Oyster Bag Sill Construction and Monitoring at Two Sites in Chesapeake Bay

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Cover Photo: Oyster bag sill built in 2016 on Whittaker Creek at Captain Sinclair's Recreational Area, Gloucester, Virginia. Photo Date: 10 July 2018. Photo credit: Shoreline Studies Program, VIMS.

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1 Introduction

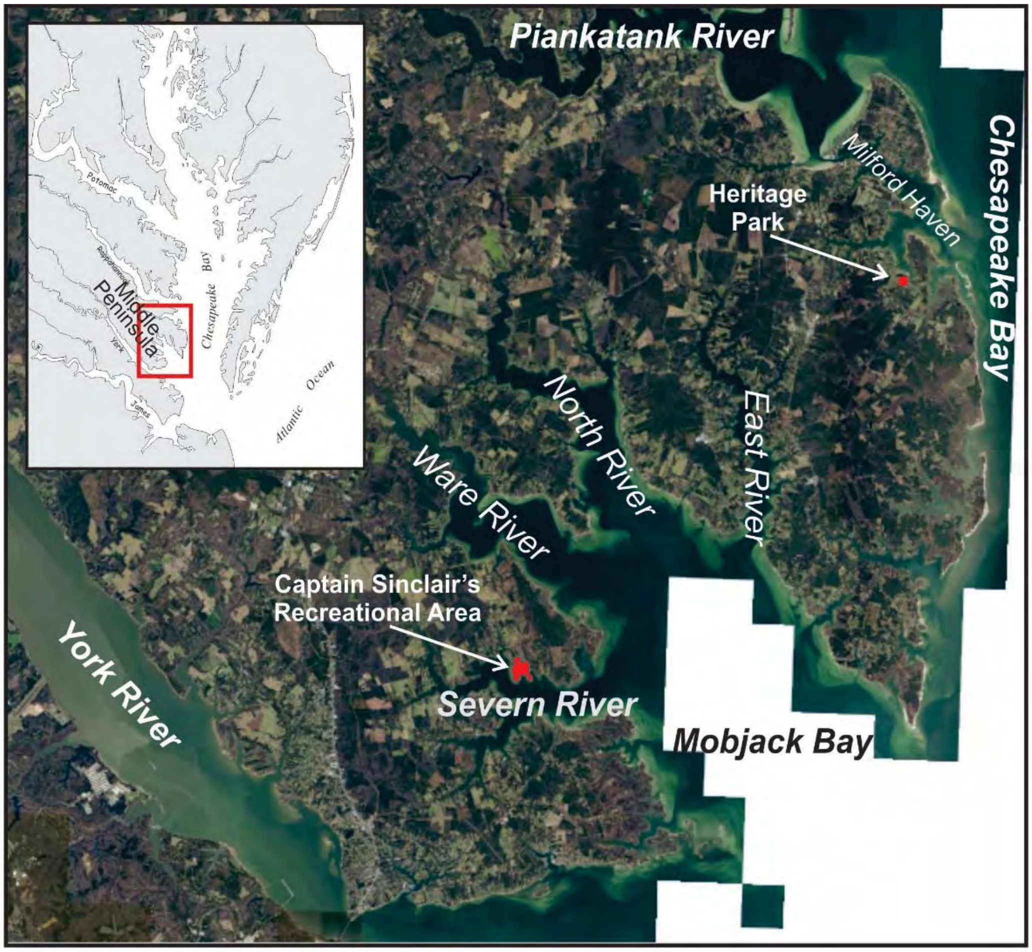

Figure 1-1. Location of oyster bag sill construction sites.

The use of oyster shell bags as a means of shore protection along fetch-limited shorelines in Chesapeake Bay is growing. This method is an innovative use of a byproduct of the seafood industry and can provide habitat creation, water quality improvement, and shore protection. The landowner can install the bags themselves, and with the new living shoreline general permit in Virginia, these projects are easier than ever to afford and install. However, oyster shells are a limited resource that are needed for large-scale oyster reef restoration with the Chesapeake Bay watershed, so determining the effectiveness of this shore protection strategy is important to allocating resources for habitat restoration.

Like all shore protection methods, the effectiveness of the strategy is tied to site-specific physical parameters and project design as well as the goals of the landowner. To provide effective shore protection, the oyster bags will have to biologically cement together to become a reef. If sand and marsh are installed along with the oyster bag sill construction, the reef will provide protection from waves while the marsh is establishing itself. For sites that are not filled with sand and planted, the structure will provide protection from waves and allow accretion behind the structure on which marsh can eventually grow.

In areas with very small fetches of less than 0.5 miles [fetch being the distance over water that wind can blow to generate waves (Hardaway & Byrne, 1999)], non-structural shore protection such as biologs and planting existing substrate can be successful. As the fetch increases above one mile, a hybrid living shoreline, usually a rock sill with marsh fringe, is recommended. However, many areas of Chesapeake Bay with fetches less than 1 mile are experiencing low erosion, but a rock sill with sand nourishment and marsh fringe may be more than needed to provide shore protection. In other cases, the shore zone may be too shallow or the site does not have land access to get the necessary construction equipment to the project area. An oyster bag sill is ideal for these locations because they can reduce the wave climate acting on the shore, do not significantly biodegrade over time, and provide additional habitat. Though many studies have verified their use as habitat friendly, few studies have tried to determine if they can be effective shore protection along the fetch-limited shorelines of Chesapeake Bay over time.

The objective of the present project was twofold:

1) Install oyster bag sills as shore protection at two sites, Captain Sinclair's Recreational Area in Gloucester and Mathews Heritage Park (Figure 1-1). The goal of this task was to determine effective construction techniques and placement guidelines for Chesapeake Bay shorelines. These sites were chosen because they are public lands, easy to access by boat, and have potential as demonstration sites to perform research on the effectiveness of oyster bag installation for shore protection. The sites also had existing oysters in the nearshore that would provide spat for the oyster bags. In addition to shore protection, the oyster bag sills provided water quality improvements through habitat restoration. The biological component of the sills was determined by sampling.

2) In addition, several existing sites on private property were assessed to determine their effectiveness for shore protection through time. The first oyster bag sill was permitted locally in 2010, but after a slow start with only one built in 2012 and two in 2014, they have been increasing in frequency. Five were permitted in 2016 and in 2017, and two were permitted in the first part of 2018. Only the oldest were assessed to determine their effectiveness over time.

2 Site Information

2.1 Heritage Park

Heritage Park is located on Billups Creek in Mathews County, Virginia (Figure 2-1). The site has approximately 9 acres with about 8.5 acres of pine forest and 0.5 acres of tidal marsh (Milligan, Hardaway, & Wilcox, 2017). The shoreline is about 700 feet long (Table 2-1). The southeast-facing shoreline has a long-term shoreline recession rate of about -0.3 feet/year.

Table 2-1. Site parameters at Heritage Park.

Site Name	**Heritage Park**
Locality	Mathews
Lat/Long	37°27'3.08"N 76°16'57.14"W
Body of Water	Billups Creek
Shore Orientation	Southeast
Site Length (ft)	700
Average Fetch Category	Very Low (<0.5 miles)
Average Fetch (miles)	0.2
Longest Fetch (miles)	0.3
Shore Morphology	Upland with marsh fringe
Distance to 6 ft contour (ft)	NA
Nearshore Morphology	Shallow Creek <4 ft MLLW
Mean Tide Range (ft)	1.1
10 yr Surge (ft MLW)	4.5
50 yr Surge (ft MLW)	5.6
100 yr Surge (ft MLW)	7.1
Erosion Rate (ft/yr)	-0.3

Figure 2-1. The Heritage Park boundary (shown in red) and historical shorelines (1937 and 2009) showing change over time (from Milligan et al., 2017).

The coast is mostly eroding tidal marsh with three low exposed upland bank segments that are 45 feet, 75 feet and 45 feet, respectively (Figure 2-2). Larger pocket marshes exist between the uplands. The uplands are very low, only about 4-5 feet MLW with a narrow marsh fringe in front (Figure 2-3, top). In some areas, the fringe has been lost completely, and the upland bank is now being impacted (Figure 2-3, mid). The site has a derelict pier.

Estuarine tidal marsh is important habitat for numerous species of fish and crabs; fiddler crabs and oysters are prevalent on the site (Figure 2-3, bottom). The marsh shoreline consists primarily of black needlerush and smooth cordgrass. The uplands are primarily pine forests with cedar trees along the marsh perimeter. No SAV or oyster leases occur in the nearshore.

Figure 2-3. Existing conditions at Heritage Park. Top: A low upland bank is protected in some areas by a narrow fringe marsh. Middle: In other areas, the marsh fringe has completely eroded. Bottom: Oysters are prevalent in the nearshore at the site.

The tide range at Heritage Park is 1.1 feet. Storm surge for the 10 year, 50 year, and 100 year return intervals are 4.5 feet, 5.5 feet, and 7.1 feet MLW, respectively. The property is in the AE zone (FEMA, 2014a).

The project site has a low average fetch exposure to the southeast of about 0.2 miles feet across Billups Creek. The Creek is about 400 feet wide about mid-way alongshore, and the nearshore is relatively shallow with the mid-channel depth only about 3 feet.

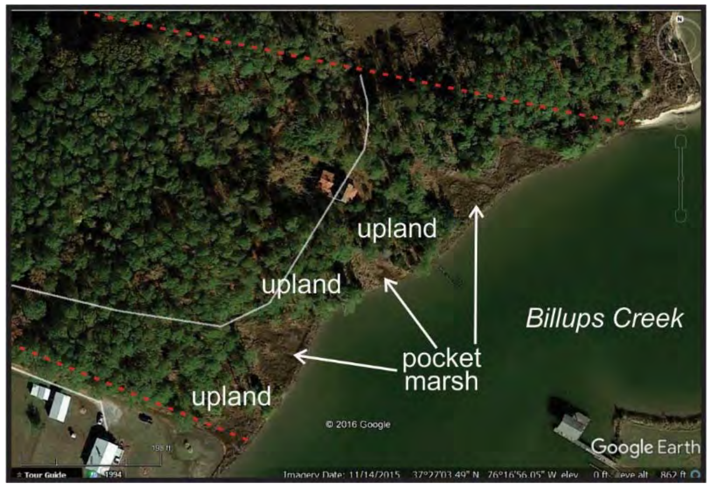

Figure 2-2. Google Earth image showing shore morphology features at Heritage Park. The approximate site boundaries are shown in red. (From Milligan et al., 2017).

2.2 Captain Sinclair's Recreational Area

Captain Sinclair's Recreational Area (CSRA) is located on the Severn River in Gloucester County, Virginia. It is a tract of land consisting of about 100 acres that was donated to the Middle Peninsula Chesapeake Bay Public

Figure 2-4. Location of shore protection structures at Captain Sinclair's Recreational Area.

Table 2-2. Captain Sinclair's Recreational Area oyster bag sill site parameters.

Site Name	**Captain Sinclair OB Sill**
Locality	Gloucester
Lat/Long	37°19'23.56"N 76°25'44.02"W
Body of Water	Severn River
Shore Orientation	Southwest to Southeast
Site Length (ft)	775
Average Fetch Category	low (0.5 to 1 mile)
Average Fetch (miles)	1
Longest Fetch (miles)	2.4
Shore Morphology	Marsh
Distance to 6 ft contour (ft)	1,000
Nearshore Morphology	Shallow
Mean Tide Range (ft)	2.4
10 yr Surge (ft MLW)	6.2
50 yr Surge (ft MLW)	7.3
100 yr Surge (ft MLW)	7.8
Erosion Rate (ft/yr)	0.3 to -2.9

Access Authority (Figure 2-4). The property has about 1.3 miles of tidal shoreline that extends from the canal on the northern end of the property, along Whittaker Creek, and to the Severn River down to small unnamed tidal creek adjacent to the old wood pier.

The upland region is very low and easily flooded during severe storm events (Figure 2-4). The maximum upland height is about 6 feet. The lowest area is marsh at the point of land where Whittaker Creek joins the Severn River which is the focus of this project. Lidar data indicates that most of the marsh was only 0 to 1 foot in 2010. The nearshore is very shallow with the 5-foot mean low water (MLW) contour about 1,900 feet offshore. Offshore of the point of land at the confluence of Whittaker Creek and the Severn River, the 1-ft contour is over 1,000 feet offshore meaning the nearshore is very shallow (Table 2-2).

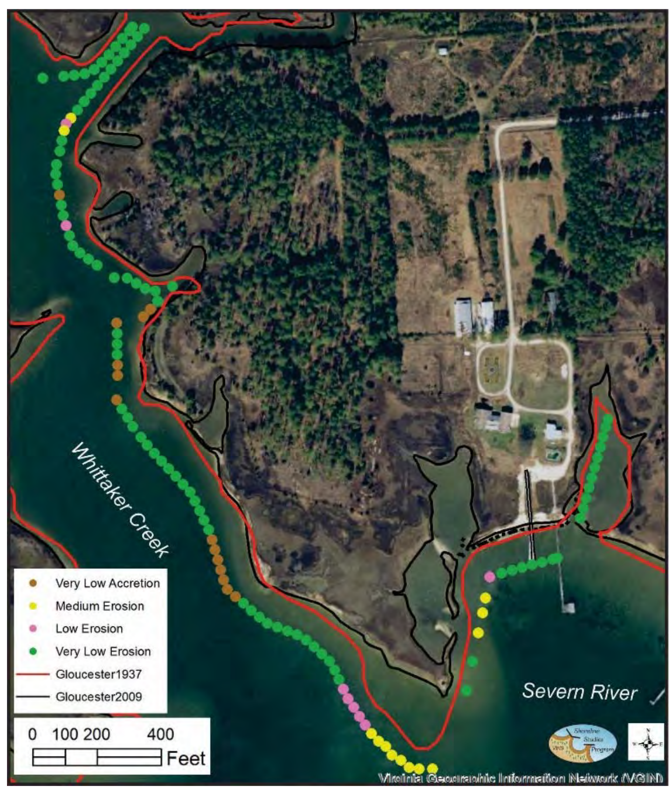

Figure 2-5. Shore change rates at CSRA (Milligan et al., 2016)

The southeast facing shoreline along the marsh point in the area where the oyster bag sill was constructed for this project has a slightly larger fetch to the east (1.02 miles) than the southwest facing shoreline (0.85 miles).

The long-term rate of change along Whittaker Creek is either very low erosion or very low accretion (Figure 2-5). Along this reach of shoreline, the low erosion rate has created small erosional marsh scarps along the shoreline or left trees and shrubs near the shoreline. Historically, shoreline erosion is greater along the more open reaches of the Severn River. The section of shore where the oyster bag sill was built has the highest erosion at the site. The point of the marsh has moved about 210 ft landward since 1937 (Figure 2-5). The southwest facing shorelines varies between 0.3 ft/yr to 2.9 ft/yr. The southeast facing shoreline is eroding at about 0.5 ft/yr.

