1	35.7	-	-	-	3.4	1.2	0.0	0.9	2.7	4.1	-	3.3	6.7	-	4.1	63.2
Rock Wharf	D	0	-	0.1	0.9	12.6	-	-	0.5	3.1	1.2	1.7	2.4	3.3	4.4	-	3.9	15.2	-	4.6	53.9
Wreck Shoal	D	0	-	0	1.2	90.0	-	-	14.2	14.3	6.5	3.7	1.8	10.0	-	-	6.8	9.7	-	9.7	167.9
Day's Point	D	0	-	0	-	4.4	-	-	0.7	3.3	0.4	0.8	0.6	-	2.5	-	0.8	0.6	-	0.8	14.9
PIANKATANK RIVER																					
Wilton Creek	D	0	0	0	0	0.3	2.1	4.0	48.2	0.7	2.2	0.7	0.5	0	0.1	-	0.1	3.1	-	1.2	63.2
Ginney Point	D	0	0	0	0.3	0.7	5.8	41.6	72.4	1.6	3.9	2.0	2.3	0	0	-	0	3.2	-	0.6	134.4
Palace Bar	D	0	0	0	0.1	1.3	3.3	61.9	25.2	1.8	1.0	0.3	1.0	0.1	0.5	-	0	4.2	-	0.7	101.4
Bland Point	D	0	0	0.1	0.1	3.5	7.0	233.6	59.3	1.2	0	0.6	0.5	0.4	1.0	-	0.1	6.9	-	1.4	315.7
Heron Rock	D	0	0	0	0	1.2	9.9	82.2	43.1	1.7	0.1	0.9	0.2	0.3	0.8	-	0.3	3.8	-	1.3	145.8
Cape Toon		D	0	0	0.1	1.2	12.7	275.1	111.8	0.7	0.6	0.3	1.2	0.1	0.6	-	0.5	3.7	-	1.6	410.2
Stove Point	D	0	0	0	0	2.7	80.9	477.8	111.4	1.8	1.4	0.4	1.6	0.6	3.1	-	0.1	21.2	-	1.3	704.3
Burton Point	D	0	0	0	0.1	1.7	16.3	159.0	124.8	1.0	0	0.4	0.4	0.5	1.2	-	0.4	8.1	-	9.1	323.0
GREAT WICOMICO																					
Glebe Point	D	0	0	0	0.2	1.2	0.9	7.6	0.1	0	0.3	0	1.6	0	0.3	-	-	0	-	0.8	13.0
Rogue Point	D	0	0	0.1	3.2	28.0	19.0	6.6	0.1	0.4	0.8	0	1.2	0.1	0.8	-	-	0.5	-	0.6	61.4
Hilly Wash	D	0	0	0	3.1	45.4	-	7.0	0.2	0.1	0.6	0.1	1.3	0	0.1	-	-	0.5	-	0.6	59.0
Harcum Flats	D	0	0	0	3.7	36.7	33.3	8.1	0.3	0.4	0.5	0.2	0.9	0	0.4	-	-	1.5	-	1.3	87.3
Hudnall	D	0	0	0	0.9	26.5	20.7	6.9	0.1	0.2	0	0	0.1	0.2	0.1	-	-	0.9	-	0.3	56.9
Shell Bar	D	0	0	0	3.2	80.1	67.9	35.6	1.3	0.3	0.7	0	1.3	0.9	0.7	-	-	1.3	-	0.7	194.0
Haynie Point	D	0	0.1	0	2.1	78.2	39.2	17.2	1.0	0.1	0.1	0.4	0.4	0.2	1.0	-	-	1.1	-	1.6	142.7
Whaley's East	D	0	0	0	1.0	34.7	74.1	10.0	2.3	0.1	0.2	0	0.2	0	0.9	-	-	1.3	-	0	125.2
Fleet Point	D	0	0	0	0.7	7.0	12.8	-	17.7	0.5	1.8	0	0.3	0	1.3	-	-	0.3	-	1.1	43.5

Table S2: Spatfall totals for historical sites (1991-2021) and modern sites (1998-2021) 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 2021 in reference to 2020 and to the five, ten, twenty, and thirty year means. Blank cells for a site indicate years where data are not available.

STATION	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Mean 16-20	Mean 11-20	Mean 01-20	Mean 91-20	Ref. 2020	Ref. 5-yr	Ref. 10-yr	Ref. 20-yr	Ref. 30-yr
JAMES																																								
Deep Water Shoal	10.6	0.7	15.7	0.6	1.7	0.5	1.3	1.2	5.7	0.7	2.0	33.8	0.1	1.6	1.0	2.1	5.3	252.3	1.7	19.7	7.0	13.6	2.8	2.3	18.0	19.5	7.6	4.3	20.2	9.7	15.8	12.3	10.5	21.2	15.6	+	+	+	-	NC
Horsehead	24.7	3.6	43.7	3.2	0.3	3.6	2.4	1.1	3.8	2.3	4.0	24.4	0.0	3.6	1.3	2.2	4.2	227.6	4.2	115.0	15.0	86.3	4.7	6.1	46.4	87.1	42.0	26.8	47.8	60.9	66.4	52.9	42.3	40.5	30.1	+	+	+	+	+
Point of Shoal	21.4	5.4	73.7	15.0	4.8	2.3	2.3	1.5	3.5	0.7	4.0	31.3	0.1	3.1	1.1	2.2	8.6	293.6	2.9	65.0	8.0	64.9	3.2	5.5	36.7	37.3	29.9	22.3	43.5	29.0	45.0	32.4	28.0	34.6	27.6	+	+	+	+	+
Swash	68.7		46.2	4.8	1.8	2.2	1.7	1.6	6.8	2.6	3.5	26.0	0.5	11.9	1.4	1.8	6.3	481.5	5.2	52.5	14.1	56.8	4.0	12.8	32.5	111.6	60.2	72.2	38.6	41.6	69.3	64.8	44.4	51.7	39.4	+	+	+	+	+
Dry Shoal	217.1	14.2	119.0	25.8	2.8	11.0	1.1	1.1	6.1	3.7	2.1	16.5	0.6	8.7	3.1	8.5	4.9	269.6	8.9	240.2	33.8	151.1	20.4	21.7	63.6	106.2	133.3	188.7	63.0	170.2	63.2	132.3	95.2	75.7	58.6	-	-	-	-	+
Rock Wharf		11.4	34.3	10.7	0.2	2.4	5.6	2.1	8.0	1.0	8.5	22.7	0.1	10.0	4.4	1.9	19.8	347.5	5.0	272.4	33.8	106.5	10.9	11.5	52.3	48.0	77.2	58.3	82.7	28.9	53.9	59.0	51.0	60.1	44.1	+	-	+	-	+
Wreck Shoal	35.3	3.3	15.5	2.2	2.6	10.0	0.7	0.7	3.1	0.9	3.2	8.3	1.3	21.6	3.1	4.1	4.1	584.3	7.1	64.1	17.5	66.4	3.3	12.3	30.4	149.3	87.7	223.2	61.3	130.5	167.9	130.4	78.2	74.2	52.5	+	+	+	+	+
Day's Point	145.6	14.2	131.5	42.2	3.0	4.6	5.6	0.4	7.3	4.3	1.6	10.5	0.1	3.6	1.6	1.9	30.8	249.2	3.0	335.0	25.6	182.9	11.1	13.3	93.1	28.1	139.3	38.6	53.5	30.5	14.9	58.0	61.6	62.7	50.6	-	-	-	-	-
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	8.9	63.2	56.4	62.1	33.6		+	+	+	+	
Ginney Point	25.4	11.4	1.7	0.0	0.5	1.3	0.0	2.2	6.4	6.8	1.2	5.9	0.2	0.2	0.3	3.9	7.1	18.3	4.5	63.7	32.0	232.0	29.3	70.5	70.4	64.1	27.9	35.8	24.3	25.9	134.4	35.6	61.2	35.9	25.8	+	+	+	+	+
Palace Bar	38.9	24.9	5.0	0.8	1.0	1.6	0.0	5.5	10.1	3.9	0.2	3.1	0.1	0.5	0.2	2.1	4.6	7.5	5.9	30.3	14.1	155.7	16.6	24.8	56.7	142.0	18.6	14.5	14.4	9.3	101.4	39.8	46.7	26.1	19.8	+	+	+	+	+
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	27.1	315.7	207.1	174.5	91.0		+	+	+	+	
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	8.8	145.8	54.2	52.7	29.3		+	+	+	+	
Cape Toon								4.5	12.3	1.2	1.8	9.1	0.1	2.0	2.6	8.2	23.5	23.4	9.9	193.2	33.1	191.2	62.9	271.0	167.5	104.3	112.0	75.9	88.4	11.2	410.2	78.4	111.8	69.6		+	+	+	+	
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	14.1	704.3	92.1	98.5	54.5		+	+	+	+	
Burton Point	16.4	11.7	6.5	0.1	1.0	1.0	0.7	1.3	14.9	2.7	0.8	4.9	0.2	1.9	0.9	2.9	10.6	7.1	3.0	19.0	17.5	172.0	21.3	58.4	379.5	474.5	43.7	34.6	54.2	19.8	323.0	125.4	127.6	66.3	47.1	+	+	+	+	+
GREAT WICOMICO																																								
Glebe Point	1.9	0.5	0.2	0.0	1.5	0.6	21.2	0.6	2.4	4.2	1.1	283.3	4.9	1.6	2.0	150.3	132.9	140.6	405.6	39.5	134.0	2122.5	49.4	251.4	234.8	1117.3	487.9	10.0	169.2	626.7	13.0	482.2	520.3	318.2	220.6	-	-	-	-	-
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	1177.7	61.4	427.5	393.2	223.1		-	-	-	-	
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	918.5	59.0	369.8	359.9	202.3		-	-	-	-	
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	884.9	87.3	412.8	369.9	220.1		-	-	-	-	
Hudnall	4.5	0.5	0.8	0.0	0.1	0.2	39.1	0.5	0.9	1.0	1.4	12.7	3.1	0.6	0.9	37.4	51.7	83.0	44.3	32.5	44.5	287.0	37.8	150.5	136.4	601.9	200.7	9.7	186.1	966.7	56.9	393.0	262.1	144.4	101.1	-	-	-	-	-
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	542.1	194.0	436.3	347.8	185.1		-	-	-	+	
Haynie Point	12.4	0.6	1.4	0.0	1.0	3.7	4.4	0.7	1.1	1.1	0.9	15.4	1.6	0.3	0.8	17.1	24.8	43.1	8.6	17.8	22.7	213.5	16.1	220.4	261.9	575.7	106.9	8.8	273.6	428.0	142.7	278.6	212.8	112.9	78.3	-	-	-	+	+
Whaley's East	7.9	0.1	0.2	0.0	0.3	2.1	1.0	0.4	1.8	0.2	0.7	2.4	0.9	0.1	0.4	6.0	21.6	1.9	2.3	16.4	5.5	144.7	4.1	83.0	82.5	747.8	101.1	7.5	165.3	280.7	125.2	260.5	162.2	83.7	58.0	-	-	-	+	+
Fleet Point	5.8	2.9	2.0	0.0	0.3	2.6	3.4	0.3	0.5	0.6	1.0	3.9	0.4	0.3	0.4	4.9	8.6	8.4	1.3	10.2	6.5	79.3	8.4	77.5	36.8	595.7	224.1	21.9	239.1	23.9	43.5	220.9	131.3	67.6	47.1	+	-	-	-	-

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 2021 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.

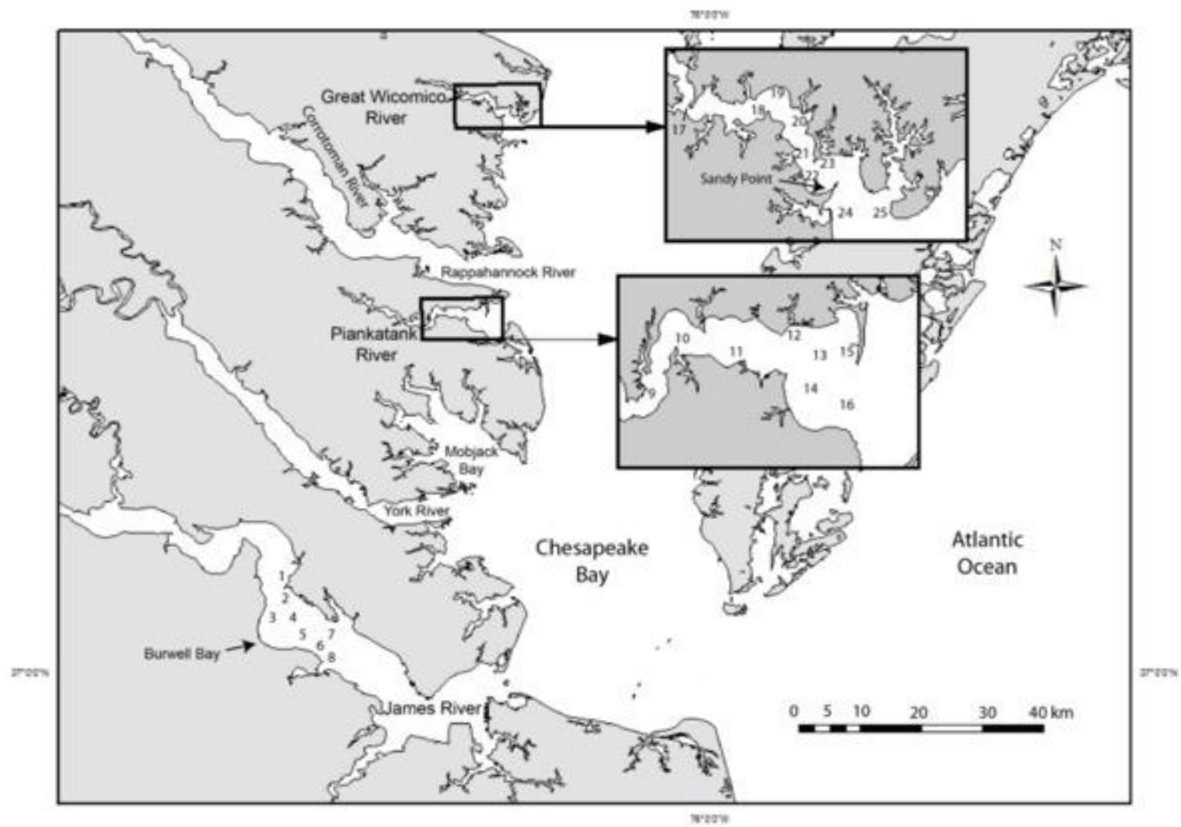


Figure S2: Diagram of the shellstring setup on buoys with pictures laying out each step (see https://www.vims.edu/research/units/labgroups/molluscan_ecology/_docs/Shellstring_manual.pdf for a detailed description of the shellstring survey methods).

