4-2021

Ecological Monitoring Program at VIMS ESL : Annual report 2020

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Recommended Citation

Ross, P. G., & Snyder, R. A. (2021) Ecological Monitoring Program at VIMS ESL : Annual report 2020. VIMS Eastern Shore Laboratory Technical Report No. 8. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/3a2z-ek23

Ecological Monitoring Program at VIMS ESL
Annual Report 2020

Paige G Ross and Richard A Snyder, Eds.

VIMS Eastern Shore Laboratory Technical Report No. 8

Eastern Shore Laboratory
Virginia Institute of Marine Science
William & Mary, Wachapreague, VA

April 2021

Contents

2020 Executive Summary

An Ecological Monitoring Program (EMP) has been established at the Virginia Institute of Marine Science Eastern Shore Laboratory (VIMS ESL) for the coastal environment near the Wachapreague lab. The goals of the initiative are to 1) provide status and trends information to scientists who study and regulators who manage Virginia's marine resources, 2) provide a scientific context for short-term research and grant proposals 3) provide pedagogical enrichment to educators for their classes, and 4) build capacity in staff expertise and training of interns and students at VIMS ESL.

The program formalizes and standardizes data collection for a long-term status and trends database as an asset provided by VIMS ESL in addition to marine operations and shore support facilities. The EMP standard methods also provide visiting scientists with protocols for consistent and comparable work. The EMP includes electronic water quality stations, oyster settlement and adult population dynamics, microbial biofilm growth, characterization of benthic communities in soft sediments and oyster reefs, sediment characteristics, and drone surveillance of salt marsh die back and Wachapreague Inlet dynamics. While this document focuses on these core areas of our monitoring activities, results of other VIMS ESL research on shellfish aquaculture, bay scallop restoration, and shorter-term grant supported research projects are reported elsewhere.

Real-time and archived water quality data, both the current electronic systems and records beginning in the 1960s, have been in demand by the aquaculture industry and scientists. Weekly biofilm growth on standardized plates provides a biological sensor for nutrients, water quality and productivity. Oyster settlement data reflects the present and potential future condition of seaside oyster populations, combining historical records with ongoing assessment. In 2020, annual cumulative spat set as high as 98,000 oysters per m^2 was recorded. Overall, it was a well above average settlement year and bodes well for seaside natural oyster reefs. Oyster population demographics in 2020 were similar to benchmarks established in 2018-2019. The epi-benthic communities of soft-sediment, intertidal oyster reefs and subtidal shell beds were described based on data gathered from >5,400 individual organisms representing ~ 90 genera. Substantial change in the vicinity of Wachapreague Inlet was documented based on yearly aerial drone surveys encompassing ~150 hectares of island/marsh and ~8,200 m of shoreline. Aerial drone near-infrared surveys continued in an area of marsh dieback (~30 hectares) and contribute to determining whether this area is continuing to expand, recovering, or has reached some form of stasis.

The program has been partially supported by donations from Chuck and Janet Woods and donors to the VIMS ESL summer intern program. VIMS ESL summer interns are high school and undergraduate students receiving paid internships from the Bonnie Sue Scholarship Foundation Fund. During 2018 and 2019, 2 local high school and 5 local college students participated the EMP research activities, providing excellent technical training in the conduct of field and laboratory research. Unfortunately, due to COVID-19 restrictions, we did not host interns this year. The full report is available at the VIMS ESL website: http://www.vims.edu/esl/.

Ecological Monitoring Program at the Virginia Institute of Marine Science Eastern Shore Laboratory (VIMS ESL)

Authors: PG Ross & Richard A Snyder

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The VIMS ESL mission is to serve as a field station and coastal seawater laboratory for basic marine science and aquaculture research, marine science education, outreach, and advisory service to the Commonwealth of Virginia, particularly with regard to marine resources of the Eastern Shore of Virginia. To implement this mission, VIMS ESL provides a platform for field and lab research, education, and advisory service activities by both resident and visiting researchers and educators from around the world.

This monitoring program was designed to support that mission in three ways:

1. To provide an environmental context for researchers and educators who may only visit briefly, establishing a value-added backdrop in which to make greater sense of short-term research results and educational programing.
2. Establish a record of long-term environmental data for tracking status and trends of this largely unspoiled coastal region
3. Engage interns and students in rigorous technical scientific training while they contribute to a larger long-term scientific program.

We consider this mission support to be as vital as the marine operations and onshore facilities support we provide for high quality marine education and research in a remote and undeveloped region of U.S. mid-Atlantic coastal marine habitat.

Geographic Setting and Rationale

The Eastern Shore of Virginia (ESVA) is the narrow southern end of the Delmarva Peninsula, averaging 10 miles wide and 85 miles long from Pocomoke Sound on bayside and Chincoteague island on seaside to Fisherman's Island National Wildlife Refuge at the mouth of the Chesapeake Bay. Its remote and rural setting features pristine natural barrier islands, bays, creeks and marshes along the Atlantic coast unfettered by human development and now protected by the Nature Conservancy, the Commonwealth of Virginia, and the federal government. The region has been designated by the United Nations Education, Scientific, and Cultural Organization (UNESCO) as part of their *Biosphere Reserve System*, has *National Natural Landmark* status with the US Department of the Interior, and is part of the *Western Hemisphere Shorebird Reserve Network*. Within the past year, we have been negotiating with the Smithsonian Institution to make the seaside coastal habitats of the ESVA part of their *Marine*

Geo global biodiversity network of sites. Data collected within the VIMS ESL program will be uploaded to *Marine Geo* as part of that collaboration.

Short watersheds with limited freshwater make the bayside estuaries and seaside creeks and shallow coastal bays unique within the Chesapeake Bay region. Extensive marshes, oyster reefs, and seagrasses add to the natural and commercial seafood value of the regional marine resources. The region provides an excellent sentinel site that integrates broader anthropomorphic impacts and environmental change in a relatively undeveloped coastal environment.

The VIMS ESL is in Wachapreague, VA, directly located on Wachapreague Channel, a location that is well situated to provide access and facilities support for research, education, and service pertaining to these regional marine resources. Extensive aquaculture occurs in the region for oysters and hard clams. The hard clam industry on the ESVA is the largest producer of cultured hard clams in the nation. Dr. Mike Castagna at the VIMS ESL was largely responsible for the research and development that created the current clam industry, taking advantage of excellent quality high salinity seawater and habitats adjacent to the laboratory, including leased bottom maintained specifically for research purposes. The Seawater Laboratory provides access to raw and filtered seawater and custom setups for research and education, and the Castagna Research Hatchery and nursery is dedicated to aquaculture research.

The VIMS ESL, as a launch point for diverse research and education activities, is somewhat unique in its access to high quality, high salinity seawater and a relatively pristine and complex barrier island/coastal lagoon system in the mid-Atlantic region. Long-term records for environmental data are generally lacking for this outdoor laboratory. From water quality data to bathymetry maps and from local community associations to diversity trends, the dearth of long-term datasets is not unique to this research lab. Sentinel, benchmark, and monitoring data are typically not well funded by agencies supporting short duration project cycles, yet are important to understand the implications of experimental work in the context of longer-term environmental processes.

The need for such data is widely acknowledged, even if budget priorities make support difficult. Current sea-level rise and climate change require records if we wish to track status and trends in the environment and marine resources. There are few examples of large-scale regional collaborative projects that endeavor to holistically develop benchmark and sentinel monitoring programs (e.g. “Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut”, 2011; Smithsonian Institution Marine Geo program).

A lack of high resolution multiparameter water quality data in support of research and education was addressed in 2016 with the creation of continuously monitored stations in Wachapreague Channel at VIMS ESL, in southern Burton’s Bay for the VIMS intertidal oyster research lease (Custis Channel), and a third station established in October 2018 in Willis Wharf

(Parting Creek). Data from these stations are accessible in near-real time (~15 min increments) online (see Chapter 2 for details), and archived records are provided on request. They have been extremely useful to researchers and educators in the ESL-Seawater Lab, for background to ongoing field research on the Custis Channel reef, and have been invaluable to the aquaculture industry hatcheries in Willis Wharf.

Specific objectives for the ESL-EMP:

1. Collect spatial and temporal data that provide environmental characterizations. The EMP dataset and reports will provide visitors with the background and context for education activities and focused research proposals and funded projects. This is a value-added asset in support of education and research conducted at VIMS ESL.

2. Establish status and trends for coastal environmental change analysis. A lack of baseline and continuing environmental data hampers analysis of change and management of marine resources in the dynamic coastal ecosystems. VIMS ESL is uniquely situated to access unspoiled coastal marine habitats that integrate regional and global environmental impacts, and thus provides access and an excellent outdoor laboratory and sentinel site for broader environmental trajectories.

3. Support aquaculture industry and commercial and recreational fishing communities. Documenting episodic events and elucidating real long-term trends can help inform local decision making by private enterprise and government regulators, enhancing resilience of this important economic sector.

4. Support student research & education.

    a. *Provide research opportunities for VIMS and William and Mary students*. The VIMS-ESL has a dedicated endowment (Owens Family Endowment) and other donor funds (ESL General endowed funds, Oceanside Conservation, Woods Family, etc.) to support student research and education. This program will provide training and tasks that get students involved with contributing to a larger scale scientific endeavor. The program also provides contextual background data allowing data mining opportunities and background for undergraduate and graduate research projects.

    b. *Provide research opportunities for interns*. ESL has an ongoing summer internship program supported by donors to the Bonnie Sue Scholarship Fund. The interns are provided summer employment and research experiences with ESL staff and visiting scientists. Projects and tasks within the EMP provide a wide range of training and experiences to assist interns in developing their careers.

   c. *Enhance ESL education programs*. The EMP supports educational field trips/lab experiences with a quantitative data gathering/sharing experience for visiting groups, who can both add to the data and use the multi-year data for instructional purposes.

5. <u>Facilitate capacity building</u>

   a. *Maintain/develop staff expertise*. Over the last several decades the ESL has developed a reputation for its benthic ecology work, identifying and quantifying community assemblages. The ongoing EMP facilitates maintaining and developing standardized procedures and equipment, staff skills, and taxonomic expertise in this area in support of collaborations, visiting researchers, and grant proposals.

   b. *Attract new users*. The EMP provides a complimentary asset to the marine operations and shore facilities provided by VIMS ESL, a value-added enrichment for scientists seeking platforms for grant funded research and educators seeking to provide opportunities for students to explore new environments.

   c. *Providing data for future funding/research*. The environmental characterization provided by the EMP program has already been used by researchers seeking grant funding to work at ESL. The opportunity to conduct research within the context of a broader understanding of the regional environment makes proposals seeking precious grant funding more competitive.

Chapter 1. Ecological Monitoring Program Overview

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Metrics

The EMP framework was designed to document the status and trends of environmental and ecological processes near the Eastern Shore Laboratory. Table 1-1 provides a list of data collected during 2018-2020. Details of specific data collection methods and locations can be found in the respective chapters.

The overall strategy was based on accumulated experience and observations of ESL staff during work on many different research projects. A stratified scheme of three geographic areas with different features was established (Fig. 1-1): Bradford Bay (shallow, diffuse tidal currents, adjacent to uplands); a portion of Burton's Bay (shallow, oyster reefs, tidal currents) and the Wachapreague Inlet vicinity (high energy, offshore weather impacts, deep channels, tidal currents). The following metrics were sampled within this geographic matrix:

- Oyster settlement
- Biofilm growth
- Benthic community: soft sediments (intertidal, shallow subtidal, & channel edge)
- Epi-benthic community: hard substrate (intertidal, & subtidal)
- Sediment mapping (intertidal, shallow subtidal, & channel edge)

Other metrics have either logistical constraints (e.g. water quality stations) or are very specific to certain locations (e.g. mapping and education-related efforts) and are not, therefore, designed with the geographic stratification:

- Water quality
- Finney Creek marsh dieback mapping
- Wachapreague Inlet marsh/island mapping

10-yr Plan

It is our intention that the EMP be a long-term dataset. To initiate the effort, we have developed a 10-yr plan for collecting various metrics (Table 1-1). The potential for rates of change in the individual metrics was used to space effort temporally. The plan is subject to adjustment based on data results, funding, needs of visiting researchers and educators, and demands of other projects on staff and resources. The EMP sampling plan will be re-visited and adjusted yearly.

Dissemination of Data

Data summaries and raw data will be made available to visiting researchers, students and the general public upon specific requests. Additionally, results of the EMP will be broadcast by the following:

- VIMS ESL Annual Report: Internal progress review and discussions
- Marine Life Day Display: Public open-house third Saturday of September each year. Presentation of updated data and discussion of emerging patterns.
- VIMS ESL dedicated webpage: The lab website will have links to downloadable reports and other products from this effort: https://www.vims.edu/esl/research/emp/index.php.
- VIMS ESL Facebook page: Ongoing analysis of results of interest to regional science and aquaculture, such as the weekly oyster spat set results, unique or unusual events: https://www.facebook.com/VIMSESL
- Peer-reviewed publications will be submitted in appropriate journal outlets and presentations of data will be made at professional meetings, especially as data are accumulated sufficiently to identify trends.

Student Involvement

The COVID-19 pandemic precluded an active student/intern program during summer 2020. However, as previously reported, multiple students intensively participated in the 2018 & 2019 EMP during June-August as part of the ESL summer internship program. Below is a list of their academic locations:

- Broadwater Academy (college preparatory high school)
- Nandua High School
- College of William and Mary
- Christopher Newport University
- Old Dominion University
- University of Miami
- Virginia Tech

Funding gratefully acknowledged

The Bonnie Sue Internship Program supported summer student interns that assisted with the project. A donation by Janet and Chuck Woods covered an intern salary and operating expenses for the project.

Table 1-1. VIMS ESL Ecological Monitoring Program 10-year sampling plan.

	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Component	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**	**Yr 7**	**Yr 8**	**Yr 9**	**Yr 10**
Oyster settlement	X	X	X	X	X	X	X	X	X	X
Oyster population demographics	X	X	X	X	X	X	X	X	X	X
Biofilms-weekly (June-July)	X	X	X	X	X	X	X	X	X	X
Biofilms-1 week rate (Chla & OM)	X			X			X			X
Benthic community--soft sediments	X	X	X	X	X	X	X	X	X	X
Epi-benthic community--hard substrate	X	X	X	X	X	X	X	X	X	X
Sediment mapping: *benthic community sites* (surficial SOM, Chla)	X	X		X		X		X		X
Sediment mapping: *benthic community sites* (Fractions @ 5 cm intervals)	X	X			X			X		
Water Quality-sonde stations	X	X	X	X	X	X	X	X	X	X
Water Quality-class data-flow etc. (Dr. Mark Brush)	X			X	X	X	X	X	X	X
Finney Creek marsh dieback mapping	X		X		X		X		X	
Wachapreague Inlet marsh/island mapping	X		X		X		X		X	

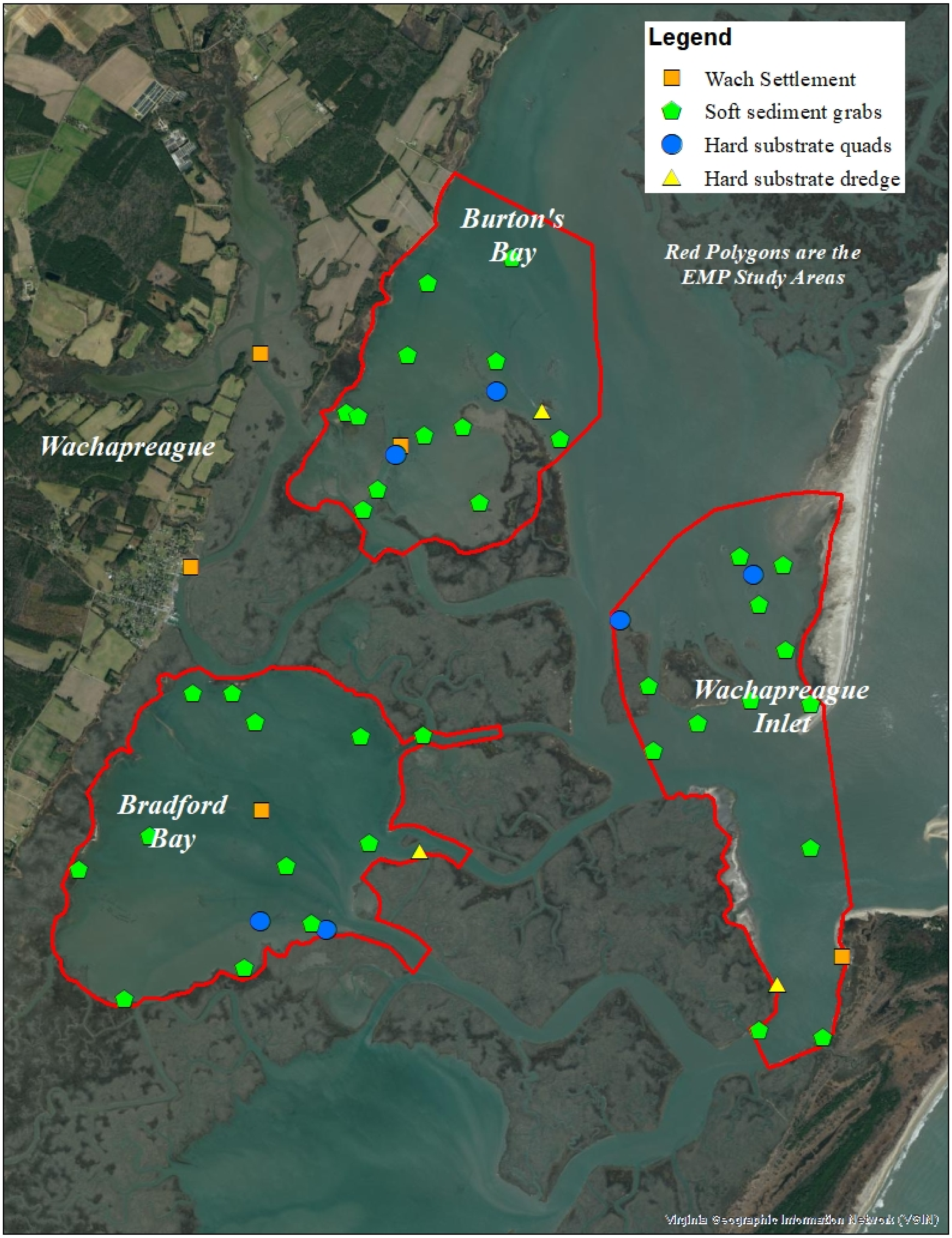

Fig. 1-1 Three geographic regions of the ESL-EMP with some sampling locations from 2020: Bradford Bay (relatively stable, but adjacent to uplands); a portion of Burton's Bay (anecdotal signs of some current changes) and the Wachapreague Inlet vicinity (very dynamic).

Chapter 2. Water Quality

Section 2-1: Fixed Sensors (continuous)

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Underway	Planned

Introduction

The VIMS-Eastern Shore Laboratory (ESL) has established and maintains continuously recording, fixed-sensor water quality stations at the two locations (Fig. 2-1-1):

- Wachapreague (37°36’27.80’’ N 75°41’08.93’’ W) *RA Snyder VIMS startup funds*
- Willis Wharf (37°30’44.22’’ N 75°48’22.40’’ W) *Steve and Barbara Johnsen donation*

Data collected from these stations can be used to identify and monitor short-term variability and long-term changes in coastal watersheds and estuarine ecosystems. Additionally, these water quality datasets can be analyzed with other ecological monitoring data to elucidate how naturally occurring fluctuations, as well as unique water quality events, correlate and impact marine ecosystems. Individual researchers and educators can access real-time and archived data for the period of their work, or longer-term records as desired. Requests for these data have been from researchers working at local, national, and global scales for research context and for tracking global climate changes. These water quality data may also be utilized to inform coastal zone management decisions by the Commonwealth of Virginia.

ESL’s water quality mission establishes long-term datasets for researchers, educators and resource managers, but also supports local fishermen and aquaculture operations by providing real-time and archived water quality data. As the largest hard clam aquaculture production in the country, the Eastern Shore’s multimillion-dollar commercial shellfish industry is important both economically and environmentally. ESL is supporting this industry by maintaining a station in Parting Creek, Willis Wharf, VA, home to three major hatchery operations, established with funding from a private donation (Steve and Barbara Johnsen) and site support from Cherrystone Aquafarms. Real-time and archived data are used by these operations, as well as regional aquaculturists and fishermen to monitor current water conditions. These data help the industry better understand and/or predict how significant events may relate to production, growth, and field grow out performance of their products, supporting practical management decisions.

Live data (15-minute intervals) from the Wachapreague and Willis Wharf stations can be found at www.vims.edu/esl/research/water_quality/. Archived data for both stations is available upon request (contact Darian Kelley at dkelley@vims.edu).

Study Area & Methods

The Wachapreague station, installed in March 2016, was chosen to support research that occurs in and near ESL's Seawater Laboratory (SWL). This station is located at ESL, and is positioned off the SWL pier in Wachapreague Channel. The Willis Wharf station, installed in October 2018, was selected to provide support for nearby commercial shellfish hatcheries. This station is located at Cherrystone Aqua Farms in Parting Creek (a western branch of the Machipongo River). Both the Wachapreague and Willis Wharf water quality stations are land-based monitoring systems that are connected to a floating pump. For these systems, surface water is pumped into a chamber (called a flow cell), where the water sample is analyzed and reported to a live telemetry and control system provided by Green Eyes LLC (Cambridge, MD). This type of setup allows water to be drained out of the flow cell chamber in between sample periods, decreasing biofouling and extending time between routine cleaning and maintenance. This sampling method has been verified by comparison with an *in situ* submerged sonde recording the same measurements.

Maintenance schedules vary depending on season and site location and are dependent on frequency and type of biofouling. The land-based Wachapreague and Willis Wharf stations are dual line systems that require weekly line changes to switch pump intakes. This consists of removing and cleaning of one pump while another remains in service, minimizing biofouling of both the lines and pump intakes. Since the pump intakes are the only portion of the land-based system that is constantly exposed to the marine environment, flow cell and sensor maintenance are minimal. Light cleaning of the flow cell wall occurs once a month. To minimize any gaps in the datasets, deployed equipment is immediately swapped with clean, calibrated equipment for maintenance of retrieved sondes.

Data for eight water quality parameters are collected at both stations (Table 2-1-1). Water temperature, salinity, specific conductance, pH, dissolved oxygen, turbidity, chlorophyll-a, and blue green algae (BGA) phycocyanin levels are measured at 15-minute intervals using a YSI multiparameter 6-port EXO2 Sonde. Dissolved oxygen, turbidity, chlorophyll, and BGA readings are determined using optical sensors (i.e. sensors that use a beam of light to calculate parameter measurements). Detailed sonde and sensor information can be found in the YSI EXO User Manual (https://www.ysi.com/File%20Library/Documents/Manuals/EXO-User-Manual-Web.pdf). EXO2 Sonde sensors are capable of holding accurate calibrations for up to 90 days with the assistance of an antifouling wiper. The central wiper cleans the sensor tips before every reading to provide accurate measurements and prevent sensor biofouling.

Suspicious spikes or outliers within a dataset are most likely caused by marine objects (i.e. macroalgae, small fish, crabs, etc.) interfering with optical sensor readings. For this report, Microsoft Excel was used to exclude questionable data during ESL's quality control (QAQC) process. Raw data was used to calculate yearly statistics for each parameter. Parameter standard deviation was used to preserve internal variation and detect questionable readings by comparing a single measurement with the measurement immediately preceding it. If the datapoint was more than ± 1 standard deviation away from the preceding datapoint, the datapoint was excluded from the dataset.

Wachapreague Channel water quality data prior to 2020 can be correlated with tidal cycles by using the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center website (https://www.ndbc.noaa.gov/station_page.php?station=wahv2). NOAA's Station WAHV2 is located adjacent to ESL's Wachapreague water quality station and monitors water level, wind direction, wind speed, gusts, atmospheric pressure, and air and water temperature. NOAA has maintained this monitoring station at ESL since 2005.

2020 Results & Discussion

Water quality data was collected at both stations during portions of 2020. However, full year coverage was hampered by severe weather causing structural failures and software and hardware hurdles that required extensive troubleshooting. Wachapreague data consists of <1 month of spring data (April 14-May 4), and <1 month of winter data (December 11-31) and will not be analyzed in this report, but is available upon request. Minimums, maximums, and averages for temperature, salinity, pH, dissolved oxygen, turbidity, chlorophyll, and blue green algae are summarized in Table 2-1-2 for the Willis Wharf station. Although this year's data is incomplete, these data, in addition to data collected in 2018 and 2019, begin to set the context for water conditions in the vicinity.

Continuous measurements allow analyses of seasonal and tidal patterns. Figs. 2-1-2 through 2-1-8 show the 2020 results for the Willis Wharf station parameters. Seasonal trends, such as warmer water temperatures and lower dissolved oxygen levels in the summer/fall, and cooler water temperatures and higher dissolved oxygen levels in the winter/spring, are recognizable (Figs. 2-1-2 & 2-1-5). Episodic events are also seen (e.g. significant salinity troughs during Feb and Sept; see Fig. 2-1-3). Often times, water quality data for shorter, specific time periods are useful for aquaculture operations timing access to water, or for researchers actively conducting studies or experiments. Archived data for both stations is available upon request.

Monitoring basic water quality parameters for seaside ESVA provides a status and trends dataset not only for the measured parameters, but also as context for research activities and commercial aquaculture. With a 1.5-meter tidal amplitude, water quality measures on seaside ESVA are strongly affected by tidal flow. Relatively fast dissipation of salinity depressions and tide and turbidity correlations are discussed in last year's report (Ross & Snyder 2020; see chapter 2-1). Observations such as these can be used by researchers and local hatcheries to effectively reduce filtration and minimize supply cost.

ESL water quality monitoring data has proved to be a useful tool in providing background information and baseline data about tidal and seasonal fluctuations, and yearly comparisons and trends for multiple researchers and organizations. For example, this data is currently being utilized by Stacy Krueger-Hadfield and Wilbur Ryan from the University Alabama at Birmingham to supplement two working manuscripts involving characterizing latitudinal patterns and microsite variation of the sea anemone, *Diadumene lineata*.

ESL monitoring data is also utilized by local aquaculture operations to identify and/or correlate notable events in production, growth, performance, and survival in relation to water conditions. Monthly water quality files are provided to two local commercial shellfish hatcheries, in addition to the real-time data provided through ESL's webpage.

ESL's multi-year monitoring data has also been requested to provide context for educational and management purposes. All archived water quality data was provided to a United States Geological Service (USGS) hydrologic technician at the Pennsylvania Water Science Center. ESL monitoring data was requested as part of an ongoing effort to compile monitoring data from the Chesapeake Bay watershed to support bay-wide management and education topics (https://www.usgs.gov/centers/cba and https://www.chesapeakebay.net/).

Water quality data from Wachapreague and Willis Wharf will continue to be collected to provide snapshots and monitor long-term trends as part of the EMP. Because distribution of marine plants and animals is often impacted by water quality, these records can be examined alongside other data collected through the EMP and provide an environmental context for future research, adding value to research funds brought to ESL for both resident and visitor research activities. Once long-term records are established, these data will be used to connect trends in species richness, population abundance, and local distribution with specific water quality events, patterns, or changes overtime.

Comparison to Previous Years

Combining multiple years of monitoring allows data to be visualized and compared for specific metrics and timepoints. Seasonal trends, reported in the Results and Discussion section above, are consistently visible across the multi-year datasets. Yearly minimums and maximums for the recorded parameters are also similar (Figs. 2-1-2 through 2-1-8).

Water temperature data from the Willis Wharf station was compared to air temperature data from NOAA's WAHV2 station for 2019 and 2020 (straight/direct line distance between site locations = 9.35 miles). Archived NOAA air temperature data was subjected to ESL's QAQC process discussed in the Methods section above. Average daily air temperatures were calculated for days when >85% of expected readings were captured for both years (n=348 days). The difference in daily air temperature averages between the two years (AT_{2019}-AT_{2020}) is shown in Fig. 2-1-9 A. A distinct positive distribution of points above the red line, highlighted by the circled area in Fig. 2-1-9 A, indicates consistently warmer air temperatures in April/May 2019 when compared to the same days in 2020. The notably warmer air temperatures in the spring months of 2019, correspond with warmer water temperatures captured by the Willis Wharf station during the same months (see Figs. 2-1-9 B & C). This type of comparison is one example of how these data can be used for 1) detecting and assessing seasonal variation between years for aquaculture and fishing operations, and 2) identifying changes or fluctuations in species richness, abundance, and distribution moving forward.

As we accumulate more years of water quality data, we will be able to compare current data to past daily average, minimum, and maximum values and start to determine trends in these water quality parameters. We plan to track these trends not only for spatial comparisons between sites, but to identify temporal long-term changes for each site individually, and for the seaside coastal environment as a whole.

Acknowledgements

We would like to thank Justin Paul, Glenn Brundage, Richard Snyder, Brian Manley, Chris Bentley, Connor Lovett, and Edward Smith for fabrication and field assistance; Green Eyes LLC for system design and software troubleshooting; and Adam Miller, John Thomas, and Gary Anderson for networking and telemetry support. We would also like to thank Steve and Barbara Johnsen for providing funding for the Willis Wharf Station, and Cherrystone Aquafarms for providing site support and utilities.

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Table 2-1-1. Description of eight water quality parameters measured at ESL's water quality stations using EXO2 Sondes.

Parameter	Unit	Description
Temperature	°C	Measurement of the intensity of heat in the surrounding water
Specific Conductance	ms/cm	Measurement of how well water can conduct an electrical current
Salinity	psu	Measurement of all salts dissolved in a water sample
pH	-	Numeric scale used to specify how acidic or basic (alkaline) a sample is
Optical Dissolved Oxygen	mg/L	Measurement of the amount of oxygen that is present in the water.
	% saturation	Percentage of dissolved oxygen concentration relative to when water is completely saturated
Turbidity	NTU	Measurement of the cloudiness or haziness of the water sample
Chlorophyll	ug/L	Measurement of chlorophyll a.
Blue Green Algae	ug/L	Measurement of the phycocyanin accessory pigment found in blue-green algae (cyanobacteria).

Table 2-1-2. Summary water quality data for the Willis Wharf station, seaside of the Eastern Shore of Virginia, during a portion of 2020.

Location: *Willis Wharf*

Time period: *Jan-Sept 2020*

	Min	**Max**	**Avg**	**SD**
Temperature (°C)	2.67	34.30	18.32	8.25
Salinity (psu)	17.50	34.54	29.00	2.76
pH	7.20	8.21	7.79	0.18
Dissolved Oxygen (mg/L)	3.13	11.85	7.52	1.87
Turbidity (NTU)	2.49	80.60	12.12	6.73
Chlorophyll (ug/L)	0.57	70.14	6.21	6.44
Blue Green Algae (ug/L)	0.30	120.99	10.16	10.35

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community, National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Fig. 2-1-1 Location of two stations equipped with fixed water quality sensors on the seaside of the Eastern Shore of Virginia.

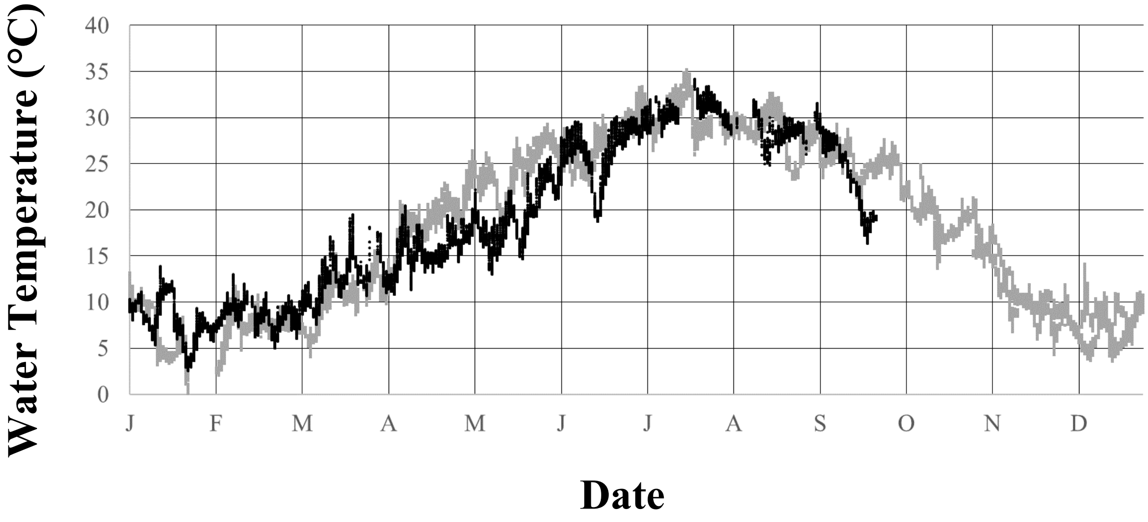

Fig. 2-1-2 Water temperature (°C) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

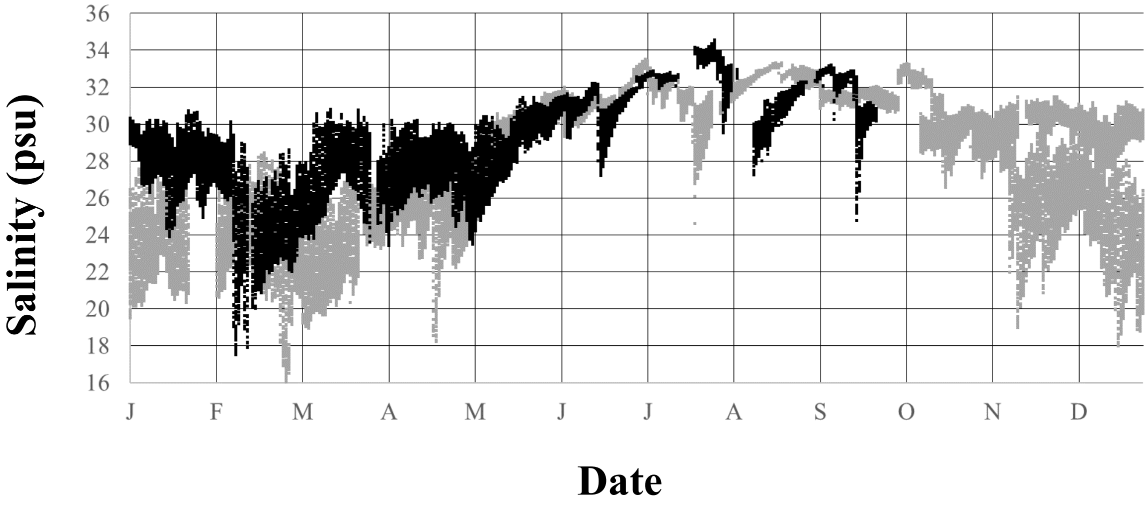

Fig. 2-1-3 Salinity (psu) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

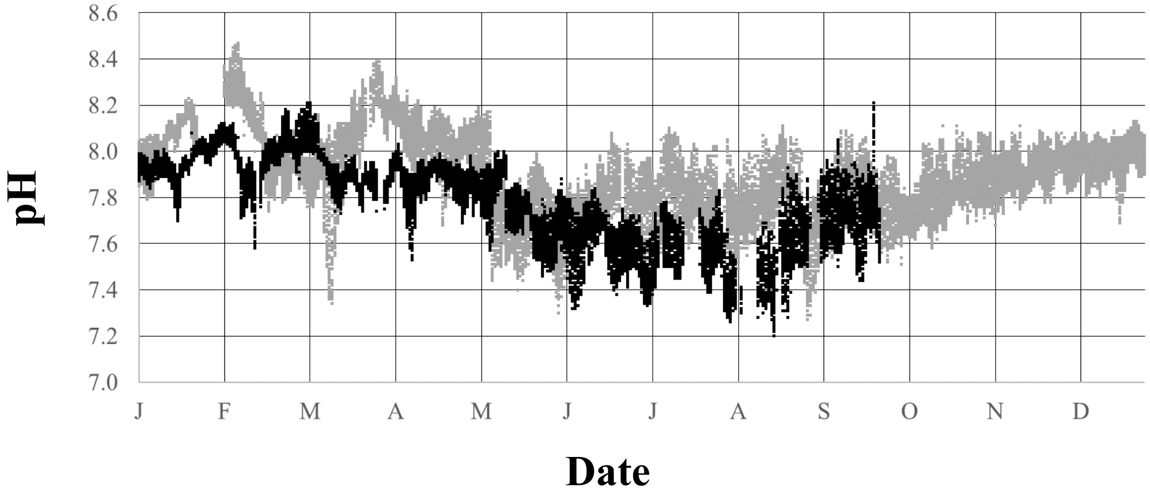

Fig. 2-1-4 Water pH (0-14 scale) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

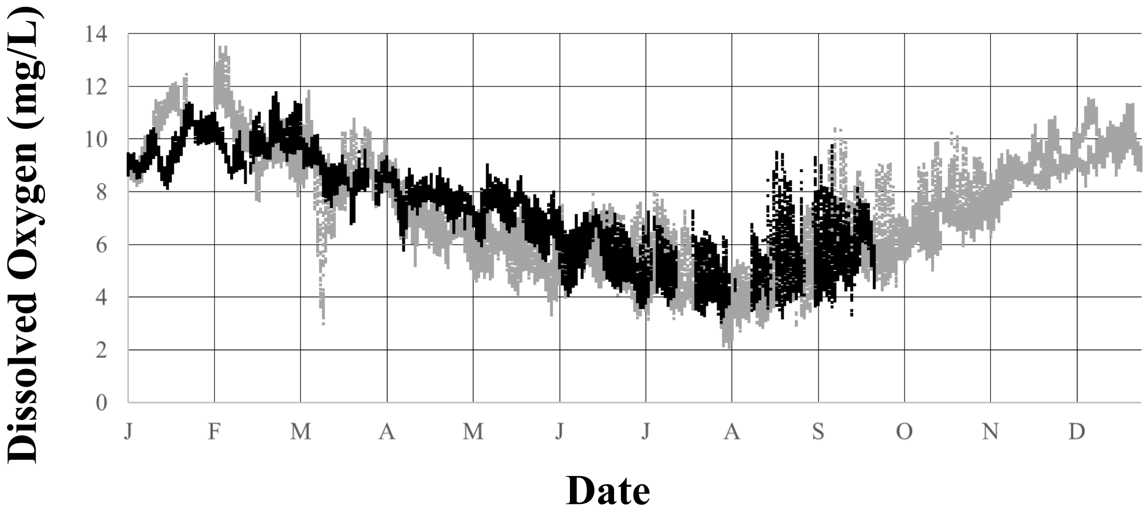

Fig. 2-1-5 Dissolved oxygen (mg/L) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