The mean tide range is 2.4 feet at Captain Sinclair. Storm surge frequencies for the 10, 50, and 100 year events are 6.2, 7.3, and 7.8 feet MLW (FEMA, 2014b). Sea-Level rise was calculated to be 3.81 mm/year (NOAA Tides and Currents, 2016). Generally, the low marshes are the areas that will be impacted most by sea-level rise at CSRA. However, the upland is low enough that the marsh may be able to migrate landward with sea level.

Submerged aquatic vegetation (SAV) is dense along the nearshore of CSRA. Because the SAV is close to the shoreline, naturally any management recommendations for this property must take it into consideration. Many oysters are distributed throughout the marsh around the property.

3 Oyster Bag Sills

Oyster shells have been used in Chesapeake Bay for decades to promote growth for oyster harvesting. In particular, oysters have been grown on shell bags since the 1950s to develop spat that could be readily transplanted. It became more popular in the 1960 and 1970s when multinucleated sphere unknown (MSX) and Perkinsus marinus (dermo) diseases impacted the oyster population and research on oyster life cycle and production began in earnest (Seagrant, 1972). By 1971, it is estimated that over 100,000 shell bags were set out in rivers around Chesapeake Bay. The goal of these bags was different than for the present project; bags were planted in the early summer so that spat would settle on them. In the fall, the bags were removed and sold if they contained 400-1,000 spat that are 0.5 to 1-inch long. This method fell out of favor as easier methods of spat growth were developed.

More recently, interest in oyster bags has been revived to not only promote oyster growth, provide habitat, and improve water quality, but also to provide shore protection. In general, the oyster bag sill has two components that work together to provide these attributes. Oyster bags offer habitat and reduce wave action so that the marsh can flourish. Research has shown that, in general, the habitat created or stabilized by the marshes in living shorelines will serve as critical nurseries for many important marine species, filter pollutants from stormwater runoff, the most significant water quality pollutant in many areas, provide aesthetic value with natural views, and protect the land from wave energy, storm surges and tides (Arkema, Scyphers, & Shepard, 2017).

In their natural settings, oysters in reefs attenuate waves, stabilize sediments, and reduce marsh retreat (Dame & Patten, 1981; Meyer et al., 1997; Piazza et al., 2005). Studies in estuaries along the Gulf of Mexico found that creating patchy and fringing oyster reefs effectively reduce marsh retreat by an average of 3 ft/year (Peyre et al., 2015; Stricklin et al., 2010) and provide as much shore protection as natural reefs. Research also has shown that constructed oyster reefs recruit oysters and harbor a diverse community of fishes and mobile invertebrates (Scyphers et al., 2010). However, adjacent habitats and bathymetric features can influence community composition and total abundance of fauna (Geraldi et al., 2009; Grabowski et al., 2005.)

The question then becomes, can oyster bag sills provide the same habitat and shore protection benefits? Early research on oyster bags indicated that shell bags that are slightly elevated off the bottom have better water circulation and recruit more oysters because the bottom shells can become befouled with slime, barnacles, and algae (Seagrant, 1972). So, the stacking of bags in sills can create more area for shellfish recruitment. Bishop and Peterson (2006) found that the intermittent exposure of intertidal oyster installations had less fouling and provided partial refuge from biological enemies. Research on shell bag intertidal oyster reefs in Delaware found that oysters were recruited shortly after the reefs were constructed; motile macrofauna immediately began using the reefs which gave the oyster reef increased species diversity and abundance when compared to an adjacent sand flat; and finally, most of the oysters survived the winter's snow and ice (Taylor & Bushek, 2008).

Another consideration is long-term effectiveness of the oyster bag sills. Research on oyster reefs has shown that oysters degrade rapidly in an estuarine environment, having a half-life of 2-10 years (Powell, Kraeuter, & Ashton-Alcox, 2006) leading to uncertainty over the long-term. Another consideration for long-term effectiveness is how the artificial reef will react to sea level rise.

Containing the shells in bags is important for stability of the shore protection structure. However, the plastic netting that is used to hold the shells has become a concern in recent years. Research has shown that plastic debris in water separates into smaller and smaller pieces and eventually becomes tiny microplastics in the water. These microplastic particles accumulate as marine debris, settle into sediment, and are ingested by marine fauna. If the oyster bags break down, they may be contributing to the microplastic problem within Chesapeake Bay. Other materials would be more difficult to use. In the 1970s, VIMS recommended plastic bags over the chicken wire because it would corrode and disappear within a year (Seagrant, 1972). No research was found that tested viable alternatives to plastic mesh bags although coir mesh is being investigated.

4 Existing Oyster Bag Sill Sites

To determine how oyster bag sills performed through time in Chesapeake Bay several sites were selected for site visit and review. Their locations are shown in Figure 4-1, and general site information is shown in Table 4-1.

Figure 4-1. Location of oyster bag sill sites that were assessed.

4.1 Site 1: NE Branch Sarah Creek 2011

Permit application number: 100045; Location: 37°15'40.89"N 76°27'56.47"W

The Site 1 project is located on Northeast Branch of Sarah's Creek (Figure 4-2). Before the project, the site shoreline consisted of an exposed and eroding upland bank and eroding marsh fringe (Figure 4-3). The oyster bag sill was installed in the spring of 2011 along approximately 190 linear feet of shoreline that was protected using 175 linear feet of oyster bag sill (Figure 4-4). The gapped oyster bag sill was constructed with 15 bags per foot and is 2.5 feet high, and about 266 cy of sand fill was placed in an area of about 3,610 ft^2. Marsh grass plantings of *S. alterniflora* and *S. patens* were placed landward of the sill on about 2 ft centers (Figure 4-5). About 100 ft^2 of existing *S. alterniflora* was impacted by the project. Filter cloth was installed under and landward of the oyster bags. A revetment along portions of the eroding, upland bank was added later.

Table 4-1. Existing oyster bag sill site parameters.

Site	Shore Orientation	Shore Type	Mean Tide (ft) (ft)	Avg Fetch (miles)	Longest Fetch (miles)	Distance to 3 ft MLW Contour (ft)
1	Southwest	upland & fringe marsh	2.3	0.12	0.38	161
2	Southeast	marsh	2.3	0.77	23.11	363
3	Southeast	marsh	2.3	0.32	1.74	140
4	Southwest	upland & fringe marsh	2.3	0.11	0.2	33
5	East	upland & fringe marsh	2.5	0.14	0.27	NA
6	Southwest	marsh	2.3	0.29	1.12	253

The site visit in September 2018 showed that the oyster bag sill was mostly intact although it has settled slightly such that some areas of the sill are not above high water (Figure 4-6). It is acting as a toe sill by perching the sand fill, and some fine-grained, muddy material has been deposited behind the sill. Oyster recruitment has been significant although mortality along the outside of the sill has occurred most likely due to ice over the winters. However, ribbed mussels and oysters have developed on the interior of the sill. Some of the bags had been split open on the outside of the sill; This likely was due to scavenging by racoons, muskrats, and crabs and by expansion due to internal ribbed mussel growth (personnel comm., W. Priest, Sept. 2018). Other fauna noted during the site visit were large numbers of fiddler crabs and juvenile fish both landward and riverward of the sill (Figure 4-7). The project had evolved to a narrow *S. alterniflora* and *S. patens* fringe with a wide, open sandy area in the middle

(Figure 4-6). Additional sand may have been placed along the shoreline. A site visit in 2016 showed that the sand came up to the back of the sill and was not planted in grass (Figure 4-8). The grass also may be controlled with herbicides as indicated by the brown grasses (Figure 4-7); however, that cannot be confirmed.

This project has been successful both in terms of habitat creation, shellfish recruitment, and shore protection. This site has been through Hurricane Sandy in 2012 and Matthew in 2016. However, maintenance sand may have been placed, and the plants have not filled in the bare area along the shoreline.

Figure 4-2. Google Earth images showing the location of Site 1.

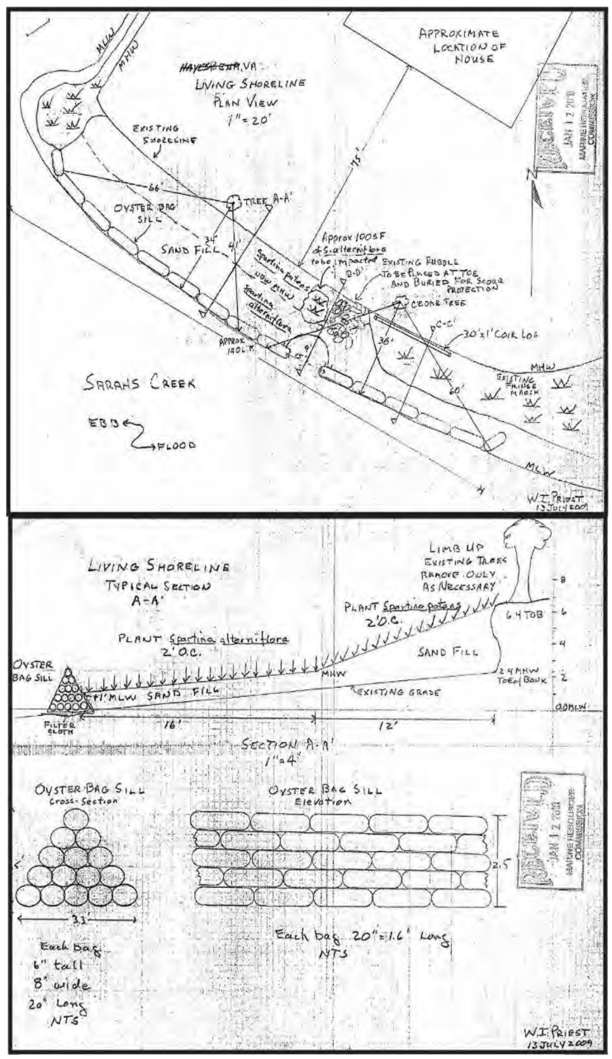

Figure 4-4. Site 1 oyster bag sill planform and cross-section from the permit application.

Figure 4-3. Site 1 before project installation. The marsh is eroding and an upland bank is exposed and eroding. Photo credit: VMRC permit application uploaded 28 Oct 2010.

Figure 4-5. Post bag and sand installation at Site 1. The sand fill is visible landward of the sill, and volunteers planted grasses on the fill. Photo credit: Walter Priest, 29 June 2011.

Figure 4-6. Present condition of Site 1 oyster bag sill (6 September 2018).

Figure 4-7. Fauna visible at Site 1 oyster bag sill. Juvenile fish also were visible.

4.2 Site 2: York River 2012

Permit application number: 120707; Location: 37°15'33.61"N 76°25'44.82"W

The Site 2 project is located on the York River behind Allens Island (Figure 4-9). Before the project, the site shoreline consisted of an exposed marsh (Figure 4-10). Though the site is on the York River, it is protected by the Allens Island marsh and generally has a low erosion rate (0 to -1 ft/yr) and average fetch of less than 1 mile. Approximately 201 linear feet of marsh toe oyster bag sill was installed in 2012. Bags were placed by hand in stacks of three (Figure 4-11). An oyster castle also was incorporated into the site. The project impacted approximately 657 ft^2 of nonvegetated wetlands.

Figure 4-8. Site 1 shown in 2016 approximately four years after installation.

During the September 2018 site visit, it was evident that the oyster bags are successfully abating erosion along the shoreline (Figure 4-12). The marsh is growing up to and sometimes through and in front of the bags. Oysters are growing in and on the bags and the oyster castle. Because of the somewhat higher energy environment, these oyster bags are clean compared to the bags at Site 1. Fiddler crabs were prevalent at the site, but the bags were intact and not subject to predation.

Location 4-9. Location of Site 2 on the York River. Google Earth images.

Figure 4-10. Site 2 before project installation. Because tide level is up, the eroding marsh cannot be seen. Photo credit: VMRC permit application uploaded 6 June 2012.

Figure 4-11. Placement of bags along the shoreline. Photo credit: Walter Priest, 14 Oct 2012

Figure 4-12. Site 2 sill in September 2018.

4.3 Site 3: Free School Creek 2014

Location: 37°19'55.40"N, 76°26'40.81"W

The sill at St. Johns Point on Free School Creek, which is a tributary of the Severn River, was part of a shore protection project for the entire site (Figure 4-13). Two rock sills with sand and marsh plantings were built along the more exposed shoreline. An oyster bag sill was placed in front of existing marsh on the less exposed section of shoreline that faces southeast (Figure 4-14). In addition, the bags were placed to follow low water in front of an eroding section of marsh.

Figure 4-13. Location of oyster bag sill at Site 3, St. Johns Point on Free School Creek.

After three years, the marsh was growing in front of the bags in one section of the sill. After four years, the area behind the bags has filled in with marsh, creating a nice marsh fringe at the site that has grown in front of the bags in some areas of the project (Figure 4-15).

Figure 4-14. Oyster bag sill at Site 3, St. Johns Point on 10 May 2017 approximately 3 years after placement.

Figure 4-15. Oyster bag sill at Site 3, St. Johns Point in September 2018 approximately 4 years after placement.

4.4 Site 4: NW Branch Sarah Creek 2017

Permit application number: 161094; Location: 37°16'0.99"N, 76°29'12.77"W

Site 4 on the northwest branch of Sarah Creek (Figure 4-16). Prior to the project installation, the shoreline was a small marsh fringe and an eroding, scarped upland bank (Figure 4-17). The project was installed in the spring/summer of 2017. The sill system extends about 264 linear feet along the shoreline as it curves around the upland bank from pier to pier with a 3 ft wide and 2 ft tall structure, sand fill, and 2,640 ft^2 marsh grass planting (Figure 4-18). The nearshore bottom is firm allowing for minimal structure settlement, and a filter cloth was placed under the structure. Both *Spartina alterniflora* and *Spartina patens* were planted. The oyster bag sill along the west facing segment has a 10 bag sill, 4 bags high, about 10 feet from the base of the bank with a top elevation of the sand and sill about +1.5 ft MLW (Figure 4-18). The bags were placed by hand, backfilled with sand, then the marsh grasses planted (Figure 4-17). Over the past year, the plants have coalesced into a vibrant marsh fringe (Figure 4-19, top right). The *S. patens* has begun stabilizing the upland base of bank. There is sparse oyster growth due in part to this past winter's heavy ice (Figure 4-19, top left).

The south side of the Site 4 is a 9 bag sill, 3 bags high. The bottom is soft and some settlement occurred during construction resulting in a sill crest elevation of about + 1.0 MLW. By September 2018 the vibrant marsh fringe continued around to the south coast (Figure 4-19, bottom left). However, the owner was still concerned about the base of bank scarp so he moved the top bag from the sill and placed it along the bank (Figure 4-19, bottom right). Oyster recruitment is concentrated along the bottom 2 rows of bags, perhaps below the impact of ice last winter.

Even though the project is just a year old, the marsh has filled in behind the structure and the upland bank has been stabilized. Though no significant storms have affected the site, the established marsh should help protect the shoreline over time.

Figure 4-16. Location of Site 4 along Sarah Creek.