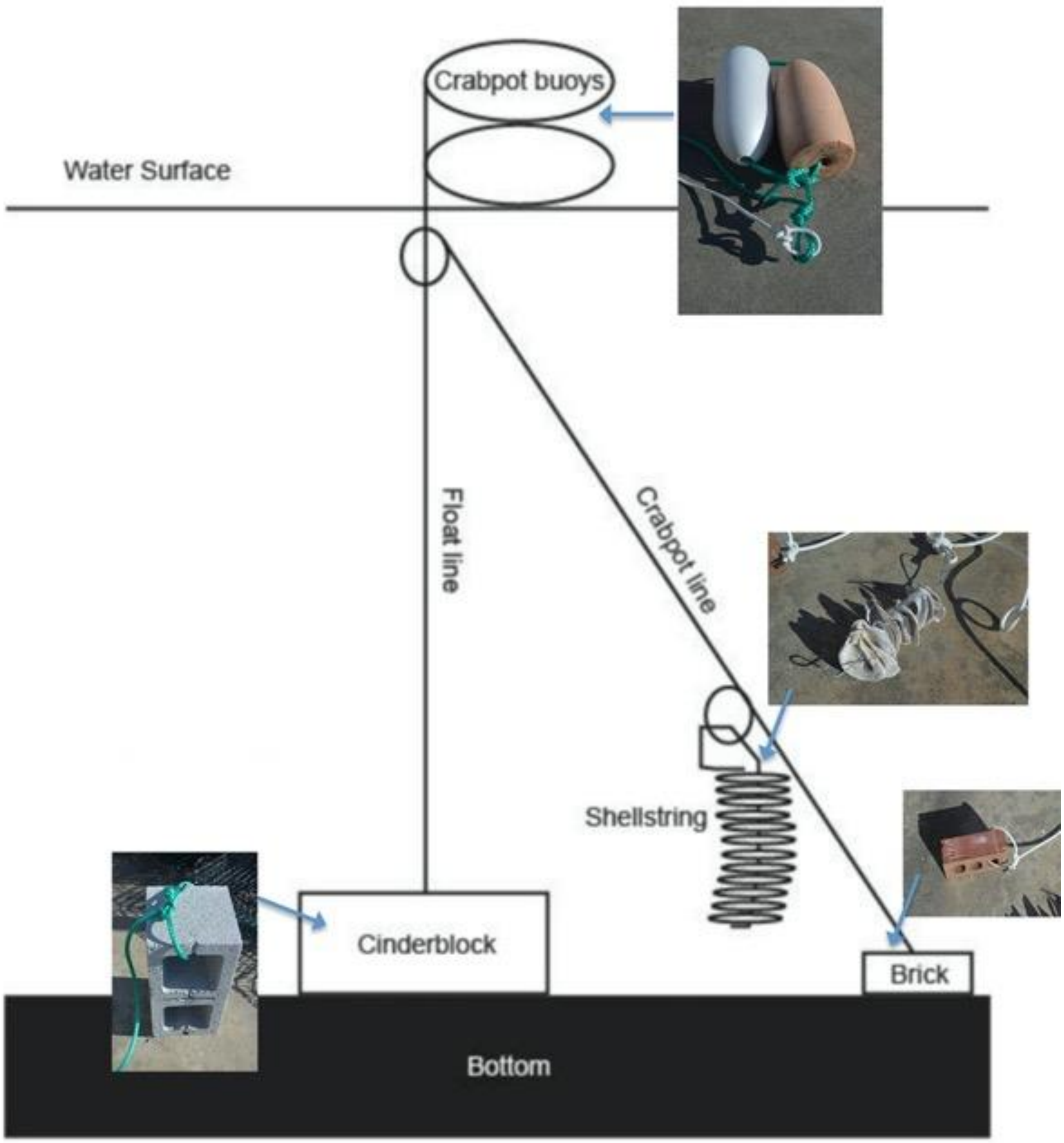


FIGURE S3: JAMES RIVER (2021) WEEKLY SPATFALL INTENSITY
EXPRESSED AS NUMBER OF SPAT SHELL^{-1}
(H = historical station: M = modern station as described in text)

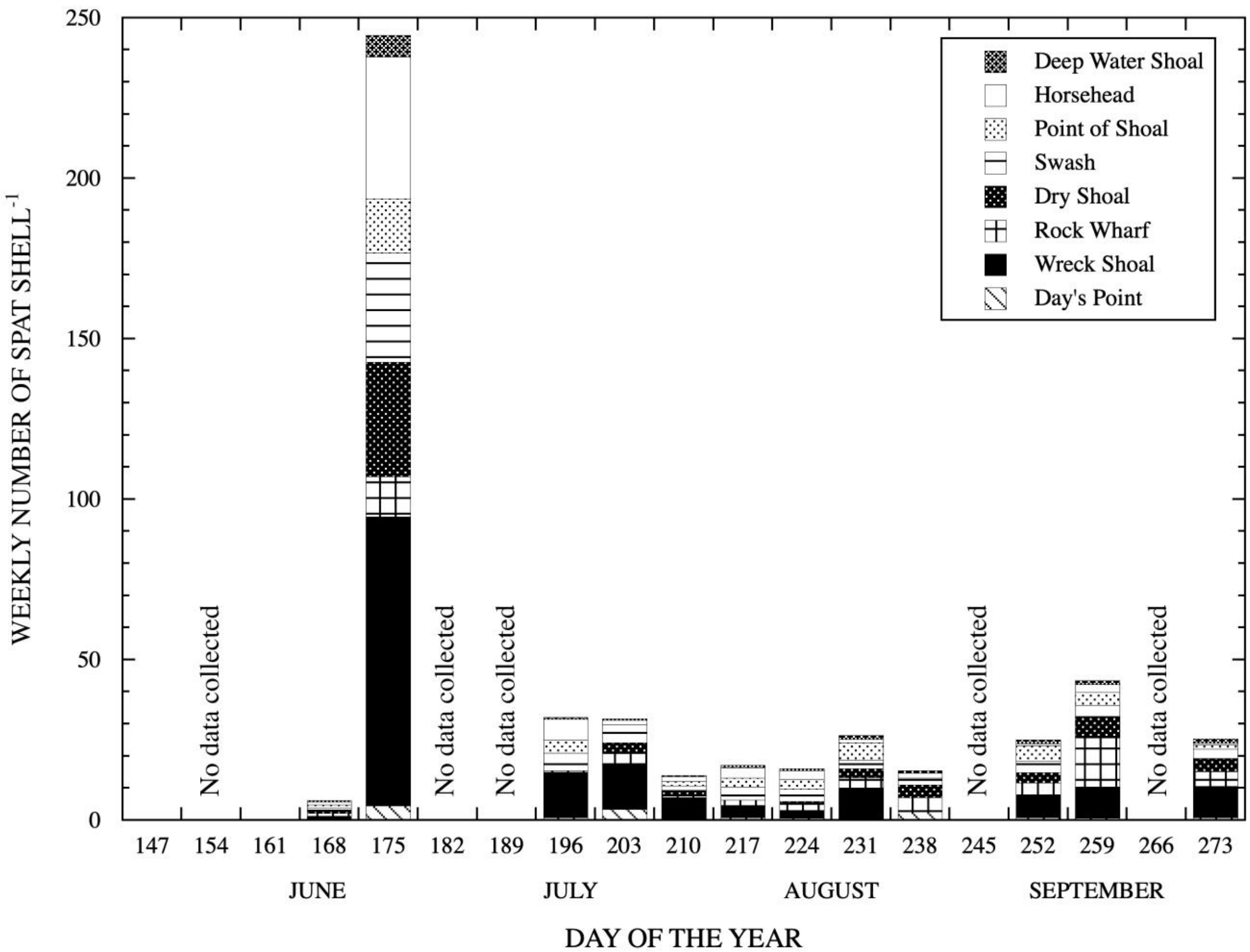


FIGURE S4: SPATFALL TRENDS FROM 1991 TO 2021 AT ALL EIGHT SITES IN THE JAMES RIVER (upriver sites in panel A; downriver sites in panel B) (expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

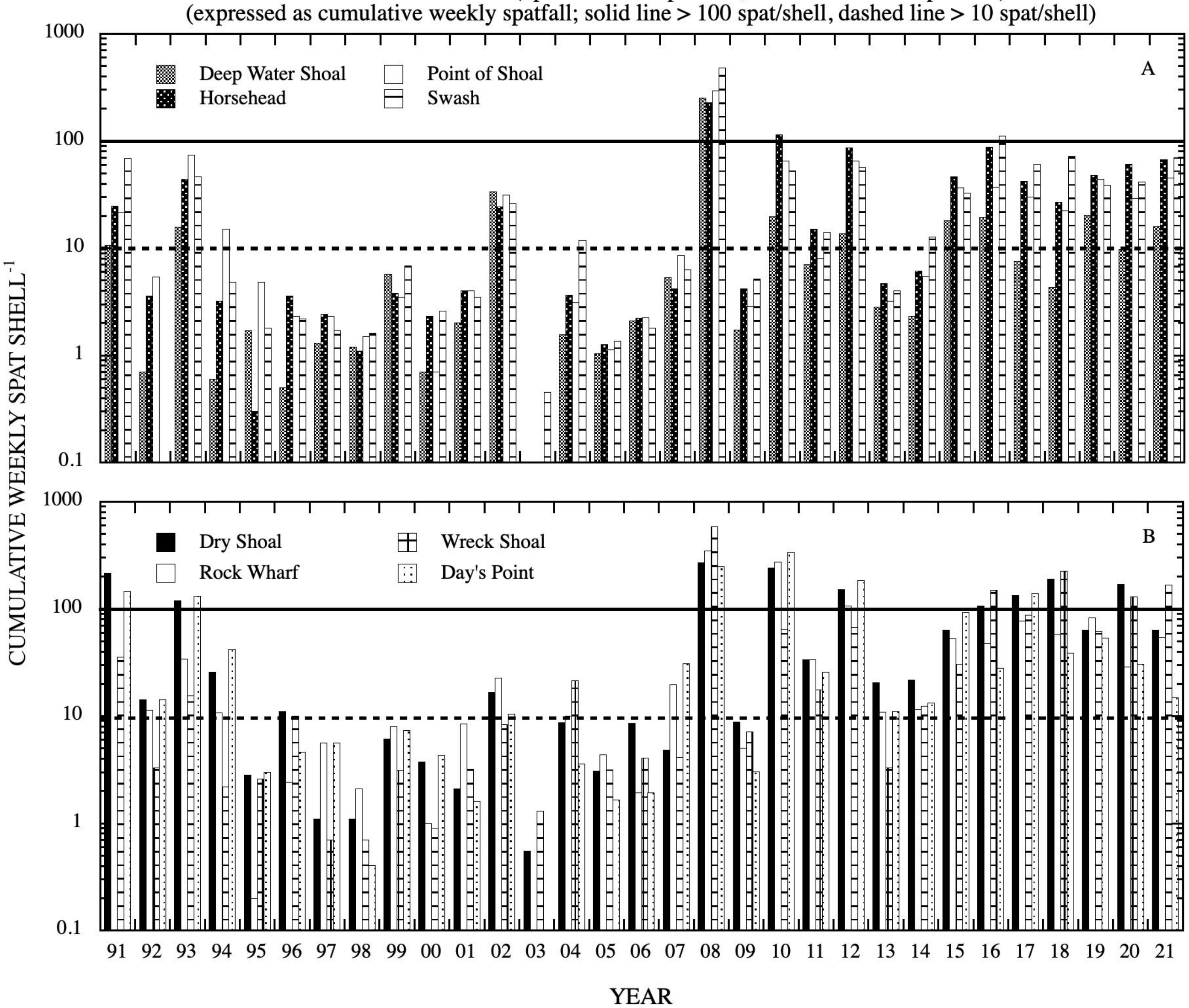


FIGURE S5: TEMPERATURE AND SALINITY IN THE JAMES RIVER DURING THE MONITORING PERIOD: 5, 10, 20 AND 30-YEAR MEANS COMPARED WITH 2021
(Error bars represent standard error of the mean; shaded area is the period of highest spatfall; > 95% in the river for the year)

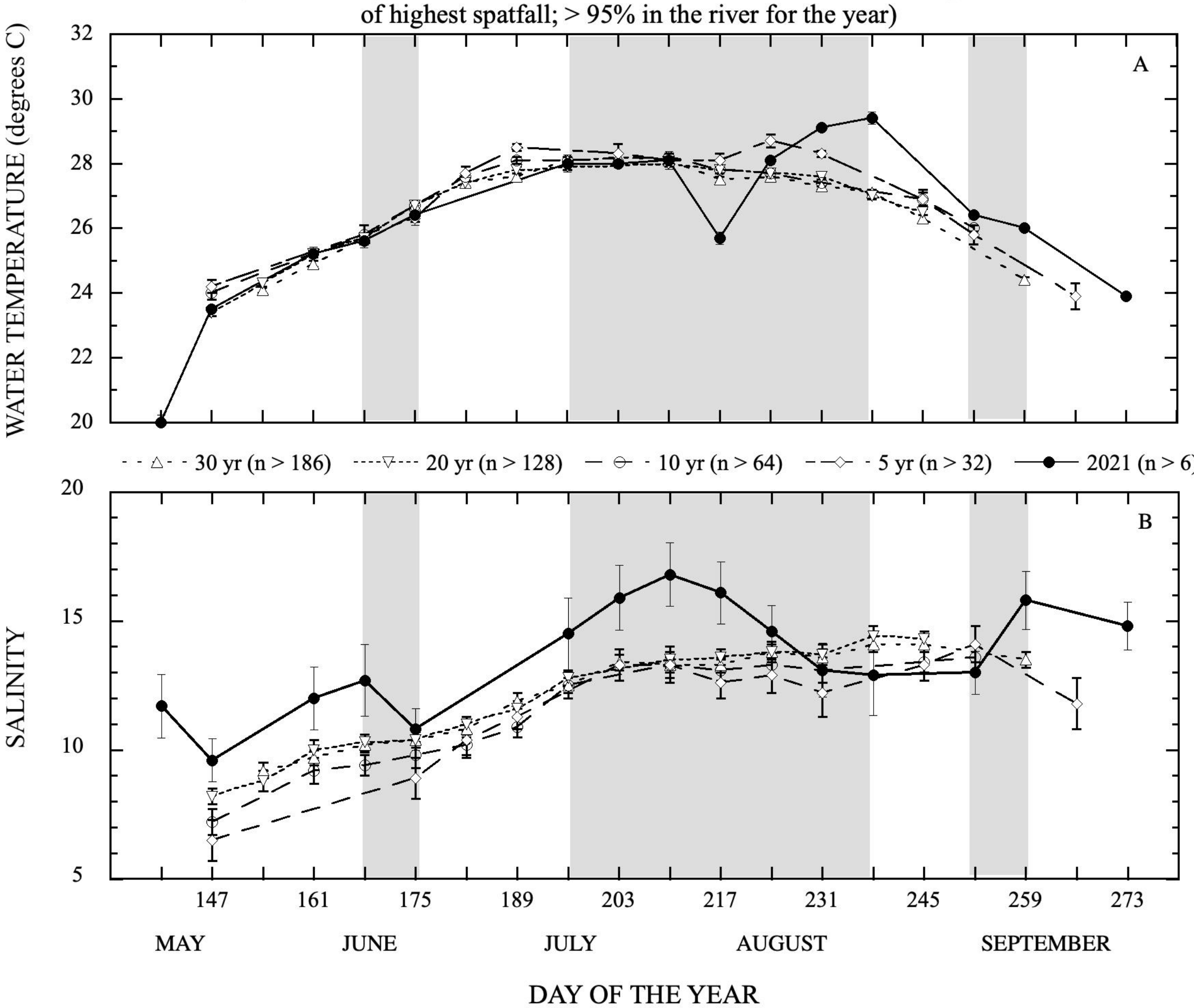


FIGURE S6: PIANKATANK RIVER (2021) WEEKLY SPATFALL INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL^{-1}: A is DOY 147 to 196, B is DOY 203 to 273 (H = historical station: M = modern station as described in text; note magnitude difference of y-axis in A & B)

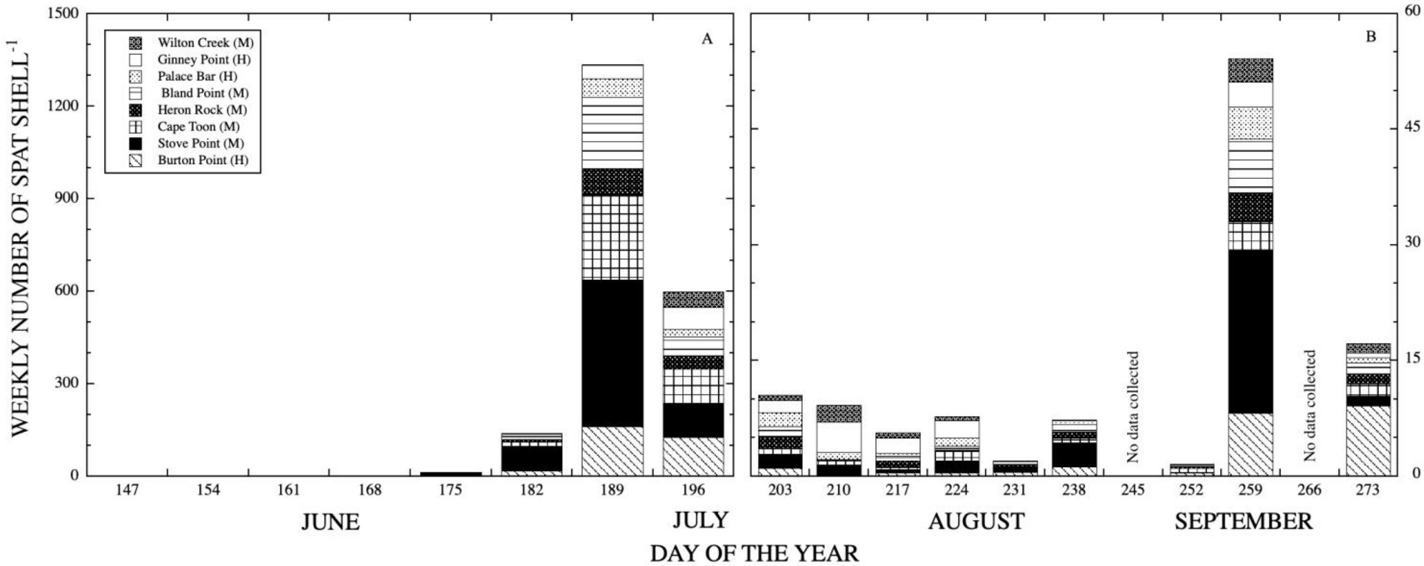


FIGURE S7: SPATFALL TRENDS IN THE PIANKATANK RIVER AT THE THREE HISTORICAL SITES (panel A: 1991 to 2021) AND THE FIVE MODERN SITES (panel B: 1998 to 2021)
(expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