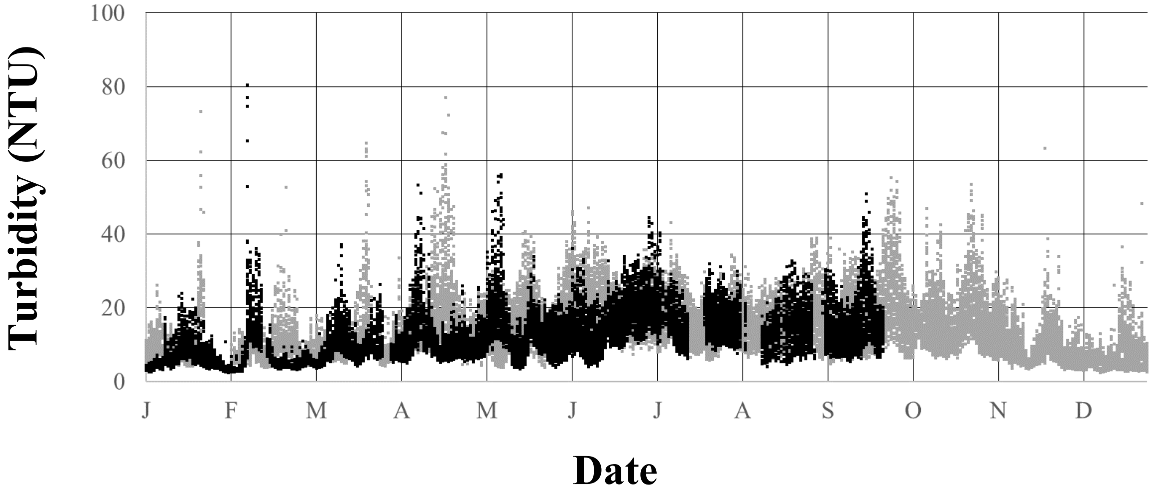

Fig. 2-1-6 Turbidity (NTU) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

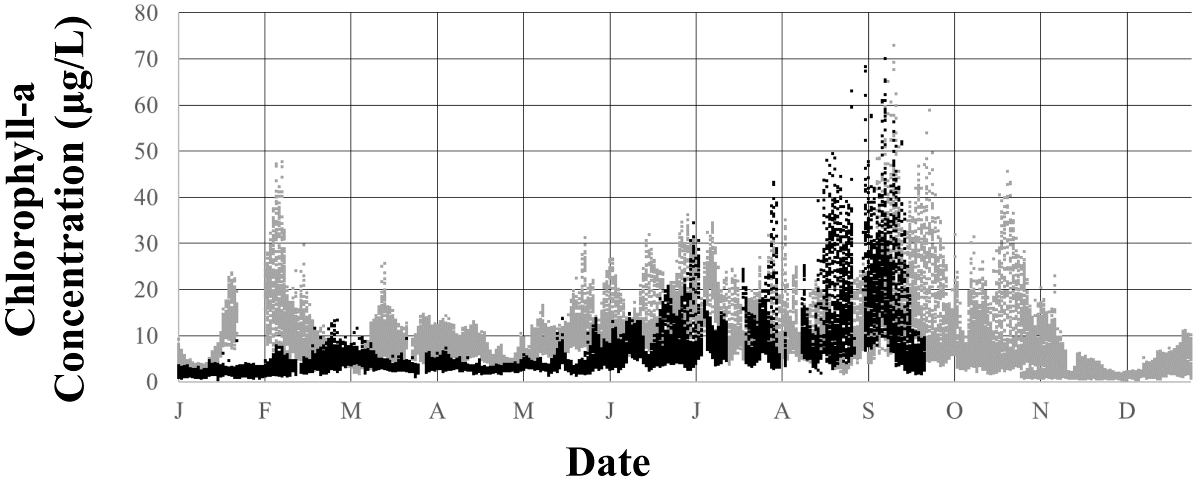

Fig. 2-1-7 Chlorophyll-a concentration (µg/L) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

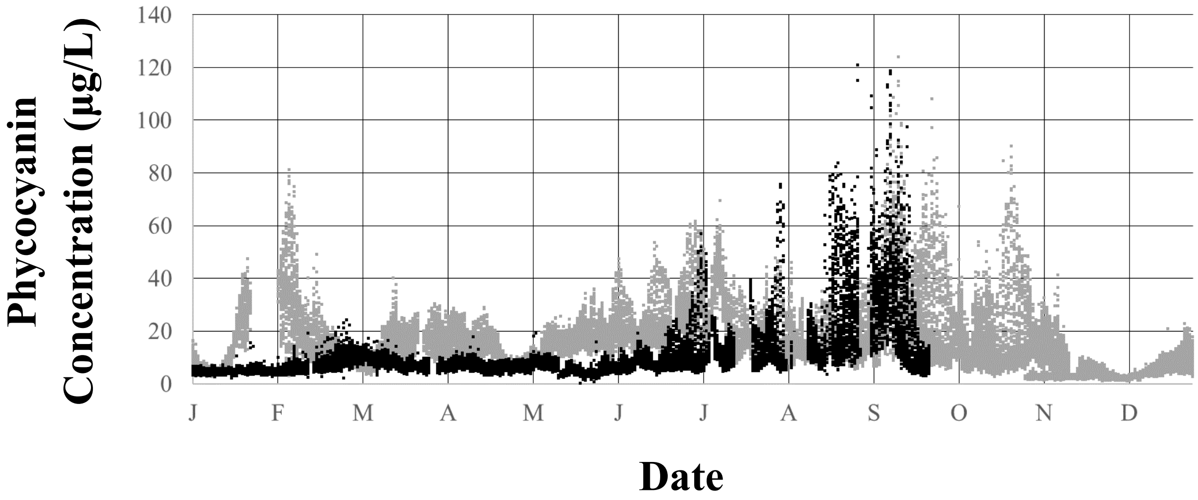

Fig. 2-1-8 Blue-green algae phycocyanin concentration (µg/L) for the Willis Wharf water quality station during 2020 (black) and all previous years collected (grey; 2018 and 2019).

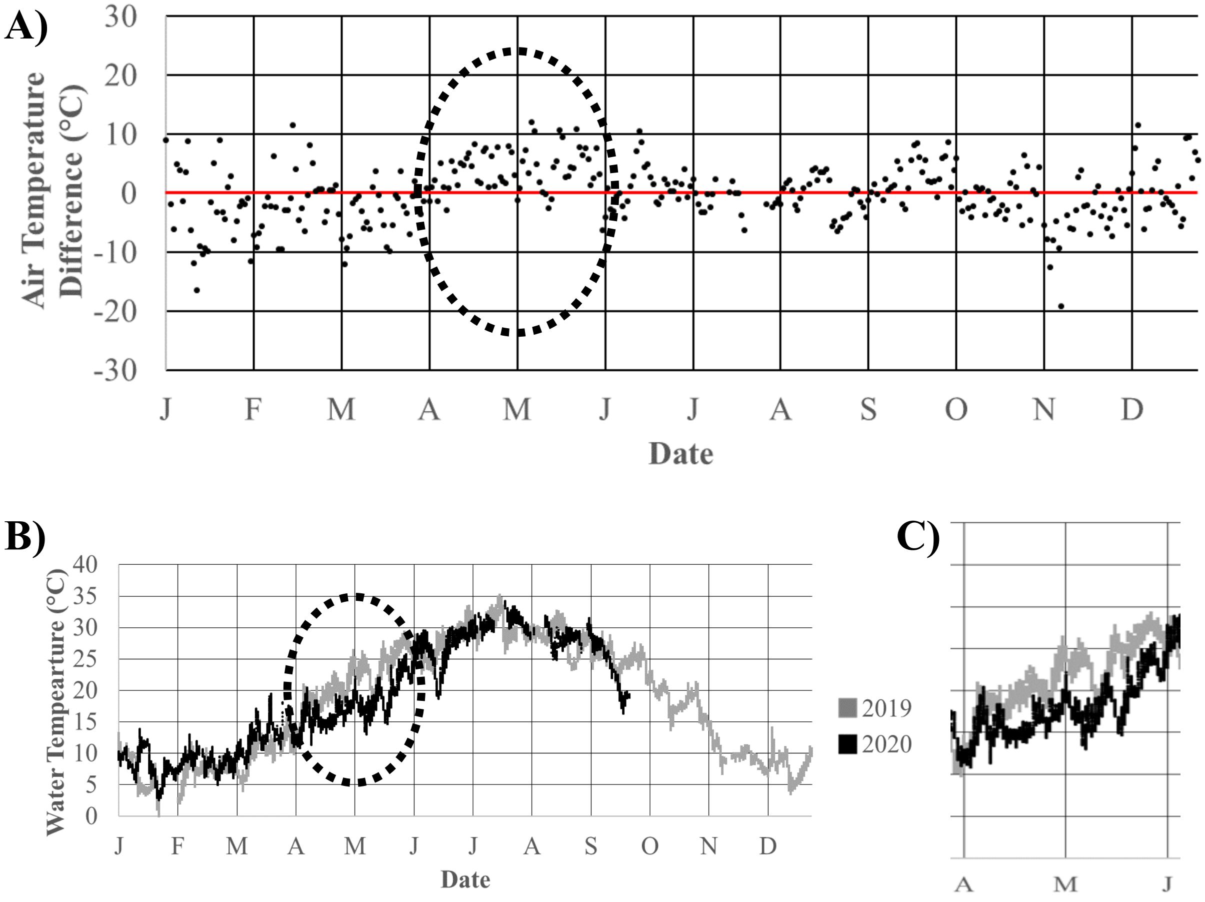

Fig. 2-1-9 Air and water temperature comparison: A) Difference in average daily air temperature (°C) between 2019 and 2020 (AT_{2019}-AT_{2020}) in Wachapreague VA, for days when >85% of expected readings were captured for both years (n=348 days), B) Water temperature (°C) for the Willis Wharf water quality station during 2019 and 2020, C) April/May water temperature enlarged. The circled areas, discussed in the Comparison to Previous Years text, highlight corresponding differences in April/May temperatures for 2019 and 2020.

Chapter 2. Water Quality

Section 2-2: Data Flow surface water characterization

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Virginia Institute of Marine Science, Eastern Shore Laboratory, Wachapreague, VA

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Partial		Cancelled (pandemic)	Planned	Planned

Introduction

Continuous measurement of water quality at fixed locations is an extremely useful tool. This data can be used in many ways, but making real-time resource management decisions and describing long-term inter-annual trends may be some of its biggest uses. However, more discrete, temporally limited water quality data that is spread over a larger geographic area is also useful. Documenting this geographic variation is useful to interpreting and extrapolating fixed location data.

Data Flow is a vessel-based, continuous spatial data collection method using georeferenced sonde readings while a vessel is underway. For these systems, surface water is pumped or hydraulically pushed into a flow cell chamber on a multiparameter water quality sonde. Data acquired by the sonde is coupled to a GPS receiver and the collated data is accumulated in a spreadsheet file on a laptop computer. By acquiring data along a vessel track, spatial gradients in water quality conditions can be mapped within relatively short time windows. These spatial data contrast with continuously sampling fixed-sensor stations where high-resolution temporal coverage is obtained with limited spatial coverage (see Chap. 2-1).

Status

Work on this parameter was scheduled for May 2020 during a William and Mary undergraduate field course taught annually at ESL. However, the class was cancelled due to the COVID-19 pandemic and data collection for this section was postponed until Spring 2021.

Methodology and data from 2017-2018 can be found here:

Ross, P. G., & Snyder, R. A. (2020) Ecological Monitoring Program at VIMS ESL - Annual Report 2018-2019. Virginia Institute of Marine Science, William & Mary. https://scholarworks.wm.edu/reports/2090

Chapter 3. Biofilm Community

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Planned	Planned

Introduction

Biofilms are communities of microbial organisms that grow on sediment and solid surfaces in submerged and intertidal areas. Various terminology has been used to define this habitat, some centered on the practical aspects of their growth (fouling, biofouling; Salta et al., 2013), but most focusing on the microalgal component (periphyton, benthic microalgae, epiphytes, etc.). However, these communities are complex, multi-trophic level systems consisting of bacteria (Zhang et al., 2019), microalgae, protists, small metazoans and newly settled invertebrate larvae. The primary structural component of biofilm is a polymer matrix (slime), typically polysaccharides of microbial origin. This polymer matrix provides some buffering of short-term environmental excursions and enhances organic substrate and mineral nutrient availability to the community. The quality of aquatic biofilms is also known to mediate larval settlement for some species, as either attractant or repellant (Dobetsov and Tiffschof, 2020)

Use of biofilms as ecological indicators is generally acknowledged to have originated with Ruth Patrick, (Patrick, 1935; 1948; 1949) who made use of the microalgal (diatom) species assemblages in biofilms correlated to water quality conditions in streams and rivers. Because of the SiO_2 frustules, permanent records of biofilm slides were easy to archive. Analysis of biofouling films can range from very simple (i.e. dry weight, organic content, Chlorophyll-a) to sophisticated determinations of taxonomic identification of species, molecular community structure analysis of prokaryotes and eukryotes, stable isotopes, etc.

Biofilm community monitoring has unique value as a biological indicator, when compared to more conventional physico-chemical water quality monitoring methods, such as point grab samples of water or continuous measures with a datasonde. By tracking biofilm growth on a new substrate over a 7 day exposure period, the bioavailability of nutrients and physico-chemical factors (temperature, salinity, oxygen, pH etc.) are integrated to establish a more complete and biological response estimate of environmental water quality. The composition of biofilms is also reflective of onsite habitat factors over relatively short distances, such as the influence of an oyster reef (Nocker et al., 2004) or hypoxia lower in the water column (Nocker, et al., 2007). Seasonal shifts in the bacterial portion of the community have also been documented (Moss et al. 2006).

Biofilm monitoring at ESL began in 2015 and is an ongoing part of the EMP status and trends database. We are tracking 7 day biofilm development in warm seasons coincident with an oyster spat settlement survey. These biofilms not only show where nutrients are available in the system, but also allow us to track benthic microalgal production as a major component of the seaside coastal system productivity. These microbial films coat the tremendous surface area represented by the rugosity of mud flats, marsh grass stems, and oyster reefs in the 1.5 m amplitude intertidal zone and shallow subtidal benthic habitats.

This year we were grateful to have the assistance of Stacy A. Kruger-Hadfield, and Guido Bonthonod in developing preliminary data to be used in pursuing grant funding with us for this work.

Study Area & Methods

Surface water biofilm arrays were deployed at five stations near Wachapreague (Fig. 3-1-1) from 5 June to 7 August 2018, 3 June to 29 July 2019, and 11 June 2020 to 7 August 2020. Arrays consisted of a floating PVC unit that holds 5 acrylic panels (9 x 20 cm; 0.018 m^2) vertically at the water surface (Fig. 3-1-2). Panels were replaced weekly and those removed were carefully transported back to the lab while being kept cool, moist and dark in an acrylic rack in a cooler. In the lab, the five panels from each site were processed for multiple metrics of the biofilm community:

- dry and ash-free dry weight
- organic matter (%) by loss on ignition
- chlorophyll (chlorophyll-a & phaeophytin)
- elemental analysis: carbon and nitrogen content and stable isotopes (^{13}C & ^{15}N)
- DNA extraction for probing specific organisms or community structure
- Microscopic examination

Biofilm material was removed from plates with pre-cleaned and sterilized squeegees and sterile seawater rinse into plastic weigh boats. For fixed archival samples, this material was transferred to 20 ml glass vials with non-acid Lugol’s iodine (2%). Some of the material was retained for live observations. For other analyses, this material was collected by filtration on pre-weighed glass fiber filters (Whatman 47 mm GF/F) using a standard filtration manifold with vacuum pump (vacuum was kept <15 mm Hg).

Total Solids & Organic Matter

Material from two sides of a plate was collected on a filter. Filters were then dried at 80-100º C to a constant weight (12+ hours). Samples were allowed to cool, weighed (dry wt) and combusted in a muffle furnace at 500º C for 1 hr. Filters were re-wetted with deionized water and re-dried at 80-100º C to a constant weight (12+ hours). Samples were then re-weighed (ash wt). Ash-free dry wt and organic matter (%) were then calculated based on these results.

Chlorophyll

One side of a plate was collected on a filter. Filters were then gently folded into quarters and placed in a 15 ml polypropylene Falcon tube which was then frozen (-20º C). Five ml of acetone (90%) was added to each tube and placed in a sonicating water bath for 15 minutes. Samples were immediately returned to -20º C freezer for 24 hrs. After the 24 hr extraction, tubes were placed into a centrifuge (IEC Clinical) and spun for 5 minutes on a setting of 5 (RCF ~960 x g). A 1 ml aliquot of supernatant was then transferred to a fluorimeter cuvette. Chlorophyll-a fluorescence of these samples was measured using a calibrated fluorimeter (Turner Fluorimeter). Phaeophyton was calculated by measuring fluorescence after acidification of the sample by addition of 50 µl HCl (10%).

Stable Isotopes (^{13}C & ^{15}N)

Two sides of a plate were collected on a filter. Filters were then dried at 80-100 C to a constant weight (12+ hours). Once dry and cooled, samples were sealed in 2 ml microfuge snap-top tubes and stored in a desiccator. Dried material flaked off of the filters was placed into foil capsules in tissue culture plates, the coded location recorded, and the plates stored in a desiccator until full. Full plates were sent to the Stable Isotope Facility at University of California-Davis for analysis of % Carbon, % Nitrogen, and % Sulfur and their respective stable isotope quantities. Details of their analytical techniques can be found on their website (https://stableisotopefacility.ucdavis.edu/13cand15n.html).

DNA and taxonomic identification

Two sides of a plate were scraped into a container using a sterile squeegee and filtered seawater. Representative samples were placed in 1.5 ml microfuge tubes and centrifuged at 10,000 x g for 5 min in a centrifuge (Thermo Fresco 21) kept at 4º C. Most supernatant was decanted off and tube closed and placed in a freezer at -80º C. DNA extractions were performed with standard commercial kits (MoBio). A single sample (ESL 6/26/2017) was processed for preliminary data following the methods outlined in Bonthond et al., (2020) to amplify the 18S-V7 using the F-1183mod and R-1443mod primers (Ray et al., 2016). We applied the two-step PCR strategy from Gohl et al. (2016), using the KAPA HIFI HotStart polymerase (Roche, Basel, Switzerland) and the pair of indexing primers. The second PCR product was purified using 1 µL of ExoSap-It following the manufacturer's protocol and sent to Genewiz for sequencing on the

Illumina MiSeq platform. The sequences were quality filtered using Mothur software (Schloss et al., 2009) and the SILVA alignment (Quast et al., 2013 release 132). Unique sequences were clustered into OTUs with the opticlust algorithm based on a 3% dissimilarity criterion. All samples are currently archived at ESL waiting for time/funding to process and sequencing.

In addition to the single sample from ESL pier (ESL 6/26/2017), we are currently sequencing a further 12 samples for 16S and 20 samples for 18S rRNA genes from 2017 and 2018. This information will be used to seek funding for a more comprehensive examination of spatial and temporal trends in the prokaryotic and eukaryotic communities in these biofilms as indicators of ecosystem productivity and biodiversity. Samples were sent to the Genomics Core Lab at the Heflin Center for Genomic Sciences in early April 2021.

2019-2020 Results and Discussion

Summary data for the past three years of biofilm plates are shown in Tables 3-1-1 and 3-1-2. Seasonally averaged 2020 Chlorophyll content in the biofilms was highest at the Inlet site followed by ESL Pier, in contrast to 2019 data that had the highest average chlorophyll content in Finney Creek followed by the Inlet samples (Table 3-1-1). The multiyear averages (Table 3-1-2) show the Inlet samples with the highest Chlorophyll content followed by Finney Creek samples, with not much difference between the other stations. Dry weight of accumulated biomass on the plates follows a different trend. The Finney station has had the highest total dry weight mass for three years running (Table 3-1-1), reflecting the input from upland stream drainage and resuspension of sediments and detrital organic material from within these creek systems. Custis channel had the next highest dry weight accumulation for 2 of the 3 years (2018, 2019) and the third highest for 2019. The inlet station had the lowest dry weight mass accumulation in 2 of 3 years (2019, 2020). The ESL pier station was the most variable between years, ranking 5th, 2nd, and 4th for 2019, 2019, and 2020 respectively. The higher chlorophyll content and lower dry weights found at the Inlet station also reflect the increased accumulation of detrital organic matter at the other stations (Table 3-1-1. The total dry weight data are roughly followed by the Ash-free dry weights (organic content; Table 3-1-1), and the percent organic matter (Ash-free dry weight/total dry weight) are strikingly consistent across all samples ranging from 11 to 17% (Table 3-1-1 and with multiyear averages ranging from 13.7 to 15.6% (Table 3-1-2).

Previous sampling of plates during the 7 day incubation period indicated exponential growth of chlorophyll over time. The data for this progression was reported in 2019, and copied here as reference for the system. Assuming this exponential growth holds for all stations and dates, the specific rate of increase (□) for organics and chlorophyll was calculated, and from that the turnover time (T_D) in days, representing a crude estimate of total system production on surfaces in the seaside ecosystem (Table 3-1-3). Based on these calculations, benthic microalgae are doubling their biomass every 1.45 days across the system. Much of this production would be consumed by surface grazers: mud and marsh snails, copepods, grass shrimp, fiddler crabs, hermit crabs and others. A significant amount of the benthic biofilm production is resuspended by tidal currents and they are also subject to consumption by planktonic grazers.

Trends by station over the summer index period (June-August) for Chlorophyll and Dry Weight are presented in Figure 3-1-3. Using chlorophyll as a proxy for living micro and macro algal biomass, Finney Creeks station was the most uncoupled for total dry weight and autotrophic components for the biofilm, indicating significant adsorption of detritus to the plates in this near-upland station. Especially during late June-early July and early August, when relatively large dry weight accumulations were measured concomitant with lower chlorophyll content. It is quite possible that accumulations of detritus and sediments during these times blocked sunlight needed for algal growth. Dual peaks in algal growth occurred in early June and late July for Finney, Custis Channel, and Bradford Bay, while the VIMS ESL pier station had a single peak in Early July, and the Inlet station had a single peak in late July. Both ESL Pier and Inlet biofilms increased in algae content over the summer, while total mass as dry weight remained relatively constant.

Taxonomic Identification

Summary results returned from DNA sequence analysis of eukaryotes in a biofilm sample (ESL 6/26/2017) are presented in Table 3-1-4. The biofilm is dominated by barnacles, macroalgae, copepods, diatoms, and unicellular protists. The preponderance of metazoan reads is in part an artifact of their greater amount of DNA relative to unicellular taxa, but even based on the number of unique OTUs taxa they are dominant members of the biofilm community. Given the 7 day age of the biofilm samples, these are likely newly settled larvae of 23 unique sequences (at a conservative 97% similarity) within at least 3 genera (+some unknowns) (Table 3-1-5). A green macroalga also dominated this biofilm (Table 3-1-4), identified as the filamentous *Dilabifilum arthropyreniae*, (Table 3-1-5) and like the barnacles, the apparent dominance of this alga was likely amplified by its multicellular form. The diatoms were well represented (Table 3-1-4), and mostly comprised of species in the genus *Navicula* and other benthic pennate forms typical of benthic diatoms (Table 3-1-5). As these algae are unicellular and given the metazoan/metaphyta bias discussed above, these organisms are dominant members of the biofilm community, a finding that correlates well with microscopy. Other protists appearing in the sequence analysis include autotrophic and heterotrophic flagellates, amoebae and ciliates. Net fungi are surprisingly well represented. These organisms are single cells living in self constructed tube nets on marine surfaces, most famously associated with seagrasses (e.g., *Labyrinthula* spp). We are seeking funding to expand this initial work to document the spatial and temporal distributions of the biofilm communities across this coastal marine environment.

Acknowledgements

We would like to thank Reba Smith, Darian Kelley, Edward Smith, Justin Paul, and Glenn Brundage for assistance. We also thank Mike Crowley for help with additional sequencing at the Genomics Core at the Helfin Center for Genomic Sciences at UAB. Sequencing was supported by start-up funds from the College of Arts and Sciences at UAB.

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Table 3-1-1. Biofilm composition averages and standard deviations (SD) for the summer monitoring period by year and by station. Chl = chlorophyll a; Dry Wt = Dry weight; Ash-Free Dry Wt = organic content; % OM is the percentage of dry weight represented by organic matter.

			Chl (µg cm^{-2})		**Phaeophytin (µg cm^{-2})**		**Dry Wt (g)**		**Ash Free Dry Wt (g)**		**% OM**	
Year	**Station Name**	**Station #**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**
2018	ESL Pier	1					0.122	0.105	0.021	0.020	16.5	3.81
2018	Burton's Bay	2					0.374	0.333	0.056	0.050	14.8	1.84
2018	Finney Creek	3					0.607	0.446	0.088	0.058	15.3	2.44
2018	Bradford Bay	4					0.321	0.215	0.047	0.030	14.7	1.48
2018	Wach. Inlet	5					0.134	0.094	0.020	0.015	14.3	1.43
2019	ESL Pier	1	21.30	21.01	1.59	1.32	0.370	0.335	0.054	0.035	17.6	5.55
2019	Burton's Bay	2	22.73	23.05	7.25	17.63	0.351	0.278	0.061	0.051	16.5	4.24
2019	Finney Creek	3	32.82	32.29			0.665	0.490	0.098	0.073	14.7	1.61
2019	Bradford Bay	4	26.76	21.92	0.85	0.94	0.313	0.178	0.054	0.032	16.9	2.82
2019	Wach. Inlet	5	30.91	36.82	0.78	1.53	0.250	0.160	0.038	0.022	15.6	2.25
2020	ESL Pier	1	29.93	13.02	0.97	1.28	0.168	0.090	0.019	0.010	12.3	4.47
2020	Burton's Bay	2	25.35	11.95	1.31	1.82	0.312	0.204	0.041	0.029	12.8	2.22
2020	Finney Creek	3	21.94	16.51	0.63	1.03	0.857	0.585	0.113	0.067	14.0	1.89
2020	Bradford Bay	4	21.84	8.73	4.39	8.70	0.259	0.207	0.037	0.031	14.2	1.42
2020	Wach. Inlet	5	39.80	16.29	0.73	1.40	0.152	0.135	0.017	0.015	11.0	3.35

Table 3-1-2. Biofilm composition multiyear averages and standard deviations (SD) for the summer monitoring period. Chl = chlorophyll a; Dry Wt = Dry weight; Ash-Free Dry Wt = organic content; % OM is the percentage of dry weight represented by organic matter.

	Chl (µg cm^{-2})		**Phaeophytin (µg cm^{-2})**		**Dry Wt (g)**		**Ash Free Dry Wt (g)**		**% OM**	
Station Name	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**
ESL Pier	25.617	17.382	1.280	1.291	0.211	0.221	0.030	0.028	15.546	4.901
Burton's Bay	24.036	17.693	4.282	0.038	0.346	0.264	0.052	0.043	14.713	3.204
Finney Creek	27.376	25.278	2.081	4.603	0.700	0.493	0.099	0.063	14.727	2.038
Bradford Bay	24.303	16.229	2.619	6.225	0.300	0.195	0.046	0.030	15.222	4.514
Wach Inlet	35.354	27.742	2.378	6.444	0.177	0.135	0.025	0.019	13.649	2.999

Table 3-1-3. The specific rate of increase (μ) for organics and Chlorophyll and the turnover time (T_D) in days, representing a crude estimate of total system production on surfaces in the seaside ecosystem (2019 data).

	Organics g m^{-2}	**Chl a mg m^{-2}**	**Organics μ day^{-1}**	**Chl a μ day^{-1}**	**Organics T_D days**	**Chl a T_D days**
Station 1 ESL Pier	5.56	21.3	0.2687	0.4435	2.58	1.56
Station 2 Burtons Bay	4.95	22.7	0.2548	0.4522	2.72	1.53
Station 3 Finney Creek	8.35	32.8	0.3193	0.5029	2.17	1.38
Stations 4 Bradford Bay	4.51	26.8	0.2439	0.475	2.84	1.46
Station 5 Wachapreague Inlet	3.32	30.9	0.2091	0.4947	3.31	1.4

Table 3-1-4. Summary identifications of biofilm community constituents by sequencing analysis of a sample taken 26 June 2017 at the ESL Pier station. The identifications are sorted by the frequency of occurrence (# Reads) for each unique taxon (OTU; operational taxonomic unit).

Number of OTUs	#Reads	Type
23	277	Barnacle
29	71	Macroalga green
37	62	Copepod, Barnacle
26	47	Diatom
15	18	Heterotrophic Flagellate
5	9	Copepod
8	9	Autotrophic Flagellate
6	8	Amoebae
4	7	Gregarine
3	4	Amphipod
4	4	Ciliate
4	4	Net Fungi
3	3	Crustacea
3	3	Gastrotrich
1	2	Arthopod
2	2	Macroalga red
2	2	Fungi
1	1	Alveolate
1	1	Dinoflagellate
1	1	Mussel
1	1	Vertebrate

Table 3-1-5. Detailed identifications of biofilm community sequences to lowest matching taxon level. The identifications are sorted by the frequency of occurrence (# Reads) for each unique taxon (OTU; operational taxonomic unit).

# OTUs	# Reads	Species	Common name/type	Notes
11	262	*Cantellius*_sp.	Barnacle	Epibiont on hydrozoans
37	62	Maxillopoda_unclassified	copepod, barnacle	thigmotactic sessile?
22	62	*Dilabifilum_arthropyreniae*	Macro algae	Green Algae
12	31	*Navicula*_unclassified	diatom	thigmotactic
7	9	*Chthamalus_proteus*	Barnacle	sessile
5	9	*Acartia_tonsa*	Copepod	zooplankton
5	7	*Blidingia_dawsonii*	Macro algae	Green Algae
4	6	Cercozoa_unclassified	amoeboflagellate	Thigmotactic
5	6	*Chthamalus*_unclassified	Barnacle	sessile
6	6	*Neobodo_saliens*	Flagellate	thigmotactic
5	5	*Navicula cryptocephala*_var._*veneta*	diatom	thigmotactic
2	5	*Neobodo_designis*	Flagellate	thigmotactic
4	5	*Rhodella_maculata*	Unicelluar	Red algae
2	5	*Heliospora* 2_*longissima*	Gregarine	Parasitic
3	4	*Corophium*_sp.	Amphipod	thigmotactic
3	4	Raphid-pennate_unclassified	diatom	thigmotactic
4	4	Chlorophyta_unclassified	Unicelluar	Green Alage
3	3	Gastrotricha_XX_unclassified	Gastrotrich	thigmotactic
2	2	Crustacea_unclassified	Crustacean	
2	2	*Nitzschia_paleaformis*	diatom	thigmotactic
1	2	*Thalassiosira*_unclassified	diatom	centric planktonic
2	2	Apusomonadidae_Group-2A_XX_sp.	Flagellate	thigmotactic
1	2	Arthropoda_unclassified	Invert	
2	2	*Bostrychia radicans*	Macroalage	Red algae
1	1	Alveolata_unclassified	Alveolate	
1	1	Lobosa_unclassified	Amoebae	thigmotactic
1	1	*Vampyrellida*_unclassified	Amoebae	resembles heliozoans
1	1	Malacostraca_unclassified	Crustacea	
1	1	*Colpodea*_X_unclassified	Ciliate	free swimming
1	1	Holosticha_heterofoissneri	Ciliate	thigmotactic
1	1	*Spirotrichea*_unclassified	Ciliate	
1	1	*Zoothamnium*_1_unclassified	Ciliate	sessile
1	1	*Minutocellus*_sp.	diatom	Planktonic?
1	1	*Nitzschia*_unclassified	diatom	thigmotactic
1	1	Mediophyceae_unclassified	diatom	centric planktonic
1	1	*Akashiwo_sanguinea*	Dinoflagellate	free swimmming
1	1	Bicoecaceae_X_sp.	flagellate	attached, thigmotactic
1	1	*Neobodo*_unclassified	Flagellate	thigmotactic
1	1	*Pseudopirsonia*_sp.	flagellate	diatom hosts
1	1	*Rhynchomonas_nasuta*	Flagellate	thigmotactic
1	1	*Thecamonas_trahens*	Flagellate	thigmotactic
1	1	*Lecudina_tuzetae*	Gregarine	Parasitic
1	1	Lecudinidae_X_sp.	Gregarine	Parasitic
1	1	Ulvales-relatives_X_unclassified	Macro algae	Green Alage
1	1	Ulvophyceae_unclassified	Macro algae	Green Alage
1	1	Mytiloida_X_sp.	Mitilida Mussel	sessile
1	1	*Geranomyces_variabilis*	Aquatic Fungi	zoospore?
1	1	Dothideomycetes_unclassified	Fungi	plant decay
1	1	*Oblongichytrium* sp.	Net fungi	attached, thigmotactic
1	1	Thraustochytriaceae_X_sp.	Net fungi	attached, thigmotactic
1	1	*Thraustochytrium_kinnei*	Net fungi	attached, thigmotactic
1	1	*Ulkenia_profunda*	Net fungi	attached, thigmotactic
1	1	*Craniata*_X_unclassified	vertebrate	

Fig. 3-1-1 Locations of 5 biofilm monitoring sites near Wachapreague, VA for 2020 (red polygons denote the ESL-EMP study areas).

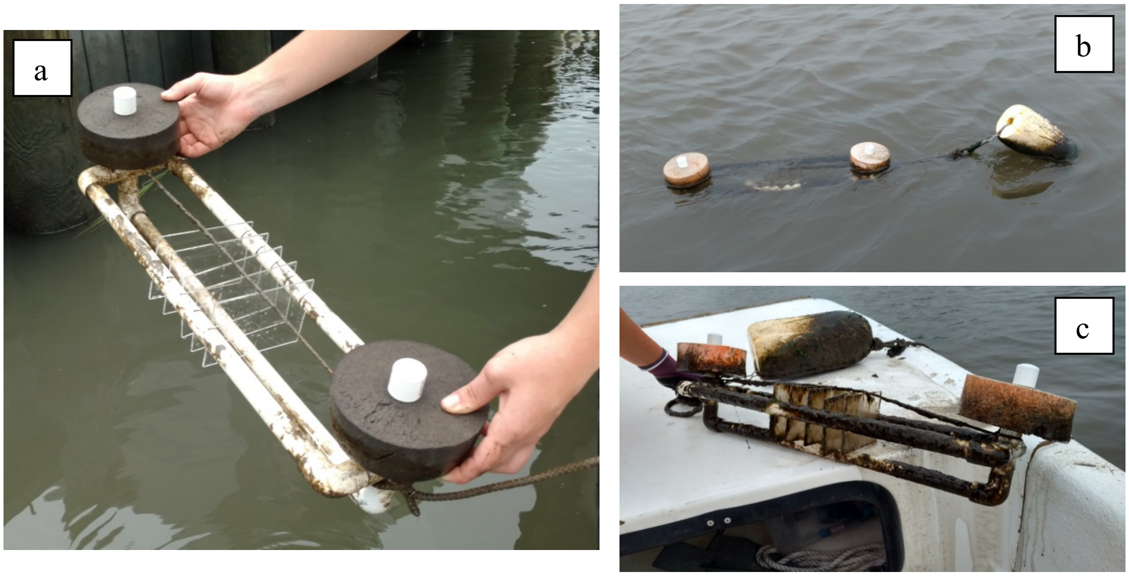

Fig. 3-1-2 Biofilm array a) before, b) during and c) after deployment.