Figure 4-17. Site 4, Top left: Shoreline prior to the project on 26 May 2016; Top right: May 2017 prior to the bags being placed; Bottom left: after bags were placed in May 2017; and lower right: after the grass was planted in July 2017. Photo credit: Walter Priest.

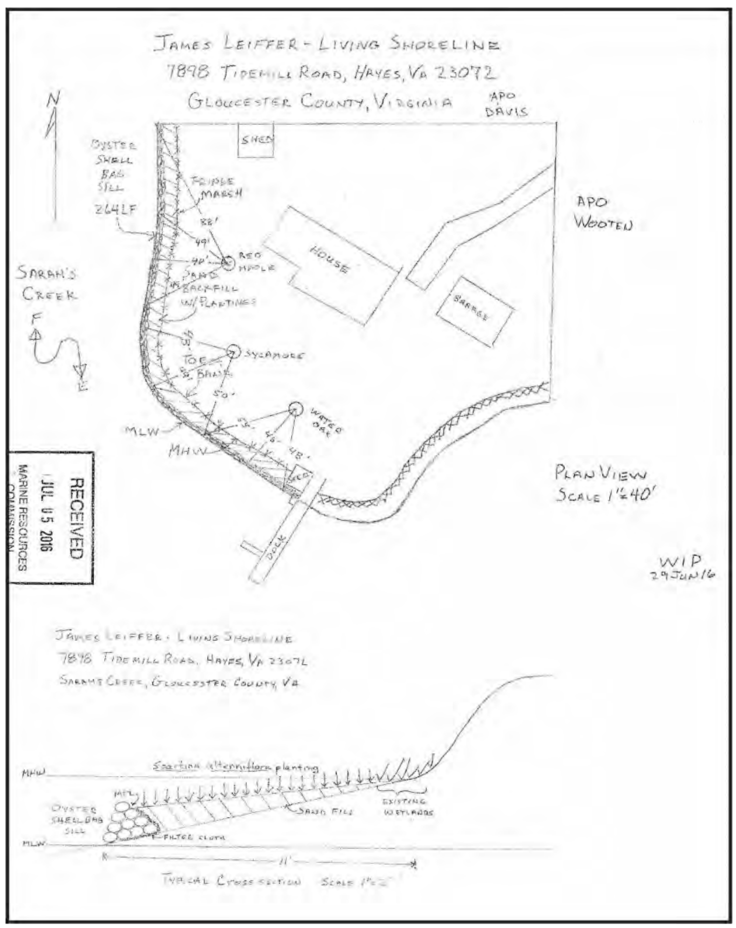

Figure 4-18. Permit application drawings for Site 4.

Figure 4-19. Site 4 oyster bag sill in September 2018.

4.5 Site 5: Cedar Bush Creek 2016

Permit application number: 160213, Location: 37°18'43.27"N, 76°33'9.52"W

Figure 4-20. Location of Site 5 on Cedar Bush Creek.

Site 5 is located on Cedar Bush Creek in Gloucester County (Figure 4-20). Cedar Bush is a small tributary to the York River. It is very shallow in the area of Site 5 with depths being less than 3 feet mean low water. Facing southeast, the site has a very low fetch. However, prior to the project, the site had an eroding upland bank and narrow fringing marsh in some areas (Figure 4-21). The site was constructed in summer 2016 and consisted of a 15 bag triangle configuration (five bags at the base) from mean low water shoreward along 170 linear feet (Figure 4-22). Approximately 128 cy of sand was pushed over the bank by bobcat, and *Spartina alterniflora* planted (Figure 4-23). No bank grading occurred, and the bank is being allowed to slough naturally. Overall encroachment was 24 ft from mean high water.

This sill has about 1.5 bags above high water and is the highest that was assessed for this project. The bags out of the water will not provide substrate for oyster growth, but oysters have been recruited on the lower bags. The marsh is growing in behind the structure (Figure 4-24). After nearly two years, the structure is intact and is providing protection for the shoreline.

Figure 4-21. Site 5 during construction. Top: the bags are stacked in a 15 bag triangle at low water. Middle: the eroding upland bank was not graded. Bottom: the sill under high water. Photo credit: VMRC permit application.

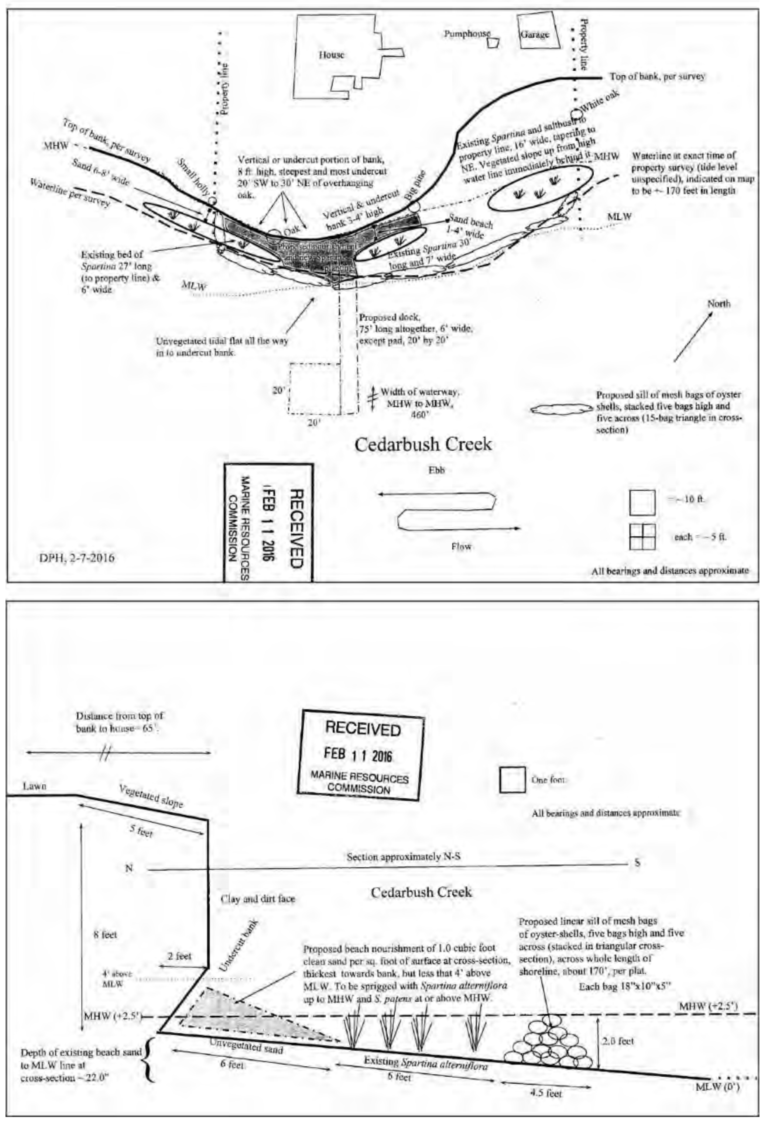

Figure 4-22. Permit application drawings for Site 3.

Figure 4-23. Site 5 during construction. Top: Sand was placed along the shoreline. Bottom: Marsh grass was planted. Photo credit: VMRC permit application.

Figure 4-24. Site 5 on March 28, 2018. After nearly two years, the bags are still intact and have stayed as placed. Marsh has filled in behind the structure. Oysters have been recruited along the sill.

4.6 Site 6: Whittaker Creek 2016

Permit application number: 160281, Location: 37°19'31.86"N, 76°25'54.81"W

As part of a National Fish and Wildlife Foundation grant, VIMS Shoreline Studies Program installed a small oyster bag sill along Whittaker Creek as a test site (Figure 2-4). The site was an eroding marsh scarp that had a very low erosion rate (Figure 4-25). The average fetch was low, but the longest fetch is over a mile. The site was stabilized with a 3-bag oyster sill approximately 60 feet long (Figure 4-26). No additional marsh grass was planted. The bottom was very soft and the lower layer of bags had to be installed to walk on to place the rest of the bags (Figure 4-25).

This oyster bag sill has been very successful in terms of both shore protection and habitat creation. After two years, the oyster bags are still intact, and many oysters are growing on the bags. Sediment has been deposited behind the structure, and the marsh edge is no longer scarped behind the

Figure 4-25. Site 6 Top: prior to installation, the site had an eroding marsh. Bottom: a 3-bag oyster bag sill was installed in July 2016.

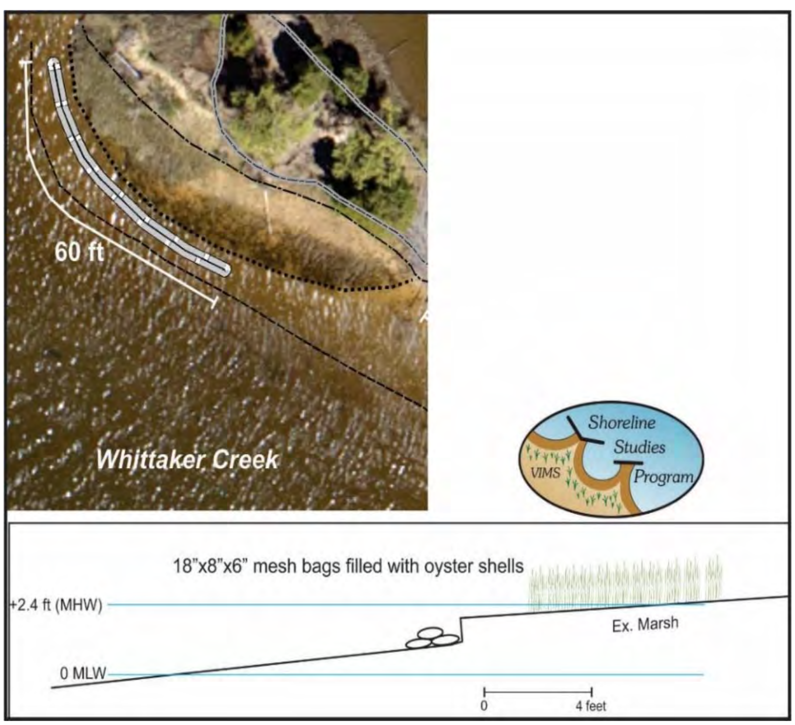

Figure 4-26. Planform and cross-section from the permit application for Site 6.

structure as it is along the marsh adjacent to the project (Figure 4-27). In addition, marsh grass runners are extending toward the sill on the newly deposited sediment.

Figure 4-27. Site 6 oyster bag sill two years after installation. The sill has provided shore protection and created habitat. A great many oysters are growing on the bags. In addition, sediment has come in behind the sill, the marsh is no longer scarped, and marsh grass runners are extending toward the sill.

5 Sill Construction and Monitoring

5.1 Heritage Park

Though Heritage Park has a relatively low fetch, it was chosen as a demonstration site because it has natural oysters and it has both upland and marsh shorelines. The design consisted of three bags (two on the bottom and one on top) placed along shore in a gapped configuration with four sections of sill approximately 60 ft, 80 ft, 100 ft, and 60 ft (Figure 5-1). The permit was received from the Corps of Engineers on March 7, 2017. The 600 oyster bags were placed by VIMS, Shoreline Studies Program and Vessel Operations personnel on March 28, 2017 with the assistance of Christopher Newport University's Invertebrate Zoology class in cooperation with Dr. Heather Harwell, assistant professor in the Department of Organismal and Environmental Biology. Site construction information is shown in Appendix A.

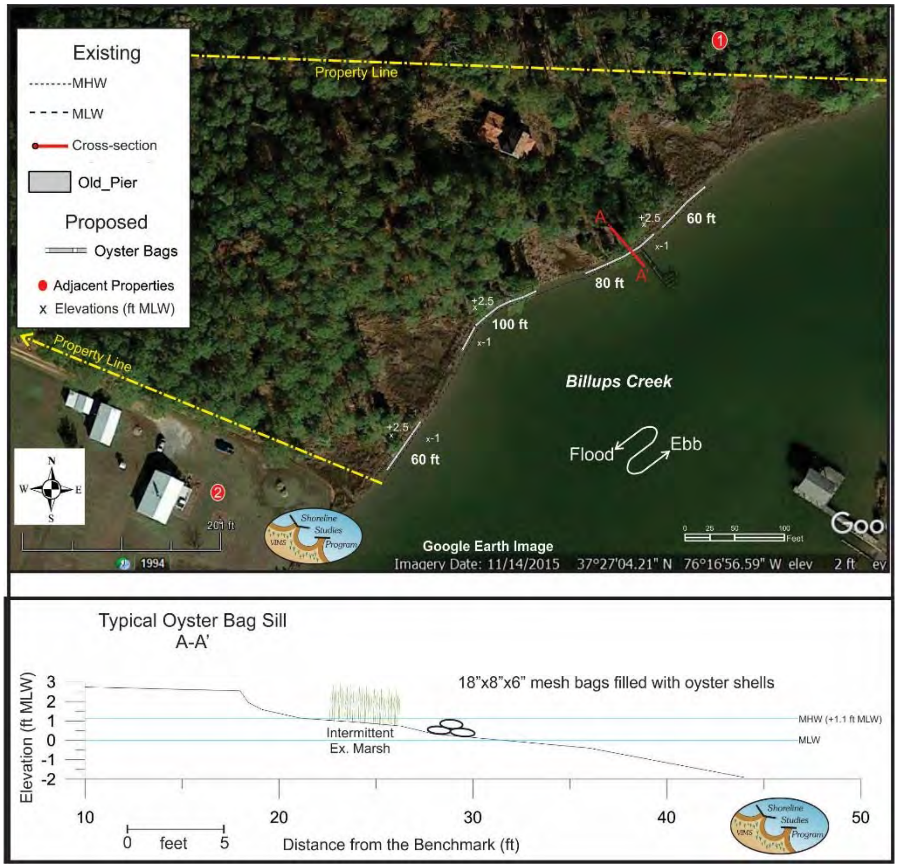

Figure 5-1. Planform and typical cross-section for the oyster bag sill project at Heritage Park.

Prior to installation of the project, the upland and marsh shoreline were exposed and eroding (Figure 5-2). The oyster bag sills were placed in front of both the upland and the marsh shorelines.

Figure 5-2. Heritage Park shoreline prior to the installation of the oyster bag sill. Both marsh and upland sections of the shoreline were eroding.

During construction, the sill design was modified somewhat based on site conditions (Figure 5-3). Sills 2, 3, and 4 were constructed as designed; however, Sill 1 was shortened slightly to create a wider gap for a kayak launch. The extra bags were placed on Sill 3. The center section of Sill 3, where it is adjacent to the upland section of shore, was built as a 5 bag sill, 3 bags on the bottom and two on the top. This widened the sill to provide more protection to the eroding upland bank.

Biologic monitoring (Appendix B) showed both live and dead oysters had been recruited to the bag and a large diversity of macrofauna inhabiting the sill. These data were taken in early August 2018 so the sill had 1.5 years (two summers) for recruitment. Measuring each shellfish (oyster live spat and box, ribbed mussels) was prohibitive though the total number present in each bag was counted. A random subsample of about 30 of each shell type was measured for size. Nearly 400 to 500 mussels with an average shell size of 19.1 mm were found in each collected bag. The live oysters in each bag numbered 64 and 86 had an average length of 36.5 mm.