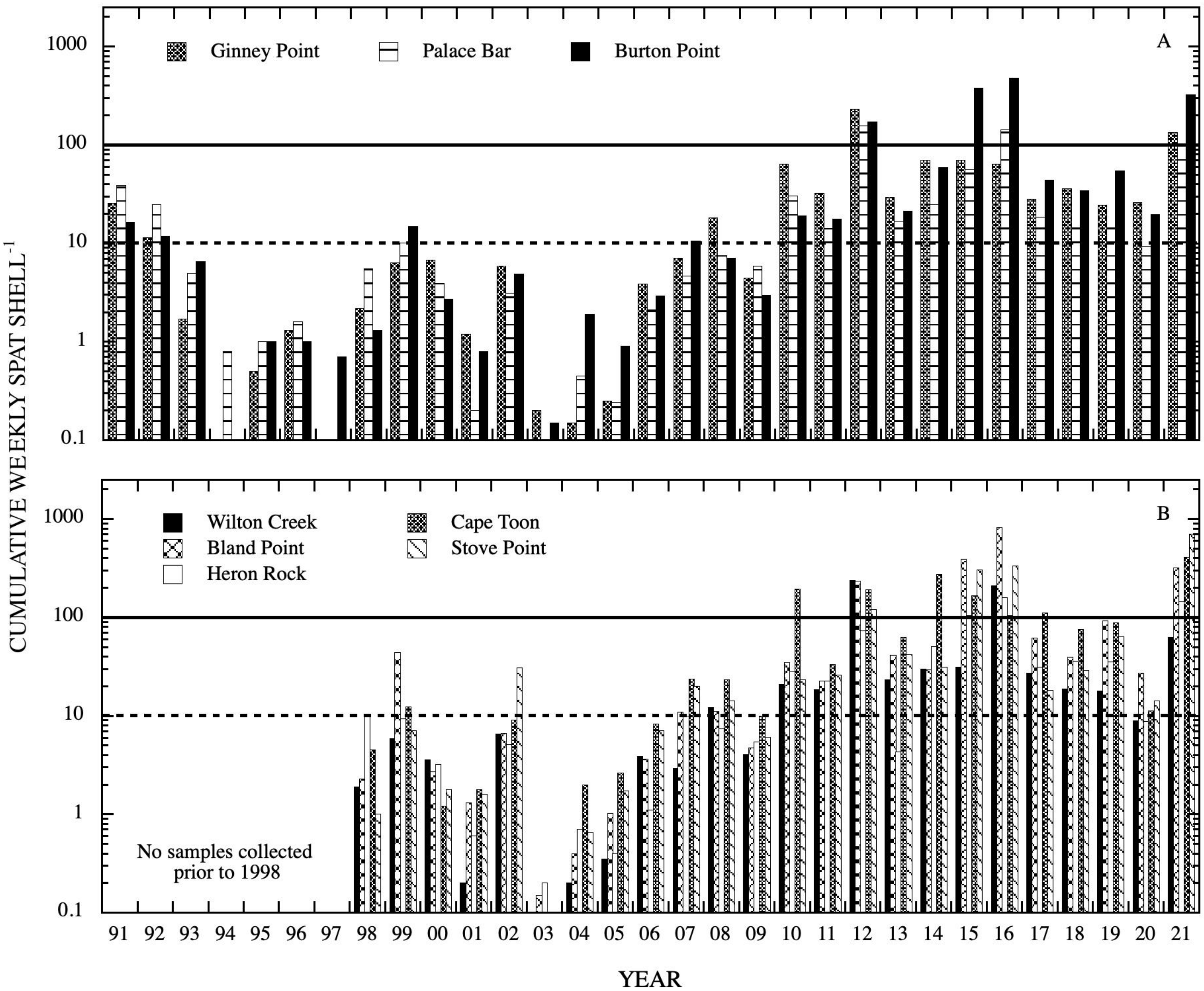


FIGURE S8: TEMPERATURE AND SALINITY IN THE PIANKATANK RIVER DURING THE MONITORING PERIOD: 5, 10, 20 AND 30-YEAR MEANS COMPARED WITH 2021
(Error bars represent standard error of the mean; shaded area is the period of highest spatfall: > 96% in the river for the year)

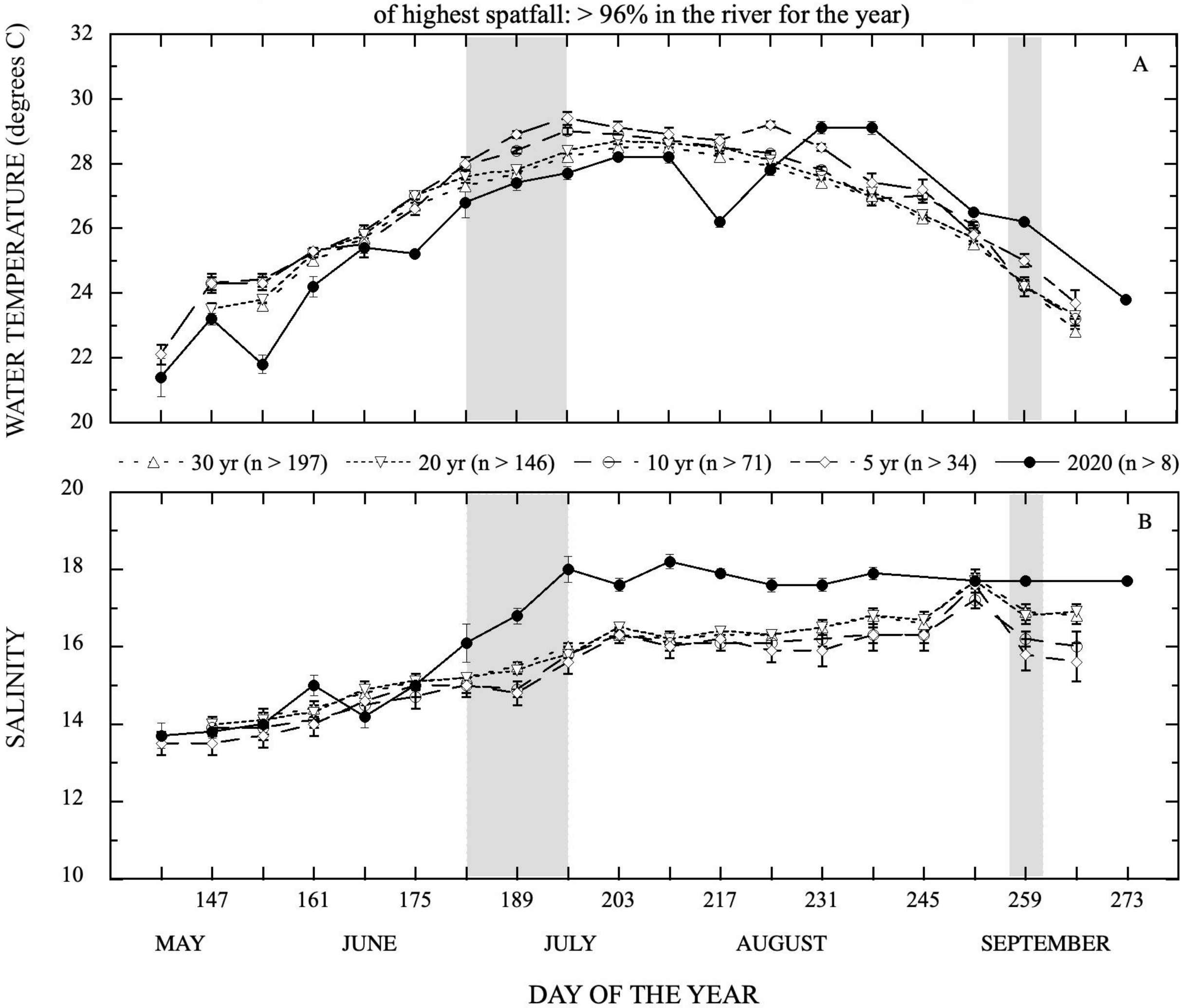


FIGURE S9: GREAT WICOMICO RIVER (2021) WEEKLY SPATFALL INTENSITY EXPRESSED AS NUMBER OF SPAT SHELL^{-1}
(H = historical station: M = modern station as described in text)

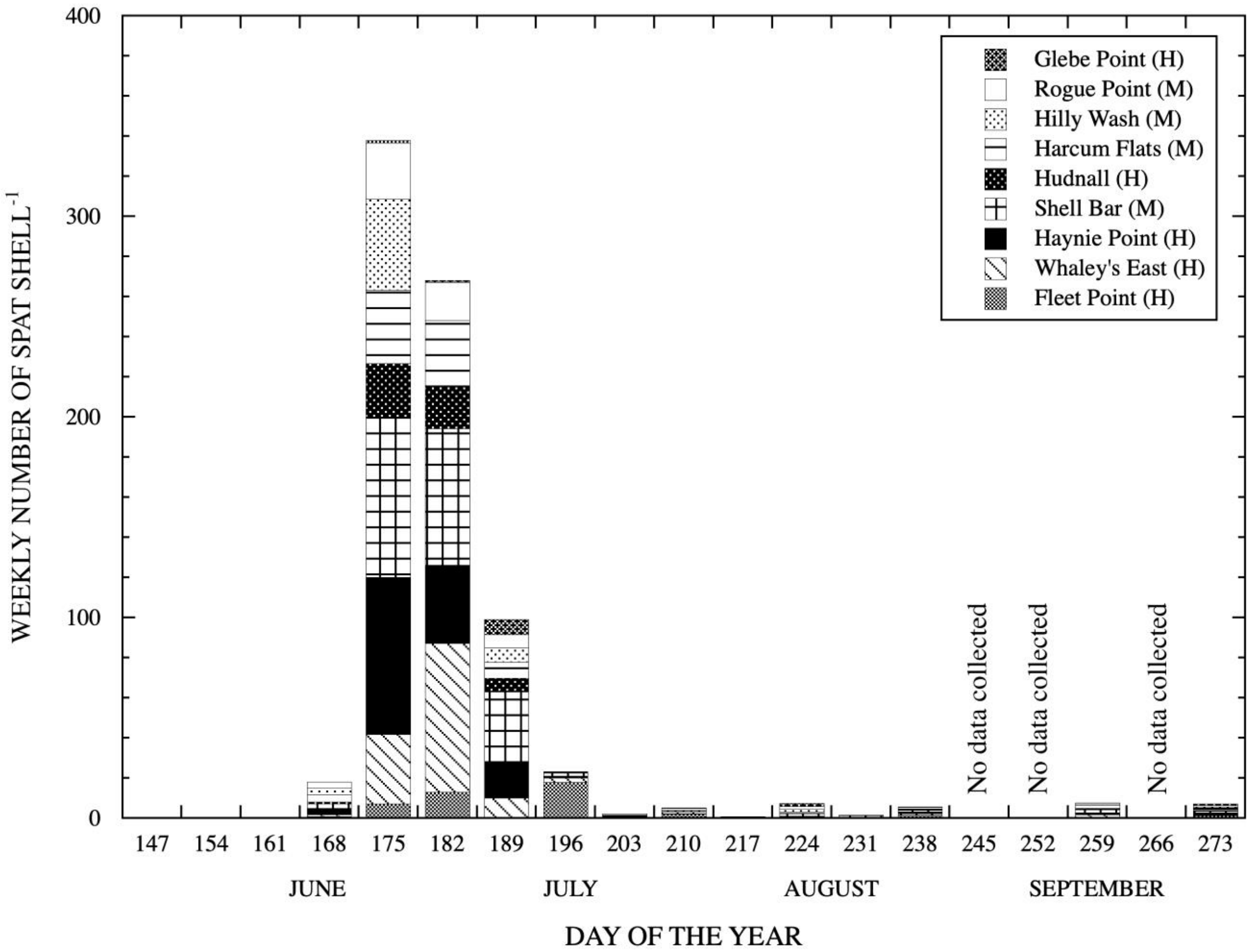


FIGURE S10: SPATFALL TRENDS IN THE GREAT WICOMICO RIVER AT THE FIVE HISTORICAL SITES (panel A: 1991 to 2021) AND THE FOUR MODERN SITES (panel B: 1998 to 2021)
(expressed as cumulative weekly spatfall; solid line > 100 spat/shell, dashed line > 10 spat/shell)

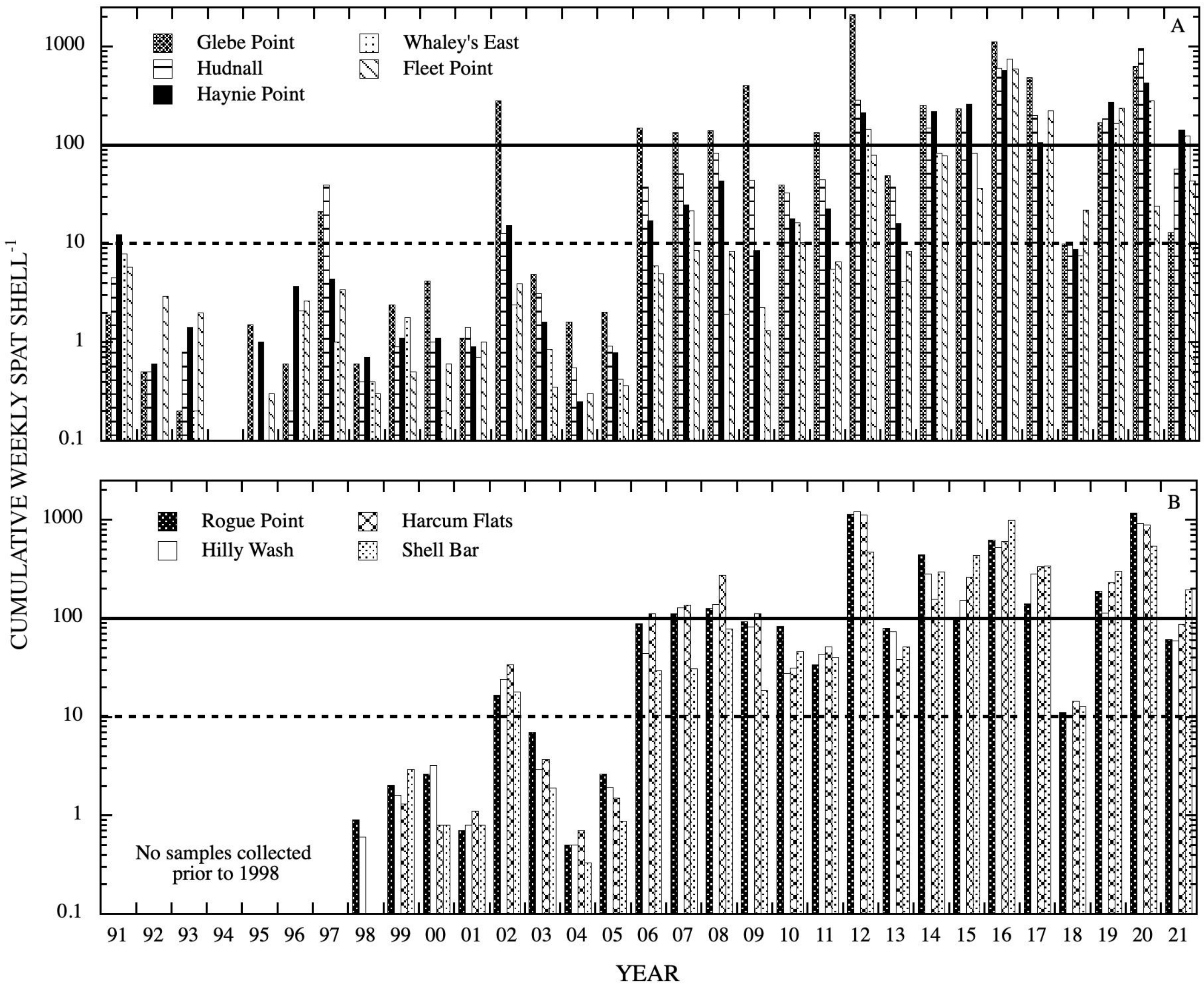
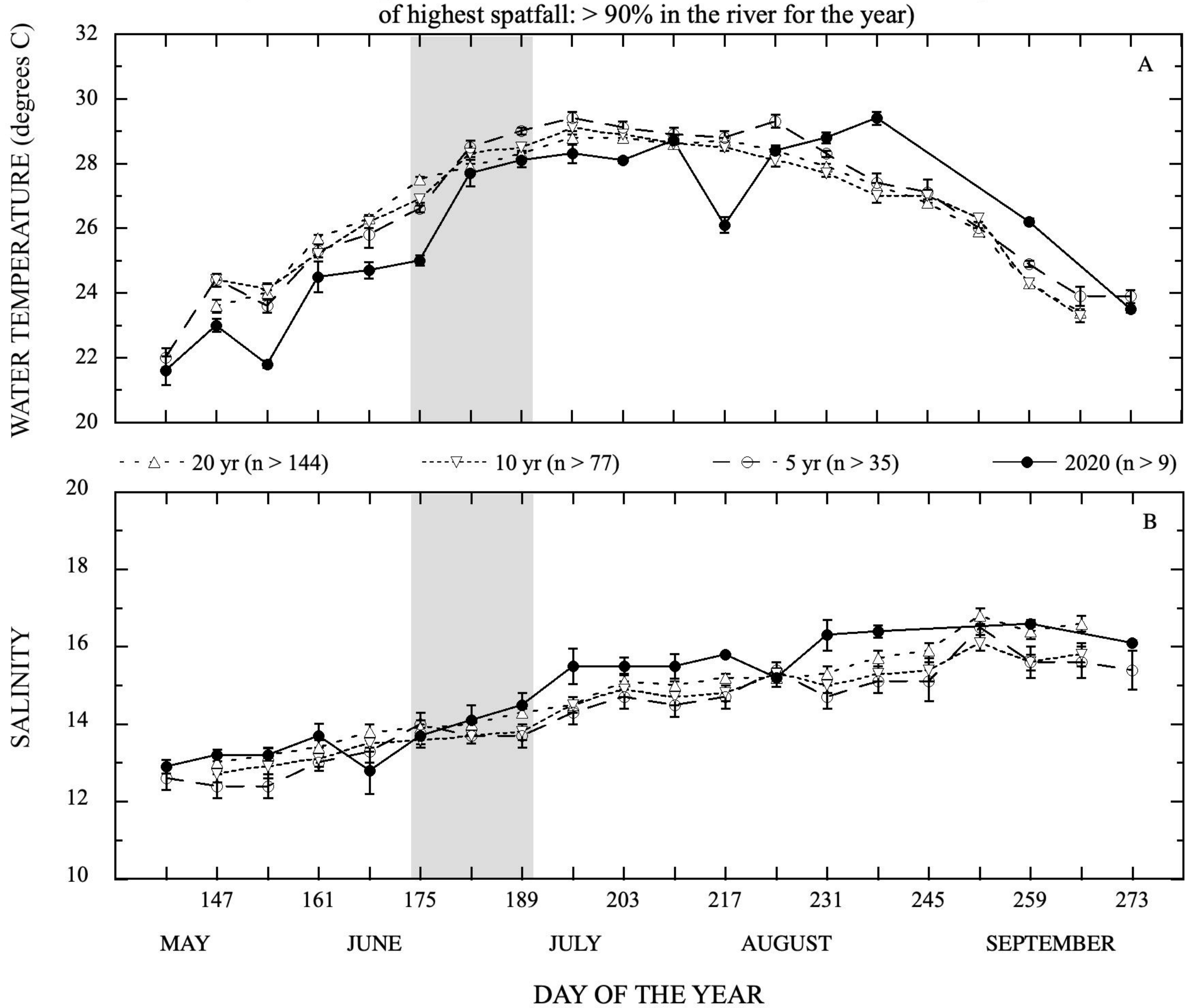


