Oyster Habitat Surveys

At Naval Support Activity Annapolis

Contract N40080-14-D-0002

N4008018F5125 Task 3

FINAL

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Oyster Habitat Surveys
Naval Support Activity Annapolis, Annapolis, Maryland

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
°C	Degrees Celsius
DO	Dissolved Oxygen
kHz	Kilohertz
MD-DNR	Maryland Department of Natural Resources
m	Meter
mL	Milliliter
MLLW	Mean Low Low Water
mm	Millimeter
Mg/L	Milligram per Liter
mS/cm	Microsiemen per Centimeter
NOAA	National Oceanic and Atmospheric Administration
NSAA	Naval Support Activity Annapolis
NTU	Nephelometric Turbidity Unit
pH	Potential of Hydrogen
POM	Particulate Organic Matter
ppt	Parts per Thousand
PSU	Practical Salinity Unit
PVC	Polyvinyl Chloride
YSI	Yellow Springs Instruments
µm	Micrometer

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1.0 INTRODUCTION

1.1 Background

Surveys were conducted at Naval Support Activity Annapolis (NSAA) under contract N40080-14-D-0002, Task Order N4008018F5125 Task 3 to assess habitat suitability for potentially restoring sites for the eastern oyster (*Crassostrea virginica*). In 2019-2020, oyster habitat suitability was evaluated by conducting side-scan sonar of the bottom habitat (to characterize sediment hardness and to survey for the presence of existing oyster reefs) and by assessing water quality, water chemistry, and sedimentation in the following bodies of water at NSAA (Figure 1-1):

- College Creek (Subzone 1.1)
- Carr Creek (Subzone 1.2)
- Mill Creek (Subzone 1.3)

This report summarizes the oyster habitat suitability evaluation methods and results and it provides recommendations for additional oyster habitat assessment methodologies to further define effective strategies for future oyster habitat restoration at NSAA.

Figure 1-1. Waterbodies Assessed for Oyster Habitat Suitability at Naval Support Activity Annapolis.

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2.0 METHODS

2.1 Initial Survey Site Selection

Initial selection of survey sites within the three creeks was conducted by reviewing water depth and habitat using National Oceanic and Atmospheric Administration (NOAA) historical bathymetric data. Selected survey sites focused on areas where water depth was greater than 1 meter (m; 5 feet) and excluded shallower habitats (Figure 2-1), based on the assumption that the shallow habitats would provide low habitat suitability for oysters. This shallow depth is typically associated with low water circulation which leads to high summer temperatures and low dissolved oxygen (DO) levels, which then can lead to stress and potential death of sessile benthic organisms such as *C. virginica*. In addition, the strong north winds that occur in the Chesapeake Bay in the winter periodically lead to extreme low tides that exposes shallow oyster reefs to freezing temperatures, leading to oyster death.

Figure 2-1. Initial Desktop Bathymetric Analysis of Creeks at Naval Support Activity Annapolis.[1]

[1] In Figure 2-1, the creek sections that are circled with a yellow polygon were excluded from surveys because they were not adjacent to Navy installation boundaries.

Teams were able to navigate and survey all three water bodies by launching from Truxtun Park, located off Spa Creek, in Annapolis, Maryland.

2.2 Water Quality

Continuous water quality monitoring was conducted at three locations from May to November 2020. Two sondes were initially deployed in May 2020 at Mill and Carr Creek at NSA Annapolis. Deployment of a third sonde in College Creek was delayed due to security concerns regarding installation activities. That sonde was deployed in June 2020. Sonde locations are listed in Table 2-1 (see Figure 1-1 for a map of their locations).

Table 2-1. Locations of Water Quality Sondes at Naval Support Activity Annapolis.

Site ID	Latitude	Longitude	Creek
Carr Creek	38.982969	-76.457074	Carr Creek
College Creek	38.985774	-76.488025	College Creek
Mill Creek	38.995479	-76.456084	Mill Creek

Temperature, salinity, pH, dissolved oxygen, and turbidity data were collected at the surface of each monitoring station using a Yellow Springs Instruments (YSI) *EXO2*© data sonde. Each sonde was housed in a mooring system for the duration of the monitoring period. The mooring system consisted of a ventilated 4-inch polyvinyl chloride sleeve attached to an 18-inch mooring buoy, anchored in place with 15 feet of nylon line attached to 6 feet of stainless-steel chain and a 16-pound *Danforth* anchor. Sondes were configured to log water quality data at 30-minute intervals. Sondes were retrieved for maintenance every two to four weeks, depending on weather and sea conditions. Each sonde was retrieved, data were downloaded, and then each sonde was replaced with a new laboratory-calibrated sonde. Table 2-2 provides a summary of sonde deployment and retrieval dates for all three monitoring stations in 2020.

Table 2-2. Deployment and Retrieval Dates for Water Quality Sondes.

Set Number	*Deployment Date*	*Retrieval Date*
1	5/13/2020	6/2/2020
2	6/2/2020	6/16/2020
3	6/16/2020	7/1/2020
4	7/1/2020	7/15/2020
5	7/15/2020	8/14/2020
6	8/14/2020	9/1/2020
7	9/1/2020	9/14/2020
8	9/14/2020	10/23/2020
9	10/23/2020	11/6/2020

Time series data, incidentally recorded when a unit was out of the water, was removed from the data set. Remaining data were screened for problems resulting from instrument malfunctions, fouling, and power failure. Data screening followed protocols developed by the *National Estuary Program* and were similar to techniques used by Versar in previous projects. Data were rejected if the values recorded in the sonde memory were outside listed specifications of the instrument. Probe ranges are listed below:

- Temperature: -5 to 45 degrees Celsius (°C)
- Specific Conductivity: 0 - 100 microsiemen per centimeter (mS/cm)
- Salinity: 0 - 70 parts per thousand (ppt)
- Dissolved Oxygen: 0 – 200 percent air saturation
- Dissolved Oxygen: 0 - 20 milligrams per Liter (mg/L)
- pH: 2 - 14 units
- Turbidity: 0 - 1200 Nephelometric Turbidity Units (NTU)

In addition, if the value of a parameter changed radically between readings (30-minute period), data were flagged and reviewed. If changes in readings were an obvious result of a probe malfunction, they were eliminated from the data set.

To determine appropriate cutoff ranges for each parameter, all raw data were graphed and visually examined to identify the natural variation of these parameters at each station. The following cutoffs were used when a parameter changed between 30-minute recording intervals:

- Temperature: change > than 1.1°C
- Salinity: change > than 5.0 ppt
- Dissolved Oxygen: change > 0.5 mg/L
- Turbidity: change > than 100 NTUs
- pH: change > than 0.5 units

To further improve the quality of the data set, graphing the data from each station allowed the identification of erroneous measurements that may have been a result of sonde malfunction or fouling. Sonde malfunctions typically resulted in null data (i.e., no data were collected) or a sudden, perfectly linear change in the parameter values, often to values outside the naturally occurring range. These data collection errors occurred occasionally with all water quality sensors and were omitted from the time series and analyses.

During the monitoring process, field crews observed multiple occasions where several probes were fouled. This fouling caused a noticeable downward change in the reported parameter values. In consultation with YSI Technical Support, the following procedure was used to account for probe fouling:

- A table was created for each of the 2- to 3-week deployments which matched up date/time of the last measurement taken with the YSI sondes prior to recalibration.
- The first measurements of the YSI sondes after recalibration and redeployment were used as reference points for data drift.