Overall, the sill has remained intact over the 1.5 years that it has been installed (Figure 5-4). The bags have remained in place with no apparent sinking or movement landward. Visual inspection determined that some fine-grained sediment is accumulating behind some sections of the structure (Appendix C) though it was not measured.

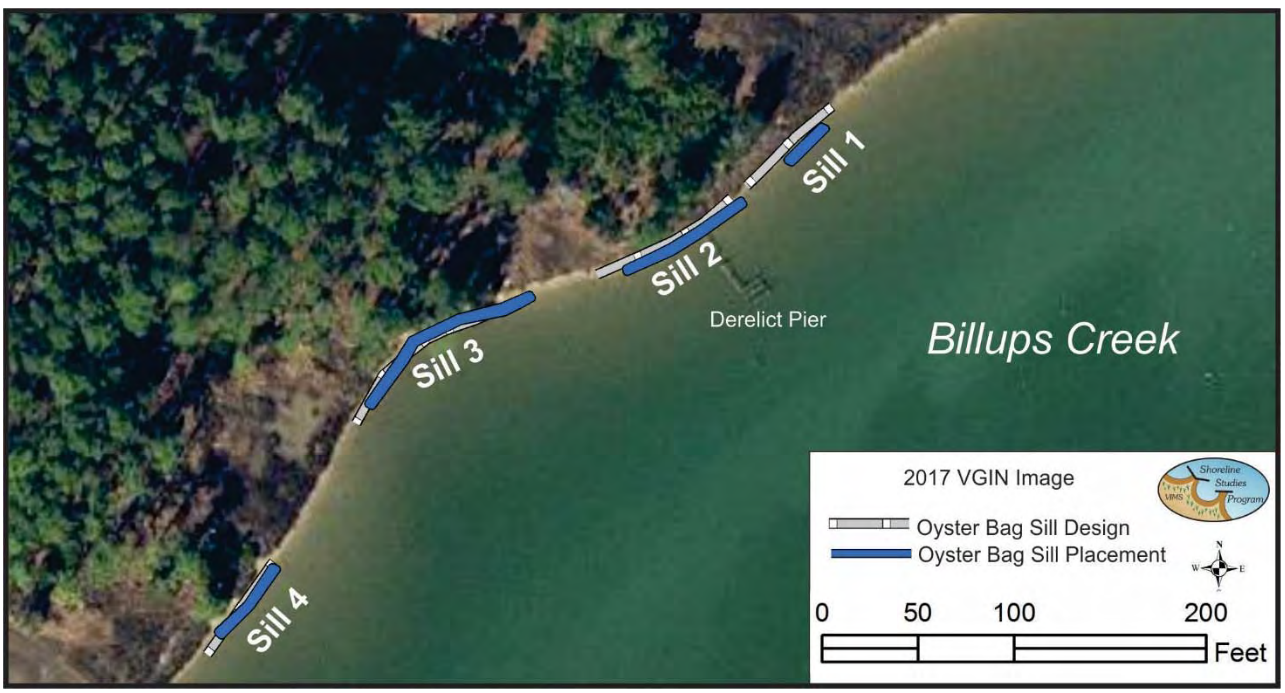

Figure 5-3. Location of the oyster bag sills as designed (gray) and actual placement (blue).

Figure 5-4. Heritage Park three months after construction (June 29, 2017).

5.2 Captain Sinclair's Recreational Area

The existing marsh at CSRA had a scarped, eroding edge (Figure 5-5). The marsh point has two directions of face that have two relatively different fetches. The southwest facing shoreline has an average fetch of about 0.85 miles and the southeast facing shoreline has an average fetch of about 1.02 miles. For this reason, the design consisted of three bags (two on the bottom and one on top) on the southwest facing shoreline and six bags (three on the bottom, two in the middle, and one on top) on the southeast facing shoreline. The bags were placed along shore in gapped sections of sill. Lengths ranged from 80-100 ft long (Figure 5-6). The permit was received from the Corps of Engineers on July 31, 2017.

The 2,000 oyster bags were placed on August 15-16, 2017 by VIMS, Shoreline Studies Program personnel with the assistance of representatives from the Department of Conservation Shoreline Advisory Service and the Virginia Marine Resources Commission. In addition, several local teens and young adults volunteered to build the sill. Oyster bags were loaded offsite and brought by boat to the marsh for placement (Appendix A). The bags were placed directly adjacent to the eroding marsh in deeper areas and slightly offshore in more shallow areas so that the structure was at approximately low water (Figure 5-7). This would provide an intertidal range for the sill.

The site was monitored for biologic impact on April 3, 2018 by students in the Christopher Newport University's Invertebrate Zoology class in cooperation with Dr. Heather Harwell, assistant professor in the Department of Organismal

Figure 5-5. Existing shoreline along the marsh at CSRA, August 6, 2017.

and Environmental Biology. Although the site only had a fall and winter on the ground, a diverse group of macrofauna inhabited the sill (Appendix B). Top bags were sampled from Sills 5, 6, and 7). Both live and dead oysters as well as ribbed mussels were present on and in the bags. On two of the three bags sampled, there were more live oysters than dead which indicates they survived their first winter.

The site was surveyed by real time kinematic global positioning system on September 8, 2017 and April 3, 2018 (Appendix C). The survey shows that the oyster bags were placed similar to what was designed (Figure 5-8). However, only three sections of sill were built on the southeast facing shoreline while 5 sections were built on the southwest facing shoreline because shore conditions were different at the time of installation. The 6-bag sill was wrapped around the southernmost point very close to the marsh to provide additional protection to the area with the largest erosion rate. A duck blind is located close to the shore in this area.

Between September 2017 and April 2018, little change occurred along the shoreline. Survey results indicate that mean high water and mean low water are relatively unchanged (Appendix C). In some areas, there is indication that sediment has been deposited behind the sills though likely not enough to be measurable. The was most notable along sills 6, 7, and 8 which are exposed to a lower fetch (Appendix C).

Overall, the 6-bag sill has fared very well. It has remained intact over the past year. The 3-bag sill has had mixed results. The sections of sill that are farther north, and therefore are more protected, remained intact as did those that were placed close to the marsh. However, the top bag on the 3-bag sills that were placed farther from the marsh because of the slope of the intertidal area tended to roll (Figure 5-9). This was even more noticeable in July 2018 (Figure 5-10). This section of shoreline has a higher average fetch than the existing oyster bag sills that were described in Section 4 which may account for the difference in sill structure. No definitive data has determined whether or not the change in structure will affect the role the bags play in shore protection.

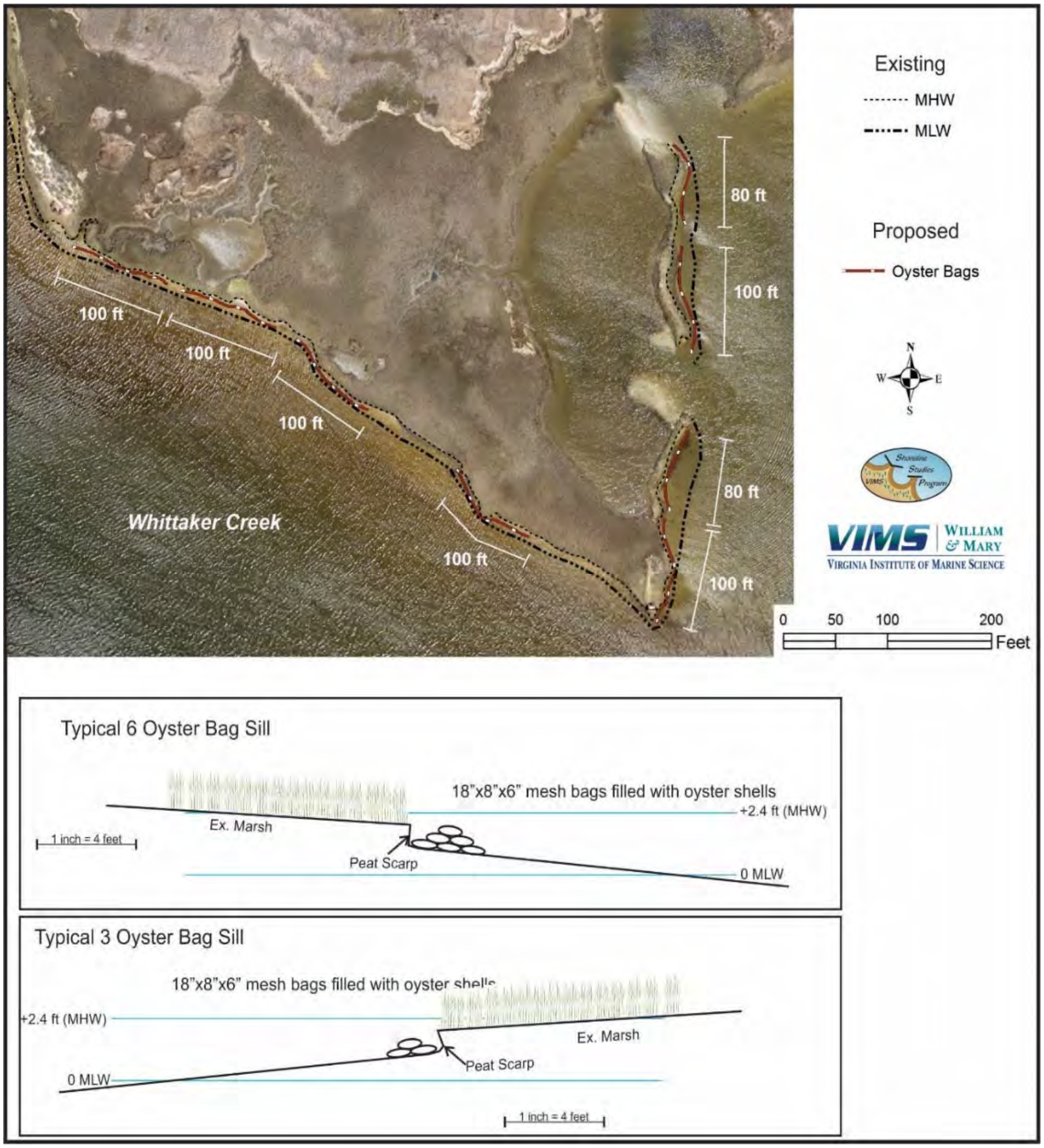

Figure 5-6. Permit application drawing for the oyster bag sill at CSRA. The southwest facing shoreline has the 3 bag sill and the southeast facing shoreline has the 6 bag sill.

Figure 5-7. Construction of the 3-bag sill (left) and 6-bag sill (right). Photo credit: Linda Tjossem.

Figure 5-8. Comparison between the location of the oyster bags sills (numbered 1-8) in the design (white)and what was installed (blue).

Figure 5-9. The three bag sill (top) that was placed on the southwest-facing shoreline has not been as stable. The top bag of some sections were rolled toward the shoreline. The six bag sill (bottom) on the point and the southeast-facing shoreline has remained intact.

Figure 5-10. The 3-bag sill tended to remain intact when placed close to the eroding marsh scarp (left). However, when the bags are placed at low water farther from the shore because of the gentle slope of the intertidal area, they tended to roll.

6 Conclusion

The oyster bag sill is a living shoreline management strategy that can create habitat, mitigate erosion, and provide climate change adaptation in Chesapeake Bay. These shore protection structures restore oyster and other shellfish habitat, and as they will not be harvested, they lead to long-term habitat creation. The assessment of existing sites that have been in place for several years indicates that in low fetch situations (<1 mile), oyster bag sills can provide shore protection through the creation or stabilization of marsh. The design of the sill should be site specific; larger fetches should have larger structures, and the bags should be placed closer to the eroding marsh scarp particularly along sites with a sand platform. When placed farther from the eroding marsh scarp, the top bags tended to roll toward the shoreline. No bag movement occurred on the sills that consisted of 6 bags. Sites that were filled with sand and planted with grass had thriving marshes. However, initial monitoring of several oyster bag sills installed without sand fill and marsh plantings indicates that sediment can be deposited behind the structure allowing marsh grass to grow riverward. Additional monitoring is needed, though, to ascertain if the marsh will be maintained over the long-term.

Both sites on which sills were constructed had oysters present on the shoreline before the project. The existence of natural oysters at the site or along shorelines nearby is a good indication that spat may attach to the bags thereby working to cement the bags together. Other shellfish, particularly mussels, also were in abundance on the sampled bags. Shellfish recruitment is critical to the long-term stability of the structure in areas with larger fetches. For sites with smaller fetches, long-term stability of the structure did not seem to be an issue. At the oldest site which was seven years old, recruited oysters and mussels were plentiful inside the bags (though these existing sills were not sampled), and any degradation of shells that occurred did not impact the stability of the structure.

Predation can be an issue for oyster implementations because the predators open the bags which can lead to scatter. Carrol et al. (2015) found that oyster recruitment was higher on systems that were shielded from predators; however, this may not be practical at most sites and, in truth, the open bags were not an issue.

Several lessons were learned for making construction easier – organize volunteers into specific jobs. Jobs included loaders who loaded the bags onto the boat. In the boat, the boat captain and one other person helped stack the bags. At the site, designated people offloaded the bags to those that handed them to the placers. The placers worked in concert to build the sill. Working at low tide was easiest, but the volunteers were able to keep working through mid-tide.

Finally, the Captain Sinclair's site is pushing the limit relative to the fetch >1.0 miles for this type of shore protection structures. The main purpose of each installation is abatement of erosion. However, it also is important that the sill becomes solidified with oysters or other binding organisms. This improves not only the shore protection component but also the habitat restoration component.

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Appendix A

Sill Construction
Heritage Park: 28 March 2017
Captain Sinclair’s Recreational Area 15-16 August, 2017

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Heritage Park, Mathews, Virginia

Oyster bag sills were delivered to the site by truck on pallets.

Pallets were moved close to the loading site by tractor.

Metal pipe was installed to lay out the locations for the sills.

The oyster bags were loaded onto a boat for transport to the site.

Oyster bag sills were transported across the creek by boat.

Students handed the bags to others who then placed the bags in water. Bags weigh about 25 lbs, and gloves are needed for handling.

Heritage Park, Mathews, Virginia

The gap between Sill 1 and 2 was left so that it could be used as a kayak launch. It was marked for that use.

Volunteers: Invertebrate Zoology class, Spring 2017, Christopher Newport University, Heather Harwell, professor.

Captain Sinclair's Recreational Area, Gloucester, Virginia

The 2,000 oyster bags were brought to a staging site by truck on pallets.

Lack of access at the site of placement meant that the bags had to be transported by boat. Because a 5 ft bank occurred at the staging area, a wooden ramp was built so the bags could slide down.

At the marsh, bags were offloaded to volunteers in the water.

Two people handed bags while another two placed them.