FIGURE S11: TEMPERATURE AND SALINITY IN THE GREAT WICOMICO RIVER DURING THE MONITORING PERIOD: 5, 10 AND 20-YEAR MEANS COMPARED WITH 2021
(Error bars represent standard error of the mean; shaded area was the period of highest spatfall: > 90% in the river for the year)



Part II. DREDGE SURVEY OF SELECTED OYSTER BARS IN VIRGINIA DURING 2021

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 September and October 2021.

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 2021 are shown in Figure D1. Geographic coordinates of the bars are given in Table D1. It should be noted that similar to 2020, the 2021 dredge survey was conducted approximately 2 to 3 weeks earlier (mid to late September versus early to mid-October) than it usually is to account for the restrictions placed on personnel due to the COVID 19 pandemic.

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 2021) and in the Great Wicomico River in 2015, samples were collected 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). In the 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 deviation did occur such that fewer samples were collected. Due to the large number of oysters observed in the 2021 samples in the James River, the number of samples was reduced (n = 3) at all of the sites to facilitate sample processing in a timelier manner. The number of samples was also reduced at both Mobjack Bay sites, both York River sites, and at Ross Rock and Broad Creek in the Rappahannock River (n = 3 at all of these sites).

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 2021 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 (ppt) 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 September 20 and October 4, in six of the major Virginia tributaries on the western shore of the Chesapeake Bay. Bar locations and geographic coordinates are shown in Figure D1 and Table D1, respectively. 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 566.6 bushel^{-1} at Nansemond Ridge to a high of 2,350.0 bushel^{-1} at Swash (Figure D2). The total number of live oysters was the third highest observed over the past thirty years of monitoring at Swash, the fourth highest at Nansemond Ridge and the sixth highest at Wreck Shoal, Long Shoal, and Thomas Rock (Figures D2B and D2C). When spat are excluded, the total number of small and market oysters combined was the second highest (Swash and Nansemond Ridge), third highest (Thomas Rock) and fourth highest (Dry Shoal) observed over the past thirty years. It should be noted that this trend at Swash and Dry Shoal is primarily being driven by small oysters. The number of oysters at Nansemond Ridge had been at fairly low levels for several years, but has generally been increasing in more recent years, such that 2021 had the second highest number of small oysters observed over the past thirty years and the highest number of market oysters (Figure D2C).

The average number of market oysters in the James River remains low when compared with historical numbers. The number of market oysters in 2021 ranged from a low of 0.7 bushel^{-1} at Swash to a high of 104.7 bushel^{-1} at Thomas Rock. When compared with 2020 numbers, there was a small, but notable increase in the number of market oysters at Deep Water Shoal and Mulberry Point and a notable decease at Long Shoal and Dry Shoal (Figure D3). 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, down in 2019 and up in 2020. 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 D2C). From 2017 to 2020, market oysters at Wreck Shoal again steadily increased, but then showed a notable decrease in 2021 (42.7 bushel^{-1} in 2017, up to 63.3 bushel^{-1} by 2020, then decreased to 40 bushel^{-1} in 2021; Figure D2C). The number of market oysters on Thomas Rock remained relatively stable from 2016 to 2020, ranging between 51 and 66 bushel^{-1} (Figure D2C), but then showed a notable increase to 104.7 bushel^{-1} in 2021. For the fifth year in a row, the number of market oysters at Swash was among the lowest observed (second lowest) since monitoring began at that site in the early 1990s (Figure D2B). The number of market oysters at Long Shoal was the lowest observed over the past 30 years of monitoring. The number of market oysters on

Deep Water Shoal, was up for the first time since the 2018 low salinity mortality event occurred on that reef.

The average number of small oysters bushel^{-1} ranged from a low of 174.0 at Nansemond Ridge to a high of 1,671.3 at Swash. When compared with 2020, there was a notable increase in the number of small oysters at Nansemond Ridge and a notable decrease at Deep Water Shoal, Mulberry Point, Point of Shoal, and Wreck Shoal (Figures D2A, D2C, and D3). With these increases, 2021 had the second highest number of small oysters over the past thirty years at both Swash and Nansemond Ridge. The number of small oysters in 2021 was the third highest at Thomas Rock and Dry Shoal. While the number of small oysters observed at Nansemond Ridge was the lowest of the ten sites monitored, the number of small oysters at that site have generally been increasing since about 2016 (Figure D2C).

Overall, recruitment in the James River in 2021 was moderate, and generally lower than that observed in more recent years (Figure D2), falling in the 73rd percentile over the past thirty years (behind 2015 through 2019). However, there was a notable increase observed when compared to 2020 at the four most upriver sites as well as at Nansemond Ridge (Figures D2A, D2C, and D3). The average number of spat bushel^{-1} ranged from a low of 187.3 at Nansemond Ridge to a high of 678.0 at Swash. Since 2008, recruitment in the James River has had several strong year classes; 2010, 2012, 2015, 2016, 2018 and 2019. This is in contrast to what was observed on the shellstrings (Part I of this report), where 2015 and 2019 were moderate years, but 2017, 2020 and 2021 were good years.

The average number of boxes bushel^{-1} was low to moderate, ranging from 34.7 at Point of Shoal to 98.0 at Swash, and was generally higher at the mid-river sites. Boxes accounted for less than 5% of the total (live oysters plus boxes) at the six most upriver sites, with the majority of those being old boxes. At the four most downriver sites, boxes accounted for 6.8 (Nansemond Ridge) to 10.6% (Thomas Rock) of the total (live oysters plus boxes). At Thomas Rock and Nansemond Ridge, 21 to 22% of the boxes were new boxes, indicating some recent mortality at those sites. Approximately 27% of the boxes at Point of Shoal were spat boxes.

Water temperature during the two days of sampling ranged between 22.6 and 23.8°C (Table D2). This was slightly warmer than what the temperature normally is during the survey, which may be due to the survey occurring one to two weeks earlier than normal. Salinity generally increased in a downriver direction (see Figure D1), from a low of 9.8 ppt at Deep Water Shoal to a high of 19.4 ppt at Thomas Rock and 17.5 ppt at Nansemond Ridge.

York River

In the York River, the average total number of live oysters bushel^{-1} was 168.7 at Bell Rock and 328.7 at Aberdeen Rock. When compared with 2020, there was a notable decrease in the number of oysters in all size categories at Bell Rock and a decrease in market oysters and spat at Aberdeen Rock (Figures D4 and D5). The number of market oysters at Aberdeen Rock steadily increased between 2014 and 2020, but there was a notable decrease observed in 2021 (Figure D5). While this was a relatively large decrease, the number of market oysters at Aberdeen Rock remains relatively high, with 2021 having the third highest number of market oysters observed over the past thirty years of monitoring. Recruitment in 2021 was light at both sites in the York River. The average number of boxes bushel^{-1} was moderate at both sites, accounting for 16 and 11% of the total (live oysters plus boxes) at Bell Rock and Aberdeen Rock, respectively. This marked the second year in a row where the number of boxes observed at Bell Rock was moderate to high. Approximately 21% of the boxes at Aberdeen Rock were new, indicating some recent mortality at that site. Water temperature on the day of sampling was around 24.5°C at both sites. Salinity was 13.4 ppt at Bell Rock and 18.6 ppt at Aberdeen Rock.

Mobjack Bay

The average total number of live oysters at Tow Stake and Pultz Bar were 442.0 and 501.3 oysters bushel^{-1}, respectively. When compared with 2020, there was a notable increase in the number of market oysters and a notable decrease in small oysters and spat at Tow Stake (Figure D4). There was also a notable decrease in the number of small oysters at Pultz Bar. It should be noted that both bars had seed removed by VMRC in the spring of 2021 (VMRC, unpublished data). Even with this removal, 2021 had the fifth highest number of market oysters observed over the past thirty years at Pultz Bar and the second highest at Tow Stake. The number of small and market oysters combined was the third highest at Pultz Bar and the second highest at Tow Stake. The total number of boxes observed in the system was low, accounting for 4 and 7% of the total (live oysters plus boxes) at Tow Stake and Pultz Bar, respectively. Approximately 27% of the boxes at Pultz Bar were new, indicating some recent mortality at that site on the day of sampling, water temperature was around 24.5°C at Tow Stake and 24°C at Pultz Bar. Salinity was around 20 ppt at both sites. There were no drill boxes observed at either site.

Piankatank River

In the Piankatank River, the average total number of live oysters bushel^{-1} ranged from a low of 503.5 at Burton Point to a high of 643.5 at Palace Bar. When compared with 2020, there was a notable increase in the number of market oysters at Ginney Point and Palace Bar and a decrease at Burton Point (Figures D7 and D8). Overall, the number of market oysters in the river was low from 1993 through 2007, but generally increased between 2008 and 2014. Since 2014, there have generally been more market oysters in the Piankatank River but numbers from one year to the next have been more variable. The same is true for small oysters. The average number of market oysters from 1991 to 2007 across all three sites was 4.6 bushel^{-1}, whereas from 2008 to 2021 the average was 50.0 bushel^{-1}, with 2021 being the third highest over the past thirty years. For small and market oysters combined the average from 1991 to 2007 was 98.5 bushel^{-1}, whereas from 2008 to 2021, the average was 328.1 bushel^{-1}, with 2021 again being the third highest over the past thirty years of monitoring. Recruitment in 2021 was relatively low to moderate at all three sites, with the overall average across the three sites ranking in the 53rd percentile over the past thirty years. The recruitment numbers observed in the dredge survey were not consistent with what was observed in the shellstring survey (Part I of this report). The number of boxes observed was low at Palace Bar and Burton Point (2 and 3% of the total live plus boxes, respectively). Boxes at Ginney Point were more abundant, accounting for around 19% of the total (live oyster plus boxes). The majority

(>84%) of boxes at all three sites were old. On the day of sampling, water temperature was around 26ºC at all three sites and salinity was between 17.4 (Ginney Point) and 18.1 ppt (Burton Point). There were no drill boxes observed at any of the sites.

Rappahannock River

In the Rappahannock River, the average total number of live oysters bushel^{-1} ranged from a low of 198.0 at Ross Rock (which experienced 100% mortality during the summer of 2018 due to a freshet) to a high of 529.5 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 2021. 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. 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. The total number of oysters on Middle Ground in 2021 was at the second highest observed over the past thirty years of monitoring.

The average number of market oysters bushel^{-1} ranged from a low of 0.0 at Ross Rock to a high of 132.0 at Drumming Ground. When compared with 2021, there was a notable increase in the number of market oysters at Long Rock, Morattico Bar and Drumming Ground (Figures D9, D10A and D10C). It should be noted that Hog House, Morattico Bar, and Smokey Point each received seed plants at least twice between the springs of 2019 and 2021. The numbers of market oysters in 2021 were the highest observed over the past thirty years at Morattico Bar, Smokey Point, Drumming Ground and Broad Creek, the second highest at Middle Ground and the third highest at Long Rock (Figure D10). Overall, the number of market oysters in the Rappahannock River has been higher since about 2008 (Figure D10). From 1991 to 2007, the average over all ten sites in any given year was less than 20 market oysters bushel^{-1}, whereas from 2008 to 2021 the average over all ten sites ranged between 22 (2008) and 72 (2021) market oysters bushel^{-1} (Figure D10).

The number of small oysters bushel^{-1} ranged from a low of 2.7 at Ross Rock to a high of 365.0 at Drumming Ground (Figures D9 and D10). When compared with 2020, there was a notable increase in the number of small oysters at Hog House and Parrot Rock and a decrease at Morattico Bar, Middle Ground and Broad Creek (Figures D9 and D10). Again, it should be noted that Morattico Bar, Smokey Point and Hog House each received seed plants at various times over the past three years. At every site except Ross Rock, the number of small oysters observed in 2021 ranked among the highest to fourth highest observed over the past thirty years.

Overall, recruitment in the Rappahannock River in 2021 was higher than what is typical for the river, ranging from 13.5 spat bushel^{-1} at Morattico Bar to 195.3 spat bushel^{-1} at Ross Rock. In recent years, recruitment has become more common at the more upriver sites (Figures D9 and

D10) with at least one spat at each of the sites in the river in most recent years, but the largest recruitment typically occurred at the more downriver sites. Recruitment in 2021 however, was highest at the most upriver sites. Recruitment at Ross Rock and Bowler's Rock were 20 and 15 times higher, respectively, than the next highest observed at those sites over the past thirty years. Looking back even further, the highest single spat count at Bowler's Rock since that site was first samples in 1947 was 64 spat bushel^{-1} (1987), with an average over the 3 samples taken that year of 34.7 spat bushel^{-1} (2021 recruitment at Bowler's Rock was an average of 134.0 spat bushel^{-1}). The highest recruitment recorded at Ross Rock since monitoring began at that site in 1969 was an average of 9.0 bushel^{-1} (2021 recruitment at Ross Rock was 195.3 spat bushel^{-1}). In general, since 2010, higher recruitment has become more common in the Rappahannock River. In the nineteen-year period from 1991 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 twelve-year period from 2010 to 2021 there were six years (2010, 2012, 2015, 2017, 2019 and 2021) with an overall average recruitment greater than 50 spat bushel^{-1}, with higher recruitment occurring approximately every two to three years.

The average total number of boxes bushel^{-1} was low to moderate, accounting for 1 (Bowler's Rock) to 11% (Middle Ground) of the total (live oysters plus dead). Greater than 17% of the total boxes at Middle Ground, Drumming Ground and Broad Creek were new boxes, indicating some recent mortality at those sites. There were no drill boxes observed at any of the sites.

Water temperature on the day of sampling ranged from 23.3 to 24.5°C. Salinity generally increased as one moved from the most upriver site (Ross Rock: 6.7 ppt) toward the mouth (Broad Creek: 17.6 ppt).

Great Wicomico River

In the Great Wicomico River, the average total number of live oysters bushel^{-1} ranged from a low of 552.5 at Fleet Point to a high of 908.5 at Haynie Point. When compared with 2020, there were small but notable increases in the number of market oysters at Fleet Point and in the number of small oysters at all three sites (Figure D11 and D12). It should be noted that in the spring of 2020, both Whaley's East and Fleet Point received a seed plant from a reef located further upriver. When compared with 2020, there was a notable decrease in the number of spat at Haynie Point and Whaley's East (Figure D11 and D12). The number of both small and market oysters at all three sites was either the second highest or highest observed over the past thirty years of monitoring. Recruitment in the Great Wicomico River in 2021 was moderate with an average over the three sites ranking in the 68th percentile of recruitment over the past thirty years. The total number of boxes bushel^{-1} was low at all three sites, accounting for less than 3% of the total (live oysters plus boxes). Between 17 (Whaley's East) and 33% (Haynie Point) of the boxes were new, indicating some recent morality at all three sites in the river. Water temperature on the day of sampling was between 25 and 26°C and salinity was around 15.5 ppt 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's public oyster grounds has been found at the upper limits of oyster distribution (lower salinity areas) in the James and Rappahannock Rivers, with the exclusion of Broad Creek in the mouth of the Rappahannock River. Presently, the abundance of market oysters in the Virginia tributaries of the Chesapeake remains low (average of 60.4 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. Overall, the number of market oysters on the thirty bars slowly declined between 2015 and 2019, with 33.6 market oysters bushel^{-1} observed in 2019. For the second year in a row, the overall number of markets on the thirty bars monitored annually saw an increase.