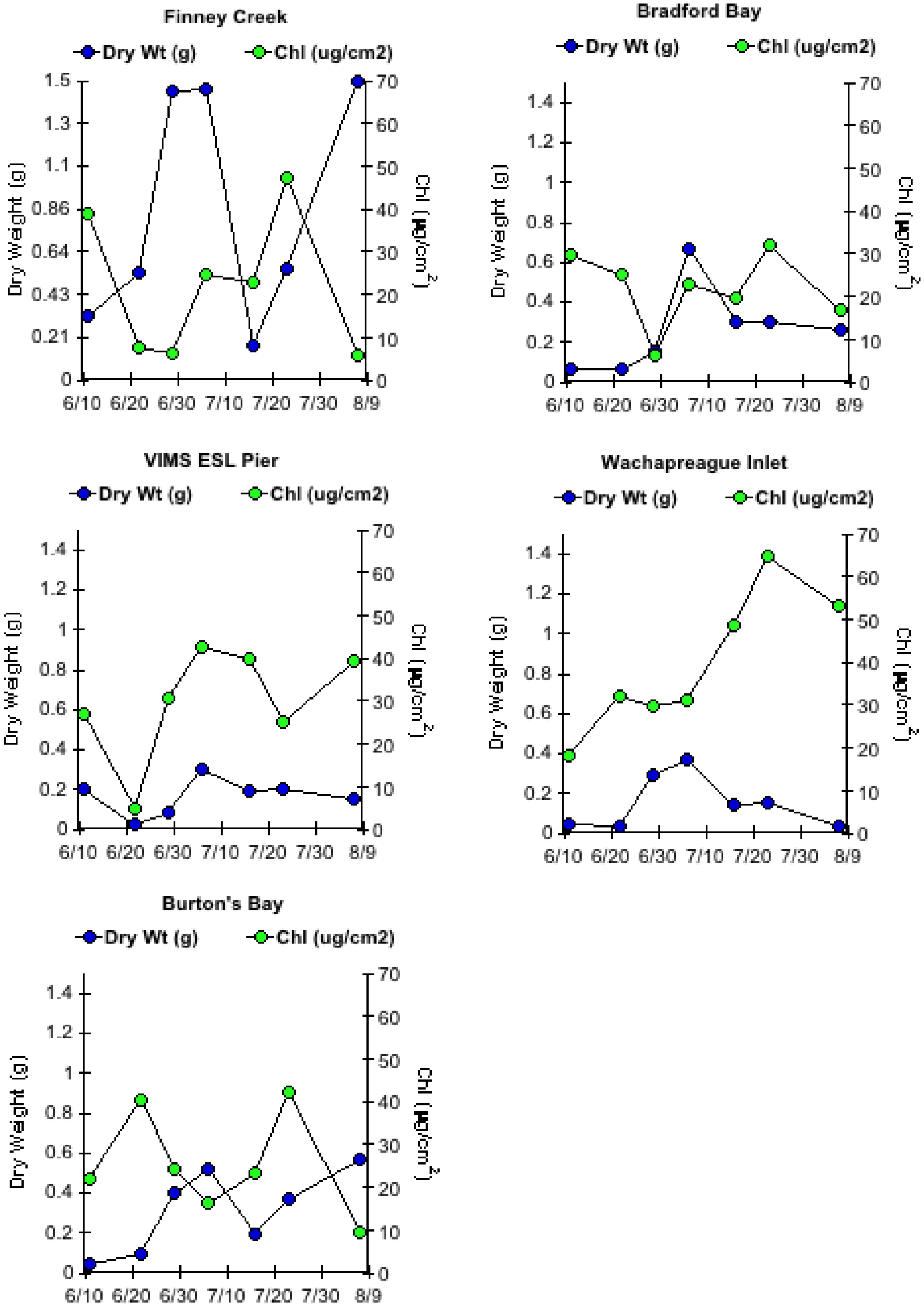

Fig. 3-1-3. The temporal dynamics of total biofilm mass (dry weight; g) and algal content as measured with Chlorophyll (Chl; µg cm^{-2}) for biofilms grown at the five stations off Wachapreague, VA during June-August 2020.

Chapter 4. Oyster Population

Section 4-1: Oyster Settlement

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Planned	Planned

Introduction

Live oyster reefs and exposed shell beds are a major ecological feature of coastal Virginia (Ross & Luckenbach 2009), although unlike most Chesapeake Bay oyster reefs, those on the seaside of the Eastern Shore of Virginia are predominantly intertidal. As a keystone and ecological engineering species, oysters provide critical reef habitat for many resident and transient organisms, including other commercial and recreational fishery species, and many non-fishery marine and avian species. This has been documented in the scientific literature for at least 145 years (Möbius, 1877).

Quantifying the initial settlement of recently metamorphosed oyster larvae is a useful metric for monitoring the status and future potential for the oyster population and its continued biogenic renewal of shelly, hard substrate. Settlement rates are assayed by quantifying settlement on artificial substrates. Oyster larvae drift as plankton in coastal waters for up to 21 days and can disperse over large areas depending on spatial environmental variables (Andrews, 1983). The timing and relative magnitude of oyster settlement between years and locations can be used to track oyster reproduction and potential recruitment. Historically, this type of information was important to oyster fishers for the timing of placing shell in high recruitment areas and is still important information for aquaculture to either capture oyster settlement for production or avoid fouling on caged oysters.

Documentation of oyster strike in the environs near Wachapreague date back to at least the first half of the 1900's (e.g. see Mackin 1946). VIMS has conducted an annual oyster spatfall survey in the western Cheasapeake Bay since the 1940's (Southworth and Mann 2018). Stations on the bayside and seaside of the Eastern Shore were included into the late 1990's. ESL has intermittently continued similar surveys in the Wachapreague vicinity since and formally established 5 monitoring stations 2018. All of these stations have intermittent data from previous years and these data will be integrated into the overall EMP as described in an earlier section. We plan to document the current temporal and spatial status of oyster settlement and evaluate trends of this important ecological component of the seaside coastal habitats.

Study Area & Methods

Oyster settlement substrate arrays were deployed at five stations near Wachapreague (Fig. 4-1-1) from May 7 to December 3, 2020. Settlement arrays consist of vertical assemblies of 6 ceramic tiles (10.8 cm x10.8 cm) hung in the water column within 0.5 m of the seabed (Fig. 4-1-2). The tiles are positioned with the unglazed side down and placed as to remain submerged at low tide. Tiles were recovered and replaced biweekly until initial settlement was observed and then were recovered and replaced approximately weekly until the cessation of settlement as measured by consecutive deployments with no settlement with falling water temperatures in the fall.

Settlement tiles were carefully transported back to the laboratory and examined under a stereomicroscope (see Fig. 4-1-2). The number of oysters were counted on the downward facing, unglazed side of tiles and standardized by tile surface area and the # days deployed to estimate a settlement rate (i.e. # spat m^{-2} $week^{-1}$). We have previously used this technique in other studies on oyster reefs and find that it provides a reliable, standardized estimate of the rates of settlement of oysters on reefs (Luckenbach and Ross 2003, Luckenbach and Ross 2004).

Although 2018 was the first formal year for the EMP, we have comparable data for the 5 sites from 2014 and 2016 (with the exception of the #5 Inlet site in 2014). We have organized this data to prioritize temporal comparisons for individual sites and overall (i.e. all sites combined). Southworth and Mann (2018) tracked oyster settlement metrics for many years in an excellent tabular format that includes comparing the current year to various longer-term averages over many sites in Chesapeake Bay. We used Southworth and Mann (2018) as a guide to organize and present EMP settlement data (e.g. see Table 4-4-1). The current 2014-2020 averages are a small temporal sample size, but this analysis will become more robust as more years of data are included. We initially developed five categories to generally visualize annual cumulative annual settlement:

Light settlement (<1,000 spat m^{-2})

Moderate settlement (1,000-10,000 spat m^{-2})

Average settlement (10,000-20,000 spat m^{-2})

Heavy settlement (20,000-30,000 spat m^{-2})

Extremely heavy settlement (>30,000 spat m^{-2})

These categories are arbitrary, based on the overall average and range of settlement during the 5 years of data in Table 4-1-1. The boundaries of these categories may be adjusted in future analyses to accommodate changes in the accumulating dataset. The current structure provides a lens through which to view the EMP data to date. This categorical range is specific to seaside ESVA and will not be applicable to oyster settlement rates in lower salinity regions, e.g., Chesapeake Bay, its tributaries, and some seaside coastal bays that have less connectivity to the Atlantic Ocean where lower settlement rates are observed.

2020 Results & Discussion

Cumulative annual oyster settlement for the 2020 season showed significant spatial variation between the 5 sites, ranging from 4,108 to 98,523 oysters m^{-2} (Table 4-1-1 and Fig. 4-1-3). The settlement season lasted 161 days between 27-May and 4-Nov (Table 4-1-2). Weekly settlement rates also varied spatially and were highest at sites #5 and #1 (Inlet and ESL, respectively), with the coastal bay stations in Bradford (#4) and Burton's (#2) bays showing intermediate, but substantially lower, settlement and the most upstream site in Finney Creek (#3) having the least settlement (Fig. 4-1-4). Generally, there was a large peak during July with a slight fall increase for a couple of locations in late August to early September. Very low settlement continued into October and early November (Fig. 4-1-5). Peak weekly settlement rates approached 45,000 oysters m^{-2} at one of the five sites and two others peeked at > 10,000 oysters m^{-2}.

Based on data for oyster settlement from 2020, it is clear that many larvae were present in the coastal lagoon and tidal creek system near Wachapreague. Hydrodynamics of tidal flushing and residence time of water masses may affect this, especially if a given area represents a nodal point where ebbing and flooding tides would concentrate plankton. The higher levels of planktonic chlorophyll seen in these sites may also support this idea (Chapter 2-2). We expect these settlement rates to translate into high recruitment rates and, ultimately, a vigorous and self-sustaining local oyster population as long as intertidal/subtidal hard substrate is available for settlement. Anecdotally, the past few years we have observed oyster clumps accumulating along Wachapreague Channel mud banks below the lower Spartina limit where oysters have been settling out on scattered shells. Should this recruitment trend continue, we may see more substantial fringing reefs develop along this waterway.

Environmental conditions, predation, and disease variables certainly have the capacity to impact the timing and intensity of both oyster spawning and subsequent settlement (e.g. Ortega and Sutherland 1992, Mann et al. 2014) and mortality (Mann et al. 2014). As we accumulate several years of data, we will be better able to compare yearly water quality data from Chapter 2 to EMP data (such as oyster settlement in this chapter) to explore these relationships. Although directly measuring oyster predation is not part of EMP, numbers of mud crabs and oyster drills on reefs (Chapter 5-2) and information on oyster disease dynamics will be useful to discern factors affecting the oyster population.

As more years of standardized data are collected for oyster settlement, we anticipate being better able to categorize the range of spat recruitment intensity both temporally and spatially. Given the historical collapse of seaside oyster populations and the potential for coastal change, establishing a long-term record of oyster spat recruitment will provide important sentinel for hard substrate habitats and their associated communities (see Chapter 5-2).

Comparison to Previous Years

Oyster settlement seemed to be well above average with sites having +48% to +155% cumulate settlement relative to the 2014-2020 average (Table 4-1-1). The ESL site (#1) and Inlet site (#5) were consistently the sites with the highest cumulative settlement in 2014, 2016, 2018, 2019 and 2020 (Table 4-1-1; note there is no data for the Inlet site for 2014).

For all sites combined, the seasonal period of oyster settlement (Maximum # days) was larger for 2020 compared to 2019 and the 2014-2020 average (Table 4-1-2). This longer period was mainly influenced by a relatively early onset of settlement combined with continued low rates into late October/early November in 2020 (Table 4-1-2). The seasonal period of oyster settlement substantially varied spatially within 2020 compared to 2014-2019 average (Table 4-1-2).

Mean intra-annual timing and weekly settlement rates show similar patterns in 2018, 2019 and 2020, including a general trend of early summer peaks with second slight settlement events during late September to early October (Fig. 4-1-6). However, the scale of this settlement has increased yearly since 2016. In high salinity areas, settlement tends to have one large peak, although a more bimodal pattern may be seen (Kenney et al. 1990), which is often more similar to the lower salinity Chesapeake Bay (see Southworth and Mann, 2017).

2020 Acknowledgements

We would like to thank Reba Smith, Darian Kelley and Chris Bentley for field assistance.

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Southworth, M. and R. Mann. 2018. The status of Virginia's public oyster resource, 2017. Molluscan Ecology Program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp.

Table 4-1-1. Summary of annual cumulative oyster settlement (# m^{-2}) at each of 5 sites near Wachapreague, VA from 2014-2020. Sampling prior to 2018 was not part of the Ecological Monitoring Program but the same protocols were used at the same sites. General intensity color scale for individual years only is shown below table.

Site #	**2014**	**2016**	**2018**	**2019**	**2020**	**Average (2014-2020)**	**2020 vs. 2019 (%)**	**2020 vs. Avg. (%)**
1-ESL	46,462	5,558	24,795	23,392	41,974	28,436	79.4	47.6
2-Burton's Bay	23,977	424	7,801	5,044	16,944	10,838	235.9	56.3
3-Finney Creek	1,579	509	1,029	833	4,108	1,612	393.0	154.9
4-Bradford Bay	775	734	5,994	2,442	8,480	3,685	247.3	130.1
5-Wach. Inlet	--	5,117	19,933	62,471	98,523	46,511	57.7	111.8
Average for All Sites Combined	*18,198*	*2,468*	*11,910*	*18,836*	*34,006*	*18,216*	*80.5*	*86.7*

Light settlement (<1,000 spat m^{-2})
Moderate settlement (1,000-10,000 spat m^{-2})
Average settlement (10,000-20,000 spat m^{-2})
Heavy settlement (20,000-30,000 spat m^{-2})
Extremely heavy settlement (>30,000 spat m^{-2})

Table 4-1-2. Summary of oyster settlement timing (date) and maximum duration (# days) at each of 5 sites near Wachapreague, VA from 2014-2020. Sampling prior to 2018 was not part of the Ecological Monitoring Program but the same protocols were used at the same sites.

Site #	**Date Metric**	**2014**	**2016**	**2018**	**2019**	**2020**	**Average (2014-2020)**	**2020 vs. 2019 (%)**	**2020 vs. Avg. (%)**
1 ESL	# days	96	125	132	154	161	134	4.5	20.5
	Begin date	26-Jun	21-Jun	12-Jun	20-May	27-May			
	End date	30-Sep	24-Oct	22-Oct	21-Oct	4-Nov			
2 Burtons Bay	# days	91	111	111	126	112	110	-11.1	1.6
	Begin date	20-Jun	5-Jul	3-Jul	3-Jun	29-Jun			
	End date	19-Sep	24-Oct	22-Oct	7-Oct	19-Oct			
3 Finney Creek	# days	118	125	132	126	71	114	-43.7	-37.9
	Begin date	26-Jun	21-Jun	12-Jun	3-Jun	29-Jun			
	End date	22-Oct	24-Oct	22-Oct	7-Oct	8-Sep			
4 Bradford Bay	# days	62	111	106	126	71	95	-43.7	-25.4
	Begin date	26-Jun	5-Jul	26-Jun	20-May	29-Jun			
	End date	27-Aug	24-Oct	10-Oct	23-Sep	8-Sep			
5 Wach. Inlet	# days	--	125	111	126	119	120	-5.6	-1.0
	Begin date	--	21-Jun	3-Jul	3-Jun	22-Jun			
	End date	--	24-Oct	22-Oct	7-Oct	19-Oct			
All Sites Combined	*Max # days*	*118*	*125*	*132*	*154*	*161*	*138*	*4.5*	*16.7*
	Begin date	*20-Jun*	*21-Jun*	*12-Jun*	*20-May*	*27-May*			
	End date	*22-Oct*	*24-Oct*	*22-Oct*	*21-Oct*	*4-Nov*			

Fig. 4-1-1 Locations of 5 oyster settlement monitoring sites near Wachapreague, VA for 2018-2020 (red polygons denote the ESL-EMP study areas).

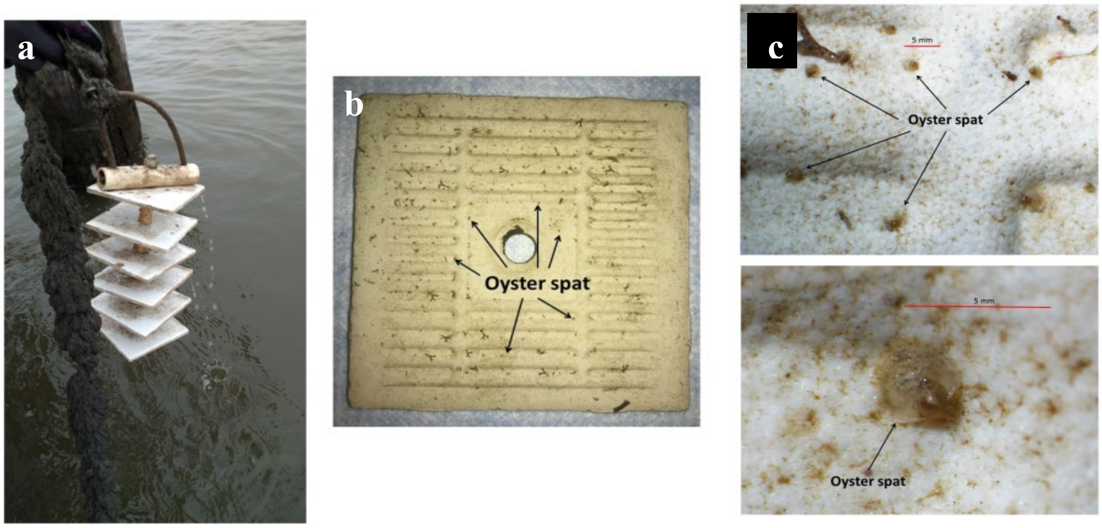

Fig. 4-1-2 Settlement monitoring: a) array being retrieved in field b) tile with oyster spat and c) images of oyster spat on unglazed side of settlement tiles under 2 magnifications.

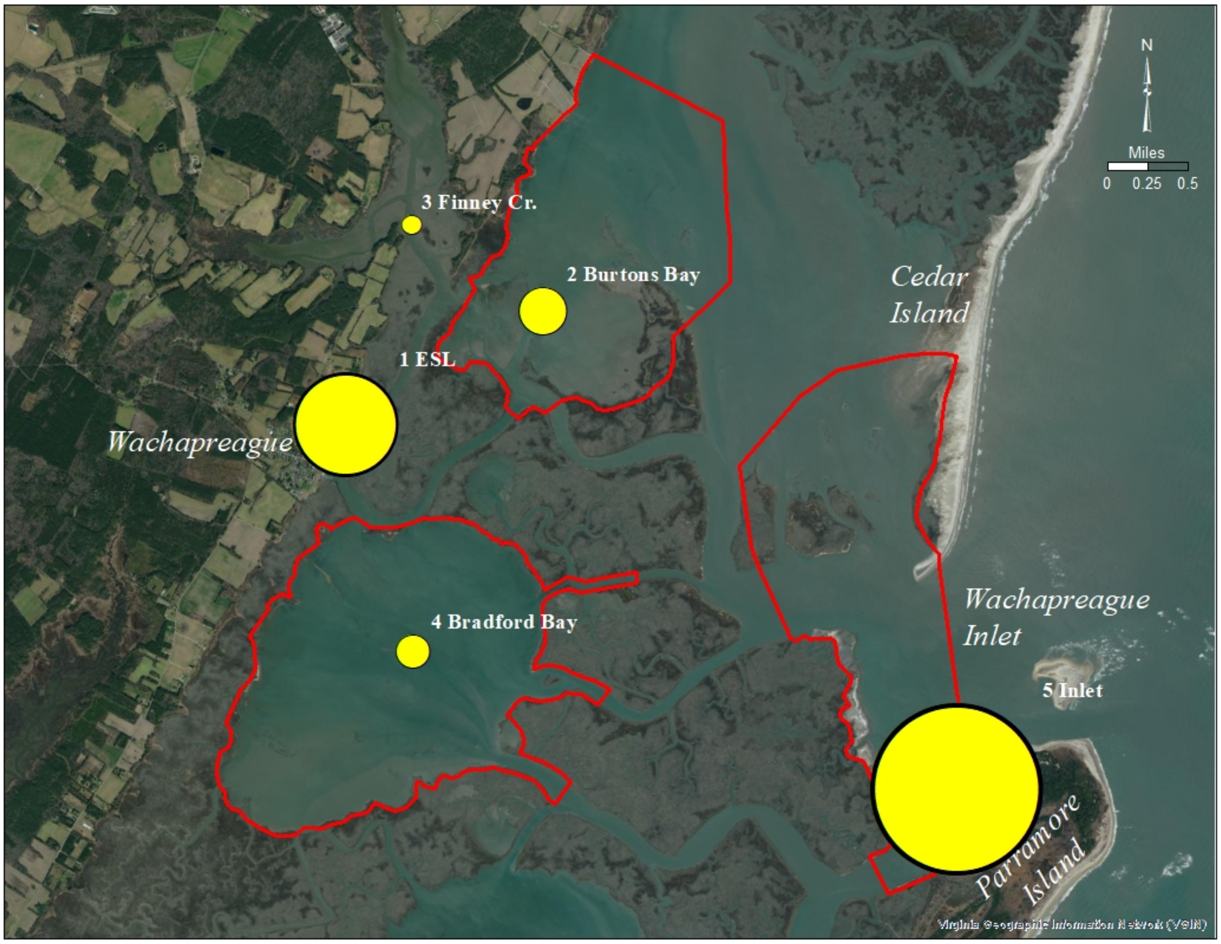

Fig. 4-1-3 Spatial pattern of 2020 cumulative oyster settlement (# oysters m^{-2}) at 5 monitoring sites near Wachapreague, VA. Size of symbols are the proportion of the total settlement to visualize the scale of differences between sites.

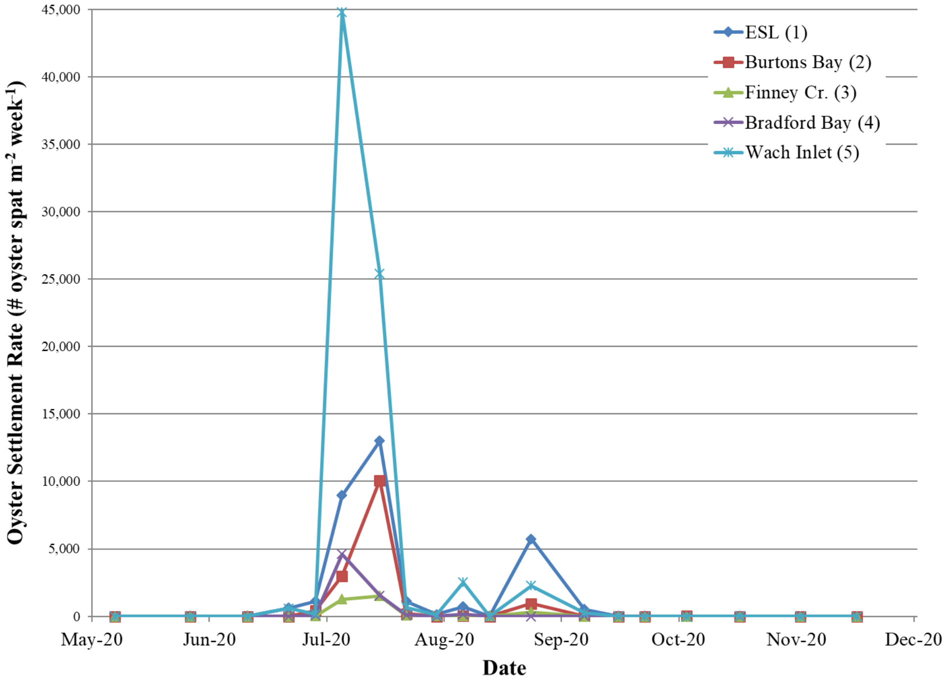

Fig. 4-1-4 Weekly oyster settlement rate (# spat m^{-2} week^{-1}) at 5 monitoring stations near Wachapreague, VA during 2020.

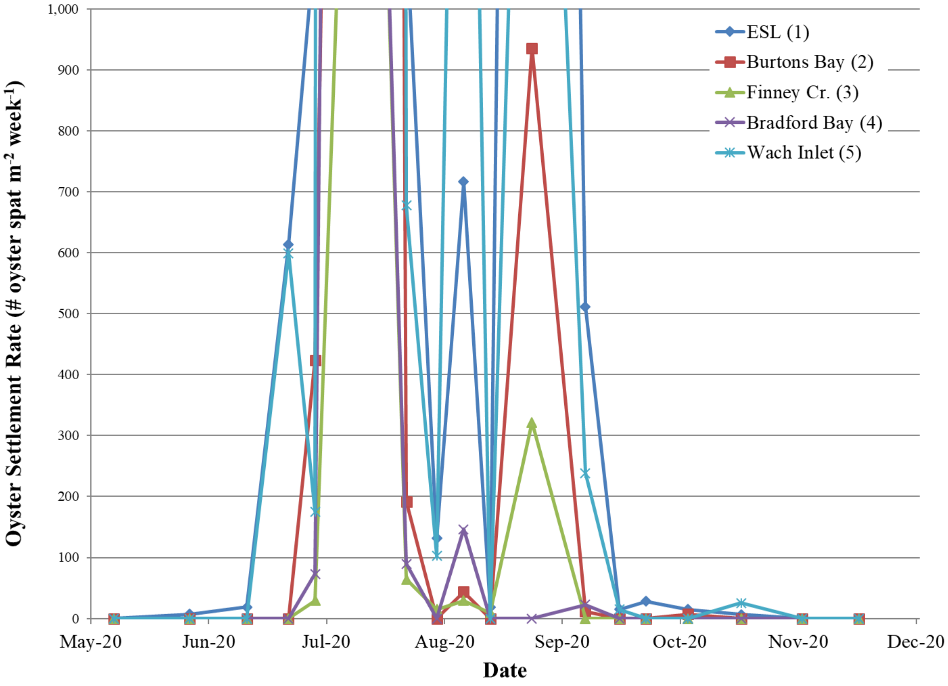

Fig. 4-1-5 Weekly oyster settlement rate (# spat m^{-2} week^{-1}) at 5 monitoring stations near Wachapreague, VA during 2020. Scale reduced to see slight settlement at end of season.

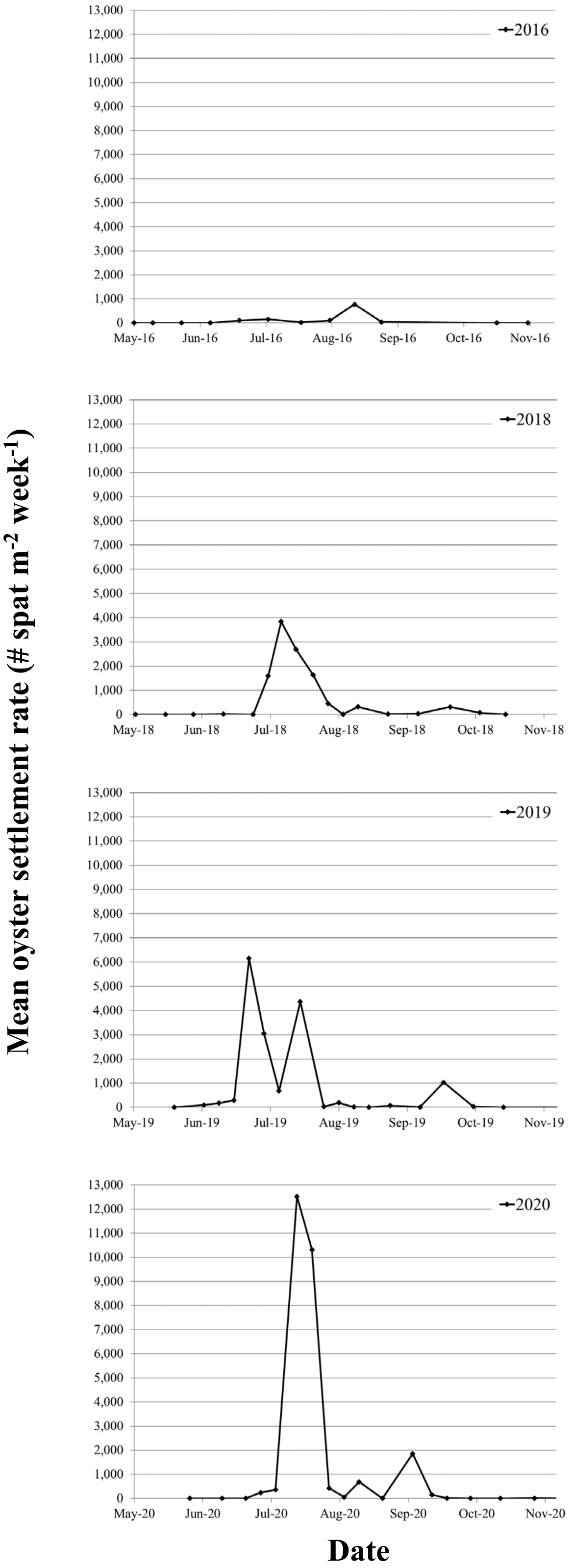

Fig. 4-1-6 Mean oyster settlement rate (# spat m^{-2} week^{-1}) at 5 monitoring stations near Wachapreague, VA by date during 2016 and 2018-2020.

Chapter 4. Oyster Population

Section 4-2: Intertidal Oyster Reef Demographics

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Planned	Planned

Introduction

Intertidal and subtidal habitats in the coastal lagoons near ESL are dominated by soft-sediment seabed ranging from coarse sand to finer sand-silt-clay areas. However, hard substrate in the forms of live oyster reefs and exposed shell beds are a major ecological feature of the area as well (Ross & Luckenbach 2009). Unlike most Chesapeake Bay oyster reefs, those on the seaside of the Eastern Shore of Virginia are predominantly intertidal. As a keystone and ecological engineering species, oysters provide critical reef habitat for many micro and macro organisms (Möbius, 1877; Knocker et al., 2006; Luckenbach et al. 2005) and enhance biogeochemical processes by clarifying water and supporting microbes mediating nutrient and carbon transformations (Kellogg et al. 2014). The resilience of intertidal oyster reefs as habitat is dependent on spat set (Chapter 4.1) and the demographics of live oysters establishing the reefs, reflecting recruitment, growth, and mortality.

There are many aspects of an oyster reef that can be used to evaluate its health (Baggett et al. 2014). However, for this EMP, we selected several representative reefs and characterized the oyster density and sizes. Trends in population density and size distribution are two of the simplest and most informative metrics used to monitor oyster demographics. Size distribution can be interpreted as an index of age-structure in the population, and density and size can be used to determine trends in survival and population biomass.

Study Area & Methods

We selected two intertidal patch reefs within each of the three EMP geographical areas to monitor (6 reefs total; Fig. 4-2-1). These were reefs that appear to be representative of other sites throughout the area. At each reef, two haphazard quadrat samples (25 cm x 25 cm; 0.0625 m^2) were collected to 15 cm deep. One of these was located within the upper ½ of reef (crest) and one in the lower ½ of reef (flank). Reefs were sampled during June 15-23, 2020. Please note that in 2018 and 2019 we also included a fringe reef in each geographic location, however these were not sampled in 2020.

Samples were transported to the lab and rinsed on a 1 mm sieve. Associated macrofauna (both infaunal and epifaunal) retained by the 1 mm sieve are reported in Chapter 5-2. Oysters were counted and measured (longest hinge-lip to nearest mm). Tissue from oysters $\geq$ 35 mm were removed and pooled into a single sample for each quadrat. This size oyster is generally considered an oyster that is not a recently settled recruit and we can efficiently remove all tissue. Tissue was dried to a constant temperature at 150° C (~48 hrs) and weighed. Samples were then combusted at 500° C for 5 hours, allowed to cool and re-weighed. Ash-free dry weight was then determined by loss on ignition.

2020 Results & Discussion

The overall oyster density on sampled reefs ranged from 504 to 3,096 individuals m^{-2} (Table 4-2-1). Individual reef densities were quite variable and there were often substantial differences between crest and flank samples within reefs. Although density of individuals is useful information, the density in terms of dry tissue biomass (g m^{-2}) is often more descriptive of the oyster population since it effectively accounts for abundance and size in one metric. The biomass density of the oyster population $\geq$ 35 mm on sampled reefs ranged from 28 to 598 g m^{-2} (Table 4-2-1) and similar differences, as noted above, were seen within reefs. For these patch reefs, some geographic differences were observed between the three regions, with the general trend of Inlet>Bradford Bay>Burton's Bay (Fig. 4-2-2).

The size frequency distribution for an oyster population can often be used to generally describe its age structure. Overall, distribution of oysters sampled on all reefs ranged from new recruits (<35 mm) up to mature adults ($\geq$75 mm) including several year classes in between. Although quite variable between patch reefs, generally there are multiple age classes present in the 2020 sampling (Figs 4-2-3 to 4-2-5). Size frequency distribution pooled by geographic area is summarized in Figure 4-2-6.

In addition to size frequency distributions, to further characterize oyster size on patch reefs, we report quantities of oysters in three traditional size categories: *"Spat" (<35 mm)*, *"Small" (35-75 mm)* and *"Market" (>75 mm)*. These categories are modified from categories that have historically been used by the oyster industry and ongoing Chesapeake Bay monitoring efforts (see Southworth and Mann 2018). Generally, individual reefs showed a similar pattern: Spat>Small>Market for 2020 (Tables 4-2-2 & 4-2-3). Size class data pooled by geographic area is summarized in Table 4-2-4.

Overall, oyster density and age structure (using size frequency distribution and size categories as surrogates) seem to indicate a generally healthy and self-sustaining oyster population. These first three years of data suggest that inter-annual variation is to be expected and no obvious trends were observed, indicating a generally stable oyster population. Longer term data will be required to resolve trends on these reefs that transcend inter-annual variation.

There were some slight geographic differences noted. As with previous years, higher oyster densities were observed in the inlet study area (Fig. 4-2-2). This corresponds to the area that had the highest oyster settlement as well in recent years (see section 4-1). Drivers of both recruitment success and reef development are likely related to food availability and predation. Relationships between the oyster population, oyster settlement and the organismal community (potential predators/competition) will likely be very complex and contribute to oyster demographics. We plan to explore these relationships once multiple years of data have been collected. However, status and trends for oysters within individual reefs to define regional patterns will be a main primary focus of this aspect of the EMP.

Comparison to Previous Years

Of the 6 reefs sampled, all but one (Q5) had either stable (+/- 10%) or increasing oyster density, both in terms of abundance and biomass of oysters in 2020 vs. 2019 and in 2020 vs. the three-year average (Table 4-2-1). When pooled by geographic regions, slight increases in oyster density (# m^{-2}) and more obvious increases in biomass (g m^{-2}) were noted for 2020 compared to 2018 and 2019 (Fig. 4-2-3). These findings correlate to the observed increased spat settlement (Section 4-1) as a main driver of recent oyster population dynamics.

Inter-annual changes were variable by reef for size distributions (Figs. 4-2-3 to 4-2-5). Pooled size distributions for the entire monitoring program show some minor age structure variations (Fig. 4-2-6). When reefs were pooled together by study area, a consistent trend of decreasing Market sized oysters was observed for each study area from 2018 to 2019 (Table 4-2-4). Although this trend continued in 2020 for the reefs in Burton’s Bay, slight increases were seen in Bradford Bay and to a larger extent in the Inlet area.

2020 Acknowledgements

We would like to thank Edward Smith and Sean Fate for field and lab processing assistance.

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Table 4-2-1. Summary of oyster density a) # m^{-2} and b) >35 mm g m^{-2} at two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2020.

A) #/m2

Study Area	Reef ID	2018	2019	2020	Average (2018-2020)	2020 vs. 2019 (%)	2020 vs. Avg. (%)
Bradford Bay	Q1	704	1,112	1,344	1,053	20.9	27.6
	Q2	2,016	2,096	2,096	2,069	0.0	1.3
Burton's Bay	Q4	2,048	1,272	1,488	1,603	17.0	-7.2
	Q5	624	1,432	504	853	-64.8	-40.9
Wach. Inlet	Q7	848	1,232	2,200	1,427	78.6	54.2
	Q9	2,592	1,888	3,096	2,525	64.0	22.6
Average of All Regions Combined		*1,472*	*1,505*	*1,788*	*1,588*	*18.8*	*12.6*

B) >35 mm Biomass, g/m2

Study Area	Reef ID	2018	2019	2020	Average (2018-2020)	2020 vs. 2019 (%)	2020 vs. Avg. (%)
Bradford Bay	Q1	97	171	286	185	66.6	54.5
	Q2	260	222	229	237	3.2	-3.5
Burton's Bay	Q4	146	165	168	160	1.9	5.3
	Q5	113	131	28	91	-78.4	-68.9
Wach. Inlet	Q7	168	232	266	222	14.9	20.0
	Q9	357	305	598	420	96.3	42.5
Average of All Regions Combined		*190*	*204*	*263*	*219*	*28.5*	*19.9*

Table 4-2-2. Summary of oyster size classes (# m^{-2}) at two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2020.

Study Area	Reef ID	Size Class	2018	2019	2020	Average (2018-2020)	2020 vs. 2019 (%)	2020 vs. Avg. (%)
Bradford Bay	Q1	Spat (<35 mm)	368	616	552	512	-10.4	7.8
		Small (35-74 mm)	208	360	640	403	77.8	58.9
		Market (>74 mm)	128	128	152	136	18.8	11.8
	Q2	Spat (<35 mm)	1,080	1,320	1,224	1,208	-7.3	1.3
		Small (35-74 mm)	656	632	712	667	12.7	6.8
		Market (>74 mm)	272	112	160	181	42.9	-11.8
Burton's Bay	Q4	Spat (<35 mm)	1,352	616	832	933	35.1	-10.9
		Small (35-74 mm)	584	568	592	581	4.2	1.8
		Market (>74 mm)	96	88	64	83	-27.3	-22.6
	Q5	Spat (<35 mm)	312	960	344	539	-64.2	-36.1
		Small (35-74 mm)	264	432	160	285	-63.0	-43.9
		Market (>74 mm)	48	32	0	27	-100.0	-100.0
Wach. Inlet	Q7	Spat (<35 mm)	376	648	1,280	768	97.5	66.7
		Small (35-74 mm)	416	496	896	603	80.6	48.7
		Market (>74 mm)	56	80	24	53	-70.0	-55.0
	Q9	Spat (<35 mm)	1,344	1,088	1,344	1,259	23.5	6.8
		Small (35-74 mm)	888	672	1,304	955	94.0	36.6
		Market (>74 mm)	360	128	448	312	250.0	43.6

Table 4-2-3. Summary of oyster size classes (%) at two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2020.