Probe fouling often resulted in gradual, linear increases in water quality measurements near the end of a given deployment. These periods of drift were identified, and the drift rate quantified. A linear correction was applied to data to remove the effects of fouling. This data screening process was commonly applied to turbidity data and, on rare occasions, salinity, and pH data. Random and significant spikes in turbidity were also identified in the time series plots and were determined to be a result of heavy fouling on the probe. These erratic data points were replaced with an average of the surrounding values to maintain the integrity of the average daily turbidity value.

2.3 Side-Scan Sonar

At NSAA, Mill, Carr, and College Creeks were surveyed for sediment hardness and assessed for the presence/absence of oyster bars at water depths of 1.5 m (5 feet) or greater. In addition, a site located near NSAA on privately-leased oyster bottom in the West River was surveyed as a reference for bottom hardness and oyster bar imaging.

Side-scan sonar was used to analyze bottom hardness and to detect potential oyster bars at NSAA. Sampling began on 7 June 2019 and concluded on 4 December 2019 (Table 2-3). Each sampling station was sampled by navigating to the survey locations and collecting data along transects in water depths of 1.5 m (5 feet) or greater.

Table 2-3. Date and Location of Side-Scan Sonar Sampling Events.

Station	*Location*	*Date*
Naval Support Activity Annapolis	Mill Creek	6/7/2019
	Carr Creek	6/17/2019
	College Creek	7/9/2019
	Carr Creek	10/2/2019
	Mill Creek	10/15/2019
West River	West River	12/4/2019

All side-scan sonar data were collected from a 5.5 m *Lowes Roughneck* johnboat using a *HumminBird© Helix 9*. Sonar data were collected in IDX video and SON side-imaging file formats. Data were recorded at 445 kilohertz (kHz) for down-imaging and 455 kHz for side-imaging with operational range scales set to 24.38 meters, which corresponded to an overall sonar swath width of 48.78 meters. Vessel positioning data were collected using the global positioning system of the *Helix 9* along transects created using *ArcGIS ArcMap© 10.6.1*. Transects were created at 16.3-meter intervals which provided a 20 percent overlap in data collected to mitigate possible gaps. Survey data were backed-up daily and archived for the formal analysis. Raw data were processed using *ReefMaster© 2.0* to calculate E2 hardness, which was imported into *ArcMap*. Processed data shapefiles were then overlaid with the topography of the water bodies as well as specific points where sediment samples were taken to allow for ground-truthing of the data.

2.4 Sediment Analysis

Sediment samples were initially collected at random sites during sonar surveys using a Petite Ponar grab. After sonar data were processed for Carr Creek, three strata were established based on the hardness data collected (data processing is described in Section 2.3 Side-Scan Sonar). Fifteen sampling sites were then randomly selected, five sites in each of the three creeks. Sediment samples at these 15 sites were collected using a Young Modified Van Veen benthic grab from a 21-foot Privateer vessel. After each sediment grab, photos of the sample were taken, and a representative portion was placed in a Whirl-Pak bag to be processed in the lab. Sediment samples from all sites were processed for silt/clay versus sand content in accordance with protocols that adhere to industry standards. Table 2-4 provides the locations of sediment collections at NSAA in 2019.

Table 2-4. Sediment Collection Locations at Naval Support Activity Annapolis in 2019.

*Site ID**	*Latitude*	*Longitude*	*Site ID**	*Latitude*	*Longitude*
CARR_1	38.98028	-76.4563	CAC1	38.99130	-76.4602
CARR_2	38.98042	-76.4553	CAC2	38.98375	-76.4575
CARR_3	38.98077	-76.4568	CAC3	38.98383	-76.4578
CARR_4	38.98080	-76.4552	CAC4	38.98613	-76.4579
CARR_5	38.98115	-76.4569	CAC5	38.98807	-76.4580
CARR_6	38.98220	-76.4558	COC1	38.98596	-76.4892
CARR_7	38.98152	-76.4557	COC2	38.98625	-76.4912
CARR_8	38.98248	-76.4576	COC3	38.98592	-76.4871
CARR_9	38.98335	-76.4568	MC1	38.99273	-76.4529
CARR_10	38.98217	-76.4549	MC2	38.99328	-76.4509
CARR_11	38.98123	-76.4614	MC3	38.99451	-76.4511

Site ID*	Latitude	Longitude	Site ID*	Latitude	Longitude
CARR_12	38.98095	-76.4611	MC4	38.99507	-76.4543
CARR_13	38.98203	-76.4616	MC5	38.99648	-76.4564
CARR_14	38.98087	-76.4619			
CARR_15	38.98158	-76.4584			

*Creek Names–PE = Pearson Creek; HP = Harper's Creek; GC = Goose Creek

2.5 Sediment Traps

Sediment traps were fabricated and deployed at each monitoring location to assess sedimentation rates. Each trap was constructed out of 4-inch polyvinyl chloride (PVC) pipe center mounted to a 12-inch by 12-inch piece of 0.5-inch plywood. A glass jar with a basal opening (diameter) of 2.5 inches was placed in each PVC pipe as a collection vessel. Each trap was carefully lowered and moored to the bottom at each location. The mooring system consisted of a heavy-duty milk crate weighted down with 20 pounds of masonry bricks with 10 feet of nylon line attached to a well-marked buoy. Traps were retrieved for maintenance every two to six weeks, depending on weather and sea conditions. During each sampling visit, sediments were collected from the trap and a new collection vessel was placed in the trap. Collected samples were stored and then transferred to Versar's laboratory for processing and analysis.

Upon transfer to Versar's lab, samples settled for five days before overlying water was removed from the sample by siphoning. The remaining sediments were sieved through a 1.0 millimeter (mm) screen to exclude any large organic organisms that were caught in the trap (crabs, grass shrimp, fish, etc.) and transferred to a pre-weighed 500 milliliter (mL) glass beaker and dried at 100°C for one week before a final dry weight was calculated. Estimated sedimentation rates were calculated by the total mass in grams collected over the deployment period and reported as an average accretion of sediments in grams per day for the length of the deployment. Table 2-5 provides the dates of deployment and retrieval of sediment traps utilized at NSA Annapolis in 2020.

Table 2-5. Deployment and Retrieval Dates for Sediment Traps in 2020.

Set Number	Deployment Date	Retrieval Date
1	6/2/2020	7/1/2020
2	7/1/2020	8/14/2020
3	8/14/2020	9/1/2020
4	9/1/2020	9/14/2020
5	9/14/2020	10/23/2020

2.6 Water Chemistry

Whole water samples were collected throughout the survey period to assess nutrient content of the water column for oyster production. Samples were collected one meter from the surface with a submersible pump, transferred into pre-labeled containers, and transported on ice to Versar's laboratory. Samples were collected at all three sonde stations once a month for the entire monitoring period (Table 2-6). Analysis of nitrogen and phosphorous levels were conducted by Martel Laboratories, Inc. in Towson, MD.

Table 2-6. Collection Dates for Water Quality Samples Taken in 2020.