One person placed the two bottom bags and the second person placed the one top bag.

Because the bags had to be transported to the site, some downtime occurred for the volunteers placing the bags.

Captain Sinclair's Recreational Area, Gloucester, Virginia

To minimize downtime, two boats were run so that one could be offloading while the other was loading.

The finished sill along one section of shoreline and eroding marsh. Photo credit Linda Tjossem.

Volunteers from VIMS, the Department of Conservation and Recreation, Virginia Marine Resources Commission, and high school students and young adults worked about 10 hours over two days to place the 2,000 bags.

Appendix B

Oyster Bag Sill Biologic Monitoring Data

Heritage Park: August 2018
Captain Sinclair's Recreational Area: April 3, 2018

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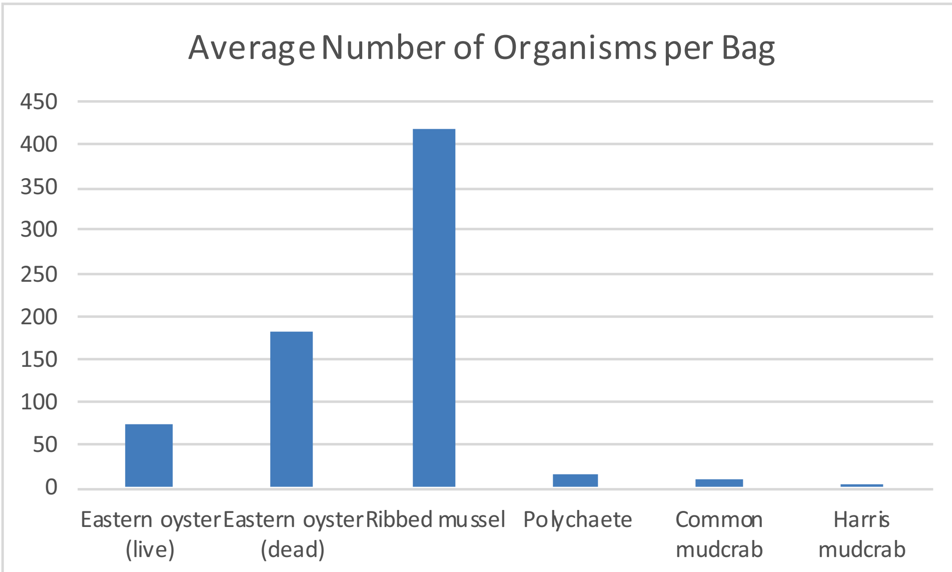
Heritage Park, Mathews, Virginia

Sampling Overview

Two bags were pulled from the Heritage Park oyster bag sill in August 2018. This data is the result of two summers of recruitment. With the help of volunteers, the macrofauna was counted. Because the abundance was too high to measure every shell, a subsample of about 30 shells was measured of live and dead oyster shells and ribbed mussels. In addition, salinity was likely lower than normal because of several large rain events immediately proceeding sampling.

Sampling Overview		August 2018		
Salinity: 15 psu				
Sampling Summary				
Bag	**Species**	**Common Name**	**Abundance**	
1	Crassostrea virginica (live spat)	Eastern oyster (live)	64	
1	Crassostrea virginica (box)	Eastern oyster (dead)	189	
1	Geukensia demissa	Ribbed mussel	364	
1		Naked Goby	1	
1		Polychaete	17	
1	Panopeus herbstii	Common mudcrab	16	
1	Rhithropanopeus harrisii	Harris mudcrab	1	
1		amphipods	to many to count	
2	Crassostrea virginica (live spat)	Eastern oyster (live)	86	
2	Crassostrea virginica (box)	Eastern oyster (dead)	179	
2	Geukensia demissa	Ribbed mussel	475	
2		Polychaete	11	
2	Panopeus herbstii	Common mudcrab	5	
2	Rhithropanopeus harrisii	Harris mudcrab	2	
2		amphipods	to many to count	

	Average Shell Height (mm)		
	Live Oyster	Dead Oyster	Ribbed Mussel
Bag 1	38.9	38.2	18.7
Bag 2	34.1	40.6	19.4
Average	**36.5**	**39.4**	**19.1**



Note: Amphipods were too many to count.

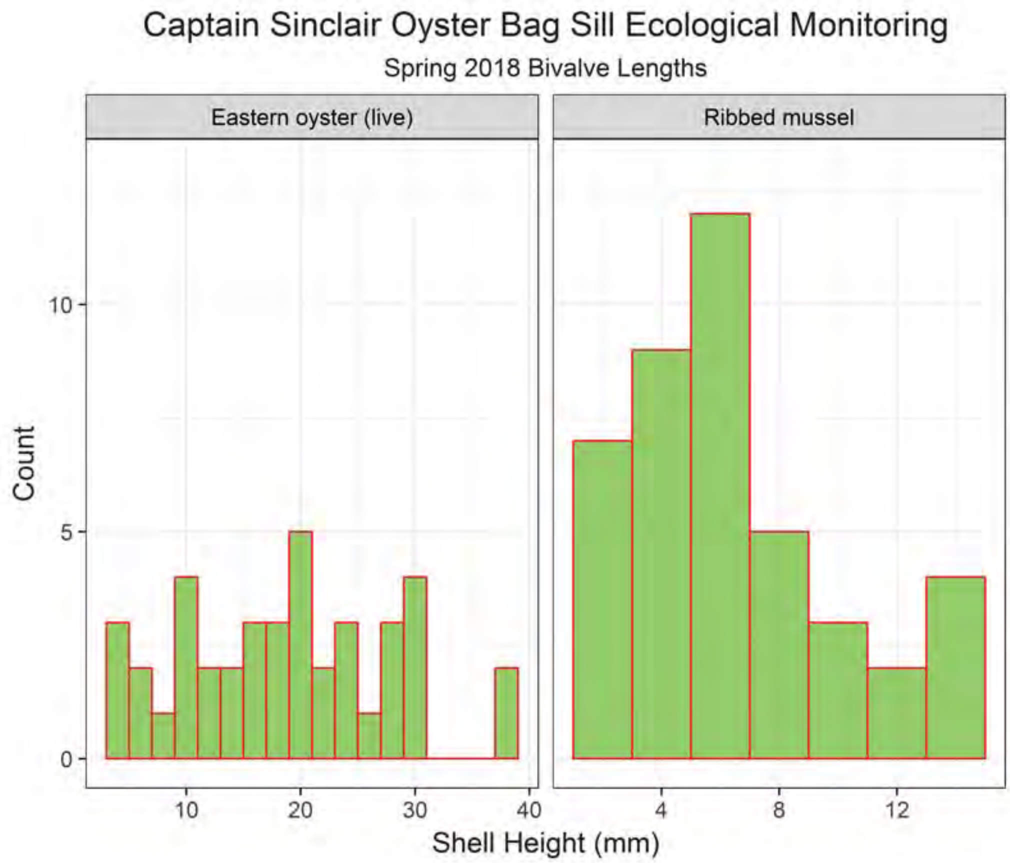
Captain Sinclair’s Recreational Area, Gloucester, Virginia

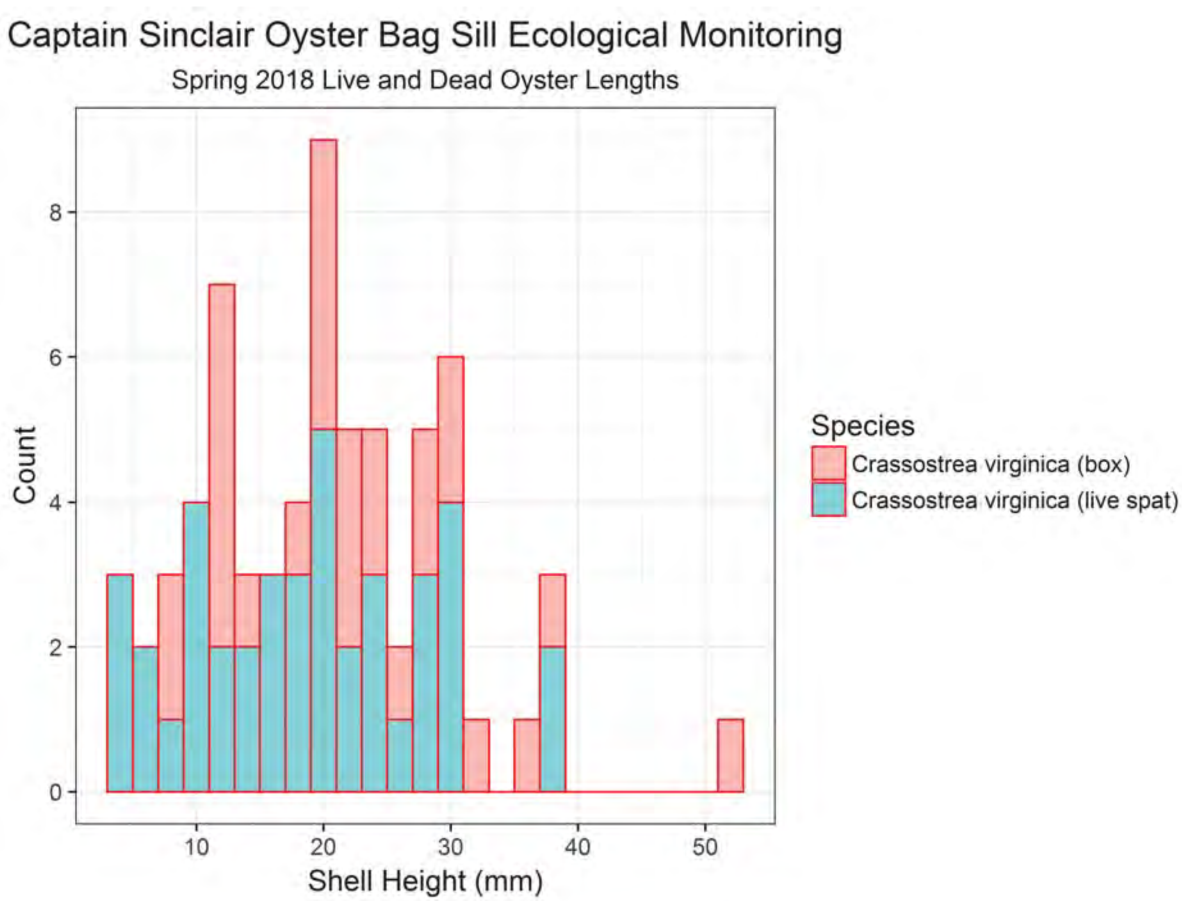
Sampling Overview
Three bags were sampled from the CSRA oyster bag sill in April 2018. This data is the result of one fall and winter of recruitment. With the help of volunteers from Christopher Newport University's Invertebrate Zoology class in cooperation with Dr. Heather Harwell, assistant professor in the Department of Organismal and Environmental Biology, the macrofauna was counted and measured.

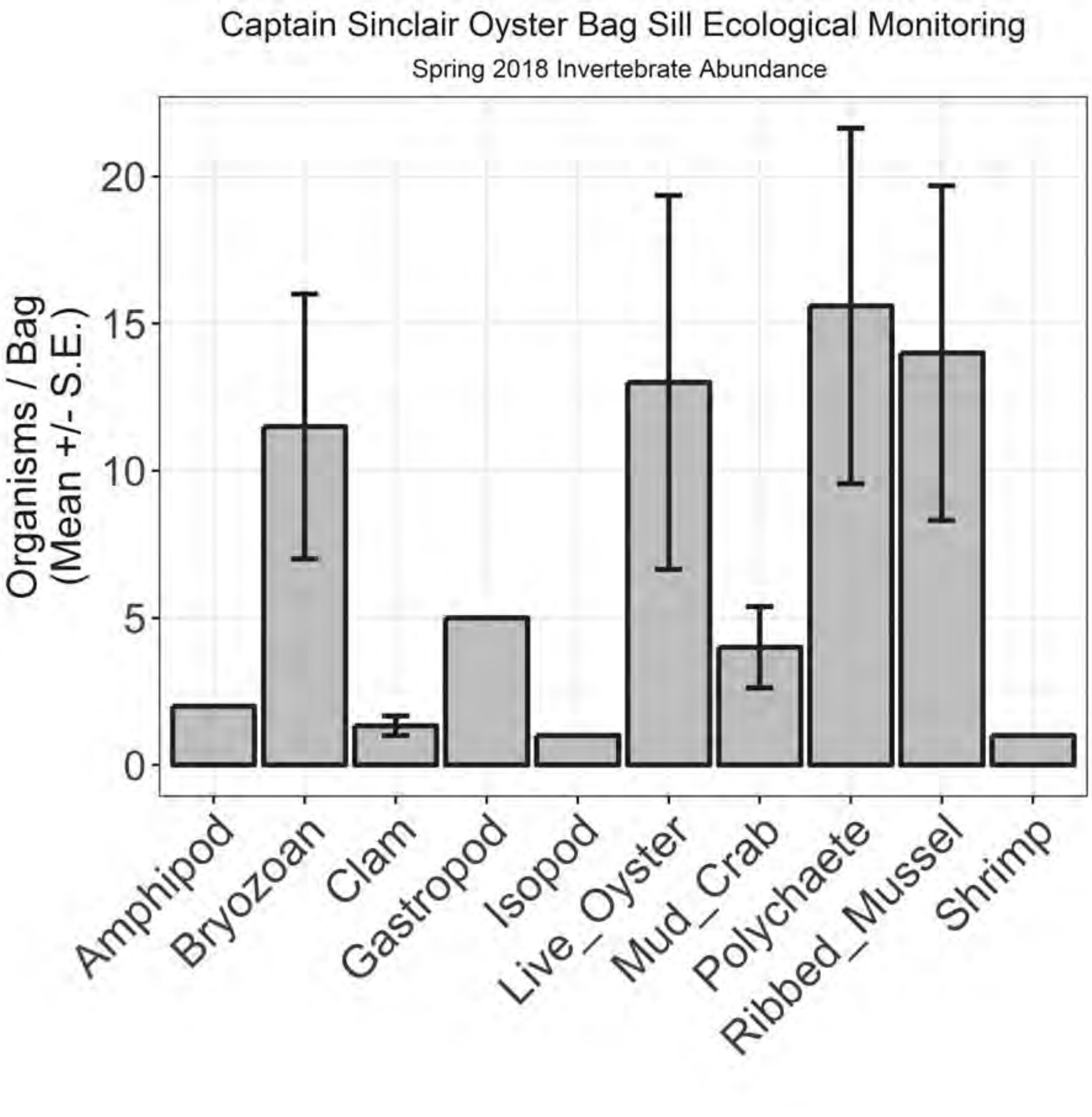
Date: 4/3/18				
Site: Captain Sinclair's				
Activity: Oyster Sill Monitoring				
Crew: VIMS and CNU Invertebrate Zoology Students				
Weather Conditions: Overcast, light wind				
Water Temp: 13°C				
Salinity: 20 psu				
Sampling Summary				
Bag	**Species**	**Common Name**	**Abundance**	**Notes**
1	Crassostrea virginica (live spat)	Eastern oyster (live)	2	
1	Crassostrea virginica (box)	Eastern oyster (dead)	15	
1	Crassostrea virginica (shell)	Eastern oyster (shell)	232	shell volumne = 4 1/2 gallons
1	Geukensia demissa	Ribbed mussel	25	
1	Nassarius vibex	Mottled dog whelk	5	
1	Mya arenaria	Soft-shelled clam	1	
1	Solen viridis	Stour razor clam	1	
1	Idotea baltica	Baltic isopod	1	
1	Common clamworm	Neanthis succinea	29	
1	Eurypanopeus depressus	Flat mud crab	4	
1	Dyspanopeus sayi	Equal-clawed mud crab	1	
2	Crassostrea virginica (live spat)	Eastern oyster (live)	24	
2	Crassostrea virginica (box)	Eastern oyster (dead)	6	
2	Crassostrea virginica (shell)	Eastern oyster (shell)	232	shell volumne = 4 1/2 gallons
2	Geukensia demissa	Ribbed mussel	11	
2	Common clamworm	Neanthis succinea	29	
2	Eurypanopeus depressus	Flat mud crab	9	
2	Membranipora tenuis	Coffin box bryozoan	16	
2	Petricola pholadiformis	False angel wing	2	
2	Gammarus mucronatus	Spine-backed scud	2	
2	Palaemonetes pugio	Grass shrimp	1	
2	Hydroides dianthus	Limy tube worm	2	
3	Crassostrea virginica (live spat)	Eastern oyster (live)	13	
3	Crassostrea virginica (box)	Eastern oyster (dead)	6	
3	Crassostrea virginica (shell)	Eastern oyster (shell)	242	shell volumne = 4 1/2 gallons
3	Geukensia demissa	Ribbed mussel	6	
3	Common clamworm	Neanthis succinea	16	
3	Eurypanopeus depressus	Flat mud crab	4	
3	Membranipora tenuis	Coffin box bryozoan	7	
3	Hydroides dianthus	Limy tube worm	2	
3	Dyspanopeus sayi	Equal-clawed mud crab	2	