For the past several decades, the bulk of Virginia's oyster population has been composed primarily of small oysters and spat. During 2021, the overall oyster population was composed of 28% spat, 64% small oysters and 8% market oysters. At twenty-six out of the thirty sites monitored, small oysters accounted for greater than 50% of the live oysters present, with spat dominating at three out of the thirty sites (Nansemond Ridge in the James River and Ross Rock and Bowler's Rock in the Rappahannock River). 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 in the Piankatank River consistently remained above 300 bushel^{-1} from 2013 to 2017. Levels dipped below 300 bushel^{-1} in 2018 and 2019, but have been back up for the past two years.

Recruitment during 2021 varied considerably from one site and river to the next throughout the Virginia portion of the Bay. There were less than 50 spat bushel^{-1} at ten out of the thirty sites (both sites in the York River, Tow Stake in Mobjack Bay and all but Ross Rock, Bowler's Rock, Hog House and Broad Creek in the Rappahannock River). There were greater than 100 spat bushel^{-1} at fourteen out of the thirty sites, with greater than 500 spat bushel^{-1} at four sites in the James River. 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 2021, the highest recruitment was observed at the two most upriver sites and this recruitment event was larger than any observed in over seventy years of monitoring at Bowler's Rock and over fifty years of monitoring at Ross Rock (VIMS, unpublished data). Recruitment overall in the Rappahannock River in 2021 ranked in the 86th percentile over the past thirty years.

The average total number of boxes observed during 2021 was low to moderate, accounting for less than 15% of the total (live oysters plus boxes) oysters at every site except Bell Rock and Ginney Point and less than 10% of the total (live oysters plus boxes) at twenty-five 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 2021 Bell Rock (for the sixth year in a row) had a relatively large number of small and market size boxes (approximately 16% of the total, live small and market oysters plus new and old boxes, respectively). There was also a large number of small and market size boxes (11 to 20%) observed at Wreck Shoal, Thomas Rock, Nansemond Ridge, Aberdeen Rock, Ginney Point, Hog House and Middle Ground.

In general, drill holes have become more prevalent in spat boxes since the early 2000s. During 2021, there were no drill holes present in any of the spat boxes observed. 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) until Hurricane Agnes (1972) eradicated them from all but the lower reaches of the James River and mainstem Bay (Haven 1974). However, individuals of both of these species and their corresponding egg masses have become more common 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 2021 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 55.557	76 27.097
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 46.832	76 39.491
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 2021. 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 sub-estuary 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	10/4	23.7	9.8	30.0	730.7	666.7	1427.4	8.0	34.7	6.0	48.7
Mulberry Point	10/4	23.5	11.1	17.3	866.7	666.0	1550.0	3.3	26.7	5.3	35.3
Horsehead	10/4	23.4	11.8	33.3	1164.7	614.7	1812.7	7.3	42.0	3.3	52.6
Point of Shoal	10/4	23.4	11.8	82.7	808.0	401.3	1292.0	4.7	20.7	9.3	34.7
Swash	10/1	23.4	12.1	0.7	1671.3	678.0	2350.0	3.3	92.0	2.7	98.0
Long Shoal	10/1	23.7	15.1	2.0	1600.7	312.0	1914.7	8.7	48.7	2.7	60.1
Dry Shoal	10/1	23.8	18.3	11.3	786.7	186.0	984.0	10.7	72.7	2.0	85.4
Wreck Shoal	10/4	22.8	15.6	40.0	546.7	368.7	955.4	10.7	75.3	2.0	88.0
Thomas Rock	10/1	23.7	19.4	104.7	335.3	187.3	627.3	16.7	57.3	0.7	74.7
Nansemond Ridge	10/1	22.6	17.5	43.3	174.0	349.3	566.6	8.7	31.3	1.3	41.3
York River											
Bell Rock *	9/24	24.6	13.4	34.7	128.0	6.0	168.7	0.7	31.3	0.0	32.0
Aberdeen Rock	9/24	24.5	18.6	54.0	266.0	8.7	328.7	8.7	33.3	0.0	42.0
Mobjack Bay											
Tow Stake	9/24	24.5	20.0	80.0	316.7	45.3	442.0	1.3	14.0	0.7	16.0
Pultz Bar	9/24	24.2	19.7	48.7	395.3	57.3	501.3	10.7	27.3	1.3	39.3
Piankatank River											
Ginney Point	9/21	26.2	17.4	114.5	359.0	41.0	514.5	0.5	119.0	0.0	119.5
Palace Bar	9/21	25.9	17.7	49.0	426.0	168.5	643.5	2.0	20.0	0.0	22.0
Burton Point	9/21	25.8	18.1	52.5	272.5	178.5	503.5	0.5	10.5	1.5	12.5
Rappahannock River											
Ross Rock	9/27	23.3	6.7	0.0	2.7	195.3	198.0	0.0	0.0	0.0	0.0
Bowler's Rock	9/27	23.5	10.4	26.0	93.5	134.0	253.5	0.0	1.5	0.5	2.0
Long Rock	9/27	24.0	13.2	80.0	104.5	23.0	207.5	0.0	3.0	0.0	3.0
Morattico Bar	9/27	24.3	15.6	80.5	108.0	13.5	202.0	0.0	15.5	0.0	15.5
Smokey Point	9/27	24.4	15.9	99.5	147.5	19.0	266.0	2.5	24.5	0.0	27.0
Hog House	9/27	23.7	15.9	46.0	144.5	55.0	245.5	1.5	23.0	0.0	24.5
Middle Ground #	9/27	24.4	16.6	62.0	350.0	22.5	434.5	9.5	43.0	0.0	52.5
Drumming Ground	9/27	24.5	17.4	132.0	365.0	32.5	529.5	4.5	22.0	0.0	26.5
Parrot Rock	9/27	24.3	17.4	66.0	198.5	30.5	295.0	0.0	12.5	0.5	13.0
Broad Creek	9/27	23.9	17.6	124.7	248.7	94.0	467.4	7.3	30.7	0.0	38.0
Great Wicomico River											
Haynie Point	9/20	26.0	15.3	107.5	630.5	170.5	908.5	6.5	11.0	2.5	20.0
Whaley's East	9/20	24.8	15.5	102.0	404.0	122.5	628.5	2.0	9.5	0.0	11.5
Fleet Point	9/20	25.6	15.4	88.5	256.0	208.0	552.5	3.0	12.0	1.5	16.5

Figure D1: Map showing the location of the oyster bars sampled during the 2021 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.

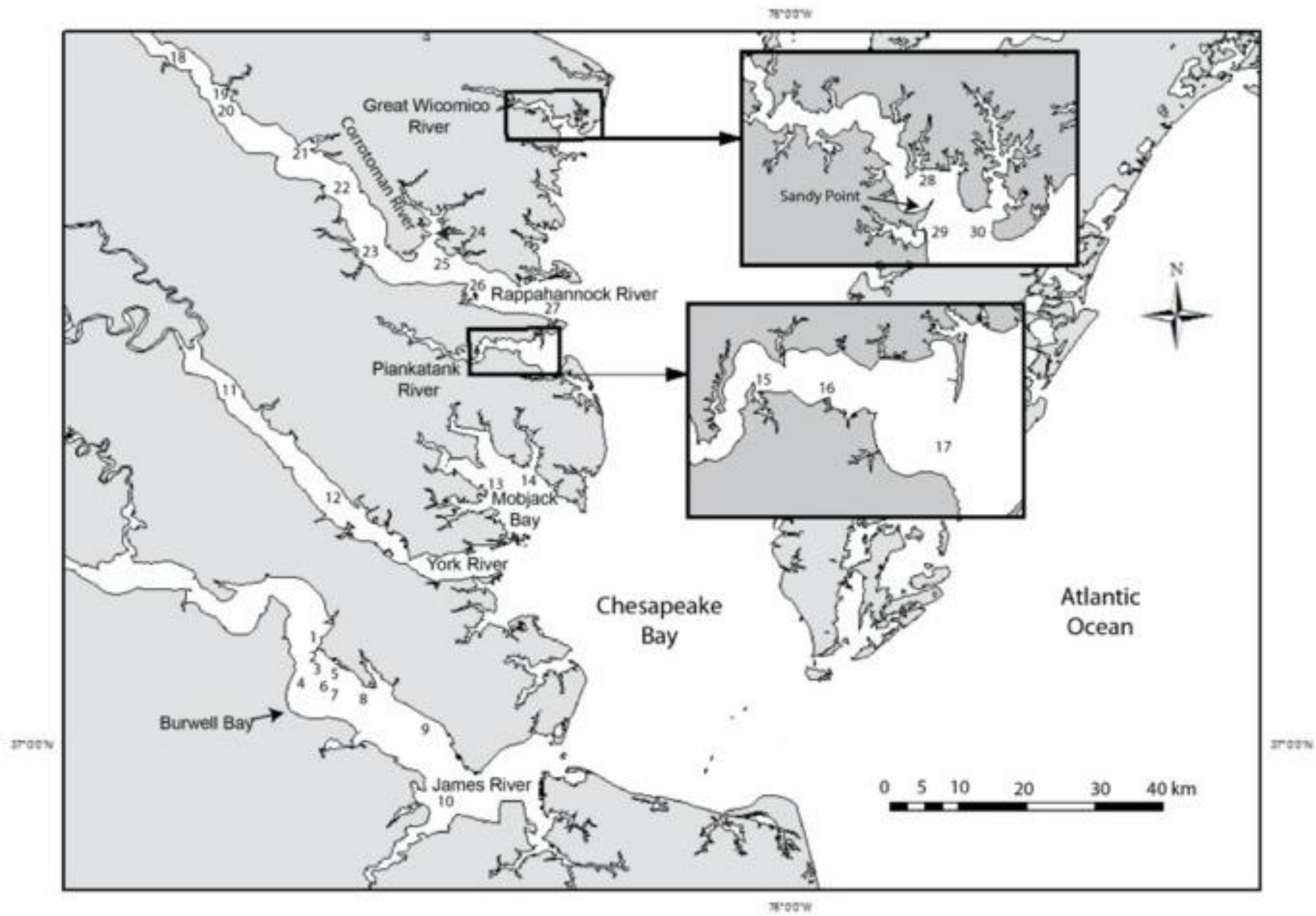


FIGURE 2A: JAMES RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)

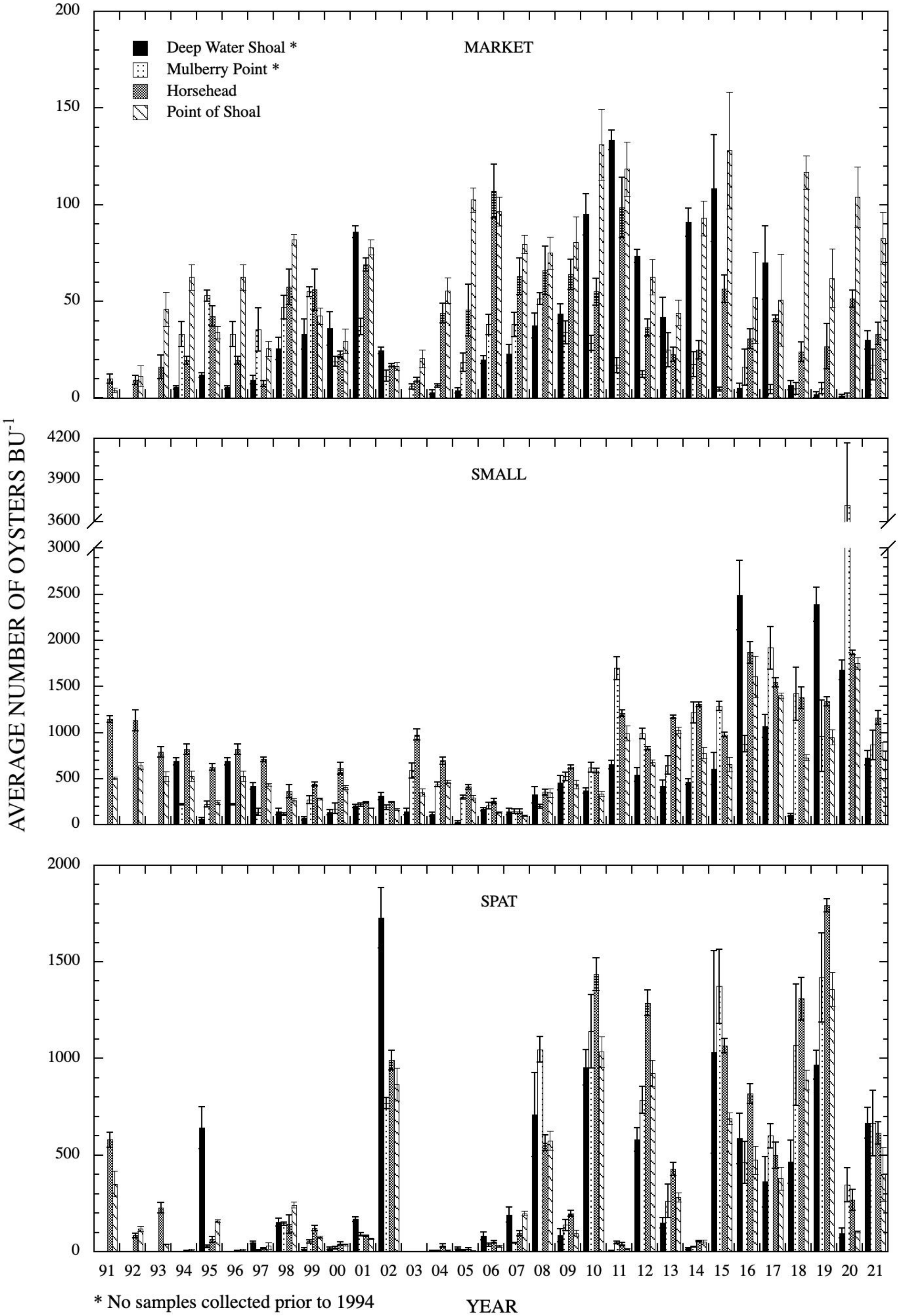
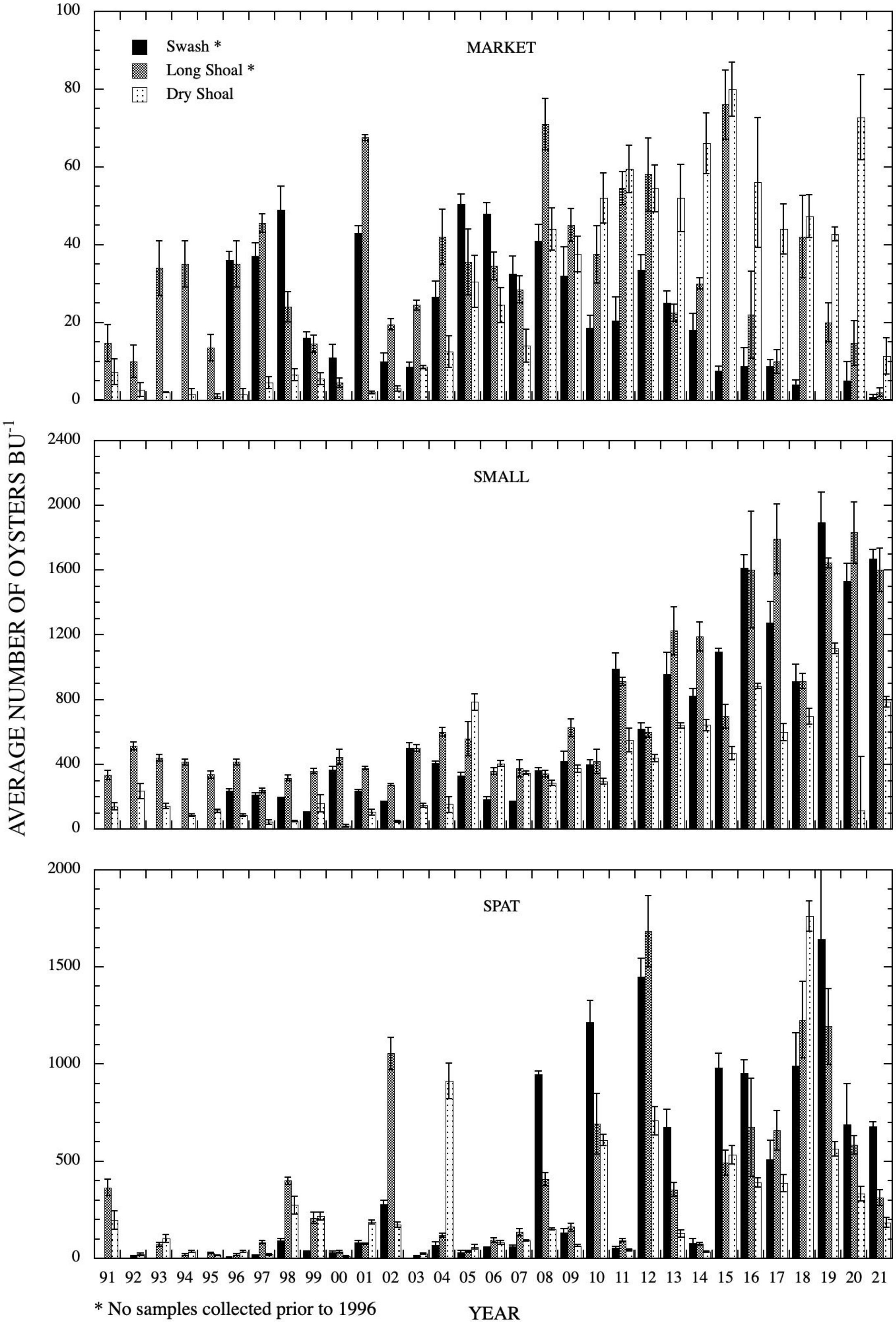