Set Number	Collection Date	Set Number	Collection Date
1	5/13/2020	4	8/14/2020
2	6/16/2020	5	9/14/2020
3	7/15/2020		

Seston samples were collected for particulate organic matter (POM) analysis and analyzed at Versar's laboratory. Methods for collecting seston from water samples are detailed in *DK-SOP-23* (Rev 2, 8/06). This is a standard operating procedure prepared by Danielle Kreeger of the Academy of Natural Sciences at Drexel University (Kreeger 2013). In summary, seston was collected on prepared glass fiber filters using vacuum filtration of water collected in 4-liter jugs from field sampling stations. Filters were frozen until laboratory analysis. For each sample (collection station sampled at a given time), 1-gallon jugs were filled and filtered. From each jug, two replicate POM samples were collected on 0.7 micrometer (µm) retention glass fiber filters (47mm diameter; Whatman type GF/F or equivalent). Results from the two replicates were averaged and reported. Filters were pre-combusted at 450^{o}C for at least 24 hours prior to filtration. Pre-weighed (to 0.01 milligram) filters were prepared in advance of sampling. For each jug of water, two filters were used for POM weight on ignition analysis. The same balance was used before and after seston. Only desiccated samples were weighed.

Seston was captured on filters using vacuum filtration by Versar staff. Filters were prepared in advance and later analyzed at Versar's lab. Filters containing seston were added to *Petrislides™* for storage in a freezer at -20^{o}C until laboratory analysis.

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3.0 RESULTS

3.1 Water Quality

Water quality was very similar between the three sonde sites at NSA Annapolis throughout the monitoring period. Temperature was driven by seasonal changes, peaking in mid-July, with an average daily temperature at sites ranging between 29 to 30°C. Salinity was shown to gradually increase throughout the monitoring period for all sites. Salinity levels were typically slightly higher at both Carr Creek and Mill Creeks, except in November, when College and Carr Creeks were higher than Mill Creek. Spring salinities were lower, 5.7 to 6.7 practical salinity units (PSU) and increased gradually through the summer and fall season. Dissolved oxygen (DO) values at all sites fluctuated monthly, with highest daily averages observed in May (14.00 to 15.09 mg/L). Individually, the three sites experienced the lowest averages of DO during different points of the year, with the lowest monthly average DO value observed at Mill Creek in August (4.55 mg/L). There were no discernable patterns for pH values; monthly fluctuations were likely tied to environmental or biological activity in surrounding waters. Localized weather and wind events affected turbidity levels on a small scale, but generally remained low throughout the monitoring period. Carr Creek turbidity values were typically the highest, ranging from 6.7 to 13.46 NTU, while College Creek turbidity levels were the lowest among all sites. Daily average values for sampled months are shown in Table 3-1.

Table 3-1. Results of Water Quality Monitoring at Naval Support Activity Annapolis in 2020.[2]

Parameter	Site	May	June	July	Aug	Sept	Oct	Nov
Turbidity (NTU)	Carr Creek	10.68	13.46	6.70	10.26	9.91	7.02	6.21
	College Creek	N/A	4.96	4.84	3.93	3.28	2.44	N/A
	Mill Creek	9.63	8.33	8.85	13.09	5.26	3.81	3.28
Dissolved Oxygen (mg/L)	Carr Creek	14.00	8.27	8.12	7.09	6.58	7.92	9.42
	College Creek	N/A	5.97	6.00	6.17	7.33	6.37	7.67
	Mill Creek	15.09	7.01	5.72	4.55	7.68	8.37	8.80
pH	Carr Creek	N/A	7.68	8.20	7.94	7.91	7.92	7.95
	College Creek	N/A	N/A	7.87	7.82	7.96	7.87	7.71
	Mill Creek	N/A	7.87	7.92	7.81	7.96	7.87	7.82
Temperature	Carr Creek	18.24	22.42	29.33	28.35	26.62	18.06	14.10

[2] The College Creek monitoring station could not be deployed in May due to security concerns near the foot bridge located on Naval Academy property.

Parameter	Site	May	June	July	Aug	Sept	Oct	Nov
(°C)	College Creek	N/A	24.88	29.73	28.56	22.59	19.62	14.55
	Mill Creek	17.80	26.34	30.23	29.26	24.20	19.41	13.58
Salinity (PSU)	Carr Creek	5.71	6.95	9.57	9.98	10.94	14.03	13.67
	College Creek	N/A	6.80	8.93	9.12	10.98	12.52	13.39
	Mill Creek	6.66	6.92	9.51	9.58	11.02	13.00	13.15

3.2 Side-Scan Sonar

An analysis of side-scan sonar data showed a correlation between depth and sediment hardness. Six strata were characterized from the hardness data collected. These strata were characterized as having increasing hardness values between 18.7 and 199.2. Strata values were generated by *ReefMaster© 2.0* and represent the relative hardness of the areas surveyed. Strata designated with a hardness value of 18.7 represented softer bottom sediments with a higher percentage of mud, while a hardness value of 199.2 represented sediments with a higher percentage of sand. The deeper waters of each surveyed creek area typically had softer sediments, which correlated to higher silt and clay percentages, while the shallower waters had a relatively higher percentage of sand. Results for each surveyed subzone for the three creeks at NSAA are reported below.

3.2.1 Subzone 1.1–College Creek

College Creek was found to have the greatest proportion of its bottom characterized by a hardness value of 90.9 or higher (60.62 percent). Hardness strata of 90.9 or greater were located throughout the eastern portion of the survey area (Table 3-2 and Figure 3-1). Review of side-scan imagery did not provide evidence of established oyster bars at this location.

Table 3-2. Subzone 1.1–College Creek Total Area and Percentages by Hardness Strata.

Hardness	*Area (m^2)*	*Area (%)*
18.7	5,180.1	6.5
54.8	26,346.0	32.9
90.9	26,923.9	33.6
127.0	20,872.4	26.1
163.1	673.7	0.8
199.2	60.8	0.1