	Average Shell Height (mm)		
	Live Oyster	Dead Oyster	Ribbed Mussel
Bag 1	8.1	22.9	8.5
Bag 2	16.4	16.8	4.9
Bag 3	26.4	28.3	5.2
Average	**17.0**	**22.7**	**6.2**

Bag 1 was taken from Sill 7
Bag 2 was taken from Sill 6
Bage 3 was taken from Sill 5


Captain Sinclair Oyster Bag Sill Ecological Monitoring
Spring 2018 Bivalve Lengths
Eastern oyster (live)
Ribbed mussel
Count
0
5
10
10
20
30
40
4
8
12
Shell Height (mm)


Captain Sinclair Oyster Bag Sill Ecological Monitoring
Spring 2018 Live and Dead Oyster Lengths
Count
0
2
4
6
8
10
20
30
40
50
Shell Height (mm)
Species
Crassostrea virginica (box)
Crassostrea virginica (live spat)


Captain Sinclair Oyster Bag Sill Ecological Monitoring
Spring 2018 Invertebrate Abundance
Organisms / Bag
(Mean +/- S.E.)
20
15
10
5
0
Amphipod
Bryozoan
Clam
Gastropod
Isopod
Live_Oyster
Mud_Crab
Polychaete
Ribbed_Mussel
Shrimp

Appendix C

Sill Monitoring

Heritage Park
Surveyed 26 Jan 2018, ten months after installation
Note: Water levels are 0.3 ft below mean low water.

Captain Sinclair's Recreational Area
Surveyed 8 September 2017, post-installation
3 April 2018, approximately eight months after installation

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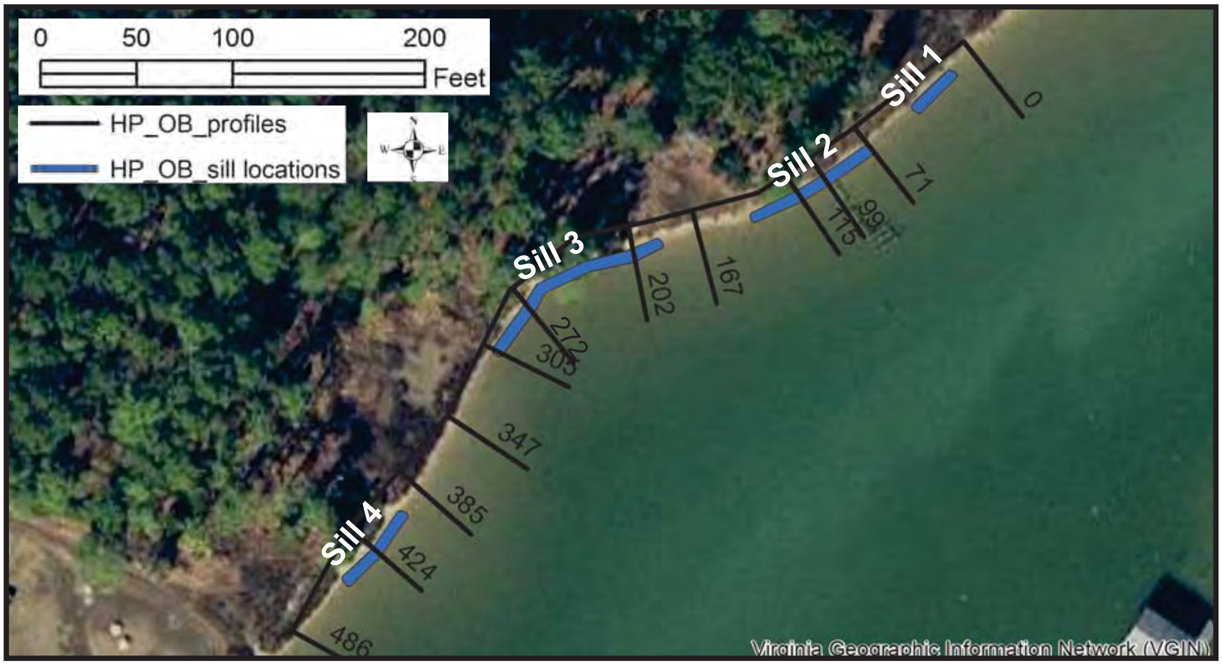
Heritage Park



Cross-sectional profile locations at Heritage Park.

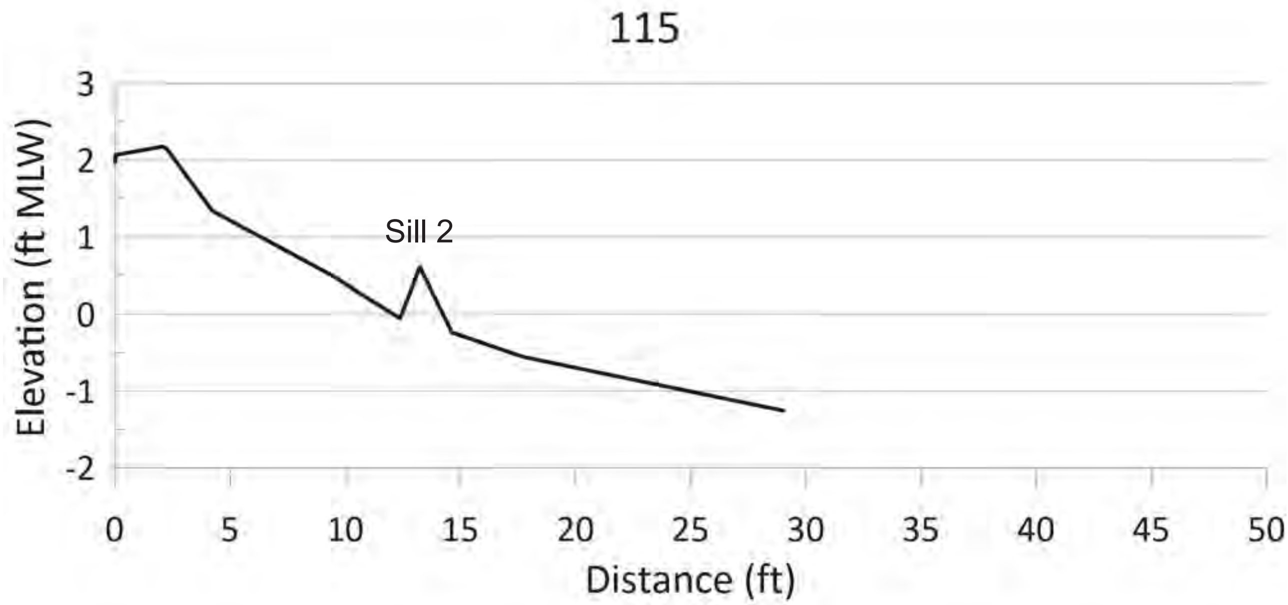
Oysters occur naturally in large numbers along this shoreline.

Heritage Park

Looking north from the Sill 1 at Heritage Park.

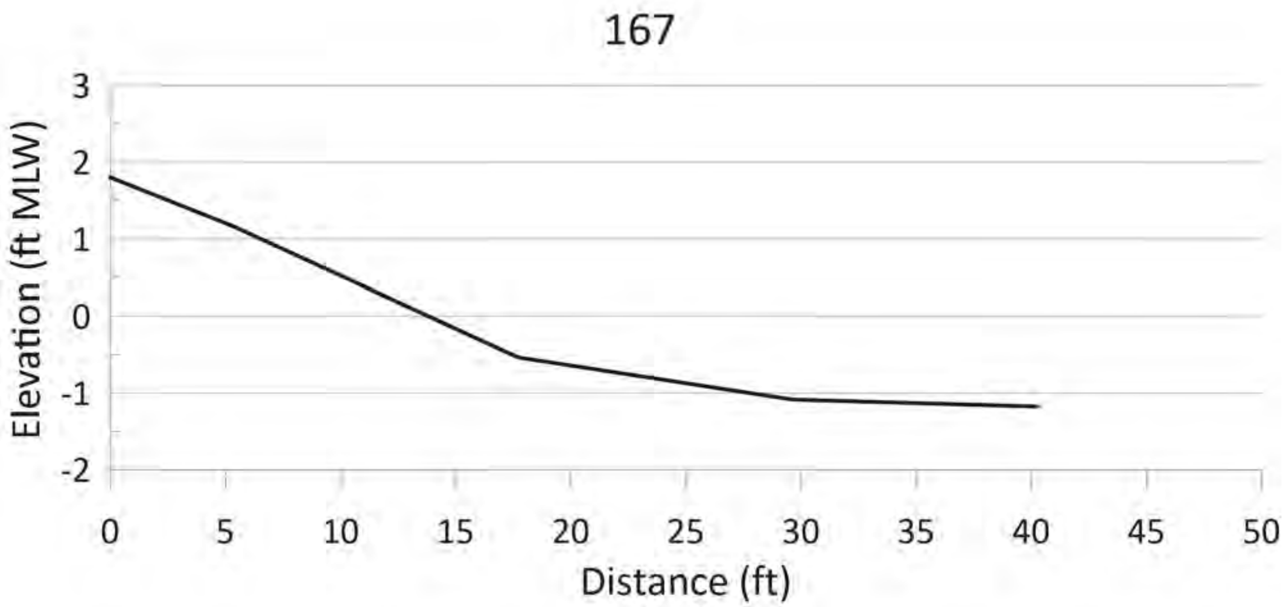
The 3-bag Sill 1.

Heritage Park



Cross-sectional profile 115 of Sill 2 fronting the upland. Survey taken 26 Jan 2018, ten months after installation. The bags were placed at about mean low water (0) and are about 0.5 ft high.

Sill 2. Some fine-grained sediment has been deposited behind the sill structure.

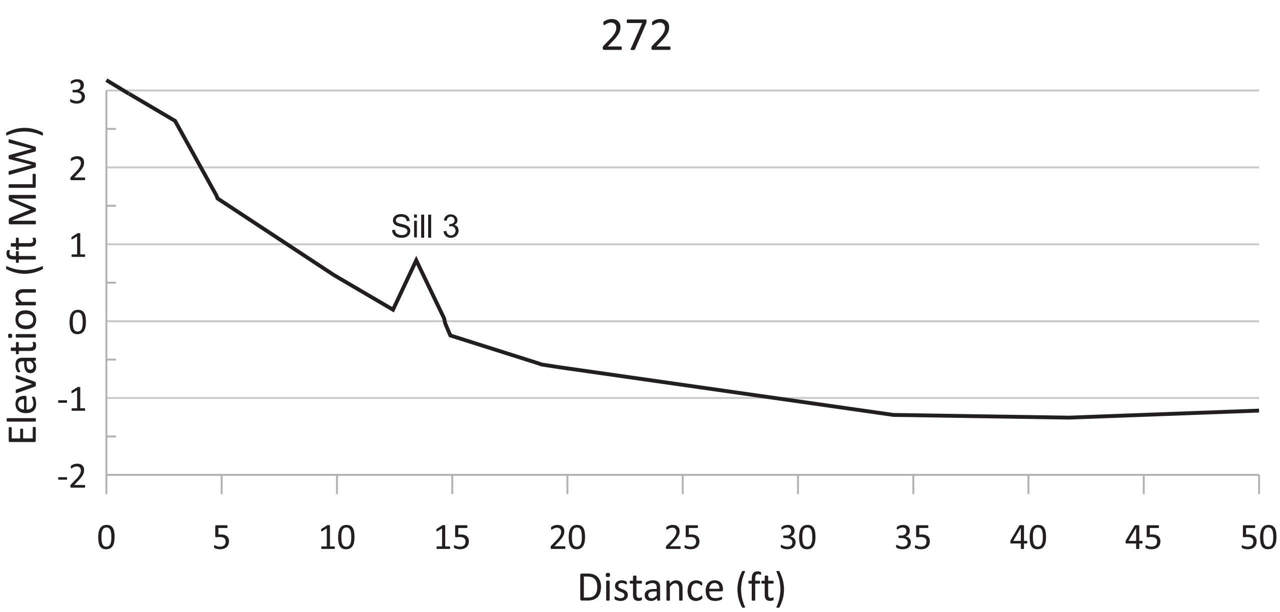


Cross-sectional profile 167 of the shoreline between Sill 2 and 3 in the marsh. Survey taken 26 Jan 2018, ten months after installation.

The shoreline between Sill 2 and 3 in the marsh looking toward Sill 3.

Heritage Park

The middle section of Sill 3 was built as a 5 bag sill, 3 bags on the bottom and two on top. because it fronted a section of eroding upland. The ends of Sill 3 are 3 bag sills.