Study Area	Reef ID	Size Class	2018	2019	2020	Average (2018-2020)	2020 vs. 2019 (%)	2020 vs. Avg. (%)
Bradford Bay	Q1	Spat (<35 mm)	52	56	41	50	-26.4	-17.4
		Small (35-74 mm)	30	33	48	37	46.0	30.1
		Market (>74 mm)	18	12	11	14	-2.5	-17.4
	Q2	Spat (<35 mm)	54	64	58	59	-8.7	-0.5
		Small (35-74 mm)	33	31	34	32	10.9	4.8
		Market (>74 mm)	14	5	8	9	40.7	-13.9
Burton's Bay	Q4	Spat (<35 mm)	67	48	56	57	15.5	-1.8
		Small (35-74 mm)	29	45	40	38	-10.9	5.5
		Market (>74 mm)	5	7	4	5	-37.8	-19.1
	Q5	Spat (<35 mm)	50	67	68	62	1.2	10.3
		Small (35-74 mm)	42	30	32	35	4.6	-8.8
		Market (>74 mm)	8	2	0	3	-100.0	-100.0
Wach. Inlet	Q7	Spat (<35 mm)	44	53	58	52	9.9	12.3
		Small (35-74 mm)	49	41	41	43	0.5	-6.2
		Market (>74 mm)	7	7	1	5	-83.3	-77.0
	Q9	Spat (<35 mm)	52	58	43	51	-24.7	-14.8
		Small (35-74 mm)	34	36	42	37	18.3	12.8
		Market (>74 mm)	14	7	14	12	113.4	23.5

Table 4-2-4. Summary of oyster size classes in terms of a) mean # m^{-2} and b) % at two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2020.

A) #/m^2

Study Area	Size Class	2018	2019	2020	Average (2018-2020)	2020 vs. 2019	2020 vs. Avg. (%)
Bradford Bay	Spat (<35 mm)	724	968	888	860	-8.3	3.3
	Small (35-74 mm)	432	496	676	535	36.3	26.4
	Market (>74 mm)	200	120	156	159	30.0	-1.7
	All	*1,356*	*1,584*	*1,720*	*1,553*	*8.6*	*10.7*
Burton's Bay	Spat (<35 mm)	832	788	588	736	-25.4	-20.1
	Small (35-74 mm)	424	500	376	433	-24.8	-13.2
	Market (>74 mm)	72	60	32	55	-46.7	-41.5
	All	*1,328*	*1,348*	*996*	*1,224*	*-26.1*	*-18.6*
Wach. Inlet	Spat (<35 mm)	860	868	1,312	1,013	51.2	29.5
	Small (35-74 mm)	652	584	1,100	779	88.4	41.3
	Market (>74 mm)	208	104	236	183	126.9	29.2
	All	*1,720*	*1,556*	*2,648*	*1,975*	*70.2*	*34.1*

B) %

Study Area	Size Class	2018	2019	2020	Average (2018-2020)	2020 vs. 2019	2020 vs. Avg. (%)
Bradford Bay	Spat (<35 mm)	53.4	61.1	51.6	55	-15.5	-6.8
	Small (35-74 mm)	31.9	31.3	39.3	34	25.5	15.1
	Market (>74 mm)	14.7	7.6	9.1	10	19.7	-13.3
Burton's Bay	Spat (<35 mm)	62.7	58.5	59.0	60	1.0	-1.7
	Small (35-74 mm)	31.9	37.1	37.8	36	1.8	6.1
	Market (>74 mm)	5.4	4.5	3.2	4	-27.8	-26.3
Wach. Inlet	Spat (<35 mm)	50.0	55.8	49.5	52	-11.2	-4.3
	Small (35-74 mm)	37.9	37.5	41.5	39	10.7	6.5
	Market (>74 mm)	12.1	6.7	8.9	9	33.3	-3.4

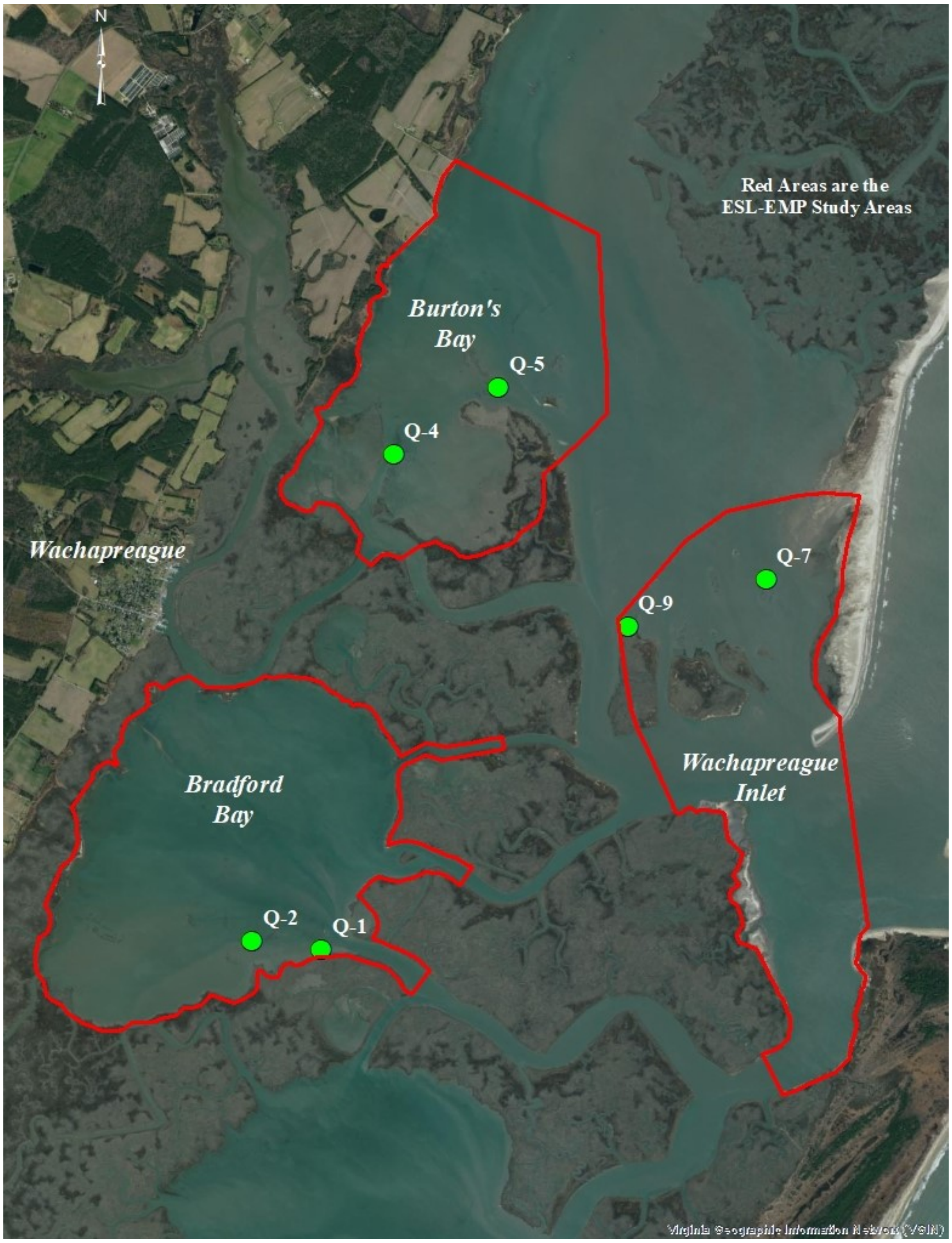


Fig. 4-2-1 Locations of 6 intertidal oyster reef monitoring sites near Wachapreague, VA for 2020 (red polygons denote the ESL-EMP study areas).

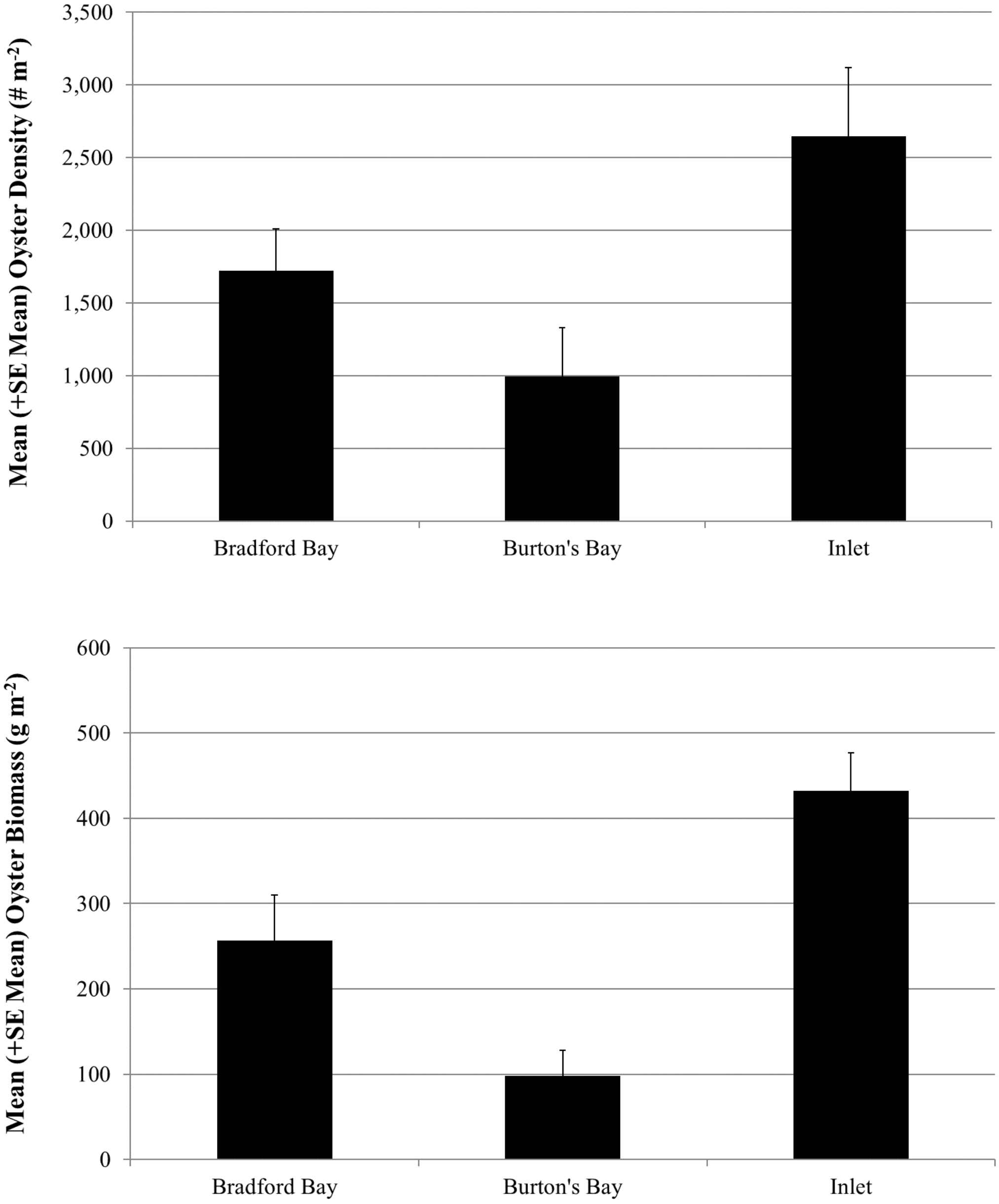


Fig. 4-2-2 Mean (+ SE) oyster density (# m^{-2}) and oyster biomass (ash-free dry wt.; g m^{-2}) at intertidal patch reefs in three geographic areas near Wachapreague, VA during 2020.

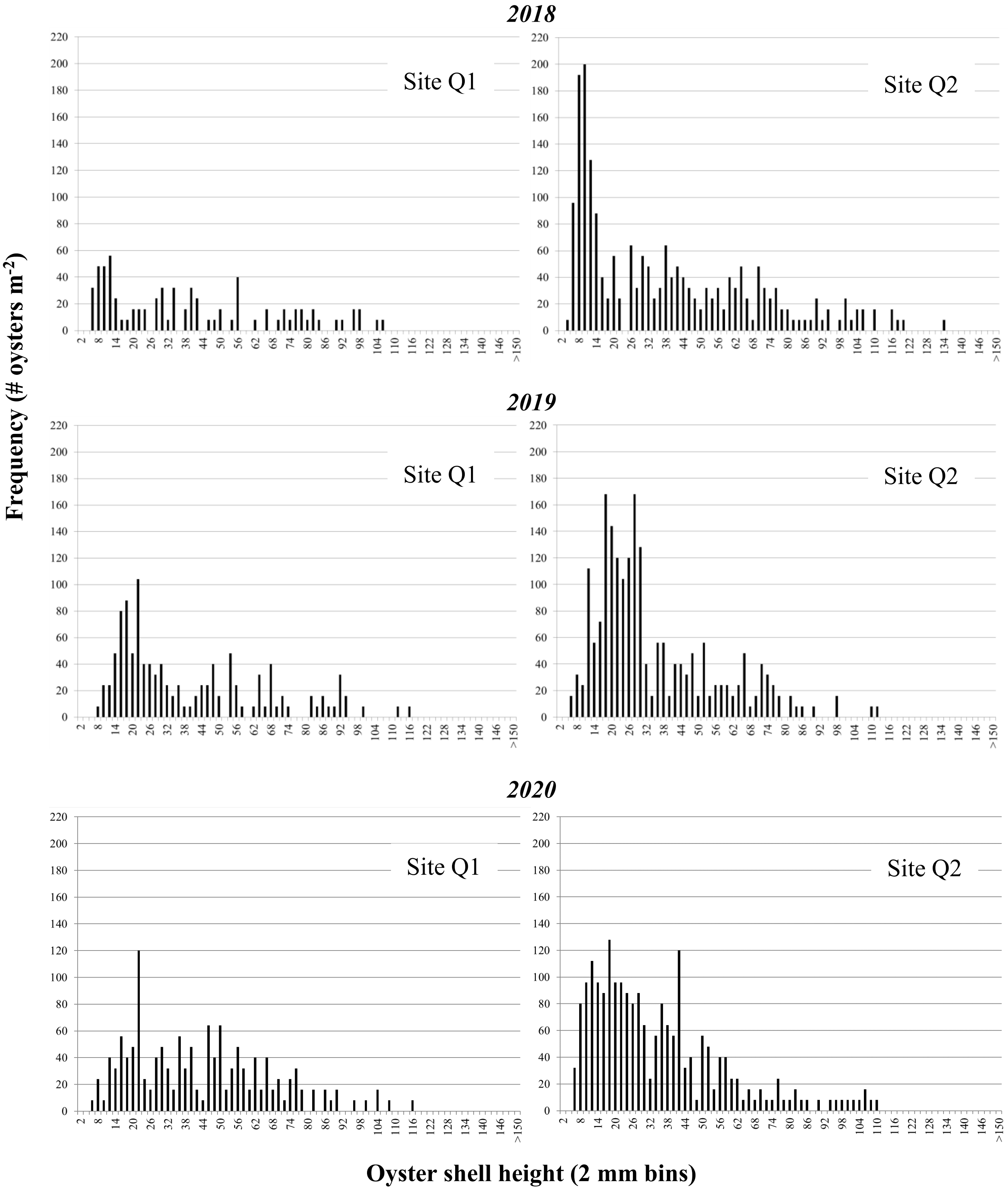


Fig. 4-2-3 Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs in Bradford Bay (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018-2020.

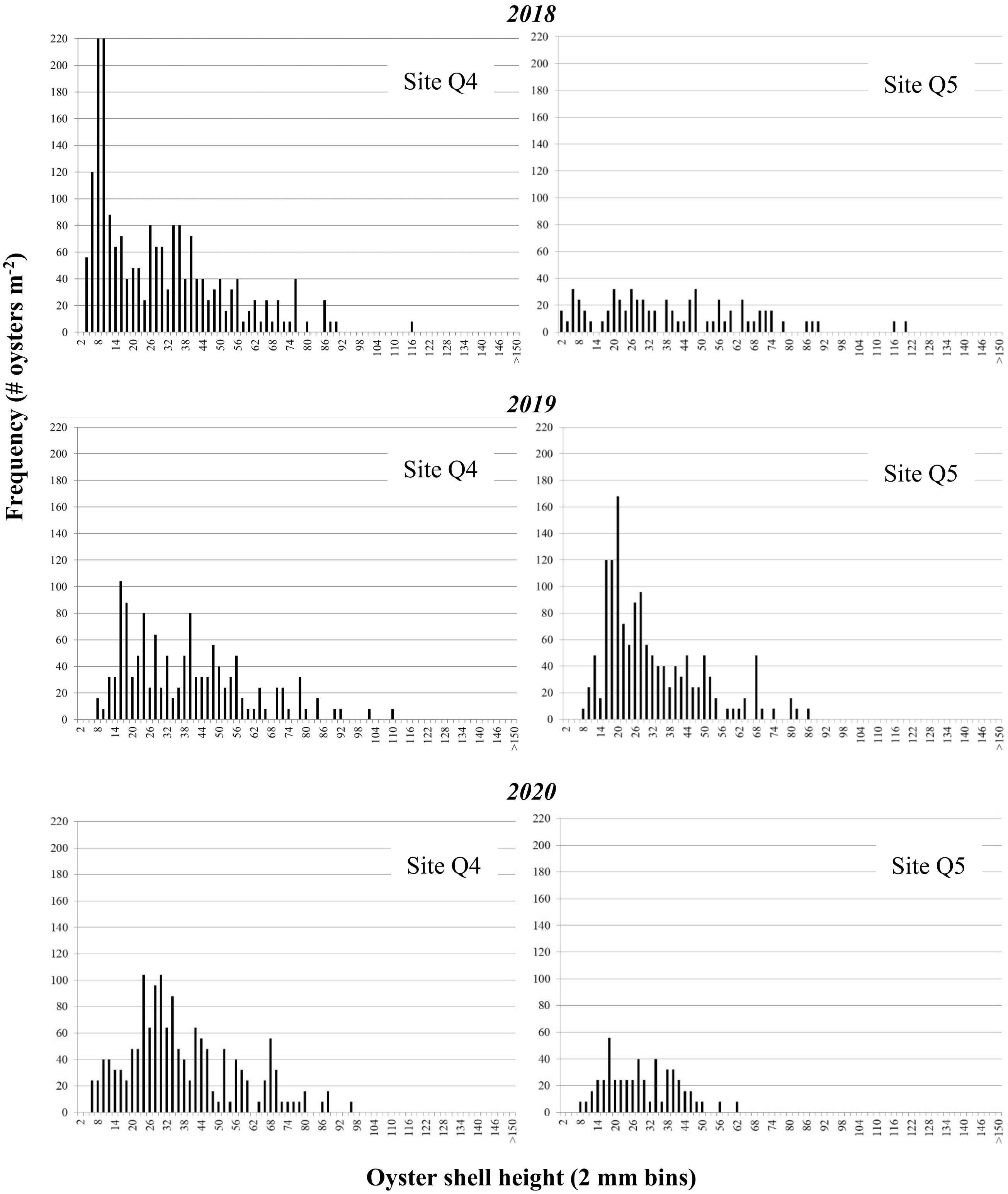


Fig 4-2-4. Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs in Burtons Bay (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018-2020.

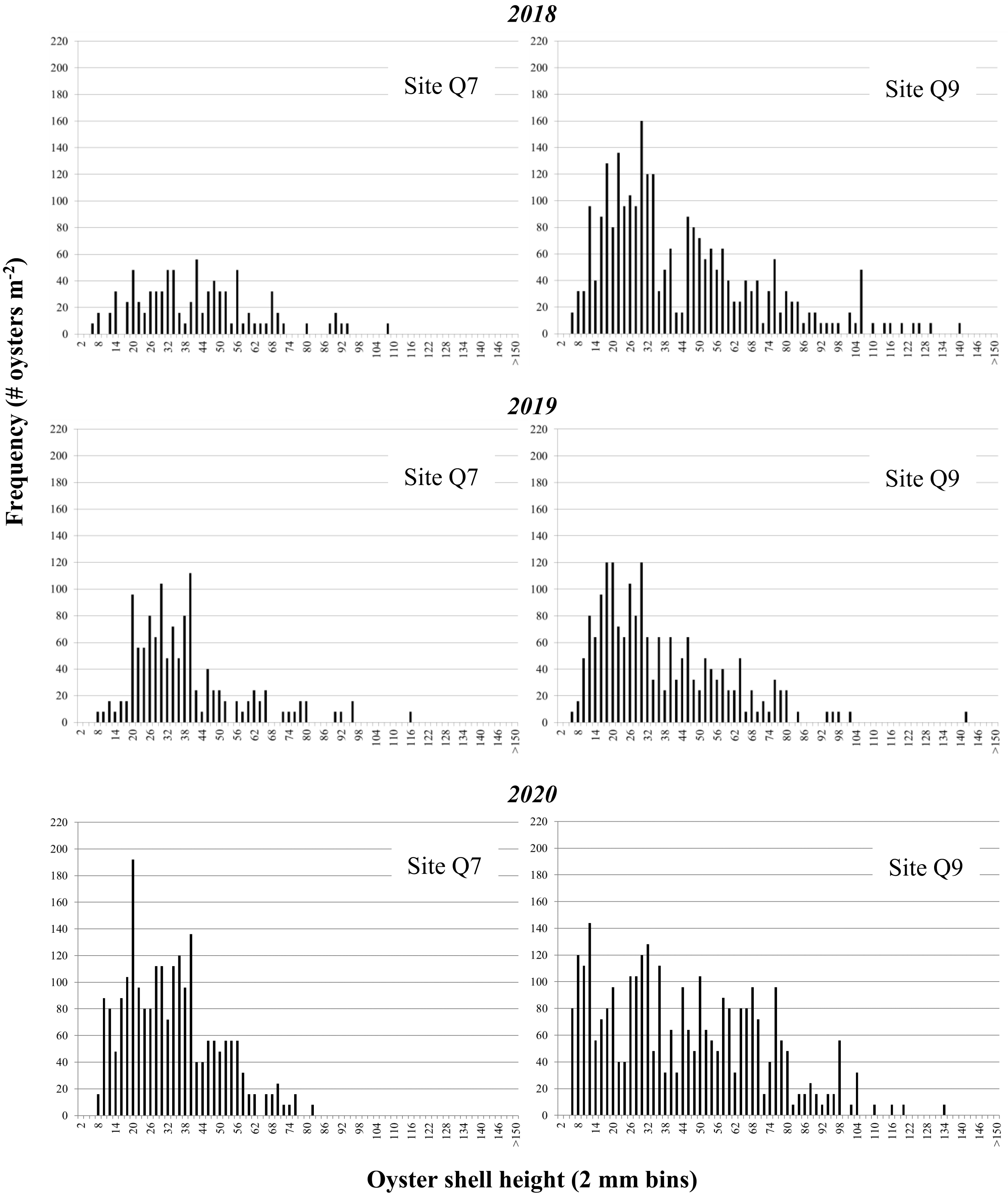


Fig 4-2-5. Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs near Wachapreague Inlet (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018-2020.

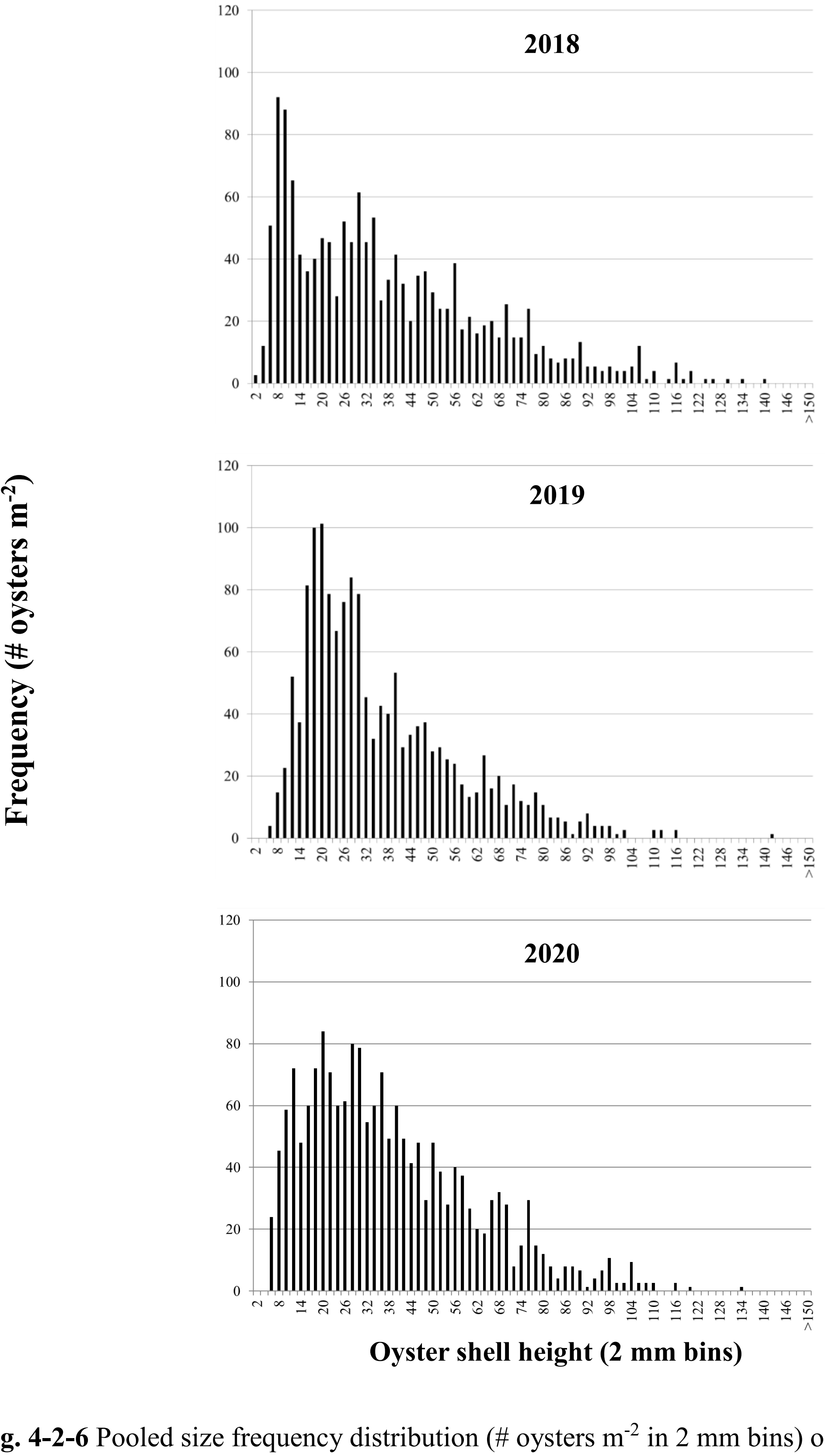
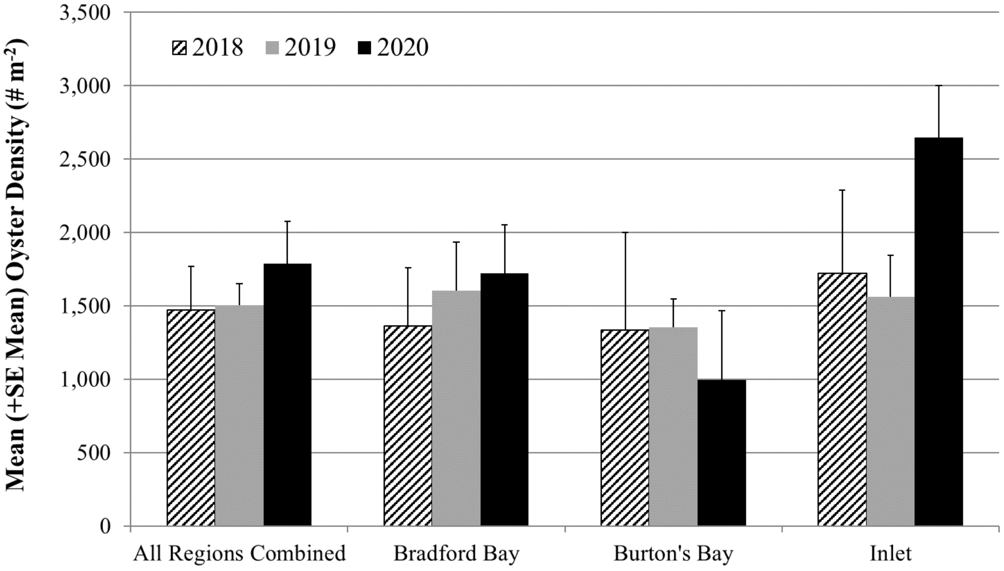


Fig. 4-2-6 Pooled size frequency distribution (# oysters m^{-2} in 2 mm bins) of oysters found on intertidal patch reefs near Wachapreague, VA in 2018-2020 (quad n=12 each year).



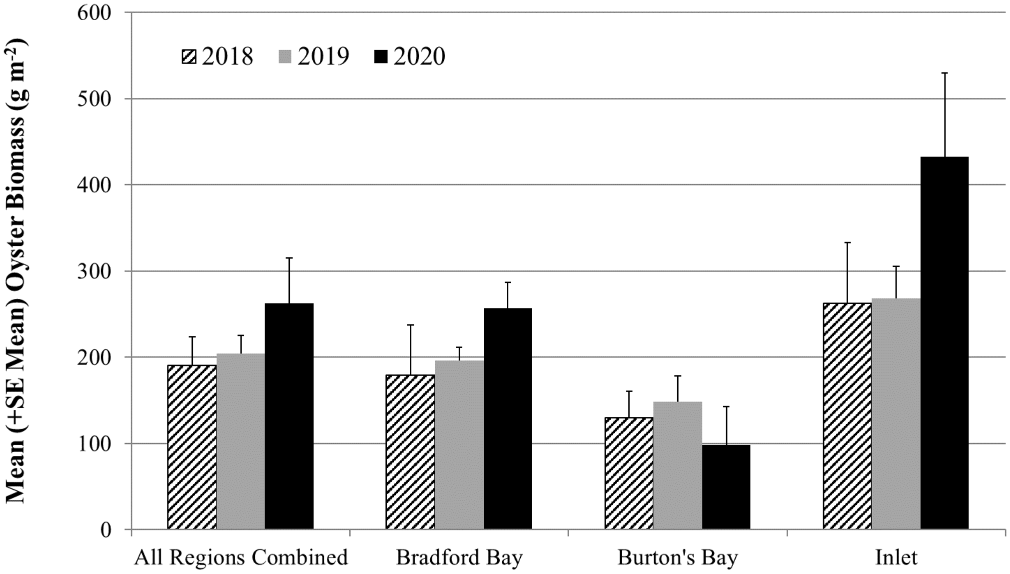


Fig. 4-2-7 Mean (+ SE) oyster density (# m^{-2}) and oyster biomass (ash-free dry wt.; g m^{-2}) at intertidal patch reefs in three geographic areas near Wachapreague, VA during 2018-2020.

Chapter 5. Epi-benthic Community

Section 5-1: Benthic Soft Sediment Community

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Planned	Planned

Introduction

Non-marsh intertidal and subtidal habitats in the coastal lagoons near ESL are dominated by soft-sediment seabed ranging from coarse sand to finer sand-silt-clay areas. Soft-sediment benthic communities in high salinity coastal ecosystems can be diverse (Gray et al. 1997) and are important to trophic webs and ecosystem health, even when compared to other habitats such as seagrass beds (Kritzer et al. 2016). Not surprisingly, they are susceptible to coastal change (e.g. Hale et al. 2017). The distribution and abundance of these species assemblages is also of importance for educators and researchers visiting VIMS ESL. In addition to tracking status and trends in the benthic communities of the coastal environment, the information can be used in planning and enriching education activities, and provides an environmental context for research proposals, experimental designs, and interpretation of research results.

Study Area & Methods

Individual sample size for characterizing soft sediment communities (SSC) needs to be as large as practical for logistic and sample processing constraints in order to encompass spatial variability or patchiness inherent in the distribution of these organisms. We established a sampling plan for 2018-2019 that included two types of gear, and adjusted the number of samples within gear type each year; see below. A Smith-McIntyre grab sampler was the main preferred technique and we supplemented this with many more, but smaller, push cores to provide more spatial coverage (see Fig. 5-1-1). Based on results from 2018-2019, only grab sampling was utilized in 2020 and this will be the only technique used for soft-sediment faunal sampling moving forward. The grab sampled a 0.0841 m^2 area to a depth of 10-15 cm. Grab sampling at 36 sites in 2020 resulted in an increase of 19.7% and 11.1% in the total area sampled relative to 2018 and 2019, respectively.

Grab samples were distributed in three geographic areas (Figs. 5-1-2). These were stratified within each area into intertidal (exposed at MLLW), shallow subtidal (>0 to $\leq$ 1.5 m deep at MLLW) and deep/channel edge (>1.5 to 2.5 m at MLLW) sub-habitats (Table 5-1-1). All samples were collected between May 12 and June 8 in 2020.

Grab samples were transferred to a 1 mm mesh fiberglass screen and placed in a 5-gallon bucket for transport to the lab. Push cores were placed in plastic bags and transported on ice in a cooler back to the lab. Within several hours of collection, both types of samples were then rinsed on a 1 mm sieve with fresh water. Macrofauna & macroflora (both infaunal and epifaunal) retained on the 1 mm sieve were preserved either by freezing or immersion in 70% ethanol, depending on the nature of the samples, e.g. samples with large amounts of fine shell or marsh detritus that were not practical to preserve in ethanol were frozen. We have had positive experience with both techniques previously and samples were very well preserved until processing and specimen identification later in the winter.

Samples were sorted using a stereo dissecting microscope and organisms were identified to the lowest practical taxonomic unit, typically to the species level. Organisms in each taxon were counted and, where appropriate, measured using taxa-specific dimensions (e.g. bivalves, snails, crabs etc.). The standard method for loss-on-ignition (LOI) was used to derive biomass. Individuals within each taxon from each sample were pooled and dried to a constant weight at 150° C (~48 hrs). Dry samples were then combusted at 500° C for 5 hours, allowed to cool and re-weighed. Ash-free dry weight was then determined by subtraction to estimate organic biomass.

2020 Results & Discussion

In total, 2,549 individual organisms were sampled representing >80 genera. The total ash-free dry biomass of the organisms collected was 34.2 g (Table 5-1-2). Amphipods, bivalves, polychaetes and gastropods dominated SSC by density (# m^{-2}), while those groups and macroalgae and sea cucumbers dominated in terms of biomass (g m^{-2}; Tables 5-1-3 & 5-1-4). Differences in the biomass density of broad taxa were observed between the three geographic areas and years (Table 5-1-5). Biomass densities for finer taxonomic groupings are reported for each of the three study areas separately in Tables 5-1-6 to 5-1-8.

Density data overall (all study areas pooled), by broad taxa and by genus are summarized in Table 5-1-9. The overall density of organisms sampled was 841.9 m^{-2} during 2020. The total biomass density of these organisms was 11.2889 g m^{-2} (Table 5-1-9).

Various basic community metrics (including taxa richness and Shannon Diversity Index) varied between study areas and years (Table 5-1-10).

The relative proportion (%) of macrofauna and macroalgae biomass varied between study areas for 2020 and within study area over time (Fig. 5-1-3). The interannual differences are, at least partially, related to a shift in sampling date where samples were collected earlier in 2019 versus 2018 (see above methods for details). Within the macrofaunal component, definite patterns of the relative proportion of broad taxa biomass were observed between study area and years (Fig. 5-1-4). For example, mollusks (mainly bivalves and gastropods) were dominant in the Wachapreague Inlet area with Burton's Bay being intermediate.

Species-specific standard measurements were made for bivalves, gastropods, fish and crabs >10 mm (Table 5-1-11). Individuals in the genera *Diodora* <10 mm were also measured. There were enough measurements for *Ensis leei* and *Tritia obsolete* to develop size frequency distributions that describe the population size/age structure (Figs. 5-1-5 & 5-1-6, respectively).

At this point we have chosen not to use a statistical approach to analyze the data in this section. Our main objective at this time is to report which organisms are present and in what quantities and sizes. Moving forward we also plan to report how these organisms are spatially distributed between and within study areas and track that over time.

Comparison to Previous Years

As mentioned earlier, adjustments to the sampling design in 2020 (i.e. transitioning to more and exclusively grab samples vs. a combination of grabs and smaller cores) resulted in an increase of 19.7% and 11.1% in the total area sampled relative to 2018 and 2019, respectively. Subsequently, there was an increase of 124% and 70.8% in the number of organisms collected relative to 2018 and 2019, respectively. While part of that is likely attributable to interannual variation and natural variation at specific sites, we feel confident that the 2020 design resulted in better sampling than the previous years and we plan to utilize this design moving forward.

A cursory survey of the overall density of organisms (both in terms of abundance and biomass) reveals no large differences from 2018-2020. There were some noticeable differences for some taxa (e.g. amphipods) while others remained very similar (e.g. polychaetes; Tables 5-1-3 and 5-1-4). For specific taxa, an example of an interesting find from 2020 was the first EMP sampling of live and rooted eelgrass (*Zostera marina*) at a site near Wachapreague Inlet (Table 5-1-4). Interestingly, there appears to be an increase in overall macrofaunal diversity from 2018-2020. Sampling effort was greater in 2020 and thus more likely to collect patchy communities, including less-common and rare organisms. The increased taxa richness found would support this (Table 5-1-10). As the EMP settles into a consistent sampling design, multiyear comparisons will be more accurate. With additional years of data to examine trends and annual differences, we will also provide more in-depth statistical analyses.

Acknowledgements

We would like to thank Sean Fate and Edward Smith for field and lab processing assistance.

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Table 5-1-1. Soft-sediment community sampling plan within three regions near Wachapreague, VA during 2018-2020.