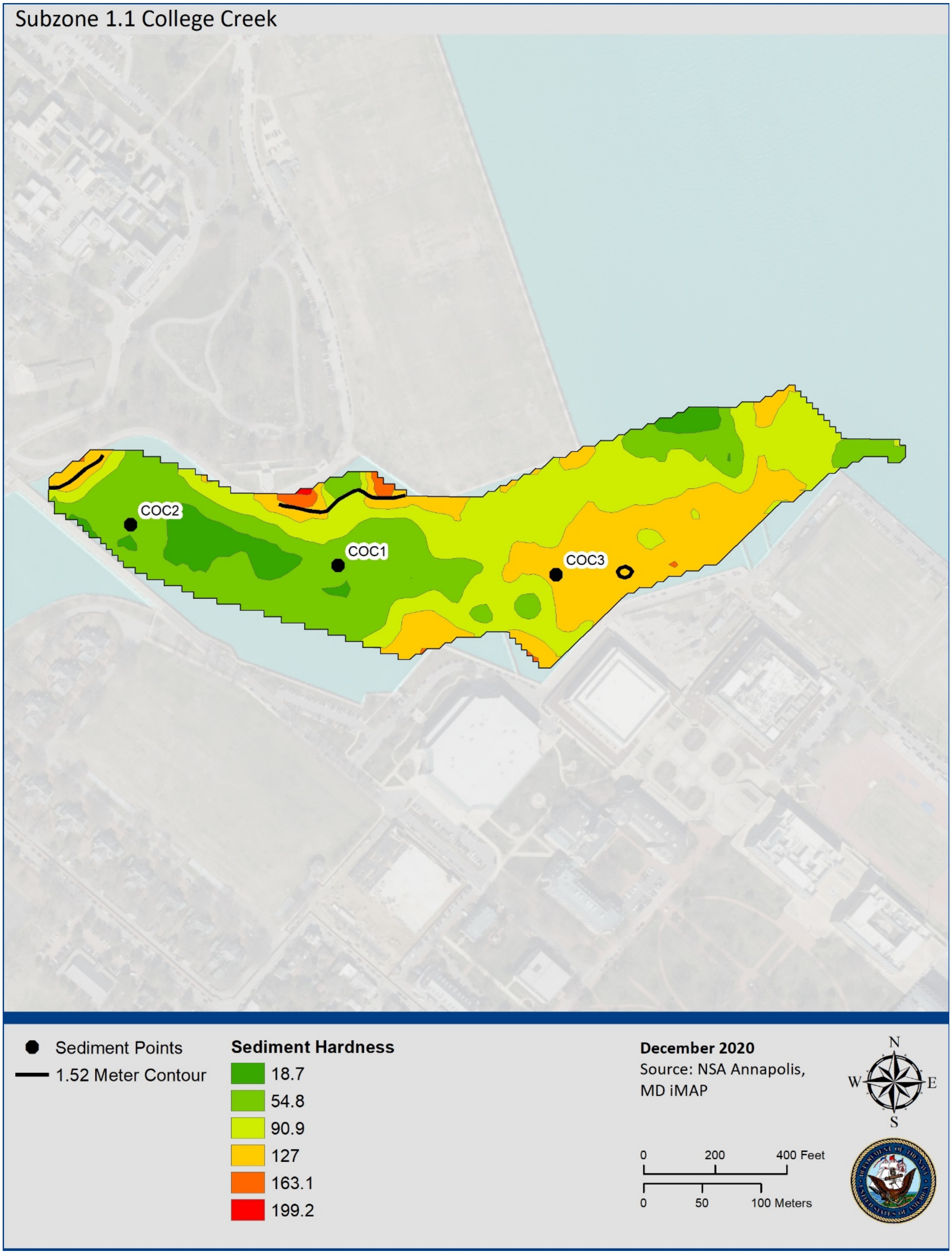

Figure 3-1. Subzone 1.1: College Creek Sediment Hardness.

3.2.2 Subzone 1.2–Carr Creek

Approximately 62 percent of Carr Creek's total area was classified as stratum 90.9 or greater. Most harder strata were found on the edges of the survey area in waters shallower than 1.5 m (5 feet). Deeper water habitats with a harder sandy bottom were found in the southeast portion of the survey area. Review of the side-scan imagery did not reveal evidence of established oyster bars in this area (Table 3-3 and Figure 3-2).

Table 3-3. Subzone 1.2–Carr Creek Total Area and Percentages by Hardness Strata.

Hardness	*Area (m^2)*	*Area (%)*
18.7	1,093.5	0.4
54.8	115,125.0	37.3
90.9	102,712.8	33.3
127.0	66,313.2	21.5
163.1	18,890.9	6.1
199.2	4,444.0	1.4

3.2.3 Subzone 1.3–Mill Creek

Mill Creek had the highest proportion of its bottom characterized by the 54.8 hardness stratum, with 70.0 percent of the total area falling in this stratum. This creek also exhibited harder sediments in the shallower edges, similar to the other creeks observed. Every instance of strata 163.1 and 199.2 were located in waters less than 1.5 m (5 feet). Bottom habitat in the 90.9 hardness stratum were located bordering the harder strata located just inside the 1.5 m delineation (Table 3-4 and Figure 3-3). Review of the side-scan imagery did not reveal evidence of established oyster bars in this area.

Table 3-4. Subzone 1.3 - Mill Creek Total Area and Percentages by Hardness Strata.

Hardness	*Area (m^2)*	*Area (%)*
18.7	24,865.8	10.5
54.8	165,580.0	70.0
90.9	25,066.0	10.6
127.0	14,095.1	6.0
163.1	6,403.2	2.7
199.2	439.9	0.2

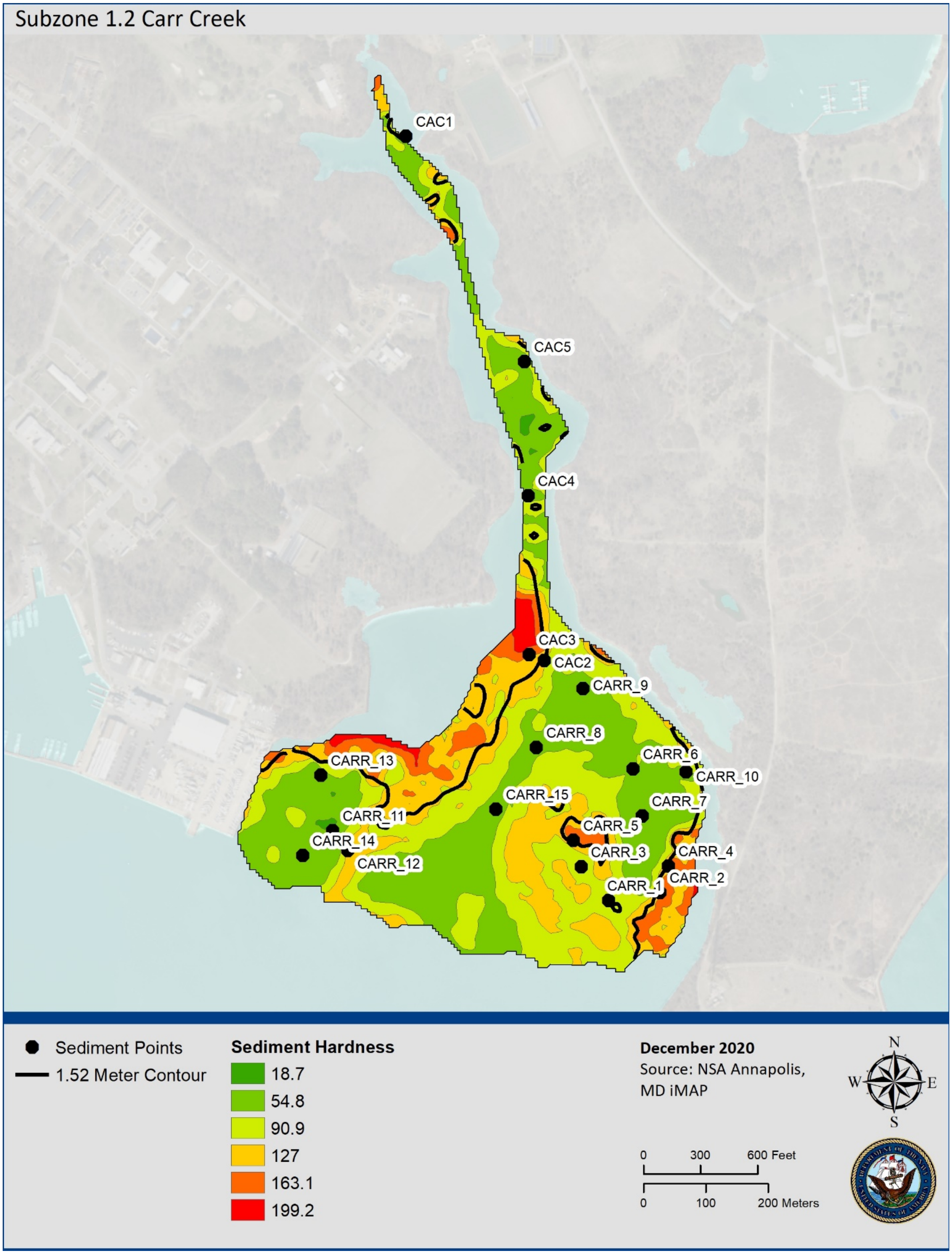

Figure 3-2. Subzone 1.2: Carr Creek Sediment Hardness.