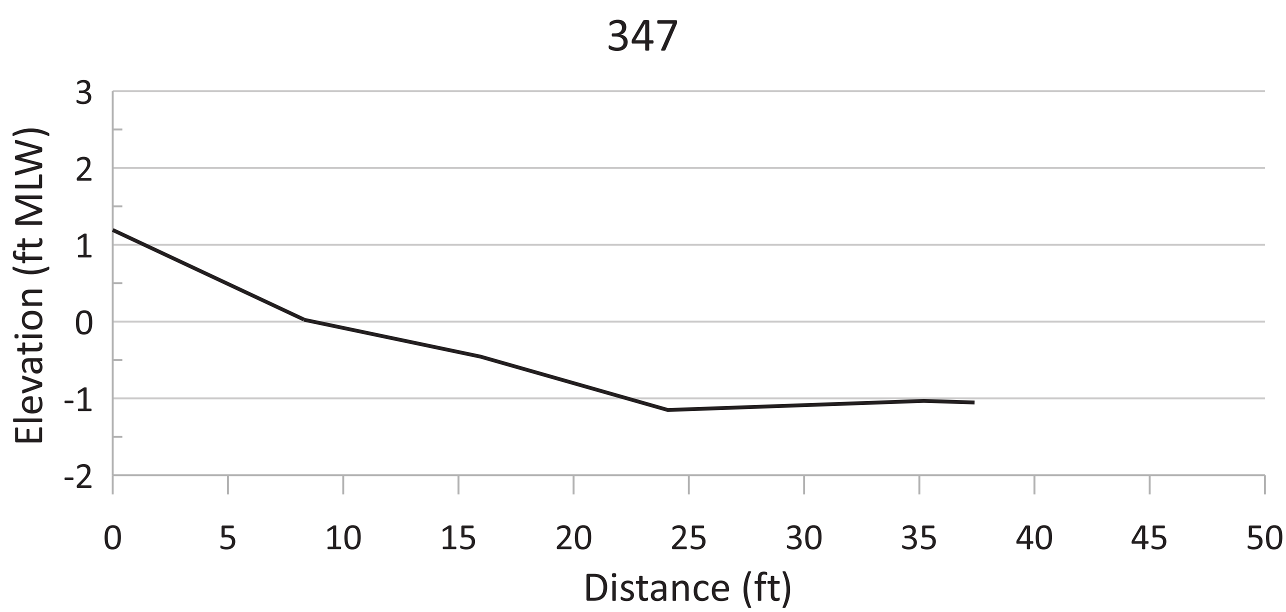


Cross-sectional profile 272 of the 5 bag section of Sill 3. Survey taken 26 Jan 2018, ten months after installation.

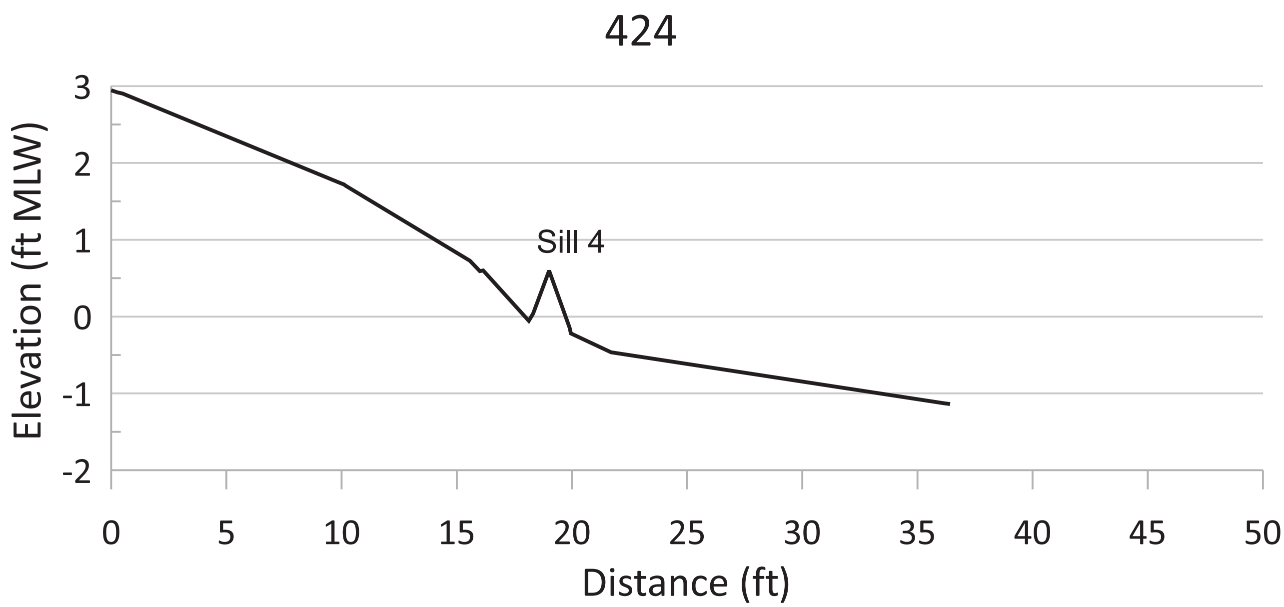
The southern end of Sill 3 flares out to follow low water.

Heritage Park

The marsh shoreline between Sills 3 and 4.



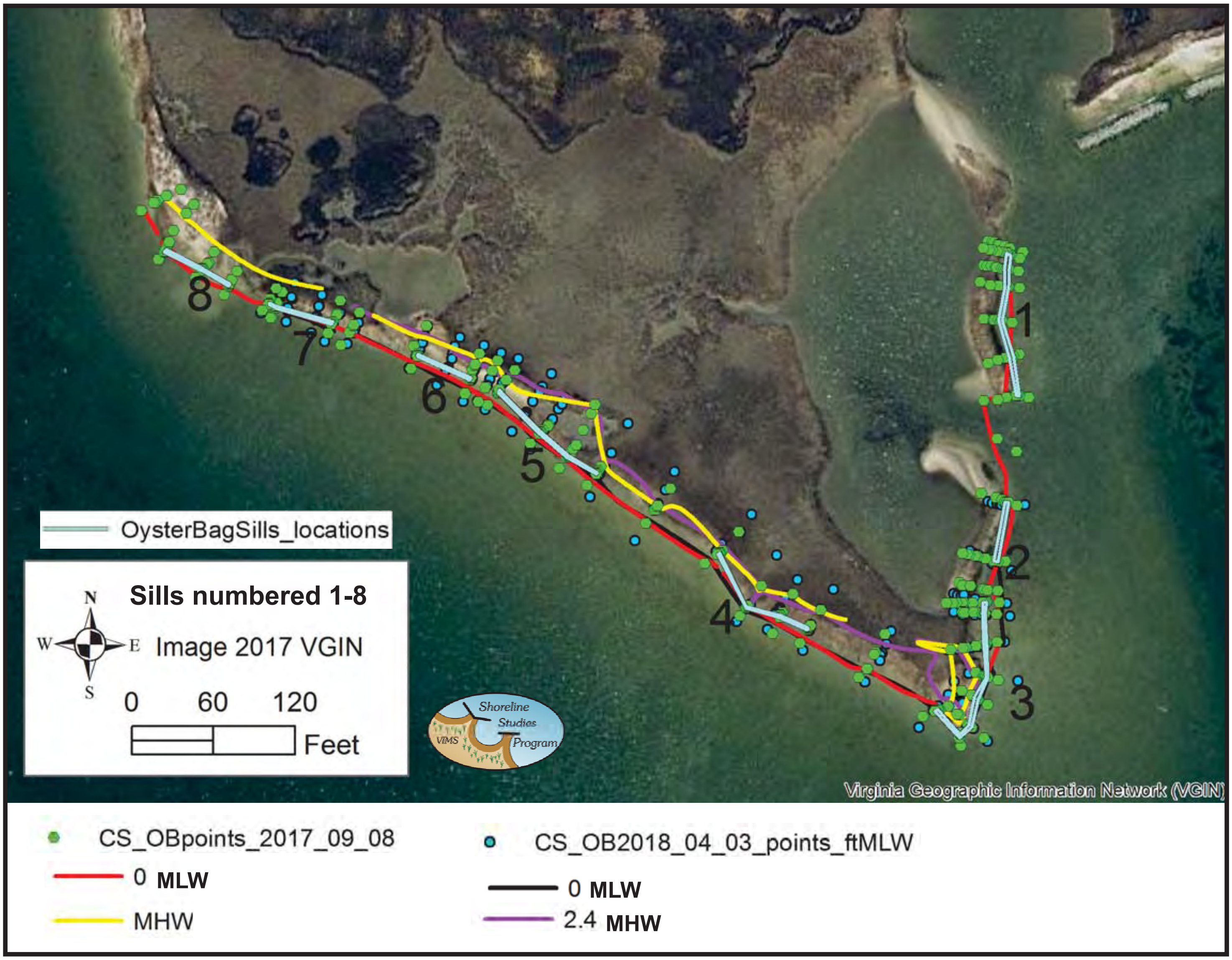
The cross-sectional profile fo the shoreline between Sills 3 and 4. Survey taken 26 Jan 2018, ten months after installation.



Cross-sectional survey 424 at Sill 4. Survey taken 26 Jan 2018, ten months after installation.

Sill 4.

Captain Sinclair's Recreational Area



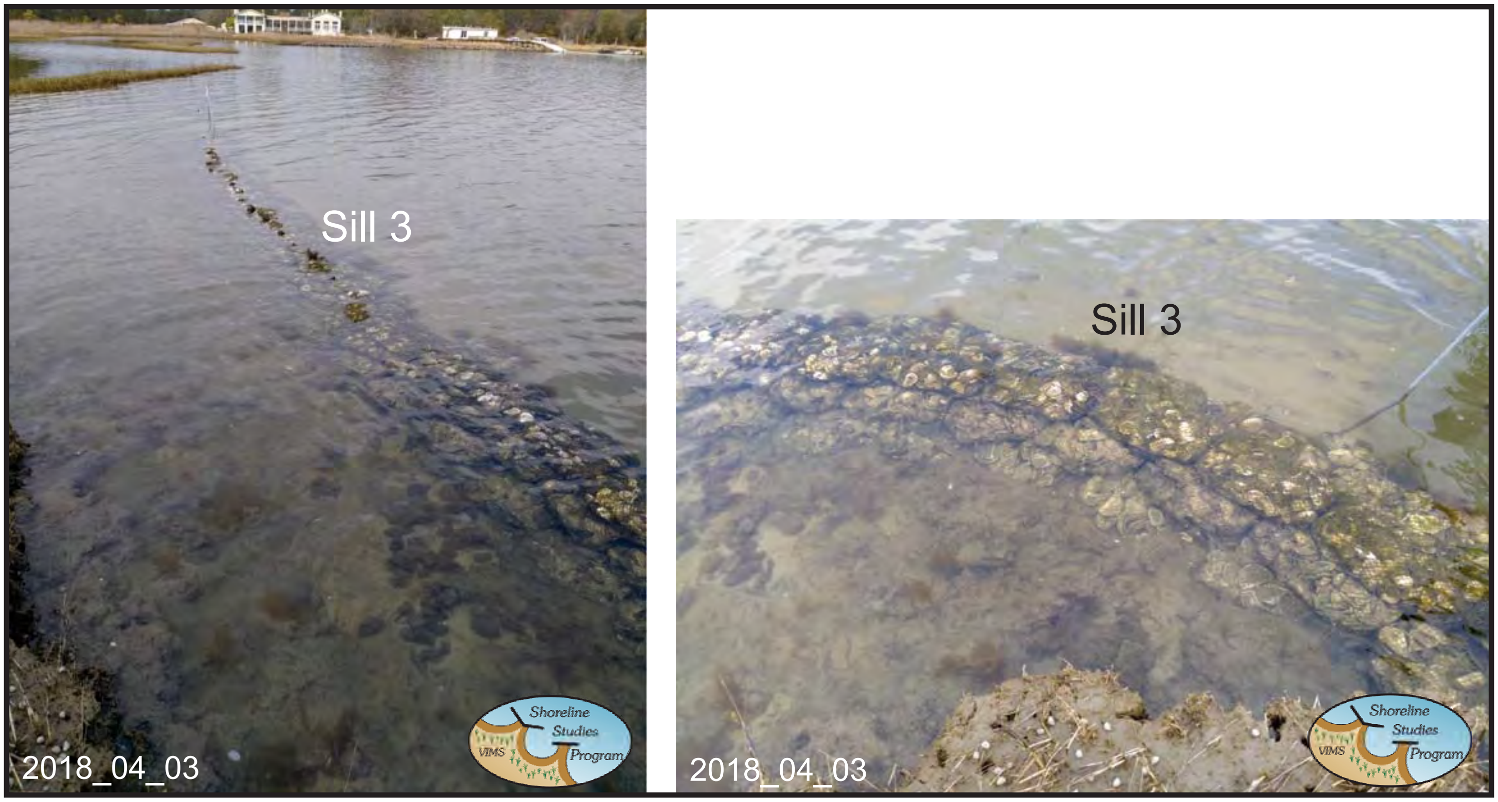
Little change occurred between the post-sill survey in September 2017 and April 2018. Mean low water and mean high water

Captain Sinclair's Recreational Area

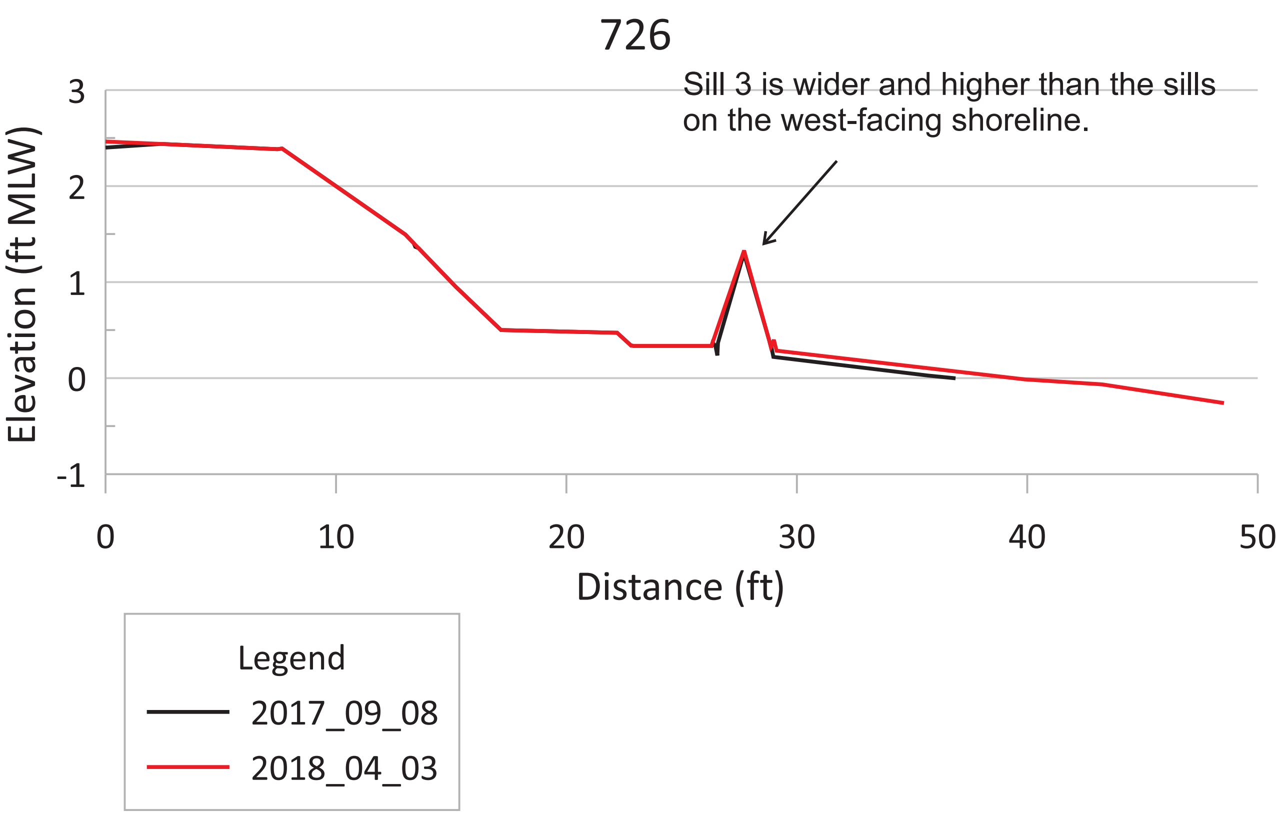
Location of cross-sectional profiles that were surveyed in September 2017 and April 2018. The profiles are shown on succeeding pages.