		2018		**2019**		**2020**	
Region	**Sub-habitat**	**# Grab Samples**	**# Core Samples**	**# Grab Samples**	**# Core Samples**	**# Grab Samples**	**# Core Samples**
Bradford Bay	Intertidal	3	9	3	7	4	0
	Shallow Subtidal	3	9	4	7	4	0
	Deep	3	9	3	7	4	0
Burton's Bay	Intertidal	3	9	3	7	4	0
	Shallow Subtidal	3	9	4	7	4	0
	Deep	3	9	3	7	4	0
Wach. Inlet	Intertidal	3	9	3	7	4	0
	Shallow Subtidal	3	9	4	7	4	0
	Deep	3	9	3	7	4	0
	Total	*27*	*81*	*30*	*63*	*36*	*0*

Table 5-1-2. Summary of the total # and biomass (ash-free dry wt., g) of individuals collected for broad taxa sampled in soft-sediment samples near Wachapreague, VA during summer 2020. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	Total #	Total Biomass (g)
All Taxa			*2,549*	*34.1782*
Macroalgae	Seaweeds	Macroalgae	+	5.0781
Vascular Plants	Sea grass	Vascular plant	+	3.3574
Worms	Polychaete worms	Polychaeta	655	5.8765
	Ribbon worms	Nemertea	3	0.1832
	Worms	Oligochaeta		
Mollusks	Snails	Gastropoda (snails)	237	3.7867
	Clams	Bivalvia (non-Crassostrea)	707	5.3583
	Slipper shells	Gastropoda (slipper shells)	3	0.0215
	Limpets	Gastropoda (limpets)		
	Nudibranchs	Gastropoda (nudibranchs)	3	0.1311
Crustaceans	Hermit crabs	Paguridae	16	0.2931
	Amphipods	Amphipoda	724	0.2706
	Isopods	Isopoda	51	0.0474
	Mud Crabs	Pleocyemata (Xanthidae)	29	0.2488
	Shrimp	Pleocyemata (Caridea)	28	0.1816
	Burrowing shrimp	Pleocyemata (Axiidea)	37	0.1995
	Asian shore crab	Pleocyemata (Varunidae)	2	0.0028
	Pea crabs	Brachyura (Pinnotheridae)	30	0.0731
	Other shrimp	Pleocyemata	1	0.0645
	Mantis shrimp	Stomatopoda		
	Cumaceans	Malacostraca (Cumacea)	7	0.0007
Other Animals	Bony Fish	Osteichthyes	1	2.5612
	Sea cucumbers	Echinodermata (sea cucumber)	2	6.3441
	Bryozoans	Bryozoa		
	Unknown	Unknown	2	0.0651
	Anemones	Cnidaria (Actinaria)	7	0.0234
	Hemichordates	Hemichordata		
	Fly larvae	Diptera	4	0.0095
	Sea spiders	Pycnogonida (sea spider)		

Table 5-1-3. Summary of the total density (# m^{-2}) of broad taxa collected in soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	2018	2019	2020
All Taxa			*449.4*	*547.6*	*841.9*
Macroalgae	Seaweeds	Macroalgae	+	+	+
Vascular Plants	Sea grass	Vascular plant			+
Worms	Polychaete worms	Polychaeta	270.4	203.0	216.3
	Ribbon worms	Nemertea	2.4	0.7	1.0
	Worms	Oligochaeta		2.9	
Mollusks	Snails	Gastropoda (snails)	65.6	106.8	78.3
	Clams	Bivalvia (non-Crassostrea)	27.3	80.4	233.5
	Slipper shells	Gastropoda (slipper shells)	0.4	0.4	1.0
	Limpets	Gastropoda (limpets)			
	Nudibranchs	Gastropoda (nudibranchs)			1.0
Crustaceans	Hermit crabs	Paguridae	1.6	4.0	5.3
	Amphipods	Amphipoda	65.2	109.0	239.1
	Isopods	Isopoda	3.6	15.0	16.8
	Mud Crabs	Pleocyemata (Xanthidae)	0.4	6.2	9.6
	Shrimp	Pleocyemata (Caridea)		7.3	9.2
	Burrowing shrimp	Pleocyemata (Axiidea)	0.4		12.2
	Asian shore crab	Pleocyemata (Varunidae)			0.7
	Pea crabs	Brachyura (Pinnotheridae)	1.2	1.5	9.9
	Other shrimp	Pleocyemata	1.2		0.3
	Mantis shrimp	Stomatopoda	0.4		
	Cumaceans	Malacostraca (Cumacea)	0.4	0.4	2.3
Other Animals	Bony Fish	Osteichthyes	1.6	1.1	0.3
	Sea cucumbers	Echinodermata (sea cucumber)		0.7	0.7
	Bryozoans	Bryozoa	+		
	Unknown	Unknown	+		0.7
	Anemones	Cnidaria (Actinaria)	2.0	1.1	2.3
	Hemichordates	Hemichordata	0.8	1.1	
	Fly larvae	Diptera	0.4	0.4	1.3
	Sea spiders	Pycnogonida (sea spider)	0.4		

Table 5-1-4. Summary of the total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2020. A blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	2018	2019	2020
All Taxa			*12.4701*	*15.6145*	*11.2889*
Macroalgae	Seaweeds	Macroalgae	6.2299	5.2736	1.6773
Vascular Plants	Sea grass	Vascular plant			1.1089
Worms	Polychaete worms	Polychaeta	2.8263	1.9699	1.9410
	Ribbon worms	Nemertea	0.4548	0.0122	0.0605
	Worms	Oligochaeta		0.0148	
Mollusks	Snails	Gastropoda (snails)	2.2492	4.2704	1.2507
	Clams	Bivalvia (non-Crassostrea)	0.5760	0.7999	1.7698
	Slipper shells	Gastropoda (slipper shells)	0.0002	0.0006	0.0071
	Limpets	Gastropoda (limpets)			
	Nudibranchs	Gastropoda (nudibranchs)			0.0433
Crustaceans	Hermit crabs	Paguridae	0.0500	0.0509	0.0968
	Amphipods	Amphipoda	0.0325	0.0658	0.0894
	Isopods	Isopoda	0.0093	0.0402	0.0157
	Mud Crabs	Pleocyemata (Xanthidae)	0.0030	0.1739	0.0822
	Shrimp	Pleocyemata (Caridea)		0.1312	0.0600
	Burrowing shrimp	Pleocyemata (Axiidea)	0.0011		0.0659
	Asian shore crab	Pleocyemata (Varunidae)			0.0009
	Pea crabs	Brachyura (Pinnotheridae)	0.0009	0.0045	0.0241
	Other shrimp	Pleocyemata	0.0009		0.0213
	Mantis shrimp	Stomatopoda	0.0006		
	Cumaceans	Malacostraca (Cumacea)	0.0004	<0.0001	0.0002
Other Animals	Bony Fish	Osteichthyes	0.0115	1.5210	0.8460
	Sea cucumbers	Echinodermata (sea cucumber)		1.0738	2.0954
	Bryozoans	Bryozoa	0.0096		
	Unknown	Unknown	0.0042		0.0215
	Anemones	Cnidaria (Actinaria)	0.0040	0.0002	0.0077
	Hemichordates	Hemichordata	0.0017	0.0284	
	Fly larvae	Diptera	0.0009	<0.0001	0.0031
	Sea spiders	Pycnogonida (sea spider)	<0.0001		

Table 5-1-5. Summary of the total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in soft-sediment samples in three study areas near Wachapreague, VA during summer 2018-2020. A blank cell indicates the absence of that taxon.

Taxonomic Grouping	Geographic Area	2018	2019	2020
All Taxa Combined	*All 3 Areas*	*12.4701*	*15.6145*	*11.2889*
All Taxa Combined	Bradford Bay	12.3345	13.9708	14.9059
	Burton's Bay	17.2472	26.4763	8.7016
	Wach. Inlet	7.8284	6.3963	10.2591
Macroalgae (Seaweeds)	Bradford Bay	5.7233	3.7211	2.8563
	Burton's Bay	10.5071	11.8216	
	Wach. Inlet	2.4594	0.2780	2.1755
Vascular Plants (Eelgrass etc.)	Bradford Bay			
	Burton's Bay			
	Wach. Inlet			3.3268
Worms	Bradford Bay	5.0218	3.2944	2.6461
	Burton's Bay	3.9349	2.0834	2.5725
	Wach. Inlet	0.8866	0.6129	0.7859
Mollusks (Snails, clams, etc.)	Bradford Bay	1.4982	1.0440	1.3105
	Burton's Bay	2.7590	9.1209	4.3514
	Wach. Inlet	4.2190	5.1861	3.5509
Crustaceans (Crabs, shrimp, amphipods etc.)	Bradford Bay	0.0574	1.3443	0.6644
	Burton's Bay	0.0375	0.1911	0.2877
	Wach. Inlet	0.2100	0.2753	0.4175
Other Animals (Fish, echinoderms, anenomes etc.)	Bradford Bay	0.0338	4.5669	7.4286
	Burton's Bay	0.0088	3.2593	1.4901
	Wach. Inlet	0.0534	0.0440	0.0026

Table 5-1-6. Summary of the total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in soft-sediment samples in the Bradford Bay study area near Wachapreague, VA during summer 2018-2020. A blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	2018	2019	2020
All Taxa			*12.3345*	*13.9708*	*14.9059*
Macroalgae	Seaweeds	Macroalgae	5.7233	3.7211	2.8563
Vascular Plants	Sea grass	Vascular plant			
Worms	Polychaete worms	Polychaeta	4.9158	3.2501	2.5310
	Ribbon worms	Nemertea	0.1060		0.1150
	Worms	Oligochaeta		0.0444	
Mollusks	Snails	Gastropoda (snails)	0.7243	0.7188	1.1624
	Clams	Bivalvia (non-Crassostrea)	0.7739	0.1850	0.1481
	Slipper shells	Gastropoda (slipper shells)		0.0017	
	Limpets	Gastropoda (limpets)		0.1386	
	Nudibranchs	Gastropoda (nudibranchs)			
Crustaceans	Hermit crabs	Paguridae		0.0693	
	Amphipods	Amphipoda	0.0243	0.0154	0.0795
	Isopods	Isopoda	0.0098	0.1087	0.0340
	Mud Crabs	Pleocyemata (Xanthidae)	0.0090	0.4703	0.1871
	Shrimp	Pleocyemata (Caridea)	0.0052	0.2943	0.1242
	Burrowing shrimp	Pleocyemata (Axiidea)	0.0033	0.3844	0.1209
	Asian shore crab	Pleocyemata (Varunidae)			
	Pea crabs	Brachyura (Pinnotheridae)	0.0027	0.0019	0.0549
	Other shrimp	Pleocyemata			0.0639
	Mantis shrimp	Stomatopoda	0.0018		
	Cumaceans	Malacostraca (Cumacea)	0.0012	0.0001	<0.0001
Other Animals	Bony Fish	Osteichthyes	0.0212	4.4816	2.5379
	Sea cucumbers	Echinodermata (sea cucumber)			4.8384
	Bryozoans	Bryozoa			
	Unknown	Unknown	0.0126		0.0441
	Anemones	Cnidaria (Actinaria)		<0.0001	0.0082
	Hemichordates	Hemichordata		0.0853	
	Fly larvae	Diptera			
	Sea spiders	Pycnogonida (sea spider)	<0.0001		

Table 5-1-7. Summary of the total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in soft-sediment samples in the Burton's Bay study area near Wachapreague, VA during summer 2018-2020. A blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	2018	2019	2020
All Taxa			*17.2472*	*26.4763*	*8.7016*
Macroalgae	Seaweeds	Macroalgae	10.5071	11.8216	
Vascular Plants	Sea grass	Vascular plant			
Worms	Polychaete worms	Polychaeta	2.9162	2.0834	2.5156
	Ribbon worms	Nemertea	1.0187		0.0570
	Worms	Oligochaeta			
Mollusks	Snails	Gastropoda (snails)	2.6483	8.3076	1.4728
	Clams	Bivalvia (non-Crassostrea)	0.1100	0.8133	2.7273
	Slipper shells	Gastropoda (slipper shells)	0.0007		0.0213
	Limpets	Gastropoda (limpets)			
	Nudibranchs	Gastropoda (nudibranchs)			0.1299
Crustaceans	Hermit crabs	Paguridae		0.0068	0.0959
	Amphipods	Amphipoda	0.0208	0.1343	0.0359
	Isopods	Isopoda	0.0130	0.0116	0.0086
	Mud Crabs	Pleocyemata (Xanthidae)		0.0146	0.0414
	Shrimp	Pleocyemata (Caridea)	0.0037	0.0197	0.0411
	Burrowing shrimp	Pleocyemata (Axiidea)		0.0034	0.0548
	Asian shore crab	Pleocyemata (Varunidae)			0.0028
	Pea crabs	Brachyura (Pinnotheridae)		0.0007	0.0066
	Other shrimp	Pleocyemata			
	Mantis shrimp	Stomatopoda			
	Cumaceans	Malacostraca (Cumacea)			0.0005
Other Animals	Bony Fish	Osteichthyes	0.0008	0.0373	
	Sea cucumbers	Echinodermata (sea cucumber)		3.2213	1.4479
	Bryozoans	Bryozoa			
	Unknown	Unknown			0.0178
	Anemones	Cnidaria (Actinaria)	0.0001	0.0007	0.0150
	Hemichordates	Hemichordata	0.0050		
	Fly larvae	Diptera	0.0028		0.0094
	Sea spiders	Pycnogonida (sea spider)			

Table 5-1-8. Summary of the total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in soft-sediment samples in the Wachapreague Inlet study area near Wachapreague, VA during summer 2018-2020. A blank cell indicates the absence of that taxon.

Category	Common Name	Taxonomic Grouping	2018	2019	2020
		All Taxa	*7.8284*	*6.3963*	*10.2591*
Macroalgae	Seaweeds	Macroalgae	2.4594	0.2780	2.1755
Vascular Plants	Sea grass	Vascular plant			3.3268
Worms	Polychaete worms	Polychaeta	0.6470	0.5763	0.7764
	Ribbon worms	Nemertea	0.2397	0.0366	0.0095
	Worms	Oligochaeta			
Mollusks	Snails	Gastropoda (snails)	3.3750	3.7846	1.1169
	Clams	Bivalvia (non-Crassostrea)	0.8441	1.4015	2.4340
	Slipper shells	Gastropoda (slipper shells)			
	Limpets	Gastropoda (limpets)			
	Nudibranchs	Gastropoda (nudibranchs)			
Crustaceans	Hermit crabs	Paguridae	0.1499	0.0765	0.1945
	Amphipods	Amphipoda	0.0524	0.0477	0.1528
	Isopods	Isopoda	0.0051	0.0003	0.0044
	Mud Crabs	Pleocyemata (Xanthidae)		0.0368	0.0180
	Shrimp	Pleocyemata (Caridea)		0.0796	0.0147
	Burrowing shrimp	Pleocyemata (Axiidea)		0.0235	0.0220
	Asian shore crab	Pleocyemata (Varunidae)			
	Pea crabs	Brachyura (Pinnotheridae)		0.0109	0.0109
	Other shrimp	Pleocyemata	0.0026		
	Mantis shrimp	Stomatopoda			
	Cumaceans	Malacostraca (Cumacea)			0.0002
Other Animals	Bony Fish	Osteichthyes	0.0126	0.0440	
	Sea cucumbers	Echinodermata (sea cucumber)			
	Bryozoans	Bryozoa	0.0288		
	Unknown	Unknown			0.0026
	Anemones	Cnidaria (Actinaria)	0.0119		
	Hemichordates	Hemichordata	0.0001		
	Fly larvae	Diptera		<0.0001	
	Sea spiders	Pycnogonida (sea spider)			

Table 5-1-9. Summary of the total individual density (# m^{-2}) and biomass density (ash-free dry wt., g m^{-2}) of genera collected in soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

	# m^{-2}			**g m^{-2}**		
Taxon (~Genus)	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
All Taxa	*449.4*	*547.6*	*841.9*	*12.4701*	*15.6145*	*11.2889*
Amphipoda	65.2	109.0	239.1	0.0325	0.0658	0.0894
Ampelisca	30.0	7.7	110.6	0.0106	0.0051	0.0329
Ampithoe	5.5	1.1	13.9	0.0022	0.0013	0.0056
Apocorophium	0.4			0.0002		
Caprella	0.8		8.6	0.0002		0.0020
Corophium	2.4	3.3	16.2	0.0011	0.0004	0.0027
Gammarus	11.5	79.6	54.8	0.0077	0.0491	0.0344
Haustorid		3.7	5.6		0.0050	0.0032
Idunella		1.1	10.6		0.0001	0.0010
Lysianopsis		6.6			0.0019	
Melita	2.4	4.4	4.6	0.0008	0.0023	0.0014
Paracaprella		0.7	0.7		0.0001	<0.0001
Batea			4.3			0.0009
Microdeutopus			6.6			0.0007
Ericthonium			4.3			0.0004
Paraphoxus			0.3			0.0001
Trichophoxus			1.7			0.0009
Unidentified amphipod	12.3	0.7	5.3	0.0098	0.0004	0.0051
Bivalvia	27.3	80.4	233.5	0.5760	0.7999	1.7698
Anadara		1.1			0.0018	
Ensis	0.4	28.6	163.2	0.0082	0.6040	0.3399
Gemma	3.6			0.0004		
Limecola	1.6	3.3	5.0	0.0014	0.0115	0.0122
Macoploma	12.3	20.6	36.7	0.0342	0.0596	0.0499
Mercenaria	2.0		0.7	0.0473		0.3685
Mulinia	1.6	21.7	1.3	0.0016	0.0172	0.0007
Mya	3.2	0.7		0.0045	0.0004	
Mytilus			18.5			0.0667
Petricolaria			5.9			0.0457
Spisula		0.4			<0.0001	
Tagelus	2.4	4.0	2.3	0.4770	0.1054	0.8862
Yoldia	0.4			0.0013		

Table 5-1-9 (continued)

	# m^{-2}			g m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Brachyura (Pinnotheridae)	1.2	1.5	9.9	0.0009	0.0045	0.0241
Pinnixa		1.5			0.0045	
Pinnixulala	1.2		9.2	0.0009		0.0233
Rathbunixa			0.7			0.0009
Bryozoa	+			0.0096		
Bugula	+			0.0096		
Cnidaria (Actinaria)	2.0	1.1	2.3	0.0040	0.0002	0.0077
Diadumene	2.0	0.7	1.0	0.0040	0.0002	0.0035
Edwardsiella		0.4			<0.0001	
Unidentified anemone			1.3			0.0042
Diptera	0.4	0.4	1.3	0.0009	<0.0001	0.0031
Diptera	0.4	0.4	1.3	0.0009	<0.0001	0.0031
Echinodermata		0.7	0.7		1.0738	2.0954
Sclerodactyla		0.7	0.7		1.0738	2.0954
Gastropoda (limpets)		1.1			0.0462	
Diodora		1.1			0.0462	
Gastropoda (nudibranchs)			1.0			0.0433
Cariopsilla			1.0			0.0433
Gastropoda (slipper shells)	0.4	0.4	1.0	0.0002	0.0006	0.0071
Crepidula	0.4	0.4	1.0	0.0002	0.0006	0.0071
Gastropoda (snails)	65.6	106.8	78.3	2.2492	4.2704	1.2507
Acteocina	2.4	4.8	11.6	0.0011	0.0040	0.0088
Astyris	0.8	2.9	11.2	0.0005	0.0087	0.0073
Bittiolum			1.7			0.0008
Busycotypus	0.4			0.1589		
Costoanachis			0.3			0.0007
Epitonium		0.4			0.0005	
Haminella		26.1	24.4		0.0541	0.0489
Nucella		0.4			0.0005	
Phrontis	1.6		0.3	0.0018		0.0002
Seila	0.4	0.4	5.0	0.0003	0.0006	0.0069
Solaridae			0.3			0.0004
Tritia	58.9	71.9	23.1	2.0865	4.2020	1.1765
Turbonilla	1.2			<0.0001		
Unidentified snail			0.3			0.0002
Hemichordata	0.8	1.1		0.0017	0.0284	
Saccoglossus	0.8	1.1		0.0017	0.0284	

Table 5-1-9 (continued)

	# m^{-2}			g m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Isopoda	3.6	15.0	16.8	0.0093	0.0402	0.0157
Cyathura	1.2	12.8	5.6	0.0033	0.0395	0.0127
Edotia	0.4	2.2	2.3	<0.0001	0.0007	0.0009
Erichsonella	1.6			0.0035		
Idotea	0.4			0.0025		
Macroalgae	+	+	+	6.2299	5.2736	1.6773
Agardhiella			+			0.1166
Bryopsis			+			0.0044
Enteromorpha			+			0.0317
Ceramium			+			0.0014
Gracilaria	+	+	+	3.0503	0.6675	0.6064
Ulva	+	+	+	3.1796	4.6061	0.9168
Malacostraca	0.4	0.4	2.3	0.0004	<0.0001	0.0002
Cumacea	0.4	0.4	2.3	0.0004	<0.0001	0.0002
Nemertea	2.4	0.7	1.0	0.4548	0.0122	0.0605
Micrura	2.4	0.7	1.0	0.4548	0.0122	0.0605
Oligochaeta		2.9			0.0148	
Oligochaeta		2.9			0.0148	
Osteichthyes	1.6	1.1	0.3	0.0115	1.5210	0.8460
Anguilla		0.4			1.4939	
Conger		0.7	0.3		0.0271	0.8460
Gobiosoma	1.6			0.0115		
Paguridae	1.6	4.0	5.3	0.0500	0.0509	0.0968
Pagurus	1.6	4.0	5.3	0.0500	0.0509	0.0968
Pleocyemata	1.2		0.3	0.0009		0.0213
Unidentifed crab	1.2		0.3	0.0009		0.0213
Pleocyemata (Axiidea)	0.4	4.4	12.2	0.0011	0.1371	0.0659
Biffarius	0.4	3.3	11.9	0.0011	0.0088	0.0646
Upogebia		1.1	0.3		0.1282	0.0013
Pleocyemata (Caridea)	4.0	7.3	9.2	0.0030	0.1312	0.0600
Alpheus		1.5	2.0		0.1064	0.0388
Crangon		0.4	1.0		0.0004	0.0071
Ogyrides	3.2	5.5	6.3	0.0026	0.0244	0.0141
Unidentified shrimp	0.8			0.0004		
Pleocyemata (Varunidae)			0.7			0.0009
Hemigrapsus			0.7			0.0009

Table 5-1-9 (continued)

	# m^{-2}			**g m^{-2}**		
Taxon (~Genus)	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Pleocyemata (Xanthidae)	0.4	6.2	9.6	0.0030	0.1739	0.0822
Dyspanopeus		0.4			0.0104	
Eurypanopeus		4.0	6.6		0.0473	0.0400
Panopeus	0.4	1.8	3.0	0.0030	0.1163	0.0422
Polychaeta	270.4	203.0	216.3	2.8263	1.9699	1.9410
Alitta	204.0	129.6	64.7	1.9320	1.1961	0.6975
Ampharete			3.3			0.0012
Amphitrite			0.3			
Arabella	1.6	1.8	6.6	0.0815	0.0742	0.1880
Arenicola	0.4			0.0011		
Capitellidae		1.8			0.0037	
Chaetopterus		0.4			0.0115	
Cirratulus		3.3			0.0483	
Clymenella	19.8	7.3	22.5	0.0775	0.0709	0.0976
Diopatra	2.4	1.5	1.7	0.0910	0.0552	0.1365
Drilonereis	24.1	33.0	48.6	0.0515	0.0546	0.0865
Eteone	0.4			0.0029		
Glycera	7.1	9.9	17.2	0.3479	0.0881	0.3969
Lepidonotus	0.4		0.3	0.0062		0.0009
Lumbrineris	0.4	0.4		<0.0001	0.0002	
Maldane	1.6	1.1		0.0044	0.0099	
Marphysa	2.8	4.4	6.6	0.0864	0.1607	0.1066
Melinna			0.3			0.0003
Nephtys		2.2	0.3		0.0050	0.0066
Onuphis		0.4			0.0003	
Orbinidae		0.7	23.8		0.0008	0.0318
Owenia			8.3			0.0048
Pectinaria	0.4	1.1	1.3	0.0009	0.0070	0.0026
Phyllodoce		1.1	1.3		0.0019	0.0011
Piromis		0.7	1.0		0.0046	0.0088
Spiochaetopterus	4.3	1.1	6.3	0.0108	0.0008	0.0065
Sthenelais		0.4			0.0210	
Syllidae			0.7			0.0051
Terebellidae			0.7			0.0021
Unidentified polychaete	0.8	0.7	0.7	0.1321	0.1550	0.1597

Table 5-1-9 (continued)

	# m^{-2}			g m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Pycnogonida	0.4			<0.0001		
Nymphon	0.4			<0.0001		
Stomatopoda	0.4			0.0006		
Squilla	0.4			0.0006		
Vascular plant			+			1.1089
Zostera			+			1.1089

Table 5-1-10. Summary of several community metrics (based on density of individual organisms, # m^{-2}) of taxa (basically at the level of genus) collected in soft-sediment samples overall and in three study areas near Wachapreague, VA during summer 2018-2020.

Community Metric	Geographic Area	2018	2019	2020
Abundance (# m^{-2})	Bradford Bay	583	616	731
	Burton's Bay	443	723	714
	Wach. Inlet	321	304	1,080
	Overall	*449*	*548*	*842*
Taxa Richness	Bradford Bay	36	44	49
	Burton's Bay	37	43	50
	Wach. Inlet	38	41	44
	Overall	*59*	*70*	*77*
Shannon Diversity Index (H')	Bradford Bay	1.50	2.45	2.90
	Burton's Bay	2.16	2.47	3.26
	Wach. Inlet	2.66	2.77	2.41
	Overall	*2.30*	*2.86*	*3.19*

Table 5-1-11. Summary of sizes (mm using species-specific standard measurements) of select species that were measured from samples collected in soft-sediment samples near Wachapreague, VA during 2018-2020. Empty cells indicate an absence of large enough individuals to measure of that species during a given year. Generally, only individuals ≥10 mm were measured*. Ranges and means are for this subset of organisms ≥ 10 mm.

	2018				2019				2020			
	# <10 mm	# ≥10 mm	Range (mm)	Avg (mm)	# <10 mm	# >10 mm	Range (mm)	Avg (mm)	# <10 mm	# >10 mm	Range (mm)	Avg (mm)
Bivalvia (non-Crassostrea)												
Ensis leei	0	1	-	28.0	2	77	10-39	27.0	354	140	10-35	16.5
Limecola balthica	4				9	2	10-10	10.0	15			
Macoploma tenta	28	3	16-20	17.3	37	19	10-13	11.2	93	18	10-19	12.2
Mercenaria mercenaria	4	1	-	21.0					1			
Mytilus edulis									41	15	10-17	13.1
Petricolaria pholadiformis									4	14	10-22	14.3
Tagelus plebius	0	4	13-65	38.8	0	9	16-24	20.6	1	6	11-74	31.8
Gastropoda (snails)												
Tritia obsoleta	0	72	10-24	17.4	6	190	10-26	17.9	11	59	11-25	17.2
Osteichthyes												
Conger oceanicus					0	1	-	58.0	0	1	-	235.0

* Most species were only measured if ≥10 mm, but *Diodora* was an exception

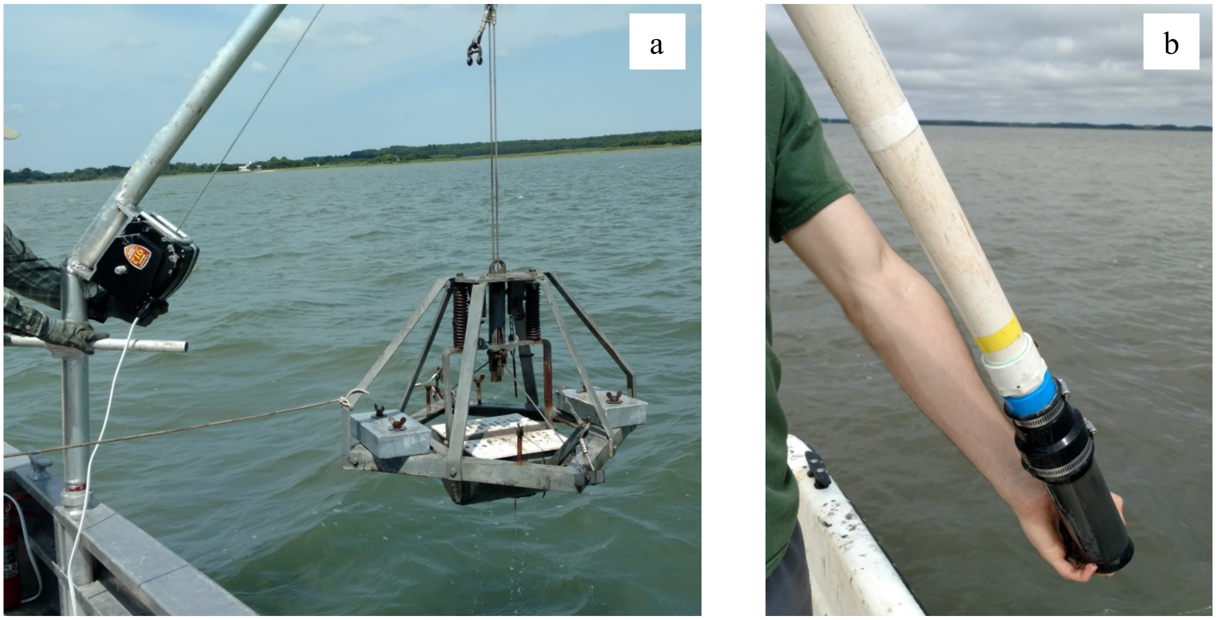

Fig. 5-1-1 Gear used to collect a) grab and b) push core samples. Subsamples from these were collected for surficial sediment organic matter and chlorophyll-a.

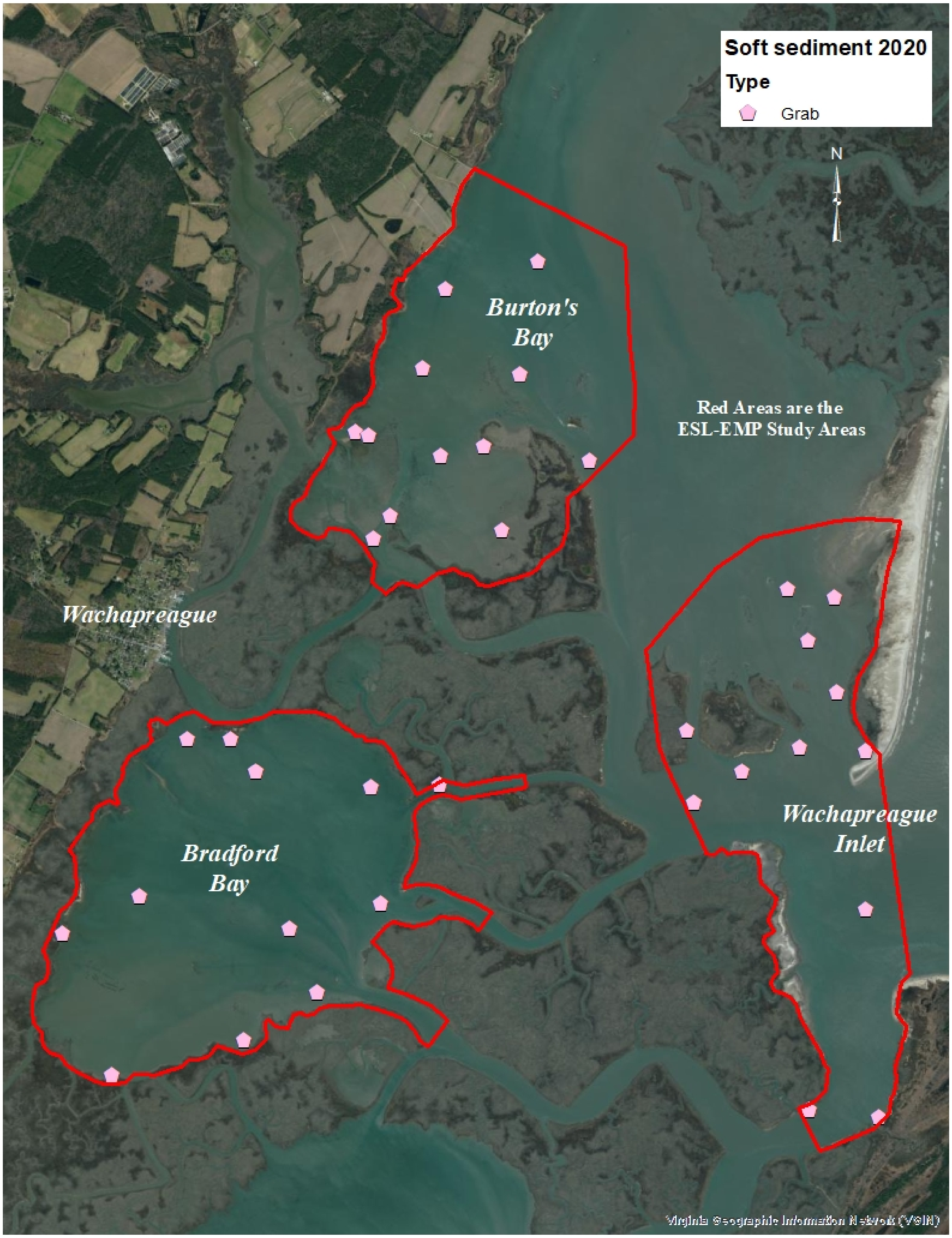

Fig. 5-1-2 Locations of 36 grab sample sites where organisms were collected near Wachapreague, VA in 2020 (red polygons denote the ESL-EMP study areas).

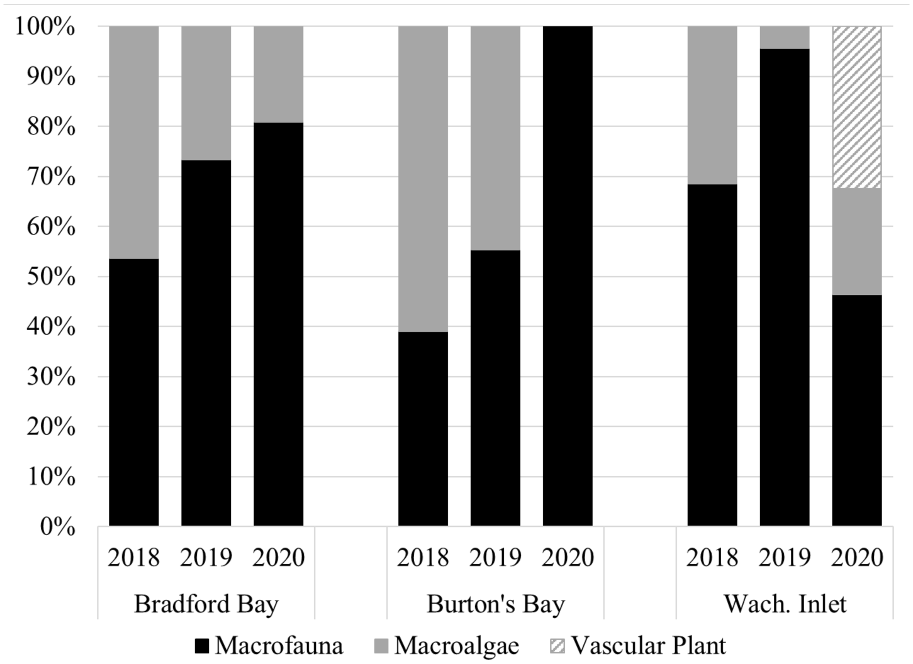

Fig. 5-1-3 Relative proportion (%) of the biomass (g m^{-2}) of macroalgae vs. macrofauna vs. vascular plants in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2020.

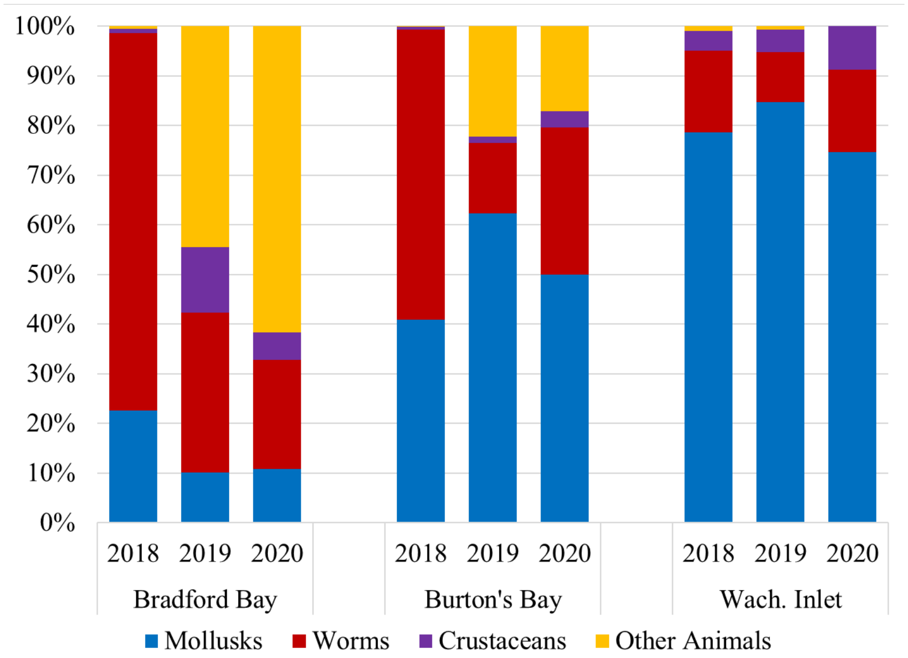

Fig. 5-1-4 Relative proportion (%) of the biomass (g m^{-2}) of macrofaunal broad taxa collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2020.