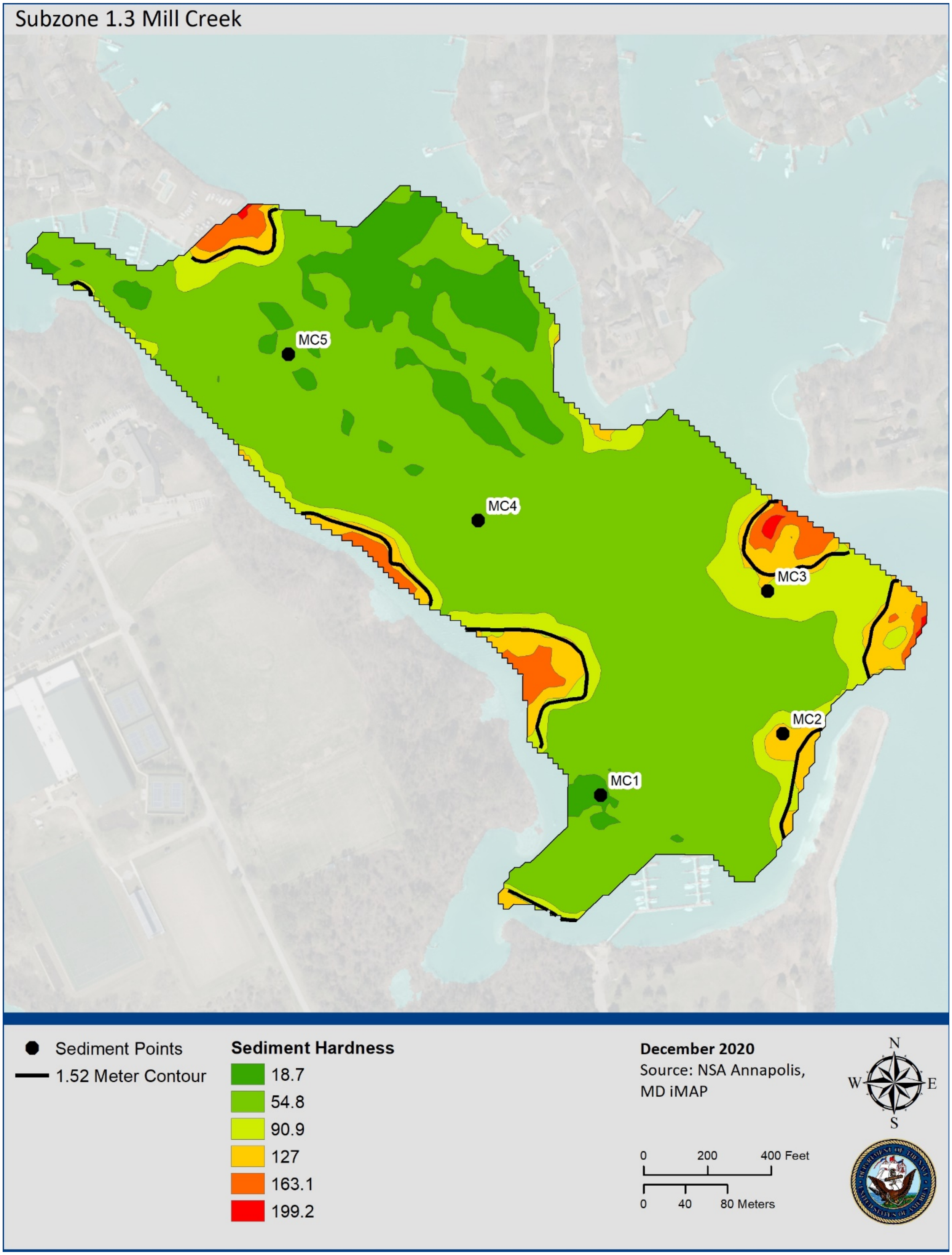

Figure 3-3. Subzone 1.3: Mill Creek Sediment Hardness.

3.3 Sediment Analysis

Bottom sediment samples (n=15) were collected at sites in Carr Creek to ground-truth sonar data and compare sediment grainsize composition to the various strata for the sampled sites at NSAA (see Appendix A for photographs of these reference sediment samples). The habitat and sediments in Carr Creek at NSA Annapolis provided a higher resolution scale that could be used to classify hardness scales and strata across the three creeks at NSAA. Sediments then were collected in Mill (n=5), College (n=3), and Carr (n=5) Creeks to compare to the reference samples from Carr Creek (see Figures 3-1,3-2, 3-3 for the sampling locations). Sediment analysis showed that areas with a hardness values of 54.8 or lower had softer sediments with higher silt/clay percentages (44.2 to 95.9 percent), while areas that were characterized with hardness values of 90.9 and above had sandier sediments with lower silt and clay percentages (0.4 to 29.3 percent). Strata 54.8 was the most prominent at 50.2 percent of the total area, followed by the 90.9 strata at 22.4 percent of the total area observed. Results for NSAA are shown in Table 3-5, and the baseline data results for Carr Creek are shown in Table 3-6.

Table 3-5. Zone 1-Naval Support Activity Annapolis Silt/Clay Percentage Results.

Site ID	*Hardness Strata*	*Silt/Clay %*	*Sand %*
MC1	18.7	84.6	15.4
CAC1	54.8	86.6	13.4
CAC4	54.8	65.9	34.1
CAC5	54.8	64.6	35.4
MC4	54.8	80.8	19.2
MC5	54.8	95.9	4.1
COC1	54.8	92.3	7.7
COC2	54.8	83.6	16.4
MC3	90.9	10.3	89.7
CAC2	127.0	7.5	92.5
CAC3	127.0	8.3	91.7
MC2	127.0	3.3	96.7
COC3	127.0	1.3	98.7

Creek Names: CAC - Carr Creek; MC – Mill Creek; COC - College Creek
Note: Results sorted by hardness strata.

Table 3-6. Zone 1 NSAA Carr Creek Silt/Clay Percentage Results for Baseline Analysis.