Sills 1 and 2 are 6 bag sills on the east-facing shoreline that fronts narrow, low marsh barriers that are covered at high water.

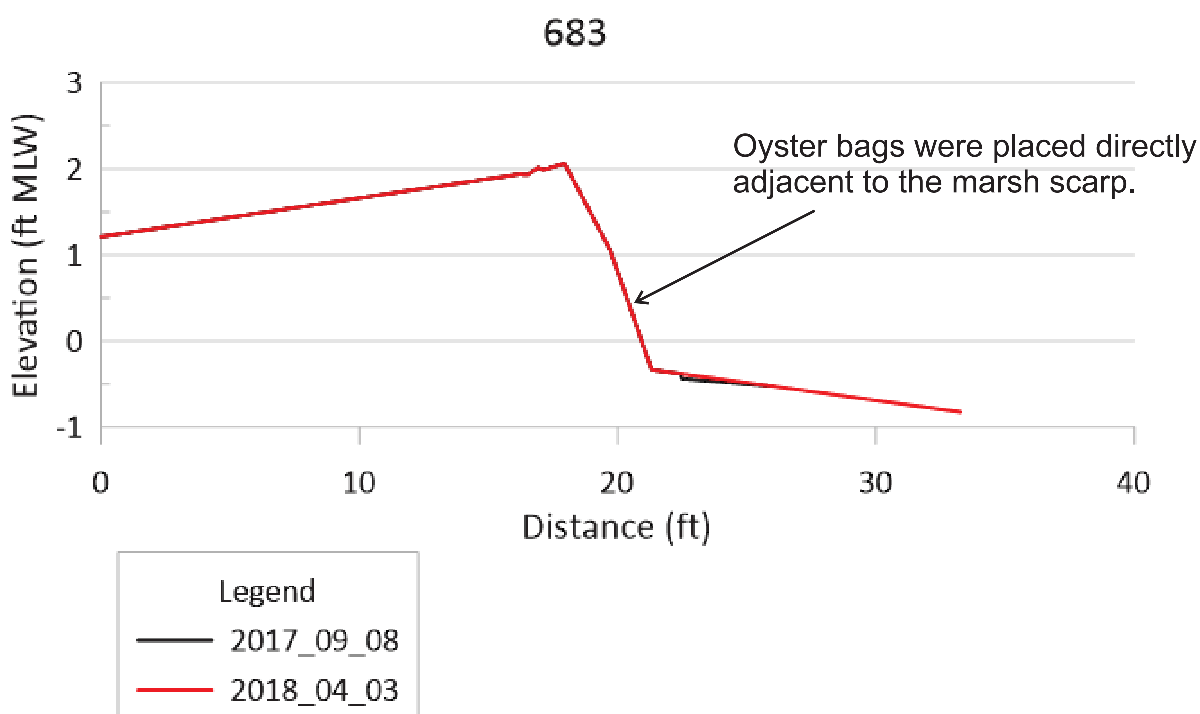
Captain Sinclair's Recreational Area



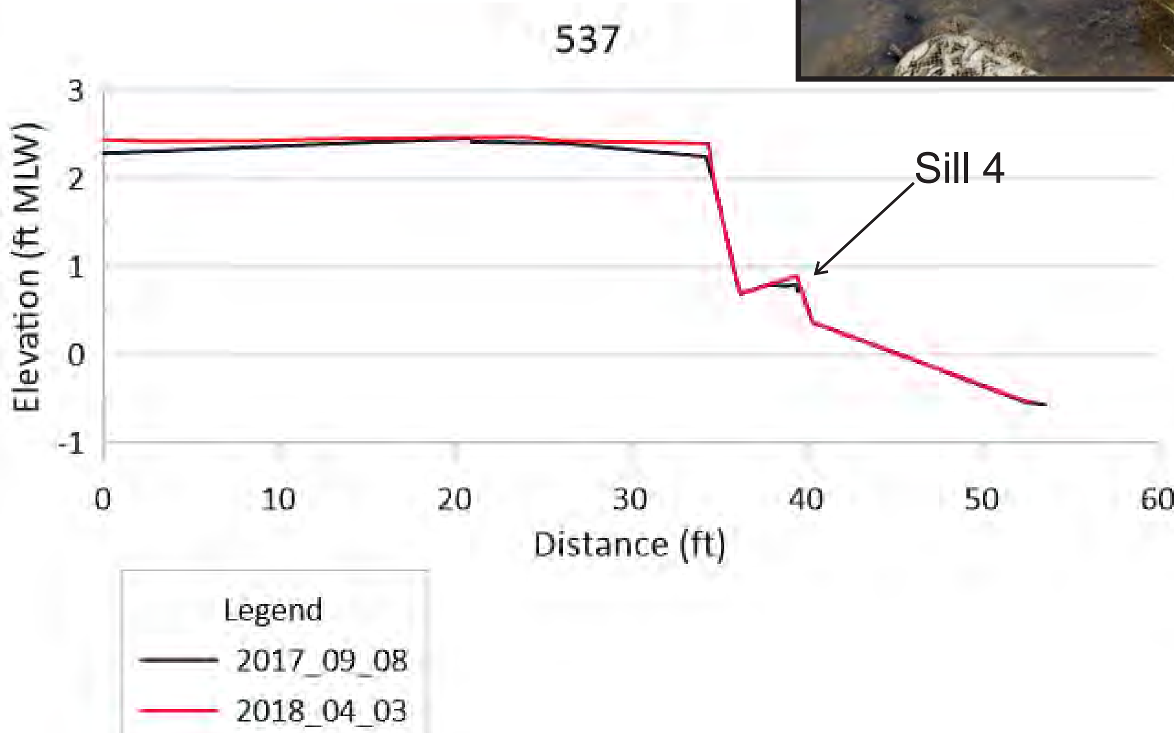
Sill 3 is a 6 bag sill on the east-facing shoreline. The bags were placed directly up against the marsh scarp at the point (Profile 683), but farther north along the shoreline, the sill moves away from the shoreline to follow because mean low water if farther offshore.



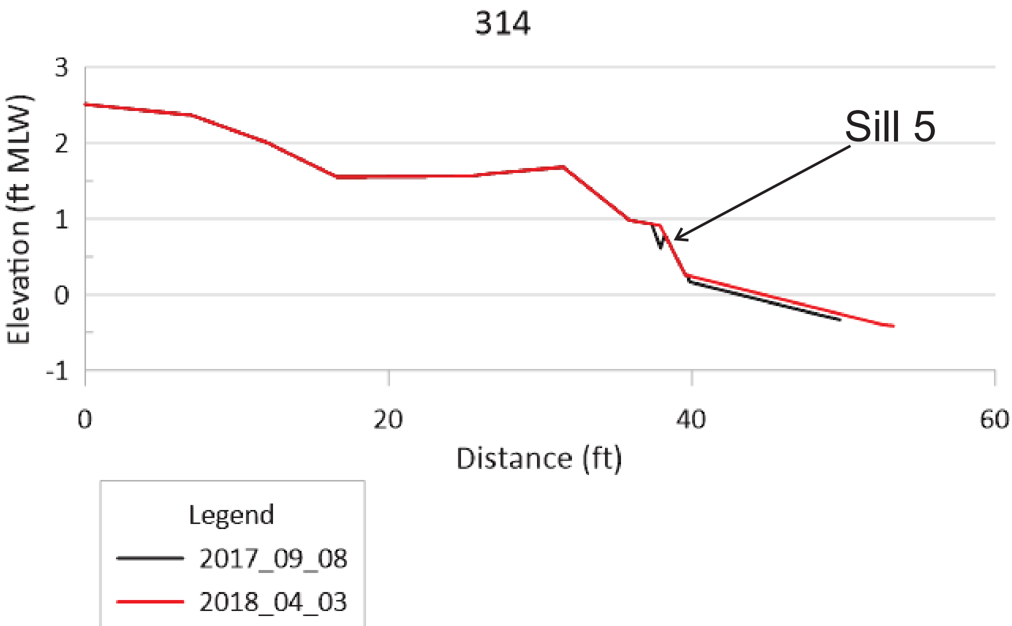
Sill 3 wraps around the point and comes in close to the marsh scarp to provide the maximum amount of protection to the shoreline. Photo credit Linda Tjossem.

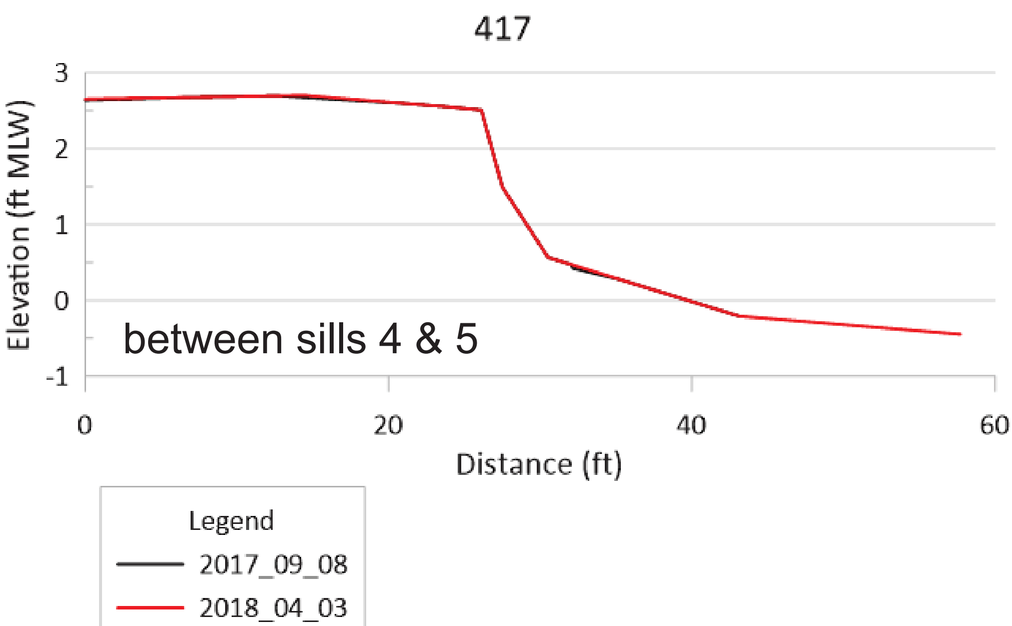


Captain Sinclair's Recreational Area

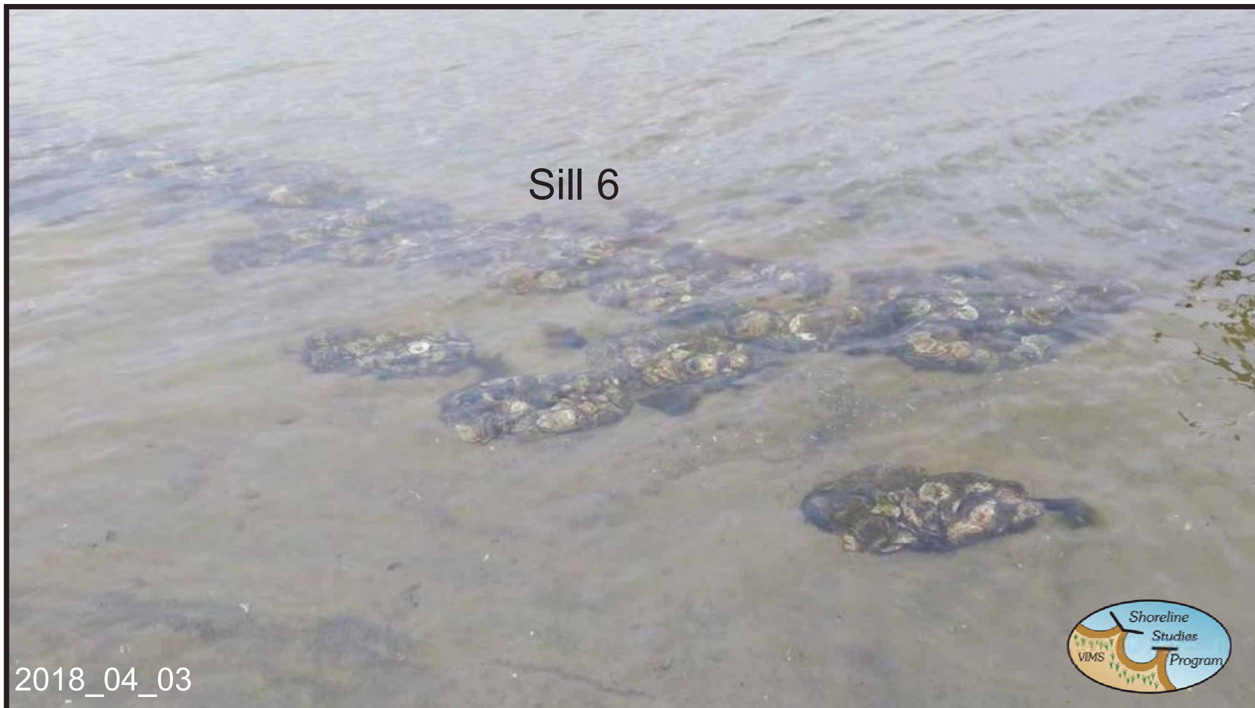


Captain Sinclair's Recreational Area





Captain Sinclair's Recreational Area



The bags in sill 6 did not maintain their structure. The bags were farther offshore and rolled in toward the marsh.

Captain Sinclair's Recreational Area

Sill 7 also had bags the rolled toward the marsh. Next to the headland, where the sill is closer to the marsh, sediment has been deposited landward of the bags.

At Sill 8, sediment has been deposited behind the oyster bag sill allowing marsh grasses to grow riverward.