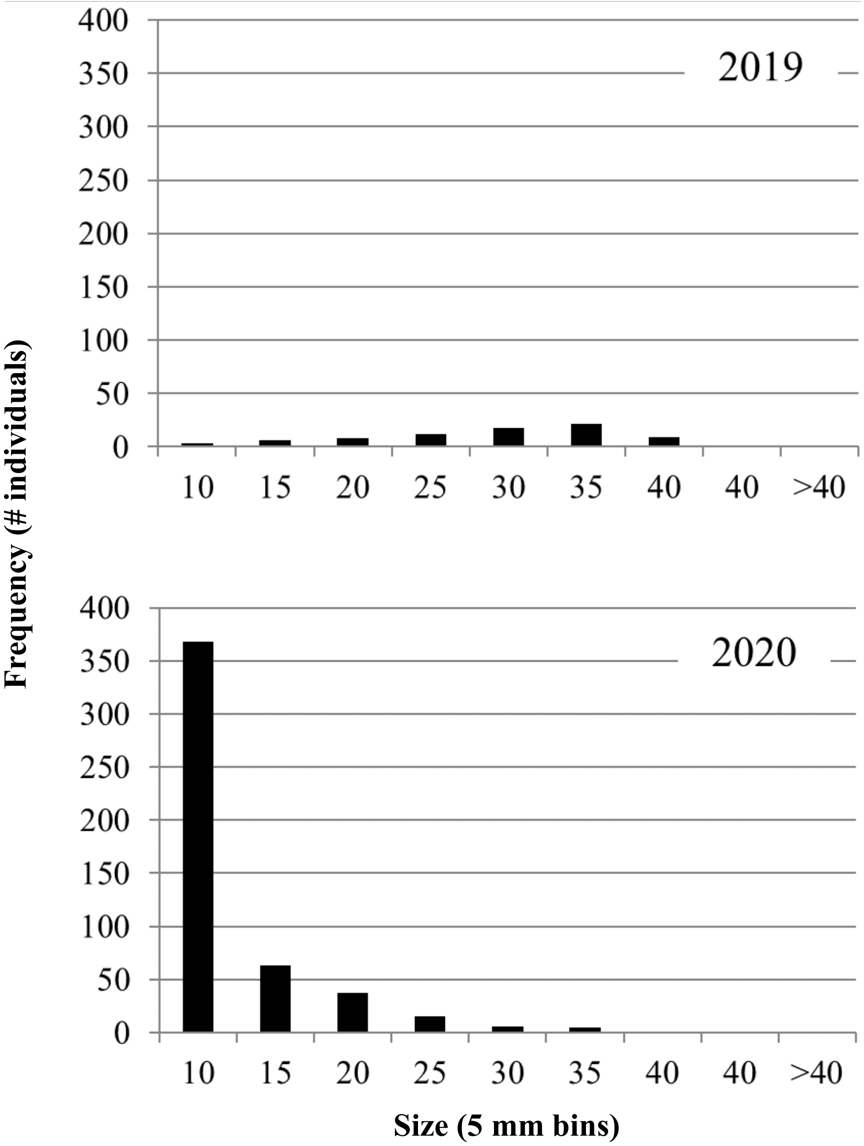

Fig. 5-1-5 Size frequency distribution (shell width, mm) of *Ensis leei* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2019 & 2020.

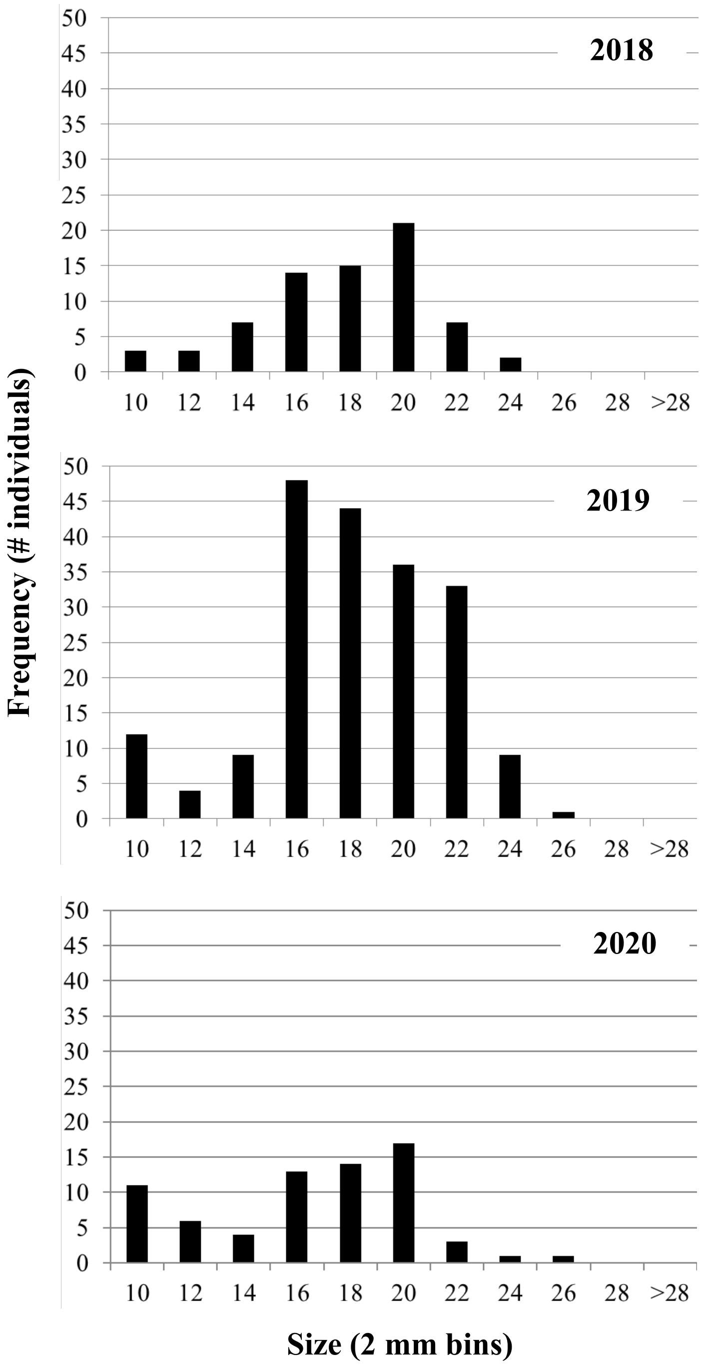

Fig. 5-1-6 Size frequency distribution (shell height, mm) of *Tritia obsoleta* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2020.

Chapter 5. Epi-benthic Community

Section 5-2: Hard Substrate Epi-benthic Community

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Complete	Planned	Planned

Introduction

Hard substrate in the form of intertidal oyster reefs and shell beds (shell hash to whole shells) are major ecological features of coastal Virginia (Ross & Luckenbach 2009). Eroding sand and wave action create deposits of old shells, while live oysters build new reefs. As a keystone and ecological engineering species, oysters and their shells provide critical hard substrate habitat in an otherwise soft and shifting sediment environment, supporting diverse and productive associated communities of micro and macro-organisms (Möbius, 1877; Knocker et al., 2006; Luckenbach et al. 2005; Bayne, 2017) and biochemical ecological services (Kellogg et al. 2014). As such, intertidal oyster reefs are extremely important habitats within the overall ecological landscape near ESL.

There are many aspects of an oyster reef that can be used to evaluate its health (Baggett et al. 2014). For this EMP we selected several representative reefs and shell beds to track the oyster population (see Chapter 4-2) and the associated epi-benthic community over space and time. Describing the macrofaunal communities and evaluating spatial and temporal trends are the metrics used to monitor the intertidal oyster reefs, and subtidal shell beds.

Study Area & Methods

We selected two intertidal patch reefs within each of the three EMP geographical areas to monitor (6 reefs total; Fig. 5-2-1). These were reefs that appear to be representative of other sites throughout the area. In 2020, we eliminated the 3 fringe reefs we had been previously monitoring (see Ross and Snyder, 2020). At each patch reef, two haphazard quadrat samples (25 cm x 25 cm; 0.0625 m^2) were collected to 15 cm deep (Fig. 5-2-2). One of these was located within the upper ½ of reef (crest) and one in the lower ½ of reef (flank). Reefs were sampled during June 15-23, 2020.

Additionally, we selected 1 subtidal shell bed in each geographic area (3 shell beds total; Fig. 5-2-1) and pulled a bottom dredge along 2 transects each to collect shell substrate and associated organisms (Fig. 5-2-2). Previously we had sampled 2 such patches in each region with one transect each. Based on the variability in the data from 2018 & 2019, in 2020 we decided to focus efforts on 1 shell bed with two transects in each region to better describe the communities. Length of dredge tows ranged from 49-61 m. Shell beds were sampled on June 9, 2020.

Upon collection in the field, both types of samples were transferred to 5-gallon buckets for transport to the lab, where they were processed within several hours of collection by rinsing on a 1 mm sieve with fresh water. Macrofauna & macroflora (both infaunal and epifaunal) retained on the 1 mm sieve were preserved either by freezing or immersion in 70% ethanol, depending on the nature of the samples, e.g. samples with large amounts of fine shell or marsh detritus that were not practical to preserve in ethanol were frozen. We have had positive experience with both techniques previously and samples were very well preserved until processing and specimen identification later in the year.

Samples were sorted using a stereo dissecting microscope and organisms were identified to the lowest practical taxonomic unit, typically to the species level. Organisms in each taxon were counted and, where appropriate, measured using taxa-specific dimensions (e.g. bivalves, snails, crabs etc.). The standard method for loss-on-ignition (LOI) was used to derive biomass. Individuals within each taxon from each sample were pooled and dried to a constant weight at 150° C (~48 hrs). Dry samples were then combusted at 500° C for 5 hours, allowed to cool and re-weighed. Ash-free dry weight was then determined by subtraction to estimate organic biomass.

2020 Results & Discussion

Detailed results for the oyster (*Crassostrea virginica*) population were reported in Chapter 4-2. Since old shell and live oysters serve as the "habitat" for their associated communities, we have focused on the non-oyster components of these communities in this section. Therefore, all totals and summaries below do not include oysters.

Intertidal oyster reefs (quadrat samples)

Data summarized here for 2018-2020 only include the quadrats collected at intertidal patch reefs (i.e. intertidal fringe reef samples from 2018 & 2019 have been dropped from the monitoring program and this analysis in the tables etc.). Therefore, these summary data from the previous 2 years will differ from those in the 2018-2019 report. In total, 2,029 individual organisms were sampled in 26 ~genera. Macroalgae comprised 57% of the biomass of organisms collected in these samples (Fig. 5-2-3). Overall, gastropods, bivalves, xanthid crabs, amphipods and polychaetes dominated in terms of macrofaunal abundance (Table 5-2-1), while mollusks (mainly bivalves) and crustaceans (mainly xanthid crabs) dominated in terms of macrofaunal biomass (Table 5-2-2 & Fig. 5-2-3). Apparent differences in the abundance and biomass of broad taxa were observed between the three geographic areas (Tables 5-2-3 thru 5-2-

6). When data was pooled for all three study areas, interannual densities at the genus level were variable, which some groups quite variable and other consistent (Table 5-2-7).

The intertidal oyster reef community (excluding oysters) was diverse and the overall Shannon-Diversity Index was 1.55 in 2020; ranging from 1.63 at the most dynamic Wachapreague Inlet site to 1.35 in the Burtons Bay area with the more stable inland site of Bradford Bay exhibiting intermediate diversity (Table 5-2-8).

For individuals >10 mm, species-specific standard measurements were made for bivalves, gastropods, barnacles, fish and crabs (Table 5-2-9). All individuals in the genus *Amphibalanus* were also measured. There were enough measurements for *Geukinsia demissa* and Xanthid mud crabs to develop annual size frequency distributions to get an idea of the population size/age structure (Figs. 5-2-4 & 5-2-5, respectively).

Subtidal shell beds (dredge)

In total, 894 individual organisms were sampled during 2020 representing ~41 genera. The relative proportion of macroalgae in samples was much reduced (Fig. 5-2-6). Crustaceans (mainly amphipods), polychaetes and ascidians dominated in terms of macrofaunal abundance (Table 5-2-10), while cnidarians (mainly coral or hydroids) and bivalves dominated in terms of biomass (Tables 5-2-11 & Fig. 5-2-6). Since there were limited samples from each region, we did not summarize data by geographic regions for purposes of this report.

The subtidal shell bed community was diverse and the overall Shannon-Diversity Index was 2.47 in 2020 (Table 5-2-13). Sizes for several groups were determined using species-specific standard measurements. There were enough measurements to report for *Anomia simplex*, *Chaetopleura apiculate*, *Diodora cayenensis* and *Amphibalanus eburneus* (Table 5-2-14).

The main objective for this portion of the EMP during 2020 was to continue to document which organisms were present and in what quantities and sizes. Comparing geographical areas and sub-habitats will be conducted in future years to address questions regarding spatial community structure and diversity, and temporal trends overall and at individual sites after multiple years of data are collected. We will also begin looking at any correlations between community composition and abiotic data described in other chapters (e.g. water quality and sediment characteristics).

Comparison to Previous Years

A cursory survey of the overall density of organisms (both in terms of abundance and biomass) reveals large differences from 2018-2020; mostly attributable large number of tiny snails (mainly *Boonea impressa*) as # m^{-2} and highly variable macroalgal biomass as g m^{-2} in 2020 samples (Table 5-2-1 and Table 5-2-2). There were noticeable interannual differences for some taxa (e.g. snails) while others remained very similar (e.g. Xanthid mud crabs; Tables 5-2-1 and 5-2-2).

For specific taxa, the high abundance of *Boonea impressa* in 2020 relative to 2018 & 2019 was a dramatic change (Table 5-1-4). *Boonea* density (# m^{-2}) increased 268% from 2018 to 2019 and another 741% from 2019 to 2020. Spatial or temporal natural population stochasticity might explain this change, although we cannot rule out a persistent ecological shift. The strategy of the EMP is to collect the long-term data to resolve such processes.

Interestingly, macrofaunal diversity was similar in 2018 & 2019 but decreased in 2020 (Table 5-2-8). However, this is directly a result of large numbers of Boonea; the index used, in essence, measures the relative spread of individuals in various taxa. Having few taxa or taxa that dominate the community lead to lower diversity indices. With only 3 years of data to examine trends and annual differences, we plan to accumulate an additional year of data prior to more in-depth statistical analysis.

2020 Acknowledgements

We would like to thank Edward Smith and Sean Fate for field and lab processing assistance.

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Table 5-2-1. Summary of the non-oyster total density (# m^{-2}) of broad taxa collected in quadrat samples on intertidal oyster reefs near Wachapreague, VA during summers 2018-2020. A "+" indicates presence of a taxon, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa		*1,166.7*	*1,669.3*	*2,705.3*
Macroalgae				
Seaweeds	Macroalgae	+	+	+
Mollusks				
Clams	Bivalvia	209.3	197.3	292.0
Snails	Gastropoda (snails)	54.7	192.0	1,572.0
Slipper shells	Gastropoda (slipper shells)	1.3		
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	457.3	281.3	341.3
Amphipods	Amphipoda	220.0	768.0	302.7
Shrimp	Pleocyemata (Caridea)	4.0		
Isopods	Isopoda	6.7	6.7	2.7
Pea crabs	Brachyura (Pinnotheridae)		2.7	2.7
Barnacles	Balanidae	32.0		20.0
Spider Crabs	Pleocyemata (Varunidae)			1.3
Worms				
Polychaete worms	Polychaeta	129.3	210.7	146.7
Other Animals				
Anemones	Cnidaria (Actinaria)	34.7	6.7	20.0
Hydroids	Cnidaria (Hydrozoa)			+
Sponges	Porifera	+		
Bony Fish	Osteichthyes		1.3	
Sea Squirts	Ascidiacea	1.3	1.3	
Beetle Larvae	Coleoptera	9.3	1.3	
Springtails	Collembola	6.7		2.7
Fly Larvae	Diptera			1.3

Table 5-2-2. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in quadrat samples on intertidal oyster reefs near Wachapreague, VA during summers 2018-2020. A "+" indicates presence of a taxon, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa		*60.3520*	*134.3088*	*171.1425*
Macroalgae				
Seaweeds	Macroalgae	16.1752	68.4069	98.0088
Mollusks				
Clams	Bivalvia	23.4732	50.4723	56.3177
Snails	Gastropoda (snails)	0.0092	0.3142	0.7299
Slipper shells	Gastropoda (slipper shells)	0.0025		
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	18.1020	11.2576	14.2657
Amphipods	Amphipoda	0.0501	0.2680	0.1175
Shrimp	Pleocyemata (Caridea)	0.0187		
Isopods	Isopoda	0.0012	0.0016	0.0007
Pea crabs	Brachyura (Pinnotheridae)		0.0417	0.0004
Barnacles	Balanidae	+		+
Spider Crabs	Pleocyemata (Varunidae)			0.0220
Worms				
Polychaete worms	Polychaeta	2.2099	3.3736	1.5807
Other Animals				
Anemones	Cnidaria (Actinaria)	0.1685	0.0297	0.0825
Hydroids	Cnidaria (Hydrozoa)			0.0137
Sponges	Porifera	0.1413		
Bony Fish	Osteichthyes		0.1392	
Sea Squirts	Ascidiacea	<0.0001	0.0039	
Beetle Larvae	Coleoptera	<0.0001	<0.0001	
Springtails	Collembola	0.0001		0.0001
Fly Larvae	Diptera			0.0028

Table 5-2-3. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in quadrat samples on intertidal oyster reefs in 3 regions near Wachapreague, VA during summers 2018-2020. A "+" indicates presence of a taxon, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Representative Taxonomic Grouping	**Geographic Area**	**2018**	**2019**	**2020**
All Taxa Combined	*Mean All 3 Areas*	*60.3520*	*134.3088*	*171.1425*
All Taxa Combined	Bradford Bay	22.2060	81.6780	92.7024
	Burton's Bay	23.6176	119.6126	40.8788
	Wach. Inlet	135.2324	201.6358	379.8464
Macroalgae (Seaweeds)	Bradford Bay		0.0120	
	Burton's Bay		37.9544	2.3556
	Wach. Inlet	48.5256	167.2544	291.6708
Mollusks (Snails, clams, etc.)	Bradford Bay	4.0212	56.3436	81.7728
	Burton's Bay	13.8768	72.4158	19.3288
	Wach. Inlet	52.5568	23.6002	70.0412
Crustaceans (Crabs, shrimp, amphipods etc.)	Bradford Bay	15.9268	20.7820	9.1460
	Burton's Bay	6.6548	7.3212	18.1512
	Wach. Inlet	31.9376	6.6036	15.9216
Worms	Bradford Bay	1.7368	4.5404	1.7272
	Burton's Bay	2.8520	1.9212	1.0428
	Wach. Inlet	2.0408	3.6592	1.9720
Other Animals (Fish, echinoderms, anenomes etc.)	Bradford Bay	0.5212		0.0564
	Burton's Bay	0.2340		0.0004
	Wach. Inlet	0.1748	0.5184	0.2408

Table 5-2-4. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in quadrat samples (n=4) on 2 intertidal oyster reefs in the Bradford Bay study area near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa				
Macroalgae				
Seaweeds	Macroalgae		0.0120	
Mollusks				
Clams	Bivalvia	4.0068	56.2612	81.0568
Snails	Gastropoda (snails)	0.0068	0.0824	0.7160
Slipper shells	Gastropoda (slipper shells)	0.0076		
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	15.8228	20.3980	9.0592
Amphipods	Amphipoda	0.0480	0.3840	0.0868
Shrimp	Pleocyemata (Caridea)	0.0560		
Isopods	Isopoda			
Pea crabs	Brachyura (Pinnotheridae)			
Barnacles	Balanidae	+		+
Hemigrapsus Crab	Pleocyemata (Varunidae)			
Worms				
Polychaete worms	Polychaeta	1.7368	4.5404	1.7272
Other Animals				
Anemones	Cnidaria (Actinaria)	0.0972		0.0480
Hydroids	Cnidaria (Hydrozoa)			
Sponges	Porifera	0.4240		
Bony Fish	Osteichthyes			
Sea Squirts	Ascidiacea			
Beetle Larvae	Coleoptera			
Springtails	Collembola			
Fly Larvae	Diptera			0.0084

Table 5-2-5. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in quadrat samples (n=4) on 2 intertidal oyster reefs in the Burton's Bay study area near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa				
Macroalgae				
Seaweeds	Macroalgae		37.9544	2.3556
Mollusks				
Clams	Bivalvia	13.8624	72.1750	18.7680
Snails	Gastropoda (snails)	0.0144	0.2408	0.5608
Slipper shells	Gastropoda (slipper shells)			
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	6.6320	7.0108	18.0488
Amphipods	Amphipoda	0.0192	0.3056	0.1004
Shrimp	Pleocyemata (Caridea)			
Isopods	Isopoda	0.0036	0.0048	0.0020
Pea crabs	Brachyura (Pinnotheridae)			
Barnacles	Balanidae			+
Hemigrapsus Crab	Pleocyemata (Varunidae)			
Worms				
Polychaete worms	Polychaeta	2.8520	1.9212	1.0428
Other Animals				
Anemones	Cnidaria (Actinaria)	0.2336		
Hydroids				
Sponges	Porifera			
Bony Fish	Osteichthyes			
Sea Squirts	Ascidiacea	<0.0001		
Beetle Larvae	Coleoptera	<0.0001		
Springtails	Collembola	0.0004		0.0004
Fly Larvae	Diptera			

Table 5-2-6. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in quadrat samples (n=4) on 2 intertidal oyster reefs in the Wachapreague Inlet study area near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa				
Macroalgae				
Seaweeds	Macroalgae	48.5256	167.2544	291.6708
Mollusks				
Clams	Bivalvia	52.5504	22.9808	69.1284
Snails	Gastropoda (snails)	0.0064	0.6194	0.9128
Slipper shells	Gastropoda (slipper shells)			
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	31.8512	6.3640	15.6892
Amphipods	Amphipoda	0.0832	0.1144	0.1652
Shrimp	Pleocyemata (Caridea)			
Isopods	Isopoda			
Pea crabs	Brachyura (Pinnotheridae)	0.0032	0.1252	0.0012
Barnacles	Balanidae	+		+
Hemigrapsus Crab	Pleocyemata (Varunidae)			0.0660
Worms				
Polychaete worms	Polychaeta	2.0408	3.6592	1.9720
Other Animals				
Anemones	Cnidaria (Actinaria)	0.1748	0.0892	0.1996
Hydroids	Cnidaria (Hydrozoa)			0.0412
Sponges	Porifera			
Bony Fish	Osteichthyes		0.4176	
Sea Squirts	Ascidiacea		0.0116	
Beetle Larvae	Coleoptera		<0.0001	
Springtails	Collembola			
Fly Larvae	Diptera			

Table 5-2-7. Summary of the total individual density (# m^{-2}) of genera collected in intertidal oyster reef samples (quadrates; n=12) pooled for three study areas near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where counting is impractical, and a blank cell indicates the absence of that taxon.

	# m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**
Amphipoda	220.0	768.0	302.7
Ampithoe	218.7	573.3	
Corophium		5.3	1.3
Gammarus	1.3	14.7	24.0
Melita		174.7	245.3
Microdeutopus			32.0
Ascidiacea	1.3	1.3	
Molgula	1.3	1.3	
Balanidae	32.0		20.0
Amphibalanus	32.0		20.0
Bivalvia	209.3	197.3	292.0
Anomia	1.3		
Gemma	1.3		
Geukensia	202.7	189.3	221.3
Limecola		1.3	
Mercenaria	2.7	4.0	
Mytilus	1.3	2.7	69.3
Petricolaria			1.3
Brachyura (Pinnotheridae)		2.7	2.7
Pinnixa			2.7
Rathbunixa		2.7	
Cnidaria (Actinaria)	34.7	6.7	20.0
Diadumene	34.7	6.7	20.0
Cnidaria (Hydrozoa)			+
Unidentified hydroid			+
Coleoptera	9.3	1.3	
Coleoptera	9.3	1.3	
Collembola	6.7		2.7
Anurida	6.7		2.7
Diptera			1.3
Diptera			1.3
Gastropoda (slipper shells)	1.3		
Crepidula	1.3		

Table continued on next page

Table 5-2-7 (continued)

	# m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**
Gastropoda (snails)	54.7	192.0	1,572.0
Astyris		1.3	
Boonea	50.7	186.7	1,570.7
Costoanachis		1.3	1.3
Eupleura	4.0		
Tritia		2.7	
Isopoda	6.7	6.7	2.7
Cassidinidea	6.7	6.7	2.7
Macroalgae	+	+	+
Fucus	+	+	+
Gracilaria			+
Ulva		+	+
Osteichthyes		1.3	
Gobiosoma		1.3	
Pleocyemata (Caridea)	4.0		
Alpheus	4.0		
Pleocyemata (Varunidae)			1.3
Hemigrapsus			1.3
Pleocyemata (Xanthidae)	457.3	281.3	341.3
Eurypanopeus	425.3	240.0	314.7
Panopeus	25.3	37.3	26.7
Unidentified Xanthidae	6.7	4.0	
Polychaeta	129.3	210.7	146.7
Alitta	68.0	165.3	106.7
Amphitrite			4.0
Arabella	1.3		
Capitellidae			8.0
Cirratulus	9.3	2.7	4.0
Cirriformia		5.3	
Clymenella		1.3	
Drilonereis	2.7	1.3	2.7
Glycera	1.3	1.3	
Hydroides			1.3
Hypereteone	4.0		
Lepidametria	1.3		

Table continued on next page

Table 5-2-7 (continued)

Taxon (~Genus)	# m^{-2} 2018	2019	2020
Polychaeta (cont.)			
Marphysa	41.3	30.7	17.3
Sabellaria			2.7
Terebellidae		2.7	
Unidentified polychaete		+	+
Porifera	+		
Halichondria	+		

Table 5-2-8. Summary of several community metrics (based on density of individual organisms, # m^{-2}) of taxa (basically at the level of genus) collected in intertidal oyster patch reef samples (quadrates; n=12) pooled for three study areas near Wachapreague, VA during summer 2018-2020. This community data does not include oysters.

Community Metric	Geographic Area	2018	2019	2020
Abundance (# m^{-2})	Bradford Bay	1,020	2,320	2,284
	Burton's Bay	1,160	1,640	2,280
	Wach. Inlet	1,320	1,048	3,552
	Overall	*1,167*	*1,669*	*2,705*
Taxa Richness	Bradford Bay	16	13	12
	Burton's Bay	19	15	17
	Wach. Inlet	13	25	26
	Overall	*28*	*28*	*26*
Shannon Diversity Index (H')	Bradford Bay	1.91	1.89	1.39
	Burton's Bay	1.94	1.75	1.35
	Wach. Inlet	1.70	2.28	1.63
	Overall	*2.01*	*2.01*	*1.55*

Table 5-2-9. Summary of sizes (mm using species-specific standard measurements) of species that were measured from samples collected in quadrat samples on intertidal oyster patch reefs near Wachapreague, VA during 2018-2020. Empty cells indicate an absence of large enough individuals to measure of that species during a given year. Generally, only individuals ≥10 mm were measured*.

	2018				**2019**				**2020**			
	# < 10 mm	**# ≥ 10 mm***	**Range (mm)**	**Avg (mm)**	**# < 10 mm**	**# ≥ 10 mm***	**Range (mm)**	**Avg (mm)**	**# < 10 mm**	**# ≥ 10 mm***	**Range (mm)**	**Avg (mm)**
Balanidae												
Amphibalanus eburneus	n/a*	42	2-14	6.1					n/a*	15	5-16	11.0
Bivalvia (non-Crassostrea)												
Geukensia demissa	30	122	10-106	37.1	16	123	10-86	38.7	15	149	10-82	35.8
Mercenaria mercenaria	4	1	11-11	11.0	3	4	47-70	56.8				
Mytilus edulis									45	7	10-16	11.0
Gastropoda (snails)												
Tritia obsoleta	23	8	11-22	16.0		13	11-24	15.7				
Osteichthyes												
Gobiosoma bosc						1	45-45	45.0				
Pleocyemata (Varunidae)												
Hemigrapsus sanguineus										1	7-7	7.0
Pleocyemata (Xanthidae)	284	73	10-34	13.3	149	86	10-33	11.5	186	65	10-34	12.5

* Snails, xanthid mud crabs and most bivalve species were only measured if ≥10 mm, but *Amphibalanus* was an exception

Table 5-2-10. Summary of the non-oyster total density (# m^{-2}) of broad taxa collected in dredge samples on subtidal shell beds (n=3) near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa		***5.714***	***1.835***	***3.835***
Cnidarians				
Coral	Cnidaria (Scleractinia)	+	+	+
Anemones	Cnidaria (Actinaria)	0.300	0.536	0.039
Hydroids	Cnidaria (Hydrozoa)	+	+	+
Mollusks				
Clams/Mussels	Bivalvia	1.019	0.367	0.026
Limpets	Gastropoda (limpets)	0.190	0.089	
Chitons	Polyplacophora	0.100	0.030	0.013
Snails	Gastropoda (snails)	0.170	0.010	0.043
Slipper shells	Gastropoda (slipper shells)	0.240	0.069	0.120
Nudibranchs	Gastropoda (nudibranchs)	0.260		0.004
Macroalgae				
Seaweeds	Macroalgae	+	+	+
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	0.400	0.010	0.090
Hermit Crabs	Paguridae			0.004
Shrimp	Pleocyemata (Caridea)	0.010		
Spider Crabs	Brachyura (Epialtidae)			0.004
Barnacles	Balanidae			0.382
Amphipods	Amphipoda	2.108	0.367	2.261
Isopods	Isopoda			0.004
Worms				
Polychaete worms	Polychaeta	0.799	0.238	0.438
Ascidians				
Sea squirts	Ascidiacea	0.030	0.050	0.296
Other Animals				
Sea spiders	Pycnogonida (sea spider)	0.060	0.010	0.107
Bony Fish	Osteichthyes	0.010		
Bryozoans	Bryozoa	+	+	
Sponges	Porifera			+

Table 5-2-11. Summary of the non-oyster total biomass (ash-free dry wt., g m^{-2}) of broad taxa collected in dredge samples on subtidal shell beds (n=3) near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019	2020
All Taxa		***0.2630***	***0.2041***	***0.2332***
Cnidarians				
Coral	Cnidaria (Scleractinia)	0.1667	0.0210	0.0661
Anemones	Cnidaria (Actinaria)	0.0015	0.0020	0.0001
Hydroids	Cnidaria (Hydrozoa)	0.0004	0.0159	0.0095
Mollusks				
Clams/Mussels	Bivalvia	0.0295	0.0581	0.0758
Limpets	Gastropoda (limpets)	0.0161	0.0090	
Chitons	Polyplacophora	0.0093	0.0015	0.0008
Snails	Gastropoda (snails)	0.0001	<0.0001	0.0004
Slipper shells	Gastropoda (slipper shells)	0.0004	0.0007	0.0104
Nudibranchs	Gastropoda (nudibranchs)	0.0001		0.0001
Macroalgae				
Seaweeds	Macroalgae	0.0320	0.0737	0.0008
Crustaceans				
Mud Crabs	Pleocyemata (Xanthidae)	0.0015	0.0001	0.0051
Hermit Crabs	Paguridae			0.0002
Shrimp	Pleocyemata (Caridea)	0.0010		
Spider Crabs	Brachyura (Epialtidae)			0.0025
Barnacles	Balanidae			0.0025
Amphipods	Amphipoda	0.0004	<0.0001	0.0002
Isopods	Isopoda			<0.0001
Worms				
Polychaete worms	Polychaeta	0.0029	0.0017	0.0005
Ascidians				
Sea squirts	Ascidiacea	<0.0001	0.0029	0.0005
Other Animals				
Sea spiders	Pycnogonida (sea spider)	<0.0001	<0.0001	<0.0001
Bony Fish	Osteichthyes	0.0001		
Bryozoans	Bryozoa	0.0008	0.0016	
Sponges	Porifera			0.0364

Table 5-2-12. Summary of the density (# m^{-2}) of genera of collected in dredge samples on subtidal shell beds (n=3) near Wachapreague, VA during summer 2018-2020. A "+" indicates presence of a taxon, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

	# m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**
All Taxa	*5.714*	*1.835*	*3.835*
Amphipoda	2.108	0.367	2.261
Ampelisca	0.050	0.060	0.112
Ampithoe	0.060	0.030	
Batea		0.010	
Caprella		0.030	0.463
Corophium	0.539	0.060	0.064
Ericthonium			0.193
Gammarus	0.779	0.030	0.107
Melita		0.099	0.047
Microdeutopus			0.073
Paracaprella	0.679	0.050	1.201
Ascidiacea	0.030	0.050	0.296
Ecteinascidia			0.296
Molgula	0.030	0.020	
Styela		0.030	
Balanidae			0.382
Amphibalanus			0.382
Bivalvia (Crassostrea)		0.060	0.004
Crassostrea		0.060	0.004
Bivalvia	1.019	0.367	0.026
Anadara	0.330	0.040	0.004
Anomia	0.609	0.327	0.009
Mercenaria	0.020		0.009
Mytilus			0.004
Noetia	0.040		
Petricolaria	0.010		
Tagelus	0.010		
Brachyura (Epialtidae)			0.004
Libinia			0.004
Bryozoa	+	+	
Bugula	+	+	

Table 5-2-12 (continued)

	# m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**
Cnidaria (Actinaria)	0.300	0.536	0.039
Diadumene	0.260	0.536	0.039
Exaiptasia	0.030		
Unknown sea anenome	0.010		
Cnidaria (Hydrozoa)	+	+	+
Bougainvillia		+	
Unknown hydroid	+		+
Cnidaria (Scleractinia)	+	+	+
Astrangia	+	+	+
Gastropoda (limpets)	0.190	0.089	
Diodora	0.190	0.089	
Gastropoda (nudibranchs)	0.260		0.004
Cariopsilla	0.190		0.004
Corambe	0.070		
Gastropoda (slipper shells)	0.240	0.069	0.120
Crepidula	0.240	0.069	0.120
Gastropoda (snails)	0.170	0.010	0.043
Astyris	0.080		0.013
Costoanachis			0.004
Nucella			0.004
Seila	0.090	0.010	0.021
Isopoda			0.004
Edotea			0.004
Macroalgae	+	+	+
Agardhiella			+
Ceramium		+	+
Codium		+	
Ectocarpus		+	
Fucus	+		+
Gracilaria	+		
Porphyra		+	
Ulva	+	+	
Malacostraca (Mysida)	0.020		
Unknown Mysid	0.020		
Osteichthyes	0.010		
Gobiosoma	0.010		
Paguridae			0.004
Pagurus			0.004

Table 5-2-12 (continued)

	# m^{-2}		
Taxon (~Genus)	**2018**	**2019**	**2020**
Pleocyemata (Caridea)	0.010		
Alpheus	0.010		
Pleocyemata (Xanthidae)	0.400	0.010	0.090
Dyspanopeus			0.004
Eurypanopeus	0.400		0.021
Panopeus		0.010	0.064
Polychaeta	0.799	0.238	0.438
Alitta	0.020	0.010	0.013
Amphitrite		0.010	
Drilonereis	0.010		0.026
Lepidonotus	0.470	0.060	0.339
Lumbrineris		0.010	
Marphysa	0.280	0.109	0.013
Ninoe		0.030	
Pectinaria		0.010	
Sabellaria	0.020		0.043
Terebellidae			0.004
Unknown polychaete			
Polyplacophora	0.100	0.030	0.013
Chaetopleura	0.100	0.030	0.013
Porifera			+
Cliona			+
Pycnogonida (sea spider)	0.060	0.010	0.107
Callipallene			0.004
Tanystylum	0.060	0.010	0.103

Table 5-2-13. Summary of several community metrics (based on density of individual organisms, # m^{-2}) of taxa (basically at the level of genus) collected in dredge samples on subtidal shell beds (n=3) near Wachapreague, VA during summer 2018-2020.

Community Metric	2018	2019	2020
Abundance (# m^{-2})	5.7	1.8	3.8
Taxa Richness	37	34	41
Shannon Diversity Index (H')	2.81	2.56	2.47

Table 5-2-14. Summary of sizes (mm using species-specific standard measurements) of several species that were measured from samples collected in dredge samples on subtidal shell beds near Wachapreague, VA during 2019-2020.

	2019			**2020**		
	#	**Range (mm)**	**Avg (mm)**	**#**	**Range (mm)**	**Avg (mm)**
Bivalvia (non-Crassostrea)						
Anomia simplex	33	25-43	35.2	2	36-49	42.5
Polyplacophora						
Chaetopleura apiculata	3	6-24	13.3	6	1-23	11.0
Gastropoda (limpets)						
Diodora cayenensis	9	6-30	17.4			
Balanidae						
Amphibalanus eburneus				89	2-11	6.2

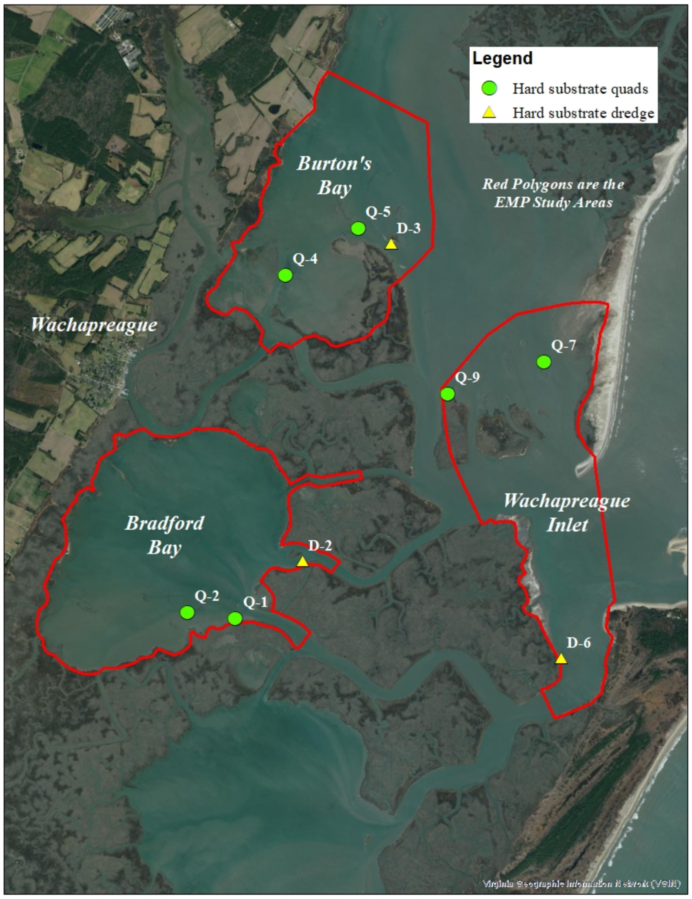

Fig. 5-2-1 Locations of 6 intertidal oyster reef (green circles) and 3 subtidal shell bed (yellow triangles) monitoring sites near Wachapreague, VA for 2020 (red polygons denote the ESL-EMP study areas).