Site ID	*Hardness Strata*	*Silt/Clay %*	*Sand %*
CARR_6	54.8	57.1	42.9
CARR_7	54.8	73.5	26.5

Site ID	Hardness Strata	Silt/Clay %	Sand %
CARR_8	54.8	67.8	32.2
CARR_9	54.8	66.5	33.5
CARR_11	54.8	89.1	10.9
CARR_13	54.8	44.2	55.8
CARR_14	54.8	85.3	14.7
CARR_15	54.8	66.5	33.5
CARR_6	54.8	57.1	42.9
CARR_1	90.9	2.9	97.1
CARR_3	90.9	3.4	96.6
CARR_10	90.9	29.3	70.7
CARR_12	90.9	11.3	88.7
CARR_2	127.0	1.7	98.3
CARR_4	127.0	0.4	99.6
CARR_5	127.0	4.8	95.2

Note: Results sorted by hardness strata.

3.4 Sediment Traps

Estimated sedimentation rates are presented in Table 3-7 below. Throughout the monitoring period, rates of sedimentation varied. With the exception of the first deployment in June 2020, sedimentation rates at Carr Creek started at 186.70 g m^{-1} day^{-1} and gradually decreased to 123.67 g m^{-1} day^{-1}. Sedimentation rates at College Creek started high in June (164.35 g m^{-1} day^{-1}) and gradually decreased to 46.70 g m^{-1} day^{-1} by mid-September. The trap at the College Creek station was lost in late September during the final deployment; no data could be collected during that period. Mill Creek data showed a similar pattern to Carr Creek with the lowest sedimentation rate observed in June (32.61 g m^{-1} day^{-1}) followed by a sharp increase between July and mid-August (202.75 g m^{-1} day^{-1}). Sedimentation rates gradually declined from mid-August through the end of the monitoring period. Overall, the lowest sedimentation rate was observed at the Carr Creek monitoring location between June and July, 11.18 g m^{-1} day^{-1}, while the highest observed sedimentation occurred at Mill Creek between July and mid-August, 202.75 g m^{-1} day^{-1}.

Table 3-7. Estimated Sedimentation Rates at Naval Support Activity Annapolis Monitoring Stations.

Site	Deployment Date	Retrieval Date	Days Deployed	Sedimentation (g m^{-1} day^{-1})	Notes
Carr Creek	6/5/2020	7/1/2020	26	11.81	
	7/1/2020	8/14/2020	44	186.70	
	8/14/2020	9/1/2020	18	124.99	
	9/1/2020	9/14/2020	13	131.95	
	9/14/2020	10/23/2020	39	123.67	

Site	Deployment Date	Retrieval Date	Days Deployed	Sedimentation (g m-1 day-1)	Notes
College Creek	6/5/2020	7/1/2020	26	164.35	
	7/1/2020	8/14/2020	44	112.11	
	8/14/2020	9/1/2020	18	41.58	
	9/1/2020	9/14/2020	13	46.70	
	9/14/2020	10/23/2020	39	**	Trap lost; no sample
Mill Creek	6/5/2020	7/1/2020	26	32.61	
	7/1/2020	8/14/2020	44	202.75	
	8/14/2020	9/1/2020	18	131.61	
	9/1/2020	9/14/2020	13	83.86	
	9/14/2020	10/23/2020	39	45.58	

3.5 Water Chemistry

3.5.1 Water Chemistry Analysis

Water chemistry analysis results are presented in Table 3-8 below. Results from water chemistry analysis were collected to provide baseline data at these sites. No specific trends could be discerned from the small set of data collected.

Phosphorous results were generally consistent between sites with the highest values observed at the Mill Creek station and the lowest values observed at the College Creek station. Nitrogen levels were also consistent across most of the monitoring sites, with the exception of Carr Creek in May 2020 where the highest reading of 1.6 mg/L was observed.

Table 3-8. Water Chemistry Results at Naval Support Activity Annapolis Monitoring Sites in 2020.

Station	Parameter	Month	Result (mg/L)
Carr Creek	Phosphorous	May	0.05
		June	0.05
		July	0.04
		August	0.07
		September	0.06
	Total Nitrogen	May	1.6
		June	0.4
		July	0.2
		August	0.6
		September	0.4
College Creek	Phosphorous	May	0.03
		June	0.06
		July	0.03

Station	*Parameter*	*Month*	*Result (mg/L)*
		August	0.07
		September	0.05
	Total Nitrogen	May	0.6
		June	0.4
		July	0.2
		August	0.9
		September	0.3
Mill Creek	Phosphorous	May	0.05
		June	0.09
		July	0.06
		August	0.07
		September	0.05
	Total Nitrogen	May	0.4
		June	0.3
		July	0.2
		August	0.6
		September	0.3

3.5.2 Particulate Organic Matter

Particulate organic matter (POM) present in the water column at the three monitoring sites varied on a season basis. Highest concentrations of POM were observed in May and June at all three locations. Concentrations at Mill Creek were generally higher than at Carr and College Creeks. The overall percentage of POM in relation to total overall particulate matter was highest in College Creek between June and August while Carr Creek had the lowest POM% during the same period (Table 3-9).

Table 3-9. Particulate Organic Matter Results at Naval Support Activity Annapolis Monitoring Sites in 2020.

Station	*Month*	*POM (mg/L)*	*POM %*
Carr Creek	May	19.2	83.35
	June	10.9	54.87
	July	6.8	55.28
	August	6.1	34.27
	Sept	6.4	52.90
College Creek	May	9.6	76.49
	June	11.4	81.42
	July	5.8	95.11
	August	6.0	78.45
	Sept	6.0	59.51

Station	*Month*	*POM (mg/L)*	*POM %*
Mill Creek	May	17.5	82.13
	June	19.2	77.27
	July	7.3	70.87
	August	6.5	62.50
	Sept	6.8	87.23

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4.0 DISCUSSION

4.1 Benthic Habitat Assessment of Existing Conditions

The purpose of this task was to locate, survey, and evaluate potential suitable oyster habitat and historic beds at NSA Annapolis. Three bodies of water were surveyed: Mill Creek, Carr Creek and College Creek. An evaluation of these creeks was conducted between June 2019 and early November 2020. Sites were field evaluated using side scan sonar bottom mapping in 2019 and additional water and sediment samples were collected for analysis in 2020.

Results from side scan sonar surveys of the three creeks provided data showing a mix of bottom habitats. Harder sandy substrates were captured in the data at College Creek and Carr Creeks, however, most of these creek locations occurred in waters that were shallower than the proposed depth in the scope of work. From data collected, the bottom habitat at Mill Creek is composed of primarily softer consolidated sediments in the surveyed area. Surveys conducted throughout Maryland's portion of Chesapeake Bay between 1999 and 2001 showed that 90 percent of the historical range has degraded from a productive substrate to mud, sand, or heavily sedimented shell (Smith et al. 2005). Data from the surveyed areas (deeper than or equal to 1 m [5 feet]) showed no evidence of habitats with an abundance of buried shell or surface shell hash.

Currently, waters of the Severn River, of which Carr and College Creeks flow into, are identified by NOAA and the Maryland Department of Natural Resources (MD-DNR) in the *Maryland Aquaculture Siting Tool* as an oyster sanctuary (NOAA and MD-DNR 2021). These data also show historical evidence of oyster bars that once existed throughout the Severn River basin. Several of those historical oyster bars existed within the area surveyed in Carr Creek but no evidence of oysters was observed during the 2019-2020 surveys. No historical records of oyster bars could be found for College or Mill Creeks.