FIGURE 2B: JAMES RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)



* No samples collected prior to 1996

FIGURE 2C: JAMES RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)

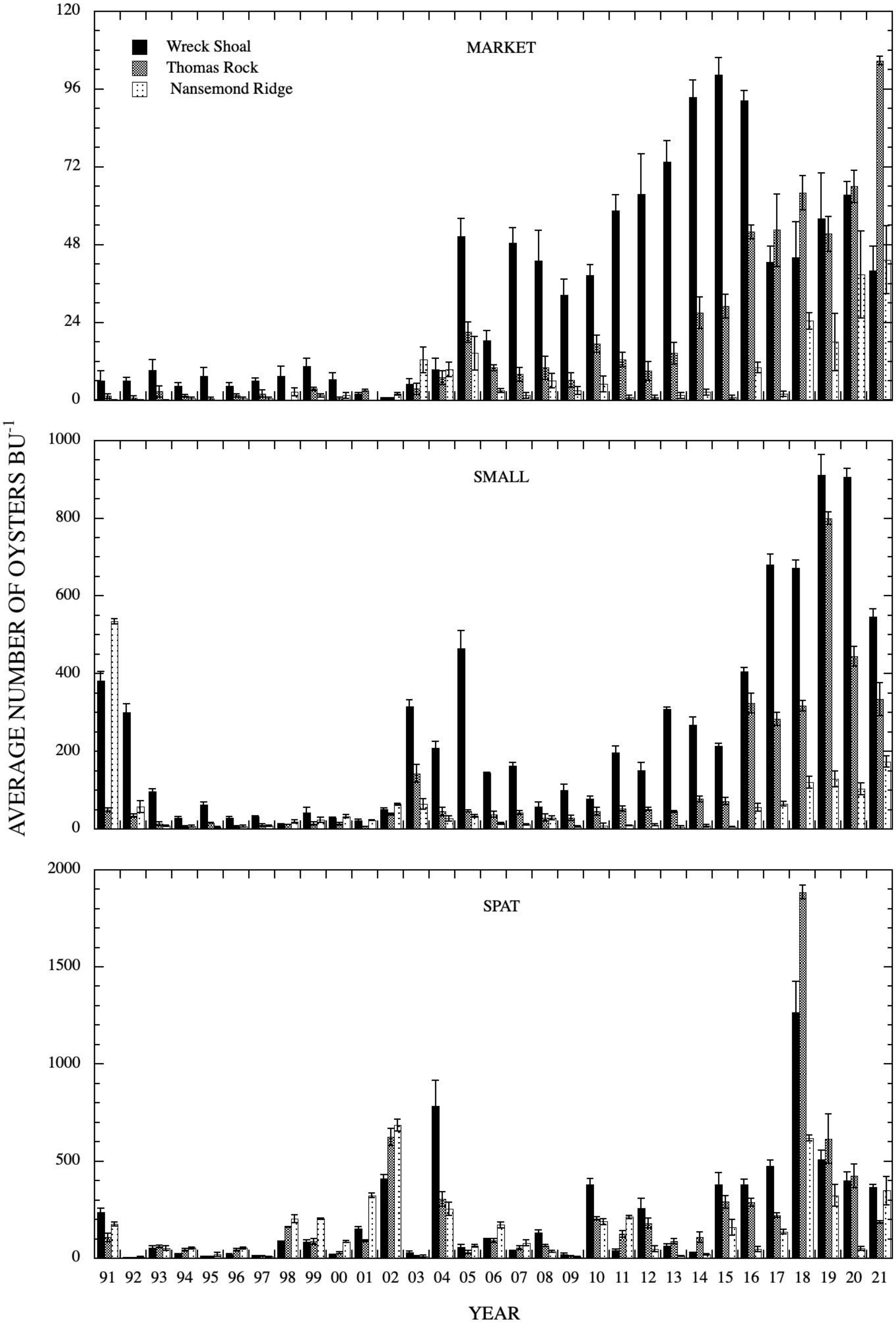


FIGURE D3: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE JAMES RIVER (2020-2021)
(Error bars represent standard error of the mean)

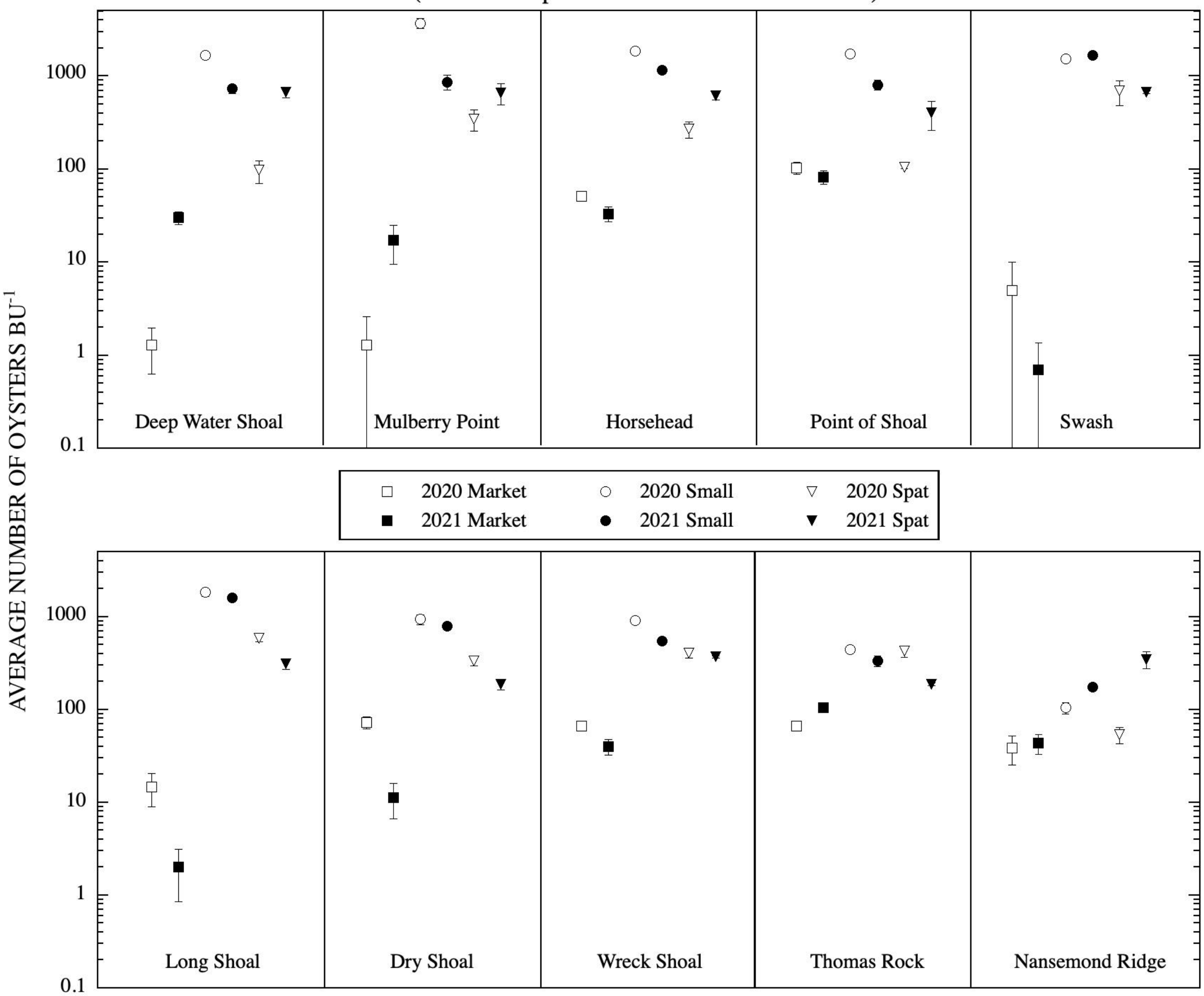


FIGURE D4: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE YORK RIVER AND MOBJACK BAY (2020-2021)
(Error bars represent standard error of the mean)

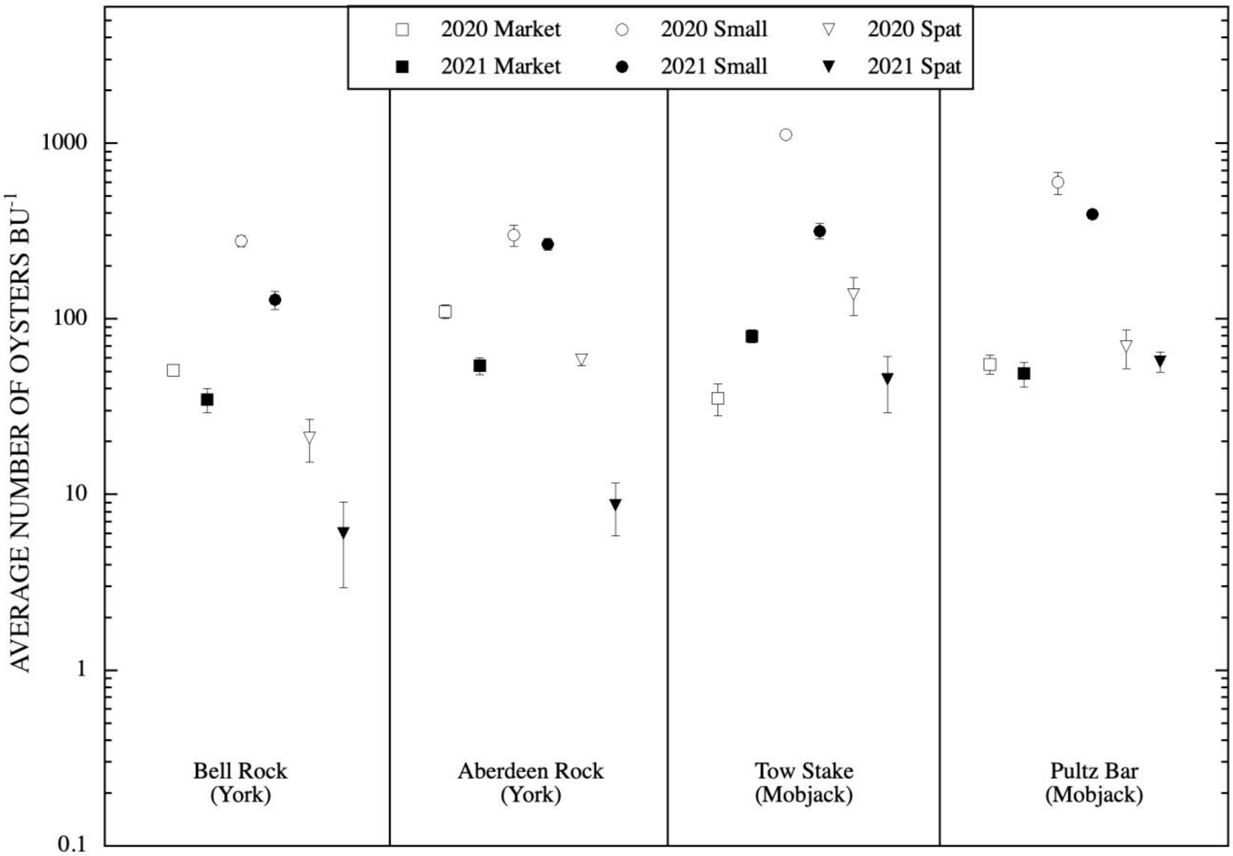


FIGURE D5: YORK RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)

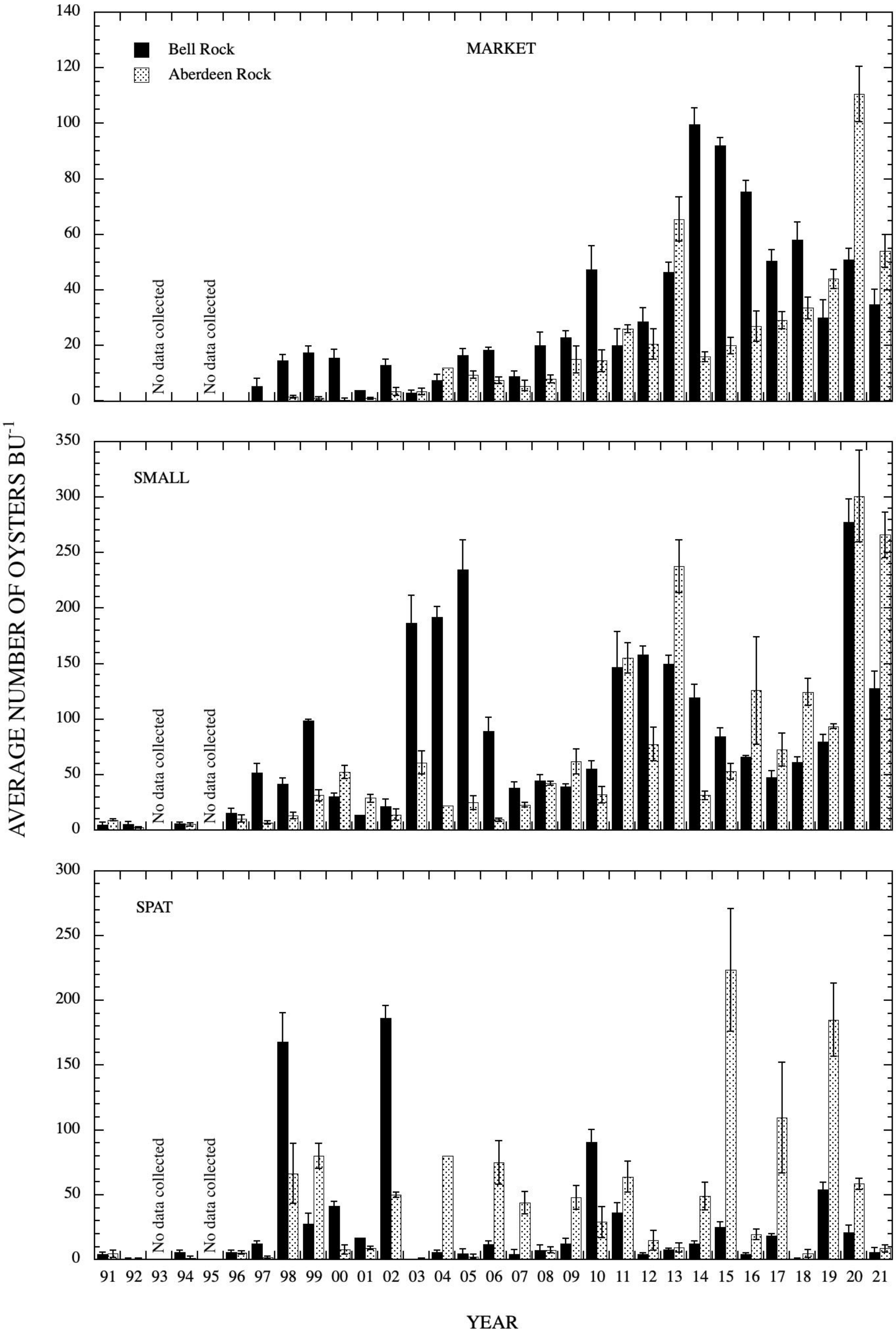


FIGURE D6: MOBJACK BAY OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)