Fig. 5-2-2 Sampling intertidal oyster reef monitoring sites via quadrats (left) and the dredge used to sample subtidal shell beds (right).

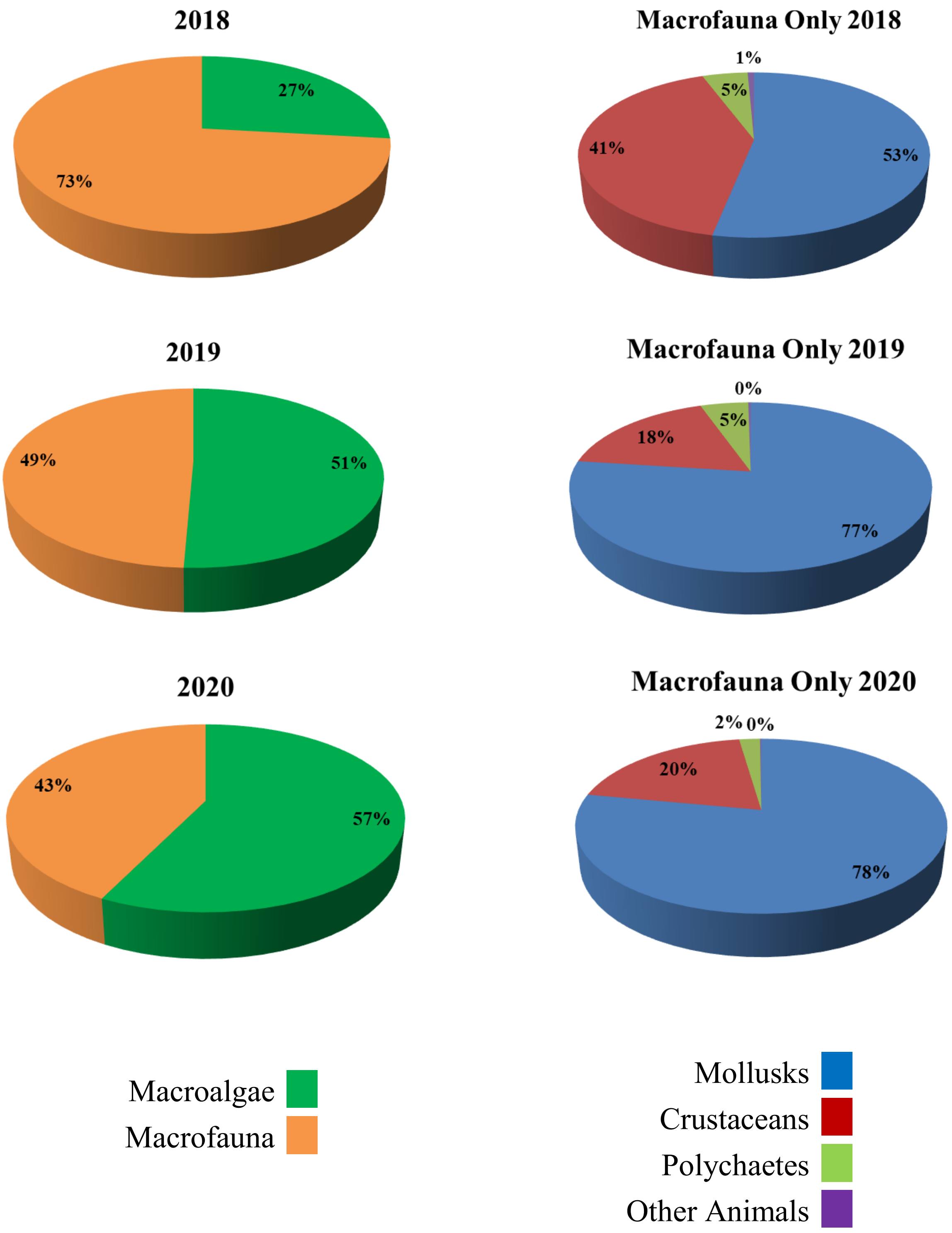

Fig. 5-2-3 Relative proportion (%) of the biomass (g m^{-2}) of various non-oyster taxa collected in intertidal oyster reef quadrat samples near Wachapreague, VA during summer 2018-2020.

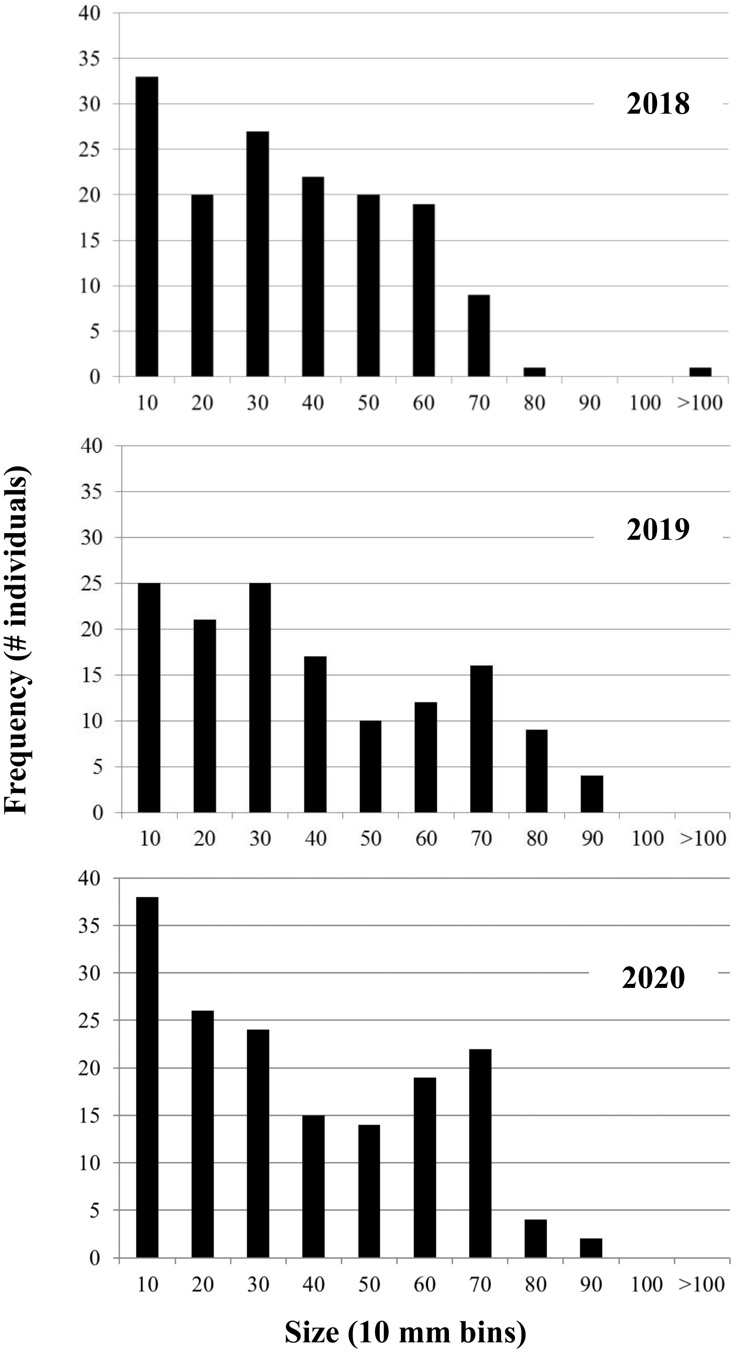

Fig. 5-2-4 Size frequency distribution (shell height, mm) of *Geukinsia demissa* collected in quadrat samples on intertidal oyster patch reefs in 3 regions near Wachapreague, VA during summer 2018-2020

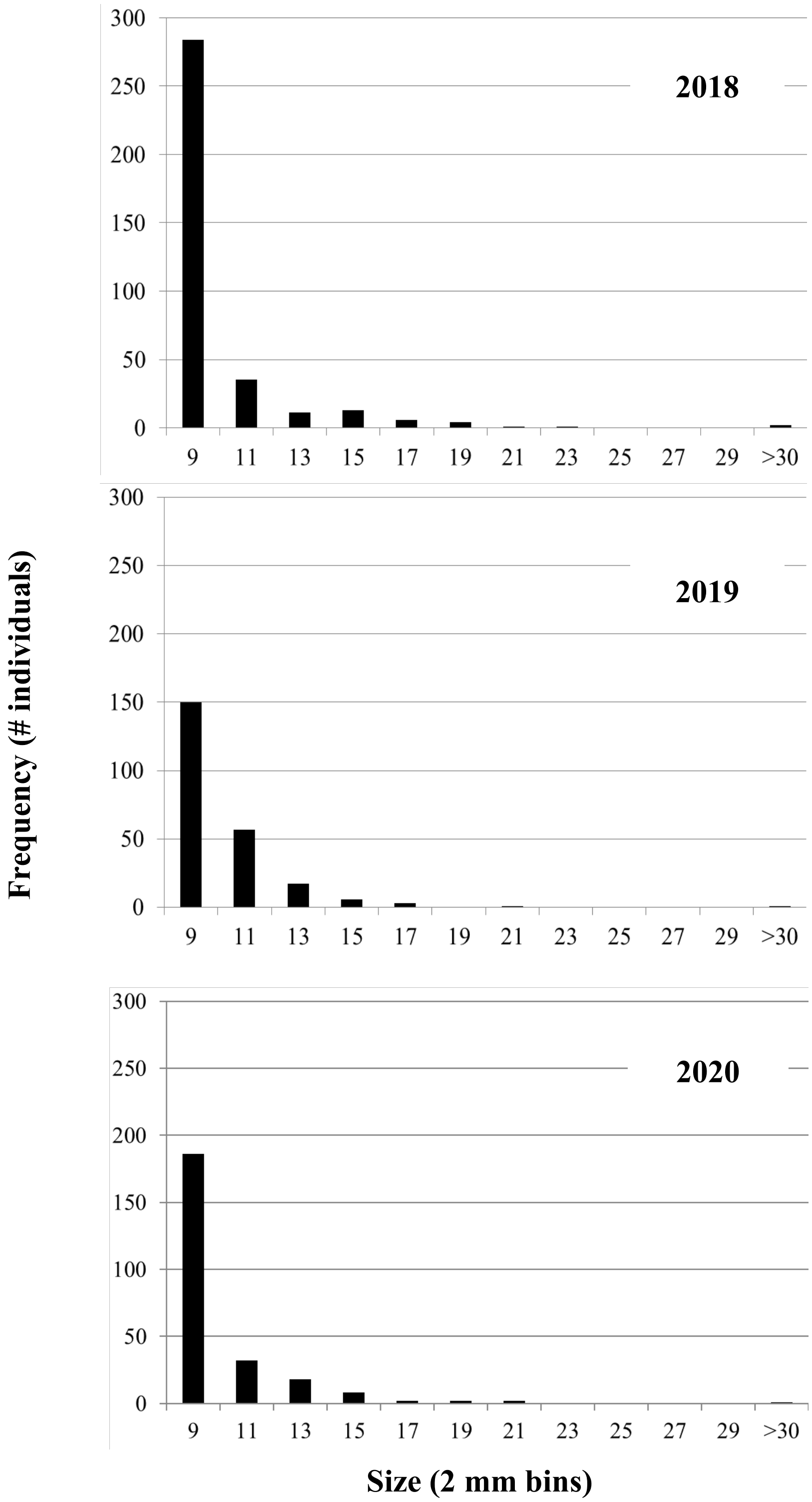

Fig. 5-2-5 Size frequency distribution (carapace width, mm) of mud crabs (*Xanthidae*) collected in quadrat samples on intertidal oyster patch reefs in 3 regions near Wachapreague, VA during summer 2018-2020.

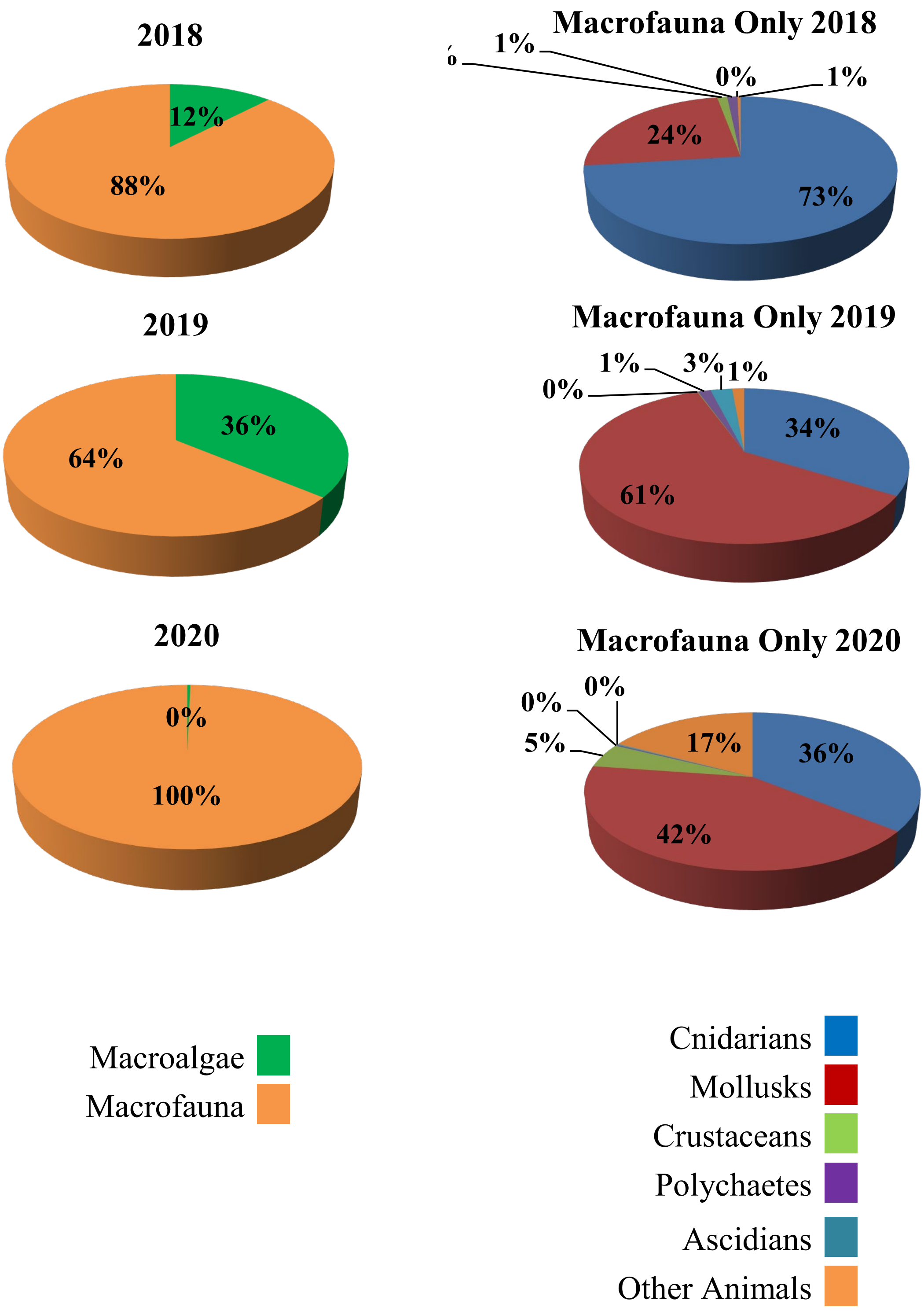

Fig. 5-2-6 Relative proportion (%) of the biomass (g m^{-2}) of various non-oyster taxa collected in subtidal shell bed dredge samples near Wachapreague, VA during summer 2018-2020.

Chapter 6. Mapping Coastal Change

Section 6-1: Wachaprague Inlet Vicinity Shoreline Mapping

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Partial	Complete		Planned

Introduction

Oceanic coastal areas are some of the most dynamic habitats in the world. Rapid changes have been and are forecast to continue to significantly impact the mid-Atlantic region in coming decades (C. Hein, personal communication; see Colgan et al. 2018). Some of the geomorphological changes are manifest from low volume yet mostly continuous sand movements, while storm events can precipitate large scale changes in relatively short time spans. We are currently in a period of fairly rapid change that affects the coastal environment of Virginia. Sea level rise and upstream coastal sand dynamics are contributing components, but other complex factors, such as underlying geology, are likely influential as well (Carletta et al., 2019; Hein et al., 2019; Shawler et al., 2019; Raff et al., 2018). Excellent interactive data on East Coast sea level rise can be found on the VIMS website, specifically the Norfolk "Sea-level Report Card" (https://www.vims.edu/research/products/slrc/localities/nova/index.php) and the NOAA sea level rise interactive web page (https://coast.noaa.gov/slr/#/layer/slr). Google Earth Time Lapse (Earth Engine: https://earthengine.google.com/timelapse/) images have documented the dynamics of the shoreline over time at satellite image scale.

Coastal change is manifest at many scales, but large-scale shoreline changes are often the most broadly noticeable. This is certainly the recent case in the Wachapreague Inlet vicinity. This area has been historically stable, and is thought to be the remains of a Susquehanna River Paleochannel (McFarland and Beach, 2019), although all such areas are inherently dynamic at some level (DeAlteris and Byrne 1975). Aerial images from the Virginia Base Mapping Program (VBMP) have documented changes on 5 to 7-year intervals and the movements of Cedar Island and the other coastal areas in recent years have been significant. Given the recent rapid changes, we plan to document biennial shoreline movement in the interim periods between VBMP image collection years. The next VBMP imaging effort for this region should be around 2021-2022. We also would provide data from drone surveillance at finer scale than what is available from the satellite remote sensing.

Study Area & Methods

The area of interest generally defines Wachapreague Inlet but also includes nearby back bay marsh areas. For 2020, the data cover the southern portion of Cedar Island and the east portion of Clubhouse Marsh (Fig. 6-1-1). The marsh islands in the vicinity of the Wye and Thorofare channels were also imaged, but a >2 m georeferencing problem prevented us from including those data for this report. We can provide those images upon request.

Two sources of aerial images were used to map marsh and shoreline edge (Table 6-1-1). VBMP images were downloaded from their server for comparison to our data. Background information for VBMP data can be accessed online (https://www.vita.virginia.gov/integrated-services/vgin-geospatial-services/orthoimagery/). In-house drone images were collected with a Zenmuse X3 visible wavelength camera on a DJI Matrice 100 quadcopter drone platform (Fig. 6-1-2). Drone collected images were geotagged with the on-board GPS. Table 5-1-1 gives some technical parameters for image acquisition by year.

Georeferenced images from both sources were brought into ArcGIS (ESRI, 2020). We manually digitized approximate neap high tide shoreline edges. This workflow creates shoreline maps with approximately 1-2 m accuracy. This error level was acceptable for our mapping objectives to document relatively substantial shoreline changes over time. We did not utilize ground control points in 2018 or 2020, but plan to do so in 2022 surveys to improve accuracy. We also plan to map natural landmarks with sub-meter accuracy GPS in 2021 to use as ground control points to retroactively adjust 2018 and 2020 imagery for future analyses.

2020 Results & Discussion

Drone surveys collected 671 images (120 m altitude; 70% overlap) that were stitched together and developed into high resolution, georeferenced orthomosaics using Pix4D software. This resulted in a survey of ~150 hectares of island/marsh which encompassed about 8,212 m of shoreline (Fig. 6-1-3).

The shoreline changes in the vicinity of Wachapreague Inlet are visually stunning. It is also apparent that changes to the inlet proper via barrier island dynamics are impacting marsh areas in the adjacent coastal lagoon system by increased energy exposure and barrier island washovers. It is likely that other, less easily observable, components of the ecosystem are also being affected. By developing the EMP with a stratified sampling design (see Chap.1 of this report), we hope to further elucidate these impacts. Short term variance makes it impossible to determine rates of change. Longer term data will provide the averaging necessary to delineate real trends emerging from the interannual variation in geomorphological processes. These data will be available to researchers for incorporation into geomorphological analyses providing context and value added to grant funding for such work.

Comparison to Previous Years

Mapping reveals that substantial changes already evident during 2009-2017 (period before implementation of this EMP) are continuing into 2020 for this area (Fig. 6-1-4). Over the first period of 8 years (2009-2017), drastic changes were seen for southern Cedar Island and the eastern face of Clubhouse Marsh (Figs. 6-1-5 & 6-1-6, respectively). The sand spit at the southern terminus of Cedar Island lost approximately 1,500 m resulting in Wachapreague Inlet widening from 475 m to 1,900 m. Note that the deep main inlet channel has generally remained in place and the ex-island portion of the inlet is relatively shallow (1-2 m deep at low tide); bisected by several small and slightly deeper channels. During this same period, as much as 115 m of marsh shoreline was lost immediately inside the inlet. From March 2017 to September 2020, losses generally continued in the marsh regions and along the eastern beach face of Cedar Island, although the spit on the southern tip of the island accreted to over double the 2017 size (Figs. 6-1-5 & 6-1-6). Although loss occurred to all the marsh edges surveyed, the magnitude of the change diminished with increasing distance away from the inlet proper.

In addition to simple visualization, we picked 30 representative sentinel points to estimate shoreline retreat over time (Fig. 6-1-7). In 2020, we were only able to quantify 14 of these locations (see Ross and Snyder 2020 for data for all 30 sites during 2009-2018). Aside from the major changes of Cedar Island, shoreline combined loss during the entire 2009-2020 period ranged from 11.3 to 0.5 m yr^{-1} (Table 6-1-2). When the two time periods are organized separately (i.e. ~Mar 2009-Mar 2017 vs. Mar 2017-Sep 2020), yearly rates of change showed variable differences between individual sentinel sites with some rates increasing, some decreasing and some remaining relatively stable (Table 6-1-3). These rates for the interior marsh areas showed a strong visual relationship to distance from the geometric center of the 2017 inlet for the period 2009-2017 (Fig. 6-1-7). We quantified that for the 8 sentinel points in the Clubhouse marsh area since it is directly facing the inlet proper and receiving significant oceanic wave energy from the expanded inlet. There is a strong quantitative relationship between shoreline loss and distance to inlet center for this area during 2009-2017 (Fig. 6-1-8). This relationship has continued, although at a slightly lower rate, during 2017-2020 (Fig. 6-1-9).

2020 Acknowledgements

We would like to thank Sean Fate for field assistance.

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Table 6-1-1. Sources and specifications of aerial images that were used to map marsh and shoreline edge.

Year	Image Source	Collection Platform	Altitude (m)	Image Resolution (cm pixel^{-1})	File Type
2009 (Feb-May)	Virginia Base Mapping Program	fixed wing aircraft	-	30.5	MrSID
2017 (Mar)	Virginia Base Mapping Program	fixed wing aircraft	-	30.5	MrSID
2018 (Sep)	VIMS-Eastern Shore Laboratory	quadcopter drone	120	5.2	JPEG
2020 (Sep)	VIMS-Eastern Shore Laboratory	quadcopter drone	120	5.2	JPEG

Table 6-1-2. Shoreline loss distance and rate (red) and gain rate (blue) of at least 2 m yr^{-1} at 14 sentinel points from 2009-2020 near Wachapreague Inlet (+ indicates net loss and – indicates net accretion). For point locations see Fig. 6-1-7.

Region	ID	Distance (m)	Rate (m yr^{-1})
Cedar Island	1	210.4	18.1
	2	358.7	30.9
	3	1190.7	102.6
	4	-219.2	-18.9
	5	8.4	0.7
	6	*n/a*	*n/a*
Clubhouse Marsh	7	6.3	0.5
	8	12.3	1.1
	9	18.1	1.6
	10	84.5	7.3
	11	131.5	11.3
	12	67.2	5.8
	13	11.0	0.9
	14	10.0	0.9

Table 6-1-3. Shoreline loss rate (red) and gain rate (blue) of at least 2 m yr-1 at 14 sentinel points by time period (+ indicates loss and – indicates accretion). For point locations see Fig. 6-1-7.

Region	ID	Mar 2009-Mar 2017 Rate (m yr^{-1})	Mar 2017-Sep 2020 Rate (m yr^{-1})
Cedar Island	1	16.2	22.4
	2	59.2	-32.2
	3	182.3	-74.3
	4	-27.9	1.2
	5	0.8	0.6
	6	0.5	*n/a*
Clubhouse Marsh	7	0.3	1.1
	8	1.1	0.9
	9	1.8	1.0
	10	6.9	8.1
	11	14.5	4.3
	12	7.4	2.3
	13	1.0	0.9
	14	0.9	0.8

Fig. 6-1-1 Area of shoreline change mapping effort in the vicinity of Wachapreague Inlet (highlighted in yellow).

Fig. 6-1-2 Drone collecting aerial images near Wachapreague, VA.

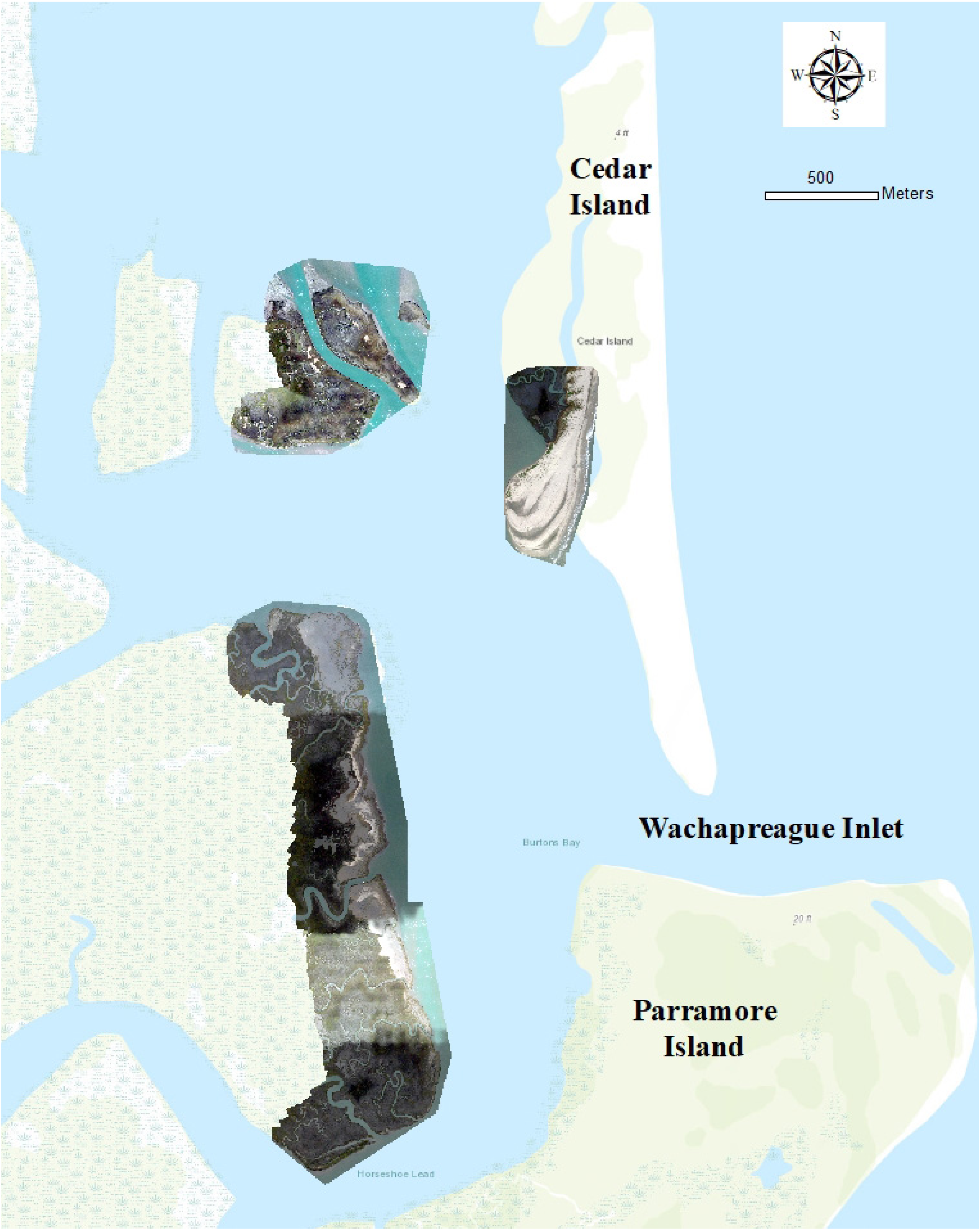

Fig. 6-1-3 Three orthomosaics derived from drone images collected in 2020 in the vicinity of Wachapreague inlet, VA (overlaid on basic base map).

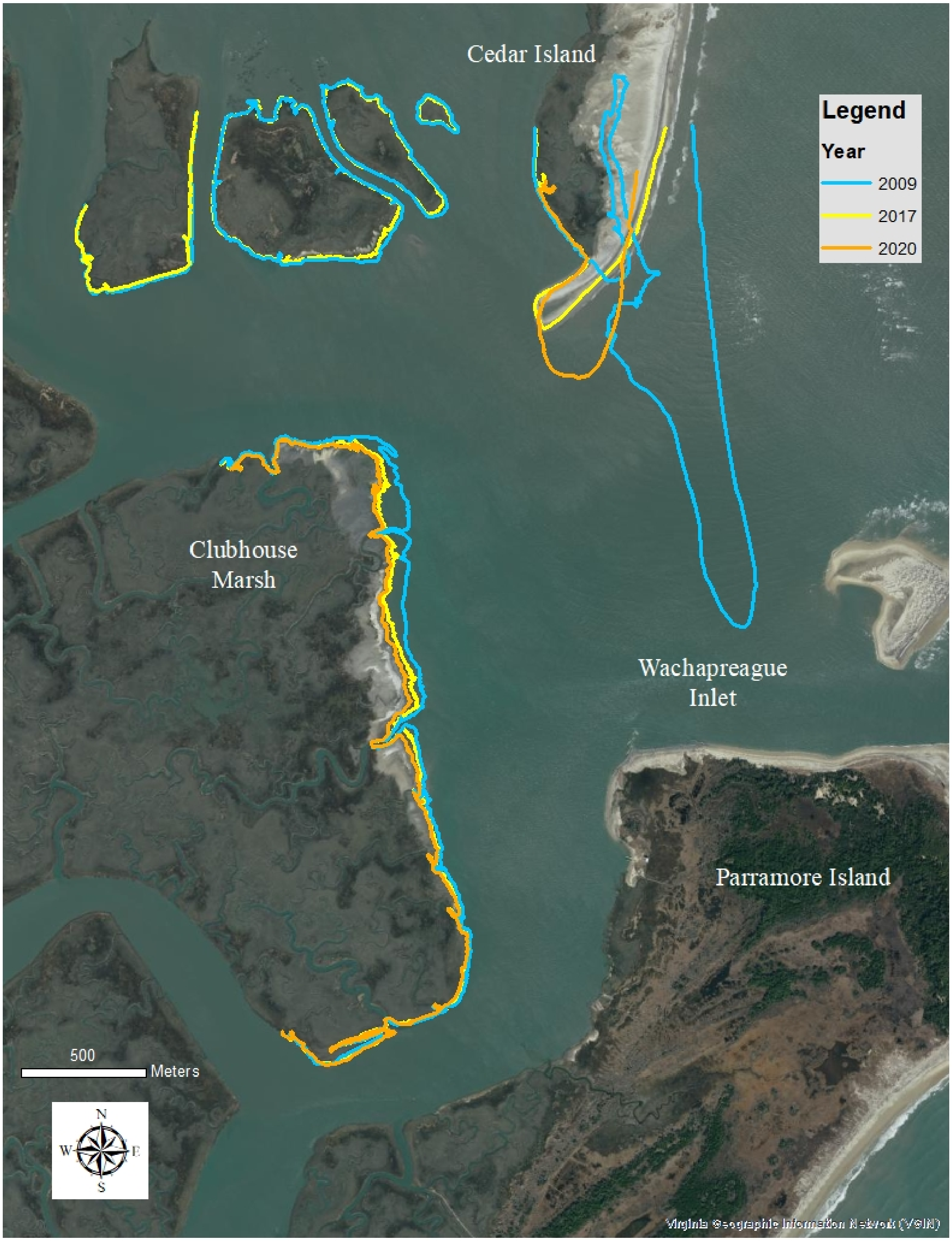

Fig. 6-1-4 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2020 (orange) in the vicinity of Wachapreague Inlet, VA. Aerial background for this figure is 2017 imagery (VBMP).

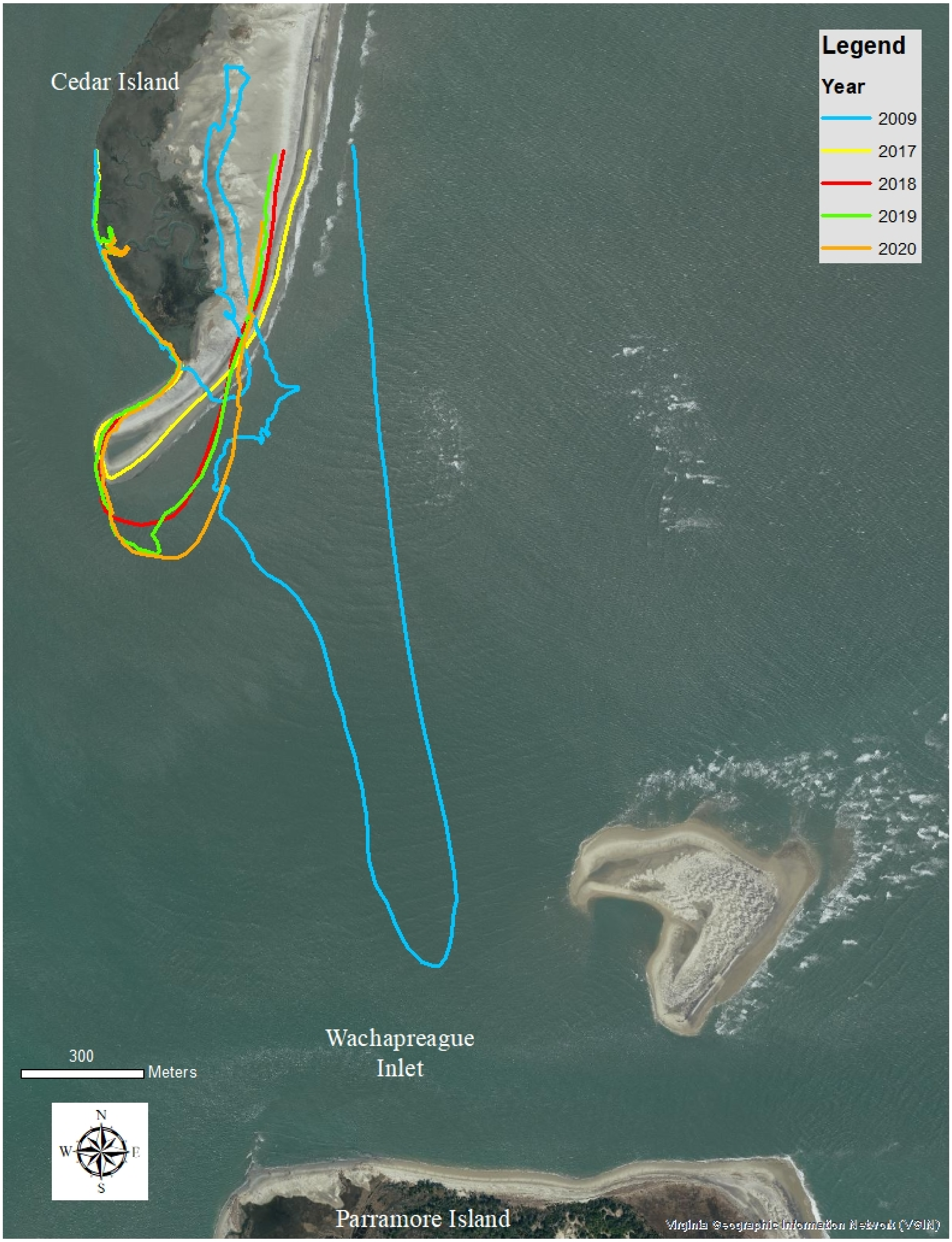

Fig. 6-1-5 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2018-2020 (see legend) for the southern portion of Cedar Island. Aerial background for this figure is 2017 imagery (VBMP).