Several restorations efforts have been conducted between 2009-2018 in upper stretches of the Severn River (NOAA and MD-DNR 2021) but little information or data were available describing the results of these restoration efforts. Recent surveys by the Oyster Recovery Partnership indicate that there are existing adult populations of oysters within the Severn River basin, but no information could be obtained on location and status of these bars (H. Ward Slacum, Jr., personal communication, October 2020).

4.2 Water Quality

Short-term monitoring of water quality parameters between May and November 2020 indicated that general requirements for oyster survival were met, however long-term fluctuations and patterns could impact oyster survival. Water temperatures at sampling locations averaged between 13.5° to 30.2°C during the monitoring period. In the geographical range where adult eastern oysters are commonly found and are able to survive, temperatures range from -2° to 36°C (Shumway et al. 1996). Although temperatures are known to fluctuate in the study area, no site-specific, long-term data were available to evaluate the winter period when temperatures would be lowest. Extreme prolonged winter events could potentially expose oyster populations in shallow waters to mortality events but temperature-induced mortality in oysters located below the Mean Low Low Water (MLLW) line in the current study areas would not be expected.

Salinity plays a significant role in the survivability of eastern oysters and in diseases that commonly affect mortality levels. Burreson and Calvo (1996) reported that the most important pathogen to effect eastern oysters since 1987 is *Perkinsus marinus*, more commonly known as Dermo. Salinities greater than 15 ppt coupled with higher water temperatures produce the right conditions for higher infection by *P. marinus* and oyster mortality rates. Further data revealed a statistically significant relationship of oysters infected with *P. marinus* along a salinity gradient and its impacts on mortality. Burreson and Calvo (1996) further reported that if summer/fall salinities ranged from 9.0 to 15.0 ppt, infection rates of *C. virginica* could be high, but mortality could be relatively low.

Salinity observations at the NSAA water quality monitoring locations averaged 9.1 to 9.9 ppt during the periods when water temperatures were the highest and reached a maximum average of around 13.7 ppt at Carr Creek in November. Thus, during 2020 monitoring, salinity levels did not appear to exceed 15 ppt for any extended period when infection and mortality would be expected to be the highest. In 2020, monthly average salinities ranged from 5.7 ppt in the Spring to 13.7 ppt in the Fall. Data reported by the MD-DNR *Eyes on the Bay Program* and the Severn River Commission showed similar salinity trends between 1990 and 1997 (MD-DNR 2021, Anne Arundel County 2021). Seasonal weather events and periodic droughts have been known to impact salinity levels in Severn River.

Dissolved oxygen (DO) readings collected at the stations showed no discernable patterns. Mill Creek exhibited the lowest DO levels in July and August when anoxic conditions are typically at their highest in waters of the Chesapeake Bay (Cooper and Bush 1991). High DO levels during May 2020 in both Carr Creek and Mill Creek may be an indication of plankton blooms which have been known to saturate DO levels in estuarine waters. Average DO levels ranged from 4.5 to 15.1 mg/L which was more than the level of 2 to 3 mg/L that most experts indicate is the lower threshold of oyster survival. In addition, observations from this monitoring did suggest that overall DO levels were generally higher and more stable at the Carr Creek station. While DO levels during this short monitoring period did remain above the minimal threshold for oyster survivability, no conclusions could be made on longer term poly-annual variability of DO levels within these three creeks.

Other seasonal parameters monitored included pH and turbidity but no conclusion on their impacts to the viability of oyster populations could be determined due to the relatively short data collection period of six months. The data collected does provide valuable baseline data that could be used in conjunction with future monitoring of water quality conditions in Carr, College, and Mill Creeks.

Water chemistry samples were collected each month from May through September during the 2020 monitoring period to provide baseline data on dissolved phosphorous and dissolved nitrogen levels, and particulate organic matter (POM). The data collected showed no obvious patterns. At this time, no conclusions could be made on their impacts to future restoration efforts. Additional monitoring is needed to discern potential seasonal changes that may affect long-term survival and growth of oysters. This includes potential impacts that nutrient loading might have on plankton blooms and bioavailability of food resources within the Severn River basin.

Versar attempted to conduct an analysis of sedimentation rates at the three stations. The limited data collected did provide some insight on the amount of sediment movement, but it is unclear whether the variation in estimated accumulations rates was the result of natural processes or due to human disturbances. Highest sedimentation rates were observed in June at College Creek while both Mill and Carr Creeks saw the highest sedimentation rates occur in July.

The relatively short monitoring period in which data was collected provides a brief snapshot of the baseline conditions at the three stations located in Carr, College, and Mill Creeks. Water quality conditions are generally favorable for oyster survivability but suitable bottom habitat crucial to growth and survival is limited in the waters selected for this study (greater than or equal to 1 m [5 feet]). Other surveys (e.g., conducted by MD-DNR, NOAA, and Oyster Restoration Partnership) show the presence of oysters in the Severn River and there are several ongoing restoration efforts outside of the NSAA study area, however, those oyster restoration efforts are limited to areas where minimal habitat and biological requirements are met. General observations of the deeper water habitats in the surveyed areas show no evidence of a large-scale presence of eastern oysters; however, individual, solitary oysters could exist based upon these conditions.

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5.0 RECOMMENDATIONS

Based on the limited data collected at the study areas, full recommendations for oyster restoration cannot be made at this time. Collected data did provide valuable background information about basic habitat types and general water quality conditions. This could contribute to decisions on future monitoring to assess the best locations for restoration. Although the study was based on waters greater than or equal to 1.5 m (5 feet) in depth, some ancillary data was collected from shallow habitats that overlapped the study area.

Since the cost of oyster restoration and reef building can be very resource intensive, it is important to make sure that all key requirements for oyster survivability are met to ensure successful restoration efforts. Based on this study's results, the following recommendations are made for each of the following sites: Carr Creek, College Creek, and Mill Creek.

5.1 Carr Creek

The surveys conducted at Carr Creek showed the most promising results. However, based upon preliminary side scan sonar results, it appears that waters deeper than 1.5 m (5 feet) in the original study area have limited to no benthic substrate suitable to establish and sustain a viable population of oysters. The existence of historical hard bottom and oyster reefs in some of the shallower sections does show some promise for restoration efforts, but the lack of shell on the sediment surface could require a resource-intensive solution to establish key, viable oyster habitat. To further define oyster habitat restoration within Carr Creek, the Marstel-Day team recommends the following actions:

1. Conduct a detailed desktop analysis of shallow, harder bottom to explore whether shell may exist nearby or could be buried. Data might exist from surveys conducted by the United States Geological Survey or other organizations.
2. Conduct shallow water investigations to assess habitat conditions, identify whether oysters are present, and to categorize habitat suitability.
3. Conduct additional long-term water quality monitoring in areas of high habitat suitability to determine if there are any interannual variations not observed during the short monitoring period and ensure any variations fulfill the requirements for oyster survivability.

After these additional ecological assessments have been completed, the feasibility of implementing successful oyster habitat restoration measures in Carr Creek will be better understood. Even if additional data support a conclusion that it is not feasible to restore oyster reefs in Carr Creek, these additional assessments may lead to identifying alternative restoration measures that can be implemented to support the ecological viability of any oysters utilizing Carr Creek (e.g., these measures may include oyster cages, living shorelines, and/or oyster castles along shorelines or existing offshore breakwaters). Furthermore, restoration measures such as living shorelines and oyster castles often can be integrated into shoreline restoration/stabilization strategies to improve shoreline protection from sea level rise and the erosion effects of storm surges.