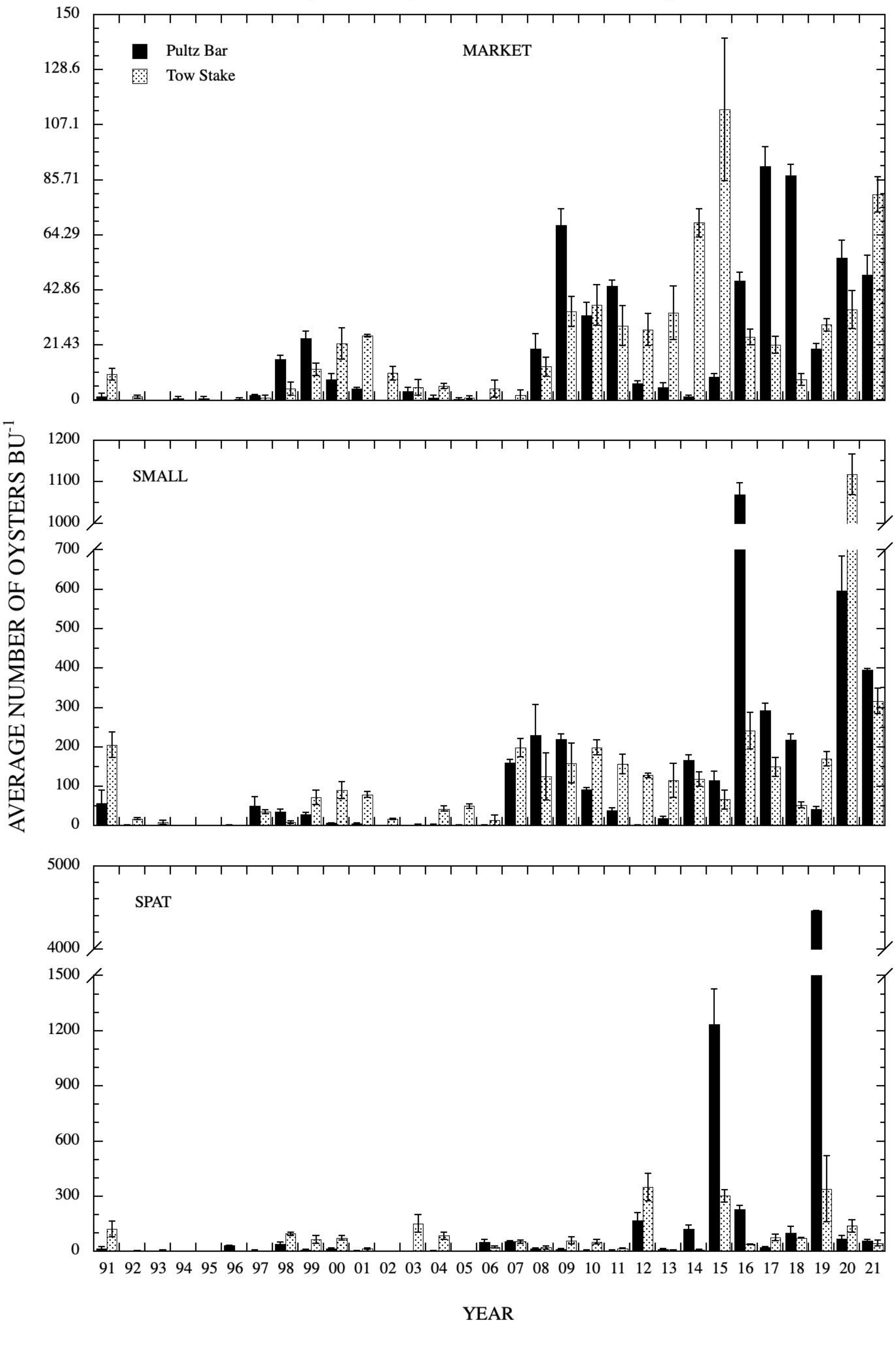


FIGURE D7: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE PIANKATANK RIVER (2020-2021)
(Error bars represent standard error of the mean)

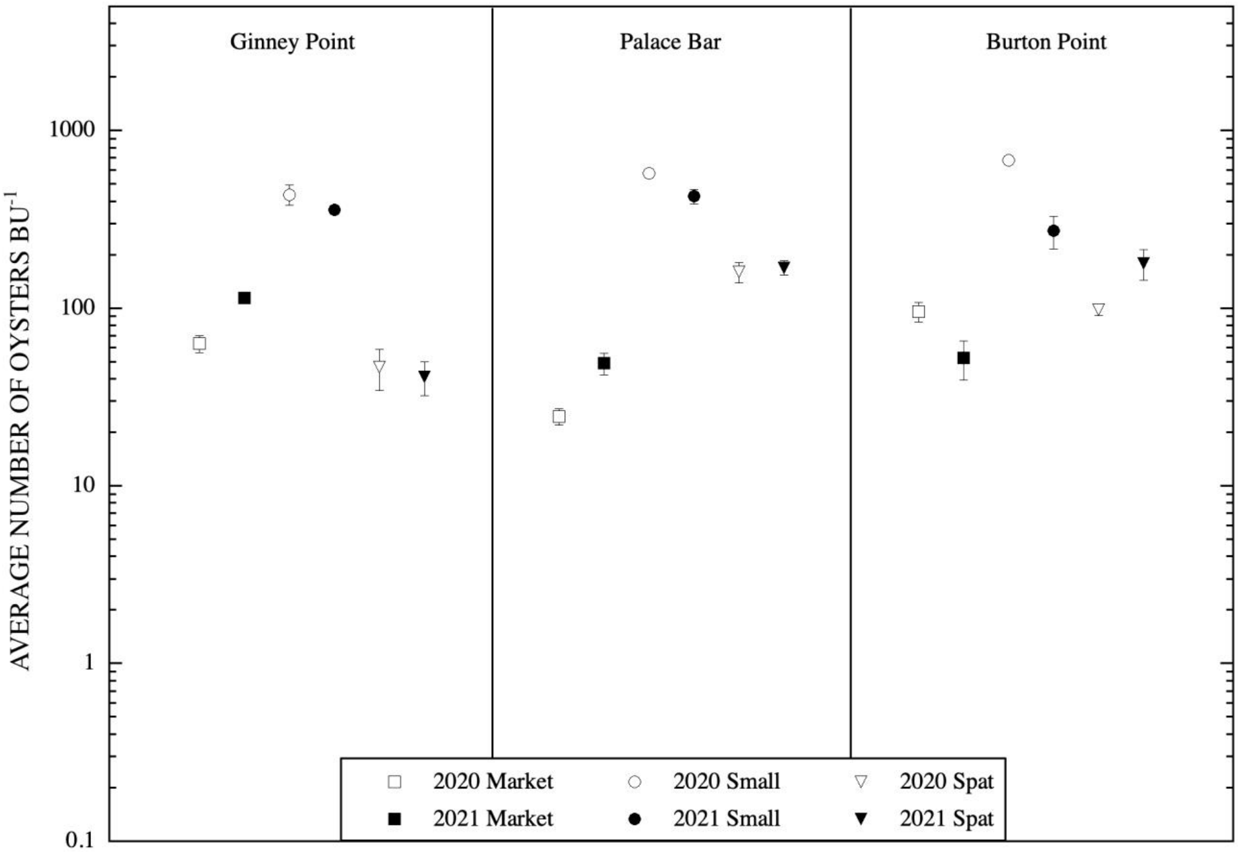
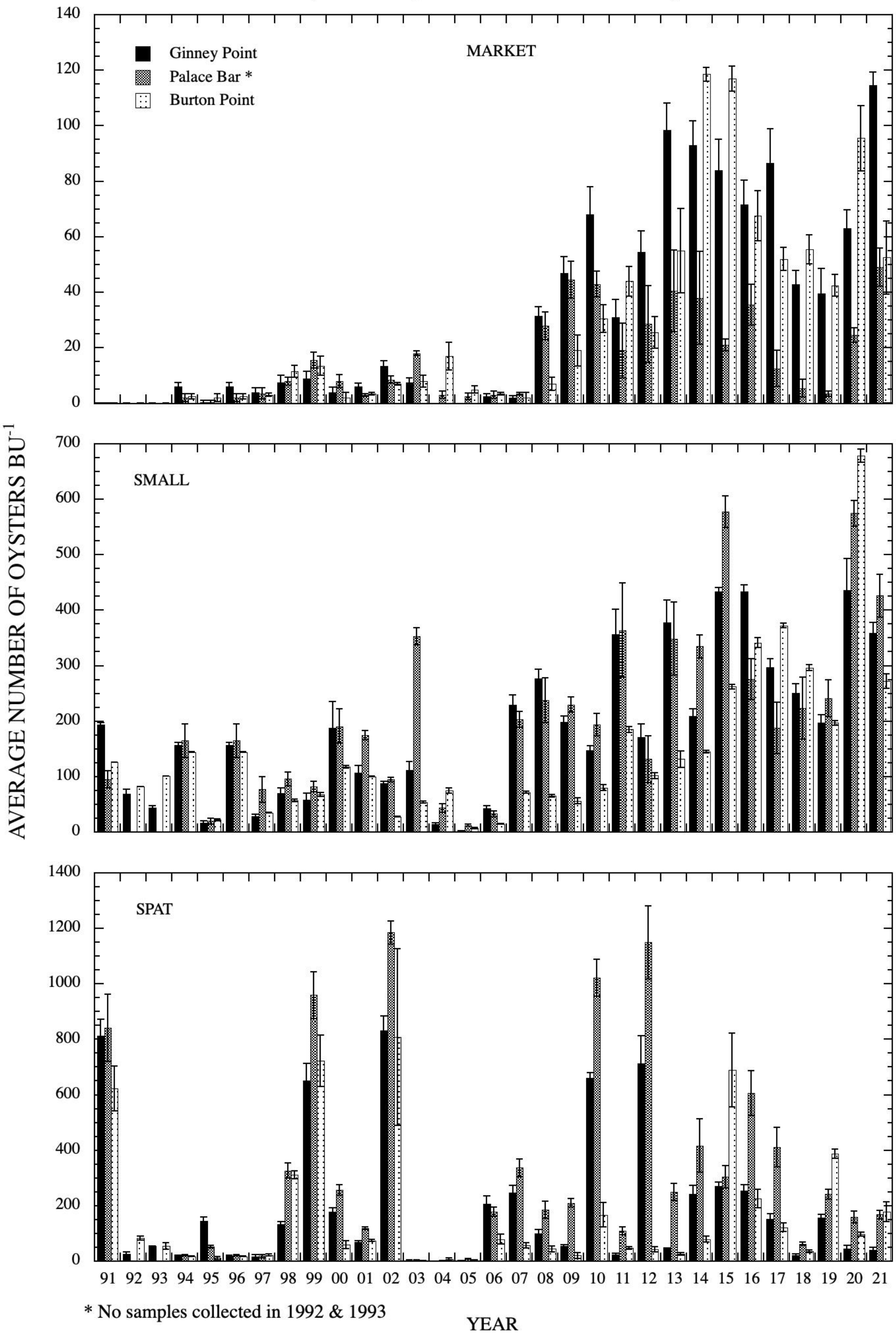


FIGURE D8: PIANKATANK RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)



* No samples collected in 1992 & 1993

FIGURE D9: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY IN THE RAPPAHANNOCK RIVER (2020-2021)
(Error bars represent standard error of the mean; * recieved a seed plant in Spring 2020)

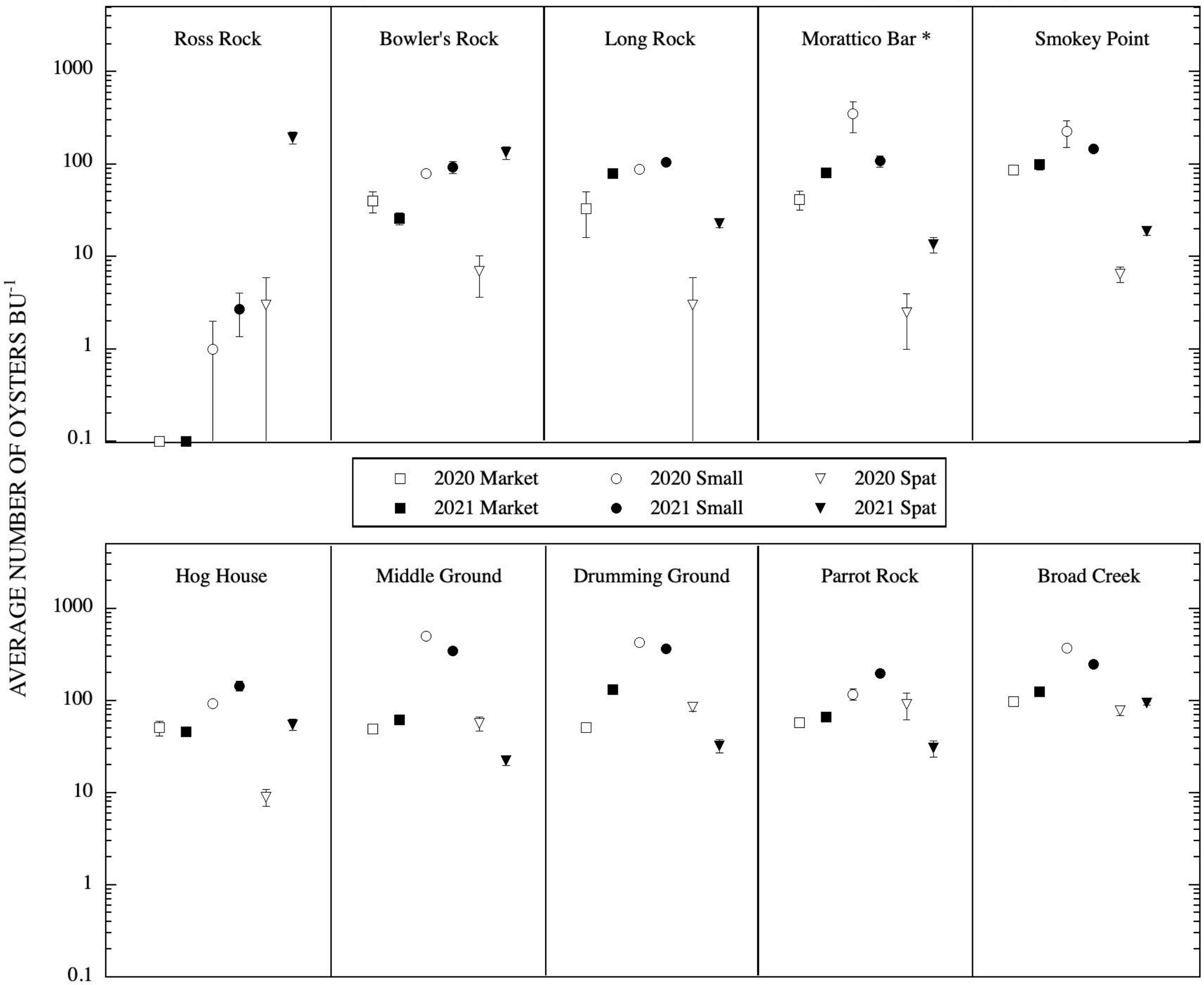
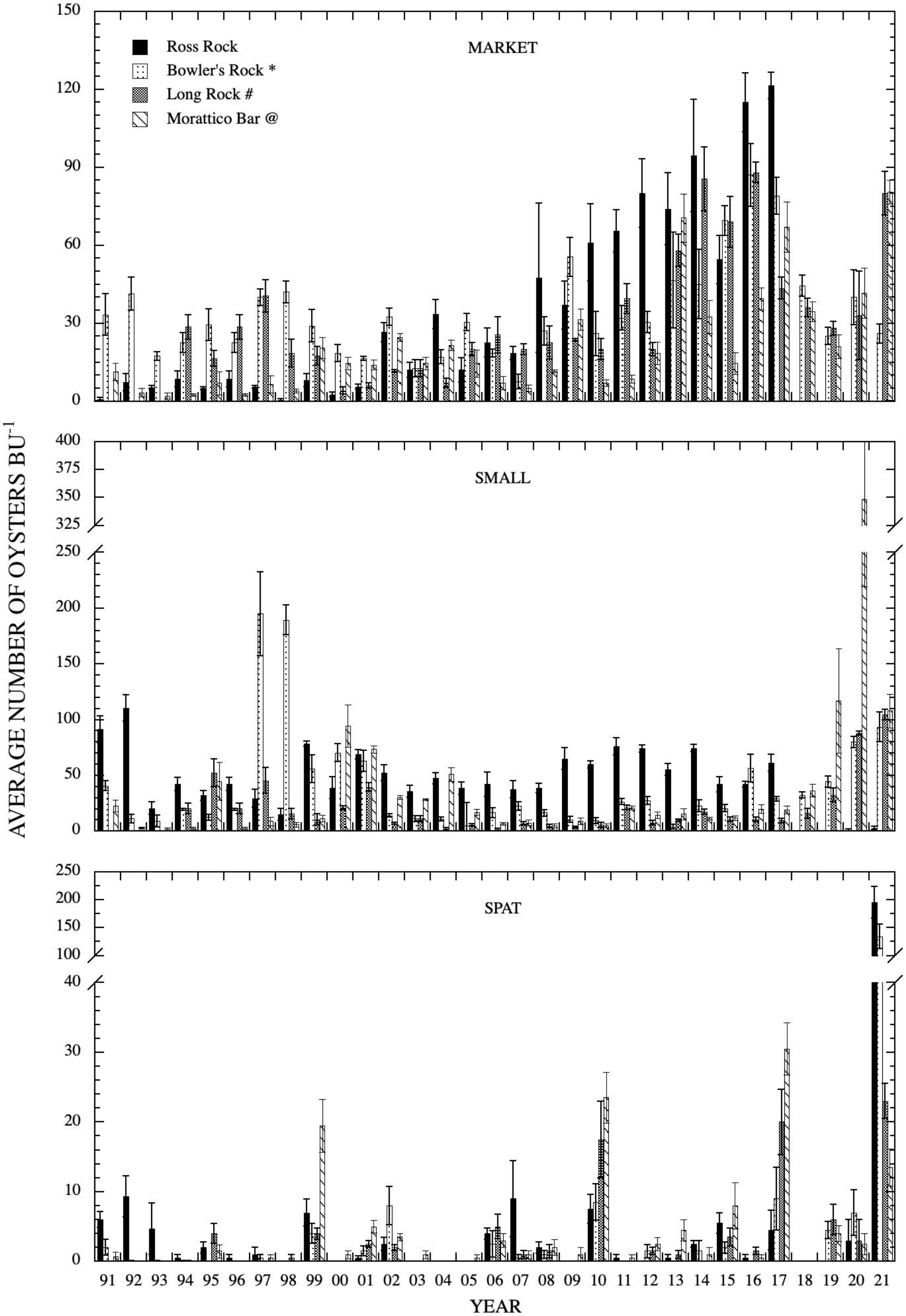
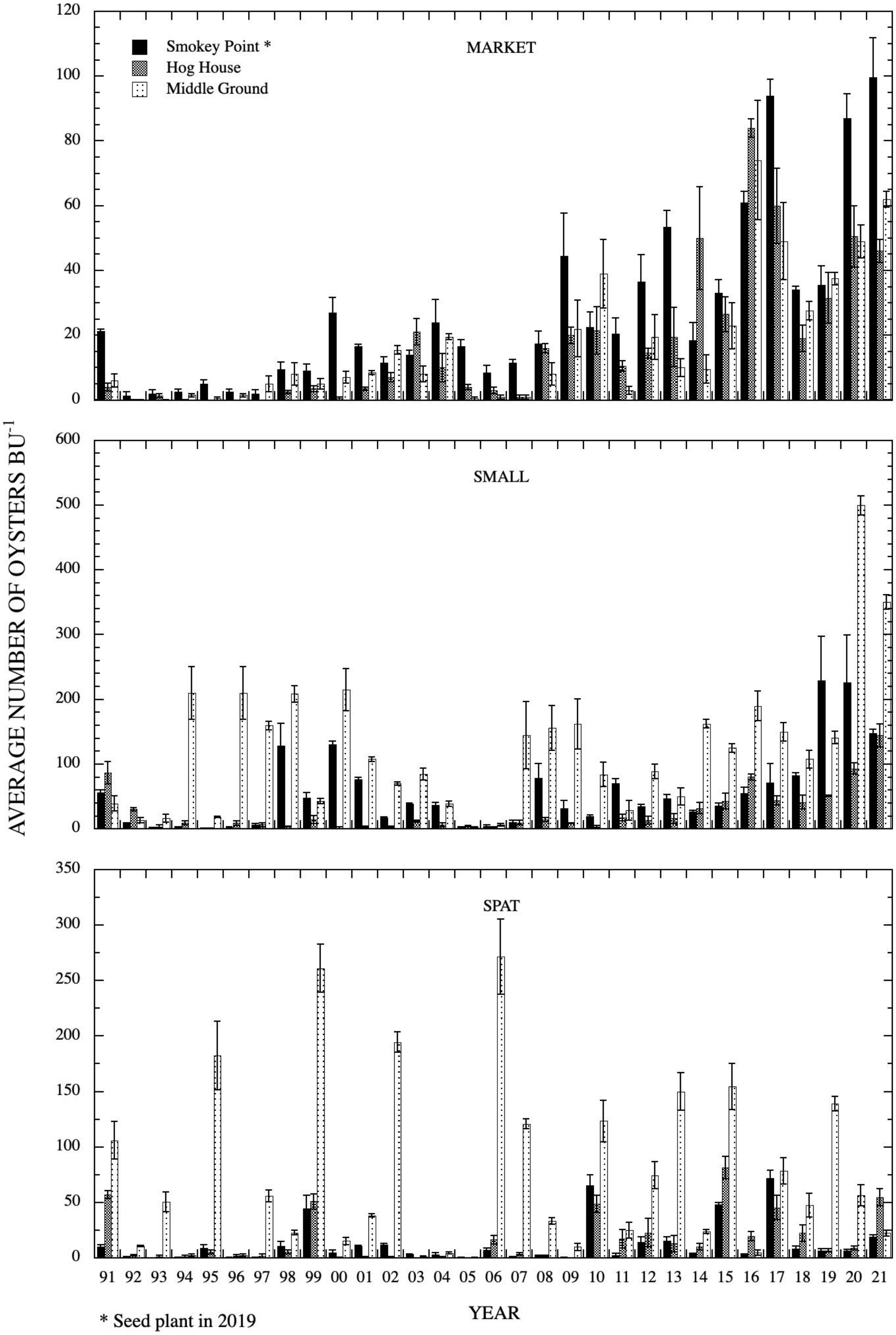