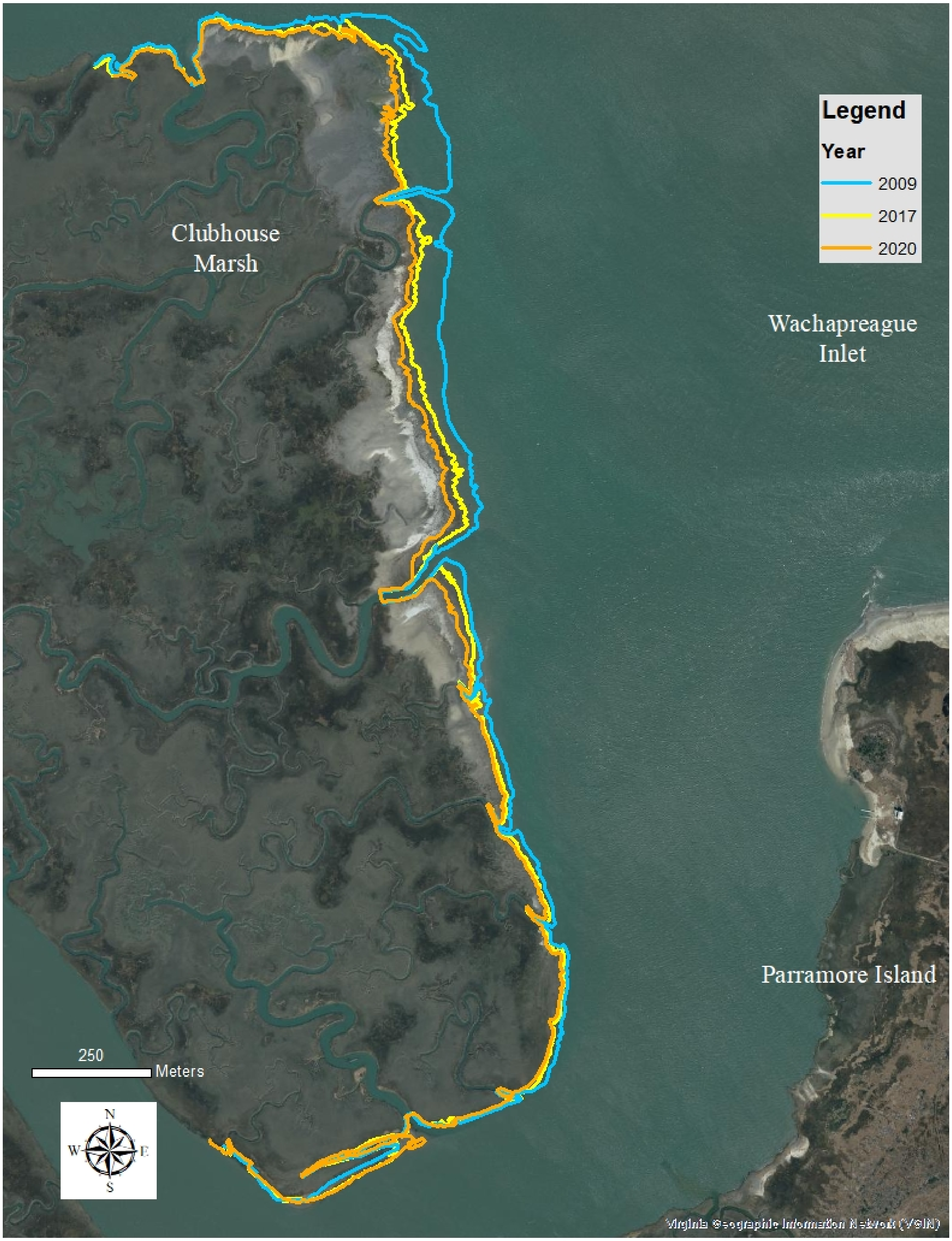

Fig. 6-1-6 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2020 (orange) in the vicinity of Clubhouse Marsh. Aerial background for this figure is 2017 imagery (VBMP).

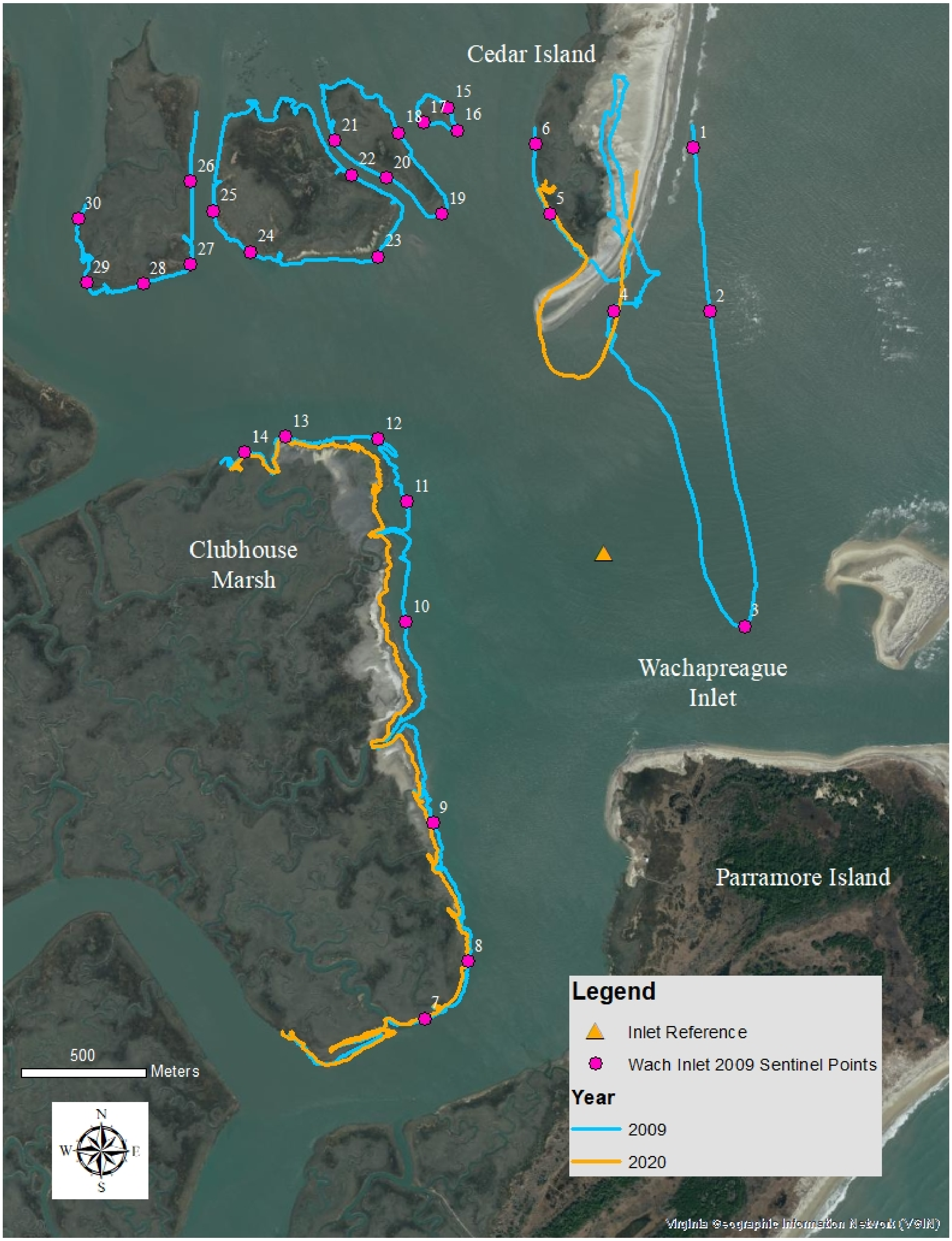

Fig. 6-1-7 Representative sentinel points to estimate shoreline retreat over time (pink dots) and a representative geometric center for the inlet (orange triangle).

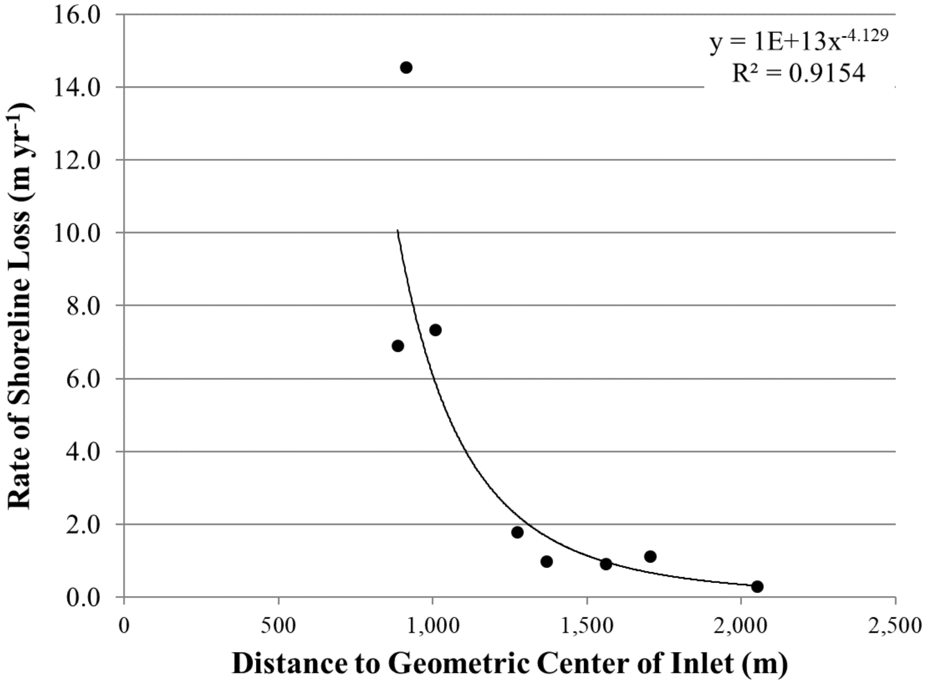

Fig. 6-1-8 Relationship between 2009-2017 shoreline loss (m yr^{-1}) and distance (m) to the geometric center of Wachapreague Inlet for 8 sentinel sites along the Clubhouse Marsh vicinity (best-fit power function with resulting model and R^2).

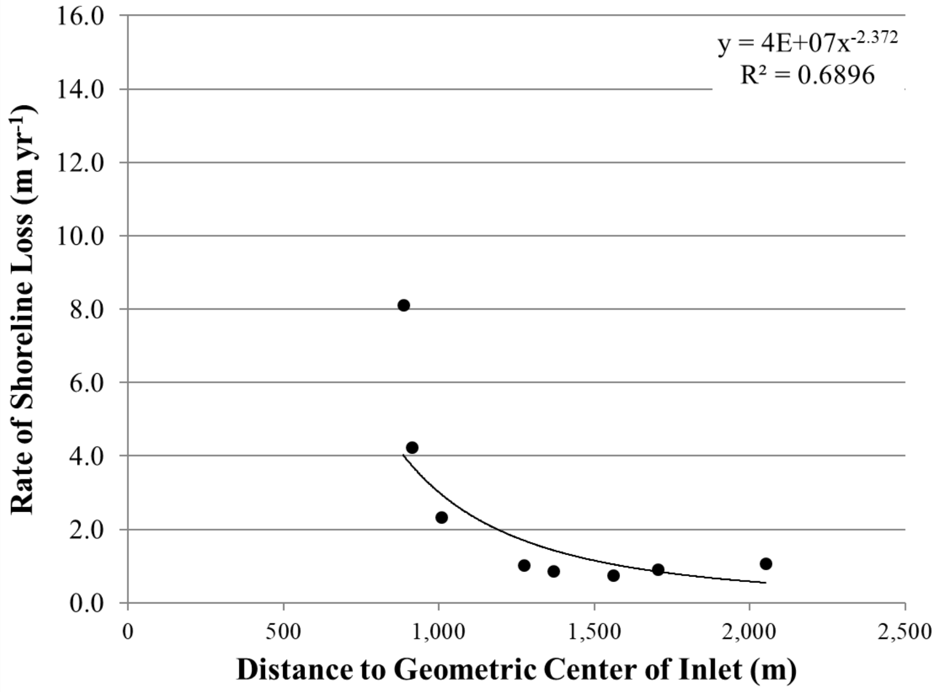

Fig. 6-1-9 Relationship between 2017-2020 shoreline loss (m yr^{-1}) and distance (m) to the geometric center of Wachapreague Inlet for 8 sentinel sites along the Clubhouse Marsh vicinity (best-fit power function with resulting model and R^2).

Chapter 6. Mapping Coastal Change

Section 6-2: Marsh Dieback Mapping

Authors: P.G. Ross and Richard Snyder

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete		Complete		Planned

Introduction

Salt marsh die backs have been observed in the Eastern United States for several decades (e.g. Alber et al. 2008). Long-term marsh loss along coastal Virginia has been attributed to relative sea level rise and barrier island dynamics (Deaton et al., 2017). Factors triggering short-term loss events have been attributed to abiotic and biotic forces including drought, storm wrack smothering, and predation (e.g. Elmer et al. 2013). Die backs and subsequent responses have even been previously studied on the seaside of Virginia's Eastern Shore (Marsh et al. 2016), but an area of persistent marsh loss that occurred rapidly near Wachapreague has been a concern and tracking changes to the area has become a priority in our monitoring program.

Starting approximately 2011, areas of marsh dieback were observed in Nickawampus and Finney Creeks, north of the Eastern Shore Laboratory, and these areas have expanded (Gutsell, 2016). Once prolific Spartina (*Sporobolus alterniflorus*) marshes have converted to mudflats with micro and macro algae production. Several researchers have made preliminary investigations without significant results, including transplants of Spartina (Luckenbach & Perry, pers. comm.), plugs of plants and organisms from die back areas into healthy marsh (Ross & Snyder, unpublished), and an investigation into environmental variables that might affect Spartina survival and growth (Gutsell, 2016). No direct cause of the dieback and its persistence has been identified to date. In conjunction with a College of William and Mary undergraduate field course taught at VIMS ESL at the end of each May, we decided to start mapping a small portion of one of these marsh areas in 2014. Initial maps were based on available aerial images and manual field mapping. However, beginning in 2018, we began mapping this area more rigorously using drone collected visible and near-infrared imagery. This report establishes a framework for tracking either further expansion, stasis, or recovery of this habitat change.

Study Area & Methods

Initially, we focused on one drain or 'gut' in the marsh just north of Wachapreague on Finney Creek (Fig. 6-2-1) during a William & Mary undergraduate field course in 2014. We utilized Virginia Base Mapping Program aerial images in conjunction with field mapping to develop a basic vegetation map. Background information for VBMP data can be accessed online (https://www.vita.virginia.gov/integrated-services/vgin-geospatial-services/orthoimagery/).

Starting in 2018, we began collecting high resolution imagery with Zenmuse X3 visible and near-infrared wavelength cameras on a DJI Matrice 100 quadcopter drone platform (Fig. 6-2-2). Drone collected images were geotagged with the on-board GPS. Table 6-2-1 gives some technical parameters for image acquisition by year. We also covered a larger area than in 2014.

Georeferenced images from both sources were brought into ArcGIS (ESRI, 2020). Prior to 2018, we manually digitized approximate habitat areas. This workflow created habitat maps with approximately 1-2 m accuracy. Starting in 2018, we processed our in-house near-infrared image orthomosaics using the standard Normalized Difference Vegetation Index (NDVI) algorithm, which has proven effective for mapping saltmarshes (e.g. Sun et al. 2016). This assigns pixel values based on reflectance in the wavelength range that correlates to chloroplasts in green vegetation and can be used as an indicator of plant health and/or density. A habitat map was then derived based on these pixel values using a supervised re-sampling methodology. This map was developed in ArcGIS with resulting shapefiles that could be used to calculate habitat area etc. Resolution with this technique was approximately 24 cm/pixel (original 2.4 cm/pixel was re-sampled based on 100 [i.e. 10 x 10] nearest neighbors).

2020 Results

The 2020 drone survey collected 342 images (60 m altitude; 70% overlap) on May 5 that were stitched together and developed into a high resolution, georeferenced orthomosaic using the Pix4D software. This resulted in a survey of ~30 hectares of marsh/mud flat, of which ~16 hectares were contained in the actual study area. Figure 6-2-3 shows the various products resulting from the workflow described above clipped by the expanded EMP study area.

Based on supervised NDVI analysis, we estimate that 6.60 hectares or 41.3% of the study area is marsh die-off that has converted to mud flats (Table 6-2-2). A small portion of this area was likely already mud flat before the die back began, especially along the creek margins and at the head of small drains (Ross, personal observation).

Comparison to Previous Years

We compared data from 2018 to the map developed in 2014 for the undergraduate class study area (Fig. 6-2-4). It is important to note that the methodologies for these two data collection efforts were quite different (see above). However, some gross comparisons were appropriate. The marsh die back area in 2014 was estimated to be 23% of the delineated study area. This had nearly tripled to 63% by 2018. Even by these gross comparisons, it is clear that the die off had substantially expanded during 2014-2018. As mentioned earlier, to better document changes moving forward, we expanded the study area for comparing drone data from

2018 and 2020. Therefore, these 2014 data are not directly comparable to the 2018 & 2020 data in this report because of the different study area delineations.

Overall, there were only minor differences between the 2018 and 2020 imagery (Table 6-2-2). Most habitat categories varied +/- ~3% or less. The exception was the combined category of *Mud* & *Sparse Grass/Mud Microbial Mat* decreasing by ~ 4% (Table 6-2-2). These subtle changes within the overall study area could be a result of actual marsh changes or normal interannual variation (both in terms of biology and image acquisition parameters). However, as would be expected, changes were not spread evenly throughout the landscape. Some areas showed more *Mud/Thin Grass* and some *Thick Grass* patches showed thinning on their perimeters, while others exhibited some marsh thickening (see Fig. 6-2-6 for examples of each scenario).

Note that there was a small difference in the *Water* habitat between years. This is the result of slightly different tidal levels at the time of surveys. We fly missions around low tide, but the actually tidal height will differ slightly from year to year. This will slightly impact the *Mud* areal footprint. We could exclude the *Water* category from the overall calculations, but have chosen to leave it in for the reports. The rationale is that, eventually at a future date, some low muddy areas may transition to inundation at low tide and we would not be able to evaluate this if we excluded the category.

The marsh changes in the vicinity of Wachapreague are visually obvious and it appears that our recent data support these casual observations. This marsh die back appeared to be an ongoing event thru 2018. Based on the comparison of 2018 to 2020 data, the extent of this continuing transition is less clear. We next plan to sample this area in 2022 and those results should further elucidate the presence or lack of continued significant change. The structural and process dynamics of the change from Spartina production to micro and macroalgae production have not been explored. If this dramatic shift in ecosystem function continues, it will undoubtedly affect food web dynamics and overall diversity and production in the system.

Acknowledgements

We would like to thank Sean Fate, Edward Smith and various William and Mary undergraduate students for field assistance.

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Table 6-2-1. Sources and specifications of aerial images that were used to map a marsh area near Finney Creek, Wachapreague, VA.

Year	Image Source	Collection Platform	Altitude (m)	Image Resolution (cm/pixel)	File Type
2009 (Feb-May)	Virginia Base Mapping Program	fixed wing aircraft	-	30.5	MrSID
2017 (May)	Virginia Base Mapping Program	fixed wing aircraft	-	30.5	MrSID
2018 (May)	VIMS-Eastern Shore Laboratory	quadcopter drone	60	2.4	JPEG
2018 (May)	VIMS-Eastern Shore Laboratory	quadcopter drone	60	2.4	JPEG

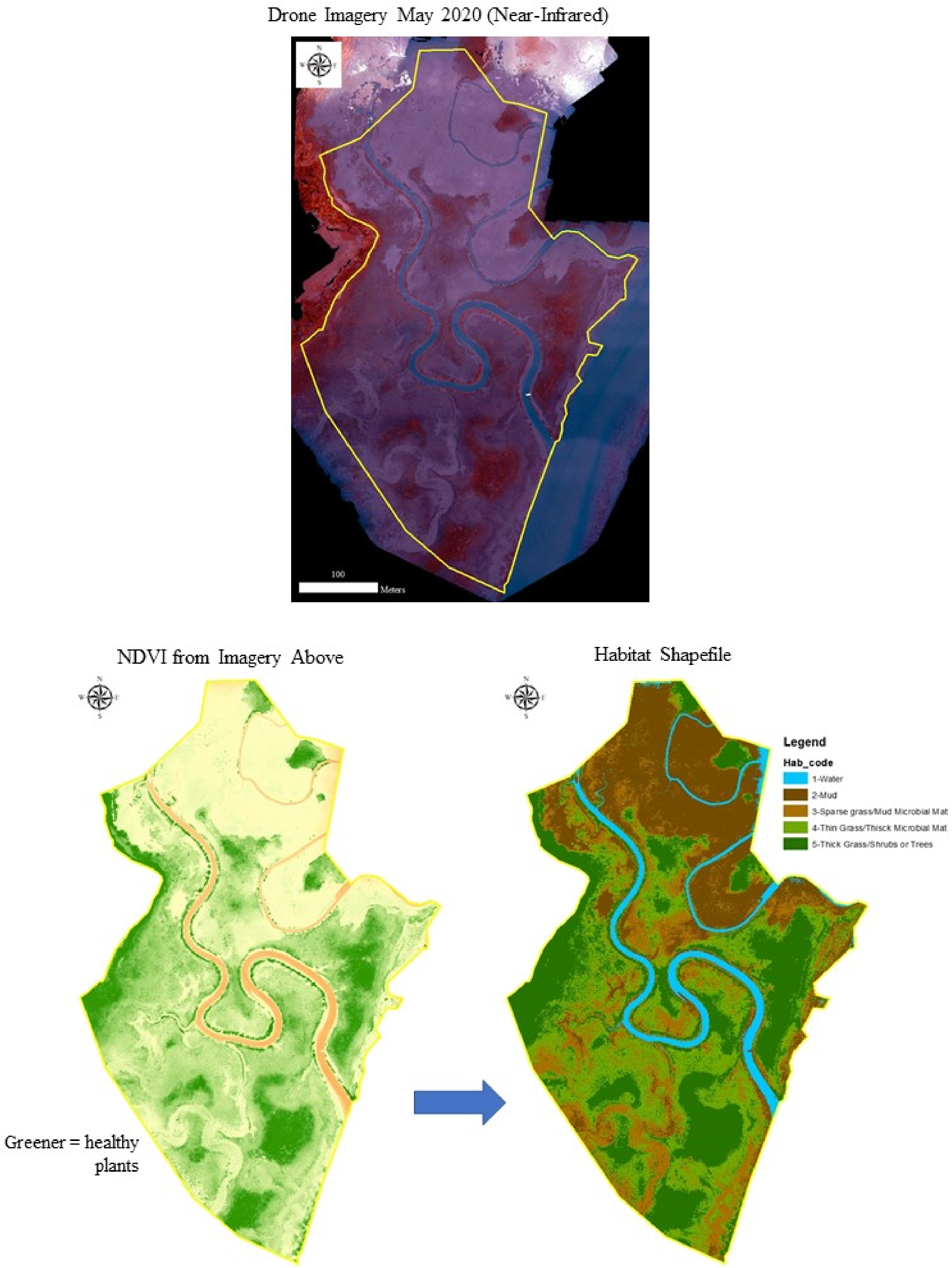
Table 6-2-2. Relative area of various habitats as determined by 2018 & 2020 supervised NDVI analysis in a marsh die back area near Wachapreague, VA.

Habitat ID	Habitat Name	2018		2020	
		Area (hectares)	% of Study Area	Area (hectares)	% of Study Area
1	Water	0.59	3.7	0.92	5.7
2	Mud *	7.22	45.2	6.60	41.3
3	Sparse Grass/Mud Microbial Mat *				
4	Thin Grass/Thick Microbial Mat	3.35	21.0	3.86	24.1
5	Thick Grass/Shrubs or Trees	4.82	30.1	4.61	28.9

* These two categories can be generally thought of as the "die-off area" and are combined here. We think that whether a given area falls in either of these two subjective habitat categories is partially driven by the extent of the microbial mat bloom at the time of imaging

Fig. 6-2-1. Area of 2018 marsh die back mapping effort in the vicinity of Wachapreague (highlighted in yellow).

Fig. 6-2-2. Drone collecting aerial images during 2018 near Wachapreague, VA.



Drone Imagery May 2020 (Near-Infrared)

NDVI from Imagery Above

Habitat Shapefile

Greener = healthy plants

Fig. 6-2-3. Near infrared orthomosaics collected in 2020 (study area is the yellow polygon). Imagery was clipped by this study area and post-processed using an NDVI algorithm which ultimately was used to create an ArcGIS shapefile for analysis.

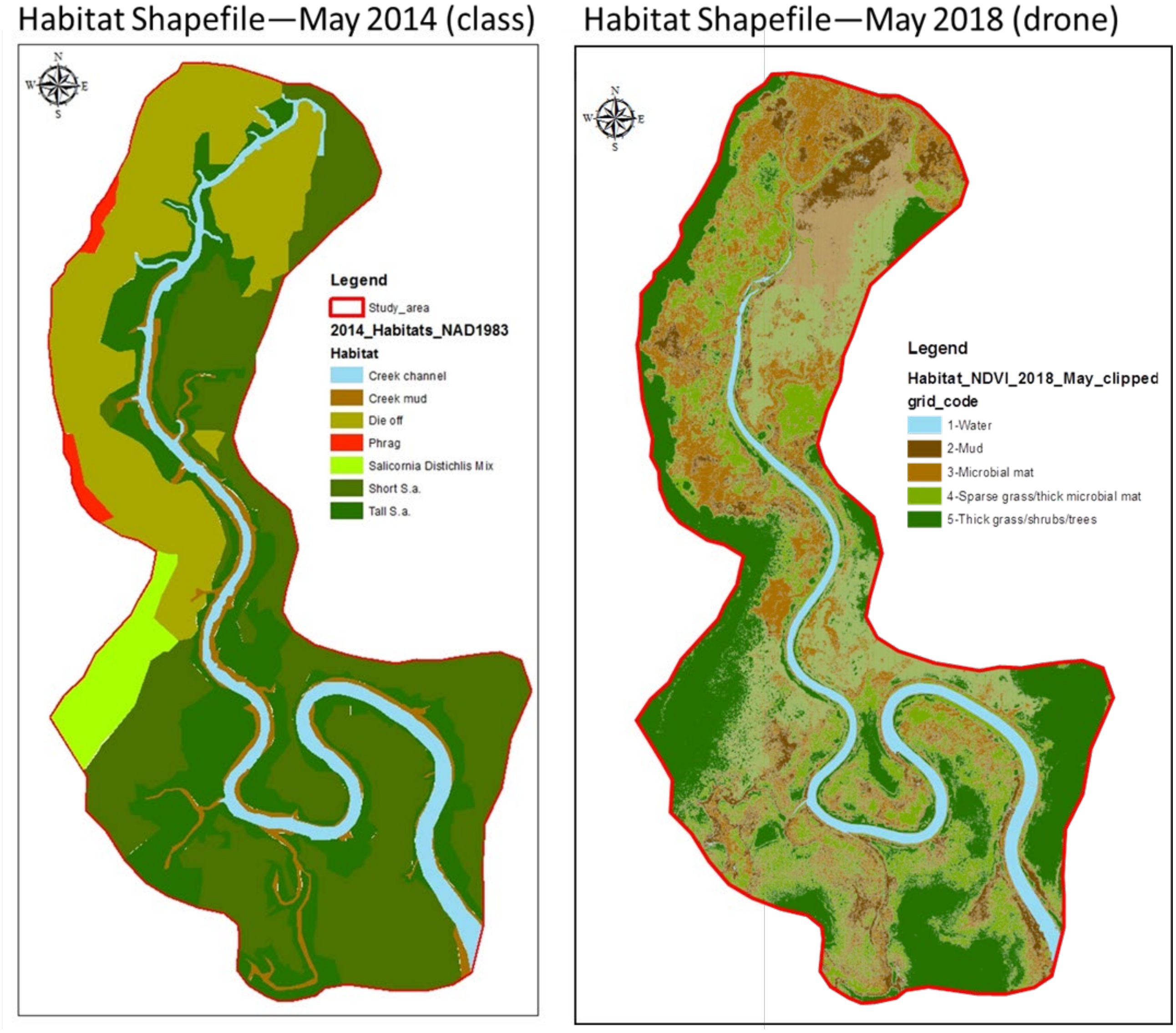


Fig. 6-2-4. Comparison of habitat shapefiles from 2014 and 2018 for a marsh dieback area near Wachapreague, VA. Note that legends/habitat categories differ due to differing methodologies (see text for details). "S.a." is the marsh grass, *Spatina alterniflora*. "Die off" in the right image would basically be the "Mud" and two "Microbial Mat" categories.

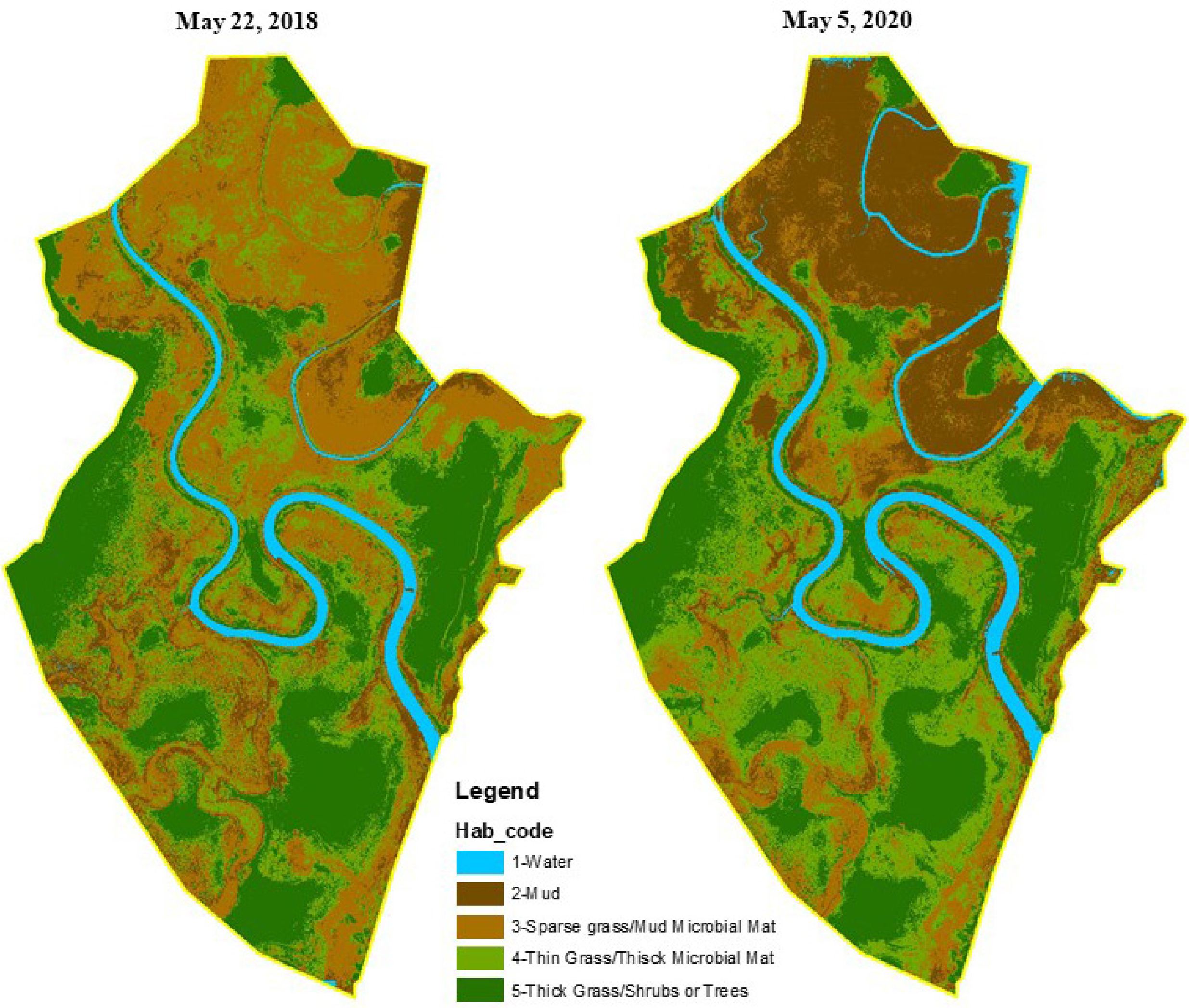


Fig. 6-2-5. Comparison of habitat shapefiles from 2018 and 2020 for a marsh dieback area near Wachapreague, VA. There appear to be interannual differences in specific regions of this study area that stand out visually.

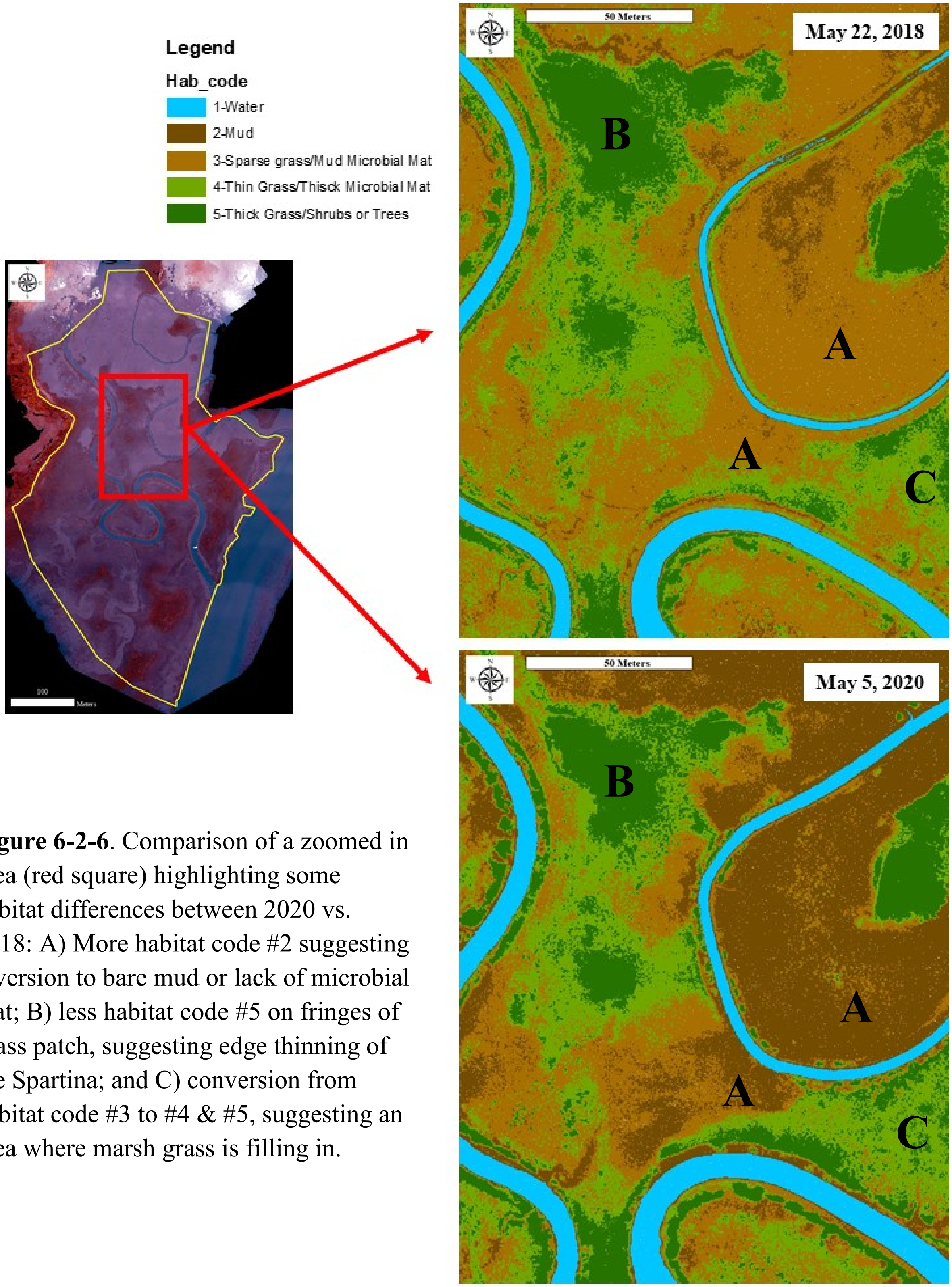


Figure 6-2-6. Comparison of a zoomed in area (red square) highlighting some habitat differences between 2020 vs. 2018: A) More habitat code #2 suggesting reversion to bare mud or lack of microbial mat; B) less habitat code #5 on fringes of grass patch, suggesting edge thinning of the Spartina; and C) conversion from habitat code #3 to #4 & #5, suggesting an area where marsh grass is filling in.

Chapter 6. Mapping Coastal Change

Section 6-3: Sediment Characterization

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5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete		Planned	

Introduction

Non-marsh intertidal and subtidal habitats in the coastal lagoons near ESL are dominated by soft-sediment seabed ranging from coarse sand to finer sand-silt-clay areas. Biological processes combined with physical variables such as water depth, current velocity, and wave energy all interact to influence sediment sorting, transport, deposition, and resuspension. These characteristics affect distribution and abundance of associated macrofaunal epi-benthic communities directly and indirectly as species' sediment preferences, larval transport and settlement, food availability, and refuge from predators. (e.g. see Seiderer and Newell 1999; Herman et al. 2001; Coblentz et al. 2015). Sediment organic matter and biogeochemical processing properties of the sediments affects biota from microbes to macrofaunal and represents a potentially significant carbon storage reservoir in changing global carbon dynamics.

Characterizing and mapping benthic sediments is often accomplished with relatively coarse resolution. We wished to provide information on a finer scale to be more useful to researchers and educators working out of VIMS ESL. Although Smith McIntyre grab samples are more useful for macrofaunal characterization, the more numerous but smaller push cores provided us with this resolution in the data. We have established baseline data and tested techniques in characterizing the sediments at some EMP sites in 2018 and 2019. Thereafter, beginning in 2021, we are planning a larger bi-annual grid sampling of the three EMP geographic areas. Our initial parameters for sediment characterization are organic matter content, surficial benthic chlorophyll-a production and particle size fraction.

Study Status

Work on this parameter was not planned for 2020. However, sediment characterization data will be collected during the 2021 field season. Methodology and data from 2018-2019 can be found here:

Ross, P. G., & Snyder, R. A. (2020) Ecological Monitoring Program at VIMS ESL - Annual Report 2018-2019. Virginia Institute of Marine Science, William & Mary. https://scholarworks.wm.edu/reports/2090

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