5.2 College Creek

The size of potential restoration area at College Creek is relatively small. Additional investigations could be done in harder substrates near the mouth where sandy sediments exist; however, side-scan sonar data showed no evidence of shell or oysters on the bottom. Use of the creek, by the U.S. Naval Academy's rowing center, as a navigable water could also limit any large-scale efforts. If alternative oyster habitat techniques are desired for College Creek (such as oyster castles), further study is required to identify these potential locations and then to conduct longer-term water quality monitoring to ensure that the general requirements for oyster survival would be met.

5.3 Mill Creek

Survey data from side-scan sonar showed no hard-bottom habitat in Mill Creek. Harder substrates were observed along shallow prominent points, but overall habitat was limited. Large-scale restoration in this area would not be feasible at this time due to limited bottom habitat. However, small-scale restoration (e.g., living shorelines and oyster cages) may be viable in the shallow, hard-bottom habitats, though further surveys of these habitats is necessary to assess habitat conditions, identify whether oysters currently are present, and to categorize habitat suitability. If it is determined that suitable oyster habitat does exist in some shallow water locations of Mill Creek, then longer-term water quality monitoring will be required to ensure that the general requirements for oyster survival can be met before funds are expended on future oyster restoration measures.

6.0 REFERENCES

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Appendix A Sediment Photographs

Figure A-1. Sediments Collected at CARR_1.

Figure A-2. Sediments Collected at Carr_2.

Figure A-3. Sediments Collected at CARR_3.

Figure A-4. Sediments Collected at CARR_4.

Figure A-5. Sediments Collected at CARR_5.

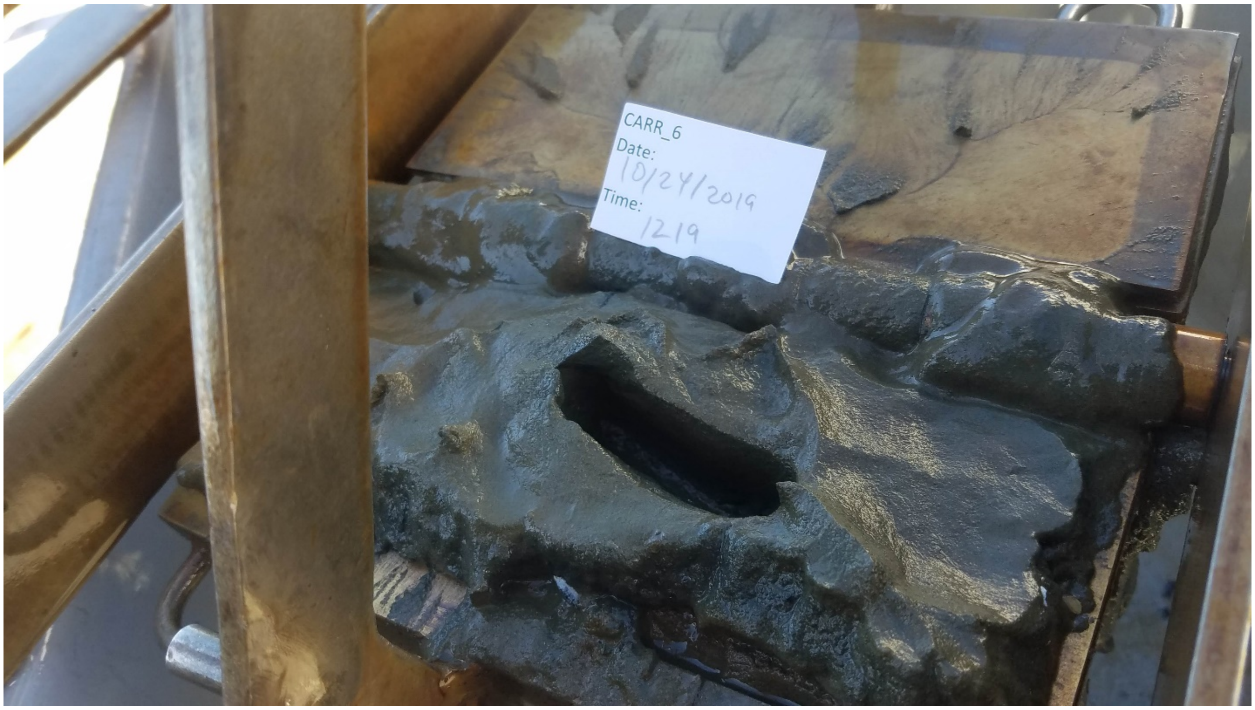

Figure A-6. Sediments Collected at CARR_6.

Figure A-7. Sediments Collected at CARR_7.

Figure A-8. Sediments Collected at CARR_8.

Figure A-9. Sediments Collected at CARR_9.

Figure A-10. Sediments Collected at CARR_10.

Figure A-11. Sediments Collected at CARR_11.

Figure A-12. Sediments Collected at CARR_12.

Figure A-13. Sediments Collected at CARR_13.

Figure A-14. Sediments collected at CARR_14.

Figure A-15. Sediments collected at CARR_15.

Appendix B Draft Report Comments

Comment #	Page #	Section	Comment By	Comments	Concur / Non-concur	Discussion / Response
1	Cover	Cover	Adrian Dascalu	Please include N4008014D0002 contract number on cover page in addition to task order number.	Concur	Added " Contract N40080-14-D-0002" to the cover page.
2	1 to 2	Introduction	Adrian Dascalu	For the introduction pages, change bottom page numbers to 1-1 and 1-2.	Non-concur	These page numbers are correct on our file version. This may be a Microsoft Word glitch. Sometimes the page numbers appear incorrectly in reader view and/or the Word software version may be different between the Navy and Marstel-Day.
3	1	Introduction; line 3	Adrian Dascalu	Task Order number should be N4008018F5125.	Concur	Added N40080 in front of 18F5125 Task 3 on line 2 of introduction.
4	1	Introduction; line 5-6	Adrian Dascalu	Habitat suitability study also included side-scan sonar for existing reefs, please add in.	Concur	corrected: "… oyster habitat suitability was evaluated by conducting side-scan sonar of the bottom habitat (to characterize sediment hardness and to survey for the presence of existing oyster reefs) and by…"
5	2-3	2.0 methods	Adrian Dascalu	The bottom page numbering for section 2.0 starts with page 2-3 and continues to 2-9. It should start with page 2-1 and continue to 2-7.	Concur	Fixed page numbering for section 2.0
6	2-3	section 2.1 line 4	Adrian Dascalu	Change "deeper" to "greater".	Concur	Changed "deeper" to "greater".
7	2-3	section 2.1 line 5	Adrian Dascalu	Change "habits" to "habitats".	Concur	Changed "habits" to "habitats".
8	2-5	section 2.2 water quality line 1	Adrian Dascalu	Comma after "data" and after "water".	Concur	Comma after "data" and after "water".
9	2-7	section 2.3 side scan sonar line 9	Adrian Dascalu	Insert "as" after "bodies".	Concur	Inserted "as" after "bodies".