FIGURE 10A: RAPPAHANNOCK RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)



* = seed plant in 1997: # = no data prior to 1994: @ = seed plant in 2019 & 2020

FIGURE 10B: RAPPAHANNOCK RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)



* Seed plant in 2019

FIGURE 10C: RAPPAHANNOCK RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)

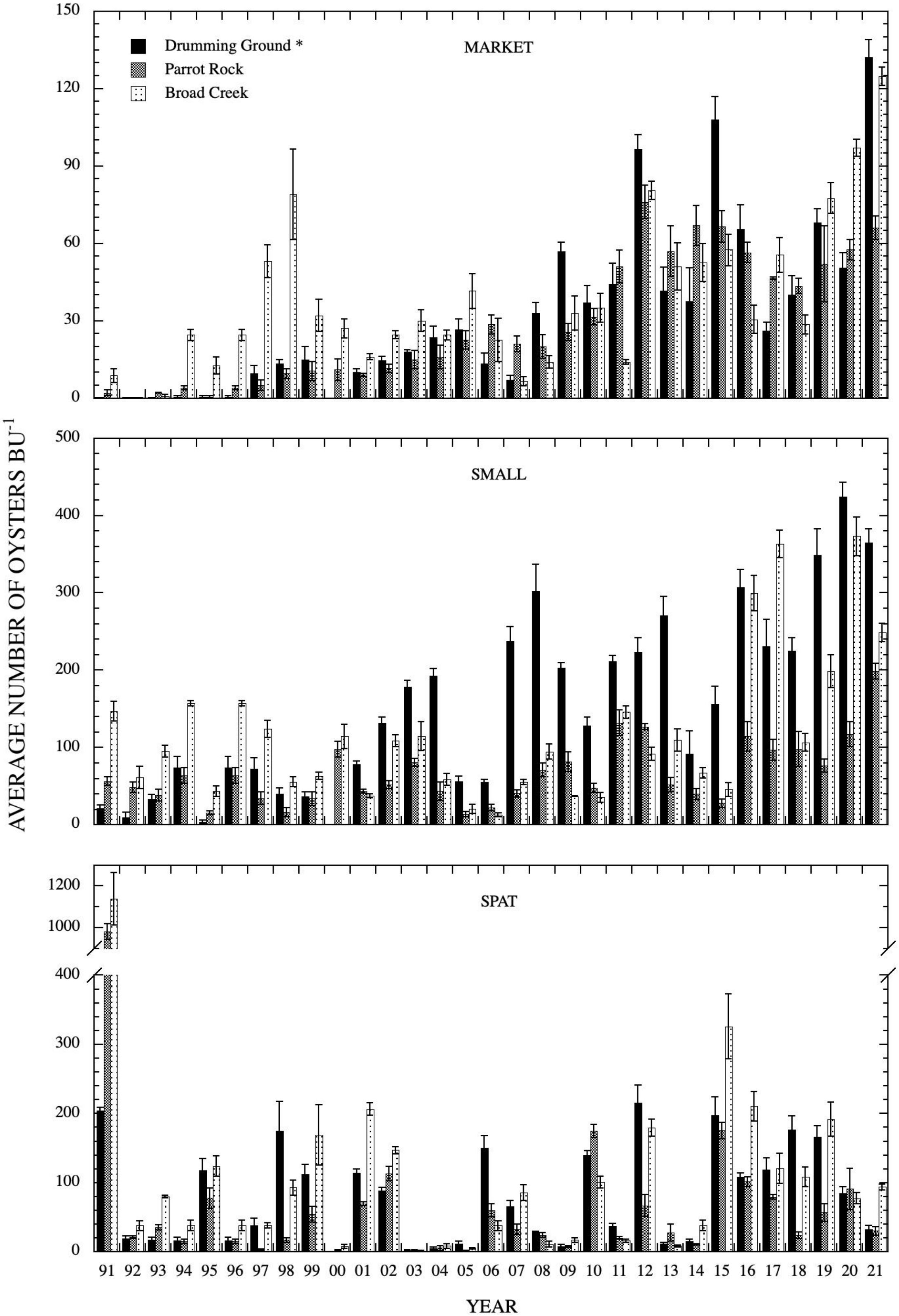


FIGURE D11: COMPARISON OF OYSTER ABUNDANCE BY SIZE CATEGORY
IN THE GREAT WICOMICO RIVER (2020-2021)
(Error bars represent standard error of the mean)

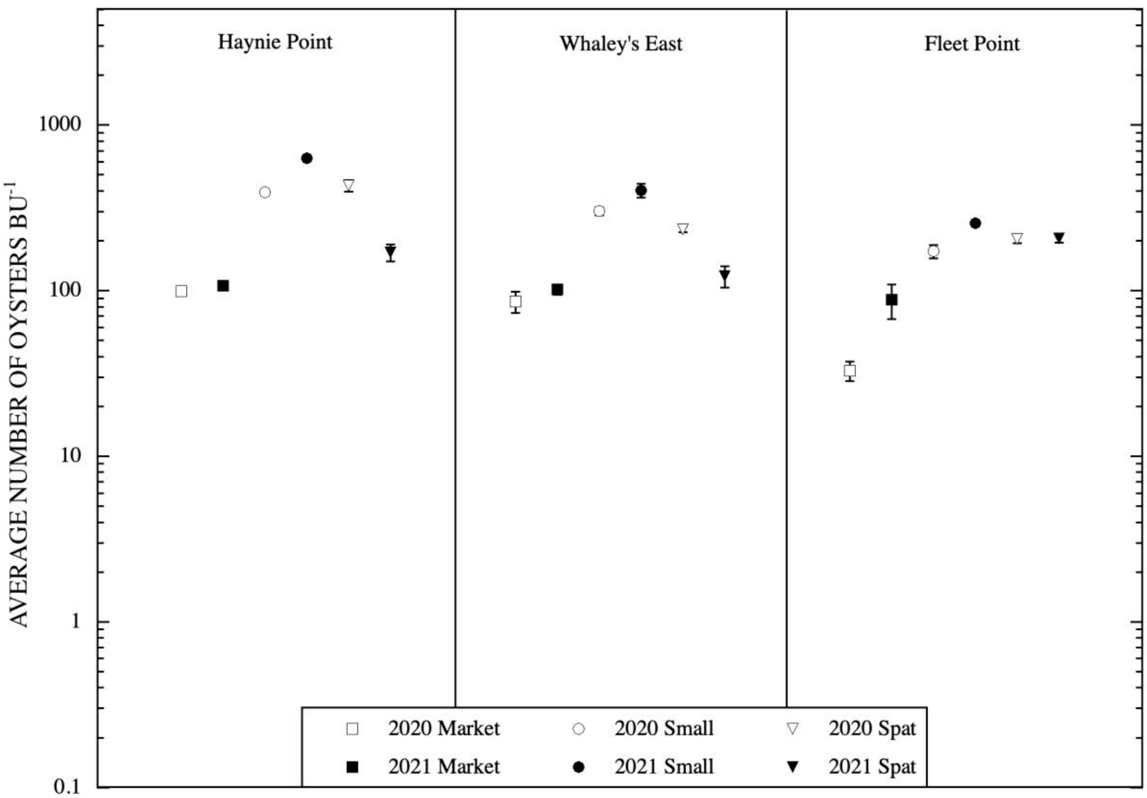
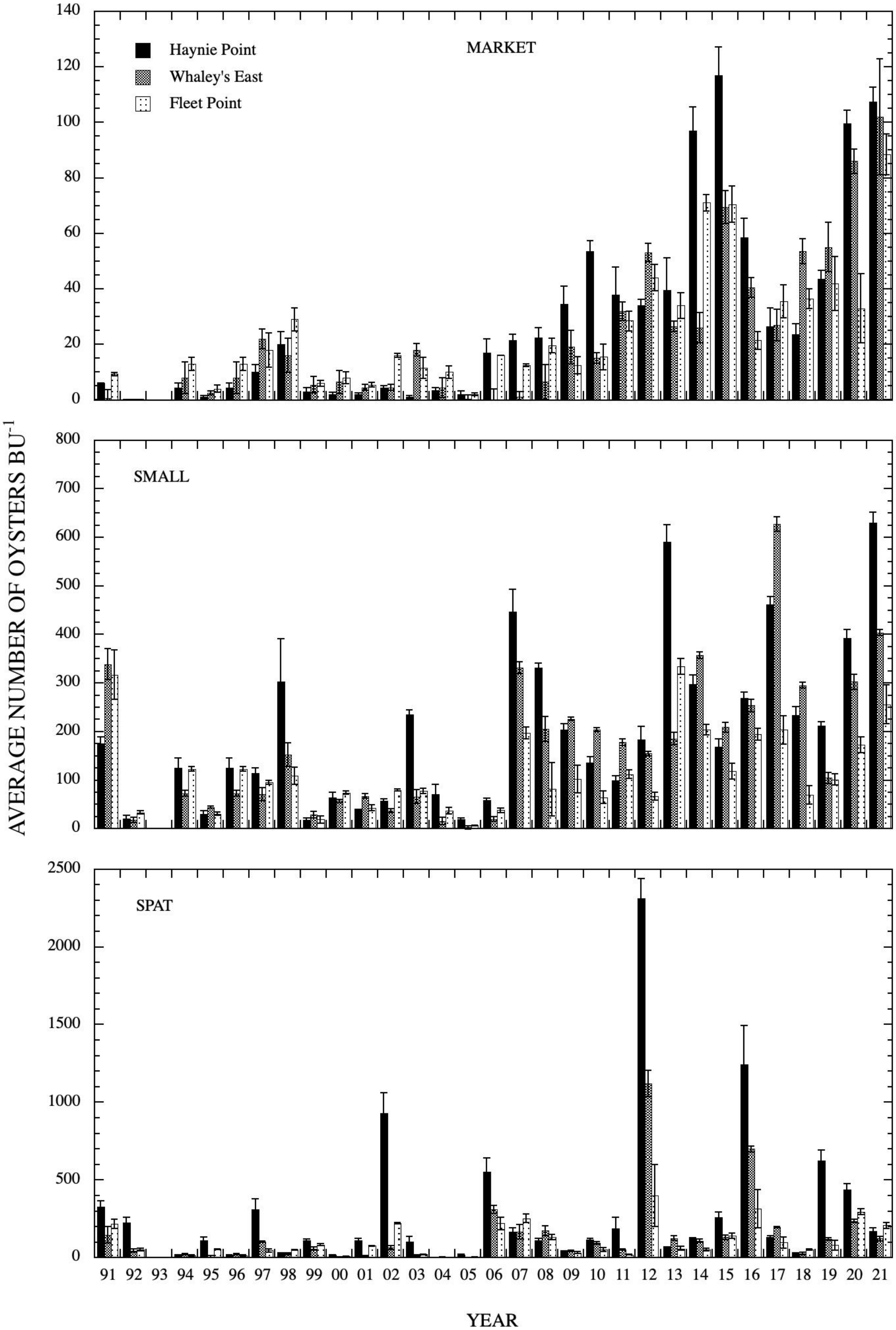


FIGURE D12: GREAT WICOMICO RIVER OYSTER TRENDS OVER THE PAST 30 YEARS
(Error bars represent standard error of the mean)



ACKNOWLEDGMENTS

These monitoring programs required the assistance of many people, without whose contributions they could not have been successfully completed. We are deeply grateful to the following: Nathan Otto (VIMS Fisheries Science) assisted in making the shellstrings and in field collection. Alexandra Marquardt, Shijun Zeng and Jasmine Whelan assisted in field collection. Cindy Forrester (Department of Fisheries Science, Budget Manager) and Grace Tisdale (Department of Fisheries Science, Purchasing Agents) helped with purchasing field equipment and materials. VIMS Field Operations Department provided assistance with boat scheduling and operation throughout the year, namely Raymond Forrest, Jim Goins and Terri Major. Andrew Button, Division Head, Conservation and Replenishment Division of the Virginia Marine Resources Commission provided the *J. B. Baylor* vessel for use during the dredge survey and assisted with data collection during the dredge survey. Vernon Rowe, William Murray and Andy Shin of the VMRC, Nathan Otto of VIMS and James Wesson provided assistance during the fall 2021 dredge survey.

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